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**Evaluation of release strategies for hatchery kokanee in Lake Roosevelt, Washington**

Running footer: hatchery release strategies kokanee

3 tables, 2 figures

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## **Abstract**

Lake Whatcom kokanee have been stocked in Lake Roosevelt since 1988 with the goals of providing a hatchery kokanee fishery and establishing a returning run for egg collection. Harvest and escapement goals have not been achieved since the program began. Four experiments were designed to evaluate release strategies in an attempt to improve adult returns to release sites. Paired releases of kokanee were made to compare imprinted to non-imprinted, early run to middle run, early release to late release, and direct hatchery releases to three different net pen releases. Hatchery and tributary returns did not differ significantly between imprinted and non-imprinted fish; however, early run fish outperformed middle run, early release date outperformed the late release fish, and hatchery releases outperformed net pen releases. The total number of kokanee recovered during the spawning migration in 1998 and 1999 was low. A combination of entrainment, predation, and hatchery practices appear to be the limiting factors that contribute to the overall low performance of Lake Whatcom kokanee in Lake Roosevelt.

## **Introduction**

Kokanee salmon (*Oncorhynchus nerka kennerlyi*), the freshwater form of sockeye salmon, represent a major fishery in the Pacific Northwest (Rieman and Myers 1992, Modde et al. 1997, Taylor et al. 2000). Some introduced kokanee stocks develop self-sustaining populations (Martinez and Wiltzuis 1995), while others are supported entirely by hatchery supplementation (Wydoski and Bennett 1981, Rieman and Myers 1992). Kokanee are pelagic, schooling fish that forage primarily on large zooplankton (Rieman and Maiolie 1995). Kokanee growth and maturity is density dependent and driven by the productivity of the rearing environment (Lewis, 1970, Rieman and Meyers 1992, Rieman and Maiolie 1995). In general, kokanee exhibit a 1:1 sex ratio, and mature between ages 3 and 4 as seen in Flaming Gorge Reservoir, Utah (Gibson and Hubert 1993), Lake Ozette, Washington (Beauchamp et al. 1995), Flathead River, Montana (Fraley 1984), and Granite Creek and Sullivan Springs, Idaho (Cochnauer 1984). Adult return rates have been reported between 2-12% in Sullivan Springs, Idaho (Cochnauer 1984, Bowles et al. 1989), but vary highly between water systems.

Lake Whatcom kokanee salmon have been stocked into Lake Roosevelt since 1988 as partial mitigation for lost anadromous salmon and steelhead runs blocked by Grand Coulee Dam (Northwest Power Planning Council 1987). The goals of the kokanee program were to improve angler harvest of kokanee in Lake Roosevelt (harvest goal = 290,000 fish) and establish a self-sustaining run of kokanee that would provide eggs for continuous hatchery production (escapement goal = 10,000 age-3). Originally, the Lake Roosevelt kokanee hatcheries (Spokane Tribal and Sherman Creek) were designed to release 8 million fry, which was half of the reservoir's carrying capacity for kokanee (Jagiello 1984, Beckman et al. 1985, Scholz et al.

1986). This stocking rate was a deliberate attempt to produce large-sized fish that would attract sport anglers.

A new production goal of 1 million residualized smolts was established in 1995 after research indicated fry releases were performing poorly (Tilson et al. 1994, 1995, 1996). Physiological data indicated Lake Whatcom kokanee smolted during the spring, which coincided with the spring drawdown and short water retention times, potentially leading to high entrainment. Managers hypothesized switching from fry to residualized smolt releases would decrease entrainment by reducing their tendency to migrate downstream.

Predation was also considered a possibility for poor fry performance. Walleye (*Sander vitreus*) are the most abundant piscivore found in Lake Roosevelt (Cichosz et al. 1999). Salmonids are an important item in walleye diets with relative important values ranging from 8% to 28% since 1993 (McLellan et al. 2003). Walleye densities are relatively high at kokanee release locations during the spring, particularly near Sherman Creek (McLellan et al. 2001a). Walleye typically eat salmonids that are 50% or less than their total length (Baldwin et al. 2003). The larger size of post-smolt kokanee could possibly limit walleye predation by excluding younger, smaller, and more abundant age classes of walleye.

