THE EVALUATION OF CONTAMINANT IMPACTS ON RAZORBACK SUCKER HELD IN FLOODED BOTTOMLAND SITES NEAR GRAND JUNCTION, COLORADO - 1996

Final Report

September 27, 2001

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This study was funded by the Upper Colorado River Endangered Fish Recovery Program. The Recovery Program is a joint effort of the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Western Area Power Administration, states of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, and the Colorado River Energy Distributors Association, and the National Park Service.

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Recovery Program Project Number CAP6-WW

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Suggested citation:

Hamilton, S.J., K.M. Holley, K.J. Buhl, F.A. Bullard, L.K. Weston, and S.F. McDonald. 2001. The evaluation of contaminant impacts on razorback sucker held in flooded bottomland sites near Grand Junction, Colorado - 1996. Final Report. U.S. Geological Survey, Yankton, South Dakota. 302 pages. (Not to be cited as a Recovery Program report.)

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LIST OF KEYWORDS

Razorback sucker
Colorado River
Endangered fish
Reproduction
Selenium
Trace elements

ACKNOWLEDGMENTS

The authors thank Todd Christenson, Marvin Ehlers, Susan Muehlbeier, and Britt Peterson of the USGS; Rocky Dial, Karen Fogelquist, and Joe Rubalcaba of the BOR, Grand Junction Projects Office, Grand Junction, CO; Frank Pfeifer, Mike Baker, Bruce Bonar, Bob Burdick, Cheryl Harris, Chuck McAda, Mike Montagne, and Toby Mourning of the USFWS, Colorado River Fishery Project, Grand Junction, CO; and Rick Krueger and Barb Osmundson of the USFWS, Ecological Services Office, Grand Junction, CO, for technical assistance; Ed Callahan for statistical assistance; and Karen Faerber for typing the report

This report was reviewed by A. Archuleta, R. Engberg, K. Maier, T. Modde, T. Nesler, G. Noguchi, and members of the Biology Committee.

By the questions we pose
Ourselves we deceive
So limited in thought
By what we chose to perceive.
Dave Marchant
(Geologist, Boston University)
(National Geographic, October, 1998, Timeless Valleys of the Antarctic Desert, p. 133)

EXECUTIVE SUMMARY

Selenium contamination of the upper and lower Colorado River basin has been documented in water, sediment, and biota in studies by U.S. Department of the Interior agencies, and academia. Concern has been raised that selenium contamination may be adversely affecting endangered fish in the upper Colorado River basin. The objective of this study was to determine if environmental exposure of adult razorback sucker (*Xyrauchen texanus*) to selenium in flooded bottomland sites affects their survival, growth, and reproductive success.

Adult razorback sucker (3 year old) were secured from Wahweap State Fish Hatchery, UT, and stocked at three sites: hatchery ponds at Horsethief Canyon State Wildlife Area (Horsethief; reference site assumed to have little or no selenium contamination), a diked tertiary channel at Adobe Creek (assumed to have a low amount of selenium contamination), and North Pond (assumed to have an elevated amount of selenium contamination) at Walter Walker State Wildlife Area (WWSWA), all near Grand Junction, CO. The young adults were from a single mating. Older brood stock (about 15 years old) held at Horsethief were used as an additional adult reference fish. Adults at Horsethief were fed a commercial diet, whereas fish at Adobe Creek and North Pond foraged on natural food items. Fish were tagged with a passive integrated transponder and stocked in July 1995 and collected for spawning in April 1996. The water source at Horsethief was the Colorado River, at Adobe Creek it was river water and irrigation drainage, and at North Pond it was a combination of ground water and irrigation supply water.

Sampling stations were established at Horsethief (4 stations), Adobe Creek (7 stations), North Pond (3 stations) at WWSWA, and the channel area at WWSWA (7 stations). On-site water quality measurements were collected weekly. Measurements collected at monthly intervals included fish muscle plugs and weight and total length (sometimes at 60-day intervals), water samples for water quality and inorganic element analyses, and aquatic invertebrates for inorganic element analyses. Fish were collected using nets and electrofishing equipment. Sediment samples were collected twice (October 1995 and April 1996) for inorganic element analyses, carbon content, and texture analysis.

Fish were collected from the three sites after the appropriate water temperatures were reached, and moved to tanks in a building at Horsethief. Fish were induced to spawn by injection with human chorionic gonadotropin hormone. Personnel of the Colorado River Fishery Project (CRFP) office, Grand Junction, CO, used standard methods to collect fish, induce spawning, and fertilize and water harden the eggs. Samples of eggs were collected for inorganic element analyses, and the remaining eggs moved to the 24-Road Fish Hatchery (24-Road) for hatching. After spawning, adults from the three sites were held at Horsethief for a 60-day depuration period. One or two fish from each site were sacrificed and selenium concentrations measured in various tissues and muscle plugs at spawning and at 30-day intervals during depuration.

A 9-day egg study was conducted in a mobile laboratory housed in the garage at the CRFP office. One-hundred-fifty eggs were collected from six spawns of adults from Horsethief and Adobe Creek and four spawns from North Pond for hatchability determinations. Each group of eggs was stocked into six groups of egg incubator cups (each containing 25 eggs) that were suspended in 2-L exposure beakers filled with 1.2 L of either reference water from 24-Road (three groups) or site water (three groups). Fifty percent of the water was renewed daily. Once daily, the egg cups were removed and placed in a petri dish containing the same

water as the beaker, and examined using a dissecting scope to record the number of live and dead eggs, and the number and type of deformities. Egg viability also was measured on groups of about 100 eggs from each spawn maintained at 24-Road, including three spawns from brood stock. Egg diameter was measured on 25 eggs from each spawn, including three spawns from brood stock.

A 30-day larval fish study was initiated with 5-day-old larvae and was conducted in a mobile laboratory housed in the garage at the CRFP office. For each of three spawns of adults from Horsethief, Adobe Creek, North Pond, and brood stock, eight groups of 10 larvae were placed in 2-L exposure beakers to assess survival, growth, abnormal development, and whole-body residues of selenium. The beakers were filled with 1.6 L of water, and fifty percent of the water was renewed daily. One set of larvae in two beakers from each source were exposed to one of four treatments: (1) reference food (brine shrimp) and reference water (24-Road), (2) reference food and site water where adults were held, (3) site food where adults were held [for Horsethief and brood stock, zooplankton were collected from Horsethief east wetland] and reference water, and (4) site food and site water. Zooplankton were collected using modified light traps, sieved to separate zooplankton <0.425 mm for feeding, and counted for feeding 40 organisms per fish in each exposure beaker. The number of live fish were counted daily, and the weight and total length of fish measured after 30 days of exposure. Larvae were collected for selenium residue analysis after about 1 week and after 30 days of exposure.

