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Factors Affecting Spawning and Survival of Bear Lake Bonneville Cutthroat Trout in St. Charles Creek, Idaho

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FACTORS AFFECTING SPAWNING AND SURVIVAL OF BEAR LAKE BONNEVILLE CUTTHROAT TROUT IN ST. CHARLES CREEK, IDAHO

by

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ABSTRACT

Factors Affecting Spawning and Survival of Bear Lake Bonneville Cutthroat Trout in St. Charles Creek, Idaho

by

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I described the spawning ecology of the Bear Lake Bonneville cutthroat trout (BLBCT) in St. Charles Creek. I tracked cutthroat trout with used radio telemetry. I conducted redd counts to describe spawning conditions. Most cutthroat trout in the Big Arm strayed into the Bear River. Cutthroat trout migrations in the Little Arm and main fork were very limited (<4 km). Redd distributions showed very similar patterns between 1989, 2000 and 2001 with most redds being built in the lowest kilometer of stream. Artificial fish transportation changed the redd distribution in 2002. More redds were built in the main fork and redds were distributed throughout the stream. Redds built in the main fork were characterized by lower levels of fine sediment and higher water velocities as compared to the redds built on the Little Arm. The results of this research will be used to aid resource managers in developing a management plan for wild BLBCT.

(96 pages)

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CHAPTER 1

INTRODUCTION

Most native inland salmonids in the western United States have undergone precipitous population declines (Behnke 1992). Anthropogenic disturbances associated with land management have been the sources of many population declines (see Meehan 1991 for reviews). Increasing demand by humans for water and power has led to the proliferation of dams and diversions in streams, which have dewatered downstream reaches and physically isolated populations (Thurow et al. 1988; Rieman and McIntyre 1993). Introductions of nonnative fish species have also been widespread throughout the West and have restricted the ranges of native salmonids through competition (Griffith 1988) and hybridization (Behnke 1992).

The distribution of salmonid populations was historically determined by a mosaic of habitat patches of different sizes and quality, shaped by the geologic setting, climate and hydrographic development of the streams (Poff and Ward 1989; Dunham and Rieman 1999). Species stability and persistence was maintained by diverse life history strategies (Rieman and McIntyre 1993). Human impacts on streams have altered the physical processes that shape fish populations, often in a synergistic manner, making it difficult to identify specific factors causing salmonid population declines. Efforts to correct anthropogenic disturbances have exhibited mixed results (Reeves et al. 1991). A recovery effort may be unsuccessful if other sources of degradation are not accounted for. For example, providing fish passage at a dam would be ineffective if sublethal and lethal temperatures occur.

Connectivity and the Role of Migrations

Recent work on stream-dwelling salmonids has re-enforced the importance of connectivity among stream systems. The detailed population demographics, movement and long-term abundance data, which are the most useful for population viability analyses, remain scarce (but see Rieman and McIntyre 1993, 1995; Dunham et al. 1997). Rieman and McIntyre (1993) hypothesized that, in stable environments, migratory life-histories may be favored. Conversely, if a stream system is disturbed, decreasing migrant survival, the life history strategy of a population may shift towards resident life history forms. Life history shifts in populations may decrease the potential for large-scale movements, and reduce the recolonization potential of individuals into areas where subpopulations have been extirpated (Rieman and McIntyre 1993, 1995; Dunham 1996). For many species, specifically the cutthroat trout (*Oncorhynchus clarki*) and bull trout (*Salvelinus confluentus*), habitat fragmentation has reduced the probability of long-term persistence for several of the populations (Rieman and McIntyre 1995; Dunham et al. 1997). Additionally, there may not be adequate suitable habitat in the remaining isolated patches to sustain populations for long periods of time (Hilderbrand and Kershner 2000). For example, assuming that populations of bull trout remained isolated, Rieman and McIntyre (1993) estimated that few of the isolated populations would persist for longer than 100 years.

Spawning migrations are a key salmonid life history component. When favorable conditions persist, spawning migrations may increase the reproductive potential of a population. Migratory individuals have the ability to place eggs in suitable locations for incubation and emergence, which may also limit intercohort competition (Leggett 1977;

Moyle and Cech 1996). Spawning and rearing habitats frequently exist in discrete patches within streams (Geist and Dauble 1998) and fish may have to move moderate to long distances to reach them. Obligate migratory salmonids requiring non-substitutable, critical habitats, may be adversely affected if fragmentation results in a large amount of inaccessible habitats (Rieman and Dunham 2000).

A number of recent studies have reiterated the importance of maintaining the migratory life histories. For example, a number of authors have described long distance migrations to spawning grounds by inland salmonids (Clancy 1988; Fraley and Shepard 1989; Schill et al. 1994; Swanberg 1997). Colyer (2002) observed several fluvial Bonneville cutthroat trout (*O. c. utah*) in the Bear River, Idaho-Wyoming migrate within the mainstem and two tributary sub-basins.

Bonneville Cutthroat Trout

The Bonneville cutthroat trout (BCT) is the only trout native to the Bonneville Basin. Bonneville Basin encompasses most of Utah and portions of southeastern Idaho, eastern Nevada and southwestern Wyoming (Duff 1988). The BCT evolved primarily as a lacustrine species inhabiting Pleistocene Lake Bonneville. During that time, BCT also expanded its range into the Lake Bonneville tributaries (Behnke 1992; Duff 1988; Trotter 1987). After the desiccation of Lake Bonneville, populations of BCT became restricted to the tributaries where fluvial populations continued to flourish (Behnke 1992). Smaller lakes in the basin, including Bear Lake in Idaho-Utah, Panguitch Lake and Utah Lake in Utah and Lake Alice in Wyoming, contained the remaining relict adfluvial populations before European settlement (Duff 1996). As with most inland cutthroat subspecies, the

numbers and range of BCT have declined considerably from the formerly large and diverse populations that existed prior to European settlement in the West in the 1800's (Behnke 1992; Trotter 1987). In most systems, anthropogenic habitat degradation, and flow regime changes caused the decline of the subspecies. Nonnative species have also adversely impacted BCT by competition and hybridization. The migratory life histories have been heavily impacted and few migratory populations remain.

Presently, Bear Lake and Lake Alice maintain the only remaining native adfluvial BCT populations. The Bear Lake Bonneville cutthroat trout (BLBCT) is an isolated, adfluvial population. The BLBCT population has been severely impacted by anthropogenic disturbances to spawning and rearing grounds. Overfishing in the early 1900's caused the initial decline of the BLBCT population they were thought to be extinct in the 1950's (Clark 1954; McConnell et al. 1957). A small number of BLBCT were found in Bear Lake in the 1960's. The source of fish is unknown, but it is possible that some individuals of the stream-resident form present in the tributaries may have migrated to the lake. Because of the poor spawning and rearing habitat conditions, the BLBCT population has been almost entirely sustained by hatchery production since 1975. Annual inputs of juvenile hatchery cutthroat trout currently range from 100,000 to 500,000 (Nielson and Tolentino 1996), but in the past have exceeded 1 million (Nielson 1986).

The heavy utilization of hatcheries to maintain the population may have reduced the BLBCT wild type. Because straying rates are high for hatchery fish (Stabell 1984), interbreeding between the hatchery and wild fish has probably occurred. Biologists are uncertain of the degree, if any, to which this has impacted the wild stock in Bear Lake or

if hatchery and wild BLBCT are reproductively isolated by differences in spawning patterns. Fleming and Gross (1993) showed a strong reproductive disadvantage for hatchery fish compared to wild fish, suggesting that the use of hatchery fish alone to recover a population may not be an adequate long-term solution for population recovery.

Irrigation diversions have long been implicated in the decline of native cutthroat trout (Clancy 1988; Dwyer and Rosenlund 1988; Gerstung 1988; Nielson and Lentsch 1988). Hazzard (1935) stated that stream flows reduced by irrigation in Bear Lake tributaries were insufficient to support spawning salmonids. In the Yellowstone River, dewatering by irrigation diversions has made many tributaries unavailable to Yellowstone cutthroat spawners (Clancy 1988). Water development has also negatively impacted migratory populations of cutthroat trout in the Snake River by physically blocking migrations, dewatering the streams and reducing water quality (Thurow et al. 1988).

Study Goals and Objectives

This study seeks to add to the knowledge of migratory BCT populations by investigating the movement patterns and resultant spawning site selection of the adfluvial Bear Lake population. In Chapter 2, I describe the spawning migrations of three groups of fish and identify the factors that limit spawning in St. Charles Creek, Idaho. Chapter 3 focuses primarily on redd site selection and the microhabitat conditions of redds within different stream segments. Finally, Chapter 4 provides a brief synopsis of the significant findings of this study and discusses the management implications.

Justification for Research

This study was initiated by IDFG because hatchery production is not considered a long-term solution to the decline of wild BLBCT. In order to provide an adequate management plan, it is important to understand the limiting factors of natural production for wild BLBCT. St. Charles Creek is the primary historical spawning tributary for BLBCT. Spawner trap data have documented few wild cutthroat trout returning to St. Charles Creek to spawn in recent years. Jacobson (1989, *unpublished data*) showed that spawning fish in St. Charles Creek typically spawn in the lowest kilometer of stream. The lowest stream reach is presently suspected to be unsuitable for egg incubation and juvenile trout because of its warm temperatures, high sedimentation rates and insufficient flow during most of the summer. The data collected in this study will provide IDFG with a record of BLBCT spawner movement and redd site selection, information useful for the development of a watershed management plan for the St. Charles Creek watershed. Hopefully, the plan will include cooperation with local landowners and the irrigation company to enhance natural production of BLBCT by increasing irrigation efficiency, which will increase flows in the stream.

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CHAPTER 2

SPAWNING MIGRATIONS AND SURVIVAL OF AN ADFLUVIAL POPULATION OF BONNEVILLE CUTTHROAT TROUT

Abstract.-Cutthroat trout populations across the western United States have become increasingly fragmented by anthropogenic disturbances. This is true for the Bear Lake Bonneville cutthroat trout, which has undergone a substantial population decline. The objectives of this study were to investigate the factors that limit the spawning migrations and survival of this population. A total of 65 fish were tagged during 2001 and 2002 and released into three separate locations within St. Charles Creek. Fifteen fish were released into the Big Arm in 2001. Sixteen fish in 2001 and 10 fish in 2002 were released into the Little Arm. Twenty-four fish were released into the main fork at the Forest Boundary during 2002. A majority of fish released in the Big Arm strayed into the Bear River system, and only two fish were observed spawning. Fish released in the Little Arm spawned primarily in the lowest kilometer of stream, which was dewatered annually during this study. Fish released at the Forest Boundary showed the highest spawning success rate, but their downstream migration was blocked by the lowest diversion structure. As a result, fish began moving back upstream, and many became entrained into other diversion structures. The results of this study suggest that the current spawning migrations in the Little Arm provide little opportunity for natural recruitment, while fish spawning in the mainstem are probably subjected to entrainment into irrigation diversions when returning to Bear Lake.

Introduction

Spawning migrations are essential life history components for salmonid populations. Although spawning migrations vary considerably, connectivity among critical habitats is always important. Inland salmonid populations historically expressed multiple life history strategies simultaneously (i.e. resident, fluvial, and adfluvial). Species with interconnected populations were able to spread the extinction risk over large spatial areas. Population connectivity provides the means for refounding populations or individuals that may have been extirpated (Rieman and McIntyre 1993). Movements among populations are generally associated with the migratory life histories (i.e. adfluvial or fluvial), which are consequently responsible for gene flow among populations (Clobert et al. 2001).

Anthropogenic disturbances in streams have increased sedimentation rates and water temperatures (see Meehan 1991 for reviews), while irrigation and hydropower dams have physically isolated contiguous stream segments and blocked migration corridors (Rieman and McIntyre 1993; Colyer 2002). Habitat fragmentation has relegated most western native salmonid populations to headwater tributaries in isolated patches (Hilderbrand and Kershner 2000; Rieman and McIntyre 1993). The isolated populations primarily express the stream-resident life history, and tend to be at high extinction risk because they tend to be small and cannot be refounded (Rieman and McIntyre 1993). Populations of redband trout (*Oncorhynchus mykiss*) (Thurow et al. 1997), bull trout (*Salvelinus confluentus*) (Rieman and McIntyre 1993; Rieman et al. 1997), and most subspecies of cutthroat trout (*O. clarki*) (Rieman et al. 1997; Dunham et al. 1997; Hilderbrand and Kershner 2000) have suffered from widespread fragmentation.

Habitat fragmentation has been identified as a key factor limiting the long-term viability of Lahontan (*O.c. henshawi*) (Dunham et al. 1997), Bonneville (*O.c. utah*), and Colorado River cutthroat trout (*O.c. pleurictus*) (Hilderbrand and Kershner 2000).

The importance of maintaining connectivity among critical habitat required by migratory populations that still exist has become increasingly clear. Recent studies of spawning inland salmonids have documented large-scale migrations (Clancy 1988; Fraley and Shepard 1989; Schill et al. 1994; Swanberg 1997; Colyer 2002). Colyer (2002) observed fluvial Bonneville cutthroat trout utilizing the mainstem of the Bear River, and two separate, but interconnected tributary sub-basins. These studies also suggest that the long-term persistence of salmonids may only be achieved by improving stream management to provide the potential for historically migratory populations to recover.

The Bonneville cutthroat trout (BCT) is the only trout native to the Bonneville Basin (Lentsch et al. 2000). Bonneville cutthroat trout historically displayed both resident and migratory life histories (Behnke 1992). Since European settlement in the 1800's, a number of factors have been responsible for considerable BCT population declines throughout its range (Trotter 1987; Lentsch et al. 2000). Kershner (1995) estimated that less than 5% of the historic available stream length was inhabited by BCT in 1995. Bonneville cutthroat trout were petitioned to be listed as threatened under the Endangered Species Act in 1998. Numerous, previously undocumented, genetically pure BCT populations have been found since 1995 (Lentsch et al. 2000) and because of an active Conservation Agreement among the involved states, the U.S. Fish and Wildlife Service recommended that listing BCT was not warranted in 2001.

An understanding of the factors that limit critical life stages is essential to the conservation or recovery of any species or population. I investigated the factors that influence spawning migrations of the Bear Lake Bonneville cutthroat trout, a unique population of large, long-lived cutthroat trout. The BLBCT is one of two remaining native adfluvial BCT populations (Behnke 1992). The spawning ecology of naturally reproducing BLBCT is not well understood (Nielson and Lentsch 1988). In order to ensure the long-term persistence of the population, it is necessary to describe the specific factors that adversely impact spawning. I investigated the spawning migrations, spawning site selection and the lakeward, downstream migrations of post-spawned fish. My specific objectives were to 1) describe BLBCT movement to spawning grounds, 2) document stream residence and spawning times, and 3) describe the post-spawning migrations, survival and return of adult BLBCT to Bear Lake. I compared BLBCT spawning migrations under normal conditions (spawning migrations observed in St. Charles Creek since at least 1989) to historic conditions (fish artificially transported upstream into historic spawning grounds).

Study Area

Bear Lake is a dimictic, oligotrophic natural lake bisected by the Idaho-Utah border (Figure 2.1). It is 32 km long and ranges from 6-13 km wide with a surface area of 282 km^2 at full pool. It has a mean depth of 28 m, a maximum depth of 63 m and a normal pool elevation of 1,805 m. Bear Lake drains a relatively small watershed of 530 km^2, and most of the tributaries are small first and second order streams. Bear Lake inflow was greatly augmented by the diversion of the Bear River into Bear Lake when a

series of canals was completed in 1917. This allowed Bear Lake to be used as a reservoir for irrigation and power production downstream in the lower Bear River. The water level now fluctuates 1.5 m/year as a result of the canal system (Birdsey 1989). For approximately 8,000 years prior to 1917, Bear Lake was probably ephemerally connected to the Bear River during wet years when Bear Lake would drain through a natural outlet at the north end of the lake (Williams et al. 1962).

