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Title: Effects of Kokanee (*Oncorhynchus nerka*) Redd Superimposition on Bull Trout (*Salvelinus confluentus*) Reproductive Success in the Deschutes River Basin, Oregon.

Abstract approved:

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Oregon's only remaining non-reservoir population of adfluvial bull trout (*Salvelinus confluentus*) is found in Odell Lake, in the headwaters of the Deschutes River. The population size is unknown, but appears to be quite small. Limited spawning and rearing habitats, combined with the effects of introduced species and other anthropogenic changes to the basin have raised concerns as to the population's viability. The lower section of Trapper Creek, a tributary of Odell Lake, is the only known spawning habitat used by this species throughout the system. Large numbers of kokanee salmon (*Oncorhynchus nerka*) also spawn in the same reach, superimposing their redds on those dug earlier by bull trout. After superimposition by kokanee, bull trout redds are virtually undetectable.

The objective of the study was to assess the effect of kokanee redd superimposition on bull trout egg-to-fry survival. Due to uncertainty in the size of the Odell Lake bull trout population much of the study was conducted on bull trout and kokanee of the Metolius River system, a neiboring Deschutes sub-basin. Emergent fry traps were used, in combination with egg burial depth measurements, scour monitors, and gravel characterization to establish actual physical overlap between both species and degree of bull trout egg pocket disturbance caused by kokanee. Results indicate that most bull trout egg pockets are dug deeper than depths reached by spawning kokanee. Kokanee were found to be very superficial spawners in the streams studied. Bull trout fry emergence data suggest that kokanee redd superimposition does not affect egg-to-fry survival rates.

Effects of Kokanee (*Oncorhynchus nerka*) Redd Superimposition on Bull Trout (*Salvelinus confluentus*) Reproductive Success in the Deschutes River Basin, Oregon

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Matthew A. Weeber, Author

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CONTRIBUTION OF AUTHORS

Dr. Guillermo Giannico, Dr. Hiram Li, and Steve Jacobs were all involved with the design and editing of chapter two.

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CHAPTER 1: GENERAL INTRODUCTION

Redd Superimposition: A Definition

All stream spawning salmonids (i.e., salmon, trout, and charr) construct nests to deposit their eggs (Quinn 2005). The nests, commonly referred to as redds, are excavated by females through a series of lateral tail thrusts towards the streambed, which create small pits in the substrate. Fertilized eggs deposited in the pits are buried by subsequent upstream digging, creating egg pockets where embryos develop until hatching and alevins grow until emergence. Compared to other riverine species (see Scott and Crossman 1973), salmonid embryos remain in the substrate for a relatively long time, ranging between 2 and 8 months (DeVries 1997). The function of egg burial is to increase offspring survivorship by decreasing the chances of predation, agitation, and exposure (van den Berghe and Gross 1984). Thus the effort made to bury eggs and the relatively long duration of the intragravel life stage implies that salmonid reproductive success is strongly linked to egg deposition. Consequently any event which disturbs the incubation period could reduce egg-to-fry survival.

Redd superimposition is one such event which has that potential. Superimposition occurs when a redd site is reused by subsequent female spawners before the embryos of the first female have had time to develop and emerge. The act of redd superimposition can be accomplished by females of the same or a different species. Redd superimposition is a concern because there is a potential that embryos can be displaced or damaged.

Study Problem

Odell Lake, Oregon, supports a unique population of bull trout (*Salvelinus confluentus*). It is the only adfluvial population in the state not contained within a man-made reservoir system (Buchanan et al. 1997). Odell is a naturally occurring high mountain lake located at the top of the Deschutes River Basin and its bull trout population has been isolated there for thousands of years. A massive geologic event severed downstream emigration during the Pleistocene Epoch (Johnson et al. 1985). In the early to mid 1900s non-native species such as lake trout (*S. namaycush*), brook trout (*S. fontinalis*), tui chub (*Gila bicolor*), and kokanee (landlocked sockeye salmon *Oncorhynchus nerka*) were introduced to supplement a growing interest in sport fishing (Higgins et al. 2005). Odell Lake currently supports a large recreational fishery on lake trout and kokanee and is considered one of the premier kokanee fisheries in the Northwest (USFS 1999). The increased competition caused by the introductions, combined with the effects of spawning and rearing habitat degradation, and hybridization with brook trout have raised concerns about the bull trout population's long term survival. Annual redd surveys conducted since 1994 indicate that the bull trout population is quite small. An average of 10 bull trout redds have been found over each of the last 13 years (Oregon Department of Fish and Wildlife, unpublished data). Due to the population's isolation, low abundance, and poor habitat, Odell Lake bull trout were listed at "high risk" of going extinct during a status review of Oregon populations (Ratliff and Howell 1992). In 1998, the U.S. Fish and Wildlife Service listed all bull trout populations in the Columbia River Basin as a threatened species under the Endangered Species Act (63 FR 31647). Prior to the listing, a scientific working group was established to identify the status of the Odell Lake population and determine objectives and goals for recovery. Many research needs were identified; including the evaluation of the effect of kokanee redd superimposition on bull trout reproductive success (USFWS 2002).

A short section of Trapper Creek, a tributary of Odell Lake, is the only spawning habitat known to be utilized by bull trout throughout the lake system. Redd surveys conducted in other lake tributaries in past years have revealed no other spawning sites (Higgins et al. 2005). Historic accounts indicate that other tributaries were used for spawning in the past (T. Wise, Oregon Department of Fish and Wildlife, personal communication). Due to a naturally occurring barrier to upstream migration, bull trout spawning is limited to the lower 1.3 km of Trapper Creek. However, most redds are found in the first 0.8 km, which also provides spawning habitat for kokanee. Although both species spawn in early fall, the majority of spawning by bull trout occurs before kokanee arrive. Due to the limited spawning habitat and high density of spawning kokanee (> 200 fish per 100 m in 2005), many of the bull trout redds are superimposed. After superimposition, bull trout redds are often unidentifiable. Much of the redd substrate is moved and redistributed during the mass kokanee spawn. The impact of such overlay on bull trout reproductive success is unknown and difficult to assess with such a small population.

Due to the uncertainty surrounding Odell Lake bull trout and their “high risk” status, a surrogate population was used to conduct much of the investigation. A population of bull trout with the same life history characteristics is found in the Metolius River sub-basin, which is also located in the Deschutes River Basin. During the status review mentioned above, bull trout in the Metolius River system were listed as “low risk” of extinction (Ratliff and Howell 1992). Bull trout spawn and rear in most of the colder river tributaries, as well as in the main river (Ratliff 1992). More than 800 bull trout redds have been identified over each of the last three spawning seasons (Oregon Department of Fish and Wildlife, unpublished data). Kokanee also use the Metolius River sub-basin for spawning. There is little overlap in spawning habitat between the two species, but some bull trout redds do become superimposed by kokanee each year. The potential impact of such overlay on the Metolius bull trout population is minor because redd density is high and distribution is broad. For these reasons the Metolius River sub-basin is ideal to study the effects of kokanee redd superimposition without harming the Odell Lake bull trout population.

The impacts of redd superimposition are still poorly understood, however, information gathered during the investigation will further aid understanding to this complex event as well as provide insight to the early life history of bull trout. Further, information on egg deposition for both kokanee and adfluvial bull trout is scant, egg depth values will help supplement the current body of salmonid egg burial work. The results of this study have direct implications for the management and recovery of the Odell Lake bull trout population. Data gathered during the investigation will help managers assess the vulnerability of the current population as well as provide insight to the management of other salmonid populations in which redd superimposition is a concern.

CHAPTER 2:

Kokanee (*Oncorhynchus nerka*) superimposed bull trout (*Salvelinus confluentus*) redds: Cause for concern?

Introduction

Given that mortality rates are often highest during the intra-gravel life stage of salmonids (Peterson and Quinn 1996; Baxter and McPhail 1999), much research has been devoted to understanding their reproductive success and embryo survival. However, redd superimposition is an often overlooked aspect of reproductive success that needs more attention (Quinn 2005). The term superimposition refers to one or more females overlaying successive redds over that of an earlier spawning female. High spawning densities of anadromous salmon (*Oncorhynchus sp.*) that result in superimposition of redds is accepted as a major cause of density-dependent mortality of embryos (McNeil 1964; Heard 1978; Chebanov 1986; Semenchenko 1988; Parenskiy 1990; Chebanov 1991; Fukushima *et al*. 1998). When spawning areas are limited, late spawners superimpose their redds on those previously dug and displace eggs deposited by previous spawners. Considering that salmonids that are similar in size will bury their eggs at roughly the same depths (DeVries 1999), egg displacement is a logical outcome. Thus when considering heterospecific fish that overlap in there spawning habitat but differ in average size and therefore potential egg burial ability, there appears to be a decreased chance of mortality caused by egg displacement if the larger species spawns first. However, when considering the implications of redd superimposition egg displacement is not the only concern.Previous superimposition works have concentrated on conspecific egg displacement and density dependent effects on a stream wide (e.g., McNeail 1964) or spawning channel scale (e.g., Essington et al. 2000); however, these studies fall short of relating survival to the level of individual redds and embryos left in the substrate. Embryos which are not displaced face potential suffocation or physical damage. Redd disturbance, such as superimposition by late spawners, has the potential of altering redd substrate composition and integrity. During redd digging, salmonids winnow sediment from the streambed. The excavated gravels and interstitial fine sediments are exposed to currents and differentially transported downstream (Kondolf et al. 1993). Massive amounts of scouring (digging) immediately upstream of redd sites could potentially introduce fines to downstream redds. High levels of interstitial fine sediments in redds can reduce the permeability of the gravel, thus reducing the amount of oxygenated water flowing past the incubating eggs (Vaux 1962; Chapman 1988; Peterson and Quinn 1996; Lapointe *et al.* 2004). Conversely, transport of sand and very fine gravel into a redd has also been shown to prevent fry from emerging to the surface by forming sand seals around the egg pockets, trapping fry and causing them to starve (Phillips et al. 1975; Meyer et al. 2005). Also of concern is the physical stress the act of digging imparts on developing embryos below the substrate surface. During certain developmental stages salmonid embryos are extremely sensitive to mechanical shock (Johnson et al. 1989). The movement of surface particles caused by digging has the potential of crushing or agitating embryos below the surface. In the present study I investigate the potential impact of heterospecific redd superimposition by examining individual redds and embryos left in the gravel. Where the spawning habitats of kokanee and adfluvial bull trout overlap there is concern that kokanee might negatively influene bull trout survival by superimposing previously built bull trout redds. Although bull trout are considerably larger than kokanee, due to kokanees high density spawning bull trout redds are often disturbed beyond recognition. What impact, if any, this has on bull trout reproductive success is unknown? Therefore my first research objective was to determine whether bull trout eggs are buried beyond spawning kokanees digging depth. A second objective was to examine the collective digging ability of a kokanee spawning cohort. Reported egg depths explain the ability of a single female, but not the collective depth reached by many individual spawners. My third objective was to assess how bull trout redd structure is altered by superimposition. Finally, my fourth objective was to determine if redd superimoposition effects emergence timing or suppresses production. To address these objectives a series of studies and experiments were conducted. Using a manual excavation technique in combination with sliding-bead monitors I examine the egg burial depths reached by spawning kokanee and adfluvial bull trout, as well as the collective scouring and depositional ability of a kokanee spawning cohort. Through intensive redd surveying, use of emergent fry traps, and substrate core sampling I examine how kokanee superimposition alters redd structure and substrate composition to influence emergence timing and production.

Materials and Methods

Study Area

Data were collected over two spawning seasons (2005–2006) in two sub-basins, Metolius River and Odell Lake, which are part of the Deschutes River basin, Oregon (Figure 1). The Deschutes River flows north along the eastern side of the Cascade Mountains to its confluence with the Columbia River. Both study sub-basins contain populations of adfluvial bull trout and kokanee, yet are geographically and physically isolated from each other.

The Odell Lake system consists of Odell and Davis lakes, plus Odell Creek which connects them and all lake tributaries (Figure 2). The system is cut off from the rest of the Deschutes Basin by a lava flow (Johnson et al. 1985). The area encompasses approximately 302 km^2 and is located in the Cascade Crest Montane Forest ecoregion (Meacham and Steiner 2002), which is characterized by moist temperate forest. All data were collected in Trapper Creek, an Odell Lake tributary (Figure 2). The creek is a second order perennial stream. Spawning is restricted to the lower 1.3 km of the creek due to a natural upstream barrier. Mean active channel width in this section is 8 m; mean discharge during October is 0.70 $m^3 \cdot s^{-1}$, and annual mean stream temperature near the creek mouth is 3 ºC. Trapper Creek is prone to yearly spring freshet events which can cause discharge to quadruple (M. Weeber, unpublished data). The creek is composed of riffle-pool habitat in its lower section. The most dominant particle size class found in pool tail-outs is small pebble (b-axis diameter 16–31 mm). Bull trout spawn in the creek from mid-August to mid-

September and kokanee spawn from mid- to late September and conclude by the middle of November.

The Metolius River system emerges from large springs on the eastern flank of the Cascade Mountains of central Oregon, draining approximately 816 km^2 (Figure 3). Within the Eastern Cascades Slopes ecoregion (Meacham and Steiner 2002) the river flows through a ponderosa pine, bitterbrush woodland landscape. The area receives little annual precipitation and is subject to extreme seasonal temperature shifts. Being predominantly spring fed, flows and water temperatures fluctuate little over the year. Water temperatures in the basin are cold; individual springs range from 4–9 °C (Lovtang 2005). The river runs for approximately 41 km before it empties into Lake Billy Chinook, a man made reservoir. Data were collected in several tributaries of the main river including Candle, Canyon, and Jefferson Creeks, as well as Heising and Roaring Springs (Figure 3). Heising Spring contains the highest proportion of bull trout redds that become superimposed by spawning kokanee and is where a majority of data were collected (Figure 4). The spring is approximately 350 m long and averages 20 m in width. The average depth is 0.5 m. Habitat is composed of glide and riffle channels surrounding small grass covered islands; no pools exist. The dominant substrate size class found throughout the spring is small pebble. Mean annual temperature is 6 ºC and discharge is approximately 3.30 $m^3 \cdot s^{-1}$ near the mouth. Bull trout spawning begins in mid-August and continues through the end of October. Kokanee spawn from mid-September through the end of October.

