The Potential Effects of the Mountain Pine Beetle on the Five Species of Pacific Salmon in the Fraser River Basin

FRST497 Grad Essay – April 2011

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ABSTRACT

The effects of the Mountain Pine Beetle epidemic in British Columbia have the potential to affect the five species of Pacific salmon that spawn in the Fraser River basin. The lifecycles of all five species were studied to try and create a comparison among the species. Facts about the beetle, the Fraser River and Pacific salmon were collected from multiple sources to showcase what they have in common. It was found that the Mountain Pine Beetle has the potential to impact Pacific salmon directly and indirectly, in both positive and negative ways. Fewer coarse woody debris inputs into small streams, increases in small tributary temperatures, peak flow levels and timing, and increased nutrient levels can be seen to affect both adult and juvenile salmon at different points in their life cycles. Future research needs to be collected, and awareness of the potential effects needs to be shared.

KEY WORDS

Coho; Sockeye; Chum; Pink; Chinook; British Columbia; Temperature; Peak Flow; Epidemic; Water; Coarse Woody Debris (CWD);

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Introduction

British Columbia's (BC) diverse ecosystems and wide-ranged habitats support a large variety of living organisms that survive off of its natural resources. With fourteen biogeoclimatic zones and eight major river basins, the province of BC is well divided. Historical events have been recorded over time to reveal natural disturbance patterns on both endemic and epidemic scales. In recent years, BC has been heavily impacted by a large-scale epidemic that has created many economic, social and environmental effects.

This literary review will introduce and discuss three main topics: the Mountain Pine Beetle epidemic, the Fraser River basin, and Pacific salmon. It will then further its discussion to compare each of the five species of Pacific salmon in the Fraser River basin, with regards to their impacts and affects from the Mountain Pine Beetle epidemic.

Mountain Pine Beetle Epidemic

The Mountain Pine Beetle (MPB), *Dendroctonus ponderosae* Hopk., is an aggressive species of bark beetle native to North America. Historically in BC, the MPB was first discovered and documented to be killing trees in 1910. Since 1910, MPB attacks have been discovered throughout the province on an annual basis. Prior to the current MPB epidemic, which peaked in 2005, the largest outbreak recorded in BC's history occurred in 1984 and destroyed over 483000 hectares (ha) of pine forests (Wood et al., 1996). Although lodgepole pine, *Pinus contorta,* is the main host species attacked by the MPB, cases of infestations throughout BC have also been found in Western white pine, *Pinus monticola,* ponderosa pine, *Pinus ponderosa,* and white bark pine, *Pinus albicaulis* (Wood et al., 1996; Taylor et al., 2003).

With a life span of approximately one year, the MPB often emerges from an infested tree over the summer season and into the fall season (Ministry of Forests, Mines and Lands, 2010b). Prior to emerging from its host in its adult form, the MPB goes through three stages of development: egg, larvae and pupa (Amman et al., 1990). Female beetles create galleries mainly in the phloem of the infested host tree, in which the eggs are laid and left to develop over time. Ultimately, it is the excess stress and energy that the host species exerts in order to defend itself, as well as structural damage to the phloem, that kills the trees.

Since the current infestation that began in 2003, it has been estimated that 675 million cubic metres of timber have been killed throughout BC (Ministry of Forests, Mines and Lands, 2010b). Cumulatively, the estimation of affected cubic meters works out to be 16.3 million ha. This is the equivalent of five times the size of Vancouver Island (Ministry of Forests, Mines and Lands, 2010b). The range of the infestation throughout BC reaches as far as Fort St. John to the north, the Alberta border to the east, Terrace to the west, and the United States border to the south.

However, due to the diverse terrain and large diversity of tree species throughout the interior, the rate of spread has slowed throughout BC (Ministry of Forests, Mines and Lands, 2010). Recent attacks have been found to be more severe than those in the past due to a number of factors. Some of these factors include an abundance of mature lodgepole pine due to increased fire management prevention strategies, combined with recently mild winter temperatures (in which the MPB would have historically been killed off), and uncharacteristically hot, dry summers (Naturally:wood, 2010). Figure 1 shows the extent of the MPB epidemic range throughout BC, as well as the location of the Fraser River Basin, which will be discussed later in this review.

