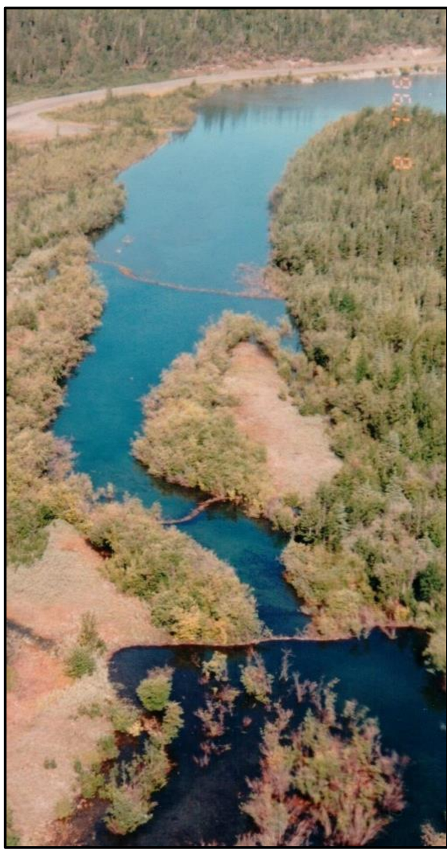
Background Paper: Management of beaver-related non-permanent obstructions to migration of Canadian Yukon River Chinook and Fall Chum Salmon.

Prepared for the Yukon Chinook Strategic Stock Restoration Initiative by A. von Finster



YUKON SALMON SUB-COMMITTEE

YUKON RIVER CHINOOK SALMON STOCK RESTORATION

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Abstract: The waters of the Yukon River Canadian Sub-Basin are almost entirely unregulated. They flow through land that has not been settled. Adult and juvenile Chinook Salmon use many of the waters for migration and other life history stages. Fall Chum Salmon migrate into a more restricted area. Beaver are abundant throughout the Sub-Basin. The dams they build may present partial- or total obstructions to upstream migrating salmon of both species. The relationship between beaver, salmon and humans is complex and has varied over time and space. This paper seeks to provide some context for the existing beaver, salmon and human relationship in the Yukon River Canadian Sub-Basin. The relationship includes management of the negative effects to salmon migration where considered appropriate.

Introduction

Salmon utilise inland waters from California to Alaska (Scott and Crossman, 1979). They have been present at low levels of abundance in the Mackenzie River Basin for an extended period (Dunmall et.al, 2013). They are well distributed in the Canadian Sub-Basin (Brown et al., 2017). This significant latitudinal and longitudinal distribution reflects the species' ability to adapt to a wide range of environments and ecosystems. The waters and lands that affected them have been shared with other organisms. In the Canadian Sub-Basin this has included invertebrates, mammals, birds and man.

Non-permanent obstructions to upstream migration of salmon are those with a reasonable expectation of being removed by nature or man. The non-permanent obstructions may be directly or indirectly attributable to human activities. Others may be generally independent of human use of the waters or lands. The obstructions may be partial or total, and the effect on salmon may vary over time.

Beaver are found throughout the Yukon River Canadian sub-basin. Beaver dams have been observed to be the major type of non-permanent obstruction to adult and juvenile Chinook Salmon and to adult Fall Chum Salmon in the Sub-Basin. Measures have been applied in some streams to manage the effects of beaver dams on upstream migration. Difficulties have been experienced in obtaining funds or legal authorization to conduct these activities. The difficulties are in whole or part due to misconceptions of the effects of beaver on upstream salmon migrations. The misconceptions are based on a long history of beaver and human interchanges elsewhere in North America, and are poorly applicable to the Canadian Sub-Basin.

The scientific/technical community has not fully addressed Yukon First Nations Traditional and Local information in decision making processes. This is important, as the duties of government were established in the preamble to Chapter 16 of the Umbrella Final Agreement (1993) between the governments of Canada, Yukon and the Council for Yukon Indians. Section 16.1.1.6 addresses the integration of management of all renewable resources; 16.1.1.7 calls for integration of the knowledge of and experience of Yukon Indian People and of the scientific communities to achieve conservation; and 16.1.1.11 requires the enhancement and promotion of the Yukon Indian People in renewable resource management.

Most control of beaver dam effects to the upstream migration of salmon in the Yukon over the past 3 decades have been conducted by Yukon First Nations. The Yukon Salmon Sub-Committee and the section of Fisheries and Oceans Canada responsible for salmon stock and habitat restoration have assisted them in acquiring funding. This has included communicating the effects of beaver dams to other parties in Canada, Alaska and more broadly.

This paper continues that process. It will provide a degree of context for the management of beaver–related obstructions to upstream salmon migration in the Canadian Yukon River Sub-Basin. A brief description of the biological and physical characteristics of the lands and waters of the Sub-Basin will be provided. The fresh water life stages of Yukon River Chinook and Fall Chum Salmon will be described. The history of beaver on the North American continent and in the Yukon will be presented. The structure and longevity of beaver dams will be described, followed by their effects on upstream salmon passage. Existing management of those effects will conclude the report.

Overview of the lands and waters of the Yukon River Canadian Sub-Basin

The Yukon River Canadian Sub-Basin is composed of watersheds. Most are based on the drainage basins of principal tributaries. The remaining two are main-stem watersheds. Each watershed contains the tributaries draining to it.

