The effects of beaver on juvenile coho salmon habitat in Kispiox River tributaries.

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Abstract

Beaver impoundments made up between 5.5 and 15.1 percent of the channel length in the lower 2 km of three tributaries to the Kispiox River, and have resulted in increases in wetted area of 8.0 - 53.8 percent, creating large areas of habitat that supported high densities of coho fry. Coho were the most abundant fish in beaver ponds, and coho densities were estimated to be 0.26 and 1.35 fish/m^2 in the two ponds that we sampled in autumn. Beaver impoundments were particularly important as coho habitat in winter, when suitable habitat for juvenile coho is rare in these streams. We recaptured more fry that were marked from previous sampling in a stream where a beaver dam was left undisturbed than in one where a dam was breached, suggesting that fewer coho emigrated from - or that survival may have been better in - the stream where the dam remained. There was little evidence that beaver dams blocked the migration of adult coho, since large numbers of fry were observed upstream of the dams. Increased water temperature in beaver ponds is unlikely to have negative effects on coho in these tributaries because maximum summer water temperatures are within the tolerance range for coho salmon. Further research is necessary to determine if reduced dissolved oxygen levels are common in beaver ponds in this area. The removal of beaver dams from Kispiox River tributaries is not recommended unless it can be demonstrated that beaver activity has resulted in negative effects on coho populations. Recommendations for further research are provided.

Introduction

Populations throughout the range of the coho salmon *Oncorhynchus kisutch* have declined severely in recent decades (Nehlsen et al. 1991; Brown et al. 1994), and some U.S. populations have been listed as threatened under the Endangered Species Act (National Marine Fisheries Service 1996). Coho populations in several tributaries of the Skeena River are currently at critically low levels. Although the most serious threats to northern coho populations are probably overfishing and poor ocean conditions, stream habitat must be managed so as to maximize coho production.

Coho populations may be limited by the amount of rearing habitat available (e.g., Marshall and Britton 1990). The activities of beaver *Castor canadensis* may result in increased area of rearing habitat for coho (Bryant 1984). Beaver dams, however, may adversely affect salmonid populations by blocking juvenile and adult movements. Water temperature is often greater in beaver ponds than in nearby stream reaches (Avery 1992; McRae and Edwards 1994), and dissolved oxygen levels may be reduced. In some situations, however, beaver dams have been shown to result in increased abundance or production of salmonids (Rupp 1954; Gard 1961; Bryant 1984; Avery 1992). It has been suggested that beaver may be detrimental to salmonid populations in eastern North America (due to higher water temperatures; maximum summer water temperature may limit eastern salmonid populations), but may benefit salmonids in the west (Marcus et al. 1990).

The effects of beaver activity on coho populations have not been well-studied in the Skeena watershed. Previous qualitative surveys have suggested that beaver dams are detrimental to coho populations in the Kispiox and that beaver activity in the basin should be controlled (Taylor 1968; Harding and Erickson 1973). Beaver dams have been removed from several tributaries in the past (FHIIP 1991), and dam removal is planned as a part of ongoing watershed restoration projects. Dams are often removed because they are thought to obstruct the movement of juveniles and adults, but the effects of dam removal on coho populations in the Kispiox watershed are undocumented. The management of beaver dams so as to obtain optimal conditions for coho populations requires a quantitative evaluation of the effects of these dams. The purpose of this study was to collect data to determine how beaver dams might affect coho populations in tributaries of the Kispiox River, and to provide a review of the literature on the effects of beaver activity on salmonid populations.

Methods

Study area

The Kispiox River is a medium sized (208,200 ha drainage area) tributary of the Skeena River located near Hazelton, British Columbia. The river and its tributaries support populations of several species of salmonids, including coho salmon *Oncorhynchus kisutch*, chinook salmon *O. tshawytscha*, chum salmon *O. keta*, sockeye salmon *O. nerka*, pink salmon *O. gorbuscha*, steelhead and resident rainbow trout *O. mykiss*, Dolly Varden *Salvelinus malma*, bull trout

Salvelinus confluentus, and cutthroat trout *O. clarki*. Non-salmonids in the basin include longnose sucker *Catostomus catostomus*, Rocky Mountain whitefish *Prosopium willamsoni*, longnose dace *Rhynichtys cataractae*, Pacific lamprey *Lampetra tridentata*, redside shiner *Richardsonius balteatus*, and northern squawfish *Ptychocheilus oregonensis*.

