Impacts of Wildfires on Environmental and Human Health in British Columbia

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Executive Summary

Over the years, wildfires have been of higher intensity and of longer durations throughout the world, which is caused either by human activities or natural factors. In British Columbia, climate change is believed to be responsible for this increasing phenomenon. Forest fires can have impacts on the environment, including physical, chemical, and biological impacts, and some impacts have been shown to have long-term impacts. These environmental impacts pose threats to aquatic species and human health. In response to wildfires that are increasing due to climate change, wildfire prevention strategies, such as reducing the fuel volume, are recommended to apply in forest management practices. In addition, postfire measures aimed to mitigate the effects of wildfires, such as the upgrading of water supply treatment plants, is believed to be important, as it has been shown that wildfires cause the formation of toxic substances to both human and salmonid species.

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Introduction

Wildfires, also known as the uncontrolled fires that burn vegetation, have been a part of the Earth's terrestrial system since 4 to 350 million years ago (Scott, 2000). In recent years, wildfires have become an increasingly common phenomenon and the number of wildfire activities around the world has increased dramatically, with more burned areas and of longer duration, causing significant economic and ecological losses. In the western United States, the average number of large wildfires rose from 140 (1980 to 1989) to 250 (2000 to 2012), and before the 1970s, the annual wildfire season lasted about five months, and the current figure is seven months (Union of Concerned Scientists, 2013). In addition to the State of California, which suffered from the worst fire season ever in 2018, there are also five States breaking wildfire records in the USA (Ruiz, 2019). At the same time, in the warm southern countries of Europe, such as Portugal and Greece, they too were experiencing the most serious wildfire activity in history, causing more than 200 deaths in 2016 (The Economist, 2018).

The increasing frequency of wildfires is also a concern in Canada and British Columbia. For example, in 2017, there were 1.2 million hectares burned in B.C., ten times the ten-year average (DW, 2018). In 2018, the area burned broke the record at 13,000 km^2 and the government had to extend a state of provincial emergency to address this situation (Lindsay, 2018). According to the B.C. Wildfire Service, half of the "Top 10 fire seasons in B.C. since 1950" happened in the recent five years, which indicates the increasing trend in the number and severity of wildfires. Furthermore, many cities in BC faced air pollution problems and other issues such as the threat to the water source during the fire season, which is a major concern for the whole province.

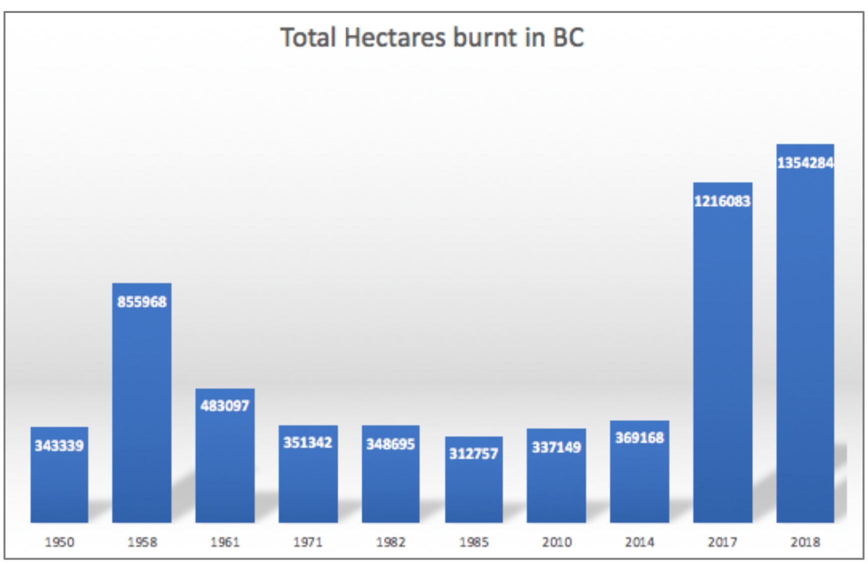

Figure 1. Top 10 fire seasons in B.C.

Source: BC Wildfire Service

Research evidence indicates that wildfires are more common because of climate change. According to Natural Resource Canada (2019), Canada is warming at a speed twice that of the global value. Due to global warming, the emission of greenhouse gases leads to an increase in average temperature, which causes more soil moisture to evaporate and leave the soil drier. Also, climate change can cause earlier snowmelt and thus the soil dries earlier and for a longer period. Drier soil and higher temperature make the forest more susceptible to server wildfires (Brändlin, 2017).

The impacts of wildfires, especially those affecting water resources, aquatic species, and air quality conditions are major concerns since these are closely related to human health concerns (New Mexico Environment Department, 2018).

Water supplies in many cities have faced challenges as a result of the impacts of wildfires on water quality. For example, in Canberra (Australia), after the fires in 2003, more than 2,800 tons of sediment and an array of metals, such as iron and manganese, were dumped into the Cotter watershed, which provides 95% of the water supply for Canberra, and required the government to build a new water treatment plant to address the problem (Struzik, 2018). Also, according to Monica Emelko (2014), an environmental engineer at the University of Waterloo, when dissolved organic carbon that is released by wildfires is mixed with the chlorine that is used to treat water, the reaction can produce carcinogens that most treatment plant technicians do not have the expertise to manage. In addition, the toxins from the burns are rich in the ash that may end in the water body, which contaminate the water resource (Leahy, 2016). All the pollutants in the water body affect water quality, especially drinking water quality, resulting in a serious human health crisis. The contamination sometimes is invisible, and the existing water treatment systems may not be aware or able to treat the water supply.

