Articles

Catalog of Chinook Salmon Spawning Areas in Yukon River Basin in Canada and United States

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Abstract

Chinook Salmon *Oncorhynchus tshawytscha* return to the Yukon River in northwestern North America each summer, migrating to spawning destinations from the lower river to more than 3,000 km upstream. These returns support numerous fisheries throughout the basin. Despite a long history of fisheries research and management, there is no comprehensive account of Chinook Salmon spawning areas in the basin. To address this issue, we cataloged, summarized, and mapped the known spawning areas of Yukon River Chinook Salmon by using a variety of sources including published articles, gray literature, and information archived in agency databases. Most of our sources were published within the past 30 y, but some refer to observations that were recorded as long ago as the late 1800s. We classified spawning areas as major or minor producers with three indicators of abundance: 1) quantitative estimates of escapement (major producer if $\geq$500 fish, minor producer if $<$500 fish), 2) radiotelemetry-based proportions of annual production (major producer if $\geq$1% of the run, minor producer if $<$1% of the run), and 3) aerial survey index counts (major producer if $\geq$165 fish observed, minor producer if $<$165 fish observed). We documented 183 spawning areas in the Yukon River basin, 79 in the United States, and 104 in Canada. Most spawning areas were in tributary streams, but some were in main-stem reaches as well. We classified 32 spawning areas as major producers and 151 as minor producers. The Chinook Salmon spawning areas cataloged here provide a baseline that makes it possible to strategically direct abundance, biological sampling, and genetics projects for maximum effect and to assess both spatial and temporal changes within the basin.

Keywords: Chinook Salmon; spawning; Yukon River

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Introduction

Chinook Salmon *Oncorhynchus tshawytscha* return to the Yukon River in northwestern North America each summer, migrating to spawning destinations from the lower river to more than 3,000 km upstream from the Bering Sea (Evenson et al. 2009; Eiler et al. 2014). These returns are comprised of stream-type fish with most individuals rearing in freshwater for a year before migrating to sea (Healey 1991). Most returning adults range from 4 to 7 y of age (Healey 1991; Schumann and DuBois 2011; JTC 2016). Almost all of the younger fish (age 4 y) are males, whereas most of older fish (ages 6 and 7 y) are females. Escapements are usually composed of more males than females (Hyer and Schleusner 2005; Eaton 2016; JTC 2016), in part because of additive marine mortality of females that remain in the sea for 1–2 y longer than most males (Healey 1991; Bugaev and Shevlyakov 2007; Myers et al. 2009) and in part because of size-selective fishing mortality on larger individuals during years when substantial large-mesh gillnet fisheries are permitted in the river (Evenson et al. 2009; Hard et al. 2009; Bromaghin et al. 2011). After spawning, Chinook Salmon die, contributing nutrients from the sea to their natal streams (Cederhom et al. 1999).

Chinook Salmon have supported commercial, subsistence, recreational, and aboriginal fisheries within the Yukon River basin for decades but experienced notable declines in abundance beginning in the late 1990s (Evensen et al. 2009; Schindler et al. 2013; JTC 2016). These declines have led to a series of fishery restrictions, including basin-wide closures in 2014 and 2015, and several failures to achieve the internationally agreed upon passage goal into Canada (JTC 2016). Declines in average age and length-at-age of annual returns have also been reported (Bigler et al. 1996; Hyer and Schleusner 2005; Lewis et al. 2015), suggesting that Chinook Salmon stocks in the Yukon River are exhibiting signs of fishing-induced evolutionary changes (Hard et al. 2008; Bromaghin et al. 2011). Rural fishing communities are concerned the bountiful Chinook Salmon runs they depended on previously may not return (Loring and Gerlach 2010). In response to the observed declines in abundance, demographic changes, and subsequent fishery restrictions, there has been a tremendous increase in Chinook Salmon research throughout the basin, guided in part by expert panel recommendations (ADFG Chinook Salmon Research Team 2013; Schindler et al. 2013; JTC 2016). It is our perspective that a thorough accounting of spawning areas in the basin would be useful for many of these research efforts.

Despite the long history of Chinook Salmon research and management within the Yukon River basin (Pennoyer et al. 1965; Evenson et al. 2009; JTC 2016), there is no comprehensive account of spawning areas in tributary rivers and main-stem reaches. Our primary objective in this study was therefore to document and map Chinook Salmon spawning areas throughout the Yukon River basin by using a wide range of data sources. Our secondary objective was to highlight the largest populations by classifying spawning areas as either major or minor producers based on three indicators of abundance: 1) quantitative estimates of escapement (major producer if $\geq$500 fish, minor producer if $<$500 fish), 2) radiotelemetry-based proportions of annual production (major producer if $\geq$1% of the run, minor producer if $<$1% of the run), and 3) aerial survey index counts (major producer if $\geq$165 fish observed, minor producer if $<$165 fish observed).

Methods

Study area

The Yukon River basin is the largest in Alaska and the fifth largest by drainage area in North America (Revenga et al. 1998). It drains an area of more than 850,000 km^2, approximately 500,000 km^2 of which is in Alaska (Brabets et al. 2000). The Yukon River flows more than 3,000 km from its headwaters in northern British Columbia, Canada, to its mouth at the Bering Sea. Average annual flow near the Yukon River mouth is approximately 6,400 m^3/s, although peak flow in early summer averages about 20,000 m^3/s and extreme flow during flood conditions could exceed 25,000 m^3/s (Curran et al. 2003). There are six major tributaries in the Yukon River basin (tributaries that contribute 5% or more to the total area drained and 5% or more to the total flow) including the Pelly, White, and Stewart rivers in Canada; the Tanana and Koyukuk rivers in the United States; and the Porcupine River that transects both countries (Brabets et al. 2000). The White and Tanana rivers originate in heavily glaciated mountains in the Wrangell, St. Elias, and Alaska ranges, and they are the primary sources of suspended sediment in the Yukon River. The Tanana and Porcupine rivers are the two largest tributaries in the basin, with drainage areas of more than 114,000 and 116,000 km^2, respectively. Despite the similarity in drainage areas, the Tanana River contributes approximately 20% of the total flow in the Yukon River basin, whereas the Porcupine River contributes less than 10%. Hundreds of small tributaries also flow into the Yukon River main stem including tundra-stained streams that meander across soft silty substrates, clear-water streams flowing over gravel, and turbid rivers that seasonally cascade from glaciers in surrounding mountains.

We subdivided the basin into nine geographic regions to illustrate the distribution of spawning areas within the river system. Regions in which all or nearly all of the drainage area are in the U.S. section of the basin included the lower Yukon River downstream from the Koyukuk River mouth (R1), middle Yukon River from the Koyukuk River mouth to the Tanana River mouth including the Koyukuk River drainage (R2), Tanana River drainage (R3), and upper Yukon River from the Tanana River mouth to the U.S.–Canada border (R4). The Porcupine River drainage (R5) flows through both U.S. and Canadian reaches of the basin. Regions in which all or nearly all of the drainage area are in the Canadian section of the basin included the northern Yukon River from the U.S.–Canada border to the White River mouth including the Stewart River (R6), the Yukon River main stem from the White River mouth to the Teslin River mouth including the White River and numerous smaller tributaries (R7), Pelly River drainage (R8), and the upper headwaters from the Teslin River mouth upstream including the Teslin River and other headwater rivers (R9).

Table 1. Three indicators of abundance that were used to classify Chinook Salmon *Oncorhynchus tshawytscha* spawning areas compiled in 2017 for the Yukon River basin as either major or minor producers. Included for each abundance indicator are numerical criteria for classification, the relative confidence hierarchy, and the time periods in which data were available.

Abundance indicator	Major producer	Minor producer	Confidence	Time period
Escapement estimates	≥500 fish	<500 fish	Highest	15–30 y ago to present
Telemetry proportions	≥1% of run	<1% of run	High	2002–2004
Aerial survey counts	≥165 fish	<165 fish	Less	Variable: 1960–present

Data sources

We reviewed a large selection of published literature, agency reports, and databases and also other less formal documents for evidence of Chinook Salmon spawning in specific streams or main-stem reaches within the Yukon River basin. Locations were classified as spawning areas if there was consistent and compelling evidence presented, such as repeated observations of prespawning or spawning fish, the presence of redds or postspawning carcasses, or other similar observations. A spawning area could be a 10-km reach downstream from a lake outlet or a 100-km reach along the main-stem or tributary river. A stream might be classified as a single spawning area if the distribution of spawning Chinook Salmon seemed to be relatively continuous even when spawning was occurring along the main stem as well as in one or more tributaries. Alternatively, a stream with discrete aggregations of spawning fish (e.g., spawning in two or more separate forks) would be classified as more than one spawning area. Strong evidence of a spawning area included streams with a history of abundance monitoring projects such as weirs (e.g., Collin et al. 2002; Mears 2015; Wilson 2017), counting towers (e.g., Brase and Doxey 2006; Savereide and Huang 2014), mark–recapture

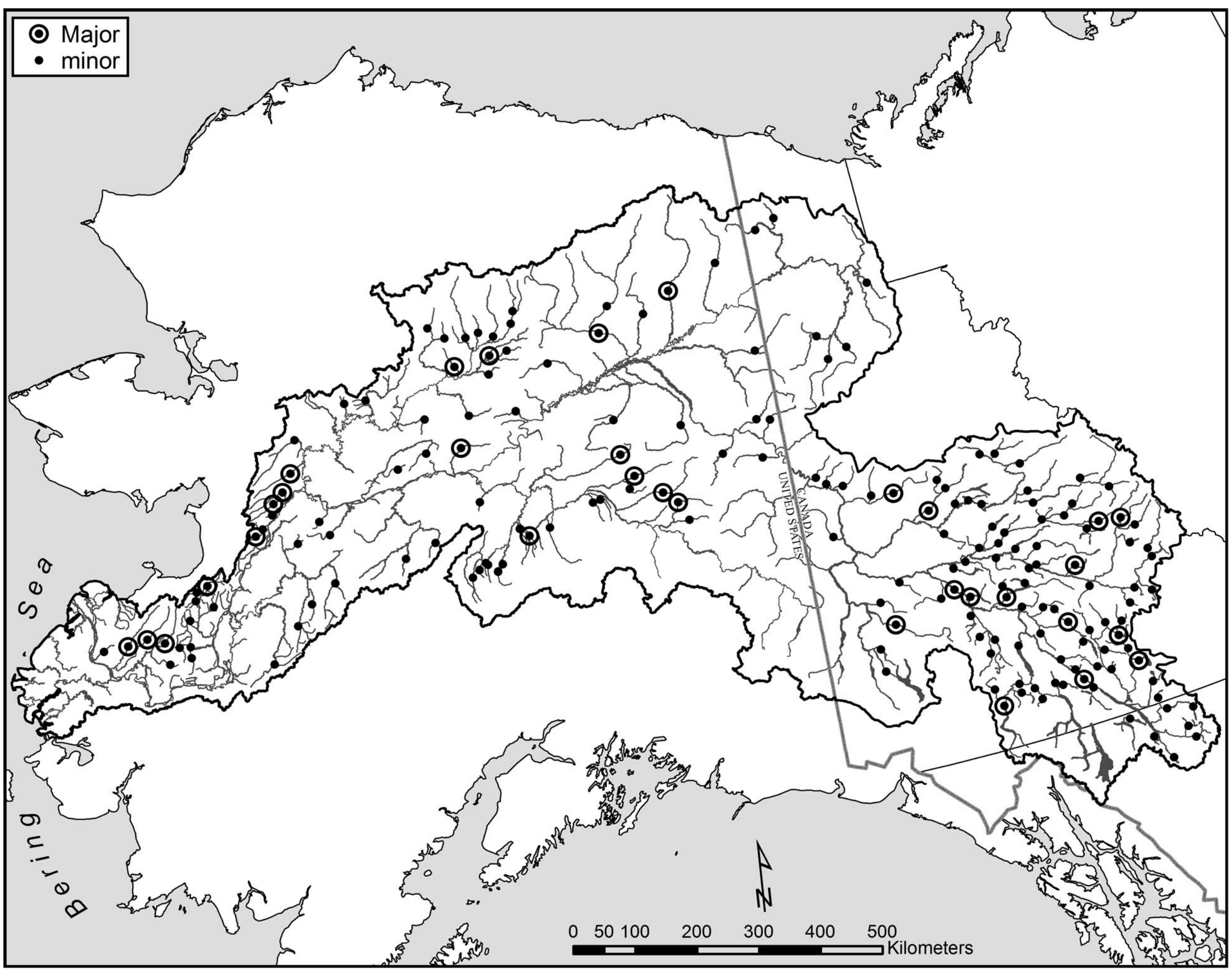

Figure 1. The distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas compiled in 2017 for the Yukon River basin in Canada and the United States. Spawning areas were classified as being major or minor producers based on three quantitative indices of annual abundance. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

Table 2. Chinook Salmon *Oncorhynchus tshawytscha* spawning areas compiled in 2017 for the Yukon River basin ordered by region then alphabetically by name, including river kilometer to stream mouth or start of main-stem spawning reach, the location of the stream mouth or start of main-stem spawning reach in latitude and longitude, our productivity classification (PC), major (**M**) or minor (m), and up to three sources that were used to verify the spawning area. Abbreviations used with stream names include river (R.), creek (Cr.), north (N), south (S), upper (U), lower (L), main-stem (MS), south main-stem (SMS), south fork (SF), north fork (NF), middle fork (MF), east fork (EF), and in most cases of identical stream names we added the first three letters of the rivers they flow into, in parentheses, to differentiate them. These and additional related data are also available in spreadsheet format as Table S1, *Supplemental Material*.

