Established forest firefighting techniques.

A qualitative review of practices among Swedish fire services

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Abstract
Methods and equipment used for fighting forest fires are different from the ones used in urban fires. Generally, the wildfires are intense, require more resources and tend to spread rapidly. The effectiveness of different suppression techniques is difficult to evaluate since they depend on terrain, weather conditions and other varying factors over time and space. The current study focuses on the several popular techniques used by firefighters for suppressing forest fires around the world and their applicability by Swedish fire services in Sweden. Eight such techniques have been found through comprehensive literature study. These are described in the report with their general application, use and popularity among Swedish fire services along with the advantages and disadvantages. Questionnaires were distributed among the Swedish fire services to collect information about prevalent practices in forest firefighting. A total of 72 persons from different fire and rescue services in Sweden participated in the survey.

It has been found that some of the techniques are more popular than others. The general trend in the Swedish fire services seems to be a direct attack at early detection of fire. All the fire and rescue services that responded to in the survey are equipped with drones and other aerial resources for the early detection of fire. In survey, 81% reported that the first action on fire is a direct attack and the resource reinforcement has improved comprehensively from other relevant organizations like MSB, home guard, farmers, forest/ landowners etc. especially after 2018. Techniques like control line/ fire lines, protective burning, cold trailing are not very well-known, knowledge and the training is limited, and have been practiced seldom in the past three years.

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Read and approved,

Muhammad Humza Khan

10th of May 2021

Summary

Forest fires are a big concern in recent years and have posed threat to human lives and property in many parts of the world. These are different from urban fires and therefore firefighters tackle them with different techniques. The effectiveness of these techniques is difficult to quantify since the research in this area is limited. Furthermore, the conditions are unpredictable in forest fires like the resources, limited availability of water, response time and terrain conditions. Several measures are taken simultaneously to contain forest fires and a combination of different suppression techniques is practiced.

The focus of this thesis study is to present a literature review of existing wildfire suppression strategies and determine their applicability to the Swedish context. This study also highlights the research gap in the suppression techniques through a scientometric analysis on the search results from the literature review. A questionnaire helped in collecting the response from the Swedish fire services to learn about the existing techniques being practiced in Sweden. The results from the literature review and questionnaire are presented simultaneously for each suppression technique.

A systematic method was developed in the review and 201 articles were studied. These articles were then further filtered based on a list of inclusion and exclusion criteria. The snowballing method was utilized to find more relevant articles. Eight different suppression techniques were identified through literature study and they are presented with their advantages and disadvantages. Analysis of the questionnaire responses is also presented to highlight the knowledge and practice of these techniques by the Swedish fire and rescue services.

It has been found that the Swedish fire services prefer direct attack as the first action on a reported forest fire. Indirect attack and other techniques, which are fire lines, prescribed burning, flanking, cold-trailing and hot spotting are not practiced very often. Aerial resources are used often for the detection of fire in forests. The reason for the frequent application of the direct attack is because of the nature of fires i.e., they are small and are detected at an early phase. Furthermore, the forests in Sweden are privately owned and they support many industries; therefore, the aim of the fire and rescue services is to minimize the damage by suppressing the fire at the earliest possible time.

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1 Introduction

Forest fires have been a major concern for the past decade which does not only impose a threat to human and animal lives but also to the planet´s biodiversity and ecosystem in several ways. Although forest fires are a part of the natural ecosystem still, they are dangerous if grow on a large scale. Regardless of how and when a forest catches fire, it is the responsibility of regional fire services to contain and suppress before it transforms from small to ultra-huge fire. Global warming and prediction of drier future summers from previous research [1] indicate that there could be more forest fires. Generally, more resources are required to tackle forest fires since the area being burnt is much larger than the residential fire and fuel is dispersed entirely over the region. The rescue of humans and animals is also important simultaneously. Detection of fires in vast forest reserves is also a challenge and conventionally smoke detection by observers or the general public is used [2]. However, latest technologies like UAVs and satellite data can be more reliable [3].

Sweden has the largest forests area in km^2 in Europe while being second after Finland for the percentage of land coverage by forests. Forests in Sweden cover 23×10^6 hectares of land which comprise around 69% of its total area[4]. Analysis of forest fire events over the period 1996-2008 has indicated that the peak burnt area in northern counties is August while April in southern counties; however, peak fire events occur in April and May in both regions [5]. The response time of firefighters, their resources and the effectiveness of different strategies for tackling urban fires have been discussed in past [6,7]. However, the same factors for forest fires have not been explored yet. In Sweden, it has been found that in urban fires, decreased response time by 1 minute may save two lives annually [7]. However, such data is scarce in wildfires scenarios. Due to scarcity of roads, limited availability of water and larger area being burnt, the suppression difficulty is increased manifold. One study has recommended the use of drones and GIS to detect forest fires since, the smoke detection might not be efficient in sparsely populated areas [2].

Due to the size of a forest fire, threats it imposes and accessibility to reach the seat of the fire is very dynamic; therefore, it is difficult to quantify the resources required and the effectiveness of one strategy. Effectiveness in wildfire suppression is defined as the ability to control fire with minimum possible damages and least possible cost [8]. However, the data is not established in Europe as well as in Sweden. Several measures are taken simultaneously to contain wildfire which might be direct or indirect attack, initial or extended attack and further operations within these domains for example: fire lines, aerial firefighting, mopping up or prescribed burning etc. The selection of a strategy is also quite challenging since the incident commanders have constraints of resources like cost, time, and manpower. Volunteers or part-time firefighters are also critical in performing operations since the standard manpower in a fire station is not enough for forest fires. On contrary, during suppression operations, no difference in skills is needed between professional and volunteers in firefighting [8]. An increase in road density, population density and fire breaks have been found to reduce the area of forest fire size [9]; however, the effect is not yet known precisely. Effectiveness of different preventative measures depending on age, gender, occupancy type etc. is presented for residential buildings [10]. Similar technique can be used to derive the some results in case of forest fires.

Research in the domain of forest fires has increased many folds in the last two decades. However, the trend is more towards the forest´s ecology and the effect of forest fires on human

lives and economy[11]–[14]. There seems to be a lack of research on the suppression tactics being used by firefighters to contain these fires except for some novel techniques of aerial firefighting which is becoming more popular recently. Firefighters and volunteers have been using conventional techniques for suppression which were once established centuries ago and are still available in firefighters' handbooks [15]–[19]

Forest fire management practices are different from the techniques used for fighting fires in urban spaces. The strategies used for forest fires vary around the globe predominantly depending on climate, vegetation and societal needs [19]. The conventional firefighting techniques being used in forests are risky and often pose threat to firefighters [20]. Therefore, the safety of firefighters is an additional constraint in such scenarios. As we know from the classic fire triangle illustrated in figure 1, a fire can be stopped by cutting fuel supply, oxygen supply or by lowering the temperature.

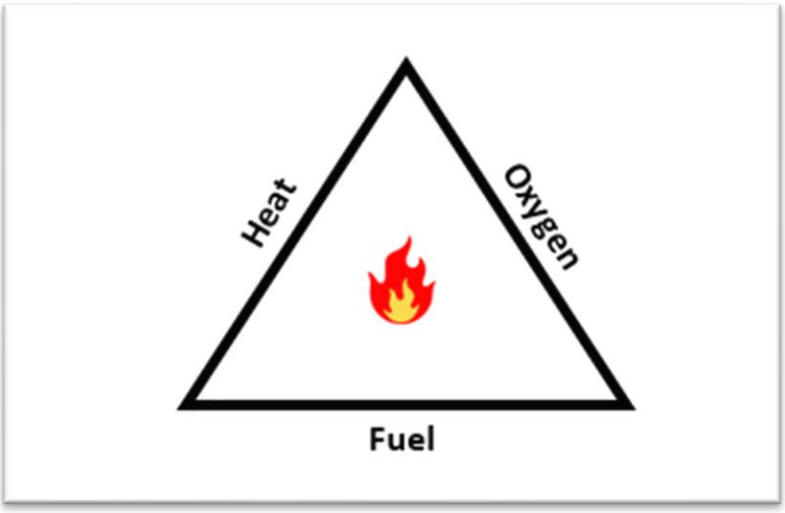

Figure 1: Classic fire triangle.

Similarly in forest fires, the firefighters need to either cut oxygen supply by spraying chemical suppressants, fuel supply by cutting vegetations or lower temperature by spraying water [21]. Practically these actions are not easy to commence since the oxygen and fuel supply is abundant in forests and applications of suppressants on a large area is quite expensive and impractical. Therefore a combination of different techniques is applied depending on the fire behaviour, resources, accessibility etc. [18]. If these techniques are applied incorrectly, fire may get out of control.

This study aims to conduct a literature review of all the firefighting techniques used for wildfires by different countries. These techniques are discussed, and their advantages and disadvantages are presented. The circumstances of applying certain techniques and their limitations are considered. An additional aim is to map the capabilities of the Swedish fire services regarding forest fires; therefore, the techniques used by fire services in Sweden and their perceived effectiveness will be studied.

1.1 Research objectives:

- Identify and highlight the research gaps regarding techniques for fighting forest fires.
- Present detailed description of various firefighting strategies and resources along with their advantages and disadvantages.

- Present how the Swedish fire and rescue services generally perceive the effectiveness of above-mentioned techniques in fighting forest fires.

2 Methodology:

This section highlights the research methods and software tools used in this study. It is further explained in sub-sections. LUB search engines (Lund Universitet, 2021) are used to find the relevant literature and the results are filtered through several criteria to find the most relevant articles. The methodology for finding literature is inspired from [22], where an extensive literature search has been done to find the most relevant articles for the subject study. The overall methodology followed in this study is shown below in figure 2.

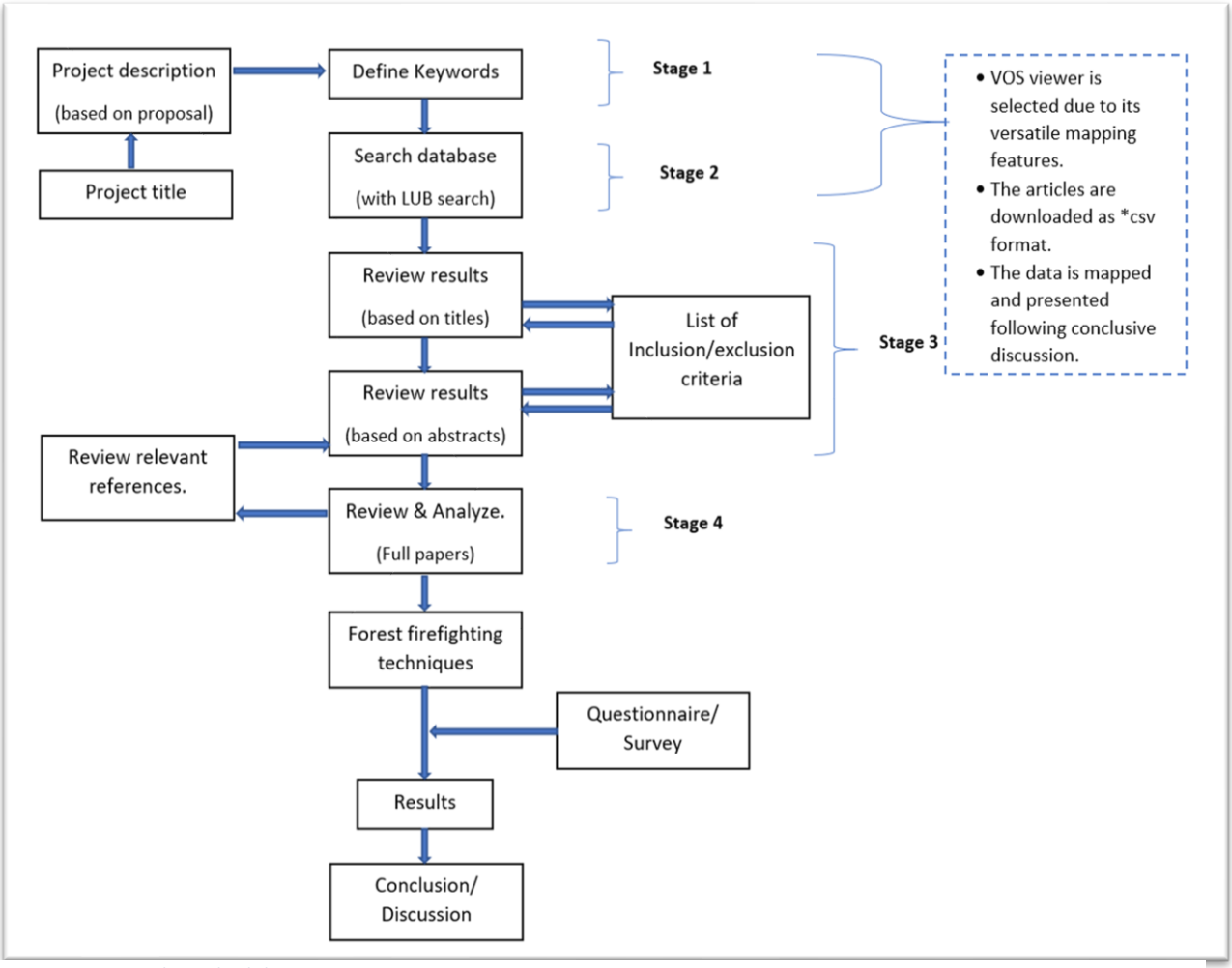

Figure 2: Research methodology.

2.1 Literature review

Defining keywords

Starting from stage 1, certain keywords were defined based on the thesis topic and input from the project supervisor. The essential keywords and the resulting articles found on LUB are tabulated below under the search database. Results were further refined using quotation marks (“”).