Overfishing, which nearly extirpated the wild cutthroat trout population, was the initial primary factor leading to the population decline in the early 1900's (Kemmerer et al. 1924; Siler 1884). The population was thought to be extinct by the 1950's (Nielson and Lentsch 1988; Behnke 1992), but a few adfluvial fish were found in the lake during the mid-1960's. Biologists are still uncertain of the source of fish. Habitat degradation in the Bear Lake tributaries also contributed to the BLBCT decline and probably prevented the remaining fish from successfully spawning. The BLBCT population probably utilized most of the Bear Lake tributaries extensively for spawning because BLBCT require lotic habitat and the tributaries to Bear Lake are generally small, limiting habitat availability. Presently, only St. Charles Creek, Idaho, and Swan Creek, Utah, provide adequate stream flow to sustain consistent spawning runs.

Hatchery production, using the native Bear Lake brood stock, has been the primary source of BLBCT recruitment since 1968 (Nielson and Archer 1976, Nielson and Tolentino 2002). All hatchery fish stocked in the system as 1-year-olds since 1993 were fin-clipped and easily identifiable; however, fry stocked into the tributaries were not marked and were indistinguishable from wild trout. I identified all fin-clipped fish as hatchery fish, and fish without fin clips as wild. Additionally, a potentially significant

component of the "wild" fish may be progeny of successfully spawning hatchery fish. This portion of the population may represent a naturalized hatchery population that does not display true wild traits. The current population of wild cutthroat trout in Bear Lake is small (7-18% of the population) (Nielson and Tolentino 2002) and the total spawning population in St. Charles Creek rarely exceeds 500 individuals (Nielson and Tolentino 1996).

St. Charles Creek, a third-order tributary approximately 20 km long, is the largest natural tributary to Bear Lake, and flows into the north and northwest ends of the lake. The stream presents a management challenge because it diverges into two smaller streams approximately 4 km upstream of its terminus. The Big Arm flows through a section of Dingle Marsh and into the north end of Bear Lake. The Big Arm was disconnected from Bear Lake when the canal system was built, and was reconnected in 1995. From 1917-1995, any downstream migrating cutthroat trout that moved into the Big Arm were lost from Bear Lake because the Big Arm connection was severed. The Big Arm was reconnected to provide an additional migratory corridor to St. Charles Creek. The Little Arm is presently the primary route to cutthroat trout spawning grounds. During the 1970's and 1980's, the Little Arm was the site of a fish trap where Idaho Department of Fish and Game collected millions of eggs for hatchery production. Anecdotal accounts suggest that the mainstem (upstream of the divergence into the Big and Little Arms) probably supported an abundant adfluvial spawning population, but now adfluvial fish are rarely observed in the mainstem (Lee Jacobson *unpublished data*). Three diversions on the mainstem remove up to half of the steam flow during the summer and they have long been considered fish migration barriers (Figure 2.2).

Methods

Radio Telemetry

I used radio telemetry to track spawning BLBCT in 2001 and 2002. I assessed the movements of three groups of fish. Group 1 was allowed to migrate up the Big Arm in 2001. The migrations of the Big Arm fish allowed me to assess the effectiveness of the passage improvements and determine spawning locations. Group 2 was allowed to spawn under current habitat and water management conditions in the Little Arm in both 2001 and 2002. Group 3 was artificially transported upstream into historic spawning grounds in the mainstem at the U.S. Forest Service Boundary in 2002 (approximately 10 km upstream of the Little Arm mouth) (Figure 2.2).

All BLBCT were trapped at the mouths of the Little Arm and Big Arm during both years. I tagged and released BLBCT in the same streams as captured in 2001. I evenly distributed radio tags among hatchery (fin clipped) and wild (no fin clip), and male and female BLBCT (Table 2.1). In 2002, I tagged only females because they ultimately established redd locations. Fish were systematically placed into one of two groups: Little Arm (Group 2) and main fork (Group 3), depending on daily stream flow and fish numbers. Although randomly selecting BLBCT into groups would have been preferred, the daily fish numbers and stream discharge were unpredictable and necessitated a systematic approach. Fish selected for Group 2 were either passed immediately upstream of the fish trap on the Little Arm, exactly as 2001, or moved from the Big Arm. Individuals selected for Group 3 were transported upstream to the Forest Boundary from both the Little Arm and Big Arm traps. Recent redd counts in St. Charles

Creek suggest that few adfluvial BLBCT migrate to the Forest Boundary from the Little Arm (Lee Jacobson *unpublished data*). I hypothesized that spawning individuals released at the Forest Boundary would exhibit a similar migration pattern to the BLBCT released near the mouth of the stream (e.g. most fish spawning within the first kilometer upstream of the release point).

I implanted radio tags using surgical methods adapted from Shill et al. (1994) and Colyer (2002) in 2001. In 2002, I tagged all fish with esophageal tags. To reduce regurgitation rates with the esophageal tags I inserted all tags into 9.5 mm diameter latex tubing prior to implantation. Tags were then inserted through the mouth and into the stomach with rigid plastic tubing. All tags were equipped with a single battery and external antenna.

Tracking

I tracked fish every two days and recorded their locations and spawning sites using a handheld GPS unit (accuracy approximately = 10 m). When a fish was located, I attempted to make visual contact. This was usually possible because St. Charles Creek is a small stream and fish were conspicuous if they were sitting on or near a redd. If a fish was in deep, complex habitat, and visual contact was not possible, I estimated its location based on signal strength. When I encountered a fish, I determined whether or not the fish was actively spawning, and if the redd was completed. A completed redd was defined as a redd where a female had been observed actively digging with a paired male on or near the redd.

Redd Excavations

I excavated redds after emergence during the first week of August to assess the number of dead eggs remaining within the substrate. This method did not provide a quantitative measurement of egg-to-fry survival, but served as a qualitative index of survival. Numerous dead eggs within a redd provided evidence that mortality was high, whereas low numbers or an absence of dead eggs suggested that survival was high.

Statistical Analyses

I overlaid a stream layer digitized from Digital Orthophoto Quarter-Quads (1 pixel=1-meter) with GPS points of fish locations using the ArcView 3.2 GIS (Environmental Systems Research Institute, Inc.). I determined the distance of each point from the mouth of the Little Arm. I then calculated the total distance moved by each fish to spawning grounds. Spawning migrations were compared using release points as references. The mouth of the Little Arm was defined as the reference point for Little Arm fish and the release point at the Forest Boundary (Stream meter 9,805) was the reference point for the main fork fish. I created a GIS map of the most upstream movement exhibited by each group to view the spatial distribution of spawning sites. With the map information, I graphed the movements of individual fish from each release point to identify common patterns displayed by spawning BLBCT.

Sample size was constrained by fish availability and the distances moved were non-normally distributed, so movement was assessed with nonparametric methods. I performed a Kruskal-Wallis test on the most upstream movements of BLBCT from release points. I compared stream residence times for fish released in the Little Arm and fish released at the Forest Boundary with a 2-way ANOVA and time before spawning

with a t-test. I determined the number of completed redds for fish released in the Little Arm and at the Forest Boundary. I also estimated the survival rate of pre- and post-spawned BLBCT.

Results

I trapped 111 fish in 2001 and 84 fish in 2002, and tagged 66 fish (31 tags in 2001 and 34 tags in 2002). In 2001, I trapped and released 42 fish in the Big Arm and 15 fish were tagged with radio tags. In the Little Arm, I trapped 36 fish and tagged 16. One fish, initially tagged in the Little Arm, moved into the Big Arm through Bear Lake, for a total of 16 tagged fish in the Big Arm. In 2002, numbers of BLBCT captured in the Little Arm trap and released immediately upstream were low, compared to 2001, because of the low lake level and severe stream flow reductions caused by upstream water diversions. Due to the low catch rate in the Little Arm in 2002, I supplemented the spawning run in the Little Arm and the main fork with fish from the Big Arm. All fish were transported from both the Big and Little Arms to the Forest Boundary during severe flow reductions in the Little Arm. Nineteen of 36 fish trapped in the Little Arm in 2002 were passed directly upstream of the spawner trap while the remaining 17 fish were transported to the main fork (see Figure 2.2 for a schematic). Another 10 fish were transplanted into the Little Arm from the Big Arm in 2002 and released upstream of the spawner trap. Ten fish were tagged and released into the Little Arm in 2002 (Figure 2.2). I released 41 fish in the main fork in 2002 and tagged 24 of them. Seventeen fish were transported from the Little Arm and 24 fish from the Big Arm into the main fork (Table 2.1).

I began radio tracking in the Big Arm on 25 May 2001 but did not locate a fish until 29 May. By 24 June, all fish had either disappeared (i.e. repeated attempts to locate fish failed) or died. I began tracking fish on 24 May in the Little Arm, and completed tracking on 15 June due to high fish mortality and stream dewatering. In 2002, I began tracking on 20 May and completed tracking on 15 July for the entire stream.

Spawning Movements in the Big Arm

The Big Arm is braided and several channels are directly connected to Dingle Marsh and ultimately to the Bear Lake outlet canal and Bear River (Figure 2.3b). The braided channels influenced the spawning migrations of BLBCT released in the Big Arm. I observed 12 fish within the Bear Lake Outlet/Bear River system downstream from Bear Lake. Two fish were located in the Bear River near Alexander Reservoir, approximately 40 km downstream from Bear Lake (Figure 2.3a). All of the fish that moved into the Bear Lake Outlet and Bear River were considered losses from the Bear Lake system because a velocity barrier at the Paris Dike on the Bear Lake Outlet Canal prevents fish from moving back into Bear Lake. Only three of the 16 of the Big Arm fish successfully migrated up the Big Arm. Two of the three fish were observed spawning in Spring Creek (Figure 2.3a). The one remaining fish did not spawn and was blocked by the lowest diversion on the Big Arm, and then observed in the Bear Lake Outlet Canal days later. One of the two fish observed spawning in Spring Creek returned to Bear Lake, and the other moved into the Bear Lake Outlet Canal after spawning. Three fish were never located after being released.

Little Arm and Main Fork Spawning Movements

Spawning BLBCT showed similar migrations between 2001 and 2002 in both the Little Arm and main fork. Upstream migrations to spawning grounds were limited for spawning BLBCT. No fish moved farther than 4,000 m upstream of either the mouth of the Little Arm or the release point on the main fork. In both 2001 and 2002, 63% (10/16 in 2001 and 5/8 in 2002) of the tagged fish in the Little Arm spawned below the lowest diversion (<1 km upstream of the Little Arm mouth). Similarly, 71% (17/24) of the tagged fish released in the main fork spawned within the first kilometer of stream upstream of the release point.

I found no significant differences among the upstream spawning movement distances of any fish groups (Kruskal-Wallis; $X^2 = 0.769$; $p = 0.681$). In 2001, BLBCT in the Little Arm moved a mean distance of 985 m to redd sites and a median distance of 493 m (Figures 2.4 and 2.5). In 2002, although the mean movement distance increased to 1,556 m, the median movement distance decreased to 342 m (Figures 2.4 and 2.5). The mean spawning distance was strongly influenced by the relatively long migrations (over 3,000 m) of three individual fish and a small sample size. The maximum migration to spawning sites by radio tagged fish was similar between both years: Little Arm maximum movements were 3,309 m and 3,876 m in 2001 and 2002 respectively. Spawning migrations of fish transported into the main fork varied little from those of fish released in the Little Arm. BLBCT moved a mean distance of 879 m and a median distance of 699 m to their most upstream redd locations from the release point (Figures 2.4 and 2.5). The maximum upstream movement exhibited by spawning BLBCT in the main fork was 3,209 m.

Post-spawning Migrations of Transported Fish

The three mainstem diversions did not initially appear to adversely impact the downstream post-spawning migrations of main fork fish. Conversely, the lowest diversion on the Little Arm blocked the post-spawning migrations of these fish. In addition, the lowest diversion dewatered the redds built below it. The lowest irrigation diversion was installed on 10 June and operated until 20 June in 2002. The operation of the lowest diversion coincided with the post-spawning migrations of the main fork fish and they were unable to move below it. Fish either moved upstream into the mainstem or resided in the upstream diversion pool (Figure 2.5). At least five fish moved back upstream near the mainstem diversion headgates. Entrainment risk probably increased as runoff decreased (late June – early July), because a larger proportion of stream flow was diverted into the mainstem diversions. Fish began disappearing near the mainstem headgates as tracking progressed (i.e. I was unable to locate the fish in the stream with radio telemetry) and entrainment was likely (Figure 2.5). The radio telemetry equipment used in this study was not capable of tracking fish in the canals and fields (a two dimensional surface), therefore I was unable to provide direct evidence of entrainment. However, post-spawned adults have been frequently observed in fields and canals in past years (*personal observation*).

Stream Residency and Redd Viability

Fish released into the main fork in 2002 spent more time (26.2 ± 12.9 days) within the stream than fish released in the Little Arm during 2001 (11.6 ± 5.2 days) and 2002 (5.3 ± 8.8 days) (ANOVA; $p < 0.001$). Fish in the Little Arm were in the stream for 3.3 ± 1.2 days prior to spawning in 2002. Fish in the main fork spent somewhat more

time (4.9 ± 3.5 days) in the stream before spawning, however this difference was not significant (t-test; $t = -1.69$, $p = 0.104$) (Table 2.2).

Ten of the 16 radio-tagged Little Arm fish completed redds in 2001. The lowest diversion dewatered the stream causing eight of the ten redds to fail. Redd excavations revealed a large number of dead eggs to support this conclusion. Although six fish moved upstream of the lowest diversion on the Little Arm in 2001, only two of the six fish completed redds. The two completed redds built upstream of the lowest diversion likely had the highest probability of producing viable fry because a minimum flow was maintained throughout the spring and summer. In 2002, 6 of 10 radio tagged fish completed redds. Three fish successfully navigated to spawning grounds above the lowest diversion, and three fish did not. The three lower redds were subsequently dewatered. Redd excavations demonstrated that eggs probably suffered high mortality in 2002 below the lowest diversion. In the main fork, 20 of the 24 implanted fish completed redds. One tagged individual was paired up with a smaller rainbow trout, and rainbow trout were acting as satellite males at several other spawning sites. Due to more stable discharge and less fine sediment in the main fork than the Little Arm, incubation success was likely higher in the main fork (*see Chapter 3*).

Survival

Spawning survival was low for BLBCT. I released three fish from the Little Arm back into Bear Lake in 2001, and 12 of the 16 implanted fish (75%) were mortalities. Four of the six fish that migrated above the lowest diversion died after it was put in place, inundating their uncompleted redds with backwater from the diversion pool. The source of mortality was unclear. In 2002, at least two Little Arm fish returned to Bear Lake after

spawning, and one was still alive when I completed tracking in July. I verified three mortalities in 2002 and two other fish disappeared (50% total mortality). I was unable to collect any survival information on the two fish that regurgitated tags. Therefore these fish were not used to calculate survival (Table 2.3).

Survival was slightly higher for post-spawned main fork fish, than Little Arm fish. I released one fish back into Bear Lake and six fish were still alive when I completed tracking on 16 July (Survival rate of 30%). I verified six (25%) post-spawned mortalities in the main fork; two mortalities were due to poaching. Eight other fish disappeared between 13 June and 3 July near the three unscreened mainstem diversions (Figure 2.5).