The switch to post-smolt releases increased returns (0.05-0.3%) of age-2 kokanee, but remained below target goals (Tilson et al. 1996, Tilson and Scholz 1997). The mature age-2 kokanee in Lake Roosevelt were considered precocial jacks because of the early maturity and predominately male composition of the run; however a normal run of age-3 kokanee with a typical 1:1 sex ratio never materialized the following year.

The goal of releasing 1 million kokanee smolts annually exceeded available hatchery capacity. Adjustments including early and late shipments of post smolt kokanee to Sherman

Creek Hatchery and net pen rearing were made to achieve the goal. A concern was that the late shipment and net pen reared kokanee imprinted to waters other than Sherman Creek, because they went through the critical imprinting period at other locations (Tilson and Scholz 1997, 1998). Thus, all kokanee were imprinted with the chemical cue morpholine and were expected to return to the Sherman Creek Hatchery, where morpholine was dripped (Tilson and Scholz 1997, 1998). Imprinting salmonids with synthetic chemicals, such as morpholine, will attract fish to streams scented with those chemicals (Scholz et al. 1976, Hasler and Scholz 1983).

Kokanee eggs from the mid-late Lake Whatcom spawning run were typically used by the hatcheries. The spawning run occurred from mid-September to early December (Tilson et al. 1996; Tilson and Scholz 1997, 1998). Sherman Creek tends to freeze by mid-November making it difficult to collect spawners. Using eggs from the Lake Whatcom early-run might increase the number of adults collected.

Concerns over the adjustments made to accommodate post smolt releases and the number returns that were lower than escapement goals prompted a series of matched pair experiments on kokanee released from Sherman Creek Hatchery and net pens in 1998 and 1999. The goal was to determine the best release strategies to maximize hatchery kokanee adult returns. We met this goal by using morpholine to increase return rates, and by comparing differences in run timing, smolt releases dates, and rearing pen differences.

## **Methods**

### **Study Area**

Lake Roosevelt was formed when Grand Coulee Dam impounded the waters of the Columbia River in 1939 (Figure 1). At full pool (430 m mean sea level; MSL) the reservoir is 243 km

long, inundates 335 km<sup>2</sup>, and has a maximum depth of 122 m (Stober et al. 1981). The minimum operating pool is 403 m MSL. Grand Coulee Dam was constructed primarily for power production, flood control, and irrigation with secondary operations for recreation, fish, and wildlife.

#### Hatchery Rearing to Release

Lake Whatcom stock kokanee-eyed eggs (1996 brood year) were obtained from the Lake Whatcom Hatchery (Washington Department of Fish and Wildlife; WDFW) in Bellingham. The eggs were incubated and the fish were raised at the Spokane Tribal Hatchery in Wellpinit. Water supply to the incubators and raceways was a combination of 8-11°C spring and well water. After swimup, fry were fed Biodiet semi-moist mash (starter feed). Older fry were fed a combination of Biodiet semi-moist grower feed (1.0, 2.5, 4.0 mm). Photoperiod was maintained at natural day length.

All test groups were exposed to the synthetic chemical morpholine during the swimup phase of development, except the non-morpholine test group. Once kokanee reached 100 mm total length (TL), they were netted out of the hatchery raceways, anesthetized with 50 mg/L concentration tricaine methanesulfonate (MS-222), and coded wire tagged (CWT) in the rostrum using a model MK4 CWT machine. Unique tag numbers were given to each experimental lot of fish. The adipose fin of all hatchery kokanee, including those not used in the study, was clipped to differentiate them from wild kokanee. Fish were released back into the hatchery raceways through a quality control device, which ensured 100% of the fish were marked.

