



Are We Missing Some Important Steps in Forest Fire Management?

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Abstract – Nacrtak

Seasonal forest fire occurs in various parts of the world. Various approaches have been taken towards fighting forest fires. However, given the fact that the world is still facing the challenge of forest fires, there is a need for consistent research in this area to reduce the threat of seasonal forest fires on humanity. This paper seeks to evaluate the present techniques for forest fire management and discuss possible additions to the way forest fire is managed to minimize its impact on wildlife and the entire ecosystem. Given the continuous tragedy of forest fires, the study seeks to answer the question, «Are we missing an important approach to forest fire management?». During this study, some site visit was done to evaluate factors that would contribute to the higher impact of forest fires on residential communities. The study presents recommendations to reduce the impact of forest fires on people (especially for those who live in the urban-wildland interphase region). Actionable strategies that can be adopted by various municipalities to reduce the impact of forest fire on residential communities are presented. This study also recommends that more effort be given to researching innovative ways to prevent the spread of forest fires.

Keywords: Forest fire management, water sprinkler technology, innovative firefighting system, biodiversity loss, automation

1. Introduction – Uvod

Forests are beneficial in cycling nutrients, climate control, carbon dioxide absorption, oxygen production, etc. However, Millions of acres of forest are lost every year because of forest fires (Aydin et al. 2019). The threat of forest fires to residential communities has been a concern in many places around the globe. Meanwhile, with appropriate building and community designs and adequate forest management practices, it is possible to keep forest fires in the forests (away from residential communities). Michetti and Pinar (2019) noted that forestland and trees are useful for their commercial and recreational uses, carbon sequestration activity, and water and climate regulation, but various forest disturbances undermine this role. Forest provides oxygen, honey, and shelter for animals and birds; hence, it is important to monitor and protect the forest and its resources (Cui 2020). A lot of time and effort are required for a site to recover from a forest fire (Jang et al. 2019). Forest fires have been around for ages. Although wildfire is often seen as a trouble to society,

it is a natural process that is important to maintain the productivity, health and diversity of the forest (Canadian Wildland Fire Strategy Assistant Deputy Minister's Task Group 2005). Axelson et al. (2009) reported that both fire and mountain pine beetle play a role in the dynamics of lodgepole pine stands in their study area. Natural Resources Canada also reported that fire is an important component of Canadian forests and will always be there, but the ongoing challenge for fire management agencies is how to allow the fire to play its ecological role in maintaining healthy forests, and also be managed in a way that provides protection to human values. National Geographic also reported that benefits that come with forest fires include: the elimination of insects and plants with disease, and the removal of canopies to allow sunshine to reach seedlings on the forest floors. However, wildfires can be prevented and adequately managed to save lives while reaping the benefits.

Even though wildfire is seen as an important and natural part of the ecosystem, it is important

that adequate actions be taken to minimize the negative impacts on residential communities (Mofolasayo 2020a). The major issue with forest fire is ensuring that the fire does not have a negative impact (such as loss of lives and properties) on people. Other factors that have also been noted include air quality, impact on health, carbon emissions, etc. Conard and Ivanova (1997) noted that fires in Russian boreal forests have a significant contribution to global CO₂. However, it is good to note that forest fires from any region around the globe contribute to global CO₂. The unwanted consequences of forest fires show the need for more study on how forest can be better managed in different parts of the globe to ensure that the unwanted effects on people are reduced. This study seeks to review the present forest fire management systems and propose systems that could be further explored to reduce the negative impacts of forest fires. This work is meant to be an article that various communities around the globe can refer to for insights on forest fire management and proactive steps to minimize its damaging impacts on residential communities.

1.1 Present forest management techniques – *Današnje tehnike gospodarenja šumama*

Like any other important resource, to have the best benefits from forests there is a need to ensure that forest resources are properly managed. Before implementing forestry practices, a forester develops a forest management plan that includes maps of the forest, objectives, a description of forest characteristic soil conditions, wetland on site, plant communities, plan of action to reach each objective. Forest management practices include timber stand improvement (thinning, mechanical treatment, chemical treatment, prescribed burning); timber harvesting (select cutting, clear-cutting, seed tree cutting, shelterwood cutting, and diameter-limit cutting); and regeneration (natural regeneration, coppicing, and artificial regeneration). Objectives of prescribed burning include control of undesirable plant species, reduction of hazardous fuel buildup, preparation of sites for regeneration, improvement of forage for livestock, etc. (Indian River Lagoon Envirothon Inc).

1.2 Present wildfire management systems – *Sadašnji sustavi upravljanja šumskim požarima*

Various approaches have been used in managing wildland fires. Management options that are listed

in the national strategy include: prescribed fire, fuel treatments using biological, mechanical and other non-fire methods, managing wildfire for resource objectives, home, communities and values at risk management options (home and community action, and building codes), human-caused ignition management options, and effective and efficient wildfire response management options (Forest and Rangelands). However, it is obvious that there are challenges in wildland fire management. The four national challenges as mentioned by the Science analysis of the national cohesive wildland Fire Management Strategy include homes, communities and other values at risk; human-caused ignition; vegetation and fuels; and efficient and effective fire response. Improper management in the last 3 will present a major risk to homes, communities and other values at risk. Ontario's strategy for wildland fire management has 5 objectives (prevent, mitigate, respond, understand, apply). For 'prevention', the strategy mentioned that the threat to people and values is reduced by decreasing the number of human-caused wildland fires. For 'mitigation', the strategy expects property owners and land managers to take action to mitigate the undesirable impacts of wildland fires on their property or other values. To ensure adequate 'response', all fires are to be assessed and dealt with appropriately. As regards 'understanding', people are to be aware and understand the ecological role of wildland fire. The last objective (Apply) aims to use prescribed burns and wildland fires to meet ecological and resource management and reduce wildland fire hazards (OMNRF 2014). It is good to note that prescribed burning also has its downside, as it requires adequate planning, good tactics, and resources to avoid the fire going out of hand. If fire goes out of hand during a prescribed burning operation, it may result in catastrophic results. In addition to developing harvesting and silvicultural regimes to reduce wildfire hazards, Coogab et al. (2019) noted that proactive fire management at the landscape levels includes thinning and prescribed burns, to protect communities at risk.