Discussion

Adfluvial Bonneville cutthroat trout populations are rare, with only 2 native populations and one introduced adfluvial populations remaining. This is the first account of BLBCT spawning migrations within their native spawning streams. Knight (1997) described spawning migrations of first-generation BLBCT in Strawberry Reservoir, Utah (introduced in 1991), where spawning migration distances were similar to migration distances in St. Charles Creek. The spawning migrations of both the Little Arm and main fork fish were quite limited, and may indicate that BLBCT are spawning opportunistically at the first available spawning sites, a strategy that differs considerably from other cutthroat trout populations in the West. Cutthroat trout come from the same stock (Behnke 1992) so there may be life history commonalities between subspecies and populations.

The BLBCT population can be compared to the Yellowstone Lake population of Yellowstone cutthroat trout (YCT) because the two populations are similar, both ecologically and taxonomically. Gresswell et al. (1994) described a complex YCT life history organization in Yellowstone Lake. Cutthroat trout in Yellowstone Lake precisely home to tributaries, resulting in the reproductive isolation of most populations. Some tributaries have different spawner abundances, spawning run timing, sex ratios and mean lengths (Gresswell et al. 1994). Adfluvial BLBCT spawning locations were probably well distributed throughout the Bear Lake tributaries in the past. Diverse spawning patterns, similar to the Yellowstone Lake YCT (Gresswell et al. 1994) and other inland salmonid populations, were probably common (Rieman and McIntyre 1993; Swanberg 1997; Colyer 2002). The present BLBCT spawning migrations are limited and a majority of the spawning occurs in a short stream reach. Additionally, spawning hatchery fish overlap with spawning wild fish.

The diverse life histories in Yellowstone Lake are important in maintaining species biodiversity. The Yellowstone Lake population is capable of adapting to changing environments (Gresswell et al. 1994). Conversely, concentrated spawning sites increase the probability that stochastic events (i.e. stream dewatering) will eliminate year classes. For example, most of the 2001 year class in St. Charles Creek was lost because of stream dewatering. Although dewatering also occurred in 2002, incubating eggs and juveniles were more likely to survive because they were more widely distributed throughout the stream.

The spawning ecology of salmonids suggests that individuals will return to highly productive areas where a large number of the offspring reach sexual maturity (Stabell

1984). Conversely, unproductive areas have limited spawning fish returns. Quinn et al. (1999) found evidence for fine-scale homing in Coho salmon (*Oncorhynchus kisutch*) populations from two different systems. The results from Quinn et al. (1999) suggest that specific locations may provide suitable spawning and rearing conditions, and thus dense spawning. In St. Charles Creek, the habitat conditions in the most densely utilized stream reach were inadequate for successful incubation and emergence (Chapman 1988). The Little Arm is characterized by large amounts of fine sediment, warm incubation temperatures and fluctuating stream flow (*see Chapter 3*).

Irrigation Diversion Effects on Wild Fish

Throughout the past century, water development may have caused differentially high mortality to the more migratory BLBCT that moved higher in the watershed. Post-spawned adult and juvenile fish entrainment was probably the most likely cause of mortality. Many of the fish released at the Forest Boundary disappeared near the mainstem diversions or were last observed near the mainstem diversions when I completed tracking (Figure 2.5). The potential of entrainment into the unscreened irrigation diversions by post-spawned adults could significantly limit the incidence of repeat spawners in the mainstem. This may be quite important for BLBCT because they are a long lived, iteroparous population (Nielson and Lentsch 1988). Cutthroat trout in Bear Lake generally do not spawn until age 5 (approximately 450 mm in length). High spawning mortality would likely simplify the age structure of the spawning run and few large repeat spawners would occur. The results of this research also suggest that late-spawning fish were probably at higher risk to entrainment than early-spawning fish (mid-June). Post-spawned fish migrating early were not entrained into irrigation diversions,

but entrainment risk increased as a higher percentage of water was diverted later in the summer.

Der Hovanisian (1995) suggested that migratory juvenile fish may be the most susceptible to irrigation diversion entrainment. A significant portion of the juvenile migratory population being entrained would reduce the probability of spawning fish returns. Sampling in the irrigation diversions has confirmed a high density of juvenile cutthroat trout, brook trout (*Salvelinus fontinalis*) and mottled sculpin (*Cottus bairdi*) (*personal observation*).

Other factors may have influenced my observations of spawning site viability in St. Charles Creek. It is possible that the dry years coinciding with this and previous work (i.e. Jacobson *unpublished data*) have influenced our interpretations of redd failure in the Little Arm. Wild fish spawning in the Little Arm may have successfully reared in the Little Arm during wet years with higher snowmelt and runoff. The observations of spawning failure could be an artifact of the relatively dry years observed in 2001 and 2002.

Fish Migrations in the Big Arm

A potentially significant segment of the BLBCT spawning population was lost from the Bear Lake system through the Big Arm in 2001. The reconnection of the Big Arm provided fish with potential access to previously unavailable spawning and rearing grounds; however, water movement through the braided channels was the most likely pathway causing the individuals to stray. The management of the Bear Lake/Dingle Marsh system is such that the water elevation in Dingle Marsh is almost always higher than Bear Lake. As a result water tends to flow from Dingle Marsh (high elevation) back

into Bear Lake (low elevation) through side channels. The large flow contribution from Dingle Marsh caused Big Arm fish to stray away from intended spawning grounds.

An alternative hypothesis is that BLBCT are exhibiting natural movements that may have historically occurred. The historical movement of BCT between Bear Lake and the Bear River is undocumented, however, there is evidence of a natural outlet at the north end of the lake that existed before the canal system was constructed. Past studies have indicated that these two systems were probably connected during wet years (McConnell et al. 1957; Williams et al. 1962). Although fish movement between the Bear Lake and Bear River systems may have been important in the past, movements are now restricted. Fish presently can only move from Bear Lake to the Bear River, but a migration barrier prevents fish from moving back into the Bear Lake system.

The Role of Habitat Fragmentation

Rieman and McIntyre (1993) and Duff (1996) identified habitat fragmentation as a critical causative factor to bull trout and Bonneville cutthroat trout population declines. The current study presented an analysis at a smaller scale of a single stream instead of a large, complex river basin. The critical habitats in St. Charles Creek are highly fragmented and discontinuous, but it may depend on the water year. For example, all spawning habitat in St Charles Creek was unavailable to BLBCT after stream flow was terminated during the middle of the spawning runs in both 2001 and 2002. Water withdrawals during the middle of the spawning run dewatered the Little Arm near the mouth, and completely blocked fish access to spawning and rearing grounds in the mainstem. Downstream post-spawning migrations were also blocked by the lowest diversion, possibly limiting adult fish survival. Subsequently, repeat spawners would be

rare if spawning fish suffered high mortality. During good water years, there may be sufficient water throughout the spawning and rearing season to provide adequate spawning and rearing conditions for BLBCT.

Spawning migrations and redd site selection are legacies of previous and present habitat conditions at the stream scale (Pringle 1997; Fausch et al. 2002). This study demonstrated the potential of the upper St. Charles Creek segment to support spawning adfluvial BLBCT, but the mainstem spawning habitat was unutilized until fish were transported. The habitat presently utilized by spawning BLBCT is unsuitable for spawning and rearing because of fluctuating stream flow and high fine sediment. The lack of spawning fish in the mainstem of St. Charles Creek suggests that migratory individuals have probably been subjected to differentially high mortality. The results of this study should aid resource managers in establishing a watershed management plan for BLBCT in St. Charles Creek. As with many populations of inland cutthroat trout the presence of adequate migration corridors for spawning and juvenile cutthroat trout is necessary for population conservation.

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Table 2.1.- Summary of tagged fish released in St. Charles Creek. The release points for both the Big Arm and Little Arm were located approximately 100 m upstream of the mouths. The release point for the main fork was at stream meter 9805. Numbers in parentheses represent standard deviations.

			Sex		Origin		Trap	
Release Point	Total	Length (mm)	Females	Males	Hatchery	Wild	Big Arm	Little Arm
Big Arm 2001	16	541 (55)	9	7	12	4	15	1
Little Arm 2001	16	569 (57)	11	5	8	8	0	16
Little Arm 2002	10	515 (51)	10	0	4	6	4	6
Main Fork 2002	24	508 (59)	24	0	17	7	14	10

Table 2.2.- Stream residence time, spawning success and number of redds built by spawning females in the Little Arm and main fork. Numbers in parentheses represent standard deviations.

Location	Residence Time (Days)	Spawning Success (%)	Redds per Female
Little Arm 2001	12 (5)	67	--
Little Arm 2002	5 (9)	86	1 (0)
Main Fork 2002	26 (13)	88	1.4 (0.6)

Table 2.3.- The fates of all spawning BLBCT released in the Little Arm and main fork during 2001 and 2002. Lake is the number of fish returned to the lake after spawning. Alive is the number of fish still alive remaining in the stream at the conclusion of tracking. Mortality is the number of fish that died either before or after spawning. Missing and regurgitation were fish that disappeared or regurgitated their tags. Missing fish were considered mortalities in the Little Arm and Main Fork. I could not obtain survival information on fish that regurgitated tags.

				Mortality				
Location	N	Lake	Alive	Pre-spawn	Post-spawn	Missing	Regurgitation	Total Survival (%)
Little Arm 2001	16	4	0	4	8	0	--	25
Little Arm 2002	10	2	1	2	1	2	2	38
Main Fork 2002	24	1	6	1	7	8	1	30

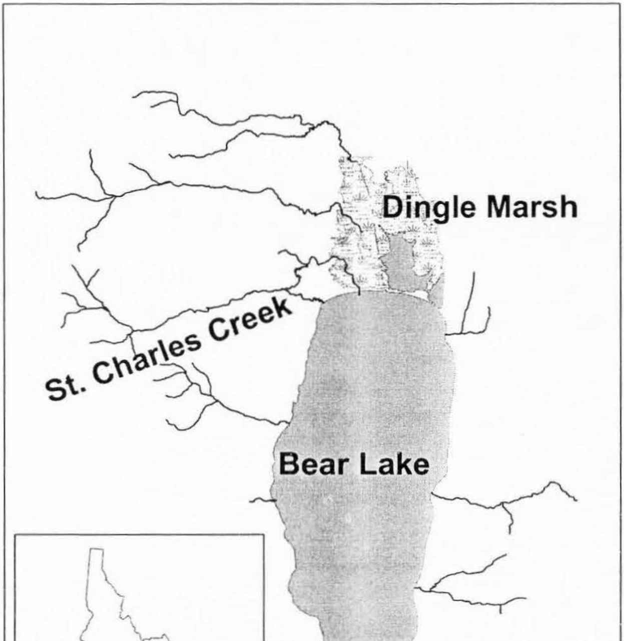

Figure 2.1.- A map of Bear Lake and its tributaries. St. Charles Creek flows into the North and Northwest ends of Bear Lake.

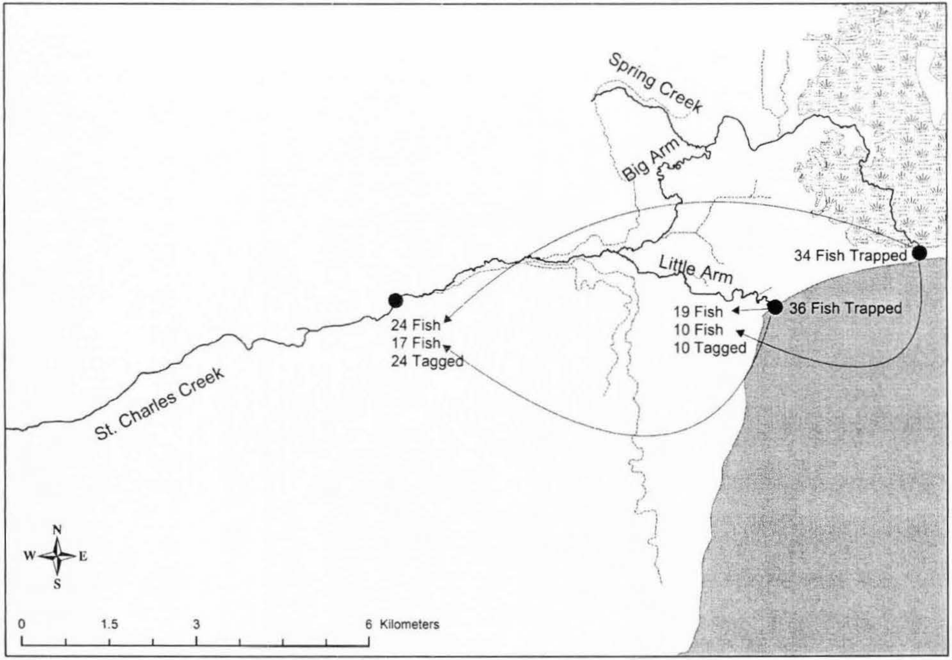

Figure 2.2.-Release locations of radiotagged fish in St. Charles Creek in 2001-2002. The arrows represent fish transported in 2002. Fish were released at the mouth of the Big Arm in 2001 only. Fish were released at the mouth of the Little Arm in 2001 and 2002, and fish were released on the mainstem at the Forest Boundary in 2002 only.

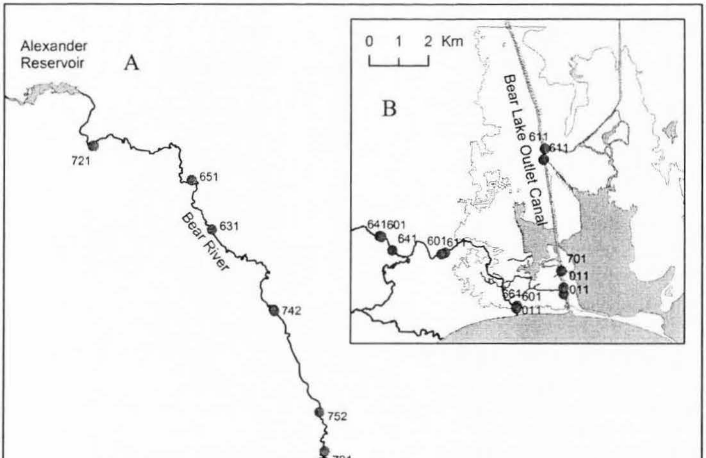

Figure 2.3.- Movements of BLBCT released in the Big Arm. The numbers associated with the points represent the tag frequency of each fish. For example 601 is the fish implanted with the tag with a frequency of 40.601MHz. The large map (A) details specific fish locations downstream of the Paris Dike in the Bear Lake Outlet Canal and Bear River. The inset (B) shows fish locations inside Dingle Marsh. Repeated numbers indicate multiple sitings of individuals on different dates.

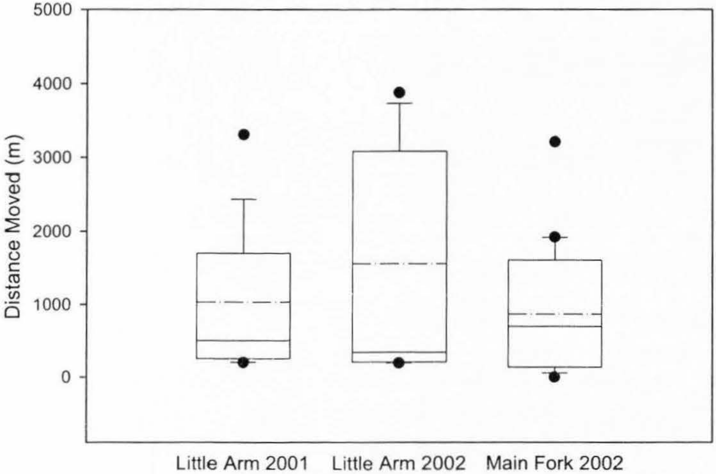

Figure 2.4.- The spawning locations of radiotagged BLBCT released in the Little Arm during 2001 and 2002 and in the Main Fork 2002. All distances represent the distance above the release points. For the Little Arm, 0 is the stream mouth, but for the main fork, 0 is the release point at stream meter 9805. The upper and lower bounds of the boxes represent the 25^{th} and 75^{th} percentiles respectively. The dashed line represents the mean and the solid middle line represents the median. The maximum movement by a radio tagged fish was 4000m in 2002.