Informal observations were made on a separate group of adult razorback suckers held in a hoop net at North Pond for 89 days. Muscle plugs from five fish were collected at 30-day intervals for selenium analysis. Various tissues from adults were sampled at the end of the exposure period for selenium analysis. Informal observations were made on razorback sucker larvae (aged 31-134 days old) held at 24-Road. Measurements of weight and total length were made on three 20-fish subgroups of larvae from the four sources at 30-day intervals, and samples were collected at the end of the observation period for selenium residue analysis.

During the adult study, selenium was elevated in water and food organisms at Adobe Creek, and in water, food organisms, and sediment at North Pond. Adults at the three sites lost weight during the first couple of months apparently while adapting to conditions at the holding sites, but gained weight during the latter portion of the study period. Although there were differences among the three sites in concentrations of inorganic elements in water, sediment, and biota, selenium was the only element elevated to concentrations of concern for adverse effects in fish. Adult razorback sucker at Adobe Creek and North Pond accumulated selenium in muscle plugs, various tissues, and eggs to concentrations reported to cause adverse effects on reproduction in studies with other fish species (Summary Table 1). Selenium concentrations in eggs from Adobe Creek adults (46 μg/g) and North Pond adults (38 μg/g) were 3-4 times higher than the proposed toxic threshold (10 μg/g) for reproductive failure. The selenium concentrations in muscle plugs from adults at Adobe Creek and North Pond were lower than in 40% of wild adults collected from the Green River in Utah. During a depuration period when adults from Adobe Creek and North Pond were held at Horsethief, fish lost 1-2% of their selenium burden in 32 days and 14-19% in 66 days, which suggested a slow rate of elimination compared to that of other fish species given in the literature.

Eggs from young adults held at the test sites had a smaller diameter and higher moisture content than those from the older brood stock. It was assumed, based on the literature, that brood stock larvae had a higher level of fitness than larvae produced by the young adults used in the

present study. There were no differences among larvae from the four sources in viability, survival, hatch, or mortality of deformed embryos or larvae. For larvae from adults held at Adobe Creek, there were more deformed embryos in eggs held in site water than held in reference water.

During the larval fish study, selenium was elevated in water and food organisms from Adobe Creek and North Pond, and in food organisms from Horsethief east wetland. Although there were differences among the three sites in concentrations of inorganic elements in water and biota, selenium was the only element elevated to concentrations of concern. The lowest survival of larvae from all sources occurred in site food treatments compared to reference food treatments (Summary Table 1). Survival of larvae from Adobe Creek and North Pond adults was lower in site water treatments compared to reference water. Survival of larvae from brood stock was higher than Horsethief larvae even though they were exposed to the same water and dietary treatments, which suggests brood stock had a higher level of fitness for dealing with contaminant stresses. Selenium residues in larvae were correlated with selenium concentrations in water and food organisms, and elevated to concentrations reported by others to cause adverse effects in larval fish.

Informal observations of razorback sucker larvae held at 24-Road suggest that delayed mortality occurred in larvae from North Pond adults. Deformities were present in larvae from all four sources, although the type of deformities and abnormal swimming behavior of larvae from North Pond adults were different from those of larvae from the other three sources. Deformities in larvae from North Pond adults were similar to those reported in the literature for selenium-induced tetratogenic deformities observed in other fish species.

Possible effects from inbreeding were a concern in the egg and larval fish studies. During the egg study, there were no differences in percent viability, percent hatch, or mortality among the three sites, and the range of values of these measures was similar to those for razorback sucker reported by others. During the informal razorback sucker larvae study, the different deformities in larvae among the three sites suggested an effect from parental exposure rather than an inbreeding effect.

A hazard assessment using selenium concentrations measured in water, sediment, invertebrates, and fish, and a published hazard assessment protocol for selenium, suggested a moderate hazard at Horsethief and high hazards at Adobe Creek and North Pond. Selenium concentrations of $\geq$4.6 µg/g in food organisms adversely affected the survival of razorback sucker larvae from Horsethief adults, which suggested a high hazard was appropriate for the Horsethief east wetland. Based on selenium concentrations measured in water, sediment, invertebrates, and fish given in published NIWQP reports of studies in the Green River and upper Colorado River basins, and biological effects measured in the present study (and the second reproduction study), selenium contamination is adversely affecting razorback sucker

Summary Table 1. Summary of selenium concentrations (μg/g or μg/L as appropriate) in muscle plug and eggs in the adults whose larvae were used in the larval fish study, and water, food, and larvae, and survival of larvae after 30 days of exposure in the larval fish study. HT: Horsethief, HTEW: Horsethief east wetland, AC: Adobe Creek, WW: North Pond, BS: Brood stock, BSH: Brine shrimp.

	Adult study		Larval study			
Site	Se in muscle plug (μg/g)	Se in eggs (μg/g)	Source & Se in water (μg/L)	Source & Se in food (μg/g)	Se in larvae (μg/g)	% Survival
HT	4.3	6.2	24-R <1.5	BSH 2.7	3.3	87
AC	12.0	45.3	24-R <1.5	BSH 2.7	7.7	84
WW	15.3	35.6	24-R <1.5	BSH 2.7	9.7	75
BS	9.8	7.1	24-R <1.5	BSH 2.7	3.6	89
HT	4.3	6.2	HT 0.9	BSH 2.7	5.1	89
AC	12.0	45.3	AC 5.5	BSH 2.7	12.7	66
WW	15.3	35.6	WW 10.7	BSH 2.7	15.2	54
BS	9.8	7.1	HT 0.9	BSH 2.7	5.2	86
HT	4.3	6.2	24-R <1.5	HTEW 5.6	No fish	0
AC	12.0	45.3	24-R <1.5	AC 20	No fish	0
WW	15.3	35.6	24-R <1.5	WW 39	No fish	0
BS	9.8	7.1	24-R <1.5	HTEW 5.6	5.4	62
HT	4.3	6.2	HT 0.9	HTEW 5.6	No fish	0
AC	12.0	45.3	AC 5.5	AC 20	No fish	2
WW	15.3	35.6	WW 10.7	WW 39	No fish	0
BS	9.8	7.1	HT 0.9	HTEW 5.6	6.9	42

INTRODUCTION

Endangered fish

As a result of its long isolation, the Colorado River basin supports some of the most distinctive ichthyofauna in North America (Figure 1). Several fish species have declined in the basin, which originally contained 32 native species, of which 75% were endemic (Minckley 1991). The upper Colorado River provides critical habitats for four endangered fish species, Colorado pikeminnow (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), humpback chub (*Gila cypha*), and bonytail (*Gila elegans*) (USFWS 1994). A combined approach for recovery of the four endangered fish in the upper Colorado River basin has been undertaken by the Upper Colorado River Endangered Fish Recovery Program, which was initiated in 1987 (USFWS 1987). The upper basin is defined as the portion of the basin above Glen Canyon Dam. The goal of this 15-year program is to reestablish self-sustaining populations of the four species while allowing continued development of water.