This study focused on the lower 2 km of three tributaries to the Kispiox River: Cullon Creek, Clifford Creek, and Murder Creek. These tributaries are all small (mean width 4-9 m; August discharge 1-7 cfs), shallow, relatively infertile (TDS 60-85 ppm) streams with predominantly gravel and cobble substrate (Taylor and Seredick 1978; Harding and Erickson 1973; Nortec 1997). The lower reaches of these streams are characterized by low gradients (1-2%) and have been affected to various degrees by the activities of beaver (Harding and Erickson 1973; Nortec 1997). In September 1997, we estimated stream and beaver pond areas on all three creeks and sampled fish populations in stream sections and beaver ponds on Clifford and Cullon creeks. Fish populations were also sampled in Clifford and Cullon creeks in January and February 1998.

Habitat

The wetted area of stream and beaver pond habitats was measured in the lower 2 km of Cullon, Clifford, and Murder creeks during the period 15-23 September, 1997. Stream width was measured every 50 m with a fiberglass tape. Impounded areas were divided into ponds (impounded stream channels) and backwaters (which included canals; extensive canals were rare). Pond and backwater widths were measured every 5-20 m (depending on total length) with a fiberglass tape, and area was estimated as the product of length and mean width. The mean height of each beaver dam encountered was estimated as the mean of five measurements from the stream substrate immediately downstream to the top of the dam. We measured water temperature in ponds and adjacent stream reaches each time ponds were visited for fish sampling.

The beaver dam on Cullon Creek was breached by high flows in October 1997 (P.J. Lemieux, personal observation). We measured the snow depth, ice depth, and water depth in several stream pools and at one transect across Cullon Creek in the lower section where electrofishing was conducted in the autumn (172 m above the mouth). Pools 1 and 2 were located 176 and 24 meters downstream of the beaver dam, respectively. Pool 3 was located 16 m upstream of the dam, in the area that was previously impounded; pool 4 was located 119 meters upstream of the dam. Pool 1 is a large, deep pool that is associated with LWD and inundated by the most downstream beaver dam on the creek. The area of the pools on Cullon Creek was estimated in winter as the product of the pool length and the mean width (mean of three measurements), although some estimates (especially pool 3) are approximate because of extremely thick (40-70 cm) surface ice in some areas. In Clifford Creek, ice and water depth were measured in the beaver pond and in seven stream pools located approximately 520 m (Pool 1), 530 m (Pool 2), 600 m (Pool 3), 630 m (Pool 4), 650 m (Pool 5), 675 m (Pool 6), and 750 m (Pool 7) upstream from the mouth; areas of stream pools and the beaver pond were not estimated.

Fish populations

Autumn

Beaver ponds

Fish population size was estimated in beaver ponds on Clifford and Cullon creeks using mark-recapture estimates. The pond on Clifford Creek was located 428 m upstream of the mouth, while the pond on Cullon Creek was 316 m upstream of the mouth, just upstream of the Kispiox valley road. At each site, between 20 and 40 "Gee" brand wire mesh minnow traps were baited with approximately 2 g of salmon roe and set for 24 h. All fish captured were measured (fork length [FL] to the nearest mm), marked (left pelvic clip), and returned to the pond. After 48 h, the ponds were resampled using the same number of traps, and fish were measured, marked, and released as above. Sampling of beaver ponds was conducted between 16-22 September 1997.

We estimated the abundance of two age-classes (0+ and >0+) of juvenile steelhead, coho salmon and Dolly Varden char (Clifford Creek only) in beaver ponds using the modified Petersen estimate (Chapman 1951)

$$N = (C_1 + 1)(C_2 + 1)/(R+1)$$

where N = population estimate, C_1=total number of fish captured on the first sampling occasion, C_2 = total number of fish captured on the second sampling occasion, and R = number of marked fish recaptured on the second sampling occasion. Length ranges for age-classes (Clifford Creek coho: 0+ = < 86 mm, >0+ = > 85 mm; Clifford Creek steelhead, 0+ = < 71 mm, >0+ = > 70 mm; Cullon Creek coho: 0+ = < 96 mm, >0+ = > 95mm; Cullon Creek steelhead: 0+ = < 66 mm, >0+ = > 65 mm) were determined from length-frequency histograms (Appendix 1). Juvenile *O. mykiss* are referred to as steelhead, although some of these fish may be resident rainbow trout.