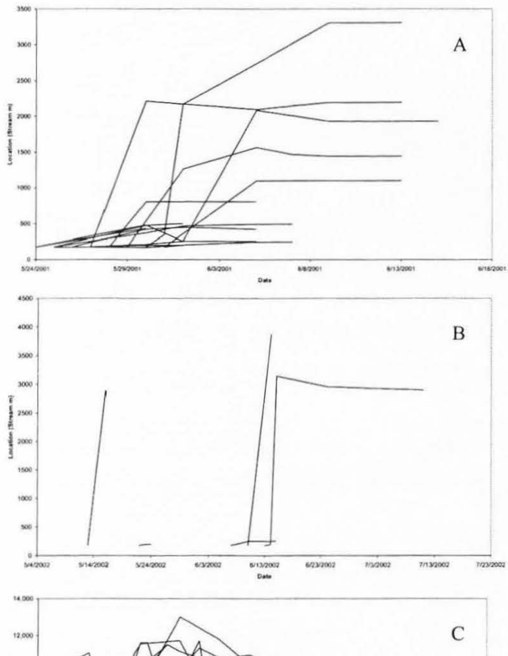

Figure 2.5.- Individual movements of spawning BLBCT in (A) the Little Arm 2001, (B) Little Arm 2002 and (C) the main fork 2002. The origin on the Y-axis represents the mouth of the Little Arm and all locations are measured relative to it. The release point on the main fork was at stream meter 9805.

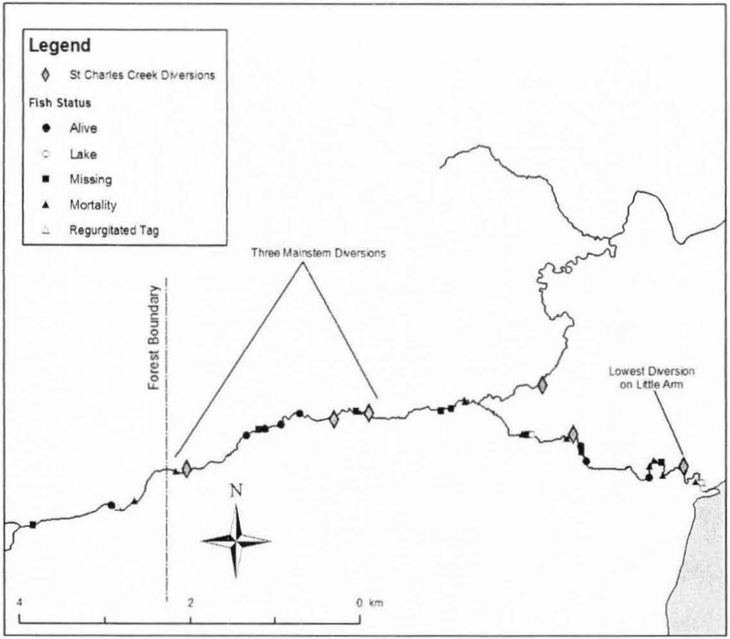

Figure 2.6.- The final locations of all radiotagged fish released in St. Charles Creek in 2002. Diamonds represent irrigation diversions.

CHAPTER 3

THE INFLUENCE OF REDD DISTRIBUTIONS AND SPAWNING HABITAT CHARACTERISTICS ON THE REPRODUCTIVE SUCCESS OF BEAR LAKE BONNEVILLE CUTTHROAT TROUT IN ST. CHARLES CREEK, IDAHO

Abstract.-Redd locations within a stream can greatly impact natural salmonid recruitment. The objectives of this study were to document the distributions and habitat characteristics of redds built by Bear Lake Bonneville cutthroat trout in St. Charles Creek, ID. Redd counts were conducted during the spawning seasons of 2000-2002. During the first two years, fish were allowed to choose spawning locations on their own. In 2002, spawning fish were transported to historic spawning grounds in the mainstem. During 2002, St. Charles Creek was divided into three separate segments in which redd microhabitat characteristics were described and the three segments were compared. Given a choice, fish spawned primarily in the lowest kilometer of the Little Arm, which was annually dewatered by upstream water use. Redds were distributed widely throughout St. Charles Creek in 2002 because fish were released at three different locations. Although the lowest kilometer of stream was dewatered, stream flow in redds built further upstream was much more stable. Redd depths were generally uniform throughout the stream. Water velocities were higher at the most upstream segment than the lowest stream segment. Less fine sediment occurred within redds built in the upper two segments. Although suitable spawning habitat is present within the mainstem of St. Charles Creek, that habitat was unused under normal conditions. The BLBCT population is at risk of experiencing complete cohort failures because a large proportion of fish use unsuitable habitat for spawning.

Introduction

An understanding of salmonid reproductive ecology is necessary to identify critical spawning areas, habitat limitations, population status, and long-term recruitment trends. Spawning site selection is a key feature of the salmonid reproductive ecology. The positioning of a redd along the longitudinal profile of a stream and within habitat units influences survival-to-emergence. Spawning site selection provides a key linkage between fish populations and the physical habitat that controls population sizes and consequently the number of reproductive adults in a cohort (Russ et al. 1996).

Redd counts provide indirect information on the spawning population size and spawning success during a given year. Conducting redd counts and assessing spawning habitat characteristics allows resource managers to increase the understanding of the multiple physical factors that control salmonid reproduction. The number of redds can be used to provide an index of the spawning population size and the relative year class strength (Beland 1996; Rieman and Myers 1996). For example, the number of Atlantic salmon (*Salmo salar*) redds counted in the Dennys River, Maine explained 47% of the variation in parr density two years later (Beland 1996). Rieman and Myers (1996) used long-term redd count data to estimate population trends of bull trout (*Salvelinus confluentus*) in Northern Idaho and Montana. In small populations, strong and weak year classes may be evident throughout future generations, resulting in a periodic pattern of abundance (Propst and Stefferud 1997; Edo et al. 2000).

Because salmonid eggs are buried within the gravel, incubation success is influenced by gravel stability, water temperature, dissolved oxygen exchange, fine sediment infiltration, and random disturbances such as other spawning fish or wading

animals (DeVries 1997). Anthropogenic disturbances have often degraded habitat conditions critical for successful egg incubation by altering the natural stream flow, sediment and temperature regimes, and by direct channel modification (Everest et al. 1987; see Meehan 1991 for comprehensive reviews).

I conducted redd surveys to develop an understanding of the present habitat use by spawning Bear Lake Bonneville cutthroat trout (*Oncorhynchus clarki*). The Bear Lake Bonneville cutthroat trout (BLBCT) is a unique population of large, long lived adfluvial Bonneville cutthroat trout. Much of the BLBCT spawning ecology is unknown with the exception of work done by Jacobson during 1989-1990 (*unpublished data*) in St. Charles Creek, and Knight (1997) in Strawberry Reservoir. Jacobson (*unpublished data*) found that BLBCT spawned primarily near the mouth of St. Charles Creek, and that irrigation water withdrawals dewatered many of the redds in that reach. Interestingly, Knight (1997) found a similar migration pattern of introduced, first generation adult BLBCT in Indian Creek, a low gradient tributary to Strawberry Reservoir, Utah. In 1989, redds in St. Charles Creek reportedly had levels of fine sediment that exceeded lethal levels for cutthroat trout survival-to-emergence in laboratory studies (Tappel and Bjornn 1983; Irving and Bjornn 1984).

Other lacustrine cutthroat trout populations exhibit complex life histories. For example, Gresswell et al. (1994) described a wide range of life-history variation among Yellowstone cutthroat trout (*O.c. bouveri*) in Yellowstone Lake. Individual populations are reproductively isolated by differences in run timing, body size, and migration direction (i.e. spawning in tributaries or the outlet). The Yellowstone Lake population is capable of adapting to environmental changes due to the life history diversity. An

important aspect of this study was to determine if cutthroat trout in Bear Lake exhibited similar life history diversity to Yellowstone Lake cutthroat trout.

The objectives of this research were to 1) describe redd distributions and characteristics within St. Charles Creek under current spawning conditions (2000 and 2001) and with fish transported into historic spawning grounds, upstream (2002), 2) identify physical habitat limitations within redds that may negatively impact egg-to-fry survival in St. Charles Creek and 3) compare the BLBCT redd habitat characteristics to published Suitability Index (SI) curves for cutthroat trout spawning and incubation.

Study Area

Bear Lake is a dimictic, oligotrophic natural lake bisected by the Idaho-Utah border (Figure 3.1). Bear Lake is 32 km long and ranges from 6-13 km wide with a surface area of 282 km^2 at full pool. Bear Lake drains a watershed area of 530 km^2, but its inflow was greatly augmented in 1917 by the diversion of the Bear River into Bear Lake. It has a mean depth of 28 m, a maximum depth of 63 m and a normal pool elevation of 1,805 m (Birdsey 1989). The lake was formed by a series of tectonic events caused by a tilted-fault block along the eastern shore during the Pleistocene. A fault zone at the north end of Bear Lake Valley periodically formed pediments on the Bear River that raised the valley threshold causing the lake level to fluctuate (Laabs and Kaufman 2003). The Bear River eroded through the pediments several times. The most recent erosional event isolated Bear Lake from the Bear River approximately 8,000 – 9,000 years ago (Birdsey 1989; Laabs and Kaufman 2003). During wet years, Bear Lake would

drain through a natural outlet at the north end of the lake, providing temporary connections between the two systems (Williams et al. 1962).

Cutthroat trout in Bear Lake have experienced long-term population decline and depression. The population declined precipitously beginning in the late 1800's from commercial fishing and habitat degradation in the spawning tributaries (McConnell et al. 1957). Commercial fishing was prohibited in Bear Lake in the 1930's; however, habitat conditions within the spawning tributaries are still impaired. Cutthroat trout production was supplemented with hatcheries using the native Bear Lake brood stock beginning in 1974 and is still the primary source of cutthroat trout recruitment in Bear Lake. Spawning fish were collected in 1974-1988 from the two main spawning tributaries (St. Charles Creek, Idaho and Swan Creek, Utah) and spawned as a conglomerate group.

Severe drought in the early 1990's, and increasing concerns about the status of the subspecies as a whole, prompted Idaho Department of Fish and Game and Utah Division of Wildlife Resources to shift the BLBCT management goals. The present goals are to increase BLBCT natural recruitment. St. Charles Creek, where most of the natural spawning and rearing habitat occurs, was to be managed for natural reproduction (Figure 3.1). Other Bear Lake tributaries lack either suitable habitat, stream length or stream flow to support consistent spawning runs. Swan Creek is the site of a trap where all BLBCT eggs are taken. Since 1993, all of the hatchery fish stocked as one-year-olds have been marked with fin clips for identification. The spawning habitat of hatchery-reared BLBCT presently overlaps with the habitat of wild fish.

The influences of hatchery fish on the wild population are unknown. However, hatchery fish comprise a majority of the population. Annual gillnet sampling from 1995-

1999 showed that 82-93% of netted fish displayed hatchery fin clips (Nielson and Tolentino 2002). The wild spawning population of BLBCT in St. Charles Creek remains quite low (37-52 individuals per year between 2000 and 2002), even after habitat improvements have been implemented throughout portions of St. Charles Creek. The low numbers of wild fish suggest that other factors may limit wild fish recruitment.

St. Charles Creek is a third order stream, 20 km long and is the largest natural Bear Lake tributary (Figure 3.2). Like most other streams in the western United States, St. Charles Creek is over-allocated with 3.1 m^3/s of water rights for irrigation, but only 0.93 m^3/s available during an average summer (Idaho Department of Water Resources Data). St. Charles Creek is a distinctive stream because, approximately 4 km upstream of its terminus, it diverges (streamflow splits) into two smaller streams. The Big Arm flows into the north end of Bear Lake and has historically been unutilized by spawning BLBCT because it was disconnected from Bear Lake when the canals were constructed in 1917. It was reconnected in 1995 but was not included in my analyses due its recent reconnection and historic disuse by BLBCT. The Little Arm, which flows into the northwest end of the Bear Lake, is the primary route to BLBCT spawning grounds. Anecdotal evidence suggests that extensive spawning historically occurred in the St. Charles Creek mainstem above the divergence into the Big and Little Arms. Presently, there is no spawning in the mainstem and BLBCT spawning occurs primarily near the mouth of the Little Arm (Lee Jacobson, *unpublished data*).

Methods

Redd Counts

I conducted annual redd counts during the spawning seasons of 2000-2002 by surveying the entire stream. I marked redds with a handheld GPS unit (±10m accuracy) during all three years and produced GIS maps detailing redd locations. In 2002, I categorized redds based on the stream segment where they were built: Little Arm (Segment 1, the most downstream segment), the Canyon Mouth (Segment 2, the middle segment), and Forest Boundary (Segment 3, the most upstream segment) (Table 3.1, Figure 3.2). Each segment was characterized by unique geomorphology, stream flow and temperature regimes. Segment delineations closely matched those defined by Jacobson (*unpublished data*).

Segment 1 was a low gradient, unconfined stream, meandering through the valley bottom with an average gradient <0.5% (Figure 3.2). Segment 1 was characterized by abundant pools (32% area) and non-turbulent fast water habitats (30% area) while the remaining habitat (38% area) was turbulent fast water (Lee Jacobson, *unpublished data*) (Table 3.1). Irrigation withdrawals during all three summers reduced stream flow in Segment 1. Under normal spawning conditions, Segment 1 was heavily used by spawning BLBCT.

Segment 2 began upstream of the divergence of the mainstem into the Big and Little Arms and ended at National Forest boundary (Figure 3.2). Segment 2 had minimally confined valley walls with a mean gradient of 1% and was characterized by a large percentage of both turbulent and non-turbulent fast water habitats (81% area). Stream flow was higher in Segment 2 because it is above the divergence (St. Charles

Creek has not split into 2 smaller streams), but three large irrigation diversions within this segment remove over half of the stream flow during the summer months.

Segment 3 was upstream of all irrigation diversions and flowed through a moderately confined valley with a gradient <2% (Figure 3.2). This segment was composed primarily of turbulent fast water habitats (74% area) but also had some non-turbulent fast water habitat (19%) and few pools (6%) (Table 3.1).

Groups of fish were allowed to spawn in the three different areas of St. Charles Creek. The redds in Segment 1 were built by 29 fish (Table 3.2) released directly upstream of the IDFG Little Arm spawner trap. Four additional redds were built downstream of the trap and were included in segment 1. The redds in segment 2 were built by 30 fish (Table 3.2) transplanted by IDFG from Swan Creek, Utah. The redds in segment 3 were built by 41 fish (Table 3.2) transplanted from the mouths of both the Big Arm and the Little Arm to the release point directly upstream of the U.S. Forest Service boundary (Stream meter 9,805).

Redd Characteristics

I quantified the spawning habitat in each of the three segments separately in 2002. I measured microhabitat characteristics at each redd within 5 days of redd completion. I defined a redd as "complete" if no fish were observed on it for three days. I measured redd length, width and water depth. Redd length was defined as the longest line of disturbed gravel parallel to the water flow. Redd width was calculated by averaging three width measurements over the redd at ¼, ½, and ¾ the length of the redd. I calculated redd area by multiplying the redd length by the mean redd width. Pit and tailspill depths corresponded with the deepest locations at each position. Mean water column velocity

(0.6 depth) was measured at both the pit and tailspill crest using a Marsh-McBirney Flowmate 2000. The macrohabitats containing redds were characterized into five qualitative types: main channel pool tailouts (riffle crests), main channel margins (<0.5 m from the bank), main channel riffles, side channel pool tailouts and side channel riffles (Lee Jacobson, *unpublished data*).

