Short-term Monitoring Study Examining the Possible Impacts of Fire Retardants on Aquatic Environments in Kootenay National Park During and After 2003 Forest Fires

April 6, 2004

Lucie Sliva

Prepared for:
Joanne Williams
Parks Canada

Summary

This report discusses the results of short-term aquatic monitoring program that addressed the possible impacts of fire control operations on Kootenay National Park (KNP) aquatic ecosystems during the summer fires of 2003. No obvious differences were observed between sites that had nutrient-based fire retardant applied immediately upstream, and sites that received water from fire affected watersheds but had not immediate retardant application upstream. There were significant differences between control (no fire) and fire-impacted sites, with the latter group displaying increase in total and dissolved phosphorus, as well as nitrate-nitrite concentrations. The only apparent effect on biological communities was in streams with largely burned watersheds, where a decrease of pollution sensitive benthic invertebrates was observed. Although no obvious effects of fire retardant application were found, it is recommended that further monitoring be implemented in KNP, as this monitoring program was designed and implemented under considerable time constraint, and not all issues, such as nutrient loading, may have been addressed completely. Furthermore, effects on aquatic environments tend to appear up to one year after the actual fire event, with regular nutrient pulses occurring after spring runoff and during major rain events. There is little information on the influence of fire-retardants on the nutrient poor alpine and montane aquatic ecosystems, and it is possible that these may also contribute to nutrient enrichment over longer term, especially in areas of steep terrain and slow vegetation growth. As the frequency of forest fires is on the rise due to changing climate and build up of fuel caused by past fire-suppression management activities, it is pertinent that short and long-term aquatic monitoring programs be developed to better deal with potential impacts of future fire control operations.

Introduction

Forest fires play a significant role in maintenance of ecosystem health by resetting the successional stage of ageing forests. However, forest fires are also instrumental in severe economical damage when they encroach human inhabited areas, and thus have been subject to control measures. These measures may have potential negative impacts on surrounding ecosystems. This study was commissioned by Parks Canada to monitor short-term impacts of 2003 fire control operations on downstream aquatic habitats of Kootenay National Park (KNP) with a focus on the effects long-term fire retardant application. Long term fire retardants are fertilizer-based chemicals, comprised primarily of phosphorus and ammonia salts, that continue to reduce or inhibit flammability after water in the mix has evaporated in a chemical reaction (Chambers et al. 2001). Thus the primary concern is with potential nutrient enrichment of downstream aquatic habitats, and the effect this could have on water quality and biological communities of systems that are naturally nutrient-limited. Although the risk of eutrophication caused by runoff from vegetation strips treated with fire retardant is considered to be small as most of the phosphorus is retained in soil in a non-leachable form (Norris et al. 1978), even a small amount of nutrient loading may have a considerable influence on the nutrient-poor aquatic systems encountered in alpine and montane ecosystems. As this monitoring program was designed and implemented under a considerable time constraint, not all issues may have been addressed completely. It is therefore recommended that a comprehensive aquatic monitoring program be developed addressing both the short and long-term impacts of future fire operations.

Site Description and Methods

The KNP 2003 forest fires lasted for month and a half from July 31st to mid September. Twelve percent of the National Park's 137,859 hectares were burned, mostly in the headwater region. The water-quality sampling scheme during and immediately after KNP 2003 fires consisted of weekly and post-rain event collection of water samples from 12 sites starting on August 15 and ending on September 23. Detailed descriptions of sites are listed in order of sampling in Table 1. All the sites, with the exception of Boom, were located in the Vermillion River catchment within the KNP boundaries (Figure 1). Four of the sites sampled were control (no retardant or fire effect), 3 sites had fire retardant applied immediately upstream, and 5 sites drained catchments that were burned but were not subject to immediate upstream application. Kootenay River below confluence with Vermilion River (KootBelowVerm) was southernmost site and Boom Creek in Banff National Park was the northernmost site sampled for water quality. Figure 2 shows the location of areas in KNP that were affected by the fires. The water quality parameters measured were: total phosphorus (TP), dissolved phosphorus (DP), nitrate-nitrite (NO3-NO2), total Kendall nitrogen (TKN), dissolved organic carbon (DOC), ammonium (NH4), pH, specific conductance, and total suspended solids (TSS). Precipitation was provided by Parks Canada for two locations within the park, MacLeod Meadows and Vermillion Crossing (Figure 2).