Search database

LUB search database was used to scoop the relevant articles from the databases of Scopus and Web of Science. This search engine from Lund University is supposed to cover the articles, books and journal papers from research publishers and subject databases. Both Web of Science and Scopus are well known for their collection of scientific articles. Therefore, it is assumed that there is little chance of missing useful and relevant articles in this context. The results of keywords on the LUB search are listed below in table 1:

Table 1:Primary keywords for search

Keyword	Refined with	Search results
"Forest fires"	Suppression	138
"Forest fires"	Firefighting	57
"Wildfires"	Suppression	4
"Wildfires"	Firefighting	2

Review articles

A total of 201 articles were selected for further review and analysis. Abstract of the articles with their titles very relevant to the thesis topic were read and further classified. A criterion for exclusion and inclusion was then defined to narrow down the search results. This criterion was updated continuously with the number of articles read and new information collected.

Following inclusion and exclusion criteria were defined for further filtering of articles:

Table 2:Inclusion and Exclusion criteria

Inclusion criteria	Exclusion criteria
Articles mentioning forest fires in the abstract.	Articles focusing more on urban fires.
Titles covering broad topics.	Not focusing on forest fires.
Firefighting techniques mentioned.	Articles mentioning pre-fire or post-fire effects.
Resources for forest fires.	Focus on the landscape or vegetation.
Information from the EU, Australia, Canada, and the US.	Articles focusing on only one community.
Overview of firefighting techniques.	Articles not in English.

Duplicate articles were already filtered out by LUB search results. An abstract was read first and if it falls under the 'inclusion criteria', the whole article was read. All the relevant citations in any article were read to look for more useful information, therefore, reducing the risk of overlooking important papers in this so-called snowballing method [23]

Review and analysis of full papers

Including the initial search from keywords and the snowballing method, authors found a total of approximately 60 articles that were within the inclusion criteria. Now at this stage, all the methods discussed for mitigating forest were studied in details and relevant information about the implementation was collected. All the methods from different articles were analyzed and only those are discussed in the next chapter which have met the following criteria:

- Techniques that are considered authentic and are widely used in forest fires around the world.
- Novel methods found in the literature review can be potentially effective in mitigating forest fires in future.
- Techniques that are explained with enough detail to quantify their effectiveness in terms of resources and can be extendable to the Swedish forest fires context.

Mapping software

A scientometric analysis has been done based on the software tool VOSviewer (Visualization of similarities viewer) which has both user-friendly and robust computation approaches. In a scientometric study, a large-scale scholarly dataset is analyzed for measuring research impact, mapping of the keywords and evolution in a domain[24]. It is an efficient way of discovering linking literature concepts that may have overlooked by manual reviews[25].

The choice of software selection must be based on its relevance to the field of study, limitations and flexibilities[26]. Several other options were available. However, VOSviewer (Version 1.6.16) was selected for mapping as it has already been in use in forest fires context [27,28]. Since VOS viewer performs detailed mapping of literature in Scopus which allows the export of data in *csv format, therefore, all the mapping charts in this paper are based on the literature search of Scopus.

2.2 Online Questionnaire

After completing the literature review, a survey/ questionnaire was conducted among the Swedish fire services. The purpose of this survey was to find the perceived effectiveness of relevant techniques in Sweden and which methods and resources are being practiced. Firefighting services in different Swedish counties/ provinces were approached through online questionnaire forms. Several emails were sent to the administration staff and to the head of the departments, for example, fire chiefs and director of fire safety etc. It was requested from them to circulate this survey among the colleagues and any other relevant persons. Their opinion about the effectiveness of different suppression techniques in forest fires of Sweden was collected. Also, the methods they prefer, and their resource equipment is an important addition to this research study. The questionnaire was written and corresponded in Swedish, keeping in mind that the fire services might have Swedish names and terms for some techniques.

The authors choose to collect information from an online questionnaire made on google forms. The idea was to collect a general response from the people associated with fire and rescue services. It was assumed that such a questionnaire may help to get more responses than

interviewing individuals separately. It was not mandatory for any participant to mention their identity and therefore anonymity of this survey helped in getting information that might have been difficult to collect otherwise. Furthermore, respondents could answer the online questionnaire anytime suitable for them.

The primary target audience of this survey was firefighters, educators, and rescue services in different Swedish counties. Questions were based on the techniques found through the literature review. The experience and role in fire services of respondents were collected through multiple choice questions in the introduction section. Furthermore, respondents were also asked to mention the county in which they work, and the workload related to forest fires in past three years. In the second section, the effectiveness of a technique perceived by fire services, its use in past and further resources required for the future were recorded through a Likert scale of one to five on Google Forms. Respondents were also inquired about the way the fire is detected in forests and the first action/ strategy applied by fire services. Finally, in the last section, some additional questions were asked regarding volunteers and their role in forest fire fighting.

Open-ended questions helped in getting more detailed information from the respondents. The form was kept anonymous keeping in mind the privacy of information provided and the structure/ culture of the firefighting department might make some participants reluctant to share their views openly [29]. The entire questionnaire used for the survey is presented in Appendix A.

3 Results

3.1 Scientometric analysis of literature

Analysis of the previous literature highlights that there is only limited research on the firefighting techniques used in forest fires. The keyword “Firefighting” was searched on Scopus within the research articles title and abstract and it resulted in 3548 articles. The total number of articles published each year was compared to the search results from the keywords “Forest fires” +” Firefighting” which resulted in 226 articles. The results from both searches are presented in the graph below:

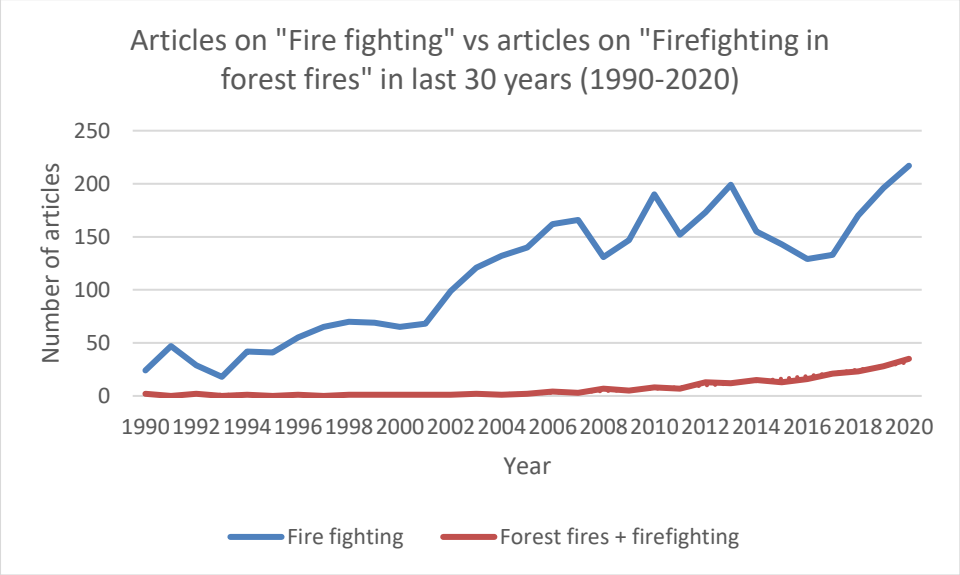

Figure 3: Articles focusing on 'firefighting' vs on 'firefighting in forest fires'in the past 30 years (1990-2020).

As can be seen from the graph above that the articles on firefighting techniques in forest fires are very few as compared to the articles on firefighting. The defined keywords were searched within the title and abstract in Scopus. Therefore, it is assumed that no articles were left even if the primary keywords of the resulted articles were not mentioning any firefighting techniques. As indicated by the graph, there has been an increase in the number of yearly articles on firefighting however the articles on firefighting in forest fires have not increased more than ten any year before 2012. This gap suggests that the firefighting techniques in forest fires are still conventional and there is a lack of new techniques and improvements in the already existing ones.

The interest in this area seems to be growing in the recent decade. There is an increase in the number of articles on ‘Forest fires’ from the year 2000 till 2020. The increase in the articles focusing on firefighting in forest fires has been tremendous; however, the total number of articles are still very limited, during the same years.

Further analysis of 226 articles from later search was done by downloading all articles from Scopus in the form of a *csv file and then exporting it to the VOSviewer. Co-occurrences of all the keywords and terms, including both from author, index, and full papers, was searched by full counting feature in VOSviewer. The threshold for a minimum number of a keyword/ term was set to ten. VOSviewer resulted in 33 keywords/terms and the link strength of these keywords/terms is presented in Figure 6 below.

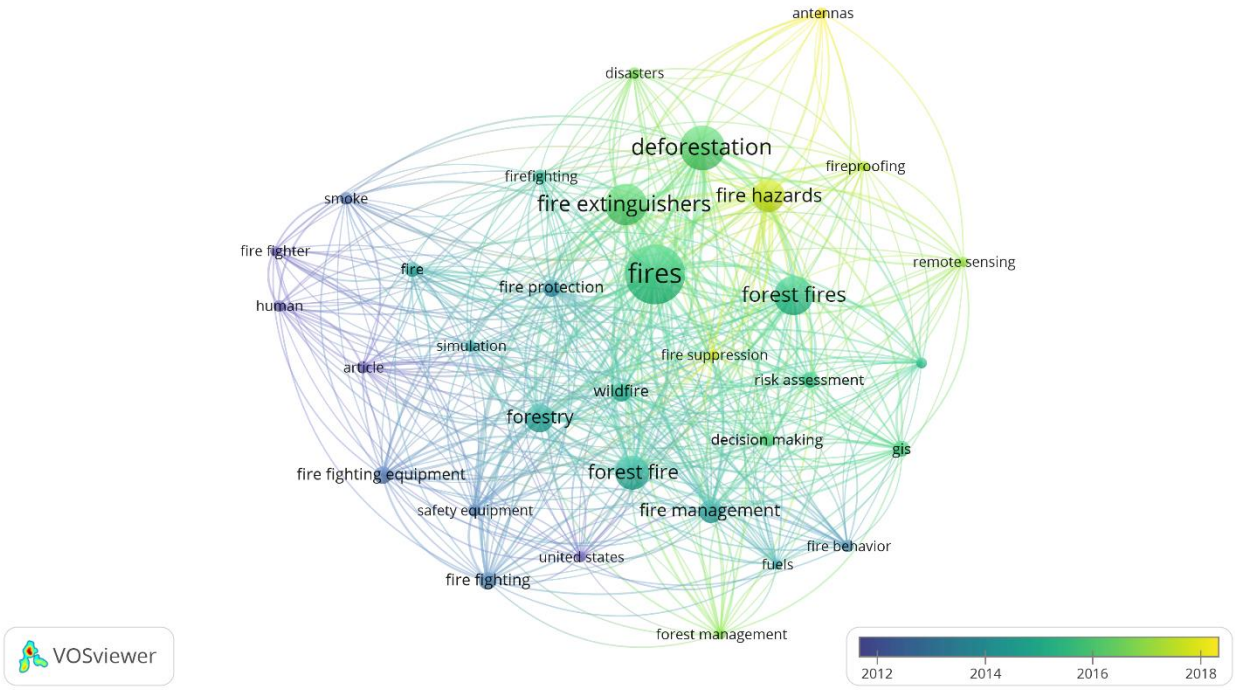

Figure 4: Keyword's co-occurrence network

In this overlay visualization from VOSviewer, the distance between two keywords/terms explains the relatedness in different articles. Related keywords/terms are located closer to each other and the lines represent the co-citation links[30]. The color combination is assigned based on the publication date of the articles.

Based on the mapping of keywords/terms above, it can be said that the trend of research is more toward deforestation, wildlife, forest fire risk assessment. The important keywords/terms for forest firefighting like 'Direct or indirect attack', 'Fireline', 'prescribed burning' and other such key terms could not be found. It highlights the gaps in the literature regarding forest fires.

3.2 Questionnaire demographics

The online questionnaire forms were sent to fire and rescue services within Sweden. The questionnaire was directed to people involved in firefighting and rescue operations. In one month, 72 responses were collected, and further analysis presented in this study is based on these responses.

The majority of the respondents were from fire and rescue services, 95.8% while the other 8.4% were from fire technical consultants, trainers, and other national emergency services. To ensure the validity of data and uniform consistency, organizations from all over Sweden were contacted. The number of respondents from different provinces of Sweden is illustrated in figure 7 below:

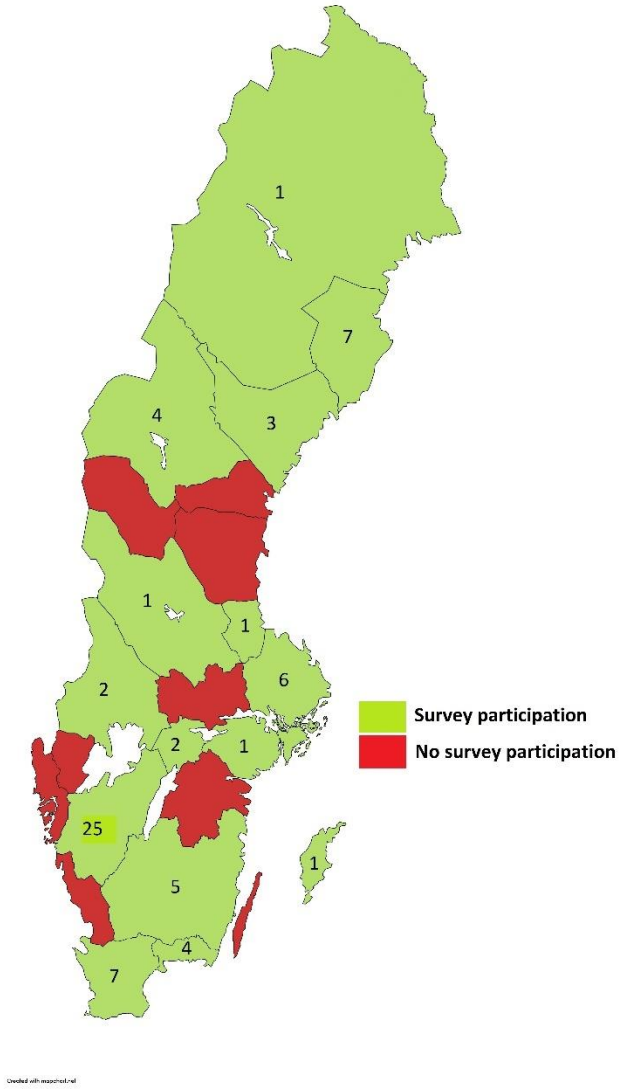

Figure 5:Map of Sweden with provinces highlighted green (Participated in Survey) and red (No survey participation).