Stream sections

Fish abundance and density were estimated by electrofishing at four sites on Clifford and Cullon creeks. Sites on Cullon Creek were located 172 m (Section 1 - below beaver pond) and 436 m (Section 2 - above pond) upstream of the mouth. Sites on Clifford Creek were located 634 m (Section 1) and 727 m (Section 2) above the mouth and were both upstream of the first beaver pond. Sites were chosen to be representative of stream habitat in the reaches sampled. Sites were sampled on 21 September (Cullon Creek) and 22 September (Clifford Creek), 1997.

A two-person crew completed three electrofishing passes at each site using a Smith-Root backpack electrofisher operating at 300-400 volts DC. All fish captured were measured (FL to the nearest mm), marked (right ventral clip), and kept in shaded buckets on the streambank until electrofishing was completed, when they were released near their point of capture. Sampling sites were completely enclosed using 10 mm stretched mesh seines before electrofishing to ensure population closure; nets were installed as quickly as possible in such a way as to minimize disturbance to fish. To minimize bias in catch probability, the crew waited at least 30 minutes between passes. After electrofishing was completed, the mean length and width of the sampled area were estimated using at least three measurements each. We computed maximum likelihood estimates of abundance for two age-classes (0+, >0+) of juvenile steelhead and coho salmon from three-pass removal data at each site. Age-classes and their length ranges are the same as for beaver ponds and were determined from length-frequency histograms (Appendix 1).

Winter

The fish population of the beaver pond on Clifford Creek was sampled on 2-3 February 1998. Twelve minnow traps were baited as above and set for 24 hours. Because of time limitations it was not possible to complete mark-recapture estimates. Fish were also sampled in three stream pools located approximately 600 m (Pool 3), 675 m (Pool 6), and 750 m (Pool 7) upstream from the mouth. All pools were located upstream of the beaver pond and the most upstream pool (Pool 7) was located just downstream of the Kispiox valley road.

We sampled juvenile salmonids from the four pools that were sampled for habitat (see above) in Cullon Creek using minnow traps during the period 26 January - 1 February 1998. Length ranges of age-classes for steelhead and coho in both creeks were the same as for autumn samples and were determined from length-frequency histograms (Appendix 1).

Results

Habitat

We encountered three active beaver dams in the lower 2 km of Murder Creek (mean height = 0.83 m; range = 0.6-1.1 m), four on Cullon Creek (mean height = 1.19 m; range = 0.75-1.5 m), and five on Clifford Creek (mean height = 1.34 m; range = 0.82 - 1.9 m). Beaver impoundments made up between 5.5 and 15.1 percent of the channel length in the lower 2 km of the streams that we studied (Table 1). We estimate that beaver activity on these streams has resulted in increases in wetted area of 8.0 - 53.8 percent in these lower reaches.

Daytime water temperatures in the three creeks ranged from 7 - 12^{o}C in autumn. We noted few examples of increased water temperatures in beaver ponds in autumn. In most instances, water temperatures measured in ponds were the same as those in upstream reaches. On two occasions, however, water temperatures in the ponds on Clifford and Cullon creeks were 1^{o} greater in late afternoon than in adjacent upstream reaches. Water temperature at all sites in winter was 0^{o}C.

As mentioned above, the beaver dam on Cullon Creek was breached in October 1997. In winter, the majority of the previously impounded area had become a shallow stream channel, although a small area just upstream of the dam (including pool 3) appeared to be relatively deep and slow-moving. The stream pools that we sampled on Cullon Creek ranged from 39-52 cm in mean depth, and were covered by 19-31 cm of snow and 23-35 cm of surface ice (Table 2). The mean water depth of the transect across Cullon Creek was 7.2 cm; mean snow depth was 21.3

There were more coho captured in stream pools in Cullon Creek (7-49% of samples) than in Clifford Creek (Table 6). The majority of the coho fry captured in Clifford Creek were in the beaver pond; few coho (0-17% of samples) were captured in stream pools. Most fish captured in stream pools in Clifford Creek were juvenile steelhead and Dolly Varden. The lowest proportion of coho in the winter samples from Cullon Creek was found in Pool 3, in the area previously impounded by beaver.

We recaptured only one marked (left pelvic clip - from fall sampling in beaver pond) coho fry in Cullon Creek, in Pool 1; no older marked coho were captured (Table 7). Several marked steelhead were captured in stream pools in Cullon Creek; the highest proportion of steelhead marked with a left pelvic clip was found in Pool 3. A large number (23, 27% of sample) of marked (LP) coho fry were captured in the beaver pond on Clifford Creek. We also captured several marked (LP) steelhead in the beaver pond on Clifford Creek; no fish marked with a left pelvic clip were captured elsewhere in the stream. Few fish bearing right pelvic clips (from fall sampling in stream reaches) were captured in either stream.