The last week of water quality monitoring also included collection of periphyton and benthic invertebrate samples, along with more detailed physical parameters (canopy cover, discharge, flow velocity, substrate size) at selected sites that were conducive to biological sampling. These sites comprised of four of the water quality monitoring stations (Wardle, KootX, UpperVerm, StanleyCat, Boom; referred to as WRD, KTN, UPV, VRS, BOM respectively in figures) as well as additional two sites (Hawk and Haffner; referred to as HWK and HFF), which drained catchments that were significantly affected by forest fires but were not subject to immediate upstream retardant application (Figure 1). Wardle, UpperVerm and Boom sites were part of a larger scale aquatic monitoring program run by Environment Canada during the same time, and additional baseline and post-fire data for these was included in this report.

Results

Water Quality Monitoring

Table 2 summarizes water quality averages, standard deviations (within-site variability) and sample size (number of times site was sampled) at each of the 12 stations sampled. A large within-sample variability (as measured by standard deviation) was common for most parameters measured. There was a greater variability in among-site average values for TP than DP, with sites draining larger catchments showing higher TP averages and within-site variabilities than sites draining smaller catchments. Control sites also appear to have lower TP concentrations. No obvious trend was observed for NO3-NO2, TKN, pH, DOC, primarily due to high within-site variability. NH4 concentration appeared highest in three sites, two of which were downstream of retardant application sites, however, due to high standard deviations and small replicate number, nothing conclusive can be said about this trend. SlidePathCul site had considerably higher conductivity values compared to the other sites throughout the study period. There were also very obvious differences in TSS values among the sites. The control sites as well as those draining smaller catchments had considerably lower TSS values than the rest of the sites.

Rain events are important to monitor during and after major fires have taken place, as fire increases the sensitivity of streams draining burned catchments and makes them susceptible to such smaller scale disturbances (Minshall et al. 2001a). Major rain events (>5cm) occurred on: August 23rd and 27th, September 9th, 10th and 17th. Minor rain events (<5 cm) occurred on August 28, September 12th, 15th, 16th, and 20th (Figure 2).

TP values ranged from 0 to 27 ug/L. Control sites and StanleyCat had consistently lower TP concentrations than the rest of the sites (Figure 3). The TP concentrations at all control sites plus StanleyCat site were negatively correlated with precipitation (KootX r=-0.72; Wardle r=-0.95; StanleyCat = -0.86; UpperVerm r=-0.78; Boom r = -0.71). A correlation matrix was used to determine similarity in water quality fluctuations among sites (Table 3). All sites on Vermilion River downstream of OchreN site were similar (r>0.7) in TP concentration fluctuations during the study period. All control and StanleyCat appeared similar (r>0.7). Peaks in TP concentrations occurred for sites downstream of OchreN on August 27th and September 5th sampling dates, the highest concentrations occurring at Simpson and VermX sites (~22 ug/L and ~ 27 ug/L for each date respectively). The first date coincided with a major rain event, but it also followed a 3- day dry period; the second date occurred after a week-long dry period.

DP ranged from 0.5 to 8 ug/L. All control sites, plus StanleyCat, DP concentrations were negatively correlated with precipitation (KootX r=-0.84; Wardle r=-0.93; StanleyCat = -0.75; UpperVerm r=-0.68; Boom r = -0.94). Three groups of sites with similar DP fluctuations over the study period were observed: 1st group comprised KootBelowVerm, Simpson and Assin; 2nd group comprised KootX, Assin, OchreS, StanleyCat, UpperVerm, Wardle and Boom; and 3rd group was composed of OchreN and SlidePathCul (r>0.7; Table 4). Concentration peaks were not as dramatic for this parameter as for TP, however, a slight increase in concentration was observed for the same dates (August 27 and September 5). More obvious was a drop in DP concentration on September 9, which coincided with the largest rain event of the sampling period (Figure 4).