Starting at the headwaters, the watersheds are:

- Upper Lakes (aka South Mainstem) – upstream of the mouth of the Teslin River;
- Teslin River;
- Mid-Main-stem – from the mouth of the Teslin to the mouth of the Selwyn River;
- Pelly River;
- North Main-stem – from the mouth of the Selwyn River to the Yukon/Alaska border;
- White River; and
- Stewart River.

The Selwyn River is an important geomorphological boundary. It is at the downstream limit of the direct effects of the most recent glaciation. The land and waters downstream drain the remnants of Beringia, while the upstream lands and waters were glaciated.

The following description of the biophysical attributes or the Sub-Basin is largely based on the "Ecoregions of the Yukon Territory: Biophysical properties of Yukon Landscapes" (Smith et al., 2004).

Most of the Sub-Basin lies within the Boreal Cordilleran Ecozone. The extreme northern- and eastern fringe is within in the Taiga Cordilleran Ecozone. Permafrost has varied from Sporadic Discontinuous in the south to Extensive Discontinuous in the north. Significant melting of near surface and deeper permafrost is occurring, resulting in ground and slope instability.

Most of the Sub-Basin was glaciated. Early glaciations (~3 million years) were most extensive. More recent glaciations have been less so. De-glaciation of the landscape continues in the White River and Upper Lakes Watersheds. Glaciated areas may contain deep deposits of glacial, glacio-lacustrine and glacio-fluvial materials. Surface water storage in lakes and subsurface water storage in surficial aquifers tends to be high. Winter stream flows are generally adequate in quantity and quality to sustain aquatic life. Large glaciers tend to have eroded deeper into the land than the smaller glaciers that were tributary to them. The valleys left by smaller glaciers often "hang" above the deeper valleys left by the larger glaciers. Tributary streams and rivers then erode channels from the hanging valleys to join the rivers in the lower valleys. These channels are initially steep but erosion may be rapid. They may now be accessible to upstream migrating salmon if flows are adequate.

Unglaciated areas are most common in the North Main-stem Watershed. They are present at upper elevations across much of the Sub-Basin. Streams and smaller rivers are eroded directly into the surrounding land by water and flow through the resulting "V" shaped valleys. Subsurface water flowing through the underlying broken bedrock is often low in oxygen and high in dissolved materials. There are no lakes. Winter stream flows may be very low, and incapable of sustaining aquatic life.

The climate has been cool, with annual mean temperatures of ~-2^{O}C in the south to ~-7^{O}C in the north of the Sub-basin. Mean precipitation has varied from ~ 250 mm in the dry south west to ~600 mm in mountains along the eastern fringe of the sub-basin. Please note that these temperatures and precipitation are based on past conditions, and may not reflect current (2019) or future values.

Most runoff occurs during the spring freshet. Maximum instantaneous flows may happen during freshet or in response to rainfall during the open water period. Stream responses to snow melt or precipitation in the unglaciated area tends to be more rapid than in the glaciated areas.

The expected response of summer stream flows to Climate Change in the sub-basin remains uncertain. Climate models generally predict increased precipitation. Increased evapo-transpiration resulting from the warmer air temperatures is unknown (Yukon Government, 2011). A greater issue is the predicted increase in inter-annual variation in temperature and precipitation and the resulting effects to stream flows. Multi-year dry periods may be followed by periods when rivers remain in flood throughout the open water period.

Chinook and Fall Chum Salmon in the Yukon River Canadian Sub-basin – fresh water life stages and habitat utilization

Chinook Salmon have a wide geographical distribution. In North America the species is distributed from mid-California north. More southerly rivers often have two or more spatially or temporally separated populations (Scott and Crossman, 1973). Yukon River Canadian Sub-basin Chinook appear to function as a single population and will be described as such.

Adult Yukon River Chinook usually start to cross the Yukon/Alaska border in late June. They ascend most tributaries large enough to support spawning. Some migrate almost to the headwaters of the various principal- and smaller tributaries. As of 2017, spawning Chinook had been observed in more than 104 streams, rivers or segments of larger rivers (Brown et al., 2017).

Small(er) streams, large rivers, lake-outlet streams or those with intermediate physical characteristics may be used for Chinook spawning. Body sizes of Chinook spawning in main-stem rivers tend to be larger than those spawning in smaller rivers and streams (Walker, 1976). Smaller streams or rivers with low flows resulting from single- or multi-year droughts are vulnerable to beaver damming. Spawning takes place in only in flowing water and has not been observed in lakes. Ground water discharge zones in streams and rivers are not preferentially spawned in (von Finster, 2009). Spawning in the upper Canadian Sub-basin is complete by early September.

Juveniles emerge from the gravel between early May in warmer waters (von Finster 1996-1) and late June (von Finster, 1996–2) in cooler waters. Fork lengths at emergence are between 35 – 38 mm (Duncan and Bradford, 2004). Emergent juveniles may be found in still-water areas. These include the advancing margins of rivers in the spring and other still water- or low velocity habitats.