Discussion

Beaver impoundments increased the surface area of the streams that we studied by an estimated 8-54 percent, and affected 5.5-15.1 percent of the total length of the streams. The relatively low proportion of Murder Creek (5.5%) that was affected by dams is presumably due to the fact that the lower part of the stream flows through a private pasture. Although the area affected by beaver in the other, less disturbed streams is greater, it is less than observed elsewhere. In northern Quebec, relatively unexploited beaver populations may influence 20-40 percent of the total length of streams of this size (Naiman et al. 1986), and water surface area may increase 10- to 20-fold (Naiman et al. 1984). Greater stream gradients in mountainous areas may, however, prevent beavers from affecting this much of the watershed (Marcus et al. 1990). Stream gradient is often the major determinant of habitat suitability for beavers; the majority of beaver activity in Colorado streams was limited to reaches with 6 percent gradient or less, and no beaver activity was observed in streams with a 15 percent gradient or greater (Allen 1983). Because coho are generally not found in high gradient stream reaches (Reeves et al. 1989), beavers may potentially affect a higher proportion of stream reaches occupied by coho than observed here.

We found high densities of coho fry in beaver ponds in autumn. Coho fry density in the beaver pond on Clifford Creek was much higher than that in stream sections, while the two were relatively similar on Cullon Creek. These ponds were also occupied to a lesser degree by juvenile steelhead and Dolly Varden (in Clifford Creek). These results suggest that the beaver ponds that we sampled provided suitable summer habitat for juvenile salmonids, especially coho fry. The greatly increased area of suitable habitat caused by beaver activity may therefore result in a substantially increased summer salmonid carrying capacity in these streams.

Winter conditions in streams may be detrimental to juvenile salmonids. Fish mortality can result from ice scour (Berg 1994), collapsing snow banks (Needham and Slater 1944), or dewatering caused by ice dams (Maciolek and Needham 1952). Ice can also reduce the area of habitat available to fish (Chisholm et al. 1987). Winter fieldwork for this study took place during a warm period (daytime air temperature -3 - 1°C) that followed a cold spell, and ice and snow conditions probably do not represent the worst case. Nevertheless, we found that surface ice extended to the substrate in some areas of Cullon Creek, which suggests that winter habitat may be limited in some reaches of this creek. In severe winters, stream habitat may be even more restricted.

Winter mortality of juvenile coho can be severe (Holtby and Hartman 1982) and may be a function of habitat quality (Murphy et al. 1984; Quinn and Peterson 1996). In winter, juvenile coho tend to aggregate in deep pools with accumulations of large woody debris (LWD) or overhanging banks (Bustard and Narver 1975; Tschaplinski and Hartman 1982; Murphy et al. 1986). Juvenile coho may also undergo extensive movements in fall, including migrations to off-channel ponds, side channels, or small tributaries in winter (Bustard and Narver 1975; Peterson 1982a; Swales et al. 1987; Brown and Hartman 1988). Beaver ponds provide excellent winter habitat for coho fry (Bustard and Narver 1975; Reeves et al. 1989; Nickelson et al. 1992), and overwinter survival may be increased in off-channel habitats and beaver ponds (Bustard and Narver 1975; Peterson 1982a; Tschaplinski and Hartman 1982). The majority of coho fry captured in winter in Clifford and Cullon Creeks were found in areas influenced by beaver activity, and the estimated density of coho fry in one such area was very high (Cullon Creek Pool 1: 4.29 fish/m^2), indicating that these areas may be preferred winter habitat for coho. Moreover, we captured a higher proportion of previously marked coho in Clifford Creek than in Cullon Creek in winter, which suggests that fry survival may have been better in Clifford Creek (or that emigration may have been less), perhaps due to the presence of the beaver pond. We did not perform a rigorous study of survival, however, and further research is required to determine if fry survival is actually better in streams with beaver ponds.

Coho salmon freshwater production may be limited by the amount of suitable winter habitat (McMahon and Hartman 1989; Nickelson et al. 1992). Beaver ponds are therefore especially important in streams such as these, where mainstem habitat with low water velocity, sufficient depth, and complex structure critical for coho in winter is rare. For example, the lower reach of Cullon Creek has little LWD and few pools; the four pools that we sampled represented the majority of suitable winter habitat for coho (less than 200 m^2) in the lower 500m of the stream. The breaching of the beaver dam on Cullon Creek equates to a loss of over 2000 m^2 of winter habitat for coho, and probably represents a significant reduction in the winter carrying capacity of the lower river for coho.