The authors could not collect any response from the provinces highlighted red. However, it is assumed that the responses collected represent a general trend for all of Sweden.

Among all the responses collected, 16.7% of respondents are firefighters (Brandman), 25% are force leaders (Styrkeledare), 44.4% are task leaders (Insatsledare), 23.6% are fire/ rescue chief (Rädningschef) while some are also from fire consultant and other national organizations. The background of all the respondents is presented below:

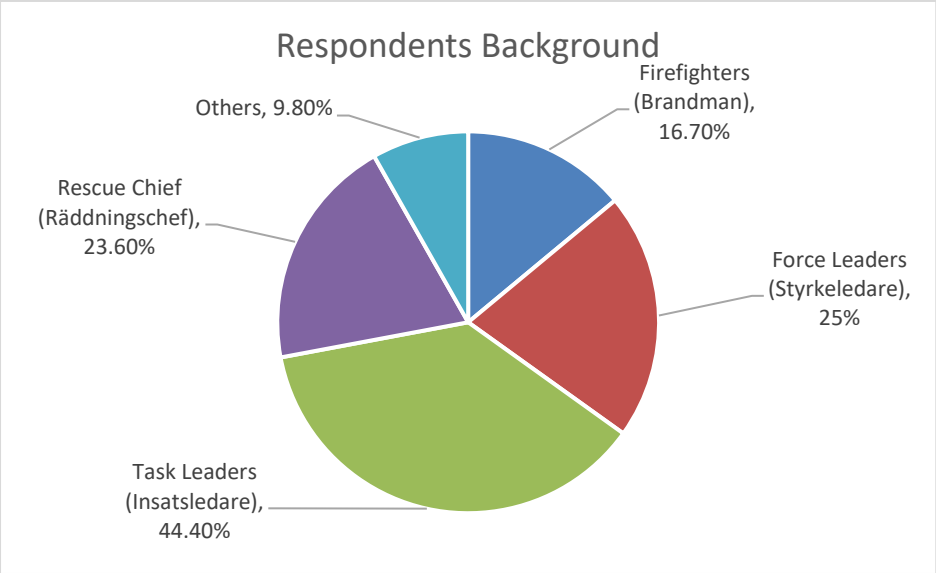

Figure 6: Working background of respondents who participated in the Survey.

Respondents also shared their experience in the number of years. Among them, 62.5% had experience of more than 10 years in forest firefighting while 27.8% had between 3-10 years and 9.7% had less than 3 years. It is presented in figure 9 below.

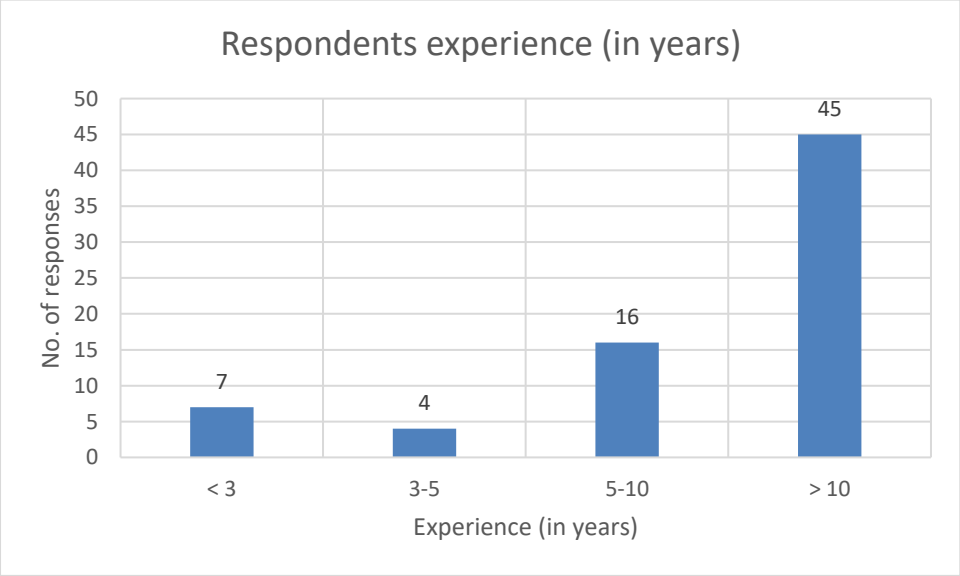

Figure 7: Experience of survey participants (in years)

Many of the respondents have long experience of forest fires, and the long experience amongst the participants is considered to strengthen the validity of responses.

The majority of the participants indicated that 2018 was an exceptional year regarding the workload, which is probably due to the high number of forest fires that year. Around 79.16% considered workload to be "Very high" for 2018. While the workload was rated as average for the year 2019 and for 2020, it was lower than the previous two years. This information is illustrated in the figure 10 below. This is a piece of evidence that the fires were less frequent after 2018 and the fire services were more prepared and equipped to suppress any reported fires.

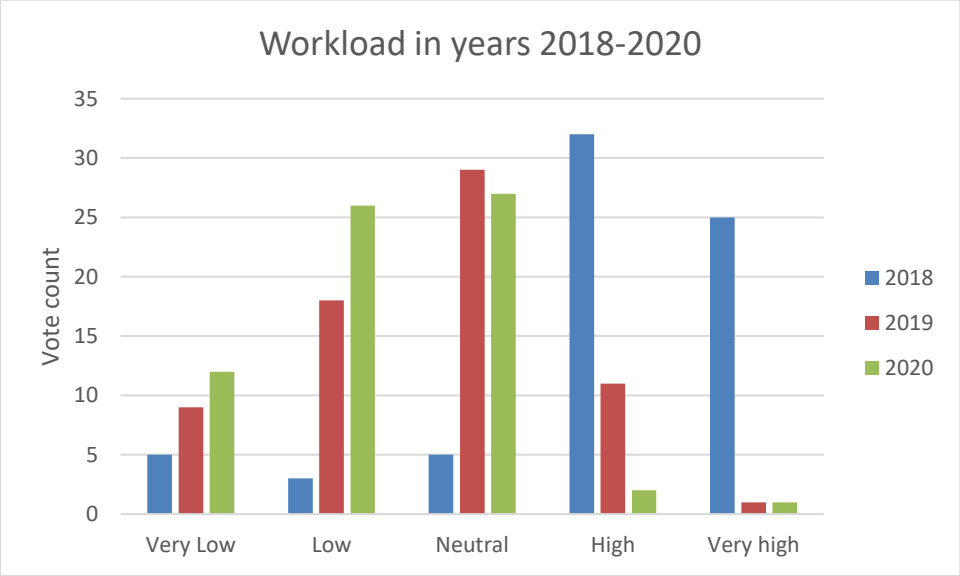

Figure 8: Forest fires related workload in Sweden in past years (2018-2020).

3.3 Resources in Swedish fire services

In an open-ended question where respondents were asked to indicate if new resources/ methods have been introduced in the past few years, it was discovered that the fire services are now equipped with more resources like aerial equipment i.e., drones, quad bikes with water tanks, smaller hoses to be used at a personal level. There has been an increased collaboration between fire and rescue services of different counties and some other national organizations like home guard etc. One of the respondents said:

> *"There has been continuous development in management and forest fire aviation resources. Also, the MSB new fire depots all over the country are an additional resource."* ***(Translated from Swedish)***

It has been observed that after the extreme fire season of 2018, there has been an emphasis on acquiring more equipment, manpower and skills within fire services organizations. Furthermore, the communication between different rescue and operational services has been improved continuously. The Swedish civil contingencies agency, known as MSB (Myndigheten för samhällsskydd och beredskap), has stored additional firefighting equipment in the form of fire depots all over the country. These depots can be accessed by fire services when they face a shortage of equipment within their organization.

The majority of the respondents i.e., 61.1% indicated that they have enough manpower to fight forest fires in their organization, 51.3% said that methods and techniques are enough, 48.6% said that sufficient equipment is present however only 34.7% showed confidence in the support from the home guard and military. This information is presented in the form of a bar chart in figure 11 below:

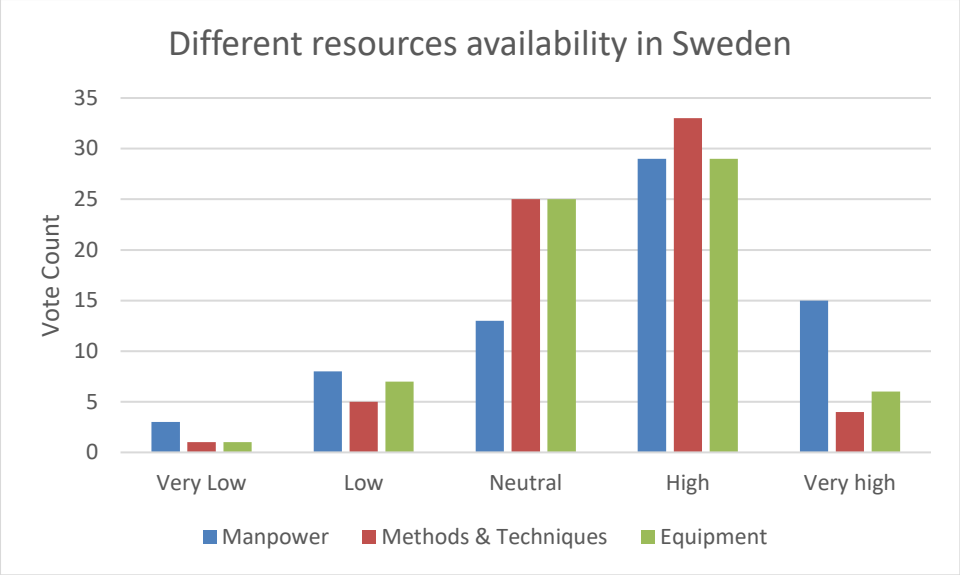

Figure 9: Resource availability in Swedish forest fire services.

Apart from the fire services, the respondents indicated that the other organizations and landowners are also actively participating in forest firefighting during the peak seasons. Landowners and forest owners are also useful resource in the detection of fires and assisting in other operations.

From the additional comments of participants, it has been noticed that in Sweden, outsourcing is a common practice for fire services where third party contractors take care of the needs in terms of equipment and machinery for fire services. Therefore, it is not necessary for a fire stations to be fully equipped with all sorts of machinery.

> *"Maskinringar, an association with which we have an agreement, and they assist with everything like personals, machines, diesel etc." (Translated from Swedish)*

In the peak season of fires, the third-party contractors and forest associations known as 'Maskinringar' help fire services by providing additional equipment like trucks, manpower and handheld tools. This also helps individual fire stations in a way that they do not need to own all equipment and tools to clear trees and bushes, which may be expensive to buy.

3.4 Established Firefighting techniques

Fire suppression actions in forests are taken based on the location of the fire, time of the season, causes of ignition and other such factors [31]. All the first steps taken toward the suppression of fire after detection are considered as an initial attack. During this initial phase, fires are small and are relatively easy to control. The objective is to contain the fire while its growing and to minimize the cost. Response time is critical otherwise fires may spread in a large area. Forest fire protection agency of Quebec SOPFEU has the aim that fire should be detected before reaching the size of 0,5 ha and an initial attack must be done within 1 hour of detection [32] and fire must be suppressed before reaching 3 ha. Such criterion is difficult to implement in other countries since the location of the fire, the direction of its spread and the resources in hand will primarily decide the selection of initial or extended attack. An extended attack can only be started if the initial attack has failed to contain the fire.

It has been found that early detection success increases the probability of a fire being suppressed [32]. Therefore, early detection is important, and the time required after detection to first suppression actions is critical. When deciding what resources to dispatch, fire managers consider the fire´s location, anticipated behaviour, and the resources available. Might be a 3 to 5 person crew [33]. The primary objective is to halt the fire growth and bring it to the state of being held (BHE).

In case that fire is not contained by the initial attack, extended attack procedures start. It is simply the extension of some tactics used in the initial attack plus some more methods on a larger scale. In Canada, if the fire is not held by the Fireline technique (See section 3.4.4) by 10:00 the next day, it is classed as an escaped fire and extended attack action commences[33]. Also, resource availability on current fire is determined by the resource usage on earlier ones. For example, if the fire services are busy extinguishing an old fire and a new fire is reported then it may take some time to attend to the later one. Eventually, the new fire may grow and might have effects on the total response time and resource management by fire services.

