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Movement Behavior and Habitat Selection of the Endangered June Sucker (*Chasmistes liorus*) in Utah Lake, Utah

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MOVEMENT BEHAVIOR AND HABITAT SELECTION OF THE ENDANGERED JUNE SUCKER (*CHASMISTES LIORUS*) IN UTAH LAKE, UTAH

by

Kris A. Buelow

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Fisheries Biology

Approved:

Todd A Crowl Major Professor	Phaedra Budy Committee Member
Karen Mock Committee Member	Byron R. Burnham Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

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ABSTRACT

Movement Behavior and Habitat Selection of the Endangered June Sucker (*Chasmistes liorus*) in Utah Lake, Utah

by

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Utah State University, 2006

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The June sucker (*Chasmistes liorus*) is a pelagic feeding sucker endemic to Utah Lake, Utah. It has been listed as an endangered species with the present population being estimated with as few as 300 individuals. Efforts to reinvigorate the population by placing breeding age individuals and augmenting the population with hatchery-reared fish have proved to have had limited success. At this stage there is an imperative to understand the behavioral traits and life history of June sucker to retrieve them from the brink. Previous efforts have been hampered by few individuals and a difficult habitat to study. Utah Lake is large, yet shallow with rough environmental conditions. In this study, methods were developed to address some of these challenges and used to describe the movement of June sucker using radio/acoustic telemetry over four seasonal time-periods. Manual and fixed position monitoring methods were used to collect fish abundance data for all tagged fish. Tagged fish were monitored at the mouth of spawning tributaries to determine the extent of spawning congregations and migrations. Lake-wide fish distributions were monitored using a randomly deployed hydrophone system in a paired sample scheme so that comparisons could be made between limnetic and littoral habitat use. Minimum linear weekly movements were produced using consecutive weekly detections. Data summarized in this study have been important in managing and monitoring wild populations of June sucker in their natural habitat.

(89 pages)

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Kris A. Buelow

CONTENTS

CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

Figure Page

LIST OF FIGURES (continued)

INTRODUCTION

Changes in the Western Landform

Environmental change has had a major influence in western North America since the formation of the continent (Christopherson 2005). Approximately 55 million years ago (mya), upheaval in the Earth's crust formed the Rocky Mountains. The Sierra Nevada and Cascade ranges were formed 5 mya. During the Pleistocene, approximately 1.8 mya, a general cooling trend brought about wide spread glacial formation (Hamblin 1989). Through periods of advancing and retreating glacial ice, large numbers of fish species were displaced from their natural ranges or lost altogether (Briggs 1986). In the eastern region of North America, river drainages ran from the north to south, allowing fish to migrate away from advancing ice sheets to more hospitable climates. In the western regions however, many drainages had an east-west orientation with many closed basins providing little or no thermal refuge from glacial conditions (Cavender 1986; Minckley et al. 1986). Consequently, western drainages suffered higher species loss than the eastern drainages (Briggs 1986).

After the retreat of ice sheets approximately 10,000 years ago, redistribution of species was disrupted in the west by a general lack of connectivity between basins and low numbers of species (Briggs 1986; Buettner and Scoppettone 1990). The low number of species in the drainages of western North America resulted in a higher rate of endemism compared to the eastern drainages of North America (Miller 1965; Minckley et al. 2003).

With fewer species and many closed basins, the end of the Pleistocene became an important time for fish redistribution in western North America (Minckley et al. 1986). During interglacial periods near the end of the Pleistocene, enormous lakes formed in many of the river valleys and basins of the western states (Minckley et al. 1986). At their highest levels the Pleistocene lakes overflowed into rivers, providing passage for fish between basins. Approximately 9,000 years ago (the beginning of the Holocene) a general warming trend brought about the end of the Great Ice Age. Warmer temperatures, increased evaporative rates, and a reduction in melting glacial ice caused the Pleistocene lakes to shrink, beginning a general trend toward aridity throughout western North America (Axelrod 1979). As the large Pleistocene lakes and rivers dried up, movement of fish between them was limited causing divergence of remaining populations and ultimately speciation, leading to the high levels of endemism currently observed (Minkley and Douglas 1991).

Desert Lake Ecology

Desert lake ecosystems are highly dynamic isolated environments (Scheffer 2001) that are subject to wide variation in temperature, high winds, and unpredictable precipitation. They are also rare and disconnected, often by great distances (Solt 1979). As the western landscape was formed through the processes of uplifting, block faulting, and water erosion, drainage basins were created and transformed. In addition to geomorphic processes, changes in weather patterns strongly influenced desert lake systems. Under current climatic conditions and present geomorphic formations, large desert lakes that can provide suitable habitat for fish are very rare. In addition to loss of connectivity, many desert lakes are the remnants of much larger historic Pleistocene lakes. In the Bonneville, Lahonton, and Klamath basins, available lake habitat has decreased from approximately 300,000 km^2 during the Pleistocene, to less than 975 km^2 at present (Minckley et al. 1986; Benson et al. 1992). The changes in habitat availability, habitat type, and increasing isolation likely caused fish species within these basins to diverge resulting in the currently observed species assemblages (Briggs 1986; Gaston 1994). The biological and climatological processes typical of desert lakes have resulted in rare, endemic species that often have a highly specialized suite of life history traits (Gaston 1994).

The distinctness of desert fish life histories are a result of environmental conditions. Desert lakes are supported by melting snow in bordering mountains, resulting in highly variable, spring runoff. For fish to persist in these habitats, they must exhibit life history traits necessary to persist in unpredictable environments (Minckley et al 1986; Scheffer 2001). Fish found in desert lake systems have adapted to frequent drought and flood conditions by exhibiting long life spans and high fecundity.

Fossil records age the *Catostomids* family (suckers), from before the Pleistocene (Miller and Smith 1981). The suckers make up a large proportion of the fish present in fossil beds from 65 mya onwards, indicating that these fish were once both widespread and abundant in western North America (Cavender 1986). The genus *Chasmistes* (lake sucker) within the family *Catostomidae*, was particularly abundant and found throughout the Bonneville (Utah), Lahontan (Nevada), and Klamath (Oregon) basin fossil records (Miller and Simth 1981).

Suckers continue to inhabit desert lakes which are relatively small remnants of the once larger Pleistocene lake habitats (Minckley et al. 1986). Currently, there are four surviving species of lake suckers found in three lake basins: Utah Lake (Utah), Pyramid Lake (Nevada), and Upper Klamath Lake (Oregon) (Scoppettone and Vinyard 1991). Upper Klamath Lake contains the Lost River sucker (*Deltisties luxatus*) and the shortnose sucker (*Chasmistes brevirostris*), while Pyramid Lake contains the cui-ui (*Chasmistes cujus*). The June sucker (*Chasmistes liorus*) which is endemic to Utah Lake.

Lake Sucker Life History

Due to the harsh and unpredictable environment of desert lakes, lake suckers have adapted to cope with periodic reproductive failure that can be caused by prolonged droughts or extreme flooding. The frequency and duration of high and low stream flow impacts the lake sucker's ability to successfully spawn in tributaries. As a result, the fish that survived in these habitats have developed unique life history strategies to cope with unpredictable, and variable environments (Minckley et al. 2003). To survive periodic recruitment failure, longevity gives lake suckers like other long lived animals, multiple opportunities to successfully spawn (Charnov 1993). All three species of *Chasmistes* (*liorus, brevirostris, and cujus*) can live > 30 years (Belk 1998; Scoppettone 1988). Longevity coupled with high fecundity lessens the need to spawn every year by providing multiple opportunities for success when conditions are favorable (Charnov 2005). There has been speculation that lake suckers do not spawn annually (Buettner and Scoppettone 1990; Scoppettone and Vinyard 1991; Coen and

Shively 2001), particularly when environmental conditions are unfavorable. The act of not spawning has been explained in terms of energy optimization (Stearns 2000; Charnov 2002). In addition to being long-lived, lake suckers are fecund, producing between 24,000 and 236,000 eggs per female depending on age, species, and size (Scoppettone and Vinyard 1991; Minckley et al. 2003). High fecundity can facilitate rapid population expansion during favorable environmental conditions.

To avoid year class failure due to unfavorable spatial and temporal environmental conditions, lake suckers utilize a wide range of spawning sites, including tributaries and shoreline springs. The cui-ui and the shortnose suckers are known to use inflowing springs as well as inflowing streams as spawning sites (Buettner and Scoppettone 1990; Lewis 2002). June sucker have been observed utilizing shoreline spawning habitats in refuge populations (Billman 2005), though it is not known whether they use shoreline spawning sites within Utah Lake.

Human activities such as the construction of water diversions and withdrawals from these lake systems (Hooton 1989) have altered historic lake levels and exacerbated unfavorable spawning condition. Extensive variation in lake depth and surface area can occur within a single season, causing unnatural changes in water temperature, turbidity, salinity, dissolved oxygen, and littoral vegetated habitat over a short time period.

Utah Lake History

Utah Lake (40° 10’ 58’’ N x 111° 43’ 46’’ W) is located in north-central Utah (Figure 1). The lake is a remnant of pre-historic Lake Bonneville, which covered nearly half of the state of Utah from 750,000 to 7250 BC (Figure 2). Today, Utah Lake is the largest freshwater lake, in terms of areas, west of the Mississippi River (Hooton 1989), covering one fourth of Utah Valley with an approximate area of 388 km^2 (96,000 acres), and containing about 900,000 acre feet of water at full pool. The lake has an annual inflow of about 750,000 acre-feet with an average outflow, including irrigation, of 350,000 acre-feet, and an annual rate of evaporation of approximately 400,000 acre-feet (Jackson 1999). Utah Lake is large in surface area but small in volume having a mean depth of 2.9 m, and a maximum depth of 4.2 m.

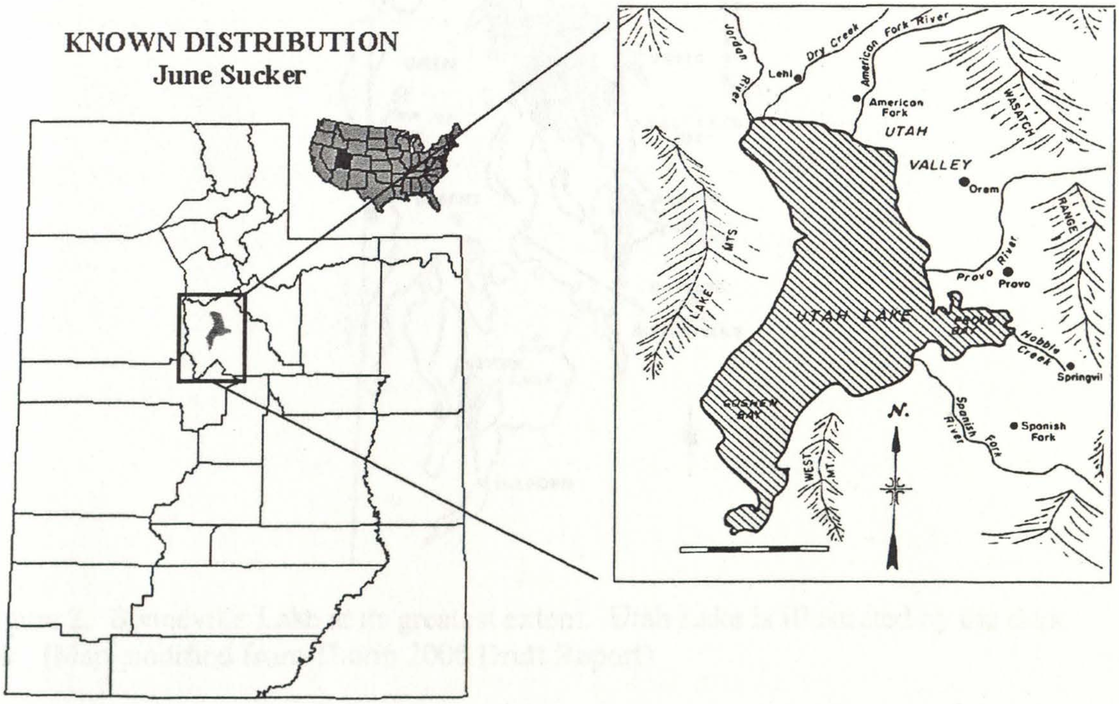

Figure 1. Position of Utah Lake and its tributaries relative to Utah County, Utah (modified from Radant 1981).

The shallow nature and high fetch of Utah Lake, coupled with frequent wind events, effectively inhibit stratification, resulting in high suspended solids (Scheffer

2001; Miller 2006). The high turbidity limits macrophyte growth. In addition, these effects are exacerbated by nonnative common carp (*Cyprinus carpio*). Carp forage in and on macrophytes as well as on the benthic organisms creating further decreases in macrophyte as well as increasing sediment suspension (Miller 2006). Utah Lake is highly eutrophic, turbid, and slightly saline with an average salinity of 1.5 g/L. The lake's limnetic zone is dominated by mud substrate with some littoral areas containing sand, rock, or gravel (3%) (Lentsch et al. 1995). While the lake has a high abundance of phytoplankton and zooplankton throughout the year, there are very few macrophytes present either in abundance or species composition (Miller 2006; Miller and Crowl

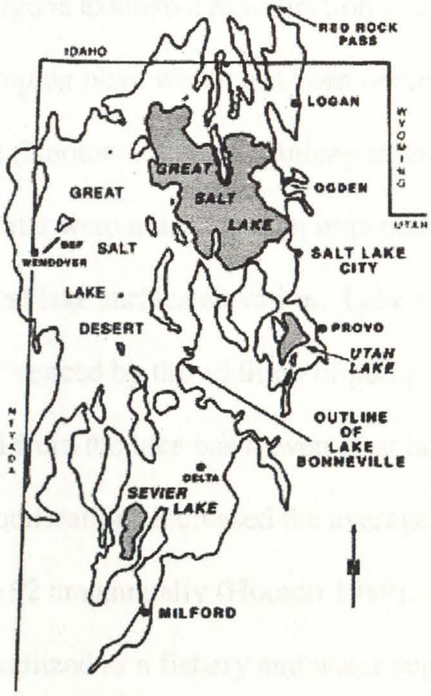

Figure 2. Bonneville Lake at its greatest extent. Utah Lake is illustrated by the dark ink. (Map modified from Thurin 2006 Draft Report)

2004). The lake has a high abundance of phytoplankton and zooplankton throughout the year (Miller 2006).

Utah Lake has five major tributaries: American Fork, Provo River, Spring Creek, Hobble Creek, and Spanish Fork (Figure 1). Historically, June sucker were found to spawn in all tributaries (USFWS 1999), yet all tributaries have been greatly altered over time and currently only the Provo River is known to have a spawning population of June sucker (Minckley and Douglas 1991).