Beaver may have beneficial effects on salmonid populations beyond a simple increase in rearing habitat area. Beaver activity may have profound effects on stream ecosystem function, and may increase the total productivity of a stream by increasing wetted area and creating productive wetlands. Beaver impoundments store large quantities of organic matter (Naiman et al. 1986), which serves as food for aquatic invertebrates. Changes in water depth, velocity, and substrate character in impounded areas often result in an invertebrate fauna that is composed of typically lentic species, although it is unclear whether invertebrate production is greater in ponds compared with the same area of unimpounded stream (Sprules 1940; Naiman et. al 1984; McDowell and Naiman 1986). Removal of beaver dams can result in drastic decreases in density and diversity of invertebrates downstream (Stock and Schlosser 1991). If total aquatic production in a watershed is increased by beaver activity, fish production may also increase.

Although beaver impoundments may create large areas of rearing habitat for juvenile coho, beaver dams are often considered to be detrimental to coho populations. The most serious potential effect of beaver dams on coho populations is the prevention of the upstream migration of adult fish. There is little published information about the ability of adult salmon to migrate over beaver dams, although debris jams have been shown to limit adult migration (Bjornn and Reiser 1991). In most areas, high water levels in autumn may allow coho to migrate over all but the largest dams. Bryant (1984) found that beaver dams ranging from 0.5 - 2.2 meters high did not impede the migration of adult coho in southeast Alaska streams. There is evidence that hundreds of adult coho regularly migrate over several dams up to 2 meters in height in another southeast Alaska stream (J.K. Hodges, U.S. Forest Service, Cordova, AK, personal communication). We found high densities of coho fry upstream of beaver dams on Cullon and Clifford creeks, which suggests that adults or fry were able to migrate over them. Moreover, we observed large numbers of fry in beaver ponds much further upstream. The distribution of spawning coho in Kispiox River tributaries should be studied in relation to the presence of beaver dams to determine if dams are barriers to migration.

Beaver dams may present a more serious obstacle to juvenile coho, and might limit their dispersal to rearing areas. Avery (1992), however, found that beaver dams did not prevent the movement of small brook trout in a Wisconsin stream; some trout moved large distances over up to 20 dams. Rupp (1954) also noted that small brook trout were able to migrate over a dam one meter high. Beaver dams in northern B.C., however, may frequently act as barriers to young coho fry (D. Bustard, personal communication). Although this is probably not a serious problem if adults have access to the entire system, it deserves further study.

Beaver impoundments may also inundate coho spawning habitat. This is unlikely to be a major problem for coho populations in the tributaries studied here because beavers impounded only 15 percent of the stream length or less; i.e., there were at least 1700 m of free-flowing stream in the lower 2 km of these tributaries despite the dams. Suitable spawning areas are abundant in these streams and are probably not limiting (S.C. Riley, personal observation).

Water temperature may be higher in beaver ponds than in adjacent stream reaches (Rupp 1954; Bryant 1984; Avery 1992), although this has not always been observed (McRae and Edwards 1994). We observed few temperature differences between ponds and adjacent stream reaches, but fieldwork was not conducted at the warmest time of year (when temperature differences would be maximal) and few measurements were made. Maximum monthly water temperatures in Cullon Creek were 19.6^{o}C and 16.7^{o}C in July and August 1995, and 18.1^{o}C and 16.1^{o}C in July and August of 1996, respectively; temperatures exceeded 18^{o}C for five hours on each of four days in July 1995, and for two hours on one day in July 1996 (Barry Finnegan, DFO, unpublished data). These temperatures are well below the lethal limit for coho (23-26^{o}C; Bjornn and Reiser 1991). Assuming that these temperatures are typical of Kispiox River tributaries, it is unlikely that elevated water temperatures associated with beaver impoundments would have a negative effect on coho in this area.

Dissolved oxygen (DO) may be below tolerable levels for salmonids in some areas impounded by beaver (e.g., Avery 1992). Bryant (1984) found only a few instances of reduced DO in beaver ponds in southeast Alaska. In northern B.C. streams, DO may reach critical levels in some ponds, particularly in off-channel ponds with limited flow, and especially in late winter (D. Bustard, personal communication). During our sampling, we found several juvenile salmonids dead in one minnow trap near the edge of a backwater on the Cullon Creek beaver pond. This backwater was a forested area adjacent to the Kispiox valley road that was flooded as a result of the beaver dam, and large amounts of dead leaves and other forest debris may have caused a high biochemical oxygen demand (BOD) that resulted in reduced DO levels. The fact that fish entered the trap suggests that DO was below tolerance levels for only part of the day, or that fish were able to tolerate low DO for brief periods while foraging. In many cases fish may be able to move within ponds and avoid areas of localized oxygen depletion. Dissolved oxygen levels may be a concern in off-channel backwaters with high BOD and little flow.