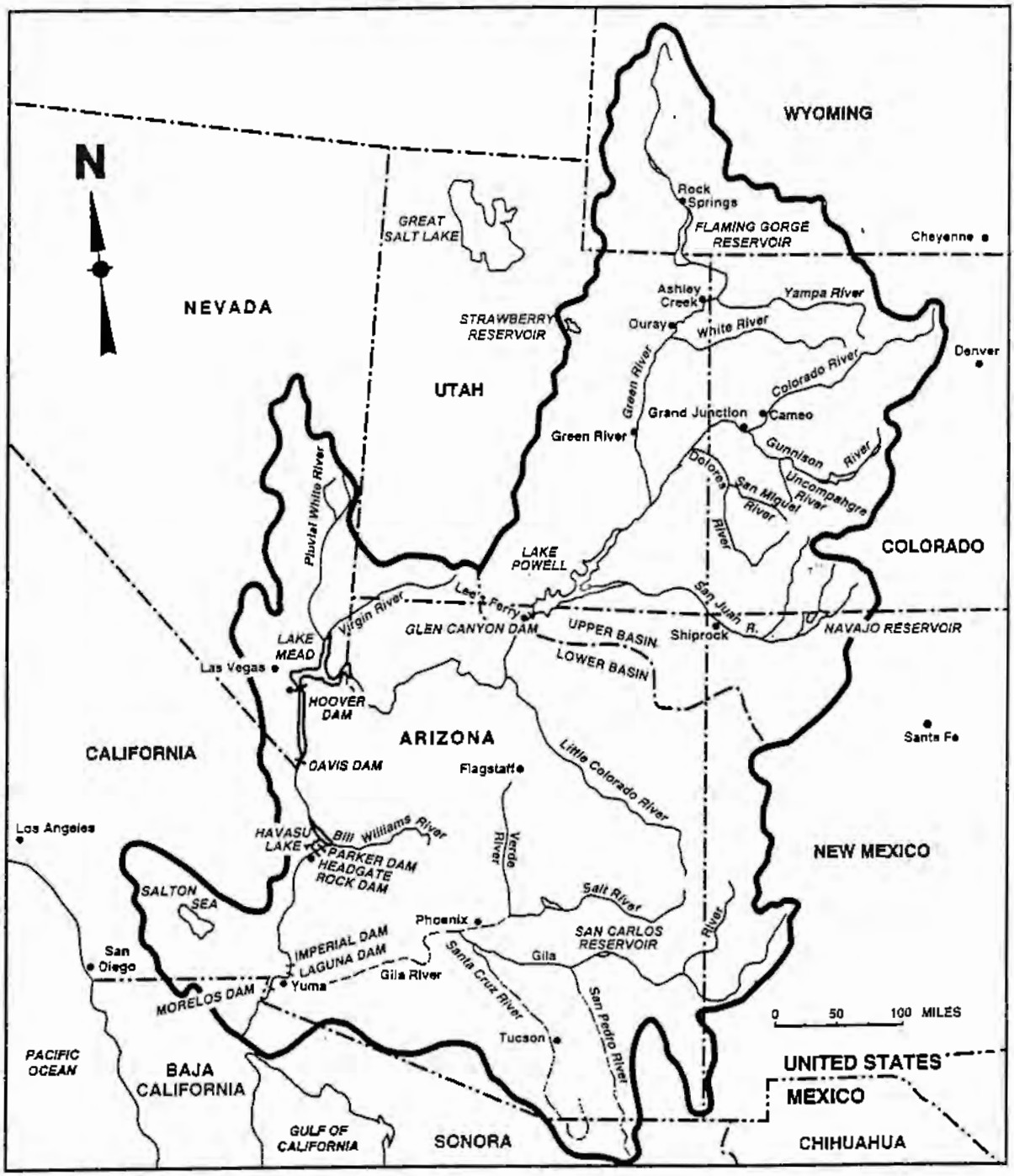
The reasons for the decline of these species are related to a combination of factors including stream alteration (dams, irrigation withdrawals, dewatering, channelization), loss of habitat (spawning sites and backwater nursery areas), changes in flow regime, blockage of migration routes, water temperature changes, competition with and predation by introduced species, parasitism, and changes in food base (USFWS 1987). Irrigation and pollution were suggested in 1976 as possible contributing factors to the decline of endangered fish (Seethaler et al. 1979). The U.S. Fish and Wildlife Service's (USFWS) Colorado River Fishery Project (CRFP), a component of the Recovery Program, contracted in 1981 to have short-term tests conducted to determine the toxicity of several inorganic and organic chemicals to Colorado pikeminnow and humpback chub (Beleau and Bartosz 1982). Those tests were conducted with older life stages of these fish, which tend to be less sensitive than young life stages (Rand and Petrocelli 1985), and seemed to indicate that contaminants were not adversely effecting the endangered fish.

Contaminant studies in the Colorado River basin

Following the discovery of selenium-contaminated irrigation return waters in the San Joaquin Valley of central California in 1982, the Department of the Interior (DOI) initiated the National Irrigation Water Quality Program (NIWQP) to identify other areas in the western U.S. that have water quality problems induced by irrigation drainage (Feltz et al. 1991). The NIWQP investigations focused on irrigation drainage facilities constructed by the DOI, where the drainwater was to a national wildlife refuge, or had the potential to impact migratory birds or endangered species. The upper Colorado River basin including the middle Green River basin of Utah and the upper Colorado, Gunnison, and Uncompahgre rivers in northwestern Colorado were identified as areas needing further study. Analysis of water, bottom sediment, and biota collected since 1986 from the middle Green River basin and the Grand Valley, located in western Colorado and includes a portion of the Colorado, Gunnison, and Uncompahgre rivers, have confirmed the presence of inorganic elements including selenium at concentrations that could be potentially harmful to fish and wildlife (Butler et al. 1989, 1991, 1994, 1996; Stephens et al. 1988, 1992; Peltz and Waddell 1991).

The NIWQP studies provided a basic foundation of survey information on the occurrence

Figure 1. Map of Colorado River basin (modified from Carlson and Muth 1989).