Young-of-year (0+) juveniles may remain in natal spawning streams for the first summer (de Graff, 2004). Densities of 0+ juveniles may be high and growth may be low in such streams (von Finster, 1989). A small number of juveniles move upstream (CAFN, 2003) to rearing and overwintering habitats. A larger and variable number of juveniles move downstream and ascend non-natal tributaries (Bradford et al., 2009; Taylor, 2017). The non-natal streams may be more than 1300 km distant from spawning locations (Daum and Flannery, 2012). Many non-natal streams are small and vulnerable to beaver damming. The dams increase the risk of obstructing upstream migrating 0+ juveniles (von Finster, 1987; von Finster and Mackenzie-Grieve, 2007).

Young-of-year juveniles start to enter non-natal tributaries in the Whitehorse area in early June (Moodie et al., 2000; von Finster and Mackenzie-Grieve, 2007; Bradford et al., 2001) at fork lengths between 45 – 55 mm. Entry to tributaries to the Yukon River in the Dawson area occurs about a month later (Duncan et al., 2004). Young-of-year juveniles may migrate significant distances up non-natal tributaries (Hunka and Schuyler, 1988).

Young-of-year juveniles also enter other Chinook spawning rivers. As an example, 14.3% of the juvenile 0+ Chinook Salmon captured in the Klondike River 27.1 km upstream of its mouth had emigrated into the river (Mackenzie-Grieve, 2016). In small, moderate gradient non-natal streams the 0+ juveniles were most numerous in small pools (Bradford et al., 2001). Young-of-year Chinook salmon seldom reside in completely still waters in non-natal rearing streams during the open water period. At any given time, 0+ juveniles in the upstream areas of a non-natal tributary tend to have greater average fork lengths than do those closer to the mouth (Moodie et al., 2001). High densities of 0+ juveniles may be found immediately downstream of partial- or total obstructions to upstream migration such as perched culvert crossings (Smart, 2007) or beaver dams (von Finster, 1987). Young-of-the-year juveniles may be absent or present only in low densities in waters with high turbidity, or where periods of high turbidity are frequent (Seakem, 1992). Densities tend to be low in non-natal streams after summer high water/high turbidity events (Hunka and Schuyler, 1988), implying out-migration during periods of high flows and turbidity.

Fish that feed on juvenile salmon include Slimy Sculpin, Northern Pike, Burbot, Lake Trout and Inconnu. Slimy Sculpin fed on emergent juvenile Chinook in Fox Creek near Whitehorse (D. Fulmer, pers. com.). Juvenile Chinook Salmon were found in Northern Pike stomachs in a 1985 investigation in the Lewes Marshes near Whitehorse. Stream dwelling juvenile Burbot commonly enter minnow traps and feed on juvenile Chinook (Taylor, 2017). Lake Trout and Inconnu probably prey on juveniles as they pass through lakes. Juvenile Chinook are almost absent in sections of streams after families of mergansers have passed through, inferring significant predation by these birds (DFO, 1992; Taylor, 1917). Kingfishers, gulls, and other birds are also believed to feed on juvenile Chinook. Mink appear to be a significant predator of overwintering juvenile Chinook Salmon (von Finster, 2005). No juveniles were identified in the stomachs of 219 predatory fish (Burbot, Lake Trout and Inconnu) captured in Lake Laberge during the winters of 1985 through 1989 (von Finster, 1991).

Successful over-wintering of 0+ juveniles has been documented in streams and smaller rivers (Bradford et al., 2001, Harder, 1989), in ground water fed off-channel habitats (von Finster, 2001) and in main-stem areas (DFO, 2018). Overwintering in small streams appears to be related to local ice formation and to groundwater sources (Bradford et al., 2001). Deposits of glacio-fluvial materials generally store water and release it over the winter in glaciated areas, creating overwintering habitats. Overwintering has not been documented in lakes.

Over-wintered juveniles grow rapidly in the spring. Average body mass may increase by more than 50% prior to migration from overwintering areas (Bradford et al., 2001). Relatively low numbers of 1+ juveniles are captured in the Canadian Sub-Basin after July 15 of any given year, and then usually only in spawning streams. These may become residuals, not migrate to sea, and spawn as precocious males (Fulmer, 2017; von Finster et al., 1998).

The downstream migration of 1+ chinook through Canada is not well documented. Duncan and Bradford (2006) found it closely followed the initial out-migration of 0+ juveniles moving downstream from natal streams. The 1+ migration appears to be directly to the Yukon River estuary. No excursions into tributary waters have as yet been documented.

Fall Chum Salmon enter the Yukon River Canadian Sub-Basin after the adult Chinook migration is completed. The Fall Chum typically spawn during freezing temperatures and after beaver can effectively build dams. Spawning takes place in areas where the discharge of relatively warm, high quality ground water is abundant. These areas are not common. Many are in side- or back channels, which are vulnerable to beaver damming. The juvenile Fall Chum salmon emerge early in the spring, and prior to the period when beaver can build dams.

Beaver – Continental- and Yukon history

In the past beaver were a commercially harvested species in many areas of North America. The species was extirpated in much of the southern portion of their range. They are now environmentally or socially iconic as a symbol of conservation for much of urban North American society. Their present social values tend to be to some degree fractured between rural areas where interests are directly affected by the species and urban areas where interests are not affected.   This is not confined to the Yukon: Needham et.al. (2010) conducted a survey on social attitudes across the US state of Oregon. They found that those people who had lands or interests affected by beaver were likely to support control of the species. Conversely, those with urban residential lots that were not affected by beaver were likely to believe that control was not necessary.