Egg Burial Depths

During the falls of 2005 and 2006, 26 bull trout redds were manually excavated throughout the Metolius River sub-basin. No egg burial data were collected for the Odell Lake bull trout population because so few redd sites are found each year and because of their “high risk” status (Ratliff and Howell 1992). In 2005, a total of 16 redds were evaluated in Candle (n = 6), Canyon (n = 3), and Jefferson Creeks (n = 6), as well as in Roaring Spring (n = 1). In 2006, an additional 10 redds were evaluated; all in Heising Spring. The examined redds were randomly selected from a previously marked pool of redds, which had been located by surveying stream reaches where high bull trout redd densities were known to occur. Each redd was evaluated using a manual excavation technique (Appendix A) whereby individual egg pockets were referenced by depth below the disturbed substate and original streambed elevations (Steen and Quinn 1999). Egg pocket depths below the disturbed substrate elevation represent the depth another female would have to dig to disturb the first female’s eggs while the redd was still structurally intact. Egg pocket depths below the original streambed elevation represent the depth the original female dug to lay her eggs and the likely depth they will be buried after the stream returns to its original topography. Thus, these are depths that would reveal vulnerability to superimposition and scour, respectively.

Egg pocket depths of spawning kokanee were evaluated in both study sub-basins using the same manual excavation technique. However, the high density spawning of kokanee in these systems prevented the identification and marking of individual redds to be excavated at a later date as was done for bull trout. The same consideration also prevented recording egg pocket depths below the original streambed elevation, therefore only depths below the disturbed substate elevation are given. Areas with kokanee redds were located by walking upstream and either observing groups of spawning fish or identifying areas that were scoured. If kokanee were present, behavioral observations were noted during a 5 minute interval (Appendix C). In both sub-basins, all fresh kokanee carcasses were measured for fork-length (FL ± 1 mm) and their gender determined. This was done to compare egg burial depth differences between the populations of the two sub-basins in relation to female size.

Kokanee Scour Monitoring

To determine the collective scouring and depositional ability of spawning kokanees, 30 sliding-bead monitors were installed in Trapper Creek. The design of the monitors and the method of setting them were similar to those described by Nawa and Frissel (1993). The monitors consist of a steel-drop point and a length of braided steel wire with beads threaded on. The point and all the threaded beads are driven vertically into the streambed so that the top of the last bead is even with the streambed surface (Figure 5a). When scouring occurs buried beads are released into the water column and swept to the end of the portion of wire that was left unburied (Figure 5b). The number of beads (multiplied by the bead diameter) that move to the end of the braided wire represent the depth of scour. In much the same way, if any sediment is deposited on top of the device, the amount of deposition can be determined by measuring the length of buried wire (Figure 5c). The monitors used during this investigation consisted of 45 plastic crafters beads (1.2 cm diameter) threaded on approximately 1.5 m of 30 kg test braided steel wire. In August 2006, before kokanee spawned, the monitors were set in eight transects with 2–6 monitors per transect in areas known to support high densities of spawning kokanee. The number of monitors placed per transect was dependent on the width of the stream and the available spawning substrate. Throughout the kokanee spawning period all monitors were examined weekly and the number of exposed beads recorded. To account for scour or fill caused by discharge fluctuations, water level was monitored weekly using a fixed gauge. In late November, after all kokanee finished spawning, monitors were assessed a final time.

Redd Disturbance

During the fall 2005 spawning season, Heising Spring was surveyed 2–4 times a week ($n = 21$ times). Sixty-four bull trout redds were identified, marked, and measured (Appendix D). Total redd length and width were measured (± 0.05 m) using a stadia rod (Figure 6). Redd surface area ($\pm 0.1\ m^2$) was approximated according to the formula for an ellipse (surface area = $\pi * (\text{length}/2) * (\text{width}/2)$). Water depth at the deepest point in the redd pot, the shallowest point over the tailspill, and at three points on undisturbed substrate around the pot were measured (± 0.01 m, Figure 6). The latter measurements were averaged to give an estimate of the water depth around the redd so that pot depth and tailspill height could be calculated (Crisp and Carling 1989). Water velocity ($\pm 0.01\ m \cdot s^{-1}$) was measured with a digital flow meter (Model 2000 flo-mate, Marsh-McBirney Inc.) at 60% depth directly upstream of the redd pot (McMahon et al. 1996). Redd perimeters were made discernable by positioning six white surveyor ground flags around the redd periphery (Figure 6). Four to five small orange rocks were also set on the redd tailspill to aid in detecting subsequent disturbances.

After the arrival of kokanee, the number observed on or directly near (± 0.5 m) each bull trout redd was recorded during each survey, as well as any observations of redd alteration in relation to the surveyor flags and orange rock movement. A 0–2 scoring system was developed to identify the degree of redd disturbance caused by kokanee digging. If no disturbance occurred, then a redd was scored ‘0’. Redds scored ‘1’ sustained “minor” disturbance; and those scored ‘2’ were “severely” altered. Redds with scores of ‘2’ were considered superimposed, meaning that significant scouring and deposition occurred to the point where the original redd perimeter and shape were unrecognizable. Succeeding pot, tailspill, and surrounding depth measurements were made on all kokanee disturbed bull trout redds after kokanee were gone to determine the amount of scour or deposition caused by the digging.

Emergent Fry Trapping

A total of 14 emergent fry traps were placed on bull trout redds in Heising Spring, 2006. All trapped redds were randomly selected from a redd pool after considering estimated fry emergence timing, presence or absence of kokanee superimposition, and visibility of original redd periphery. Seven of the 14 traps were set on bull trout redds considered superimposed by kokanee, the remaining seven were placed on undisturbed redds.

Trap placement timing was determined using cumulative Celsius temperature units (CTU) (Leitritz and Lewis 1976). Temperature data loggers (Optic StowAway^{TM}) were set in Heising Spring in July 2005 and set to record hourly stream temperatures (± 0.01 ºC). Gould (1987) found that bull trout require an average of 820 CTU from date of egg fertilization to time of first emergence. To minimize any negative impacts associated with trap installation and ensure that traps were in place before predicted fry emergence, all traps were set between 700–800 CTU (125–175 days after redds were first observed).

Fry emergence traps were similar to those used by Tagart (1984), and were borrowed from the California Cooperative Fishery Research Unit at Humboldt State University. Each trap consisted of a mesh net secured to a steel frame, a downstream collection tube, and PVC live-well (Figure 7). For a more detailed description of the trap design as well as methods for setting and checking see Sparkman (1999).

Traps were checked and cleaned daily until fry emergence began to slow, at which time they were checked and cleaned once to twice a week. Captured fry were transferred for identification and enumeration into a 19 L bucket with stream water. All captured fry and alevins were identified to species and recorded as either live or dead. After enumeration fry were released into the stream margin.

Core Sampling

To account for differences in substrate composition between kokanee superimposed and undisturbed bull trout redds two substrate core samples were taken from each trapped redd (n = 28). Collection methods and sorting techniques followed those first described by Shirazi et al. (1979). A 0.25 m diameter by 0.56 m long modified McNeil sampler (McNeil and Ahnell 1964) was used to collect the redd substrates to a depth of 0.20 m. Collecting redd substrates to this depth was sufficient to characterize the egg pocket environment (Lotspeich and Everest 1981). The core was excavated by hand and the removed substrate transferred to a 19 L bucket for seperation. To account for the remaining suspended sediment within the core water column a sub-sample was removed. The sub-sample was later extrapolated to account for the actual volume of water in the core.

Substrate samples were sorted by decreasing particle size class: ≥ 64, 32, 16, 8, 4, 2, 1, 0.5, 0.25, 0.125, 0.0625, and < 0.0625 mm. Weight (g) and volume displacement (ml) was determined for each size class. Particles ≥ 4 mm were sieved by hand in the field using standard brass testing sieves (W.S. Tyler Inc. Mentor, OH). After drying completely, the remaining sample was taken to Oregon State University’s Central Analytical Laboratory for mechanical separation. Extrapolated suspended sediment weight and volume values were added to the weight and volume of particles in the smallest size class.

Sediment particle size distribution and gravel indices (i.e., cumulative percentage of fine sediments less than 3.33 mm and geometric mean particle diameter in mm) for each sample were determined using methods described by Platts et al. (1983) and Shirazi et al. (1979). The values (Appendix E) were calculated using custom software GRAVEL © (Goforth 1992). GRAVEL © was used to characterize the entire redd by pooling the two samples collected. The program uses the ‘method of moments’ to calculate geometric mean particle size and expresses percent fine sediments on a cumulative basis by weight or volume. In this case, weight and volume for each particle size class were highly correlated ($r^2 = 0.97$, $p < 0.03$); therefore, cumulative percentage of fine sediments was expressed by weight.

Statistical Analyses

I used an α value of 0.05 in all tests and S-PLUS statistical software (version 7.0, Insightful Corp. 1988) for all analyses. A paired t-test was used to test for differences between bull trout egg pocket depth below the original streambed and disturbed substrate elevations. To test for differences in stream characteristics (i.e. water velocity and depth) between kokanee disturbed and undisturbed bull trout redds I used one-way ANOVA. Two-tailed t-tests were used to test for differences in the number of fry that emerged and in emergence timing between superimposed and undisturbed redds as well as to test for differences in kokanee size and egg pocket depth between the two study sub-basins. Pearson’s product-moment correlation analyses were used to test for associations between depth of scour, amount of deposition, water velocity, and stream depth at sliding-bead monitor locations.

Regression analysis was used to evaluate relationships between the number of fry that emerged from a redd, presence or absence of superimposition, and various redd variables. The dependent variable was the number of emergent bull trout fry captured per trap. The original sample size of 14 trapped redds was reduced to 13 after one of the observations was dropped due to an abnormally low count, which proved to be a significant outlier in the response. Due to the small number of observations regression models were only used to evaluate potential relationships, models were not used to project the data.

Approximate redd surface area, flow over the redd, geometric mean particle diameter (Dg), cumulative percentage of fine sediments < 3.33 mm, and presence or absence of superimposition were chosen as independent variables. Independent variables were selected *a priori*. The percentage of fine sediment value was chosen based on what other studies have used as the cutoff below which sediments are considered detrimental to embryo survival (Koski 1966; Sparkman 2004). The independent variable, superimposition, was treated as an indicator (Ramsey and Schafer 2002: 245–247); coded ‘0’ for undisturbed and ‘1’ for kokanee superimposed redds. Each independent variable was regressed independently with the response and then again with the indicator variable included. All other possible subsets of independent variables were used in model selection. Independent variables showing strong correlations ($r > 0.95$) were not included in regression models together (i.e. geometric mean particle diameter and cumulative percentage of fines). The number of models used in the analysis was limited to 13 to reduce the risk of over fitting models to a relatively small number of observations (e.g., Harvey et al. 2002). The same consideration prevented including more than two independent variables in a model at one time and including interactions among variables.

Models were evaluated using Akaike's information criterion adjusted for small samples (AIC_c) and estimates of the posterior relative probabilities for each model (Burnham and Anderson 1998). AIC_c is an information-theory-based approach to estimating the fit between candidate models and data. The approach allows comparison of models with varying numbers of parameters to minimize information loss. Posterior relative probabilities further determined which independent variable was favored over others using 'weight of evidence' expressed as probabilities. Values were derived from AIC_c and the assumption of equal prior probabilities for all models (Burnham and Anderson 1998). The probability of a particular independent variable being included in the "best fitting" model was determined by summing the probabilities of all candidate models that included that particular independent variable (Burnham and Anderson 1998).

Results

Egg Burial Depth

Bull Trout

Egg pockets were found in 24 of the 26 redds evaluated (Table 1). The number of egg pockets found per redd ranged from 0 to 4 (Mean = 2.0, SD = 1.0). There was no significant difference ($F_{4,19} = 1.13$, $p > 0.05$, one-way ANOVA) in mean egg pocket depth between the redds sampled in the five study streams. Mean egg pocket depth per redd below the disturbed substrate elevation was 14 cm (SD = 3.5). The deepest egg pocket was 22 cm below the disturbed substrate and the shallowest, 5 cm. Mean egg pocket depth below the original streambed elevation was 11.2 cm (SD = 6.6). Egg pocket depth below the disturbed substrate elevation was significantly greater than the depth below the original streambed elevation ($p < 0.04$, paired t-test).

Kokanee

In Heising Spring a total of 14 kokanee scoured areas were evaluated. Egg pockets were found in 25% of the 16 excavations completed, however, buried eggs were observed in all. The depth to the top of the egg pockets ranged from 5–10 cm (Mean = 8 cm, SD = 2). In Trapper Creek a total of 23 kokanee scoured areas were evaluated. Thirty-seven excavations were made. Kokanee eggs were observed in all areas, either buried or on the surface. Egg pockets were found in 46% of the excavations. The depth to the top of egg pockets ranged from 1–10 cm (Mean = 5 cm, SD = 2). The mean fork-length of female kokanee was 32.4 cm (SD = 1.8, n = 44) in Trapper Creek and 28.7 cm (SD = 2.0, n = 15) in Heising Spring. Female kokanee in Trapper Creek were significantly ($p < 0.05$, two-tailed t-test) larger than female kokanee measured in Heising Spring.

Kokanee Scour Monitoring

Kokanee digging was observed on or directly near all sliding-bead monitors. Twenty-nine of the original 30 monitors installed were re-located to determine the amount of scour and deposition. One monitor in transect eight could not be located and was assumed to be buried or removed. Some amount of scour occurred at all but five monitor locations and deposition occurred at all but one (Figure 8). A significant negative association was found between depth of deposition and water velocity at monitor locations($r^2 = 0.19$, $p < 0.05$). The depth of scour per monitor ranged from 1.2–8.4 cm (Mean = 4.0 cm, SD = 2.3) and deposition depths ranged from 1.0–15.5 cm (Mean = 4.7 cm, SD = 2.9). The net change in streambed elevation per monitor ranged from -4.2 to +6.8 cm (Mean = +1.3 cm, SD = 3.2).