Utah Lake has undergone extensive modification as a result of the construction of an impoundment and pumping plant which has been operated at the lake's outlet on the Jordan River since 1952 (Hooton 1989). Beginning in the early 1900's, modifications to aquatic habitat were made through impounding and diverting tributary inflows which altering natural lake surface elevation. Lake surface elevation fluctuations were further influenced by the addition of pumps at the outlet, which allowed water to be pumped from the lake basin even after lake levels dropped below the natural outlet. These modifications increased the average fluctuation in lake surface elevation from < 60 cm to > 92 cm annually (Hooton 1989).

Utah Lake has been utilized as a fishery and water supply since settlement of Utah Valley in the mid 1800's (Carter 2004). June sucker as well as Bonneville cutthroat trout were heavily utilized as food for humans and feed for livestock. As a result of human consumption and habitat alterations, a nonnative fish stocking program was initiated to mitigate losses of native game fishes due to overexploitation. Native fish stocks were further reduced by these stocking practices through predation and competition. At least 18 invasive nonnative fish persists in Utah Lake to day.

June Sucker Biology

In the middle of the 19th century, written records from researchers, naturalists, and journalists describe June sucker populations as being stable and abundant. The fish was commonly used as a food source by Native Americans and later by early pioneers (Heckmann et al.1981; Scoppettone and Vinyard 1991; NAS 2003). In 1889, suckers were so abundant in Utah Lake that David Starr Jordan described the lake as being the "greatest sucker pond in the universe" (USFWS 1999). Shortly thereafter, lake sucker populations began to decline (Minckley and Douglas 1991). Heavy development after the 1902 Reclamation Act was especially damaging to lake systems throughout the west (Hooton 1989) bringing about habitat alterations (i.e., damming, diverting, diking), increased pollution, and additional nonnative species introductions (Vitousek et al. 1997). Lake suckers throughout the west began to decline and by the 1980's all four species were federally listed under The Endangered Species Act (Carter 1969; Hartman 1973; Scoppettone and Vinyard 1991; Martin and Saiki 1999).

The June sucker is a long-lived, deep-bodied lake sucker, with a terminal mouth, endemic to Utah Lake, Utah (Miller and Smith 1981; Singler and Singler 1987). It is taxonomically characterized by morphmetric and behavioral traits tied to its pelagic feeding behavior. Mouth morphology and dendric gill raker structure are consistent with open water feeding behavior. Historically, the June sucker was potadromous with fish spawning in many of the Utah Lake tributaries, including, but not restricted to, the Provo River, Spanish Fork, American Fork, Hobble Creek, and Current Creek (Cope and Yarrow 1875). However, the only known active spawning currently occurs in the

Provo River (USFWS 1999). Fish arrive at the Provo River to spawn between May and June depending on water levels and water temperature (Scoppettone and Vinyard 1991).

On April 30, 1986, the June sucker was federally listed as an endangered species with critical habitat (51 FR 10857). At the time of listing the wild population was estimated at approximately 1,000 individuals (Keleher et al. 1998). The June sucker was federally listed due to their localized distribution and failure to recruit adult fish, as well as other continued threats to their survival (USFWS 1999). Current population estimates indicate adult wild population numbers as low as 300 individuals (Cooke et al. 2005). The U.S. Fish and Wildlife Service designated the species a recovery priority of 5C; a species that is highly susceptible to extinction and has a low recovery potential (USFWS 1999). Declining abundance of June sucker can be attributed to habitat changes caused by flow alterations (i.e., reservoirs, irrigation), degraded water quality, competition with and predation by nonnative fish species, and commercial fishing. In addition, changes to critical habitat (such as littoral zone vegetation needed for juvenile rearing) have been substantially modified by carp introductions (USFWS 1999; Miller 2006) and water level fluctuation (VanderKooi and Buelow 2001).

Currently, the most significant threat to the survival of the June sucker in Utah Lake is the presence of introduced nonnative predators and competitors (Thomas 1998; USFWS 1999; SWCA 2002). Native stream and lake fauna worldwide have been threatened by introductions of nonnative species (Miller et al. 1989; Moyle and Williams 1989; Myers 1997; Miller 2006). Of the 14 fish species native to Utah Lake, only the June sucker and Utah sucker (*Catostomus ardens*) are currently found in the lake; all other species are restricted to tributaries or have been extirpated from the lake (USFWS 1999; Appendix 1). Since 1871, a total of 30 nonnative fish species have been introduced into Utah Lake, with 15 becoming established (SWCA 2002; Appendix 2). June sucker have established viable reproducing refugia populations outside the present Utah Lake Basin, the most successful of which is established in Red Butte reservoir (Billman 2005). Populations within this reservoir were established from Utah Lake stock, suggesting that the current June sucker stock can produce stable populations in the absence of predation.

Background and Research Justification

Current understanding of June sucker life history is generally not well understood due to paucity of data. Research on age structure (Belk 1998; Billman 2005), reproductive biology (Modde and Muirhead 1994), the vulnerability of juvenile June sucker to predation (Modde and Muirhead 1994; Crowl et al. 1995; Belk 1998; Thomas 1998; Belk et al. 2001), population dynamics of refuge populations (Billman 2005), and bioenergetics (Boits 2005) have been conducted, but little is known about juvenile, sub-adult or adult fish in their native habitat.

Adult June sucker have been difficult to study in their natural habitat due to extremely low number of individuals relative to the large size of the lake. Active efforts to capture lake suckers started in 1991, utilizing a variety of methods such as trammel netting, trawl netting, and trap netting. These efforts have yielded little success in catching June sucker under the conditions present in Utah Lake (USFWS 1999). Passive fish capture techniques are generally ineffective when populations of targeted fish are low and sparsely dispersed or grouped over a large area (Radant and Shirley 1987; Hubert 1996). Since 1997, not a single June sucker has been captured using passive capture techniques (USFWS 1999). As the number of June sucker continue to decline, active fish capture methods have been used during the spring spawning runs to capture adult June sucker (USFWS 1999). These captures have provided information on spawning fish captured in spawning tributaries (Provo River).

Data describing the time June sucker congregate and enter the Provo River to breed, and the effects of temperatures and flow rates on the timing of fish migrations have not been completely investigated. More information regarding cui-ui spawning habits in Pyramid Lake has been compiled. It is believed that cui-ui spawning is initiated by warming temperatures in the spawning tributaries which follow high spring flows (Scoppettone and Vinyard 1991). It is clear that the pre-post spawning habits of Utah Lake June sucker must be identified to make educated decisions regarding adaptive management.

In this study preliminary tests were conducted to determine the feasibility of using radio/acoustic telemetry to monitor the movement behaviors of tagged June sucker in Utah Lake. Radio/acoustic telemetry techniques were specifically designed to monitor the movements of tagged fish in a shallow, turbid, and slightly saline desert lake. These methods have provided distributional and movement behavior of 24 tagged June sucker between April 1, 2004 and February 15, 2005.

There were two overall goals of this research. The first goal was to describe the timing and potential cues associated with June sucker moving to the mouth of the Provo River to spawn. The second goal was to describe adult habitat use during four seasonal periods in Utah Lake. The specific objectives of this study were to (i) describe the extent and duration of pre-spawning behavior for tagged adults, (ii) determine the extent to which post-spawn June sucker utilize Provo Bay, (iii) determine the seasonal movement patterns for tagged adult June sucker in Utah Lake, (iv) compare seasonal habitat selection patterns between wild and re-introduced June sucker and, (v) determine the short term movement behavior during the four sample seasons.

To make comparisons between basic behaviors exhibited by June sucker four basic hypothesis were tested: (i) June sucker select tributary inflows as habitat during non-spawning periods, (ii) June sucker exhibit non-random distributional behavior throughout Utah Lake, (iii) June sucker will exhibit no differences in lake wide distributions between sexes or origins, and (iv) June sucker select substrate habitats disproportional to its availability. This ecological and life history information is essential for the continued management and, ultimately, recovering June sucker.

METHODS

Radio/Acoustic Telemetry

Telemetry Background

Radio telemetry has been used as a method for monitoring free ranging fish in their native environments for several decades (Winter 1996). Methods have been developed to monitor movement, behavior, and physiology from animals not easily observed in the wild, while having minimal influence on the animal's behavior (Winter 1996).

While a useful tool, radio telemetry data can be biased in several manners. Often the numbers of animals that are economically feasible to tag is small relative to wild populations. There is also difficulty and sizeable cost associated with tracking large numbers of individuals, making it difficult to draw inferences between the sample population and the entire population. This bias is traditionally mediated by randomly selecting individuals for study with the assumption that any fish in the population has an equal chance of being included. In large populations this can be difficult especially in situations where multiple behavioral traits are exhibited.

Utah Lake Radio/Acoustic Telemetry

The Utah Lake habitat has posed problems with respect to monitoring the movements and behavior of June sucker. Due to the large area of the lake and the low number of June sucker present, the use of nets and other passive or active gear have presented very few individual captures since the listing of the species. Previous radio/acoustic telemetry projects using active search techniques met with limited detections and prematurely ended. These studies likely realized limited success due to reduced radio/acoustic transmission caused by high specific conductivities, shallow water, and high turbidity. The combination of reduced signal strength and a limited knowledge of the highly mobile nature of June sucker behavior cause a dramatic increase in the amount of effort required to search the large basin of Utah Lake. These factors result in an extremely low detection rate and an inability to relocate or follow tagged individuals.

After conducting a pilot season in 2003, a radio/acoustic telemetry method was designed that utilized both active and passive tracking strategies, with an emphasis on passive monitoring stations randomly positioned in Utah Lake. Spawning behavior was monitored by fixed stations at the mouth of The Provo River. Active radio tracking techniques were used to identify shallow inshore littoral areas being used by tagged fish during the post-spawn period. Seasonal movement patterns and general lake-wide distributions were monitored using randomly positioned hydrophones, with hydrophone pairs simultaneously positioned in the littoral and limnetic zones as well as on the east and west shores of the lake.

Capture and Tagging

Capture Techniques

All tagged fish from 2003 were captured by the Utah Division of Wildlife Resources during their annual monitoring of the June sucker spawning migration in the Provo River. Capture techniques involve nighttime spotlighting and dip-netting of spawning adults from the Provo River. In 2003, only naturalized (non-wild) adult fish (originally stocked into Utah Lake from the Ogden Nature ponds, Camp Creek Reservoir, and Red Butte Reservoir) were selected for implantation with transmitters to minimize potential impacts to the wild population. June sucker were identified as naturalized/non-wild by individual Passive Integrated Transponder tags (PIT) that had been inserted into the body cavity prior to being stocked in Utah Lake.

In 2004, 16 additional adult June sucker were implanted with CART tags (10 wild & 6 naturalized), six of these fish were captured prior to the spawning run in Utah Lake using trammel nets, and 10 during the spawning run in the Provo River by the Utah Division of Wildlife Resource using the methods described above.

Tagging Procedure

Prior to tagging, fish were identified as June sucker using morphometric characteristics defined in the June Sucker Recovery Plan (USFWS 1999). Fish exhibiting characteristics common to the Utah sucker (*Catostomus ardens*) were not selected for inclusion in this study, however fish possessing these morphological traits were tagged and monitored in a companion study. Between the two sucker morphologies present in Utah Lake, an apparent continuum of morphologies exists suggesting complex genetic histories. Only fish exhibiting thin, sparsely papulose lips with a wide separating lip gap, and a large terminal, obliquely positioned mouth, were chosen for inclusion in this survey.

All fish were captured and held in live-wells for 12 hours prior to surgery, to observe their condition (Winter 1996), and 1-3 hours post surgery to visually monitor their recovery from anesthesia (Hart 1975). Fish were held no longer than 3 hours post-surgery to minimize stress associated with captivity. Fish were anesthetized prior to surgery by submersion into tricaine methanesulfate (MS-222) and kept in a water bath until loss of equilibrium was realized (Summerfelt and Smith 1990). During surgery the fish's gills were irrigated with anesthetic solution until the transmitters had been implanted.

Surgical techniques were similar to the modification of Ross and Kleiner's (Ross and Kleiner 1982) shielded-needle technique, which was designed to reduce visceral damage to fish during surgery (Isaak and Bjornn 1996). Surgeries took less than six minutes and were conducted during the early hours of the day, under the cover of shade to minimize effects of heat stress. Fish were given oxytetracycline at a dosage of 50mg/kg of body weight, injected into the body cavity, to reduce the chance of surgery related infection (Martinelli and Shively 1997). Sutures were made with a non-absorbable monofilament to help ensure wound healing and to reduce tag expulsion.

To minimize the effect of the transmitters and surgery on fish behavior, the tag-to-body-weight ratio was held to < 2% of the fish's total body weight. It has been suggested that transmitters weighing < 2% of a fish's total weight can reduce surgery related mortality (Winter 1996). This criterion was met with the exception of two fish tagged in 2003, when fish of adequate size were not available. In these two individuals, the tag was equal to 2.1% of the fish's body weight. Mortalities related to tag-to-body weight ratios exceeding 2% were not realized in this study.

June sucker mortalities were not observed during surgeries in this study, however, three mortality signals were detected. It was not determined if these signals were the result of tag expulsion or an actual mortality. On one occasion, a tag expulsion was observed because the sucker was recaptured in the spawning tributary one year post-expulsion.

Preliminary Methodology Tests

Based on a pilot study aimed at maximizing the efficiency of tracking fish in Utah Lake (Appendix 3), coded acoustic/radio transmitter (CART) were selected for use in this study. CART tags were digitally encoded and programmed to transmit intermittently from June 2003 through June 2005. Transmitters had a life expectancy of 715 transmittable days, with dimensions approximately 16 mm x 60 mm and 25.3 g in air. The advantages of using the CART tags were that they allowed all tagged fish to be detected using both acoustic and radio signals, enabling tagged fish to be tracked in the high saline conditions of Utah Lake using acoustics, and by radio signals in the turbulent condition of the Provo River. To manually track tagged fish, a radio receiver system (SRX_400) and a four element Yagi antenna was used to determine fish position to within 10m. The SRX_400 is capable of tracking and logging digitally encoded transmitters, allowing for multiple fish (up to 221) to be placed on the same frequency but still providing identification of individuals. In addition, four wireless hydrophones were incorporated into the lake wide sampling (WHS_1100) in conjunction with two shore-based receiver data-loggers (SRX_400A) for the purpose of monitoring the movements of tagged fish within Utah Lake.

In 2003, tagged June sucker (n=9) movements were monitored using both manual tracking from a boat, and passive monitoring using fixed-position wireless hydrophones anchored in the substrate. The hydrophones were placed in a manner that allowed the directionality of movement into and out of a bay could be determined based on the sequence of detections. Manual tracking was conducted in areas where tagged fish were believed to be present based on prior knowledge.