Air pollution after a wildfire is also a major threat to human health **(**CBC, 2018**)**. Not only does the wood-fire smoke contribute to poor air conditions, but also toxic smoke, which may contain heavy metals, such as copper, arsenic, lead, and other toxic substances may be released from the burning of plastic, cars and other man-made materials (Atkin, 2017). Smoke from the fires in the urban areas can put people at a greater risk of serious illness. Furthermore, according to DOE/Pacific Northwest National Laboratory (2009), toxins, such as alkaloids found in smoke from forest fires, can affect both human and ecosystem health.

The threat to the aquatic ecosystem for fish species is also bound to escalate. For example, the Vancouver Sun reported that, after a fire, a lake's nitrogen concentration doubled, the phosphorus concentration was four times than before, and the mercury content of the fish increased five-fold (Vancouver Sun, 2018). What is more significant is that after a long high-severity forest fire, the additional nutrients introduced into the water body can lead to eutrophication, which means a large increase of algae reproduction that consumes a large amount of dissolved oxygen (Rogers, 2017). Thus, the aquatic system will become unsuitable for the aquatic species, due to the low oxygen concentration and fish species especially can be significantly affected, negatively.

Objective

When the surrounding environment is affected by the large wildfires, the impacts on the air, water, fish species will all contribute to an influence on human health. For example, toxic water used for local agriculture can become contaminated for crops and the absorbed toxins may be harmful to human health, and polluted potable water may not be safe to drink. Not only the direct health effects on the fish species but also the increasing concentration by bioaccumulation has a potentially harmful effects on human's health through the food chain. Thus, it is important to understand the cumulative effects of wildfires and therefore important to assess and attempt to mitigate the impacts.

This report is based on the literature review on the impacts of wildfire on environmental and human health in British Columbia. During the process, I first review the history of wildfires in BC to show the number of wildfires, severity, burnt area, causes, and projected future trends. The review and synthesis lead to the following questions.

1) what are the specific impacts of wildfires on human health and environmental services such as fish habitats in BC?

2) what are the impacts of wildfire over different time frames?

Also, I will assess reasons for the increasing frequency of wildfires, whether it is caused by human activities or climate change. As a result, I will provide specific suggestions for different approaches to mitigate this increasing phenomenon.

Background

Wildfires have become great concerns in BC which have brought many recent problems, and the severity and the amount of burnt area are expected to increase. Since the wildfires in BC are caused either by human activities or lightening, it is important to detect whether the increasing amount of human activities or climate change is responsible for the increasing wildfire phenomena and then provide potential solutions aimed at the specific causes. According to the “Wildfires Season Averages in ten years” from BC Wildfire Service, the amount of person-caused fires has decreased (Figure 2), while the trend of lightning-caused wildfire has increased (Figure 3). Thus, more and more wildfires are caused by natural lightning, and the drier climate during the fire season.