All the techniques found in the literature review to fight forest fires are discussed in detail below. For each technique, a description is written with the general introduction. Then relevant information found in literature is presented. For example, when, where and how to apply a certain technique based on different predefined benchmarks or thresholds. The adequacy to apply a certain technique in Sweden is presented through the questionnaire response. The reputation of a technique among the Swedish fire services is presented by illustrating how often a technique is used in the past three years and how effective it is considered by the survey participants. Finally, the advantages and disadvantages of all techniques are presented after seeking relevant literature and careful personal observation.

3.4.1 Direct attack (Direkt angrepp)

Any treatment applied directly to fire and flames front is known as a direct attack. This includes fire engines, firefighters and aircrafts applying suppression techniques/ materials directly on the seat of the fire. This strategy is usually applied when the fuel burning is limited and there are not many chances of it spreading rapidly.

Different countries have their criteria of classifying and applying direct attack. It is an offensive technique where firefighters are within 10 meters of the flame zone to spray suppressants[34]. The firefighters may start operations from the front or the tail of the fire. It is supposed to be safer to attack the fire from tails and flanks.

3.4.1.1 General application

It is based on the experience and judgement of the incident commander to choose a direct attack in a specific scenario since the intensity of flames, rate of spread, flame length and available resources can only be determined after analysing a fire scenario. However, different countries have defined some thresholds which can assist incident commanders in decision making. For example, through literature review, it was found that western Australia, the USA, Canada, New Zealand, and Europe have defined some criteria presented below. Different thresholds for using direct attack are tabulated in the table 3 below:

Table 3: Thresholds for Direct attack defined in the literature.

Country	**References**	**Criteria for direct attack**		
		Rate of Spread (Km/h)	Flame Length (m)	Fire Intensity (KW/m)
Western Australia	[35]	≤0.4	-	≤2000
USA	[36]	-	1.2-1.4	≤1730
Canada	[37]	-	≤2.6	≤2000
Europe	[38]	-	1.5-2.5	-
New Zealand	[21]	-	-	500-2000

3.4.1.2 Applicability in Sweden

In a direct attack, the aim is to put the fire out when it is smaller in size therefore, time is also a critical factor in operations. In question 8 of the survey, the participants were asked to indicate if they go for direct attack, indirect attack, or other options after the first detection of fire. The majority i.e., 56 respondents indicated that their organization go for direct attack, see Figure 12.

It reflects that the Swedish fire services prioritize the direct attack in forest fires and the reason might be that most of the forests are owned privately in Sweden[39]–[41] and support many other industries therefore keeping the burnt area minimum is the priority. Another reason could

be the efficient early detection and reporting of fires helps fire services to go for direct attack when the fire is small.

The graph below presents the response to the question.

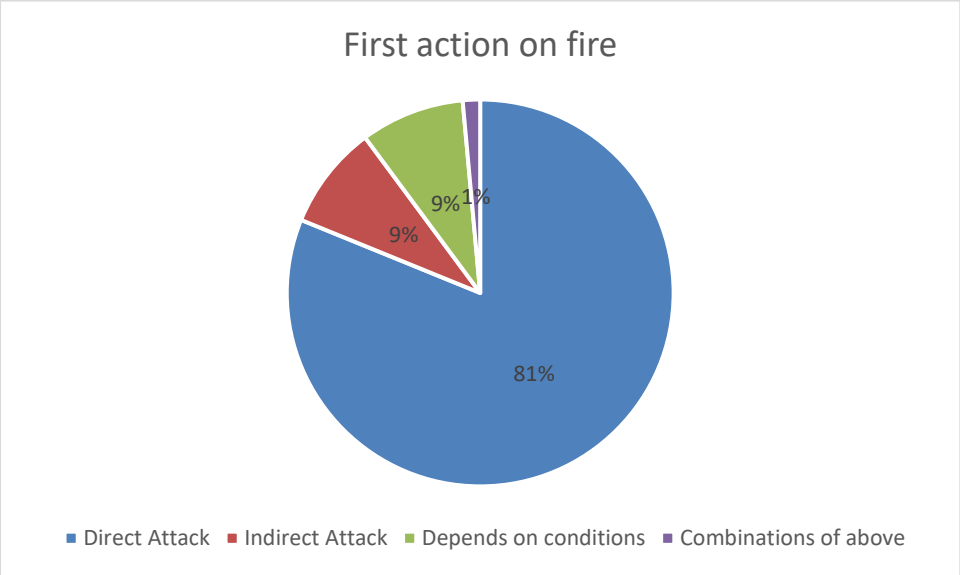

Figure 10: First action on fire after detection in Swedish fire services.

The other reason is that the better availability of flying resources from the Swedish Civil and Contingency Agency (MSB) and more resources from EU funds have made it possible to detect fire at an early stage and start operations for suppressions. MSB has made fire depots all around the country which are containers equipped with additional resources like hoses, pumps, nozzles etc. Also, the increase in awareness and education has led to the early detection and suppression of such fires.

Only one respondent has said that it depends on the size of the fire, its surroundings and time of the day to choose either direct or indirect attack.

3.4.1.3 Advantages:

- Reduced burnt area.
- Fewer resources required since the fire size is small.

3.4.1.4 Disadvantages:

- Only possible on fires with low intensities.
- The crew are more exposed to harsh conditions and may need rest after intervals.
- Fire can quickly escape depending on the weather conditions.

3.4.2 Indirect attack (Indirekt angrepp)

Indirect suppression techniques on fires focus on limiting the potential fuel supply which might catch fire. For example, by cutting vegetation or reducing the temperature by applying water. It is a traditional way of firefighting where fire trucks and advanced equipment is not needed. It has been in use by rural people where dirt is used to put the fire out. An indirect attack may prove to be ineffective in circumstances like high wind and changing weather. High-intensity winds may cause the jumping of fire over the control line[18].

Different strategies are used in an indirect attack like making fire lines by personals using hand tools or machines, dropping retardants from aeroplanes and backburning. The aim is to construct these fire line as close as possible to the fire seat, therefore, reducing the overall area burnt and containing the fire quickly.

3.4.2.1 General application

Just like direct attack, several countries have defined their thresholds for indirect attacks. The table 4 below presents some of such criteria authors could find through literature review.

Table 4: Thresholds for an indirect attack in literature

Country	**References**	**Criteria for Indirect attack**		
		Rate of Spread (Km/h)	Flame Length (m)	Fire Intensity (KW/m)
Western Australia	[35]	≤0.8	-	2000-4000
USA	[36]	-	2.4-3.4	1730-3460
Canada	[37]	-	2.6-3.5	2000-4000
Europe	[38]	-	≤8	-
New Zealand	[21]	-	-	2000-4000

3.4.2.2 Applicability in Sweden

The indirect attack is usually used when the size of the fire is big, or the fire intensity is too high to let firefighters go closer to the fire and start spraying water. Only six of the respondents replied that the indirect attack is also practiced in Sweden (see figure 12). In case of big forest fires, the local fire services are also assisted by the Home guard, army, and private farmers. Large forest companies and forest owners are also available to help extinguish the fire and to assist with auxiliary tasks. The other six indicated that it depends on the conditions to choose direct or indirect attack and one person mentioned that it is the combination of techniques that are usually applied in forest fires.

3.4.2.3 Advantages

- Crews are less exposed to heat and toxic gases.

- Time is available to contain a fire.

3.4.2.4 Disadvantages

- There is a chance of fire escaping with varying wind and terrain conditions.
- The area burning is greater.
- More crew are needed.

3.4.3 Aerial firefighting (Brandbekämpning från luften)

Aerial firefighting is the use of aircraft and other aerial resources such as helicopter, drones etc in the detection and suppression of fires. The availability of aircraft and the increase in their capacity of the payload has abled them to be used in forest fires. In the establishment of fire services, the aircraft can either be contracted or fire services may own helicopters for rescue operations.

3.4.3.1 General application

Aerial firefighting plays an important role in containing and suppressing fire in the early stages also known as "initial attack"[42]. They can be used for detecting fire at an early stage since dense forests may not be very accessible for watchtowers/ ground crews. The aerial attack works in coordination with the incident commanders on the ground. Apart from detecting and suppressing fires, helicopters can also carry firefighters and equipment to inaccessible places. Furthermore, aerial observation of the fire helps in getting an overview of the area and may assist in decision making.

A foaming agent is mixed with water to increase its suppression capacity. In some countries like Canada, they are leased from private owners in the seasons of high forest fires however different practices are established in different countries. Aircraft must be readily available to fly for the initial attack on the fire in extreme likely fire seasons.

After each hour, the amount of fireline constructed is calculated from both the air tankers and the crew working on the ground. It is recommended that only 40% of the fireline must be made by air tankers [33]. If helicopters are used to throw bucket water on a fire, then the speed of the helicopter determines the efficiency of drop. It has been found that high speed will decrease the efficiency of suppression and lower the helicopter fly, better will be the efficiency[43]. In Canadian forest fire services, the response time consists of pre-travel delay and travel time required by the air tanker to reach the fire seat.[42] This response time is critical in forest fires.

3.4.3.2 Applicability in Sweden

In response to question 12 in the questionnaire, what flying resources are available within the county´s fire services, it has been noticed that almost all counties, represented by the respondents, are equipped with drones to detect fires. Each local fire station has been provided with three or four drones with at least two of them with thermal imaging capability. Apart from drones, there is a volunteer air force made up of locals with private planes who help in fire season. Also, there are several reconnaissance flights with helicopters and planes in extreme fire seasons. Since some of the counties are flying zones, it is not easy to operate private planes and helicopters in such areas therefore drones are a better alternative.

In question 13 and question 14 of the survey, 98.6% of the respondents have shown confidence that the flying resources are efficient in the detection of forest fires at early stages while 92.9% have responded that flying resources are efficient in extinguishing forest fires. This information is presented below in figure 13 and figure 14.

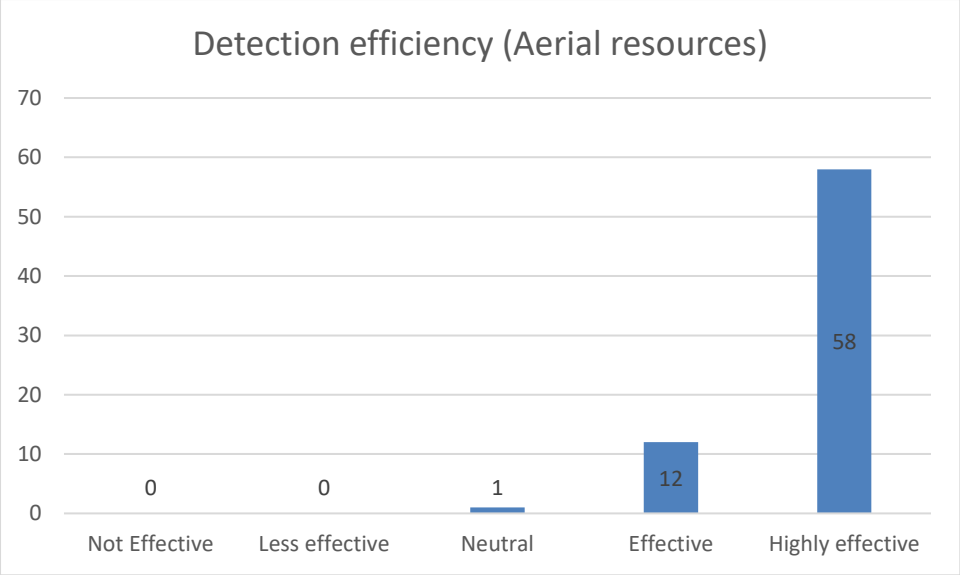

Figure 11: Anticipated effectiveness of Aerial resources in detecting forest fires.

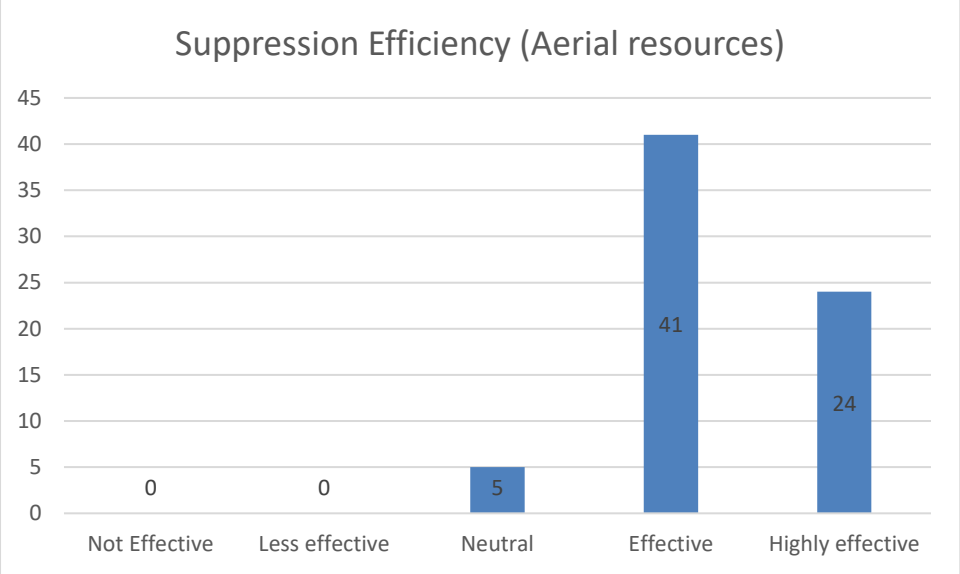

Figure 12: Anticipated effectiveness of Aerial resources in suppressing fire.