Nitrate-nitrite (NO_3-NO_2) concentrations varied from 9 to 257 ug/L, with most sites following similar fluctuation patterns over time. No correlation was observed between precipitation and NO3-NO2 concentration at any of the sites. Although, there was a high degree of similarity in NO_3-NO_2 fluctuations over time among sites, no clear grouping was observed (Table 5). The only site that was different in this parameter from the rest of the sites was Boom, which had considerably lower NO_3-NO_2 concentration (Figure 5). There appeared an increase in NO_3-NO_2 concentration at all sites over the sampling period. Wardle had an unusual peak in this parameter on September 9th, which was also the date of the largest rain event.

TKN concentrations varied from 0 to 125 ug/L. No correlation was found between precipitation and TKN concentration at any of the study sites. There was a large similarity in TKN fluctuation at the sites sampled over the monitoring period, with the exception of SlidePathCul, which was not correlated with any other sites, and Boom, which was correlated only with OchreS (Table 6; Figure 6).

DOC concentrations varied from 0.49 to 2.02 mg/L. No correlation was found between precipitation and DOC concentration at any of the study sites. There was a very high similarity in the fluctuation and concentration of this parameter among most of the sites (Table 7; Figure 7). Three of the control sites (KootX, UpperVerm and Boom) had consistently higher values, while Wardle was characterized by consistently lower DOC values than the rest of the sites. This is in contrast with other studies, which showed DOC increase in streams draining burned watersheds compared to reference streams (Minshall et al. 2001a).

High values of NH_4 were observed at two sites (Assin and OchreS, 43 and 16 ug/L respectively) in the beginning of the monitoring period, and StanleyCat had a relatively high value at the end of the monitoring period (12 ug/L; Figure 8). Unfortunately, these could not be compared to other sites for the same sampling date due to lack of data. NH_4 concentrations decreased considerably for all sites at the end of the sampling period and appeared very similar. Not enough data was available to run any statistical analyses on this parameter.

pH varied little among sites and over the time (Figure 9). Not enough data was available to run any statistical analyses on pH.

Overall ionic content is indicated by specific conductance. This parameter ranged between 92 and 638 uS/cm. There was no correlation between precipitation and conductance. All sites were correlated in their conductance fluctuations over the monitoring period (Table 8). The conductance values for the SlidePathCul were consistently higher than values for the other sites (Figure 10). This is most likely because most of the flow at this site originated from ground water.

Turbidity and total suspended solids (TSS) were highly correlated (r=0.89), thus only TSS data was shown here. TSS ranged from 0 to 95 mg/L. TSS fluctuations at several sites were positively correlated with precipitation (KootBelowVerm r=0.85; KootX r=0.94, Ward r=0.98, VermX r=0.71; Boom r=0.96). There appeared two obvious groups of sites with similar TSS concentrations and fluctuations (Figure 11). The first group is composed of all sites on Vermillion River below VermX as well as KootBelowVerm; this group is characterized by large fluctuations and higher concentrations in TSS, with peaks occurring on August 15th, 27th and September 9th sampling dates, the latter two coincide with major rain events. The second group shows relatively slight TSS fluctuation, lower TSS concentrations, and comprises of all the control sites as well as SlidePathCul and StanleyCat. No clear grouping was observed using correlation analysis, mainly due to overlapping between several groups (Table 9).

Biological Monitoring

There was a general decreasing temporal trend in temperature, which coincides with seasonal air temperature decrease from July to October (Figure 12a). An increasing trend for specific conductance from July to October (Figure 12b) can be explained by increasing contribution of groundwater towards base-flow over that time period.

Discharge was highest at KootX (KTN), followed by StanleyCat (VRS) and Haffner (HFF) and Hawk (HWK; Figure 12d). TSS decreased temporally at Boom (BOM) and Wardle (WRD) reference sites, but increased drastically at UpperVerm (UPV; Figure 12d). UpperVerm and Hawk sites had highest TSS values. However, when TSS was corrected for discharge, the reference site UpperVerm had lower TSS loading than StanelyCat, the site below the cat guard (Figure 12e). Flow velocity was variable and did not show any specific trend (Figure 12f).

Figure 13 displays the nutrient water chemistry at the sites that were sampled for biological parameters. TP and DP appeared in general to be higher in the reference than in burn streams, however the overall concentrations were relatively low for all streams (Figure 13 a&b). No obvious patterns were apparent for NO3-NO2, TKN or DOC parameters (Figure 13 c,d&e). No information was available for NH4 for Hawk or Haffner Streams, however there is an indication of higher NH4 values at StanleyCat site below the cat guard (Figure 13f).