Social attitudes on beaver management in the Yukon have been affected by those of North American Society. It is useful to have a very brief overview of the history of continental human-beaver interactions.

There is uncertainty as to the sequence of the original peopling of the Americas. Current thought postulates both an interior- and a coastal dispersal from Beringia southward (Potter et al., 2018). Beaver were present prior to human occupation south of the glaciated area. In northwestern Canada both beaver and humans moved into lands that had recently been covered by glaciers as the last ice age ended.

Scientific/technical estimates of continental beaver abundance are generally stipulated as those existing immediately prior to Eurasian contact. Pollock et al. (2003) refer to a population estimate of 80 – 400 million made in 1929 by Thomas Seton, a prominent author of animal fiction. Pollock was more conservative and provided an estimate of around 55 million. The estimates were based on observed- or reported numbers of beaver along some length of stream (ie beaver per lineal mile or kilometer) or area of lake/pond (beaver per square mile or kilometer). This was then multiplied by an estimate of the total lengths of streams and areas of lakes/ponds in North America. The estimates of beaver abundance do not appear to address the pre-contact use and management of beaver by the various indigenous peoples.

Beaver appear to have been largely extirpated from the continental United States as a result of trapping and land settlement. References to the extent of beaver reduction tend to be local to individual states or features. Statements in reviews of scientific/technical information on beaver reflect this, and to be very general in nature (Baker and Hill, 2003; Pollock et al., 2003). Government sponsored introductions of beaver and unassisted recolonization appear to have returned beaver to all- or most of their past range. In the eastern and southern parts of the United States beaver have resulted in negative impacts to infrastructure or other resources. Regulatory attitudes have changed as a result. In Mississippi beaver were heavily trapped, nearly extirpated, then protected and are now considered a nuisance species and subject to state-funded control (Shwiff et al., 2011). The western and Pacific areas of the United States pose an interesting situation. The Wildlife Services of the federal Department of Agriculture has been killing beaver. The Fish and Wildlife Service of the Department of the Interior appear to be advocates of beaver (Pollock et al., 2015).

The fur trade was a foundational economic activity in what is now western- and northern Canada. The Hudson's Bay Company (HBC) was incorporated in 1670 and maintained some degree of monopoly over much of the fur trade into the late 19th century. The "made beaver" became the currency of the HBC (McKay, 1967). Beaver were becoming depleted in Western Canada by the early 19th century. George Simpson became Governor of the HBC in 1821. In 1824 he initiated a program of beaver conservation. Certain of the HBC trading establishments were told not to purchase beaver pelts from local trappers. However, trappers simply took the pelts south and sold them to American traders. The market for beaver pelts collapsed in or about 1843 as silk hats replaced beaver (Ray, 1975). Beaver pelts continued to be traded, but at a lower valuation.

In what is now the Yukon River Canadian Sub-Basin, indigenous peoples closely followed the retreating glaciers as the glacial period ended. They camped beside the remaining peri-glacial lakes (Heffner, 2008). Movement into the de-glaciating lands and waters by beaver and indigenous humans was probably roughly synchronous. Both have occupied the land since then. Beaver were eaten, their teeth were used as cutting tools and bone and their pelts were used for a wide range of purposes. First Nations pursued spring beaver hunts (Weinstein, 1992; Mishler and Simeone, 2004; Vuntut Gwitchin First Nation and Smith, 2009; McClennan, 1975) and trapped or otherwise harvested beaver during the remainder of the year. They did so in accordance with their laws and codes of conduct.

Pre-contact trading occurred between the inland and coastal indigenous peoples. It was augmented from the 1730s onward by trade with the Russians though intermediary First Nations. Existing trading routes and relationships were followed. The Hudson's Bay Company entered the market somewhat later through an agreement with the Russian government (Wright, 1976). Coastal Chilkat traders penetrated well into the interior for furs (YHMA, 1995; Glave, 2013) to trade on the coast. Beaver pelts were included with those of other furbearers. Beaver at the time were scarce along the coast of British Columbia and Alaska (Emmons, 1991).

The industrial fur trade did not directly penetrate the upper drainage of the Yukon River until the 1840s when the Hudson's Bay Company entered. Bell established Lapierre House in 1846; Murray established Fort Yukon in 1847; and Campbell established Pelly Banks in 1845 and then Fort Selkirk in 1848 (Wright, 1976). As noted above, the core market for beaver pelts collapsed in or about 1843. Beaver were not extirpated or reduced to low levels of abundance in the Yukon River Canadian Sub-Basin to satisfy the European hat market.

Pressure on Yukon beaver may have occurred later, although this is arguable. High beaver pelt prices during the Great War resulted in a perception of depleted populations. The Commissioner of the Yukon closed beaver trapping from 1918 – 1924. Similarly, high beaver pelt prices during and after World War II resulted in a trapping closure from 1946 to 1949. "Perception" is used advisedly, as McCandless (1985) was not convinced that the closures were based on actual biological data. Beaver pelt prices fell significantly during the period of closure and were low when trapping could legally resume in 1949. The price of pelts has remained low since then.