Region	Spawning area	River kilometer	Latitude	Longitude	PC	Source(s)
R1	Andreafsky R.	167	62.03384	−163.22608	**M**	Barton 1984a; Estensen et al. 2012; State of Alaska 2016a
R1	Anvik R.	512	62.68145	−160.21492	**M**	Eiler et al. 2014; Estensen et al. 2015; Lozori 2015
R1	Archuelinguk R.	135	62.12526	−163.77831	m	Barton 1984a; State of Alaska 2016a
R1	Atchuelinguk R.	203	61.96979	−162.79381	**M**	Barton 1984a; Johnson and Litchfield 2016b; State of Alaska 2016b
R1	Beaver Cr. (Anv)	596	62.84266	−160.72184	m	State of Alaska 2016b
R1	Bonasila R.	492	62.53199	−160.22531	m	Barton 1984a; Eiler et al. 2014; State of Alaska 2016a
R1	California Cr.	1070	64.00915	−157.84916	m	Eiler et al. 2014; Johnson and Litchfield 2016a; State of Alaska 2016a
R1	Dishna R.	945	63.60424	−157.28677	m	Barton 1984a; Eiler et al. 2014; State of Alaska 2016a
R1	EF Andreafsky R.	175	62.05638	−163.10428	**M**	Estensen et al. 2012; Flannery et al. 2012; Mears 2015
R1	Hawk R.	596	62.50100	−160.88336	m	State of Alaska 2016b
R1	Iditarod R.	682	63.03080	−158.76702	m	Eiler et al. 2014
R1	Kaltag R.	724	64.33492	−158.72654	m	Bergstrom et al. 1999; Hayes et al. 2008; State of Alaska 2016b
R1	Nageethluk R.	321	62.33442	−162.13821	m	Johnson and Litchfield 2016b; State of Alaska 2016a; State of Alaska 2016b
R1	Ninemile R.	763	64.62664	−158.30058	m	State of Alaska 2016b
R1	Nulato R.	777	64.70664	−158.14220	**M**	Crawford and Lingnau 2004; Estensen et al. 2012; Eiler et al. 2014
R1	Otter Cr. (Anv)	657	63.24298	−160.69624	m	State of Alaska 2016b
R1	Rodo R.	719	64.27798	−158.71060	**M**	Johnson and Litchfield 2016a; State of Alaska 2016a; State of Alaska 2016b
R1	SF Nulato R.	784	64.72893	−158.20951	**M**	Barton 1984a; Estensen et al. 2012; State of Alaska 2016a
R1	Stuyahok R.	583	62.47045	−160.82530	m	State of Alaska 2016b
R1	Swift R. (Anv)	632	63.07119	−160.71701	m	State of Alaska 2016b
R1	Tolstoi Cr.	982	63.45075	−157.26260	m	Eiler et al. 2014
R1	U Innoko R.	1054	63.81910	−156.62302	m	Alt 1983; Eiler et al. 2014
R1	Yellow R.	610	62.92178	−160.68326	m	Barton 1984a; Johnson and Litchfield 2016a; State of Alaska 2016a
R2	Clear Cr. (Hog)	1327	66.21785	−155.49660	m	Esse and Kretsinger 2009; State of Alaska 2016b
R2	Dakli R.	1215	66.00191	−156.25164	m	Barton 1984a; State of Alaska 2016b
R2	Fish Cr.	1619	66.60957	−151.58990	m	Johnson and Litchfield 2016a; State of Alaska 2016a; State of Alaska 2016b
R2	Gisasa R.	908	65.26160	−157.68171	**M**	Olsen et al. 2009; Flannery et al. 2012; Carlson 2015
R2	Hammond R.	1929	67.45991	−150.03437	m	Barton 1984a; State of Alaska 2016b
R2	Henshaw Cr.	1574	66.55242	−152.22569	**M**	Estensen et al. 2012; Flannery et al. 2012; McKenna 2014
R2	Hot Springs Cr.	1029	65.18223	−154.91410	m	Barton 1984a, 1984b; State of Alaska 2016b
R2	Indian R.	1374	65.86875	−154.40366	m	Barton 1984a; State of Alaska 2016a; State of Alaska 2016b
R2	Iniakuk R.	1704	67.09142	−153.08800	m	State of Alaska 2016b
R2	Jim R.	1670	66.78791	−151.19599	m	Conitz et al. 2012; State of Alaska 2016a; State of Alaska 2016b
R2	John R.	1798	66.91280	−151.65372	m	State of Alaska 2016a; State of Alaska 2016b
R2	Kala R.	870	64.60601	−156.75918	m	State of Alaska 2016b
R2	Kanuti Kilolitna R.	1640	66.20533	−152.04457	m	Rost 1986
R2	Kateel R.	945	65.45254	−157.62838	m	VanHatten 2005; State of Alaska 2016a; State of Alaska 2016b
R2	Little Melozitna R.	1257	65.63905	−153.19201	m	Barton 1984b; Eiler et al. 2014; State of Alaska 2016b
R2	Malamute Fk.	1689	67.03108	−153.26900	m	Johnson and Litchfield 2016a; State of Alaska 2016a; State of Alaska 2016b
R2	MF Koyukuk R.	1836	67.04514	−151.07306	m	Schmidt and Decovich 2012; State of Alaska 2016a; State of Alaska 2016b
R2	NF Koyukuk R.	1836	67.04780	−151.07903	m	Johnson and Litchfield 2016a; State of Alaska 2016a; State of Alaska 2016b
R2	Sethkokna R.	1297	64.32422	−152.98843	m	Eiler et al. 2014; Kretsinger and Karlan 2016 (personal communication)*; State of Alaska 2016a
R2	SF Koyukuk R.	1587	66.58157	−151.93845	**M**	Wiswar 1998; Flannery et al. 2012; State of Alaska 2016b
R2	Sulukna R.	1273	64.12473	−154.04626	m	Gerken and Esse 2016 (personal communication)*

Table 2. Continued.

Region	Spawning area	River kilometer	Latitude	Longitude	PC	Source(s)
R2	Tozitna R.	1096	65.13657	−152.41543	M	Olsen et al. 2009; Beaudreault et al. 2010; Eiler et al. 2014
R2	Wild R.	1812	66.95205	−151.47400	m	Johnson and Litchfield 2016a; State of Alaska 2016a
R2	Yuki R.	904	64.71527	−156.12256	m	State of Alaska 2016b
R3	Barton Cr.	1372	64.35395	−150.21526	M	Barton 1984a; State of Alaska 2016a, 2016b
R3	Bearpaw R.	1427	64.09117	−150.69957	m	Barton 1984a; Eiler et al. 2014; State of Alaska 2016a
R3	Birch Cr. (Kan)	1518	63.88550	−151.59761	m	Eiler et al. 2014; State of Alaska 2016a
R3	Chatanika R.	1379	65.08766	−149.30156	M	Barton 1984a; Brase and Doxey 2006; Eiler et al. 2014
R3	Chena R.	1481	64.79882	−147.91186	M	Flannery et al. 2012; Eiler et al. 2014; Saveriede and Huang 2014
R3	Clear Cr. (Kan)	1356	64.41725	−150.37607	m	Barton 1984a; State of Alaska 2016a
R3	Clear Cr. (Tan)	1468	64.74308	−147.92138	m	Eiler et al. 2014; Brinkman et al. 2015; State of Alaska 2016a
R3	Cosna R.	1183	64.86015	−151.40718	m	Johnson and Litchfield 2016a; State of Alaska 2016a
R3	Goodpaster R.	1688	64.18193	−145.59063	M	Eiler et al. 2014; Saveriede and Huang 2014; State of Alaska 2016a
R3	McDonald Cr.	1491	64.70698	−147.60741	m	State of Alaska 2016a, 2016b
R3	McKinley R.	1516	63.87620	−151.56087	m	Eiler et al. 2014
R3	Moose Cr.	1495	63.88717	−150.90410	m	Eiler et al. 2014; State of Alaska 2016a, 2016b
R3	Nenana R.	1384	64.56434	−149.10654	m	Barton 1984a; Eiler et al. 2014; State of Alaska 2016a
R3	Salcha R.	1553	64.46625	−146.98127	M	Flannery et al. 2012; Eiler et al. 2014; Saveriede and Huang 2014
R3	SF Chena R.	1610	64.88366	−146.67242	m	Barton 1984a; Eiler et al. 2014; State of Alaska 2016a
R3	SF Goodpaster R.	1741	64.20450	−145.17326	m	Eiler et al. 2014; State of Alaska 2016b
R3	Unnamed1	1501	63.88539	−151.38034	m	Johnson and Litchfield 2016a; State of Alaska 2016a
R3	Unnamed2	1506	63.86782	−151.44679	m	Johnson and Litchfield 2016a; State of Alaska 2016a
R4	Beaver Cr. (Yuk)	1480	66.20976	−147.55106	m	Collin and Kostohrys 1998; Collin et al. 2002; Eiler et al. 2014
R4	Birch Cr. (Yuk)	1566	66.52162	−146.16736	m	Barton 1984a; Eiler et al. 2014; State of Alaska 2016a
R4	Charley R.	1852	65.31166	−142.78060	m	Eiler et al. 2014; State of Alaska 2016b
R4	Christian R.	1598	66.65983	−145.89011	m	Rost 1986
R4	EF Chandalar R.	1703	67.10231	−147.24193	m	Rost 1986; Eiler et al. 2014
R4	Hodzana R.	1472	66.29182	−147.77573	m	Eiler et al. 2014; State of Alaska 2016b
R4	Kandik R.	1870	65.37428	−142.51300	m	Eiler et al. 2014; State of Alaska 2016a, 2016b
R4	Nation R.	1920	65.19990	−141.69944	m	Eiler et al. 2014; State of Alaska 2016a, 2016b
R4	Ray R.	1315	65.87743	−149.80426	m	Johnson and Litchfield 2016a; State of Alaska 2016a
R4	Seventymile R.	1965	64.92722	−141.30201	m	State of Alaska 2016b
R4	Teedriinjik R.	1580	66.63708	−146.01604	M	Melegary and Osborne 2008; Flannery et al. 2012; Eiler et al. 2014
R5	Coleen R.	1862	67.07125	−142.49884	m	Conitz et al. 2012; Eiler et al. 2014; State of Alaska 2016a
R5	Fishing Branch R.	2360	66.45084	−138.58796	m	Steigenberger et al. 1975; Anderton 2003, 2005a
R5	Miner R.	2345	66.44797	−138.59311	m	Steigenberger et al. 1975; Snow et al. 2012; Eiler et al. 2014
R5	Old Crow R.	2028	67.58295	−139.80046	m	Steigenberger et al. 1975; Anderton 2003, 2005a
R5	Rock R.	2219	67.28832	−137.10605	m	Snow 2016
R5	Salmon Fk.	1838	66.54684	−142.56701	m	Eiler et al. 2014; McKenna and DeCovich 2016; State of Alaska 2016a
R5	Sheenjek R.	1696	66.73925	−144.56734	M	Rost 1986; Conitz et al. 2012; Eiler et al. 2014
R5	Timber Cr.	2226	68.16726	−139.94798	m	Anderton 2005a
R5	Whitestone R.	2345	66.50182	−138.41533	m	Cox 1999; Anderton 2003
R6	Beaver R.	2715	63.95875	−133.89369	m	Cox 1999; Cox et al. 1997
R6	Chandindu R.	2129	64.25266	−139.71558	m	Duncan 2000; Flannery et al. 2012; Eiler et al. 2014
R6	Coal Cr.	2070	64.47858	−140.42105	m	Cox et al. 1997; Besharah 2002; Duncan 2002
R6	Crooked Cr.	2443	63.38027	−136.68950	m	Barton 1984a; Cox et al. 1997; Smith 1997
R6	Emerald Cr.	2776	63.38032	−131.80274	m	Mercer 2005
R6	Fifteen-Mile R.	2123	64.28371	−139.81442	m	Cox et al. 1997
R6	Hess R.	2608	63.55241	−133.95902	m	Cox 1999
R6	Janet Cr.	2527	63.61854	−135.47825	m	Smith 1996; Cox 1999; Osborne et al. 2003
R6	Klondike R.	2168	64.05033	−139.43613	M	Flannery et al. 2012; Mercer 2012; Eiler et al. 2014
R6	Mayo R.	2489	63.58642	−135.91665	m	Cox 1999; Osborne et al. 2003; Flannery et al. 2012
R6	McQuesten R.	2385	63.55385	−137.44255	M	Tobler 2003a; Can-Nic-A-Nick Environmental Sciences 2011; MacDonald 2013
R6	N Klondike R.	2211	63.96263	−138.68839	m	Duncan 2002, 2006; Mercer 2005
R6	N McQuesten R.	2491	63.84733	−136.31217	m	Barton 1984a; Nacho Nyak Dun FirstNation 1998; Tobler 2003a
R6	Ollie Cr.	2808	63.30618	−131.28618	m	Cox 1999; Osborne et al.2003; Wilson 2010
R6	Pleasant Cr.	2615	63.51904	−133.91105	m	Cox 1999; State of Alaska 2016b
R6	Rackla R.	2755	64.11580	−134.38412	m	Osborne et al. 2003; Mercer 2005

Table 2. Continued.