Redd Disturbance

Half (n = 32) of the bull trout redds identified were disturbed to some degree by kokanee. Twenty redds sustained “minor” disturbances and 12 redds were “severely” disturbed. Most scouring occurred on the pot and tailspill edges, in the pot itself, or the slope where the pot transitions to tailspill. Scouring directly over the tailspill crest rarely occurred, although tailspill height was often reduced as kokanee worked progressively downstream from the transitional area. Eighteen bull trout redds were identified as experiencing some amount of kokanee induced pot deposition and 15 were identified as experiencing some amount of kokanee induced tailspill scour. Subsequent measurements on those redds revealed a mean amount of deposition to the pot of 5 cm (SD = 3.8, range = 1–13) and a mean decrease in tailspill height of 7 cm (SD = 4.7, range = 3–17). Severely disturbed redds were located near the spring margins out of the main thalweg. Water velocities over redds with no disturbance were significantly ($p < 0.05$, two-tailed t-test) greater than velocities over redds receiving minor disturbance, which in turn had significantly greater velocities than redds with severe disturbance ($p < 0.05$, two-tailed t-test) (Figure 9). There were no differences ($F_{2,55} = 0.64$, $p > 0.05$, one-way ANOVA) in redd depth between the three redd types prior to kokanee disturbance (Figure 9).

Emergent Fry Trapping

Emergent fry catches in Heising Spring ranged from 31–2,601 individuals (Table 2), and totaled 17,340. A total of 7,305 bull trout emerged from undisturbed redds and a total of 10,035 emerged from superimposed redds (Figure 10). Mean emergent fry production per undisturbed redd was 1,044 (SD = 682), and 1,434 (SD = 773) per superimposed redd. There were no significant differences ($p > 0.05$, two-tailed t-test) in the number of fry that emerged, percent mortality, or emergence timing (time to: first, peak, 50%, and 90% emergence, or period of emergence) between the two tpyes of redds sampled.

Regression Analysis

Regression models revealed that the indicator variable, "superimposition," was not significant ($p > 0.05$) when regressed with the other independent variables (Table 3). Of the 13 models analyzed, none showed significant relationships (Table 4) and four different models, each containing a separate physical variable, were within two AIC_c units of the strongest model (Table 4). Further inspection of the data revealed that one observation (HSS1) strongly influenced (Cook's distance = 1.9–2.9) the overall results (e.g. Figure 11). When the same models were analyzed with the outlier removed, eight of the models became significant (i.e. $p < 0.05$) and only one model is within two AIC_c units of the strongest model (Table 5). The influence of this single observation is further reflected by the cumulative posterior probability that geometric mean particle size is included in the best-approximating model rises from 0.41 to 0.93 when the observation is excluded from the data set (Table 6). The best-approximating model of bull trout fry production included both geometric mean particle size and redd surface area as independent variables (Table 5), but increasing surface area negatively influenced fry production, which is contrary to what one might expect. I could not readily identify mechanisms that would account for the apparent negative relationship between redd surface area and emergent production. Area alone explains less than 1% of the variation in emergent bull trout fry production (Table 5). Furthermore, inspection of the regression output for the model revealed that redd surface area is an insignificant variable (i.e. $p > 0.05$), and was therefore dropped from the model leaving only geometric mean particle size, which is the next best-fitting model (Table 5). Interestingly, the top four models included geometric mean particle size and all the models showing a significant relationship included a substrate type variable (Table 5). Neither flow over the redd nor redd surface area explained fry production very well.

Discussion

Conspecific redd superimposition is frequently associated with density-dependent mortality of embryos in anadromous salmonid species (e.g., Essington et al. 2000). This study shows that when considering redd superimposition by species that differ substantially in size and spawning behavior, the impacts of redd superimposition are less evident. Bull trout egg pocket depths were on average nine cm deeper than kokanee egg pocket depths, suggesting that bull trout eggs are buried deeper, on average, than either a single spawning female kokanee or a spawning cohort can reach. Sliding-bead monitor results demonstrated that the collective digging ability of kokanees is similar to depths reached by single females. Scour depths mirrored deposition depths indicating that the net effect of digging is minimal. Bull trout egg pocket depths below the disturbed substrate elevation were greater than depths below the original streambed level, further suggesting that where overlap in spawning habitat exists the potential for egg displacement is reduced. Redd alteration and fry trapping results revealed that although the structure of bull trout redds may change considerably due to kokanee superimposition, bull trout fry do emerge from superimposed redds. Furthermore, substrate conditions remain an important abiotic factor and may often deserve primary consideration when determining emergence production.

Bull trout egg burial depth measurements were consistent with observed values (Block 1955; McPhail and Murray 1979; Leggett 1980; Shepard et al. 1984a, 1984b), suggesting that adfluvial bull trout bury their eggs approximately 10–20 cm below the substrate wherever their redds are found. In contrast to bull trout egg burial depths; I found that kokanee bury their eggs significantly shallower. Spawning observations revealed that kokanee are superficial spawners, leaving many eggs exposed on the spawning ground. Buried eggs found in both study sub-basins were rarely deeper than seven cm. Egg pockets were more difficult to locate than those found in bull trout redds. Although female kokanee were larger on average in Trapper Creek, egg burial depths were similar in both study sub-basins. Kokanee were observed using similar sized substrate in both Heising Spring and Trapper Creek.

In terms of potential for mortality caused by superimposition, I observed that bull trout eggs were generally closer to the original streambed surface than the disturbed redd substrate. When egg depth below the disturbed substrate level exceeds the depth below the original substrate level it implies that fish would gain an advantage in protecting their eggs against superimposition if later spawning females are smaller than the first (Steen and Quinn 1999). The association between egg pocket depth below the disturbed and original substrate levels is dictated by the lateral placement of egg pockets in redds. In redds where egg pockets are located closer to or directly beneath the highest point of the tailspill, the disturbed substrate depth will most likely exceed the original depth, as was the case with the majority of egg pockets found in this study. In contrast, Steen and Quinn (1999) found that most egg pockets in coho salmon redds were located well upstream of the tailspill crest and were therefore, generally, closer to the disturbed substate elevation than the original streambed surface. Therefore, they hypothesized that in terms of vulnerability to superimposition, egg pockets in coho salmon redds were extremely suscebtible to being disloged by successive spawning.

Furthermore, my results show that kokanee, when superimposing bull trout redds, rarely scour out or deposit more than 5–7 cm of substrate. The degree of bull trout redd disturbance was most influenced by water velocity over the redd. Bull trout redds located near the spring margins in areas of reduced flow were more likely to become disturbed by kokanee than redds in higher flow areas. Therefore, it did not appear that kokanee were specifically targeting bull trout redds, but rather water velocities where bull trout redds happened to be. Studies of spawning site selection have indicated that kokanee are more selective for water velocity than for either water depth or substrate characteristics (Parsons and Hubert 1988; Mullner and Hubert 1995).

Though kokanee were capable of altering the structure of some redds, fry emergence trapping revealed no differences in fry emergence numbers or timing between superimposed and undisturbed redds. Bull trout fry emerged from all seven of the superimposed redds in this study and, on average, in greater numbers than from undisturbed redds, suggesting that kokanee are having little if any effect on their survival. However, the absence of a kokanee effect could be due to some uncontrolled factor or the small sample size. Most superimposed redds were located near the spring margins. Thus, if channel margins provide better spawning habitat for bull trout, and kokanee were also attracted to the same areas then their disturbance could diminish any positive effects redd proximity to the stream bank might have on bull trout production. Due to the high variation in the number of fry captured per redd a much larger sample size may be required to detect any real trends.

Why more fry were captured from superimposed than undisturbed redds remains unclear. Water velocity was the only abiotic variable measured that differed significantly between the two redd types; however regression analyses indicated that the probability of flow being included in "best" models was low. Variables describing the composition of the spawning substrate, particularly geometric mean particle size, explained the highest proportion of variation in the response. The percentage of fine sediment below some threshold is often found to be the best predictor of embryo survival in both lab and natural emergence studies (Koski 1966; Tagart 1984; Sparkman 2004). Koski (1966) found that substrates passing through the 3.33 mm sieve size had the highest correlation ($r^2 = -0.69$) with coho survival and that 27 to 51 percent of the substrate in 22 sampled redds were below that size. I found considerably less fine sediment below 3.33 mm in redds sampled in Heising Spring, suggesting that fine sediments were not limiting fry production in sampled redds. However, in areas where the percentage of fines is a concern, the added impact of superimposition might elicit a greater negative effect.

Salmonid spawning interactions have been studied extensively to determine progeny loss caused by superimposition (e.g., Fukushima *et al*. 1998; Essington et al. 2000; Blanchfield and Ridgway 2005). The data presented here are the first in which heterospecific redd superimposition has been documented on an individual redd basis. Although no direct effect of superimposition was found it is important to continue to monitor redds in highly spawned areas. Egg pocket location, both laterally and vertically within a redd is an important indicator of vulnerability to superimposition.

Thus, studies of egg burial depth should measure the vertical and lateral location of the eggs themselves and refrain from using surrogate measurements such as redd surface area or water velocity. I suggest that egg burial depth measurements be taken from the top of egg pockets to the disturbed and original streambed surfaces. Egg pocket depths in relation to the highest and lowest points of the redd might also be beneficial, but should be used with caution as redd structure will change over the incubation period. Further, I suggest that when considering vulnerability to superimposition, placement of the redd within the channel, and estimated stream velocity at the time of redd construction be measured. Also important to consider are abiotic variables such as substrate composition and inflow rate as these variables can impact embryo survival considerably.

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TABLE 1. Mean egg pocket depths from 26 bull trout redds evaluated in the Metolius River sub-basin, 2005–2006.

Location	Redd #	# of egg pockets	Mean depth below disturbed substrate elevation (cm)	Mean depth below original steambed elevation (cm)
Candle Creek	Cand1	2	7	-1
Candle Creek	Cand2	2	10	0
Candle Creek	Cand3	1	21	12
Candle Creek	Cand4	0	-	-
Candle Creek	Cand5	1	15	14
Candle Creek	Cand6	2	9	13
Canyon Creek	Cany1	1	18	12
Canyon Creek	Cany2	4	13	7
Canyon Creek	Cany3	1	16	9
Jefferson Creek	Jeff1	3	13	14
Jefferson Creek	Jeff2	1	10	14
Jefferson Creek	Jeff3	0	-	-
Jefferson Creek	Jeff4	1	13	6
Jefferson Creek	Jeff5	3	11	10
Jefferson Creek	Jeff6	1	13	14
Roaring Spring	Roar1	3	14	2
Heising Spring	Heis1	4	13	3
Heising Spring	Heis2	1	19	20
Heising Spring	Heis3	2	16	19
Heising Spring	Heis4	1	17	6
Heising Spring	Heis5	3	12	13
Heising Spring	Heis6	2	20	11
Heising Spring	Heis7	2	15	26
Heising Spring	Heis8	1	14	16
Heising Spring	Heis9	2	16	20
Heising Spring	Heis10	3	10	9

TABLE 2. Bull trout fry emergence production and timing from 14 redds trapped in Heising Spring, Metolius River, 2006.

Redd No.	Date of Redd Formation	# of emergent bull trout fry	Temperature Units (Calendar Days) to: First Emergence	Peak Emergence	50% Emergence	90% Emergence	Period of Emergence (days)
HSU1	9/21/05	1992	784 (139)	834 (148)	834 (148)	862 (153)	44
HSU2*	9/07/05	1610	814 (144)	865 (153)	876 (155)	942 (167)	59
HSU3	9/21/05	1509	784 (139)	807 (143)	823 (146)	873 (155)	52
HSU4*	9/04/05	779	825 (146)	825 (146)	842 (149)	932 (165)	39
HSU5*	9/14/05	763	774 (137)	808 (143)	808 (143)	836 (148)	36
HSU6	9/18/05	621	852 (151)	890 (158)	901 (160)	928 (165)	66
HSU7*	9/11/05	31	791 (140)	802 (142)	813 (144)	930 (165)	28
HSS1	9/14/05	2601	774 (137)	796 (141)	796 (141)	824 (146)	36
HSS2*	9/14/05	2109	745 (132)	757 (134)	785 (139)	885 (157)	66
HSS3*	9/07/05	1686	769 (136)	808 (143)	825 (146)	903 (160)	67
HSS4	9/11/05	1364	763 (135)	791 (140)	796 (141)	825 (146)	38
HSS5	8/24/05	1226	945 (167)	995 (176)	995 (175)	1072 (189)	44
HSS6	8/24/05	533	1028 (181)	1061 (188)	1061 (188)	1072 (191)	36
HSS7	9/04/05	516	808 (143)	842 (150)	893 (159)	1003 (179)	43

HSU: Heising Spring undisturbed redd
HSS: Heising Spring kokanee superimposed redd
* redds in which fry were captured during the first trap check

TABLE 3. Individual *p*-values for independent variables in regression analysis in which the indicator variable “Superimposition” was included. Values in parentheses reflect an analysis conducted after the removal of one outlier.

	***p* – values**				
Model	**Dg**	**Fines**	**Flow**	**Area**	**Super**
Dg + Super	0.19 (< 0.01)				0.36 (0.34)
Fines + Super		0.45 (< 0.01)			0.45 (0.38)
Flow + Super			0.48 (0.91)		0.87 (0.90)
Area + Super				0.25 (0.35)	0.30 (0.59)

Dg = geometric mean particle diameter
Fines = cumulative percentage of fine sediments <3.33 mm
Flow = water velocity over redd
Area = approximate redd surface area
Super = presence or absence of superimposition

TABLE 4. Models of emergent bull trout fry catches in Heising Spring, 2006, using four physical variables and one indicator variable. Listed are the 13 models used to test for best-fit, as measured by Akaike's information criterion (AIC_c). The symbol Δ_i indicates the difference in the AIC_c value of the given model and that of the best fitting model, while the symbol w_i (weight) indicates the probability that the given model is the "best" among the whole set of candidate models. The plus and minus signs indicate the influence of the variable on emergent fry production.