The removal of beaver dams from Kispiox River tributaries has been recommended in the past (Taylor 1968; Harding and Erickson 1973), and dams continue to be removed as part of watershed restoration projects. Dams also are also removed as part of road maintenance activities. Given the drastic reduction in rearing habitat that can result from dam removal, we recommend that dams only be removed if they can be demonstrated to have negative effects on coho populations or if they are flooding roads or property. It is important to note that any dam removal must be done pursuant to the DFO 'No Net Loss' policy. Moreover, if adult migration is the only concern, there are less drastic methods that can be used to allow adults to migrate over the dam without removing it entirely. For example, it is possible to create a small notch in the dam which will allow adults to migrate over the dam and still retain a large proportion of the pond habitat intact. Beavers can be temporarily prevented from repairing the dam by installing motion-sensitive alarms nearby (P.J. Lemieux, unpublished data).

In summary, we found that beaver activity on Kispiox River tributaries created large areas of habitat that supported high densities of coho fry. These habitats appear to be particularly important in winter, when suitable habitat for juvenile coho is rare, and removal of beaver dams may result in a substantial decrease in the carrying capacity of streams for coho. Further research is necessary to determine if beaver dams impede the movements of juvenile or adult coho. Increased water temperatures in beaver ponds are unlikely to have negative effects on coho populations in this area, but reduced levels of dissolved oxygen may be a problem in some off-channel backwaters associated with beaver impoundments. Coho salmon and beaver have co-evolved in this region, and beaver dams may create winter habitat that is critical to coho in interior streams. The routine removal of beaver dams is not recommended if coho salmon production is the primary management consideration.

Recommendations

1. The removal of beaver dams from Kispiox River tributaries is not recommended unless it can be demonstrated that beaver activity has resulted in negative effects on coho populations. If adult migration is the only concern, dams can be modified to allow adult access without removing them entirely.

2. It is necessary to determine to what extent beaver dams are barriers to the migration of adult or juvenile coho, and to determine the characteristics of dams that are. The distribution of spawning coho should be studied in relation to the location of beaver dams to determine if the dams act as barriers to adults. Similarly, the distribution of coho fry should be studied in relation to the location of spawning areas and beaver dams to assess the likelihood that fry dispersal is affected by the presence of dams. The physical characteristics of dams (height, water depth and velocity below dam) should be assessed in order to develop criteria that could be used to identify dams that might act as barriers.

3. A large scale-survey is recommended to determine if coho production is affected by beaver activity. The standing stock, carrying capacity, or smolt production of coho should be compared among a number of streams with varying levels of beaver activity. These variables could also be estimated in streams before and after removal of beaver dams.

4. Research should be undertaken to determine if growth or survival of coho fry is greater in beaver ponds.

5. Measurements of dissolved oxygen should be taken in a large sample of beaver ponds in the area to determine if reduced DO levels are a concern.

6. Future mark-recapture estimates made in winter should be conducted with a large number of traps to account for lower capture rates in winter. Multiple mark-recapture estimates would result in more reliable population estimates.

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Table 1. Area of beaver ponds and stream reaches on three tributaries of the Kispiox River, B.C., in autumn, 1997. Sampling was limited to the lower 2 km of each stream.

	Clifford Creek	Cullon Creek	Murder Creek
Total length of stream (m)	1721	1794	1896
Total length of ponds (m)	306	210	110
Total length surveyed (m)	2027	2004	2006
Percent of total length impounded	15.1	10.5	5.5
Total stream area (m^2)	7697	9476	6166
Total impounded area (m2)	6223	4870	885
Total area of stream and ponds (m2)	13920	14346	7051
Total area of stream if unimpounded (m2)	9053	10675	6532
Percent increase in habitat area from unimpounded strear	53.8	34.4	8.0

Table 2. Habitat characteristics of stream pools sampled in late January 1998 in Cullon Creek, B.C.