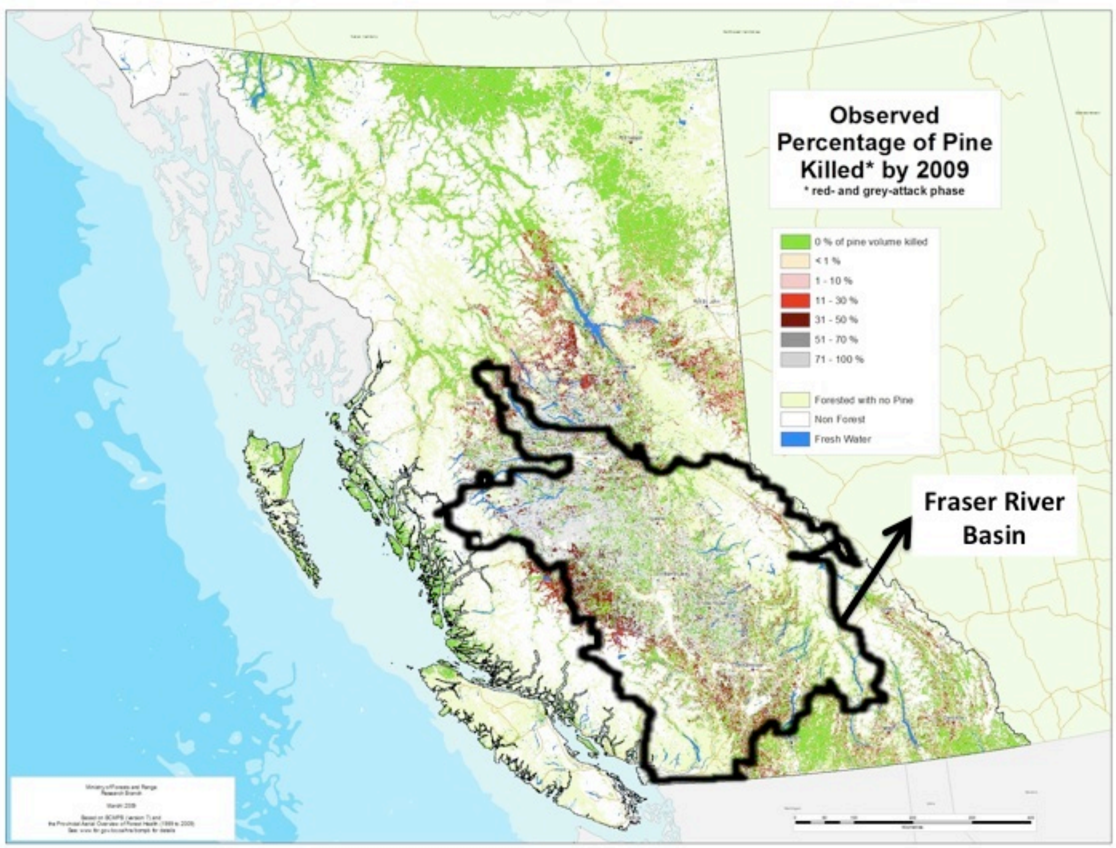

Figure 1: The areas hardest hit by the Mountain Pine Beetle within the Fraser River Basin (black line), and the percentage of attacked or killed pine throughout British Columbia (adapted from the Ministry of Forests, 2010: http://www.for.gov.bc.ca/hre/bcmpb/BCMPB.v7.2009Kill.pdf).

With extensive damage to pine forests throughout many areas of BC, immediate and long- term plans have been created and implemented to protect BC's natural resources. Specifically in regards to BC's river systems, the province plans to execute the following three actions to address and minimize factors of risk related to the MPB (Province of British Columbia, 2006-2011):

1. Identify and monitor critical water supplies for fish habitat, and to address risks;

2. Encourage immediate and long term economic sustainability for the communities through protecting fish and wildlife habitat for recreation opportunities;
3. Identify and monitor areas of unstable terrain caused by the infestation to protect infrastructure, water quality and fish habitat.

Many potential effects on hydrological processes can occur due to the MPB and the associated management options. In the third stage of attack known as grey attack, the trees needles fall off and the tree branches are left bare (Franklin et al., 2003). The susceptibility of falling down or being blown down increases significantly in this stage (Chan-McLeod, 2006). When the forest canopy is reduced or removed, hydrological processes are interrupted and can often lead to varying effects (Redding et al., 2008). Furthermore, an increase in available nutrients, specifically Nitrogen (N), Phosphorous (P), and dissolved organic Carbon (C) in freshwater streams may be observed due to an increase of dead pine trees caused by the MPB epidemic (Clow et al., in press).