Independent variable(s) in model	***p*-value**	$R^2_{adj.}$	Δ_i	w_i
Dg (+)	0.26	0.12	0.00	0.19
Flow (-)	0.36	0.08	0.55	0.14
Dg (+), Flow (-)	0.19	0.21	0.75	0.13
Area (+)	0.44	0.06	0.86	0.12
Fines (-)	0.58	0.03	1.21	0.10
Dg (+), Super (+)	0.35	0.12	2.34	0.06
Flow (-), Area (+)	0.38	0.11	2.56	0.05
Fines (-), Flow (-)	0.38	0.09	2.58	0.05
Area (+), Super (+)	0.43	0.08	2.85	0.05
Dg (+), Area (+)	0.52	0.04	3.36	0.04
Fines (-), Super (+)	0.64	0.01	3.91	0.03
Flow (-), Super (-)	0.66	<0.01	3.98	0.03
Fines (-), Area (+)	0.73	<0.01	4.25	0.02

Dg = geometric mean particle diameter
Fines = cumulative percentage of fine sediments <3.33 mm
Flow = water velocity over redd
Area = approximate redd surface area
Super = presence or absence of superimposition

TABLE 5. Models of emergent bull trout fry catches in Heising Spring, 2006, using four physical variables and one indicator variable, after the removal of one outlier. Listed are the 13 models used to test for best-fit, as measured by Akaike's information criterion (AIC_c). The symbol Δ_i indicates the difference in the AIC_c value of the given model and that of the best fitting model, while the symbol w_i (weight) indicates the probability that the given model is the "best" among the whole set of candidate models. The plus and minus signs indicate the influence of the variable on emergent fry production.

Independent variable(s) in model	***p*-value**	$R^2_{adj.}$	Δ_i	w_i
Dg (+), Area (-)	0.0005	0.80	0.00	0.39
Dg (+)	0.0003	0.75	0.15	0.36
Dg (+), Super (+)	0.001	0.75	2.52	0.11
Dg (+), Flow (-)	0.002	0.73	3.50	0.07
Fines (-)	0.002	0.62	5.00	0.03
Fines (-), Area (-)	0.005	0.66	6.24	0.02
Fines (-), Super (+)	0.009	0.62	7.57	0.01
Fines (-), Flow (-)	0.01	0.59	8.22	0.01
Area (+)	0.41	0.07	15.73	<0.01
Flow (+)	0.98	<0.01	16.58	<0.01
Area (+), Super (+)	0.62	0.01	18.99	<0.01
Flow (-), Area (+)	0.71	<0.01	19.32	<0.01
Flow (+), Super (+)	0.99	<0.01	20.22	<0.01

Dg = geometric mean particle diameter
Fines = cumulative percentage of fine sediments <3.33 mm
Flow = water velocity over redd
Area = approximate redd surface area
Super = presence or absence of superimposition

TABLE 6. Cumulative relative probabilities of a given independent variable being included in the "best-fitting" model. Probabilities derived from 13 models of emergent bull trout catches in Heising Spring, 2006, using four physical variables and one indicator variable. Results in parentheses reflect an analysis conducted after the removal of one outlier.

Independent variable	**Cumulative Probability**
Dg	0.41 (0.93)
Flow	0.38 (0.07)
Area	0.23 (0.40)
Fines	0.20 (0.06)
Super	0.16 (0.12)

Dg = geometric mean particle diameter
Fines = cumulative percentage of fine sediments <3.33 mm
Flow = water velocity over redd
Area = approximate redd surface area
Super = presence or absence of superimposition

FIGURE 1. Map of the Deschutes River Basin showing the location of the two study sub-basins, Odell Lake and Metolius River. Location of the Deschutes River Basin in Oregon is shown.

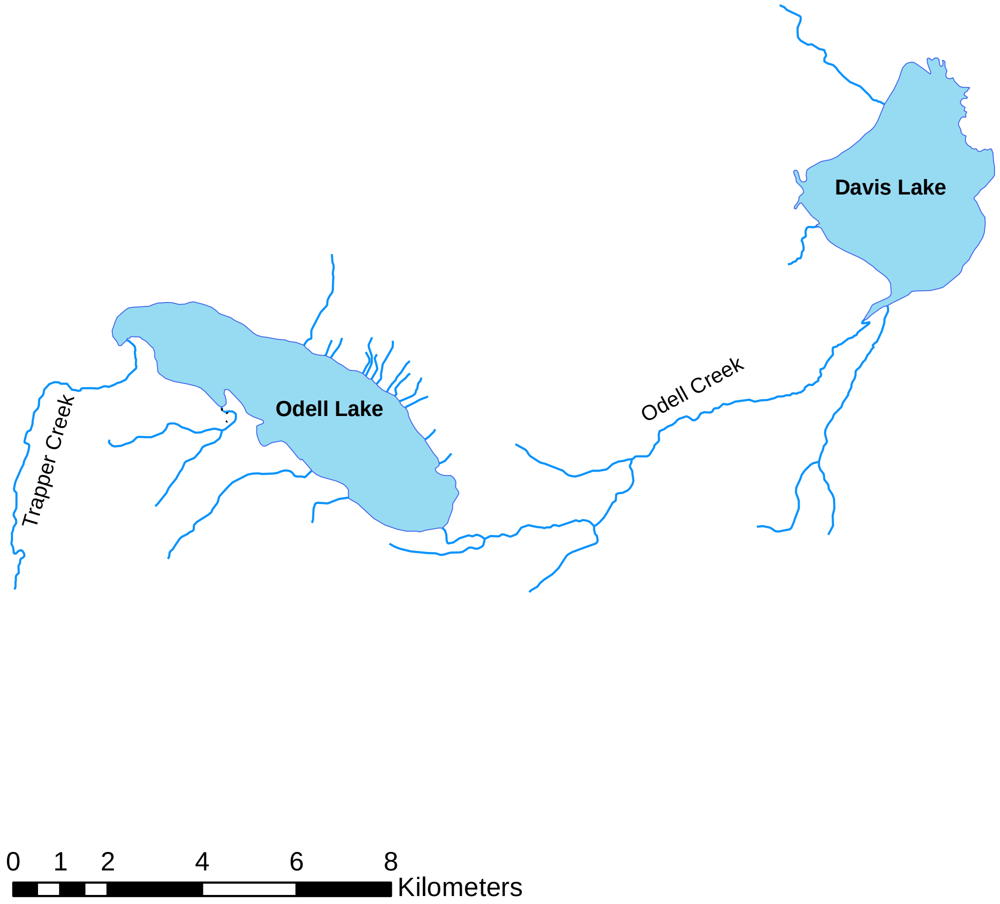

FIGURE 2. The Odell Lake sub-basin showing Odell Lake and Creek, Davis Lake, and Trapper Creek where data were collected.

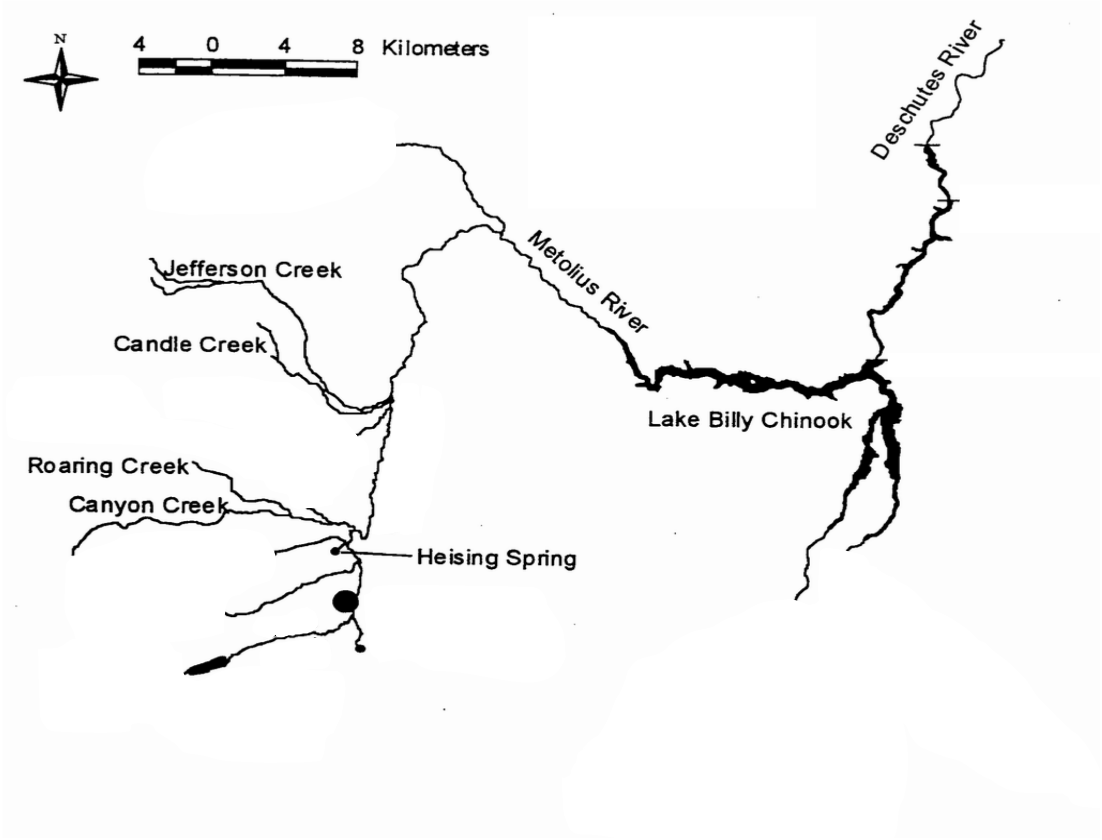

FIGURE 3. The Metolius River sub-basin showing Lake Billy Chinook, the Metolius River, and the streams in which data were collected (adapted from Ratliff et al. 1996).

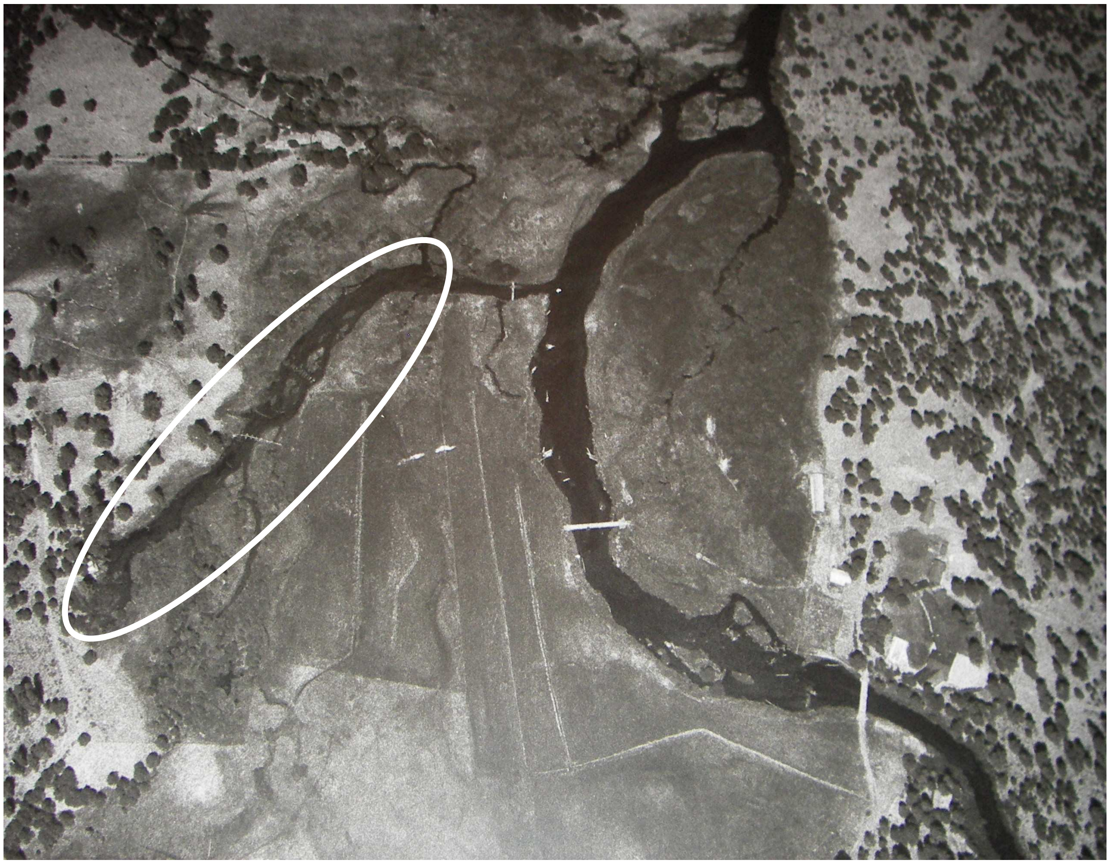

FIGURE 4. Aerial photograph of a section of the Metolius River (1/4000 scale); Heising Spring is circled.

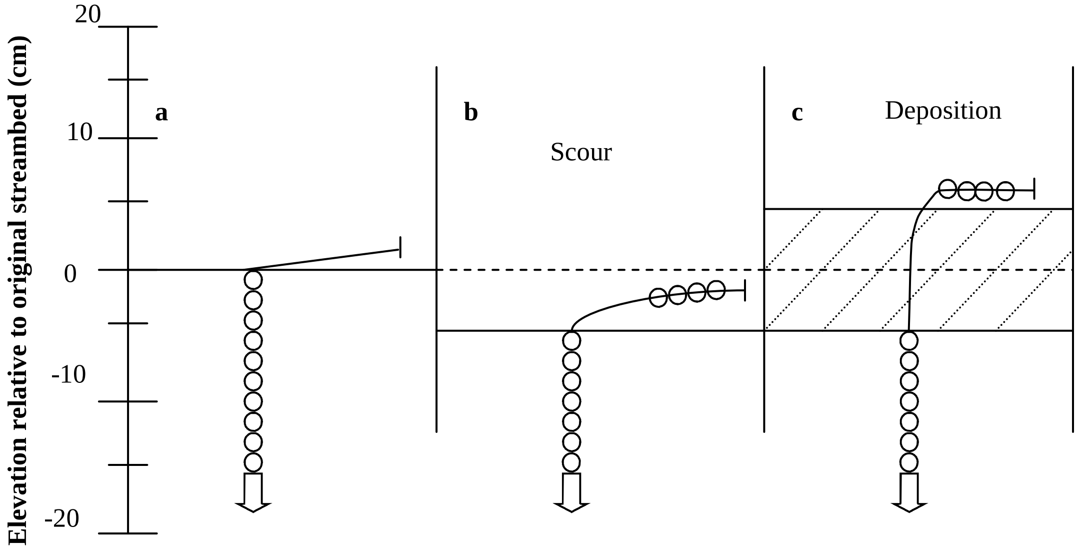

FIGURE 5. Scour and deposition measured with a sliding-bead monitor. (**a**) Side view before any scour or deposition occurs. (**b**) Depth of scour, measured by the number of released beads after digging occurs. (**c**) Device is buried after scour event. Length of buried wire represents amount of deposition. Net change in streambed height equals length of buried wire minus scour depth. (adapted from Nawa and Frissell 1993).

