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Fire, people and reindeer in the boreal forest

The role of fire in the historical and contemporary interactions between Sami reindeer herding and forest management in northern Sweden

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Abstract

In the boreal forest of northern Sweden, fire was used from around 1920 to 1970 as a forest regeneration measure, and then abandoned for some decades. Since the 1990s, fire restoration has been carried out through regeneration and conservation burning in commercial and protected forests. The same forest is also used as reindeer pasturelands by indigenous Sami herders. The overall aim of this thesis was to investigate the human dimensions of fire regimes in the Swedish boreal forest, with a focus on interactions between fire, Sami reindeer husbandry and forest management during the 20th century and up to the present. This goal was addressed through an interdisciplinary approach combining historical ecology and environmental anthropology. The results show that while forest managers conceive fire as a natural perturbation, Sami herders have conflicting feelings about fire, as they have had to endure the effects of imposed burning strategies on their livelihood. While burning can promote summer pasture and maintain the long-term availability of winter pasture, it destroys lichen pasture temporarily and Sami ecological knowledge shows that burning also affects the behaviour and movement patterns of the reindeer. These pitfalls already affected reindeer herding during the first half of the 20th century, and even triggered an early form of consultation with the forestry sector. Today, while generally opposed to all external measures that affect reindeer grazing grounds, Sami herders increasingly see in burning a way to restore winter pasturelands. They use the consultation process with forest owners to negotiate for burning that serves their interests. The fire regime thus reflects a combination of technical constraints, forest management and nature conservation objectives, and conditions posed by Sami herders. However, in order for Sami herders to actually assert their interests, true fire co-management would have to be implemented.

Keywords: fire regimes, Sami reindeer herding, forest management, interdisciplinarity, Swedish boreal forest

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Feux, rennes et humains dans la forêt boréale: Le rôle du feu dans les interactions historiques et contemporaines entre l'élevage de rennes sami et la gestion forestière dans le Nord de la Suède

Résumé

Dans le nord de la Suède, le feu a été utilisé comme mesure de régénération forestière entre les années 1920 et 1970, puis abandonné pendant deux décennies. Depuis les années 1990, la restauration du feu a été mise en œuvre à travers des brûlages de régénération et de conservation dans les forêts commerciales et protégées. Ces mêmes forêts sont utilisées par les éleveurs autochtones samis comme pâturages pour leurs rennes. L'objectif général de cette thèse était d'étudier les dimensions humaines des régimes de feux dans la forêt boréale suédoise, en se concentrant sur les interactions entre l'élevage de rennes sami et la gestion forestière pendant le 20ème siècle jusqu'à aujourd'hui. Pour atteindre cet objectif, une approche interdisciplinaire combinant histoire écologique et anthropologie environnementale a été utilisée. Les résultats montrent que les gestionnaires forestiers conçoivent le feu comme une perturbation naturelle à restaurer, alors que les éleveurs samis éprouvent des sentiments ambivalents à l'égard du feu, ayant subi les effets de stratégies de brûlage imposées par le secteur forestier sur leur mode de vie. Tandis que le brûlage favorise le pâturage d'été, et maintient la disponibilité du pâturage d'hiver sur le long terme, il détruit temporairement les pâturages de lichen. Les savoirs écologiques samis montrent que le brûlage affecte aussi le comportement et le patron de déplacement des rennes. Ces écueils affectaient déjà l'élevage durant la première moitié du 20ème siècle, et avaient même initié une première forme de consultation avec le secteur forestier. Aujourd'hui, bien que généralement opposés à toute mesure extérieure qui affecte les pâturages des rennes, les éleveurs samis voient dans le brûlage un moyen de restaurer les pâturages d'hiver. Ils se servent du processus de consultation avec les propriétaires forestiers pour négocier une utilisation du brûlage qui serve leurs intérêts. Le régime de feux reflète ainsi une combinaison de contraintes techniques, d'objectifs de gestion forestière et de conservation de la nature, et de conditions posées par les éleveurs samis. Afin que les éleveurs samis puissent réellement faire valoir leurs intérêts, une véritable co-gestion du feu devrait cependant être mise en place.

Mots-clés: régimes de feux, élevage de rennes sami, gestion forestière, interdisciplinarité, forêt boréale suédoise

Skogsbrand, människor och renar i den boreala skogen: skogsbrandens roll under historien och idag i relation till samisk renskötsel och skogsskötsel i norra Sverige

Sammanfattning

I norra Sverige användes hyggesbränning som en metod för skogsföryngring från 1920-talet till 1970-talet, för att sedan i stort överges under den sista delen av 1900-talet. Sedan 1990-talet har man återinfört skogsbranden både i form av hyggesbränning och naturvårdsbränning, det senare i såväl produktionsskogar som i skyddade skogar. Samma marker har också använts som renbetesmarker av samiska renskötare under mycket lång tid. Det övergripande målet med den här avhandlingen var att utforska de mänskliga dimensionerna av skogsbrand och skogsbrandsregimer i den boreala skogen, med fokus på interaktioner mellan skogsbranden, den samiska renskötseln och den moderna skogsskötseln under 1900-talet fram till idag. För att lyckas med detta har jag i denna avhandling anlagt en tvärvetenskaplig metodik som kombinerar metoder och teorier från historisk ekologi och miljöantropologi. Resultaten visar att medan skogsförvaltare uppfattar skogsbrand som en naturlig störning som måste återinföras, har samiska renskötare motstridiga känslor när det gäller bränning, eftersom de direkta effekterna av skogsbrännings påverkar deras möjligheter till utkomst. Medan bränning kan gynna sommarbete och vidmakthålla den långsiktiga tillgängligheten av vinterbete, så förstör det på kort sikt lavbetet på vinterbetesmarker. Samisk ekologisk kunskap visar att bränning (och nya brandfält) också påverkar renars beteende och deras rörelsemönster i landskapet. Dessa hinder påverkade renskötseln redan under den första hälften av 1900-talet och ledde till och med till en tidig form av samråd mellan renskötare och skogsbruket. Idag, medan de i allmänhet motsätter sig alla skogsvårdsåtgärder som påverkar de krympande betesmarkerna, ser samiska renskötare alltmer bränning som ett sätt att återställa förlorat vinterbete. De använder samrådsprocessen med skogsägare för att förhandla om bränning på ett sätt som tjänar deras intressen. Brandregimen i den boreala skogen idag återspeglar en kombination av tekniska begränsningar, skogsskötselsmål, naturvårdsintressen och villkor som samiska renskötare ställer. Men för att samiska renskötare faktiskt ska kunna hävda sina intressen på allvar, måste en starkare samplaneringsprocess av skogsbränningar införas.

Nyckelord: brandregimer, samisk rennäring, skogsskötsel, tvärvetenskap, boreal skog

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I. Cogos, S., Östlund, L., Roturier, S. (2019). Forest fire and indigenous Sami land use – place names, fire dynamics and ecosystem change in northern Scandinavia. Human Ecology, 47 (1), 51-64.

II. Cogos, S., Roturier, S., Östlund, L. (2020). The origins of prescribed burning in Scandinavian forestry: the seminal role of Joel Wretlind in the management of fire-dependent forests. European Journal of Forest Research, 139, 393-406.

III. Cogos, S., Östlund, L., Roturier, S. Using historical sources and Indigenous knowledge to reconstruct the twentieth-century history of prescribed burning and reindeer herding in Swedish Sápmi (submitted to Environment and History, under review)

IV. Cogos, S., Östlund, L., Roturier, S. Forestry, nature conservation, Sami reindeer herding and fire: fire domestication as a negotiation process. (manuscript)

Papers I and II were published with open access.

English translations of Swedish institutions' names

English translation	**Swedish name**
County Administrative Board	*Länsstyrelsen*
Lapp Administration	*Lappväsendet*
National Board of Agriculture	*Lantbruksstyrelsen*
National Board of Forestry	*(Kungliga) Skogsstyrelsen*
National Forest Company	*Domänverket* until 1992 and then *Sveaskog*
National Swedish Forest Administration	*(Kungliga) Domänstyrelsen*
National Union of Swedish Sami	*Svenska Samernas Riksförbund (SSR)*
Swedish Environmental Protection Agency	*Naturvårdsverket*
Swedish Forestry Act	*Skogsvårdslagen*
Swedish Institute for Language and Folklore	*Institutet för Språk och Folkminne*
Swedish National Land Survey	*Lantmäteriet*

1. Introduction

1.1 The human dimensions of fire on Earth

The "human dimension of fire regimes on Earth" is now accepted by the scientific community (Bowman *et al.* 2011). While fire has been able to occur on the Earth for about 400 million years, once sufficient levels of oxygen in the atmosphere were reached (Scott 2000; Pyne 2019), the shared history of humans and fire started about 1.5 million years ago, when hominins acquired the ability to contain and ignite fire (Gowlett 2016; Hlubik *et al.* 2019). Pre-historical fire domestication has been conceived as a "civilising process" (Goudsblom 1987), and a "hominisation driver" (de Lumley 2006), by allowing the development of complex social organisation and social life (Dunbar & Gowlett 2014). The role of fire domestication in the biological evolution of the human line, notably through the effects of cooking on energy expenses and brain development has also been highlighted, though it is also debated (Gowlett & Wrangham 2013; Attwell *et al.* 2015; Cornélio *et al.* 2016; Wrangham 2017). Fire domestication has also been designated as the starting point of the Anthropocene by some authors (Glikson 2013; Scott 2019), and more recently a "social-ecological regime shift" (Biggs *et al.* 2016). Thus, fire domestication constitutes a determining process in human history, which had reciprocal effects on both ecosystems and human societies.

Since then, fire–human interactions have continued to shape socio-ecosystems in various ways. Historical use of fire has allowed local and indigenous societies to modify their environments for various purposes, such as the production and management of food resources, the production of construction and craft materials, or the management of settlements and

infrastructures. Fire has also been used in the context of political claims and in warfare (Lewis 1978, 1993; Lewis & Ferguson 1988; Anderson 1999; Brown 2000; Williams 2000; Kimmerer & Lake 2001; Dumez 2004; Bowman *et al.* 2011). These interactions gave rise to "cultural landscapes" or "cultural ecosystems", i.e. systems that developed under the joint influence of ecological and anthropogenic processes (Clewell & Aronson 2013).

Given its potential to transform environments, fire has also been a source of dispute with respect to land use throughout history. With the onset of the industrial era, local and indigenous burning practices were criticised and banned by State institutions in most of the "Western world" and its colonies. They were replaced by fire management strategies steered by national and colonial interests (Fairhead & Leach 1995; Faerber 2000; Kimmerer & Lake 2001; Krebs *et al.* 2010). During the 19th century and the first half of the 20th century, national fire management strategies were principally directed at the preservation of agricultural and silvicultural resources, and thus included strict fire suppression (Krebs *et al.* 2010; Pyne 2012).

In the 1970s, forest managers and scientists realised that fire suppression had actually increased the risk of large wildfires. In addition, during the same period, the ecological sciences underwent a paradigm shift that entailed the recognition of fire as an integral component of ecosystem functioning (Leopold *et al.* 1963; Kilgore 1981; van Wilgen *et al.* 2003; Pausas & Keeley 2009; Krebs *et al.* 2010). These realisations led to the rehabilitation of fire in the environment (Pyne 1998; Shlisky *et al.* 2007; Pausas & Keeley 2009; Krebs *et al.* 2010; Bowman *et al.* 2011; Pyne 2012). Since then, prescribed burning programmes have been initiated in many countries, with various aims. These chiefly include fuel reduction for the mitigation of wildfire risks, preservation of cultural landscapes, and biodiversity conservation (Brockett *et al.* 2001; Brown *et al.* 2004; Rigolot 2009; Driscoll *et al.* 2010; Fernandes *et al.* 2013; Halme *et al.* 2013; Russell-Smith *et al.* 2013; Durigan & Ratter 2016; Eloy *et al.* 2019).

Today, fire management has been largely appropriated by State institutions in the Western countries and their former colonies, driven by ecological criteria. In some regions, however, indigenous and local burning practices are still being undertaken, chiefly in relation to resource management (see examples in Australia: Bird *et al.* 2005, 2016; Indonesia: Russell-Smith *et al.* 2007; Africa: Laris 2002; South America: Mistry *et al.*

2005; France: Dumez 2004; Ribet 2005, 2011). These practices are increasingly recognised by scholars and environmental managers as fire management systems able to mitigate wildfire risk, promote biodiversity, and even reduce carbon emissions (Laris 2002; Burrows *et al.* 2004; McGregor *et al.* 2010; Russell-Smith *et al.* 2013). In recent decades, some countries have undertaken fire co-management programmes involving indigenous and local communities (Bird *et al.* 2008; McGregor *et al.* 2010; Russell-Smith *et al.* 2013; Eloy *et al.* 2019). Whether they use fire or not, indigenous and local peoples are recognised for holding a rich and holistic knowledge about their environment, including ecological processes. Numerous scholars have called for the inclusion of indigenous and local knowledge (ILK)[1] in the management of natural resources since the 1980s (Berkes 1993; Berkes *et al.* 2000).

Thus, fire regimes, i.e. the set of biophysical parameters characterising the temporal and spatial patterns of fire occurrence (Krebs *et al.* 2010; Pyke *et al.* 2010), are the result of historical and contemporary interactions between humans, the environment and fire, which involve not only ecological but also social, cultural and political dimensions. Fire is also the object of various and sometimes conflicting representations, rooted in different worldviews, which underlie fire management practices. In this thesis, I argue that investigating historical and contemporary interactions between humans and fire, not only in ecological terms but also in social, cultural and political terms, is essential to understand the evolution of fire regimes and to make informed choices in terms of current and future fire management. Moreover, investigating the role of indigenous and local populations in shaping the fire regimes, and related indigenous and local knowledge, can contribute to the recognition of their legitimacy to participate in fire management strategies, from which they are often excluded.

Because fire connects an array of issues belonging to different spheres of knowledge – ecological, political, social and cultural – understanding the role of fire in human–nature interactions requires a holistic approach relying on the natural, human and social sciences. Some scholars have highlighted a

[1] In this thesis I use the expression "indigenous and local knowledge" to refer to a heterogeneous ensemble designated in the scientific literature through the terms "traditional ecological knowledge" (TEK), "indigenous knowledge", "indigenous and local knowledge", "local ecological knowledge", etc. (Gadgil *et al.* 1993; Berkes *et al.* 2000; Roué 2012). The definition of Berkes *et al.* (2000) is widely used in the literature, and defines "traditional ecological knowledge" as a "cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment".

need to improve our understanding of human–fire relationships through a multidisciplinary and historically informed approach (Bowman *et al.* 2011). Arguing that little consideration has been given to "the social systems that give rise to documented fire practices", Coughlan and Petty (2012) urge to go further and to undertake a truly interdisciplinary approach, binding social and natural sciences. With this thesis, I intend to contribute to this task, through the case of Swedish Sápmi, i.e. the land of indigenous Sami people, and by employing an interdisciplinary approach involving chiefly environmental history, environmental anthropology and ecological history.

The need to understand the historical and contemporary interactions between humans and fire is particularly important in the present context of escalation of large forest fires. During the time it took to carry out this thesis work, we have been starkly reminded of the presence of fire in our surroundings, as demonstrated by the fires in Fort McMurray, Canada, in 2016, in California in 2016, 2017,2018 and 2020, in Chile in 2017, in Southern Europe and Sweden in 2018, and in Amazonia and Australia in 2019-2020, to cite some of the examples gaining the most coverage by the press. This upsurge of "wildfires" that has occurred on every inhabited continent in recent decades is considered unprecedented compared to historical fire regimes (Pechony & Shindell 2010; Adams 2013; Jones *et al.* 2016; Zask 2019). Some studies highlight the role of climate change in this increase of forest fires, but the driving factors are numerous and complexly interwoven (Krawchuk *et al.* 2009; Pechony & Shindell 2010). Knowledge about historical and contemporary fire–human interactions will be of much value in dealing with this new context.

1.2 Managing fire in northern Sweden: forestry, nature conservation and Sami reindeer herding

The history of fire regimes in the Swedish boreal forest is an eloquent example of the dynamics that occurred within the Western world in relation to fire management. From the onset of the industrial era in the 19th century, fire management in Sweden was driven by forestry, through the simultaneous application of fire suppression and regeneration burning (Sw.: *hyggesbränning*)[2] as a soil preparation measure to regenerate Scots pine

[2] To designate burnings carried out to regenerate forests after clearcutting, I use the expression "prescribed burning" in **papers I, II and III**, which is used in the literature in a generic way to describe burnings carried out

forests. Regeneration burning was abandoned in the 1970s to be replaced by mechanical soil preparation, which is less costly and presents no risk of triggering wildfires (Holmgren 1959; Zackrisson 1977; Granström 1991; Niklasson & Granström 2000; Granström & Niklasson 2008; Wallenius 2011). However, since the 1990s, fire has been recognised as an essential component of the Fennoscandian boreal forest ecosystem, necessary to maintain habitat and biological diversity (Kuuluvainen *et al.* 2002; Halme *et al.* 2013). Since then, there has been a renewed interest in the use of fire in the context of nature conservation. Policies have been introduced to promote the reintroduction of fire in commercial and protected forests through regeneration burning and conservation burning (Sw.: *naturvårdsbränning*), i.e. burning standing forests. Most forestry companies in Sweden comply with the Swedish FSC (Forest Stewardship Council) standard, which requires them to burn 5% of their regeneration area on mesic and dry lands over five years (Swedish FSC standard 2010), and carry out both regeneration and conservation burning. In addition, the County Administration Boards (Sw.: *Länsstyrelsen*) carry out conservation burnings in protected forests. Through this renewed interest and use of fire, a new "fire culture" is emerging in northern Sweden among forest managers.

Fire management also represents an important issue for indigenous Sami reindeer husbandry[3]. In Sweden, the Sami carry out reindeer herding over an area roughly covering the northern half of the country (Figure 1), including forestlands, which they have a right to use for reindeer pasture. They are currently confronted with a situation where the availability of ground reindeer lichens (*Cladonia* spp.), the main food source for reindeer in winter, has been decreasing markedly over the 20th century due to encroachment by industries, including forestry, mines and hydro-electric power, and various types of infrastructure (Sandström *et al.* 2006; Berg *et al.* 2008; Kivinen *et al.* 2010, 2012; Moen & Keskitalo 2010; Herrmann *et al.* 2014). According to Sandström *et al.* (2016), the area of lichen-rich forests has declined by 71% in Northern Sweden over the last sixty years. Fire restoration represents

to fulfil specific management goals. In **paper IV** and in this thesis, I use the expression "regeneration burning" to distinguish burnings carried out for forest regeneration purposes from burnings carried out for nature conservation purposes in standing forests ("conservation burning"). I use the expression "controlled burning" as a generic term to designate any burning carried out by humans.

[3]The term "reindeer herding" is usually employed to refer to the activity of herding the reindeer, how it is organised and carried out, while "reindeer husbandry" refers to the livelihood connected to reindeer herding as a whole, including social, cultural and economic aspects.

mixed prospects for Sami reindeer husbandry. Burning in reindeer pasturelands can lead to the destruction of the lichen pasture for several decades, whilst fire suppression in old-growth forests reduces the abundance of reindeer lichen in the long term, as nutrient levels of unburned stands increase, thus favouring dwarf shrubs to the detriment of lichens (Berg *et al.* 2008; Moen & Keskitalo 2010). It is also suggested that burning could be used to restore reindeer lichen pastures in association with artificial introduction of lichens (Roturier *et al.* 2017).

Figure 1. Extent of the Sami reindeer herding area in Sweden and delineation of the cultivation line above which Sami herding communities have their year-round grazing lands. In the two counties studied in this thesis, Norrbotten and Västerbotten, the forest area is 9.7 million ha of which 7.2 million ha is productive forest (Swedish University of Agricultural Sciences 2020).

Because, due to fire suppression, fire has been virtually absent from the boreal forest for more than a century, many uncertainties remain as to the effects of fire and burning on Sami reindeer husbandry. Some studies have addressed the impact of fire on reindeer pasture from an ecological standpoint, in Fennoscandia (Skuncke 1969; Kumpula *et al.* 2000) and North America (Klein 1982; Morneau & Payette 1989; Thomas *et al.* 1996; Joly *et al.* 2003, 2010; Rupp *et al.* 2006; Collins *et al.* 2011; Anderson & Johnson 2014). Some have explored the evolution of historical fire regimes, and the role of humans as a factor of change (Zackrisson 1977; Niklasson & Granström 2000; Nilsson & Wardle 2005; Carcaillet *et al.* 2007; Wallenius 2011). However, all in all, there are few works that address the historical or contemporary relationships between fire management and Sami reindeer herding (see: Helle & Aspi 1984; Hörnberg *et al.* 1999, 2018).

Investigating the historical influence of Sami people on fire regimes is a challenge notably because of the difficulty of disentangling anthropogenic from non-anthropogenic fire ignitions (Granström & Niklasson 2008). Moreover, the Sami being a people of oral tradition, written sources providing information on the subject are limited, and usually convey the Swedish perspective from the colonisation of the northern part of the country.

Written sources suggest that the Sami were averse to fire because it could destroy ground reindeer lichens (Granström & Niklasson 2008). Conflicts were reported between the Sami and southern settlers who progressively established themselves in northern Sweden from the 16th century because the latter used fire to create favourable conditions for agriculture, notably for the improvement of grazing conditions for cattle, and to a minor extent slash-and-burn agriculture. They set fire to lichen-rich reindeer pastures, sometimes deliberately, to drive the Sami further away (Massa 1987; Granström & Niklasson 2008; Pyne 2012). However, some studies suggest that, in the past, the Sami might have used fire repeatedly over the years to maintain lichen-rich environments in the long term (Hörnberg *et al.* 1999, 2018). Besides, fire still has a wide range of uses among Sami people even today, as described by Ryd (2005). Otherwise, very little is known or documented about the historical interactions between Sami reindeer husbandry and fire or about the influence of Sami reindeer herding on historical fire regimes. Thus, there is a need to gain a better understanding of these interactions in order to provide a basis for fire restoration. Investigating

the history of fire management from a Sami perspective, through an environmental history approach, can complement the narrative that has been presented so far, mostly built on written sources and thus on a Swedish perspective.

In the current context of fire restoration, Sami reindeer herders have the opportunity to discuss controlled burning with forest managers through the process of "consultation". Consultation was implemented in the 1979 Swedish Forestry Act (Sw. *Skogsvårdslagen*), which requires forest owners to consult Sami reindeer herders before undertaking any measures in forestry that affect year-round reindeer herding areas (Swedish Forestry Act 1979: 429). In 2010, this obligation was extended to cover a larger area through the FSC certification (Swedish FSC standard 2010) (see Figure 2). However, flaws in the consultation process have been pointed out in many instances, and the need for a forest management process that effectively includes Sami reindeer herders has been raised (Widmark 2006; Sandström & Widmark 2007; Larsen & Raitio 2019). Investigating the contemporary interactions between Sami reindeer herding and fire management through the prism of environmental anthropology could pave the way towards a fire management system that would better include Sami herders and the knowledge they hold about ecological processes, including fire.

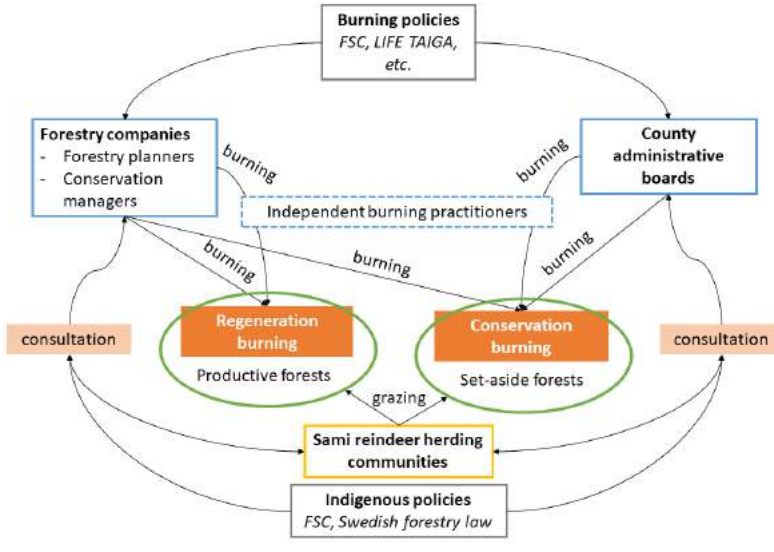

Figure 2. Burning management system in northern Sweden today.

1.3 Objectives

The overall aim of this thesis is to understand the human dimensions of fire regimes in northern Sweden by examining the historical (20th century) and contemporary interactions between fire, forest management and Sami reindeer husbandry. This objective is addressed through various perspectives and methods crosscutting several scientific disciplines, chiefly including environmental history, environmental anthropology, and historical ecology. This thesis focuses on different land users who are, or have been involved, directly or indirectly, in fire management and controlled burning, including foresters (such as forestry planners working for forestry companies and forestry entrepreneurs), conservation managers (working for forestry companies or for the County Administrative Boards in Northern Sweden), and Sami reindeer herders. While foresters and conservation managers are directly participating in the construction of a new "fire culture", through the management of controlled burning, Sami reindeer herders have not been actively included in this process so far. One aim of this thesis is to show how and why their knowledge and their participation could contribute to building this new "fire culture". The studies constituting the thesis cover a time frame that spans from the early 20th century up until today, and a study area including several locations in the two northernmost counties, Norrbotten and Västerbotten. This thesis addresses several questions that are specific to or intersect with the papers on which it is based:

- What knowledge and representations of fire is historical and contemporary fire management based upon? (**II; IV**)
- What are the historical and contemporary impacts of fire management on Sami reindeer husbandry? (**I; III; IV**)
- How did the governance of fire management evolve across the 20th century, up until today, regarding Sami reindeer husbandry? (**III; IV**)
- How did fire–human interactions shape fire regimes, and *vice versa*, in northern Sweden through the 20th century and up to the present? (**I; II; III; IV**)

It concludes with the lessons that can be drawn from an interdisciplinary approach to fire–human interactions, studied from a long-term perspective.

2. Background: a history of fire

2.1 Fire and humans across history

2.1.1 What are we talking about when we talk about fire? Fire regimes and fire types

Fire can be defined as a chemical reaction of combustion. Combustion produces heat and light, but it also changes the properties of the fuel it depends on. Fire**,** thus, has the ability to transform the environment, for better or worse. Indeed, "fire" encompasses different realities and phenomena, each of them raising specific issues for human populations. Defining the contours of the fire processes at play is a key step in understanding the interactions between human societies and fire, and the implications of fire for the living world.

A practical way to characterise fire processes occurring in the environment – outside of urban settings – is through the concept of "fire regime", widespread in fire ecology. The term "fire regime" emerged in France in the 19th century and in the French African colonies in the first half of the 20th century to describe traditional burning practices of local populations, considered by colonial scientists to be a cause of natural destruction (Krebs *et al.* 2010). Thus, it originally carried a negative connotation; however**,** from the 1960s it was used to describe the ecological characteristics of fire dynamics of both anthropogenic and non-anthropogenic origins (Krebs *et al.* 2010). While initially considering only the biophysical characteristics of fire, the term progressively integrated environmental, economic, social and cultural parameters (Krebs *et al.* 2010).

Based on previous definitions, Pyke *et al.* (2010) proposed characterising fire regimes according to three main criteria: temporality (seasonality, frequency), spatiality (size, patchiness), and magnitude (fireline intensity, fire severity, fire type). These characteristics are determined by a series of drivers, which can be either abiotic (weather and climate, landscape position, lightning ignitions), and thus not controllable by humans, or biotic (fuel layer, fuel type, fuel load, fuel chemistry, fuel packing ratio, fuel distribution, and human ignitions). Humans can act on these biotic drivers, and thus influence the fire regime in many different ways. Anthropogenic control of fire regimes can be exerted through the control of ignitions, but also through the control of the fuel load, its structure and its distribution in the landscape. To sum up, "fire regime" incorporates the characteristics of fire dynamics in terms of temporality, spatiality and magnitude occurring within a particular space and time, which are determined by abiotic and biotic factors, including anthropogenic and non-anthropogenic factors.

Anthropogenic and non-anthropogenic fires are distinguished by the source of ignition. Anthropogenic fires can be further characterised by the objectives that motivated fire ignition and by the burning technique employed, in the case of intentional fires. Researchers in archaeology, anthropology and history have described historical and contemporary burning techniques used by local and indigenous communities, and their objectives (Sigaut 1975; Lewis 1978; Métailié 1978; Lewis & Ferguson 1988; Russell-Smith *et al.* 1997; Anderson 1999; Shelvey & Boyd 2000; Williams 2000). Some have established typologies of burning practices according to various criteria, which can be used to describe and characterise anthropogenic fires. Today, especially in the western countries, fire is mostly used and managed by State institutions and their personnel (Castellanou *et al.* 2010), and burning practices usually follow standard guidelines. In this thesis, I will focus on anthropogenic fires ignited in the Swedish boreal forest in the context of forest management carried out since the late 19th century.

Non-anthropogenic fires are usually triggered by lightning ignitions. However, based on the assumption that every pyrogenic ecosystem on the planet has been influenced by human land-use for several centuries at least, it can be argued that purely "natural" fire regimes do not exist. Even though the source of fire ignition is not anthropogenic, the environment in which fires occur is never "natural", in the sense that it is not free from human influence. This is especially the case today when humans have modified the

Earth system as a whole through greenhouse gas emissions and global warming. I thus argue that every fire regime on Earth is a reflection of interactions between human societies and ecosystems. Fire regimes can thus be considered to be social-ecological processes (Scheller *et al.* 2019).

2.1.2 Anthropogenic fires in pre-industrial contexts

Since they learned how to control fire, human societies have set fire to their environments for various purposes, using various techniques. Thus, even in locations with supposedly no or low human incidence, like the boreal forest, fire regimes have been shaped by human practices, giving rise to cultural landscapes (Lewis & Ferguson 1988; Berkes & Davidson-Hunt 2006; Bowman *et al.* 2011; Trauernicht *et al.* 2015). For example, the moor landscapes in European Atlantic countries result from about 5,000 years of burning by local populations (Dodgshon & Olsson 2006; Hjelle *et al.* 2010; Lázaro 2010). In addition, fires built by humans, notably in the context of daily use**,** such as cooking or craft, sometimes escaped control and spread to the environment, which contributed to the modification of the fire regimes, albeit unintentionally.

Until fire suppression was massively enforced in the 19th century, burning was part of local and indigenous communities' relationship with their environment. The reconstitution, a posteriori, of local and indigenous burning practices contributed to the recognition of their role in shaping the landscapes before the arrival of European settlers (Williams 2000; Liebmann *et al.* 2016). This helped to dispel the idea that indigenous lands were a vast "wilderness" free for settlers to occupy as they pleased (Williams 2000). Indeed, the writings of early European settlers arriving in America and Australia described intense fires created by indigenous inhabitants (Pyne 1990; Crowley & Garnett 2000; Figure 3). Furthermore, Liebmann *et al.* (2016) showed how the depopulation of Native Americans in the Southwest United States after European colonisation triggered an increase in the frequency of extensive surface fires after 1640 due to the abandonment of indigenous land use. These observations go against the romanticised view that prevailed within the Western world, according to which indigenous peoples, notably native Americans, did not manage their habitat and had little or no impact on the landscape or fire dynamics (Berkes & Davidson-Hunt 2006).

Figure 3. Aborigines using fire to hunt kangaroos, by Joseph Lycett, approximately 1775-1828. Source: National Library of Australia

Since the early works of Carl O. Sauer (1947; 1961) and Omer C. Stewart (1951; 1963), scholars have reconstructed historical fire-use practices that pre-industrial societies developed on every inhabited continent (see examples for North America: Lewis 1978; Lewis & Ferguson 1988; Anderson 1999; Shelvey & Boyd 2000; Williams 2000; Australia: Russell-Smith *et al*. 1997; France: Sigaut 1975; Métailié 1978). Skilful use of fire has allowed local and indigenous societies to manage natural resources to reach various objectives (Table 1). Lewis (1993) described 70 reasons for burning by Native Americans. Scholars in various disciplines have established typologies and classifications of burning techniques, according to various criteria. Dumez (2004) used Hall's (1984) distinction between "extensive" and "intensive" fire use in South Africa to establish a classification of anthropogenic fires. Thus, he describes extensive fires as fires involving the destruction of the plant litter and the seasonal regeneration of the vegetation. One of the objectives of this type of burning is to promote the production of grass and feed herbivores, either to attract wild animals that will be hunted, or to provide pasture for domesticated animals. Extensive fires can also be ignited in order to encourage the establishment of berry-bearing plants (Gottesfeld 1994). In contrast, intensive fires are aimed at

managing cultivated areas. "Precultural burnings" are intended to prepare the soil for cultivation (Dumez 2004), for example in the context of slash-and-burn agriculture. These can be distinguished from "postcultural burnings", which are intended to facilitate the collection of the products of cultivation (Dumez 2004).

Table 1. Classification of intentional anthropogenic fires according to burning objectives, based on Berkes & Davidson-Hunt 2006; Williams 2000; Lewis 1978; Lewis & Ferguson 1988; Dumez 2004.

Production and management of food resources	Cultivation (clearing and fertilisation of fields, facilitating collection)
	Pastoralism (improvement of pastures)
	Collecting edible insects
	Hunting (promoting game species by improving forage, driving game animals into corridors and traps)
	Promoting berry patches and other plant resources, notably medicinal plants
	Management of pests, such as rodents and insects
Production of construction and craft materials	Production of basketry material
	Tree felling
Management of settlements and infrastructure	Maintaining landscape features to facilitate travel, such as travel corridors, portages, campgrounds and trails
	Protecting infrastructure and settlements, for example creating fuel breaks around camps and villages, clearing village sites
Other	Long-distance signalling
	Arson and warfare
	Political land claims

Local and indigenous burning practices were generally characterised by the ignition of frequent and small-sized fires. This contrasts with the fire regimes that would occur in regions with low human influence, where the ignition pattern would be mostly determined by lightning ignitions and thus less frequent fires (Williams 2000; Kimmerer & Lake 2001). The timing of indigenous burnings also differs significantly from the seasonality of lightning ignitions (Barrett & Arno 1982; Lewis 1993; Williams 2000). Local and indigenous burnings were usually carried out under seasonal conditions where the possibility that the fire would escape control was

minimal (Kimmerer & Lake 2001). Repeated burnings would also contribute to the reduction of fuel loads, and thus to the reduction of wildfire risks (Kimmerer & Lake 2001). At the scale of the landscape, these burning patterns often created a "fire mosaic" (Lewis & Ferguson 1988; Laris 2002), that is, a mosaic of habitat patches corresponding to different stages of vegetation after the fire, or even fire refuges. This heterogeneity would allow continuous availability of a variety of biotic resources. Trauernicht *et al.* (2015) thus argue that "pyrodiversity", i.e. the patch mosaic of successional habitat created by the spatial and temporal dynamics of fire in the landscape, is a result of anthropogenic burning patterns. Local and indigenous burning practices were also associated with increased biodiversity (Kimmerer & Lake 2001; Berkes & Davidson-Hunt 2006; Trauernicht *et al.* 2015).

Some of these local and indigenous burning practices are still used in some parts of the world today. In Europe, burning is used to improve grazing lands in several areas, notably in the Mediterranean region (Dumez 2004; Ribet 2005; Métailié 2006; Lázaro 2010). In the United Kingdom, the burning of heathlands is still practiced (Davies *et al.* 2008). In many regions, mostly located in tropical areas, burning is still used to prepare cultivation lands (van Vliet *et al.* 2012), for example in Asia (Tangjang 2009; Wangpan & Tangjang 2012; Li *et al.* 2014), South America (Litow *et al.* 2001) and Africa (Brown 2006; Araki 2007). Despite recent recognition of their benefits for wildfire risk mitigation and biodiversity conservation (Laris 2002; McGregor *et al.* 2010; Russell-Smith *et al.* 2013), local and indigenous burning practices, like slash-and-burn agriculture, are still questioned and criticised by State institutions, environmental managers and scholars (Kull 2002; Myllyntaus *et al.* 2002; Börner *et al.* 2007; Styger *et al.* 2007). This demonstrates the need for a better understanding of these ancient fire uses and their role in shaping fire regimes and the associated cultural landscape depending on the ecological context.

2.1.3 The fire suppression era

The 19th century marked an unprecedented break in fire–human interactions, and a shift in the fire regimes of many areas around the world. At that time, European states enforced strict fire suppression within their national territories and colonies. On the one hand, the colonial States sought to control the resources they had under their control, and they saw local and indigenous

burning practices as a threat to these resources. In the context of growing industrialisation, wood and agricultural resources in the tropics became particularly valuable, and this strengthened the distrust of colonial states with regard to local burning practices (Pyne 1997b; 1998; Kull 2002; Krebs *et al.* 2010). It was an aspect of the colonial appropriation of the lands to enforce fire regimes that complied with the colonial representations of fire and their interests (Pyne 1990; 1998; Kimmerer & Lake 2001; Cronon 2011).

