MANAGEMENT BRIEFS

Enhanced Incubation Success for Kokanee Spawning in Groundwater Upwelling Sites in a Small Idaho Stream

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Abstract.—Kokanee (*Oncorhynchus nerka* lacustrine sockeye salmon) spawned in groundwater upwelling in the North Fork of the Payette River, Idaho. Intragravel water temperatures in groundwater-influenced redds exceeded surface flow water temperature by 2.4–2.6°C. In redds without groundwater influence, intragravel and water column temperatures did not differ by more than 0.2°C. Although redds constructed in upwelling sites contained significantly more fine sediments (<0.83 mm) and were constructed in areas of significantly lower surface water velocities than redds not influenced by upwelling, preemergent survival of fry from redds in upwelling sites (84%) significantly exceeded that from redds in other areas (66%). Higher incubation temperatures at upwelling sites accelerated rates of development, protected embryos from freezing, and may increase survival of fry recruiting to Payette Lake.

Current knowledge on effects of groundwater or spring upwelling on salmonid incubation success is limited (Hansen 1975; Carline 1980; Sowden and Power 1985). Upwelling may enhance embryo survival by providing a more stable thermal environment and increasing water exchange rate past embryos (Bjornn and Reiser 1991). Sheridan (1962) documented warmer winter temperatures at upwelling sites but concluded that most intragravel dissolved oxygen downwelled from the stream. High fractions of fine sediments reduce embryo survival (Phillips et al. 1975; Hausle and Coble 1976; Tappel and Bjornn 1983) and size of emerging fry (Shumway et al. 1963; Koski 1966; Phillips et al. 1975; Tappel and Bjornn 1983). However, incubation success and fry quality may not depend on substrate quality in areas of groundwater upwelling with sufficient (>6.0 mg/L) dissolved oxygen (Sowden and Power 1985; Bjornn and Reiser 1991).

Use of spring or groundwater upwelling sites for spawning has been reported for bull trout *Salvelinus confluentus* (Heimer 1965), sockeye salmon *Oncorhynchus nerka* (Lister et al. 1980; Lorenz and Eiler 1989), pink salmon *O. gorbuscha* (Krueger 1981), rainbow trout *O. mykiss* (Sowden and Power 1985), and brook trout *S. fontinalis* (Hansen 1975; Webster and Eiriksdottir 1976; Fraser 1985; Snucins et al. 1992; Curry et al. 1994). However, we found no studies that reported the use of upwelling areas by spawning kokanee (lacustrine sockeye salmon), and none compared incubation success of salmonids that spawned in upwelling sites with that of cohorts that spawned in areas unaffected by groundwater. In this study, we assessed the use of groundwater upwelling areas by spawning kokanee. We compared preemergent survival, water depth and velocity, and fine sediment composition of kokanee redds in upwelling areas with the same variables in redds that lacked evidence of groundwater inflow.

Study Area

The North Fork of the Payette River (NFPR) originates in Northwest Valley County, Idaho (Figure 1) and flows in a southerly direction to Payette Lake near McCall, Idaho. Elevations in the basin north of McCall range from 1,533 m (at Payette Lake) to more than 2,800 m, and annual precipitation ranges from 76 to 150 cm, primarily as snowfall. Historically, Payette Lake harbored runs of sockeye salmon, and records indicate that 75,000 kokanee and sockeye salmon were harvested in the NFPR in the late 1880s (Everman 1896). Dams on the Payette River eliminated sockeye salmon runs in the 1920s. The present kokanee population provides the primary sport fishery in