1.2.1 Six levels of forest fires – *Šest razina šumskih požara*

Based on a set of visual indicators, wildfires are ranked on a scale of 1 to 6 by BC Wildfire Services. Rank 1 (Smoldering ground fire: has a slow rate of fire spread, white smoke and no open flame). Rank 2 (Low vigour surface fire: has a visible open flame, slow rate of spread of surface fire, inconsistent or organized flame front). Rank 3 (Moderate

vigorous surface fire: has an organized flame front with a moderate rate of spread, and may have occasional candling within the fire or along the perimeter). Rank 4 (Highly vigorous surface fire with torching, or passive crown fire: characterized by the organized flame front with moderate to fast rate of spread on the ground, grey to black smoke, short-range spotting and short aerial burst in the forest canopy). Rank 5 (Extremely vigorous surface fire or active crown fire: characterized by organized crown fire front, black to copper smoke, and moderate to long-range spotting and independent growth of spot fire), and Rank 6 (A conflagration or blow up; extreme and aggressive fire behaviour: characterized by violent fire behaviour, possible fireballs and whirls, long-range spotting and independent growth of spot fire, organized crown front and dominant smoke column which influences fire behaviour may also be seen). The amount of fuel that is in the forest will influence the expected rank of the fire if the fire erupts. Hence, it is important for every municipality to be proactive in reducing the amount of fuel in forest areas that are closer to residential communities.

In addition to direct attack, using water delivery systems, hand tools and heavy equipment, BC wildfire services noted that hand-constructed control lines are likely to be effective for rank 2 fire, but hand-constructed control lines may be challenged in rank 3 fire. Control lines that are made by heavy equipment are said to be generally effective for rank 3 fire. Other measures such as the use of fix-wing air tankers, helicopters conducting tanking operations, etc. may be needed to support ground crew. Approaches to attend to other ranks of fires are also presented by BC Wildfire Services.

2. Reducing the chances of forest fires – *Smanjenje mogućnosti šumskih požara*

Despite the knowledge about the devastating impacts of forest fires and how forest fires spread, humanity at large has not yet come to a consensus on how to keep forest fires in the forest (away from residential communities). A review of current forest fire management practices and a questionnaire that is geared towards achieving a consensus on how to keep forest fires in the forest (away from residential communities) was presented (Mofolasayo 2020a). For a wildfire to start, there has to be a sufficient quantity of heat, fuel, and oxygen. Destruction of properties by wildfire can be influenced by the closeness of the property to thick forests or other

combustible materials and the type of material with which the property is designed. When residences are too close to dense forests that have a high chance of burning, there is a possibility that there will not be enough room to get firefighting materials together on time to prevent property loss during wildfire episodes (Mofolasayo 2020b). Hence, in the approval of new community designs, it is important to ensure adequate planning for wildfire emergencies (to ensure that communities are designed to minimize the chance of property loss during wildfires, and also to ensure that sufficient resources are made available to reduce the chance of forest fire and to extinguish the fire if fire erupts). The sources of heat that could start a wildfire could be from lightning, human activities e.g., fire from cigarettes, open burning, etc. Adequate measures to reduce chances of forest fire encroachment on residential communities include ongoing community awareness campaigns on fire smart strategies, appropriate land management and urban planning strategies to establish adequate buffers between forests and communities, use of innovative firefighting systems (using automation systems to assist with fire detection and suppression), and adequate use of early detection and monitoring systems. Since spot fires begin when embers that are being transported by convective lifting fall on combustible surfaces like combustible roofs, dry vegetation, etc., more attention on the creation of adequate buffers between wildland and residential communities is seen as a good endeavour (Mofolasayo 2020a).

Canadian Council of Forest Ministers Wildland Fire Management Working Group (2016) reported that close to half of all yearly wildland fires are caused by humans and that the human-caused wildland fires tend to be most destructive as oftentimes they are located close to industrial development and populated areas. The approach to minimizing person-caused wildfires will involve continuous public education, the institution of strict forest management laws and adequate penalties for breaking the laws, to ensure that people are more conscious of the possibility that a forest fire can occur from various human actions. Public education may encourage efforts to ensure that the environment is cleaned of unwanted combustible materials. Intense public education may also be used to create more awareness of the possible impact of dropping burning substances (either in the forest or outside the forest). There are great opportunities to influence the occurrence of preventable wildland fires (Canadian Council of Forest Ministers Wildland Fire Management Working Group 2016). There may be a need for

the establishment of adequate laws and penalties to ensure that people do not drop burning substances. An increase in public education about responsible use of engines or vehicles will be appropriate. It will not be a bad idea to have laws that require all vehicles or engines that can burn to come with fire extinguishers which the owner may quickly apply in case there is a fault with the vehicle that leads to fire. For people who desire to make a camp-fire, it will be good to have regulations that require that such people will have to get a permit before they can make a campfire; requirement for such permits may also include a record of the location where the campfire is to be ignited, a note to confirm that adequate provision has been made to put off the fire before the team leaves the campfire site. Regular inspection of sites after campfires will be a good practice. If permits for campfires make it compulsory to indicate the GPS coordinate of the location for the campfire, it should be easy for designated officials to locate and conduct a good inspection of the site after the campfire. Employing a reasonable number of workers for camp patrols to consistently monitor forests where human activities are frequent will be a good endeavour. The use of drones and video surveillance for activities in forests that are in the wildland-urban interface will also be good. Proactive monitoring of forests would include having an adequate budget for preventative measures rather than procrastinating preventative measures until there is a big wildfire that requires a huge amount of reactive measures.