In an attempt to try to economically recover from the recent attacks, large scale salvage harvesting has occurred throughout many areas of the province. Salvage harvesting involves the removal of timber after an event with the intention of supplying a different class product. It has the potential to impact the amount, timing, and quality of water originating from upland watersheds (Redding et al., 2008; Natural Resources Canada, 2010). Salvage harvesting also has the potential to disrupt coarse woody debris (CWD) inputs into river systems and streams from their natural levels. CWD is important to aquatic ecosystems as it provides shade and cover from temperature extremes and predators, and provides slope stability, which stabilizes soil surfaces (decreasing erosion into streams) (Stevens, 1997). Fewer inputs of CWD can lead to many long-term problems in aquatic environments. Salvage harvesting in riparian areas may have long-term effects, as seen in several studies done in watersheds around the province. In one particular study, the effects of decreased CWD levels are still seen from harvesting done in the 1970's (Redding et al., 2008). As discussed by Redding et al. (2008), maintaining a natural amount of CWD in riparian areas is vital to fish habitats and populations. Furthermore, if strands killed by MPB were left to regenerate naturally instead of being salvage logged, hydrologic changes would occur more gradually which would allow fish and other aquatic species a greater chance to adapt.

Although there is limited research on the effects of rainfall interception following a MPB attack, studies have been done that assess snow levels and snowmelt (Redding et al., 2008). These two important factors are commonly used to identify peak-flow timing and levels in streams and could change with a reduced forest cover due to a high percentage of dead pine in attacked stands. Snow levels and snowmelt depend on the amount of forest cover and the amount of removed or blown down trees. Due to ablation rates and solar radiation, snow can persist in canopy-covered forests for up to eight days longer then in it would be able to in an open stand (Redding et al., 2008). Forest canopies play an important role in the uptake and interception of precipitation, and are important for evapotranspiration. Evapotranspiration represents an exchange of latent heat and water mass between the forest floor and the atmosphere, and is part of the long-term global water balance equation (Loaiciga et al., 1996). More importantly, evapotranspiration helps balance out the magnitude of precipitation and runoff, and can affect the rate at which snow levels may dissipate from the forest floor. Forest canopies also help to decrease water levels of flow over land and help to decrease infiltration rates into the groundwater system. An example of the importance and influence of a forest canopy can be seen below in Figure 2.

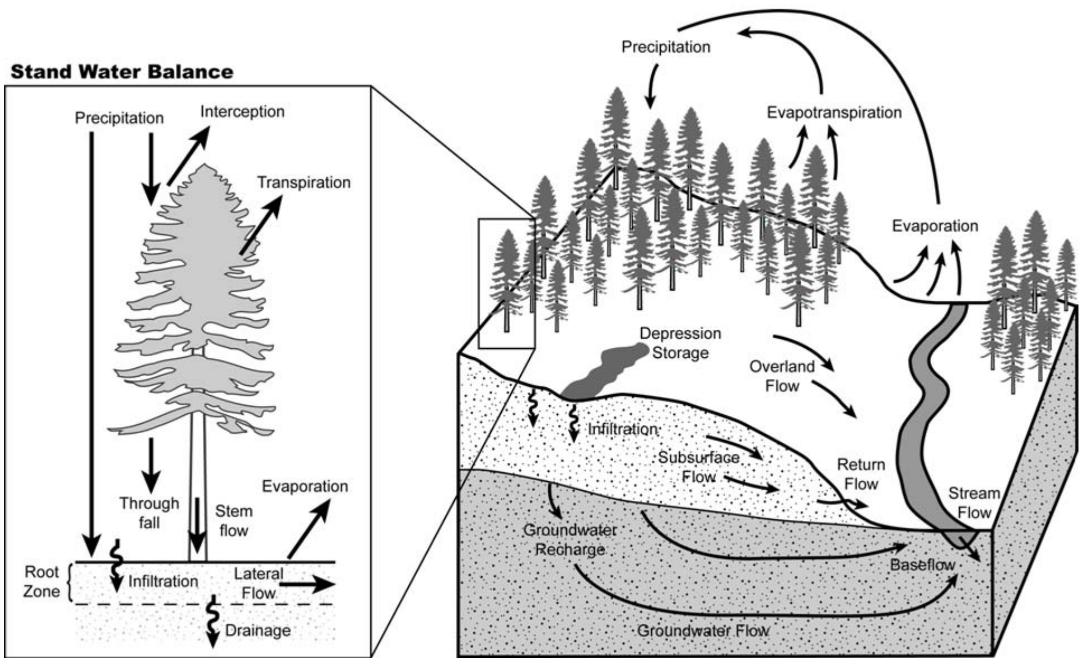

Figure 2: Shows a hillslope hydrologic cycle. The importance and influence of a forest canopy can be seen when considering the interception of precipitation (adapted from Redding et al., 2008).

Salvage logging activities increased significantly around the province when the outbreak first occurred in early 2003 due to uplifts in AAC to help manage for the beetle killed stands. Although an increase in AAC was observed throughout the province, forest legislation requires that the protection of reserves around riparian areas be maintained to at least seven percent retention (Peter & Bogdanski, 2010). However, in recent years due to a decline in forest product markets, large-scale harvesting activities have subsequently declined, and placed pressure on smaller communities that rely on forest activities (Peter et al., 2010). Declines in harvesting activities may lead to further problems for the province of BC, as stands killed by the MPB carry a short shelf life (amount of time before the dead pine becomes unusable and falls down) (Peter et al., 2010). This variable shelf life may lead to a large increase in CWD along the forest floor, which in turn may increase the risk of fire throughout many stands. Large-scale fires throughout stands may reduce the amount of CWD along riparian areas and management zones, which would further decrease inputs into streams. The combination of salvage logging activities and decreased CWD inputs could lead to varying impacts to freshwater streams.