On the other hand, the emerging ecological sciences, often grounded in colonial contexts (Robin 1997), contributed to shaping negative representations of fire. At the beginning of the twentieth century, the representations of fire in the scientific community were determined by the paradigm of ecosystem equilibrium, which prevailed at the time. This view developed within western science under the strong influence of American ecologists, notably Frederic E. Clements, one of the founders of plant ecology (Callicott 2002). He developed the understanding of ecosystems as uniform biotic communities pre-determined by soil and climatic conditions, undergoing linear changes, along a process that he called "succession", and leading to a state of equilibrium, the "climax" (Callicott 2002; Clewell & Aronson 2013). Thus, ecologists and forest managers saw ecological perturbations, like insect outbreaks, floods, or fire, but also human activities, as destructive forces, external to the functioning of ecosystems, which jeopardised the natural succession towards the climax (Pyne 1997; Kuuluvainen *et al.* 2002). Colonial scientists believed that local burning practices were the cause of phenomena of savannisation, soil degradation, desiccation and desertification, which had supposedly degraded pre-existing primeval and luxurious forests in Africa and other subtropical regions (Fairhead and Leach 1995; Kull 2000; 2002). Métailié (1981) and Pyne (1998) also note the contempt of scientists of the 19th and 20th century in Europe for the use of fire, which they considered to be archaic.

Fire suppression thus became the dominant fire management strategy in Europe and its colonial lands, and in North America. In eastern North America, the suppression of indigenous burning practices was enforced as early as the 1700s, associated with the eradication of indigenous populations and land-uses (Kimmerer & Lake 2001; Carroll *et al.* 2010; Cronon 2011). In Yellowstone National Park, established in 1872, fire suppression was instituted in 1886, and became effectively implemented in 1945 (Turner *et al.* 2003). In Ponderosa pine forests of Western North America, Forest

Services implemented strict fire suppression in the early 20th century in the hope of preventing wildfires and preserving timber resources (Langston 1995). Fire suppression in the USA notably went through a public awareness campaign, resting on the famous "Smokey Bear" figure (Figure 4). In Europe and its colonies, as the economic value of timber rose, burning practices were legally restricted or prohibited (Krebs *et al.* 2010; Fernandes *et al.* 2013). In central and western Europe, local burning practices persisted during the first half of the 20th century, until modernisation following World War II, which entailed a strict ban on burning practices (Lázaro 2010). Active fire suppression was coupled with urbanisation and population migrations from rural areas to cities. This contributed to what Pyne called the "pyric transition", that is, a shift in the fire regime, where fire was removed from the open landscape to be contained in industrial facilities (Pyne 2017).

Figure 4. First 'Smokey Bear' poster, 1944.

2.1.4 The era of fire restoration?

Advances in several scientific fields, principally during the 1970s, led to an understanding of the negative impact of fire suppression and to reconsider the role of fire in the environment. Within the field of ecological sciences,

the paradigm shift that occurred in the 1970s led to the recognition of ecological perturbations, including fire, as integral parts of ecosystem functioning (Callicott 2002; Krebs *et al.* 2010). This shift was triggered by the realisation that the climax theory was more an ideal than an observable entity, since perturbations kept occurring and environmental conditions kept changing (Clewell & Aronson 2013). Moreover, ecologists recognised the detrimental effects of the exclusion of ecological perturbations for ecosystems. In the case of fire, the detrimental effects of fire suppression for ecosystem functioning and forest regeneration, but also for wildfire risks came to be recognised by the scientific community and forest services (Pyne 1998). In the mid-20th century in the USA notably, it was increasingly recognised that the prolonged absence of fire led to fuel accumulation and to the emergence of large wildfires (Parsons & DeBenedetti 1979; Pyne 2001; Krebs *et al.* 2010). Clement's equilibrium theory was thus progressively abandoned, and replaced by the non-equilibrium paradigm (Pickett & Ostfeld 1995; Fiedler *et al.* 1997; Callicott 2002). In this concept, ecosystems are conceived as heterogeneous units undergoing recurrent disturbances occurring at different temporal and spatial scales in the ecosystem (Clewell & Aronson 2013). These advances led to new recommendations concerning fire management. In the USA, the return of fire to ecosystems was already formalised in a report presented in 1963 by Aldo Leopold, considered one of the founders of environmentalism (Leopold *et al.* 1963; Krebs *et al.* 2010).

At the same time, during the 1970s, ecological restoration emerged as a way to counteract ecological degradation caused by industrialisation and urbanisation, and to restore ecological perturbations deemed necessary for ecosystem functioning, including fire (Egan *et al.* 2011; Clewell & Aronson 2013). Ecological restoration is currently recognised as a major issue for biodiversity conservation**,** and is highlighted in international reports and conventions, like the Convention on Biological Diversity (CBD 2012: decision XI/16), the Aichi Biodiveristy Targets (CBD 2010: decision X/2) and the International Panel for Biodiversity and Ecosystem Services (IPBES 2018).

After about a century of fire suppression, prescribed burning was introduced as one way to carry out ecological restoration. Prescribed burning had been used in forestry management in the early 20th century in the USA and northern Europe as a forestry measure, to prevent the accumulation of fuel, thin dense tree stands, and prepare the soil for forest regeneration (Krebs

et al. 2010; Lázaro 2010). It started to be implemented as a regular management tool in the 1980s in the context of wildfire prevention and biodiversity conservation (Montiel & Kraus 2010). There is now a consensus in the scientific community to use prescribed burning as an ecosystem management tool, notably in North America (Brown *et al.* 2004), Australia (Russell-Smith *et al.* 2013), southern Europe (Fernandes *et al.* 2013), and northern Europe (Halme *et al.* 2013).

A determining step in ecological restoration is the choice of the reference state, or reference ecosystem, which will define the objectives of the restoration operations. In the first developments of ecological restoration, the reference state often corresponded to the climax (Callicott 2002; Clewell & Aronson 2013), or to a pre-human state of the ecosystem, often imagined as the pre-European settlement state in the Americas and Oceania, or as a pre-industrial state (Jackson & Hobbs 2009). Since then, it has been argued that, considering changing environmental conditions, restoring a past stage of a degraded ecosystem is not always feasible nor desirable, especially in the context of future environmental uncertainties posed by climate change (Brown *et al.* 2004; Halme *et al.* 2013). The upsurge of wildfires that has been occurring over recent years again challenges the model of fire management that has been developed and forces the scientific community to re-evaluate the role and the place of fire in ecosystems, and thus the goals of ecological restoration.

In addition, the reconsideration of the nature/culture dichotomy, which had structured Western science in its understanding of the role of humans in nature, also has consequences for the goals and principles of ecological restoration (Egan *et al.* 2011). At the same time as the rise in environmental concerns in the ecological sciences during the 1970s, the social sciences seized on the subject of human-nature relationships and thus fuelled a debate as to the role of humans in ecosystem functioning (Egan *et al.* 2011). It was demonstrated that no ecosystem on Earth was free from direct or indirect human influence, even the mythic Amazonian "virgin" forest (Balée 1998; Levis *et al.* 2017). In the case of fire, once it was recognised that fire regimes have been influenced by humans for millennia on every inhabited continent, restoring a "natural" fire regime becomes a meaningless proposal. Choosing the reference for fire restoration thus involves taking into account the human influence in the reconstitution of historical fire regimes (Pyne 2001; Seijo & Gray 2012). In colonial contexts, this entails investigating the role of

indigenous burning practices in shaping fire regimes and ecosystems (Pyne 1997b; Kimmerer & Lake 2001; Storm & Shebitz 2006).

Moreover, recognising the role of human populations, notably local and indigenous peoples, in shaping ecosystems, has led the proponents of ecological restoration and scholars to recognise that ecological criteria alone cannot be considered in the choice of the reference ecosystem and the restoration objectives. It is now acknowledged that restoration goals are never neutral nor purely objective, and that restoration practices will have consequences for the society that, locally, will have to live with the restoration process and the restored ecosystem. Therefore, it is argued that restoration planning should take into account the social and cultural implications of ecological restoration (Egan *et al.* 2011; Clewell & Aronson 2013). In addition, restorationists also recognise that insights from human and social sciences are needed in order to reveal, formalise and fully integrate sociocultural dimensions into restoration design (Egan *et al.* 2011). Possible ways to integrate sociocultural factors into restoration practices comprise programmes based on participation, community-based programmes, or the inclusion of local and indigenous ecological knowledge in restoration planning (Carroll *et al.* 2010; Egan *et al.* 2011; Uprety *et al.* 2012; Clewell & Aronson 2013; Mistry *et al.* 2019).

2.2 Fire and forest management in northern Sweden

2.2.1 Pre-industrial fire regimes

The boreal forest is a pyrogenic ecosystem, characterised by recurrent fires and fire-adapted species. In Fennoscandia, the tree layer of the boreal forest is dominated by Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and birches (*Betula pubescens* and *Betula pendula*), with a minor component of a few other deciduous tree species from the genera *Salix, Populus* and *Sorbus* (Esseen *et al.* 1997). Understory vegetation consists of three main components, present in different proportions depending on the forest type. These include ericaceous dwarf-shrubs, the most abundant being bilberry (*Vaccinium myrtillus*), lingonberry (*Vaccinium vitis-idaea*), black crowberry (*Empetrum nigrum*), and heather (*Calluna vulgaris*), feather mosses (*Pleurozium schreberi, Hylocomium splendens*), and reindeer lichens, a

functional group including *Cladonia stellaris, C. arbuscula, C. rangiferina* and *C. uncialis* (Nilsson & Wardle 2005).

Fire is considered to be the primary natural disturbance of the boreal forest ecosystem (Niklasson & Granström 2000), most specifically in Scots pine forests, and it has acted as a major revitalising factor since the deglaciation of the Scandinavian peninsula and the establishment of the boreal forest some 10,000 years ago (Wallenius 2002). Pre-industrial landscapes were characterised by a mosaic of habitats structured in great part by fire regimes, which maintained open all-aged multi-storeyed stands (Östlund *et al.* 1997). The fire rotation controlled the age-class distribution of forest stands, and the diversity of fire types contributed to the diversity of the vegetation composition (Zackrisson 1977; Nilsson & Wardle 2005).

Some researchers have undertaken the task of characterising historical fire regimes and their drivers in northern Fennoscandia, and demonstrated the influence of human populations in shaping fire regimes in previous centuries (Tirén 1937; Niklasson & Granström 2000; Wallenius *et al.* 2004; Granström & Niklasson 2008; Rolstad *et al.* 2017). In his seminal fire history study, Zackrisson (1977) established the frequency and dates of historical forest fires in a river valley in northern Sweden located at latitude 66°-64°. He found that during the period 1551-1975, about 1% on average of the study area was affected by fire every year. He calculated that the mean interval between fires was about 80 years. He also showed differences in the fire frequency depending on the forest type, topography, exposure, and biotope. Notably, Scots pine forests of the lichen-*Calluna* type established on flat, sandy river terraces have a mean fire frequency of 45.8 years, while mixed coniferous forests of the *Vaccinium myrtillus* type on north-facing hillslopes with moraine soils have a fire frequency of 122 years. Wallenius *et al.* (2004) calculated a mean fire interval of 63 years for the period 1340-2000 in a study area located in Russian Karelia at latitude 64°58'.

Granström and Niklasson (2008) proposed hypotheses for the possible control of fire regimes by humans in the boreal forest based on the potential benefits and drawbacks that fire could present for historical livelihoods. The first inhabitants of northern Fennoscandia established themselves about 9,000 years ago, after the deglaciation of the Scandinavian Peninsula (Bergman *et al.* 2004). They lived off hunting, gathering and fishing, and established settlements along the main watercourses (Bergman *et al.* 2003). They hunted reindeer and moose (*Alces alces*), which had a strong cultural

value (Lundberg 1997). Thus, Granström and Niklasson (2008) suggest that fire would have been valuable for early inhabitants of the area because it created favourable habitats for the moose. Human populations might thus have taken advantage of the natural fire regime without seeking to modify it, but Granström and Niklasson (2008) suggest that burning would have been an attractive option to ensure the availability of moose habitat. Pyne (2012) suggests that fire could also have been used to facilitate bear hunting, and to create bait to lure wild reindeer.

Before the colonisation of northern Fennoscandia by southern settlers, starting in the 1500s, the area was inhabited by indigenous Sami people, whose subsistence then relied on a combination of hunting, fishing and reindeer herding. It is commonly believed that Sami people were averse to fire because it could destroy ground lichens that constituted the reindeer's main winter pasture (Niklasson & Granström 2000). The settlers who increasingly occupied the area from the 1500s imported their agricultural practices, which included burning of the forest floor to create cattle pasture and, to a minor extent, slash-and-burn agriculture (Hamilton 1997; Niklasson & Granström 2000; Carcaillet *et al.* 2007; Pyne 2012). Population growth and the onset of these burning practices correspond to an increased number of fires from the 1600s in Sweden (Zackrisson 1977; Niklasson & Granström 2000), but also in other regions of Fennoscandia (Lehtonen *et al.* 1996; Lehtonen & Huttunen 1997; Wallenius *et al.* 2004; Rolstad *et al.* 2017). Niklasson and Granström (2000) calculated that 0.8% of a study area located in northern Sweden at latitude 63°56' burned each year prior to 1650. This increased to reach 1.4% during the period 1650-1870, with a peak of 2.8% during the period 1830-1860. They could find no correspondence between the climatic trends since the 1500s and the changes in the fire regime, but found a better correspondence with changes in human population and land-use. Intensification of agriculture by settlers during the 18th and 19th centuries induced a shift in the fire regimes, going from very large fires of several thousand hectares to smaller ones (Niklasson & Granström 2000; Carcaillet *et al.* 2007).

2.2.2 Modern forestry, fire suppression and the regeneration burning era

From the second half of the 19th century, a sharp decrease in the number of fires and burn area has been observed (Zackrisson 1977; Engelmark 1984;

Lehtonen & Huttunen 1997; Niklasson & Granström 2000; Wallenius *et al.* 2004; Wallenius 2011). Zackrisson (1977) calculated a mean interval since the last fire of about 155 years**,** compared to the 80 years he had calculated for the whole 1551-1975 period. This increase was due to the fire suppression strategy that was implemented in northern Sweden from the 1860s. At that time, in the context of industrialisation, the value of timber increased and forestry became a major economic resource for Sweden (Östlund *et al.* 1997; Roberge *et al.* 2020). Fire suppression was thus carried out to protect timber resources, enforced by newly established public forest services and implemented through strict legislation regulating fire use (Niklasson & Granström 2000; Wallenius 2011; Pyne 2012). The use of fire by farmers was prohibited, education and surveillance campaigns were carried out, as well as active extinguishing of forest fires (Zackrisson 1977; Granström & Niklasson 2008; Wallenius 2011). Thus, fire was eliminated from the boreal forest ecosystem.

Instead of fire, forestry became the major driver of the boreal forest ecosystem during the 20th century (Östlund *et al.* 1997; Berg *et al.* 2008). From the 19th century, selective cutting, or high-grading, was carried out in northern forests. This consisted of logging trees with high economic value, while trees of lesser value were left standing, with a reliance on natural tree regeneration in the gaps created (Roberge *et al.* 2020). However, as early as the 1850s, poor regeneration of high-graded forests was observed, and the boreal forest was increasingly considered to be mismanaged and "degenerated" (Holmgren 1959; Granström 1991; Östlund & Roturier 2011; Lundmark *et al.* 2013). In 1883, the National Board of Forestry (Sw.: *Skogsstyrelsen*) called attention to the alarming state of the northern forests and initiated scientific investigations to solve the regeneration issue (Holmgren 1959). This notably led to the establishment of the Swedish Forestry Act in 1903, which introduced the obligation for forest owners to ensure the regeneration of the forest stands they felled (Ekelund & Hamilton 2001; Widmark 2006).

Despite the fire suppression strategy, and the distrust raised by the use of fire because of the risk of triggering wildfire, some forestry scholars and managers discussed the role of fire in the regeneration of Scots pine stands as early as the 1880s (Holmerz & Örtenblad 1886; Holmgren 1959; Granström 1991; Nilsson & Wardle 2005). The expansion of Norway spruce over Scots pine in forests that had undergone high grading was a strong

argument in favour of burning (Holmgren 1959). Burning followed by natural regeneration or sowing was advocated as a forest regeneration method and applied in several districts in Norrbotten County (Holmgren 1959; Granström 1991).

However, burning still raised some doubts and criticism, as some of the prescribed fires escaped control (Granström 1991), and because wildfires had been a frequent issue for the early forest industry. Moreover, in the 1890s, Norway spruce started to acquire more economic value, which mitigated the interest in burning as a tool to regenerate Scots pine (Holmgren 1959; Granström 1991). Besides, clearcutting, which was experimented with in some parts of Sweden from the 1880s, was supposed to be sufficient to ensure forest regeneration, and it was applied more widely from the early 1910s (Holmgren 1959; Lundmark *et al.* 2017).

However, the results of these new methods were judged unsatisfactory, notably in Malå State Forest district, where regeneration methods like digging ditches and sowing on clear-cut areas gave poor results (Holmgren 1959; Jonsson 1965). From 1920 to 1952, Joel Ephraim Wretlind (1888-1965) was forest manager in the State Forest district of Malå and he experimented with burning as a forest regeneration method from the 1920s. He is known in the northern Swedish forestry community as the "father of regeneration burning" (Segerstedt 2015), or the "prophet of modern forestry" (Öckerman 1998). At the beginning of the 1940s, the failure of the high-grading system, still used as the dominant logging method in northern Sweden, became obvious, and Malå forests stood out as an exception with respect to the quality of regeneration (Ebeling 1959; Granström 1991). The wide application of burning for forest regeneration purposes in the 1950s-1960s is attributed to Wretlind's tenacity to have burning recognised as an efficient regeneration method (Granström 1991; Pyne 2012).

Wretlind was the first to theorise exhaustively about the conditions required to carry out regeneration burning, the burning technique, as well as economic aspects, notably in two reports he published in forestry journals in 1932 and 1948. Wretlind particularly recommended burning forest stands established on "raw-humus", that is a soil composed of a ground layer of organic matter covering mineral soil, which were hard to regenerate in northern Sweden. This was particularly the case for Norway spruce and mixed forest stands with a ground vegetation composed of feather mosses

and bilberry (Wretlind 1932, 1948). Wretlind's writings are still a reference when it comes to regeneration burning (Weslien 1996).

Between 1952 and 1955, about 35,000 ha was burned every year on average in Sweden, representing 17% of the regeneration area. Up to 44,000 ha were burned during the peak year, 1953 (Uggla 1957). Regeneration burning was associated with clearcutting, which became the predominant logging method in Swedish forestry from the 1950s (Kuuluvainen *et al.* 2012). At that time, mechanisation started to permeate forestry**;** chainsaws and tractors to carry the timber replaced saws, axes, horses and timber floating (Eliasson 2011; Roberge *et al.* 2020). Mechanical soil scarification followed by regeneration through seeding or planting was introduced in the 1970s, and it progressively replaced regeneration burning as a soil preparation method (Granström 1991; Östlund *et al.* 1997).

2.2.3 Sustainable forestry and fire restoration

In the 1970s, Swedish forestry took a new turn with the integration of environmental considerations into the management of productive forest areas (Enander 2007), triggered by the growing environmental movement and the evolution of ecological and forest sciences (Simonsson *et al.* 2015). From the 1960s, ecologists and environmentalists raised concerns about the integrity of the forest ecosystem (Lindkvist *et al.* 2011; Sténs *et al.* 2019). The negative effects of forestry on forest species were acknowledged, and the forestry sector implemented conservation and environmental measures in response to criticism expressed by the public (Enander 2007). The environmental revolution in Swedish forestry was really achieved in the 1990s, pushed by the international influence of the 1992 Rio summit (Simonsson 2016). A new Forestry Act was adopted in 1993, which affirmed the objective to combine productivity and environmental factors, including biodiversity preservation (Swedish Forestry Act 1993: 1).

The role of fire in the conservation of the boreal forest ecosystem and biodiversity has been an important focus of discussion about sustainable forest management (Eckerberg & Buizer 2017). In the 1990s, ecosystem degradation due to forestry and fire suppression was widely assessed (Östlund *et al.* 1997). The absence of fire resulted in a decrease in multi-aged and semi-open Scots pine forests, and in fire-adapted and fire-dependent species, notably deciduous tree species like Silver birch (*Betula pendula*),

goat willow (*Salix caprea*), and aspen (*Populus tremula*). This decrease affected other fire-adapted organisms that depended on these species, including insects, birds, lichens, mosses and fungi (Östlund *et al.* 1997). In addition, the prolonged absence of fire in unmanaged areas or nature reserves was deemed to be the cause of the evolution of the boreal forest ecosystem from a fire-adapted mixed Scots pine forest to spruce dominance (Zackrisson 1977).

Sustainable forest management thus included the implementation of conservation measures aimed at preserving or restoring ecosystem structures and processes linked to ecological disturbance regimes that had been suppressed, including fire (Östlund *et al.* 1997; Angelstam 1998; Nilsson & Wardle 2005; Roberge *et al.* 2020). The Swedish Environmental Protection Agency (Sw.: *Naturvårdsverket*) introduced fire management in protected areas owned by the state in 1993 and, from 2005, required Swedish counties to develop regional fire management strategies (Eckerberg & Buizer 2017). In addition, the European Union has implemented environmental policies that favour fire restoration, like the project "Life Taiga", which provided that Swedish County Administrative Boards would light 120 fires in nature reserves across Sweden between 2015 and 2020 (Life Taiga 2020). Major objectives of fire restoration are to preserve the forest landscape by counteracting the phenomenon of "sprucification" occurring in Swedish forests, and to favour fire-dependent species.

In parallel to the national and European policies, the development of independent forest certification systems in the 1990s also contributed to the introduction of biodiversity conservation into forestry and to the rehabilitation of fire. The Swedish Forest Stewardship Council standard was initiated in 1996 by the World Wildlife Fund (WWF) and the Swedish Environmental Protection Agency (Keskitalo *et al.* 2009). Its content was established by a working group that included stakeholders with interests in forest management, namely forest owners' associations, forestry companies, environmental NGOs, workers' unions and the Sami people (Simonsson 2016). The Pan European Forest Certification (PEFC) standard was established soon after, by the forest owners' association who had withdrawn from the FSC working group because they deemed its requirements too high (Simonsson 2016). In Sweden, the FSC standard is adopted by most forestry companies and thus covers most of the productive forest surface – about 10 million hectares of forest – compared to PEFC which is more common

among small-scale forest owners (Widmark 2006; Keskitalo *et al.* 2009). While the PEFC standard does not require burning, the (FSC Sweden 2010: 67) includes fire restoration as one of the objectives of sustainable forestry:

> Fire-fighting and prevention has become so successful that some intentional burning has become necessary to mimic natural boreal disturbance dynamics and maintain biological diversity.

The standard (FSC 2010: 6.3.12) thus includes an obligation for forest owners to apply controlled burning within their forest stands:

> Managers of major holdings shall take all reasonable measures to burn an area equivalent to at least 5% of the regeneration area on dry and mesic forest land over a five-year period. Felling and burning operations shall be designed to promote fire-dependent species (…).

The standard also includes modalities to encourage the application of burning in standing forests, then called conservation burning, which is considered more beneficial in terms of nature conservation than burning clearcut areas. Thus, if burning is applied in a production forest area where the remaining timber volume is between 15% and 30% of the original volume, the actual burned area is multiplied by 1.5. If the remaining volume is equivalent to at least 30% of the original volume, the area is multiplied by 2. If burning is undertaken in a standing forest area that has been set aside for conservation purposes, the area is multiplied by 3. In addition, the standard also states that if burning is followed by natural regeneration without mechanical soil preparation, the burned area is multiplied by 1.2.

As a result of the national policy and the sustainable forestry standards, fire is currently employed in productive forests as a forest regeneration measure, through regeneration burning, and in forests set aside for conservation or nature reserves by forestry companies or the County Administrative Boards, through conservation burning (Figure 5). Despite these quotas, fire levels remain way below the historical ones. Today, fire affects 0.006% of the Swedish forest per year, of which 65% is prescribed fires and 35% wildfires (Ramberg *et al.* 2018).

Figure 5. Top: forest stand that was clearcut and burned in Västerbotten; bottom: result of a conservation burning in a set-aside forest in Norrbotten. Photos: S. Cogos

Recently, the question of fire management is further challenged by the increase in wildfires in Sweden, with a possibility that the risk of large wildfires will further increase due to climate change (Eriksson *et al.* 2016). One fire consumed 14,000 ha of continuous forest near Stockholm in 2014, becoming the largest forest fire since the mid-20th century. In 2018, the summer was exceptionally dry, and about 25,000 ha of forest burned in different places in the country (Roberge *et al.* 2020). According to Struzik (2017), we are entering a new "wildfire paradigm" that will lastingly transform boreal forests.

2.3 Fire and Sami reindeer herding in Sweden

2.3.1 Historical livelihoods and the colonisation of Sápmi

Until recently, the idea of the boreal landscape as a "virgin" environment influenced by natural processes prevailed in the scientific community (See for example Hytteborn *et al.* 1987; Hofgaard 1993; Linder *et al.* 1997; Gu *et al.* 2001). However, to the trained eye, the marks of historic land use by indigenous Sami people, though subtle, are omnipresent in the boreal forest landscape, especially in forests that have been spared by forestry (Östlund & Bergman 2006; Berg *et al.* 2011; Rautio *et al.* 2014; Norstedt *et al.* 2017).

While the origins of the Sami people and the timing of their arrival in the area have long been a subject of research and debate, it is argued that Sami ethnicity developed in Fennoscandia between the second millennium BC (Östlund *et al.* 2004) or around 0-900 AD (Rautio 2014), depending on the sources. Within the Sami population, a gradual transition from a subsistence based on hunting, of principally moose and reindeer, towards reindeer husbandry occurred, implying a change in land use and settlement patterns (Bergman *et al.* 2013). The timing of this transition is still a subject of debate (Bergman *et al.* 2008; Rautio 2014). Aronsson (1991) situates the beginning of this transition around 2000 BP, while Bergman *et al.* (2008) obtained results indicating a transition around 1000 BP. It is also suggested that a tax decree established by the Swedish Crown in 1602 and requiring Sami people to pay taxes in reindeer meat would have led to an increase in wild reindeer hunting, thus reducing wild reindeer populations, and an increase in the domesticated reindeer herds as an alternative (Moen & Keskitalo 2010). Anyhow, reindeer have always been a central element of the Sami culture and livelihood, providing fur, a means of transportation, craft material, and food.

Some studies have suggested that the importance of other resources in the historical Sami livelihood has been underestimated. Notably, Rautio *et al.* (2014; 2016) showed the importance of plant food resources, such as Scots pine inner bark and *Angelica archangelica* in Sami subsistence. Norstedt and Östlund (2016) studied historical Sami settlement patterns, which, combined with ethnographic descriptions of forest-dwelling Sami, indicate a subsistence centred on fish. Norstedt (2018) also questions the dualistic categorisations that are often made concerning the dynamics and diversity of

the Sami livelihoods: hunting / herding, intensive herding / extensive herding, forest Sami / mountain Sami. She argues that, in reality, more complex relationships between these categories have been at play.

While the Sami had been in contact with Nordic farmers, traders and tax collectors established along the Scandinavian coasts for centuries, actual colonisation started with the progressive establishment of settlers coming from southern Fennoscandia from the 1500s. Agriculture started to expand from the Baltic coastal area towards the inner lands, and settlers progressively colonised lands occupied by the Sami (Marklund 2015). At that time, the Sami were organised in communities within delimited areas, autonomously governed (Norstedt 2018).

Although they had been paying taxes to the Swedish Crown since at least the 16th century, the active influence of the Swedish state on Sami land governance only became significant from the late 17th century (Lantto 2000; Norstedt 2018). The Swedish Crown implemented a colonisation policy that included the progressive transfer of Sami land-governing capacity to the Crown (Norstedt 2018). One objective was to establish a firmer control over the area and its resources (Lantto 2000). The Crown also encouraged the establishment of settlers in the area, in order to exploit lands that were considered unutilised (Lantto 2000). Contacts with the settlers and increasing pressure on reindeer herding lands led some Sami reindeer herders, especially those living all year round in forest areas, to adopt small-scale agriculture (Lantto 2000). They had goats or cows, which they kept on a farm, in addition to their reindeer. From the mid-18th century, the Swedish Crown defined borders in northern Sweden to separate lands dedicated to agriculture from lands dedicated to reindeer husbandry**,** thus confining Sami herders to a smaller area within the western half of the region (Moen & Keskitalo 2010; Marklund 2015). Moreover, the Crown divided the forestlands into private lands allocated to farmers and state-owned lands, within areas previously under autonomous Sami governance. Sami herders only received a right of usage of the forestlands (Brännström 2017; Norstedt 2018).

In 1886, the first Reindeer Grazing Act was passed**,** meant to establish protection of the reindeer pasture rights for Sami herders (Norstedt 2018). Lantto (2011) argues that the Reindeer Grazing Act became an "instrument of control" over the Sami, who were considered to be inferior to general Swedish society. The Reindeer Grazing Act also entrusted the County

Administrative Boards with the task of delineating new Sami reindeer herding communities (Sw.: *lappbyar*, later *samebyar*) (Lantto 2000; Norstedt 2018). Although some of these new entities relied on traditional reindeer herding lands, they represent a colonial interference in Sami reindeer herding self-organisation (Norstedt 2018). This interference was strengthened by the establishment of the Lapp[4] Administration, and its Lapp bailiffs (Sw.: *lappfogdar*). Until 1971, these State agents were in charge of ensuring the communication between the reindeer herding communities and the State, as well as ensuring that the Reindeer Grazing Act was respected. More generally, they exercised power over the Sami autonomous decision-making capability (Norstedt 2018).

Colonisation processes also had impacts on the languages spoken by the Sami. Currently, there are ten recognised Sami languages, five of them being spoken in Sweden. However, the assimilation into the Swedish culture that the Sami underwent profoundly affected the use of these languages (Huss 2001; Müller-Wille 2004). Until the 1950s, the Sami were forced to speak Swedish at school, and the Sami language progressively disappeared from some families (Huss 2001). Today, national legislation supports the protection of so-called minority languages. The Law on National Minorities and Minority Languages (Sveriges Riksdag, lag (2009: 724)) affirms the recognition of the Sami languages as national minority languages.

In Sweden, the Sami have been recognised as an indigenous people by the Swedish parliament since 1977 (Sametinget 2020a). Since 2010, the Swedish Constitution has recognised the duty of the State to ensure that the Sami are able to preserve their culture and maintain their livelihood (Larsen & Raitio 2019). However, the country has received criticism and warnings from international organisations, including the United Nations Committee of Racial Discrimination, and the Council of Europe, for its failure to comply with the obligation to protect Sami rights (Larsen & Raitio 2019). In January 2020, the outcome of the lawsuit initiated by the Girjas reindeer herding community against the Swedish State opened the way for a new recognition of Sami rights and autonomy over their traditional lands and resources. The Supreme Court of Sweden delivered a verdict in favour of the Girjas community, thus recognising its rights to control the hunting and fishing rights on the community's lands (Östlund *et al.* 2020).

[4] "Lapps" (*lappar* in Swedish) was used by colonists as the name for Sami people until the 20th century. The word is considered pejorative by Sami people, and the word "Sami" (*Same* in Swedish) is now used exclusively.

2.3.2 Sami reindeer herding today

Today, reindeer husbandry remains one of the foundations of the Sami sociocultural identity, although it is practiced by a minority of Sami, with about 2,500 of the 20,000 Sami in Sweden earning an income from reindeer herding (Sametinget 2020b). In Sweden, only people recognised as Sami and who belong to a reindeer herding community have the right to carry out reindeer herding. There are 51 reindeer herding communities in the country, of which 33 are mountain communities, 10 forest communities, and eight concession communities (Figure 1). In contrast to the mountain and forest communities, in which the ownership of the reindeer can only be granted to Sami people, the reindeer belonging to a concession community can be owned by landowners. However, the care of the reindeer has to be provided by Sami people, who are then employed by the herding community.

Within herding communities, the herders undertake transhumance between summer and winter pasture areas. Within mountain communities, the reindeer and their herders migrate between summer pastures that are located in the Scandinavian mountain range and winter pastures in the inland forests, up to the coast of the Baltic Sea. Forest and concession communities undertake migrations between seasonal pastures located in the forestlands. From spring to autumn, the reindeer have access to a variety of grazing sources, including grasses, herbaceous plants, tree shoots, shrubs, and mushrooms. Winter is the critical period of the reindeer herding cycle, because the reindeer rely principally on ground and arboreal lichens (Figure 6). Ground lichens principally grow in low-productivity Scots pine forests, and constitute up to 80% of the reindeer forage in the winter (Heggberget *et al.* 2002). The reindeer access them by digging through the snow.

Figure 6. Top: ground reindeer lichen (*Cladonia stellaris*); bottom: arboreal lichen (*Bryoria fuscescens*). Photos: S. Cogos

Within reindeer herding communities, herders cooperate in the supervision of the reindeer during specific activities that punctuate the reindeer-herding year. During the winter, the social organisation is based on smaller groups of herders often belonging to the same extended family, akin to the traditional *siida* organisational unit. One of the highpoints of the reindeer-herding year is the marking of the reindeer calves, which are born in May. Early in the summer, the herders gather all the reindeer of the community, regroup them in corrals, and mark the calves they own with their individual ear mark, consisting of a specific pattern of notches cut in the calves' ears. The reindeer

are then released and they can graze freely within summer pasturelands until the autumn. They are gathered again in September, before the rut, for the slaughter of some of the males. Later in the autumn, the reindeer are gathered again to be separated into smaller herds belonging to the same winter group. The reindeer are then regrouped in the spring to carry out the migration towards calving lands. The reindeer herding year is thus composed of periods during which the reindeer can roam freely within the pasturelands, interspersed with short periods of active control of the reindeer's movements by the herders.

Until the 1960s, the herders travelled by ski or foot within their herding area, using reindeer as pack animals. Since then, they have adopted snowmobiles, cars, quad bikes, and helicopters. They can also transport the reindeer by truck to different pasture areas during the winter migrations, to avoid difficult routes. Motorisation has made herding easier in many respects, but has also introduced new costs related to fuel consumption. More recently, many reindeer herders have adopted technologies such as GPS, GPS collars to remotely follow the movements of their reindeer, and even drones, used to watch or guide the reindeer remotely. It could be said that Sami herders have fully embraced modernity, but some actually strive to maintain a more traditional livelihood despite increasing difficulties.

Today, the herders face an increasing lack of winter reindeer pasture. Both ground- and arboreal lichens are decreasing, principally due to forest management and land encroachment (Berg *et al.* 2008; Horstkotte *et al.* 2011; Sandström *et al.* 2016). Moreover, the herders are facing increasingly frequent bad weather conditions in the winter. Repeated freeze-thaw events caused by fluctuating winter temperatures lock the ground lichen pasture under the ice. The consequences of a lack of winter pasture can be disastrous, as the reindeer tend to scatter while looking for pasture, or to starve.

Because of these difficulties, reindeer herders are increasingly forced to feed their reindeer artificially in the winter. They buy pellets, hay, or cultivated reindeer lichen, which adds to their expenses (Figure 7). In areas particularly affected by forestry, notably in concession reindeer herding communities, the herders are increasingly forced to keep their reindeer in enclosures during the winter to ensure their access to fodder. Some regret the fact that it is impossible to conduct their livelihood in a traditional way, based on free grazing in the forest.

Figure 7. A reindeer herder and his grand-daughter feed the reindeer with pellets and cultivated ground lichen. Photos: A. Poiret, 2019

2.3.3 Fire, lichens and reindeer: ecological interactions

A number of studies have investigated the ecological interactions between fire, reindeer lichens and reindeer, and how they evolve over time. After a fire, the composition of the understory vegetation follows predictable changes, forming a typical post-fire chronosequence that presents a similar pattern across the whole boreal region (Ahti & Oksanen 1990; Coxson & Marsh 2001). After having destroyed the ground vegetation, fire leaves the soil bare for three to ten years. The first species that can establish after the fire are usually lichen species, which do not need to obtain their water or nutrients from the soil and need no roots. They are thus pioneer species that can establish by fragmentation or dispersal on poor soil without a humus layer (Crittenden 2000). The first reindeer lichens (*Cladonia* spp.) start establishing after a mean period of 30-40 years, with variations up to 120 years depending on geographical conditions. The reindeer lichen cover usually increases until it reaches a peak 40 to 120 years later, as the lichen mats become denser, which reduces the overall productivity (Uggla, Evald 1958; Ahti & Oksanen 1990; Miller 1996; Thomas *et al.* 1996; Kumpula *et*

al. 2000). Over time, the tree canopy closes and organic matter accumulates, which favours moist conditions on the soil surface. Vegetation productivity increases, and vascular plants and bryophytes establish and thrive at the expense of lichens (Ahti & Oksanen 1990; Miller 1996). After a mean period of 80-100 years, ericaceous dwarf shrubs such as lingonberry, bilberry, crowberry and heather, as well as an increasing biomass of feather mosses become dominant and these species end up replacing lichens until a new disturbance occurs (Nilsson & Wardle 2005) (Figure 8).