N
WYOMING
NEVADA
UTAH
COLORADO
ARIZONA
NEW MEXICO
CALIFORNIA
GREAT SALT LAKE
STRAWBERRY RESERVOIR
FLAMING GORGE RESERVOIR
Rock Springs
Cheyenne
Denver
Ashley Creek
Yampa River
Ouray
White River
Green River
Colorado River
Grand Junction
Cameo
Green River
Gunnison River
Dolores River
San Miguel River
Uncompahgre River
Piute/ White River
LAKE POWELL
Lee's Ferry
Virgin River
GLEN CANYON DAM
UPPER BASIN
LOWER BASIN
San Juan R.
Shiprock
NAVAJO RESERVOIR
LAKE MEAD
Las Vegas
HOOVER DAM
DAVIS DAM
Flagstaff
Little Colorado River
Santa Fe
Los Angeles
HAVASU LAKE
Bill Williams River
PARKER DAM
HEADGATE ROCK DAM
Verde River
SALTON SEA
Salt River
Phoenix
SAN CARLOS RESERVOIR
San Diego
IMPERIAL DAM
LAGUNA DAM
Yuma
Gila River
Gila
Santa Cruz River
San Pedro River
MORELOS DAM
Tucson
0 50 100 MILES
PACIFIC OCEAN
BAJA CALIFORNIA
GULF OF CALIFORNIA
SONORA
CHIHUAHUA
UNITED STATES
MEXICO

of selenium in fish collected from a variety of aquatic ecosystem components that suggested selenium and possibly other contaminants might be sufficiently elevated to be contributing to the decline of endangered fish. Selenium in soils of the western states is derived from weathering of outcrops of Cretaceous marine rocks in the Rocky Mountain and Great Plains regions, which comprises an area of approximately 300,000 square miles (Presser et al. 1994).

The U.S. Fish and Wildlife Services' National Contaminant Biomonitoring Program (NCBP) has documented elevated selenium concentrations in fish collected from stations located in the upper and lower Colorado River basins. The NCBP monitors temporal and spatial trends in concentrations of persistent environmental contaminants, including selenium, that may threaten fish and wildlife, and was the 85th percentile as an arbitrary point distinguishing "high" concentrations (Walsh et al. 1977, May and McKinney 1981, Lowe et al. 1985, Schmitt and Brumbaugh 1990). Selenium concentrations in whole-body fish from the Colorado River basin have been among the highest in the nation (Walsh et al. 1977, Lowe et al. 1985, Schmitt and Brumbaugh 1990). In samples collected in 1972-1973, selenium concentrations exceeded the 85th percentile in fish at five of six stations in the Colorado River basin: Green River at Vernal, UT (the only upper basin station) and Colorado River at four sites in Arizona (Imperial Reservoir, Lake Havasu, Lake Mead, and Lake Powell). In 1978-1981 and 1984, selenium concentrations exceeded the 85th percentile at six of seven stations; the five above plus the Colorado River at Yuma, AZ. The only station at which selenium concentrations in fish have not exceeded the 85th percentile was on the Gila River (San Carlos Reservoir, AZ).

Prior to the NIWQP and NCBP studies, studies in the 1930s by the U.S. Department of Agriculture reported elevated selenium concentrations in water in the upper and lower Colorado, Gunnison, and San Juan rivers due to irrigation activities (Anderson et al. 1961). Elevated selenium concentrations were also reported in water 48 and 112 km southeast of the mouth of the Colorado River in the Gulf of California. The long-term contamination of the lower Colorado River basin (Anderson et al. 1961) may have been one of the factors contributing to the disappearance of endangered fish in the early 1930s as reported by Dill (1944). More recently, elevated selenium concentrations in water, sediment, and biota in the lower Colorado River basin documented in a NIWQP study were identified as coming from the upper basin (Radtke et al. 1988, Radtke and Kepner 1990).

Wide spread selenium contamination of the Colorado River basin has been reported. In the upper basin, Stephens and Waddell (1998) reviewed several NIWQP investigations, data in the National Water Data Storage and Retrieval System of the USGS, DOI Floodplain Habitat Restoration Program, and contaminant assessment reports of the USFWS, and reported that selenium was present at concentrations harmful to fish and wildlife at several locations in the Green River basin, UT, including Ashley Creek, Anderson Bottom in the Canyonlands area, Desert Lake Waterfowl Management Area, Escalante Ranch, Sheppard Bottom in Ouray NWR, Stewart Lake, Pariette Wetlands, and the Price and Yampa rivers. Bussey et al. (1976) measured 10 inorganic elements in various fish tissues collected from Lake Powell and concluded that only selenium was elevated to concentrations of concern from a human consumption standpoint. In muscle tissue, selenium concentrations were 12.2 µg/g in largemouth bass (*Micropterus salmoides*) and 16.8 µg/g in black crappie (*Pomoxis nigromaculatus*), which were higher than the proposed toxic threshold (8 µg/g) for adverse effects in fish (Lemly 1996b). Selenium concentrations, however, were 6.4 µg/g in walleye (*Stizostedion vitreum*).

Hamilton (1998) reviewed similar sources plus university studies primarily from the

lower Colorado River basin and reported selenium contamination throughout the upper and lower Colorado River basin. He concluded that selenium concentrations were sufficiently elevated to be causing reproductive problems in endangered fish such as the razorback sucker. In a follow-up paper, he reviewed historical data on selenium concentrations in the upper and lower basins, along with historical records and reviews of the occurrence of native, later endangered fish, and presented a hypothesis that suggested selenium contamination from irrigated agriculture in the 1890-1910 period caused the decline of native fish in the upper basin in the 1910-1920 period and in the lower basin in the 1925-1935 period (Hamilton 1999). Although many of the studies reviewed in Hamilton (1998, 1999) documented elevated selenium concentrations in various aquatic components, none of the studies assessed biological effects in endangered fish from exposure to selenium or other inorganic elements.

In an effort to stabilize and enhance populations of razorback sucker and other endangered fishes in the upper Colorado River, the Floodplain Habitat Restoration Program within the Recovery Program undertook to restore floodplain habitats for use by razorback sucker larvae and adults. The proposed strategy for achieving these goals was to reconnect selected floodplain habitats to the main river channel in a manner that simulated historic hydrological conditions. An important component of this Restoration Program was to select sites that after restoration, would not pose contaminant problems to the fish, especially from selenium. This study was conducted to derive the necessary toxicological information for assessing the suitability of selected flooded bottomlands as habitat for razorback sucker.

Razorback sucker

The life history and status of the razorback sucker has been reviewed by Bestgen (1990). Briefly, the razorback sucker was considered common in the upper and lower Colorado River basins in historical times, but since the 1940's has become rare except for populations in the Green River and Lakes Mead and Mohave. Razorback suckers are generally thought to inhabit moderate to large streams and rivers and use a variety of habitats including low-velocity areas (backwaters, sloughs, oxbow lakes), near-shore runs, and shallow channels adjacent to, or over, mid-stream sandbars. The diet of razorback sucker varies depending on life stage, habitat, and food availability, and the diet of adults in rivers may be different than adults in reservoirs. Springtime congregations of razorback sucker have been found in off-channel impoundments and tributaries. Spawning behavior of razorback sucker is apparently influence by water temperature and flow (Tyus and Karp 1990), but Modde and Wick (1997) suggested that increases in discharge probably have a greater influence on initiating fish movement in late spring to spawning sites such as Razorback Bar in the Green River.