Fraser River Basin

Comprised of 21 million square kilometers (km^2) of forest and 13 watersheds, as seen by Figure 3, the Fraser River basin makes up approximately one quarter of BC (Fraser Basin Council, 2004). Historically, the river basin has played a huge role for the residents of BC because it has, providing food, power, transportation and many other natural resources. As it flows down the center of the basin, the Fraser River stretches 1399 km from the Rocky Mountains to Richmond (Fraser Basin Council, 2004). The Fraser River has the fifth largest drainage area in Canada and is joined by numerous rivers including the Nechako, Stuart, Quesnel, Blackwater, Chilcotin and Bridge-Seton River (Fraser Basin Council, 2004).

The hydrologic system of the Fraser River has the potential to provide huge economic benefits. However, recent changes to this river system could have negative implications to all living organisms that rely on it, including salmon species. Peak flows for the Fraser are dominated by snowmelt, and are expected to increase significantly in discharge by the mid 2050's compared to the current standards (Schnorbus, 2010). This could be partially caused by the effects of the MPB, as some of the most affected areas of the province exist within the Fraser River Basin's boundaries (Figure 1). This may result in higher runoff levels in the winter and early spring and a shift in flow timing (less runoff in the summer and fall) (Schnorbus, 2010).

Figure 3: The Fraser River Basin Watersheds (Fraser Basin Council, 2004).

The Fraser River is one of the world's most productive salmon river systems. In addition to the five species of Pacific salmon that rely on it, the river also supports 65 different species of fish, hundreds of birds, mammals, plants, and trees (Fraser Basin Council, 2004). River temperatures play an important role in the success and reproductive fitness of many Pacific salmon species (Ferrari et al., 2007). It has been predicted that within the next 50-100 years, temperatures in the mainstem of the Fraser River and oceans will raise by 2-4^{0}C (Rand et al., 2006). This may cause problems for aquatic species in the future.

Pacific Salmon

Pacific salmon, family Salmonidae, have been a major part of BC's history, economy and culture for thousands of years (Fisheries and Oceans Canada, 2008b). Fisheries and Oceans Canada is currently responsible for managing the five species of Pacific salmon in the province to ensure their survival for future generations. As part of the genus Oncorhynchus, Pacific salmon can be considered to be the dominant members of the fish community and include pink, chum, Chinook, coho, and sockeye salmon (Fisheries and Oceans Canada, 2003c; Rand, et al., 2006).

With very complex life cycles, Pacific salmon are anadromous, meaning they can travel between freshwater and marine environments. The lifecycle for all salmonids follow the same six steps, however the timing in which these processes occur varies among species. These processes and timing differences will be further discussed in depth for each salmonid species later in this review.

The females of all Pacific salmon species dig redds, a form of nest, out of gravel beds and lays their eggs. Sizes of redds can vary depending on the species and size of the parent (Fisheries and Oceans Canada, 2003c). The embryo development into alevin, and the timing of fry emergence often depend on water temperatures and external factors. For every thousand eggs laid, only a few adult salmon survive to perpetuate their species and begin the life cycle over again (Fisheries and Oceans Canada, 2008). There are advantages and disadvantages to every species of Pacific salmon with their lifecycles in relation to the effects of the Mountain Pine Beetle (Fisheries and Oceans Canada, 2003c).

In 2009, it was predicted that over 60 percent of the Fraser Basin watershed had been affected by the recent MPB attack and that 67 percent of mature pine throughout the province of BC was thought to be infested (Pacific Fisheries Resource Conservation Council, 2009; Ministry of Forests, 2003). Land, waterways, streams and lakes across multiple jurisdictions, agencies, industries, and sectors have been affected by the MPB (Pacific Fisheries Resource Conservation Council, 2009). This makes management strategies increasingly complex.

Forests attacked by MPB have had effects such as more extreme water cycles, flash flooding, higher water tables, erosion, and longer summer droughts (Pacific Fisheries Resource Conservation Council, 2009). Attacked forests are no longer able to intercept snow and rain, provide shade for the forest floor, slow spring melting, or absorb large quantities of water. These characteristics among others of a MPB attacked forest can be detrimental to salmon. As well, salvage of trees killed by MPB will only intensify the risks already posed to Pacific salmon by climate change. Dead affected trees that are still standing may be better than no trees at all, as the removal of riparian vegetation may lead to a decrease of CWD (Bunnell et al., 2004; Pacific Fisheries Resource Conservation Council, 2009). Inputs of CWD create large, deep pools of slow-moving water and riffle pools, which are often a habitat requirement of many salmonid species. Furthermore, CWD is important for spawning habitat as it traps gravel, breaks up steep areas, and gives streams a lower gradient (Bunnell et al., 2004).