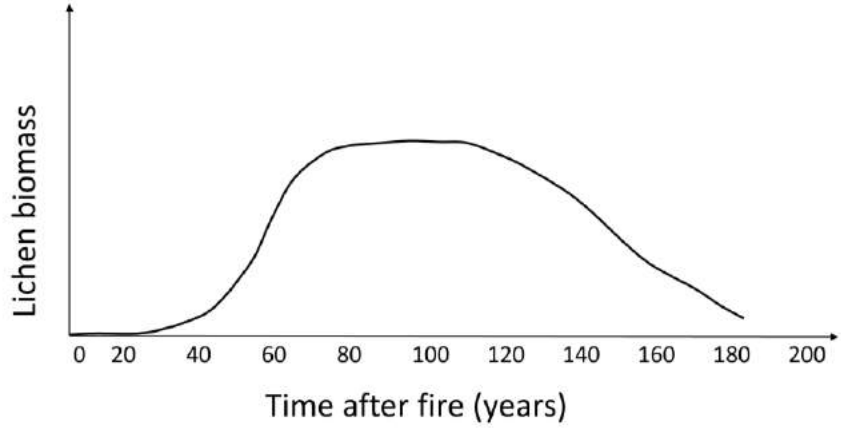

Figure 8. Evolution of the lichen biomass after a fire, based on Kumpula et al. (2000); Ahti and Oksanen (1990) and Nilsson and Wardle (2005).

The effects of fire for reindeer lichen pastures thus depend on the spatial and temporal scales considered. The short-term versus long-term effects of fire on reindeer pasture have long been discussed (Klein 1982). If occurring in a reindeer lichen-rich winter pasture, fire has a short-term negative effect on reindeer forage because it destroys the lichen for several decades (Klein 1982; Morneau & Payette 1989; Thomas *et al.* 1996; Joly *et al.* 2010). However, in the long-term, burning of shrub-type forests with a thick humus layer favours lichen as it eliminates the competing vegetation (Kivinen *et al.* 2012). Under these conditions, the maximum lichen cover, representing sufficient forage for the reindeer, generally occurs 50 to 80 years after fire (Klein 1982; Thomas *et al.* 1996; Rupp *et al.* 2006; Collins *et al.* 2011; Anderson & Johnson 2014). At the landscape scale, fire creates a mosaic of vegetation types of different ages, including lichen-rich pine heaths, and

therefore maintains long-term forage availability (Zackrisson 1977; Klein 1982; Ahti & Oksanen 1990; Miller 1996; Nilsson & Wardle 2005; Rupp *et al.* 2006; Kivinen *et al.* 2012; Anderson & Johnson 2014).

2.3.4 Historical fire–Sami reindeer herding interactions

Although of low intensity and spatially broad in scale, historical Sami land use had long lasting effects on the boreal forest ecosystem (Josefsson *et al.* 2009; Rautio *et al.* 2014). One unresolved question about historical Sami land use is whether they used fire to manage resources in the context of reindeer herding, and thus actively influenced the fire regimes. As we have seen, while fire destroys reindeer lichen pasture in the short term, it can maintain the availability of lichens in the long-term at the landscape scale. Fire, therefore, has contrasting effects on reindeer winter pasture; this leaves us uncertain as to a possible use of fire by the Sami. In his book, considered to be the first piece of Sami literature, Johan Turi, a Sami reindeer herder who described the life of the Sami in the early 20th century, gives us some clue about the relationship that Sami may have had with fire at the time. He wrote:

> "When a wolf arrives in an unwatched herd, it can kill in one night the whole herd, and when a wolf killed many reindeer, the Sami say: 'it burned like fire' (the Sami call the wolf the fire) and another to ask: 'did it cause some damage?', answer: 'what does fire not burn when it occurs?'"[5]. (Turi 1910)

An excerpt of the records from the Jokkmokk municipality related in Hultblad (1968) provides us with another piece of information about how Sami reindeer herders regarded forest fire, with an account from 1790:

> "[Anders Nilsson Kati] had most of his reindeer lichen land destroyed by a forest fire and made a claim to get two mountains on [Anders Larsson]'s land instead, called Årroivari and Oxvopni, since [Anders Larsson], as a settler, did not need them (…)."

[5] All citations of non-English sources were translated by the author.

These writings convey a rather negative view of fire among Sami people, representing it as a threat, impossible to control. Other than such sporadic writings, most of the historical sources on which researchers can rely about Sami land use and fire provide external perspectives. Among such sources, rulings from the 18th and 19th centuries relate conflicts between Sami reindeer herders and settlers because the latter used to set fire to lichen-rich forests, sometimes deliberately to force the herders to leave (Massa 1987; Granström & Niklasson 2008; Pyne 2012). Pyne (2012) recalls how Petrus Laestadius, a priest and missionary born in 1802, denounced the burning practices of the settlers because they presented risks of wildfire and endangered the Sami way of life and their survival. The accounts of Gustaf von Düben (1873), a Swedish physician who carried out an ethnographic description of the Sami, provide valuable insights about how the relationship between the Sami and fire was understood at the time, including the effects of fire on reindeer pasture, and more specifically in relation to the fires ignited by the settlers:

> Even through the most insignificant forest fire, that is fires that are called wildfires, the reindeer lichen is reduced to nothing, and it takes, according to the data we have gathered, at least ten years before the lichen comes back at such places. Through forest fire, combined with ground fire, the upper layer of the soil is more or less consumed, and it would take centuries before new [soil] can form, and before all the marks of the devastation that has affected the land are wiped out. Immense stretches of Lappland's forestland have been affected by forest fires of a more or less severe nature, and this started when the settlers became established there. Gaining an occasional pasture for their cattle, destroying reindeer pasture for the Lapps and in this way keeping the reindeer away from the meadows, (…) have been previously, and still are to some extent, sufficient reasons for the settlers to ignite forest fires. (…) during the dry summer 1868, fire raged, diligently ignited, unstoppable in the area closest to the mountains in the Pite Lappmark area, in the Lule Lappmark area and elsewhere, so that the reindeer pasturelands of the Lapps in the latter [area] were reduced by half, and many of them were forced to seek a new place for the reindeer. Fire also raged during the summer of 1871 in the upper parts of Jokkmokk and the Lapps look at the future with anxiety.

Von Düben contrasted the attitude of the settlers who set fire to the forest carelessly, to the attitude of the Sami who sought to preserve the forest from fire, thus acting as caretakers of the forest:

> Fire is [the forest Lapp's] worst enemy, for, as mentioned above, it destroys reindeer pasturelands for decades, or even for centuries. The forest Lapp is thus a caretaker of the forest like no one else in Lappland. His welfare depends on protecting the forest against fire; [its destruction] precedes his ruin, or forces him to move to other areas not affected by fire. The visible proof for this is not only the fine forests that still stand where the forest Lapps have dwelled, but also the diligence with which he hurries to every fire, the skill and efficiency with which he smothers [fires], the patience with which he watches every fire that is ignited within his land, the anxiety that can be read on his face when he finds out that a forest fire erupted. It is for that reason, and it is his, and only his, merit that unburned forest areas are still found in Lappland (…).

These accounts shaped the widespread belief that Sami reindeer herders were averse to fire because it destroyed the reindeer pastures. However, the subject of Sami reindeer herding–fire interactions is not that simple.

Archaeological studies can also provide some clues about the question. However, disentangling anthropogenic from natural sources of historical fire ignitions often proves impossible, and interpretations of fire regime control by humans in the distant past usually remain in the field of hypotheses. Hörnberg *et al.* (1999; 2018) conducted archaeological surveys that indicate an active use of fire by humans in northern Sweden at least 2000 years ago. They discuss the hypothesis that fire may have been used repeatedly to maintain lichen-dominated areas, thus improving winter grazing resources for hunted and domesticated reindeer. Thus, their results challenge the widespread hypothesis suggesting that Sami reindeer herders would have been averse to burning. In the same way, peat sample analyses in the southern part of the Swedish reindeer herding area have shown the presence of carbon deposits at regular intervals for the period 1300-1800, suggesting repeated burnings (Berglund 2012).

Some information also indicates that burned areas could constitute good spring, summer and autumn pastures, as reindeer would search for forbs and fireweed (Pyne 2012). This is particularly relevant for forest Sami, who keep their reindeer in the forest all year long. The burning of grass by Sami

reindeer herders in mountain birch forests in order to improve summer pasture has been reported (Berglund 2012). It is also well known, locally, that burned areas are sought after by the reindeer because they can escape the insects that harass them in the summer. Reindeer herders used to build small fires to create smoke and repel insects within the corrals, and some still do. This is a technique used in other reindeer herding areas, for example Siberia (Anderson *et al.* 2014; Davydov 2014). In the area of Tärendö, Norrbotten County, there is also a locally known example of a Sami reindeer herder, Johan Erik Ruosni (born in 1846), who used to set fire to large forest areas to provide favourable conditions for his reindeer. Pyne (2012) inferred the reasons that could have pushed Sami reindeer herders to use fire by establishing an analogy with Siberian reindeer herders, who are known to create spring pastures through deliberate burnings. Other pastoralist people have used fire to improve grazing conditions for their animals (Fernández-Giménez & Fillat Estaque 2012; Molnár 2014). The question of whether Sami reindeer herders have used fire in the context of reindeer herding is thus far from resolved, and all in all, very little is known about the way they dealt with forest fires and about their representations of fire.

2.3.5 Impacts of regeneration burning and fire suppression on Sami reindeer herding

Fire management implemented for forestry since the late 19th century has various effects on reindeer herding, notably on lichen winter pasture, some of which have been studied and documented. Regeneration burning, used as a soil preparation measure after clearcutting, has mostly been used in moist forests with a thick raw humus layer, and thus a low potential to be used as reindeer winter pasture (Eriksson 1976). In such forest types, it has been argued that burning favours the growth of plant species suitable for summer and autumn grazing, such as *Deschampsia flexuosa* (Eriksson 1976). However, if burning was used in dry Scots pine forests, it would destroy the lichens for several decades, as discussed in section 2.3.3. In contrast, mechanical soil preparation measures associated with clearcutting destroy some percentage of the ground lichen pasture for several decades (Eriksson & Raunistola 1990; Roturier & Bergsten 2006), but do not trigger the growth of fodder. Moreover, compared to mechanical soil preparation, burning has the advantage of burning out the logging debris which otherwise prevents

lichen growth, stops the reindeer from accessing it, and makes the herders' movement across the clearcut difficult (Berg *et al.* 2008; Roturier 2009).

Forestry measures associated with forest regeneration also have effects on reindeer pasture. Clearcutting affects the opportunity for reindeer to access the pasture in winter. Snow tends to be denser in open stands compared to standing forest (Eriksson 1976; Pruitt 1979), which makes it harder for the reindeer to dig through to the lichen. Planting methods and growing conditions in commercial forests also have an impact on the lichen cover. Forest stands tend to be denser than previously, which has translated into an increase in the standing volume since the beginning of the 20th century (Berg *et al.* 2008; Figure 9). Denser forest stands are associated with light conditions that are less favourable for lichen growth (Čabrajič *et al.* 2010). Moreover, denser forest stands tend to be moister and more fertile, favouring the growth of mosses and vascular plants to the detriment of lichens (Ahti & Oksanen 1990; Nilsson & Wardle 2005; Berg *et al.* 2008). Fertilisation has similar effects (Roturier 2009). High stem density also prevents herders from driving snowmobiles through forest areas, and thus gathering the reindeer in such stands (Roturier 2009). In addition, harvesting of old-growth forest and shorter forest regeneration rotations have reduced the percentage of old-growth forest in northern Sweden since the late 19th century (Berg *et al.* 2008), and thus the availability of arboreal lichens which mainly grow in older forests (Holien 1996; Dettki & Esseen 1998; Jaakkola *et al.* 2006). Moreover, the fragmentation of continuous old-growth forest due to forest exploitation prevents the dispersal of arboreal lichens (Dettki & Esseen 1998).

Figure 9. Top: clearcut and scarified forest stand in Malå municipality, Västerbotten county; bottom: dense forest stand in Pajala municipality, Norrbotten county. Photos: S. Cogos

In parallel, fire suppression, associated with commercial forest management since the 19th century, has had effects on the long-term availability of ground reindeer lichens. Without fire, lichen-rich Scots pine stands established on moister soils tend to become more fertile, which favours mosses and ericaceous dwarf shrubs to the detriment of reindeer lichens (Berg *et al.* 2008). Berg *et al.* (2008) report that the burning levels during the regeneration burning era never reached those of the pre-industrial fire regimes, which induced changes in the regeneration conditions of ground

reindeer lichens. Thus, they suggest that fire suppression might have favoured lichen availability at first, because it spared existing lichens, but became detrimental for lichen availability with time. However, despite these insights, little is known about the effects of controlled burning on the reindeer herding system.

2.3.6 Regulation of the forestry–Sami reindeer herding interactions

The impact of forestry measures on reindeer pasture represents a major issue for Sami reindeer herding. Since the first Swedish Reindeer Grazing Act in 1886, the rights of Sami herders over their pasturelands have been regulated, as well as their interactions with landowners, including forestry companies and private forest owners. In 1979, the Swedish Forestry Act introduced the obligation for all forest owners, including private owners, to consult Sami reindeer herding communities before carrying out any forestry measure in the reindeer herding area (Hagsgård 2016). However, this did not concern concession herding communities. The Swedish Forestry Act and the Swedish Reindeer Grazing Act together require both the forestry industry and the reindeer herding sector to consider the impacts of their activity on the other, but they do not describe how this should be implemented in practice, leaving this responsibility to the two parties (Widmark 2006).

The consultation process usually follows a series of steps: forest owners send a list of the forestry measures that they are planning in advance to the herding community concerned so that its members have time to gather and make a common decision. The herding community can either agree on the planned measures, demand some adjustments, or refuse. In the case of disagreement, the two parties can resort to a process of mediation provided by the National Forestry Agency.

However, flaws in the consultation system have been highlighted, and conflicts between the two livelihoods persist (Sandström *et al.* 2006; Keskitalo *et al.* 2009). The uneven power balance between forest managers and reindeer herding communities has been pointed out (Sandström & Widmark 2007; Eckerberg & Buizer 2017). In the case of fire management, the Sami have not been included in the overall management strategy, and the consultation is the only arena where they can negotiate the use of fire on their herding lands.

In Sweden, the forest certifications established in the 1990s, including the FSC, set stricter requirements than national legislation concerning the interactions between forestry and Sami reindeer herding (Keskitalo *et al.* 2009). The preparation of the Swedish FSC standard involved, among other organisations, the Swedish Sami Union. The 2010 FSC standard recognises the rights of the Sami to use the land "based on customs from time immemorial", and affirms how "the overall objective of the forest management is to (…) respect the cultures of local populations and Sami people, respectively, and their time-honoured rights". It includes the obligation for forest owners to consult Sami reindeer herding communities and describes the attributes of the consultation process. Regarding controlled burning, the 2010 FSC standard specifies:

> Managers with landholdings within the reindeer husbandry area shall not use prescribed burning on lichen areas of importance to reindeer husbandry (FSC Sweden 2010: 3.2.6S).

A new FSC standard was established in 2020, and notably aims to strengthen the influence of Sami reindeer herding communities in forest management (FSC Sweden 2020b). Its efficiency in improving the inclusion of Sami reindeer herders in decisions taken in the context of forestry will thus have to be demonstrated in the coming years.

3. Theoretical approaches and methodologies: investigating the human dimensions of fire regimes

3.1 Interdisciplinarity

3.1.1 Why choosing interdisciplinarity?

I will not attempt here to review definitions of interdisciplinarity, which are already the subject of numerous publications, with no resulting consensus (e.g. Klein 1990; Morillo *et al.* 2003; Huutoniemi *et al.* 2010; Mitcham 2010). It can generally be said that interdisciplinarity involves the hybridisation of methods and approaches belonging to disciplines usually separated by epistemological barriers. This thesis is thus an interdisciplinary one, because it draws on concepts, approaches and methodologies that belong to different scientific disciplines, and binds them together in a cohesive framework. I will rather attempt to explain and discuss the use of an interdisciplinary approach in the context of my research on fire–human relationships in the boreal forest.

Interdisciplinarity can be justified on the basis of the subject of research. As we have seen in section 2.1, fire regimes result from anthropogenic and natural factors that are deeply interwoven, and it is thus very hard to disentangle them and study them separately. No fire regime is purely natural, nor purely cultural, and, thus, fire connects issues belonging to different areas of knowledge – ecological, cultural, sociological, historical, political, geographical – that are typically addressed by distinct scientific fields. Addressing such phenomena through a single disciplinary approach would

necessarily miss some aspects essential to gaining a full understanding. Instead, understanding a subject such as fire requires a holistic approach, involving the effective hybridisation and integration of concepts and methods from various disciplines, rather than a simple juxtaposition. Pyne (2017: 1) argues:

> The other ancient elements have whole departments devoted to their study. Fire does not. It has no academic home of its own. It has no organizing concept. It is, intellectually, what it is in nature: a synthesis of its surroundings. (…) If fire wants a place in the academy or the realm of high culture, it will have to be more than the sum of individual subdisciplines.

In addition, fire connects issues belonging to the natural sciences and the human and social sciences, two areas of knowledge that have long been divided and hard to reconcile. As Descola (2011) notes, natural sciences and cultural sciences were fully separated during the second half of the 19th century, both epistemologically and in practice, with the division within universities and research institutions. Descola (2011: 9) argues that the result of such separation was to "make much harder the understanding of situations of interface between material phenomena and moral phenomena". If it is necessary to reconnect the natural and human and social sciences to fully understand phenomena like fire, in what some authors have called a "broad interdisciplinarity" (Jollivet & Legay 2005), the task is far from easy, since each area of knowledge has followed its own epistemological path for more than a century.

Producing an interdisciplinary thesis can be all the more challenging since, despite increasing calls to practice interdisciplinarity in academia (Morillo *et al.* 2003), there is no unified framework or guidelines to steer interdisciplinary PhD students through the meanders of such an undertaking. This is why, together with two of my fellow PhD students, we carried out a study to characterise the research practices of interdisciplinary theses in environmental sciences, and to investigate the related challenges and difficulties. To address these goals, we sent a questionnaire to PhD students carrying out a thesis in environmental sciences in France. The methodology and the results are summarised in Chassé, Cogos and Fouqueray (in press).

Some authors solve the epistemological problems posed by broad interdisciplinary research by adopting a constructivist and pragmatic

approach. Interdisciplinarity can then be conceived as a fluid process, built and rebuilt in various ways as research projects develop and during interactions with other researchers (Borderon *et al.* 2015). Jollivet and Carlander (2008) use the term "bricolage", i.e. a work not subjected to theoretical rules, to speak about interdisciplinary courses. Thus, establishing a unified theoretical framework for interdisciplinary research would be superfluous, because the modalities of the approach would be conditional on fluctuating determinants and would need to be constantly redefined.

The interdisciplinary approach employed in this thesis is the result of both my academic background and research environment, and the subject of my research. The combination of approaches, methods and concepts together forms a particular but consistent framework, suited to tackling the issues emerging from the research context.

3.1.2 Academic pathway, disciplines and theoretical foundations: a reflexive exercise

In this section, I attempt to summarise my academic background, the literature and influences that punctuated it, in an effort to clarify the implicit drivers and intentions that underlie any scientific work. Attempting to clarify the background is all the more relevant in the case of an interdisciplinary thesis, which does not follow a classical approach, and which cannot be attached to any constituted and unified school of thought.

I started my academic journey studying the ecological sciences in Canada, with the intention of becoming a conservation biologist in Arctic environments. However, the lack of consideration of the human aspects in the way ecosystems and interactions between components of the living world were studied left me wondering. On the one hand, I could not be satisfied with the inclusion of humans only as a factor of ecological disturbance or degradation. On the other hand, I was puzzled by the fact that research fieldwork left aside local populations, who evidently held detailed and extensive knowledge about their environment, including ecological processes. I questioned this for both scientific (how can we not include such rich and locally grounded sources of knowledge in our observations?), and political reasons (how can we not integrate local communities into research campaigns carried out on their own lands, especially in colonial contexts?).

My reading led me to discover the scientific movement that had grown around traditional ecological knowledge (TEK) (Freeman 1992; Berkes *et al.* 1994, 2000; Huntington 2000; Roué 2012; Berkes 2017). In this, the knowledge held by local and indigenous populations about the living world was highlighted and promoted. My reading also led me to the field of ethnoecology (Conklin 1954; Nazarea 1999; Bahuchet 2012), dedicated to the study of the relationships between human societies and their environment, in terms of knowledge and practice, but also in terms of representations. To explore these paths, I undertook an interdisciplinary master's degree in the anthropology of the environment at the French National Museum of Natural History. There, I was provided with an overview of the diversity of interactions that connect humans to the living world. I learned to consider other systems of knowledge not as beliefs, symbols or metaphors, but as another truth about the world (Nadasdy 2007). I came to consider science and indigenous and local knowledge as being different, but equally relevant, systems of knowing, interacting with and experiencing the world, thus leading to different perceptions and understandings of reality.

I thus came to realise that ecological sciences were one way to regard and understand the living world, among many others. I was introduced to the work of Philippe Descola, who teaches us that science, as we call it in the western part of the world, emerged within a specific ontology born in Europe, which can be called naturalism, and which relies on particular ways of "composing" the elements of the world (Descola & Charbonnier 2014). Namely, humans and non-humans[6] share the same physicality (we all come from a similar cellular ancestor and are built with the same elementary materials), but different interiorities (humans are beings of culture, gifted with self-awareness, and thus separated from beings of nature). Anthropology teaches us that other societies have other ways of "composing" worlds, other ways of conceiving the relationships between humans and non-humans, and that science cannot be imposed as a universal explanation of the world. Claude Lévi-Strauss (2014: 53) wrote, for a series of presentations he gave in Japan in 1986:

[6] The term "non-humans" has been increasingly used in human and social sciences over the last decades, associated with approaches aiming to reconsider the agentivity of living beings other than humans. It avoids the use of "nature", which is more symbolically charged and grounded in the Western culture.

> The anthropologist only invites every society not to believe that its institutions, its traditions and its beliefs are the only ones possible; he dissuades it to imagine that, because it deems them good, these institutions, traditions and beliefs are inscribed in the nature of things and that it can, with impunity, impose them on other societies whose system of values is incompatible with its own.

To Adell (2011), anthropology leads us to understand boundaries of knowledge not as frontiers but as spaces of discussion, controversy and debate between different modes of thinking. Thus, ecological sciences and ecological indigenous and local knowledge can (and should) be combined to build a more comprehensive and diverse picture of the reality that we seek to describe and understand, as scientists. The complementarity between traditional – or local, or indigenous – ecological knowledge and scientific ecological knowledge has been promoted in many instances (Moller *et al.* 2004; Thapa *et al.* 2008; Gagnon & Berteaux 2009; Rist *et al.* 2010; Kimmerer 2013; Lyver *et al.* 2018).

Moreover, through my reading, I came to understand the deep political value of knowledge. In environmental management settings, especially in colonial contexts, the way different sources of knowledge are mobilised and acknowledged constitutes a major political issue for local and indigenous communities (Nadasdy 1999). My research position can thus be qualified as politically committed, as I strive to investigate and highlight the multiple perspectives and narratives that coexist about the world, and especially narratives that have been overwritten by dominant ones.

I tried to take the full measure and understand the implications of the increasing calls of indigenous scholars to truly include multiple sources of knowledge in resource management and to decolonise research (Smith 1999; Simpson 2004; Louis 2007). I cannot be certain, though, that I have achieved the decolonisation of my research practice. Although my thesis project is anchored in a long-term commitment at the local level through the works of my thesis supervisors, I have only been able to lay the groundwork necessary for true co-construction of knowledge, in which local and indigenous inhabitants would play an active role in setting the goals, the focus and the methodologies of the research carried out (Prior 2007; Asselin & Basile 2018). Such an achievement demands time and local commitment, which the timeframe and the agenda of an academic thesis do not make easier.

Finally, the configuration of my thesis supervision gave a further twist to my scientific approach. This thesis was undertaken in the context of international co-supervision. In France, I am affiliated to an interdisciplinary research team called "Ecological Trajectories and Societies", itself belonging to the research department "Ecology, Systematics, Evolution". The supervision by Samuel Roturier, eco-anthropologist, provided an anchor in ethnoecology and ecology. In Sweden, I am affiliated to a research department called "Forest ecology and management", and I am co-supervised by Lars Östlund, ecological historian.

This co-supervision added a last string to my bow: history. I discovered the links that had been established between ecological sciences and history. In my thesis, I have leaned towards historical ecology (**paper I**), and towards environmental history (**papers II and III).** "Historical ecology" has developed within ecological sciences as an attempt to study historical interactions between ecosystems and humans, considered to be a factor of ecological change (Girel 2006; Crumley 2018). By including history in the study of ecosystems, the objective is to better understand their current functioning and to provide a basis for management goals in a way that integrates the role of human populations in the composition of ecosystems across time (Szabó 2010). The field of "environmental history" developed in parallel in the 1970s in the USA (Quenet 2014), and is grounded in history and geography. One major goal is to deconstruct dominant narratives about nature and the role of humans in it (Cronon 1996), notably the narratives produced by colonial States about the role of indigenous populations in the supposed degradation of nature (Fairhead & Leach 1995, 1996; Kull 2000). As Quenet (2014) argues, environmental history acknowledges that "actors of history are not only humans, but also non-humans, that is plants, trees, air masses, waters, soils, microbes (…)". To this list, we could add fire.

My approach to the question of fire–human interactions in a Sami context and the resulting papers are thus anchored in this background, which reflects a will to understand interactions between humans and their environment in a way that does not neglect the political issues at play, nor the historical foundations that have shaped the systems that unfold before our eyes today and the narratives about them.

3.2 Study areas

The studies carried out in the context of the papers comprising this thesis are based on different pieces of fieldwork, all located in the northernmost part of Sweden, in the Västerbotten and Norrbotten counties, within the Swedish part of Sápmi (Figure 10). Each piece of fieldwork covered different spatial scales. They were all located within the boreal forest ecosystem.

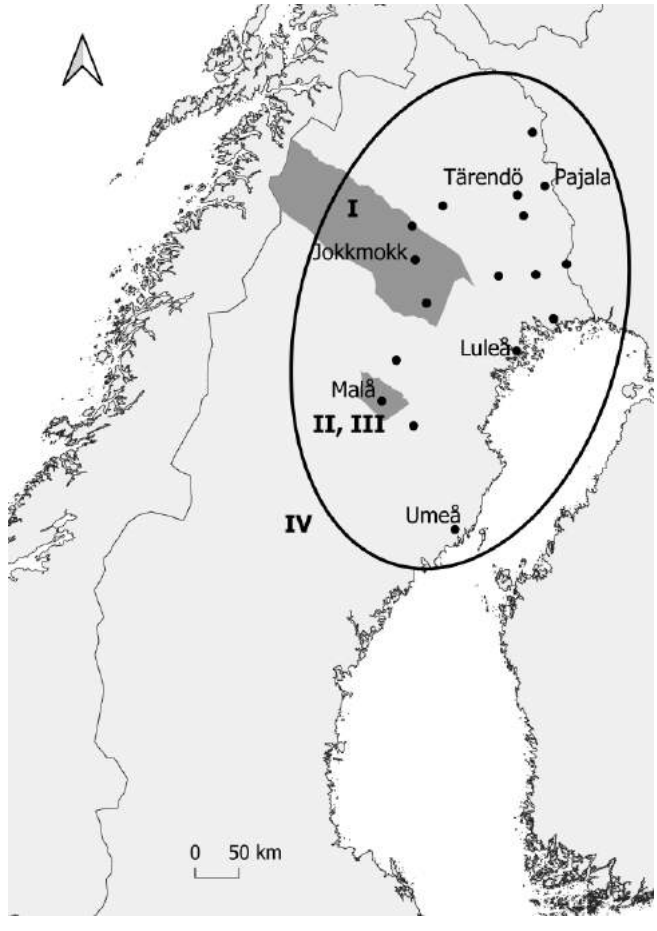

Figure 10. Study areas of the papers in northern Sweden. Study area of **paper I** corresponds to the municipality of Jokkmokk. **Papers II and III** treat an area corresponding to the municipality of Malå. **Paper IV** is based on fieldwork comprising several locations of northern Sweden, indicated by the black dots. The names of the principal locations are indicated.

3.2.1 Jokkmokk

Paper I is based on fieldwork covering the municipality of Jokkmokk, Norrbotten County. The municipality covers an area of 19,334 km^2, centred at approximately 66°37'N; 19°50'E. It includes commercial and protected forestlands in the east, and mountain lands in the west. It encompasses lands of five Sami reindeer herding communities: three mountain communities (Sirges, Jåhkågasska and Tuorpon) and two forest communities (Udtja and Slakka). The area of Jokkmokk is included in the Lule Sami linguistic area. The language is still actively used in the area, notably within reindeer herding communities. The North Sami language is also widely spoken in the area since the forced displacement of Sami families from the North in the early twentieth century. Jokkmokk is also a central location in Sweden for the Sami culture, with the presence of the 400 year-old Sami winter market, the Mountain and Sami Museum Ájtte, an outpost of the Swedish Sami parliament, a Sami handicraft school and many artists and artisans. It is also an important place of political engagement for the preservation of the Sami culture and livelihood, with a strong resistance movement against a mine development in a place named Gállok, which is within the lands of the Jåhkågasska reindeer herding community. The vitality of the Sami culture and Sami language made Jokkmokk an appropriate area for fieldwork to investigate Sami place names.

The fieldwork carried out **for paper I** included compiling ecological inventories for study sites defined as the locations encompassed by the topographic features designated in Sami place names incorporating the Sami word *roavve*, which means a Scots pine forest that has burned (Figure 11). Within each study site, 200×200 m squares were centred at the coordinates assigned to the place name. In cases where the study site was a hill or a mountain, this position usually corresponded to the top. Aerial photographs and topographic maps were used to adjust the location of the study areas in the cases where the coordinates provided by the National Land Survey did not correspond to the feature referred to in the place name. Fifteen *roavve* sites were inventoried **for paper I**.

Figure 11. One study site of **paper I**, Tjiednekroavve, seen from a mire. Photo: S. Cogos

3.2.2 Malå

Papers II and III deal with the history of regeneration burning in the State Forest district of Malå, which is within the municipality of Malå, Västerbotten County, at a latitude between 64°31'N and 65°31'N. Established in the late nineteenth century, the Malå State Forest comprised forestlands owned by the National Forest Company. Joel E. Wretlind was forest manager for the district from 1920 to 1952. At that time, the district was divided into smaller management units covering about 59,800 ha in 1954 (Wretlind 1955). From 1921, Wretlind experimented with regeneration burning as a forest regeneration tool, and applied it extensively in the 1940s and 1950s in Malå State Forest. Malå became the centre for disseminating the regeneration burning technique in Sweden.

Malå municipality also includes the annual grazing lands of the Malå reindeer herding community. The area belongs to the historical Ume Sami language area, although the language has not been actively spoken since the end of the twentieth century as a result of colonisation. Together with the region of Arvidsjaur, Malå is considered the core of the forest Sami culture and livelihood (Marklund 2015).

Malå thus represented an essential fieldwork location to investigate both the history of regeneration burning in northern Sweden, and the historical interactions between fire management and Sami reindeer herding.

3.2.3 Tärendö and Tornedalen

For **paper IV**, I took the area located around the town of Tärendö, Norrbotten County as a starting point for my investigation into the role of the interactions between forestry, nature conservation and Sami reindeer husbandry in contemporary fire domestication. Today, Tärendö is within the municipality of Pajala. According to local foresters, the area is home to a "burning culture", which has been continuously transmitted within the forestry sector over the 20th century, up until the present, due to a combination of geographical and historical factors. Notably, the low population density and the presence of many wetlands ensured the safe application of regeneration burning over the years.

The Finns imported swidden agriculture to the area, and this was practiced until the 1800s (Samuelsson 1993). Before the arrival of settlers from Finland and southern Sweden in the 1600s, the area was home to Sami communities practicing reindeer herding (Hederyd *et al.* 1991; Samuelsson 1993). Today, the reindeer herding communities of the area are organised in concessions, which means that the care of the reindeer is provided by Sami people, but any landowner can own reindeer, and have their own earmark. In concession reindeer herding communities, Sami reindeer herders have no hunting rights, and the forestry companies are not bound by Swedish law to carry out consultations with the herders.

Tärendö is also the place where the reindeer herder Johan Erik Ruosni is known for having set fire to tens of thousands of hectares of forest to create favourable environments for his reindeer (P.-J. Perttu, pers. communication, 2019). Combining a rich history of fire–human interactions and forestry–reindeer herding interactions, the area thus constituted a valuable place to study burning practices and their interactions with Sami reindeer herding. In the area, I interviewed reindeer herders from the concession herding communities of Sattajärvi, Tärendö, Korju and Muonio, as well as forestry planners and burning practitioners.

In **paper IV**, I expanded the spatial scale of my study area to match the scales of the institutions that are relevant to the research questions. Sami

reindeer herding communities function at a relatively local scale, while local offices of forestry companies are responsible for districts operating at larger spatial scales, and the County Administrative Boards are responsible for nature conservation at the scale of the county. Their staff usually operates from the main towns of the region. **Paper IV**, therefore, included interviews carried out in other locations in Norrbotten and Västerbotten (Figure 10).

3.3 Investigating fire history in relation to ecosystem change

One objective of **paper I** was to determine the vegetation characteristics of places bearing names including the Sami word *roavve,* in order to determine how they had evolved in the last ca. 100 years, and to evaluate the role of fire and fire suppression in this evolution. Thus, we characterised the vegetation by means of a botanical survey and statistical analyses, and we determined the time since the last fire (TSLF) at the study sites through dendrochronology

3.3.1 Forest ecology

Vegetation survey

Vegetation inventories were compiled at 15 study sites. The arboreal vegetation was characterised by measuring tree density and the basal area for the three dominant species, i.e. Scots pine, Norway spruce, and birches. The density was measured by counting the number of trees of each species in an 11.3-meter radius (400 m^2). The basal area was measured for each tree species with a relascope. The ground vegetation was characterised by evaluating the percent cover of ground reindeer lichens, mosses, bilberry, lingonberry, and crowberry inside a circle of 10 m radius, according to the method of Hägglund & Lundmark (2004).

Statistical analysis

Statistical analyses were performed to interpret the results of the vegetation surveys. Principal component analysis (PCA) was performed in conjunction with hierarchical clustering, using the ade4 package (Chessel *et al.* 2004) with the R 3.4.0 software (R Core Team 2013). We plotted the position of

each study site with respect to the first two principal components of the PCA in a biplot. To represent the vegetation composition at each site within the score plot, radar charts showing the values of the vegetation variables for each site were generated using the fmsb package. We tested the correlation between the PCA scores and two measured variables supposed to be explanatory, namely time since the last fire (TSLF) and tree density, to investigate the distribution of the sites along the principal component axes. We also performed linear regressions to determine the extent to which TSLF could explain the variability within the vegetation variables among the sites.

3.3.2 Biological archives: dendrochronology

Several methods can be employed to reconstruct fire history, each of them covering different time spans (Conedera *et al.* 2009). To investigate recent fire history, up to several centuries back in time, it is possible to use dendrochronology, i.e. the analysis of tree-ring growth patterns, to detect past fires (Zackrisson 1977; Stokes 1996; Wallenius 2002). This method relies on the fact that the growth rate of trees varies according to seasonal climatic variations, resulting in visible annual rings. The growth rate is also affected by environmental conditions and events, caused by ecological or anthropogenic factors, which are visible in the tree-ring pattern (Speer 2010). Dendrochronology can thus be used to date tree growth conditions spanning the lifetime of the tree, and this includes the fire history (Arno & Sneck 1977). Fire events can be dated through the dating of fire scars, which are marks left by fire on fire-adapted trees, such as Scots pines. Fire can partially damage the living part of a tree, for example if the fire pauses and burns slowly at the foot of the tree. If the tree survives the fire, the wound caused by the fire will progressively be covered by new cambium every year, thus forming a scar (Figure 12.a). A tree can survive multiple fires, which can leave multiple fire scars.

The technique of dating fire thanks to fire scars consists of coring into the scar with an increment borer (Figure 12.c,d). In some cases, especially in commercial forests that have been logged, the only trees bearing fire scars in the forest stand are dead (Figure 12.b). In such cases, it is possible to extract cross-sections from the dead trees or snags with fire scars (Figure 12.e). However, because it is impossible to know when the trees died, it is impossible to determine the year of the fire just from the cross-section. Thus,

cross-dating with a masterchronology has to be performed. Masterchronologies are built by dating many different trees in an area submitted to homogeneous climatic and geographic conditions (Schweingruber 2012). Dead trees – and fire scars – can thus be dated by superposing and matching their tree-ring pattern onto the masterchronology. To date the cross-sections taken from dead trees, I used a pre-established masterchronology from the Torneträsk area (Grudd *et al.* 2002).

Determining the age of the forest stand can also help in interpreting the fire history, and the effects of past fire on forest regeneration (Arno & Sneck 1977). In **paper I**, the stand age was determined by extracting a tree core from the presumed oldest tree, in even-aged stands. If the stand comprised several age-classes, we cored one tree for each age-class.

The dating of the samples collected in the field is then performed in the lab. I examined the tree-ring patterns using a LINTAB™ tree-ring measuring station with a resolution of 1/100 mm, and I analysed the measurements using the TSAP-Win™ software package (Rinntech technologies).

In some cases, no significant match was found between the samples and the masterchronology, and it was not possible to date the fires. In such cases, the age of the Norway spruce trees present in the stands was taken as a proxy for the TSLF. Because Norway spruce trees usually do not survive forest fires (Pitkänen *et al.* 2003), it can be assumed that forest stands dominated by Spruce trees have not undergone any fire during their lifespan.