It is good to note that the above recommendations are not to restrict the freedom of anyone from having recreational activities in the forest, it is just to ensure that people can use the forest in a more responsible manner. Coogab et al. (2019) noted that wildfire management practices in Canada go with five emergency management phases viz: preven-

tion, mitigation, preparedness, response and recovery, but currently, most resources and efforts are spent on response. It was suggested that more efforts be spent on prevention, mitigation, and preparedness phases. The data available for the past 25 years showed that suppression costs in the USA have increased substantially (Doerr and Satin 2016). In Canada, expenses on wildland fire management can reach up to \$1 billion in a year (Canadian Wildland fire strategy-assistant Deputy Ministers Task Group 2005). The huge cost that wildfires attract (and the associated losses during wildfires) calls for more proactive ways to ensure that reasonable procedures and systems are established to ensure the avoidance of preventable wildfires.

3. Methodology – *Metoda rada*

The approach for this project includes a review of the literature and a field visit to explore factors that can contribute to the negative impacts of forest fires on various municipalities around the globe. Some pictures were taken during field visits for a graphical illustration of the suggested approach to reduce the impact of forest fires on residential communities. Actionable strategies that various municipalities can institute to further reduce the impact of wildland fires on their communities (while creating jobs and making good use of forest resources) are highlighted. Various areas for future research in forest fire prevention and management are highlighted.

4. Results and discussion – *Rezultati i rasprava*

Pictures that were taken during field visits were used to explain areas where various communities can concentrate more efforts to reduce the impact of forest fires on residential communities.



Fig. 1 Avoid increased intensity of wildfire from dead trees lying around in the forest

Slika 1. Izbjegavati pojačani intenzitet šumskih požara od mrtvih stabala koja leže u šumi

4.1 What can be done to reduce the speed by which seasonal forest fires encroach on people within various communities? – Što se može učiniti da se smanji brzina kojom sezonski šumski požari ugrožavaju ljude unutar različitih zajednica?

The intensity of seasonal forest fires will depend on the amount of combustible fuel that is available on its path. More effort may be required to extinguish a fire with high intensity than a fire with lower intensity. The head fire intensity (the predicted energy output or intensity of the fire at the head or front of the fire) being one of the standard gauges that fire managers use to select appropriate suppression methods and estimate the difficulty of extinguishing the fire is dependent on total fuel consumption and the rate of spread. Total fuel consumption (the predicted weight of fuel that is consumed by the fire both on the crown of the trees and the forest floor) is based on foliar moisture, rate of spread and surface fuel consumption (Natural Resources, Canada). Various factors could contribute to trees falling in the forest. The action of strong winds (windthrow) could contribute to trees falling. Trees that have been severely weakened by the impacts of winds and diseases could also be more susceptible to the action of strong winds. These dead trees are fuel that could facilitate the spread of wildfires. These calls for adequate management of fuels in the forest. To reduce the chance and the strength of forest fires as they get close to residential communities, it is important that the quantity of fuel in the forest that is close to the residential communities be greatly reduced. Fig. 1 shows some fallen trees that could contribute to the intensity of fire if there is an ignition or an encroachment of forest fire towards the community.

For a forest fire to occur, there has to be a heat source, oxygen, and fuel (fire triangle). There is an abundance of oxygen in our environment, and the

heat source can also be easily generated either by humans or from natural effects such as lightning. If there is no combustible fuel in a certain area, the spread of forest fire is not expected in that place. As mentioned in Fig. 2, the reduction of tree density and the amount of combustible materials in the forest areas that are close to residential neighbourhoods is important. If we use the approach in which some forest fires are to be allowed in a geographical location due to perceived ecological benefits and limitation of resources to fight the forest fires, then it will be reasonable to also take a proactive approach to create boundaries for which the forest fires are not expected to cross.

During the 2016 high-river forest fire episode, it was reported that the fire jumped the Athabasca River. Since water is not combustible, naturally, it is expected that fire will not burn in a body of water. Although a body of water can serve as a barrier for fire, given that high winds can blow fire embers to a considerable distance, in future, it should not be unexpected that, even though the fire will naturally not burn in the water itself, a small body of water will not prevent fire from getting to structures at the other side of the river. Reduction of the density of combustible materials in the forest that is close to residential neighbourhoods will help reduce the amount of combustible materials that can increase the intensity of fire, increase the atmospheric temperature, initiate pyrolysis in wood materials that are close by and also generate more embers that could eventually be transported by wind and start spot fires in other places in the area where there is no fire. The effort to utilize forest resources rather than allow them to burn will also include the removal of trees that are dead but are still standing. This will also help reduce the density of combustible materials. This is important mostly for areas that are close to residential communities. Fig. 3 shows some trees that are dead but are still standing. When close to



Fig. 2 Remove all dead trees from the forest floor and find beneficial uses for them

Slika 2. Ukloniti sva mrtva stabla sa šumskoga tla i pronaći im korisnu upotrebu



Fig. 3 Remove dead but standing trees in the forest and reduce fuel density in forests close to residences

Slika 3. Ukloniti mrtva, ali stojeća stabla u šumi i smanjiti gustoću goriva u šumama blizu naselja

residential communities, these need to be removed (and used for other beneficial purposes) to reduce the severity of wildfires.