The remaining population of razorback sucker in the middle Green River basin in Utah has been estimated, using similar datasets, at about 1,000 individuals in 1988 (Lanigan and Tyus 1989) and at 300 to 600 in 1992 (Modde et al. 1996). Razorback sucker are rare in the upper Colorado River basin, where only 10 fish were found in the river between 1989 and 1996 (C. McAda, USFWS, personal communication).

The present study was conducted at three sites near Grand Junction, CO, in the general area where razorback sucker had historically been observed, i.e., the gravel pit at what is now Walter Walker State Wildlife Area, or is currently held in hatchery ponds for propagation purposes, i.e., Horsethief Canyon State Wildlife Area. Although wild fish are free to move about

the Colorado River and its tributaries, which may vary their exposure to various stresses, the adults in this study were held in specific locations as part of an exposure to selenium and other inorganic elements. After exposure, adults were hand spawned in late spring when water temperatures reached a level associated with naturally spawning of razorback sucker. Following spawning, tests were conducted with eggs and larvae.

Objective

The objective of this research was to conduct partial life cycle studies to determine if environmental exposure of adult razorback sucker to selenium and other inorganic elements in flooded bottomland sites affects their survival, growth, and reproductive success.

ADULT STUDY

This section of the report will describe the methods, results, and discussion of the adult razorback sucker portion of the reproduction study. Also included is information derived from informal observations of adult razorback sucker held at North Pond.

Methods

One hundred eight razorback sucker were acquired on July 6, 1995, as 3-year-old adults from Wahweap Fish Facility, Big Water, UT, operated by the Utah Division of Wildlife Resources. The adults were transported to Grand Junction, CO, by personnel of the CRFP and the U.S. Bureau of Reclamation. Parents of these fish were from the San Juan River arm of Lake Powell, UT. All the fish used were progeny of a single spawn of two adult razorback sucker (female: PIT 7F7F19036C, and male: PIT 7F7D055802). Fish were treated with oxytetracyline via intraperitoneal injection administered by personnel of the CRFP before release at the three study sites to treat potential infections incurred during transport or after release at the study sites. An additional 36 were transferred from Wahweap to Horsethief on July 27, 1995, and an additional 26 transferred on September 8, 1995.

Site descriptions

The partial life-cycle chronic toxicity study was conducted by exposing adult fish for about 9 months to water and natural foods at three sites adjacent to the Colorado River in the Grand Valley near Grand Junction, CO: Horsethief Canyon State Wildlife Area (reference site; hereafter referred to as Horsethief), Adobe Creek, and North Pond at Walter Walker State Wildlife Area (WWSWA) (Figures 2-6). The Horsethief facility is operated by the CRFP, Grand Junction, CO. The Horsethief site was located about 19 km (12 miles) west of the Grand Junction city limits, the Adobe Creek site was located about 5 km (3 miles) west of the Grand Junction city limits, and the North Pond site was located about a half km to the southwest of the Grand Junction city limits.

Sampling stations were established at each site a few months before fish were stocked for the study as follows: Horsethief (HTi [inlet] and HTo [outlet]), Adobe Creek (AC1 through AC7), and WWSWA (WW1 through WW10). At Horsethief, fish were held in earthen ponds, either pond 1 or 6, along with other endangered fish stock (Figure 3). The water in the ponds was maintained by water pumped directly from the Colorado River near Fruita, CO, and was believed to have little or no selenium contamination. The Adobe Creek site was a tertiary river channel about 200 m long and 3 to 5 m wide and was isolated from river flow by dikes at both ends. Both dikes have large gate valves and the downstream dike also had an overflow water control structure (Figure 4). Fish were held in the section of the channel with sample stations AC3, AC4, and AC5. The water level at Adobe Creek was maintained with water pumped from the secondary channel (location AC2). Overflow water from an irrigation ditch (AC7) also entered the diked area. Water at the site was maintained at about 1.5 m deep, and was believed to have relatively low levels of selenium contamination. The North Pond site was an isolated pond about 1 ha (2.5 acre) in size with a maximum depth of 1.5 m located on a terrace about 2 m above the floodplain (Figure 5). Water in North Pond was supplied primarily by ground water

Figure 2. Map of three sites located in the Grand Valley near Grand Junction, Colorado, used for a reproduction study with razorback sucker.