Spawning Behavior

Provo River Hydrophones

During the 2004 field season, June sucker movements from the mouth of the Provo River up into the lower river was monitored using two remote wireless hydrophones. The hydrophones were placed at the mouth of the Provo River beginning April 1, 2004 and remained through June 22, 2004. Technical problems were experienced between May 5, and May 9, causing data to be missed for a 92-hour period. Data collection was based on a pair of hydrophones and a shore-based radio receiver. One hydrophone was placed in the lake close to the mouth of the river so that it could receive tags moving through the river inlet, while the second hydrophone was placed in deeper water approximately 500m from the river mouth where congregating fish could be detected (Figure 3). The littoral hydrophone was mounted on an iron fence post secured in the lake bed while the pelagic hydrophone was suspended from a buoy anchored to the lake bed. A radio receiver was placed on shore with an antenna monitoring detections by each hydrophone and monitoring tagged fish as they moved into the river. The direction of travel was determined by observing the sequence of detections for each fish, whether into or out of the river.

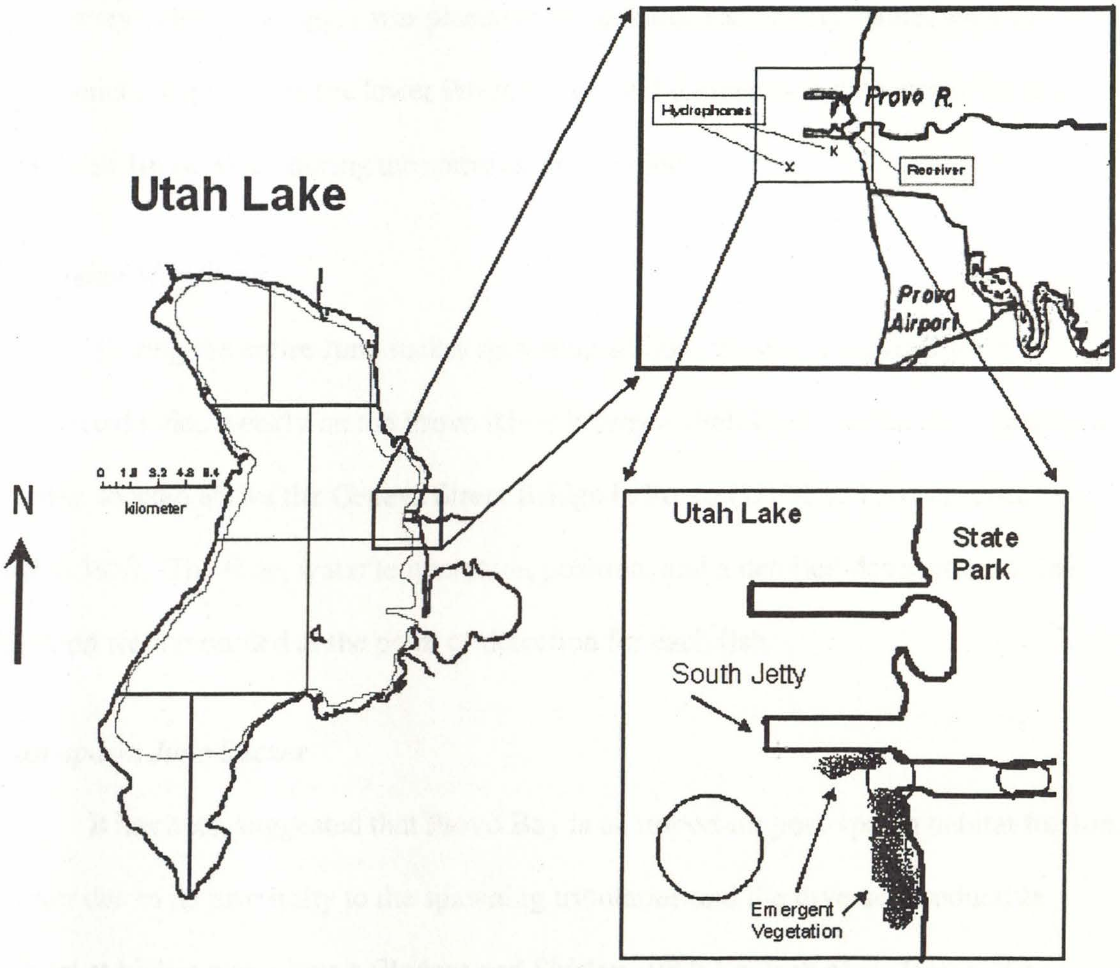

Figure 3. The Provo River confluence with Utah Lake. The ovals from left to right indicate the relevant reception cells for the pelagic and littoral hydrophones and the radio receiver.

The deep water hydrophone detected tagged fish as they approached the river and monitored congregating fish in the vicinity of the Provo River before entering. The shallow hydrophone monitored tagged fish entering and leaving the river inlet and detected them as they passed into the lower river. By delineating the sequence of detections by the hydrophones, and the number and proximity of tagged fish to the mouth of the Provo River was determined. Water temperature was monitored using three HOBO temperature data loggers (Model HOBO H8) during the entire length of the survey. One data logger was placed at the point of each hydrophone, with an additional one placed in the lower Provo River. All temperature data was collected hourly in 1m of water during the entire sample period.

Upstream Movement

During the entire June sucker spawning season, telemetry surveys were completed twice weekly on the Provo River between Utah Lake and the first upstream barrier, located above the Geneva Street Bridge in Provo (UTM 12T, 0441120E; 4454158N). The time, water temperature, position, and a detailed description of the location were recorded at the point of detection for each fish.

Post-spawn June Sucker

It has been suggested that Provo Bay is an important post-spawn habitat for June sucker due to its proximity to the spawning tributaries and the diverse, productive habitat at higher water levels (Radant and Shirley 1987; Lentsch et al. 1995). To monitor the presence of tagged fish in Provo Bay during the post-spawn period, a pair of wireless hydrophones was placed in the mouth of the bay so that the detection area covered the inlet. The hydrophone pair was deployed in a manner such that tagged fish moving into or out of the bay could be detected by one hydrophone followed by the second. In this manner, by comparing the timing and sequence of detections, direction could be determined. Hydrophones were in the mouth of the bay between April 15, and June 25, 2004.

Water temperature was monitored in Provo Bay using the same type of temperature loggers used in the Provo River. One temperature logger was placed by each hydrophone, and another one placed approximately 3 km from the bay in the open limnetic zone of Utah Lake. In the mouth of the bay, water depths were less than 1m for the majority of the sample period so temperatures were recorded at the mid-point of the water column.

Utah Lake Movement Behavior & Habitat Selection

Influence of River Tributaries on Non-spawning Behavior

To test the hypothesis that fish utilize tributary inflows during non-spawning periods, a monitoring protocol was designed to randomly survey lake areas with tributaries and lake areas without tributaries. Due to poor radio attenuation on tags in water deeper than 1.5 m, manual tracking was limited to shallow water habitats (<1.5 m) in 2004. The lake was divided into eight strata with four strata with tributaries and four strata without tributaries (Figure 4). Lake areas less than 1.5 m were identified within each stratum (Figure 4).

Within each selected stratum, three 1500 m long transects were completed so that one was centered at a tributary inflow, one distant (> 2.0 km) from an inflow, and one on the western side of each stratum where tributaries were absent (Figure 4). At the point of fish capture detailed descriptions were made of the capture location including substrate composition, water depth, and temperature.

In 2004, surveys were completed between 4:00 and 12:00 hours due to poor weather conditions and frequent thunderstorms. Transects were randomly selected by overlaying a NAD 27 km grid over the areas identified as being < 1.5 m deep and numbering each square kilometer (Figure 4). Once a site was selected, a transect was

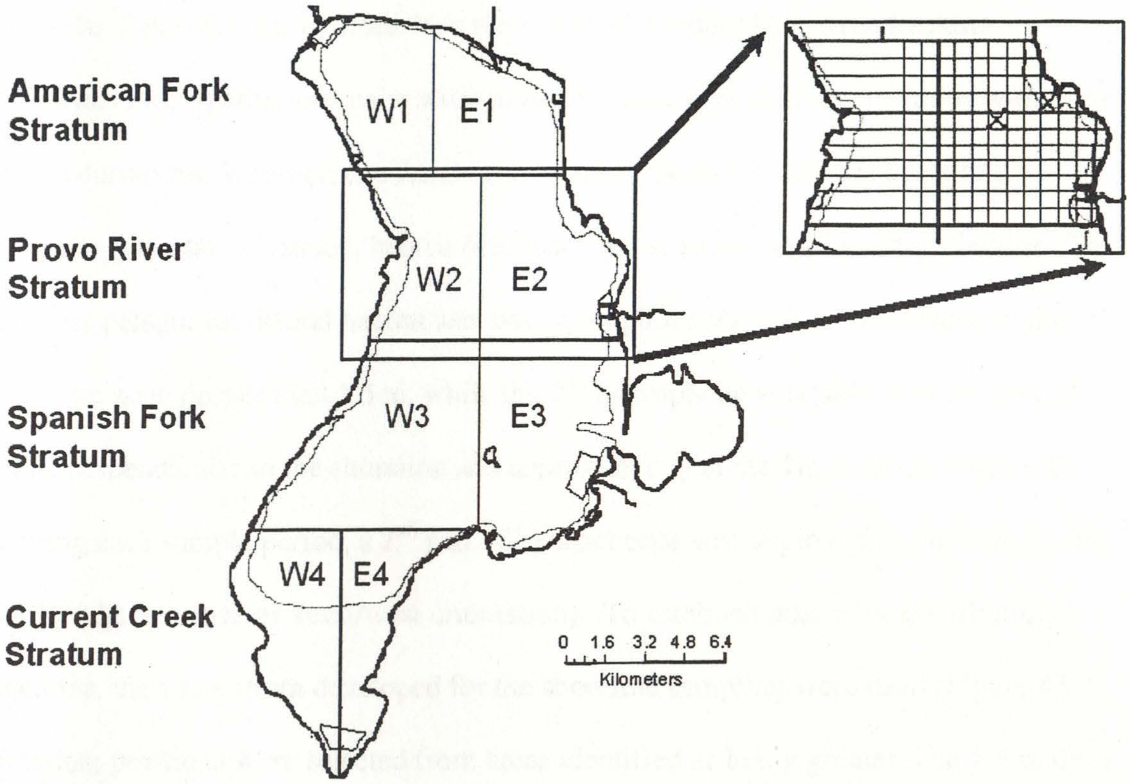

Figure 4. The strata boundaries as they were used in the Utah Lake study. Dark horizontal and vertical lines indicate the approximate boundaries of the eight sample strata. The gray contour line indicates the 1.5m water contour. Areas enclosed by polygons are the approximate zones designated as being river inlets. The exploded view shows an example of the grid system used to select sample sites.

completed by starting on one side traveling along the 1m contour through the selected stratum. Fish detected during a random survey as a result of a previously detected fish were only included in this analysis if they fell within the detection range (300 m) of the transect centerline.

Habitat Selection Study

To test the hypothesis that fish randomly utilize all areas of the lake, a survey was conducted to randomly monitor the abundance of tagged fish over four seasonal periods. Four wireless hydrophones were used to conduct lake-wide tracking surveys. Two hydrophone pairs were placed in randomly selected positions within the strata during two summer, one fall, and one winter period to address questions regarding habitat utilization, habitat selection, and seasonal aggregation behavior. To address pelagic vs. littoral habitat use, one hydrophone was randomly placed in the limnetic zone deeper than 1.5 m, while the 2nd hydrophone was placed in the littoral zone perpendicular to the shoreline and approximately at the 1m contour (Figure 4). During each sample period, a 2nd pair of hydrophones was deployed as outlined above in the adjacent stratum (east/west orientation). To establish lake wide distributional patterns, the same strata developed for the shoreline sampling were used (Figure 4). Random positions were selected from areas identified as being greater than 1.5 m deep on USGS NAD 27 square kilometer grid, in the same manner as shoreline sampling.

Hydrophones were located in a single position for a period of 6-9 days before being relocated into the next strata. To make comparisons, the entire sample period was divided into four separate seasonal sample periods based on variability in mean water temperature (Appendix 4).

The wireless hydrophones collected data at each site continually, recording detections at a maximum rate of 1 record every 22 seconds. Data recorded at this rate can result in large numbers of detections over short periods of time, especially for fish exhibiting sedentary behavior, spending long periods of time near a hydrophone. Due to the duration of sampling at a stationary position, all detections in this study have been defined as a single detection during a 12 hour light and a 12 hour dark period.

Therefore an individual fish is only indicated once during a high light period (06:00 and 17:59) and once during a low light period (18:00 and 5:59) daily.

All detection data were analyzed using PROC FREQ in SAS (SAS Institute 1999), for length of sample and the number of detections per individual per day. To test the hypothesis that fish behavior was not a result of heritage or sex, an effort was made to tag an equal ratio of sexes and wild vs. supplemental June sucker (Appendix 5). A Cochran-Haenszel Statistics for RxC tables using SAS was used to test for significant differences between tagged fish abundances in the littoral vs. limnetic zones, differences between seasonal spatial distributions, and between wild vs. natural fish.

Substrate Selection

In order to test the hypothesis that fish selected areas of the lake based on substrate type, substrate was identified at each sample site and compared to lake-wide availability as described by Lentsch et al. (1995). Substrates were described through visual observation of samples collected from each site. Due to the vast preponderance of available mud habitats compared to bedrock, cobble, and sand, all non-mud habitats were combined for analysis. These variables were then correlated to fish abundances among the sample strata to determine selection of substrate by fish.

Weekly Movements

An estimate of minimum linear weekly distance traveled for tagged fish during the four sample periods was produced using the distances between the randomly placed lake-wide hydrophone sample sites. During each of the four sample season there were eight positions sampled, providing known distances between the hydrophone sets. Each time a fish was detected by a neighboring hydrophone sets, during two consecutive weeks, the distance between those detections was used to produce an overall mean distance traveled for that individual. To test for significant differences between mean distances traveled by individuals during each season, an ANOVA was used.

RESULTS

Capture and Tagging

In 2003, 12 adult June sucker were tagged, with three becoming mortalities (Appendix 6). Two mortalities occurred in the Provo River shortly after surgery, while a third occurred in the spawning tributary during the early winter. Of the 16 fish tagged in 2004, only a single mortality was observed in the Provo River; the tag was recovered two weeks after the fish was released (Appendix 6). Thus the total sample includes a tagged population of 24 individuals over the two years. The total tagged fish population included 11 females and 13 males, with 11 fish identified as wild and 13 tagged fish identified as being either from the Fisheries Experiment Station in Logan, UT, or from the Red Butte Reservoir refuge population (Appendix 6). All supplemental fish had been stocked into Utah Lake at leased two years prior to being included in this study.

