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Perception of wildfire behaviour and fire suppression tactics among Swedish incident commanders

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Abstract

Unlike most regions with high-intensity wildfire potential, Sweden lacks specialized wildfire suppression organization. Instead, wildfire suppression is handled by highly decentralized and multitask municipal rescue services. This prompts the question how the incident commanders (ICs) perceive and interpret variation in fire behaviour and how they respond to wildfire incidents with regard to dispatching for initial attack and selecting tactics. To elucidate this, we exposed a spectrum of Swedish ICs to a questionnaire and round-table-exercises of different fire scenarios.

The informants had on average 13 years of experience as incident commanders and had on average managed 6 wildfires over the last 5 years. Despite minimal formal wildfire training the respondents showed reasonable consensus in rating of fire behaviour in response to fuels and weather, suggesting that their knowledge was built on personal and group experience. Likewise, they gave estimates on rate of production of hose-lays similar to published expert assessments from Canada. When exposed to a spectrum of fire scenarios, resource dimensioning by ICs was linearly related to the Canadian FWI-index, although most organizations did not have any preordained schemas or rules of initial dispatching resources to guide them.

Tactics employed were based mainly on accessing the fire from the nearest road and using direct attack with hose-line laid from the engine and water ferried on trucks. In a scenario where initial attack failed, suppression crews typically fell back on roads, which however would be breached by intense fire, and which also exposed the operation to risk of being outflanked. This response was in fact similar to that employed during a 2014 catastrophic wildfire in central Sweden and may indicate a fundamental flaw in tactics employed for large and intense fires.

The present structure of the Swedish wildfire suppression system developed during the second half of the 1900s and depends on rapid access to the fire by a relatively small number of firefighters. The study suggests a relatively high capacity for suppressing forest fires, despite that the organization is primarily rigged for other purposes and that ICs have minimal formal training in this area. Climate change-scenarios suggest longer fire season and more risk days in parts of the country, but the future wildfire scene may be even more sensitive to de-population and diminishing economic resources in heavily forested regions of the country.

1. Introduction

Swedish wildfires are handled by multipurpose rescue services organized at municipal level having extensive autonomy and no legally binding targets regarding resource levels or formal training of staff. Instead, the 290 municipalities (median population 16 300) are obliged to organize and pay for their fire protection, which should be capable of dealing with hazards based on a local risk assessment.

Wildfires constitute only a fraction of rescue services workload, the bulk being car accidents and structural fires. Most wildfires are easily contained, but some escape initial attack (annually 270 forest fires >0.5 ha and since 1996 a handful larger than 1000 ha (Sjöström & Granström, 2020). Fires are suppressed free of charge, but mop-up is the responsibility of the landowner.

Scandinavian climate-projections suggest increasing frequency of high-risk days (Yang *et al*, 2015). Future outcome will however depend also on preparedness and capacity of response organizations. Due to municipal autonomy, no national wildfire-fighting doctrine or detailed tactics manual existed at the time of the study although a national guidance document was published in 2020 (Hansen *et al*, 2020). Here we elucidate perceptions of wildfire behaviour and tactics among Swedish ICs by interviewing and performing round-table-exercises of four wildfire scenarios from alarm to extinguishment.

Incident commanding typically evolve by deliberation/discussion/testing, but we focus on initial response and perceptions. Expert opinion has earlier been used to estimate fire-fighting variables e.g. situation-specific hose-lay production rates (Parker *et al*, 2007). The round-table-exercise scenarios presented operation pictures reflecting what an incident commander (IC) can encounter following an alarm call, and through this semi-realistic approach we elucidate normally concealed questions: Do ICs distinguish complexity levels regarding weather and other initial factors and does this reflect initial deployment? What tactics are employed, related to available resources and likely fire behaviour?

2. Methods

We interviewed 20 trained ICs with wildfire commanding experience from 8 municipalities (1-3 participants each). They were questioned regarding fire behaviour and suppression, e.g. estimated rates-of-spread (ROS) in two fuel-types given detailed weather (Figure 1) and hose-lay production rates, with/without simultaneous watering as well as individual experience/training and their organization's deployment capacity.

Scenarios spanned from simple (easily controllable) to complex (certainly escaping initial attack), based on weather, position, wind and access roads, containing at least one additional challenge (Table 1).

Table 1- Scenario weather and CFFWIS (Taylor et al., 1997) indices (ordered by increasing FWI-value, #-numbers refer to game chronology).