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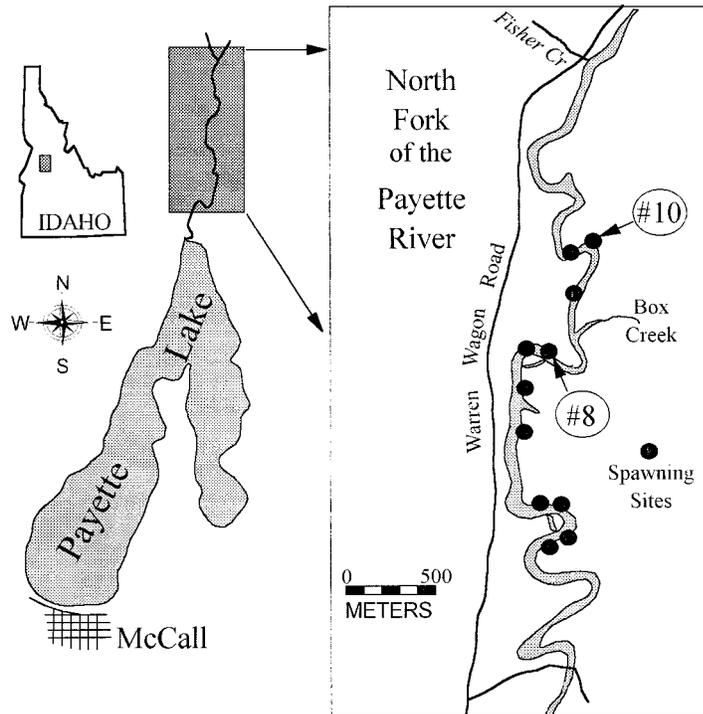
FIGURE 1.—Kokanee spawning sites in the North Fork of the Payette River upstream from Payette Lake, north of McCall, Idaho. Sites 8 and 10 exhibited evidence of groundwater upwelling.

Payette Lake. Timber harvest in the upper reaches of the drainage has reportedly impacted fish habitat through increased loading of fine sediments (USDA 1991).

Kokanee from Payette Lake spawn in the lower 7 km of the NFPR upstream from the lake. This reach averages 22 m in width (range, 4.5–58.6 m) and meanders with moderate braiding. Kokanee spawn in a few discrete stream sections at high densities and rarely spawn in, or upstream of, Fisher Creek (Figure 1). Spawning commences in late August and peaks in mid- to late-September (Bennett and Frost 1995).

Methods

One hundred kokanee redds were located and marked during peak spawning (September 19–29) in 1993. We enclosed 11 distinct spawning sites with 3.8-cm-mesh fencing to prevent additional spawning and removed the fences when most spawning ceased in mid-October (Figure 1). Each fenced site encompassed up to 20 redds; 6–14 of these redds (based on exclosure size) were randomly selected for marking and sampling. We identified individual redds by their characteristic

pit and tailspill and marked them by driving a numbered reinforcing bar into the substrate at the pit center. We measured depths and water velocity (at 0.6 of the water depth) with a Swoffer meter at the estimated egg pocket location on the upstream face of the tailspill. Since we needed estimates of substrate quality but did not want to disturb the egg pockets of fenced redds, we also marked redds with similar depth and velocity immediately adjacent to fenced sites (2–4/site).

Spring sampling began on March 11, 1994, when most spawning areas were free of snow and ice. We identified 2–4 redds adjacent to fenced sites and randomly selected 1–3 redds within each site and sampled substrate with a 15.5-cm core sampler (McNeil 1962) at the estimated egg pocket location. We dried substrate samples for 4 d at 101°C and mechanically sieved them for 1 min through 12 U.S. Standard sieves with mesh sizes of 76–0.25 mm. To eliminate sampling bias (Adams and Beschta 1980; Chapman et al. 1986; Young et al. 1991), we excluded particles greater than 25 mm from the analysis. We then converted sieve sizes to categories of substrate size and calculated percent fine sediment (<0.83 mm). Mean

percent fines (<0.83 mm) was calculated for each site and used as an estimate of gravel quality for redds at that site.

We hydraulically sampled redds in the exclosures (McNeil 1964; Magee and Heiser 1971). A portable gasoline-powered water pump rated for 2.2 L/s pumped water from the river. A 0.8-m metal wand with a distally oriented air vent to allow air intrusion that created an air–water mixture was mounted at the end of a 15.2-m-long, 2.5-cm-diameter hose. During sampling, we inserted the wand into the redds and vigorously moved for 2 min over an area of approximately 0.5 m^2 believed to contain the egg pocket. The air–water mixture lifted dead and live eggs and alevins up and into the water column where a 2.2-m^2 drift screen constructed of 2-mm-mesh nylon netting collected them. This technique collects 91–98% of the dead eggs, embryos, and alevins contained in kokanee redds (Bennett and Frost 1995). Live and dead embryos and alevins were preserved in 10% formalin for later analysis.