Residualized kokanee bound for the northern net pens were trucked to the Kettle Falls boat launch and loaded into net pens in November 1997. Nets were slowly pulled 1.7 km to the mouth of Sherman Creek cove. In January, one net was moved an additional 2.4 km across the

river to the mouth of the Colville River, and the other remained at the mouth of Sherman Creek cove. Kokanee bound for the lower reservoir net pen sites were trucked to the Seven Bays boat launch and loaded into net pens in November 1997. The Seven Bays net pens were kept in the cove and the Lincoln net pens were slowly pulled 7.1 km to the cove. Kokanee smolts were transferred from the Spokane Tribal Hatchery to the Sherman Creek Hatchery in March 1998. Dates of release varied between 16 May and 12 July 1998 (Table 1).

In previous studies of Lake Roosevelt kokanee, tag retention was determined from returning fish because all hatchery kokanee were double marked with a coded wire tag and an adipose fin clip. In 1998, only the experimental kokanee were coded wire tagged. Therefore, the average tag retention between 1995 and 1997 (0.79) was used as the correction factor in 1998, when the fish were age-2, and again in 1999, with the age-3 fish (Tilson and Scholz 1997).

#### Experimental Design for Coded Wire Tag Release Groups

The four experiments tested return rates of: 1) morpholine exposed vs. non-exposed, 2) early run vs. middle run, 3) early release date vs. late release date, and 4) three net pen releases (Sherman Creek Hatchery vs. Sherman Creek net pens, Sherman Creek net pens vs. Colville River net pens, and upper reservoir net pens vs. lower reservoir net pens).

Each experiment was evaluated using two performance measures; returns to Sherman Creek Hatchery and returns to all tributaries in the reservoir. Chi-square tests for independence was used in all statistical analysis ( $P = 0.05$ )(Zar 1999).

#### Adult Collection

Morpholine was dripped into Sherman Creek at the hatchery (at a steady state concentration of  $5 \times 10^{-5}$  mg/l) between August and December 1998 to attract the morpholine-exposed kokanee. Returning mature kokanee were recovered 15 August - 10 December 1998 (age-2) and 16

August - 1 December 1999 (age-3). Weekly boat electrofishing surveys were conducted at Sherman Creek cove to collect returning kokanee (3-5 amps, 50-500 V with 50%, 120 pps DC current). Backpack electrofishing was also utilized when kokanee moved into Sherman Creek. Five passes through the reservoir were conducted during the study period to assess tributary returns. A pass consisted of boat electrofishing for 10 min transects at 121 primary embayments. In 1998, an additional 147 embayments were sampled on at least one occasion to capture possible strays. In 1999, the primary 121 embayments were sampled five times. Sites were sampled at 2 wk intervals during both years. The Spokane Tribe of Indians (STI), Colville Confederated Tribe of Indians (CCT), and WDFW collected additional kokanee during their regular fall sampling periods to maximize the sample size.

All captured kokanee were checked for a CWT with a handheld CWT detector, TL measured to the nearest mm, and a sub-sample was weighed. Kokanee with CWT were killed and the heads were placed in individually numbered bags for laboratory analysis. All CWT were extracted and read twice using a dissecting microscope to determine and confirm the binary code.

## **Results**

A total of 2,317 age-2 CWT hatchery kokanee were collected in 1998 (Table 2). The majority of kokanee were captured in the upper reservoir sections (8-10), primarily at Sherman Creek (73.5%). Few fish were captured in the middle and lower reservoir sections with exception of Hawk Creek (section 4) where 9.4% of the fish were recovered (Figure 1). Overall, 77% of all the fish recovered were released from Sherman Creek Hatchery, including 74% of the fish recovered at Hawk Creek and 87% of the fish recovered at Sherman Creek. The kokanee run

peaked on 4 November 1998 at Sherman Creek, with a catch-per-unit-effort (CPUE) of 316 fish/hr. The age-2 female to male ratio, including non-CWT hatchery kokanee, was 1 female: 8 males. Mean TL of mature age-2 females was 290 mm (SE 2.4; n = 153) and males was 300 mm (SE = 0.5; n = 2,245) (Figure 2). Mean weight of mature age-2 females was 304.9 g (SE = 30.1; n = 38) and males was 298.6 (SE = 2.5; n = 1,113).