I assessed redd substrate composition using digital photography and subsampled gravel with pebble counts. Six photographs of the substrate were taken at different locations on each redd through a Plexiglas box placed on the water. I moved upstream in a zigzag pattern from the most downstream edge of the pit to the crest of the tailspill taking pictures at roughly identical locations on each redd. Each photograph contained a 54 mm metal rod, which was used for scale in each photograph.

Using ArcView 3.2 GIS (Environmental Systems Research Institute) I placed fifty random points on each photograph and measured the intermediate axis of the corresponding sediment particle. Particles selected for measurement were sampled with replacement. This pebble count method reduced the bias attributed to random manual pebble counts (Marcus et al. 1995; Kondolf 1997). In manual pebble counts, the observer walks across a stream, sampling particles at each step. Manual pebble counts underestimate fine particles because they are often undetected by the observer. I calculated median gravel size (d50), geometric mean gravel size (dg), percent fines less than 1 mm and percent fines less than 10 mm. The median and geometric mean are standard expressions of the central tendency of gravel size. Particles with a diameter less than 1 mm have been reported to reduce the incubation survival of salmonid eggs. Particles less than 10 mm diameter have been reported to limit salmonid emergence

survival (Tappel and Bjornn 1983; Irving and Bjornn 1984; Chapman 1988; Kondolf 2000).

Data Analyses

I plotted the number of redds found in each stream kilometer to assess the distribution of redds. I summarized redd characteristics and compared my redd habitat characteristic measurements to Suitability Index (SI) curves generated for spawning cutthroat trout (Hickman and Raleigh 1982). Cutthroat trout (SI) curves were produced from literature reviews describing the habitat requirements and preferences of cutthroat trout (Hickman and Raleigh 1982). Hickman and Raleigh (1982) indexed habitat suitability between 0 (unsuitable habitat) and 1 (optimal habitat). The values do not reflect probability of use. Suitability Index curves for gravel were not well defined by Hickman and Raleigh (1982); therefore, I used cutthroat trout survival curves estimated by Tappel and Bjornn (1983) and Irving and Bjornn (1984) as surrogates for SI curves. For example, if survival was estimated to be 0.36 by the Irving and Bjornn (1984) equation, then the suitability would be 0.36. Using the SI curves, I assessed four different variables hypothesized to impact survival-to-emergence in stream spawning salmonids: Average maximum temperature, water velocity over the pit, and gravel characteristics (2 values).

Results

I counted 178 redds in three years. Redd totals were 51, 77, and 50 for 2000, 2001, and 2002, respectively. The redd distributions within St. Charles Creek were strikingly similar between 1989 (Lee Jacobson *unpublished data*), 2000 and 2001 (Figure

3.3). A majority of the redds were found in the first kilometer of the Little Arm (45-68%), but it was subjected to multiple dewatering events during the spawning and incubation periods during all three years of this study and 1989. Consequently, water temperatures fluctuated widely and reached sub-lethal and lethal levels (Schrank et al. 2003; Johnstone and Rahel 2003) on a number of occasions (Figure 3.4).

Redd Distributions and Habitat Use

In 2000 and 2001, 91% and 94% of the redds respectively were built in the Little Arm (Segment 1). The remaining redds during each year were built within the first two kilometers upstream of the divergence (Segment 2). No fish spawned above the Forest Boundary (Segment 3) in 2000 or 2001.

Artificial transportation of spawning BLBCT into the upper segments (2 and 3) shifted the redd distribution considerably in 2002 (Figure 3.3). Only 14% of the redds (compared to 91% and 94% during the previous two years) were located in the Little Arm in 2002. The main fork above the three mainstem diversions supported 78% of the redds in 2002 compared to an average of 12.3% for the previous years.

In addition to changes in the large scale spawning distribution, the BLBCT also used habitats differently among the three segments. In the lower segments (Segments 1 and 2), BLBCT spawned predominately in main channel pool tailouts. However in Segment 3, over half of the fish spawned in main channel margins and another 35% spawned in side channels (Figure 3.7).

Microhabitat Characteristics

Microhabitat characteristics were generally similar between the lower two

segments (1 and 2), but were different in Segment 3 (Table 3.3). Mean redd area was similar between Segment 1 (1.35 ± 0.62 m^2) and Segment 2 (1.52 ± 0.76 m^2), but was only half that size in Segment 3 (0.79 ± 0.28 m^2) (Table 3.3). Mean water velocity at the pit was also higher in Segment 3 (49 ± 16 cm/s) than the lower segments (Segment 1 = 39 ± 14 cm/s, Segment 2 = 41 ± 16 cm/s) (Table 3.3). Tailspill velocity was higher than pit velocity at all segments (Segment 1 = 52 ± 16 cm/s, Segment 2 = 57 ± 25 cm/s and Segment 3=60 ± 14 cm/s). Mean pit depth was consistent between stream segments, ranging from 30 ± 7 cm in Segment 2, 32 ± 6 in Segment 1 and 33 ± 6 cm in Segment 3 (Table 3.3). Tailspill depth showed an increasing trend from downstream (Segment 1 = 15 ± 5 cm) to upstream segments (Segment 2 = 18 ± 7cm, Segment 3 = 24 ± 8 cm) (Table 3.3).

I observed differences among the gravel characteristics of the three stream segments. The mean d50 and dg were smallest in Segment 1 (d50 = 10.9 ± 4.2 mm, dg = 8.2 ± 3.2 mm). Segment 2 had the largest d50 (21.5 ± 7.8 mm) and dg (16.7 ± 9 mm), nearly twice the values for each variable in Segment 1 (Figure 3.8; Table 3.3). The redds built in Segment 1 had the highest percentage of fine sediment in both the 1 mm (9.3 ± 6.0 %) and 10 mm (50.6 ± 14.7 %) categories. Redds built further upstream in St. Charles Creek had lower fine sediment. On average, redds in Segment 2 had the lowest percentage of fine sediment in the stream (percent fines < 1 mm = 3.7 ± 3.3 %; percent fines < 10 mm = 28.9 ± 10.8 %).

Temperature was generally higher downstream during the incubation period. Maximum summer temperatures in the Little Arm redds averaged 20.55 ± 2.61° C

(Figure 3.4). Average maximum summer temperatures were 14.81 ± 0.00° C in segment 2 (Figure 3.5) and 13.81 ± 0.40° C in segment 3 (Figure 3.6).

Application of Suitability Index Curves

In general, suitability index values for redds built in the Segment 1 (Little Arm) were lower than other segments (Table 3.4). Suitability values for velocity were high throughout the stream (Segment 1 = 0.85 ± 0.19; Segment 2 = 0.84 ± 0.16; Segment 3 = 0.90 ± 0.12). The Irving and Bjornn (1984) survival curve resulted in high suitability values (high predicted incubation survival) throughout St. Charles Creek with an average predicted survival rate over 0.98. In contrast, the Tappel and Bjornn (1983) survival curve using percent fines < 6.35 mm as the only independent variable, suggested gravel suitability in Segment 1 (0.31 ± 0.18) was much lower than Segments 2 and 3 (0.56 ± 0.22 and 0.43 ± 0.19, respectively). Suitability values for temperature were also low in Segment 1. With an average maximum temperature of 20.55° C, the mean suitability of redds in Segment 1 was 0.14 ± 0.20. Several redds built near the mouth had temperature SI values of 0. Temperature suitability values in Segments 2 and 3 were much higher (Segment 2 = 0.73 ± 0.00; Segment 2 = 0.82 ± 0.03, respectively).

Discussion

St. Charles Creek is a critical spawning and rearing tributary for BLBCT natural reproduction. The BLBCT population is one of only two remaining native adfluvial BCT populations. Therefore, our understanding of the anthropogenic impacts on stream function and spawning areas for BLBCT may be applied to other migratory BCT

populations. The habitat needs for BCT spawning in general are not well documented and are less well understood for migratory populations.

The BLBCT population spawned in marginal habitats in 2000 and 2001. Redds near the mouth of St. Charles Creek were dewatered during all three spawning seasons. Jacobson also described redd dewatering within the same reach in 1989. Silver et al. (1963) and Shumway et al. (1964) found that well-oxygenated water flowing over the egg pocket is critical for successful incubation. Even if dewatering did not kill the eggs, incubation under hypoxic conditions likely produced smaller juveniles that suffered high mortality. Smaller juvenile cutthroat trout would also be at a number of disadvantages, specifically to larger non-native brook trout of the same age (Griffith 1972).

The redd distributions in St Charles Creek show that a large number of individuals are spawning opportunistically (i.e. the first suitable site they can find). We observed clusters of spawning near the release points and few spawning individuals migrating further upstream (Figure 3.7). This may be a suitable spawning strategy during wetter years when stream flow is abundant. However, 10 out of the last 15 years have been drought years, suggesting that this spawning pattern is probably not sustainable for the long-term.

Aside from the artificially transported fish in 2002, the observation of spawning individuals within the upper segments of St. Charles Creek has been rare. Jacobson (*unpublished data*) noted a small number of redds built in the mainstem in 1989. Anecdotal reports from local landowners suggest that Segment 3 historically supported an abundant spawning population. Presently, BLBCT rarely spawn in Segment 3 and concentrate most of their spawning in the Little Arm near the mouth. Although this

pattern may produce viable offspring during wet years when stream flow is sufficient, dewatering usually occurs in both normal and dry water years. Placing redds over a small spatial area of the stream puts the population at high potential risk for cohort failures, which were observed in 2000 and 2001. This spawning pattern differs greatly from Yellowstone cutthroat trout in Yellowstone Lake. The Yellowstone Lake population exhibits diverse spawning migrations and run timing (Gresswell et al. 1994).

The BLBCT display an obligate migratory life history, meaning they require specific critical habitats that are nonsubstitutable (Rieman and Dunham 2000). The Bear Lake population requires suitable spawning and rearing habitat in Bear Lake tributaries. Because critical spawning and rearing habitats have been degraded and fragmented, recruitment and life history variation is low. Hatchery production has been the primary and necessary source of BLBCT recruitment since 1974 (Nielson and Archer 1976; Nielson and Tolentino 1996). Although hatcheries may increase overall fish numbers, they probably do not adequately improve the status of the population. For example Fleming and Gross (1993) found that individual hatchery coho salmon had lower reproductive success than wild individuals. In addition, hatchery fish raised outside of their native watershed lack natal sites and do not display homing behaviors (Stabell 1984). As a result hatchery fish may spawn in suboptimal habitats. In Bear Lake, hatchery fish overlap spawning areas with wild fish, which may have decreased the life history variability. For example, BLBCT individuals spawned in what appeared to be the first suitable spawning site encountered. As a result most spawning occurred in small areas of the stream.

Redd totals were affected by low precipitation and snow pack levels during all three years of this study. The 2000 and 2001 water years were the 4^{th} and 1^{st} driest water years respectively during the last 54 years (NOAA Weather Station data at Lifton, ID). Although precipitation improved in 2002 (17^{th} driest year on record), redd numbers were also impacted by the low water level in Bear Lake. At the beginning of the spawning season in 2002, the water level was already at 1802 m, 3.7 m below full pool. A large area of lakebed was exposed and spawning fish were required to migrate across approximately 1.5 km of stream flowing over unprotected lakebed before reaching spawning grounds (*personal observation*). The pumping station at the north end of Bear Lake drew the water level down to 1800.6 m by fall. Since 1918, Bear Lake has been drawn down to this level only two other times, during the droughts of the mid 1930's and early 1990's (PacifiCorp Bear Lake Elevation Data at Lifton).

Despite the low runoff and lake levels in 2002, fish reached historical spawning grounds because they were artificially transported into the mainstem. The overall BLBCT egg-to-fry survival in St. Charles Creek was probably higher in 2002 than in 2000 and 2001. Had fish not been artificially transported into Segments 2 and 3, most of the 36 fish captured at the Little Arm trap would have spawned within the first kilometer of stream. Fish transportation resulted in a larger number of individuals spawning in suitable spawning habitat.

Redd Site Characteristics

Water depth appeared to be an important variable in determining BLBCT spawning locations. In both 1989 and 2002, BLBCT consistently spawned in water with mean depths between 29 cm and 33 cm at the pit. Tailspill depth was slightly more

variable, but with the exception of Segment 3, tailspill depths averaged 15-20 cm. Jacobson's pit velocity measurements were higher during 1989 than my measurements in 2002. Mean pit velocity in the Little Arm in 1989 was 52 cm/s while my measurements from 2002 averaged 39 cm/s. The water velocity differences could reflect different flows between 1989 and 2002. The higher pit velocities measured at Segment 3 relative to Segments 1 and 2 were not surprising because of the higher gradient and faster overall water velocities in Segment 3. The redds built by stream dwelling rainbow trout (*Oncorhychus mykiss*) in Oregon exhibited depth and velocity values similar to St. Charles Creek (Smith 1973). Golden trout (*O. aquabonita*) in a tributary to the South Fork of the Kern River, Oregon, strongly selected for velocities observed in this study, however golden trout selected much shallower water depths for spawning (Knapp and Vredenburg 1996). The larger fish spawning in St. Charles Creek probably explains this difference.

Chapman (1988) suggested that the gravel characteristics of the egg pocket were likely different than at other locations within the redd. Exact egg pocket locations can only be determined by redd excavation. However, due to the small number of redds and the status of the species, I was unwilling to risk the egg mortality associated with excavation. Therefore, I assessed surface gravel characteristics of redds in their entirety. Jacobson (*unpublished data*) described a higher average percentage of fines <1 mm (32.1%) within Little Arm (Segment 1) redds in 1989, than I found in 2002 (9.25%). Jacobson also observed a higher average percentage of fine sediment <1 mm within the main fork redds in 1989 (19.5%) compared to 2002 (3.67% in Segment 2 and 5.89% in Segment 3). Ocular estimates were used in 1989 to assess gravel characteristics, whereas

I assessed gravel with pebble counts on photographs. The use of alternative gravel assessment methods was probably the reason for such large differences. Estimations of gravel composition using different methods are sometimes not comparable (Church et al. 1987).

In lab studies, Irving and Bjornn (1984) did not find substantial increases in cutthroat trout egg mortality until percent fines <1 mm was greater than 8%. The average redd in the Little Arm exceeded that value. The high percentage of fines <10 mm within the redds in both Segments 1 and 3 may also be limiting emergence survival. Irving and Bjornn (1984) also found that once gravels less than 9.5 mm increased above 30%, emergence survival decreased precipitously for cutthroat trout. In St. Charles Creek, the mean percentage of fines less than 10 mm was 50.5% in Segment 1 and 37.3% in Segment 3; however fines < 10 mm in Segment 2 were at the survival threshold (31%).

The use of different habitat units by spawning BLBCT between the stream segments was probably reflective of the corresponding available habitat. For example, the higher stream gradient in the upper segments (2 and 3) generated higher water velocities and therefore coarser gravel composition and fewer pools. Individual BLBCT spawned along the stream margins and within side channels in Segment 3 because both habitats had lower water velocities and smaller substrate particles than main channel habitats.

Suitable spawning habitat in St. Charles Creek was unused in this study, except when BLBCT were artificially transported to it. Improvement of BLBCT natural recruitment in St. Charles Creek can be achieved by either enhancing the spawning habitat near the mouth with stable flow or by improving the migration corridor. The

migration corridor from Bear Lake to the higher quality spawning grounds at the Forest Boundary segment could be improved by screening irrigation diversions, and fish could be transported to the upper segments to reestablish a spawning population.