When asked for the use of flying resources in the past 3 years, 31.9% have never used any flying resources in their county primarily because of the nature of fire and 34.8% used very seldomly. 10.1% have either used some flying resources or have used more often. Use of flying resources in past three years in Sweden, as collected from the survey respondents, is presented in figure 15 below:

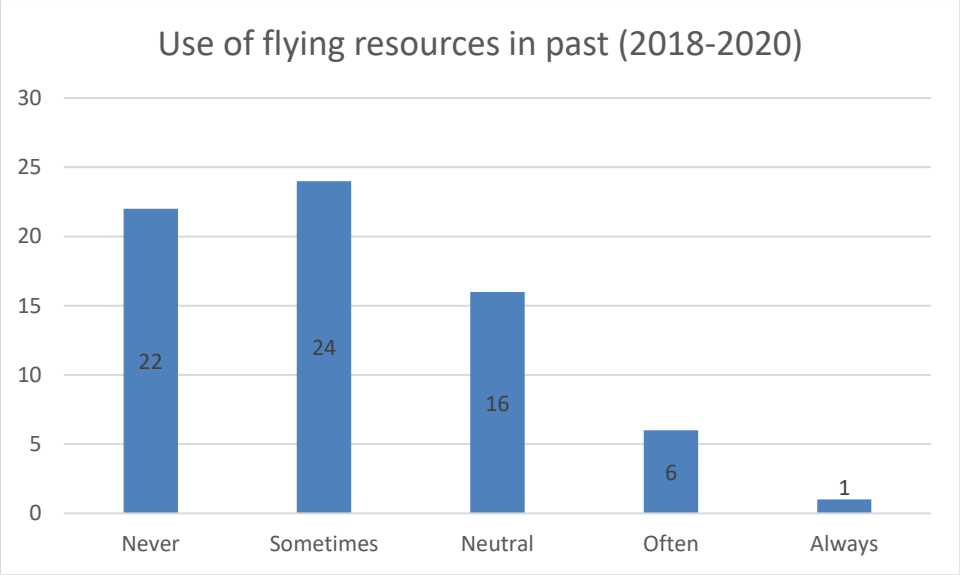

Figure 13: Use of aerial resources in past (2018-2020).

48.6% have indicated that forest fires are initially detected and brought into notice through some flying resources.

3.4.3.3 Advantages

- It has proved to be effective especially for early attack since they can arrive at the fire spot quite quickly. [8].
- Can be used in both initial and extended attack.

3.4.3.4 Disadvantages

- High cost of operations and difficult to reach areas with high smoke and extreme wind turbulence.
- Lower efficiency in large fires since the payload capacity for suppressants is limited.

3.4.4 Fire lines (Brandgator)

Fires lines are also referred to as control lines. It is a suppression technique in which firefighters create a boundary around the fire to keep it within limits. A control line can be natural or manmade. For example, a river, rocks, a road, or lack of plantation can serve as a control line. Manmade fire lines can be made from handheld tools or with machines. The man-made fireline is made by clearing out trees and plants from a certain line around the fire. A wet line is made by applying fire retardants or spraying water in a case where clearing terrain is not suitable.

3.4.4.1 General application

Fire lines remove the vegetation, a potential source of fuel, to stop fires from spreading. It can be permanent in some areas to divide forests so that there is a reduced risk of burning down the whole area. Explosives have also been used in past to create control lines by destroying vegetation before the arrival of fire. Road and driveways can also act as fire lines. The clearing width depends upon the kind of vegetation, topography and burning conditions [17].

To speed up the process, build dozers equipped with blades are used to create fire lines faster and efficient. The width of a fire line depends on the intensity of the fire [44]. These control line can also be made wet by applying water and suppressants. To make fire line more effective and to save time, it is often recommended to start them from an anchor point such as rocks, trails or some points with low vegetation fuel[38].

3.4.4.2 Applicability in Sweden

In response to question 16 of the survey, 54.4% of the respondents indicated that fire lines are an effective way to tackle forest fires. For many respondents, 38.2% responded 'neutral', indicating that they had not much idea about the effectiveness of this technique. This is perhaps due to the reason that the general trend to tackle forest fires is with the direct attack in Sweden. Another reason may be that there are not very large fires in Sweden just like that are in the U.S.A, Canada, or Australia. Therefore, the first implied strategy is to suppress the fire when it is small, (see figure 12). Therefore, making fire lines and cutting vegetation is usually not practiced often in Sweden. Anticipated effectiveness of fire lines by the survey respondents is illustrated below in figure 16:

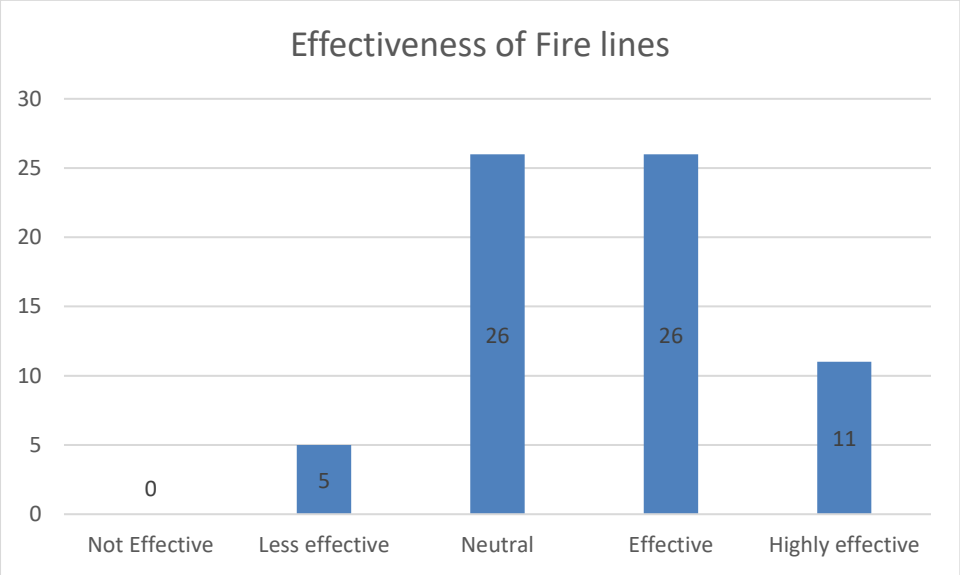

Figure 14: Anticipated effectiveness of control line/ fire lines among Swedish fire services.

In response to Question 19 in the survey, as presented in figure 17, 37.3% of people responded that they never used fire lines in the past three years of firefighting while 37.3% have used seldom. Again, the reason is the same that the priority is to suppress the fire is in the initial phase with a direct attack. Only 7.5% have used it in past three years. It can also be due to the varying terrain conditions in different parts of Sweden.

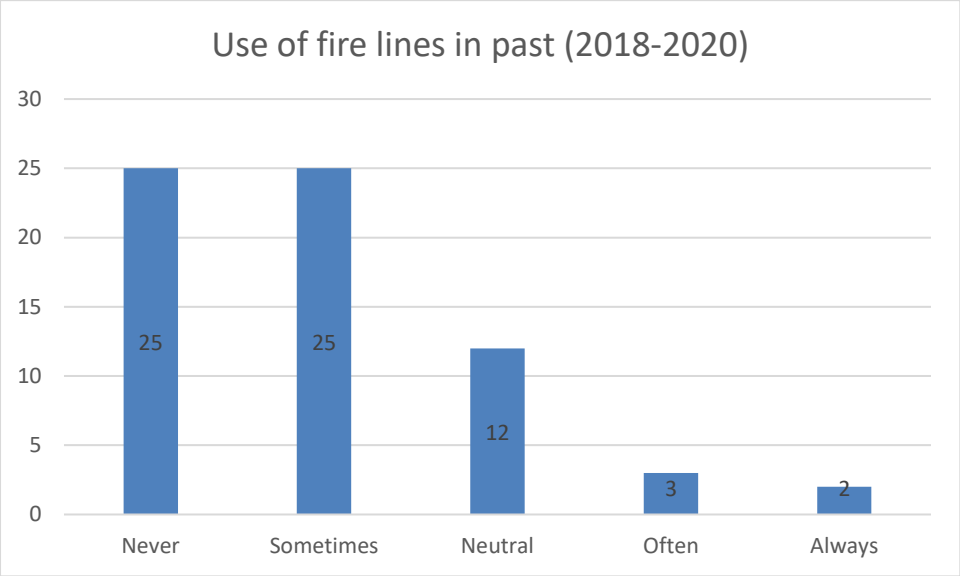

Figure 15: Use of control line by Swedish fire services in past (2018-2020).

In response to question 18, 50.7% indicated that they will need more labour/ manpower in future to create fire lines. 63.8% recommend that they should be equipped with machines like build dozers to create fire lines. 68.1% suggested that more knowledge and education about fire lines must be promoted in a fire service organization. Others, 39.1% said that handheld tools like chainsaws and blades for cutting vegetation can be useful in future. It can be seen in figure 18 below:

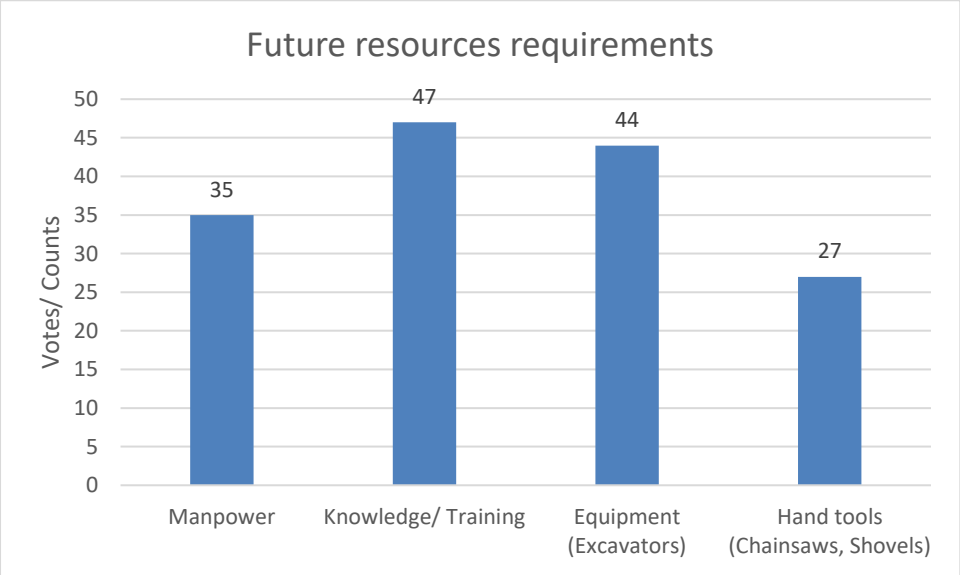

Figure 16: Future resource requirements by the Swedish fire services for control lines.

3.4.4.3 Advantages

- A relatively cheaper method and can be applied easily with only manpower especially in areas where fire engines cannot reach easily.
- Workers are not working in smoke while creating a fire line.
- Generally, there is time to make such lines.

3.4.4.4 Disadvantages

- Fires may escape the control line in strong winds and can spread.
- It takes some time to build, and time is crucial if the fire is growing rapidly.
- Fire lines created deeper/ steep (Slope ≥30%) into the soil is a source of erosion and degrade water quality.[45]
- Added complexity in surrounding the whole fire in a limited time.
- It increases overall fire size. Since the crew takes some time to build a control line.

3.4.5 Protective burning (Skyddsavbränningar)

Also known as clean-burning and firing out. It is an extended version of the control line where the vegetation, plants and trees are burnt deliberately to create a control line and to consume fuel already before the arrival of fire. It makes sure that lack of fuel will stop the fire spread and there is little chance of escaping these established boundaries.

It is called a parallel attack when the fire line is constructed parallel to the fire so that there is enough space for the workers, also it can shorten the fire line by cutting across the unburned pikes [16].

Another type of burnout is prescribed burning where some vegetation is burnt in advance of fire season making some solid natural fire lines. Such practises are common in Australia where the wildland-urban interface is at more risk yearly due to extreme bush fires[46].

Another slight variation of burnout is backburn/ backfiring. In this strategy, after establishing the control line, firefighters ignite the fuel inside the control line parameter. This fire grows toward the main fire front and in this way, there is no chance of fire coming to the control line and escape from there. This technique is also known as fighting fire with fire. To speed up the process, counter firing is also used which is just another fire within the fire area to consume fuel rapidly [16].

3.4.5.1 General application

The main purpose of this strategy is to secure the control lines by minimizing the chances of fire escape through burning all the possible vegetation fuel. Aerial burning has also been used in past for such purposes. The choice of this strategy is based on the incident commander´s decision and depends on the fire intensity and flame length. Usually, a combination of tactics is applied with protective burning to ensure that no efforts go in vain.

Such strategies are more commonly applied in Australia where there is a large wild urban interface and the fires in bushes are out of control. The decision is made by the operation´s chief and the incident commanders based on several factors. It is an effective tactic however the complexity requires planning and thorough evaluation.

This technique is usually applied when there is no location of known fire edge, the fire is predicted to be extreme in fire season.

3.4.5.2 Applicability in Sweden

In response to question 20, 58% of respondents think that this strategy is or can be effective in forest fires. 31.9% had not much idea about their effectiveness in the context of Swedish forest fires and only 8.7% considered protective burning to be an ineffective method to some extent. The response collected from participants is presented in figure 19 below.