A total of 20 age-3 hatchery kokanee were collected in 1999 (Table 2). Kokanee were collected at a few of the major tributaries, but due to the low numbers collected they exhibited no apparent geographic pattern. The majority (70%) of age-3 kokanee recovered were released from Sherman Creek Hatchery. The female to male ratio was 1 female: 5 males. Mean TL of age-3 females was 376 mm (SE = 43.8; n = 3) and males was 348 mm (SE = 16.8; n = 17). Mean weight of mature age-3 females was 300 g (n = 1) and males was 414 g (SE = 64.7; n = 14).

### Experimental Results

Returns of age-3 kokanee were generally too low to compare treatments adequately; therefore results are presented only for age-2 adult returns.

No significant difference was found between age-2 morpholine exposed and non-exposed kokanee that returned to Sherman Creek and tributaries throughout the reservoir (Table 3). Significantly more early run age-2 kokanee returned to Sherman Creek ( $P < 0.01$ ) and the tributaries ( $P < 0.01$ ) than middle run kokanee. Significantly more early (29 May 1998) release age-2 kokanee returned to Sherman Creek ( $P < 0.01$ ) and at the tributaries ( $P < 0.01$ ) than late release fish (13 July 1998). Significantly more Sherman Creek Hatchery release age-2 kokanee returned to Sherman Creek ( $P < 0.01$ ) and were collected at tributaries ( $P < 0.01$ ) than fish released from the Sherman Creek net pens. Significantly more Sherman Creek net pen released

kokanee returned to Sherman Creek ( $P < 0.01$ ) and were collected at tributaries ( $P < 0.01$ ) compared to the Colville River net pen release. Significantly more kokanee from the upper reservoir net pen releases (Kettle Falls Marina, Sherman Creek, and Colville River) were recovered at Sherman Creek ( $P < 0.01$ ) and were collected at tributaries ( $P < 0.01$ ) as age-2 fish compared to the lower reservoir net pen releases (Lincoln and Seven Bays) (Table 3).

## **Discussion**

The study focused on kokanee release strategies designed to increase return rates and promote a hatchery kokanee fishery. The morpholine vs. non-morpholine experiment was designed to evaluate the ability of Lake Whatcom kokanee to imprint to Sherman Creek water during a second imprinting period. Lake Whatcom kokanee experience two periods of elevated thyroxine levels, one during swimup and the other during smolting (April and May), which initiate imprinting (Tilson et al. 1995). The lack of a significant difference between morpholine exposed and non-exposed groups (Table 3) indicated that Lake Whatcom kokanee held at Sherman Creek Hatchery during smoltification were imprinting to the water. Based on our results kokanee can be imprinted to waters if they are held in them through smoltification, even if they experience a different water source during the first imprinting period (swimup).

The kokanee from the Lake Whatcom early run group had significantly more returns than the late run group (Table 3). The reason for the significant difference in return rates was not apparent, because Sherman Creek cove did not freeze during the study period, as it had in the past, and all returning kokanee were collected. However, early run eggs should be used, when available, due to the higher return rates observed in this study and the chance that the cove may freeze in the future.

Net pens are a necessary tool for rearing kokanee post-smolts because of their large release size and the limited hatchery space. Sherman Creek Hatchery releases had significantly higher returns than the Sherman Creek net pen (Table 3), suggesting net pen rearing kokanee is not equivalent to hatchery rearing. The net pens at the mouth of Sherman Creek cove were considered comparable to the hatchery released fish because they were morpholine imprinted and exposed to chemical cues associated with Sherman Creek water through the second imprinting period. The kokanee in the other net pens were morpholine imprinted also, but return rates were significantly lower than those of the Sherman Creek net pens. Our results indicate that net pen reared kokanee should not be expected to return to egg collection locations, and thus should be considered a put-and-take fishery.