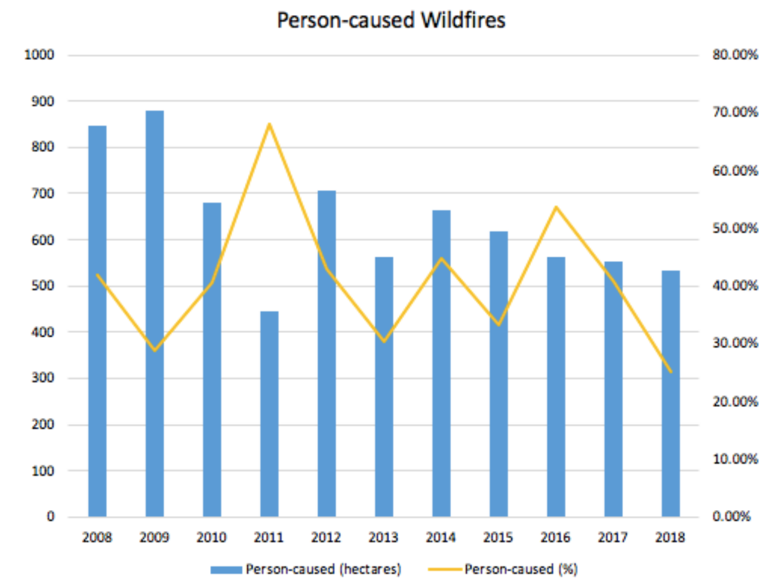

Figure 2. Person-caused wildfires in 2008-2018

Source: BC Wildfire Service

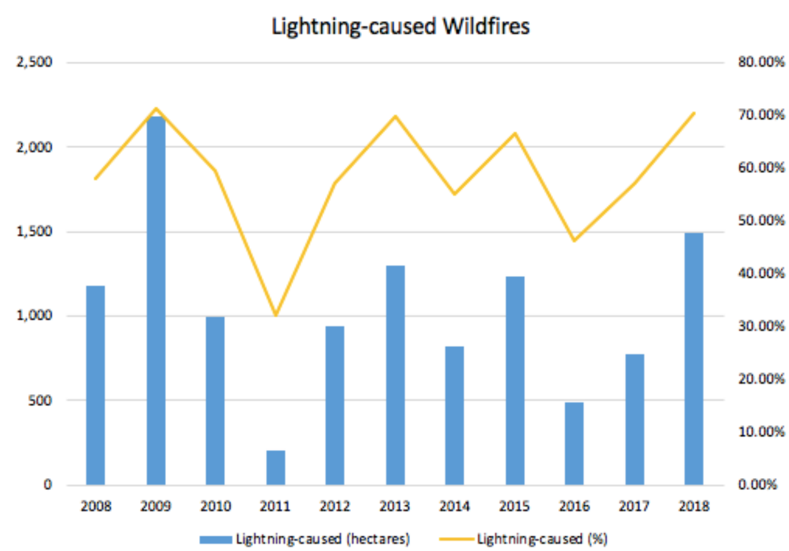

Figure 3. Lightning-caused wildfires in 2008-2018

Source: BC Wildfire Service

The Ministry of Environment British Columbia, reports that the average temperature per century has increased by 1.4 °C from 1900 to 2013, higher than the global average figure (Ministry of British Columbia, 2016). Although the highest increase in average temperature was in the winter (2.2 °C), the average temperature still significantly increased in spring and summer when fires were more prone to occur. The average spring temperature of the Northern Boreal Mountains increased by 1.8 °C, which is the highest in BC, while the coastal and southern interior mountains have the lowest average temperature increase of about 1 °C. On the other hand, in the northern area of BC, the summer temperature has increased by between 1.4 and 1.6 °C, while the temperature in the central and southern regions increased by 0.6 to 0.8 °C per century. In addition to the El Niño and other natural factors, the increasing greenhouse gas emissions caused by a large scale human activities is also contributing to the warming climate.

In addition, the average precipitation for the whole province has increased by 12% per century and the increase in the south is higher than in other regions. At the same time, the value of snow water equivalent (SWE) is decreasing across the province and the snowmelt is arriving earlier than before, the amount of snow melted in the spring and early summer is becoming less and thus a drier and longer dry season, which is more likely to catch fire with ignitions (Westerling et al., 2006). Thus, due to the climatic characteristics of British Columbia reporting that more precipitation occur in winter and less precipitation in summer, forest fires are more likely to occur when the average temperature in spring and summer increases year by year, resulting in more evaporation in the forest and lower soil moisture (BC Campus, 2019).

The mountain pine beetle epidemic since the 1990s in British Columbia has caused considerable death of trees, which is perfect fuel for the spreading of a wildfire (Natural Resource Canada, 2019). The intensity of a wildfire is determined by fuel type, fuel amount and climate, as a result, when there is a large volume of fuels available, the ignition rate of the wildfire is increased and the severity increases.

Under the scenario that the emission of greenhouse gases becomes half of the current figure by 2050, the average temperature in BC is projected to increase 2.5 °C and the precipitation is expected to increase by 10%, while the summer will become drier with more heatwaves (Metro Vancouver, 2017). Meanwhile, the area burnt in Canada is expected to increase by 74-118% in a century even if other factors which can affect the area burnt such as vegetation and ignitions remain constant (Flannigan et al., 2005). Based on these projections, we can assume that the frequency and severity of wildfires in BC are likely to increase; therefore, there is a need for strategies towards the coming challenges (Figure 4) to prevent more damage and cost.