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Table 3.1.- Stream segment characteristics in St. Charles Creek. Turbulent fast water habitat constitute riffles and cascades, while non-turbulent fast water habitats constitute all glides and runs.

			Percent of Area		
				Fast Water	
Segment	Length (m)	Gradient (%)	Pools	Turbulent	Non-Turbulent
Little Arm	5004	0.34	32	37	30
Canyon Mouth	4801	0.99	17	31	50
Forest Boundary	8331	1.78	6	74	19

Table 3.2.- Numbers, Mean Length, and demographic characteristics of fish released in St. Charles Creek during all three years. The fish data reported here for 2000 and 2001 reflect only fish from the Little Arm because Big Arm fish were not included in the analyses. The recorded fish length in Segment 2 represents the mean length of all 30 fish, but the standard deviation was not available. I was also unable to obtain information regarding hatchery vs. wild.

		Length					
Year	n	Mean	Range	Pct. Female	Pct. Male	Pct. Hatchery	Pct. Wild
2000	48	543.1 (85.1)	337-701	60.4	39.6	35.4	64.6
2001	68	524.0 (68.9)	362-664	64.7	35.3	61.8	38.2
2002							
Segment 1	29	516.3 (92.3)	242-740	51.7	48.3	55.2	44.8
Segment 2	30	553	---	66.7	33.3	---	---
Segment 3	41	518.4 (62.3)	412-710	58.5	41.5	73.2	62.3

Table 3.3: Redd characteristics in St. Charles Creek. Also included are observations from redd counts performed in 1989 by Jacobson. Values in Parentheses are standard deviations. D50, Geometric mean and % gravel < 10mm were not measured in 1989.

			Pit		Tailspill					
2002	n	Redd Area (m^2)	Depth (cm)	Velocity (cm/s)	Depth (cm)	Velocity (cm/s)	D50 (mm)	Geometric Mean (mm)	% < 10mm	% < 1mm
Little Arm	11	1.35 (0.62)	32 (6)	39 (14)	15 (5)	52 (16)	10.9 (4.2)	8.2 (3.2)	44 (6)	6 (2)
Canyon Mouth	15	1.52 (0.76)	30 (7)	49 (14)	18 (7)	57 (25)	21.5 (7.8)	16.7 (9.2)	44 (18)	7 (6)
Forest Boundary	23	0.79 (0.28)	33 (6)	41 (16)	24 (8)	60 (14)	17.0 (8.2)	12.2 (6.2)	31 (10)	5 (5)
1989										
Little Arm	36	3.38 (1.37)	29 (7)	52 (18)	20 (21)	71 (17)				32 (15)
Main Fork	10	2.29 (0.82)	30 (9)	50 (22)	16 (7)	80 (16)				19 (11)

Table 3.4.- Suitability values derived from suitability index curves for cutthroat trout. I.B. Gravel is the survival curve estimated from Irving and Bjornn equation and T.B. Gravel is survival estimated from the Tappel and Bjornn equation.

Segment	Suitability			
	Velocity	Temperature	I.B. Gravel	T.B. Gravel
1	0.851 (0.189)	0.147 (0.204)	0.984 (0.015)	0.305 (0.184)
2	0.836 (0.163)	0.728 (0.000)	0.997 (0.004)	0.560 (0.221)
3	0.904 (0.117)	0.823 (0.030)	0.904 (0.117)	0.433 (0.189)

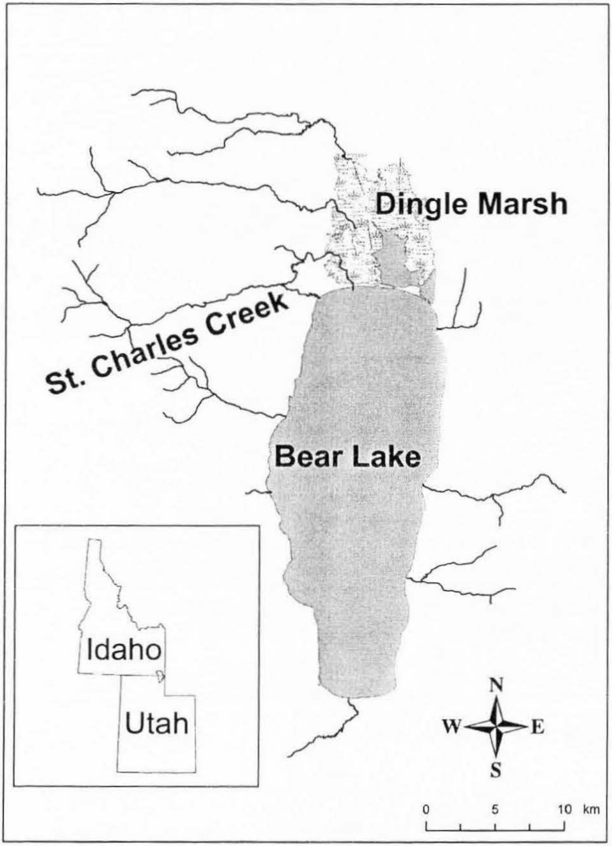

Figure 3.1: A map illustrating Bear Lake and its tributaries. St. Charles Creek flows into the northwest end of the lake.

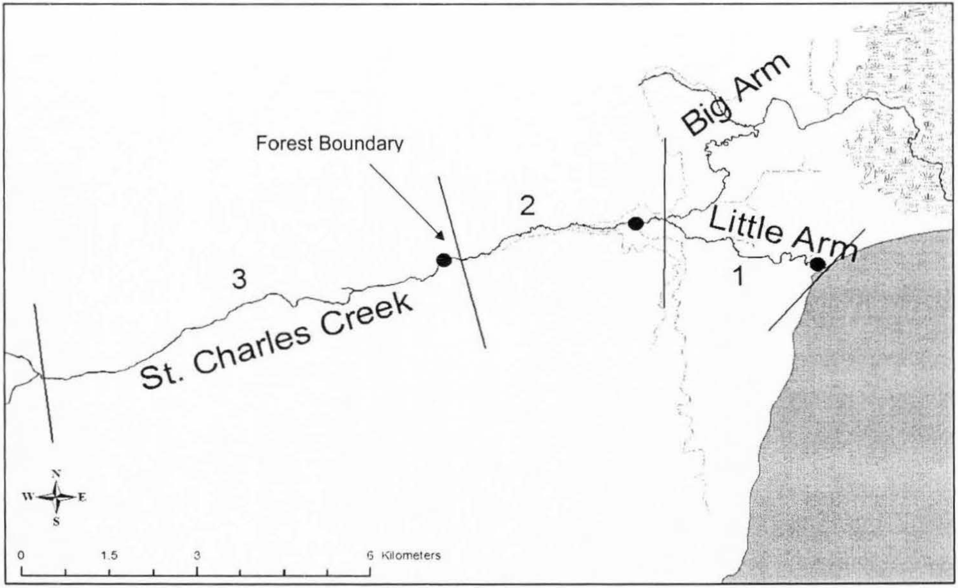

Figure 3.2: Close up of St. Charles Creek showing the different stream segments. The Big Arm, which flows into the north end ff Bear Lake, was not used in my analyses. The stream segments are 1) Little Arm 2) red roof and 3) Forest Boundary. The Black points on the map represent the release points of the three groups of fish in 2002. The dashed gray lines represent irrigation diversions

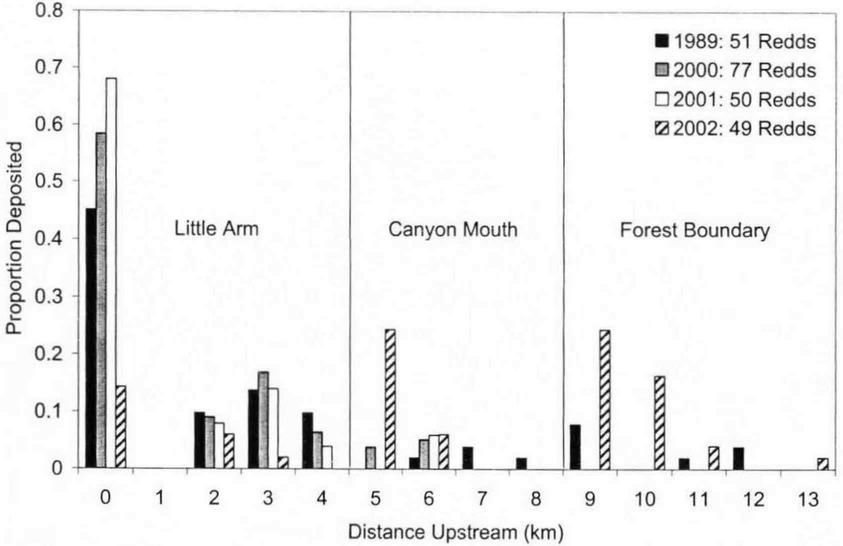

Figure 3.3: Relative frequency distributions of redds in St. Charles Creek from 1989, 2000-2002.

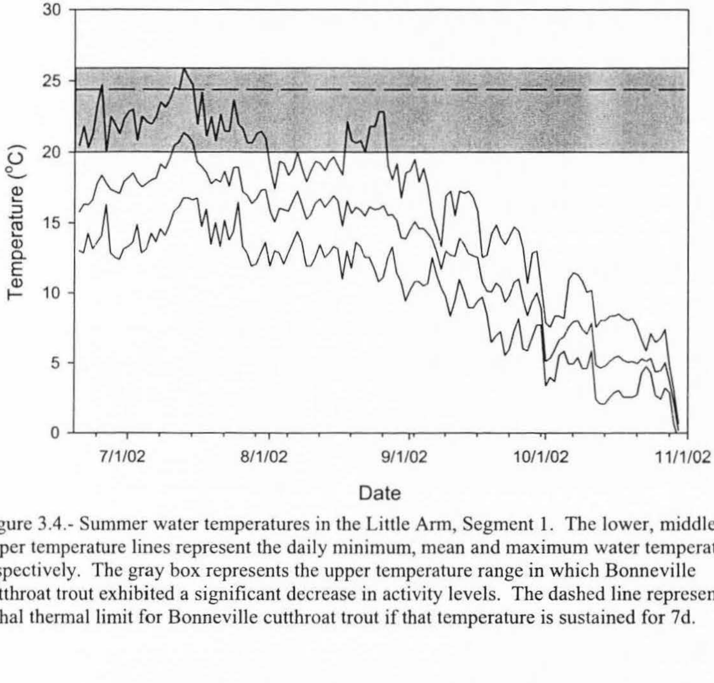

Figure 3.4.- Summer water temperatures in the Little Arm, Segment 1. The lower, middle and upper temperature lines represent the daily minimum, mean and maximum water temperatures respectively. The gray box represents the upper temperature range in which Bonneville cutthroat trout exhibited a significant decrease in activity levels. The dashed line represents the lethal thermal limit for Bonneville cutthroat trout if that temperature is sustained for 7d.

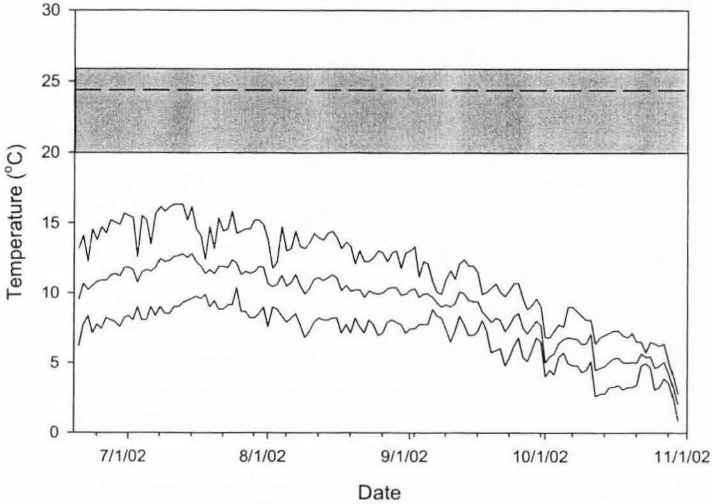

Figure 3.5.- Summer water temperatures in Segment 2. The lower, middle and upper temperature lines represent the daily minimum, mean and maximum water temperatures respectively. The gray box represents the upper range of temperatures in which Bonneville cutthroat trout exhibited a significant decrease in activity levels. The dashed line represents the lethal thermal limit for Bonneville cutthroat trout if that temperature is sustained for 7d.

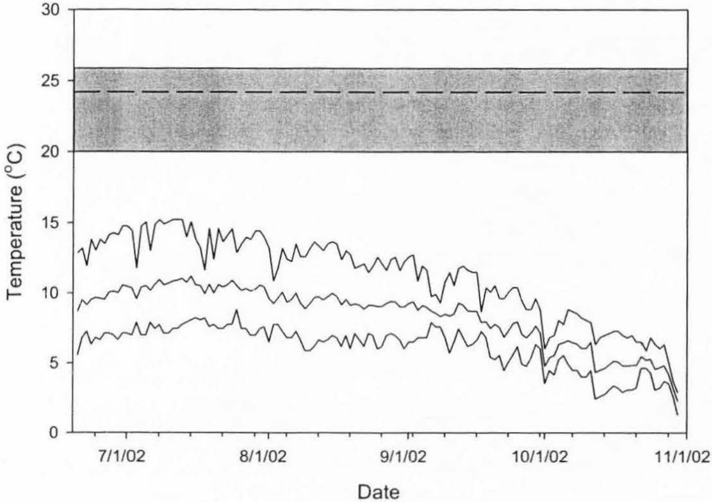

Figure 3.6.- Summer water temperatures in Segment 3. The lower, middle and upper temperature lines represent the daily minimum, mean and maximum water temperatures respectively. The gray box represents the upper range of temperatures in which Bonneville cutthroat trout exhibited a significant decrease in activity levels. The dashed line represents the lethal thermal limit for Bonneville cutthroat trout if that temperature is sustained for 7d.

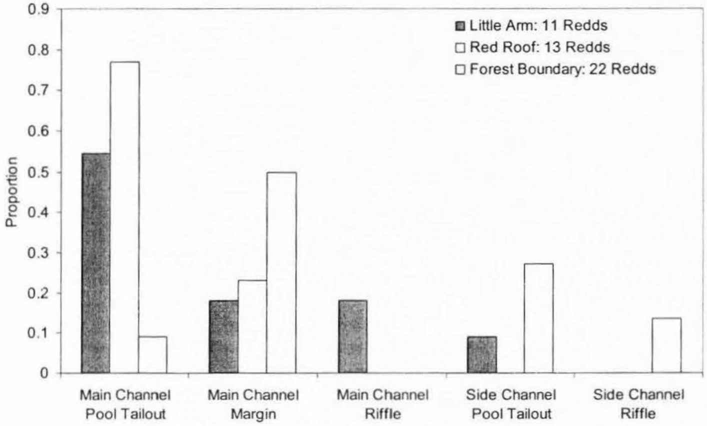

Figure 3.7.- Macrohabitat use by BLBCT released in each stream segment in 2002.