Figure 12. a. A fire scar on a living Scots pine tree; b. a fire scar on a dead Scots pine tree; c. coring into a Scots pine tree with a fire scar; d. extracting the core from the increment borer; e. after sawing a cross-section in a dead Scots pine tree with a fire scar. Photos: a, b, d, e: S. Cogos; c: S. Roturier

3.4 Reconstructing the history of fire management though written sources

Paper II aimed to reconstruct the history of regeneration burning in northern Sweden through the analysis of the motivations and methods of one of its strongest advocates, Joel E. Wretlind, and to examine the consequences of his forestry practice on the local fire regime. To do that, I analysed written historical records kept at the Swedish Regional Archives in Härnösand. The data collected came from two separate archives: the National Forest Company's archive for Malå district, and Wretlind's personal archive. All the archive sources used in this thesis and the related papers are listed in Appendix 1. The data collected from the National Forest Company's archive are notably from Malå district's annual reports, which present, among other

information, the total area burned each year through regeneration burning or uncontrolled fires. Other sources provided information about burning, notably the area of burned stands, the dates of burning, and the forest type. The National Forest Company's archive also contained letters exchanged between Wretlind and representatives of various institutions dealing with forest management, including the National Board of Forestry, the National Swedish Forest Administration, the County Administrative Board, and the Royal County Governor of Västerbotten. Some of these letters addressed the subject of burning.

The Wretlind archive comprised documents that Wretlind himself had conserved, including drafts and published versions of various reports he had written, photographs and newspaper articles related to forest management, programmes of excursions, and descriptions of experiments he had carried out in the field. Between 1959 and 1960, he was recorded giving a detailed account of his experiments, methods and results, which constitute the "forest testament" that he could not manage to write because of his health. The recordings were later entirely transcribed and stored in Wretlind's archive.

Paper III aimed at investigating the history of fire management and regeneration burning in Malå during the mid-20th century from the perspective of Sami reindeer husbandry. It was specifically aimed at gaining an understanding of the impact of regeneration burning carried out at this time on reindeer herding. To achieve this objective, written sources from the National Forest Company were also analysed, and notably some letters written by Lapp bailiffs and the National Union of Swedish Sami (SSR). Wretlind's "forest testament" was also used, as well as the results of a questionnaire that Wretlind submitted to Malå reindeer herders in 1954, dealing with the effects of regeneration burning on reindeer grazing. Except for letters written by SSR, all these documents convey the perspective of State institutions and their representatives. The Sami perspective is largely absent from the written records.

The time span covered by these written accounts corresponds to the first half of the twentieth century, up to the 1970s. As to the geographical scope, some written sources are specific to Malå district, while others relate to Northern Sweden in general.

3.5 Investigating the human dimensions of fire regimes through environmental anthropology

3.5.1 Semi-structured interviews and ethnographical fieldwork

In order to investigate the sociocultural as well as political aspects of fire regimes in northern Sweden, and to understand fire–human interactions from the point of view of the human actors, I carried out semi-structured interviews with foresters (forestry planners and forestry entrepreneurs), nature conservation managers, and Sami reindeer herders. These interviews were the bases of **papers I, III and IV,** as well as the films *The place(s) of fire* and *The man who burned trees*. The technique of semi-structured interviews consists of initiating an open discussion with the interviewees based on pre-established but non-definitive topics. According to Brinkmann (2014: 286), semi-structured interviews allow "much more leeway for following up on whatever angles are deemed important by the interviewees", compared to structured interviews based on questionnaires. This allows the emergence of issues or topics that had not been foreseen by the researcher, and thus a more empirical approach. Moreover, the informal nature of the interview allows the participants to go beyond a strict interviewer – interviewee relationship and to establish exchanges on more equal terms.

Paper I is based on semi-structured interviews with reindeer herders from reindeer herding communities in the municipality of Jokkmokk. The interviews dealt with the significance of Sami vocabulary and place names related to forest fire, and notably the word *roavve*. The purpose of the interviews was to include the Sami perspective about these names and the places they referred to, and to understand how they were connected to Sami reindeer herding. This allowed me to gain new insights into the interactions between forest fire and Sami reindeer herding. Topographic maps were used as a support tool during the interviews. I also interviewed the consultant in the Lule Sami language at the Sami parliament in Jokkmokk in the context of **paper I**.

Paper III aimed at investigating the Sami perspective of the 20th century history of fire management and regeneration burning, and thus at providing an alternative account of the history of regeneration burning in Sweden. To

that end, I carried out interviews with Sami reindeer herders from Malå reindeer herding community, as well as two older herders from Västra Kikkejaure herding community, located in the neighbouring municipality of Arvidsjaur. The interviews dealt with the historical and contemporary interactions between Sami reindeer herding and regeneration burning, in sociopolitical terms but also in ecological terms.

The results of **paper IV** are based on interviews carried out in different locations in the Västerbotten and Norrbotten counties with Sami reindeer herders, forestry planners, forestry entrepreneurs, and nature conservation managers. The interviews dealt with the practice of each group of actors' livelihood in relation to fire management. They also touched upon the interactions established between each group of actors in the context of fire management, including the consultation process between forest owners and Sami reindeer herders.

The films are based on interviews carried out together with a master's student in geography, Andréa Poiret. We interviewed Sami reindeer herders, forestry planners, and controlled burning practitioners from various locations in northern Sweden. For the purpose of the film *The place(s) of fire*, we also interviewed two researchers in ecological history, including my thesis supervisor Lars Östlund. In this instance, the interviews were aimed chiefly at investigating the representations of the interviewees about fire.

Some tangential topics were also addressed in most of the interviews. Thus, all the interviews conducted with reindeer herders touched upon ecological processes related to forest fire and their consequences with respect to Sami reindeer herding, and thus addressed Sami ecological knowledge. The subject of the interactions between Sami reindeer herding and forestry or other land-exploiting industries also frequently came up during the interviews with Sami herders. The interviews carried out with regeneration and conservation burning practitioners often addressed technical aspects of burning, as some of them would explain in great detail, sometimes with pictures as support, the processes of regeneration and conservation burning. We also discussed issues of transmission of knowledge and know-how related to burning.

In total, I interviewed 25 reindeer herders belonging to 11 reindeer herding communities in Norrbotten and Västerbotten Counties, nine forestry planners, five conservation managers, and two forestry entrepreneurs. The interviewees were of all ages, from twenty-somethings to over 90, but most of them were men. Among all the herders interviewed, only one was a woman. There was also one woman among the forestry planners I interviewed, and one woman among the nature conservation managers. Although both the worlds of reindeer herding and forest management are becoming more balanced in terms of gender, they are still largely dominated by men. The gender imbalance in the people I interviewed is thus a reflection of the situation in the professions considered. The interviews performed in the context of making the films were carried out together with A. Poiret, and thus two of them were conducted in English. Otherwise, I conducted all the interviews in Swedish. The interviews were recorded and fully transcribed.

Furthermore, as part of a master's degree internship conducted by Juliette Picard and supervised by S. Roturier, aimed at building a model to represent the effect of different controlled burning regimes on reindeer lichen pasture, a workshop was organised with reindeer herders and forest managers in September 2019. The workshop was intended to confirm the choices made in the construction of the model with field practitioners, and to discuss some aspects of the model. It provided an opportunity for me to hear what the herders and the foresters had to say about fire management in an original context, since thinking in the context of the construction of a model raises unprecedented questions, and thus unheard-of explanations.

Ethnographic fieldwork classically involved long-term stays, often several years, in one or several communities. Ethnographies usually tried to describe every socio-cultural aspect of a community in order to draw up a holistic account of the life of this group of people (O'Reilly 2012). Today, given the time frame of doctoral theses, ethnographic fieldwork tends to be shorter and more narrow in its scope. In the context of an interdisciplinary thesis especially, the amount of time dedicated to ethnographic stays is necessarily shorter than in a classical thesis in ethnology. In total, I spent 25 weeks in the field in various locations in northern Sweden over the four years of my PhD. Repeated stays at some locations allowed me to meet and interview some of the interviewees several times. On two occasions, I was invited to assist with the feeding of the reindeer in the winter. Some interviews also led

to excursions into the forest, including burned stands, with both reindeer herders and forestry planners, where we could discuss issues related to fire management in the field. However, I could not take part in any controlled burning during my thesis, principally because of the impossibility of planning the day of a burning in advance, combined with the constraints of an international thesis. I had to plan my fieldwork without knowing whether some burning would be organised in the area I had planned to stay.

3.5.2 About "representations" and "domestication"

Here, I attempt to provide definitions about key concepts that I use in this thesis, which can be interpreted in different ways depending on the scientific field and thus pose some difficulties in the context of an interdisciplinary thesis.

First, the concept of representation, which I use **in paper IV**, and in section 4.1 of this thesis, is used in every human and social science, most notably in geography, cognitive sciences, sociology and anthropology. To Friedberg (1992), the cognitive sciences are interested in "mental representations", while sociology deals with "social representations", and anthropology with "systems of representations" gathering a body of ideas and values specific to one society. According to Mathieu (2000), in geography, representations of space, subjective by essence, are opposed to a concrete or objective definition of geographical space. Apart from a few exceptions, the term is rarely defined when it is employed. Mathieu (2000) defines social representations as systems of interpretation and symbolisation that drive how people interact with the world and with each other, built through a cognitive and physical interaction with reality. Representations are built through a sensory relationship with reality, i.e. through perception. Thus, representations are situated at the interface between human conscience and the environment. However, Mathieu (2000) argues that the concept of representations has not been mobilised to any great extent in the study of relationships between humans and the natural environment. Yet the necessity of including representations in the study of human–environment interactions has been raised. For example, the anthropologist M. Godelier (1974: 39) argued:

> It is necessary to analyse carefully the system of representations that individuals and groups, belonging to a specific society, are formulating about their environment. It is based on these representations that these individuals or these groups act upon the environment.

To Friedberg (1992), systems of representations are the driving forces of practices carried out by humans in the environment, and thus determine the shapes taken by this environment. Diverging representations of the environment can thus underlie conflicts between groups of people about the use of this same environment. Investigating these representations is thus an essential step in understanding how different groups of people interact in relation to a shared environment.

To sum up, "representation" can be understood as the dual process through which human conscience (collective or individual) grasps reality and through which reality is evocated, for example through a word, a discourse, a picture, a memory, a piece of knowledge.

Secondly, in **paper IV**, I also introduce the concept of domestication to describe the fire management system in the Swedish boreal forest. In the literature, "fire management" is used almost exclusively to describe contemporary interactions between humans and fire (see for example Pyne 1984; Russell-Smith *et al.* 1997; Bowman *et al.* 2004; Mistry *et al.* 2005; Butz 2009). In contrast, "fire domestication" is confined to the pre-historical process through which hominins learned to control fire (de Lumley 2006; Bowman *et al.* 2011; Albertyn *et al.* 2012; Biggs *et al.* 2016). However, focusing on "management" is not without consequence for the framing of research. To Henry Fayol (2016), whose work predates the management concept and theory, "to manage is to forecast and plan, to organise, to command, to co-ordinate and to control". Thus, "management" steers the attention to aspects related to social organisation and strategic action in a utilitarian perspective. In contrast, the domestication framework allows us to study aspects of fire–human interactions that are left aside by the "fire management" framework. Notably, what is actually going on between fire and humans when they interact with each other? What is going on between humans themselves when they interact about fire? How do people think about fire?

Anthropology has addressed and revisited the question of the domestication of plants and animals. Differing from an understanding of domestication as a one-time historical process, anthropologists have interpreted domestication as a continuous process, always renewed and renegotiated (Shanklin 1985; Digard 1988). Thus, Scott (2019: 35) proposes an understanding of domestication as the "continuous effort of *Homo sapiens* to shape all of their environment as they please"[7]. However, this idea has not been much applied to fire in the scientific literature. Despite this, as we have seen, human groups across the world have developed various techniques to control fire and reach various objectives, which have never ceased to be renewed over time. Fire domestication can, therefore, also be considered a continuous process, in which the domesticated status of fire is never fully acquired and must always be renewed. Scott (2019, 54) argues that fire can be considered a "semi-domesticated" element.

In the case of plants and animals, the mutuality of domestication has also been demonstrated (Cassidy & Mullin 2007). It is argued that in the same way that domesticated species undergo modifications in terms of physiology, morphology, behaviour and sociability, human groups also are changed through the domestication process. In various disciplines, including zoology and anthropology, domestication is thus conceived as a coevolution process (Cassidy 2007; Stépanoff *et al.* 2017), in which domesticated organisms have domesticated us as much as we have domesticated them (Budiansky 1992; Scott 2019). This view applies very well to fire, if we consider the major effects that fire domestication had on the evolution of hominins. Thus, Scott (2019, 59) suggests that we actually are "pyrophites", i.e. a species adapted to fire, like some tree, plant and mushroom species, and argues that "we have literally been domesticated by fire". This view highlights the active role played by domesticated beings or processes, including fire, in domestication systems.

3.5.3 Toponymy: place names as markers of ecological change?

In **paper I**, I investigated Sami place names connected to fire and used them as historical landmarks to study ecological change, in connection with Sami reindeer herding. A few studies have used place names as historical

[7] Translated to English from the French edition

landmarks to reconstruct past ecological conditions and study ecological change and historical land uses in other geographical areas (Sousa & García-Murillo 2001; Henshaw 2006; Conedera *et al.* 2007; Sousa *et al.* 2010; Jones 2016). Place names often describe the places they refer to in a literal way, thus providing us with a picture of what these places looked like at one point in the past. It is then possible to compare this picture with the ecological characteristics of the place today. For example, Sousa *et al.* (2010) use place names as environmental indicators of climate change by showing how place names related to wetlands reveal the desiccation of these wetlands in a natural reserve in Spain. Place names are considered to be amongst the most stable linguistic elements in a language, transmitted orally often unaltered across several generations (Thornton 1997; Burenhult & Levinson 2008), making them particularly suitable to be used as historical markers of ecological change.

As in many languages, Sami place names are often compound words including a generic term that designates a topographic feature (lake, river, hill…) and an additional term that particularises the feature and the place in question. This additional term can be a literal or metaphorical description of the place, or refer to various elements of the Sami landscape and culture, such as plants, animals, myths, religion, people, or events. A number of Sami toponyms are connected to reindeer herding. For example, *Vuojatädno*, a river located in the mountain area North-West of Jokkmokk, means the "river with places where the reindeer herd can swim over".

In **paper I**, I investigated Sami place names connected to forest fires. I first undertook research into Sami vocabulary connected to forest fires based on dictionaries compiled by linguists in North Sami (Nielsen & Nesheim 1979; Svonni 2013) and Lule Sami (Grundström 1946-1954; Korhonen 1979), and place name records (Grundström 1927; Collinder 1964; Korhonen & Anderson 2010). I found three Sami words and their derivatives related to forest fire in the place names of the study area, corresponding to Jokkmokk municipality: *buollem* or *buollám*, *guorbba* and *roavve*. *Buollem* and *buollám* derive from the verb *buollet*, 'to burn', and mean 'burned' or 'burned forest area' (Grundström 1946-1954; Korhonen 1979). *Guorbba* means 'burned place' or 'terrain that has been destroyed by forest fire' (Grundström 1946-1954; Korhonen 1979). *Roavve* means 'a place where there has been a forest fire' (Collinder 1964; Grundström 1946-1954; Korhonen 1979; Korhonen & Anderson 2010). Nielsen and Nesheim specify

that it is "covered with young trees", and to Svonni (2013) the word refers to a pine heath.

To find place names comprising Sami words related to forest fire, I used the Swedish National Land Survey's online map of place names, as well as the place names records of the Swedish Institute for Language and Folklore. I was able to identify 39 place names comprising these words (30 for *roavve*, five for *buollem* or *buollam*, and four for *guorbba*). In addition, I found one *roavve* place name, Tjájároavve, in Ruong (1964). I also looked for the identified place names on the first ordnance survey maps of the area, published in 1890 and 1893, and filled out with names by Grundström (1927-1934), as well as in a 1936 place names register (Pellijeff 1992[1936]). The spelling of Sami languages, established in the early 20th century, has undergone several transformations during recent decades. The spelling of the place names mentioned in **paper I** and in this thesis follows the official Sami orthography for Sami place names (Nyström *et al.* 2007). In **paper I**, I focused on place names including the word *roavve* because they were the most numerous in the study area, and also because some definitions referred to a forest type – a pine heath –, which suggested the possibility of comparing this type with the vegetation of these places today.

The approach of using place names as historical ecological landmarks is not without difficulties. First, in most cases, it is impossible to know exactly when the places were named, and thus how much time has passed since then. Secondly, it is often difficult to know exactly the boundaries of the place designated, unless they are obvious in the naming, for example in the case of a lake or a mountaintop. In many cases, names refer to areas or topographical entities less easily delineated, like hills. Thirdly, place names can undergo linguistic variations across time, which can deviate them from their original meaning. Moreover, it is generally impossible to know what motivated the original assignation of the name. In the case of *roavve* place names, a doubt can arise: has the place been so-named because it has actually burned, or because its features look like a place that has burned? Interpreting the meaning of place names in a contemporary context poses the risk of incorrect interpretations (Sousa & García-Murillo 2001). Moreover, place names are not always straightforward descriptions of the environment. Conedera *et al.* (2007) point out that place names often "represent a creative process, a subjective interpretation reflecting the feelings of local inhabitants at the time of naming". Investigating the perspectives of local inhabitants about the

names and the named places through an ethnological inquiry can be a way to avoid misinterpretations.

The difficulties actually stem from the fact that place names are not just geographical markers, simply describing the places they designate. Place names are, before anything else, cultural constructs, reflecting the relationships established between humans and their environment. To Thornton (1997: 209):

> Place names tell us something not only about the structure and content of the physical environment itself, but also how people perceive, conceptualize, classify and utilize that environment.

Thus, place names reflect the representations of the local inhabitants about the landscape they inhabit, but also their manner of inhabiting and interacting with the landscape and its places, in the past and in the present. It is essential to bear these aspects of place names in mind in order to avoid misinterpretations.

3.5.4 Film as a method complementary to research

In the context of this thesis, I supervised an internship conducted by a first year master's student in geography with experience in photography, Andréa Poiret. We carried out fieldwork in northern Sweden together, aimed at investigating the representations of fire by researchers, forestry planners and reindeer herders, with the intention of creating a film on this theme. The method consisted of conducting and recording semi-structured interviews, and then A. Poiret took photographs of the interviewees in their work environment. We selected sections of interviews, and A. Poiret edited a film based on these excerpts and the photographs (*The place(s) of fire*).

After the interview we had with him, a forestry planner in charge of regeneration burning for his company took us on an excursion to the forest to show us his technique of burning Scots pine trees to create fire scars. I filmed the process, and edited a film based on the film clips and excerpts of the interview (*The man who burned trees*).

Many authors have written about the different aspects of film and filming in anthropology (Rouch 1974; 1978; Ruby 2000). It has not been the focus of my research, but rather a side project, so I will not address this topic in

any great detail. However, I do wish to explain what motivated me to make these films and to include them in my thesis. One of my main motivations was that the film format – like other formats based on media other than text – allows dimensions of the relationship between humans and their environment to be conveyed that cannot be transmitted in the written form. Jean Rouch (1978: 7) wrote that "recording and then projecting images and sounds introduces a concrete element which books – even illustrated ones – leave out". Some sensory dimensions can thus be transmitted through film. Visual of course, through the pictures and the video, but also sound. During this fieldwork, we also recorded sounds of the environments we travelled through, which were the environments of our interviewees, some of which we included in the first film. Recording sounds forces us to consider other dimensions of the fieldwork and to be attentive to the "soundscape", i.e. the overall sonic environment of an area (Porteous & Mastin 1985). Although I have only scratched the surface of these sensory aspects in my thesis, and it is not the focus of my research, I wanted to stress the interest they present to fully embracing and understanding, in a holistic way, a subject of research such as the interactions between humans and the environment.

Moreover, through film, the discourse is conveyed more directly, through the actual voice of the interviewees. The way we conducted the interviews, the choice of the excerpts to include, and the way to present them required, of course, a certain level of interpretation of the discourse of the protagonists. However, the discourse is still freed from the analytical dimension inherent in the research work, and is able to incorporate some emotional dimensions. Interviewing people about their way of life, and livelihood, can touch upon sensitive or emotional issues, which are usually not the focus of scientific inquiry. Nevertheless, these dimensions and issues are essential in shaping the representations that people formulate with respect to the world and the way they act in it. These films were one way to convey these dimensions.

Finally, films are formats that can be disseminated and shared easily with the public, and to those who participated in them, much more easily than scientific writing. This was one of my main motivations for experimenting with other media to convey the results of my research. In the introduction to his book *Picturing culture: explorations of film and anthropology*, Jay Ruby (2000) cites an excerpt of an interview with Jean Rouch, who said:

> The idea of my film is to transform anthropology, the elder daughter of colonialism, a discipline reserved to those with power interrogating people without it. I want to replace it with a shared anthropology. That is to say, an anthropological dialogue between people belonging to different cultures, which to me is the discipline of human sciences for the future.

The films included in this thesis are a first and embryonic attempt to convey the sensory and emotional dimensions of the results of my research and to democratise them.

4. Results and discussion

4.1 Representing fire: conflicting representations of an ambivalent phenomenon

The management of fire in the boreal forest and the application of burning brings together several groups of actors who inhabit and act upon the landscape, namely forestry planners and practitioners, including burning practitioners, conservation managers, and Sami reindeer herders. As stated in section 3.5.2, groups of individuals act upon the environment based on their representations of it. Investigating representations of the environment is thus key in understanding the positioning of each group of actors in the frame of environmental management, and thus how they interact with each other. In this section, I specifically focus on "representations" as discourses evocating fire. In addition, it is important to note that representations about one specific element of the environment, like fire, do not stand alone. They are rooted in a wider system of representations about the world, common to a particular cultural group, together forming a specific worldview, or ontology. Although I focus here on representations relating to fire, it is important to understand how they are connected to the wider picture.

4.1.1 Forestry: fire as a "natural" way to regenerate forests

Joel Wretlind and the beginnings of regeneration burning

Since the beginnings of forestry in the Swedish boreal forest, foresters had to make choices about how to deal with fire. As we have seen in section 2.2.2, forest managers first sought to exclude fire from the boreal forest

landscape to preserve timber resources. However, foresters focusing on regeneration issues progressively began to consider the role of fire in regenerating commercial forests. Thus, with modern forestry, new fire management practices emerged and with them, new representations of fire developed.

In **paper II**, I examined the motivations of forest manager Joel Wretlind in his use of fire in forest regeneration. Historical records and published literature show that Wretlind's personal approach to forest management and fire played an important role in shaping fire management, and in the development of regeneration burning in the mid-20th century in northern Sweden. Investigating Wretlind's personal writing and ideas, notably the recordings forming his "forest testament", can shed light on his representations of fire and the wider history of fire management in northern Sweden, and help us to understand the foundations of today's representations of fire within the forestry sector.

As shown in **paper II**, in his writings, Wretlind recounts how he came to consider fire to be an efficient and appropriate forest regeneration method. Through a combination of personal observations of past fires and burnings, inspiration from literature in the emerging science of forestry, and experimentation, he came to develop his own views about fire and its use in forestry. Wretlind thus came to advocate burning as the foremost regeneration method on raw-humus forest stands with a thick moss cover. To Wretlind, the objectives of regeneration burning were to provide exclusive access to nutrients for the tree seedlings by eliminating the moss layer and competing vegetation, and to increase the soil fertility.

Throughout his discourse, Wretlind often invokes "nature" in support of his arguments in favour of burning. To him, burning had to be favoured as a forest regeneration method because it reproduced "nature's processes", or "nature's style". Thus, in relation to the results of his burning experiments, he argued:

> I have had many prominent foresters here who were astonished by the results. They are actually not surprising: I have started my work by doing background investigations into how these natural forest stands came about. (…) What happened in nature should be reproduced now if we follow nature's directives". (Appendix1: 15c).

Wretlind speaks about "nature" as an autonomous being, orchestrating and maintaining natural processes and elements in ways that humans cannot reproduce. To Wretlind, fire was one of nature's ways to control these elements. The use of fire thus amounts to allowing nature to do its work. Wretlind recounts, for example:

> Where nature has taken care of the regeneration through a forest fire that was so severe that even the acidic hollows burned, the richest plant material is often found just within them, mostly birch, but also pine and spruce. I have therefore, on my burned stands, thrown wood and brush into them [the hollows] so that they also are burned. As a result, within the parts of Nasbergsfältet [one of his experimental areas] burned for self-regeneration between 1923 and 1926, the strongest regeneration can be found in some of these hollows. Nature can do what we cannot". (Appendix 1: 13).

His faith in nature's ways also made him reluctant to use mechanical soil preparation methods. As stated in **paper II**, Wretlind invokes God as the hand behind nature's work, and thus indirectly relates forest fire to God's work. For example, he considered the results of artificial regeneration "quite pitiful" compared with the "natural forests God gave to us after fire" (Appendix 1: 13).

To Wretlind, this trust in nature was not incompatible with economic considerations. In his writings, there is no contradiction between the control of fire to reach objectives of productivity and the preservation of a natural process. To the contrary, to him, the reproduction of nature's ways, through burning, is necessary to ensure forest productivity, efficient regeneration, and good timber production.

We can see from Wretlind's writing that long before the conceptualisation in scientific terms of the role of perturbations in ecological functioning, and the emergence of ecological restoration, there was a will to maintain and reproduce natural processes – such as fire – deemed indispensable to the good functioning of the boreal forest and to its regeneration. Of course, spontaneous, uncontrolled fires were still seen as a threat to the forest resource. However, as long as it was controlled, fire came to be seen as highly desirable by Wretlind and foresters who adopted his methods in the 1950s-1960s.

Burning practitioners and foresters today: fire is still seen as a guarantee of good and "natural" forest regeneration

Similar considerations to those found in Wretlind's writing can be found in the current discourse of burning practitioners and foresters. As shown in **paper IV**, the foresters I interviewed also refer to "nature" or to a "natural" character when they talk about the role of fire in forest regeneration. One forestry entrepreneur and experimented burning practitioner, and one forestry planner from the Tärendö area presented a similar reasoning:

> I think it is the best soil preparation method, because it is natural. It is nature's own way to get it [the forest] to grow (interviewee 43, forestry entrepreneur, Tärendö, February 2020).

> I think burning is an excellent soil preparation method, and it is a natural method, because forests have always burned. (interviewee 38, forestry planner, Tärendö, Februrary 2020)

The foresters I interviewed did not consider fire to be a threat to the forest that had to be suppressed at all costs. On the contrary, to them, fire had always been part of the functioning of the boreal forest. They saw fire as an integral component of the boreal forest, and of its "normal function", as one of them said. Another one argued:

> You see the trees are growing fast even. The young plants they are growing fast in the burned area. So I do not think it [fire] is a disaster for nature, I do not think so. It is one of the legs it stands on, I think. (interviewee 20, forestry planner, Norjsö, 2019)

Thus, in the same way that Wretlind considered burning to be an optimal method to regenerate forest because it reproduced nature's ways, the forestry planners I interviewed still considered burning to be the best forest regeneration method. One forester we interviewed for the film *The place(s) of fire* repeated many times his conviction that burning was "the most natural way of renewing pine forests":

> It makes me very glad to see that it produces very effectively, and we can see that this is really something that *Pinus sylvestris* is made for, through hundred thousands of years. This is the method that is the most natural of them all. (…) You feel in your whole body that this is the natural way of renewing forests. (interviewee 32, forestry planner, Tärendö, 2019)

This conviction went beyond practical considerations of regeneration efficiency and forest productivity. To him, using fire was a way to perpetuate natural processes, and allowed him to achieve a feeling of fulfilment in his job as a forester. For another forestry planner and burning practitioner, burning was a way of "paying back nature", and "serving nature" (interviewee 20, Norsjö, 2019). This suggests that – some – foresters consider themselves to be responsible for nature because of their impact on the forest, and that, by igniting fires, they somehow restored some integrity to the natural system that they contributed to degrading.

In their sociological study of foresters in France, Boutefeu and Arnould (2006) note that foresters are engineers have been trained to manage economic resources, and that a functionalist understanding of forests has prevailed until recently. However, they also raise the role of sensitive dimensions in the work of foresters, notably aesthetic dimensions, which they reconcile with a more rationalistic view of forests. Analysing the representations of foresters regarding the care of regular woodland (French: "futaie régulière"), Boutefeu and Arnould (2006: 65) write:

> The idea of a beautiful, slender forest is connected to the satisfaction known when raising a stand of majestic, straight, clean and tidy stems, with no brush. The forester expects to be able to contemplate the regular woodland like a cathedral.

Similar aesthetic considerations arose in the discourse with the foresters I interviewed. Notably, several of them described Wretlind's forests, which were regenerated with fire and which have today reached maturity, as ideal forests in terms of homogeneity and regularity. A retired forestry planner confided that many of the stands that they considered beautiful, with a high density of pine trees, even, and growing well, arose from burnings (interviewee 44, Kalix, 2020) (Figure 13).

Figure 13. Top: a "Wretlind forest" in Malå municipality, regenerated through regeneration burning, shown by a forester as an example of an ideal forest stand: homogeneous, even-aged, with straight stems, and a clear vision through the trees; bottom: forest stand burned in 1948 in the area of Tärendö, described by a forestry planner as a stand that used to be a "bad forest", now "restored".

Thus, while forestry is a very technologically-driven and productivity-oriented activity, foresters in the field are still concerned with the preservation of what they consider to be a natural forest, and an ideal landscape. Through years of interacting with the forest, they develop a

profound understanding of the ecological processes at play, and they care for the integrity of this place they work with and inhabit. To many foresters, the forest is more than just a workplace. Many of them carry out all sorts of activities in the forest, often hunting. They connect their activity as foresters to a wider network of interactions with the forest and take on the role of caretakers. This was especially the case for the forester featured in the film *The man who burned trees*. He demonstrates a holistic vision of nature and of how he could, and should, contribute to its functioning. While he is surely an exception in his approach to forestry and in his practice of burning trees, his discourse intersects with the discourse of other foresters I interviewed in their desire to take care of the forest and of all the living beings that inhabit it, and in their trust that fire is a favoured way to reach such objectives.

4.1.2 Nature conservation: fire as an ecological perturbation to restore and a tool to increase naturalness

As we have seen in 2.2.3, with the rise of sustainable forestry in the 1970s, fire stopped being seen as a tool to regenerate commercial forests, to be seen as a means to preserve biodiversity and restore boreal forest ecosystems. Through the FSC standard, fire restoration became framed as a forest management objective, and conservation burning came to be implemented by conservation managers working for the County Administrative Boards or forestry companies. The conservation managers I interviewed have fully integrated the view that ecological perturbations like fire are an integral part of ecosystem functioning. As stated in **paper IV**, conservation managers, like forestry planners, conceive fire to be a "natural phenomenon", or a "natural process", which must be restored. To them, it is important, therefore, to restore fire as a process with a value in its own right, and to counteract fire suppression, now considered to represent an ecological degradation.

As shown in **paper IV**, fire, through conservation burning, is also conceived as a way to preserve a forest landscape deemed to be natural. It is notably a way to counteract the phenomenon of "sprucification" that is happening in the Swedish boreal forest, i.e., an increase in Norway spruce forests in areas historically dominated by Scots pine, partly attributed to fire suppression. To conservation managers, this phenomenon drives the boreal forest landscape away from its natural composition. Burning is seen as a particularly effective way to preserve Scots pine forests, which are associated with a history of recurrent fires, and are "marked by perturbation", as one

conservation manager said. On top of being a means to preserve a process and a specific landscape, fire is also a way for conservation managers to preserve associated structures and species. They explained how fire creates "substrates" that will host fire-dependent species and thus a whole web of connected organisms.

Conservation managers put nature conservation objectives into practice through formalised frameworks of decision-making. Notably, conservation managers refer to "natural value evaluations" (Sw.: *"naturvärdesbedömning*") to decide whether conservation burning would be a suitable measure to apply in protected forest stands. Conservation managers and forestry planners carry out natural value evaluations when they come across forest stands with potential conservation interest. The natural value evaluation follows a pre-established protocol. For example, the National Forestry Company (Sveaskog 2020) requires the establishment of sampling points within the area being considered, and the compilation of an inventory of the number of ecologically-valuable trees and dead trees per hectare, forest history, forest continuity, age of the oldest tree layer, and occurrence of rare or endangered species. Forests with a high "natural value" can be set aside for conservation or designated nature reserves. Conservation managers must then establish a plan for the management of the area. They can decide to let the forest follow "free development" if they consider that the ecological value is high enough and that doing nothing is the best way to preserve it. Forests that present a "lower natural value", or "trivial values" as one conservation manager said, can be assigned to "nature conservation management". This typically applies to forests that are deemed to display an "obvious human impact", according to this same conservation manager.

Using a concept such as "natural value" both reveals and imposes particular representations of the environment. To Bernard (2005), who studied the appropriation of performance indicators by foresters in France, Belgium and Luxembourg, indicators express representations and management principles, but they also impose categories of thought and judgement. Systems of indicators such as the natural value evaluation are designed to standardise and homogenise procedures. One conservation manager recognised that "it is very good to have numbers, because then we can compare" (interviewee 42, Luleå, 2020). However, such systems of indicators also inevitably steer and constrain local representations of the forest. Here, the "natural value evaluation" system is grounded in a scientific

understanding of the forest in which "naturalness" is numerically measurable.

Conservation burning is conceived as one nature conservation measure that can be applied to "strengthen" or "preserve" the natural value of a forest stand. The biologist of the Norrbotten County Administrative Board explained:

> I think that species and the natural environment are so severely threatened today, that it may be better to keep the most beautiful areas untouched, and instead burn the forests of lesser quality, because we will get a better quality there eventually. (interviewee 40, Luleå, 2020)

Forestry planners use the nature evaluation system as well and refer to it when considering the necessity of using fire in the forest:

> It would need to burn a bit more, especially in those eco-parks. (…) They have these really old pine forests that have burned many times, and they would need to burn again to keep the natural value there. There are enormously big "armour-bark" pines that are really old and cope well with fire. Then a new generation of pines will grow from underneath. And if you burn again most of them disappear, it becomes dead wood, and a few of the younger ones get through and get fire scars, and they grow again. So it would be needed. (…) If we want to preserve the natural value, then we must undertake conservation burning. (interviewee 38, forestry planner, Tärendö, 2020)

To conservation managers, but also to forestry planners, fire confers a natural quality to an environment considered to be degraded, and allows increasing the "natural value" of an environment deemed not natural enough.

4.1.3 Sami reindeer herding and fire: threat in the past, opportunity for the future

Today, Sami reindeer herders are usually not in direct contact with forest fire. With the exception of some herders who work for forestry companies in the summer and sometimes participate in regeneration or conservation burnings, fire management is in the hands of foresters and firefighters, in the

case of uncontrolled fires. However, reindeer herders experience the consequences of fires and burnings on the forest, and on reindeer herding. With the exception of summer 2018, forest fires and burns are so rare nowadays that this experience remains limited. However, the herders have kept alive the memory of earlier periods in history when natural fires had a much greater influence on the forest, and thus on their livelihood. This memory still weighs heavily on how reindeer herders view fire and burning activities.

Thus, because of how forest fires could have affected reindeer herding in the past, some herders still see fire as a threat. As we have seen, reindeer winter pasture is central to Sami reindeer herding, and herders' representations of fire and burning are inevitably connected to reindeer pasture. An older reindeer herder from Jokkmokk recounted the situation experienced by some of his ancestors:

> Fire is bad for the forest. The lichen was destroyed, so they were forced [out], they could not have their reindeer there, and they were forced to move, they looked for lands at some other place. (interviewee 6, reindeer herder, Jokkmokk, 2017).