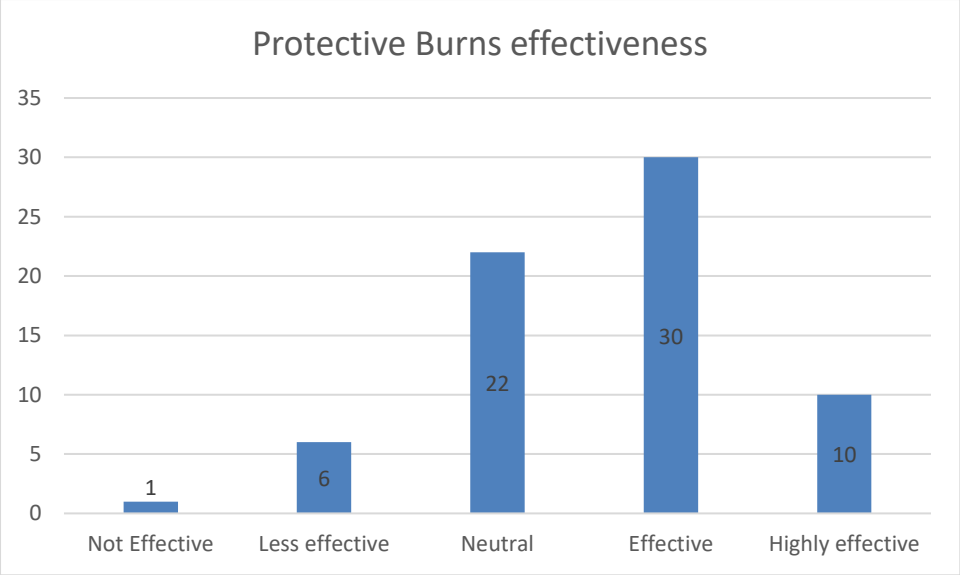

Figure 17: Anticipated effectiveness of protective burning among Swedish fire services.

The majority of the participants, as presented in figure 20, 92.7% never or very seldomly used this technique in the last three years. Again, the reason might be the culture of Swedish fire services since they prefer direct attack and suppress the fire in the initial stages when it is small.

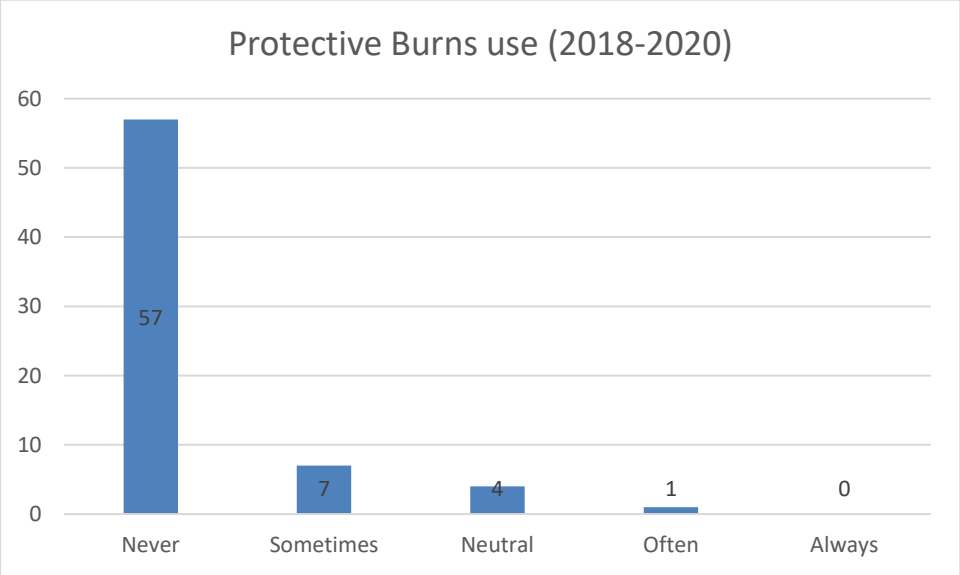

Figure 18: Use of protective burning by Swedish fire services in past (2018-2020).

3.4.5.3 Advantages

- Better chances of stopping a spreading fire.
- Can be prepared ahead of a fire season.
- Spares the crew to focus on other fires.
- Stops rapidly moving bush fire effectively.

3.4.5.4 Disadvantages

- Can be unnecessary burning in some cases.
- More intense fire can cause trouble or spread out of control lines.

3.4.6 Flanking (Flankerande)

In this method, instead of fighting flames from the direction of their spread, firefighters start suppression procedures from behind or from sides. Starting from the already burnt areas and sides of the fire, firefighters will spray the water on flames or on the ground to make sure there are no re-ignitions, and the intensity of the fire front blaze can be reduced.

3.4.6.1 General application

This technique can be applied even when the fire is too intense for the firefighters to start a direct attack. Usually, after burning a fuel, the fire spreads out to the area containing more fuel and the burnt fuel behind will have reduced fire intensity. Firefighters can start their operations from such weak points and start moving after the fire toward the fire heads.

3.4.6.2 Applicability in Sweden

In response to question 22, as presented in figure 21, 45.9% considered this to be an effective technique to apply however 49.2% have no idea about its effectiveness. It is again the reason that fire services in Sweden prioritize direct attack and suppress the fire with initial attacks.

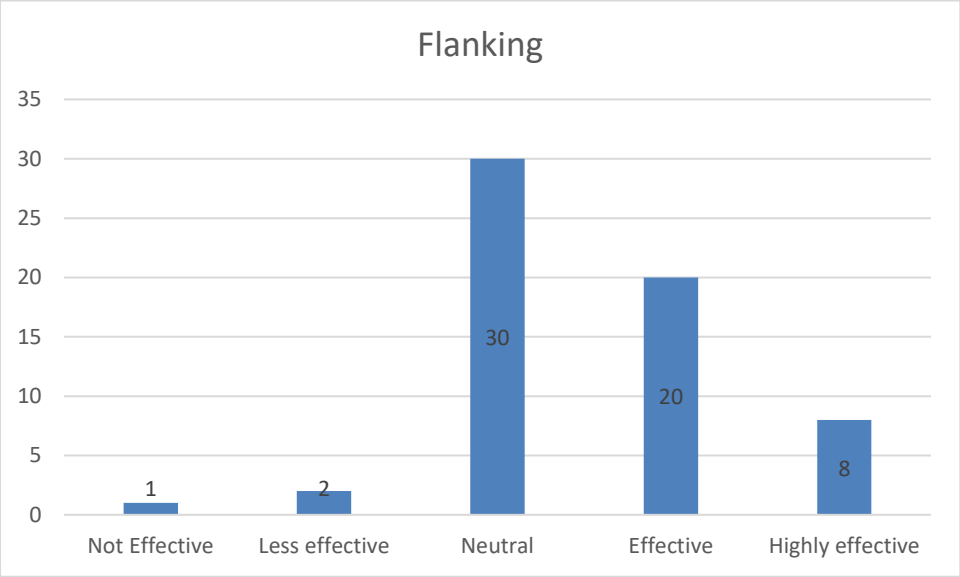

Figure 19: Anticipated effectiveness of Flanking among Swedish fire services.

While responding to question 23, only 21.3% of people said that they have used such technique in forest fires in Sweden while 52.5%, the majority have never or very seldomly used it. 26.2% had no idea about its use in their organization. Use of flanking technique by respondents in past three years (2018-2020) is illustrated in figure 22 below:

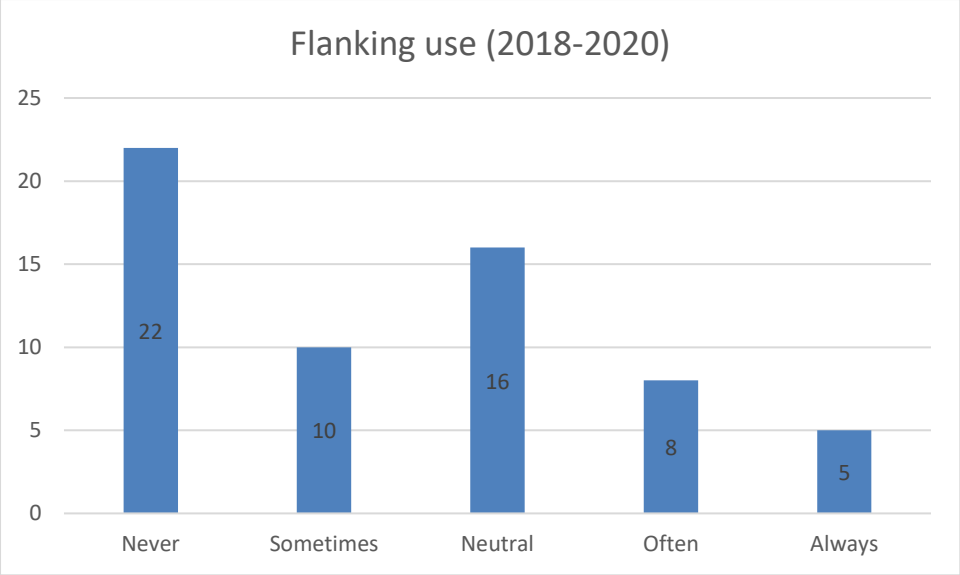

Figure 20: Use of Flanking by Swedish fire services in past (2018-2020).

3.4.6.3 Advantages

- Saves crew from the blazing fire front.
- Usually provides some time to start operations.

3.4.6.4 Disadvantages

- Can result in the greater area burnt.
- Firefighters may find themselves surrounded by the fire if the fire grows in the periphery.

3.4.7 Hot Spotting & knockdown (Punktvis antändning)

It is also known as point ignition. Hot spotting is a technique to attack some selected areas of burning fuel which may ignite more fuel in proximity. Extra manpower and attention are given to these hotspots. This can also be defined as the most active and dangerous portions of wildfire. Some combination of dirt, water or fire retardants can be applied immediately.

3.4.7.1 General application

It is often the first steps of the initial attack and is considered a direct attack. The rule is to attack the point where the fire is most likely to escape [16]. It cools down the head of the fire, stopping it to overgrow until the help arrives.

3.4.7.2 Applicability in Sweden

In response to question 24, as presented in figure 23, 24.1% responded that they think this technique can be effective in forest fires while the majority 56.9% had no idea if this is an effective technique or not. A few, 18.9% responded that it is a less effective technique. The reasons are the same that such methods are seldomly applied in Sweden as compared to other countries.

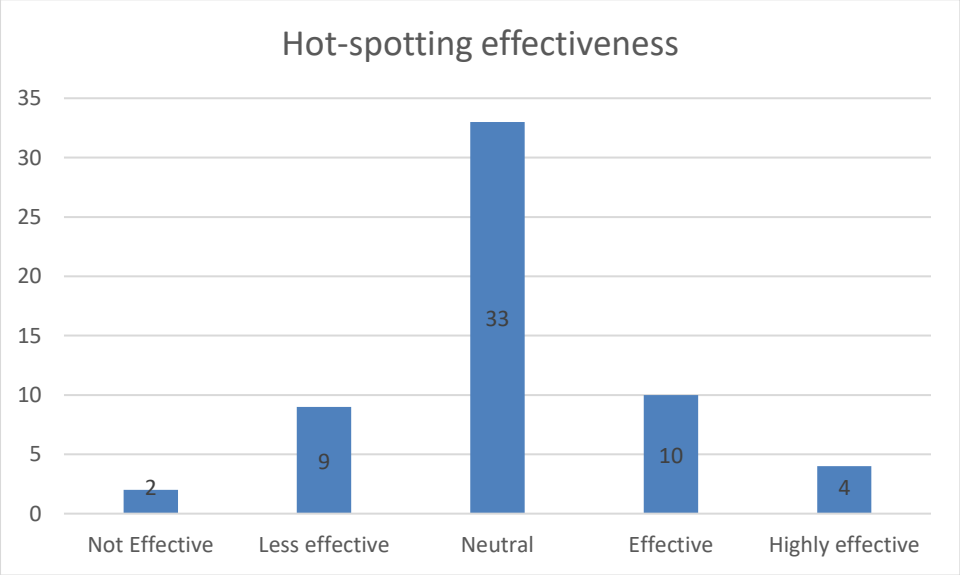

Figure 21: Anticipated effectiveness of Hot spotting among Swedish fire services.

While responding to question 25, as presented in figure 24, 93.6% reported that they never or very seldom used this strategy in the past 3 years while the remaining 4.8% responded that they are unaware if such a method has been applied in Sweden. Based on this, it can be said that this technique is not popular or taught in Swedish fire services perhaps because of it being less effective in Sweden´s context or maybe lack of knowledge or teaching.

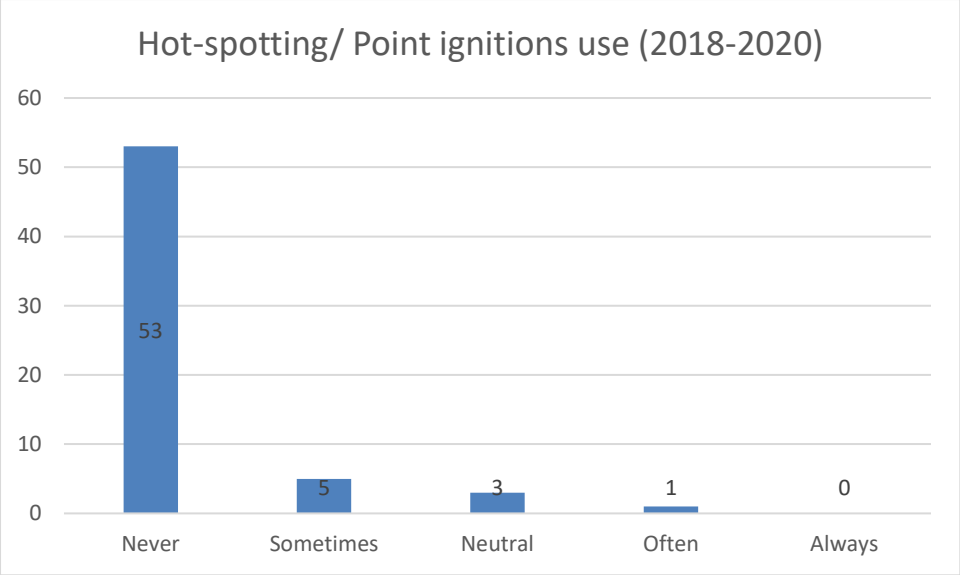

Figure 22: Use of Hot spotting by Swedish fire services in past (2018-2020).