Wildlife management is a responsibility of the Yukon Government. In 1949 the Yukon Territorial Government (now Yukon Government) imposed a system of registered trap line concessions on the people of the Yukon. The owner of the trapping concession was granted harvesting rights to the fur bearing animals within its boundaries. This included beaver. First Nations could not hunt or otherwise harvest beaver unless they owned the trapping concession.

Since the signing of the Yukon Land Claims Umbrella Final Agreement in 1993 citizens of Yukon First Nations may harvest fur-bearing animals for food. They may also trade non-edible wildlife products with members of Yukon First Nations.

The relative abundance of beaver in the Yukon is not monitored. The Yukon Government has no public estimate of total or regional abundances. As the species does not generate meaningful economic returns it has been difficult to justify public expenditures in its management. It is widely believed that Beaver numbers have increased and in the Yukon and are high today (Urquhart, 2000; Cruikshank, 1990; Jang, 2001).

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Beaver Dams – Structure and Longevity

Effects of beaver behavior on upstream migrating salmon may be separated into three broad types. The first type includes those beaver that tunnel into, or build lodges on the banks of rivers or the shores of lakes. These are locally called "bank beavers". They pose no risk to salmon unless their behaviour changes and they move into smaller streams.

The second type of beaver behaviour is where the beaver dam lake outlets. These dams must have a measurable influence on the level of the lake waters. Lake outlet dams have been documented at Fox Lake near Whitehorse (Zealand, 1986) and Hutshi Lake (Pumphrey, 2002) at the head of the Nordenskiold River and others. These dams may significantly reduce downstream creek flows and result in insufficient volumes of water to allow Chinook salmon spawning. Lake outlet dams may suddenly fail and release significant volumes of water (Pumphrey, 2002). Breaching lake outlet dams should not be necessary for salmon passage and is not recommended.

The third type of beaver behaviour is where the beaver dam streams. Dams on smaller rivers, streams, and spring brooks are used by a "beaver colony". Each beaver colony includes a primary dam. This is almost always the first one built. The beaver residence (aka lodge, house) is located in the pond created by the primary dam. Secondary dams may be constructed upstream and/or downstream of the Primary Dam (von Finster and Mackenzie-Grieve, 2007). Downstream secondary dams usually backwater the creek to the toe of the next dam located upstream. Upstream secondary dams are generally located at the upstream end of the pond resulting from the primary (or next secondary upstream) dam. Beaver dams in streams have the potential to obstruct salmon.

Beaver colonies in streams are very widely distributed across the Yukon's landscape. They are increasingly observed above treeline in mountainous terrain (Jung, 2017). Spring brooks (ground water fed channels) in rivers with well-developed floodplains and the lower reaches of small tributaries are regularly dammed (Taylor, 2017; de Graff, 2011).

Numbers of beaver dams in streams in unglaciated terrain have been limited by the rapid response of stream flows to precipitation and the resulting floods. Dams are rare and short lived in the confined valleys typical of this terrain (von Finster, 2012). Dams may be built in smaller streams where they enter river bottom lands.

Streams in glaciated terrain generally flow through wider valleys and have stepped gradients. Lower gradient sections supporting beaver colonies are separated by higher gradient sections without colonies. Most dams in lower gradient areas will fill with sediment in a relatively short period of time.

Most primary scientific/technical literature addressing the various effects of beaver dams is discipline- or interest specific (Butler and Malanson, 2005; Westbrook et.al., 2006; Woo and Waddington, 1990). They provide little information on the physical structure(s) or longevity of beaver dams.

There are few classification systems in the scientific literature regarding types of dams. This may reflect differences between the scientific communities and management agencies. The management agencies should have guidance to determine where, when and how beaver are to be controlled. Determination of the different processes of beaver management across the range of the species would be a fertile field of research. However, it is beyond the scope of this paper.

Two projects that classified beaver dams were found in the scientific literature and are briefly described below. Woo and Waddington (1990) classified beaver dams on a section of the James Bay coastal plain in northern Ontario. They classified dams on the mode of outflow. Most active dams had "overflow", where the top of the dam was level and the outflow was diffused across it. Some active dams had "gap flow", where the outflow was concentrated at one or more points. All inactive dams had been breached or had "underflow" through a failed portion of the dam.

Malison et.al. (2014; 2015; 2016) conducted a series of investigations on beaver effects on salmon in a coastal river valley bottom in western Alaska. She classified sections of stream channel and spring brooks as early, mid- and late successional. The term "successional" was related to the vegetation surrounding each channel and by implication the stability of the channel and the surrounding valley floor. Early successional streams might be blocked by a dam, while mid- and late successional streams or stream segments were almost always behind one or more dams.

In the Yukon, DFO Habitat staff in Whitehorse were concerned with the effects of beaver dams on fish movements in the early 1990s. They were also concerned with actions that were being used to remove beavers and dams such as explosives, heavy equipment and petro-chemical agents. A set of area-specific Draft Guidelines were prepared as part of DFOs National Fish Habitat Action Plan. The Guidelines were based on the type of stream in which the dam was built. It included notes on the cross sectional structure of beaver dams. They advocated hand breaching of beaver dams where necessary.