BC's salmon are known to be remarkably resilient and some species may even thrive in areas of higher and earlier peak flows, warmer water temperatures, and fewer amounts of CWD that may be caused directly or indirectly by the MPB (Pacific Fisheries Resource Conservation Council, 2009). However, as these environmental changes are occurring on a relatively short-term timeline, Pacific salmon may not have the time to fully adapt. This may lead to different stages of a salmonid's lifecycle being negatively affected. Increases in water temperature and annual flow have been detected throughout the middle of the last century (Ferrari et al., 2007). As Pacific salmon are relatively restricted to their optimal river temperatures, even a slight increase from the normal temperature can be problematic. Adult salmonids cease feeding when they begin their migration from salt water to fresh water; they rely on their stored up energy to return to their spawning grounds (Rand et al., 2006). With warming temperatures, metabolic rates are increased, which in turn uses up the salmonid's energy supply faster than in normal temperature conditions (Ferrari et al., 2007). Strong relationships have been found between water temperatures of the Fraser River and the mortality rates of Pacific salmon (Ferrari et al., 2007). Back in 2004, Fraser River salmon suffered an increase in mortality rates due to a rise in temperature, which can be observed in Figure 4 (Brander, 2007). Between the year of 2000 and 2100, river temperatures during the summer months in the mainstream of the Fraser are projected to increase by $0.13^{0}C$ per decade (Ferrari et al., 2007).

The late summer months, specifically July and August, are likely to have the greatest effect on Pacific salmon within the mainstream of the Fraser River (Ferrari et al., 2007). Increasing temperatures may influence the Fraser Rivers hydrological factors, including the timing and magnitude of snowmelt runoff (Ferrari et al., 2007). High stream flows, due to a decrease in evapotranspiration and faster snow melt as discussed previously can cause fish to move into side-channels, which provide shelter from fast-moving water, higher water temperatures, and invertebrates (Bunnell et al., 2004). However, fish can become accustomed to these more favorable conditions and may not reach their desired destinations. As well, egg survival can be decreased due to higher temperatures and increases of sedimentation from stream bank erosion (Bunnell et al. 2004).

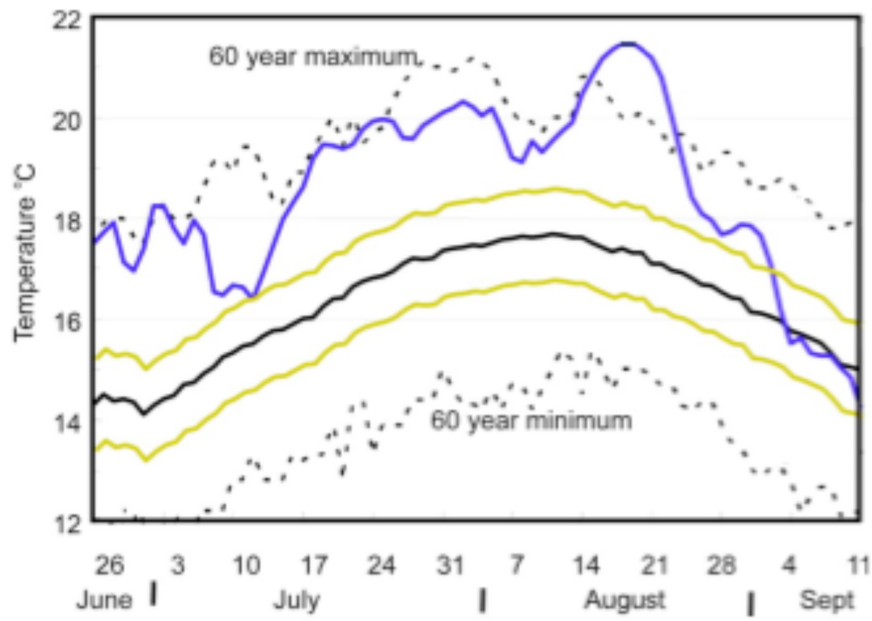

Figure 4: Fraser River water temperatures, summer 2004, reached the highest ever-recorded temperatures over several days (blue line), causing a spike in salmonid mortality rates. The black solid line shows a 60-year mean, plus or minus 1 standard deviation (yellow lines) (adapted from Brander, 2007).