Preliminary Methodology Tests

The radio component of the CART tags had a maximum detection range of 300 m at a depth of 1 m and 100 m at a depth of 2.5 m (Table 1). Increasing specific conductivity significantly affected the range at which a radio tag could be detected. As the 2003 field season progressed, lake-wide specific conductivities increased from 900 to 2300 ms, further suppressing radio attenuation. It was hypothesized that the acoustic component of the CART tags would out-perform the radio transmitter component; however, due to the shallow, highly turbid nature of Utah Lake, this difference was not apparent (Table 1).

Table 1. Detection distances (m) at different water depths for all radio and acoustic receiving devices.

Gear Type	Water Depth (M) 1.0	 1.5	 2.0	 2.5
4 element Yagi antenna	300	225	160	<100
Handheld hydrophone	300	300	325	380
4 element Yagi antenna from plane	500	N/A	N/A	150
WHS_1100 Wireless Hydrophone	250	300	400	N/A

As water depth increased and turbidity decreased, the range of the acoustic transmitters increased. The WHS_1100 (Lotek Wireless Co.) remote wireless hydrophone was tested on July 17, 2003 and was more sensitive than the previously tested hand-held hydrophone, with a range >400 m in 1 m of water. Further equipment testing results related to these surveys are listed in Appendix 3.

Radio telemetry surveys were conducted throughout Utah Lake from the summer, to the winter of 2003, to identify areas within the lake utilized by tagged June sucker. Seven out of nine tagged fish were detected in the eastern portion of the Provo River, Spanish Fork and the American Fork strata (Figure 5). During the early summer June sucker were found with a relatively high frequency (23 detections) south of the spawning tributary. As the summer progressed, fish dispersed. Because efforts to find tagged fish in 2003 were not randomized data were not used in further analysis.

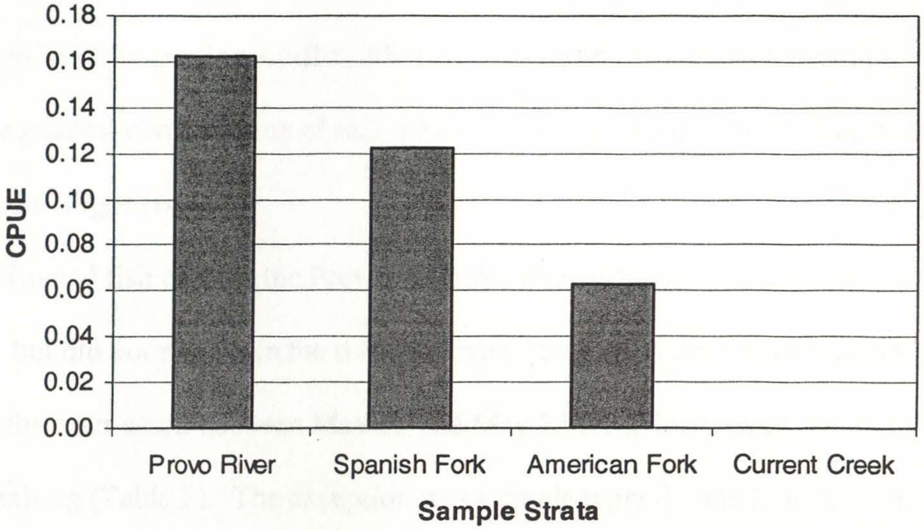

Figure 5. The 2003 June sucker CPE, using a hand-held receiver. East and west strata were combined due to low detection rate.

Spawning Behavior

Provo River Hydrophones

During the 1,840 h of continuous monitoring effort, nine fish from the 2003 tagging effort and four fish of the 16 tagged in 2004, tagged during the winter of 2004, (prior to the spawning season), were detected at the mouth of the Provo River. The 12 additional June sucker captured and tagged in the Provo River during the 2004 spawning run (April 30 - June 15, 2004) were not included in this spawning analysis due to the likely disruption of normal spawning behavior caused by capture and surgery.

All June sucker tagged prior to the 2004 spawning season were detected by the hydrophones at the mouth of the Provo River, resulting in a total of 570 detections. Eight fish entered the lower Provo River and moved more than 500 m upriver where they were observed by the radio monitoring system. The other fish were never detected moving up the river by the monitoring equipment. Fish were present at the mouth of the Provo River beginning April 1, 2004, and persisted throughout the sample period, with the greatest congregation of individuals occurring in early April prior to increasing river flows (Figure 6).

Tagged fish entered the Provo River for short time periods between April 3 and April 8, but did not remain in the river for more than two hours before exiting. Fish entered the river again between May 15 and May 25 for a duration of one to three days before exiting (Table 2). The exception was a single tagged male (tag #29, which spent 37 consecutive days in the Provo River, between April 7 and May 14, 2004.

Flow data in the Provo River at (UTM 12T 0439790E;4454180N) was collected

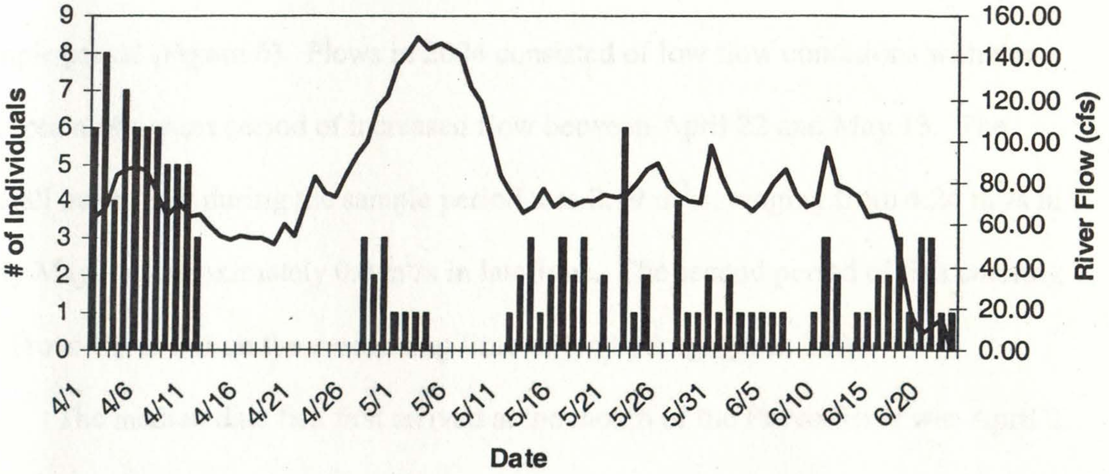

Figure 6. Number of June sucker present at the Provo River mouth from April 1-June 22, 2004. Line indicates mean daily river flow (flow data provided by CUWCD).

Table 2. First and last capture for June sucker at the mouth of Provo River between April 1 and June 15, 2004.

Code	Sex	Origin	Released Year	First Capture	Last Capture	Into River	Out of River	# of Days Detected
1	F	S	2003	4/2	6/22	4/3&4/8	4/4&4/9	14
18	M	S	2003	5/23	6/16	--	--	5
29	M	W	2003	4/7	6/20	4/7	5/14	5
34	F	S	2003	4/2	5/31	--	--	6
100	F	S	2003	5/23	6/21	--	--	2
129	M	S	2003	4/29	--	--	--	1
143	M	S	2003	4/3	5/21	4/3	?	2
183	M	W	2003	4/6	6/18	--	--	2
203	F	S	2003	5/14	--	--	--	1
116	M	S	2004	4/29	6/20	5/15	5/18	10
133	M	W	2004	4/28	5/25	5/25	5/25	3
204	F	S	2004	4/30	6/10	5/19	5/19	8
12	F	W	2004	4/30	6/11	5/18	5/18	5

[1] Origin S = Supplemental fish introduced into Utah Lake; W = Wild fish captured and tagged in Utah Lake.

[2] The dates given under the columns "Into River" and "Out River" refers to the data at which tagged fish were detected moving into or out of the Provo River

by the Central Utah Water Conservancy District (CUWCD) throughout the entire sample period (Figure 6). Flows in 2004 consisted of low flow conditions with the exception of a short period of increased flow between April 22 and May 13. The overall mean flow during the sample period was 2.19 m^2/s, ranging from 4.24 m^2/s in early May, to approximately 0.0 m^2/s in late June. The second period of fish entering the Provo River fell on the descending limb of the hydrograph in 2004.

The median date fish first arrived at the mouth of the Provo River was April 2 for females (N=6) and April 3 for males (N=7; Figure 7). The was no significant difference between arrival dates of the sexes (P = 0.348; df = 10). The median date

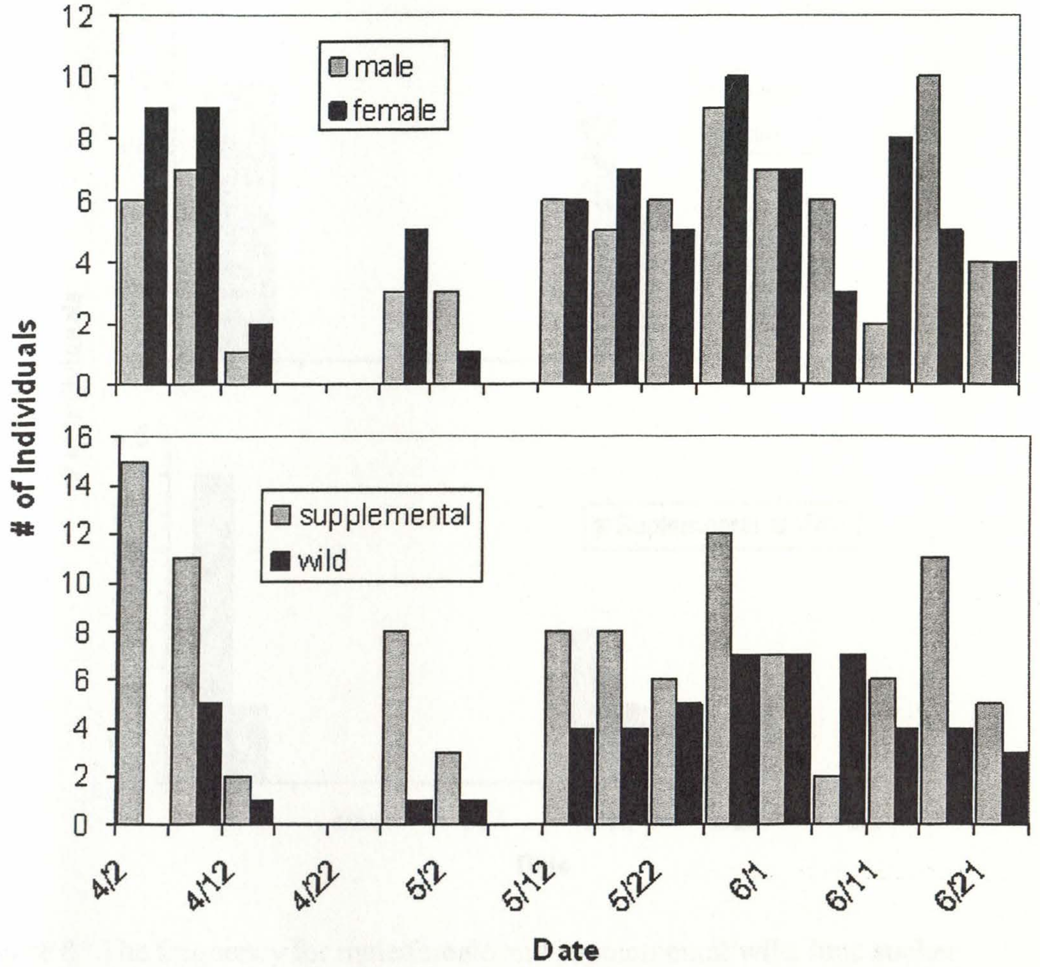

Figure 7. Detection frequencies for male/female and supplemental/wild June sucker recorded in the Provo River, 2004.

supplemental and wild fish first arrived at the mouth of the Provo River was April 2 for supplemental fish (N=9) and April 6 (N=4) for wild fish (Figure 7). There was no significant difference between these groups (P = 0.344; df = 8). The median time female/male June sucker to entered the lower Provo River was April 28 and April 26, respectively (Figure 8). There was no significant difference between groups (t-test, p=0.489). Tagged, supplemental fish entered the lower Provo River with a median

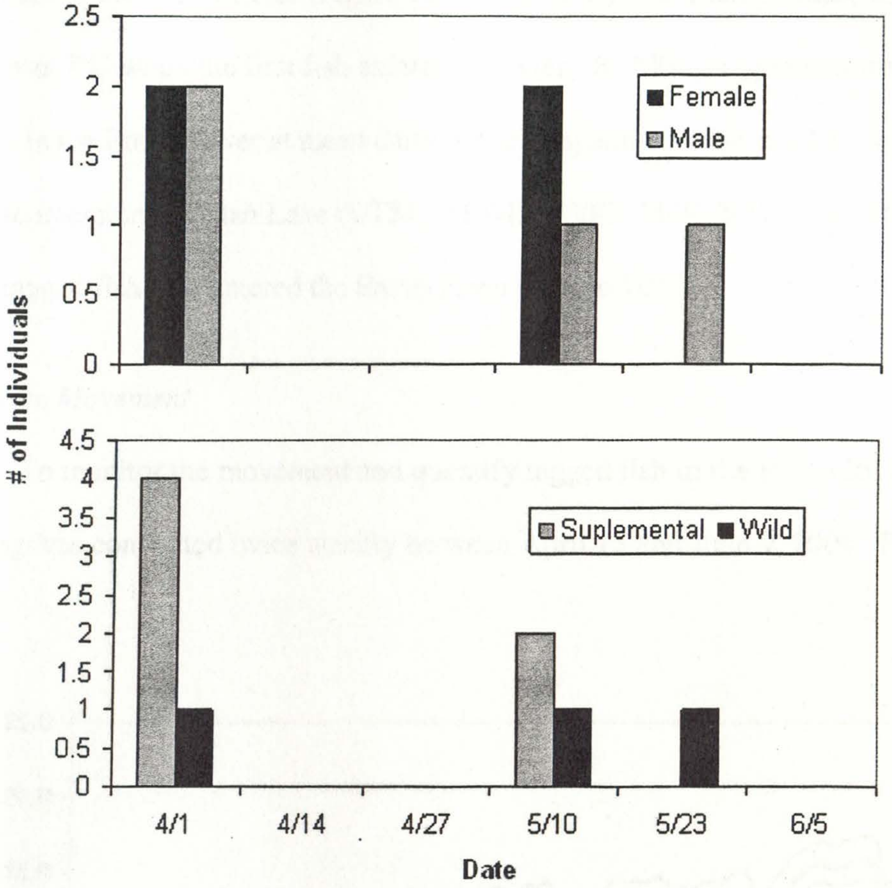

Figure 8. The frequency for male/female and supplemental/wild June sucker entering the Provo River in

time of April 8 (N=5), while tagged wild fish entered on May 18 (N=3) (Figure 8).