Stream	Pool	Area (m^2)	Mean water depth (cm)	Mean snow depth (cm)	Mean ice depth (cm)
Cullon Creek	1	45.4	45.7	19.2	34.2
	2	28.4	41.9	20.3	32.1
	3	19.3	38.9	20.2	35.5
	4	15.8	52.4	31.2	22.8
Clifford Creek	Beaver pond		37.1		26.7
	1		39.5		20.5
	2		14.0		29.0
	3		22.0		18.0
	4		7.0		9.0
	5		14.0		21.0
	6		29.0		21.0
	7		62.7		24.7

Table 3. Catches and population and density estimates for juvenile salmonids in beaver ponds on Clifford and Cullon Creeks, B.C., in autumn 1997. C1 = catch on first capture occasion, C2 = catch on second capture occasion, R = number of recaptures on second capture occasion. Population estimates followed by an asterisk are the sum of individuals captured; too few were captured to reliably estimate population size.

Stream	Total area of pond (m^2)	Species	Age	C1	C2	R	Population estimate (N)	Variance of N V(N)	Lower confidence limit LCL(N)	Upper confidence limit UCL(N)	Density estimate (D) (fish/m^2)	Lower confidence limit LCL(D)	Upper confidence limit UCL(D)
Cullon Creek	2432	Coho	0+	319	300	149	641	737	588	694	0.264	0.242	0.286
		Coho	>0+	39	58	7	294	7848	120	468	0.121	0.049	0.192
		Steelhead	0+	48	49	6	349	13438	122	576	0.143	0.050	0.237
		Steelhead	>0+	87	63	20	267	1800	184	350	0.110	0.076	0.144
		Dolly Varden					4*						
		Chinook					15*						
		Total					1570				0.644		
Clifford Creek	865	Coho	0+	507	514	222	1172	1971	1085	1259	1.355	1.255	1.456
		Coho	>0+	69	31	12	171	1156	105	238	0.198	0.121	0.275
		Steelhead	0+	17	11	2	71	1248	26	140	0.082	0.030	0.162
		Steelhead	>0+	13	17	4	49	269	26	82	0.057	0.030	0.094
		Dolly Varden	0+	10	12	1	71	2109	21	161	0.082	0.024	0.186
		Dolly Varden	>0+	38	5	2	77	1153	41	144	0.089	0.047	0.166
		Cutthroat					2*						
		Total					1613				1.862		

Table 4. Catches and population and density estimates for juvenile salmonids in reaches of Clifford and Cullon Creeks, B.C, in autumn 1997. Population estimates followed by an asterisk are the sum of individuals captured; too few were captured to reliably estimate population size. SE(N) = standard error of population estimate.

Stream	Section	Area (m^2)	Species	Age	Total captured	Population estimate (N)	SE(N)	Lower confidence limit	Upper confidence limit	Density estimate ($fish/m^2$)
Cullon Creek	1	185.64	Coho	0	9	9	0.69	9	10	0.05
			Steelhead	0	123	137	7.31	123	151	0.74
			Steelhead	1	11	11	0.79	11	13	0.06
			Total		143	157				0.85
Cullon Creek	2	298.08	Coho	0	79	93	8.83	79	110	0.31
			Steelhead	0	127	206	44.63	127	293	0.69
			Steelhead	1	19	20	2.11	19	24	0.07
			Dolly Varden	0	3	3*				
			Total		228	322				1.08
Clifford Creek	1	70.07	Coho	0	13	13	1.09	13	15	0.19
			Steelhead	0	8	8	0.51	8	9	0.11
			Steelhead	1	8	8	0.11	8	8	0.11
			Dolly Varden	0	8	8	0.59	8	10	0.11
			Dolly Varden	1	1	1*				
			Total		38	38				0.54
Clifford Creek	2	73.39	Coho	0	9	9	0.26	9	10	0.12
			Steelhead	0	31	33	2.74	31	38	0.45
			Dolly Varden	0	10	10	0.24	10	10	0.14
			Total		50	52				0.71

Table 5. Catches and population and density estimates for juvenile salmonids in stream pools in Cullon Creek, B.C., in January 1998. C1 = catch on first capture occasion, C2 = catch on second capture occasion, R = number of recaptures on second capture occasion. At all sites except Pool 1, too few were captured to reliably estimate population size. LCL = lower confidence limit of population estimate, UCL = upper limit.