Trees that are dead, but still standing and the density of fuel in the forest will contribute to the intensity of the fire from the forest. Various combustible debris on forest floors as in Fig. 4 will also contribute to the intensity of wildfires around residential neighbourhoods. Hence, it is important that municipalities adopt proactive measures (such as removing combustible debris while reducing the tree density in forests close to residential neighbourhoods) to reduce fire intensity and make fire suppression efforts easier (if forest fires eventually occur).



Fig. 4 Clear forest floors from combustible debris (especially those close to residential communities)

Slika 4. Očistiti šumska tla od zapaljivih ostataka (posebno onih u blizini stambenih zajednica)

The above task is one that may require the employment of more people for the management of forest resources around residential communities (especially in wildland-urban-interphase). Proceeds from the harvested resources from the forest can be used to supplement the salaries of the workers. To reduce the impact of wildfire on residential communities, it is important that more attention be focused on pre-

vention efforts rather than focusing on the response to fire.

4.1.1 Management of forest fires with limited resources – *Upravljanje šumskim požarima s ograničenim resursima*

Given the huge size of forests in different places, depending on the size of the forest, it can be challenging to reduce the amount of combustible materials in the entire forest. Hence, it is reasonable to create a boundary to separate the 'major forest' from forests that are closer to (and may have negative impacts on) residences. Previous work has indicated that the primary objective of fire agencies was to control all fires through early detection and initial attack when the fire is still small (i.e., hit them hard, hit them fast), but it was later realized that total fire exclusion is not ecologically desirable nor economically feasible. The awareness of the ecological role of fire fostered a new fire management strategy (Canadian Wildland Fire strategy-assistant Deputy Ministers Task Group 2005). To reduce the impact on residential communities, an approach of zero tolerance for wildfire for forests in the specified boundaries close to residential communities will be ideal. Forest fire encroachment into any municipality will not be difficult if adequate buffers do not exist between the forest and the municipality. The balance between judicious use of the limited available resource, and the impact (such as smoke, health effects, etc.) of forest fire on residential communities may be challenging to address if adequate boundaries have not been established to specify the areas in which «hit them quick, hit them hard approach will be used» (i.e., areas in which there should be zero tolerance for spread of forest fires). The creation of adequate buffers between zones that are specified as zero tolerance for forest fires, and zones in which forest fires can be allowed will be a reasonable way to improve

the management of forest fires. Other systems such as water sprinkler technology may be designed and installed in some parts of the forest that are close to the wildland-urban interface, to control the moisture level and reduce the possibility of ignition of those areas. As communities grow with increased population, new boundaries may be created to make forests around residential neighbourhoods more manageable. In some parts of the world, the installation of lightning spikes on buildings and some infrastructures is not uncommon. Lightning spikes are expected to help collect electric charges from the lightning and safely dissipate them to the ground. More research on how lightning spikes technology may be helpful to minimize the possibility of forest fire in places close to wildland-urban interface is recommended. In addition to creating a buffer between the 'major forest' and the areas that are marked as «zero tolerance areas» for wildfires, when designing a fire management plan for a forest, to prevent the fire from having impacts on people in residential communities, there is a need to answer these research questions:

- ⇒ Given the density of combustible material in the forest at the wild-land urban interphase, what is a safe distance between the forest and the residences to prevent the negative impact of heat from forest fires on the residences?
- ⇒ Given various wind speeds, what is the maximum distance that the wind can blow fire embers from a portion of the forest to result in an ignition in another part of the forest?

It is well known that the quantity of heat that is generated when burning a small quantity of wood materials would not be of concern (e.g. when making a campfire). However, the amount of heat that would be generated from the combustion of large quantities of combustible materials from the forest can be of great concern. A good answer to the questions above will help in determining the amount of buffer that is needed to be given between the residences and the forest. Adequate buffer between the forest and residential properties is expected to help reduce the chance of property loss during forest fires. This is also expected to make firefighting operations easier to manage. Fig. 5 shows an illustration of a residential building that is situated close to a little forest nearby. As illustrated, if a fire episode occurs, fire suppression effort will be more difficult for firefighters when the buildings are too close to the combustible materials than if the building is a little farther away from combustible materials.



Fig. 5 Establish reasonable buffers between the forest and residential communities

Slika 5. Uspostaviti razumne tampon-zone između šume i stambenih zajednica

4.2 Reducing biodiversity loss – *Smanjenje gubitka biološke raznolikosti*

Fire is a positive factor that is important for plant health and survival in many ecosystems, but in some others, it can be a source of negative impacts like loss of biodiversity, social and economic consequences, and ecological impacts (International Association of Wildland Fire 2016). Hence, while striving to develop a comprehensive management plan for forest fire management, it will be good to consider ways by which all the negative impacts can be minimized. An important question here will be «How can we minimize biodiversity loss during forest fire?». While it will be difficult to prevent biodiversity loss for any plant species that can be destroyed by the fire in a certain forest during forest fires (except an effort is made to have the same species in other places that are not affected by the fire and re-introduce them back to the forest after the fire), it should not be too difficult to make allowance for the reduction in the loss of animal life during forest fires. Since fire is not expected to burn where there is no fuel, the creation of some open areas with no combustible debris (where some animals may run during fire episodes) in some sections of the forest will be a good approach to protect animal life. Where necessary, artificial ponds may also be created in some buffer regions of the forests to serve as shelter for animals during forest fires. It is important to continue research on novel methods to protect biodiversity loss during forest fire episodes. Potential areas to explore include the creation of artificial ponds and some open areas (in the forest) where some animals could have a lower likelihood of being killed by wildfire and the creation of other forest fire shelter areas to protect wildlife. When a fire erupts, animals that manage to get into the fire sanctuary zone may receive better protection during