3.4.7.3 Advantages

- Reduces the chance of fire escape.
- Can help in burning the whole area inside the control line just like in protective burning.
- Is applied when the incident commander is confident that fire will not escape.

3.4.7.4 Disadvantages

- Requires complex planning and often incident commanders avoid it due to increased workload.
- Can be dangerous for the crew since they may find themselves surrounded by fire.

3.4.8 Cold trailing (Kall eftersläpning)

Cold trailing is also known as the mop-up technique. In this method, the risk of reignition is reduced by combing an already scorched ground. If there is some material still burning, suppressing such fire can help reduce the risk of starting another fire due to wind or more fuel. The area can further be treated with water or foam retardants if there is still a chance of re-ignition.

3.4.8.1 General application

This technique is just like a check to make sure if all the fuel has been burnt significantly or is there still something burning under the soil. It is a laborious job that requires a lot of firefighters to scorch an already burnt place. The efficiency can be increased by using thermal cameras to detect any burning remains in soil however often surveying at the night can be helpful.

This technique also requires some water to apply to the soil if there are any burning remains. It is a slow job where water is of importance since it can reduce the time. Applying an adequate amount of water is the key and hard work is required to thoroughly clean the area. [16]. It is started as soon as the main fire is suppressed.

3.4.8.2 Applicability in Sweden

In response to question 26, 25.8% of respondents agree that it can be an effective technique in forest fire operations but the majority 53.4% had not no idea about its effectiveness. While 20.7% consider this to be an ineffective technique. Anticipated effectiveness of cold trailing among the respondents is illustrated in figure 25 below:

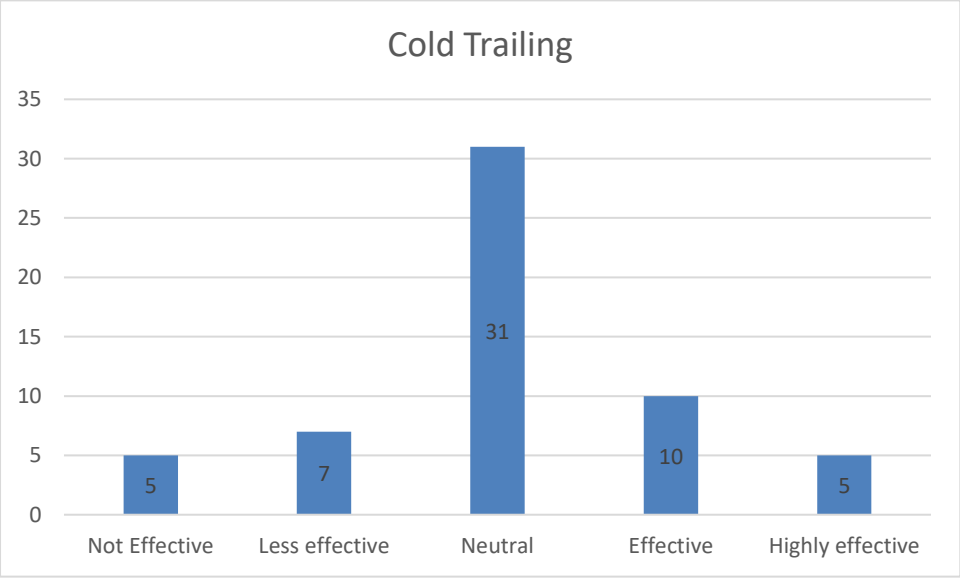

Figure 23: Anticipated effectiveness of Cold-trailing among Swedish fire services.

While responding to question 27, as presented in figure 26, 71% of respondents reported that they never used cold trailing in the past three years of forest fires in Sweden. Some, 12.9% have used it very seldomly while few, 9.7% had no information about its use. Only 6.4% said that they have used it somewhere. Again, we can say that perhaps it is not the responsibility of fire services to apply this method; therefore, the response collected is more 'neutral' as in Figure 25. One of the respondents wrote:

"Landowner is responsible for post extinguishing procedures. Poor post-extinguishment is very common and has resulted in many re-ignitions especially in 2018 when it was dry". (Translated from Swedish)

Skogsägarna Södra, an association of forest owners and forest companies are responsible for post-extinguishing in Sweden. Since the firefighters are usually busy in peak fire seasons and they need to attend to more fires; therefore, it is logical that after putting out the fire, it is the responsibility of local forest associations or farm owners to clean up and reduce the chances of post extinguishment fires.

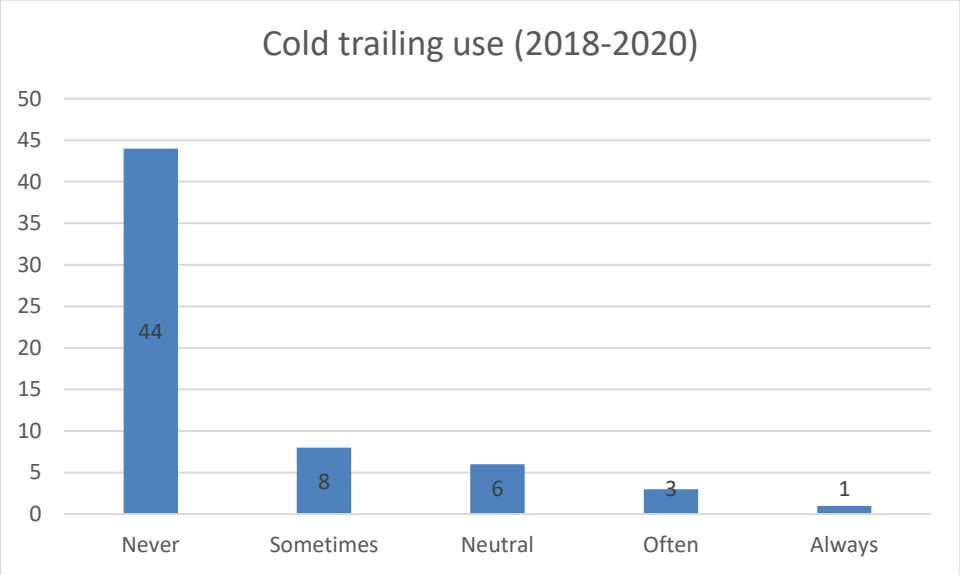

Figure 24: Use of Cold-trailing by Swedish fire services in past (2018-2020).

3.4.8.3 Advantages

- Makes sure that the burning is accomplished completely.

3.4.8.4 Disadvantages

- Requires manpower if the burnt land is vast.
- Requires water to suppress or make the ground cold.

4 Discussion

The objectives of this study are met by highlighting the limited literature available on the suppression techniques for forest fires by presenting a scientometric analysis. Then by identifying different well established and novel suppression techniques for fighting forest fires and find their applicability, effectiveness, and resource requirement through literature review. Furthermore, the utilization of these techniques by the Swedish forest and fire services was determined through an online questionnaire.

Due to the limitations of relevant research articles in this domain, only eight most popular suppression techniques could be identified. Thresholds for practicing could only be found for the direct and indirect attack in handbooks. Authors were unable to find that when and where fire lines, prescribed burning, hot-spotting, cold trailing and flanking are meant to be used exclusively. Some novel techniques under development or in practice might have been overlooked in this study. Techniques like backburning, soil throwing, and fire line explosives found from various resources were dropped from this study. First due to the limited literature available to report them properly. Secondly, due to the lack of such practices among the Swedish fire services.

The online questionnaire could collect only 72 responses from all over the country. Some counties have not participated at all, and some have only one or two respondents. This may affect the results in a way that there might be different regional practices. Only 72 responses are not sufficient for generalizing the results for an entire country. However, considering the knowledge and experience of the respondents, the authors have assumed that the results are uniformly valid for the entire country. A few respondents mentioned that they have served several areas/ counties during their work experience of more than ten years. Therefore, it is assumed that the responses from the counties which have not participated, would be similar.

The Focus group of this questionnaire was firefighters and the people associated with the fire and rescue services. This focus group was chosen not because they are anyway representative of the general population but based on the knowledge of the problem being discussed here. However, the authors collected a few responses from participants who were fire consultants, researchers and from other national organizations etc. This may affect the results since they might see forest fires from a different perspective.

In the questionnaire, the respondents were requested to identify the effectiveness of a technique on a Likert scale of one to five. The term ‘effectiveness’ was not defined exclusively. Whether it is in terms of resources, ease of application or suppression capacity on fire. It is very important to mention here that the response collected can be considered as the subjective opinion of an individual. The respondents have marked some techniques as effective in one question; however, in another question, they mentioned that they have never or seldom used this technique in the past three years. Therefore, it is not advisable to generalize the effectiveness of a technique based on the collected response. Future research in similar domain can help verify the results of this study.

5 Conclusion

Limited literature in the domain of firefighting in forest fires is highlighted with the help of a scientometric analysis by using VOSviewer. A network visualization chart is presented, highlighting the important keywords/terms from 226 articles found on the Scopus database. Important terms/ keywords, for example, the names of firefighting techniques in the context of forest fires could not be found. Furthermore, it was found that the keywords/ terms with the highest link strength were deforestations, risk assessment and fire management, showing the trend in the literature. To meet the second objective of finding the established forest firefighting techniques around the world, a methodology was adapted to scoop the most relevant literature. A total of 60 articles were filtered through several criteria after the initial selection of 201 articles found on the LUBsearch database. A questionnaire survey helped in finding the applicability of these techniques among the Swedish fire and rescue services.

A total of eight suppression techniques applicable in forest fires are found from the literature search. They are discussed with their general application, applicability among the Swedish fire and rescue services. Furthermore, the advantages and disadvantages of each technique, as per literature and various sources, is mentioned. These suppression techniques practiced by firefighters around the world are discussed with their general application and the applicability among the Swedish fire services. Certain thresholds have been established in countries like the USA, Canada, Australia, New Zealand, and the EU for choosing a technique in suppressing forest fires. However, it is seldom that one technique is sufficient. In forest fires, a combination of different techniques is usually applied, and it depends on the experience and judgement of the incident commander. In Sweden, it has been found that some of the techniques like direct attack and the use of flying resources are more popular than the others.

The results of this study conclude that the general trend among Swedish fire services is to opt for direct attack and almost 81% of the respondents have indicated direct attack to be their first course of action after the detection of fire. In the survey, 98.6% of the respondents have shown confidence that flying resources are efficient in the detection of forest fires at early stages while 92.9% have indicated that flying resources are useful in extinguishing forest fires. Some other techniques like protective burning, cold-trailing, flanking and to some extent fire lines, which are being practiced frequently in U.S and Australia, are not very popular among the Swedish fire services. In the survey, 34.7% of the respondents never used fire lines in the past three years while the other 34.7% used very seldom in their forest firefighting experience. While talking about protective burning, 92.7% of respondents never or seldom practiced this technique. Similar trends are found for other indirect techniques.

Future research

Further research on the effectiveness of the firefighting techniques, their application criteria and resource requirement may prove to help verify the findings of this study. A comprehensive study on the existing culture, training and practices among the fire services can result in useful information. There might be different practices around the world based on regional conditions and resources; however, a pilot study on one community may result in helpful findings and can produce extendable results.

It is yet to be discovered that the preference for some techniques among the Swedish fire services is whether because of the Swedish forests and terrain conditions or due to the lack of knowledge, teaching, and training about other techniques. It can be found out by organizing a comprehensive research study on the effectiveness of different forest firefighting techniques and the existing culture of training and teaching among the Swedish fire and rescue services.

Bibliography

[1] M. Rummukainen, S. Bergström, G. Persson, J. Rodhe, and M. Tjernström, "The Swedish regional climate modelling programme, SWECLIM: A review," *Ambio*, vol. 33, no. 4–5, pp. 176–182, 2004, doi: 10.1579/0044-7447-33.4.176.

[2] R. Husseini, D. T. Aboah, and H. Issifu, "Fire control systems in forest reserves: An assessment of three forest districts in the Northern region, Ghana," *Sci. African*, vol. 7, p. e00245, 2020, doi: 10.1016/j.sciaf.2019.e00245.

[3] S. Karma *et al.*, "Use of unmanned vehicles in search and rescue operations in forest fires: Advantages and limitations observed in a field trial," *Int. J. Disaster Risk Reduct.*, vol. 13, pp. 307–312, 2015, doi: 10.1016/j.ijdrr.2015.07.009.

[4] M. Sverige, *Markanvändningen i Sverige*. .

[5] I. Drobyshev, M. Niklasson, and H. W. Linderholm, "Forest fire activity in Sweden: Climatic controls and geographical patterns in 20th century," *Agric. For. Meteorol.*, vol. 154–155, p. 174, 2012, doi: 10.1016/j.agrformet.2011.11.002.

[6] M. Runefors, "Measuring the Capabilities of the Swedish Fire Service to Save Lives in Residential Fires," *Fire Technol.*, vol. 56, no. 2, pp. 583–603, 2020, doi: 10.1007/s10694-019-00892-y.