Figure 14 shows trends in physical parameters important to periphyton growth and measures of periphyton biomass and nutrient content. Canopy cover is highest in two of the reference sites, Boom and Wardle (Figure 14a), and the substrate size for periphyton growth is smallest in KootX site (Figure 14b). Higher periphyton biomass tends to be found in open sites with larger, more stable substrate. The relatively low concentration of nitrate to phosphorus in periphyton shows that algae in these streams are phosphorus limited (Figure 14 c&d). KootX displayed highest chlorophyll *a* and ash free dry mass (AFDM) concentrations, the former is a measure of autotrophic biomass and the latter is a measure of total biofilm biomass (Figure 14 e&f). KootX consistently showed different trends in most of the variables measured from the other sites.

The relative contribution of major benthic invertebrate groups and the Ephemeroptera Plecoptera Trichoptera index (%EPT) is given in Figure 15. The proportion of benthic invertebrates in most reference sites as well as at StanleyCat site is dominated by plecopterans (stone flies). The relative abundance of ephemeropterans (mayflies) and tricopterans (caddisflies) is low at all sites. The %EPT shows the proportion of the benthic invertebrate community that is comprised of these three pollution sensitive groups. The highest scores were at Wardle, StanleyCat, Boom and UpperVerm sites respectively. KootX and Hawk had very low scores, and Haffner had an intermediate score. Chironomidae (midges) are more tolerant of degraded environmental conditions in aquatic environments. Similar pattern of impact is shown using this indicator group as was observed with the %EPT index. Streams that drained largely burned areas (Hawk and Haffner) had higher proportion of chironomidae than the others. The chironomidae proportion was also very large at KootX (60%).

Discussion

The largest environmental threat posed by long-term fire retardants is ecosystem enrichment (Chambers et al. 2001). Following rainfall, fire retardant residues are either washed into the soil, or are transported via overland flow on impermeable soil, especially on steep terrain and after high intensity rainfall events (Gould et al. 2000). Stream pollution therefore tends to occur in run-off prone environments and if retardants are dropped close to water courses. This is where proper retardant application practices are very important. No obvious differences were revealed between sites that had fire retardant applied immediately upstream and sites on streams that drained fire affected watersheds. This may be due to a greater nutrient input into receiving waters via runoff and/or aerial ash deposition during and immediately after the forest fires, than from the fire retardant application during that time period. Aerial deposition during firestorms has been observed to be significant enough to raise phosphorus and nitrogen levels 5-60 times above background levels (Spencer et al. 2003). It is difficult to capture an effect of nutrient addition if discharge data is not available for all monitoring sites, as the variability in this parameter among sites will have different effects on the dilution of point and non-point source pollutants. It is also unfortunate that there is a lack of a good dataset for NH4 to compare with the phosphorus values. Higher than background NH4 concentration was observed in the existing data for OchreS, Assin and StanleyCat sites, two of which were located immediately downstream of retardant application. Although the values observed for all nutrient parameters did not exceed established water quality criteria, it is important to consider that montane and alpine ecosystems are naturally nutrient poor, and it is possible that even small amount of nutrient enrichment may have a significant effect that could cause a dramatic shift in trophic status, even if the effect is temporary (Chambers et al. 2001).

Differences were observed between control and fire-impacted sites, with the latter group displaying increase in total and dissolved phosphorus, as well as nitrate-nitrite concentrations. Increase in concentrations of dissolved chemicals has been commonly observed in stream water draining burned watersheds immediately after a forest fire (Minshall et al. 2001a; Schindler et al. 1980; Spencer et al. 2003; Tiedemann et al. 1978). The control sites as well as those draining smaller catchments were also characterised by considerably lower TSS values than burned stream sites. This agrees with other studies that have observed increase of sediment levels after fires due to increased flow rates, soil erosion and debris torrents (Helvey 1980; Minshall et al. 2001a). An increase in nutrients as well as suspended solids has also been noted after spring runoff and heavy rains in burned watersheds up to several years after the fires have occurred (Minshall et al. 2001a; Spencer et al. 2003). This was caused by ash deposition of phosphorus and nitrogen via overland runoff from burned areas. Impacts were accentuated by steep terrain and slow recovery of vegetation (Minshall et al. 2001a), both of which are characteristic of the area studied in KNP.