To assess the loss of kokanee eggs to decomposition or invertebrate predation during the incubation period, we buried 15 Whitlock–Vibert (W–V) boxes containing kokanee eggs on September 24–25, 1993. Each box contained 200 kokanee eggs and was anchored to rebar driven into the substrate. Boxes were buried 10 cm deep in spawning gravels at sites 3, 4, and 7.

Water temperatures at the water–substrate interface and 6 cm below the substrate surface were obtained at each site on March 14, 1994, with a YSI model 57 meter (Yellow Springs Instruments Corp., Yellow Springs, Ohio). We measured intragravel temperature 10 min after burying the probe 6 cm beneath the gravel.

Arcsine transformation of percent hatching success was not required as most proportions ranged from 30% to 70% (Steel[2] and Torrie 1980). We excluded from analysis samples that contained less than 25 eggs or alevins (dead or live). Heirarchical (nested design) analysis of variance (ANOVA; Zar 1984) was used to compare incubation success, water depth and velocity, and fine-sediment (<0.83 mm) composition between redds influenced by groundwater with those unaffected by upwelling.

Results

We hydraulically sampled 87 of the 100 marked redds. Thirteen redds could not be sampled due to excessive snow and ice. Of the sampled redds, 40 contained no live embryos or fry because of complete or partial dewatering and freezing; we analyzed data for the remaining 47 redds.

Water temperatures at the water–substrate interface on March 14 ranged from 0.2°C to 0.4°C for all sites. On the same date, intragravel water temperatures at sites 8 and 10 (Figure 1) were 2.6°C and 2.8°C, respectively, indicating the presence of groundwater upwelling. Alevins collected from sites 8 and 10 (13 redds) were at or near the postlarval stage as there was little or no visible yolk sac. Recently hatched alevins, markedly less developed than those from sites 8 and 10, or viable embryos were collected from the remaining sites (34 redds) where intragravel water temperatures were colder and similar to river water temperatures.

We recovered the W–V boxes on March 15, 1994. We observed minimal (mean, 2.8%; range, 0–6.5%) loss of kokanee eggs during the incubation period. Consequently, we did not adjust our data for egg losses.

Hatching success for 13 redds in groundwater upwelling sites (mean = 84.3%; 95% confidence interval, CI = 78.8–89.7%) significantly (P = 0.02) exceeded that for 34 redds that lacked upwelling (mean = 65.6%; 95% CI = 56.6–74.6%; Figure 2). Mean percent fine sediment (<0.83 mm) for redds in upwelling areas (17.4%; 95% CI = 15.4–19.4%) was significantly (P < 0.001) higher than in redds in other areas (9.4%; 95% = CI 8.4–10.1%). Fine sediment content also differed significantly within upwelling sites because mean fines in site 10 (20.4%) significantly (P < 0.001) exceeded that in site 8 (13.8%). Water velocity measured at redds in upwelling sites (11.5 cm/s; 95% CI = 6.6–16.4 cm/s) was significantly (P < 0.001) lower than at redds in nonupwelling areas (38.2 cm/s; 95% CI = 32.8–43.7 cm/s). Mean water depth for redds in upwelling areas (22.7 cm; 95% CI = 19.0–26.4 cm) was not significantly (P = 0.882) different from mean depth of redds in other areas (22.4 cm; 95% CI = 20.4–24.4 cm).

Discussion

Kokanee in the NFPR spawned at high densities in discrete areas upstream from Payette Lake. We found evidence of spring or groundwater upwelling in 2 of the 11 spawning sites that we studied. Embryos at upwelling sites hatched at higher rates, although they incubated in areas of lower water velocities and higher fine sediment content. Lorenz and Eiler (1989) found low water velocities and high fine sediment content in upwelling areas used by spawning sockeye salmon.
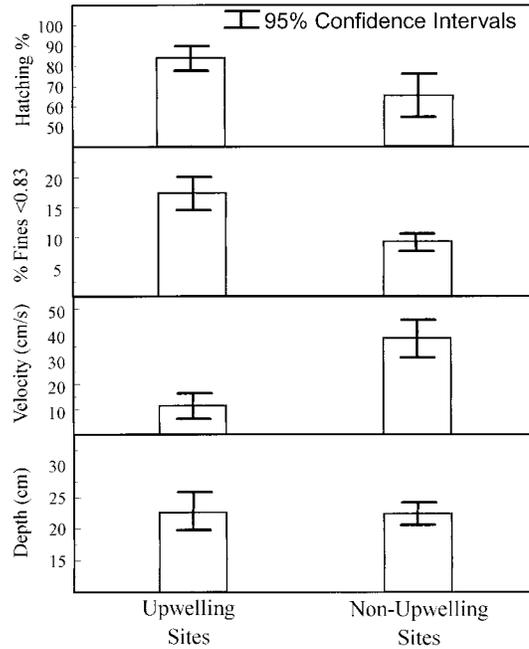
FIGURE 2.—Comparison of means and 95% confidence intervals for hatching success, water depth and velocity, and percent fine sediment (<0.83 mm) between redds constructed in areas of groundwater upwelling and redds lacking evidence of groundwater influence.