Case	**#3**	**#2**	**#1**	**#4**
RH (%)	48	42	33	31
Temperature (°C)	18	25	21	18
Windspeed (m/s)	1	2	3	6.5
FD-class	Moderate	Moderate	Very high	Extreme
FWI-value	11.4	16.4	22.4	35.3
DMC-BUI-DC	33-55-437	40–56–228	47–68–317	43–54–177
FFMC-ISI	88-3.9	89.9–6.1	91–8.0	92–18.6
Challenges	Poor road access	Steep slope impacts ROS/direction	Possible new head if flank not secured	Extreme conditions

Initial information offered: ignition time and point (on topographic maps), daily fire-danger (FD-) class (grouping FWI-values into e.g. *Moderate*=7-17; *High*=17-22; *Very high*=22-28 and *Extreme*>28) plus current weather (windspeed/direction, RH, temperature). Once the initial response crew arrived (30 minutes travel to nearest accessible road) burnt length/width and flame lengths was communicated and photos from real equivalent fires were presented, showing vegetation, smoke, flames etc. Fire behaviour was extracted from the Canadian FBP system (Taylor *et al*, 1997) using fuel type C-3 surrogating for *Pinus sylvestris*-dominated forests and S-1 for clear-felled areas.

Figure 1- Left: forest scenes (1-2) presented for grading potential fire-behaviour. Right: fire scenes (head - scene 1, backing – scene 2) for assessing ROS.

Informant knew they could ask for information they normally obtain from headquarters, such as CFFWIS indices or weather variables. CFFWIS was nationally employed 1996, but without nation-wide supplementary training efforts.

All scenarios occurred on forest-company land. If called for, companies could send a mop-up crew of six with basic equipment (shovels, pump, 500m hose) within 2 hours.

All decisions/actions were logged including respondents' comments. Tactical decisions (attack routes, water-sources, and hose-lays/crews/vehicles) were noted on maps. Scenarios were sequentially run as semi-directed interviews (Huntington, 2000) with follow-up questions upon ambiguities. E.g., if ICs asked headquarters for current weather prognosis, the facilitator first asked for which variables before delivering.

3. Results

3.1. Training

IC experience averaged at 12.6 years and 5.8 wildfire deployments last five years. Their average wildfire training during initial schooling was 4.6/2.4 days of theory/practice, without live fire-training in field. 44% had follow-up training averaging <1 day over five years. One informant had participated in prescribed burning.

3.2. Perceptions of fire behaviour and production rates

Respondents overestimated ROS in both fire scenes (Figure 1, A-B) while underestimating potential ROS in forests under given weather-scenarios (Forests 1-2) (Table 2). When asked in which forest (Figure 1-left) fire would spread the fastest, all identified Forest 1 and highlighted differences in fuel structure as main cause. Some specifically commented on structure and species ("*more lichens*", "*Calluna dwarf shrubs*", "*dead branches lower to the ground*").

Table 2- Informants answers concerning ROS and hose-line construction.

Question	**Respondent's average (range/σ)**	**Reference answer**
ROS: Fire scene A	5.4m/min (1-15)	2-3m/min (observed)
ROS: Fire scene B	1.7m/min (0.5-5)	~0.5m/min (observed)
Most fire intensity potential (1/2), Figure 1	Forest 1 (everyone)	1
ROS[1]: Forest 1 (RH=30%, Wind=5m/s)	12.7m/min (2-25)	25m/min (FBP C-4)
ROS[1]: Forest 2 (RH=30%, Wind=5m/s)	4.9m/min (1-15)	15m/min (FBP C-3)
Advance rate: 5-person crew laying a 500m 42mm hose-line, from engine, without watering.	24.9m/min (σ=12.3)	
As above including watering of hose	13.1m/min (σ=6.8)	
Advance rate: additional extension of 500m without ATV	8.6m/min (σ=5.5)	
Secure duration: wet-line a hot, windy day	1.6hrs (σ=0.7)	
Advance rate: re-wetting 500m	17.8m/min (σ=15.5)	
Advance rate: 2-person crew mop-up 5m wide belt	5.6m/min (σ=5.8)	

[1] After two precipitation-free summer weeks.

Production rates constructing hose-lays were relatively consistently estimated, ~25 min for 500m from the engine without watering and twice the time if watering. A wet-line was considered secure for nearly 2h (1-3h) on hot-windy days. Mop-up of a 5m belt along established hose-line: ~6m/min after prolonged drought (Table 2).

3.3. Deployment vs fire-danger

Initial deployment varied with fire-danger (indices/weather) and almost linearly with FWI-values (Figure 2). Typically, minimum 2 "units" (2 officer + 8 firefighters) from two different stations were deployed, each travelling with one engine (~3m^3, one pump and 500m hose), one tanker (8-10 m^3) and IC riding a separate vehicle. For severe cases, 1-2 ATVs were brought on trailers.

This basic initial deployment was increased by adding units. Initial deployment varied between respondents but even for the most severe scenario 45% initially deployed only two units, immediately requesting substantially larger forces once shown pictures of the smoke column.