Region	Spawning area	River kilometer	Latitude	Longitude	PC	Source(s)
R6	S McQuesten R.	2491	63.84439	−136.30215	m	Barton 1984a; Nacho Nyak Dun First Nation 1998; Tobler 2003a
R6	Sixty Mile R.	2246	63.56330	−139.76211	m	Mercer 2005; Duncan 2006
R6	U Stewart R.	2608	63.56046	−133.96579	m	Osborne et al. 2003
R6	Watson Cr.	2548	63.53574	−135.15401	m	Osborne et al. 2003; Mercer 2005
R7	Bearfeed Cr.	2654	62.16793	−135.07765	m	Walker et al. 1974; Tobler and Marjanovic 2011
R7	Big Cr.	2450	62.61606	−136.99351	m	Mercer and Eiler 2004; Tobler and Marjanovic 2011
R7	Big Salmon R.	2652	61.88011	−134.92084	**M**	Tobler and Marjanovic 2011; Estensen et al. 2012; Eiler et al. 2014
R7	Drury Cr.	2692	62.19613	−134.38761	m	Walker et al. 1974; Tobler and Marjanovic 2011
R7	Incised Cr.	2583	62.04335	−136.27931	m	Pumphrey 2001; Tobler and Marjanovic 2011
R7	Kirkland Cr.	2669	61.74405	−136.04099	m	von Finster 1995 (personal communication)*; Pumphrey 2001; Tobler and Marjanovic 2011
R7	Klottasin Cr.	2415	62.56538	−139.51004	m	Otto 1998a; Cox 1999; Mercer and Eiler 2004
R7	Kluane R.	2523	61.87685	−139.72029	m	Beak Consultants Limited 1977; Cox 1999
R7	Klusha Cr.	2676	61.73597	−136.01366	m	Otto 1998b; Pumphrey 2001; Tobler and Marjanovic 2011
R7	Little Salmon R.	2591	62.05396	−135.66633	**M**	Estensen et al. 2012; Sandone 2013; Eiler et al. 2014
R7	MS Yukon R.	2422	62.76184	−137.30600	**M**	Walker 1976; Milligan et al. 1985; Mercer and Eiler 2004
R7	N Big Salmon R.	2684	61.76209	−134.61391	m	Mercer 2005; Tobler and Marjanovic 2011; von Finster 2014
R7	Nisling R.	2429	62.46299	−139.48170	**M**	Otto 1998a; Mercer 2005; Wilson 2006
R7	Nordenskiold R.	2573	62.10214	−136.30123	m	Tobler and Marjanovic 2011; Flannery et al. 2012; Eiler et al. 2014
R7	Northern Cr.	2748	61.84719	−133.97581	m	Walker et al. 1974; Mercer 2005; Tobler and Marjanovic 2011
R7	S Big Salmon R.	2710	61.60735	−134.43774	m	Walker et al. 1974; Barton 1984a; Tobler and Marjanovic 2011
R7	Scurvy Cr.	2798	61.21519	−133.24122	m	Walker et al. 1974; Osborne et al. 2003; Tobler and Marjanovic 2011
R7	Selwyn R.	2373	62.80351	−138.28462	m	von Finster 1985 (personal communication)*
R7	Tatchun Cr.	2510	62.28553	−136.32524	**M**	Flannery et al. 2012; Eiler et al. 2014; JTC 2016
R7	Tincup Cr.	2535	61.88768	−139.54533	m	Wilson 2002; Estensen et al. 2012; MacDonald 2013
R7	Walsh Cr.	2644	61.92001	−134.94149	m	Tobler and Marjanovic 2011
R8	Anvil Cr.	2713	62.44431	−134.12903	m	Mercer 2005
R8	Big Campbell Cr.	2963	61.77272	−131.12878	m	Mercer and Eiler 2004; Mercer 2005
R8	Big Kalzas R.	2580	62.89228	−135.48500	m	Sparling 2003; Flannery et al. 2012; MacDonald 2013
R8	Blind Cr.	2792	62.17998	−133.22044	**M**	Estensen et al. 2012; Flannery et al. 2012; Wilson 2017
R8	Earn R.	2648	62.73648	−134.69729	m	Sparling 2003; Flannery et al. 2012; State of Alaska 2016b
R8	Glenlyon R.	2701	62.48280	−134.16357	m	Cox 1999; Tobler and Marjanovic 2011; Flannery et al. 2012
R8	Hoole R.	2912	61.74899	−131.71061	m	Mercer and Eiler 2004; Mercer 2005; State of Alaska 2016b
R8	Husky Dog Cr.	2843	63.09347	−132.46149	m	Barton 1984a; Cox 1999
R8	Lapie R.	2832	62.02919	−132.60824	m	Environmental Management Associates 1993; State of Alaska 2016b
R8	Little Kalzas R.	2581	62.89029	−135.47070	m	Cox 1999; Mercer and Eiler 2004; Flannery et al. 2012
R8	Macmillan R.	2542	62.86734	−135.89869	m	Cox 1999; Mercer and Eiler 2004
R8	Mica Cr.	2482	62.81637	−136.56697	m	Wilson 1999; Selkirk Renewable Resource Council 2010; Tobler and Marjanovic 2011
R8	Mink R.	2945	61.73167	−131.33599	m	Northern Natural Resource Services Limited 1977
R8	Moose R.	2666	62.99185	−134.73103	m	Barton 1984a; Cox 1999; Selkirk Renewable Resource Council 2007
R8	N Macmillan R.	2775	63.04392	−133.27713	m	Barton 1984a; Mercer and Eiler 2004; Mercer 2005
R8	Needlerock Cr.	2515	62.80606	−136.21247	m	Wilson 1999; Mercer and Eiler 2004; Tobler and Marjanovic 2011
R8	Otter Cr. (Pel)	2994	62.46388	−131.31970	m	Osborne et al. 2003; Mercer and Eiler 2004
R8	Prevost R.	3018	62.60323	−131.17081	m	Barton 1984a; Cox 1999; Mercer 2005
R8	Riddell R.	2843	62.84403	−132.42122	m	Cox 1999; Mercer and Eiler 2004
R8	Ross R.	2848	61.98582	−132.41851	**M**	Cox 1999; Mercer and Eiler 2004; Estensen et al. 2012
R8	Russel Cr.	2768	63.03624	−133.39035	m	Barton 1984a; Cox 1999
R8	S Macmillan R.	2775	63.02977	−133.28706	**M**	Barton 1984a; Mercer and Eiler 2004; Mercer 2005
R8	Tay R.	2683	62.56823	−134.35439	m	Cox 1999
R8	Tummel R.	2617	62.75663	−135.06402	m	Sparling 2003
R8	U Pelly R.	3034	61.98023	−132.41312	m	Barton 1984a; Osborne et al. 2003; Mercer 2005
R8	Woodside Cr.	3034	62.03462	−130.55849	m	Mercer and Eiler 2004
R9	Boswell R.	2802	61.05201	−134.21503	m	Cox 1999; Tobler 2003b
R9	Flat Cr.	2850	60.85838	−135.51759	m	Zurachenko and Finnson 1998
R9	Gladys R.	3000	59.79783	−132.28314	m	Cox 1999; Tobler 2003b; State of Alaska 2016b
R9	Hayes R.	3026	59.59260	−132.18228	m	Cox 1999; Tobler 2003b

Table 2. Continued.

Region	Spawning area	River kilometer	Latitude	Longitude	PC	Source(s)
R9	Hundred-Mile Cr.	3120	61.05367	−132.93026	m	Osborne et al. 2003; Mercer and Eiler 2004; Mercer 2005
R9	Ibex R.	2896	60.80230	−135.72990	m	Beak Consultants Limited 1977; Environmental Management Associates 1980; Zurachenko and Finnson 1998
R9	Jennings R.	3017	59.66589	−132.14129	m	Cox 1999; Osborne et al. 2003; State of Alaska 2016b
R9	Klinkit Cr.	3086	59.42831	−131.35852	m	von Finster (personal communication)*
R9	L Teslin R.	2704	61.56791	−134.89504	**M**	Barton 1984a; Eiler et al. 2014; Mercer 2014
R9	McConnel R.	3183	61.28087	−132.50050	m	Cox 1999
R9	McIntyre Cr.	2813	60.76843	−135.08937	m	Waugh and Young 1998
R9	M'Clintock R.	2886	60.55894	−134.48936	m	Wynne-Edwards 1947; Brown et al. 1976; Cox 1999
R9	McNaughton Cr.	3109	59.92992	−131.25818	m	Environmental Management Associates 1980; Cox 1999
R9	McNeil R.	3204	61.16358	−132.28708	m	Cox 1999; Mercer and Eiler 2004
R9	Mendenhall R.	2911	60.75587	−136.04315	m	Sparling and Connor 2003 (personal communication)*
R9	Michie Cr.	2921	60.67396	−134.47274	m	Barton 1984a; Matthews 1999; Kwanlin Dun First Nation 2006
R9	Morley R.	2968	60.09433	−132.49389	m	Beak Consultants Limited 1977; Environmental Management Associates 1980; State of Alaska 2016b
R9	N Swift R.	2850	60.81041	−133.85732	m	Barton 1984a; White Mountain Environmental Consulting 1997; Sparling 2002
R9	Red R.	3078	60.73591	−132.11357	m	White Mountain Environmental Consulting 1998; Mercer and Eiler 2004
R9	Rose R.	3142	61.18147	−132.98201	m	von Finster 1996 (personal communication)*
R9	S Swift R.	3009	59.73765	−132.18442	m	Beak Consultants Limited 1977; Environmental Management Associates 1980; State of Alaska 2016b
R9	Sidney Cr.	3066	60.75712	−132.94218	m	White Mountain Environmental Consulting 1998; Cox 1999
R9	Smart R.	3066	59.93373	−131.75616	m	Environmental Management Associates 1980; Barton 1984a
R9	SMS Yukon R.	2704	61.57195	−134.90756	m	Brown et al. 1976; Walker 1976; Mercer 2005
R9	Squanga Cr.	2891	60.54162	−133.43034	m	White Mountain Environmental Consulting 1997
R9	Takhini R.	2818	60.84144	−135.18337	**M**	Barton 1984a; Mercer 2005; Flannery et al. 2012
R9	Thirty-Mile Cr.	3050	60.66817	−132.85710	m	White Mountain Environmental Consulting 1998; Cox 1999
R9	U Nisutlin R.	3142	61.17490	−132.96455	**M**	White Mountain Environmental Consulting 1998; Estensen et al. 2012; Eiler et al. 2014
R9	U Teslin R.	3049	59.48494	−132.09988	m	Barton 1984a; Cox 1999; Osborne et al. 2003
R9	Wolf Cr.	2855	60.62501	−134.91311	m	Matthews 1999; Yukon Fish and Game Association 2007; Flannery et al. 2012
R9	Wolf R.	2971	60.27560	−132.55151	**M**	Barton 1984a; White Mountain Environmental Consulting 1998; Estensen et al. 2012

* Details of personal communications appear in the Record of Personal Communications on page 587.

projects (Skaugstad 1993), and visual aerial surveys (e.g., Barton 1984a; Nacho Nyak Dun First Nation 1998; Snow et al. 2012; State of Alaska 2016b). Genetics publications with lists of streams where baseline samples have been collected (e.g., Smith et al. 2005; Beacham et al. 2008; Flannery et al. 2012) as well as agency reports related to supplemental sampling (e.g., Conitz et al. 2012; Snow et al. 2012; MacDonald 2014) were similarly useful. The basin-wide telemetry study (Eiler et al. 2014), along with its associated localized aerial tracking surveys (e.g., Anderton 2003; Osborne et al. 2003; Mercer 2005) provided reliable information on spawning destinations, including several areas that had not been previously reported. We also reviewed information from the Alaska Anadromous Waters Catalog (Johnson and Litchfield 2016a, 2016b; State of Alaska 2016a) that consolidates a wide range of reports and observations in the U.S. portion of the basin, as well as historical and traditional knowledge accounts from terminal fisheries (e.g., Cox 1999; Anderton 2005b; Tobler and Marjanovic 2011) and less formal agency and Yukon River Panel reports (e.g., Walker 1976; Rost 1986; Besharah 2002; Klugie et al. 2003). In many cases, information from telemetry studies and other short-term projects helped strengthen the support for many of these other less definitive observations.

Assessment criteria

We classified Chinook Salmon spawning areas as major or minor producers by using three indices of abundance: 1) quantitative escapement estimates from weirs, counting towers, or sonar programs; 2) radiotelemetry distribution data; and 3) aerial or stream survey counts (Table 1). We focused on patterns of annual abundance as productivity indicators reasoning that high-quality spawning and rearing habitat will consistently produce more fish than low-quality habitat. Healey (1982) used similar abundance indicators (although telemetry data were not available) to classify 326 British Columbia spawning streams into four abundance categories ranging from less than 200 to more than 5,000 spawning fish. Data from some spawning areas in the Yukon River basin would have supported this level of analysis, but most would not.