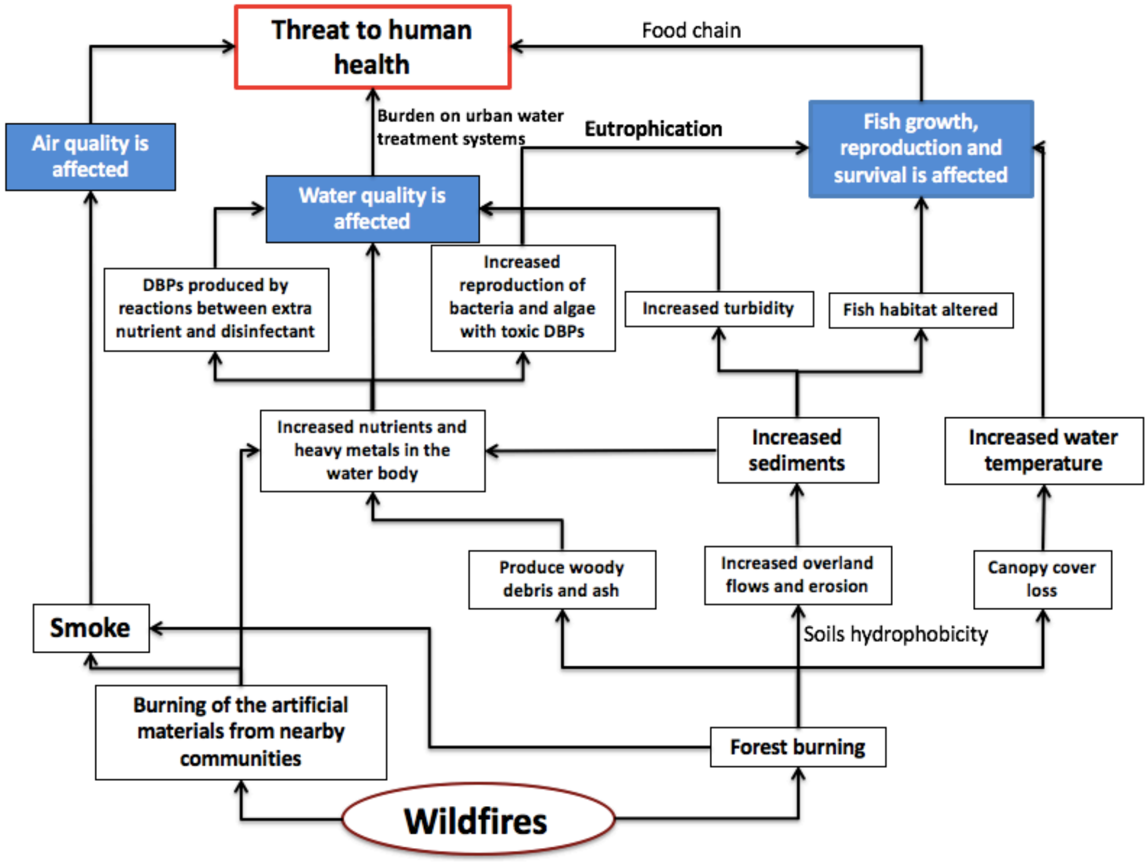

Figure 4. Impact hypothesis diagram

Impacts of wildfires on water quality

Physical impacts

The most significant physical impacts on water quality are the increase of sediments in the streams (Meixner, 2004). Although the effects of wildfires are very complex and debated, this report focuses the effects on high-intensity fires on the soil.

When the soil is under a fire for a long duration, the soil structure will be destroyed as the organic matter is burned (Ice, 2004). In addition, the soil normally becomes hydrophobic which means that the soil repels water and causes the infiltration and percolation rate to decrease. The hydrophobic layer on the top is caused by a waxy substance produced due to the burning of the plants with high heat, and the soil particle is covered by the waxy substance after cooling which lead to water repellency (USDA Natural

Resources Conservation Service, 2000). As a result, there will be more overland and stream flow and which result in more sediment into the receiving water bodies.

The increasing sediment can negatively affect the stabilization of the habitats of aquatic species, such as fish and insects, thus habitat protection is important (Meixner, 2004). Also, when a large amount of sediment is introduced into the water, this not only increases the turbidity of the stream but also blocks and disturbs the channels which may influence the effectiveness of drinking water supplies. When there is increased sediment accumulated into the water resource, the drinking water treatment facilities may not be fully able to remove the sediment and ensure drinking water security, which may pose a threat to public health.

Since the fire season often takes place in the summer, there is a higher chance to have heavy precipitation after the wildfire, which can cause a large load of sediments to get into the streams and increase the turbidity of the water. As the climate change trends in BC mentioned before, the precipitation of summer season is expected to increase and possibly with more frequency of heavy precipitation while the total amount of precipitation may decrease. Therefore, when the water content reaches the saturation point of the soil, there will be no more water stored, thus eventually the water content may not be higher than the before, the soil becomes drier because the decrease of total rainfall (Plant & Soil Science eLibrary, 2019). According to Peter Jordan (2012) experiments the watershed-scale sediment yield didn't increase due to the low precipitation intensities, but within the increasing possibility of heavy rainfall in summer, there is a greater risk to have more overland runoffs.

According to Hitt (2003), when a wildfire that lasts for a long period with high severity occurs in a forest area, the temperature of the streams in the burning zone rises, leading to a series of consequences. After testing the temperature of Deadhorse Creek in the 2002 wildfire in Montana, USA and compared to the temperature of the streams without the effect of burning, the researchers found that the highest temperature of the river (17.2 °C) on the day of the wildfire was 7.8 °C higher than the temperature in the non-combustion zone, while it was 4.4 °C higher than the highest stream temperature of the previous year. The increase in water temperature caused by wildfires is not the only cause of the high-intensity combustion in the area but also has a strong connection with the reduction of canopy cover caused by fire. Studies show that the decrease of shade in the riparian area will cause the water temperature to fluctuate (above 14 °C to below 21 °C) (Amaranthus, 1989). Thus, wildfires that burn and destroy a large number of trees in the forested area can lead to the increase of water temperature, which may have detrimental effects on aquatic organisms.

Chemical impacts

In addition to the physical impacts of wildfires on water quality, the chemical characteristics of the water resource are also changed after server wildfires. Studies show that after a wildfire, a large load of nutrients contained in ash and sediment my be introduced into the water body as a result of the combustion of forest floor and soil (Emelko, 2011).

Ash is a residue of particles that remains or deposits on the ground after a wildfire. Ash is highly mobile and can be transported to source water such as streams, lakes, and reservoirs by wind, overland runoff and water erosion in days or weeks (Bodi et al., 2014). The composition of the ash is mineral material and charred organic components. Based on different fuel load, fuel type, and combustion completeness, the proportion of the composition is different; when the fuel type and fuel load remain still, there will be more mineral materials contained than the charred organic components than if the combustion completeness is higher (Marche et al., 2014). Therefore, when wildfires are serve and last longer, the ash produced from the wildfires is expected to be rich in mineral materials (above 450 ° C), which may result in elevated pH in water bodies. The main components of mineral ash are inorganic carbonates of calcium, magnesium, sodium, potassium, silicon, and phosphorus, while at temperatures above 580 ° C, the most common chemical forms are oxides (Bodi et al., 2014).

Studies have shown that nutrient loading increases significantly after a fire, especially phosphorus and nitrogen (Meixner, 2004). Based on the different temperature of the forest fire, the two elements are converted to different forms. Nitrogen is easily volatilized at lower temperatures (200-500 ° C). Phosphorus will volatilize at higher temperatures (770 ° C), also at higher temperatures, nutrient such as calcium and magnesium will generally react with oxygen to form an oxides, as a major component of relatively soluble light-colored ash (Ice, 2004). Despite the volatilized nitrogen, the nitrogen which is likely to be move into water is exported as nitrate. Since most of the phosphorus is carried in sediments (a small portion of P is in the ash), thus resulting in increased erosion after a wildfire which can increase the amount of phosphorus exported into the aquatic system (Meixner, 2004).