Although there are many direct, and indirect impacts from the MPB epidemic, slower increases in temperature and external environmental factors may provide salmon with the chance to adapt and better survive (Ferrari et al., 2007).

Species 1: Chinook, *Oncorhynchus tshawytscha*

Oncorhynchus tshawytscha, commonly known as Chinook, is the largest of the five Pacific salmon species in BC and relies on larger rivers, specifically the Fraser (Ferrari et al., 2007). Like all Pacific salmon, Chinooks are semelparous, meaning they die after spawning (Fisheries and Oceans Canada, 2010e). Unlike some species of Pacific salmon, Chinook return to spawn at various ages, ranging from two to eight years (Fisheries and Oceans Canada, 2010e). This gives them an advantage at every stage of their life cycle, as they can be flexible in their decision to progress to the next level. It has been shown that this flexibility can reduce the risk of mortality of Chinook across different runs and habitats when threatened by external factors (Healey, 1991).

One population of Chinook salmon spawns in the upper reaches of the Fraser mainstem, where as a majority of the other populations spawn in almost every large tributary along the Fraser (Bradford & Taylor, 1997). Areas with coarse gravel and few large cobbles tend to be the preferred spawning grounds of Chinook salmon (Healey, 1991). It has also been found that areas of stable flows, such as small tributaries, are the preferred spawning areas of this species (Fisheries and Oceans Canada, 2003c). After hatching from the redd, fry migrate down the river edges and surfaces of areas with deep water (Healey, 1991). It has been suggested through research that shortly after emerging from the redd, fry have a flow-sensitive period in which they risk being swept downstream by strong currents (Bradford et al., 1997). Inputs of CWD would normally help to protect fry from these strong currents, however due to the MPB epidemic input levels are decreased in many areas. While in their freshwater habitats, Chinook salmon feed on larval and adult insects as a food source (Healey, 1991). Rearing time in freshwater can vary in length from one month to one year (Fisheries and Oceans Canada, 2003c; Bradford et al., 1997). After spending several years in a marine environment, they return to their original spawning grounds. This return happens earlier in the year then any other of the four species of Pacific salmon, with April stocks migrating further upstream than later summer stocks (Fisheries and Oceans Canada, 2010e).

External factors such as increased water temperatures and poor water quality can lead to lifecycle problems for Chinook salmon. Increased water temperatures can lead to an increase in disease due to weakened immune systems. Ovarian disease in fish hatchery stocks can be a concern in Chinook salmon and is responsible for up to 20% of the returning salmon in spawning populations (Healey, 1991). As well, poor gravel percolation or poor water quality can lead to an increase in egg mortality (Healey, 1991).

Chinooks are most closely related to coho salmon, and together they form a subgroup. The remaining other three species, chum, pink and sockeye form a second subgroup (Healy, 1991).

Species 2: Chum, *Oncorhynchus keta*

Chum salmon, *Oncorhynchus keta,* have the widest natural geographic distribution of all the Pacific salmon species (Salo, 1991). Throughout BC, they are known to spawn in over 800 streams and tributaries (Salo, 1991). Chum salmon are considered to be the second biggest Pacific salmon species, next to Chinook. Chum salmon are not as highly specialized as either pink or sockeye salmon, which makes them more versatile to adapt between freshwater and saltwater environments (Salo, 1991).

Like pink salmon, chums have short freshwater lifecycles and extensive marine advancements (Salo, 1991). With the exception of the occasional late summer run, chum are known to spawn throughout the winter months in the Fraser River from early October to January. This makes them the latest of the five species to spawn each year (Fisheries and Oceans Canada, 2010f). Areas of high turbulence, strong currents and accessibility to marine environments are often preferred spawning sites for chum salmon (Fisheries and Oceans Canada, 2010f).

Incubation and emergence of fry depend on several stream factors including flow, water temperature, dissolved oxygen levels, gravel composition, spawning time, and genetic characteristics (Salo, 1991). Changes to these stream conditions may lead to varying effects on chum salmon. Shortly after emerging as fry, chum salmon leave their estuary environments within days of hatching to access tidal waters (Fisheries and Oceans Canada, 2010f). In large river systems such as the Fraser, chum salmon may stay in tidal waters for several months before they fully transition into a marine environment (Fisheries and Oceans Canada, 2010f).

The return rate of adult chum salmon back to their original spawning grounds is considered to be high and usually occurs between two and five years of age (Salo, 1991). Chum salmon are known to spend several days at the mouth of the river in which they wish to spawn before ascending into it and are often reluctant to enter streams with large barriers (Salo, 1991). Being less mobile and capable of surpassing obstacles within streams, chum salmon are known for spawning in the lower reaches of the Fraser River (Fisheries and Oceans Canada, 2003c).