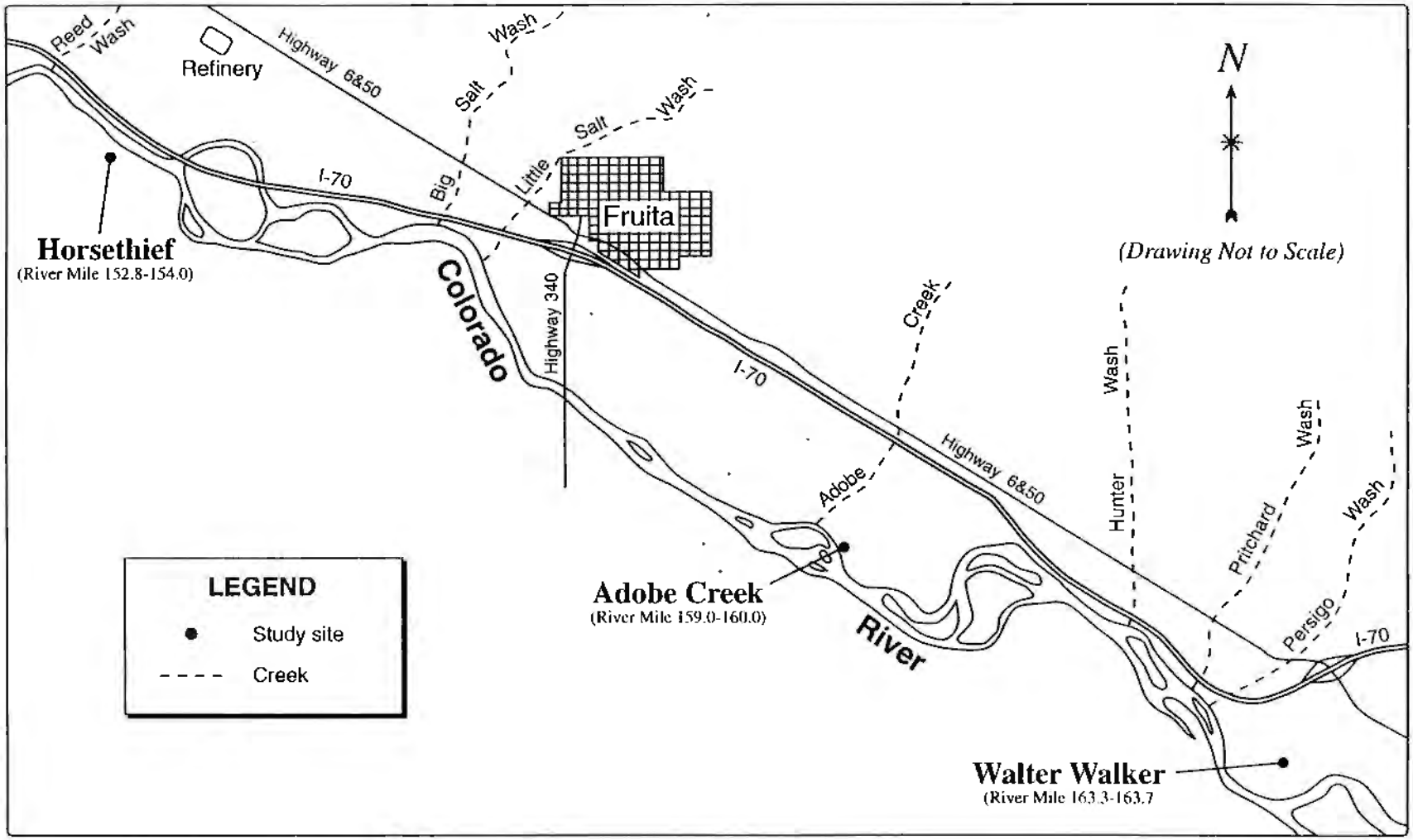

Reed Wash
Refinery
Highway 6&50
Salt Wash
Salt Wash
Big
Little
I-70
Fruita
N
(Drawing Not to Scale)
Horsethief
(River Mile 152.8-154.0)
Colorado
Highway 340
I-70
Creek
Wash
Hunter
Pritchard
Wash
Wash
Adobe
Highway 6&50
Persigo
I-70
LEGEND
Study site
Creek
Adobe Creek
(River Mile 159.0-160.0)
River
Walter Walker
(River Mile 163.3-163.7

Figure 3. Map of ponds and east wetland at Horsethief Canyon State Wildlife Area near Grand Junction, Colorado.

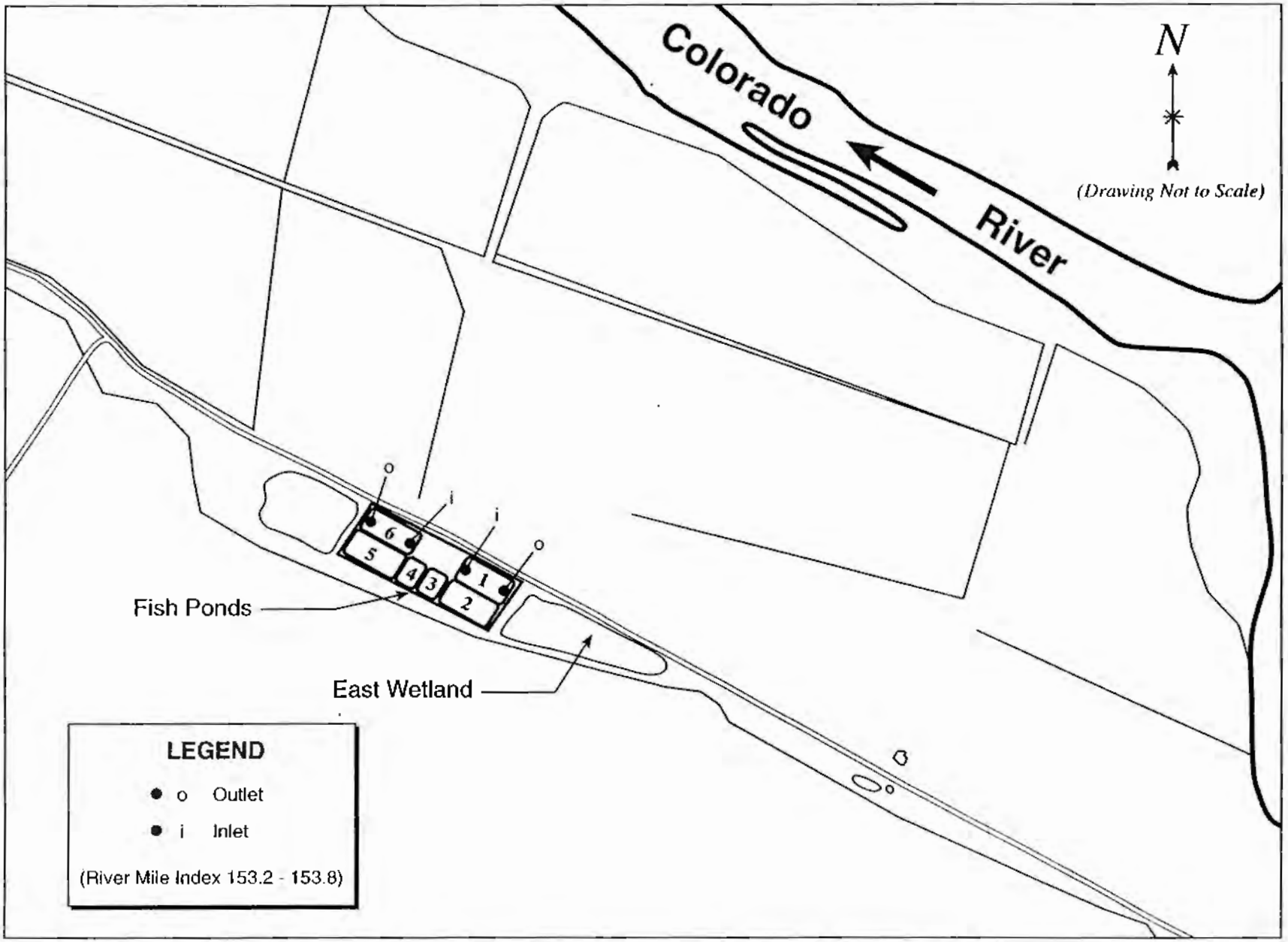

Colorado River
N
(Drawing Not to Scale)
o
i
i
o
6
5
4
3
1
2
Fish Ponds
East Wetland
LEGEND
o Outlet
i Inlet
(River Mile Index 153.2 - 153.8)

Figure 4. Map of sampling stations at the Adobe Creek site near Grand Junction, Colorado. Fish were held in the diked area with sampling stations AC3, AC4, and AC5.