seasonal forest fires. Rain could be helpful in fighting forest fires. It may not be reasonable to deploy fire-fighting officers to the forest during heavy rain. As the surface fire moves to the crown fire, the foliar moisture content is a major factor in the canopy ignition process (Keyes 2006). Hence a good research question here is «In order to minimize the possibility of crown fire, how can we increase the foliar moisture content?». Mankind has been able to develop various forms of irrigation systems. Present irrigation systems may be further improved such as spraying water to reach tree canopies and increasing the moisture content, especially for the portion of the forest that is closest to the wildland-urban interface. The use of innovative firefighting systems using autonomous water sprinkler technology (that can spray water to great heights) will be a commendable endeavour. If desired, some water sprinklers (having nozzles that can spray water from the top of the trees, simulating the rain) can be attached to trees. This can help to reduce the conditions that favour fire while creating a reasonable form of shelter for animals that manage to get to these places, and also serving as fire breaks to prevent the further spread of wildfires. Further studies on this and its effectiveness in the reduction of biodiversity loss are recommended.

4.3 How can we reduce the impact of forest fires that are caused by lightning? – *Kako možemo smanjiti utjecaj šumskih požara izazvanih munjama?*

The effort to reduce the impact of forest fires that are caused by natural forces such as lightning is one that requires good attention and efficient wildfire management systems. Modelling and prediction of forest fires occurrence are important to reduce the losses to forest fires (Zhang et al. 2019). It has been reported that forest fires come with some benefits and also some disadvantages. The challenge is how to minimize the disadvantage while maximizing the benefits. Our forests are filled with great resources that could benefit humans in everyday living. If forest fires are to be allowed in some parts of the forest, management of these fires becomes crucial. Hence, there is a need to establish standards and processes by which forest fires can be adequately managed to ensure that they do not constitute a threat to people. Forest fire management will include the use of historical records for the management of seasonal forest fires as described below.

4.3.1 Using historical records to correlate the location of forest fires with the impact on air quality for various communities – *Korištenje povijesnih zapisa za povezivanje lokacija šumskih požara s utjecajem na kvalitetu zraka za različite zajednice*

Although previous work/s has indicated that forest fires are ecologically desirable in some geographical locations, the negative impacts of forest fires on people in various communities are not desirable anywhere. In order to ensure that forest fires do not adversely impact people in various communities, more research is recommended in the use of historical records (considering wind speed and direction of wind) to analyze the air quality in various places at various times with the location of forest fires in different places. It is hoped that studies in this area will be able to give a reasonable description of how far the impact of forest fires can go. Other ways in which forest fires impact people in various communities may be evaluated. It is recommended that this study be carried out in various jurisdictions globally to have more robust data for analysis of the impact of forest fires, and to determine boundaries for which seasonal forest fires will not be allowed to exceed to reduce impact on people.

It is hoped that evidence-based results (to be generated from such studies) to show the impact of forest fires on people (as regards air quality) in various communities will be a good basis for establishing adequate boundaries for forest fire intervention. Such studies should be able to come up with a map that will indicate regions for which the approach of ‘hit them hard, hit them fast’ would be justifiable.

4.4 Early detection and monitoring of forest fires – *Rano otkrivanje i praćenje šumskih požara*

Prediction of fire spread and behaviour in the fire line on the field is very important in the effort to minimize risks to firefighters and prevent loss of human life (Mondero et al. 2019). Akinola and Adegoke (2018) also noted that forest fire risk assessment is the most important step in forest management as it gives information on where the risk is highest, to minimize the risk to life, natural resources and property. Jang et al. 2019 noted that because of their high temporal resolution over large areas, geostationary satellite remote sensing systems are a useful tool for the detection and monitoring of forest fires. Monedero et al. (2019) presented the Wildfire Analyst, a pocket edition application of a mobile tool

that shows punctual fire characteristics and estimated behaviour based on information that is input by the user. Early intervention is not always possible because of issues such as the impact of high winds that are worsened by various fuel sources in the forest and terrain that are difficult to access (Aydin et al. 2019). Although it has been said that forest fires come with various benefits for the health of the forest, Kohl et al. (2019) mentioned that the frequency and intensity of wildfires are increasing and that they emit large quantities of organic and inorganic pollutants. With this knowledge, it is important to intervene early to minimize the impacts of forest fires, especially in places close to wildland-urban interphase. Early detection coupled with adequate preparedness can facilitate early intervention to reduce the negative impacts of wildfires. Fire detection is an effective way to save lives and reduce the loss of material properties that are caused by fire (Kruger 2017). A concerted approach to fire management is important to minimize the risks. It is important that various communities around the globe share knowledge and information on fire detection and early response strategies to reduce the impacts of wildfire on human life in different places around the globe. After the adequate mapping of forests to identify which areas are to be tagged as zero tolerance zones for wildfires (to minimize the impact on people in residential communities), early detection of fires will be very helpful to ensure quick response to extinguish the fire. This is also hoped to result in a decrease in the amount of resources that will have to be spent if the fire is discovered after it has become big. Since an advanced fire management computer system is now available to determine where lightning strikes occur, predict the location and probability of wildfire occurrence, predict the rate of spread of wildfire, etc., it will be good to put the system to good use in every municipality. For example, for every lightning, if there are adequate systems that can trace the lightning to its final impact to know if it started a fire somewhere, then early detection and management of lightning-caused forest fires can be achieved.