Chum salmon that spawn in the late summer (early September to October) respond to high flows caused by summer snow melts. Fall and winter runs depend on an excess of rainfall to increase the water levels that are necessary for spawning up small streams (Salo, 1991). With warming river temperatures caused by salvage logging along the landscape, summer snowmelts may occur earlier and water shortages may occur later in the year. This is a potential problem for the late summer run of chum.

Species 3: Coho, *Oncorhynchus kisutch*

Unlike the other species of Pacific salmon, coho salmon, *Oncorhynchus kisutch,* are widely dispersed and have the capabilities to rear in a wide range of habitats from small tributaries and channels of low gradients, to large river systems (Fisheries and Oceans Canada, 2003c). Coho are capable of spawning in locations close to their marine environments, but can also travel great distances to spawning grounds if necessary (Fisheries and Oceans Canada, 2003c). Juveniles, while highly adaptable, require well-established habitats year round to rear in prior to venturing downstream (Fisheries and Oceans Canada, 2010g).

Although adult coho salmon are capable of spawning in a wide range of habitats, certain characteristics are preferred in their freshwater environments to ensure successful reproduction of offspring. Stable gravels of 1-20 centimeters (cm) located within the winter low-flow boundary of the channel may be considered ideal habitats for spawning (Reeves et al., 1989b). Once fry emerge in the spring from the stable gravels, they rear in shallow (<30 cm), slow flowing tributary streams for the first 1-2 years of their lives until they mature enough to travel to their marine environment (Reeves et al., 1989b). During the summer months, they move into deeper pools of streams and in the winter months they rear in sheltered (>80 cm) areas of backwater pools or beaver ponds. Coho salmon spend 0.5-1.5 years at sea before they migrate back to their original spawning stream (Fisheries and Oceans Canada, 2003c).

Interior Fraser River populations of yellow-listed coho salmon are listed as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Bunnell et al., 2004). Changes in environmental stream conditions due to the MPB may lead to detrimental effects for this interior population. Specifically, the effects of salvage logging as previously discussed may increase temperatures and cause fewer CWD inputs (Bunnell et al., 2004).

Furthermore, warming temperatures could shorten the incubation time of eggs and can be fatal to adult salmon if they remain within a 22-24 degree Celsius range for too long (Ferrari et al., 2007).

Species 4: Pink, *Oncorhynchus gorbuscha*

Pink salmon, *Oncorhynchus gorbuscha,* are considered to be the smallest of the Pacific salmon (Fisheries and Oceans Canada, 2010h). With a fixed two-year lifecycle, they migrate to spawning grounds between July and October (Fisheries and Oceans Canada, 2010h). Unlike sockeye, coho and Chinook, pink salmon migrate to the ocean almost immediately upon emerging as fry in the spring. This gives pink salmon an advantage because they depend less on freshwater habitats that have been affected by the MPB (Fisheries and Oceans Canada, 2003c). For these reasons, pink salmon are the most abundant salmon species in the Fraser River basin and also the least likely to be affected by the MPB (McDaniels et al., 2010).

Species 5: Sockeye, *Oncorhynchus nerka*

The Fraser River is the largest producer of sockeye salmon, *Oncorhynchus nerka,* in the province of BC (Rand, et al., 2006). Sockeye are the most well known of the Pacific salmon and they are capable of travelling great distances from their marine environments to their spawning grounds (Fisheries and Ocean Canada, 2010i). Sockeye run from June to November and tend to spawn in rivers that feed into lakes (Fisheries and Ocean Canada, 2010i). They are characterized by an abundant four-year lifecycle (Burgner, 1991). After hatching from the redd, sockeye can spend up to several years rearing in nearby freshwater lakes before migrating to their destined marine environments (McDaniels et al., 2010). Many lakes throughout the province have been affected by the MPB epidemic through increases in leaf litter as a source of DOC. This increase may have a positive effect on sockeye salmon, as DOC can be a vital resource in aquatic food webs (Meyer et al., 1998). Increases in DOC can also impact the odor of a stream, which enables sockeye to return to their natal stream environments more easily when they return to spawn (Meyer et al., 1998).

Some salmon species are thriving with changing conditions, while others are suffering. One run that is suffering in particular is the early Stuart sockeye, which migrate through the heart of the beetle infestation found northwest of Prince George (Fisheries and Ocean Canada, 2010i). The Stuart population is the first population to embark each year on its journey of 1100km to the spawning grounds (Rand, et al., 2006). This exposes the Stuart population to the highest peak water flows throughout the year from spring melts. Adult migration of sockeye has become progressively later in the Fraser River, which could affect the Stuart population if peak flows are not high enough (Nelitz et al., 2010). Peak flows have been decreasing by as much as 18% in some areas, as summer month's progress (McDaniels et al., 2010).