In 2004, June suckers moved into the shallow water of the Provo River mouth independent of time of day. There were 302 fish detected at the mouth of the Provo River recorded between 06:00 and 17:59 (high light period), and 268 between 18:00 and 05:59 (low light period).

Water temperatures in the Provo River ranged between 5- 20°C during the sample period with a daily mean of 12 °C (SD 2.45; Figure 9). Mean daily water temperatures in the lake were 15°C (SD. 2.45) when tagged fish were first detected at the mouth of the Provo River (Figure 10). Mean daily water temperature in the Provo River was 7°C when the first fish entered the river. In 2004, tagged fish were not present in the Provo River at mean daily water temperatures above 14°C. Mean daily water temperature in Utah Lake (UTM 12T 0434430E: 4449730N) was 15°C (SD 2.45) when tagged fish first entered the Provo River (Figure 10).

Upstream Movement

To monitor the movement and quantify tagged fish in the Provo River, manual tracking was conducted twice weekly between April 15 and June 9, 2004. Radio

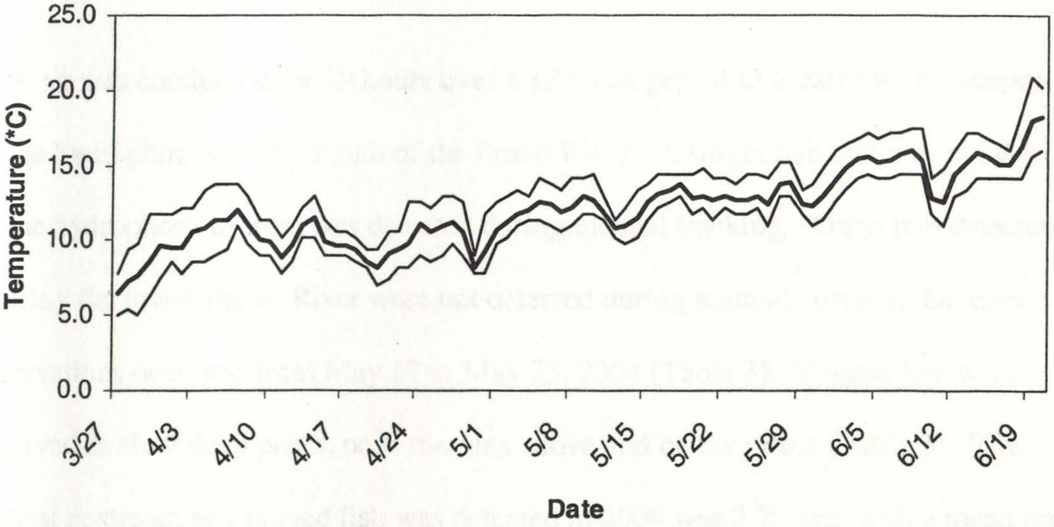

Figure 9. Water temperatures in the lower Provo River 2004. Thin lines represent the minimum and maximum daily temperature, while the heavy line represents the mean daily temperature.

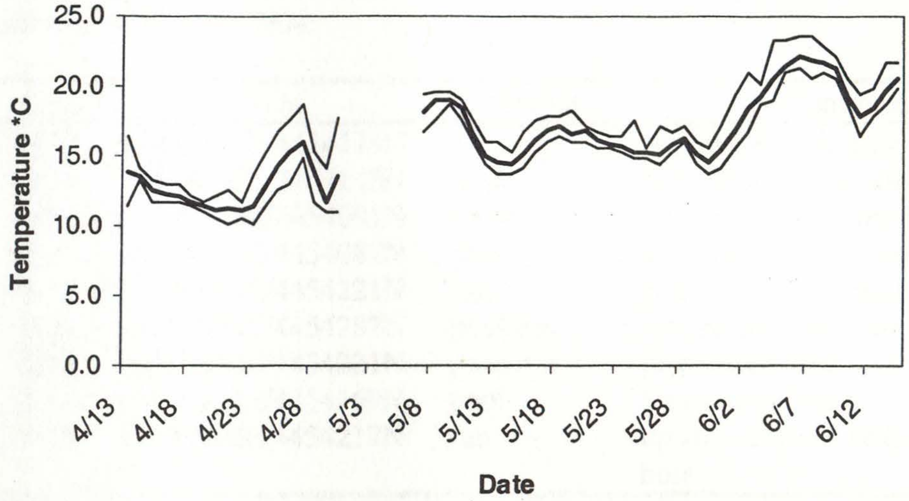

Figure 10. Minimum, maximum, and mean daily water temperature at a single pelagic site in Utah Lake between 4/13/04 and 11/4/04, measured at a depth of 1 m in 2 m total depth.

tracking was conducted for 29 hours over a 12-week period to locate the fish recorded by the hydrophones at the mouth of the Provo River. A single fish that was not detected by the hydrophone system was detected during manual tracking. Three fish detected entering the lower Provo River were not detected during manual surveys. Dates of observations occurred from May 12 to May 23, 2004 (Table 3). Tagged fish were observed in slow deep pools, or in the runs above and below pools (Table 3). The farthest upstream any tagged fish was detected in 2004 was 3.75 km, with a mean travel distance for all fish being 2.49 km (SD 1.29, N=5; Figure 11). Based on locations fish were observed, fish could have moved farther up river.

Table 3. All tagged June sucker detected during manual radio tracking in the Provo River between 4/15 and 6/9/04.

Code	Date	UTM	Habitat	Comment
12	5/12	12439115E/4454174N	pool/run	just above fish weir
12	5/14	12439097E/4454145N	pool	just above center street bridge
12	5/18	12438873E/4454091N	pool/run	just below fish weir
18	5/23	12437809E/4454087N	pool	just above center street bridge
29	5/12	12439936E/4454221N	run	just above swimming hole
116	5/18	12437490E/4454282N	pool/run	just below fish weir
133	5/12	12439926E/4454221N	pool/run	just above weir
133	5/14	12439123E/4454169N	pool	Swimming hole
133	5/18	12439892E/4454217N	run	up stream from swimming hole

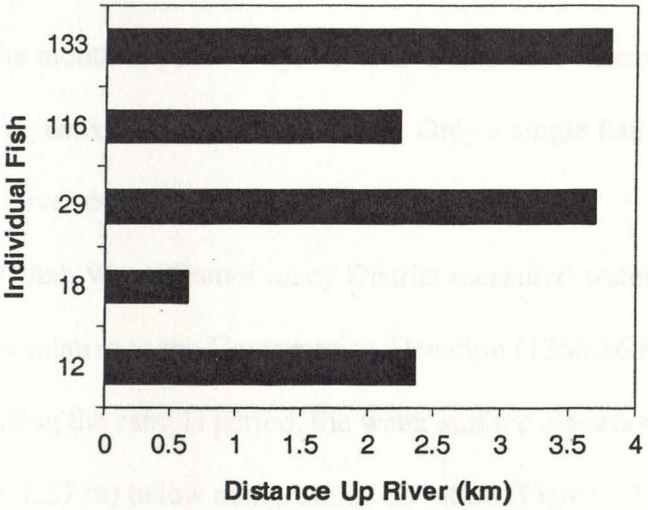

Figure 11. The maximum detected distance (km) traveled up the Provo River from its confluence with Utah Lake for five June sucker detected in 2004.

Post-spawn June Sucker

In 2004, the mouth of Provo Bay was continuously monitored between April 12 and June 15 (1,296 total hours). Due to equipment and battery failure, data were lost or missed on two brief occasions (May 15-May 16 for 20 hours, and May 23-May 26 for 68 hours).

Nine of the 13 fish tagged prior to the 2004 spawning season were detected in Provo Bay either prior to, during, or after the spawning season. Additionally, seven of the additional 11 surviving June sucker tagged during the 2004 spawning season, were detected moving into Provo Bay after the spawn. In total, 67% of the 24 tagged fish entered the mouth of Provo Bay between April 12 and June 15, 2004.

Sixteen June suckers were detected at the mouth of the Provo River prior to being detected in the mouth of Provo Bay, while five fish were detected at the mouth of the bay prior to being detected at the Provo River. Only a single fish was not detected in either the Provo River or Provo Bay during 2004.

The Central Utah Water Conservancy District measured water surface elevations of Utah Lake hourly relative to the Compromise Elevation (1368.26 m) of 1980 (Hooton 1989). During the sample period, the water surface elevation dropped by 0.33 m (from -1.24 m to -1.57 m) below compromise elevation (Figure 12). Water surface elevation in Utah Lake lower than -1.57m below compromise reduces total water depth in Provo Bay to < 8cm. This undoubtedly reduced habitat availability and quality within the bay.

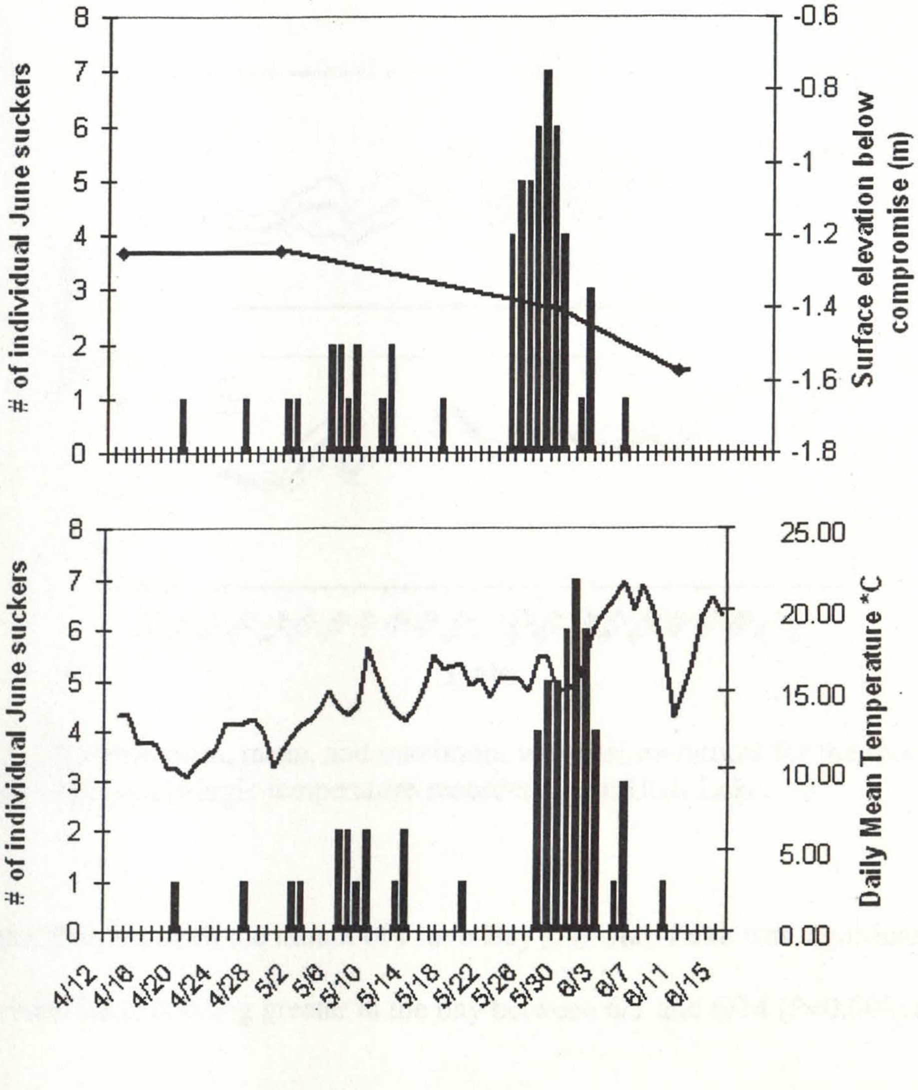

Figure 12. Water surface elevations and mean daily water temperature compared to the daily number of individuals tagged June sucker present in the month of Provo Bay.

Water temperatures in the mouth of Provo Bay ranged from 8-26°C, with a mean of 15°C (SD 3.64). Shortly after the peak in June sucker abundance, there was an increase in mean daily water temperature in the bay (Figure 12). The increase in temperature was due to a decrease in water depth (Figure 12). The daily range in water temperature was more significant in Provo Bay than in the lake (Figure 13). The diel

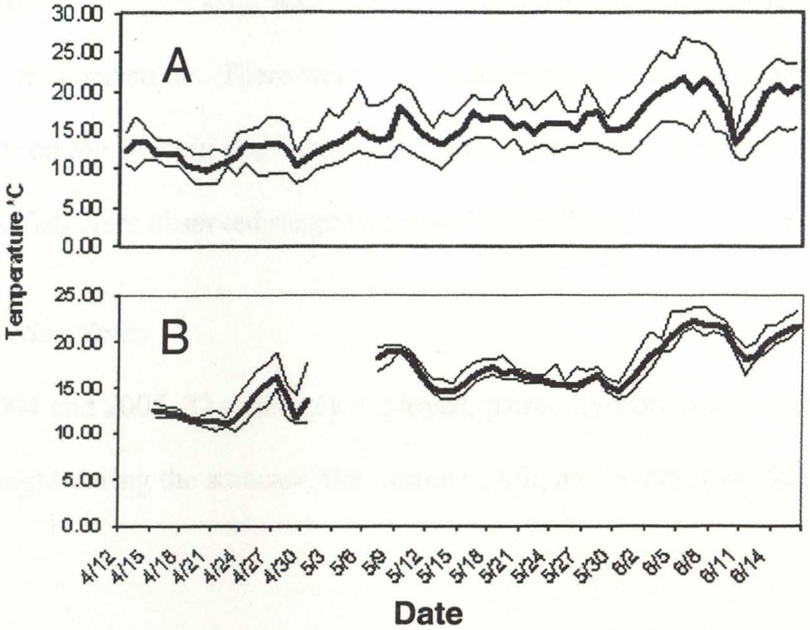

Figure 13. The minimum, mean, and maximum water temperatures for the mouth of Provo Bay (A) and a pelagic temperature recorder (B) in Utah Lake.

temperature flux between the mouth of Provo Bay and Utah Lake was significantly different with the flux being greater in the bay between 6/1 and 6/14 (P=0.008; df=17).

Utah Lake Movement Patterns & Habitat Selection

Influence of River Tributaries on Non-Spawning Behavior

To determine the importance of tributaries as post-spawn June sucker habitat, three 1.5 km transects were sampled during the four sample seasons. Between June 22 and July 28, 2004, ten independent detections were obtained for nine individual fish,. Each survey covered an approximate area of 300,000 m^2.

Ten tagged fish were located on the east side of the Spanish Fork stratum (3E) and the east side of Current Creek stratum (4E) (Figure 14; for strata explanation see

Figure 4). Nine individual fish were detected in the shallow, inshore areas on the east side of the 3E stratum over sand substrates. A single detection was made in the 4E stratum over mud substrate. There were no fish detected in transects near the tributaries, or on the western shore during this study the study. Water temperatures at places where fish were observed ranged between 20-24°C in 1 m of water.