The Draft Guidelines were field tested internally. They were then distributed to other governments and consultants for use and comment. Comments were addressed in the final draft "Guidelines for the Management of Beaver in Fish Bearing Streams in the Yukon" (DFO, 1999) and were implemented. A change in Canadian federal government policies resulted in DFO moving toward National Guidelines (or "Codes of Practice") and abandoning area-specific guidelines. However, no beaver related Code of Practice was prepared for beaver effects, despite concerted efforts to do so.

The longevity of dams tends to be poorly documented in the scientific/technical literature. Statements regarding the non-permanent nature of dams are common (Kemp, 2010; Pollack et.al., 2015; Baker and Hill, 2003) but are seldom based on actual dates of dam initiation and failure. Most reports only provide a description of the downstream effects of one or more dam's failure (Hillman, 1998; Case et.al., 2003; Westabrook et.al., 2006) but not of the age of the dam(s). This is a serious shortcoming, as many of the statements made regarding the potential benefits of dams have an implicit assumption that each dam will remain in place for an extended period.

Von Finster and Mackenzie-Grieve (2007) investigated of juvenile Chinook Salmon – beaver interactions to gain some insight on the longevity of dams in glaciated terrain in the Canadian Sub-Basin. The longevity of dams were also monitored during the Fox Creek Chinook Salmon Stock Restoration Project and preparations for it.

None of the dams monitored in Croucher- or Fox Creek lasted more than ~3 years. Most were abandoned following structural failures: two failed after the adjoining valley walls had eroded around an end of a dam; one failed due to a flow path forming under the dam; and one filled with sediment. Both creeks flow through secondary valleys eroded into weakly consolidated (~10,000 year old) glaciofluvial and glaciolacstrine soils. It is likely that beaver dams on other creeks would last for longer or shorter periods. This would depend on the characteristics of the lands they flow through, the sediment sources they abut, the volumes of water they carry and the stream gradients that they are confined to.

The time between beaver damming events in the YR Canadian Sub-Basin can be determined to some extent by the age of the flooded and dead riparian forest within the footprint of the pond. Climax old growth riparian forests in this area are generally composed of white spruce and are nominally 100 years or more in age. Destroyed old growth white spruce forest was documented in 1999 at Michie Creek (von Finster, 1999) implying that no dams had been built in the preceding century. Areas of dead spruce have since been observed in association with active and inactive beaver dams across the south and central Yukon. Old growth white spruce forest destruction is presently (2019) occurring behind a beaver dam on the west side of the Alaska Highway at Wolf Creek near Whitehorse.

Effects of Beaver dams on adult Chinook and Chum Salmon passage.

Salmon passage and beaver dams will be examined in a continental- and then a local context. There is wide agreement that the effects of beaver on upstream fish passage may be species or life stage specific, or depend on environmental/hydrological conditions (Kemp, 2010; Pollock et.al, 2003; Grieve, 2000; Mitchell and Cunjak, 2007; Mallison et.al., 2014, 2015, 2016; Pollock et.al., 2015).

In Pacific and Western North America, consideration of the potential effects of beaver dams on the upstream migration of fish has generally been limited to resident trout, charr and salmon Rainbow Trout (Steelhead) and coastal Coho Salmon are most often referred to. The upstream passage of juvenile Coho Salmon over beaver dams has generally been based on their presence in waters upstream of one or more dams. However, evidence has not been presented proving that the juveniles actually migrated over the dam (Murphy et al., 1989). They could be the progeny of fish that spawned above the dam or had entered the beaver dam due to flood plain inundation from larger channels.

There are a number of reviews that describe the effects of beaver on fish movements and other resources (Baker and Hill, 2003; Pollack et al., 2003 & 2015). The reviews tend to minimize the potential for beaver dams to obstruct upstream fish migration. Pollack et al. (2015) provides a good example. He noted that beaver dams may obstruct passage under low stream flows and then speculated that, regardless of flows "…salmon and trout *are able to* (emphasis added) jump sufficient heights to…clear the dams". The supporting reference given (Powers and Orsborn, 1985) is specifically limited to the effects of waterfalls and/or culverts on upstream fish passage. The reference is therefore largely inapplicable, as beaver dams are structurally different than water falls or culverts.

A shortcoming of scientific reviews is that they tend to be limited references to formal, refereed publications. It is likely that most of the available information on beaver related fish passage issues has been generated or otherwise recorded by operational government management staff, consultants, First Nations or salmon stewardship groups. It is therefore in the "gray literature". There are numerous examples of beaver related Pacific Salmon issues in the gray literature. Examples include Pehl (2009) found few juvenile Coho above a beaver dam in the interior of British Columbia and abundant Coho in an adjacent un-obstructed ground water channel; Cooperman et.al. (2006) determined that beaver dams limited the use of constructed ground water channels in the interior of BC by juvenile salmon; and Gottesfeld and Latremouille (2011) identified beaver dams as a recurring issue with upstream passage of adult sockeye in a spawning stream. The public press is also a valid source of information as it can reflect the immediacy of an issue such as fish passage.

Additionally, scientific reviews tend not to access written or orally transmitted multi-generational local/traditional/indigenous knowledge. In the Canadian Sub-Basin, an example of this knowledge may be found in Cruikshank (1990). She transmits the wisdom of the late Mrs. Annie Ned (born sometime in the 1890s) who recounted, in respect of the extirpated Chinook Salmon population of what is now the Mendenhall River: "…king salmon used to go up…to Ten Mile Lake, but in my time there were too many beaver and king salmon didn't go through."