Entrainment and predation have been identified as possible reasons for low return rates. Lake Roosevelt kokanee have been collected downstream of Grand Coulee Dam at Rock Island Dam's Fish Passage Facility (McLellan et al. 2001b). Entrainment over Grand Coulee Dam has not been quantified, and downstream fish passage data cannot be used because there is no estimate for the number of kokanee that remain in any of the four reservoirs between Grand Coulee and Rock Island Dams. Predation by walleye on hatchery kokanee 41 d after release near Sherman Creek in 1999 and 2000 was estimated to be 15.0% (54,073) and 9.4% (34,076; Baldwin et al. 2003). Annual reservoir-wide predation could be higher depending on long-term feeding rates, however predation was not considered the only limiting factor for kokanee recruitment in Lake Roosevelt (Baldwin et al. 2003).

The large age-2 kokanee and unusual sex ratio observed in previous Lake Roosevelt studies (Tilson and Scholz 1998) were present in the current study. Lake Roosevelt kokanee averaged 290 and 300 mm for age-2 females and males in 1998, which were larger than mature 3

or 4 yr old kokanee in Dworshak reservoir (Fredericks et al. 1995), Coeur d'Alene Lake, Pend Oreille Lake, and Priest Lake, Idaho (Reiman and Myers 1992) which ranged between 225 and 263 mm. A typical female: male ratio for kokanee is 1:1; however, hatchery kokanee in Lake Roosevelt had ratios of 1:8 in 1998 and 1:5 in 1999. The large size of post-smolts at release enables them to be immediately vulnerable to the fishery, but limits the available harvest time to 5 mo before they mature. Regardless, egg takes would be possible except the highly skewed sex ratios severely limit the number of females returning.

Precocity (early maturity at age-2) and the unusually high number of males observed are typical signs of a jack run. However, due to the lack of a normal run returning as age-3 fish, their large size at age-2, and a precocity study that found up to 63% of the fish were precocial with a 1:7 female: male ratio before release (Chuck Lee, Spokane Tribe of Indians, personal communication) indicated the age-2 run was not a jack run but was in fact the mature run.

Precocious maturation has been positively correlated with fast growth in salmonids (Foote et al. 1991). Higher water temperatures coupled with an unlimited food source in the hatchery setting could be causing the early maturity. Craig et al. (1996) observed sex ratios of 2-5 females to 1 male in sockeye salmon and kokanee when water temperatures (8.9-9.7 °C) were raised (10.4-12.0 °C) during embryonic development. The control groups that were not subjected to a temperature change maintained a 1:1 sex ratio. The Spokane Tribal Hatchery initially incubates eggs in cold spring water (9-11 °C), and then switches to well water (11-17.8 °C) in the spring when the spring water starts to warm. The switch or fluctuations in the spring water temperature could be occurring at critical times during development resulting in the abnormal sex ratios. These data indicate that precocity and sex determination issues in hatchery kokanee are related to hatchery practices most likely linked with temperature and an unlimited

food supply. Interestingly, the male to female ratios observed in the Lake Roosevelt hatchery kokanee were opposite those observed by Craig et al. (1996).

The coastal Lake Whatcom stock of kokanee has not performed up to expectations in Lake Roosevelt. Hatchery rearing methods including water temperature regimes (fluctuations, well or spring), nutritional levels (feed), and hatchery methods (grading) need to be evaluated to address precocity and sex ratio issues. Beacham and Murray (1989) suggested interior stocks are locally adapted to lower water temperatures compared to coastal stocks. A kokanee stock native to the upper Columbia River might perform better in Lake Roosevelt, and be more ecologically responsible when considering impacts on downstream stocks of sockeye salmon listed under the Endangered Species Act (ESA). Kokanee populations such as those in the Arrow and Kootenay Lakes, British Columbia and Chain Lakes, Washington should be evaluated as an alternative to Lake Whatcom stock.

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TABLE 1. Date, release location, run time, total estimated length (mm) at release (converted from fish per pound), and number of kokanee released in Lake Roosevelt, 1998. Kokanee were exposed to morpholine during the hatch and swim-up stage of development.