According to a three-year study on wildfires in southeastern Australia in early 2003, the impacts of wildfire in the first year increased the total exports of P and N by about 5-6 times, reaching 1.6 kg/ha of phosphorus and 15.3 kg/ha of total nitrogen. In the second year after the fire, the concentration and load of P and N decreased rapidly, approaching the value prior to the burn. Also, due to the reduction in sediment transport, the amount of nutrient delivered as particulate matter was reduced (Lane et al., 2008).

Although the Australian case shows that nitrogen concentrations started to decline significantly in the second year after the fire, studies in different regions differ. For example, based on the four-year study of the large wildfires burning in Glacier National Park in the summer of 2003 (Mast et al., 2008), the stream nitrate concentration was ten times greater than the unburned drainage before the first snowmelt season. The annual export volume of total nitrogen in the burnt drainage was higher than the value of the unburned area. In this case, the nitrogen concentration continues to increase in the winter during this four-year estimation, while the concentration decreased to the unburnt level during the growing season. The study also found that the long-term impact of fire on other nutrients, including dissolved organic carbon, was very small; however, the concentration of sulfate and chloride has an increasing trend after two years of the wildfire.

Also, after a forest fire, the increase in storm runoff, due to soil hydrophobicity can cause high-concentration of particle-bound compounds carried by the sediment to enter the water body, including many trace metals such as lead and cadmium (Burke et al., 2013).

Dissolved organic carbon (DOC) concentration is also affected by the wildfires. According to the study at the Lost Creek Wildfire in Alberta in 2003, compared to an unburnt area with the DOC concentration at 5.1 NTU, 3.8 mg/L, the burnt area has higher concentration at 15.3 NTU, 4.6 mg/L (Emelko, 2011). The concentration of DOC is also contributed to the level of natural organic matter (NOM), and the elevated concentration can cause the introduction of taste and odor-causing chemicals into the water source as a result of increased activities of algae and bacteria. When residual organic matter reacts with a disinfectant, which is commonly used in the water supply treatment such as chlorine, thus may form carcinogenic disinfection by-products (DBPs) (Emelko, 2011).

As the wildfire season gets longer and the burning area expands, the work of putting out the fire is expected to use more and more consumption of wildland fire retardants. The general public's perception is that the use of a large number of chemical fire extinguishing agents will bring environmental pollution and increase the concentration of chemicals, further degrading water quality. However, according to research by Crouch et al. (2006), the results may not be as perceived by the public. They used the published data of flame-retardant components: ammonia, phosphorus, and cyanide to determine the concentrations in the streams near the four wildfire-burning regions. By comparing the chemical data of streams using wildland fire retardant and rivers without wildland fire retardant, the value of ammonia, phosphorus, and total cyanide between the two systems did not change significantly, and weak acid dissociable cyanide was basically not detected in either area Therefore, when considering the major impacts of wildfire on water quality, the impact of wildland fire retardant on water quality may not be a concern, as it was reported to be minimal compared to the other impacts that wildfires can bring.

Due to the increase in streams temperature mentioned before, there are some related chemical impacts. In terms of the Deadhorse Creek wildfire, it was shown that the interaction between rapid temperature rise and other effects of wildfires, such as nutrient-rich ash, may cause an increase in streams alkalinity and an increase in chemical toxicity affecting the stream biota. In addition, the data shows that the peak water temperature on the day of the wildfire on August 27 increased the percentage of ammonia in solution by 16-46% relative to the area not burned. Also, relatively high temperatures reduce the solubility of dissolved oxygen (from 1.13 mg / L to 9.6 mg / L in pure water). When the concentration of ammonium rises to a certain value, ammonium dissociation can lead to a sufficient concentration of ammonia to reach a concentration (0.2-1.1 mgk) which can cause the death of trout (Hitt, 2003).

While the burning of forested areas is likely to introduce heavy metals from minerals into the water, the spreading trend of wildfires near local communities in recent years has also brought new threats to the water resource. Heavy metals such as copper, arsenic, lead and other toxic substances may be released from the burning of plastic, cars and other man-made materials in the communities, and the ash produced by the burning of the community facilities can be transported to the nearby streams and worsen the water contamination.

Biological impacts

Eutrophication of water bodies as a result of an increase in nitrogen and phosphorous can cause a water pollution problem. The excess nutrients cause a proliferation of aquatic plants, notably algae. Under natural conditions, as the river entrains alluvial deposits and aquatic debris at the bottom of the lake, the lake will transition from a flat nutrient lake to a eutrophic lake, which will evolve into a swamp (National Ocean Service, 2019). This is an extremely natural slow process; however, due to external factors such as wildfires, a large number of nutrients entering the water body will accelerate the process. The increasing concentrations of phosphorus and nitrogen will enable aquatic organisms, especially algae to reproduce rapidly, causing changes to the ecological balance.

Last but not least, the metabolites of actinomycetes and blue-green algae are the volatile organic compounds geosmin (trans-1,10-dimethyl-trans-9-decal) and MIB (2-methylisoborneol), which lead to the taste and odor of surface water (Wnorowski, 1992).