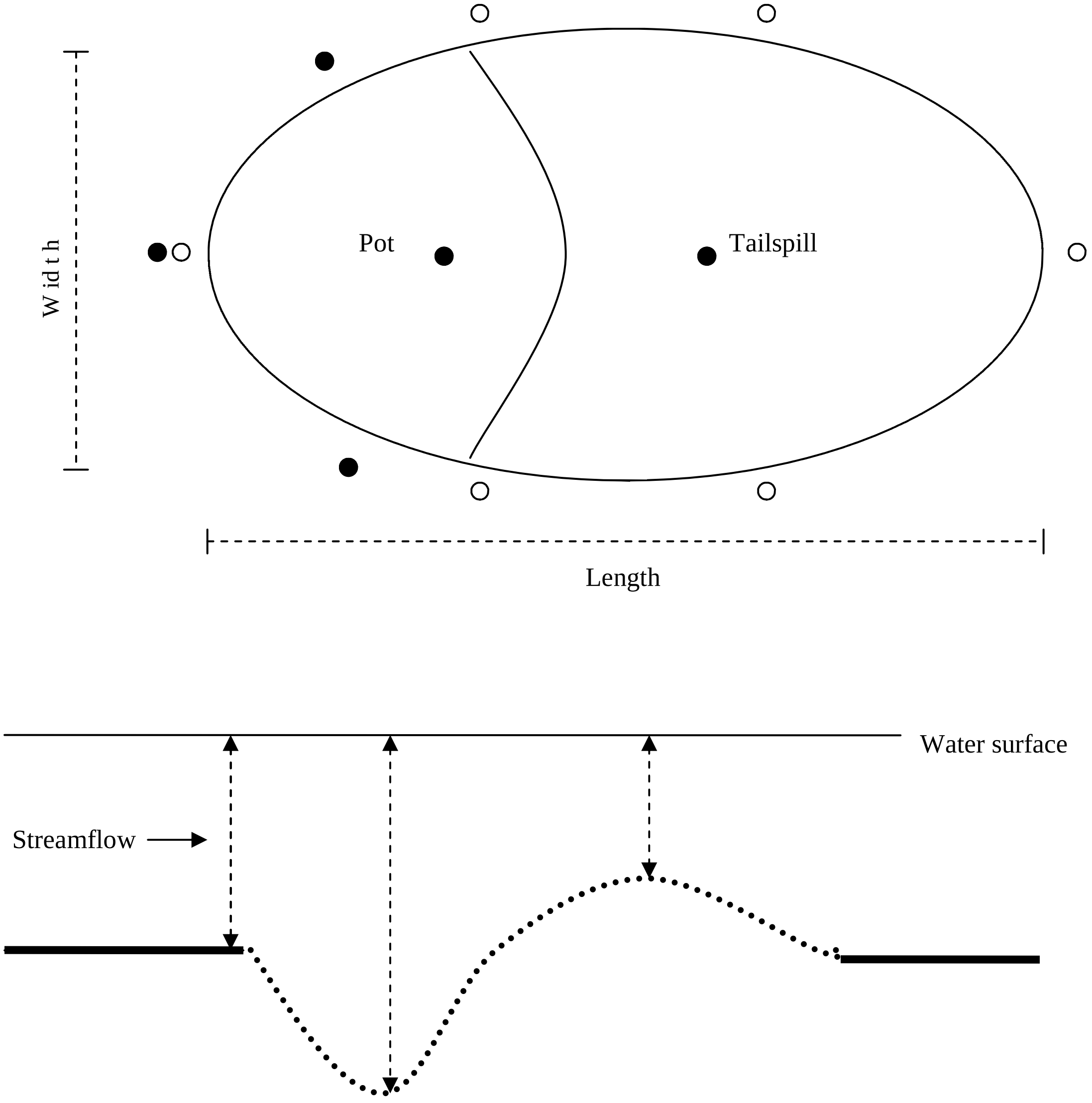

FIGURE 6. Diagrammatic top and side views (not to scale) of a typical bull trout redd. Top panel: locations where depth measurements were made (closed circles) and where surveyor flags were placed to mark redd periphery (open circle). Bottom panel: arrows indicating where depths were measured.

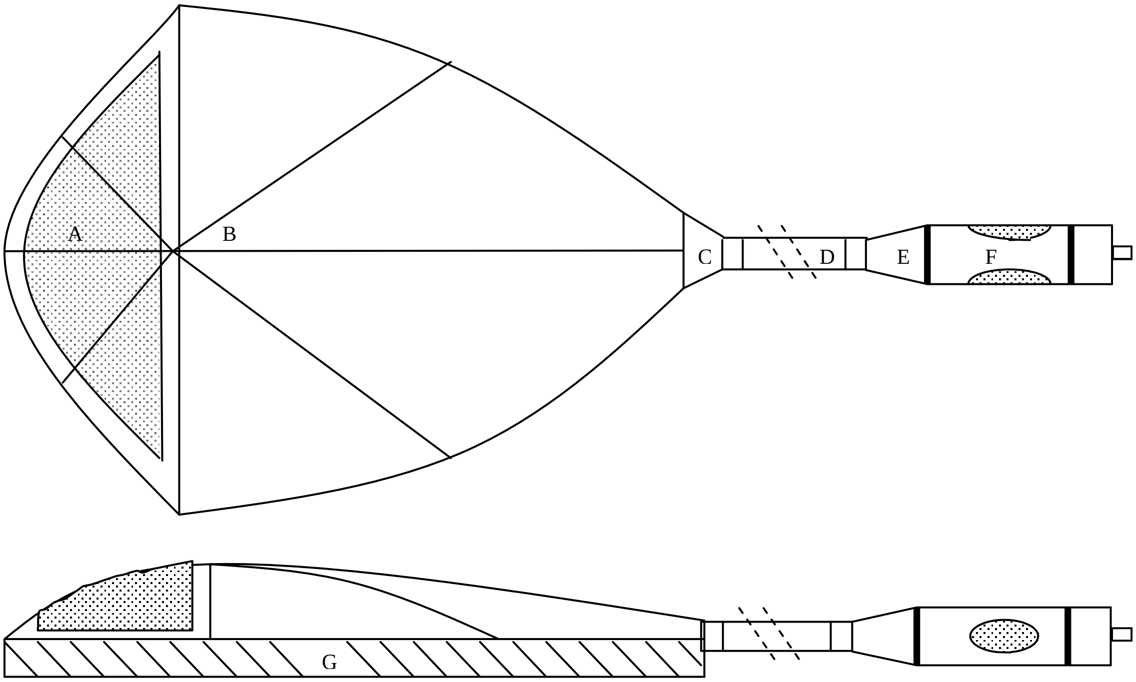

FIGURE 7. Diagrammatic top and side views (not to scale) of emergence fry trap used to capture bull trout. Top panel: A = location of upstream portion of mesh netting, B = trap frame as viewed through remainder of netting, C = cod end of trap, D = hollow flex-tube (full length not shown), E = PVC live-well, F = locations of live-well cutouts. Bottom panel: G = trap apron (buried).

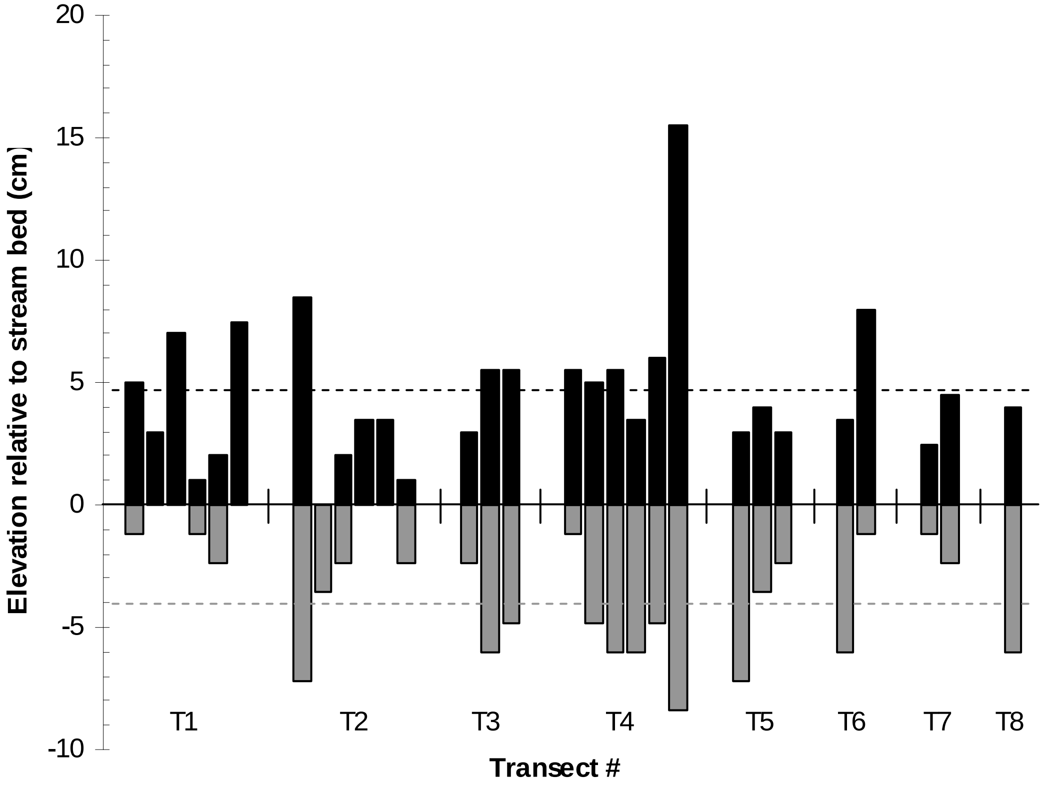

FIGURE 8. Depths of scour (▨) and deposition (■) at each sliding-bead monitor across all transects. Dashed lines represent the mean depth of scour and deposition pooled across all monitors.

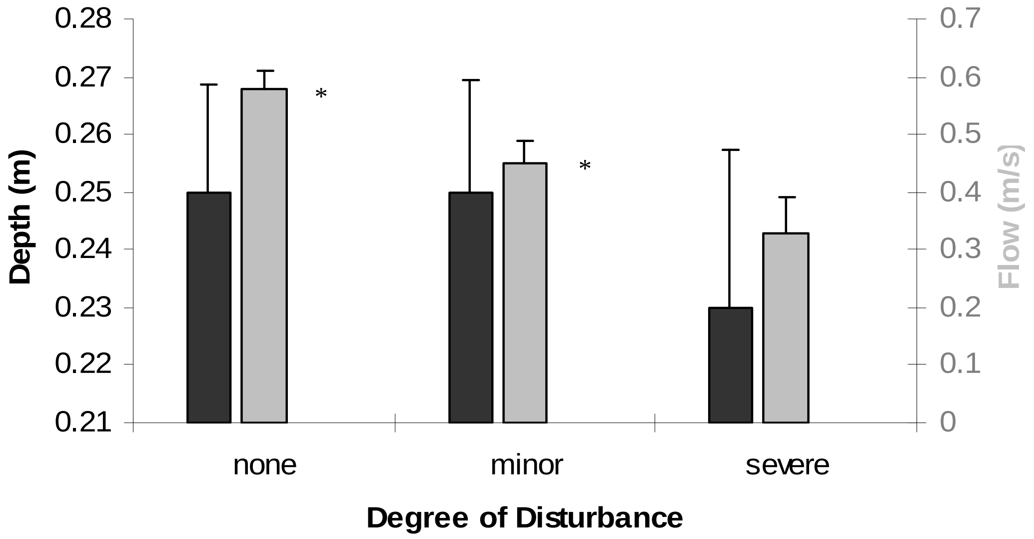

FIGURE 9. Mean depths to (■) and flows (■) over bull trout redds in Heising Spring that suffer no, minor, or severe disturbance by spawning kokanee. Error bars represent 95% upper confidence levels and asterisks show significant differences.