Table 3. Number of Chinook Salmon *Oncorhynchus tshawytscha* spawning areas compiled in 2017 for the Yukon River basin by region, including some of the larger tributary rivers within certain regions, along with a breakdown of those classified as major and minor producers (Table 1).

Region	Drainage	Major	Minor	No. of spawning areas
R1	Lower Yukon River	7	11	18
	Innoko River	0	5	5
R2	Middle Yukon River in Alaska	1	6	7
	Koyukuk River	3	14	17
R3	Tanana River drainage	5	13	18
R4	Upper Yukon River in Alaska	1	10	11
R5	Porcupine River drainage	1	8	9
R6	Northern Yukon River in Canada	1	5	6
	Stewart River	1	13	14
R7	Yukon River main stem in Canada	4	13	17
	White River	1	3	4
R8	Pelly River drainage	3	23	26
R9	Upper headwaters	1	8	9
	Teslin River	3	19	22
Combined		32	151	183

Because we considered three indicators of abundance, classification criteria were specific to each indicator. Our highest quality abundance indicators in the Yukon River basin were the quantitative escapement projects and the radiotelemetry distribution data. Spawning streams with a series of annual escapement estimates from weirs or other high-accuracy quantitative methodologies were classified as major producers if they averaged 500 or more Chinook Salmon per year and minor producers if they averaged less than 500 per year. In deciding on this threshold value, we consulted some of the reviews on minimum viable population levels (e.g., Flather et al. 2011; Jamieson and Allendorf 2012) with the intent of using a biologically based value in common use, but we found very little guidance on the matter. In fact, Flather et al. (2011) concluded that there was no population size that would guarantee population persistence. We examined additional literature monitoring genetic health of Chinook Salmon populations based on the effective number of breeders per generation (e.g., Allendorf et al. 1997; Shrimpton and Heath 2003; Olsen et al. 2009), and although general guidelines were discussed, estimates of the relationship between effective number of breeders and annual census values were highly variable and provided little guidance for our purposes. Essentially, our thresholds are arbitrary values along a continuum.

Eiler et al. (2014) estimated the proportional contributions of numerous spawning streams to basin-wide Chinook Salmon production during the 3 y of project operation, 2002–2004. Proportional contributions were based on the distribution of radio-tagged fish weighted by run timing and progressively increased harvest exposure as fish moved upriver. We classified spawning areas as major producers if they averaged 1% or more of the total return and minor producers if they averaged less than 1%. This threshold value probably represents an annual escapement value greater than 500 spawning fish in most cases, but the relationship between spawning fish to number of radio tags varied among years (Mercer and Eiler 2004; Mercer 2005; Spencer et al. 2009) and becomes increasingly volatile with low numbers of tags. The 1% criterion for classification as a major producer standardized distribution across years of the project and avoided the high variation inherent in low values, even though this level represents a somewhat larger escapement than our quantitative classification criteria.

Aerial survey counts have been shown to be variable proportions of annual escapements (Jones et al. 1998; Hilborn et al. 1999). We developed an adjustment factor between aerial survey counts and accurate escapement estimates obtained from weirs, counting towers, or sonar programs by using paired data from four spawning streams in the Yukon River basin in which both types of data were available: East Fork Andreafsky, Gisasa, Chena, and Salcha rivers (Brase and Doxey 2006; JTC 2016). These four spawning streams provided 67 pairs in total of aerial survey counts and escapement estimates. A least-squares linear regression of these data revealed that there was a significant positive linear relationship between the two values ($P < 0.001$, $R^2 = 42\%$). The average aerial survey to escapement proportion was 0.33 (SE $= 0.025$, range 0.013–0.961). Based on these results, spawning streams with a record of aerial survey counts were classified as major producers if they averaged 165 or more fish observed per year ($500 \times 0.33 = 165$) and minor producers if they averaged less than 165 fish observed per year. Spawning areas without any indications of abundance were classified as minor producers.

Historical accounts of traditional fisheries in upriver reaches of the basin (Cox 1999; Anderton 2005b; Tobler and Marjanovic 2011) provided evidence of substantial Chinook Salmon fisheries that would not have occurred unless fish were present in great abundance. Because many of these historical accounts were from many decades ago, they were not used by themselves to classify streams as major or minor producers, but they verified the temporal persistence of certain highly productive spawning areas.

Although these three indices of production level were not directly comparable, the results for spawning areas that were classified using two or more methods were usually classified the same. In a few instances, different abundance indices for a particular spawning area were not in agreement. We then used a relative confidence hierarchy for classification decisions based on the type of information being considered, high-accuracy escapement projects (highest confidence), radiotelemetry proportional estimates (high confidence), and aerial survey counts (less confidence; Table 1).

We tabulated and mapped geographic information on Chinook Salmon spawning areas. Locations of the

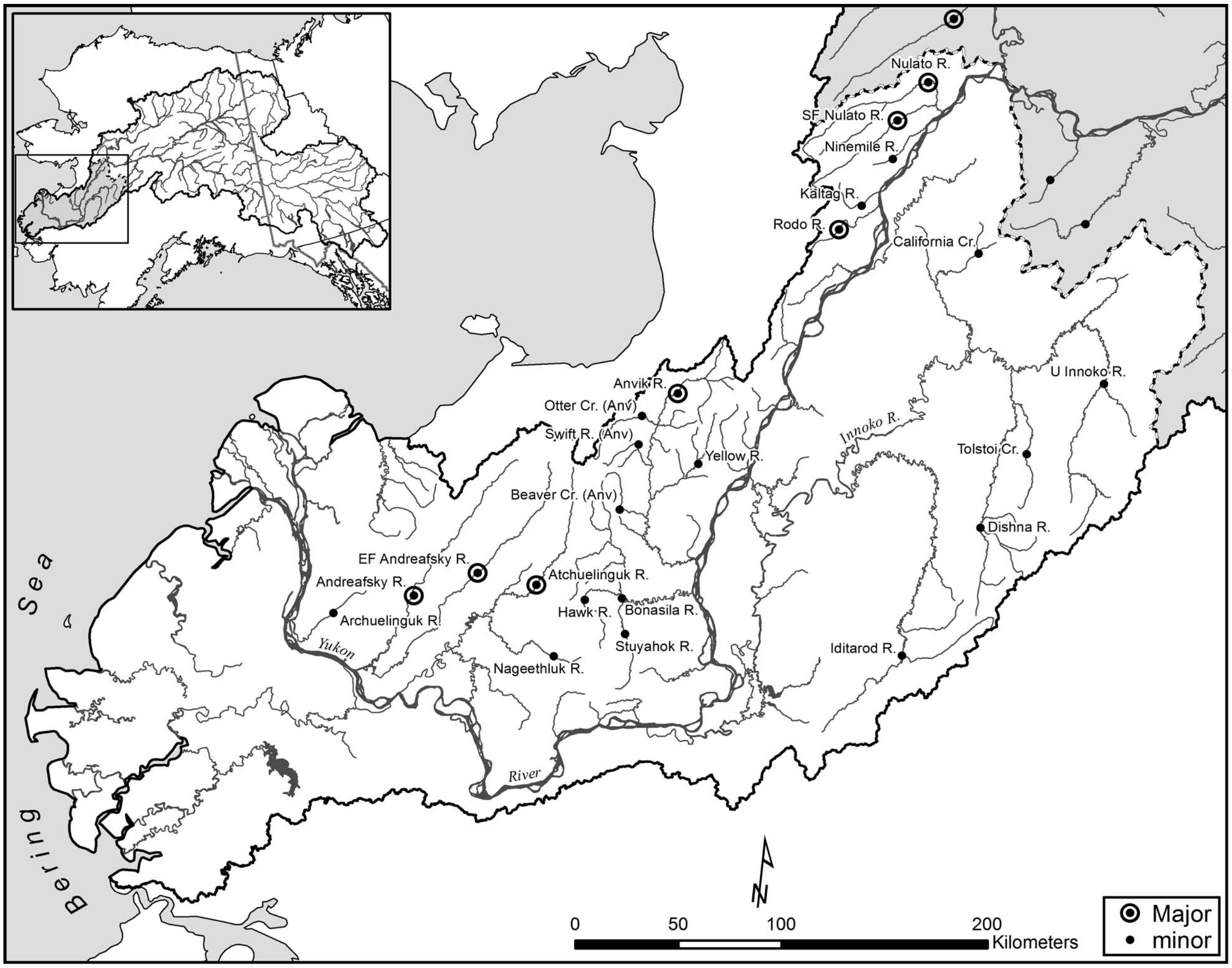

Figure 2. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the lower Yukon River region (R1), Yukon River basin in the United States. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

mouths of spawning streams, or the start points of main-stem spawning reaches, were recorded as latitude and longitude in decimal degrees by using WGS84 datum. We used *Google Earth* (https://www.google.com/earth/) to measure approximate distances in river kilometers (rkm) following a path fish could swim up the largest channels from the south mouth of the Yukon River (N latitude 62.57484, W longitude −165.01919), which is the largest distributary (McDowell et al. 1987), up the Yukon River main stem and various tributaries to each stream mouth and start point of main-stem reach. In addition, we identified coordinates of upstream locations within each spawning stream or main-stem reach for mapping clarity because identifying a stream of interest with a position at its confluence can be ambiguous. These upstream locations are for mapping clarity only and should not be interpreted as delineating a specific spawning site within a stream. Summarized and detailed geographic data, along with reference source information, are presented in tabular form and in a series of maps illustrating the distribution of Chinook Salmon spawning areas within the Yukon River basin.

Results

Overview

We documented 183 Chinook Salmon spawning areas in the Yukon River basin, with 79 in the United States and 104 in Canada (Figure 1; Table 2). Evidence was available to classify 32 spawning areas as major producers, with 18 in the United States and 14 in Canada. The remaining 151 were classified as minor producers, with 61 in the United States and 90 in Canada. Spawning areas were identified from just upstream of the Yukon River delta (rkm 135), to the upper reaches of the Teslin River (rkm 3,204). Details on the distribution and classification of Chinook Salmon spawning areas are discussed below for the nine different regions of the basin. Table 3 summarizes these data among regions and some of the larger tributary rivers within regions. Table 2 provides detailed information for all documented spawning areas.

Table 4. Data used to support the classification of 32 Chinook Salmon *Oncorhynchus tshawytscha* spawning areas compiled in 2017 for the Yukon River basin as major producers, including escapement projects (weirs, counting towers, sonar operations, etc.), radiotelemetry proportion estimates, and aerial survey counts. Data include mean values followed by the number of years of available data in parentheses. Approximate or extrapolated values are preceded by a tilde. An example is the Big Salmon River drainage where the large majority of fish spawn in the main stem and the other four spawning areas in the drainage receive few fish by comparison. The sonar counts and the radio telemetry proportion estimates are germane to the drainage and are therefore slightly high values for the main-stem spawning area.

Region	Spawning area[a]	Escapements	Telemetry	Survey counts
R1	Andreafsky R.			1,130 (48)
R1	Anvik R.		~3.2% (3)	1,075 (34)
R1	Atchuelinguk R			456 (13)
R1	EF Andreafsky R.	3,748 (25)		1,306 (46)
R1	Nulato R.			789 (33)
R1	Rodo R.			314 (13)
R1	SF Nulato R.			580 (35)
R2	Gisasa R.	2,289 (22)		723 (34)
R2	Henshaw Cr.	966 (14)		306 (18)
R2	SF Koyukuk R.	1,438 (2)		301 (20)
R2	Tozitna R.	1,381 (9)	1.1% (3)	
R3	Barton Cr.			232 (9)
R3	Chatanika R.	997 (7)		
R3	Chena R.	6,450 (28)	4.8% (3)	1,956 (15)
R3	Goodpaster R.	2,034 (9)	3.6% (3)	860 (20)
R3	Salcha R.	9,051 (28)	9.1% (3)	3,583 (17)
R4	Teedriinjik R.		3.0% (3)	
R5	Sheenjek R.		2.0% (3)	
R6	Klondike R.	2,377 (3)	2.0% (3)	
R6	McQuesten R.		~2.6% (3)	
R7	Big Salmon R.	~5,380 (11)	~5.2% (3)	911 (43)
R7	Little Salmon R.			559 (27)
R7	MS Yukon R.		4.9% (3)	
R7	Nisling R.		~1.3% (3)	
R7	Tatchun Cr.	618 (3)		201 (27)
R8	Blind Cr.	588 (17)		
R8	Ross R.			331 (15)
R8	S Macmillan R.		~1.1% (2)	
R9	L Teslin R.	~5,000 (4)	~4.9% (3)	
R9	Takhini R.			260 (16)
R9	U Nisutlin R.			439 (41)
R9	Wolf R.			221 (36)

[a] R. = river; Cr. = creek.

A supplementary data file (Table S1, *Supplemental Material*) with this information is available in spreadsheet format as well.