Impacts of wildfires on air quality

During the wildfire season in summer, the sky is filled with smoke, the dust in the air is visible to the naked eye, and the sky is no longer as clear as usual. Smoke is a mixture of a gas and particulate matter produced when a substance burns. In addition to giving a burning sensation to the eyes, the tiny particles contained in smoke also enter the human respiratory tract and the lungs through breathing, causing damage to human health. When the particles enter the lungs, it makes breathing more difficult and may worsen other chronic diseases such as asthma or heart disease. In addition, wildfire smoke contains carbon monoxide, a colorless, odorless, toxic gas, whose concentration is extremely high in the heart of the combustion zone and the concentration will decrease with distance but still maintain harmful level (Natural History Museum of Utah, 2019). When carbon monoxide enters human blood, it causes symptoms including headache, dizziness, nausea and decreased mental function (Breath The Lung Association, 2019).

In addition, wildfire smoke contains other chemicals, many of which can irritate the eyes, nose, and throat (Natural History Museum of Utah, 2019). Based on a study of the effects of wildfire events in October 2003 on pollutant levels in the Los Angeles Basin, PM 10 concentrations varied the most, by three to four times, and CO and NO levels increased by about two-fold (Phuluria, 2005). A study of air quality in Mexican mountain fires from 1992-1999 showed that the concentration of Total Suspended Particles (tsp) in 1998 was two to three times higher than the pre-fire 1997 data (Bravo et al., 2002). Based on research by Sapkota et al. (2005), due to the wildfires in Quebec, Canada in 2002, the USA city Baltimore's air quality was affected. Baltimore's ambient fine PM increased by a factor of 30 due to this wildfire. Also, research has shown that wildfire smoke particles can also travel farther across Siberia to British Columbia (Cottle et al., 2014). From these examples, it can be seen that the impact of wildfire on air is not only local to the burning area, as smoke can also be carried to other remote areas by the wind.

Forest fires cause a large number of trees and forest floor or duff to burn, and the burning of these substances leads to the production of a large number of polycyclic aromatic hydrocarbons (PAHs), some of which are carcinogenic. The main components of polycyclic aromatic hydrocarbons from forest floor combustion are Phenanthrene, dodecahydrochrysene, alkylated cycolopenta (def)phenanthrene and alkylated phenanthrenes (Tan et al., 1992).

In addition to the burning of the duff and wood in the forest, the burning of houses, community facilities, and vehicles cause the fire to become more toxic. Because of the potential of burning heavy metal components and other construction materials. The burning of these man-made materials often has an unpleasant odor, which may be more harmful to air quality than just smoke from the burning of forests (Atkin, 2017). However, from current research and news reports, the impact of forest fires on air quality is short-term than the impacts on water quality.

Further impacts of wildfires on fish species

As the residence of streams, since wildfires have significant impacts on water quality (physical, chemical, biological), this effect also affects the survival of aquatic life. As an example, salmonids are a very valuable resource in BC, thus it is important to protect the salmonids from the perspective of tourism, fisheries and species conservation. Thus understanding the impact of forest fires on fish species, especially salmonids, is important. Salmonids are a key species in BC and have an irreplaceable position in the local ecosystem. If their survival is threatened, the ecosystems and other species that depend on them will also be seriously affected (BC Tomorrow, 2017).

Another study on the potential habitat loss of cold-water fish species in the North Platte River Drainage in Wyoming (Rahel et al., 1996) shows that even if the temperature rises slightly, the habitat of fish will be significantly reduced. For example, when the temperature rose by 1-5 °C, 9-76% of the current geographic range of habitat for cold-water fish was lost.

One of the most direct effects of wildfires is the destruction of vegetation cover on the vegetative slopes which help stabilize structures, as a result of the lack of moist soil and the loss of stability by the roots. The consequence of this situation is a large amount of sediment and wood debris on the slope may be moved and enter the stream channel, accompanied by ash rich in nutrients. As mentioned in the previous section, the increase in nutrients in streams is beneficial to aquatic lives to some extent because it enables more food for fish, but once the concentration is too high, it is likely to cause eutrophication. In the case of eutrophication, algae bacteria blooms lead to the decrease of the dissolved oxygen in the water, eventually resulting in the death of fish. At present, changes in nutrients is unknown as to have any effect on fish habitats, and the results of eutrophication due to wildfires are rare due to factors such as river dilution.

The biggest change to fish habitats is caused by a large load of sediment, water volume and debris in the channels, especially those brought by the storms, postfire. These “foreign visitors” are not all causing damage. Large woody debris often increases the diversity of habitats by providing coverage and creating breeding areas, but on the other hand, the movement and redistribution of bed materials may replace the alevins in the channel and destroy the eggs (Meehan, 1991). The gravels that often follow can also destroy and reconstruct negatively the spawning area. According to the 2000 landslide study in Oregon, it appears that changes in the geomorphology at the bottom of the channel are beneficial to the long-term effects of fish habitats (Miller and Benda, 2000). During rearing and high flow periods, the waves of sediment and wood debris can help create habitat pathways that bring benefits to fish. In general, wildfires can make a big difference to fish habitats.