5. Reducing the impacts of forest fires on residential communities – *Smanjenje utjecaja šumskih požara na stambene zajednice*

Mofolasayo (2020b) reviews how various communities can be designed to provide places that can be used as temporary places of shelter pending the time

that rescue efforts can reach people in the community. If the risks and challenges of evacuating people from a community become physically unattainable, a place of temporary shelter during encroachment of forest fire is a good thing. Sometimes, fire encroachment on communities does not give much room for a full evacuation of people without recording fatalities. Runefors et al. (2017) reported that the effectiveness of different preventive measures to reduce the number of fire fatalities is dependent on a number of factors such as age, occupancy type, whether an individual is living alone, etc. A community with a reasonable number of elderly people who require some assistance during emergency evacuation procedures may be at a higher risk for more fatalities during fire encroachment than communities where there are more agile youths. Adequate plans for evacuation procedures are important, especially for communities with lots of elderly people. The type of road network to multiple destinations from a city can facilitate the evacuation of people to alternative destinations.

Using knowledge of what has worked in previous fire episodes, Mofolasayo (2020b) recommended some strategies to create a temporary place of shelter for people pending the time that rescue efforts can reach the people during forest fire episodes. These include artificial beaches. Large outdoor pools are seen as a potential place for temporary shelter. It was recommended that further research be done to know how long this will be able to last to keep people safe before greater rescue efforts are done. Buildings that are constructed with fire-resistant materials and also equipped with external fire extinguishing systems such as automatic sprinklers to suppress the threats of fires were recommended, as well as huge water spray parks that are designed to ensure that the source of the water will not be cut off as a result of power interruption during a fire emergency (this may be powered by renewable energy such as wind and solar power, and a standby electricity generator). The study recommended that more research be done on water sprinklers for neighbourhood firefighting that can identify fire (with consideration for the intensity of the fire) and can function autonomously to fight and eradicate the fire. The study also recommends that every community take steps to evaluate facilities in the community to confirm that there are places that can serve as temporary places of shelter during fire emergencies. Among other things, public education on safe steps when there is an encroachment of forest fire into different communities was also recommended.

Citing a previous work, Walls et al. (2017) mentioned some responses that are currently being implemented to reduce the increasing number of fire deaths. These include heat detectors, community training initiatives, new construction materials, fire breaks, etc. The application of fire breaks can help prevent the spread of fires to many residential areas in a community. Fire breaks can be designed in multiple ways. It could be an intentional construction of open areas without any structures in between communities, it could also be areas where reliable and functional autonomous fire detection and autonomous fire suppression and fire extinguishing systems have been established for all buildings in the communities. This would be ideal for buildings that are close to urban wildland interphase. Improvement of design standards of buildings in urban wild-land interphase regions to include automatic fire detection and fire extinguishing capabilities will not only help alleviate burdens on fire-fighters and fire extinguishing resources during fire seasons, it will also help ensure a reasonable degree of fire breaks (preventing further encroachment of fires into more residential neighbourhoods within a city). Fire risk assessment is important to control the risk of fire while improving preventive measures. Fire risks can be controlled. The ability to resist fire through risk assessment can also be improved (Wang et al. 2021). It is important to inspect and maintain fire safety equipment to ensure that they are in good working condition during emergencies (Chen et al. 2020). In addition to the above, it is important to remove unnecessary combustible materials around various buildings. These can be disposed of or stored in a special storage (away from residences).

Fig. 6 shows examples of unnecessary combustible materials around different buildings. These are fire hazards that can increase the intensity of fire

around a building during the encroachment of forest fires on residential communities.

5.1 Reducing the chance of fire spread in residential communities – *Smanjenje mogućnosti širenja požara u stambenim zajednicama*

Summary of strategies for local governments to reduce the severity and impact of wildfire on residential communities:

- ⇒ Conduct extensive public education on fire smart strategies through town hall meetings, handbills, television and radio programs, social media, billboards, etc.
- ⇒ Inform residents of new bylaws to encourage residents to embrace 'fire smart' strategies
- ⇒ Perform periodic inspections on the surroundings of different residences for obvious fire hazards (drone surveys can be helpful)
- ⇒ Where necessary, employ more people for physical inspection of neighbourhoods for fire hazards. This will not only create more employment for people, but it should also help create more awareness of fire-smart strategies
- ⇒ Warn residents who store fire hazards close to their properties
- ⇒ Institute a fine if residents are non-compliant with fire smart strategies after a number of warnings (to be specified in the bylaws)
- ⇒ Reduce the density of combustible materials in the forest around residential neighbourhoods (Create a special department that is adequately staffed for ongoing monitoring and reduction of the density of combustible materials in the forest around residential neighbourhoods).



Fig. 6 Remove unwanted combustible materials around buildings

Slika 6. Ukloniti neželjeni zapaljiv materijal oko zgrada

Summary of strategies for management of forests close to communities (e.g., Urban-Wild-land Interface):

- ⇒ Establish a reasonable break (space) between the buildings and the forest close to the residences
- ⇒ Create a reasonable space (buffer) between the major forest and the forest close to urban areas. This break can be a wide space between the big forest and the forest that is close to the urban areas. This space would be helpful for the fire-fighters to manage and prevent fires from encroaching into the communities that are close to the wildland-urban interface
- ⇒ As communities grow and people encroach near the break between major forests and the urban area, create another break (buffer) further into the forest
- ⇒ Clear the forest of dead trees. Dead trees can include trees that do not come back alive after the winter and are still standing. Dead trees can also include trees that are blown down by the wind (wind throw action), those that have died from the impact of insects and diseases, etc. Rather than wait for forest fires to burn these dead trees and emit lots of carbon into the atmosphere, these dead trees can be used for biofuels, while the carbon emissions can be managed through adequate carbon capture technologies at the plants where the biofuels are used
- ⇒ If there are not enough resources to adequately manage the big forest, the immediate forest close to the urban areas can be marked as areas with zero tolerance for forest fires. This means that more attention would be given to the forest in immediate areas that are close to the urban areas

A reasonable space between thick forest and urban areas would be a space that is large enough for flying embers to have cooled down to the extent that they would not ignite new fires in residential communities. The risk of wildfires in forests that are closer to urban areas can be reduced by reducing the amount of combustible materials in the forest (removing dead trees on forest floors, reducing tree density, removing combustible materials that are close to buildings, installing automatic water sprinklers that can reach great heights such as tree canopies, the exterior portion of buildings, including the roofs of buildings, etc.). Further study is recommended on what a reasonable buffer between wildland and urban interface would be in various communities around the globe.