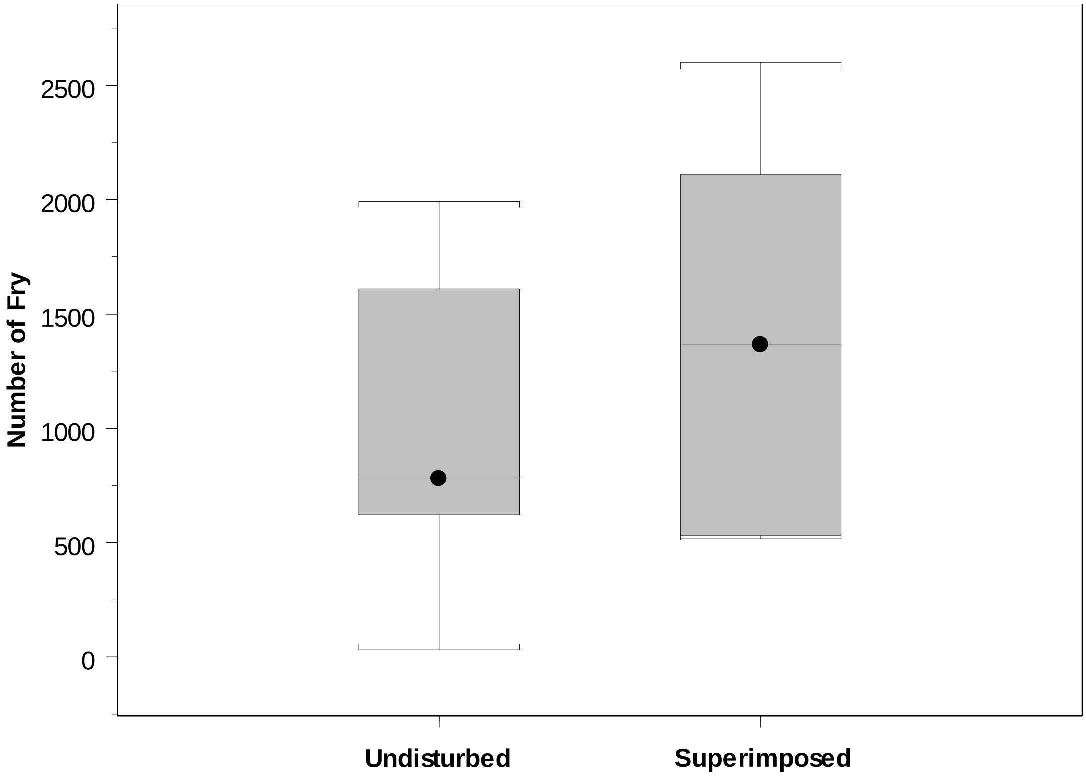

FIGURE 10. Box plots representing the numbers of emerged bull trout fry captured from undisturbed and kokanee superimposed redds. Plots show upper and lower quartiles, and mid-lines represent the median number of captured fry.

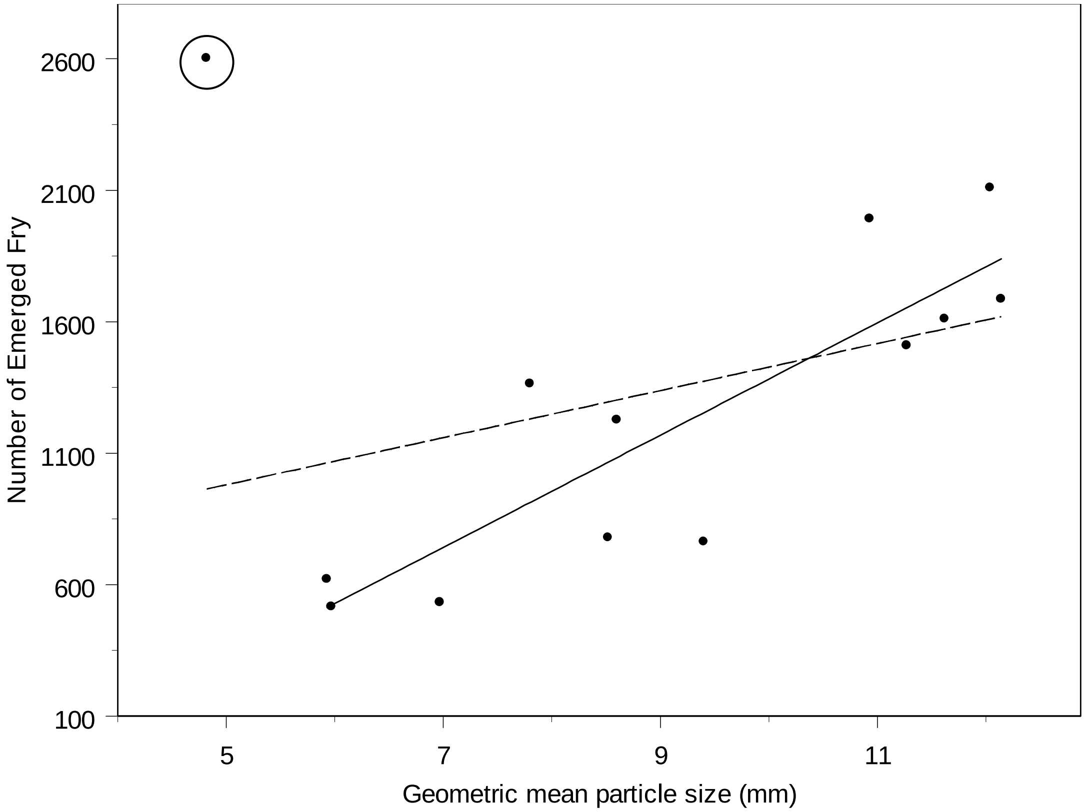

FIGURE 11. The number of emerged bull trout fry captured per redd versus geometric mean particle size. Regression lines depict the relationship with (dashed line) and without (solid line) an outlier (circled).

CHAPTER 3: FINAL DISCUSSION

The results of my study do not indicate that kokanee redd superimposition negatively effects bull trout reproductive success. Egg burial and scour monitoring results revealed that, on average, bull trout bury their eggs significantly deeper than either a single female kokanee or a spawning cohort can reach. Furthermore, despite the presence of high numbers of spawning kokanee, most kokanee disturbed bull trout redds sustained only minor structural alterations. Emergent fry trapping showed that bull trout fry do emerge from kokanee superimposed redds, indicating that embryos do remain viable throughout the incubation period.

When considering the implications of my study findings it is necessary to consider the differences between the Odell Lake and Metolius River systems. Due to the small bull trout population size in Odell Lake and the limited number of bull trout redds found in Trapper Creek, much of the study was conducted in the Metolius River sub-basin, particularly in Heising Spring. The validity of using a surrogate system to develop management strategies applicable to bull trout in Odell Lake should be taken into consideration. Differences exist in spawning habitat characteristics, stream hydrology, kokanee spawner size, and kokanee spawner density between Trapper Creek and Heising Spring.

Spawning substrate data (Appendix F) was collected at bull trout redd sites in Trapper Creek using the same methods described in chapter two for redd sites in Heising Spring. Substrate core samples were removed from five Trapper Creek bull trout redds. The samples were taken in 2006, but from redds marked in 2005 to avoid harming incubating embryos. Surface substrate, “pebble counts,” were completed on seven redds in 2005. No significant difference was found in percentage of fine sediment between redds sampled in Trapper Creek and Heising Spring; however geometric mean particle size at Trapper Creek redd sites was considerably larger. Surface substrate sampling confirms this finding; a higher percentage of large size surface particles were encountered at Trapper Creek redd sites. The percent composition of particle sizes less than or equal to “pebble” size (32–63 mm) was similar between redds sampled in both study streams, however the percent composition of “cobble” size (64–256 mm) particles was significantly greater at Trapper Creek redd sites. In addition, no “boulder” size (> 256 mm) particles were found at Heising Spring redds, however boulders were encountered at two of the seven redds sampled in Trapper Creek. Trapper Creek bull trout redds were frequently observed between large in stream boulders and redd features (i.e., pot and tailspill) were often less distinct than those observed in Heising Spring. Despite these differences, while removing a core sample from one of the Trapper Creek redds a remnant egg pocket was encountered approximately 15 cm below the substrate surface. This implies that adfluvial bull trout bury their eggs at approximately similar depths regardless of differences in sediment size between the two streams sampled.

In addition to differences in spawning substrate composition, stream hydrology is also different between the two study streams. Heising Spring is entirely spring fed; multiple small springs and seeps are found throughout its length, thus discharge remains constant year round. Trapper Creek receives much of its water from snowmelt and is prone to seasonal freshets. The implications of fluctuating hydrology on embryo survival are different than those encountered in spring fed systems (Rennie and Millar 2000). Because discharge does not fluctuate in Heising Spring, minimal natural redd scour occurs. Heising Spring redd sites can often be distinguished from the surrounding substrate long after fry have emerged. Whereas redds in Trapper Creek experience varying levels of seasonal discharge and are often indistinguishable by the time fry emerge. This indicates that bull trout embryos in Trapper Creek face the added threat of natural scouring, which could act in combination with superimposition to produce a synergistic type effect. Therefore, although kokanee scouring is unlikely reaching bull trout egg pockets in Trapper Creek, kokanee superimposition could potentially reduce the thickness of the substrate covering the eggs so that flood events have a greater chance of reaching the incubating embryos (Montgomery et al. 1996). This however is unlikely given that collective kokanee scouring depths and depths of sediment deposition were approximately equal, suggesting that the net effect of digging is negligible.

The size and density of kokanee spawners is another difference between Heising Spring and Trapper Creek that should be considered. Female kokanee were, on average, larger in Trapper Creek than those in Heising Spring. Larger females have the potential to scour deeper than smaller fish (DeVries 1999). However, kokanee egg burial results from the two systems suggest no difference in burial depth. Egg pockets in Heising Spring were in fact slightly deeper than those found in Trapper Creek. Taking into consideration the larger surface particle size in Trapper

Creek, larger kokanee size might be off set, which could account for why no difference in burial depth was observed.

In addition to having larger kokanee, Trapper Creek also has more spawners per square meter. Greater than 50 spawners were observed in a single spawning area at one time in Trapper Creek. The greatest number of spawners observed at one time in Heising Spring was 15 in one area. Trapper Creek is composed of pool-riffle habitat so spawners often concentrate in pool-tailouts, whereas Heising Spring is composed entirely of riffle habitat and is also much wider, thus kokanee spread out more. The implications of greater spawner density would suggest a greater potential impact of superimposition (Chebanov 1991). However, Parenskiy (1989) reports that overcrowding on the spawning ground is accompanied by the formation of aggregations under stress that are totally or temporarily excluded from spawning. He goes on to conclude that: “At optimum density, redds are regularly distributed, there is low frequency of aggressive interactions, and most eggs are spawned.” Conversely, spawning at a density exceeding the optimum causes the appearance of a large number of subdominant fish, greater competition, lower breeding rate, and formation of stress contagiats, which can result in repeated digging of some nests (Parenskiy 1989). This may explain some of the discrepancies I observed in kokanee spawning behavior between Heising Spring and Trapper Creek. I observed more aggressive behavior, fewer pairings, and more eggs on the stream bottom in Trapper Creek. Sliding-bead monitor and egg burial data from Trapper Creek confirm these observations, suggesting a high rate of spawning site reuse and shallow egg depositions. Therefore, although kokanee spawner densities may be higher in Trapper Creek, collective scouring depths may be off set because of it.

Although my findings suggest that kokanee superimposition does not pose a direct threat to the Odell Lake bull trout population, redd surveys should continue in Trapper Creek. Regular surveys are an important tool in monitoring a population's status (Dunham et al. 2001). A management option adopted by the Oregon Department of Fish and Wildlife to protect bull trout redds from kokanee superimposition in Trapper Creek is to place protective screens over all identified redds before kokanee arrive. The screens prevent kokanee from digging directly on the redds. However, they are difficult to maintain due to debris that collects on the surface, which must be cleaned off regularly. The effect of screening redds in this manner on bull trout embryo survival is unknown. Therefore, based on my findings that suggest that kokanee are superficially altering the streambed the use of the screens may no longer be necessary. The time and energy spent maintaining the screens could be used for other research needs.

Future superimposition research should concentrate on further streambed monitoring in Trapper Creek. The relationship between streambed composition and bull trout embryo survival and fry emergence needs to be defined over a wider range of substrate compositions (Shepard et al. 1984a). The relationship between natural streambed scour and scour caused by kokanee superimposition also warrants further consideration. The amount of streambed scour caused by spring runoff in Trapper Creek needs addressing. How or if superimposition affects redd substrate permeability remains unclear. Further study in general is needed on the influence of permeability as it relates to embryo incubation and groundwater hydraulics (Baxter and Hauer 2000). Although permeability appeared similar between superimposed and undisturbed redds in Heising Spring, redd substrate composition and stream hydrology is different in Trapper Creek. How superimposition influences intra-gravel flow and groundwater characteristics in Trapper Creek needs further study.

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APPENDICES

Appendix A: Egg burial depth methodology

Redds considered suitable for egg burial depth evaluation were easily accessed and out of the main thalweg so a diver could evaluate them safely and without considerable egg loss. The physical redd structure (pot and tailspill) and periphery needed to be clearly defined, undisturbed (i.e., no superimposition or physical alteration), and entirely visible (i.e., not under a log or the bank).