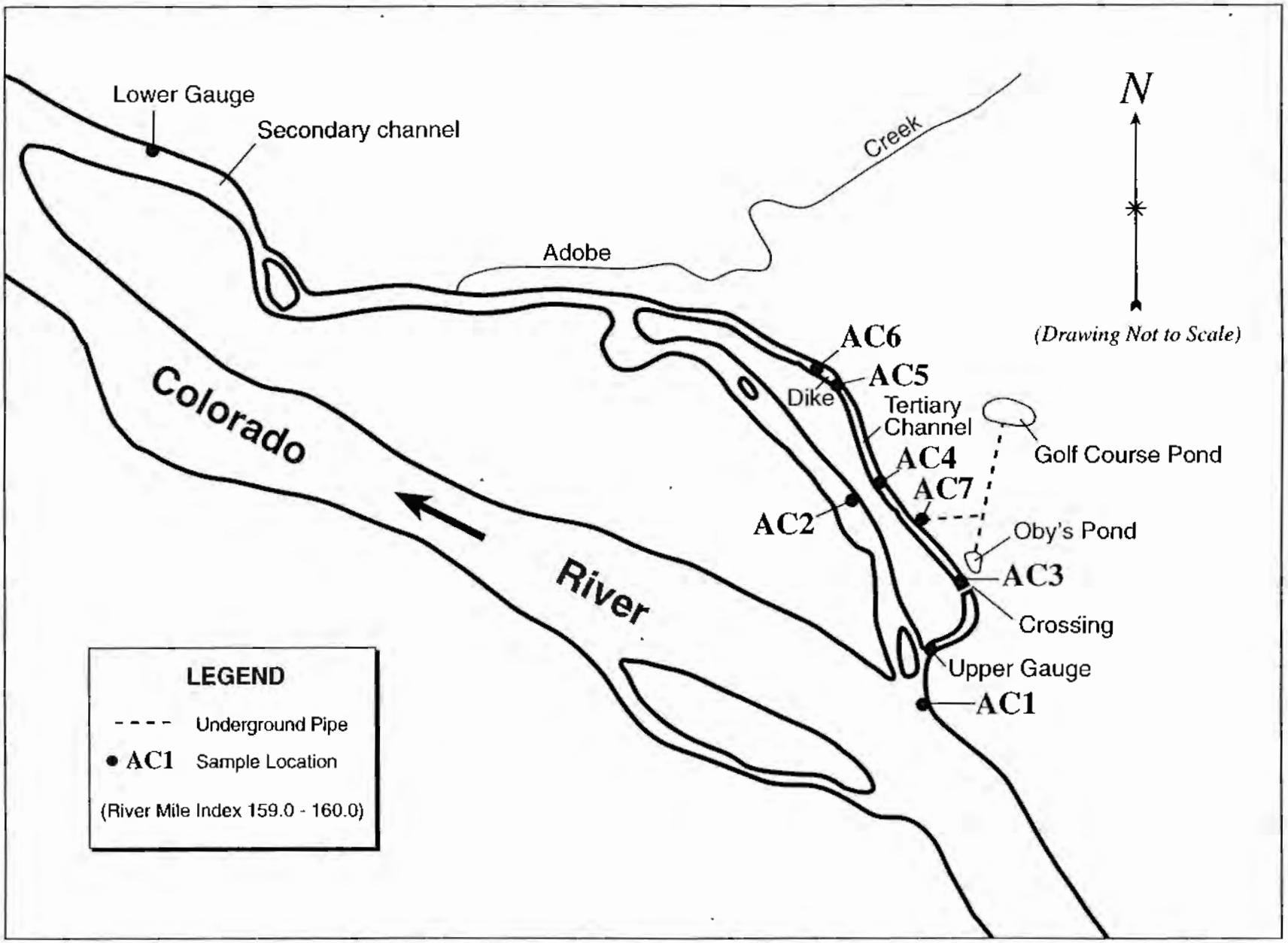
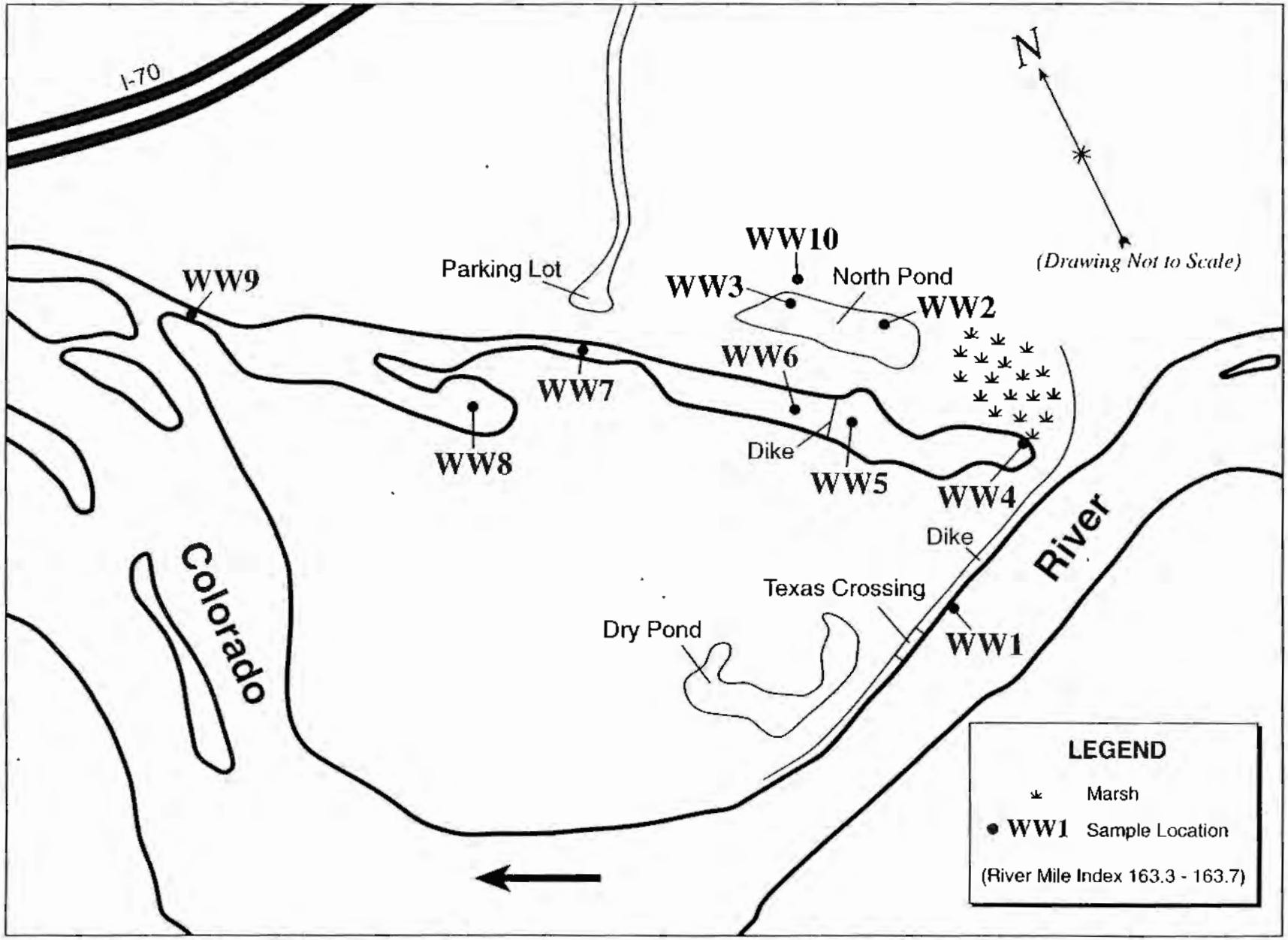