Upon alarm, station officers contacted landowners and surveyed available helicopters. For case #4, helicopters were called early on and 1/3rd requested 40-50 people from the military. One informant had a local system how to mix these (1+1) with professional fire-fighters.

Generally, deployment sizes relied on IC judgement, based on FD-class or windspeed but two different municipalities had independently developed their own rule-based dispatching schema using FD-class for initial crew sizes.

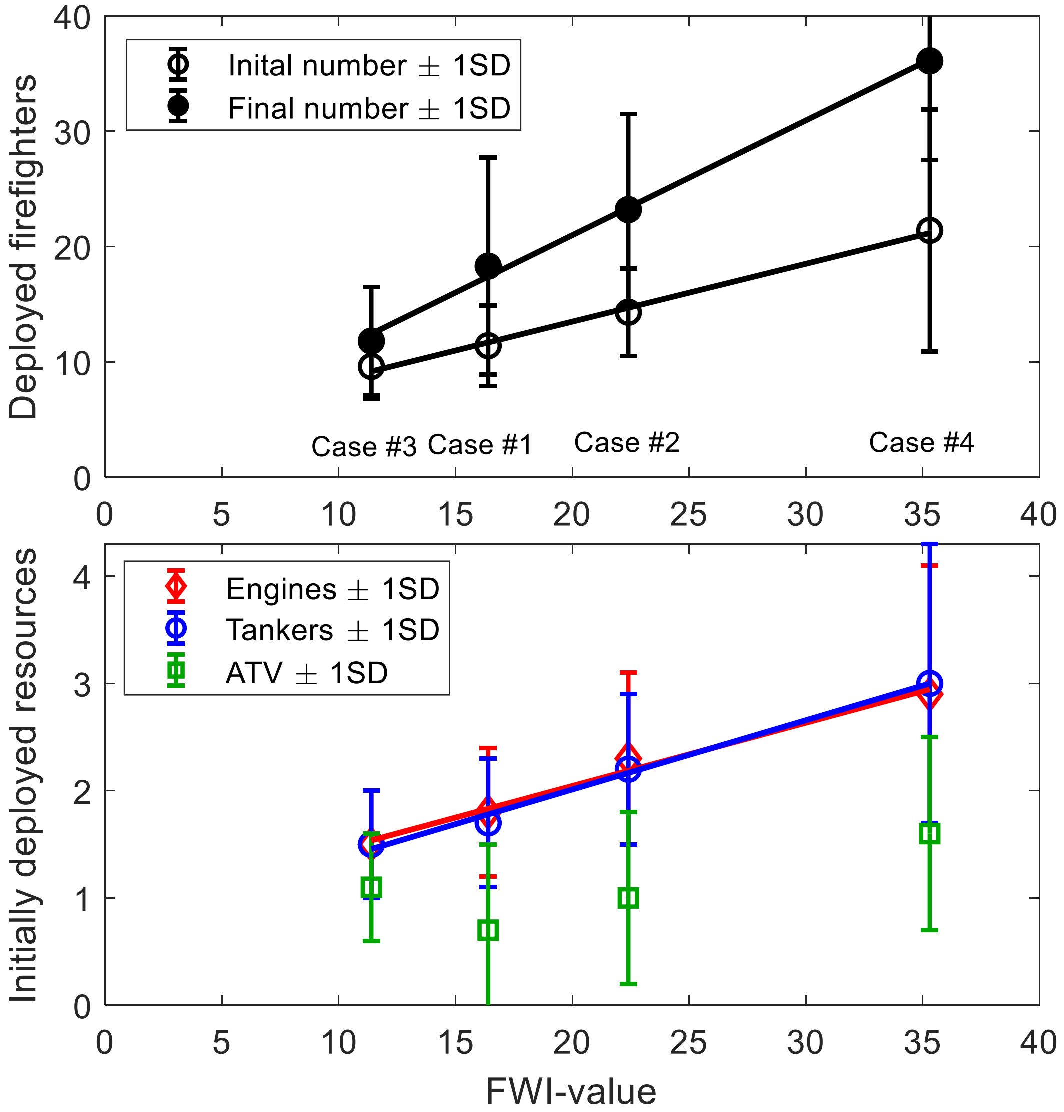

Figure 2- Initial resource deployment against scenario FWI-value (average ±1 standard deviation).

3.4. Suppression tactics

Standard procedure was driving to closest road position, sending 1-2 foot-scouts (sometimes with a drone), and start hose-laying from the engine once the fire location was verified (first 76-63mm hoses, transitioning to 42-38mm). Frequently, informants kept one unit at a distant staging point until engaging them from another direction. When fire was far from road access (2km, case#3), ATVs were often used for situational awareness and material transport. Hose-lay water supply was typically ferried by tankers from nearby accessible lakes, but occasionally smaller pumps were placed in nearby streams/lakes to feed hose-lines locally. Only two respondents used swatters/brooms on low-intensity backing and flanking flames. Landowner crews were not involved in the suppression stage.