Habitat Selection Study

In 2004 and 2005, 32 randomly deployed, paired hydrophone surveys were completed; eight during the summer, late summer, fall, and winter (n=24). Efforts were

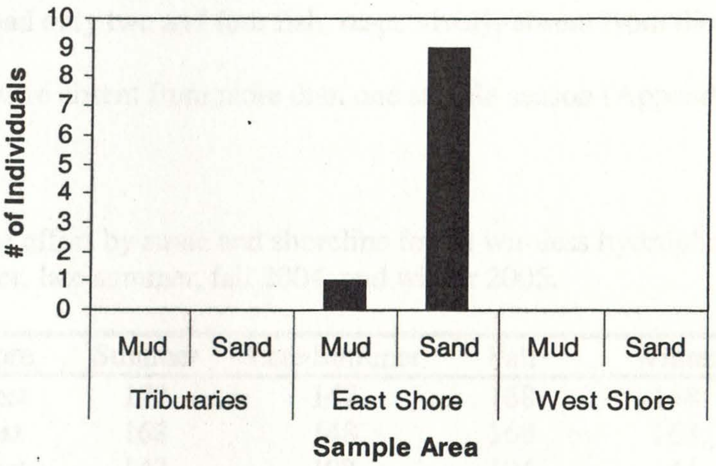

Figure 14. Number of tagged June sucker detected during manual tracking conducted for the tributary use surveys.

made to keep the duration of each sample even, however due to uncontrollable factors this was not possible (Table 4). In data analysis, correction was made to the number of detections and for the duration of each sample. Seasonal sample periods were defined from the variation in mean daily lake temperatures taken in Utah Lake at 1m of depth during all sample efforts (Table 5). The summer period was characterized by relatively high temperatures. The late summer sample was conducted during a period of variable lower mean daily water temperatures. The fall sample was characterized by rapidly dropping temperatures and the winter samples by stable low mean daily lake temperatures.

During all four sampling seasons, 6,766 detections were recorded for the 24, tagged fish (Appendix 7). All 24 tagged fish were detected during at least two of the four sample seasons. During the summer four fish were not detected. During the late summer all 24 fish were detected in at least one stratum, while the fall and winter sample-periods had only two and four fish, respectively, absent from the samples. Only two tagged fish were absent from more than one sample season (Appendix 7).

Table 4. Hours of effort by strata and shoreline for all wireless hydrophone sets made during the summer, late summer, fall 2004, and winter 2005.

Strata	Shore	Summer	Late Summer	Fall	Winter	Totals
1W	West	172	142	168	168	650
1E	East	168	148	168	168	652
2W	West	142	193	194	144	673
2E	East	142	168	168	144	622
3W	West	143	171	193	144	651
2E	East	187	200	195	144	726
4W	West	243	219	190	192	844
4E	East	168	220	219	168	775

Table 5. Mean, minimum, and maximum temperature during each sample season in 2004 and 2005.

	Summer	Late Summer	Fall	Winter
Date	7/6/04-8/10/04	8/11/04-9/22/04	10/10/04-11/4/04	1/20/05-2/15/05
Mean	23.70	18.50	11.92	3.70
Minimum	20.57	13.32	7.83	1.17
Maximum	25.17	23.24	17.90	5.44
STDV	0.98	3.16	2.42	0.09

No significant differences were observed for hydrophone performance among seasons (Table 6). No significant difference was detected between the distances a tag could be detected within seasons. There was a significant difference between littoral and limnetic sets over all seasons (P = < 0.001, df = 31).

The summary statistics for strata by season showed the observed frequencies are significantly different (P = 0.001, α = 0.05; Appendix 8) from a random distribution for the 1012 independent detections. During all four sample seasons fish exhibited spatially clustered behavior. During the four sample seasons 2004/05, tagged fish exhibited long distance movements and frequent shifts in position among strata with many individuals being present in multiple strata during one sample period (Figure 15).

Table 6. Seasonal means (rounded to the nearest 1 m) for range tests performed on hydrophones sets during the lake wide sampling. Each cell shows the mean distance during season and one standard deviation.

	Summer		Late Summer		Fall		Winter	
Shore	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic
East	380$^+$/.35	400$^+$/.0	350$^+$/.40	375$^+$/.3	375$^+$/.3	400$^+$/.0	450$^+$/.5	455$^+$/.5
West	370$^+$/.40	400$^+$/.0	340$^+$/.25	350$^+$/.0	375$^+$/.3	400$^+$/.0	430$^+$/.25	450$^+$/.0

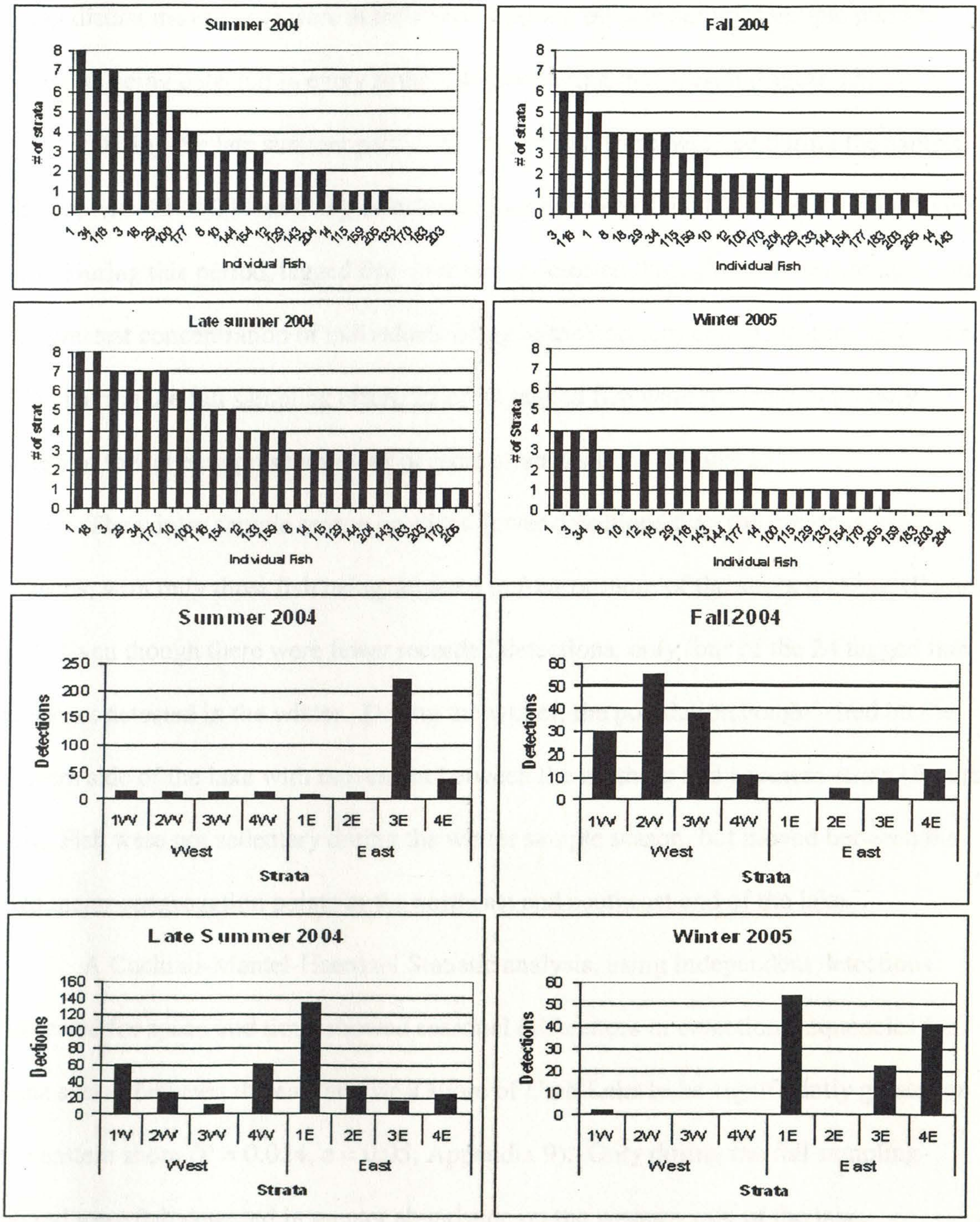

Figure 15. The top four boxes show the number of strata individual June sucker were detected in during each sample season. The bottom four boxes show the distribution of independent detected for each strata during each season. Locations represented by the x axis are illustrated in Figure 2.

Long distant movements were at their zenith during the late summer sample period, with fish being detected in every strata sampled during that season (Figure 15).

During the late summer period, all tagged fish were detected during the sample period, with 14 of 24 fish being detected in four or more of the 8 east/west strata (figure 15). During this period, tagged fish were being detected throughout the entire lake with the greatest concentration of individuals being in the northern end of stratum 1E (Figure 15). During the fall sampling effort, 22 of 24 tagged fish were detected, with only seven of them being present in four or more strata sections (Figure 15).

The winter sample season provided fewer detections than the previous sample seasons, with only three fish being detected in four or more of the strata sections (Figure 15). Even though there were fewer recorded detections, only four of the 24 tagged fish were not detected in the winter. During the winter, the population congregated on the eastern side of the lake with movement between the northern and southern strata (Figure 15). Fish were not sedentary during the winter sample season, but moved between the two major congregation points in the northeast and southeast end of the lake.

A Cochran-Mantel-Haenszel Statistic analysis, using independent detections corrected for space and time, showed seasonal differences in detection frequencies for June sucker between the east and west shore of Utah Lake to be significantly greater on the eastern shore ($P = 0.024$, $\alpha = 0.05$; Appendix 9). Only during the fall sampling-period were fish detected in greater abundance on the western side of the lake.

Variation between detection rates in littoral vs. pelagic hydrophone sets showed no significant difference ($P = 0.1678$, $\alpha = 0.05$) between across seasons (Table 7). There was a significant difference during the summer, late summer and fall sample

Table 7. Summary statistic for the PROC FREQ procedure in SAS (1999) for littoral vs. pelagic detections of tagged fish, over all seasons, using the Cochran-Mantel-Haenzel method. Table scores are shown in Appendix 7.

Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	1.9021	0.1678
2	Row Mean Score Differ	1	1.9021	0.1678
3	General Association	3	34.05778	<.0001
	Total Sample Size = 1012			

periods when considered independently (P = 0.001, α= 0.05). Use of the littoral zone was highest during the summer, but declined during the late summer and fall (Appendix 10). During the winter, the numbers of detections in both zones were nearly equal. There was no difference in habitat use of the littoral and limnetic zones in relation to light period (high-light 6:00–17:59 pm and low-light 18:00–5:59 pm). During all seasons in both zones, there were less detections during low-light periods than high high-light periods.

Substrate Selection

June sucker favored substrate types inconsistent to habitat availability. Mud habitats in Utah, are estimated to comprise 97% of the lake bottom, while all other substrate types combined (sand, coble, bedrock) are estimated to comprise 3% of the total (Lentsch et al. 1995). During lake-wide surveys conducted in 2004, mud substrate habitats were observed to make up 87% of littoral and 97% of limnetic habitats as averaged over all four seasons. To determine whether fish are selecting habitats disproportionately to the availability, detections expected based on habitat proportion were calculated and compared to the observed values (Arcos 2000; Table 8). A chi-square goodness of fit test showed the actual values to differ significantly from the expected values (Chi-square = <0.0001). During these surveys, only 32% of detections were made over mud substrates, which was significantly fewer than the expected range of values (87%-97%).

Table 8. June sucker observed and expected detection rates for mud substrates a during the 2004 lake wide hydrophone sampling (for 87% mud substrates).

Individual Code	Observed Frequency	Expected Frequency	Observed/ Expected
1	151	163	0.93
3	48	58	0.83
8	23	34	0.69
10	16	35	0.45
12	11	16	0.67
14	6	31	0.19
18	83	95	0.88
29	48	60	0.80
34	49	63	0.78
100	14	15	0.90
115	9	16	0.55
116	57	105	0.54
129	10	15	0.68
133	8	10	0.78
143	3	6	0.50
144	14	31	0.45
154	23	50	0.46
159	9	9	0.95
170	4	3	1.16
177	15	39	0.39
183	4	5	0.78
203	3	3	1.16
204	9	41	0.22
205	15	17	0.87
SUM	**632**	**920**	**0.69**

Weekly Movements

June sucker exhibited the greatest linear weekly movement during the late summer study period (Figure 16) The mean linear weekly distance traveled by June sucker during the summer, late summer and fall sample periods in 2004 were found to be significantly different ($P < 0.001$, $\alpha=0.05$; Table 9). The winter sample period had too few consecutive detections for individuals, so comparisons for that season were not made.

The minimum linear distances traveled by individual fish disregarding consecutive weekly detections was 20.39 km during the winter (Figure 16). Mean distances calculated disregarding consecutive weekly detections produced values for the summer of 27.15 km, late summer 31.29 km, and 18.00 km in the fall (Figure 16).

Table 9. Summary statistics for a single factor ANOVA, comparing the variability of the mean minimum linear weekly distance traveled by individually tagged June sucker during the summer, late summer and fall sample periods. The winter sample period was excluded from this analysis because too few detections were made for individuals on consecutive weeks.