Before excavation began water depth at the deepest point in the redd pot, the shallowest point over the tailspill, and at three points on undisturbed substrate around the pot were measured. The latter measurements were averaged to give an estimate of the water depth around the redd (1 in Figure A.1) so that the depth of egg pockets could be referenced from different elevations. After the physical redd data were recorded a diver entered the water at the upstream end of the redd to begin excavation. Beginning near the bottom of the pot, where the tailspill begins to slope upward, and along the redd centerline; a depth measurement (± 1 cm) was made from the water surface to the disturbed substrate surface (2 in Figure A.1). A section of stove-pipe (length = 18 cm, diameter = 15 cm), cut in half lengthwise offered a curved shield used to prevent adjacent substrate from falling into the pit as digging proceeded. Two lead anchors attached to the stove-pipe shield prevented it from being swept downstream when not held by the diver. As substrate was removed, either by hand or with a small hand trowel, the stove-pipe shield was progressively pushed farther down into the excavated pit. The stove-pipe shield combined with the body of the diver provided cover from flow, thus minimizing egg loss. When an egg pocket was reached, the depth from the stream surface to the top of the egg pocket was measured (3 in Figure A.1). An egg pocket was defined as a space in the gravel containing five or more eggs (Crisp and Carling 1989) separated by no more than a few egg diameters (DeVries 1997). After measurement, the eggs were carefully concealed by back-filling the pit with the removed substrate. The diver then moved approximately 15 cm downstream onto the unaltered part of redd tailspill and repeated the process. After this work was completed down the centerline of the redd, unaltered substrate that remained on the left and the right sides of the tailspill was subsequently excavated. The number of excavations per redd varied, with larger redds being dug at more locations than smaller ones. Egg pocket depths (EPD) below the disturbed sustrate and original streambed elevations were calculated as follows:

$$\text{EPD}_{\textit{disturbed}}\ \text{(4 in Figure A.1)} = \text{EPD}_{\textit{below water level}} - \text{disturbed substrate depth}$$

$$\text{EPD}_{\textit{original}}\ \text{(5 in Figure A.1)} = \text{EPD}_{\textit{below water level}} - \text{original streambed depth}$$

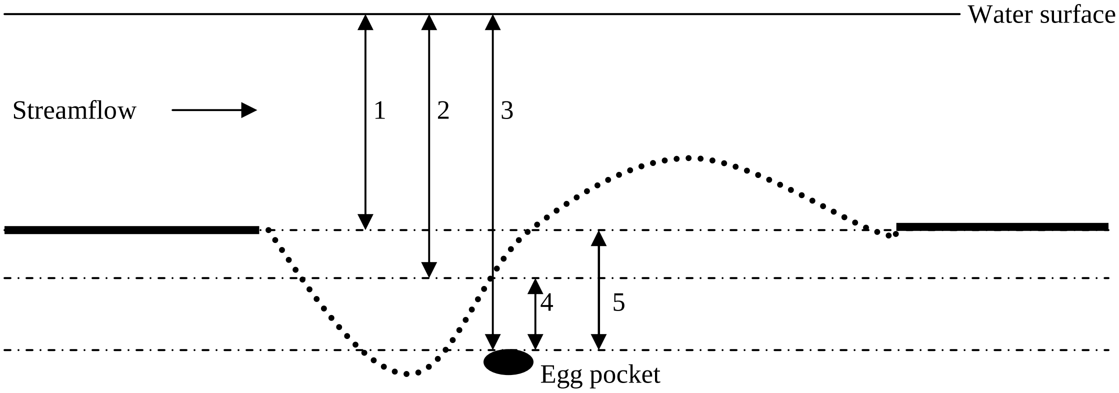

FIGURE A.1 Diagrammatic side view (not to scale) of a typical bull trout redd depicting the various depths measured to determine egg burial depth: 1 = depth from the water level to the original streambed elevation, 2 = depth from the water level to the disturbed substrate elevation, 3 = depth from the water level to the top of the egg pocket, 4 = depth from the disturbed substrate to the top of the egg pocket ($EPD_{disturbed} = 3 - 2$), and 5 = depth from the original streambed elevation to the top of the egg pocket ($EPD_{original} = 3 - 1$) (adapted from Steen and Quinn 1999).

Appendix B: Egg burial depth considerations

To estimate the efficiency of the excavation technique described in Appendix A, depth measurements to the bottom of pits in which no egg pocket was found were completed on half the redds examined (n = 13). If no egg pocket or obstacle (i.e., large immovable particle, hardpan, or silt) was encountered during the excavation, a depth measurement was taken from the stream surface to the bottom of the pit before back-filling proceeded.

The mean pit depth was 21 cm (SD = 3.0, n = 22) and ranged from 15–26 cm. Excavations reaching beyond 21 cm often resulted in collapse. This meant that sediment began to backfill the excavated pit and further digging was no longer possible. However, pit depth did vary and excavations reaching beyond 21 cm did occur. Excavation depth appeared to be correlated with surrounding substrate composition. Courser substrates resulted in greater depth while finer substrates resulted in earlier pit collapse.

In spite of this; the excavation technique in combination with the stove-pipe shield proved to be successful because 1) the top of most egg pockets were located shallower than 21 cm, and 2) egg loss was minimal (0–3 eggs/pocket). Past studies using manual excavation to determine egg burial depths have observed varying degrees of egg loss depending on flow conditions (Ottaway et al. 1981). This may have caused varying degrees of error in previously reported depths because eggs may have been washed away before a measurement could be made. Crisp and Carling (1989) promote the use of the freeze-core method as a more accurate and complete technique to measuring egg pocket depths. The technique allows measurement to any portion of the egg pocket. However, freeze-coring destroys embryos, therefore its use is limited to populations that are not threatened or listed as endangered. Egg burial depth data which is founded on spawning observations can be influenced by parallax, refraction, and observer calibration errors (DeVries 1997).

The method used in this study reduces the flow field around the excavation; thus egg loss is limited and pit collapse is reduced, allowing the diver to make quick accurate measurements. However, the technique is limited; if egg pockets are expected to be deeper than approximately 20 cm than another technique may prove more beneficial.

Appendix C: Kokanee spawning observations

Kokanee spawning observations were made in both Heising Spring (Metolius River sub-basin) and Trapper Creek (Odell Lake sub-basin) during egg burial depth evaluations. Spawning fish were located by walking upstream and observing groups. The approximate surface area covered by the group of spawners, the number of kokanee in the area, suspected or observed locations were females dug, and behavioral observations were noted during a five minute interval. The following is a synopsis of those observations as well as a discussion of the some of the differences I observed between kokanee in the two sample streams. Also presented are considerations for future kokanee egg burial measurements.

Kokanee were often observed in large groups composed of one to three females and multiple males. Collection of spawned out carcasses in Heising Spring and Trapper Creek revealed that 18% and 42% respectively, of the kokanee collected were females. Rarely was a single pair observed, rather fish were observed in groups. However, as the spawning season progressed and the number of kokanee decreased in both sub-basins more pairs and smaller groups were observed. In Heising Spring, anywhere from one to upwards of 18 fish were observed at one time on a spawning site. A spawning site was defined as the area of substrate disturbed by a spawning group. The area encompassed by a group depended on the number of individuals. One large spawning site in Heising Spring was greater than 5 m^2. The average size of a spawning site was 1.5 m^2. In Trapper Creek it was often difficult to identify how many kokanee were in a group because densities in the stream were high (> 200 fish per 100 m in 2005) and kokanee tended to concentrate in pool tailouts. Smaller groups and more pairs were observed in Heising Spring. In 2006, fewer kokanee returned to spawn in Trapper Creek compared to 2005. Still, during peak return, groups greater than 40 fish were present.

Males were often observed moving between groups. These “floaters” often faced aggression from both females and other males, but the encounters were usually nothing more than a short chase sequence before the new male was allowed to settle. Females were usually positioned at the head of groups and those observed digging were courted by multiple males positioned downstream. Females were rarely observed digging, but those that were moved progressively upstream scouring small pits no more than a few centimeters deep without depositing eggs. Little effort (2–3 tail thrusts) was put into the act of digging before the female moved on. Although eggs were rarely observed being released, when they were, multiple males would come in to fertilize. This was observed twice in Trapper Creek and once in Heising Spring. After fertilization the females were never observed covering or fanning the eggs. Underwater observations of the stream bottom confirmed this finding. Many uncovered eggs were found in both sub-basins. In some pool tailouts in Trapper Creek more than a hundred kokanee eggs were observed on the stream bottom. Fewer exposed eggs were observed in Heising Spring. Kokanee eggs found covered by substrate were often less than a few centimeters below the surface and appeared to be more spread out than those eggs encountered in bull trout redds.

Individual redds were often difficult to identify and digging was rarely observed although a high rate of conspecifics redd superimposition seemed to occur. Parenskiy (1989) reports similar behavior for anadromous sockeye salmon that spawn at high densities. While investigating the relationship between spawning success and behavior on the spawning grounds he states that “overcrowding is accompanied by the formation of aggregations under stress that are totally or temporarily excluded from spawning” and refers to these aggregations as “stress contagiats.” He goes on to conclude that: “At optimum density, redds are regularly distributed, there is low frequency of aggressive interactions, and most eggs are spawned. Spawning at a density exceeding the optimum causes the appearance of a large number of subdominants and nonterritorial fish, greater competition, lower breeding rate, and formation of stress contagiats.” And that “the presence of stress contagiats results in repeated digging of some nests.”

Parenskiy’s (1989) description of anadromous sockeye spawning behavior may explain some the discrepancies I observed in spawning behavior between kokanee in Heising Spring and Trapper Creek, as well as my inability to locate egg pockets. Kokanee densities (fish/m^2) were often greater in Trapper Creek throughout most of the spawning season. Thus I observed more aggressive behavior, fewer pairings, and more eggs on the stream bottom. Heising Spring offers more consistent depth and flow conditions throughout, thus kokanee spread out over a greater area. Although “stress contagiats” were still observed in Heising Spring, especially during peak abundance, fewer aggressive interactions were observed. Grover (2006) found that kokanee crowd into the best habitat at the peak of the spawning run regardless of densities.

Most of the egg burial measurements made in both sub-basins were done after peak abundance occurred, therefore any eggs located on the stream bottom would likely have been washed away and any egg pockets would likely have been superimposed multiple times. When considering measuring egg burial depth for species that spawn at high densities, the timing of the measurements should be considered. Measurements made before peak abundance occurs might yield more consistent results.

Appendix D: Bull trout redd measurements

TABLE D.1 Physical measurements and degree of kokanee disturbance of all bull trout redds found in Heising Spring, Metolius River, 2005.

Redd #	**Length (m)**	**Width (m)**	**Surface Area (m^2)**	**Surround depth (m)**	**Pot Depth (m)**	**Tailspill Height (m)**	**Flow ($m \cdot s^{-1}$)**	**Degree Disturbed**
1	1.60	1.70	2.14	0.19	0.12	0.03	0.55	0
2	3.20	1.60	4.02	0.24	0.17	0.06	0.59	0
3	2.80	2.10	4.62	0.22	0.13	0.01	0.34	1
4	2.25	1.30	2.30	0.26	0.15	0.06	0.62	0
5	2.40	1.20	2.26	0.18	0.10	0.03	0.62	0
6	1.80	1.45	2.05	0.17	0.15	0.02	0.62	0
7	2.70	1.58	3.34	0.25	0.10	0.08	0.34	1
8	2.90	1.35	3.07	0.26	0.07	0.07	0.65	0
9	2.80	1.85	4.07	0.23	0.12	0.05	0.38	1
10	1.55	1.05	1.28	0.23	0.10	0.07	0.35	3
11	3.60	1.25	3.53	0.25	0.09	0.13	0.52	3
12	3.40	2.80	7.48	0.35	0.17	0.01	0.18	3
13	2.80	1.85	4.07	0.31	0.14	0.13	0.72	0
14	2.20	1.10	1.90	0.22	0.12	0.10	0.39	1
15	2.25	1.25	2.21	0.23	0.13	0.12	0.41	1
16	2.60	2.20	4.49	-	-	-	-	1
17	2.70	1.60	3.39	0.32	0.13	0.12	0.72	0
18	1.95	0.95	1.45	0.26	0.05	0.05	0.55	0
19	2.95	1.50	3.48	0.25	0.09	0.06	0.42	1
20	1.70	1.20	1.60	0.20	0.17	0.04	0.73	0
21	1.65	1.10	1.43	0.22	0.07	0.08	0.46	1
22	2.65	1.63	3.38	0.32	0.02	0.15	0.48	1
23	2.45	1.75	3.37	0.23	0.21	0.00	0.64	0
24	-	-	-	-	-	-	-	0
25	1.85	1.25	1.82	0.25	0.10	0.00	-	1
26	2.20	1.25	2.16	0.25	0.09	0.11	0.57	0
27	1.70	1.00	1.34	-	-	-	-	1
28	1.45	0.80	0.91	0.23	0.06	0.06	-	1
29	2.40	1.65	3.11	0.24	0.05	0.12	0.31	3
30	-	-	-	0.34	0.19	-	-	1
31	2.60	1.45	2.96	0.24	0.08	0.02	0.51	1
32	2.55	1.75	3.50	0.26	0.13	0.06	0.55	0
33	1.60	0.60	0.75	-	-	-	-	0
34	2.35	1.55	2.86	0.27	0.14	0.06	0.43	0
35	2.10	1.30	2.14	0.22	0.22	0.03	0.55	0
36	2.50	1.35	2.65	0.15	0.10	0.00	0.45	3
37	2.35	1.15	2.12	0.24	0.08	0.08	0.23	3

TABLE D.1 – Continued

Redd #	**Length (m)**	**Width (m)**	**Surface Area (m²)**	**Surround depth (m)**	**Pot Depth (m)**	**Tailspill Height (m)**	**Flow ($m \cdot s^{-1}$)**	**Degree Disturbed**
38	1.30	0.80	0.82	0.21	0.05	0.13	0.32	0
39	0.95	0.85	0.63	-	-	-	-	0
40	1.80	1.10	1.56	0.24	0.06	0.10	0.51	1
41	1.65	1.00	1.30	0.22	0.06	0.09	0.55	0
42	2.35	1.65	3.05	0.23	0.13	0.09	0.43	0
43	2.65	1.55	3.23	0.25	0.16	0.13	0.57	0
44	1.15	0.60	0.54	0.41	0.06	0.16	0.59	0
45	2.60	2.15	4.39	0.35	0.16	0.05	0.51	1
46	1.80	0.90	1.27	0.25	0.17	0.03	0.52	1
47	1.70	0.95	1.27	0.24	0.08	0.07	0.48	3
48	2.05	2.00	3.22	0.24	0.07	0.07	0.53	1
49	2.10	1.63	2.68	0.25	0.09	0.09	0.56	0
50	-	-	-	0.24	0.10	0.02	0.60	0
51	2.30	1.25	2.26	0.20	0.10	0.07	0.38	3
52	-	-	-	0.22	0.06	0.07	0.62	0
53	1.90	0.80	1.19	0.18	0.12	0.05	0.66	0
54	2.00	1.00	1.57	0.20	0.09	0.04	0.24	3
55	-	-	-	-	-	-	-	1
56	1.75	1.15	1.58	0.22	0.05	0.09	0.29	3
57	-	-	-	0.22	0.05	0.06	0.34	3
58	1.20	0.70	0.66	0.25	0.14	0.02	0.70	0
59	1.30	0.78	0.79	0.25	0.08	0.09	-	1
60	1.95	0.98	1.49	0.28	0.11	0.07	0.55	0
61	2.05	1.15	1.85	0.27	0.07	0.12	0.26	3
62	1.98	1.10	1.71	0.35	0.16	0.06	0.59	0
63	2.00	1.33	2.08	0.25	0.12	0.04	0.63	0
64	2.38	1.70	3.17	0.23	0.13	0.07	0.45	0

(-) indicates no measurement was obtained

TABLE D.2 Physical measurements of 26 bull trout redds evaluated for egg burial depth, Metolius River sub-basin, 2005–2006.