Date Released	Location Released	Run Time	Total length at Release	Number Kokanee Released
19 May	Lincoln NP	middle	158	39,099
20 May	Seven Bays NP	middle	159	38,858
23 May	Kettle Falls NP	middle	152	53,421
16 May	Colville River NP	middle	156	75,554
29 May	Sherman Creek NP	middle	151	44,499
28 May	Sherman Creek	middle	158	58,124
28 May <sup>1</sup>	Sherman Creek	early	158	57,191
28 May	Sherman Creek	early	158	68,198
12 July	Sherman Creek	early	181	30,575

<sup>1</sup> Not exposed to morpholine

TABLE 2. Effort, number of coded wire tagged (CWT) kokanee, and catch-per-unit-effort (CPUE) per location in Lake Roosevelt, 1998 and 1999. Numbered locations correspond with Figure 1.

Location	1998			1999		
	Effort (hr)	CWT (n)	CPUE (fish/hr)	Effort (hr)	CWT (n)	CPUE (fish/hr)
<b>Lower Reservoir</b>						
1 Grand Coulee/Spring Canyon	7.2	15	2	4.5	5	1
2 Keller Ferry	6.0	35	6	3.6	0	0
3 Sanpoil River	3.0	0	0	1.9	0	0
<b>Middle Reservoir</b>						
4 Hawk Creek/Seven Bays	17.0	235	14	13.0	2	0
5 Fort Spokane	5.8	18	3	4.8	0	0
6 Hunters	12.1	43	4	5.0	3	1
7 Gifford	4.5	2	0	2.1	0	0
<b>Upper reservoir</b>						
8 Bradbury Beach	7.4	107	14	4.7	0	0
9 Kettle Falls/Sherman Creek	28.8	1,766	61	18.1	4	0
10 Evan/China Bend	3.8	15	4	2.8	0	0
<b>Spokane River</b>						
11 Porcupine Bay	11.9	16	1	10.1	0	0
12 Little Falls	10.3	65	6	6.9	6	1
Grand Total	117.8	2,317	20	77.2	20	0

TABLE 3. Number of kokanee recovered per coded-wire-tag number (CWT) and chi-square results per experiment for kokanee collected at Sherman Creek and at tributaries to the reservoir, 1998-1999. Sherman Creek (SC) and Colville River (CR).

Test Group	# Recovered	% Recovered	$\chi^2$	P-value
<i>Sherman Creek</i>				
Imprinted	528	0.77		
Non-imprinted	483	0.84	1.92	0.17
<i>Tributaries</i>				
Imprinted	722	1.06		
Non-imprinted	634	1.11	0.72	0.40
<i>Sherman Creek</i>				
Early run	528	0.77		
Middle run	365	0.63	9.56	< 0.01
<i>Tributaries</i>				
Early run	722	1.06		
Middle run	458	0.79	24.37	< 0.01
<i>Sherman Creek</i>				
Early release	528	0.77		
Late release	97	0.32	70.11	< 0.01
<i>Tributaries</i>				
Early release	722	1.06		
Late release	123	0.40	107.24	< 0.01
<i>Sherman Creek</i>				

SC Hatchery	365	0.63		
SC net pen	123	0.28	65.82	< 0.01
<i>Tributaries</i>				
SC Hatchery	458	0.79		
SC net pen	171	0.38	67.43	< 0.01
<i>Sherman Creek</i>				
SC net pen	123	0.28		
CR net pen	69	0.09	60.08	< 0.01
<i>Tributaries</i>				
SC net pen	171	0.38		
CR net pen	115	0.15	63.46	< 0.01
<i>Sherman Creek</i>				
Upper net pens	224	0.13		
Lower net pens	6	0.00	86.78	<0.01
<i>Tributaries</i>				
Upper net pens	351	0.20		
Lower net pens	29	0.04	97.19	< 0.01

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Figure 1. Lake Roosevelt with 12 sampling sections, Spokane Tribal Hatchery on Chamokane Creek (a tributary of the Spokane River), Sherman Creek Hatchery, two lower reservoir net pen sites, and three upper river net pen sites.

Figure 2. Length frequency distribution of age-2 female and male hatchery kokanee collected in Lake Roosevelt, 1998.