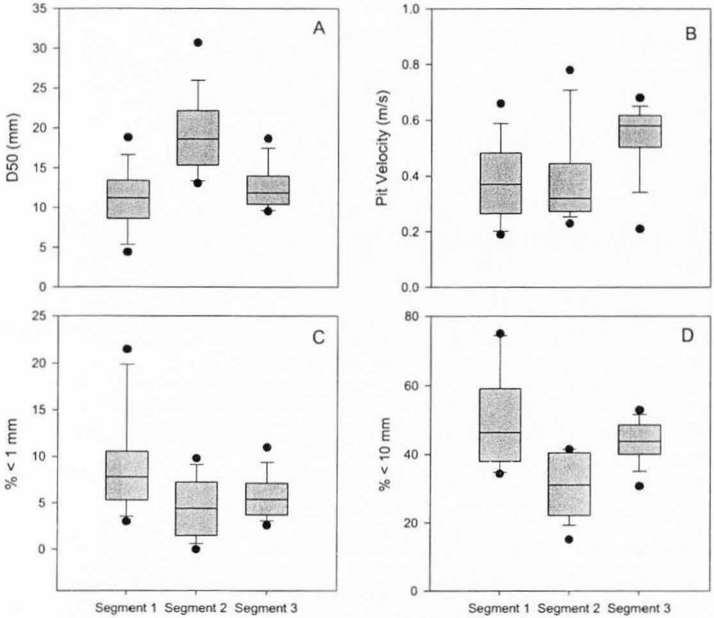

Figure 3.8: Habitat characteristics at the different stream segments in St. Charles Creek. Segment 1 had lower D50 (A) and pit velocities (B), and higher percent gravel less than 10 mm (C) and 1 mm (D).

CHAPTER 4

DISCUSSION

Assessing the factors that limit natural reproduction of migratory salmonids is important for the conservation and recovery of those populations. Accurate information describing habitat limitations, fish movement and demographic data will provide managers with an appropriate framework to which a recovery plan can be created. However, these data can often be difficult and expensive to collect and in many cases the data are not available.

The goal of this research was to provide insight into movement patterns exhibited by a potentially highly migratory population of Bonneville cutthroat trout. I attempted to determine the factors that limit the spawning migrations and spawning success of the Bear Lake Bonneville cutthroat trout. To satisfy the objectives of this research, I focused specifically on two aspects of the spawning ecology of the BLBCT, the spawning migrations and redd habitat characteristics at different scales.

Spawning movements of the BLBCT population appear to be quite limited in St. Charles Creek. As a result of limited spawning migrations, under normal conditions, most fish spawned near the mouth of St. Charles Creek. During all three years of this study, the lowest reach of stream was dewatered by upstream irrigation withdrawals at the peak of the spawning migration and then at multiple times throughout the remainder of the summer.

Habitat fragmentation caused by irrigation water withdrawals may also be a primary factor limiting the natural reproduction of BLBCT in St. Charles Creek, although it may be periodic. This suggests that at certain times, fish are free to move among

stream segments. Irrigation diversions operated at critical times for migrating fish represent a major obstacle for pre and post-spawned adults. Irrigation diversions on St. Charles Creek dewatered spawning grounds near the mouth, entrained post-spawned individuals and physically blocked downstream migrations. A detailed analysis of diversion entrainment is necessary in order to quantify the exact number of fish entrained by irrigation diversions. This research suggests that fish migrations were adversely impacted by both low lake levels and upstream irrigation water use. Irrigation diversions have been implicated in past studies for limiting the availability of spawning habitat for BLBCT in most of the Bear Lake tributaries.

Spawning habitat showed differences among stream segments. Spawning habitat was more suitable in the upper two segments. However, BLBCT normally do not migrate to these segments, generally spawning near the mouth. The spawning habitats near the mouth of St. Charles Creek had higher percentages of fine sediment and had lower median gravel sizes. The lowest kilometer of stream was also dewatered multiple times, limiting the probability of successful spawning and egg incubation.

Although much of the early life history of adfluvial Bonneville cutthroat trout remains unknown, this study highlighted the need to maintain migration corridors and provide sufficient discharge for incubating cutthroat trout eggs. In St. Charles Creek specifically these two factors appeared to strongly determine where a fish spawned and the potential success of spawning.

APPENDIX

Table A-1.- Tagged fish released in the Big Arm during the spawning run of 2001. Provided is the date that the fish was implanted, fish length, sex, any identification of marks, tag number given by its frequency and where the fish was originally captured.

Date	Length (mm)	Sex	Mark	Tag	Origin
5/24/2001	538	m	Hatchery	40.752	Big Arm
5/24/2001	562	m	Hatchery	40.741	Big Arm
5/25/2001	555	f	Hatchery	40.721	Big Arm
5/25/2001	477	f	Wild	40.701	Big Arm
5/25/2001	503	f	Wild	40.711	Big Arm
5/25/2001	557	m	Hatchery	40.691	Big Arm
5/26/2001	682	m	Wild	40.661	Big Arm
5/26/2001	499	f	Hatchery	40.671	Big Arm
5/26/2001	530	m	Hatchery	40.731	Big Arm
5/27/2001	472	f	Hatchery	40.651	Big Arm
5/27/2001	565	f	Hatchery	40.641	Big Arm
5/27/2001	549	f	Hatchery	40.631	Big Arm
5/27/2001	533	f	Hatchery	40.621	Big Arm
5/28/2001	525	f	Wild	40.611	Big Arm
5/28/2001	480	m	Hatchery	40.601	Big Arm
5/29/2001	626	m	Hatchery	40.011	Little Arm

Table A-2.- Tagged fish released in the Little Arm during the spawning run of 2001. All information is the same as the previous table.

Date	Length (mm)	Sex	Mark	Tag	Origin
5/24/2001	487	f	Hatchery	40.071	Little Arm
5/24/2001	576	f	Hatchery	40.051	Little Arm
5/24/2001	629	f	Wild	40.061a	Little Arm
5/25/2001	664	f	Hatchery	40.031	Little Arm
5/25/2001	557	m	Hatchery	40.041	Little Arm
5/25/2001	564	f	Wild	40.021	Little Arm
5/26/2001	615	f	Wild	40.091	Little Arm
5/27/2001	585	m	Hatchery	40.111	Little Arm
5/27/2001	626	m	Hatchery	40.011	Little Arm
5/27/2001	650	m	Hatchery	40.081	Little Arm
5/27/2001	492	f	Wild	40.101	Little Arm
5/28/2001	525	m	Wild	40.121	Little Arm
5/29/2001	540	f	Hatchery	40.141	Little Arm
5/30/2001	514	f	Wild	40.151	Little Arm
5/31/2001	590	f	Wild	40.061b	Little Arm
5/31/2001	496	f	Wild	40.131	Little Arm

Table A-3.- Fish released in the Little Arm during the spawning run of 2002.

Date	Length (mm)	Sex	Mark	Tag	Origin
5/13/2002	475	f	Wild	40.011	Little Arm
5/16/2002	574	f	Hatchery	40.021a	Little Arm
5/22/2002	500	f	Wild	40.061a	Little Arm
6/7/2002	492	f	Hatchery	40.721	Big Arm
6/8/2002	592	f	Hatchery	40.731	Big Arm
6/9/2002	590	f	Hatchery	40.741a	Big Arm
6/10/2002	465	f	Wild	40.751	Little Arm
6/11/2002	483	f	Wild	70.741b	Big Arm
6/13/2002	463	f	Wild	40.761	Little Arm
6/13/2002	519	f	Wild	40.741c	Little Arm

Table A-4.- Fish released into the main fork of St. Charles Creek during the spawning run of 2002.

Date	Length (mm)	Sex	Mark	Tag	Origin
5/19/2002	632	f	Wild	40.031	Little Arm
5/20/2002	540	f	Wild	40.051	Little Arm
5/27/2002	551	f	Hatchery	40.061b	Big Arm
5/28/2002	524	f	Hatchery	40.021b	Big Arm
5/28/2002	462	f	Wild	40.041	Little Arm
5/29/2002	528	f	Hatchery	40.071	Big Arm
5/29/2002	472	f	Hatchery	40.081	Big Arm
5/29/2002	515	f	Hatchery	40.091	Little Arm
5/30/2002	584	f	Hatchery	40.101	Big Arm
5/30/2002	532	f	Hatchery	40.111	Big Arm
5/30/2002	534	f	Wild	40.121	Big Arm
5/30/2002	572	f	Hatchery	40.131	Big Arm
5/30/2002	418	f	Hatchery	40.141	Big Arm
5/31/2002	540	f	Hatchery	40.151	Big Arm
6/2/2002	528	f	Hatchery	40.611	Little Arm
6/2/2002	415	f	Hatchery	40.621	Little Arm
6/2/2002	543	f	Hatchery	40.631	Little Arm
6/3/2002	481	f	Hatchery	40.651	Big Arm
6/3/2002	439	f	Wild	40.641	Little Arm
6/3/2002	502	f	Wild	40.661	Little Arm
6/3/2002	412	f	Wild	40.671	Little Arm
6/6/2002	532	f	Hatchery	40.681	Big Arm
6/6/2002	492	f	Hatchery	40.699	Big Arm
6/6/2002	464	f	Hatchery	40.711	Big Arm

Table A-5.- Kruskal-Wallis test for differences in spawning migrations of fish released in the Little Arm 2001 (LA2001), the Little Arm 2002 (LA2002) and the main fork 2002 (MF2002).

Group	N	Sum of Scores	Expected Under H_0	Standard Deviation Under H_0	Mean Score
LA2001	13	314	292.5	38.87	24.15
LA2002	7	173	157.5	31.16	24.71
MF2002	24	503	540	42.42	20.96

Kruskal-Wallis Test; $X^2 = 0.7693$; DF = 2; Pr > $X^2 = 0.6807$

Table A-6.- ANOVA comparing the effect of location on stream residency of spawning BLBCT.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3288.43	1644.21	14.44	<0.0001
Error	44	5008.81	113.84		
Corrected Total	46	8297.23			
R-Square	C.V.	Root MSE	Mean		
0.3963	58.86	10.67	18.13		

Table A-7.- Characteristics for all redds built in St. Charles Creek in 2002. Segment abbreviations are as follows: LA = Little Arm, FB = Forest Boundary and CM = Canyon Mouth. GPS coordinates are in UTM NAD-27 Zone 12.