Effects of precipitation events were evident primarily in phosphorus and TSS data. Phosphorus concentrations were negatively correlated with precipitation most likely due to the dilution effect. Total loads of phosphorus could not be calculated due to lack of discharge data for most sites. Environment Canada installed an automated flow meter at Vermilion Crossing towards the end of this study period, thus future interpretation of nutrient loads in this river will be possible if further water quality monitoring was to take place. TSS was positively correlated with precipitation, indicating significant overland runoff of carrying loose solids towards water-courses during rain events.

Although periphyton biomass, as measured by chlorophyll *a*, was considerably higher at KootX site than at the others, it did not exceed aquatic plant biomass standards

(Chambers et al. 2001). The phosphorus limitation of periphyton is common for lotic environments. No apparent difference was found in periphyton or biofilm biomass among the burn, reference or retardant application sites. Research in Yellowstone Park following the 1988 forest fires has shown that periphyton biomass decreased in a number of streams, however, this decrease was not observed until a year after the fire event (Minshall et al. 2001a; Minshall et al. 1997). In contrast, (Spencer et al. 2003) observed that there was no short or long term effects on periphyton biomass following the 1988 Red Bench Fire in Glacier National Park. They reasoned that this was caused by the terrain of their study site which was relatively gentle compared to that of the Yellowstone Fire study. It is thus predicted, that with the relatively steep terrain occurring in many burned parts of the KNP, future periphyton biomass will be reduced, possibly affecting higher trophic levels.

The results of the benthic invertebrate survey indicate that the invertebrate community in two of the burn sites, Hawk and Haffner, has been affected as early as one month after the fire event. This is in contrast to the results of other studies, which have not found an immediate and direct post-fire effect on benthic invertebrates (Minshall 2003; Minshall et al. 2001a; Spencer et al. 2003). This may be due to a relatively larger burned proportion of the watersheds being drained by these two streams compared to the other sites. Minshall et al. (2001b) have observed that beyond a certain threshold, the greater extent of a catchment exposed to fire, the greater the impact on the macroinvertebrate community. The limit of this threshold was proposed to be 25-50% and probably varies with climate and topography. In relation to this, StanleyCat site appeared relatively pristine based on its water quality and biological status. This may be explained by the fact that only a small proportion of the catchment at this point was burned. The reason for the delay in impacts on periphyton and benthic invertebrates in other studies was due to the later appearance of indirect effects such as increased erosion, which cause channel cutting and sediment scouring. These indirect effects appeared to have a greater impact than direct effects of increased nutrient loads. For example Minshall et al. (2001b) did not observe any effects until one year after the Yellowstone 1998 fire. These effects were comprised of a significant increase in runoff of exported nutrients, altered substratum, removed organic matter and periphyton, and changed species composition and abundance in benthic invertebrates.

One reference site, KootX, appeared to have a degraded biological status, as measured by a higher periphyton biomass, low %EPT score and high midge larvae abundance, compared to the other reference sites. These differences may be attributed to natural variability such as difference in stream order (4th compared to 2nd for most of the headwater streams), however, they could also be caused by the fact that a considerable proportion of this catchment is located outside the KNP boundaries where resource extraction, such as timber harvesting, occurs. Although for these reasons this site cannot be considered a suitable reference site for the other headwater streams sampled, it was important to include it as a reference for the water quality monitoring portion of this study, as it captures significant proportion of the Kootenay watershed that was not impacted by the fires. The results derived here though raise questions about the ecological health of the Kootenay River upstream of its confluence with Vermilion River.