The main-stem spawning areas of the Yukon River or its principal tributaries are too large to be dammed by beaver. There is an undefined number of smaller spawning rivers and streams that may be beaver dammed when stream flows are lower than normal. A smaller number of Chinook spawning streams may be vulnerable to damming by beaver in virtually all years. Unfortunately, these include some of the Canadian sub-basins most productive streams.

No systematic assessment of the geographical extent of beaver damming of Yukon River Chinook spawning streams has yet occurred. However, beaver dams have been observed or reported on a number of spawning streams over the decades. These include Kirkman Creek, Tatchun River, Michie Creek, Byng Creek, M'clintock River, Wolf Creek, McIntyre Creek, Ibex River, Blind Creek, Nordenskiold River, Incised Creek; Mica Creek; Needlerock Creek; Swift River (North), Fox Creek, Bearfeed Creek, Janet Creek and Squanga Creek. Other Chinook spawning creeks are considered vulnerable on the basis of the size of their watershed areas or the potential buffering of downstream flows by lakes. These include Tincup Creek, Pleasant Creek, Emerald Creek, Ollie Creek, Drury Creek, Northern Creek, Little Kalzas River, Earn River, Glenlyon River, Wolf River, Red River, and One Hundred Mile Creek. Finally, Beaver damming has been associated with the extirpation of Chinook Salmon spawning populations in Klusha Creek and the Mendenhall River.

Yukon River Canadian Sub-basin adult Chinook Salmon have a narrow period of time in which to spawn. Information of dates of duration – that is, the dates of first and last entry - to smaller Chinook spawning streams is limited. However, Tatchun River had an average duration of Chinook Salmon entering the stream of 19 days between 1997 and 1999 (Otto, 1998a, 1998b and 1999). Blind Creek had an average duration of the majority of the Chinook entering the stream of about 17 days over 16 years of data (Wilson, 2015). Both streams had enumeration fences and accurate counts of the salmon. Both enumeration projects counted the majority of the migration, and a small number of fish probably entered before and after the fence was put in place.

Summer low flows may occur when adult Chinook enter their spawning streams. This is in contrast to coastal Coho Salmon, which can wait for autumn storms to increase flows over beaver dams. The adult Chinook lack the ability to hold below beaver dams for extended periods waiting for increased flows. Additionally, adults holding below beaver dams are vulnerable to predation by bears and other mammals.

The health of individual Chinook Salmon migrating upstream, or appearing at the spawning grounds is not well understood. They may be affected by higher water temperatures during upstream migration, particularly under low water/warm water conditions. They may also be negatively affected as a result of gill nets encountered and escaped from on their long migration upriveer: many adult salmon at the Whitehorse Rapids fish ladder show gill net scars. The returning adult Chinook Salmon may simply lack the energy to be able to swim over or around beaver dams or to evade the predators below the dams.

Fall Chum Salmon spawn in relatively confined geographical areas of the Sub-Basin. Most of the spawning habitat is not vulnerable to beaver damming. However, some ground water fed back channels are vulnerable, particularly in low water years. Beaver dams may be built in summer and obstruct the upstream migration of adults into the sloughs when the Fall Chum Salmon appear in late autumn. This occurred at the Glacier Creek Slough complex on the Kluane River. A major spawning location was totally obstructed by a beaver dam near the mouth (von Finster, 1996-3).

Effects of Beaver dams on juvenile Chinook Salmon passage

The upstream migration of juvenile Yukon River Chinook Salmon into non-natal tributaries was first identified in the 1970s (Walker, 1976). Juvenile overwintering was identified in 1989 (Harder, 1989) and was investigated in some detail by Bradford et.al. (2001). The large numbers of juveniles captured established the importance of small, non-natal streams for juvenile rearing and overwintering.

In 1986 a very rough estimate of 50% of available juvenile Chinook Salmon rearing habitat being located upstream of at least one beaver dam had been determined for the south- and central Yukon (von Finster, 1986). The estimate was in response to a request by DFO Pacific Region for local offices, such as Whitehorse, to assess the effects of beaver activities on salmon habitats. An investigation of the effect of beaver on juvenile Chinook Salmon upstream passage was initiated.

The investigation took place on Flat Creek, a known Chinook Salmon rearing stream. The stream had an active beaver dam about 5 km up from the mouth. The dam had a maximum height of 1.7 meters. Some of the outlet flow crossed the forest floor at each end of the dam. This type of beaver dam allowed limited opportunities for juveniles to pass the dam. On September 3, 1986, 5 salmon roe baited minnow traps were set downstream of the dam, 3 were set in the still waters of the beaver pond, and 2 were set in a free flowing section of the creek upstream of the pond. A complete obstruction was located about 100 meters above the upstream limit of the pond, limiting further dispersion. Traps were pulled on September 4. Captures of juvenile 0+ Chinook Salmon downstream of the dam averaged 36.5 juveniles/trap. No juveniles were captured in the pond. An average of 15 0+ juveniles/trap were captured above the pond. Fork lengths of 0+ juveniles captured downstream of the dam had a range of 56-81 mm, and averaged 66.34 mm. Those captured upstream of the dam and pond had a range of 70-84 mm and averaged 76.83 mm (von Finster, 1987). This investigation indicated that a dam could partially obstruct the upstream movement of some or most juvenile Chinook Salmon. It demonstrated that juveniles would congregate below an obstruction such as a beaver dam.