The higher survival in upwelling sites that contained higher proportions of fine sediment supports the contention that embryo survival cannot be predicted based on substrate characteristics alone in groundwater-fed streams (Sowden and Power 1985; Bjornn and Reiser 1991). Sheridan (1962) indicated most groundwater originates from rain or snowmelt. Dissolved oxygen levels, dependent on biochemical oxygen demand as water percolates through ground, may vary considerably. Although we did not measure dissolved oxygen levels at these sites, high survival indicates that adequate dissolved oxygen must have been present.

Whether kokanee can detect areas of groundwater upwelling sites by temperature differential is unknown. Perhaps they home to these sites. Freshly excavated redds in upwelling sites lacked the characteristic pit-and-tailspill morphology. Redds in these areas consisted of larger cobble that was swept clean of overlying sand and finer particles. The resulting redd appeared "nestlike" and similar to that described by Snucins et al. (1992) for brook trout that spawned in upwelling areas. Deposited eggs likely fell into crevices and were at shallower depths than normally associated with salmonid redd formation. During hydraulic sampling of these redds, we excavated dead embryos and alevins from shallower depths than those at other sites.

Lorenz and Eiler (1989) identified three advantages to spawning in upwelling areas. First, the hydraulic action of upwelling groundwater provides a loose and unconsolidated substrate for spawning and fry emergence. Second, fry may have developed a specialized behavior to emerge from gravel beds covered by uncompacted fine sediments (Bams 1969). Third, upwelling groundwater provides a more constant incubation temperature and may not freeze as readily as surface water in harsh winter conditions (Reiser and Wesche 1979).

Increased rate of development associated with warmer incubation temperatures may provide the most important advantage to kokanee spawning in groundwater upwelling areas, especially in high elevation areas like the NFPR. In upwelling areas, we collected predominantly fry that were ready to emerge (many with parr marks), whereas alevins collected in other areas were hatching or recently hatched and were less developed. Earlier recruitment to Payette Lake should increase first-year growth and survival by producing larger fry that are better able to avoid predators. Conversely, fry

recruiting early may find limited food resources in years of prolonged ice cover.

In 1993, 8.4% of adult kokanee in a 7.2-km reach of the NFPR spawned in upwelling or spring areas, although these areas constituted only 1.9% of available habitat (F. O. Frost, University of Idaho, unpublished data). Upwelling sites obviously attract spawning kokanee. Fry produced in upwelling sites probably constitute less than 10% of the total recruitment. However, they should survive at a higher rate than less developed alevins, especially if forced to emerge early following early season flood-and-scour events. Consequently, fry production in upwelling areas may prevent weak year-classes or year-class loss of self-sustaining kokanee in systems similar to the NFPR.

Although visual identification of upwelling sites is not possible, redd excavation in areas of unusually low water velocity (<20 cm/s) may indicate the presence of groundwater upwelling. Parsons and Hubert (1988) observed no kokanee spawning in sites with water velocity less than 24 cm/s, and Mullner and Hubert (1995) found no kokanee spawning where water velocity was less than 20 cm/s. In our study, water velocity at redds located in upwelling areas averaged 11.5 cm/s.

We believe managers should recognize the importance of upwelling sites to naturally reproducing populations and take steps to identify and protect these habitats. Low-velocity spawning sites should be evaluated for temperature differential between surface and intragravel water. Large differences (>1.5°C) between intragravel temperatures and surface water temperatures indicate groundwater upwelling areas (Lorenz and Eiler 1989). Managers should consider affording special consideration to identified areas of groundwater upwelling used by spawning salmonids, especially if sensitive or threatened populations are involved.

Acknowledgments

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