Before fire suppression was effectively implemented in the late 19th century, forest fires could occur pretty much anywhere in the boreal forest, with a higher frequency in dry Scots pine forests, thus destroying reindeer winter pasturelands. According to such accounts, reindeer herders were at the mercy of unpredictable fires and simply had to endure their consequences. As a result, they tended to be rather averse to fire:

> It is not strange that people were scared of fire because fire is dangerous for people. Back in the days, people were very vulnerable to fire. (…) It had a strong meaning for people who lived back then. If it burned somewhere, it had consequences. (interviewee 4, reindeer herder, Jokkmokk, 2017)

Natural forest fires thus represented a threat, as did fires ignited by humans who colonised the Sami area. Some herders I interviewed still had strong feelings about the fires that were ignited by settlers until the late 1900s to create pasture for their cattle, sometimes purposely to push the Sami away:

> When the settlers came, they burned an incredible amount, to get pasture for their animals. They burned, but… reindeer herders were chased away naturally. They did not dare protest against this. And they had few reindeer, small herds that they could move. They moved until there was pasture. (interviewee 6, reindeer herder, Jokkmokk, 2017)

There is also some resentment about how burning was managed for forestry during the mid-20th century. During the 1950s-1960s, especially, regeneration burning was applied on a large scale, as we have seen in 2.2.2. Older herders remember this period and younger ones have heard stories from their parents. They hold similar opinions about how foresters sometimes burned lichen-rich forests, thus destroying reindeer winter pasture:

> My parents they were active when they [the foresters] started with the burnings, so they had the opinion that fire was a catastrophe (…) In the 1950s, (…) they burned a lot, they burned, they did not choose, they burned even though they destroyed the reindeer pasture, they burned dry heaths. And the scepticism comes from there. (interviewee 4, reindeer herder, Jokkmokk, 2017)

> He [his dad] was sceptical, naturally. (…) because he knew that it would change, the lands that would be burned, there would be a change, and then we did not know how. So, it is clear that he was scared of fire. (interviewee 23, reindeer herder, Arvidsjaur, 2018)

The representations of reindeer herders about fire and burning are actually complex, notably due to the complexity and different effects of fire on the forest, which vary over time, as discussed in section 2.3.3. What is bad in the short term is not necessarily bad in the long term. The herders are thus torn between conflicting representations of fire, which reflect the conflicting effects of fire at different time scales. In addition, when it comes to burning, the tumultuous relationships between reindeer herding and forestry come into play and complicate the picture even more:

> They were sceptical, they did not like it. (…) Because they burned in unsuitable lands. So that… But it was not only bad. There were areas where it was good that

> they burned. And even, I know that in the area here, many reindeer herders thought that it should burn. But during the worst burning period, they burned every type of land, and it was not good. Because the lichen lands, they do not recover. Or, they recover, but it takes several generations (…) before reindeer lichen comes back. (…) Along the Pite river, there was a ranger of the State Forest Company [Sw.: *kronojägare*], he used to set fire to every type of land. So I remember, where it was newly burned, you could only see stones. And it was inappropriate. Maybe today a little reindeer lichen has started to come back on these lands. (…) It was in the 1950s. (interviewee 22, reindeer herder, Arvidsjaur, 2018)

Even though some herders recognise the positive effects of fire, to them, fire is not a harmless tool to use, and must be handled with great care. The Sami have actually turned tending campfires into an art, described by Yngve Ryd (2005) in his book *Eld* ("fire"). This is why, when discussing whether Sami herders might have ignited fires in the forest in the past, to facilitate the production of food or pasture resources for example, several herders I interviewed were sceptical. According to them, fire was considered too dangerous to be ignited deliberately in the forest:

> I have never heard that people have deliberately used fire, from what I know. Because fire was always… Because people lived in *kåta* [the Sami traditional hut], it was important, you had to be careful, for example when people lived in *kåta* in the winter, and when they built up a fire, because it could start to burn. It could have consequences if an uncontrolled fire got started. Forest fires were uncontrolled, and they had consequences. (interviewee 4, reindeer herder, Jokkmokk, 2017)

The first older herder cited here did not believe that Sami people had used fire either, because to him, it went against the "Sami way" of interacting with "nature", and the parsimonious use of its resources:

> It does not suit the Sami way either, because we are so careful about nature, we do not log a birch or other tree if we do not have to, or need to. We do not shoot an animal if we do not need to. We do it only if we must. Either to protect the reindeer or for the food, for example. And this has always been true, from what I

> have heard, since long ago in my family. It has been [the way] in my family for a long time. That we do not take any surplus, we take just what we need. (interviewee 6, reindeer herder, Jokkmokk, 2017)

Forest fire necessarily leaves a visible and substantial imprint on the forest landscape. From what is known, through archaeological studies and from the Sami people themselves, historical Sami land use has left only tenuous marks on the boreal forest landscape. Leaving no trace behind is even claimed to be a principle to follow in nature by some Sami herders I interviewed. One herder recounted how you could easily distinguish a fire hearth made by a tourist from a hearth made by a Sami: Sami hearths are just big enough to meet the immediate needs for a fire, while tourists' hearths are unnecessarily big.

If igniting a whole forest fire hardly fits such an ethic of resource use, some information nevertheless indicates that Sami reindeer herders probably have set fire to forests in the past, as mentioned in 2.3.4. The story of Johan Erik Ruosni, the Sami known for having ignited thousands of hectares of forest in the late 1800s, is well known among Sami herders of the Tärendö area, and the thought that he burned forests purposely for the sake of his reindeer is not surprising to them.

The distrust of fire and its uses expressed by some of the herders I interviewed can thus be explained by the fact that Sami burning practices are too old to be part of living memory, and/or because of regional disparities. There are actually differences in the herding modalities between mountain and forest herding communities that might explain different uses and views of fire. Mountain herders would spend the summer in the mountain lands, away from any possible forest fire:

> Most often, the Sami came up from the mountains, so they did not know if it [land] had burned unless they saw it. When they migrated down, there was snow in the trees, and they did not see that it had [burned], unless the reindeer started to dig there. Then they could look at what was on the ground, and they could see if it was black. Then it had burned. With the means they had at the time, people could not know so much. They were away half the year. They left in May and came back in November, December until Christmas, to the forestlands. (interviewee 3, reindeer herder, Jokkmokk, 2017)

In contrast, herders from forest communities used to spend the whole summer in forestlands and would have had direct contact with any forest fires. Like today, herders belonging to forest herding communities sometimes participated in the regeneration burnings carried out in the 1950s-1960s. In the film *The place(s) of fire*, an older reindeer herder from Arvidsjaur recounts his experience with regeneration burning. Although such experiences may not have all been positive, it still allowed reindeer herders to develop some familiarity with fire. Furthermore, because they dwell in forests all year round, forest Sami herders could, and can, follow the evolution of the vegetation and the recovery of reindeer pasture at burned places every year, in the long run. As a matter of fact, the reindeer herders of forest communities I interviewed were generally positive about fire and burning, and they connected fire with the occurrence of winter reindeer pasture:

> The heathlands there, it is good because it has burned, burned so hard that nothing grows much except for reindeer lichen (interviewee 1, reindeer herder, Jokkmokk, 2017).

This association between fire and good winter reindeer pasture is also reflected in Sami place names connected to fire. As shown in **paper I**, the definition of the Sami word *roavve*, found in many place names of the Lule Sami area, connects forest fire to lichen-rich forests and thus good reindeer winter pasture. This shows that, for as many years as this word has existed at least, the Sami have been perfectly aware of the long-term effects of fire on ground lichen regeneration.

Some of the herders I interviewed also considered fire to be an integral part of forest functioning and nature, thus coinciding with the view held by forestry and conservation managers:

> If the forest never burns, it dies, so to say, it becomes old and, becomes nothing… While forest fires entail renewal, actually. It gives the opportunity for other species to establish. (…) Nature works so that what is death for one individual is life for another. It is so. So that, there is an evolution in nature, change is part of nature. (interviewee 4, reindeer herder, Jokkmokk, 2017)

This herder explained that he came to this understanding of fire by observing burned areas and how lichen would recover, but also by reading about the ecology of lichens. However, such scientific ideas are sometimes taken with a grain of salt. One herder recounted about the large forest fire that occurred in 2006 in Muddus national park:

> There have been many researchers in the area, entomologists. They have put insect traps, everywhere. Researchers from everywhere. I met a researcher who installed insect traps. They claim that it is natural, that it should burn. It is a natural cycle, they claim. (interviewee 2, reindeer herder, Porjus, 2017)

In addition, today, herders compare burning with other soil preparation measures used in forestry, and they are unanimous in their preference for burning compared to mechanical methods, sometimes on the grounds that burning would be more "natural":

> It changes a lot, the forest, it changes over time. It can be good for a while and then it becomes worse. And this is why we think that it is good if it burns, so that it becomes more natural, like it has been before, instead of tons of soil preparation, like harrowing and ploughing. It is more natural with burning. (interviewee 1, reindeer herder, Jokkmokk, 2017)

Thus, reindeer herders' representations of fire are complex and contrasting. They mirror the complicated history of colonisation, in which fire was used as a tool to destroy resources essential for reindeer herding, thus driving them away from their lands, sometimes deliberately. To the herders, especially the older herders that I interviewed, burnings carried out for forestry have been a continuation of the despoiling of their lands, and contributed to shaping negative representations of fire. Today, the ecological discourse claiming that fire is part of nature and contributes to the regeneration of the forest in a natural way is gaining traction among reindeer herders, although, as place names like *roavve* demonstrate, the Sami have long known about the role of fire in the boreal forest. Reindeer herders' representations of fire will probably continue to evolve rapidly, as many of them are starting to consider burning as a way to restore reindeer pasture, as we will see in section 4.3.

4.2 Knowing fire: the challenge of transmitting a body of knowledge about fire in the era of fire suppression

Until the 19th century, fire was much more present in the boreal forest compared to present times. Settlers had to deal with natural forest fires, but they also ignited their own fires for agricultural purposes. A whole body of knowledge was surely connected to agricultural burning. Castellanou *et al.* (2010) discuss how farmers using burning for various purposes in Europe, including Swedish farmers practicing slash-and-burn agriculture, held a deep understanding of weather and wind conditions that allowed them to achieve their objectives with burning. However, the onset of active fire suppression in the late 1900s connected with the rise of modern forestry, and the associated shift of livelihood, changed the dynamics of knowledge associated with fire and burning practices. In the Swedish boreal forest, forestry became the main driver of the fire regime, first through active fire suppression, and later through controlled burning for forest regeneration, which entailed the development of a new body of knowledge related to fire. With the return of fire use in the boreal forest in the context of sustainable forestry in the 1990s, burning for biodiversity conservation now mainly drives the fire regime in northern Sweden. As for Sami herders, although they have supposedly not – or rarely – been directly involved in burning processes, and even less in burning plans, they have nonetheless been confronted with the effects of fire and burning on reindeer pasture. In this section, I seek to answer the following questions: Based on what knowledge does fire management rely? How has knowledge about fire been transmitted among and between groups concerned with fire management, i.e. foresters, nature conservation managers, and Sami reindeer herders?

4.2.1 The "burning culture" of fire suppression

In northern Sweden, fire suppression did not mean an absence of interaction with or knowledge about fire. Active fire suppression meant extinguishing natural forest fires, and thus entailed the development of a whole body of knowledge and know-how related to firefighting and fire behaviour. During the first half of the 20th century, there were no airplanes nor water-pumping systems to extinguish fires. When a forest fire occurred, many men were called in to build firebreaks using shovels, form chains with water buckets,

and set counter-fires that would prevent the fire from spreading further (Figure 14):

> Back in the day, you had a spade, and a water bucket. And you could ignite with birch bark. There was no other choice than extinguishing fire with fire. Burn up the fuel before the fire arrived so that it stayed there. (interviewee 44, retired forestry planner, Kalix, 2020)

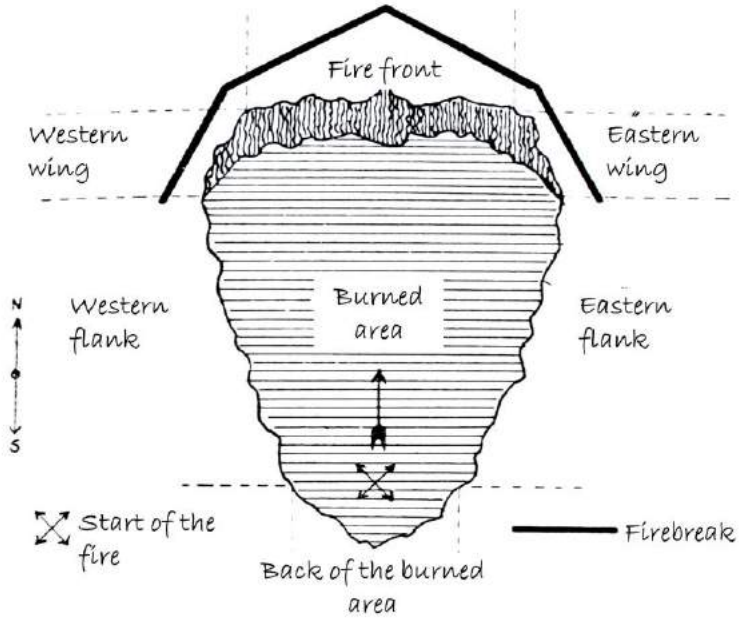

Figure 14. The positioning of a firebreak to stop a fire, in a booklet about fire suppression, published by the Committee of forest fire protection. Source: Skogsbrandskyddskommittén I Gävelborgs län 1940 (Appendix 1: 18). The legend was translated by the author.

A whole technical system developed in the context of fire suppression, which was for example described in a booklet published by the "Committee of forest fire protection" (Figure 15). Extinguishing forest fires thus relied on technical know-how and a good knowledge of fire behaviour, notably of how it moves in a landscape depending on topography, vegetation and weather conditions.

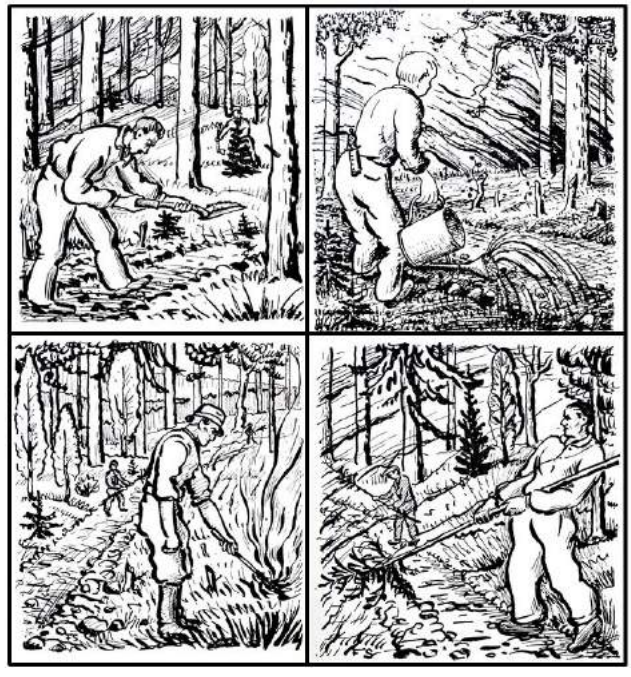

Figure 15. Different steps in the process of extinguishing forest fire. Source: Skogsbrandskyddskommittén I Gävelborgs län 1940 (Appendix1: 18).

Then, in the 1970s, mechanisation rendered fire suppression even more efficient, notably thanks to airplanes carrying water, water-pumping systems and telecommunications. The practical experience of using fire against fire, with the use of counter-fires, disappeared from the firefighting services. As one experienced burning practitioner said, "nowadays, people trust pumps and airplanes (interviewee 43, Tärendö, forestry entrepreneur, 2020). However, foresters who kept using regeneration burning kept this know-how alive:

> We ignite, we extinguish with fire actually. It is the way we do it, when a panic starts, we ignite even more. But we ignite at the right places so to say. This is what is important. To remove the fuel that is burning. (interviewee 43, forestry entrepreneur, Tärendö, 2020)

The fires of summer 2018 exposed the limits of the firefighting system developed since the 1970s, which proved to be inefficient when the fires

reached a certain size, and when several fires occurred at the same time. Several foresters I interviewed raised the possibility that large forest fires might become more frequent in the boreal forest in the near future, as a result of global warming. They explained how, because of this risk, and because of the 2018 experience, firefighters now learn from experienced burning practitioners how to make efficient firebreaks and build counter-fires. They even take courses with burning practitioners working in forestry to better understand the functioning of forest fires and learn how to control them effectively:

> Since 2009, I have a company on the side, we do burning, and we provide training courses for the civil protection service and such. (…) We mostly have courses about fire behaviour, for the civil protection service. (interviewee 26, conservation manager and forestry entrepreneur, Umeå, 2019)

In their study of fire management decision-making in Sweden, Eckerberg and Buizer (2017) mention the establishment of a project between 2009 to 2012 aimed at fostering a dialogue between the County Administrative Boards, forest owners and entrepreneurs, and the Civil Protection Services about forest fire and controlled burning.

A shift thus seems to be occurring in Sweden in the way forest fires are dealt with, which has also occurred in other countries that developed fire suppression systems based on the use of fire, for example in the reduction of fuels and the creation of firebreaks (Harrington 1981; Rigolot 2009). Such a shift implies transfer of knowledge from experienced burning practitioners to the firefighters who had put their "faith" in water, as one burning practitioner said. Thus, Castellanou *et al.* (2010) mention how, in the past decades in Europe, there has been a shift from fire exclusion to fire management, implying a shift from 'more resources' to 'more knowledge'. Changes in livelihoods and in the environment entail changes in the fire regimes, which in response entail a dissemination of knowledge related to fire.

4.2.2 Revitalising and maintaining the burning culture in commercial forestry

Shortly after the onset of fire suppression, from the late 19th century, a new body of knowledge developed together with the development of regeneration burning. As shown in **paper II**, Malå became the dissemination centre of the regeneration burning technique, through the work of Joel Wretlind and his efforts to formalise and spread his methods. From the late 1940s, forestry planners from all over northern Sweden came to Malå and witnessed the results of Wretlind's experimental burnings that he had carried out since the 1920s (Granström 1991; Öckerman 1998) (Figure 16). They learned from Wretlind's techniques, which they applied in their own districts. The technique and the associated body of knowledge and know-how were thus transmitted across the forestry districts of northern Sweden (See box 1a; Figure 17).

Figure 16. Young forest stand within Malå State Forest district regenerated through burning carried out in 1924 and natural regeneration. Photo: J.E. Wretlind, 1947. Source: Wretlind archive.

However, as we have seen in section 2.2.2, from the 1960s, regeneration burning was replaced by mechanical soil preparation methods. According to some foresters, the abandonment of regeneration burning was also due to the growing environmentalist movement, which originally considered burning to be a threat to the forest. Over two decades, and until the return of fire as a nature conservation measure in the 1990s, regeneration burning practically disappeared in northern Sweden, and with it, regeneration burning practitioners. This meant, in most parts of northern Sweden, a break in the transmission of the body of knowledge connected to regeneration burning that had been developed during the first half of the 20th century.

A few regions where regeneration burning has been used continuously over the 20th century, up until today were exceptions. This is the case of the region of Tärendö, where several forestry planners today refer to burning as a "tradition", and to a "burning culture", which was passed on across generations:

> In Tärendö the culture for burning was there, and it has been there even during the nature conservation period [the 1970s]. So the idea of burning to regenerate forests was always there. (…) There is a tradition, people have kept going with burning. There are many places where the tradition has ceased, so it has not been preserved. (interviewee 44, retired forestry planner, Kalix, 2020)

Thus, foresters explained that in the Tärendö area, the knowledge never disappeared, as there had always been at least one person with the experience, who was able to pass it on to others. A forestry planner even recounted how, in 1986, the National Board of Forestry recruited a skilled burning practitioner from Tärendö area who used to burn in the 1940s and 1950s, to participate in burning campaigns with forest owners and help them with the planning and the burning process.

In other regions, even though there was a gap in the actual practice of burning, foresters who started to burn again in the 1990s were sometimes able to consult older burning practitioners who had carried out regeneration burning up until the 1970s:

> When I started to work in the forest, the oldsters who worked with me… it was surely in 1978, it was 42 years ago, they talked about their escapades with

> burnings, and I participated a lot, and watched. (…) We contact the old guys and ask, "how did you do [in this situation]?", and "what should we think about that?". (interviewee 45, forestry planner, Gällivare, 2020)

Another forestry planner in Malå recounted how, when he started to work in forestry in 1976, he worked with some older foresters who had worked with Joel Wretlind. Thus, he believed that today's burning technique had been "inherited" from Wretlind's time. Wretlind's writings have actually been used as a reference in reports about conducting regeneration burning since the 1990s (Westerberg 1997).

Despite these examples, burning practitioners who started to burn in the 1990s were often left with the challenge of learning how to master fire on their own, through "learning by doing", as several of them explained. Although the principles and the theory of regeneration burning have been formalised and written down, notably by Joel Wretlind (1932; 1948), reading the theory, or even listening to the advice of older burning practitioners, does not mean that one has mastered the burning technique in the field. Not all knowledge is conveyed through speech, or written words, and some can only be transmitted through actions, especially technical know-how, which must be demonstrated in practice to be fully transmitted. Foresters I interviewed recounted the challenge of learning how to burn in a context where fire and the practice of burning had practically disappeared, without having someone to teach them, thus revealing the role of action in the transmission of technical knowledge and know-how:

> The first time we made a fire with my company, in my area, we had an old guy… He had been in a lot of fires before, and he thought we were such cowards, oh, we were such cowards! We said "stop that! Stop that! Don't go so fast!", and he just raised his hand, and he never answered. We were really afraid: "oh no, it's burning!", and we were in the same place as a lot of people today, they have not seen fires before. He wasn't impressed, I can tell you. So, that kind of experience is more or less gone, and that's the problem. (interviewee 20, forestry planner, Norjsö, 2019)

Since the 1990s, a whole generation of foresters, now close to retirement, has consolidated the body of knowledge and know-how related to burning

that they had partly inherited from the previous generation. This knowledge has also evolved, as foresters now include concepts, tools and theories of forest science to interpret forest functioning and ecological processes related to fire.

However, several foresters I interviewed were actually worried that the practice of regeneration burning was again at risk of disappearing, and with it, the related knowledge and know-how. They pointed out several factors to explain this possible decline. First, some of them raised the issue that forestry companies' hierarchies were pushing forestry planners, at the field level, to burn less in order to reduce the associated costs:

> They want to reduce the [regeneration] burnings. It is money that drives this. Burning demands work, time, and it can easily get out of control and become very expensive, if it ends up burning somewhere. So it is a bit more expensive than the usual mechanical soil preparation. It is, it is more expensive. And then, they count really in the short term, they would rather have mechanical [soil preparation], and avoid the risk of provoking a forest fire. (interviewee 38, forestry planner, Tärendö, 2020).

Forestry planners, who have the field experience, argue that burning is actually cheaper in the long term, because it avoids the need to carry out several stand clearings. A retired forestry planner pointed out the problems created by the disconnection between the decision-makers in the hierarchies of the forestry companies, who "sit in their office" (interviewee 44, Kalix, 2020), and the workers in the field. Decision-makers are not always trained in ecological sciences and their management strategies are more oriented towards economic profitability. In contrast, local workers, who have experience in the field, consider the whole chain of processes and operations involved in forest regeneration in the long term.

Some older foresters also pointed out the lack of experience of younger forestry planners in charge of burnings, which made them very – too – cautious when it came to burning, and willing only to burn forest stands with very low risk, in case they lose control of the fire:

> They burn, but they rather want to burn islands in mires, or in lakes, where you cannot go with machines, then they burn. But there is a bit of fear, I think. (interviewee 43, burning practitioner, Tärendö, 2020)

Thus, a retired forestry planner explained how burning was in a state of "phasing-out": it appeared to him that there are fewer and fewer people able to burn, so fewer burnings can be carried out when the weather conditions are suitable, leading to fewer opportunities to transmit the necessary know-how. Moreover, he raised the point that, with increasing dryness and increasing fire risk in the summer, the civil protection service has issued fire bans during which forestry companies could not carry out burning. However, these bans are put in place when there are the weather conditions that are actually required to burn. As a result, many foresters today highlight the importance of preserving the knowledge associated with burning, and they strive to pass it on to the new generation of foresters:

> There are not so many people who are good at burning. There are a few but there is a risk that the knowledge will disappear. We are a bit scared, because we are fewer and fewer. There are not so many people who work in the forest anymore either, for the knowledge to be preserved. This is why we burned here too, all the personnel, all of us were there the whole time… So that, when new people arrive, they can come with us and burn, and participate in the planning, and see why we do it like this and like that. (interviewee 38, forestry planner, Tärendö, 2020)

Several forest managers mentioned that the transmission of the knowledge and know-how related to controlled burning was crucial when facing a context where large forest fires might occur more and more frequently.

Figure 17. a. Burning an anthill before carrying out regeneration burning in Malå under Wretlind's supervision in the 1940s (source: Wretlind archive); b. burned anthill in Tärendö area in 2016 (photo: S. Cogos); c. firebreak created during Wretlind's time (source: Wretlind archive); d. excavator digging a firebreak today (photo: P.-J. Perttu).

Box 1a: Regeneration burning burning technique

First, the stand is chosen based on its potential to be safely delineated, with the presence of natural fire barriers such as water bodies if possible. The size of the stand should be large enough to reduce the costs per hectare, but small enough to allow control over the burning. Today the stands that are burned are 12 ha on average (Ramberg 2017). Once the stand has been chosen, it must be logged, taking account of the fact that it is going to be burned. During the first half of the 20th century, forest regeneration was ensured by seed trees that had to be chosen before logging. During logging, the debris must be removed from the edges of the stand, as well as shrubs and dead trees, to ensure the security of the boundaries. Firebreaks must be created along any borders of the stand that are not protected by natural barriers. These usually consist of trenches down to the mineral soil. Anthills must be burned in advance because they can smoulder for weeks and present a risk of fire re-ignition once the burning has been performed (see Figure 17). Once the stand has been logged, burning is usually performed during the next few years, when the logging debris has dried sufficiently, and before new vegetation starts to grow. In the year of the burning, the weather conditions must be right if the burn is to be successful. A sufficient level of dryness of the stand vegetation and of air humidity must be reached. The required conditions for burning are usually met around mid-June. If the weather conditions are bad during early summer, burning can be delayed until August or even September. Within the time window suitable for burning, the wind conditions must also be assessed in order to pick the appropriate day for burning. The right wind conditions are constant and weak to moderate wind. On the day of the fire, the burning team is gathered; it comprises a burning leader and about five to a dozen workers. The equipment has evolved since the 1960s: water buckets and birch bark torches have been replaced by water pumps and drip torches. Today, some burning practitioners use a helicopter to assist with surveillance from the air and water application to some parts of the stand. The burning process itself follows the technique of what is known internationally as “strip-head fire”. The team starts by burning the first strip of vegetation along the firebreak on the side opposite to the wind direction, to secure the border. Then, parallel ignition strips are burned successively. Once the burning is completed, the stand must be watched until the fire is completely extinguished.

4.2.3 From regeneration to conservation burning: learning to burn to restore pyrogenic habitats

In northern Sweden, conservation burning started to be used as a nature conservation measure in the 1990s by forestry companies on land set aside for conservation, and by the County Administrative Boards in nature reserves (see box 1b for a description of the technique). As stated in **paper IV**, even before conservation burning was formalised as such, forestry companies used to burn small patches of standing forest in combination with regeneration burning. Conservation burning has been carried out primarily by employees of the forestry companies or forestry entrepreneurs who were mainly trained to undertake regeneration burning under the guidance of older burning practitioners. Thus, conservation burning has some of its roots within forestry and builds on the technical know-how developed in the frame of regeneration burning. Conservation managers responsible for conservation burning within forestry companies recounted how they had learned the fire ignition technique and all the set up aimed at securing the stand, with water pumps and fire hoses, from older burning practitioners.

This heritage actually raises the doubts of some forest managers as to the suitability of the technique they use when they burn for conservation purposes. One forestry planner, formerly responsible for nature conservation at the National Forest Company, shared her thoughts in this regard:

> Those who work for SCA [an international forestry company, one of the main forest owners in northern Sweden], those who are good at burning, most often they come from a regeneration burning background, which was a really, really common regeneration method back in the day. And the question is whether the method is the right method to use, if we want to burn for conservation. I think that, often, it can be so that we are a bit too effective when we burn for conservation, that we want it to go fast, so we burn areas a bit too fast. And then, we do not get the optimal… We have not really been able to develop the skill yet, of how to burn for conservation in the best way. And we have not followed any formal training about it either, unless, we have learned with one another, with the older ones. So it is may be something we are lacking. (interviewee 39, forestry planner, Överkalix, 2020)

Adapting a well-established technique to different objectives and to different fuel conditions – a standing forest instead of a clearcut – can thus prove to be a challenge. Besides, as mentioned in **paper IV**, one conservation manager explained how his forestry company was still lacking a strategy that would allow them to plan the burning pattern in the long-term and at the landscape scale. His colleague agreed and recognised similar difficulties concerning the choice of the forest stands to burn. Despite the "nature value evaluation" system, there is no obvious choice, and conservation managers must eventually rely on their "local knowledge" and their "own feeling" (interviewee 41, Luleå, 2020). Burning practitioners must eventually learn from their mistakes:

> Concerning the knowledge, I think that we are a bit unsure when it comes to conservation burning. (…) They burned an area that we had set aside when I was a nature conservation specialist. And unfortunately, a lot of trees died, within the forest we burned. And of course it is disappointing when we have chosen a forest with a high nature value, and we have burned it… (interviewee 39, forestry planner, Överkalix, 2020)

Conservation burning practitioners thus get to learn for themselves, in the field, and refine the technique based on their own experience and observations.

Research also plays a significant role in the construction of the body of knowledge connected to conservation burning. Indeed, as stated in **paper IV**, some Swedish researchers specialising in fire ecology contributed to the development of the conservation burning technique. One researcher in particular, Anders Granström, is known for his experience in the matter, both theoretical and practical, as he has participated in and led many conservation burnings since the 1990s. He has contributed to the training of burning practitioners working for forestry companies and for the County Administration Boards through courses during which they are given a theoretical foundation covering the burning technique and fire behaviour, but also practical experience through burning demonstrations. Conservation managers also read scientific literature published about fire ecology and conservation burning. The basis for the knowledge related to conservation burning is thus a mixture of the legacy of the regeneration burning era, contemporary scientific knowledge, and field experience. This body of

knowledge circulates within but also among the companies and organisations from different regions.

There is a tradition within Swedish forestry of organising meetings to gather together forest managers from different regions and discuss different themes, with field visits to present the results of diverse forest management methods. These gatherings are one occasion where knowledge about conservation burning is exchanged. As a result of these processes of knowledge building and exchanges, experienced conservation burning practitioners have developed a detailed understanding of fire and practical experience of burning, allowing them to reach the objectives of conservation burning.

In order to characterise the variation in fire use techniques and the factors that explain this variation across Europe, Montiel and Kraus (2010) established a typology of fire use techniques based on the level of skills mobilised by burning practitioners. This typology comprises four levels of skills: group A: "control ignition progress to prevent fire from escaping control"; group B: "control ignition to achieve a desired intensity and residence time"; group C: "control fire effects on the ecosystem through fire intensity and residence time"; group D: "apply fire to slow down or re-direct a crown fire with extreme fire behaviour". I would argue that both conservation and regeneration burning practitioners in Sweden today generally reach the first level. To Montiel and Kraus (2010), this level requires knowledge of fire behaviour and of how to steer a fire in order to reach the objectives established. Some experienced burning practitioners certainly reach the second level, which requires long experience allowing them to control the ignition pattern but also the fire intensity, and thus some knowledge about how the topography, the weather, the type of fuel influence fire behaviour:

> I am interested in fire, the very phenomenon, and what drives the fire, in the dryness, and the humidity. (…) I can read the intensity, or anticipate how it will behave depending on what the forest looks like. (interviewee 26, conservation manager and burning practitioner, Umeå, 2019).

The most experienced practitioners surely attain the third level, which involves controlling the effects of the fire on the ecosystem, and thus a "profound understanding of fire effects and their causes" (Montiel & Kraus

2010). Such a level of skills and knowledge is certainly exemplified by the burning practitioner featured in the film *The man who burned trees*.

Box 1b: Conservation burning technique

Conservation burning follows the same principles and the same burning technique as those applied in regeneration burning. However, the fact that burning is performed in a standing forest, and is intended to deliver nature conservation objectives, means that there are specific technical requirements. Because there is no logging debris on the ground, the fuel is less abundant compared to a clear-cut, which can make ignition more difficult. Moreover, because of the tree cover, the ground vegetation can dry less easily. It is thus possible to thin the stand beforehand to ensure an effective burn. In addition, because one objective is to foster heterogeneity, some forestry measures can be applied before burning to introduce some heterogeneity, for example, the creation of artificial clearings or the felling of individual trees, to ensure the presence of dead wood. The pattern of ignition of the burning strips and the space between them can also be modulated to favour heterogenous effects of burning.

4.2.4 Knowing about fire among Sami reindeer herders

Before fire suppression, Sami reindeer herders, whether they once set fire to the forest themselves or not, were definitely familiar with forest fires, which occurred regularly on their lands. Understanding forest fires, their pattern of occurrence within the landscape, the conditions under which they occurred, and how they modified the forest, must have been vital for reindeer herders who relied on the forest for their subsistence. Thus, there must have existed a rich body of knowledge related to these aspects among the Sami community.

The existence of such a body of knowledge about fire is actually revealed by Sami vocabulary and Sami place names. The investigation carried out in the context of **paper I** showed that a Sami vocabulary connected to forest fire existed – and is still used to some extent – within Sami languages. The meaning of the Sami word *roavve*, present in many place names of the Jokkmokk area, shows the extent of Sami knowledge about fire ecology. Indeed, according to the definitions provided by reindeer herders, *roavve*

does not just mean 'burnt forest'. As described in **paper I**, it also refers to the type of vegetation resulting from the fire:

> *Roavve*, it is a heath where there has been a forest fire, and… it is an old forest-fire place, which after many years can become very good for reindeer pasture, but it takes many years before it becomes a reindeer pasture at such a place. So, my interpretation of *roavve* is that it has been a forest heath, with an old forest, which has burned away. And then, the lichen and everything has grown, and reindeer pasture begins to grow, lichen for example, and wavy hair-grass [*D. flexuosa*] as well. It is a grass that often grows at burned places. (interviewee 8, reindeer herder, Jokkmokk, 2017)

In addition, the definition also implies a temporal dimension, which suggests careful observations on a long-term basis and a detailed understanding of the ecological processes that unfold after a forest fire. *Roavve* corresponds to a specific stage of the forest vegetation that occurs after some time has passed since the fire occurred:

> It is the result, they do not call it [*roavve*] just when it has burned, but when it has been a few years, and vegetation comes back to the area. And reindeer lichen grows, and a young forest takes over, I think it is then one calls such a place *roavve*. (interviewee 8, reindeer herder, Jokkmokk, 2017)

These explanations also show the central role of reindeer pasture in the Sami definition of *roavve*. More generally, this suggests the importance of the reindeer and reindeer pasture in how Sami herders interpret fire processes. The interviews that I carried out with reindeer herders about fire and burning revealed that their knowledge of the matter was not related to the fire process itself, nor to the ecological effects of fire in general, but to the effects of fire on reindeer pasturelands and reindeer behaviour (see further in section 4.3). In the same way, based on their fieldwork within two African pastoralist societies, Bollig and Schulte (1999: 511-512) state that "pastoralists are not interested in grasses as such, but only in the relation[ship] between grasses and herds".

However, if fire suppression initiated in the 19th century probably improved reindeer pasture at first because it allowed ground lichens to

regenerate as suggested by Berg et al. (2008), it appears that, for reindeer herders, fire suppression also meant a disconnection from forest fire and its effects on the environment. As we have seen, in the 20th century, and especially from the 1970s, fire suppression became so effective that fire virtually disappeared from the boreal forest, and thus from reindeer herding. One herder believed that Sami vocabulary connected to fire had disappeared at the same time that fire disappeared from the boreal forest:

> They have disappeared, these expressions… Because then, there were surely names for different stages after forest fires for example. (…) But we have been extinguishing forest fires for so long, so that they have simply disappeared. (…) And surely, there were some expressions in Sami for the smoke from fire, I am certain about that. Because it had a strong significance for people who lived at that time. (interviewee 4, reindeer herder, Jokkmokk, 2017)

This reindeer herder from the area of Jokkmokk even asserted that he had "never heard of [a forest fire]", except for the burnings carried out by foresters. Today, in many areas, there are few such burnings, and thus the reindeer herders have little experience of them. Even though some herders who have their reindeer in the forestlands all summer, sometimes participate in extinguishing forest fires or in regeneration burnings, for the most part, reindeer herders are not actively involved in burning processes and planning. As a result, while reindeer herders are well aware of the benefits that burning could eventually represent for reindeer herding, they admit their lack of knowledge when it comes to the burning process itself:

> It is a bit hard to know, how hard it must burn, (…) and it is actually the question whether we can learn how fires work. Here all the forest fires have been extinguished… (interviewee 1, reindeer herder, Jokkmokk, 2017)

> They [foresters] have no idea about our conditions, and what we need. At the same time, I don't really know if we have full knowledge about this either. We have just seen examples of when they have burned too hard, for example. (interviewee 16, reindeer herder, Malå, 2018)

Nevertheless, because they are facing a decrease in reindeer lichen pasture, due to land encroachment from various industries, Sami herders have become increasingly attentive to the vegetation changes and the underlying ecological processes, particularly vegetation succession. They make their own observations about processes related to lichen growth, favourable conditions for lichens, etc. As one herder told me, "reindeer herding is becoming so vulnerable, and pressured by society, that we look at everything" (interviewee 16, reindeer herder, Malå, 2018). With the return of fire to the boreal forest through regeneration and conservation burning, and the increasing occurrence of large forest fires, Sami herders are increasingly considering and analysing the role of fire and burning in lichen regeneration. This can be a challenge given the difficulty of studying the effects of fire, which spread across decades, and which can be altered by forest management. However, reindeer herders rely on their own observations but also on the experience of their elders to interpret the role of fire in lichen regeneration:

> We wonder, where lichen has come back where it has burned once, and we try to ask the older people why it works here but not here. And then, they explain that it has burned too much, or too little… And then we have our own experience. I have seen now, they burned in Svanvik this summer, and a few years ago, but it is so recent that we have not seen the outcome yet, it will be a few years before we can see… (interviewee 16, reindeer herder, Malå, 2018)

Moreover, scientific investigations and experiments about the regeneration of reindeer lichens after forest fire or burning have been carried out in Sweden, notably as part of an investigation involving reindeer herders, foresters from the National Forest Company, and a researcher – Samuel Roturier, co-director of this thesis. Thus, interactions have been established between reindeer herders and scientists, who come to exchange knowledge about the ecology of fire (Roturier *et al.* in press). Fields of knowledge are permeable, and reindeer herders integrate scientific concepts into their understanding of the environment. One herder explained that he had been visiting experimental plots of lichen regeneration after fire to examine the results and reflect on the methods that had been used. He had also read about the ecology of lichen, and had integrated the concept of "cycles in nature" to

interpret the ecological processes at play in the regeneration of lichen after a forest fire:

> Nature works in cycles, there are cycles in nature. For example, if you think about the old days, several hundred years ago, a mountain burned, a violent forest fire. It is poor in nutrients, what can survive? The lichens come first. They will stay until birch leaves fall, so that a topsoil is formed. It becomes richer and richer in nutrients. And then, when it has become rich enough, the character of the mountain changes, so to say. The species like grass and such, which need nutrients, start to grow. Lichen takes nutrients from the air. And grass, plants and such things, they take nutrients from the ground. (…) When the species that take nutrients from the ground come in, they start to create shade. Light is important for the reindeer lichens, because the lichens work on photosynthesis. Then the character of the area changes, there is more lingonberry, bilberry, little by little. So that such cycles occur in nature, and they work over a very long time. (interviewee 4, reindeer herder, Jokkmokk, 2017)

The integration of other types of knowledge made him consider the functioning of the boreal forest ecosystem in novel ways, and to him, an understanding of these "cycles in nature", and of the fact that "nothing is fixed in nature", was lacking among reindeer herders.