Lower Yukon River (R1)

Twenty-three spawning areas were identified in the lower Yukon River region in Alaska (Figure 2; Tables 2 and 3). Seven of these spawning areas were classified as major producers (Table 4) including the Andreafsky River (west fork), based on a 48-y record of aerial survey counts that averaged 1,130 fish (Barton 1984a; Estensen et al. 2012); the East Fork Andreafsky River, based on a 25-y record of weir-based escapements that averaged 3,748 fish (Estensen et al. 2012; Mears 2015); the Atchuelinguk River, based on a 13-y record of aerial survey counts that averaged 456 fish (State of Alaska 2016b); the Anvik River, based on 3 y of telemetry proportion data that averaged 3.2% of the run (Eiler et al. 2014); the Rodo River, based on 13 y of aerial survey counts that averaged 314 fish (State of Alaska 2016b); and the Nulato River (north fork) and South Fork Nulato River, based on aerial survey counts that averaged 789 fish ($n = 33$) and 580 fish ($n = 35$), respectively (Estensen et al. 2012). Nine years of counting tower and weir escapement estimates that averaged 1,978 fish into the combined Nulato River system support the major production level classifications of the two forks as well (Crawford and Lingnau 2004). Spawning Chinook Salmon were located in five tributaries of the Innoko River drainage during the basin-wide telemetry study (Eiler et al. 2014). However, the total estimated return to the Innoko River averaged $<0.5\%$ of the run and did not exceed 0.7% of the run annually, so all of the individual spawning areas in the drainage were classified as minor producers. All seven of the major producing spawning areas in the lower Yukon River region were in streams that flowed from headwaters in the Nulato Hills, a mountainous area northwest of the Yukon River.

Middle Yukon River in Alaska (R2)

Twenty-four spawning areas were identified in the middle Yukon River region in Alaska (Figure 3; Tables 2 and 3). Four of these spawning areas were classified as major producers (Table 4) based on weir escapement estimates including the Gisasa River, based on a 22-y record that averaged 2,289 fish (Carlson 2015); Henshaw Creek, based on a 14-y record that averaged 966 fish (McKenna 2014); South Fork Koyukuk River, based on a 2-y record that averaged 1,438 fish (Wiswar 1998); and Tozitna River, based on a 9-y record that averaged 1,381 fish (Beaudreault et al. 2010). This classification was corroborated for the Gisasa, Henshaw, and South Fork Koyukuk rivers based on aerial survey counts (Estensen et al. 2012; State of Alaska 2016b) and for the Tozitna River based on the basin-wide telemetry proportion data (Eiler et al. 2014). Other documented spawning areas in the Koyukuk, Melozitna, and Nowitna river drainages, as well as smaller main-stem tributaries, were classified as minor producers.

Tanana River drainage (R3)

Eighteen spawning areas were identified in the Tanana River drainage in Alaska (Figure 4; Tables 2 and 3). Five of these spawning areas were classified as major producers (Table 4) including Barton Creek, based on a 9-y record of aerial survey counts that averaged 232 fish (State of Alaska 2016b); Chatanika River, based on a 7-y record of tower counts that averaged 997 fish (Brase and Doxie 2006); Chena River, based on a 28-y record of escapement that averaged 6,450 fish; Salcha River, based on a

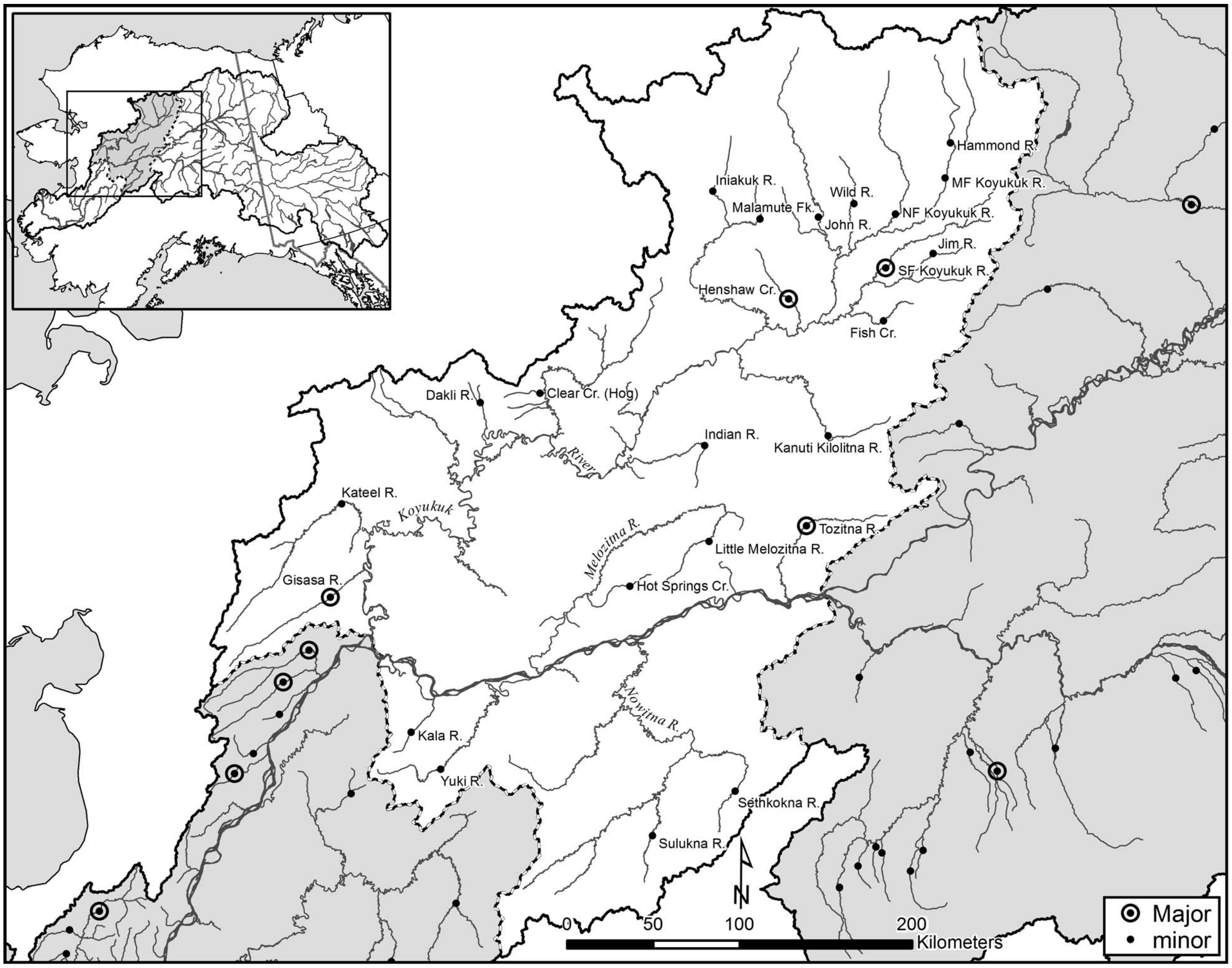

Figure 3. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the middle Yukon River region (R2), Yukon River basin in the United States. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

28-y record of escapement that averaged 9,051 fish; and the Goodpaster River, based on a 9-y record of escapement that averaged 2,034 fish (Estensen et al. 2012; Savereide and Huang 2014). Telemetry proportion data suggest that the Salcha and Chena rivers were two of the largest spawning populations in the Yukon River basin, averaging 9.1 and 4.8% of the Chinook Salmon run, respectively (Eiler et al. 2014). Four of the five major producing spawning areas in the Tanana River region flow southwest from headwaters in the Yukon–Tanana uplands. All but one of the minor producing spawning areas are on the south side of the Tanana River, including a cluster of small tributaries of the glacial Kantishna River.

Upper Yukon River in Alaska (R4)

Eleven spawning areas were identified in the upper Yukon River region in Alaska (Figure 5; Tables 2 and 3). The Teedriinjik River (known as Chandalar River until its name was changed in 2015) was the only spawning area in the region classified as a major producer (Table 4). This river drains a portion of the eastern Brooks Range and has long been known as a major fall Chum Salmon *Oncorhynchus keta* spawning area (Barton 1984a; Daum and Osborne 1998). Aerial surveys of the Teedriinjik River were typically conducted in the fall (September and October) to coincide with the return of fall Chum Salmon (Barton 1984a), but too late to observe Chinook Salmon during their late July–August spawning period. Chinook Salmon have been known to spawn in the Teedriinjik River since the mid-1980s (Rost 1986; Daum 1989); however, Eiler et al. (2014) established the spawning area as a major producer based on 3 y of telemetry proportion data, averaging just over 3% of the entire run. A weir was operated for 4 y on Beaver Creek (Collin and Kostohrys 1998; Collin et al. 2002), which drains a portion of the north side of the Yukon–Tanana uplands. The average annual escapement was 187 Chinook Salmon, ranging from 114 to 315 fish, leading to a classification of the stream as a minor producer. Nine other spawning areas in the region were classified as minor producers.

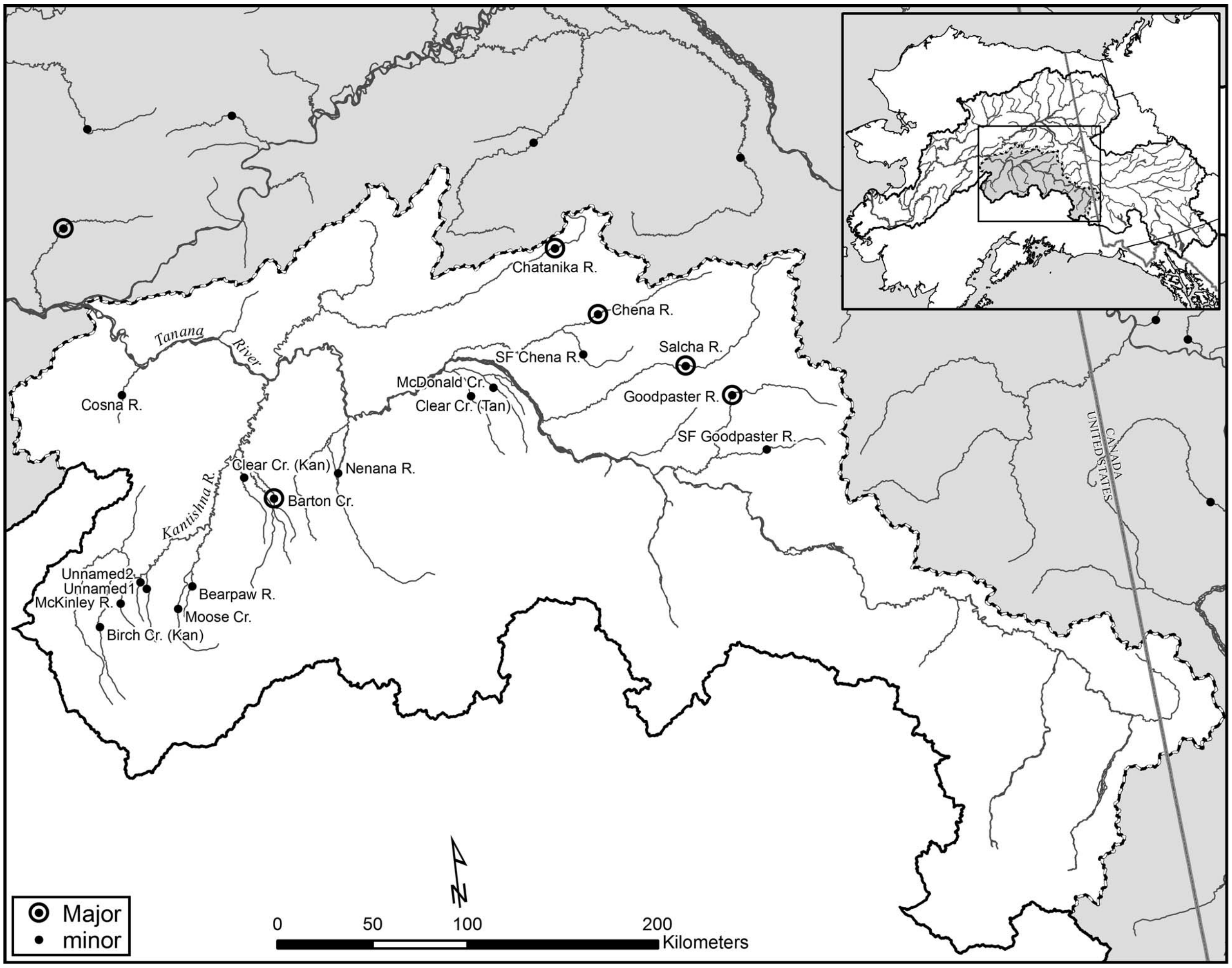

Figure 4. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the Tanana River drainage (R3), Yukon River basin in the United States. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

Porcupine River drainage (R5)

Nine spawning areas were identified in the Porcupine River drainage in the United States and Canada (Figure 6; Tables 2 and 3). The Sheenjek River was the only spawning area in the region classified as a major producer (Table 4). Similar to the Teedriinjik River, the Sheenjek River drains a portion of the south slope of the eastern Brooks Range, known to be a major producer of fall Chum Salmon (Barton 1984a; Dunbar 2013); and most of the aerial surveys in the drainage reported by Barton (1984a) took place in September and October, too late for observing spawning Chinook Salmon. Rost (1986) conducted an aerial survey of the Sheenjek River in August 1985 and counted 45 spawning Chinook Salmon, establishing it as a spawning area. Eiler et al. (2014) subsequently reported an average production of almost 2% of the run in the Sheenjek River during the 3 y of the basin-wide telemetry study, establishing the stream as a major producer. Two other U.S. tributaries, the Coleen and Salmon Fork Black rivers, and six Canadian tributaries, including two streams in the Old Crow River drainage and four streams in the upper Porcupine River, were all classified as minor producers. The distribution of radio-tagged fish during the telemetry project (Anderton 2003, 2005a) and aerial survey counts of spawning fish and redds (Snow et al. 2012) indicate that the largest spawning area in the Canadian portion of the drainage is the Miner River. Future assessment projects may provide sufficient evidence to reclassify this stream as a major producer.