The effects of wildfires on salmonid populations may be enormous. According to a three-year study of wildfires in three headwaters from the Tonto National Forest in Arizona, wildfires in 1990 caused the extinction of two salmon species in the river: brook trout Salvelinus fontinalis and rainbow trout, Oncorhynchus mykiss. At the same time, the densities of aquatic macroinvertebrate in the stream dropped to near zero in the first month after the fire. After one year, the species diversity of the two streams only recovered by 25-30%, and the amount of the salmon that returned to the two rivers fell by 75% compared to the value before the fire (Rinne, 1996). Although this study does not give specific information on the causes, it raises awareness and attention about the impact of wildfire on fish.

Studies of coastal streams in central California have shown that the average daily temperature in a pool that burned most severely after a fire was raised by 0.6 ° C, a temperature rise that takes 20 years by normal processes. The increase in temperature also leads to the increase bioenergy cost of cold-water salmonids, and the higher energy costs the burnt pool has, the more the total salmonids biomass in the pool is reduced (Beakes et al., 2014).

Further impacts of wildfires on human health

Since the wildfires affect the environment in many aspects (water, air, and aquatic lives), human health, which is closely related to the environment is also affected by wildfires.

The "news" media have reported that local residents have suffered from the related diseases due to the impacts of wildfires and the number of citizens who go to the health clinics has increased significantly when the smoke from wildfires that has spread to the cities. Some common symptoms of smoke exposure include irritating eyes, runny nose, headache, and common allergies worsen (Breath the Lung Association, 2019).

In addition, according to CBC News, residents in the vicinity of the wildfire area are more likely to get depressed by the smoke and ash that permeates the sky and staying indoors, instead of outside, poses a threat to citizens' mental health (CBC, 2018).

Health problems related to wildfires are mainly concentrated in the respiratory system, heart, and lungs. For example, the fine particles inhaled can result in more server diseases. When particles smaller than 2.5 microns in diameter enter the lungs, they are difficult to be removed. According to the lung association, smoke generated during the wildfire season is very harmful to the human body, especially those suffering from lung diseases such as asthma or chronic obstructive pulmonary disease (COPD). A COPD lung attack (COPD episode) may be as deadly as a heart attack. COPD lung attacks and asthma emergencies can lead to hospitalization or even death (Breath The Lung Association, 2019).

Compared to the direct effects of forest fires on air quality and human health, the potential threat from water quality problems raised by wildfires to human health is a challenge affecting drinking water security. When forested areas, which provide a large portion of surface water to the cities are significantly affected by forest fires, the impacts such as the introduction of sediments, extra nutrients make it more difficult for the water supply treatment plants to treat the water.

In the absence of a fire, the water source in the forest area far from the cities is normally not polluted and the water quality is good, but at the same time, the forest area is also more vulnerable to the effects of climate change, such as the increasing frequency of forest fires. The impacts of wildfires, mentioned in the previous section, on water quality are all problems that need to be addressed in urban water supply treatment. The increase in surface runoff leads to an increasing load of debris and sediments, which can lead to a burden of solids removal during the water treatment process, and excessive solids that need to be treated put stress on the water treatment plants. In addition, a massive amount of algae can damage the process of coagulation and flocculation, which are common processes for treating drinking water (Bernhardt, 1984). In addition, the "overload" will not only increase operating costs but also increase the risk of insufficient effectiveness of water treatment (Emelko, 2011). For example, in Australia, the city of Canberra had to add more equipment to deal with the problem due to sediments, eight times more than usual. (Struzik, 2018).

The consumption of chemicals will increase as more nutrients, heavy metals, algae, and bacteria are processed. In addition to the more consumption of chemical products, technicians are more worried about the occurrence of new substances. According to Emelko (2011), due to wildfires, there are large swings in water quality which challenges the water treatment process. As mentioned in the previous section, many new pollutants are produced, and it is possible that they react with the substances used to treat water. The reaction of chemicals may produce new carcinogenic disinfection by-products (DBPs) that many technicians have no experience in handling. Moreover, DBPs such as volatile organic compounds geosmin (trans-1,10-dimethyl-trans-9-decalol) and MIB (2-methylisoborneol), which lead to the taste and odor of surface water, are the metabolism product of actinomycetes and blue-green algae. The concentration of these substances, which are significantly increased due to the increase in water temperature and nutrients, requires professionals to come up with viable solutions. At the same time, because the existing evaluation guidelines for drinking water quality do not include many of these new substances brought about by wildfires, and no new facilities are being modified to deal with the new threats, the drinking water which public believe to be safe is not as secure.

Changes in water quality that cause changes in fish can also pose a threat to human health. Changes in the concentration of nutrients in the water and the increase in substances such as heavy metals may cause these substances to accumulate in the body of the fish. Although a small enrichment may not cause much health problems for the fish, but these toxins may be passed through the food chain to the human body. Accumulation can lead to health problems. Similarly, when crops such as vegetables and grains are irrigated in the fields by wildfire-affected water, the crops may absorb those toxins and eventually be absorbed by humans.

According to Yeo (2018), although the public has a skeptical distrust of the food near the burning area, in fact, the quality of the food has not changed significantly and does not affect human health. Therefore, there is uncertainty about the safety of the vegetable crops.

Conclusion

Recommended solutions

In the context of the increasing frequency of wildfires and the greater damage caused, the solution to the impacts of wildfires on the environment and human health may be divided into wildfire prevention measures and post-fire management measures.

Wildfire prevention strategies

As the main cause of the wildfire in BC is climate change instead of human activities, to prevent more wildfires in the summer which is predicted to be hotter and drier, the most favorable measure to reduce the possibility of wildfires is to reduce the fuel volume in the forest.