Rising temperatures have been recorded throughout the Fraser River since the 1950's and have significantly increased in recent years due to external factors such as a reduction in CWD related to the MPB attack (Mathes, et al., 2010). Increasing temperatures are considered to be one of the biggest threats to Pacific salmon. Sockeye salmon enter freshwater spawning grounds when river discharge and temperature are at a prime (Mathes, et al., 2010). In areas of heavy salvage logging where the riparian vegetation has been removed, temperature increases may be considered to be harmful to the emergence of fry for early-spring emerging species like sockeye (Bunnell et al., 2004). Once fry emerge, they travel down the stream in which they emerged from to the nearest lake to rear in. In areas where water temperatures reach a threatening level, juvenile salmon will move into cooler water tributaries to seek refuge, and may not make it to their destined rearing habitat. Fry that do make it to lakes to rear spend one to two years before they travel down to their marine environments as smolts. High river temperatures can also result in fish not being able to recover from stress and strenuous exercise. This may lead to an increase in diseases for sockeye that include gill damage or kidney parasites, which may reduce swimming efforts (Mathes, et al., 2010).

Sockeye are known to be highly adaptable to changing environmental conditions. This allows for the opportunity of adaptation to the warming conditions for this species (McDaniels et al., 2010). Sockeye are also able to remain at sea a year longer than usual if necessary to store the essential amounts of energy needed to make the long journey up the river (Cox et al., 1997). Past mortality rates have never exceeded 20% for a run, but in recent years, mortality rates for runs have exceeded 60-90% (Mathes, et al., 2010). Despite the rising summer temperatures, migration times have yet to change and summer peak flows have yet to decrease (Mathes, et al., 2010). This could be one of the main reasons for the demonstrated increase in the mortality rate of recent years.

Comparison

All five species of Pacific salmon may be potentially impacted directly or inderectly at some point of their lifecycle by the effects of the MPB. Some species will be negatively affected, while others may benefit. The degree of which each species will be affected by the MPB may depend on timing, and environmental or genetic conditions. As previously discussed, the MPB may have many potential effects on streams and rivers throughout the Fraser River basin including peak flow levels and timing, water quality, temperature increases and CWD inputs.

Warmer water temperatures in small tributary streams caused by decreases in CWD and harvested dead pine along riparian areas may have negative effects on many species of Pacific salmon throughout the younger stages of their lifecycles. With the exception of chum and coho salmon, which prefer warmer temperatures, interruptions, delays and increased mortality may be seen in the remaining species (Fisheries and Oceans Canada, 2010g). Increases in temperature may benefit chum salmon, which require stream temperatures to be at least 4^0C. Winter temperatures below 4^0C account for large numbers of egg mortality in chum salmon (Salo, 1991). Coho salmon that migrate to warmer waters in the winter may be able to benefit by conserving energy from not migrating. Furthermore, increases in disease for Pacific salmon due to warming water temperatures may be seen. Sockeye and Chinook salmon tend to be more affected by internal parasites and diseases when in comparison to the other three species.

Timing and levels of peak flows due to faster snowmelts and decreased evapotranspiration may also lead to problems in salmon lifecycles. Salmon species like Chinook, sockeye and chum swim upstream to spawn when peak flows reach ideal levels. With peak flow levels and timing being altered by the MPB's effects, salmon may be eventually forced to alter their timing of migration to match the peak flows.

Finally, pink and chum salmon spend the least amount of time in their freshwater spawning habitat before migrating to a marine environment. Less time spent in the Fraser River potentially gives these two species the advantage of being less exposed to effects by the MPB epidemic. However, an increase in CWD from MPB attacked trees may lead to negative effects for Chum salmon. Chum salmon are not strong jumpers and these natural barricades may be enough to prevent them from travelling back to their original spawning streams.

Conclusion

The Fraser River basin and the province of BC have been significantly impacted by the MPB in recent years. Home to all five species of Pacific salmon, the Fraser River hosts some of the largest salmon spawning runs in the world. Affected by such a large-scale epidemic, the Fraser is likely to have several hydrological impacts and effects as examined in this review.

Several tools can help protect salmon species from the MPB epidemic. Some examples may include, adaptive and ecosystem-based management, mapping tools to identify vulnerable areas within the Fraser basin, and increased awareness (Pacific Fisheries Resource Conservation Council, 2009). The Fraser River basin and its freshwater resources are a major source of economic value for the province of BC (Ferrari et al., 2007). Conservation and restoration efforts should be focused at the watershed scale, as evaluation and results are more easily compared at this level (Reeves et al., 1994).

Although there remains some uncertainty regarding the degree to which the MPB will affect all five species of Pacific salmon, it can be concluded that the protection and conservation of salmon stocks would be the best method of reducing the risk of long-term effects.

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