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	476.5057	3	158.8352	17.40131	4.97E-09	2.703594
Within Groups	839.755	92	9.127772			
Total	1316.261	95				

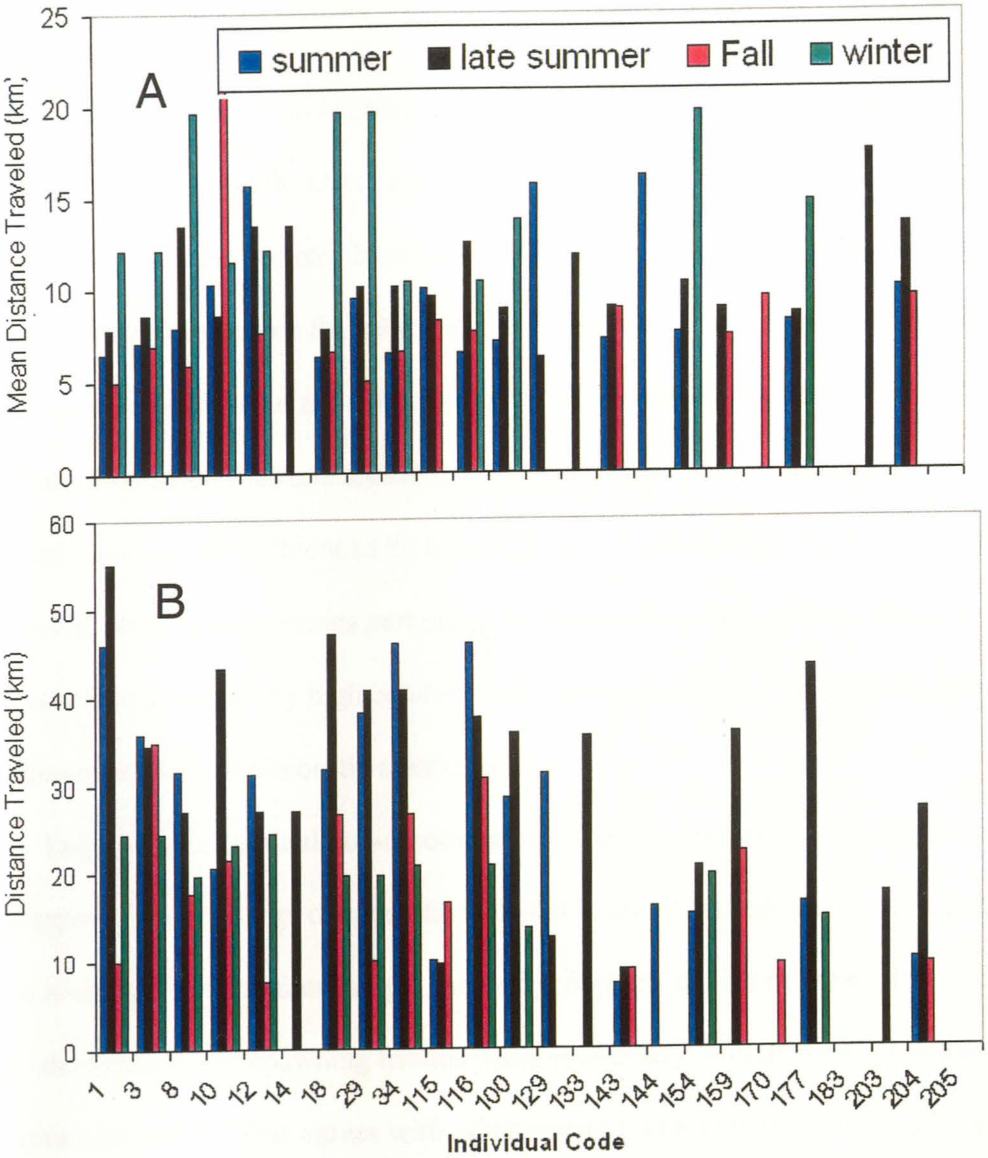

Figure 16. The minimum linear weekly mean distances traveled for individually tagged June sucker during the four 2004/05 sample seasons is illustrated in box A. In box B the minimum linear distance traveled for each season for individually tagged June sucker in 2004/05, disregarding consecutive weekly detections.

DISCUSSION

The June sucker is an endangered species and resides in Utah Lake, Utah. Utah Lake is a large lake (96,000 acres) and very little is known about what areas of the lake are utilized by the June sucker. In order to make better management decisions about habitat restoration to restore the June sucker, the movement patterns of the June sucker were monitored year-round and spawning grounds and spawning times were identified. This study shows that the June sucker is a highly mobile species year round. Spawning times and locations are influenced by stream flow and water temperature. This study also demonstrated that questions pertaining to fish movement in a large, shallow, turbid desert lake characterized by high conductivities and a highly mobile study species can be addressed using radio/acoustic telemetry.

Tagged fish exhibited non-random lake-wide distributional behavior during all four sample seasons. Large congregations of fish were observed during several of the sample seasons. The summer sample showed groupings of fish in the central east side of the lake between the spawning tributary and Provo Bay, which could be related to post-spawn behavior. This agrees with other research that shows the Klamath basin and suckers Pyramid Lake congregate prior to spawning (Coen and Buelow 2001; Minckley et al. 2003). Other species exhibit grouping in relation to food to the abundance of food resources. In the lower Columbia River, OR the northern pikeminnow (*Ptychocheilus oregonensis*) congregates seasonally to prey upon migrating juvenile fishes below dams and fish ladders (Martinelli and Shively 1997). The fall sample showed fish congregated in the center two western strata and by the winter sample fish had moved into the north and southern most eastern strata. Limnological data was not collected during this study, but could have been helpful in describing causal reasons for this behavior. One possible explanation for the easterly orientation of winter fish detections may be the presence of fresh water springs along the eastern shore of Utah Lake (SWCA 2002). The late summer sample season exhibited the weakest congregating behavior during this entire study. June sucker activity was at its highest during this time period, which may explain reduced congregating behavior. Fish behavior during this time period was nomadic likely due to fish searching for areas of higher food densities.

The mouth of Provo Bay, even during this time of relatively low water elevations, was exploited by a high proportion of tagged fish prior to and after the spawning season. Abundance of tagged fish declined to zero in the mouth of Provo Bay as water levels in Utah Lake receded to -1.6m below Compromise, suggesting that there is a minimum for habitat selection. The upper temperature tolerances for the June sucker were likely exceeded during the low water elevation, causing the decline in the number of fish present in the bay. One hypothesis derived from this study for the importance of Provo Bay to adult June suckers may be that the bay provides higher daytime temperatures and hence, greater productivity during the pre/post spawning period. In 2003 and 2004, a combination of bay morphology and prevailing northwest winds created a water surge that moved into the bay during wind events and out of the bay during ensuing calm periods (personal observation). This phenomenon may create a nutrient source at the mouth of the bay and concentrating production. This hypothesis will require further investigation to determine concentrations of food resources in this area in relation to the rest of the lake. Provo Bay provides important habitat for the

June sucker, and protecting it and keeping it contiguous with the lake may be of importance to June sucker survival.

June suckers traditionally enter the spawning tributaries in May into June (Scoppettone and Vinyard 1991; Gutermuth and Lentsch 1993). Fish tagged in 2003 and 2004 made forays into the river, but spent very little time in the river. This behavior could be a result of lower flows in the Provo River in 2004, as compared to historical levels. The historical mean length of time June suckers remained in the Provo River during spawning ranged between 5 and 8 days (Shirley 1983; Radant and Hickman 1985; Radant and Shirley 1987), however this study shows that spawning only lasted an average of 3 days. This suggests that either the length of time required by fish to spawn could be shorter than previously believed, or that fish found conditions in the river inadequate for spawning in 2004. If fish are choosing not to spawn based on lower than normal water levels it may be possible to encourage spawning through increased flows in the river through reservoir release upstream. Simulating water flows has been used to stimulate spawning behavior in pallid sturgeon (*Scaphirhychus albus*)on the Missouri River in areas where stream flows and channel morphology have been severely altered (USFS 2000)

Supplemental June suckers have been added to increase the population; however there are concerns over spawning behaviors between supplemental and wild fish causing loss of genetic diversity through drift (USFWS. 1999). In tambaqui (*Colossoma macropomum*) populations genetic variability has been lost as the result of mixing of hatchery raised individuals that later become mixed with wild populations (Calcagnotto 2000). Nickelson et al. (1986) showed loss of diversity when hatchery reared Coho salmon (*Oncorhynchus kisutch*) were used to rebuild wild runs in Oregon streams. Supplemental fish entered the Provo River on a median 16 days earlier than wild fish. There was overlap in the range of dates for both groups, however further investigation into spawning behavior of introduced supplemental fish and wild fish is necessary to determine if significant separation exists.

June suckers have not been observed spawning in Utah Lake during any type of fishery survey. Anecdotal and observational information from commercial fisherman and angles suggest that lake spawning may exist. Lake spawning may be one possible explanation for why such a high proportion of tagged fish congregated off the river but were never detected in the river. The mouth of the Provo River offers several rocky shoreline areas that could provide the necessary habitat to attract spawning adults. In addition, June sucker have been observed spawning on rocky shorelines in the Red Butte Refuge population (Billman 2005).

This study design rigorously tested the use of littoral vs. limnetic habitats over all four seasons and showed that the overall use of littoral habitats by adult fish was greater during the earlier part of the season. Decreases in littoral habitat use as the season progressed are at leased partially due to reduced habitat quality in these areas caused as lake water levels decline. Emergent vegetation became dewatered by late summer, changing the littoral zone from a vegetated habitat to a homogenous mud/clay substrate without vegetation. Shoreline vegetation may provide benefits to the littoral zone by keeping water temperatures cooler providing a complex and more diverse habitat. In Upper Klamath Lake, Oregon VanderKooi, and Buelow (2001) showed conditions in and around emergent vegetation provided high quality habitat for shortnose and Lost River suckers.

June suckers selected non-mud habitats disproportionate to their availability during this study. The relationship between detections and non-mud substrate suggests that fish were not feeding in relation to a substrate, but in relation to lake currents and wave action that maintains these hardened non-mud substrates. In Utah Lake, exposed sand, rock, or gravel substrates are often in locations where wind driven currents collide with the shorelines. As a result of these currents impacting the shoreline, food resources may be concentrated making feeding for adult June sucker more efficient.

The two main methods utilized in this study, fix position monitoring of tributaries and lake wide randomly deployed hydrophones, proved promising for future monitoring of Utah Lake June sucker and could be used in sampling in other lake systems with nomadic mobile species. Using these methods, a high proportion of tagged June sucker were monitored over the entire sample period. In contrast with the passive techniques, all active efforts to track fish on Utah Lake using either radio or acoustic signals were found to require excessive effort while providing minimal data. The limitations of radio tags under high specific conductivities (>900 ms), combined with a highly mobile sparsely populated fish, made manually searching extremely difficult and only produced a few detections.

In conclusion, the June sucker is a highly mobile species which utilizes large portions of its available range over short period of time. It will be important to continue to monitor and protect Utah Lake and its tributaries as a contiguous habitat to maintain and perpetuate the June sucker into the future. This study is part of a large ongoing effort to build on the existing knowledge pertaining to June sucker ecology and life history.

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APPENDIX

Appendix 1. Species native to the Utah Lake drainage (reproduced from SWCA 2002).

Common Name	Scientific Name	Status
Bonneville cutthroat trout	*Oncorhynchus clarki Utah*	Extirpated
Mountain whitefish	*Prsopium williamsoni*	Not present
June sucker	*Chasmistes liorus*	Federally endangered
Utah sucker	*Catosomus ardens*	Rare
Mountain sucker	*Catostomus platyrhnchus*	Not present *
Utah Chub	*Gila atraria*	Extirpated *
Redside shiner	*Richardsonius balteatus*	Extirpated *
Leatherside chub	*Gila copei*	Not present
Least chub	*Iotichthys phlegethontis*	Extirpated
Speckled dace	*Rhinichthys osculus*	Not present *
Longnose dace	*Rhinichthys cataractae*	Not present *
Mottled sculpin	*Cottus bairdi*	Not present *
Utah Lake sculpin	*Cottus echinatus*	Extinct

* Species not present in Utah Lake that are abundant in tributaries.

Appendix 2. Utah Lake watershed native species (reproduced from SWCA 2002).

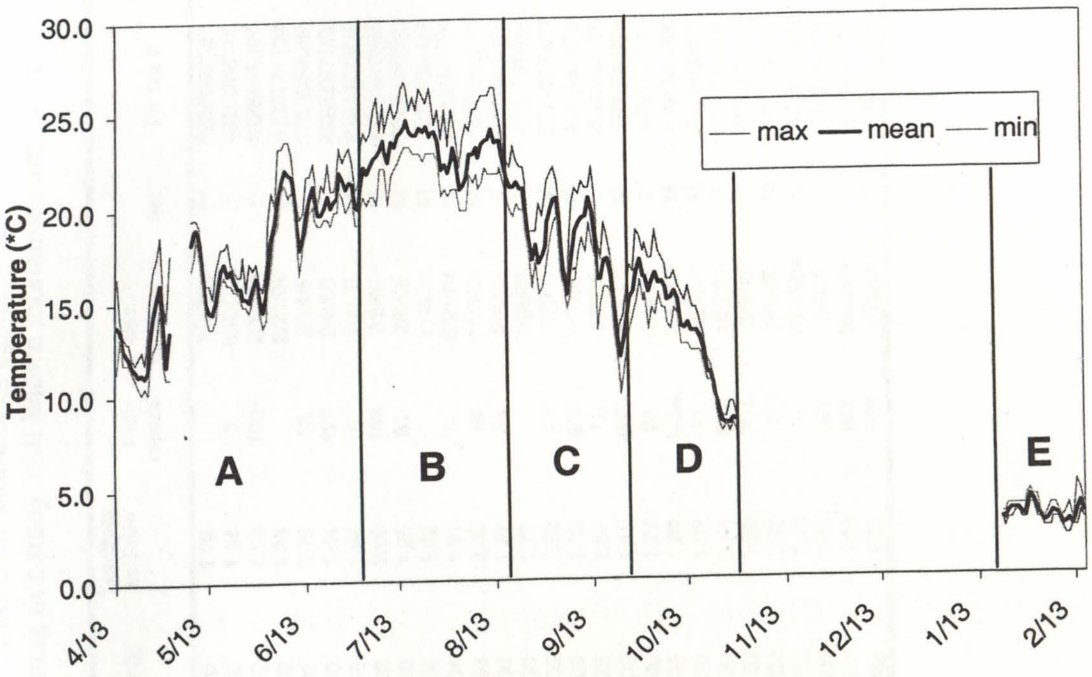
Common Name	Scientific Name	Date Introduced
Carp	*Cyprinus carpio*	1881
White bass	*Morone chrysops*	1956
Black crappie	*Pomoxis nigromaculatus*	1890
Yellow perch	*Perca flavescens*	1890
Channel catfish	*Ictalurus punctatus*	1911
Walleye	*Stizostedion vitreum*	1952
Black bullhead	*Ameriurus melas*	1871
Large mouth bass	*Micopterus salmoidies*	1890
Smallmouth bass	*Micropterus dolomieu*	1912
Fathead minnow	*Pimephales promelas*	1968
Bluegill	*Lepomis macrochirus*	1890
Green sunfish	*Lepomis cynellus*	1890
Brown trout	*Salmo trutta*	1900
Mosquitofish	*Gambusia affinis*	1930
Rainbow trout	*Oncorhynchus mykiss*	1897

Appendix 3. A brief description of preliminary methods tested on Utah Lake in 2003.

Adult June sucker have been very difficult to study in their natural habitat due to problems associated with low population numbers and the extreme abiotic characteristics of Utah Lake. Common high winds and shallowness create frequent large waves making travel on the lake difficult. In addition, placing equipment within the main body of the lake requires heavy mooring or attachment to substrate. Methods used to date (i.e., trammel, gill, trap and trawl nets) have not been effective in capturing June sucker due to low population numbers of highly mobile fish (Hubert 1996).