Most respondents recognized/noted challenges such as slope-influence on ROS, or the danger of not controlling a flank early, allowing flames to circumvent a lake forming a high-intensity head fire. However, for the most severe scenario (#4), most respondents concentrated on the fire head, without securing the flanks from an anchor point. On this fire several respondents also worked exclusively along roads with hose-lays/watering from vehicles, setting up control lines far from the fire perimeter, thus adding risks in case of wind-shifts. As the high-intensity head reached the prepared lines, only two informants acted to control spot-fires. Two informants discussed expanding fire breaks using burn-out operations, but only one had relevant prior experience.

Mop-up time varied significantly, between 1-12h (case#1), after which landowner crews continued. Typically, hose-lines, pumps were precautiously left on site.

4. Discussion

Even in structured, hierarchical systems as in USA, variations occur among IC's risk perception (and McBride, 2013) but in decentralized Swedish organizations the competence is highly depending on individual- and group- field experience, developed through local rather than national organizational cultures. Most ICs had only a few days of formal theoretical/practical wildfire suppression instructions. Parallel to collective fire-knowledge in regions of active fire-use in land management (Johansson *et al*, 2012) the respondents did, however, exhibit considerable consensus in perception and judgement, suggesting reasonable degrees of field knowledge.

Initial deployments were rarely rule-based but depended on intuitive scaling of resources according to perceived fire behaviour, but with a two-units-minimum deployment. Most likely, ICs primarily based decisions on the 6-grade FD-class since few referred to FWI-values or its subcomponents. However, windspeed was also considered a separate risk factor and, on site, the colour and size of smoke columns were important signals.

Due to budget constraints, initial resources are weighed against the perceived risk of escaping initial attack (Lee *et al*, 2013), particularly so for helicopters, primarily called from the private sector (military helicopters are occasionally available at no cost for municipalities). Already, rescue service costs are 4X higher per capita in rural compared to urban regions (Anon., 2014). Another factor mentioned was resource conservation, to buffer for additional emergencies within the municipality.

Line construction rates have never been issued or discussed among Sweden's fire-fighting community, but our estimates were on par with previous Canadian results (Hirsh *et al*, 1998; 2004) and therefore one-crew hose-laying at 17m/min is a reasonable estimate for operational guidelines and modelling (Duff and Tolhurst, 2015). Reliable rates for hose-laying and re-wetting are important particularly as these often become limiting factors when fires escape.

The standard tactic of ferrying water by tanker is potentially vulnerable. First, the typical 76mm hose-lay from an engine means that its $3m^3$ capacity is emptied already by filling the first 660m. Then, to supply four nozzles implies one tanker (~$10m^3$) arriving each 30 minutes. Thus, one stationary engine and two rotating tankers can feed a hose-lay continuously but, will tie-up at least half of two-unit crew of 10.

Once fires were reached, the crews mostly proceeded to circle them close to the perimeter but sometimes well ahead of the fire, most evident for the worst-case scenario with high ROS and elongated perimeter. Here, no flanks were secured from safe anchor points, inviting outflanking risks. Further, strategies for controlling spot-fires were not planned-for. In fact, this scenario was based on a disastrous fire 2014 with similar response (Anon., 2015), suggesting results are indicative of typical response in case of fast-spreading and intense fires.

Time-to-initial-attack (median 25 minutes, 75% <30 minutes) vary greatly with population density within Sweden, and directly relate to likelihood of escape (Sjöström and Granström, 2020). The present-day system with few professional fire-fighters relies on Sweden's dense forest-road network (average distance <500m (1990), (Anon., 1991)). Road density correlates positively with fire occurrence and negatively with burnt area (Pinto *et al*, 2020). Median driving distance is 15 minutes and with 500m hose-lay within 20 minutes two standard 1+4-units may in fact be adequate for suppressing most low-intensity fires.

Though mostly adequate (89% of forest fires <0.5ha (Sjöström and Granström, 2020)), high-ROS or intense fires can quickly overwhelm such small forces. Even with helicopters, substantial ground crews are needed to secure perimeters. There are few stand-by firefighters in rural regions (Lindblad *et al*, 2015) and a deployment of as few as 40 fire-fighters (Case#4) drains resources over a large area. Additionally, tactics are vulnerable, e.g. relying on roads as fire breaks without burning off fuels ahead. This is, however, expected given that ICs seldom have been trained for or experienced complex wildfire scenarios.

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6. Literature

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