Northern Yukon River in Canada (R6)

Twenty spawning areas were identified in the northern Yukon River region in Canada (Figure 7; Tables 2 and 3). Two spawning areas in the region were classified as major producers (Table 4), the Klondike and McQuesten rivers. The Klondike River was classified as a major producer based on an average escapement of 2,377 fish per year during three seasons of sonar operations (2009–2011; Mercer 2012). This classification was further supported by the telemetry proportion study, which suggested that the Klondike River produced an average

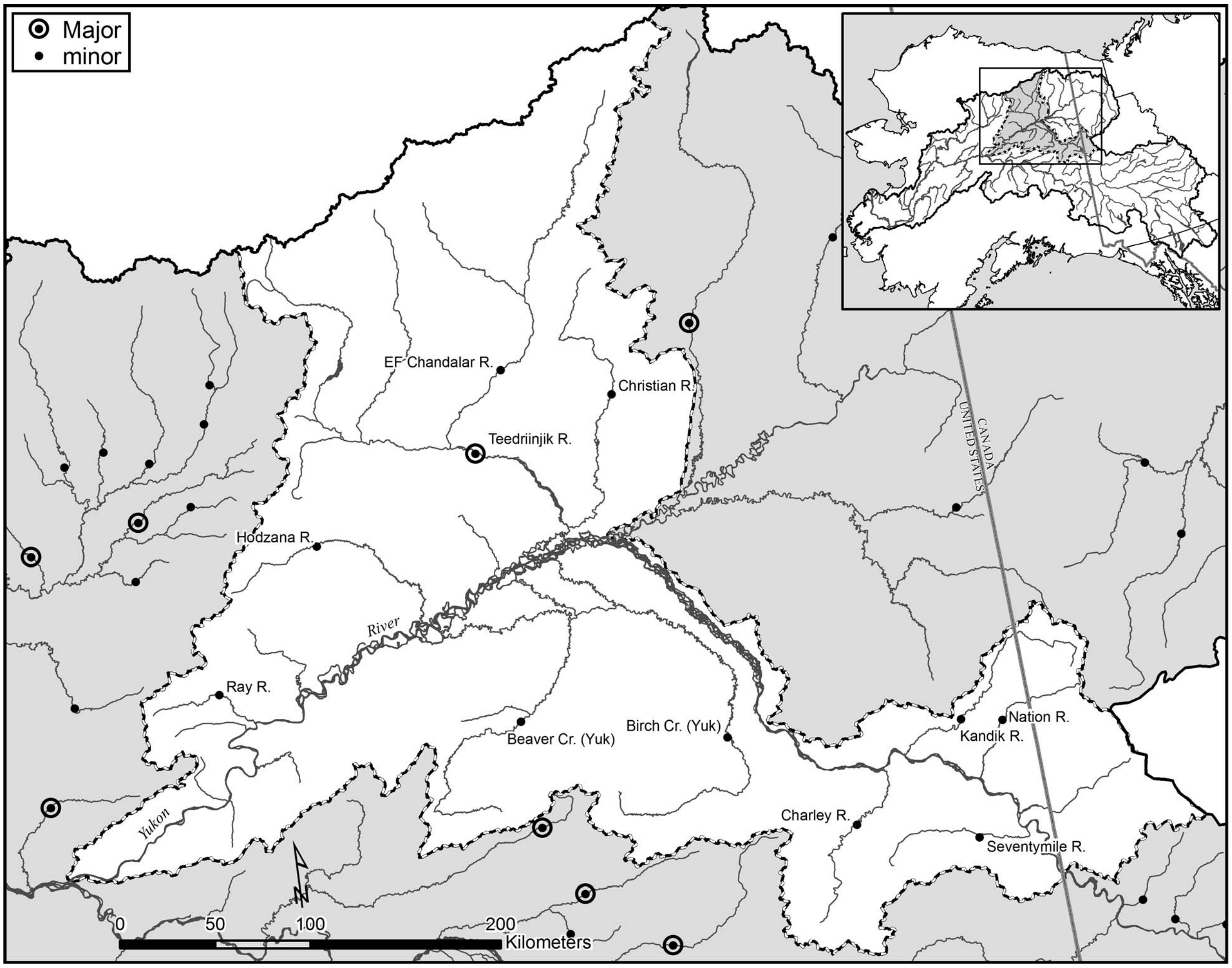

Figure 5. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the upper Yukon River region (R4), Yukon River basin in the United States. In September 2015, the U.S. Board of Geographic Names changed the name of the main-stem Chandalar River to Teedriinjik River, which is used here. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

of about 2% of the run during the 3 y of operation (Eiler et al. 2014). The main-stem McQuesten River was classified as a major producer based primarily on telemetry proportion data. Eiler et al. (2014) estimated that an average of 5.4% of the entire run returned to the Stewart River, but they did not estimate the contributions of individual spawning areas within the drainage. However, radio tracking surveys during the 3 y of this study showed that most of the radio-tagged fish returning to the Stewart River migrated to the McQuesten River (Osborne et al. 2003; Mercer and Eiler 2004; Mercer 2005). We therefore inferred that approximately 2.6% of the run was produced in the McQuesten River. Historical accounts of traditional fisheries and more recent survey data (Cox et al. 1997; Nacho Nyak Dun First Nation 1998; Tobler 2003a) support this classification as well. The other 18 spawning areas in the region were classified as minor producers. Historical accounts, however, suggest that Chinook Salmon returned to the Mayo River in large enough numbers to support a substantial aboriginal fishery before a dam was constructed in 1952 with no provision for fish passage (Cox 1999; Tobler and Miles 2004). The dam effectively blocked access to major spawning areas extending upstream approximately 90 km to the outlet of Mayo Lake. Chinook Salmon are still observed in the lower Mayo River (Osborne et al. 2003; Mercer 2005), but there is no indication that the numbers are large. A weir was operated on the Chandindu River for 4 y between 1998 and 2003, with annual escapements averaging 146 Chinook Salmon (range 85–239; Duncan 2000; McCready 2004), which led us to classify it as a minor producer. No other quantitative escapement monitoring projects have been conducted in this region.

Yukon River main stem in Canada (R7)

Twenty-one spawning areas were identified in the Yukon River main-stem region in Canada (Figure 8; Tables 2 and 3). Four spawning areas and one main-stem reach in the region were classified as major producers including Tatchun Creek, the Nisling, Little Salmon, and

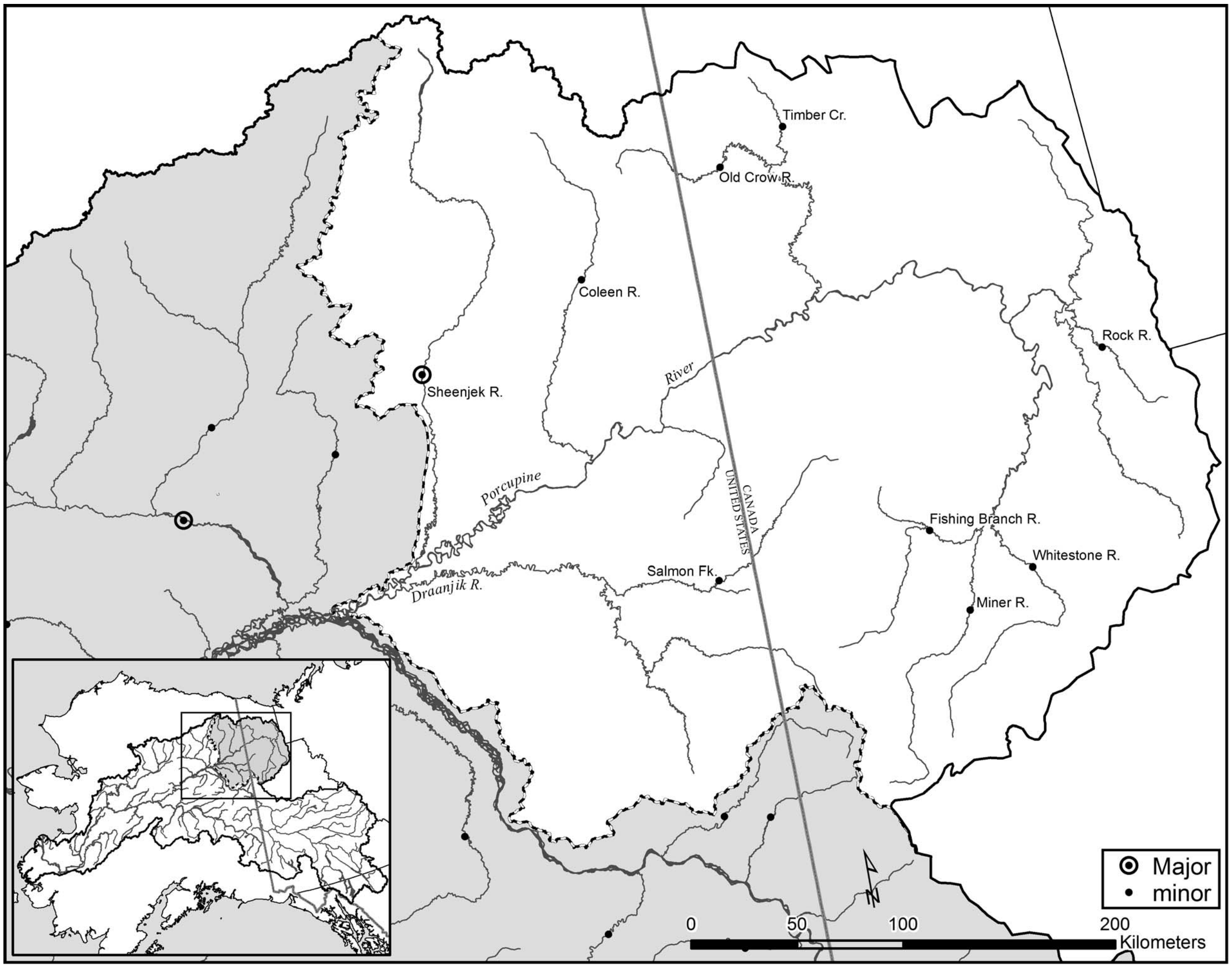

Figure 6. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the Porcupine River drainage (R5), Yukon River basin in the United States and Canada. In May 2014, the U.S. Board of Geographic Names changed the name of the main-stem Black River to Draanjik River, as is used here. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

Big Salmon rivers; and the Yukon River main stem between the mouths of the White and Teslin rivers, respectively (Table 4). Tatchun Creek is a small tributary of the Yukon River with a 27-y history of aerial and stream walk counts averaging 201 fish (range 52–643) and weir counts from 1997 to 1999 with an average escapement of 618 (range 252–1,198; Estensen et al. 2012). The Nisling River, a tributary of the White River, was classified as a major producer because the White River produced an average of 2.6% of the run during the 3 y of the telemetry study (Eiler et al. 2014), with approximately 51% of radiotagged fish located in the Nisling River (Mercer and Eiler 2004; Mercer 2005; Wilson 2006). We therefore inferred that approximately 1.3% of the run was produced in the Nisling River. The Little Salmon River was classified as a major producer based on a 27-y record of aerial survey counts that averaged 559 fish (Estensen et al. 2012). The Big Salmon River was classified as a major producers based on an 11-y record of sonar escapements that averaged 5,380 fish per year into the drainage (Mercer and Wilson 2016). Although five spawning areas have been identified in the drainage, aerial survey records over 43 y (Estensen et al. 2012) and aerial tracking surveys during the 3 y of the telemetry project (Osborne et al. 2003; Mercer and Eiler 2004; Mercer 2005) indicated that a large majority of fish spawn in the main-stem Big Salmon River. Further support for this classification was provided by the telemetry study, which estimated an average of 5.2% of the run produced in the Big Salmon River (Eiler et al. 2014), and aerial survey counts, which averaged 911 fish (Estensen et al. 2012). Spawning Chinook Salmon were observed in several reaches along the Yukon River main stem during the 1970s and 1980s (Walker et al. 1974; Walker 1976; Milligan et al. 1985), although in the large river environment it was not possible to know the extent or magnitude of spawning activity in the main stem. Large numbers of radio-tagged fish, however, remained in the middle and upper reaches of the main stem during the 3 y of the telemetry study, averaging 4.9% of the run