High levels of turbidity and conductivity reduce the efficiency of radio and acoustic telemetry. Several preliminary tests were performed in Utah Lake to determine the methods that maximized the ability to detect tagged fish. In January 2003, coded acoustic/radio tags (CART) were tested using a SRX_400 (Lotek Wireless) telemetry receiver, in combination with a four element Yagi antenna and a hand-held, omnidirectional hydrophone. Three surveys were conducted from a fixed wing aircraft using methods described in Winter (1996). To test the efficiency of aircraft surveys on Utah Lake, two test tags were place in the water column; one at 1 m deep and one at 2 m of water. In addition, two WHS_1100s hydrophones were tested to determine their success in monitoring the presence of tagged fish.

Appendix 4. Water temperature measured (UTM 12T 435222E; 4449836N) in 2m of water at a depth of 1m in Utah Lake, 2004/05. The thermograph is separated by lines and labeled with letters A-E indicate periods separated by changes in temperature. A = Spawning season, B = summer, C = late summer, D = fall, and E = winter.



Appendix 5. Physical characteristics and location information for all June sucker tagged and tracked between June 2003 and February 2005. Fish origin refers to whether the fish is wild or introduced. Number of captures refers to the number of detections. Date of last contact refers to the date a fish was last detected during this study. All known mortalities are listed in the fate column.

Code	Implant Date	Freq.	Fish Origin	Tag Location	Standard Length (mm)	Weight (g)	Tag :Body wt. Ratio	# of captures	Date of Last Contact	Sex	Pit Tag #	Fate
109	5/22/03	148.48	supplemental	UDWR pens	418	1200	1.92		7/28/03	F	223E007357	Mortality
203	5/22/03	148.6	supplemental	UDWR pens	413	1400	1.64	3	10/24/04	F	432D256718	
34	5/28/03	148.48	supplemental	UDWR pens	419	1450	1.59	100	2/14/05	F	432B08522F	
44	6/5/03	148.48	supplemental	UDWR pens	420	1700	1.35		8/21/04	F	4329771104	Mortality
100	6/5/03	148.48	supplemental	UDWR pens	500	2900	0.79	18	2/1/05	F	1F530F403F	
1	6/5/03	148.48	supplemental	UDWR pens	380	1400	1.64	427	2/8/05	F	432E5B7C02	
183	5/22/03	148.6	wild	UDWR pens	405	1250	1.84	8	2/4/05	M	2241174B36	
18	5/22/03	148.48	supplemental	UDWR pens	385	1100	2.09	168	2/8/05	M	432E5A735D	
29	5/22/03	148.48	wild	UDWR pens	413	1840	1.25	81	2/8/05	M	7F7A16631B	
121	5/22/03	148.48	supplemental	UDWR pens	404	1424	1.62		11/4/04	M	223F73650A	Mortality
143	6/5/03	148.6	supplemental	UDWR pens	380	1204	1.91	9	9/21/04	M	432B367E37	
129	5/28/03	148.6	supplemental	UDWR pens	375	1150	2.00	16	11/3/04	M	432B296F2E	
3	5/14/04	148.48	wild	UDWR pens	442	1900	1.21	98	2/8/05	M	22410a4749	
5	5/27/04	148.48	supplemental	UDWR pens	394	1300	1.77		7/25/05	F	42557d133a	Mortality
8	5/11/04	148.48	supplemental	UDWR pens	399	1500	1.53	47	2/5/05	M	2241107A17	
10	5/28/04	148.48	supplemental	UDWR pens	438	1200	1.92	453	2/7/05	F	432b263d35	
12	4/30/04	148.48	wild	Utah Lake	411	1375	1.67	19	2/8/05	F	432b2e2906	
14	5/28/04	148.48	wild	UDWR pens	448	2000	1.15	652	1/24/05	M	7f7b19787e	
115	425/04	148.6	supplemental	Utah Lake	392	1300	1.77	24	2/5/05	F	4256495c6c	
116	4/25/04	148.6	supplemental	Utah Lake	362	1200	1.92	1034	2/14/05	M	4308640568	
133	4/25/04	148.6	wild	Utah Lake	395	1200	1.92	11	9/21/04	M	4255636f32	
144	6/2/04	148.6	wild	UDWR pens	493	2720	0.85	992	1/27/05	F	20370d5f3d	
154	5/27/04	148.6	supplemental	UDWR pens	405	1450	1.59	704	2/3/05	F	4254667461	
159	5/12/04	148.6	wild	UDWR pens	415	1800	1.28	11	2/1/05	M	7f7d3d6c01	
170	5/27/04	148.6	wild	UDWR pens	414	1600	1.44	4	10/23/04	M	42555f0439	
177	6/2/04	148.6	wild	UDWR pens	415	1480	1.55	661	2/8/05	M	7f7d3d4e7a	
204	4/30/04	148.48	supplemental	Utah Lake	395	1500	1.53	667	10/20/04	F	432d1e2207	
205	5/14/04	148.6	wild	UDWR pens	412	1835	1.25	562	1/25/05	F	436401487c	

Appendix 6. Explanation and results from preliminary equipment testing in 2003.

On March 13, 2003, the radio signal component of the CART tags was tested from an airplane and found to be detectable from an elevation of approximately 500 m above the lake, for tags submerged in water 1 m deep. Efforts were made to locate randomly positioned tags using the aircraft with little success, and when tags were placed in water depths greater than 1.5 m they were not detectable. During all three aerial surveys conducted in 2003, only two fish were detected. As a result of the inefficiency and high cost of aerial surveys, they were discontinued.

The hand-held SRX 400A radio receiver in conjunction with a 3 element Yagi antenna was used to monitor radio tagged fish in the Provo River. Signals were detectable from over 500 m in the relatively fresh water (specific conductivities < 400 ms) of the Provo River. In the conductive lake conditions, however, the hand-held radio was generally ineffective for randomly detecting fish for several reasons. The first difficulty was that the narrow detection width for radio signals decreased the chance of encountering a tagged fish. The second was the shallow water of Utah Lake may have made it difficult to approach fish without disturbing them once they had been discovered. On several occasions tagged fish behaved as if they were moving away from the boat when in close proximity (<100 m). It was never determined if fish were moving away from the boat at distances > 100 m causing them to not be detected during surveys at long distances.

The remote wireless hydrophones were placed in the mouth of Provo Bay to monitor the mouth of the bay for the presence of tagged fish. In the bay a relatively

Appendix 6. (continued)

high number of detections for tagged fish were obtained relative to radio tracking methods. Date from the 2003 field efforts were not used in analysis due to the preliminary nature of data collection. The tests conducted in 2003 were undoubtedly priceless in completing future seasons.

Appendix 7. All detections for all tagged June sucker during all 4 seasons. Data is shown by season for both the east and west side for each stratum.

		Strata								
		1		2		3		4		
Code	Season	east	west	east	west	east	west	east	west	sums
1	Summer	2	8	10	4	9	4	13	19	69
	Late Summer	46	52	19	17	16	6	64	0	220
	Fall	0	0	0	0	0	90	7	4	101
	Winter	17	0	0	0	1	0	20	0	38
3	Summer	0	1	0	2	36	0	1	1	41
	Late Summer	13	7	1	2	0	1	8	0	32
	Fall	0	2	0	5	1	2	2	1	13
	Winter	8	0	0	0	1	0	4	0	13
8	Summer	0	1	0	0	1	0	1	0	3
	Late Summer	22	5	0	0	0	0	5	0	32
	Fall	0	0	0	2	0	3	3	7	15
	Winter	1	0	0	0	0	0	1	0	2
10	Summer	1	1	0	0	433	0	0	0	435
	Late Summer	6	2	2	1	1	0	2	0	14
	Fall	0	4	0	0	0	0	2	0	6
	Winter	0	1	0	0	3	0	0	1	5
12	Summer	0	1	0	0	7	0	0	1	9
	Late Summer	5	1	0	0	0	0	2	0	8
	Fall	0	0	0	1	0	1	0	0	2
	Winter	2	0	0	0	1	0	1	0	4
14	Summer	0	0	0	0	644	0	0	0	644
	Late Summer	2	2	0	0	0	0	2	0	6
	Fall	0	0	0	0	0	0	0	0	0
	Winter	0	0	0	0	3	0	0	0	3
18	Summer	0	0	4	2	2	2	4	9	23
	Late Summer	41	18	4	6	2	4	27	0	102
	Fall	0	3	0	11	0	6	3	1	24
	Winter	13	0	0	0	2	0	7	0	22
29	Summer	1	2	0	0	1	1	0	2	7
	Late Summer	26	8	1	2	0	0	9	0	46
	Fall	0	0	0	0	0	7	1	2	10
	Winter	4	0	0	0	0	0	10	0	14
34	Summer	2	4	1	3	7	3	3	4	27
	Late Summer	21	9	2	3	0	0	12	0	47
	Fall	0	3	0	8	0	7	0	1	19
	Winter	4	1	0	0	0	0	2	0	7

Appendix 7. (continued)

		Strata								
		1		2		3		4		
Code	Season	east	west	east	west	east	west	east	west	sums
115	Summer	0	0	0	0	14	0	1	0	15
	Late Summer	3	1	0	0	0	0	0	0	4
	Fall	0	5	0	3	0	1	0	0	9
	Winter	0	0	0	0	0	0	1	0	1
116	Summer	1	1	1	2	407	2	77	1	492
	Late Summer	31	60	1	0	0	0	55	0	147
	Fall	0	130	0	1	186	3	1	0	321
	Winter	8	12	0	0	0	0	2	0	22
129	Summer	0	1	0	0	9	0	0	1	11
	Late Summer	3	0	1	2	0	0	0	0	6
	Fall	0	4	0	0	0	0	0	0	4
	Winter	0	0	0	0	0	0	0	0	0
133	Summer	0	0	0	0	0	0	0	0	0
	Late Summer	4	3	0	1	0	0	3	0	11
	Fall	0	0	0	0	0	0	0	0	0
	Winter	0	0	0	0	0	0	0	0	0
143	Summer	0	0	1	0	1	0	0	0	2
	Late Summer	2	0	2	0	0	0	0	0	4
	Fall	0	1	0	2	0	0	0	0	3
	Winter	0	0	0	0	0	0	0	0	0
144	Summer	0	1	0	0	290	0	0	0	291
	Late Summer	2	0	0	0	0	0	0	0	2
	Fall	0	0	0	638	0	0	0	0	638
	Winter	0	0	0	0	0	0	60	0	60
154	Summer	0	0	0	0	518	0	3	59	580
	Late Summer	0	2	0	0	27	0	58	0	87
	Fall	0	0	0	0	0	1	0	0	1
	Winter	34	0	0	0	0	0	1	0	35
159	Summer	0	0	0	0	0	0	0	0	0
	Late Summer	1	1	0	1	0	6	11	0	20
	Fall	0	1	0	1	0	1	1	0	4
	Winter	0	0	0	0	0	0	0	0	0
170	Summer	1	0	0	0	0	0	0	0	1
	Late Summer	0	0	1	0	0	0	0	0	1
	Fall	0	0	0	1	0	1	0	0	2
	Winter	0	0	0	0	0	0	0	0	0
177	Summer	0	0	0	2	633	2	0	0	637
	Late Summer	1	1	4	1	12	0	1	0	20
	Fall	0	0	0	6	0	0	0	0	6
	Winter	2	0	0	0	3	0	0	0	5

Appendix 7. (continued)

		Strata								
		1		2		3		4		
Code	Season	east	west	east	west	east	west	east	west	sums
183	Summer	0	0	0	0	0	0	0	0	0
	Late Summer	3	0	1	0	0	0	0	0	4
	Fall	0	0	0	0	0	1	0	0	1
	Winter	2	0	0	0	0	0	0	0	2
100	Summer	0	0	0	5	1	1	1	1	9
	Late Summer	2	2	0	1	0	1	3	0	9
	Fall	0	2	0	0	0	0	0	0	2
	Winter	0	0	0	1	0	0	1	0	2
203	Summer	0	0	0	0	0	0	0	0	0
	Late Summer	0	1	0	0	0	0	1	0	2
	Fall	0	0	0	1	0	0	0	0	1
	Winter	0	0	0	0	0	0	0	0	0
204	Summer	0	0	0	0	518	0	143	0	661
	Late Summer	2	1	0	0	0	0	1	0	4
	Fall	0	0	0	1	0	1	0	0	2
	Winter	0	0	0	0	0	0	0	0	0
205	Summer	0	0	0	0	71	0	0	0	71
	Late Summer	1	0	0	0	0	0	0	0	1
	Fall	0	0	0	0	0	0	0	1	1
	Winter	0	0	0	0	489	0	0	0	489
	sums	340	366	56	739	4350	158	641	116	6766

Appendix 8. The table scores as produced by SAS PROC FREQ (SAS Institute 1999). Row values indicate the total independent detections recorded in each stratum. The column values represent each sample season.

Frequency Percent Row Pct Col Pct	Summer	Late Summer	Fall	Winter	Total
American Fork	25	196	30	56	307
	2.47	19.37	2.96	5.53	30.34
	8.14	63.84	9.77	18.24	
	6.93	53.12	18.40	47.06	
Provo River	28	59	60	0	147
	2.77	5.83	5.93	0.0	14.53
	19.05	40.14	40.82	0.0	
	7.76	15.99	36.81	0.0	
Spanish Fork	238	28	48	22	336
	23.52	2.77	4.74	2.17	33.20
	70.83	8.33	14.29	6.55	
	65.93	7.59	29.45	18.49	
Current Creek	70	86	25	41	222
	6.92	8.50	2.47	4.05	21.94
	31.53	38.74	11.26	18.47	
	19.39	23.31	15.34	34.45	
Total	361	369	163	119	1012
	35.67	36.46	16.11	11.76	100.00

Appendix 9. The table frequencies produced in SAS 1999. Values were derived from detections rates filtered so that only one detection per hydrophone for each individual was used per 12 hour period.

Frequency Percent Row Pct Col Pct	Summer	Late Summer	Fall	Winter	Total
	284	209	29	117	639
East shore	28.06	20.65	2.87	11.56	63.14
	44.44	32.71	4.54	18.31	
	78.67	56.64	17.79	98.32	
	77	160	134	2	373
West shore	7.61	15.81	13.24	.20	36.86
	20.64	42.90	35.92	.54	
	21.33	43.36	82.21	1.68	
Total	361	369	163	119	1012
	35.67	36.46	16.11	11.76	100.00

Appendix 10. The summary statistics for PROC FREQ and summary statistic for shore by season using the Cochran-Mantel-Haenzel method in SAS.

Frequency Percent Row Pct Col Pct	Summer	Late Summer	Fall	Winter	Total
	145	97	22	53	317
Littoral	14.33	9.58	2.17	5.24	31.32
	45.74	30.6	6.94	16.72	
	40.17	26.29	13.50	44.54	
	216	272	141	66	695
Limnetic	21.34	26.88	13.93	6.52	68.68
	31.08	39.14	20.29	9.50	
	59.83	73.71	86.50	55.46	
Total	361	369	163	119	1012
	35.67	36.46	16.11	11.76	100.00