It also provided insight into the complexity of Yukon River Chinook rearing streams, and the difficulty of measuring the effects of one or more beaver dams on the upstream migration of juvenile 0+ salmon. Juvenile Chinook Salmon grow best when they have abundant food. It is likely that lower levels of abundance would result in less energy expended in social interactions with other juveniles. An example of this was observed in Clinton Creek, where a 0+ juvenile Chinook attained a fork length of 111 mm (von Finster, 2007). The 0+ juvenile was in a sparse population located at the upstream limit of passage in an area of unlimited food supplies. Juvenile 0+ Chinook Salmon below obstructions, conversely, will congregate. They will access to less food and face increased completion from other juveniles. Providing upstream access to juveniles that are concentrated below beaver dams (or other obstructions) should result in the fry being able to distribute themselves along the creek and to benefit as a result.

Management of the effects of beaver dams on salmon passage in the Yukon River Canadian Sub-Basin

Most management of the effects of beaver to upstream migration of salmon in the Canadian Sub-Basin since the mid-1990s has been conducted by First Nations. The First Nations have conducted this in accordance with their laws and customary practices. A smaller number of beaver dams have been breached by Fisheries and Oceans staff and Stream Stewardship groups.

Beaver dams have typically been breached. The dams have been pulled apart by hand to form the breach. Small tools such as axes, rakes, and come-alongs are often used. Chains saws have been used but are hazardous. Breaches have generally been located at the pre-existing channel. The breachs have been wide- and deep enough for the salmon to migrate upstream. The Yukon Salmon Sub-Committee (YSSC) have developed a video to assist persons that wish to breach dams. The video is Adult Chinook Restoration Strategies: Breaching Beaver Dams and can be found on YSSC's website (www.yssc.ca).

Beaver dams have been breached to maintain existing Chinook Salmon spawning populations. This has included streams with small populations of spawning Chinook Salmon but with high social/cultural value. Some examples have included McIntyre Creek near Whitehorse (TKC, 2011) and Mica Creek near Pelly Crossing (Klugie et.al., 2003). Breaching of beaver dams has also occurred on streams with large(r) and even major populations. Examples include Tatchun River near Carmacks (Brown, 2003) and Michie Creek near Whitehorse (KDFN, 2005).

Beaver dams have been breached to restore Chinook Salmon spawning populations. This has occurred at Wolf Creek (YFGA, 2003) and Fox Creek near Whitehorse (Fulmer, 2017). Beaver dams were breached on Klusha Creek, tributary to the Nordenskiold River in the late 1990s by the Little Salmon/Carmacks First Nation to restore an extirpated Chinook Salmon population. Adult Chinook Salmon moved into the creek to spawn in 2001 (von Finster, 2001). However, flows in the creek were reduced to levels inadequate to support spawning in each of 2003 and 2004 (Jang, 2004) and the project was abandoned. This was thought to have resulted from a long term drying trend in the Yukon (Fleming and Clarke, 2005). It is now attributed to climate change.

Beaver have been removed through trapping or shooting (Brown, 2000; von Finster, 2000; Fulmer, 2017). This has generally been conducted by First Nations, who then use the beaver carcasses in traditional ways. Removal of the beaver also reduces risk of spawning habitat being backwatered and degraded under- or in the zone of influence of beaver ponds. These ponds may flood or backwater formerly productive salmon spawning areas.

Juvenile Chinook Salmon are much more widely distributed in the Sub-Basin than are the adults. They may use much smaller streams to rear and overwinter (Bradford et al, 2001). The juveniles are small, hard to see and do not attract large predators such as eagles or bears. This makes obstructions more difficult to find. However, drones are starting to be used to locate beaver dams on known Chinook rearing streams. The dams can then be investigated to determine whether they are obstructing juvenile Chinook Salmon.

Both First Nations and Stream Stewardship groups have breached dams to allow juvenile Chinook Salmon to migrate upstream. On a technical level, breaches in beaver dams have to be considerably deeper than those for adult salmon to allow the much smaller fish to pass the dam. As the period of upstream migration for juveniles is longer than those of the adults the breach should be maintained for a longer period of time.

An alternate method is to capture juvenile 0+Chinook Salmon below beaver dams using salmon roe baited minnow traps. The juvenile salmon can be released immediately above the dam, and most or all will then move upstream. This reduces the potential to disturb both the beaver and the juvenile Chinook. The YSSC have developed a video to assist persons that wish to move juveniles above dams. The video is Juvenile Chinook Restoration Strategies: Bypassing Beaver Dams and can be found on YSSC's website (www.yssc.ca).

Finally, management of the effects of beaver dam obstructions to upstream migration of salmon in the Canadian sub-basin should be done in a legal manner. The administrative and legal environment of the Yukon has been, and will continue to be, subject to constant change. We cannot anticipate the changes or the direction they may take. It is advisable to contact the Yukon Government Conservation Officer, the relevant First Nation(s) and Fisheries and Oceans Canada if you are planning to manage the effects of beaver on upstream salmon migration. These organisations are responsible for administration of the laws that may affect your project.

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