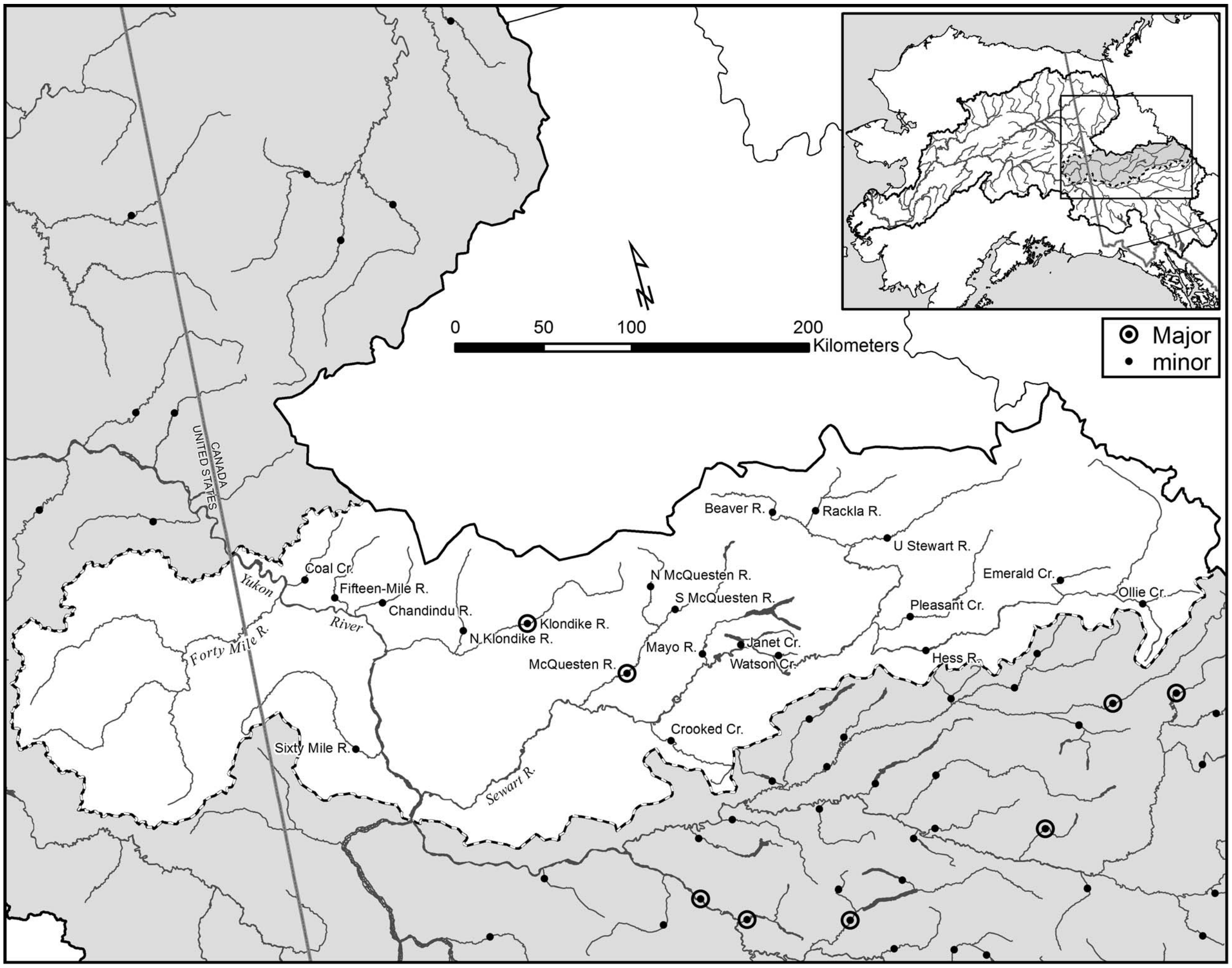

Figure 7. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the northern Yukon River region (R6), Yukon River basin in Canada. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

annually (Eiler et al. 2014), indicating that the main stem was a major producer. The 17 remaining areas, including tributaries of the White River and the Yukon River main stem, were classified as minor producers.

Pelly River drainage (R8)

Twenty-six spawning areas were identified in the Pelly River drainage in Canada (Figure 9; Tables 2 and 3). Three of these areas were classified as major producers (Table 4). Blind Creek is the only stream in the Pelly River drainage with long-term escapement data from weir counts (Wilson 2017). Average escapement over a 17-y period (1997–2016 with three seasons missed) was 588 fish (range 157–1,155). Eiler et al. (2014) estimated an average of 9.5% of the entire Yukon River run returned to the Pelly River during the basin-wide telemetry study. Radio-tagged fish were widely distributed throughout the drainage with notable concentrations observed in Blind Creek, Ross River, and South Macmillan River (Mercer and Eiler 2004; Mercer 2005). Of these three streams, Blind Creek received the fewest number of radio-tagged fish during the 2003 and 2004 seasons with escapements of 1,155 and 792 Chinook Salmon, respectively (Wilson 2017). Consequently, we assumed that comparable or greater numbers of fish returned to the Ross and South Macmillan rivers, which were therefore classified as major producers. This classification was further supported by a 15-y record of aerial survey counts in the Ross River (beginning in 1968) that averaged 331 fish (range 102–949; Estensen et al. 2012). Sparling (2003) observed 395 Chinook Salmon in the Earn River during a helicopter survey in 2002, suggesting that this stream might be a major producer. However, Barton (1984a) reported an average of 39 fish annually during four aerial surveys conducted between 1968 and 1983, so we classified the Earn River as a minor producer. Altogether, we classified 23 spawning areas as minor producers in the Pelly River drainage.

Upper headwaters (R9)

Thirty-one spawning areas were identified in the upper headwaters region in Canada (Figure 10; Tables

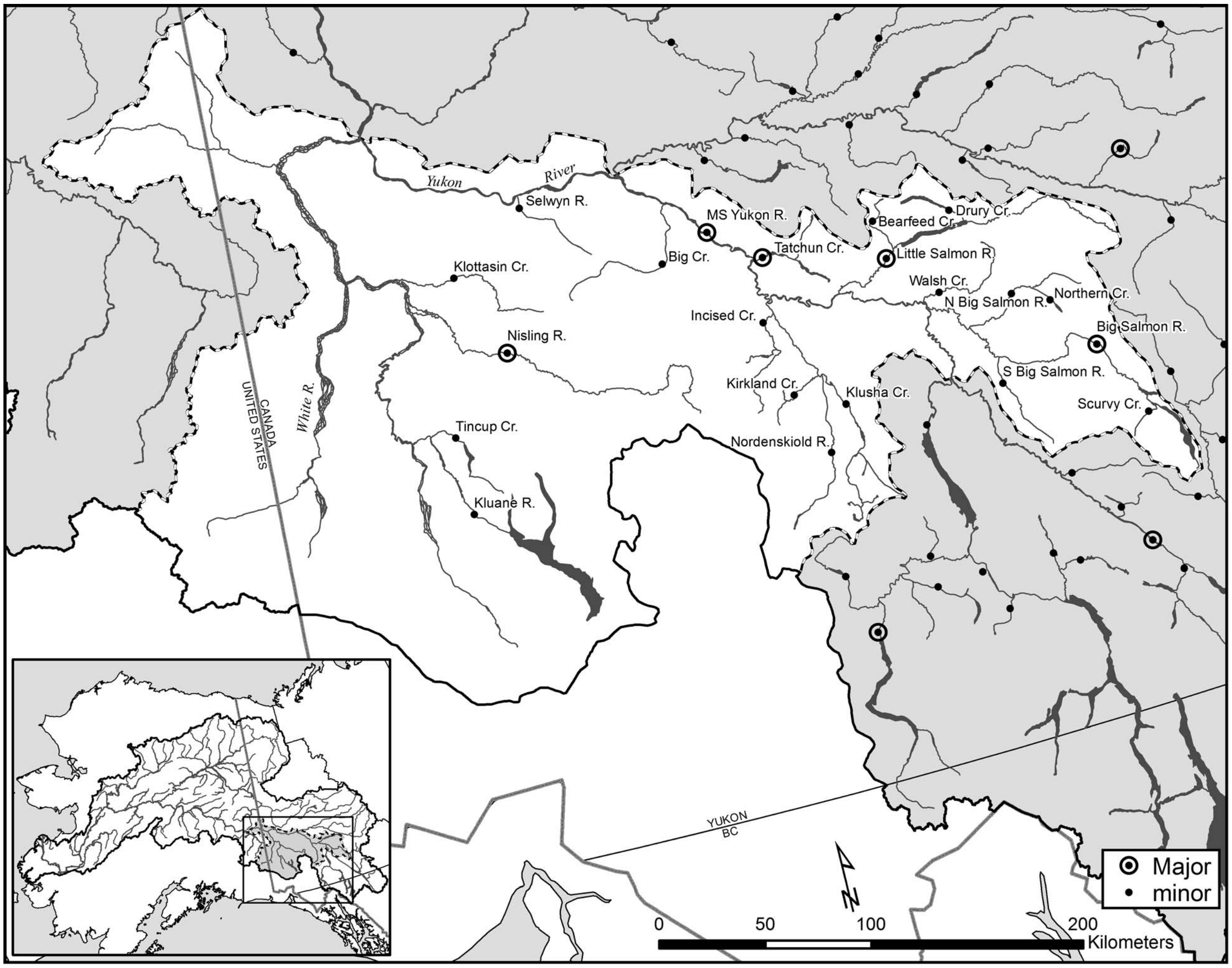

Figure 8. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the Yukon River main-stem region (R7), Yukon River basin in Canada. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

2 and 3). Four spawning areas were classified as major producers including the Teslin River downstream from Teslin Lake, the Wolf and upper Nisutlin rivers in the upper Teslin River drainage, and the Takhini River downstream from Kusawa Lake (Table 4). Eiler et al. (2014) estimated that an average of 9.8% of the entire run returned to the Teslin River during the basin-wide telemetry study. During all 3 y, the terminal locations of over half of the tagged fish were between the Teslin River mouth and the outlet of Teslin Lake (Osborne et al. 2003; Mercer and Eiler 2004; Mercer 2005). Consequently, this main-stem reach was classified as a major producer. The Wolf River was classified as a major producer based on a 36-y record of aerial surveys averaging 221 fish (Estensen et al. 2012). Similarly, the upper Nisutlin River was classified as a major producer based on a 41-y record of aerial surveys between the late 1960s and 2010, averaging 439 fish. The Takhini River was classified as a major producer based on a 16-y record of aerial survey counts, averaging 260 fish (Barton 1984a). The Morley River may have been a major producer in the past, but recent data do not support this classification. Barton (1984a) reported average counts of 166 fish (range 7–571 fish) during 12 aerial surveys between 1969 and 1983, which by itself would result in the area being classified as a major producer. During the basin-wide telemetry study however, only a single radio-tagged fish was located in the river (Osborne et al. 2003; Mercer and Eiler 2004; Mercer 2005), suggesting that the Morley River currently supports a smaller return. Another river with classification complications is Michie Creek, which is located upstream from the Whitehorse Rapids Dam (Gordon et al. 1960) and is supplemented annually with juveniles produced in the Whitehorse Rapids Fish Hatchery that are marked with coded wire tags and clipped adipose fins (Boyce 2000; Yukon Energy 2005; JTC 2016). During its 41 y of operation, the hatchery has released an average of approximately 150,000 juveniles annually, mostly upstream from the dam and mostly in Michie Creek (JTC 2016). Approximately 50% of the Chinook Salmon enumerated at the Whitehorse Rapids Fishway are thought to return to Michie Creek (Matthews 1999).

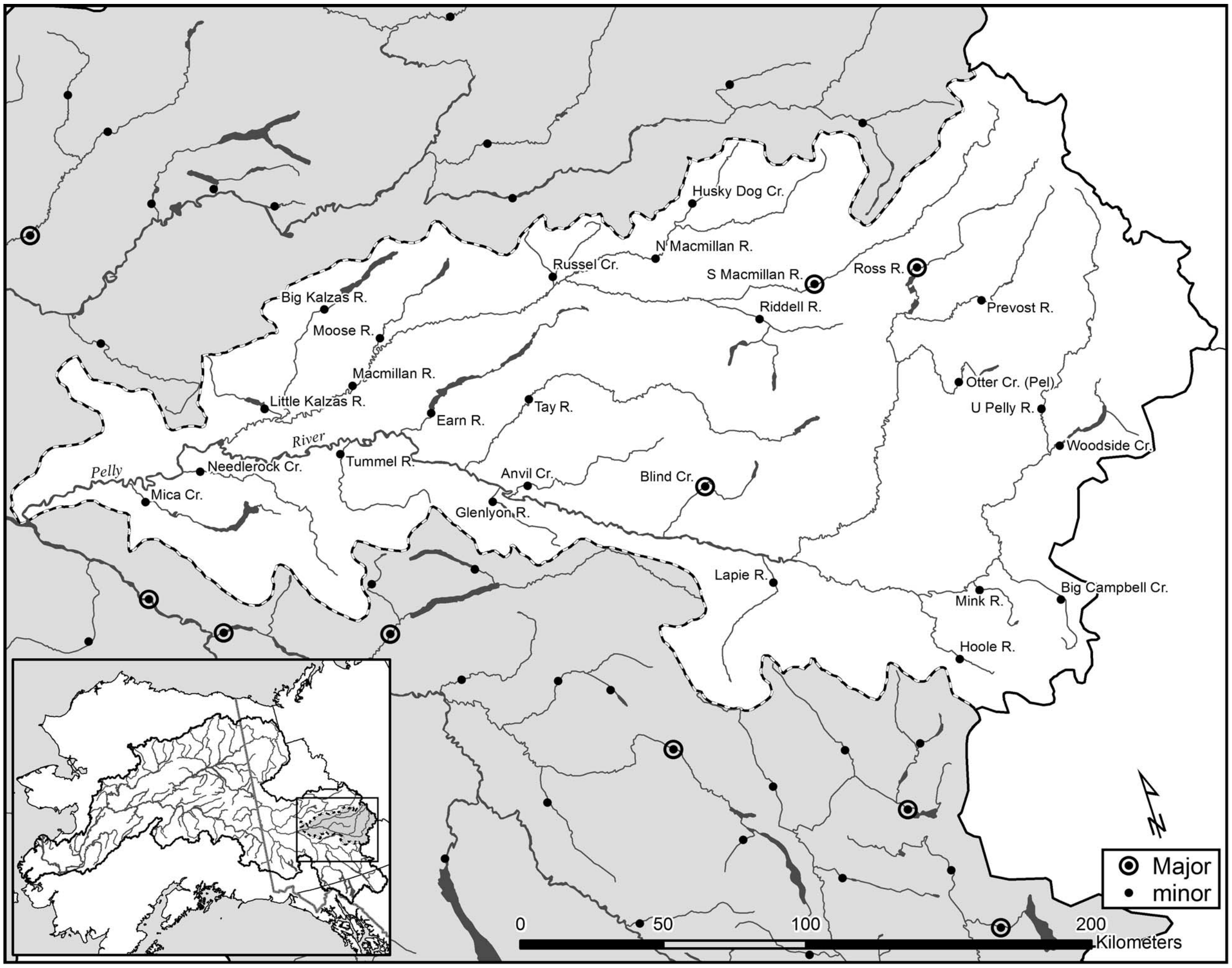

Figure 9. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the Pelly River drainage (R8), Yukon River basin in Canada. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

The 1990–2015 average fishway count was about 1,300 fish, suggesting an average escapement of about 650 fish to Michie Creek (JTC 2016). However, during this same time period an average of 57% of the returns through the fishway were first generation hatchery fish without adipose fins, indicating that the Michie Creek spawning population is supported primarily by hatchery rather than wild production. We therefore have classified Michie Creek as a minor producer. Altogether, 27 spawning areas in the upper headwaters region were classified as minor producers.