6. Additional research questions for future studies – *Dodatna istraživačka pitanja za buduće studije*

This study recommends that more effort be given to continuous research on innovative ways that may be applied to prevent the spread of forest fires. It will be good to have the following topic addressed by researchers in various municipalities:

- **Research question I: How can we design and incorporate reliable autonomous exterior fire-fighting systems into the engineering design of infrastructures to ensure better protection for the occupants in the episode of normal forest fires until greater intervention (and rescue effort) is available?**

This research question should address how to prepare building designs that will better withstand the threat of seasonal wildfires. A good application for this will be for important buildings in the communities, museums, hospitals, community buildings, churches, remote residential areas like camps for workers in the oil fields, etc. It can even be used in residential homes.

- **Research question II: Can we apply the concept of 'artificial rain' using water sprinkler technology systems to reduce the chance of forest fire?**

This research question should address how foliage moisture content can be increased using water sprinkler technology systems to reduce the possibility of seasonal forest fires going beyond certain portions of the forest (especially for places in the wildland-urban interface).

- **Research questions III: How can we better design and construct residential communities to ensure better safety for people during encroachment of seasonal forest fires, pending the time that a greater intervention can be accessed?**

This research question should address how residential communities can be redesigned to better guarantee the safety of people during encroachment of forest fires. It should also look into the possibility of creating a temporary place of shelter during seasonal wildfire episodes. Mofolasayo (2020b) looked into this topic. Continuous research on the subject is recommended.

Going back to the major question of this study, «Are we missing important steps to forest fire management in various municipalities around the globe»? If we have not established adequate plans in

our communities to reduce the chance of occurrence (and the severity) of forest fires as described, it can be said that «we are missing important steps in forest fire management». This study recommends that every community improve on preventive efforts to reduce the chance of occurrence as well as reduce the impact of forest fires on residential neighbourhoods as described.

7. Conclusion and recommendations – *Zaključak i preporuke*

The threat and the devastating impact of wildfires on residential communities call for a continuous review of strategies that are employed in forest fire management in different municipalities around the globe. This study highlighted present techniques for forest fire management, discussed areas where more efforts will be beneficial to reduce the impact of forest fire on residential communities, and also highlighted areas that would benefit from further research in forest fire management. Among other things discussed, the establishment of a boundary (considerable gap) between huge forests and forests that are close to wild-land urban interphase to ensure that there is at least a manageable portion of the forest that allows for fire suppression efforts to protect the communities without creating heavy toll on fire officials will be beneficial to reduce the impact of forest fires on residential communities (especially in the face of limited resources for the management of forest fires). The creation of reasonable buffers between the forest and the buildings to reduce the chance of forest fire encroachment on the buildings while creating adequate space that should make fire suppression more manageable for firefighters is recommended. Continuous efforts to ensure proactive measures for the reduction of the density of combustible materials in the forest are seen as a good measure to reduce the severity of wildfires. This is expected to create more jobs for people in various communities while making forest fires more manageable. These efforts will include continuous monitoring and removal of dead trees from forest floors, the removal of dead but standing trees, and the reduction of tree density in forest areas that are closest to residential communities. The creation and maintenance of a fire prevention department (not only a firefighting department) that monitors and controls fuel stock in different communities next to urban-wildland-interphase areas would be a commendable endeavour. Rather than wait until wild-fire comes to devour huge combustible materials in the forest close to residential communities, where

control burning is used, this department (in conjunction with the firefighters) could use a proactive approach in planning control burning to reduce the chance of forest fire in areas close to residential communities.

The inclusion of biodiversity loss planning in the forest management plan will be beneficial. This study recommends an increase in research on techniques to prevent biodiversity loss during wildfire episodes. Potential areas for further research on this have been mentioned in this study. A design that automatically activates the water sprinklers for the fire sanctuary or fire breaks to automatically spray water on certain sections of the forest (periodically like an artificial rain) whenever the atmospheric temperature reaches a certain stage will be commendable. Using automation systems, this design may be such that it will continually spray water if fire is detected to prevent the spread of the fire beyond this zone. The percentage of person-caused forest fires is significant. In addition to the above, this study recommends an increase in public education, awareness and enforcement to reduce the possibility of person-caused wildfires (some strategies for this have been laid out in this report). A previous work (referenced in this study) mentioned that foliar moisture content is a major factor in the canopy ignition process. To reduce the chance of canopy ignition, further study is recommended on how to increase the foliage moisture content of trees using an improved water sprinkler technology approach (similar to the irrigation systems), especially for areas close to residential neighbourhoods. More research is recommended on how to design residential buildings in a way that can autonomously respond to the threats from the encroachment of seasonal forest fires. More research is also recommended on how to design residential neighbourhoods to better guarantee the safety of people pending the time that a greater intervention can be assessed whenever encroachment of forest fires threatens residential communities.

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Sažetak

Propuštamo li neke važne korake u upravljanju šumskim požarima?