Location	Area (m^2)	Species	Age	C1	C2	R	Total captured	Recapture rate	Population estimate	LCL	UCL	Density (fish/m^2)
Pool1	45.37	coho	0+	87	68	30	125	0.34	195	153	237	4.29
			>0+	4	1	0	5	0.00				
		steelhead	0+	25	14	4	35	0.16	77	24	130	1.70
			>0+	35	21	6	50	0.17	112	48	177	2.47
Pool 2	38.37	coho	0+	22	2	0	24	0.00				
			>0+	1	0	0	1	0.00				
		steelhead	0+	3	5	0	8	0.00				
			>0+	14	3	2	15	0.14				
Pool 3	19.29	coho	0+	2	0	0	2	0.00				
			>0+	1	0	0	1	0.00				
		steelhead	0+	6	2	0	8	0.00				
			>0+	14	6	1	19	0.07				
Pool 4	15.79	coho	0+	3	12	0	15	0.00				
			>0+	1	0	0	1	0.00				
		steelhead	0+	3	5	2	6	0.67				
			>0+	13	18	2	29	0.15				

Table 6. Numbers and proportions of different salmonid species captured in minnow traps and by electrofishing in stream reaches, pools, and beaver ponds in Cullon and Clifford creeks, B.C., in autumn and winter.

Season	Stream	Location	0+ coho		> 0+ coho		0+ steelhead		>0+ steelhead		0+ Dolly Varden		>0+ Dolly Varden		All chinook		All cutthroat	
			Total captured	Proportion in sample	Total captured	Proportion in sample	Total captured	Proportion in sample	Total captured	Proportion in sample	Total captured	Proportion in sample	Total captured	Proportion in sample	Total captured	Proportion in sample	Total captured	Proportion in sample
Autumn	Clifford Creek	Beaver pond	799	0.80	88	0.09	26	0.03	26	0.03	21	0.02	41	0.04			2	0.00
		Section 1	13	0.33			8	0.20	8	0.20	8	0.20	1	0.03			2	0.05
		Section 2	9	0.18			31	0.61			10	0.20					1	0.02
	Cullon Creek	Beaver pond	470	0.59	90	0.11	91	0.11	130	0.16	4	0.01			15	0.02		
		Section 1	9	0.06			123	0.86	11	0.08								
		Section 2	79	0.35			127	0.56	19	0.08	3	0.01						
Winter	Clifford Creek	Beaver pond	86	0.69			26	0.21	7	0.06	4	0.03	1	0.01				
		Pool 3					2	0.09	15	0.68			5	0.23				
		Pool 6							2	0.67			1	0.33				
		Pool 7	2	0.17			7	0.58	1	0.08			2	0.17				
	Cullon Creek	Pool 1	125	0.57	6	0.03	35	0.16	50	0.23					4	0.02		
		Pool 2	24	0.49	1	0.02	8	0.16	15	0.31					1	0.02		
		Pool 3	2	0.07	1	0.03	8	0.27	19	0.63								
		Pool 4	15	0.29	1	0.02	6	0.12	29	0.56					1	0.02		

Table 7. Numbers of fish captured and proportion of fish bearing marks from previous sampling at sampling sites in Clifford and Cullon creeks in winter 1998. No marked >0+ coho were captured in either stream. LP = left pelvic clip (from fall sampling in beaver ponds) and RP = right pelvic clip (from fall sampling in stream reaches).

		0+ coho					0+ steelhead					>0+ steelhead				
Stream	Location	Total captured	Number marked LP	Number marked RP	Proportion marked LP	Proportion marked RP	Total captured	Number marked LP	Number marked RP	Proportion marked LP	Proportion marked RP	Total captured	Number marked LP	Number marked RP	Proportion marked LP	Proportion marked RP
Cullon Creek	Pool 1	125	1	0	0.01	0.00	35	0	0	0.00	0.00	50	2	1	0.04	0.02
	Pool 2	24	0	0	0.00	0.00	8	0	0	0.00	0.00	15	1	0	0.07	0.00
	Pool 3	2	0	0	0.00	0.00	8	4	0	0.50	0.00	19	6	0	0.32	0.00
	Pool 4	15	0	0	0.00	0.00	6	0	0	0.00	0.00	29	2	0	0.07	0.00
Clifford Creek	Beaver pond	86	23	0	0.27	0.00	26	3	0	0.12	0.00	7	3	0	0.43	0.00
	Pool 3	0	0	0	0.00	0.00	2	0	0	0.00	0.00	15	0	0	0.00	0.00
	Pool 6	0	0	0	0.00	0.00	0	0	0	0.00	0.00	2	0	0	0.00	0.00
	Pool 7	2	0	0	0.00	0.00	7	0	2	0.00	0.29	1	0	0	0.00	0.00

Appendix 1. Length frequency histograms for coho and steelhead from Cullon and Clifford creeks.

	Clifford Creek coho	Clifford creek steelhead	Cullon creek coho	Cullon Creek steelhead
Beaver ponds				
Stream				
Winter