Sami herders interact with forest managers, in the context of the consultations, but also when they work for forestry companies during the summer. Some herders participate in controlled burnings, and thus have the opportunity to gain their own experience and have direct contact with fire. Moreover, some herders I interviewed had integrated the vocabulary specific to forestry, and they were able to interpret the effects of burning on the forest from a forestry perspective. Thus, they have a dual understanding of burning.

It appears that today's reindeer herders are developing a contemporary body of knowledge about fire and burning, and the role of fire in the regeneration of reindeer pasture, based on a combination of their own observations, knowledge transmitted from their elders, and other sources of knowledge, such as scientific knowledge. Such conclusions fit with the concept of indigenous knowledge not as static and impermeable, but as a hybrid, heterogeneous, and always-changing ensemble that is not fixed in time or space (Dove *et al.* 2007).

To conclude, the study of the body of knowledge related to fire and burning within each group of actors shows how knowledge circulates across time, space, and between groups and individuals. As Adell (2011) states, knowledge is never fixed, nor stuck inside an individual, and it is grounded in a double process of heritage and transmission. My observations of the case of fire and burning also show that construction of knowledge draws on multiple sources and backgrounds and is never homogenous. The body of knowledge held at the individual level is, thus, a reflection of the interactions established between groups of actors, mixed with their own observations and experiences, and incorporating inherited elements. There is, indeed, permeability between groups when it comes to knowledge about fire. This permeability is reinforced in a context where each group of actors is uncertain about the best fire management strategy to apply in relation to their interests after decades of fire suppression.

4.3 Burning on grazing lands: fire as a threat to Sami reindeer herding?

The question of the effects of fire and burning on reindeer pasturelands, and thus on reindeer herding is a complex one, notably because fire has a range of effects on reindeer pastures that become apparent in different ways, spatially and temporally. Some research has been undertaken examining the interactions between fire and reindeer lichen, but usually it has not included the functioning of the reindeer herding system and its spatial and temporal land-use patterns. Including reindeer herders' knowledge in the assessment of the effects of the fire regime on reindeer pasture is thus essential to understand how fire management interacts with the reindeer herding system today.

4.3.1 *Roavve* places, a testimony of past forest fires and good reindeer pastures

The investigation into the meaning of the Sami word *roavve* that I carried out for **paper I** shows that the Sami associated fire with good reindeer pasture in the past. Indeed, according to herders, *roavve* means a lichen-rich Scots pine forest established after a forest fire, which usually constitutes good reindeer winter pasture. Whether they have used fire or not to promote

reindeer pasture, they were at least aware of the positive effects of fire on reindeer pasture in the long-term, and took advantage of them. This challenges the view that Sami people were generally averse to fire (Granström & Niklasson 2008).

In **paper I**, we assumed that place names including the word *roavve* designated locations that corresponded to the definition of *roavve* at some point in the past. As stated in **paper I**, *roavve* is a semantic category that connects multiple domains: botanical (lichen-rich Scots pine forest), ecological (established after a forest fire) and land use (good winter reindeer pasture). It is then possible to connect the *roavve* category to ecological variables in order to characterise the evolution of the vegetation and the fire history at *roavve*-places. As stated in section 3.5.3, place names, which are very durable linguistic elements, can thus constitute markers of ecological change. This durability is confirmed, in the case of *roavve*, by the concordance between the meaning of the word about one century ago, as found in dictionaries, and the meaning provided by Sami herders today. In the case of *roavve* places, it is impossible to determine when exactly they were named. However, it can be concluded that they are at least older than their occurrence on the first ordnance maps of Northern Sweden, published in 1890. *Roavve*-places are thus testimonies of the state of forest habitats before fire suppression was implemented in the late 19th century.

The ecological inventories compiled for **paper I** showed that the 15 *roavve*-places exhibited high variability in their vegetation composition, in terms of reindeer lichen cover, ground vegetation and tree composition. This suggests that the vegetation at most of the *roavve*-places has deviated from the characteristics they once exhibited. The statistical analyses carried out in **paper I** showed that the time since the last fire (TSLF) could explain some of the variations in vegetation composition between the 15 sites.

Some of the sites presented the defining characteristics of *roavve*, i.e. high reindeer lichen cover and a tree layer dominated by Scots pine, and had relatively low TSLF values (mean TSLF for these sites: 108 ± 37 years). This suggests that these sites were at a stage of the post-fire succession corresponding to the *roavve* stage described by reindeer herders, and that the *roavve* characteristics had been maintained by relatively recent fires.

Some sites exhibited a ground vegetation dominated by mosses and ericaceous dwarf-shrubs and a tree layer dominated by Norway spruce. These sites also had old Scots pine trees scattered throughout the forest,

suggesting the historical presence of a sparse Scots pine forest, thus probably corresponding to the *roavve* type in the past. These sites had a relatively high TSLF value (mean TSLF for these sites: 151 ± 66 years), which was consistent with the literature indicating that spruce becomes dominant in the absence of perturbations such as fire (Steijlen & Zackrisson 1987; Esseen *et al.* 1997).

Some sites were dominated by ericaceous shrubs and Scots pine trees despite a relatively high TSLF value (mean TSLF: 159 ± 84 years), and some other sites were young and dense Scots pine plantations with a low reindeer lichen cover despite having a relatively short TSLF (mean TSLF: 99.5 ± 79 years). In **paper I**, we hypothesised that factors other than TSLF could explain the characteristics of the vegetation at these sites. Indeed, tree density also explained the variation in vegetation between the sites. A high tree density can explain the low reindeer lichen cover at sites with a relatively short TSLF. Indeed, high tree density creates light conditions that are not optimal for lichen growth (Čabrajič *et al.* 2010). High tree density at our study sites was connected with active forest management and dense planting practices for some sites, and with an absence of management and perturbations at some other sites. Indeed, in non-exploited forests, high tree density has been linked to the abandonment of selective cutting practices together with fire suppression (Esseen *et al.* 1997; Hedwall & Mikusiński 2014). Soil characteristics also surely play a role in the long-term characteristics of the vegetation at *roavve*-places, although we did not take any direct measurements of soil composition in our ecological survey. The persistence of dominant Scots pine for a long time after the last fire could be explained by sustained nutrient-poor edaphic conditions that prevent vascular plants from outcompeting ground lichen (Nilsson & Wardle 2005; Taylor & Chen 2011).

To sum up, these results show that fire suppression is partly responsible for a decrease in reindeer lichen cover at *roavve*-places, replaced by mosses and ericaceous dwarf-shrubs, and thus an overall degradation of winter reindeer pasture. This is supported by the negative correlation between the lichen cover and TSLF obtained in our results, which is consistent with the long-term pattern of lichen cover evolution after fire (Ahti & Oksanen 1990; Kumpula *et al.* 2000). While fire triggers the establishment of ground lichens after a few decades, in the long-term lichens are eventually outcompeted by other species more adapted to moister and richer environments. Fire

suppression was associated with densification in commercial and non-exploited forests, and the effects were probably modified by different edaphic conditions at different sites. Before fire suppression, *roavve*-places were good reindeer winter pastures sites. Winter pasture being a key component of the reindeer herding cycle, our results thus suggest that fire suppression has detrimental effects on reindeer herding in the long-term.

4.3.2 Sami reindeer herding and fire during the regeneration burning era (1950s-1960s)

After decades of fire suppression, which was probably beneficial for Sami reindeer herding at first (Berg *et al.* 2008), foresters used regeneration burning extensively in northern Sweden particularly during the 1950s-1960s. Coupled with a strong influence of forestry exploitation on the boreal forest landscape, regeneration burning had consequences for Sami reindeer herding. In the 1950s, Sami reindeer herding communities expressed their concern and presented complaints about the impact of forestry measures such as burning and clearcutting on their pasturelands (Mattsson 1984; Lantto 2000).

In the same period, the effects of burning on reindeer herding started to be assessed by foresters and by scientists. A field of research dedicated to the biological aspects of reindeer herding emerged in Sweden (Lantto 2011), notably with the creation of the organisation "Lapp Administration – Reindeer Husbandry Research", established in 1951 by Folke Skuncke, former forest manager. As stated in **paper III**, the question of the interactions between forest regeneration and reindeer herding was also addressed during fieldtrips organised in the 1950s, which gathered together representatives from the forestry sector and reindeer herding communities. A "public education course" on the subject "*Reindeer husbandry and Norrland's forest management"* was organised in Jokkmokk in 1954. The report of the course published by Lapp Administration – Reindeer Husbandry Research (Lappväsendet-Renforskningen 1955) is a rich source of information, helping us to understand how foresters at the time interpreted the effects of burning on reindeer herding. The report includes a contribution by Joel Wretlind, based on the questionnaire he submitted to Malå reindeer herders in 1954 about the effects of burning on reindeer pasture, as well as contributions from Folke Skuncke, Fredrik Ebeling, chief forest manager for

the Lower Norrbotten district, and Lapp bailiff Edvin Kangas, responsible for the region of Luleå.

As stated in **paper III**, foresters at that time recognised that ground lichens would not re-establish for several decades following a fire, even though systematic investigations into lichen regeneration had not yet been carried out. Thus, they recommended not burning lichen-rich forests for the sake of reindeer herding.

Contributors to the Jokkmokk course also mentioned the positive effects of burning for reindeer pasture, provided it was not applied to lichen-rich forest stands. They stressed that in mesic or humid forest types, burning favoured the growth of *D. flexuosa,* which could provide reindeer pasture in the summer and the autumn. Wretlind based his affirmations regarding this question on the questionnaire he submitted to Malå reindeer herders. Additionally, in the questionnaire, he included snow conditions as a factor possibly limiting the access of reindeer to the pasture favoured by burning in the winter, and discussed the matter in his contribution.

Skuncke added nuance to the picture and recognised that the beneficial effects of burning for summer pasture would last only for some years after the burning, as the ground vegetation would progressively be replaced by mosses and ericaceous shrubs. He also recognised that burning would be less beneficial for mountain reindeer herding communities, which could not take advantage of the increased summer pasture in burned forest stands. Lapp bailiff Kangas also tempered talk of the positive effects of burning by stressing how regeneration burning could lead the reindeer to disperse outside the lands of their herding community by disturbing the diversity of the pasture types that the reindeer need at different times of the year, for example during the calving season.

In contrast, Ebeling questioned the claims of Sami herders as to the negative effects of burning on their pasturelands, since burning was not carried out on lichen-rich areas and affected areas that he considered "insignificant" compared to the extent of the reindeer herding area:

> With regard to the Lower Norrbotten district, the total area that was burned during the years 1951-1953 represents only 83 km^2, i.e. 1.2% of all the forest area over three years, or 0.4% per year on average. It affected insignificant areas. When we also know that we do not burn the dry forest types (which comprise most of the district's forests) and the fact that only mesic forest types are burned – which

> means, the forest types that can, under special circumstances, constitute occasional winter pasture affected by cultivation, and thus pasture of bad quality – the apprehensions expressed concerning regeneration burning seem somewhat exaggerated.

Ebeling's account reveals an understanding of reindeer herding in which reindeer pasture is equated with the total quantity of lichen, with no consideration of the pasture pattern and spatial organisation, or grazing conditions. As stated in **paper III**, such an understanding only covers the biological aspects of reindeer herding, and the impacts of forestry in terms of total loss or gain of fodder.

Based on available written sources for the period, the effects of regeneration burning on Sami reindeer herding during the 1950s-1960s were generally deemed insignificant or positive, with some questions as to the durability and the spatiality of these positive effects. Except for a few documents conveying the concerns of Sami herders about burning and its effects on reindeer pasture, written sources only convey the perspective of foresters and scholars in relation to the question. However, we can see from the different interpretations of Ebeling, Wretlind, Skuncke and Kangas that including the Sami point of view instantly brings new aspects and complexity into the picture. Indeed, Wretlind demonstrated an effort to include the opinion of Sami herders on regeneration burning, notably through his questionnaire, which reflects a better understanding of reindeer herding than Ebeling: he considered the effect of burning on the overall availability of reindeer pasture, but also the possibility of actually accessing the pasture, determined by snow conditions. Skuncke and Kangas also used to interact with Sami herders and they were thus able to integrate constraints related to the reindeer herding system in their reasoning. As stated in **paper III**, Skuncke mentioned how "the factors that decide whether a stand or a forest type gives occasional or permanent pasture, or whether it is an indispensable reindeer pasture or not, are more numerous than just the biological ones".

To counter written sources about the effects of regeneration burning on reindeer herding during the 1950s-1960s, it is possible to access the Sami perspective on the matter through the memory of older reindeer herders who were active then. Concerning the effects of burning on the establishment of reindeer pasture, two older herders from Arvidsjaur, who were at the

frontline of the regeneration burning era in the 1950s-1960s, recognised that, in some areas, in the "deep moss" lands, burning was positive. They saw how the forest became a bit dryer, and how the reindeer lichen could slowly come back after some time. In Malå, some younger herders recalled how their older relatives were generally positive about Wretlind's burnings because they favoured the emergence of summer and autumn pasture.

However, the two herders from Arvidsjaur mentioned how, during the 1950s-1960s, foresters would burn "every land", even areas where there was some reindeer pasture:

- At the end of the 50s, they burned incredible amounts.
- In every place. There was no logic, everything was to be burned, all land was to be burned. And it was not good, these burnings. If they burned on the right lands, then it was good. But this is the thing with forestry. If they are good at something, then they do it everywhere. (…) There were places where it was highly unsuitable. (…) Dry lichen heaths. Then it is hard to get [the lichen] back, it takes a generation at least. (interviewees 22 and 23, reindeer herders, Arvidsjaur, 2019).

Moreover, they recalled regeneration burnings that sometimes got out of control, thus setting fire to extensive forest areas, like the forest fire that occurred in Reivo forest reserve in 1966 and affected over 300 ha. A reindeer herder from Malå also argued that when regeneration burning spread, foresters used to burn "everything".

Furthermore, the two herders from Arvidsjaur explained how the sudden increase in burned areas at that time, combined with forestry operations such as clear-cutting, "changed completely the behaviour of the reindeer" (interviewee 22, reindeer herder, Arvidsjaur, 2018), with the usual herding pattern disturbed. They explained how the reindeer abandoned the large mires where they used to stay in the summer to gather on burned areas, because the dust produced by trampled ashes deterred mosquitoes and other insect pests. This change of movement pattern of the reindeer forced reindeer herders to adapt their herding practice, and to abandon old herding places. Although these testimonies of the past cannot provide more precise analyses of the quantitative impacts that burnings carried out in the mid-20th century had on the herding lands, they show how herders evaluate these impacts by considering factors and processes that cannot necessarily be foreseen by

foresters or scientists. This suggests the necessity of including Sami ecological knowledge when attempting to understand the consequences of fire management on the reindeer herding system as a whole, and not only on the total amount of pasture, as attempted in **paper III**.

4.3.3 Sami reindeer herding and fire from the 1990s up to the present

Today, it is possible to consider the perspective of Sami reindeer herders themselves about regeneration and conservation burnings carried out since the 1990s. As stated in section 4.2.4. Sami reindeer herders have developed their own interpretation concerning the ecological effects of fire**;** this is based on their ecological knowledge and mainly focused on the interactions between fire and the reindeer and reindeer pasture.

Concerning winter lichen pasture, herders are well aware of the fact that, although fire initially destroys ground reindeer lichens in lichen-rich stands, fire can also create lichen-rich habitats. This is well established in their interpretation of the word *roavve*. Their observations about the regeneration pattern of reindeer lichen after fire coincide with the conclusions of research in ecology: ground lichens need 50 to 60 years to re-establish in a burned forest stand. As stated in **paper IV**, reindeer herders also see burning as a way to remove less palatable plant species such as ericaceous dwarf shrubs, heather and mosses, which have outcompeted ground lichens. Reindeer herders generally agree that burning can improve the pasture in the summer and autumn in the short term by favouring the growth of "strong" and "green" fodder, including the grasses *Deschampsia flexuosa* and *Deschampsia cespitosa*, fireweed (*Chamaenerion angustifolium*), and birch tree shoots.

Additionally, to reindeer herders, burning is an interesting alternative to mechanical soil preparation measures carried out by foresters in forest stands where reindeer lichen is absent. On top of favouring the growth of summer pasture for a few years, burning leaves the ground undisturbed, compared to mechanical soil preparation methods such as harrowing:

> If you burn, you preserve the structure of the ground. It does not create deep holes, and it is possible to travel around, and it becomes green pasture quickly. So I consider that burning is positive for reindeer herding because you get reindeer pasture back more quickly, compared to soil preparation, because then, you turn

> the earth over, and it takes a long time before the reindeer like to be there. (interviewee 36, reindeer herder, Kitkiöjoki, February 2020)

Investigating Sami ecological knowledge brings insights that allow us to understand the effects of fire and burning not on only the overall availability of reindeer pasture but also on the behaviour of the reindeer and the reindeer herding pattern across the landscape and over the year, as demonstrated in **paper III**. First, reindeer herders mention how the effects of fire on reindeer pasture depend on the opportunity for the reindeer to actually access and graze the pasture. In the winter, this opportunity is in great part determined by the snow conditions. For Sami herders, 'pasture' implies the presence of fodder but also that the reindeer can access it through the snow, as has been demonstrated for lichen pasture (Roturier & Roué 2009). This constraint also applies to *D. flexuosa*, which can be used as a winter pasture if the snow conditions allow it, as some reindeer herders pointed it out. Snow conditions are determined in first place by the weather. Freeze-thaw events result in the formation of a crust of ice over the snow cover, which prevents the reindeer from accessing the pasture. According to several studies and to the observations of Sami herders, such freeze-thaw events are increasingly frequent today due to climate change (Heggberget *et al.* 2002; Bokhorst *et al.* 2008; Furberg *et al.* 2011). Thus, even though burning would increase the overall quantity of ground lichens in the long term, access to the pasture in winter is not guaranteed and might worsen due to climate change.

Secondly, fire management and burning strategies affect the vegetation and thus reindeer pasture, but also the behaviour of the reindeer, most notably by attracting the reindeer to burned places, where they can escape mosquitoes. While older herders described this as a significant upheaval of the herding pattern in the 1950s-1960s, today, reindeer herders see this as a benefit because they have a greater chance of finding their reindeer when they are gathered on burned areas. One herder hypothesised that the potential to find and gather the reindeer easily on burned areas was the reason why the Sami Johan E. Ruosni burned large forest areas in the Tärendö area in the late 1800s, rather than to increase summer pasture.

As mentioned in **paper III**, pasture is not only important as a source of fodder for the reindeer. It is also one way for the herders to control the reindeer, to keep them gathered, and to predict their movements. Because Sami reindeer herding relies on a loose way of herding, in which the reindeer

are left to roam freely for long periods in the landscape, the spatial distribution of the patches of pasture within a reindeer herding community is important to reindeer herders. Like in other pastoralist societies based on free-roaming periods, "animals play an active part in the pastoral mobility system" (Stépanoff *et al.* 2017), and herders need ways to control this mobility. As stated in **paper III**, pasture is one means for the herders to steer and predict the movements of their reindeer, as patches of fodder act as natural enclosures that keep the reindeer stationary as long as food is available:

> [Lichen] makes reindeer herding easier when we watch over the reindeer. (…) The reindeer disperse less. You do not need to watch them so closely, or drive the snowmobile and such. (interviewee 4, reindeer herder, Jokkmokk, 2017)

Conversely, under bad grazing conditions, for example due to bad snow conditions that lock the pasture under the ice, pasture cannot play its role of enclosure anymore:

> It has been quite bad pasture these last years, so the reindeer have been quite free; we have lost control over them sometimes. (interviewee 3, reindeer herder, Jokkmokk, 2017)

Thus, to fully understand the effects of burning on reindeer herding, the effects on the total amount of pasture, but also on reindeer behaviour and mobility patterns must be considered. Furthermore, the herders assess the effects of burning at a landscape scale, and not only at the stand level. They consider the spatial configuration of the burned stands in relation to the seasonal mosaic of pasture patches and habitats within the reindeer herding community's lands. The need to consider the spatial configuration of the burned stands in combination with the seasonal land-use patterns of the reindeer when evaluating the effects of fire on reindeer was mentioned by Lapp bailiff Kangas in the report of the 1954 Jokkmokk course, but also, later, in the case of wild caribou in North America (Klein 1982).

In short, herders do not solely consider the effects of fire on pasture, but also – and primarily – on the reindeer. Addressing Sami ecological knowledge to understand the consequences of fire management – principally

here regeneration burning – on reindeer herding is thus essential to understand how burning affects not only the total amount of reindeer pasture, but the reindeer herding system as a whole.

4.3.4 Burning as a way to restore reindeer pasture?

One herder considered that most of the areas rich in ground reindeer lichens would eventually disappear, little by little. He considered that reindeer herders needed to think about how to restore reindeer pastures if they wanted to preserve their way of life and livelihood, because, to him, relying increasingly on additional fodder in the winter was not economically viable. Thus, he believed that reindeer herders should follow the example of foresters in the way they manage the availability of the resources they rely on:

> I think that forestry, say what you want, but they are good at regenerating, restoring the lands for their needs. They are. And we, in reindeer herding, we do nothing. There is a lot to be done. Foresters like pines, they create favourable conditions for the pines. And we like lichens. So we should create favourable conditions for the lichens. Because lichen is the most important reindeer pasture. (interviewee 4, reindeer herder, Jokkmokk, 2017)

To him, burning represented a good "soil preparation" method for reindeer lichen restoration. Well aware of the role of fire in ensuring the long-term availability of ground lichen pasture, some reindeer herders are actually considering burning as a way to restore reindeer lichen pastures, especially in pine forests that used to be lichen-rich and used as winter pasturelands and that are now dominated by other species:

> The worst enemy for ground lichen, it is heather. It covers up the lichen, so that the lichen disappears. So I hope that reindeer herders learn that, when a lot of heather starts to grow, they set fire, and let it burn [he laughs]". (interviewee 37, reindeer herder, Sattajärvi, 2020)

As stated in **paper IV**, there is a tendency among herders to see an opportunity for taking advantage of the comeback of fire in the boreal forest

through regeneration and conservation burning to favour lichen pastures. According to a number of herders, forestry planners and conservation managers in several regions, reindeer herders regularly propose burning certain forest stands instead of other forest regeneration measures during the consultation with forest owners, because they believe that it would benefit reindeer pasture.

However, the project of restoring reindeer pastures through burning is not easily achievable in the current context. Except for rare exceptions, burning is exclusively managed and carried out by forest owners, including forestry companies and State institutions, for forestry or nature conservation purposes. Thus, reindeer herders depend on them, and on the constraints imposed by the objectives and the technique of regeneration and conservation burning, for the application of burning. To reindeer herders, burnings carried out by forest managers do not necessarily meet their needs, notably in terms of burning intensity:

> I think that the regeneration burnings they do now, they are so insignificant, and it does not burn as hard as reindeer herders would want to. It mostly becomes a bit black on the surface, and for the reindeer lichen's sake, it would need to burn harder than is currently done. (interviewee 1, reindeer herder, Jokkmokk, 2017)

An ideal burning, according to one herder, would be not too hard nor too deep, in order to preserve the seeds giving rise to the green fodder used in the summer, but hard enough to destroy the moss and dwarf shrubs which prevent lichens from growing.

Several herders also believed that, in reality, burnings carried out by forestry operatives could not benefit reindeer pasture because the effects of fire were counteracted by forestry practices in commercial forests. They explained that planting practices and shorter logging rotation times result in dense forest stands where lichens cannot establish because of the lack of sunlight reaching the ground:

> If someone would burn lichen lands, it would take a really long time before you would get lichen back, if you would not plant it artificially. But, in any case, it is dense forests that cause lichen to disappear. So even if you would burn, they will regenerate the forest again. (interviewee 14, reindeer herder, Malå, 2018)

As stated in section 2.3.5, studies in ecological sciences have also shown that planting methods in commercial forests lead to denser forest stands, resulting in poorer growth conditions for ground reindeer lichens (Ahti & Oksanen 1990; Nilsson & Wardle 2005; Berg *et al.* 2008). The results reported in **paper I** with respect to *roavve*-places indicate the same situation: the ground lichen cover was low in commercial forest stands, which had a high tree density. Thus, the potential of burning as it is carried out today remains limited for the restoration of reindeer pastures.

A few burning initiatives carried out specifically with the aim of restoring reindeer pasture have been undertaken in northern Sweden in recent years, involving reindeer herders, forestry planners and researchers. A lichen spreading experiment was conducted on a large area burned by a natural fire in 2006, at a place called Stora Klusåberget, near the village of Harads, Norrbotten County, in cooperation with local reindeer herders (see Roturier *et al.* 2017). The objective was to see if it was possible to benefit from the effects of fire, which burns off mosses and ericaceous dwarf-shrubs, without wating for decades before the establishment of a lichen cover, by artificially spreading lichen fragments. A lichen-spreading machine was even developed to distribute the lichen fragments more evenly across the stand (Figure 18).

A fieldtrip organised in 2015 to showcase the results of this experiment gathered forestry planners, reindeer herders and researchers to discuss the outcome of the experiment (Figure 19). This fieldtrip encouraged forestry planners in other regions to carry out similar experiments, and the idea continues to circulate within reindeer herding communities, the forestry community, and the County Administrative Boards. Some herders visit the experimental site, and the promising results encourage reindeer herders all over northern Sweden to consider the possibility of applying the same technique on their herding lands. Indeed, they see spreading lichen after burning as a way to accelerate the lichen regeneration process, which otherwise takes several decades and often makes them reluctant to agree to the burning of some forest stands containing reindeer lichen.

Figure 18. A reindeer herder spreading lichen on a burned forest stand with a machine specifically developed for this purpose. Photo: S. Cogos, 2016.

Figure 19. A discussion between forestry planners and a reindeer herder during the 2015 fieldtrip to the experimental site of Stora Klusåberget, where lichen was spread after a forest fire. Photo: S. Cogos.

If a burning strategy aimed at restoring lichen pasture was to be implemented on the initiative of forest owners, it would have to take account of the needs and functioning of reindeer herding. For burning to deliver reindeer herding requirements in terms of winter pasture, the burning strategy would need to consider the spatial pattern of the pasturelands within the reindeer herding community concerned. Indeed, the burned stands would need to be included in a winter pasture area, but without disturbing existing pastures and reindeer migrations routes. Even with respect to summer pasturelands, reindeer herders explain how the reindeer need a variety of habitats to serve specific needs. For example, reindeer need spruce forests in the spring and the summer to find shelter and a place to cool down during warm days. They also need mixed forests with deciduous trees, where they can find a diversity of food sources in the summer and autumn. Thus, burned stands, which attract the reindeer in the summer during the first years following the burning, would ideally have to be located in a way that would fit this mosaic of habitats. Furthermore, the way pastures and habitats are connected is also essential for the reindeer, and the burned stands would thus have to be connected to a cohesive pasture area:

> Reindeer pasturelands today, they can be favourable to lichen growth, but then if it has been logged somewhere, there can be one kilometre with no reindeer pasture. So when the reindeer come there and pass by, they go away. So if we plant reindeer lichen, we must plan it so that it becomes connected. (interviewee 4, reindeer herder, Jokkmokk, 2017)

As mentioned in section 4.4.3, reindeer herders consider the whole reindeer herding system and the landscape as a whole when they evaluate the effects of management measures, or the potential for burning, in contrast to forest managers who tend to think at the forest stand level.

Thanks to the Stora Klusåberget experiment, using burning as a way to restore reindeer pasture is an idea that is gaining ground among reindeer herders, but also within forestry companies, and among conservation managers. Results of research but also the herders' and foresters' own observations support the potential to use this technique to counteract the current reduction in reindeer pasture. However, the burning strategy is still principally determined and implemented in the field by forest management organisations, including forestry companies and the County Administrative

Boards, principally to deliver nature conservation objectives. If the burning strategy was intended to benefit reindeer pasture, including the Sami as partners in experimentation and decision-making would be essential. Finally, herders temper the significance of burning for the benefit of reindeer herding by also considering other aspects of forest management, which counteract the positive effects of fire. Involving reindeer herders in planning and implementing burning strategies might thus lead to more in-depth questioning of the outcomes of commercial forestry activities.

4.4 Governing fire: conflicts and negotiations about burning

Because, in the Swedish boreal forest, fire is strongly controlled by humans in a multi-cultural setting with overlapping land uses, diverging views about how to manage fire inevitably arise. We have seen that Sami reindeer herders are not unequivocally against controlled burning, provided it is carried out under certain conditions. However, the burning strategy is still exclusively in the hands of forest owners, principally big forestry companies and the State in the case of nature reserves, steered principally by nature conservation objectives. It is through the consultation process that most of the interactions about fire management occur between Sami herders and forest managers. In this section, I analyse and discuss the question of how Sami reindeer herders have been considered in the planning of fire management, including controlled burnings, from the mid-20th century up until today, and how they interact with forest managers regarding fire management.

4.4.1 Formal inclusion of Sami reindeer herding in forest and fire management during the last 100 years

In **paper III**, I investigated how Sami reindeer herders were included in the management of controlled burning during the first half of the 20th century, principally based on historical written sources. The analysis of the written sources showed that the use of regeneration burning was regulated quite early on with respect to reindeer herding. Indeed, as early as 1923, the National Forest Administration sent a circular letter to the chief forest managers in northern counties, which required forest managers to obtain the approval of

the responsible Lapp bailiff before regeneration burning was carried out. In cases where the Lapp bailiff opposed the burning, the matter had to be submitted to the district's chief manager. This shows how regeneration burning was central to the interactions between forestry and reindeer herding at the time. It also demonstrates a certain care for Sami reindeer herding by Swedish institutions in charge of forest management. Although this effort can be considered to be a progressive step for the time, it must be noted that the Sami did not directly participate in the decisions taken about burning, and had to go through the Lapp bailiff responsible for their district to explain their position and assert their interests.

In the 1950s, forestry started to have a pervasive impact on reindeer herding, as clearcutting and soil preparation methods such as soil scarification and burning over large expanses destroyed and fragmented grazing areas. The conflicts between reindeer herders and forestry thus increased (Widmark 2006). During the same period, the impacts of forestry on reindeer herding started to be addressed through a scientific approach, as described in section 4.3.2. The organisation "Lapp Administration – Reindeer Husbandry Research", established in 1951 by former forest manager Folke Skuncke, aimed to clarify the relationships between forestry and reindeer husbandry. At the same time, Sami organizations, notably the National Union of Swedish Sami (SSR), raised awareness about the impacts of forestry, including regeneration burning, on reindeer herding.

As discussed in **paper III**, increasing concern from the Sami communities about the impacts of burning on reindeer pasture, pressure from the Sami organisations, and consideration of Sami reindeer herding by the scientific community and institutions, led to the organisation of fieldtrips gathering representatives of reindeer herding and forestry, which aimed to discuss the interactions between the two livelihoods. Regeneration burning was a central topic of these fieldtrips. The "popular education course" organised in Jokkmokk in 1954 on the theme "*Reindeer husbandry and Norrland's forest management"* marked a turning point in the inclusion of the Sami in the debate since, for the first time, Sami reindeer herders were able to participate. However, the lecturers on the course were all foresters or State representatives, and the contributions of the Sami were not recorded in the report that was published subsequently (Lappväsendet-Renforskningen 1955). On top of discussing the benefits of regeneration burning on reindeer herding (see section 4.3.2), the report also included recommendations for

better inclusion of Sami reindeer herding interests in forestry planning, such as teaching about the needs and conditions for reindeer herding in northern Sweden's forestry schools.

Subsequently, and still under the pressure of SSR, the State reaffirmed the 1923 circular letter in a new letter issued in 1958, which asked the National Forest Company to carry out systematic consultations with the Sami Administration and reindeer herding communities before the implementation of forestry measures such as regeneration burning. However, this obligation only concerned the National Forest Company, and not private forest owners or other forestry companies. Written documents analysed for **paper III** show that despite these efforts, some concerns still persisted among Sami herders, notably regarding regeneration burning. The discussions and conflicts around the question of regeneration burning thus contributed to bringing to the fore the needs and difficulties of Sami reindeer herding in the face of modern forestry.

After some initiatives addressing the effects of modern forestry on reindeer herding during the 1970s (Gustafsson & Persson 1989) the consultation as it is carried out today was inscribed in the Swedish Forestry Act in 1979. This time, it applied to every forest owner, including private owners with lands within the reindeer herding area, and concerned the year-round herding lands. Established in 1996, the Swedish FSC standard extended the scope of the consultation system to encompass herding lands outside the year-round herding area, notably lower-altitude conifer forestlands, which are both the most productive lands and reindeer winter grazing lands.

The 2020 version of the FSC Swedish standard draws on international standards for the regulation of indigenous peoples' rights, and strengthens the expectations that Sami herders should be able to actually influence forest management during the consultation. Thus, the section of the 2020 standard on "indigenous peoples" rights" states that "the organization [the forest owner] shall recognize and *uphold* the rights, customs and culture of *Indigenous Peoples* as defined in the United Nations Declarations on the Rights of Indigenous Peoples (2007) and ILO Convention 169 (1989)". Rather than a simple consultation, the 2020 FSC standard requires large forest owners (owning more than 5,000 ha of productive forestland) to offer a "participatory planning process" to the reindeer herding communities "whose legal or customary rights are affected by management activities

planned within the landholdings", including controlled burning (FSC Sweden 2020b). The report states that the "participatory planning process has been developed jointly with representatives of the Sami reindeer herding [sector] and is based on the principle of Free, Prior and Informed Consent (FPIC)". The new standard defines the modalities of this "participatory planning" process. Thus, reindeer herding communities must provide a description of how they use the land, either "digitally, verbally, or through physical copies of maps" so that both parties can plan forest management on a landscape scale on the basis of information. The standard also stipulates that "if the reindeer herding community, after going through the process, finds that the measures proposed make impossible the conduct of reindeer herding, they can choose not to give their consent for the measure" (FSC Sweden 2020a). In cases of disagreement, the standard requires the formation of a committee of conflict resolution, and a follow-up to be conducted to evaluate and improve the process.

Thus, as discussed in **paper III**, written sources show that the use of burning by foresters triggered the inclusion of Sami interests in forest management. Since the first regulation of forestry–reindeer herding interactions in the early 20th century, the inclusion of Sami herders in forest management, and thus in the planning of controlled burnings, has slightly improved thanks to strengthened requirements regarding the consultation by forest owners. Sami herders now have the opportunity to negotiate the implementation of controlled burning on their herding lands.

4.4.2 Negotiations about controlled burning

Even during the time of Joel Wretlind, regeneration burning was an object of conflicts and negotiations between foresters and reindeer herders. Following the 1923 circular letter issued by the National Forest Administration and the instructions for an early form of consultation, Wretlind had to submit his plans for burning to be approved by the reindeer herders through the Lapp bailiff. As stated in **paper III**, Wretlind's written accounts show how the Sami sometimes opposed his burnings, and how he tried to convince them to let him burn the forest stands he had chosen. In some cases, these disagreements led Wretlind to abandon his plans and to employ other forest regeneration methods. In other cases, he managed to defend his case and to go on with the burnings despite the reluctance of the

Sami. As stated in section 4.3.2, some older reindeer herders from the neighbouring region of Arvidsjaur recounted that forest managers in the 1950s burned anything and everything without considering the demands of the Sami. Still, the herders tried to steer the burning towards their own interests during the consultations:

> Since I started to participate in these consultations, with the National Forest Company and such, we tried to steer the burnings to areas where it did not cause any damage, or less damage at least. (interviewee 22, reindeer, herder, Arvidsjaur, 2019)

Since its return in the 1990s, controlled burning has become an increasingly important issue in the negotiations between reindeer herders and forest managers, and a topic of discussion during the consultations they have together, as highlighted in **paper IV**. The role of the FSC certification is central in these discussions because it widens the consultations to all forest owners and provides concrete burning objectives for forestry companies. Because forestry companies are tied to the FSC requirements, burning has the potential to represent a middle ground for forestry and reindeer herding, provided it is carried out in ways that satisfy both parties. Reindeer herders seek to take advantage of this context to negotiate the implementation of burning.

According to the interviews I carried out, conservation burning is usually not a source of disagreement, because it principally concerns smaller areas, and because conservation managers have many areas to choose from. Moreover, nature conservation does not have the same economic interests as forestry, and conservation managers can afford to change their plans about burning with few repercussions. Besides, conservation burnings are undertaken in standing forests and thus are not associated with clearcutting or other forestry measures that could have adverse effects on reindeer herders.