Redd Number	Group	Habitat Type	GPS Lat	GPS Long	Fish Length	Redd Length	Redd Width	Redd Area	Pit Depth	Pit Velocity	Tailspill Depth	Tailspill Velocity	Gravel Characteristics (mm) d50	d84	d16	dg	mg	sg	Percent Less than 0.85 mm	1 mm	3 mm	6.35 mm	9.5 mm	10 mm	Average Max Temp	Suitability Index Gravel I.B.	Gravel T.B.	Velocity	Temperature
LA-001	LA	1	468120	4662804		1.60	0.683	1.093	26.00	21.00	0.08	0.23	18.81	48.34	2.76	11.54	13.55	4.19	9.20	10.10	16.70	27.50	34.40	37.40	17.25	1.000	0.394	0.567	0.405
LA-002	LA	1	468291	4662711	632	1.70	1.233	2.097	26.00	19.00	0.07	0.40	13.50	27.88	2.81	8.65	10.17	3.15	10.60	10.70	17.60	28.20	40.60	42.40	17.25	0.990	0.377	0.494	0.405
LA-003	LA	3	468381	4662573	463	1.53	0.783	1.199	30.00	46.00	0.08	0.51	8.58	14.73	2.50	6.06	6.79	2.43	5.00	6.10	18.90	38.30	57.40	59.70	17.25	0.975	0.176	1.000	0.405
LA-004	LA	4	469824	4662275		1.10	0.490	0.539	30.00	35.00	0.21	0.34	15.14	39.60	3.72	12.14	13.03	3.26	4.90	5.20	13.10	21.90	31.30	34.40	22.43	1.000	0.541	0.934	0.000
LA-005	LA	1	469760	4662258		1.65	0.833	1.375	41.00	34.00	0.18	0.54	4.40	12.81	0.56	2.67	3.15	4.79	19.80	21.50	36.00	61.00	72.90	75.00	22.43	0.959	0.021	0.916	0.000
LA-006	LA	1	469742	4662266		1.85	0.950	1.758	38.00	49.00	0.19	0.73	12.10	28.47	4.35	11.12	11.41	2.56	3.60	3.90	13.10	22.90	35.50	39.80	22.43	1.000	0.514	1.000	0.000
LA-007	LA	2	469730	4662277		1.90	0.867	1.647	38.00	24.00	0.14	0.39	11.18	31.41	2.79	9.37	9.92	3.35	8.70	9.00	17.20	31.80	44.10	46.40	22.43	0.987	0.294	0.668	0.000
LA-008	LA	2	469715	4662342	492	1.10	0.583	0.642	27.00	37.00	0.17	0.65	6.00	15.81	0.64	3.17	3.92	4.98	17.30	18.80	31.20	53.90	69.60	74.00	22.43	0.962	0.043	0.965	0.000
LA-009	LA	3	469721	4662363		1.45	0.533	0.773	30.00	66.00	0.22	0.68	13.24	23.22	4.15	9.82	10.82	2.36	7.50	7.80	13.30	22.30	34.10	35.10	22.43	1.000	0.530	0.818	0.000
LA-010	LA	1	469729	4662371		3.40	0.750	2.550	42.00	54.00	0.18	0.67	8.61	19.19	3.35	8.02	8.19	2.39	2.90	3.00	14.60	35.90	53.20	54.40	22.43	0.979	0.215	1.000	0.000
LA-012	LA	1	468348	4662656	463	1.42	0.867	1.231	28.00	41.00	0.17	0.54	8.64	17.37	3.29	7.56	7.88	2.30	4.70	5.60	14.00	33.80	54.50	57.50	17.25	0.977	0.253	1.000	0.405
Little Arm Mean						**1.70**	**0.78**	**1.35**	**32.36**	**38.73**	**0.15**	**0.52**	**10.93**	**25.35**	**2.81**	**8.21**	**8.99**	**3.25**	**8.56**	**9.25**	**18.70**	**34.32**	**47.96**	**50.55**	**20.55**	**0.984**	**0.305**	**0.851**	**0.147**
Little Arm Standard Deviation						**0.62**	**0.21**	**0.62**	**6.14**	**14.49**	**0.05**	**0.16**	**4.20**	**11.19**	**1.24**	**3.17**	**3.39**	**0.99**	**5.53**	**5.95**	**7.71**	**12.78**	**14.59**	**14.72**	**2.61**	**0.015**	**0.184**	**0.189**	**0.204**
MF-001	FB	4	463245	4662414	528	1.20	0.933	1.120	33.00	62.00	0.18	0.74	11.86	27.55	2.26	7.90	9.03	3.49	4.60	5.60	22.10	31.80	41.70	43.80	14	0.989	0.294	0.905	0.808
MF-002	FB	4	463246	4662414	584	1.20	0.783	0.940	36.00	61.00	0.25	0.63	14.11	30.43	2.63	8.95	10.39	3.40	7.40	8.30	17.90	27.30	38.00	39.80	14	0.992	0.399	0.923	0.808
MF-003	FB	4	463264	4662412	481	1.40	0.567	0.793	49.00	54.00	0.37	0.57	13.62	33.89	3.32	10.81	11.50	3.19	4.00	4.30	15.20	26.70	37.00	38.00	14	0.994	0.414	1.000	0.808
MF-004	FB	1	463266	4662397	412	0.90	0.533	0.480	38.00	43.00	0.38	0.45	10.26	24.33	3.11	8.71	9.17	2.80	4.50	5.40	15.30	34.90	47.20	49.30	14	0.984	0.232	1.000	0.808
MF-005	FB	4	463258	4662391	439	1.40	0.617	0.863	39.00	21.00	0.30	0.27	16.68	113.01	4.11	21.56	19.73	5.24	1.90	2.60	12.40	25.90	39.50	40.90	14	0.991	0.435	0.567	0.808
MF-006	FB	2	463219	4662341	472	1.30	0.617	0.802	29.00	50.00	0.26	0.60	18.68	40.60	3.66	12.22	14.04	3.32	7.30	7.60	14.50	22.70	29.00	30.80	14	1.000	0.520	0.956	0.808
MF-007	FB	2	463197	4662337	528	1.40	0.667	0.933	29.00	58.00	0.20	0.84	12.41	23.60	3.21	8.71	9.77	2.71	3.20	4.30	14.40	29.60	41.20	41.50	14	0.990	0.343	0.970	0.808
MF-008	FB	2	463200	4662349		1.40	0.950	1.330	25.00	63.00	0.13	0.73	9.89	23.73	3.07	8.53	8.88	2.78	1.40	3.40	15.50	35.60	48.00	53.00	14	0.984	0.220	0.885	0.808
MF-009	FB	2	463200	4662344		1.20	0.550	0.660	29.00	49.00	0.15	0.65	10.82	22.84	2.14	7.00	8.08	3.26	5.20	5.70	18.60	32.90	45.20	46.60	14	0.986	0.271	1.000	0.808
MF-010	FB	2	463202	4662361	415	1.30	0.483	0.628	26.00	56.00	0.25	0.69	9.56	50.99	1.57	8.95	9.12	5.70	8.20	11.00	19.40	38.40	49.70	50.80	14	0.981	0.175	0.995	0.808
MF-011	FB	2	463218	4662334	412	1.25	0.417	0.521	37.00	68.00	0.27	0.79	11.16	26.99	2.07	7.48	8.53	3.81	2.50	3.50	23.00	30.00	45.30	46.60	14	0.986	0.334	0.767	0.808
MF-012	FB	2	463213	4662219	532	1.80	0.600	1.080	30.00	46.00	0.24	0.53	26.92	61.24	8.82	23.24	24.33	2.64	2.40	2.90	7.40	12.10	16.80	19.10	14	1.000	0.785	1.000	0.808
MF-013	FB	2	462776	4662102	472	1.00	0.467	0.467	28.00	35.00	0.18	0.41	11.67	27.65	0.67	4.32	6.00	6.40	18.90	20.60	29.20	36.40	45.20	45.70	14	0.985	0.206	0.934	0.808
MF-014	FB	2	462777	4662110	464	0.80	0.400	0.320	30.00	42.00	0.23	0.47	12.40	32.76	1.76	7.59	8.92	4.32	8.00	9.20	23.00	33.50	40.60	41.90	14	0.990	0.259	1.000	0.808
MF-015	FB	1	462809	4662101	543	1.20	0.633	0.760	32.00	60.00	0.26	0.63	34.90	62.40	1.95	11.03	16.15	5.66	9.40	9.80	18.40	22.50	25.10	25.20	14	1.000	0.525	0.940	0.808
MF-016	FB	2	462845	4662072	515	1.10	0.500	0.550	28.00	55.00	0.24	0.59	22.81	44.95	8.60	19.67	20.60	2.29	0.60	0.60	4.90	11.50	18.70	20.90	14	1.000	0.798	1.000	0.808
MF-017	FB	4	462832	4662079	515	1.40	0.500	0.700	40.00	31.00	0.30	0.51	40.31	78.99	7.06	23.62	28.13	3.34	8.40	8.60	11.90	15.00	18.00	18.50	14	1.000	0.720	0.855	0.808
MF-018	FB	5	462683	4662045	543	1.20	0.550	0.660	32.00	67.00	0.27	0.65	21.19	39.16	3.05	10.93	13.59	3.58	0.40	0.50	15.00	27.80	33.60	34.40	13.55	1.000	0.387	0.794	0.846
MF-019	FB	4	462656	4662037	572	1.70	0.533	0.907	30.00	26.00	0.18	0.56	18.76	33.55	5.03	13.00	14.65	2.58	4.70	5.00	13.40	18.30	23.90	25.40	13.55	1.000	0.637	0.728	0.846
MF-020	FB	2	462532	4662015	502	2.25	0.683	1.538	27.00	31.00	0.13	0.82													13.41			0.855	0.857
MF-021	FB	5	461861	4661864	528	1.10	0.650	0.715	28.00	57.00	0.18	0.57	12.69	23.83	2.61	7.89	9.22	3.02	6.40	8.90	18.20	26.90	40.30	43.70	13.41	0.990	0.409	0.983	0.857
MF-022	FB	4	461664	4661781	528	1.40	0.617	0.863	29.00	26.00	0.15	0.48	12.29	22.37	4.80	10.36	10.94	2.16	0.00	0.00	7.70	23.10	34.90	40.10	13.41	1.000	0.509	0.728	0.857
MF-023	FB	5	459874	4661575	540	1.30	0.450	0.585	48.00	53.00	0.47	0.61	20.63	104.60	6.05	25.16	23.48	4.16	1.70	1.80	7.90	17.70	23.60	24.10	12.31	1.000	0.653	1.000	0.929
Forest Boundary Mean						**1.31**	**0.60**	**0.79**	**32.78**	**48.83**	**0.24**	**0.60**	**16.97**	**43.16**	**3.71**	**12.15**	**13.38**	**3.62**	**5.05**	**5.89**	**15.70**	**26.39**	**35.57**	**37.28**	**13.81**	**0.993**	**0.433**	**0.904**	**0.823**
Forest Boundary Standard Deviation						**0.30**	**0.14**	**0.28**	**6.42**	**14.25**	**0.08**	**0.14**	**8.21**	**26.05**	**2.20**	**6.18**	**6.14**	**1.17**	**4.22**	**4.58**	**5.84**	**7.83**	**10.45**	**10.76**	**0.40**	**0.007**	**0.189**	**0.117**	**0.030**
MF-024	RR	1	466480	4663166		2.20	0.867	1.907	23.00	78.00	0.15	1.10	21.83	39.45	6.57	16.10	17.77	2.45	0.00	0.00	7.00	15.00	21.70	22.10	14.81	1.000	0.720	0.431	0.728
MF-025	RR	1	466488	4663155		1.55	0.600	0.930	29.00	45.00	0.22	0.84	21.47	44.13	2.88	11.27	13.93	3.92	6.50	9.80	16.20	20.30	24.40	24.60	14.81	1.000	0.564	1.000	0.728
MF-026	RR	1	466479	4663158		1.15	0.667	0.767	43.00	66.00	0.26	0.81	22.29	52.09	6.65	18.61	19.70	2.80	0.60	1.00	7.30	15.60	21.70	22.50	14.81	1.000	0.705	0.818	0.728
MF-027	RR	1	466494	4663161		1.60	0.567	0.907	19.00	23.00	0.02	0.14	13.55	36.48	2.25	9.05	10.33	4.03	8.40	8.70	19.30	27.30	38.10	38.80	14.81	0.992	0.399	0.636	0.728
MF-028	RR	2	466470	4663142		1.55	1.950	3.023	30.00	27.00	0.20	0.38	18.03	61.68	2.05	11.25	13.13	5.48	4.80	7.10	24.30	37.60	40.80	41.60	14.81	0.990	0.187	0.756	0.728
MF-029	RR		466471	4663147		1.50	0.450	0.675	26.00	29.00	0.17	0.36	14.93	40.55	1.65	3.18	9.98	4.96	5.20	6.20	20.70	32.70	39.10	41.10	14.81	0.992	0.275	0.808	0.728
MF-030	RR	1	466400	4663140		3.40	0.767	2.607	39.00	43.00	0.19	0.59	22.80	62.93	6.66	20.48	21.16	3.07	0.80	1.30	4.50	14.20	20.50	22.10	14.81	1.000	0.738	1.000	0.728
MF-031	RR	2	466385	4663140		0.90	0.550	0.495	21.00	32.00	0.09	0.35	16.40	48.95	3.54	13.16	14.13	3.72	1.40	2.00	12.90	25.10	32.80	33.20	14.81	1.000	0.456	0.877	0.728
MF-032	RR	2	466378	4663131		2.65	0.700	1.855	30.00	41.00	0.15	0.43	30.69	64.88	10.33	25.89	27.31	2.51	1.40	1.90	4.60	9.80	14.90	15.20	14.81	1.000	0.832	1.000	0.728
MF-033	RR	1	466369	4663127		1.80	0.600	1.080	30.00	27.00	0.18	0.38	13.06	36.08	2.73	9.93	10.85	3.63	6.20	7.30	17.30	29.50	40.20	41.50	14.81	0.990	0.346	0.758	0.728
MF-034	RR		466374	4663127		2.20	0.800	1.760	25.00	28.00	0.11	0.42	18.60	40.43	3.79	12.35	14.15	3.26	3.80	4.40	13.10	21.20	29.30	31.10	14.81	1.000	0.560	0.783	0.728
MF-035	RR	1	466244	4663041		2.60	0.800	2.080	35.00	27.00	0.25	0.55	30.54	44.13	10.94	21.97	24.44	2.01	0.90	1.00	3.90	9.70	13.80	14.10	14.81	1.000	0.833	0.756	0.728
MF-036	RR	1	465836	4663078	532	1.80	0.650	1.170	33.00	47.00	0.23	0.74	24.51	56.86	4.40	15.81	18.25	3.60	1.10	1.30	10.80	21.20	27.70	31.40	14.81	1.000	0.560	1.000	0.728
MF-037	RR	1	465735	4663142		2.30	0.967	2.223	34.00	40.00	0.17	0.61	12.44	42.11	3.63	12.36	12.36	3.41	2.10	2.60	13.60	30.20	40.50	42.30	14.81	0.990	0.329	1.000	0.728
MF-038	RR	1	465728	4663114		1.70	0.750	1.275	37.00	61.00	0.25	0.80	40.84	136.50	14.57	44.60	43.14	3.06	0.20	0.40	3.60	7.20	11.10	11.80	14.81	1.000	0.877	0.923	0.728
Red Roof Mean						**1.93**	**0.78**	**1.52**	**30.27**	**40.93**	**0.18**	**0.57**	**21.47**	**53.82**	**5.51**	**16.74**	**18.04**	**3.46**	**2.89**	**3.87**	**11.94**	**21.11**	**27.77**	**28.89**	**14.81**	**0.997**	**0.560**	**0.836**	**0.728**
Red Roof Standard Deviation						**0.64**	**0.35**	**0.76**	**6.77**	**16.38**	**0.07**	**0.25**	**7.83**	**24.84**	**3.80**	**9.24**	**8.66**	**0.92**	**2.69**	**3.29**	**6.69**	**9.19**	**10.44**	**10.78**	**0.00**	**0.004**	**0.221**	**0.163**	**0.000**

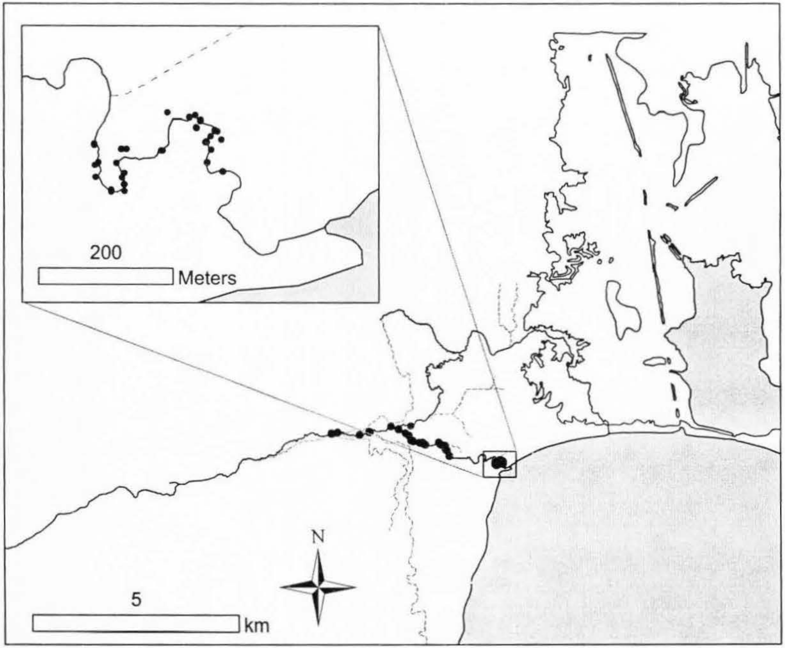

Figure A-1.- Redd locations for 2000. The dashed lines represent irrigation diversions.

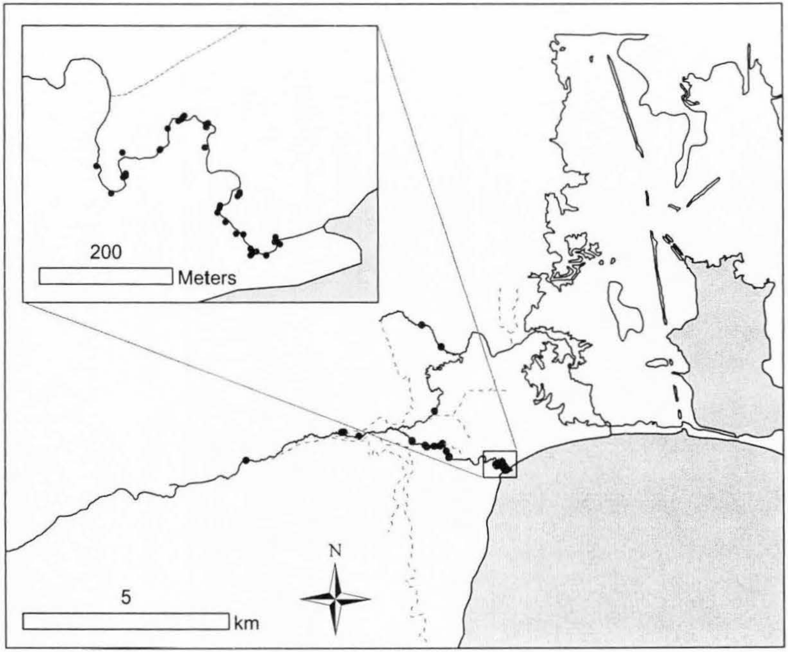

Figure A-2.- Redd locations for 2001. The dashed lines represent irrigation diversions.

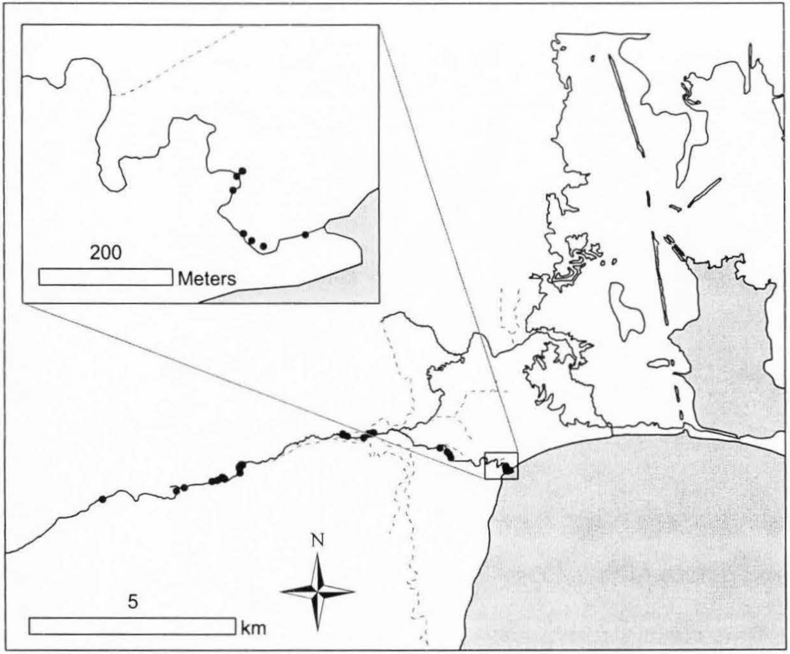

Figure A-3.- Redd locations for 2002. The dashed lines represent irrigation diversions.