As the data shows that the number of forest fire incidents caused by human factors has decreased year by year, thus suggests that the education and publicity work on forest fire prevention and related regulations need to be expanded. Since the average temperature of the Province is expected to rise and the summers to be drier, this condition provides lightning more effectiveness to ignite forests. Reductions in the amount of fuel in the forest is recommended.

As BC has abundant forestry resources, and trees are natural fuels, it is very important to consider for the “thinning” of trees. Based on experiments conducted on the historic 2002 Rodeo-Chediski fire in Apache-Sitgreaves National Forest in the southwestern United States (Storm and Fulé, 2007), thinning is closely related to the reduction of burning severity. After the fire, more trees survived and the flame intensity was lower than that of the untreated area. It seems that the thinning can effectively reduce the fuel in the forest and inhibit the wildfire from becoming severe. According to the Washington Forest Protection Association (2019), selective logging, thinning, brush removal and pruning are practices used by foresters to cut down crowded trees, branches and bushes of the forest. In areas where fuel is excessively accumulated, reducing the combination of small trees and cleaning brushes and controlling combustion may be the most effective way to reduce the risk of catastrophic wildfires and remove so-called ladder fuels, including tall grasses, shrubs and branches can reduce wildfires from spreading upwards, from low plants to higher trees (Storm and Fulé, 2007).

Secondly, prescribed burning is a very effective way to reduce the incidence of fire. Prescribed burning refers to burning in the area under human control, to clean up surface fuels such as excess leaves, dead trees, and debris. Although this will still bring environmental damage to a certain extent, from a longer-term perspective, this can effectively reduce the amount of fuel in the forest and the probability of uncontrollable wildfires will also decrease. If wildfires do occur, the severity of wildfires will also decrease due to fuel reduction, and it is more difficult for the flames to expand and the smoke emissions from fuel combustion will be reduced. Overall, the environmental cost will be smaller.

Thirdly, through the cooperation of local governments with local residents such as First Nation and other stakeholders including water suppliers, in cooperation can assess the high-risk areas of wildfire behavior, it is possible to construct a landscape-level fuel interruption site to interrupt wildfires progress (Gilmour, 2019). Last but not least, the treatment for the mountain pine beetle in the BC forests should continue through more research. This epidemic not only leads to the loss of forest resources, but it also causes more and more trees to die and become better fuel.

Postfire management

Postfire management may be divided into two parts: update of water supply treatment systems and prevention of surface runoff and erosion. First, various types of protective structures can be used to reduce the effects of landslides caused by vegetation reduction in areas such as slopes, thus can reduce the amount of soil and ash that enters the water body through a landslide. Secondly, through straw mulching and other treatments, the possibility of surface runoff and erosion in severely burned areas may be reduced, and there will be a decrease in sediments, debris and ash getting into the water bodies, leading to the decrease of the concentration of nutrients and heavy metals. Applying the above strategies can fundamentally mitigate the impact on water quality, thereby reducing damage to aquatic organisms.

The update of the water supply treatment system to protect the public's drinking water safety needs to be addressed. Although the above measures will reduce the harm, the impact of wildfire on water quality problems will still exist. First, potential new contaminants should be treated as new targets, while technicians make efforts on researching how to address DBPs produced by the reaction between chemicals, such as disinfectants and new contaminants. To allow the public to drink safer drinking water, new chemicals as testing indicators should be added in the drinking water safety guidelines.

Due to the more frequent and destructive wildfires, existing drinking water treatment systems in British Columbia may not be able to guarantee effective in the future under aging conditions, resulting in the inability to ensure the safety of drinking water

(Kendall,2015). Therefore, the existing systems need to be updated with emergency response in case of unexpected situations.

Long-term and short-term impacts of wildfires

From the literature reviewed, some studies on the effects of wildfires in different regions have different results, such as the difference in the concentration of some substances in water. These differences are caused by the combination of local climate, hydrological conditions, and other factors. But in general, there are generalizations of the impacts of wildfire on the environment and the impacts on human health, some effects dissipate over time, such as nitrogen in the aquatic system.

For sediment, ash, debris, and other substances, their impact on water quality is relatively short-lived. With the restoration of local soil and vegetation cover, surface runoff and erosion will be reduced, and the amount of material entering the water will also be reduced. Similarly, the increase in water temperature caused by canopy loss will be improved by the recovery of the canopy cover. Although the impact of air quality has a broad geographic concern, the air quality problem caused by smoke is short-termed due to precipitation and wind, and will not have long-time effects on human health. However, the habitat changes of fish species due to debris and sediments is long-term, but the habitat can recover as less sediments and debris enter the water system. As a consequence, there will be a new biological cycle in the aquatic environment.

On the other hand, the chemical effects on water resources are of more concern, which last for a few years. For instance, the concentrations of nutrients (such as nitrogen and phosphorus) are detected at elevated levels than the concentrations before the fire for at least 5 years (Lane et al., 2014).

Recommendations

From this report, the following recommendations are made:

1. Efforts should be made to reduce the volume of fuel in the forest, particularly in reference to pine beetle-killed forest. Forest management practices that remove dying trees, such as thinning and using prescribed burn, reduce the fuel volume.

2. Consideration should be given to the construction of barriers on slopes to reduce volume of sediment load.

3. More research is required for water treatment personnel to address concerns regarding new chemicals caused by wildfires.

4. Although in British Columbia, the amount of man-caused wildfires has decreased, public education and fire-prevention regulation must be encouraged and continued.

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