In contrast, regeneration burning is more contentious as Sami herders see both benefits and risks in its conduct, depending on different factors, as discussed in section 4.3.3. Regarding lichen-rich forests, because of the decline in winter lichen pasture, reindeer herders seek to preserve any existing pasture they have access to, and they are thus firmly against burning such forest stands. The FSC standard actually prevents burning lichen-rich

areas, for the sake of reindeer herding, and forest managers know that such forest types are the most important winter pasture for reindeer herders. While lichen-rich forests are *de facto* excluded, discussions can arise about burning other forest types. In the case of forests with a ground vegetation dominated by thick moss cover and ericaceous dwarf-shrubs, reindeer herders can see some benefits in burning, as it generates summer pasture without degrading existing reindeer pasture. Moreover, as discussed in **paper IV**, Sami herders often see burning as a way to avoid soil preparation measures, such as soil scarification, that are more detrimental to herding.

Thus, Sami herders seek to steer burning towards their own interests. Sometimes, they spontaneously propose burning stands that would benefit their pasturelands, or suggest the burning of a forest stand as an alternative to the one proposed by forest managers. Sometimes, they also impose burning as a condition for accepting other forestry measures, like clearcutting. Moreover, as suggested in **paper IV**, burning can represent a common ground of experimentation for reindeer herders and forest managers, since both groups are somewhat uncertain as to its effects on forest succession.

Sami herders also seize opportunities to assert their interests relative to burning in arenas other than the consultation. In February 2020, the Västerbotten County Administrative Board organised a seminar on the theme "conservation burning and reindeer herding – effects on reindeer pasture", gathering reindeer herders from all over Sweden, forestry planners and conservation managers, as well as researchers. At this event, one Sami herder gave a talk during which he asserted the necessity for the government agencies and institutions to include Sami knowledge and interests in forest management, but also the needs of the reindeer, which he was able to represent, as a reindeer herder. As stated in **paper IV,** Sami herders negotiate the planning of burning not only for their own sake, but also for the sake of the reindeer. In return, the reindeer are invoked to help and as a bargaining tool in the Sami herders' attempts to assert their rights and interests. As heirs of an animist ontology, Sami herders are involved in a reciprocal relationship with their reindeer, which implies a reciprocal responsibility binding humans and reindeer. As discussed in **paper IV**, by introducing the needs of the reindeer into the planning of controlled burnings, Sami herders not only assert their need to carry out their livelihood and to fulfil their responsibility

towards the reindeer, but they also challenge and disrupt fire management as it had been conceived so far, and also the broader forestry model.

4.4.3 The limits of the consultation

Negotiations between Sami herders and forest managers are largely limited to and constrained by the framework of the consultation, the limits of which have been pointed at by Sami herders, and related in scientific studies (Sandström *et al.* 2006; Widmark 2006; Sandström & Widmark 2007; Larsen & Raitio 2019). Early forms of the consultation process, initiated in the 1920s, were criticised by reindeer herders. A 91 year-old herder recounted how the first consultations he participated in during the late 1940s proceeded, showing the great imbalance in the decision-making power between forest managers and reindeer herders:

> The first time I participated in a consultation, I was 17, and it was right at the beginning. It was in 1946 or 1947. (…) Then came the forest managers, with their green costumes and everything, there were many of them, and they gave us a long lecture about how important it was that they could carry out clearcutting, because, if they were not able to clear-cut such large areas, there would be unemployment. (…) Then Sweden would go bankrupt. (…) During the consultation, we had no say, unless, we just had to listen. And if we protested, then 'there would be unemployment in Sweden'. It is not easy to pull through this. (…) The first years, yes, surely the first ten years I was in, then you could only… There was not much consultation. Yes, we talked, but we had no say in the matter. Or nothing to oppose. Until they realised that it was nonsense with all these big clear-cuts, then it became better, but by then the forest was gone. (interviewee 22, reindeer herder, Arvidsjaur, August 2018)

Reindeer herders interviewed in the study conducted by Sandström and Widmark (2007) stated that the consultation system had improved over time. Some of the reindeer herders I interviewed felt the same, notably older herders who had seen the evolution of the process over several decades:

> In recent years, they [the consultations] have started to have some effects. It can well be nicely called consultation, but… despite that, they did exactly what they wanted. They would say like "now we will undertake these measures". But they

> took no consideration... Because today, now we actually have veto rights for many things. But not before. (interviewee 23, reindeer herder, Arvidsjaur, February 2019)

Despite some improvement, reindeer herders still express their doubts and scepticism about the consultation process, and they still feel that they have very little power to influence the decisions taken with respect to forestry measures, and to assert their interests. Many Sami herders argue that they are only able to delay the forestry measures they deem detrimental for reindeer herding for some years. Several of them noted that, because the amount of forest that is old enough to be logged has become so low, forest managers have no alternative but to come back to consider the same forest stands every year, even though the Sami had opposed activities in these stands some years before:

> For the most part, we are at odds, totally at odds for the most part. Because they want to exploit the forest, and we want to keep the forest. The National Forest Company, they do not have any old forest left. And we have managed to spare, we have managed to delay. We go like: "yes, but take this spruce forest instead", so that we have managed to keep some hectares here and there, for reindeer herding's sake. But now it is the only forests they have left. So all the consultations we have are only about those we have said "no" to, or managed to postpone. So, it is a very wearisome process. (interviewee 14, reindeer herder, Malå, August 2018)

About ten years earlier, Sandström and Widmark (2007: 10) reported the same interpretation of the situation from the standpoint of forest managers, who admitted that "it [was] becoming more difficult to consider the needs of reindeer husbandry since the amounts of forest mature enough to harvest (and thus lichen resources) [were] becoming increasingly limited".

Moreover, negotiations about burning remain limited by the fact that forest managers are the ones who will eventually carry out the burnings, and thus they impose their own constraints:

> They have these 5% to burn, so we try to set them in strategic places for us. But then, burning requires a lot of knowledge, which this generation does not have

> anymore. So they can burn but… they would rather burn on an island in a lake, so that it will be easy and simple to watch and not so much risk if it spreads. So that we could not get [them to burn] so many objects, in practice. (interviewee 14, reindeer herder, Malå, August 2018)

According to many reindeer herders interviewed by Sandström and Widmark (2007), the consultation process was unsuccessful because they were included too late in the planning of the forestry measures. They wished to be included earlier in the process in order to have a real opportunity to influence the outcomes of forest management (Sandström *et al.* 2006; Sandström & Widmark 2007). Reindeer herders I interviewed raise the same issue today, and draw the same conclusions:

> We are a hinderance when we come in too late. We are no hinderance if we have the opportunity to participate from the start, so that we can plan together. "May be this place you are considering is unsuitable, but this is a suitable place, can we do something here?", "ah we had not thought about that", maybe they say. Instead, we come in so late in the planning that they have already presented a plan to the National Board of Forestry. Then it is too late. And it is wrong. (interviewee 36, reindeer herder, Kitkiöjoki, February 2020)

In the consultation as it operates now, the voice of reindeer herders comes in as a last minute factor to integrate into a well-established strategy, and thus inevitably acts as a hinderance.

In 2006, Widmark (2006: 51) discussed some reasons why the consultation system had not solved the conflicts existing between forestry and reindeer herding, and why reindeer herders felt particularly disadvantaged. She pointed out "the lack of clarity regarding the power distribution within consultations", a "confusion regarding property rights" and "the vagueness of the legal framework". Indeed, she raised the fact that Swedish Forest Policy is based on the principle of "freedom-under-responsibility", which is formulated in terms of objectives rather than directives, and thus fails to provide clear guidelines as to how the consideration of reindeer herding should be applied. The discourse of reindeer herders today compared to the conclusions of Widmark (2006) and

Sandström and Widmark (2007) shows that, in a little more than ten years, the situation has not really changed.

4.4.4 Towards co-management of controlled burning?

With respect to delivering results based on the common interests shared by Sami herders and forest managers regarding the use of fire, the consultation framework has proved far from sufficient. To one herder, overcoming the limitations inherent in the consultation process with forestry and addressing the difficulties related to carrying out their livelihood comes down to a political choice:

> Sweden must decide, "will reindeer husbandry continue to exist or not?" This is the big question. If the answer to that is "yes, it should continue to exist", then we must create the conditions to have food [for the reindeer], natural food. (interviewee 14, reindeer herder, Malå, August 2018)

Another herder stressed the need to implement an actual collaboration between forest management and reindeer herding in the planning of the burnings, instead of the consultation:

> If we work together, then I think that we can develop nature conservation in a positive way. But reindeer herding must be included. If you push reindeer herding away in every respect, then you do wrong. I consider it so. Reindeer herding is important in every respect. Forestry must listen to reindeer herding, nature conservation must listen to reindeer herding, and then we can develop together, then something good will come out of it. This is how I see it at least. (interviewee 36, reindeer herder, Kitkiöjoki, 2020).

Rather than being consulted at the last stage of the planning process, herders strongly express their desire to be considered as true partners when developing fire management strategies. With the consultation process as it is now, herders tend to stand against management measures proposed by forest managers because they have not been included in a common burning strategy. However, burning represents a middle ground for both Sami herders

and forest managers, and greater inclusion of Sami herders could thus guarantee that burning is beneficial for both groups.

Possible solutions for improvement of the consultation process have also been proposed by scholars (Sandström *et al.* 2006; Sandström & Widmark 2007). Based on interviews with reindeer herders and forest managers, Sandström and Widmark (2007) compiled a list of criteria to improve the consultation system, including knowledge about the others' livelihood, the same level of decision-making, systematic use and sharing of maps, the presence of a negotiator and trust.

In other regions, co-management programmes for natural resources that include indigenous peoples and aim to redress the inequality of power between land users, have been implemented for a few decades in various contexts and places, with various results. In the case of fire management, some countries have taken advantage of the fire restoration movement to implement cooperative fire management systems, which include indigenous burning practices and indigenous peoples in the planning of the burning measures, for example in Australia (Bliege Bird *et al.* 2008; McGregor *et al.* 2010; Russell-Smith *et al.* 2013). In South America, some scholars now argue for "intercultural fire management" (Rodríguez *et al.* 2018) and for "intercultural and participatory management" (Eloy *et al.* 2019).

Moreover, knowledge of local and indigenous peoples has been recognised by many scholars as an invaluable source of knowledge about natural resources and environmental issues, and as a basis to inform sustainable management of natural resources and conservation, including ecological restoration (Gadgil *et al.* 1993; Berkes *et al.* 2000; Long *et al.* 2003; Shebitz, Daniela 2005; Molnár *et al.* 2008; Rist *et al.* 2010; Uprety *et al.* 2012; Molnár 2014; Lavrillier & Gabyshev 2018). Molnár (2014) argues that in Europe, the consideration of ecological knowledge of pastoralist societies in resource management has been neglected compared to other regions. For example, he notes that "in Africa, the application of traditional ecological knowledge of pastoralists to range management resulted in an increasing appreciation of local herding practices, and contributed to a paradigm shift in management" (Molnár 2014).

Although Sami reindeer herders do not have immediate practical knowledge about fire use, they still hold a rich and detailed knowledge about the forest, its functioning, its composition, its deepest nooks and crannies. Moreover, inclusion of Sami ecological knowledge could contribute to

implementing a fire management system that includes historical land uses and their influences on historical fire regimes. Indeed, as indigenous inhabitants and land-users of the boreal forest, the herders and their reindeer contributed to shaping the boreal landscape that conservation managers seek to preserve today. Claiming to preserve historical ecosystems or to restore them without including the Sami, their knowledge, and the role of their historical land-use would be to miss an essential piece of the puzzle. In the same way, Molnár (2014) argues that management methods today must be based "on those that have shaped the particular landscape for centuries".

Although some scholars have also warned against the risks of exploitation and distortion of indigenous and local knowledge in co-management projects, and highlighted the limits and biases of existing programmes of co-management (Kull 2002; Nadasdy 2003; 2005; Houde 2007), including Sami ecological knowledge in fire management could help to legitimise their participation as primary actors in fire management and restoration.

Several forestry planners I interviewed noted that there is currently increasing pressure on the forestry sector to be more effective and economically profitable, thus jeopardising possible initiatives for collaboration with Sami reindeer herding in fire management. To overcome this situation, there must thus be a political will to include Sami reindeer herders in forest and fire management, and to implement fair and democratic fire management. Time will tell whether the guidelines provided by the 2020 FSC standard will resolve some of the flaws identified, and guarantee greater inclusion of Sami reindeer herders in forest management by moving from a consultation approach to co-management.

4.5 Domesticating fire: a symmetrical approach of humans-fire interactions

This section presents a symmetrical analysis of human–fire interactions, that is, I analyse how humans influence fire, and in return, how fire influences humans. "Fire" is understood here as the ecological fire disturbance, which translates into the actual phenomenon of burning, but also into an absence of burning. Indeed, because the absence of fire – resulting from fire suppression – has effects on the environment, humans are led to position themselves vis-à-vis fire even when it is absent. Humans make choices and build strategies regarding fire that are rooted in their representations and knowledge about

fire, and which are influenced by power relations. In return, fire influences and acts on humans during direct interactions with burning practitioners, but also during negotiations between groups of actors about the place of fire in the boreal forest. Indeed, in northern Sweden, the very presence of the fire phenomenon induces interactions between groups of actors, namely forest managers and Sami herders. These human–fire interactions, in combination with environmental factors, result in specific fire regimes, i.e. specific patterns of fire occurrence in time and space. In the words of Pyne (1997a: 19): "as a dialectic between humans and nature, fire regimes express the values, institutions, and beliefs of their sustaining societies".

4.5.1 Fire regimes as results of interactions between humans and fire

In **paper II**, I analysed how Joel E. Wretlind's use of burning translated into the evolution of the local fire regime in Malå. Today, the burning strategy, and thus the fire regime, are mostly driven by nature conservation objectives. In this thesis, I have not analysed in any quantitative way the translation of the technical and strategic choices related to controlled burning in terms of contemporary fire regime. As a matter of fact, there is no database at the national level gathering data relating to all burnings carried out in Sweden, which makes it difficult to gain an overview of the burning pattern at the national, or even regional level (Ramberg *et al.* 2018). Moreover, over half of the forestlands belong to more than 300,000 small-scale private forest owners (Eckerberg & Buizer 2017), for which the data are even more inaccessible. Nevertheless, some studies have summarised the characteristics of the burnings carried out by forestry companies and the County Administrative Boards for some periods. These characteristics can be related to factors that drive the burning strategy (Figure 20).

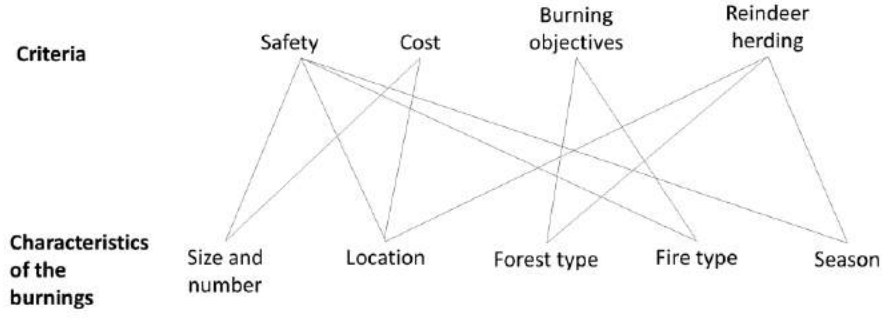

Figure 20. Criteria considered in the planning of controlled burning in relation with the characteristics of the burning determined by these criteria.

Total burned area

As described in **paper II**, in Malå, Wretlind started to experiment with regeneration burning in 1921, one year after his posting as forestry planner, after he discovered the poor regeneration condition of the Malå forests. Wretlind's experimental burnings mainly took place during the 1920s and 1930s, which is visible in the evolution of burned area and number of burnings (Figure 21). He continued to experiment with burning until the mid-1930s, when the disavowal of his methods by the forestry community encouraged him to take a leave of absence to focus on his experiments. This absence translated into a reduction in the burnings and burned area in Malå forests from the mid-1930s to the 1940s. Burning started again in the 1940s, when Wretlind returned to his position in Malå and succeeded in convincing his peers of the efficiency of regeneration burning. Burning continued to be used after Wretlind's retirement, and decreased progressively until the 1970s. This pattern can be compared with the pattern obtained by Östlund *et al.* (1997: fig. 9) for Lycksele Parish, neighbour to Malå municipality: they generally follow the same trends, except for the late 1930s – early 1940s, when burning continued to be used in Lycksele.

The results of **paper II** show that the use of regeneration burning in Malå during the period when Wretlind was active (1921-1935 ; 1944-1950)

affected 0.6% of the area of the Malå state forest per year on average. This represents an increase compared to the levels estimated by Niklasson and Granström (2000) for the 1ast decades of the 1800s in a river valley 140 km southeast of Malå (0.25% per year on average) (Figure 21). During the peak year in Malå, 1950, the burned area amounted to 1161 ha, i.e. 1.9% of Malå state forest. This is still below, but approaches the historical peak calculated by Niklasson and Granström (2000) for the period 1830-1860, corresponding to 2.8% of the area per year. By comparison, Östlund *et al*. (1997) found that regeneration burning used during the periods 1920-1940 and 1950-1960 affected up to about 1% of their study area in Lycksele parish annually during the peak year.

During the whole period in Malå, there were very few uncontrolled forest fires, affecting small areas compared to the regeneration burnings, thanks to fire suppression.

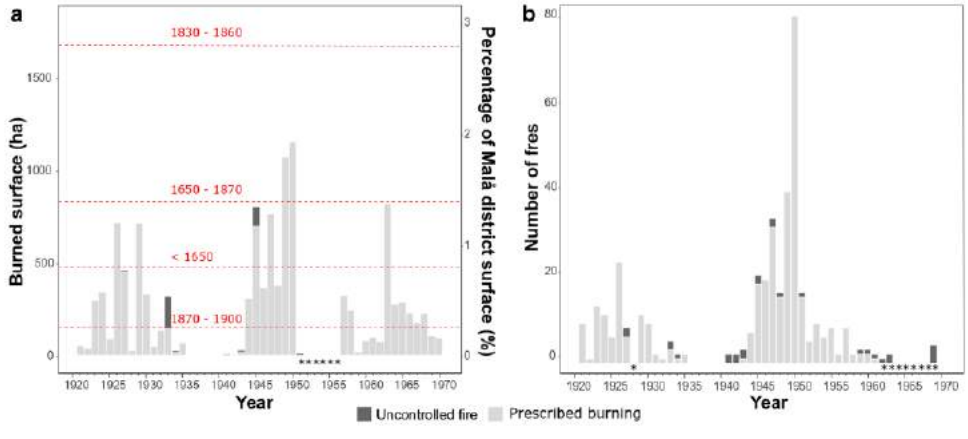

Figure 21. a. The total area burned through regeneration burning (light grey) and uncontrolled fires (dark grey) and b. the number of fires attributed to regeneration burning (light grey) and uncontrolled fires (dark grey), per year in Malå state-owned forests. The red-dotted lines in a. indicate historical levels of burned area calculated by Niklasson and Granström (2000) for various periods. The stars indicate missing data for regeneration burning.

Since the resumption of fire restoration in the 1990s, the total burned area each year increased among large forest owners from about 400 ha in total in the early 1990s to over 1700 ha in 1997 (Eckerberg & Buizer 2017). Ramberg (2017; Ramberg *et al*. 2018) has gathered data on the burnings carried out by the main forestry companies in Sweden and by 15 County

Administrative Boards between 2011 and 2015, and uncontrolled forest fires (Table 2). According to her data, during this period, 0.006% of the total forest area (excluding the exceptionally large Västmanland fire that occurred in 2014) burned annually, with 35 % caused by natural fires and 65 % by controlled burnings (Ramberg et al. 2018). Conservation burning carried out by forestry companies and the County Administrative Boards represented 40% of the area burned through controlled burning, while regeneration burnings carried out by forestry companies represented 50% of the burned area (the remaining 10% were not characterised) (Ramberg 2017). Compared with the percentages quoted in **paper II** for Malå forests, and in Granström and Niklasson (2000), these data indicate that the total area burned today remains far below historical levels, and that controlled burnings do not compensate for fire suppression.

Table 2. Total area affected by controlled burnings carried out by 15 Swedish County Administrative Boards and major forestry companies between 2011 and 2015, from Ramberg (2017). "Burning" corresponds to an undetermined category provided by one forestry company. The burned proportion of the forest area is calculated for a total forest area of 30.5 millions ha (Ramberg et al. 2018).

Burning type		**Area (ha)**	**Proportion of the forest area (%)**
Conservation burning -	County Administrative Boards	861	0.0028
-	Forestry Companies	1664	0.0054
Regeneration burning		2975	0.0097
"Burning"		641	0.0021
Uncontrolled fires		3231	0.011
TOTAL		**9372**	**0.03**

Size and number of the burnings

In regeneration burning, the size of the burnings is a compromise between safety and economic criteria, as Wretlind discussed in his writings (1932; 1948). On the one hand, the larger the stand, the harder it is to control the progress of the fire and to keep track of the actions of the burning team. On the other, the larger the stand, and the fewer burnings, the lower the burning costs per hectare. According to the data from the National State Forest Company, the mean area of the stands burned between 1921 and 1970 in

Malå National forests was 25 ha (± 13.8), with a minimum size of 0.2 ha and a maximum of 152 ha. In comparison, Niklasson and Granström (2000) found that 90% of the total burned area was due to fires larger than 1000 ha before 1650, compared to 55% after 1650.

Today, burned stands still tend to be relatively small. According to an experienced burning practitioner I interviewed, the stands they burned were usually between 20 and 40 ha. About half of the burned stands in the study of Westerberg (1997), reviewing about 50 regeneration burnings carried out in 1996-1997, were smaller than 10 ha. Westerberg (1997) argues that this is the minimum size needed to keep the costs per hectare small. According to the data obtained by Ramberg (2017), stands burned through controlled burning during 2011-2015 were 12 ha on average. Uncontrolled fires affected even smaller areas (3 ha on average) because of fire suppression measures (Ramberg 2017).

As for the number of burnings, Wretlind's fire management and burnings in Malå translated into more numerous burnings per unit of time and area (1.5 burnings $(10^4\ ha)^{-1}\ year^{-1}$ during 1921–1961) compared to the historical fire regime reconstructed by Niklasson and Granström (2000) (1.17 fires $(10^4\ ha)^{-1}\ year^{-1}$ for the peak period 1840–1860).

Today, Ramberg's (2017) data indicate that 466 burnings were carried out in total by both the County Administrative Boards (76 burnings) and the forestry companies (390 burnings) for the period 2011-2015, i.e. 3.05×10^{-2} burnings $(10^4\ ha)^{-1}\ year^{-1}$, calculated for the total forest area in Sweden, i.e. 30,5 millions ha. Compared with results obtained by Niklasson and Granström (2000) and the data for Malå state forests, the number of burnings per unit of time and area is much below historical levels. However, it must be noted that, for burnings performed by forestry companies, Ramberg's (2017) data were obtained from four large forestry companies, which represent the majority but not all burnings carried out in Sweden by forestry companies during this period. These numbers are thus slight underestimates.

According to Niklasson and Granström (2000), there has been a tendency towards more numerous and smaller fires with time in northern Sweden. Rolstad *et al.* (2017) found a similar trend for the period 1625-1800 in a study area located in the Norwegian boreal forest, associated with an increase in population density. Regeneration burnings carried out in Malå during

Wretlind's management and today's burnings in Sweden thus follow this same trend, although the purpose of the burnings has changed.

Location of the burnings

To Wretlind, the safe and easy delimitation of the stand was the foremost criterion in the choice of location, for both safety and economic reasons. Thus, he recommended that the stand should preferably be bordered by mires and lakes, which reduced the costs of securing the stand, and possible costs related to fire escaping to a neighbouring commercial forest stand. Wretlind also advised avoiding choosing stands that were bordered by recently burned stands because they could catch fire again through ground fire (Wretlind 1932).

Today, the choice of location of the burning is primarily determined by safety criteria as well, and forest managers prioritise burning stands that are surrounded by wetlands and waterbodies, ideally islands or peninsulas, where the risks of the fire escaping are minimal (Figure 22). This can represent a deviation form historical fire regimes, since the chances of a forest fire occurring on an island are smaller than on continuous dry land, as some conservation managers pointed out.

Today, the presence of Sami reindeer herding in the area where the burning is carried out can also influence the choice of stands to be burned. As stated in section 4.4 and in **paper IV**, Sami herders sometimes negotiate about the burnings proposed by forest managers, including their locations, notably if they are located close to strategic places for reindeer herding, such as migration routes or reindeer corrals. Some forest managers also try to spread out burnings to avoid concentrating them on the lands of just one reindeer herding community.

According to both forestry planners and conservation managers, there is currently no coordination at the regional level between forestry companies and County Administrative Boards to spread out the burnings in a strategic way at the landscape scale, although some forest managers regret this absence of coordination.

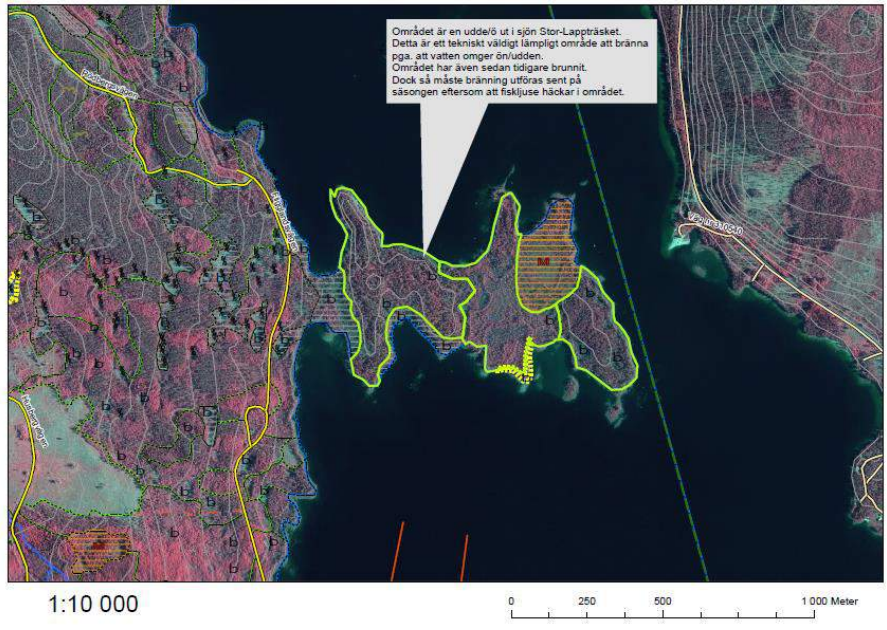

Figure 22. Example of a planned nature conservation burning in Norrbotten County by the National Forest Company. Explanations state: "The area is a peninsula out in the lake Stor-Lappträsket. It is a very easy area to burn technically because water surrounds the peninsula. The area has also burned before. However, the burning must be carried out late in the season because ospreys are nesting in the area" (source: G. Emanuelsson, Sveaskog).

Forest type

In Malå, Wretlind mostly applied burning on what he called "raw-humus" forest stands, that is, forests with a ground layer of organic matter covering mineral soil, and with a thick moss cover; these were hard to regenerate without burning. In contrast, Scots pine heaths are easily regenerated without soil preparation measures. Thus, between 1921 and 1931, when Wretlind experimented with regeneration burning, 91.6% of the burned area comprised moss-rich forest and 8.4% Scots pine heath forest (Wretlind 1932). According to inventories carried out in 1959 and 1960 (Appendix 1:10; 11), more than 90% of the burnings carried out between 1921 and 1960 were performed in mesic and humid ericaceous shrub forests. As noted in **paper II**, this pattern thus reverses the trend of the historical fire regime in terms of burned forest type. Indeed, according to Zackrisson (1977), in his study area located in a river valley southeast of Malå, the mean fire frequency

was higher for lichen-*Calluna* forests i.e. Scots pine heaths (52.4 years) than for *Vaccinium vitis-idaea* forests (58 years) and *Vaccinium myrtillus* forests (98 years). Thus, forest types that were seldom affected by fire were prioritised for burning because they were hard to regenerate, and forests with a historically high fire frequency were burned less often.

In the study by Westerberg (1997), regeneration burning was mostly applied to mesic areas with bilberry that were of medium fertility and had a moderately thick humus layer. This corresponds to stands that are hard to regenerate without any soil preparation measures, as theorised by Wretlind (1932; 1948). As for conservation burning, according to the data collected by Ramberg (2017), conservation burning carried out by County Administrative Boards is mostly applied in mixed coniferous forests dominated by Scots pine on sand or peat soil. The description of the stands often included the words "old", "nature" or "affected by fire" (Ramberg 2017). This reflects the objectives of conservation burning, which are to restore natural fire dynamics, and to maintain historical Scots pine forests by reducing the occurrence of Norway spruce. Fire is thus preferentially applied in forests that have a history of recurring fires.

The presence of Sami reindeer herding also influences the type of forest that is burned. This is mainly driven by the FSC certification, which prevents burning of lichen-rich stands for the sake of reindeer herding. On one hand, this can represent a deviation from historical fire regimes, and go against conservation objectives, since lichen-rich forest stands, also corresponding to dry Scots pine heaths, are the forest types that historically burned most frequently. On the other hand, reindeer herders sometimes propose burning forest stands that they know have been lichen-rich in the past, to get the lichen back. Burning such stands would thus be in line with fire restoration objectives.

Fire type

The type of fire occurring during the burnings is also determined by a compromise between safety and efficiency. In the case of regeneration burning, fire must not be too intense, to guarantee the safety of the burning and remain controllable. However, fire must be intense enough to destroy the vegetation that could compete with the tree seedlings, and to induce the required soil transformation in order to increase fertility. In regeneration

burning, the objective is also to obtain a homogeneous effect of fire across the stand, to ensure even regeneration. In conservation burning, in contrast, one main objective is to induce heterogeneity in the forest stand, which, as stated in box 1b (section 4.2), can be achieved by carrying out forestry measures beforehand, but also through the burning technique. Then, in both regeneration and conservation burning, practitioners seek to avoid underground fires because they could spread to neighbouring forest stands. This is ensured through the presence of firebreaks and by wetting the edges of the stand. According to forest managers, in the case of conservation burning, the fire usually progresses as a surface fire and rarely develops into a crown fire because of the low intensity.

Experienced burning practitioners can influence the properties of the fire during burning, in terms of intensity, speed, and pattern, by modulating the speed and the location of the ignition points, as described in **paper IV**. They can also act upon the fuel load to steer the progress of the fire. Through their technical skills and their knowledge of fire behaviour, burning practitioners thus seek to reach the specific objectives associated with regeneration and conservation burning, which, in turn, influence the type of fire that is generated, and the resulting fire regime.

Season

Data analysed in **paper II** show that in Malå, during the period 1921-1951, 28.9% of the burnings were carried out before 15 June, 44.9% between 15 June and 15 July, 19.1% between 15 July and 15 August, and 7.2% after 15 August. This distribution can be compared with the natural pattern based on lightning ignitions. According to Granström (1993), lightning ignitions in boreal Sweden peak in late June and early July, with 12% of the ignitions occurring prior to 15 June and 3% after 15 August. Regeneration burning conducted under Wretlind's management resulted in a shift towards early season fires, with a higher proportion of ignitions occurring prior to 15 June compared to the lightning ignition pattern. As stated in **paper II**, this seasonal pattern reflects Wretlind's recommendations to carry out burning as early as possible in the snow-free season, as soon as the ground was dry enough, to ensure an efficient burn. These conditions usually occurred around mid-June. Wretlind also recommended not waiting for too long after the required level of dryness was reached to avoid the risks of fires becoming too intense.

Today, the same reasoning is applied by burning practitioners. They ideally wait for the required levels of air humidity and stand dryness. In Westerberg's (1997) study, 70% of the burnings were carried out in June, none in July, and 20% in August. However, today, fire bans established during periods of drought, when the risks of forest fires are high, can prevent burning practitioners carrying out burning at the optimal time. In addition, as stated in **paper IV**, reindeer herders can also ask forest managers to delay the burnings until the autumn when the calving period is over. Furthermore, today, forest managers take into consideration the effects of the burning on the fauna and flora and sometimes delay the burnings accordingly, as in the example presented in Figure 22. These factors would bring the fire regime outside the historical seasonal window, since, following the lightning ignition pattern, few fires occur after 15 August.

To conclude, the results of **paper II** clearly show that during the study period (1921-1970), the fire regime was very strongly determined by human fire management, through both anthropogenic burning, carried out under Wretlind's management from 1921 to 1950, and fire suppression. This is still the case today, as most of the burned area is the result of controlled burnings, and as fire suppression is still the rule for uncontrolled forest fires. Fire management not only controls the total burned area, but also the characteristics of the fire regime in terms of size and number of burnings, location, forest type that is burned, type of fire, and seasonality. These characteristics result from the technical choices applied by burning practitioners according to the objectives for burning. Such an analysis also reveals how a combination of sociocultural, economic, and technical factors comes into play in shaping fire regimes.

4.5.2 Fire as an actor of fire management

In **paper IV**, I discuss how fire can be interpreted as an actor of the fire management system – conceived as a domestication system – in two senses. First, fire is described as an actor by the burning practitioners I interviewed. Secondly, fire can be interpreted as an actor in the sense of the actor–network theory.

Burning practitioners I interviewed use a vocabulary usually referring to animals to describe fire behaviour: fire "creeps", "crawls", "runs", and "jumps". The association between fire and animal behaviour is also present in the metaphor used by Johan Turi in his book (see section 2.3.4: the wolf "burned like fire"). It is present in collective representations in other contexts as well: for example, the fire that destroyed 590,000 ha of forest in Fort McMurray, Canada in 2016 was called "the Beast" (Struzik 2017). Thus, in the fire domestication process as it is described by burning practitioners, fire is not passive, but active. Burning practitioners must learn how to steer fire behaviour and keep it under control in order to reach their objectives, while fire can "escape" at any moment. As Scott (2019: 54) writes, "when it is not closely watched, fire easily escapes from its captivity, going back to a hazardous wild state". Thus, in **paper IV**, I argue that burning practitioners are engaged in a form of negotiation with fire: fire is never fully domesticated, and it must constantly be watched, maintained and renewed. Similarly, Coughlan and Petty (2012) argue that the "knowledge and practice of fire use is a dialectic process between humans and their environment". The literature in anthropology about animal domestication shows that it is a reciprocal and continuous process, in which both humans and non-humans are active (see section 3.5.2), and the relationships that people have with fire show that such an understanding can be applied to elements like fire as well.

For forestry and conservation managers, once ignited, fire exerts an autonomous action on the environment that can hardly be imitated artificially, for example through "fire-mimicking measures" used when burning is considered necessary but too dangerous to be carried out. Based on her study of French pastoralists using burning to enhance their pasturelands, Ribet (2011) suggests that, rather than a tool, fire can be considered to be an agent[8]. The notion of fire agency was also used by Miller and Davidson-Hunt (2010) to describe how the Anishinaabe people of Pikangum First Nation in Canada conceived the action of fire in the landscape. Burning practitioners consider that fire is able to produce unique effects in the environment, and to make this environment more "natural". One main result discussed in **paper IV** is that, for burning practitioners and forest managers in northern Sweden, fire is an actor delivering naturalness.

[8] When it is used to confer agency to the subject in question, the term "agent" can be considered equivalent to "actor", which has become dominant in related literature.

Considering fire as an actor also makes sense under the lens of the actor-network theory, in which the domestication of fire can be analysed as a socio-technical network. The actor-network theory is one of the approaches developed over a few decades by scholars in different fields in order to redefine the status of non-human beings and to include humans and non-humans in a single framework of interactions. According to this approach, non-humans, even inanimate objects, are actors in such networks (Akrich *et al.* 2006). Through that lens, fire can also be considered to be an actor in its own domestication, not in the sense that it has an intentionality, but in the sense that it produces actions and effects within the network and on its actors. Such an interpretation thus coincides with conceptions of domestication as a reciprocal process, in which the domesticated element is not passive but active. The actor–network theory also helps us to understand how a technique, here burning as a forest management tool, can lead to reconfigurations of the relationships between humans and non-humans, and between humans themselves (Akrich *et al.* 2006). In northern Sweden, negotiations about the use of regeneration burning between reindeer herders and foresters during the 20th century contributed to shaping interactions between the two sectors, notably by leading to the implementation of the consultation process (see **paper III**). Likewise, fire restoration, since the 1990s, has opened up new opportunities for negotiation involving Sami herders during the consultation with forestry representatives (see **paper IV**). Moreover, through projects aimed at lichen pasture restoration after burning, new interactions between reindeer herders, researchers and foresters are being established, as they become partners in experimentation.

Thus, fire does not solely endure the action or the decisions of humans regarding its place and its behaviour in the landscape. It also acts in return, whether it is during the burning processes, in which burning practitioners must contend with its agency, or in the context of fire management, in which the presence of fire induces unprecedented interactions between the human groups of actors.

4.6 Studying the human dimensions of fire regimes through the lens of interdisciplinarity

As noted in the introduction and discussed in section 3.1**,** there have been various requests in the scientific literature to investigate the human dimensions of fire regimes through a multidisciplinary approach (Bowman *et a*l. 2011), or even further, through an interdisciplinary approach (Coughlan & Petty 2012). Such approaches are deemed necessary to tackle the deeply interwoven ecological and anthropogenic aspects of fire regimes. The combination of historical ecology, environmental anthropology and environmental history used in this thesis has proved well suited to meet this challenge. Each approach combined with the others provides insights about different aspects of the fire regimes.