[7] H. Jaldell, "How Important is the Time Factor? Saving Lives Using Fire and Rescue Services," *Fire Technol.*, vol. 53, no. 2, pp. 695–708, 2017, doi: 10.1007/s10694-016-0592-4.

[8] G. Xanthopoulos, G. M. Delogu, V. Leone, F. J. M. Correia, and C. G. Magalhães, "Firefighting approaches and extreme wildfires," *Extrem. Wildfire Events Disasters Root Causes New Manag. Strateg.*, pp. 117–132, 2019, doi: 10.1016/B978-0-12-815721-3.00006-0.

[9] G. A. S. J. Pinto, F. Rousseu, M. Niklasson, and I. Drobyshev, "Effects of human-related and biotic landscape features on the occurrence and size of modern forest fires in Sweden," *Agric. For. Meteorol.*, vol. 291, no. June, p. 108084, 2020, doi: 10.1016/j.agrformet.2020.108084.

[10] M. Runefors, N. Johansson, and P. van Hees, "The effectiveness of specific fire prevention measures for different population groups," *Fire Saf. J.*, vol. 91, no. March, pp. 1044–1050, 2017, doi: 10.1016/j.firesaf.2017.03.064.

[11] A. J. D. Ferreira *et al.*, "Strategies to prevent forest fires and techniques to reverse degradation processes in burned areas," *Catena*, vol. 128, no. April 2019, pp. 224–237, 2015, doi: 10.1016/j.catena.2014.09.002.

[12] M. Versluijs, S. Eggers, G. Mikusiński, J. M. Roberge, and J. Hjältén, "Foraging behavior of the eurasian three-toed woodpecker (Picoides tridactylus) and its implications for ecological restoration and sustainable boreal forest management," *Avian Conserv. Ecol.*, vol. 15, no. 1, pp. 1–11, 2020, doi: 10.5751/ACE-01477-150106.

[13] E. Pastor, J. A. Muñoz, D. Caballero, A. Àgueda, F. Dalmau, and E. Planas, "Wildland–Urban Interface Fires in Spain: Summary of the Policy Framework and Recommendations for Improvement," *Fire Technol.*, vol. 56, no. 5, pp. 1831–1851, 2020, doi: 10.1007/s10694-019-00883-z.

[14] C. Poletti, G. Dioszegi, K. W. Nyongesa, H. Vacik, M. Barbujani, and J. N. Kigomo, "Characterization of Forest Fires to Support Monitoring and Management of Mount Kenya Forest," *Mt. Res. Dev.*, vol. 39, no. 3, pp. R1–R12, 2019, doi: 10.1659/MRD-JOURNAL-D-18-00104.1.

[15] R. Hansen, *Vägledning i skogsbrandsläckning*. 2020.

[16] N. W. C. G. (U.S.), *Wildland Fire Suppression Tactics Reference Guide PMS 465*. National Wildfire Coordinating Group, 1996.

[17] T. Heikkilä, R. Grönqvist, and M. Jurvelius, *Wildland Fire Management Handbook for Trainers*. 2010.

[18] G. Penney, *OF WILDFIRE Guidance for wildfire*, no. September. 2020.
[19] A. Weintraub, R. Epstein, S. (Online service), C. Romero, J. Miranda, and T. Bjørndal, *Handbook Of Operations Research In Natural Resources. [electronic resource]*. Springer Science+Business Media, LLC, 2007.
[20] T. Cooner, "Fire on the mountain," *Timber Harvest.*, vol. 55, no. 4, pp. 72–86, Jun. 2007, doi: 10.2307/j.ctvckq9kd.12.
[21] M. E. Alexander, "Fire behaviour as a factor in forest and rural fire suppression," *For. Res. Rotorua, Assoc. with Natl. Rural Fire Authority, Wellingt. For. Res. Bull. No. 197, For. Rural Fire Sci. Tech. Ser. Rep. No. 5. 30 p.*, no. Forest research bulletin 197, p. 30, 2000.
[22] P. Eriksson, "Rev iew of w ildfire indices Indices applicable for a Sw edish context," 2020.
[23] K. Säfsten and M. Gustavsson, *Research methodology : for engineers and other problem-solvers*. Studentlitteratur, 2020.
[24] K. Börner, C. Chen, and K. W. Boyack, "Visualizing knowledge domains," *Annu. Rev. Inf. Sci. Technol.*, vol. 37, no. 1, pp. 179–255, Jan. 2003, doi: https://doi.org/10.1002/aris.1440370106.
[25] H. N. Su and P. C. Lee, "Mapping knowledge structure by keyword co-occurrence: A first look at journal papers in Technology Foresight," *Scientometrics*, vol. 85, no. 1, pp. 65–79, 2010, doi: 10.1007/s11192-010-0259-8.
[26] X. Liu, "Full-Text Citation Analysis : A New Method to Enhance," *J. Am. Soc. Inf. Sci. Technol.*, vol. 64, no. July, pp. 1852–1863, 2013, doi: 10.1002/asi.
[27] P. R. Mourao and V. D. Martinho, "Forest entrepreneurship: A bibliometric analysis and a discussion about the co-authorship networks of an emerging scientific field," *J. Clean. Prod.*, vol. 256, p. 120413, 2020, doi: 10.1016/j.jclepro.2020.120413.
[28] P. Nardi, G. Di Matteo, M. Palahi, and G. Scarascia Mugnozza, "Structure and evolution of mediterranean forest research: A science mapping approach," *PLoS One*, vol. 11, no. 5, pp. 1–21, 2016, doi: 10.1371/journal.pone.0155016.
[29] D. Morgan, "Successful Focus Groups: Advancing the State of the Art." Thousand Oaks, California, 1993, doi: 10.4135/9781483349008.
[30] N. J. van Eck and L. Waltman, "{VOSviewer} manual," *Leiden: Univeristeit Leiden*, no. November, 2013, [Online]. Available: http://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.1.pdf.
[31] K. L. Riley, M. P. Thompson, J. H. Scott, and J. W. Gilbertson-Day, "A model-based framework to evaluate alternative wildfire suppression strategies," *Resources*, vol. 7, no. 1, pp. 1–26, 2018, doi: 10.3390/resources7010004.
[32] A. Cardil, M. Lorente, D. Boucher, J. Boucher, and S. Gauthier, "Factors influencing fire suppression success in the province of Quebec (Canada)," *Can. J. For. Res.*, vol. 49, no. 5, pp. 531–542, 2019, doi: 10.1139/cjfr-2018-0272.
[33] D. L. Martell, R. J. Drysdale, G. E. Doan, and D. Boychuk, "Evaluation of Forest Fire Initial Attack Resources.," *Interfaces (Providence).*, vol. 14, no. 5, pp. 20–32, 1984, doi: 10.1287/inte.14.5.20.
[34] G. Penney, D. Habibi, and M. Cattani, "Firefighter tenability and its influence on wildfire suppression," *Fire Saf. J.*, vol. 106, no. August 2018, pp. 38–51, 2019, doi: 10.1016/j.firesaf.2019.03.012.
[35] G. Penney and S. Richardson, "Modelling of the radiant heat flux and rate of spread of wildfire within the urban environment," *Fire*, vol. 2, no. 1, pp. 1–24, 2019, doi: 10.3390/fire2010004.
[36] P. L. Andrews and R. C. Rothermel, "Charts for interpreting wildland fire behavior characteristics.," *US Dep. Agric. For. Serv. Gen. Tech. Rep.*, no. INT-131, 1982, doi: 10.2737/INT-GTR-131.
[37] M. E. Alexander, "Calculating and interpreting forest fire intensities," *Can. J. Bot.*, vol.

60, no. 4, pp. 349–357, Apr. 1982, doi: 10.1139/b82-048.
[38] A. Techniques, “Training : Apply Techniques and Tactics to Control Vegetation Fire.”
[39] G. (1) Lidestav *et al.*, *Interactions between forest owners and their forests*. (1)Department of Forest Resource Management, Swedish University of Agricultural Sciences: Palgrave Macmillan, 2017.
[40] E. C. H. Keskitalo 1974, “What Can an Understanding of the Changing Small-Scale Forest Owner Contribute to Rural Studies?: The Swedish Case,” *Small-scale For.*, Jan. 2019, doi: 10.1007/s11842-019-09427-3.
[41] L. Eriksson, “Effects of Policy Measures and Moderating Factors on Climate Change Adaptation Among Private Forest Owners in Sweden,” *Soc. Nat. Resour.*, vol. 31, no. 4, pp. 409–423, 2018, doi: 10.1080/08941920.2017.1382629.
[42] N. A. Clark and D. L. Martell, “The use of aircraft tracking GPS data to develop models of the use of airtankers in forest fire management,” *INFOR Inf. Syst. Oper. Res.*, vol. 57, no. 4, pp. 535–562, 2019, doi: 10.1080/03155986.2019.1706398.
[43] D. Simoes, A. Rodrigues, A. B. Reis, and S. Sargento, “Forest Fire Monitoring through a Network of Aerial Drones and Sensors,” *2020 IEEE Int. Conf. Pervasive Comput. Commun. Work. PerCom Work. 2020*, 2020, doi: 10.1109/PerComWorkshops48775.2020.9156137.
[44] NSW Department of Planning Industry and Environment, *Fire Management Manual 2020-2021*. 2020.
[45] A. M. Christie, W. M. Aust, S. M. Zedaker, and B. D. Strahm, “Potential erosion from bladed firelines in the appalachian region estimated with usle-forest and wepp models,” *South. J. Appl. For.*, vol. 37, no. 3, pp. 140–147, 2013, doi: 10.5849/sjaf.12-021.
[46] F. Tedim *et al.*, “Defining extreme wildfire events: Difficulties, challenges, and impacts,” *Fire*, vol. 1, no. 1, pp. 1–28, 2018, doi: 10.3390/fire1010009.

Appendix A

Online Questionnaire made on Google Forms

Q1: Vilket har varit ditt huvudsakliga arbetsområde de senaste tre åren (2018–2020)?
Q2: Vilken har varit din huvudsakliga roll i ditt arbete med skogsbränder de senaste 3 åren (2018–2020)?
Q3: I vilket län arbetar du huvudsakligen?
Q4: Hur många års erfarenhet av arbete med skogsbränder har du?
Q5: Hur många skogsbränder har du upplevt under de senaste tre åren (2018–2020)?
Q6: Hur har arbetsbelastning varit under åren 2018–2020 med avseende på skogsbränder?
Q7: Har det under den tid som du jobbat med skogsbränder tillkommit ny taktik eller metodik för skogsbrandssläckning?
Q8: Vilken generell teknik tillämpas oftast först när en skogsbrand har upptäckts inom din organisation?
Q9: Finns det tillräckligt med resurser för att bekämpa skogsbränder i din organisation? (behöver bara besvaras om du är från en räddningstjänst)
Q10: Hur ofta används värmekameror vid skogsbränder inom din räddningstjänst/organisation?
Q11: Hur effektiva är värmekamera i skogsbränder?
Q12: Vilken typ av flyg resurser utöver vad som finns i nationellt har din organisation tillgång till för användning skogsbränder (t.ex. drönare)?
Q13: Hur effektiva tror du flygande resurser kan vara vid detektion av skogsbränder?
Q14: Hur effektiva tror du flygande resurser är för att bekämpa skogsbränder?
Q15: Ange hur ofta har din organisation använt de nationella flygande resurserna (flygplan och helikopter) för brandsläckning av skogsbränder de senaste tre åren (2018–2020)?
Q16: Hur effektiva är brandgator (både naturliga såsom breda vägar och vattendrag samt mekaniskt framtagna genom undanröjning av vegetation)?
Q17: Har din organisation tillräckliga resurser för att skapa brandgator effektivt vid skogsbränder?
Q18: Vilka resurser anser du att din organisation behöver mer av för att skapa brandgator?
Q19: Vid hur många skogsbränder har brandgator utnyttjats under de senaste tre åren (2018–2020) inom din räddningstjänst/organisation?
Q20: Hur effektiva tror du skyddsavbränningar är?
Q21: Vid hur många skogsbränder har skyddsavbränningar använts under de senaste tre åren (2018–2020) inom din räddningstjänst/organisation?
Q22: Hur effektiva är flankerande?
Q23: Vid hur många skogsbränder har flankerande använts under de senaste tre åren (2018–2020) inom din räddningstjänst/organisation?
Q24: Hur effektivt är punktvis antändning?
Q25: Vid hur många skogsbränder har punktvis tändning använts under de senaste tre åren (2018–2020) inom din räddningstjänst/organisation?
Q26: Hur effektivt är kall eftersläpning?
Q27: Vid hur många skogsbränder har kall eftersläpning använts under de senaste tre åren (2018–2020) inom din räddningstjänst/organisation?
Q28: Vilket är det vanligaste sättet som skogsbränder upptäcks inom ditt organisationsområde?

Q29: Tar din organisation hjälp av andra organisationer/företag vid skogsbränder? Om JA beskriv vilken typ av företag/organisationer detta är:
Q30: Tar din organisation hjälp av frivilliga vid skogsbränder? Om JA beskriva hur ni använder frivilliga:
Q31: För mer information, kan vi kontakta dig?
Q32: Vad heter du?
Q33: Vad är din e-postadress?
Q34: Om du har något övrigt att tillägga får du gärna göra det här

Appendix B

The response collected through the online questionnaire is presented in a separate EXCEL spreadsheet. This response has been modified in a way that the personal information and free text answers are removed. Only the number of votes for some specific questions can be seen for validation of the data and use in future research. This excel sheet is downloadable from the Lund University webpage.