Sezonski se šumski požari događaju u različitim dijelovima svijeta. U borbi protiv šumskih požara primjenjuju se različiti pristupi. Međutim, s obzirom na činjenicu da se svijet još uvijek suočava s izazovom šumskih požara, postoji potreba za dosljednim istraživanjima u ovom području kako bi se smanjila opasnost od sezonskih šumskih požara za čovječanstvo. Ovaj rad nastoji procijeniti postojeće tehnike za upravljanje šumskim požarima i raspravlja o dodatnim mogućnostima u načinu upravljanja šumskim požarima kako bi se smanjio njihov utjecaj na divlji svijet i cijeli ekosustav. S obzirom na stalnu prijetnju šumskih požara ovim se istraživanjem nastoji odgovoriti na pitanje: Propuštamo li važan pristup u upravljanju šumskim požarima? U sklopu provedenoga istraživanja obavljeni su posjeti određenim lokacijama kako bi se ocijenili čimbenici koji pridonose pojačanom utjecaju šumskih požara na stambene zajednice. Studija također daje preporuke za smanjenje utjecaja šumskih požara na ljude, posebno na one koji žive u međupodručju urbano-divljih regija. Prikazane su djelotvorne strategije koje se mogu primijeniti u različitim općinama kako bi se smanjio utjecaj šumskih požara na stambene zajednice. Posebno se naglašava potreba ulaganja više napora u istraživanje inovativnih načina za sprječavanje širenja šumskih požara.

Prijetnja i razorni utjecaj šumskih požara na stambene zajednice zahtijevaju kontinuiranu reviziju strategija koje se primjenjuju u upravljanju šumskim požarima u različitim općinama diljem svijeta. Kao mogući dodaci postojećim tehnikama upravljanja šumskim požarima u ovoj se studiji ističe uspostavljanje granice (značajnoga razmaka) između velikih šuma i šuma koje su blizu urbano-divljemu prijelaznomu zemljištu kako bi se time osiguralo postojanje barem upravljivoga dijela šume koji bi omogućio da napor u suzbijanju požara radi zaštite zajednica bez stvaranja velikoga danka za vatrogasne službenike budu korisni u smanjenju utjecaja šumskih požara na stambene zajednice (posebno u svjetlu ograničenih resursa za upravljanje šumskim požarima). Također se preporučuje stvaranje razumnih tampon-zona između šume i stambenih zgrada da se smanji mogućnost prijenosa šumskoga požara na zgrade uz istodobno pružanje odgovarajućega prostora koji bi vatrogascima trebao olakšati suzbijanje požara. Kontinuirani napor u osiguranju proaktivnih mjera za smanjenje gustoće zapaljivoga materijala u šumi drže se dobrom mjerom za ublažavanje jačine šumskih požara. Očekuje se da se time otvori više radnih mjesta za ljude u različitim zajednicama, a šumske požare učini lakšim za upravljanje. Takvi napor uključuju neprekinuto praćenje i uklanjanje mrtvih stabala sa šumskoga tla, uklanjanje mrtvih, ali stojećih stabala te smanjenje gustoće stabala u šumskim područjima koja su najbliža stambenim zajednicama. Osnivanje i podržavanje odjela za prevenciju požara (ne samo odjela za gašenje požara) koji nadzire i kontrolira zalihe goriva u različitim zajednicama u blizini područja između urbanih i divljih područja bio bi dobrodošao pothvat. Taj bi odjel (zajedno s vatrogascima) mogao upotrijebiti proaktivan pristup u planiranju kontroliranoga paljenja kako bi se smanjila mogućnost šumskoga požara u područjima u blizini stambenih zajednica. Korisnim se također smatra uključiti planiranje gubitka bioraznolikosti u planove gospodarenja šumama te se preporučuju pojačana istraživanja o tehnikama sprječavanja gubitka bioraznolikosti tijekom epizoda šumskih požara. Potencijalna područja za dodatna unapređenja i daljnja istraživanja u tome spomenuta su u radu. Sustav koji automatski aktivira raspršivače vode za vatrogasna skloništa ili požarne prolaze

i automatski prska vodu na određene dijelove šume (povremeno poput umjetne kiše) kad god atmosferska temperatura dosegne određenu razinu bio bi vrijedan pohvale. Primjenom sustava automatizacije dizajn može biti takav da u slučaju otkrivanja požara neprestano prska vodu kako bi se spriječilo širenje požara izvan zahvaćene zone.

Postotak šumskih požara koje su uzrokovali ljudi vrlo je značajan. S tim u vezi, a uz navedeno, preporučuje se podizanje razine javnoga obrazovanja, osviještenosti i provedbe propisa kako bi se smanjila mogućnost šumskih požara uzrokovanih ljudskim faktorom. Nadalje, sadržaj vlage u lišću spominje se kao glavni čimbenik u procesu paljenja krošnje te se preporučuje, radi otklanjanja mogućnosti paljenja krošnji, daljnje istraživanje o tome kako povećati sadržaj vlage u lišću drveća korištenjem pristupa unaprijeđene tehnologije raspršivanja vode (slično sustavima za navodnjavanje), posebno u područjima u blizini stambenih četvrti. Dodatna se istraživanja preporučuju pri projektiranju stambenih zgrada tako da mogu autonomno odgovoriti na prijetnje od prodora sezonskih šumskih požara. Također se upućuje na istraživanja o tome kako dizajnirati stambena susjedstva koja mogu zajamčiti bolju sigurnost ljudi u slučaju procjene većih intervencija kad god šumski požari zaprijetu stambenim zajednicama.

Ključne riječi: upravljanje šumskim požarima, tehnologija raspršivanja vode, inovativni sustav gašenja požara, gubitak bioraznolikosti, automatizacija

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