First, the historical ecological perspective provides a solid basis for understanding the non-anthropogenic processes at play in fire regimes in the long term: what happens to the forest vegetation after a fire? How long does it take for certain species to establish? What are the long-term consequences of an absence of fire for the forest vegetation? Going beyond the "nature/culture" divide and understanding fire regimes in all their dimensions implies paying equal attention to every process occurring within the system, of both human and non-human nature. Ecological sciences and historical ecology are one way to look at and interpret the non-human processes at play. Furthermore, ecological processes unfold over long time spans, especially in the boreal forest, and one event in the past can have repercussions several decades or centuries ahead. Thus, the historical ecological perspective allows an understanding of the present, and the "current patterns and processes in nature" (Szabó 2010). In **paper I**, investigating the fire history of the inventoried sites allowed to develop an understanding of their present characteristics and the variability of the vegetation across the sites.

In addition, the historical ecological perspective allows connections to be made between the ecological history of the forest and its management history. For example, the results of **paper I** allowed the development of an understanding of the influence of the forest density, determined by management practices, on the ecological post-fire chronosequence. From an applied perspective, knowledge of historical forest management provides a

basis upon which to implement management measures today. As Szabó (2010) puts it, "the past provides a standard against which to check the current wave of fashion". For example, results of **paper II** about regeneration burning in Malå offer a reference point for controlled burnings carried out today, and can be used as a reference by today's forest managers.

From a methodological perspective, having a good understanding of the ecological processes at play allows the researcher to delve deeper in the interviews with the actors at the local level. The finer the understanding of the interviewer about the ecological processes investigated, the further the interviewees will go with their explanations. Moreover, gaining such an understanding not only through scientific literature but through field experience, through ecological inventories, encourages the researcher to pay close attention to the ecological components and processes of the system studied, and to experience, to some extent, the same environment as the interviewees, thus facilitating comprehension between the two parties.

The environmental history approach combined with an investigation of Sami ecological knowledge, as carried out in **paper III**, allows the investigation of multiple interpretations of the past, and the construction of a fuller and more balanced picture of history. As discussed in **paper III**, historical reconstruction implies a double subjectivity: the subjectivity of the sources, and the subjectivity of the historian. In the case of northern Sweden, historical sources available to reconstruct the history of forest management are mainly written sources, and thus mostly convey the point of view of state institutions and representatives. Then, the historian selects questions and sources according to contemporary preoccupations, cultural background, research environment, etc. In **paper III**, the historical analysis of past fire management and its effects on Sami reindeer herding included the perspective of the foresters and institutions through written sources, and the perspective of Sami herders through Sami ecological knowledge. Investigating contemporary Sami ecological knowledge allowed a reinterpretation of historical sources in the light of the indigenous perspective. The Sami perspective revealed the complexity of interactions between regeneration burning and reindeer herding that had not been captured in written sources. Indeed, insights from the Sami perspective raise the importance of considering the impacts of burning on the reindeer herding system, including the behaviour and the movement pattern of the reindeer,

and not simply on the total amount reindeer pasture. Thus, including the Sami perspective through contemporary Sami ecological knowledge allowed questions to be raised that would not otherwise have been addressed, and it counterbalanced the narrative accessible through historical sources. Such an approach is especially relevant in colonial contexts where history is rarely told from the perspective of indigenous peoples.

As for the environmental anthropological approach, it firstly allows the researcher to investigate and highlight different interpretations and understandings of fire regimes and fire management and to put them in perspective in relation to one another. Thus, the anthropological approach, as developed in **paper IV**, allowed the investigation of representations of fire and the boreal forest and the related body of knowledge and know-how held by the actors involved, as well as the interactions between groups of actors, which underlie fire management.

Furthermore, investigating local and indigenous knowledge about fire management combined with the historical and ecological approach highlights unexplored aspects of fire regimes. As discussed in section 3.1.2, anthropology teaches us that there are multiple ways to view and to understand the world, and that "science" is one among others. Molnár *et al.* (2008) recall that "both western science and traditional knowledge aim to understand the surrounding world". If we consider that our job as scientists is to observe, describe and understand the world, then including multiple types and sources of knowledge can only contribute to expanding and deepening our understanding of the world. Thus, in **paper I**, combining ecological investigations with Sami ecological knowledge allowed the development of a more full understanding of the history of the places studied, incorporating intertwined natural and cultural processes and dimensions: *roavve*-places are ecological habitats affected by fire perturbations, but also reindeer herding lands, which bear cultural dimensions transmitted through place names. Furthermore, from an applied perspective, highlighting and recognising the existence of different modes of interpretation of the world, and more specifically indigenous knowledge, challenges the dominant management system and its foundations, and constitutes an argument for the implementation of a fairer system.

Of course, the interdisciplinary "journey" is not without difficulties and limitations. It is already difficult enough to master one research field, one disciplinary area. One individual researcher can hardly pretend to master several. Indeed, interdisciplinary research carried out at the individual level is necessarily limited by the capacity for one researcher to fully absorb the conceptual and methodological backgrounds of the disciplines mobilised. As an interdisciplinary researcher using methods from ecological sciences, I would surely not compete with a full-time ecologist in the detailed understanding of ecological processes, such as the post-fire chronosequence. Similarly, I have not analysed every aspect of the sociocultural life of the groups of actors I interacted with, as an ethnographer would do.

On the basis of my academic background, I followed every thread that allowed me to understand in the best way the processes and phenomena that I was able to observe. Thus, I adhered to a constructivist and pragmatic approach to interdisciplinarity: research practice results from a series of experiences and observations that, once assembled, form a cohesive framework of interpretation.

Furthermore, the very fact that interdisciplinarity leads us to tackle questions through multiple perspectives allows the building of bridges of knowledge and understanding objects of study in a holistic way. Meine (1999) argues that "natural scientists and historians may gaze upon the same landscape, but they see different things and draw different lessons from what they see". Interdisciplinary researchers are able to cross the boundaries between fields and to integrate these multiple visions into a single research framework. Thus, Szabó (2010) argues in the case of historical ecology that "interdisciplinary research produces synergetic results that, in optimal cases, are more than the simple sum of information gathered from individual disciplines". I argue that the outcomes of interdisciplinary research are, if not greater, at least different from what would have been the sum of outcomes of each discipline individually. The capacity to build bridges and connections between fields, methods and concepts opens the door to addressing unprecedented questions, and thus producing novel results, which are located at the interface between the disciplines mobilised, and thus cut across the "natural" and the "cultural" boundaries.

5. Conclusions

There is, today, renewed interest in fire and the associated processes in ecosystem functioning. In this context, the main objective of this thesis was to investigate the human dimensions of fire regimes in boreal Sweden. More precisely, the studies focused on the interactions between fire, Sami reindeer herding, and forest management today and during the 20th century. I used an interdisciplinary approach combining historical ecology and environmental anthropology to examine the ecological and socio-cultural aspects of fire. The broad interdisciplinary approach employed in this thesis is particularly suited to tackling subjects of study such as fire regimes. Indeed, the results of this thesis reaffirm that fire is not a purely natural phenomenon, and highlight the importance of the human dimensions of fire regimes. Studying fire regimes without a combination of natural sciences with human and social sciences would be missing the mark. The results arising from the research questions addressed in this thesis and in the papers it is based upon can be summarised as follows:

1) What knowledge and representations of fire is historical and contemporary fire management based upon?

In today's forest management, fire is seen as a natural perturbation to be restored. For forest managers, it is the most natural method to regenerate Scots pine forests, and for conservation managers it is a critical process in the restoration of biodiversity. For Sami reindeer herders, fire is more ambiguous, because of its contrasting consequences for reindeer pastures, and because of the use of fire during colonisation of the boreal forest. Historical sources and the accounts of reindeer herders suggest that, before the fire suppression era, the Sami often had to endure forest fires with little power to control them. From the 19th century, the Sami had forest

management and forestry practices imposed on their herding lands, including regeneration burning in the mid-20th century. During this period, they were mostly excluded from decisions related to fire management. Although they are convinced that fire is part of the boreal forest, their relationship with fire is inseparable from the history of encroachment of their herding lands, which can explain the Sami's mistrust of fire.

For all, representations of fire are associated with bodies of knowledge about fire and burning, which have been intermixed with one another, and challenged by the fluctuating use of controlled burning in northern Sweden during the 20th century. Since the return of fire through regeneration and conservation burning in the 1990s, controlled burning practices are based on a hybrid body of knowledge that incorporates heritage from the mid-20th century's burning practitioners, learning by doing, and new scientific insights from ecological sciences. As for Sami herders, although they do not generally have access to the practical experience of burning, they have continuously observed and followed up the effects of fire on their herding lands, which they can combine with the experience of their elders. Thus, a new "burning culture" including new actors is slowly emerging in northern Sweden, on the foundations of historical fire regimes and renewed practices.

2) What are the historical and contemporary impacts of fire management on Sami reindeer husbandry?

Although some studies have investigated the effects of fire on reindeer pasture and reindeer herds in Fennoscandia and North America, little is known about how fire regimes affect reindeer pastoralism, i.e. an itinerant and dynamic system including the herd, herders and grazing resources. The study of the ecological history of *roavve*-places (a Sami linguistic category designating a habitat where there has been a forest fire and which is rich in reindeer lichen, and thus a good winter pasture) reaffirms that fire suppression is detrimental for maintaining such habitats in the long term. The study also showed that fire was associated with good pasturelands in Sami knowledge. Thus, whether the Sami used burning or not in the past, the study of *roavve* strengthens the hypothesis that they were aware of the positive effects of fire on reindeer winter pasture over time.

During the first half of the 20th century, fire management simultaneously consisted of the general suppression of wildfire on the one hand, and regeneration burning in some forests on the other, which affected reindeer

herding in several ways. According to written sources, burning was mostly beneficial for reindeer herders because it favoured the growth of summer pasture. However, interpreting this history through Sami ecological knowledge shows that burning not only affected the total amount of reindeer pasture, but also the behaviour of the reindeer and their movements across the landscape, which affected control of the reindeer herd. Overall, fire management, added to other land encroachment, made herding unpredictable and difficult. Today, Sami herders consider burning moss-rich lands to be a way to favour summer pasture, to regenerate lichen in the long term, and to avoid detrimental soil preparation measures for reindeer herding. However, they remain opposed to burning forests with reindeer lichen due to the critical decrease of winter grazing lands they have experienced during recent decades.

3) How did the governance of fire management evolve across the 20th century, up until today, regarding Sami reindeer husbandry?

Since the 19th century, decisions about burning and fire management in general have been in the hands of landowners and state institutions. However, historical sources of the National Forest Company showed that the issue of fire became a matter of dispute between reindeer herders and the forestry sector very early on. In 1923, an early form of consultation of Sami reindeer herders was implemented by the National Forest Company, focusing especially on the issue of burning. Tracing the history of consultations shows that the issue of fire triggered a dialogue between the two sectors, and a process that led to the regulation of the consultations in the 1979 Swedish Forestry Act. In the 1990s, the FSC certification imposed burning objectives on forestry companies on the one hand, and strengthened consideration of indigenous people on the other. Today, Sami herders are using the consultation process to negotiate the application of regeneration or conservation burning, and to steer the burnings towards their own interests. However, because the Sami come in at the last stages of the planning process, there is often a mismatch between what they would like to burn, and the proposals that are presented to them. The decision process and the power imbalance between Sami reindeer herding and forest management thus hinder potential agreement.

4) How did fire–human interactions shape fire regimes, and *vice versa*, in northern Sweden through the 20th century and up to the present?

Humans have contributed to the fire regimes of the boreal forest throughout history. During the first half of the 20th century, the fire regime of the Malå state forest was strongly influenced by forest manager Joel Wretlind through his experimentation and development of regeneration burning. Despite opposition from the forestry community about the use of burning, Wretlind succeeded in making burning the foremost regeneration method for Scots pine forests during the 1950s-1960s. Since the 1990s, the fire regime has been driven by a fire management strategy focused on nature conservation, through regeneration and conservation burnings. Human management of fire during these periods has influenced the fire regime, compared to the pre-industrial situation. Indeed, technical constraints and choices, steered by a compromise between safety, cost and burning objectives (mainly the need to achieve good regeneration in logged commercial forests, and ecological restoration and biodiversity conservation in protected forests), have influenced the fire regime in terms of size and number of burnings, location, burned forest type, fire type, and seasonality of the burnings.

In return, fire influences human practices and representations of the boreal forest, and even participates in shaping interactions between groups of actors involved in fire management. Based on a symmetrical analysis of the human–fire interactions, fire can firstly be conceived as an actor of fire domestication. Burning practitioners describe and treat fire as something never fully mastered nor domesticated. They must contend with the behaviour of fire, which they are able to steer through their technical skills, but which is not under total human control. The domestication of fire is a continuous process in which fire is as active as humans are. Secondly, fire can be interpreted as an actor of fire management, conceived as a socio-technical system, in the sense of the actor–network theory. The renewal of the burning issue in the management of the boreal forest leads the groups of actors to take management decisions that result from negotiations about the place of fire in their activities, thus transforming the interactions between them.

5) Future prospects for equitable fire management in northern Sweden

In the current context, the imperative to restore fire for nature conservation purposes on the one hand, and the need to prevent the risk of forest fires due to climate change on the other, force forestry and conservation managers, as well as policy makers, to make decisions regarding fire. Thus, questions arise concerning the governance and management of fire.

First, the results of this thesis show that fire regimes are the product of interactions between humans, chiefly forest owners including forestry companies, state agencies, and small private owners in northern Sweden. In contrast, the Sami currently have little influence on the fire regimes. While they are able to influence burning strategies a little, Sami herders are still not included as genuine partners in fire management, although, historically, they contributed to shaping the boreal forest landscape. Fire restoration as it is currently carried out in northern Sweden presents a risk of perpetuating colonial power relations. Moreover, the results of the thesis also show that, while Sami herders are not fundamentally against burning in their herding lands, they might still oppose burning because the planning process takes only limited consideration of their interests. The question of how Sami herders should be included in fire management must, therefore, be raised, to avoid possible obstacles in the planning process. What type of governance should be implemented to guarantee the actual participation of Sami herders? Should they be included in the planning process from the beginning? Even though the new FSC standard raises the importance of including indigenous rights, the suggested modalities of the contributions of the Sami to the planning process can still be questioned. The standard requires forest owners to send documents regarding the proposed management activities to the reindeer herding community before the participatory planning meeting (FSC 2020). However, "participation" should not be limited to a validation or vetoing of decisions taken by others, but should include every party connected to the whole planning process in every step of that process.

Secondly, the results of this thesis suggest that, being the result of various historical pathways, combined with environmental factors, management objectives, and interactions between groups of actors, every fire event is unique. Likewise, every fire event will have different consequences for different forests, different groups of actors, and at different locations. In that respect, the agency of fire underlines the unique ways it acts on human

societies. In other words, there is not a single type of fire nor a single way to manage fire. Therefore, can burning be imposed from the top or does it have to answer local needs? How should forest and fire policies be developed to include local experience of the boreal forest? Since its first version, the FSC standard has addressed the question of Sami reindeer herding and fire through the prohibition of burning lichen-rich forests, thus only highlighting the opposition of Sami herders to burning. However, although the results of this thesis confirm the reluctance of Sami herders to burn lichen-rich forests, they also show that the Sami sometimes suggest to forest managers that burning is undertaken in locations that would also benefit reindeer herding. Burning represents common interests for Sami herders, forestry and conservation managers, which suggests that local actors could reach agreement about forests to burn based on their local experience and knowledge of the field. This reaffirms the need to include the local actors, who best know the lands and will live with the consequences of fire for decades, in the planning of every burning. It also raises the issue of the proper scale at which to address fire management. Because burning has a strong symbolic power and relies on material experiences of fire, i.e. a culture of fire, the management of fire in the boreal forest must be grounded in the diversity of knowledge and livelihoods of the forest inhabitants.

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Popular science summary

Forest fires have occurred spontaneously in the Swedish boreal forest since the deglaciation of the Scandinavian peninsula about 10,000 years ago. Human populations that progressively established in the area have certainly experienced the effects of forest fires, but they have also influenced, directly or indirectly, the way fires occur in the landscape. The spatial and temporal dynamics of the fires, corresponding to what are called "fire regimes", represent a major issue for several groups of actors within the boreal forest, including for the forestry sector, which has become an essential economic resource for Sweden since the beginning of the industrial era in the 19th century. On the one hand, the forestry sector implemented strict fire suppression to preserve silvicultural resources, whilst on the other, the burning of clear-cut forest stands appeared to be an efficient tool to ensure forest regeneration, after years of exploitation with no care for the renewal of the forest. During the first half of the 20th century, the regeneration burning technique was developed, and became the foremost regeneration method, notably thanks to the efforts of forest manager Joel E. Wretlind. However, mechanisation of the forestry sector from the 1970s temporarily put an end to the use of regeneration burning.

Since the 1990s, the role of fire as an ecological perturbation necessary for the functioning of the boreal ecosystem has been recognized by the scientific and forestry sectors. Today, fire represents an issue for biodiversity conservation. A policy of fire restoration has been implemented in Sweden, notably through the forest certification standard FSC (Forest Stewardship Council), which requires forestry companies to burn 5% of their regeneration area over five years. Regeneration burnings are thus carried out once more by forestry companies, and conservation burnings, which consist of burning

standing forests, are carried out by forestry companies and county administrative boards in protected forests.

The use of fire also affects Sami reindeer herders, the indigenous people of northern Fennoscandia, a region that extends across the Scandinavian peninsula, Finland, Karelia and the Kola peninsula in Russia. Indeed, Scots pine forests represent reindeer winter pasture, principally comprising ground lichens. Forest fires have a major influence on lichen availability. In the short term, they destroy the lichen, and it takes several decades to re-establish. Fire also destroys plant species that outcompete the lichens, allowing the lichens to recolonise certain habitants, thus maintaining their long-term availability. Beyond these observations, very little is known about the historical relationships between Sami reindeer herding and fire. Sami herders have been subjected to the different strategies of fire management implemented within their herding lands during the last 150 years. Indeed, as a result of several centuries of colonial policy, the Sami have only been permitted a right of usage of the forestlands that are the pastures for their reindeer, while the settlers practicing agriculture, and then the foresters, were allowed by the Swedish Crown to own the lands. Fire management stands out as a highly strategic issue for Sami reindeer herders today, in a context where the availability of ground lichens has dramatically decreased over recent decades, because of encroachment by other land uses, including forestry. Since 1979, Swedish law has provided reindeer herders with the chance to contest forestry measures, including burning, planned on their herding lands, through a consultation process.

The main objective of my thesis was to study the interactions between Sami herders and forest managers in relation to the use of fire during the last 150 years. I developed several research questions to address this objective: on what types of knowledge and representations of fire (that is, discourses about fire) does historical and contemporary fire management rest? What are the historical and contemporary effects of fire management on Sami reindeer herding? How did the regulation of fire use vis-à-vis Sami reindeer herding evolve during the 20th century and up to the present? How did the interactions between the different groups of actors concerned influence the fire regimes? How did the question of fire-use influence the relationships between the different groups of actors?

To answer these questions, I used different methods belonging to different scientific disciplines, including ecological history (that is, the study of the

role of human populations in shaping ecosystems across history) and environmental anthropology (that is, the study of relationships between human populations and their environment in social and cultural terms). I carried out ecological surveys and I dated forest fires at places designated by Sami place names as old burned forests, in order to understand the effects of fire dynamics on reindeer pasturelands. I conducted research in the archives to investigate the implications of regeneration burnings carried out during the first half of the 20th century for Sami reindeer herding. I conducted interviews with Sami reindeer herders, forestry managers and nature conservation managers to understand the position of each group, and how each group interacted with one another concerning the use of fire.

The results of my research show that in the forestry sector today, fire is seen as a natural perturbation that needs to be restored. To forestry managers, burning represents the most natural method to regenerate pine forests. To conservation managers, fire is seen as an essential process for biodiversity conservation. To Sami reindeer herders, fire is ambiguous because its effects on reindeer pasture can be both negative or positive depending on how it occurs in the landscape, but also because the Sami have mostly been subjected to fire management strategies imposed by land owners (first farmers and then foresters). For each group, fire is the object of a body of knowledge that has been transmitted across generations and that spread from one group to the other. Since their reinstatement in the 1990s, burning practices rest on a body of knowledge inherited from the regeneration burning era, but also on learning by doing, associated with recent scientific knowledge. As for Sami herders, although they do not have access to the practical experience of burning, they have nonetheless been able to observe the effects of fire on their herding lands. Thus, a new "culture of burning" is today emerging in northern Sweden within these groups of actors.

My results also reaffirm the role of fire in maintaining ground lichens and thus winter reindeer pasture. The study of Sami place names shows that the Sami were perfectly aware of the positive effects of fire on reindeer pasture in the long term. In addition, the study of archive sources shows that regeneration burning practiced during the first half of the 20th century was considered to be positive for reindeer herding because it favoured the growth of reindeer summer pasture (composed mainly of herbaceous plants). However, including the point of view of Sami herders in the questions allows an understanding of the complexity of the effects of burning on reindeer

herding. Indeed, the effects of fire must not only be considered in terms of total availability of pasture, but also in terms of the reindeer movements within the herding territory at different times of the year. Today, while the herders are strictly opposed to burning lichen-rich forests, they consider increasingly burning forests without lichen as a way to regenerate lichens in the long term, but also as a way to avoid forest regeneration measures that are more damaging to reindeer herding.

As for the inclusion of Sami herders in fire management during the last 150 years, archive sources show that the Swedish state implemented regulations concerning the interactions between forestry and reindeer herding, notably concerning burning, from the early 20th century. As early as 1923, a ruling by the national forestry company required forestry managers to obtain the consent of the state representative of the Sami before carrying out regeneration burning. My research shows that the question of fire triggered a dialogue between the forestry and the reindeer herding sectors, which contributed to the development of the consultation process in 1979. Today, Sami herders use the consultation process to negotiate the implementation of burnings and steer them towards their own interests. However, the Sami are included at the final stages of the decision-making process about burning, and there can be a mismatch between the burning objectives they would like to achieve, and the burnings proposed by forest managers. While burning currently represents common interests for Sami herders, forestry managers and nature conservation managers, and thus a possible middle ground, the power imbalance in the decision-making process hinders potential agreement. My results lead me to raise the question of how Sami herders should be included in fire management. I argue that fair and democratic fire management should include every actor concerned equally. Sami herders, who contributed to shaping the boreal forest that forest managers seek to preserve, should not be side-lined.

Populärvetenskaplig sammanfattning

Skogsbränder har uppstått spontant i de svenska boreala skogarna sedan inlandsisen drog sig tillbaka för cirka 10 000 år sedan. De befolkningsgrupper som gradvis etablerade sig i området har förvisso drabbats av skogsbrändernas konsekvenser men har samtidigt, direkt eller indirekt, påverkat hur bränderna har uppträtt i landskapet. Bränders dynamik i tid och rum brukar kallas”brandregimer” och utgör en avgörande fråga för flera grupper av aktörer i den boreala skogen, bland annat skogsbruket, som sedan början av industrialiseringen på 1900-talet har blivit en viktig ekonomisk resurs för Sverige. Skogsbruket har å ena sidan infört en mycket kraftfull brandbekämpning för att skydda skogsresurserna. Å andra sidan framstod kalhyggesbränning som ett effektivt verktyg för att säkerställa skogsföryngring efter flera decenniers skogsavverkning utan en tanke på skogens förnyelse. Under den andra hälften av 1900-talet förbättrades teknikerna för hyggesbränning och infördes som den främsta metoden för skogsföryngring, i synnerhet tack vare skogsförvaltaren Joel E. Wretlind som envist lyckades få det att erkännas som just en skogsföryngringsmetod. Mekaniseringen av skogsbruket från 1970-talet och framåt innebar emellertid att hyggesbränningarna tillfälligt upphörde.

I vetenskapliga kretsar och i skogsvården erkänns sedan 1990-talet skogsbrandens roll som en nödvändigt ekologisk störning för att det boreala skogsekosystemet ska fungera. Bränning utgör i dag en metod för att bevara den biologiska mångfalden. Ett system för att restaurera skogsbränder införts, bl.a. genom det svenska skogscertifieringsorganet FSC (Forest Stewardship Council), som ålägger skogsbolagen att bränna fem procent av sina föryngringsarealer inom en femårsperiod. Hyggesbränningar genomförs alltså återigen av skogsbolagen medan naturvårdsbränningar, som är

planerade bränder av ståndskog, genomförs av skogsbolagen och länsstyrelserna som förvaltar de skyddade skogarna.

Användningen av bränning berör även samiska renskötarna. Tallskogarna i norra Sverige utgör vinterbetesmarker för renarna, som då främst livnär sig av markväxande renlavar. Skogsbränderna har emellertid stora konsekvenser på tillgången till lavar. På kort sikt förstör de lavarna, som behöver flera årtionden för att återhämta sig. Men bränderna eliminerar samtidigt arter som konkurrerar med renlaven och som gör det möjligt för den att återerövra vissa miljöer så att dess tillgång säkerställs på längre sikt i landskapet. Förutom dessa observationer har vi mycket lite information om det historiska samspelet mellan renskötsel och bränder. Renskötarna har drabbats av de olika strategierna för bränning som har genomförts på deras renskötselområden under de senaste 150 åren. Efter flera århundraden av kolonialpolitik har samerna bara fått bruksrätt till den skogsmark som deras renar använder som betesmark, medan nybyggarna som bedrev jordbruk och därefter skogsbrukarna fick äganderätt till marken av den svenska kronan. Kontrollerade bränder framstår som en mycket strategisk fråga för dagens renskötare, i ett sammanhang där tillgången till marklavar har sjunkit dramatiskt under de senaste årtiondena p.g.a. att andra former av markanvändning har gjort intrång på deras betesmarker, i synnerhet skogsbruket. Sedan 1979 tillåter svensk lag renskötare att motsätta sig planerade skogsbruksåtgärder inom deras renskötselområden, däribland bränningar, genom en samrådsprocess.

Huvudsyftet med min avhandling är att studera interaktionerna mellan renskötare och skogsförvaltare när det gäller användning av bränning under de senaste 150 åren. Jag har utvecklat flera frågeställningar för att uppnå det här syftet, däribland: På vilken typ av kunskaper och vilka representationer (det vill säga de resonemangen som förs om skogsbrand) av skogsbrand bygger den samtida och historiska hanteringen av bränder? Vilka är de historiska och samtida effekterna av bränder på samisk rennäring? Hur har reglerna kring bränning i förhållande till renskötseln utvecklats under 1900-talet och fram till i dag? Hur har interaktionerna mellan de olika grupperna av aktörer påverkat hur bränder uppstår i den boreala skogen? Hur har frågan kring bränning påverkat relationerna mellan de olika grupperna av aktörer?

För att besvara dessa frågor har jag använt olika metoder från olika vetenskapliga områden, däribland miljöhistoria (dvs. studiet av de mänskliga befolkningarnas roll för bildandet av ekosystem genom historien) och

miljöantropologi (dvs. studiet av relationerna mellan befolkningsgrupper och deras omgivning ur ett socialt och kulturellt perspektiv). Jag har gjort miljöundersökningar och daterat bränder på platser som i sina samiska ortsnamn betecknar tidigare brända skogar, för att förstå effekterna av brändernas dynamik på renbetesmarkerna. Jag har forskat i arkiven för att undersöka konsekvenserna på rennäringen av de hyggesbränningar som gjordes under den första hälften av 1900-talet. Jag har genomfört intervjuer med samiska renskötare, skogsförvaltare och naturvårdsförvaltare för att förstå hur var och en ställer sig till användning av bränning, och hur de olika grupperna samverkar med varandra kring frågan om bränning.

Resultaten av min forskning visar att bränderna inom det moderna skogsbruket ses som en naturlig störning som bör återinföras. För skogsförvaltarna utgör bränning det mest naturliga sättet att föryngra tallskog. För naturvårdsförvaltarna är bränderna en viktig process för att bevara den biologiska mångfalden. För de samiska renskötarna är frågan kring bränderna mer splittrad, dels för att effekterna på renarnas betesmarker kan vara både negativa och positiva beroende på hur bränderna hanteras i landskapet, och dels för att samerna främst har fått ta konsekvenserna av den brandhantering som har beslutats av markägarna (jordbrukare, sedan skogsbrukare). Bränderna är för de olika aktörerna föremål för kunskaper som har förts vidare från generation till generation och som har spridits från en grupp till en annan. Sedan bränderna återinfördes på 1990-talet bygger de på den samlade kunskapen från den föryngringsbränning som utövades under den första hälften av 1900-talet, men också på mer ”praktisk fältkunskap”, tillsammans med de senaste vetenskapliga rönen. De samiska renskötarna har å sin sida ingen praktisk erfarenhet av att använda sig av bränder, men de har däremot kunnat konstatera deras effekter på sina betesmarker. Det här har lett till att en ny ”bränningskultur” nu håller på att växa fram i norra Sverige bland dessa olika aktörer.

Mina resultat bekräftar också skogsbrandens roll när det gäller att upprätthålla marklavar och därmed renarnas vinterbetesmarker. Undersökningarna av de samiska ortsnamnen visar att samerna var fullt medvetna om brändernas positiva, långsiktiga effekter på renbetet. Mina genomgångar av arkivdokument har också visat att den hyggesbränning som utövades under den första hälften av 1900-talet sågs som positiv för rennäringen eftersom den främjade återväxten av sommarbetesmarker för renarna (som bl.a. utgörs av örter och gräs). Genom att integrera samernas

ståndpunkt i den här frågan går det att förstå bränningarnas komplexa konsekvenser på rennäringen. När man ska bedöma brändernas konsekvenser måste man förutom att beakta den sammanlagda tillgängliga betesmarken för renarna också ta hänsyn till renarnas förflyttningsmönster över hela sitt renskötselområde under olika tider på året. Trots att renskötarna starkt motsätter sig bränning av lavrika skogar betraktar de i dag i allt större utsträckning bränning av lavfattiga skogar som ett sätt att förnya lavtillgången på lång sikt, men också som ett sätt att undvika tillämpande av andra skogsföryngringsåtgärder som kan vara mer skadliga för rennäringen.

När det gäller de samiska renskötarnas medverkan i hanteringen av bränder under de senaste 150 åren visar arkivdokumenten att den svenska staten redan under tidigt 1900-tal införde regler för samverkan mellan skogsbruket och rennäringen, bl.a. beträffande bränningar. Enligt en förordning från Domänverket (i dag Sveaskog) ålades skogsförvaltarna redan 1923 att inhämta samtycke från en representant för samebyarna innan man skulle genomföra hyggesbränningar. Mina efterforskningar visar att frågan om bränderna gav upphov till en dialog mellan skogsbruket och rennäringen, som bidrog till att inrätta samrådsprocessen 1979. I dag använder renskötarna samrådsprocessen för att förhandla kring bränningar och för att i större utsträckning kunna styra dem i sitt eget intresse. Samerna medverkar dock inte förrän i de sista stegen av samrådsprocessen, och det kan därför finnas skillnader mellan de mål för bränning som samerna vill genomföra och dem som skogsförvaltarna vill genomföra. Även om bränning i dag utgör ett gemensamt intresse för såväl renskötare som skogsförvaltare och naturvårdsförvaltare, och alltså ett område där de skulle kunna nå samsyn, begränsas de potentiella avtalen av beslutsprocessens ojämlika maktfördelning. Mina resultat föranleder mig alltså att ställa frågan om hur de samiska renskötarna ska kunna integreras i processen för planering av skogsbränningar. Jag stöder den uppfattningen att en rättvis och demokratisk planering borde integrera de olika aktörerna i lika stor utsträckning, i synnerhet de samiska renskötarna som har bidragit till att forma den boreala skogen som skogsförvaltarna i dag vill bevara.

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Appendix 1. Archive sources

Archive sources presenting, when existing, the reference code of the source in the archive, the name of the document in Swedish, and the description of the document.

National Forest Company's archive for Malå State Forest		
I.	(B, I, ac) Södra Malå revir konceptbok - 1924-1926	Letters received in southern Malå State Forest from state institutions related to forest management, forest managers, etc., between 1924 and 1926
II.	(B,I,b) Huvudserie Malå revir Konceptbok - 1927-1935	Letters received in Malå State Forest from state institutions related to forest management, forest managers, etc., between 1927 and 1935
III.	(II) Kopior av årsberättelser jämte bilagor	Malå district's annual reports and annexes
IV.	(D, IV, 1) Skogsodlingsliggare	Register of forest cultivation measures carried out between 1921 and 1951
V.	(E,II,7; 23) Circular letter 'S.IV:235': sent by K. Fredenberg and E. Wiel-Berggren (National Forest Administration) to the chief forest managers in Skellefteå district on 20 February 1923	
VI.	(E,II,7;23) Letter 'S.I.224'; 9 Sept: sent by E.W. Höjer and P.-G. Hultman (National Forest Administration) in 1962	
VII.	(E,II,7;23) Motion by Jovva Spik, Jokkmok, 8 January 1959, SSR national meeting	
VIII.	(E,II,7;23) Letter 'S.I.1918'; 12 December 1958 sent by H. Olsson and B. Mineur (National Forest Administration) to the chief forest managers in Upper Norrbotten, Lower Norrbotten, Skellefteå, Umeå, and Middle Norrland districts, as well as forest managers in Norrbotten and Västerbotten counties	
IX.	(E,II,7;23) "Angående skogsrenskötseln och skogshanteringen inom Skellefteå överjägmästarsdistrikt"	Letter by E. Kangas, 9 May 1955, about forest reindeer herding and forestry within the chief forest manager's district of Skellefteå

X.	(E, II, 43) Protokoll för inventering av naturlig föryngring pa bränd mark med fröträd" (1960)	1960 record of a natural regeneration inventory on burned stands with seed trees, indicating past forestry measures.
XI.	(H, IV) 1959 års åtgärdsinventeringsprotokoll	Record of a 1959 forestry measure inventory
XII.	(H,IV,7) Uppskattningshandlingar och avverkningsplaner till år 1959 kartlagda skogar i Malå revir; Andersson 1960	Evaluation documents and exploitation plans for the 1959 mapped forests in Malå State Forest, including a general description of the district (its forest composition and its management history)
Wretlind archive		
13.	Jägmästare Wretlinds diskussionsinlägg vid Norrlands skogsvårdsförbunds exkursion den 29/8 1957:	Transcription of forest manager Wretlind's contribution at the excursion of the Association of Forest Managers of Northern Sweden on 1957/8/29.
14.	Letter"Angående riksbrandsinspektörens förslag till cirkulär och anvisningar angående säkerhetsåtgärder vid hyggesbränning," August 13, 1955	Letter written by Wretlind: "Concerning the proposition of the State Fire Inspector for a circular letter and instructions relative to safety measures during prescribed burning," August 13, 1955.
15.	Transcriptions of recordings for study areas 1, 2, 3, 4, 5, 6, forming Wretlind's 'forest testament':	
	15.a. Studieområde 1: Självföryngring efter hyggesbränning på mark av myrtillustyp	Study area 1: Natural regeneration after prescribed burning in bilberry forest types
	15.b. Studieområde 2: Föryngrigsbetingelser på mark av frisk ristyp	Study area 2: Regeneration conditions in mesic ericaceous
	15.c. Studieområde 3, 4, 5: Föryngringbetingelser inom ett större sammanhängande granskogsområde	Study areas 3, 4, 5: Regeneration conditions within a spruce forest area
	15.d. Studieområde 6: Näsbergsfältet	Study area 6: Näsbergsfältet
16.	Tal I Malå kyrkan den 4 mars 1954 vid invigningen av detta	Speech in Malå church 4 March 1959 for the inauguration of this year's Sami

	års Samemästerskap av jägmästare J.E. Wretlind:	Championship by forest manager Wretlind
17.	Letter by G. Nordwall to Lapp bailiffs E. Kangas, E. Malmström, E. Edbäck, H. Johansson, the County Administrative Boards in Luleå and Umeå, sent on 22 June 1951	
18.	Korta anvisningar I skogseldsläckning. (1940). Skogsbrandskyddskommittén I Gävleborgs län	Booklet providing recommendations to extinguish forest fires, published by the committee of forest fire protection of Gävleborg county
19.	Program för exkursion i Malå revir den 11/9 1951 för klarläggande av hyggesbränningarnas betydelse för renskötseln	Programme for the fieldtrip in Malå State Forest on 11 September 1951 to clarify the implications of prescribed burnings for reindeer herding
20.	Letter sent by L. Wallmark to the lecturers of the 1954 Jokkmokk course, including Wretlind	
21.	Renskötseln och den norrländska skogshanteringen	Programme of the popular education course held in Jokkmokk on 9-15 September 1954, Reindeer herding and the Norrland's forestry
22.	Questionnaire submitted by Wretlind to Malå reindeer herders in 1954	
23.	Invitation letter and programme for a course in Arvidsjaur sent to Wretlind by Wallmark	

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The overall aim of this thesis was to investigate the human dimensions of fire regimes in the Swedish boreal forest with a focus on interactions during the last 150 years between fire, Sami reindeer husbandry and forest management. While generally considered to be a natural phenomenon, fire gives rise to diverse representations that influence fire management in Sweden. Today, fire regimes are strongly shaped by human interactions and negotiations involving Sami reindeer herding, commercial forestry and nature conservation.

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