Discussion

Based on our review of the information, spawning Chinook Salmon were widely distributed throughout the Yukon River basin, with fish traveling from 135 km to more than 3,200 km to reach their final destinations. More than 180 spawning areas were identified, ranging from lower river tributaries to the upper headwaters. Eiler et al. (2014) observed that fish returning to the Canadian portion of the basin were more uniformly distributed, whereas those returning to U.S. portion were more clumped in their distribution, which is consistent with our findings (Figure 1).

Chinook Salmon spawning populations in the Yukon River basin seem to be consistent with a metapopulation structure as described by Policansky and Magnuson (1998) and Schtickzelle and Quinn (2007) for Pacific salmon and other anadromous fish. Salmon metapopulations are generally defined as groups of local spawning populations that experience a range of habitat qualities and environmental variables, yet are in close enough proximity to enable a small amount of gene flow through straying. Theoretically, this type of population structure is capable of surviving environmental perturbations that might lead to extinction of one or more local populations while providing a source for the colonization of suitable but vacant habitat (Hanski and Gilpin 1991; Harrison 1991; Hanski 1998). Average straying rates in stream-type Chinook Salmon have usually been estimated as $<5\%$, with straying more common between nearby streams than more distant reaches (Quinn 1993; Candy and Beacham 2000; Westley

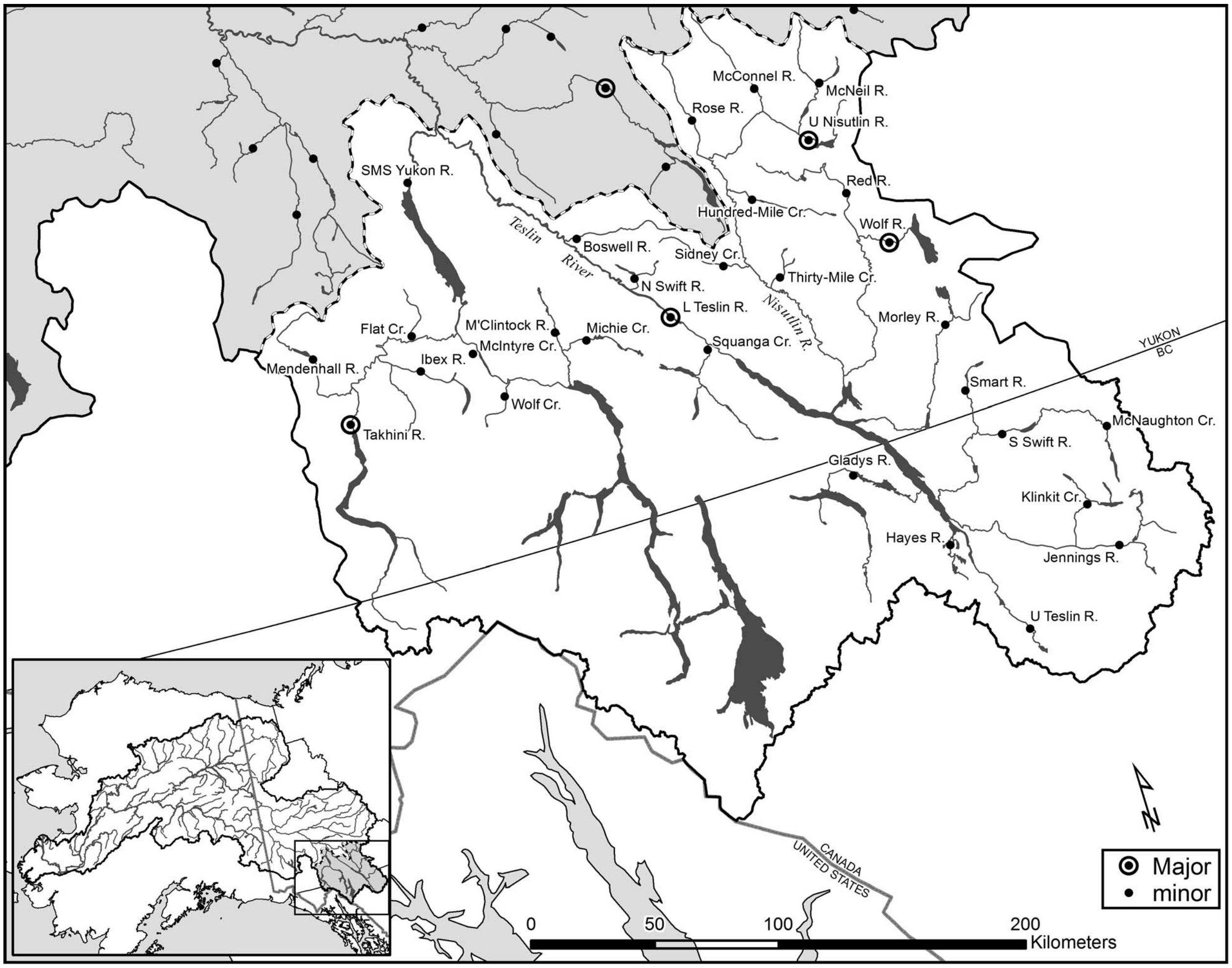

Figure 10. Distribution of major and minor producing Chinook Salmon *Oncorhynchus tshawytscha* spawning areas (Table 1) compiled in 2017 for the upper headwaters region (R9), Yukon River basin in Canada. Note that the symbols identify the streams and main-stem reaches cataloged in this manuscript, but do not represent actual spawning locations.

et al. 2013). Investigations of genetic diversity and structure among Chinook Salmon spawning populations in the Yukon River indicate that geographic structuring is most pronounced at the country of origin level (upper reaches of the basin vs. lower reaches), less pronounced among regional spawning aggregations, and weakest among local spawning populations within a region (Smith et al. 2005; Beacham et al. 2008; Flannery et al. 2012). All these lines of evidence are consistent with a metapopulation structure in the Yukon River basin.

Chinook Salmon returning to the Yukon River basin originated in a mixture of major and minor producing spawning areas. We based the assessment on three different indices of spawning abundance. Healey (1982) used similar indices (i.e., escapement estimates and aerial surveys, but no telemetry-based distribution information) to classify 326 Chinook Salmon spawning populations in British Columbia into four size categories ($<$200, 200–1,000, 1,000–5,000, and $>$5,000 fish) and concluded that a majority of populations in British Columbia were very small (49% $<$200 fish, 81% $<$1,000 fish). For comparative purposes, we reclassified the mean stream escapement estimates presented by Healey (1982; Table 10) by using our numerical size criteria ($\geq$500 = major producer, $<$500 = minor producer) and found that we would have classified 67% ($n = 218$) of the spawning areas in British Columbia as minor producers and 33% ($n = 108$) as major producers. Our data suggest that small populations are even more prevalent in the Yukon River with 83% ($n = 151$) of spawning areas classified as minor producers and only 17% ($n = 32$) as major producers.

These 183 Chinook Salmon spawning areas identified here represent the current knowledge for the Yukon River basin, but there is nothing absolute about this number or the relative production levels of these localized populations. It is unlikely that additional major spawning aggregates exist within the basin given the extensive coverage by aerial surveys (Barton 1984a; State of Alaska 2016b), the pipeline assessment work conducted in the upper basin during the 1970s and 1980s (e.g., Walker 1976; Beak Consultants Limited 1977), the contributions of Canadian First Nations conducting fisheries research in familiar drainages (e.g., Nacho Nyak Dun First Nation 1998; Sparling 2003), the basin-wide telemetry study (e.g., Anderton 2005a; Eiler et al. 2014), and the on-going compilation of information provided by the Alaskan *Anadromous Waters Catalog* (Johnson and Litchfield 2016a, 2016b; State of Alaska 2016a). However, it is likely that some minor spawning aggregations remain undocumented due to turbidity in certain reaches of the basin that prevent viewing during aerial surveys, the remote nature and limited access of many tributaries, and other detection challenges. Other authors may also split or combine spawning areas or classify escapement levels differently and achieve different totals. Similarly, the relative size of these spawning populations may change over time in response to changing habitat conditions or improved assessment methods and abundance estimates. Streams that are currently vacant may eventually be colonized (Schtickzelle and Quinn 2007), discovered, and added to this catalog. Alternatively, the number of fish currently using established spawning areas may decline to the point where they become vacant. Nonetheless, the Chinook Salmon spawning areas cataloged here provides a baseline that makes it possible to assess both spatial and temporal changes within the basin.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Table S1. Chinook Salmon *Oncorhynchus tshawytscha* spawning areas compiled in 2017 for the Yukon River basin ordered by the country in which a spawning area is found, region, and drainage listed sequentially from the Yukon River mouth upstream to the final spawning destinations.
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Wildlife Service). Reviews by J. Adams (U.S. Fish and Wildlife Service); J. Conitz, B. Borba, and A. Padilla (Alaska Department of Fish and Game); M. Bradford (Fisheries and Oceans Canada); the Associate Editor of the JFWM; and two anonymous reviewers improved the focus, quality, and clarity of the manuscript.

Any use of trade, product, website, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Sulukna River: Gerken J, Esse D. 2016. In July 2007, Jon Gerken (U.S. Fish and Wildlife Service) and Dave Esse (Bureau of Land Management) conducted a boat survey of river conditions on the Sulukna River in the upper Nowitna River drainage in preparation for an upcoming Inconnu *Stenodus leucichthys* spawning habitat project. They observed between 50 and 100 prespawning Chinook Salmon along the course of the river and captured and photographed several of them.

Sethkokna River: Kretsinger C, Karlan B. 2016. Following a July 30, 2014, aerial helicopter fish survey of the Sethkokna River in the upper Nowitna River drainage, Carl Kretsinger and Bob Karlan (Bureau of Land Management) reported observing 98 Chinook Salmon along the course of the river, all associated with spawning redds. They observed approximately 40 redds.

Selwyn River: Department of Indian Affairs and Northern Development, Department of Fisheries and Oceans, Department of the Environment, and Yukon Territorial Government. 1985. An Environmental Review of Big Creek, Yukon as related to Placer Mining, Prepared for Placer Research and Development Committee. According to Al von Finster (Fisheries and Oceans Canada), who participated in the review, spawning Chinook Salmon were observed in the Selwyn River.

Kirkland Creek: In 1995, Al von Finster (Fisheries and Oceans Canada) filed a 5-page memo with Fisheries and Oceans Canada describing observations of Chinook Salmon spawning in Kirkland Creek during an overflight of Division Mt. Coal and potentially affected water bodies and stream courses.

Rose River: On August 15, 1996, Al von Finster (Fisheries and Oceans Canada) filed a 1-page memorandum with the Habitat and Enhancement Branch, Yukon and Transboundary Rivers Division, Department of Fisheries and Oceans, documenting his observation of Chinook Salmon spawning in the Rose River.

Klinkit Creek: In the late 1980s, helicopter pilots supporting mineral exploration in the Klinkit Lake area reported observing Chinook Salmon spawning immediately downstream of the lake outlet to habitat biologist Al von Finster (Fisheries and Oceans Canada).

Mendenhall River: On August 24, 2003, Paul Sparling and Mark Connor filed a preliminary report with the Yukon Department of Highways and Public Works on a fisheries utilization assessment conducted at the Alaska Highway crossing on the Mendenhall River, August 19th & 20th, 2003. They reported that they captured several fish species including a juvenile and an adult Chinook Salmon.