Redd	Location	Length (m)	Width (m)	Surface Area (m²)	Surround Depth (m)	Pot Depth (m)	Tailspill Height (m)	Flow ($m \cdot s^{-1}$)
1	Candle Crk	1.75	0.80	1.10	0.27	0.02	0.13	0.46
2	Candle Crk	1.50	0.75	0.90	0.24	0.06	0.14	0.23
3	Candle Crk	1.95	1.10	1.70	0.25	0.04	0.08	0.52
4	Candle Crk	2.80	1.40	3.10	0.34	0.12	0.16	0.42
5	Candle Crk	2.00	1.05	1.60	0.16	0.09	0.06	0.41
6	Candle Crk	2.90	1.20	2.70	0.31	0.11	0.13	0.48
7	Canyon Crk	2.40	1.03	1.90	0.25	0.15	0.04	0.34
8	Canyon Crk	2.70	1.25	2.70	0.31	0.12	0.11	0.38
9	Canyon Crk	2.60	1.20	2.50	0.32	0.07	0.08	0.62
10	Jefferson Crk	1.60	0.80	1.00	0.24	0.11	0.02	0.72
11	Jefferson Crk	2.80	1.33	2.90	0.34	0.10	0.12	0.51
12	Jefferson Crk	2.90	1.20	2.70	0.26	0.13	0.8	0.73
13	Jefferson Crk	2.30	1.05	1.90	0.29	0.06	0.11	0.53
14	Jefferson Crk	2.00	0.95	1.50	0.19	0.09	0.09	0.18
15	Jefferson Crk	1.70	0.90	1.20	0.13	0.08	0.01	0.51
16	Roaring Sp	3.00	1.10	2.60	0.35	0.07	0.15	0.59
17	Heising Sp	2.20	1.40	2.40	0.44	0.05	0.14	0.22
18	Heising Sp	2.70	1.60	3.40	0.24	0.10	0.03	0.42
19	Heising Sp	1.50	1.00	1.20	0.19	0.14	0.03	0.49
20	Heising Sp	2.00	1.50	2.40	0.25	0.08	0.08	0.46
21	Heising Sp	1.50	1.00	1.20	0.23	0.10	0.05	0.58
22	Heising Sp	2.00	1.50	2.40	0.29	0.12	0.07	0.36
23	Heising Sp	1.50	1.00	1.20	0.22	0.17	0.01	0.56
24	Heising Sp	2.50	1.20	2.40	0.31	0.11	0.04	0.57
25	Heising Sp	1.50	1.50	1.80	0.27	0.18	0.03	0.71
26	Heising Sp	2.00	1.50	2.40	0.32	0.12	0.06	0.49

Appendix E: Fry trapping - General findings

The following are observations and general findings noted during the emergence trapping period. In addition to the 14 bull trout redds trapped in Heising Spring, two other bull trout redds (RS1 and RS2) were trapped in Roaring Spring, Metolius River sub-basin, using the same methods described in Chapter Two.

Bull trout emerged from all sampled redds. A total of 26,355 bull trout fry were enumerated. The mean production per redd was 1,239 fry (SD = 729). The mean percent mortality per redd was 3.1 (SD = 4.2) and ranged from 0–15.7%. The majority of bull trout captured were fully formed (i.e. buttoned up) fry; only 5 alevins were observed. The numbers of fry captured per trap check ranged from 1–910, although greater than 2,000 individuals were captured in a single day over multiple checks of a single trap. A sub-sample (n = 120) of bull trout fry were retained from redd RS1 and measured for total length (± 0.5 mm). Fry ranged in size from 25–35 mm and averaged 27.5 mm (SD = 1.4).

A total of 710 kokanee fry were captured from four of the superimposed redds in Heising Spring. No kokanee were captured from any of the undisturbed redds. The number of kokanee captured per trap ranged from 34–511 individuals, of which 92 % were fully formed fry. For those redds in which kokanee did emerge, the number of days between first bull trout and kokanee emergence ranged from 28–66 days.

In Roaring Spring, 9,015 bull trout fry were captured from the two traps set there. Trap RS2 was removed before the emergence period concluded due to consistently high trap induced mortality. A total of 2,667 fry were captured over five trap checks before it was removed. Thirty-nine percent of the fry caught were deceased, most likely due to turbulent flows impinging fry against the live-well screens. A total of 6,348 fry were captured from redd RS1. Unlike the redds sampled in Heising Spring, both redds sampled in Roaring Spring were not observed on a daily basis and therefore could have been reused by multiple spawning pairs. When both redds were first encountered, multiple spawners were observed in the immediate vicinities. A high rate of bull trout redd reuse was observed over the last three spawning seasons in Heising and Roaring Springs, both within and between years. The progeny of multiple females may account for the unexpectedly high number of fry that were captured from both redds in Roaring Spring.

As identified by catch distributions, the most common pattern of bull trout emergence was skewed to the left (Figure E.1). Peak emergence was often reached within the first few days after emergence began and then tailed off over several weeks. Sparkman (2004) and Koski (1966) observed similar catch distributions while trapping emerging coho salmon. Fry were present during the first check in six of the traps sampled. However, in only one of those redds was a large number was captured. Twenty-seven percent of the fry trapped from redd HSU4 were captured during the first trap check. Less than 9 % of the total catch was captured during the first check in each of the other five redds. Small numbers of fry were still being captured (i.e. 1–2 fry/trap check) out of half of the Heising Spring traps and the Roaring Spring trap when trapping was terminated.

Reiser et al. (1998) found that emergent fry traps in streams may negatively impact fry emergence by reducing intra-gravel flow and allowing excessive silt and debris to settle on the redd. The portion of the apron buried at the upstream end of the traps used in this study likely reduces intra-gravel flow through the redd. It is possible that the act of setting the trap elicited a flight response, triggered by the water velocity reduction, causing fry to emerge prematurely. However, the mean number of temperature units across all trapped redds to time of first emergence, 821 CTU, was similar to what Gould (1987) found in lab experiments (820 CTU), suggesting that emergence timing was unaffected. The median number of temperature units (784 CTU) however was much lower, implying that the majority of fry emerged earlier than predicted. Bull trout fry emerged from 12 of the 16 traps before 820 CTU were reached, which indicates that fry traps must be placed as close to the predicted emergence time as possible to ensure maximum efficiency.

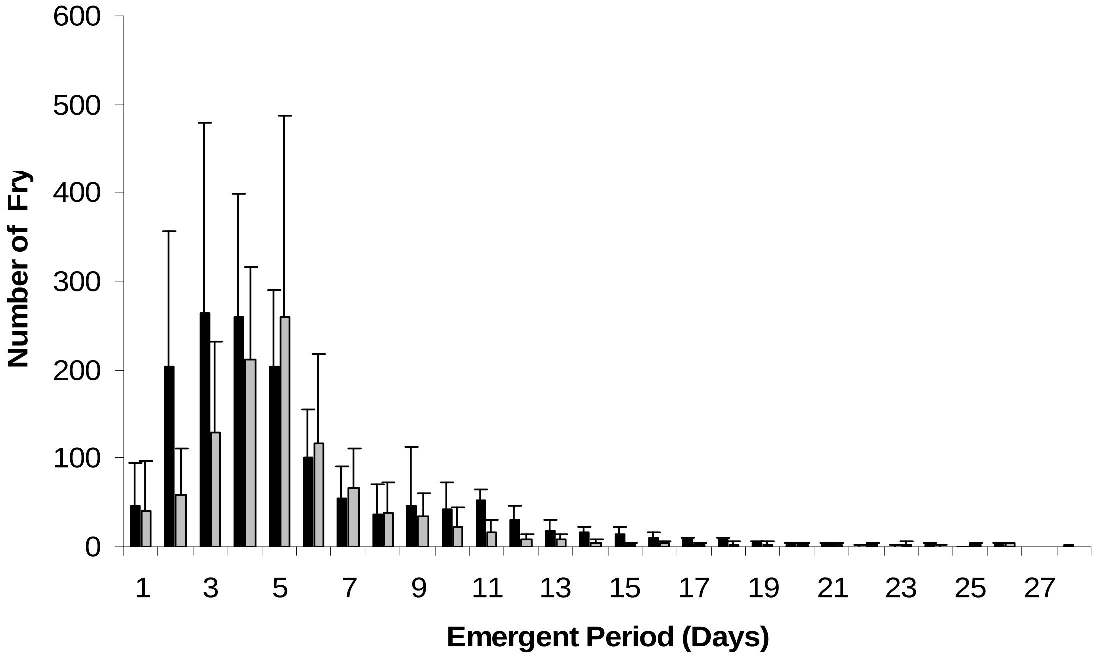

FIGURE E.1 Mean bull trout fry emergence distributions for superimposed (black bars) and undisturbed (grey bars) redds through the first 28 days of emergence. Error bars represent 95% upper confidence levels.

Appendix F: Substrate sampling data

To compare differences in spawning substrate composition between the Metolius River sub-basin and that in Trapper Creek, Odell Lake sub-basin, two sample techniques were used. The surface substrate composition at bull trout and kokanee spawning locations were evaluated using Wolman pebble counts (Wolman 1954). In addition, core samples were removed from bull trout redds in Trapper Creek using the same methodology described in Chapter Two for bull trout redds in Heising Spring. Presented here are the methods used to obtain pebble counts as well as the results of both the surface and core substate sampling. For a discussion of the differences in spawning substate composition between the two systems refer to Chapter Three.

The redd tailspill is composed of substrate extracted from the pot and is therefore a good representation of the type of coarse substrate a fish is capable of turning over (Kondolf and Li 1992). Pebble counts were completed on a random sub-sample of bull trout redd tailspills and on various kokanee scoured areas. Due to the high densities in which kokanee spawn, individual kokanee redds are rarely clearly defined so the counts were completed in areas scoured out by multiple fish.

A 1 m^2 grid made of 0.025 m polyvinyl chloride pipe (PVC) with wire stretched across the frame every 0.10 m was used. Once at a bull trout redd site the grid was secured over the tailspill on the stream bottom. The grid was positioned so that it encompassed the maximum amount of tailspill area. Kokanee scoured areas were located by walking upstream and observing locations where groups of kokanee were digging. Once an area was found the grid was tossed over the shoulder in the general direction of the scoured area, allowed to settle on the stream bottom, and then secured. Particles were removed from the center of each grid square until 100 particles had been collected. To reduce any size selectivity error, the particle collector looked away from the grid square once the center was located and removed the first particle that was touched by the fingertip. Using a substrate size template (FISP US SA-97), the size of each removed particle was sorted into a size class based on the modified Wentworth scale (Cummins 1962). The percentage composition of each particle size class was calculated for each pebble count. The number of pebble counts made on each species spawning sites was pooled to obtain an average composition, which was then used to compare between species and streams.

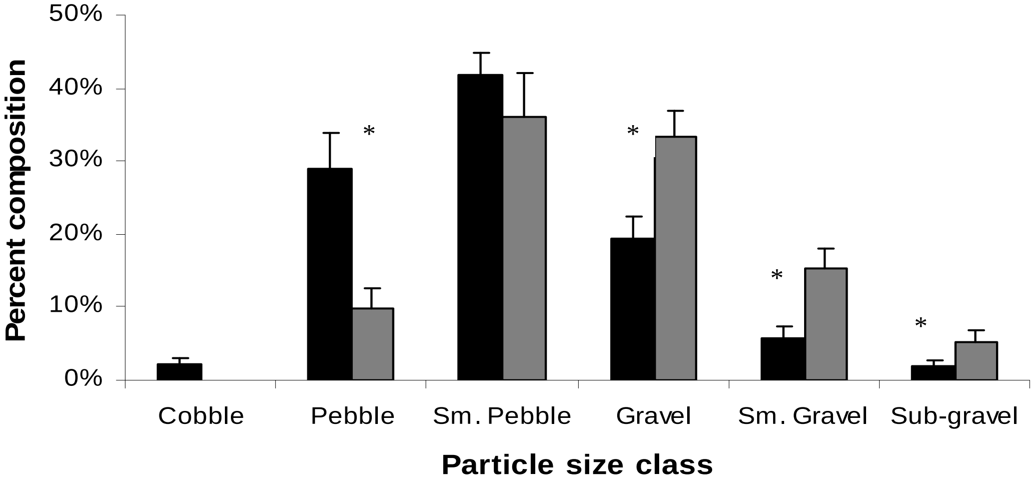

FIGURE F.1 Mean percent composition of surface substrates on bull trout redds (■) and kokanee (▨)spawning areas in Heising Spring, 2005. Error bars represent 95% upper confidence levels and asterisks show significant differences.

TABLE F.1 Mean percent composition of surface substrates on bull trout redds sampled in Heising Spring, four Metolius River tributaries, and Trapper Creek. Samples sizes are included in parentheses.

	Heising Spring (n = 19)	Metolius R. Tributaries (n = 8)	Trapper Creek (n = 7)
Boulder > 256 mm	0%	0%	1%
Cobble 64–256 mm	2%	11%	13%
Pebble 32–63 mm	29%	35%	26%
Small Pebble 16–31 mm	42%	35%	44%
Gravel 8–15 mm	19%	15%	12%
Small Gravel 4–7 mm	6%	3%	2%
Sub-gravel < 4 mm	2%	1%	1%

TABLE F.2 The geometric mean particle size (Dg) and cumulative percentage of fine sediment < 3.33 mm from redds sampled in Heising Spring (HS), Roaring Creek (RS), and Trapper Creek (TC), 2006. Redds in Heising Spring are separated by those redds left undisturbed (HSU) and those superimposed by kokanee (HSS).

Stream/ Redd No.	**Dg (mm)**	**% Fines <3.33 mm**
HSU1	10.93	18.37
HSU2	11.62	15.28
HSU3	11.27	17.24
HSU4	8.52	20.94
HSU5	9.40	21.96
HSU6	5.93	31.00
HSU7	13.44	16.90
HSS1	4.82	34.39
HSS2	12.04	17.26
HSS3	12.14	19.03
HSS4	7.80	24.09
HSS5	8.60	21.26
HSS6	6.97	24.71
HSS7	5.97	29.40
RS1	11.17	16.53
TC1	11.02	16.05
TC2	15.75	9.15
TC3	15.00	7.10
TC4	8.61	22.11
TC5	16.42	6.90