Conclusions and Recommendations

As the frequency of temperate forest fires is on the rise due to the combination of changing climate and build up of fuel caused by past fire-suppression management activities (Bisson et al. 2003), it is important that short and long-term aquatic-monitoring programs should be developed for future fire events. The streams located in the National Parks of the Rocky Mountains are important headwaters for some major river systems of western Canada. A short-term program should be designed so it can be rapidly implemented when needed. The primary emphasis at this point should be on water quality and the measurement of physical characteristics that tend to be variable, such as discharge. If possible, the collection of one set of biological samples, such as benthic invertebrates and periphyton, would be helpful at this point to have, so data is available for comparison with later sampling efforts. As it is difficult to make conclusions based on the limited dataset provided by any short-term monitoring study, it is recommended that a longer-term program be put in place. It has been observed in other studies that although nutrient concentrations returned to background concentrations within several weeks after a fire, periodic nutrient pulses were observed during the first as well as subsequent years, especially during spring runoff (Spencer et al. 2003). There is little information on the effect of fire-retardants on alpine and montane aquatic ecosystems, and it is possible that these may contribute to nutrient enrichment in the longer term. Although it is assumed that the nutrients would be consumed by forest vegetation by next year (Chambers et al. 2001), this process may be reduced by the steep terrain and slow vegetation growth typical of this area. The long-term monitoring program therefore should at least comprise post-snowmelt and 1-year post fire time periods, and should include physical, chemical and biological sampling.

Acknowledgements

I would like to thank Megan Jamison and Murray Campbell for valuable help in the field and the laboratory, as well as Dr. Sue Watson, Dr. Patricia Chambers (Environment Canada) and Joanne Williams (Parks Canada), for contributing to the funding of this and the related Science Horizons project, their role in developing the sampling program, and their input on this document. I also thank Dave Gilbride (Parks Canada) for providing GIS data.

References

Bisson, P. A., B. E. Reiman, C. Luce, P. F. Hessburg, D. C. Lee, J. L. Kershner, G. H. Reeves et al. 2003. Fire and aquatic ecosystems of the western USA: current knowledge and key questions. Forest Ecology and Management 178:213-229.

Chambers, P. A., M. Guy, E. S. Roberts, M. N. Charlton, R. Kent, C. Cagnon, G. Grove et al. 2001. Nutrients and their impact on the Canadian environment., Pages 241., Agriculture and Agri-Food Canada, Environment Canada, Fisheries and Oceans Canada, Health Canada and Natural Resources Canada.

Gould, J. S., P. K. Khanna, P. T. Hutchings, N. P. Cheney, and R. J. Raison. 2000. Fire Management: Assessment of the effectiveness and environmental risk of the use of retardants to assist in wildfire control in Victoria, Pages 54. Victoria, Australia, Department of Natural Resurcs and Environment.

Helvey, J. D. 1980. Effects of a north central Washington wildfire on runoff and sedimnent production. Water Resources Bulletin 16:627-634.

Minshall, G. W. 2003. Responses of stream benthic macroinvertebrates to fire. Forest Ecology and Management 178:155-161.

Minshall, G. W., J. T. Brock, D. A. Andrews, and C. T. Robinson. 2001a. Water quality, substratum and biotic responses of five central Idaho (USA) streams during the first year following the Mortar Creek fire. International Journal of Wildland Fire 10:185-199.

Minshall, G. W., C. T. Robinson, and D. E. Lawrence. 1997. Postfire responses of lotic ecosystems in Yellowstone National Park, USA. Canadian Journal of Fisheries and Aquatic Sciences 54:2509-2525.

Minshall, G. W., T. V. Royer, and C. T. Robinson. 2001b. Response of the Cache Creek macroinvertebrates during the first 10 years following disturbance by the 1988 Yellowstone wildfires. Canadian Journal of Fisheries and Aquatic Sciences 58:1077-1088.

Norris, L. A., W. L. Hawkes, W. L. Webb, D. G. Moore, W. B. Bollen, and E. Holcombe. 1978. A report of research on the behaviour and impact of chemical fire retardants in forest streams., Forestry Science Laboratory. PNW Forest and Range Experimental Station.

Schindler, D. W., R. W. Newbury, K. G. Beaty, J. Prokopowich, T. Ruszczynski, and J. A. Dalton. 1980. Effects of a windstorm and forest fire on chemical losses from forested watersheds and on the water quality of receiving streams. Canadian Journal of Fisheries and Aquatic Sciences 37:328-334.

Spencer, C. N., K. O. Gabel, and F. R. Hauer. 2003. Wildfire effects on stream food webs and nutrient dynamics in Glacier National Parks, USA. Forest Ecology and Management 178:141-153.

Tiedemann, A. R., J. D. Helvey, and T. D. Anderson. 1978. Stream chemistry and watershed nutrient economy following wildfire and fertilization in Eastern Washington. Journal of Environmental Quality 7:580-588.