Lower Gauge
Secondary channel
Creek
Adobe
N
(Drawing Not to Scale)
AC6
AC5
Dike
Tertiary
Channel
AC4
AC7
Golf Course Pond
AC2
Oby's Pond
AC3
Crossing
Upper Gauge
AC1
Colorado
River
LEGEND
Underground Pipe
AC1 Sample Location
(River Mile Index 159.0 - 160.0)

Figure 5. Map of sampling stations at the Walter Walker State Wildlife Area site near Grand Junction, Colorado.


I-70
N
(Drawing Not to Scale)
WW10
WW3
North Pond
WW2
Parking Lot
WW9
WW6
WW7
WW8
Dike
WW5
WW4
Dike
River
Colorado
Texas Crossing
Dry Pond
WW1
LEGEND
Marsh
WW1 Sample Location
(River Mile Index 163.3 - 163.7)

discharge, which was believed to contain elevated selenium concentrations. The south side of North Pond had a dike and water overflow structure installed to maintain water levels and confine fish. Fish were held in North Pond with sample stations WW2 and WW3. Water levels were supplemented by inflow at WW10 from Independent Ranchman's Ditch. Flooding of the Colorado River in spring 1996 caused water levels at Adobe Creek and North Pond to raise substantially for several weeks. However, to the author's knowledge, no fish escaped from these areas nor were wild adults introduced into these areas.

Hatchery brood stock adults previously collected from various locations (upper Colorado River, Etter Pond adjacent to the Colorado River, the Colorado River arm of Lake Powell, and the San Juan River arm of Lake Powell) and held at Horsethief were also used in the study as additional reference fish that supplied larvae for the larval fish study.

Staff gages were installed at WW9, and near AC1 and AC6 to monitor water elevation. Gage heights were recorded daily at WW9 from April 12 to August 28, 1995, and from March 14 to June 16, 1996, and on an irregular basis for the other two stations from March 14 to June 16, 1996.

Fish stocking and sampling

Thirty-six adults were randomly stocked by personnel of the CRFP at each site on July 7, 1995, and maintained at each site until they were collected during the last week of April 1996. Additional adults not needed in the study were held at Horsethief. Prior to stocking, each fish was PIT tagged, measured for total length and weight, and a muscle plug sample taken from the area adjacent to the dorsal fin for selenium analysis. Muscle plugs were collected using a 4- or 5-mm biopsy punch, placed in cryotubes, stored on ice in the field, stored in a freezer (-20°C) while awaiting analysis, and shipped on dry ice when transported to the sample preparation laboratory. After the muscle plug was collected, the wound was treated with full-strength Betadine solution. Fish held at Horsethief were fed the same commercial standard fish food fed to other stocks of razorback sucker routinely maintained there. Fish at Adobe Creek and North Pond were not fed artificial food and foraged for natural food items at the site.

Due to the mortality of 17 fish at North Pond 1 month after stocking because of suspected low dissolved oxygen concentrations (fish were held overnight at day 30 sampling in a hoop net and had limited access to areas of the pond with higher dissolved oxygen concentrations), North Pond was restocked with 17 fish from Horsethief on August 10, 1995.

At 30-60 day intervals after stocking, fish were sampled in cooperation with the CRFP using trammel nets or boat-mounted electrofishing equipment. Captured fish were identified by their PIT tag, measured for total length and weight, inspected for general health, and a muscle plug was taken for selenium analysis. Not all fish stocked at Adobe Creek and North Pond were recovered at each sampling period because of the difficulty in locating and capturing the fish.

Natural food organisms were collected monthly from as many of the 17 stations as practical for chemical analysis. Collections were accomplished primarily using modified light traps (Espinosa and Clark 1972), and infrequently by plankton tow net, sediment grab samplers, and round Hester-Dendy samplers. Light traps were set overnight and the trapped zooplankton and other aquatic invertebrates were collected the following morning. At each sampling station, the contents of all the light traps were combined and concentrated by filtering the samples through the basket of a 153 μm plankton net. The combined samples were then backwashed into

a 3.8-L plastic jar filled with site water, covered, and transported to the laboratory in coolers. In the laboratory, the samples were thoroughly mixed and a subsample was collected in a glass vial and preserved in 70% ethanol. The subsample was used to make semi-quantitative estimates of species composition at each station.

Sediment grab samples for separation of benthic invertebrates were collected in plastic jars and transported in coolers to the laboratory. Sediment samples were washed through a set of sieves and the invertebrates extracted from the debris using stainless steel forceps.

Generally, two sets of aquatic invertebrate samples were collected from each sample station on a monthly basis when available, placed in Whirl-Pak bags, and stored frozen at -20°C. One set was analyzed for selenium concentrations by atomic absorption spectrophotometry, and the other set was analyzed for concentrations of inorganic elements by inductively coupled argon plasma (ICP) spectroscopy analysis. One sample from two different lots of the commercial diet fed to adults at the Horsethief reference site also was collected for selenium analysis.

Spawning

In late spring of 1996 after water temperature rose to 16°C (~60°F) and remained there for about a week (last week of April), fish held at Adobe Creek and North Pond were captured by personnel of the CRFP between April 24 and 29 using trap (fyke) nets and electrofishing methods and transported to the fish holding building at Horsethief. Adults held in earthen ponds at Horsethief were collected using a seine. All fish were held in 1.3 m-diameter tanks in the holding building supplied with flowing Colorado River water supplemented with oxygen delivered through diffuser bars. Muscle plugs were taken from all fish for selenium analysis. Muscle plugs also were taken from 14 hatchery brood stock fish held at Horsethief.

To induce spawning, fish were injected with human chorionic gonadotropin hormone on each of 3 consecutive days, beginning 5 days prior to spawning date. Fish were not injected on the fourth day, and were spawned on the fifth day. All females were injected at the rate of 220 International Units (IU) per kg of body weight. All males were injected at the rate of 660 IU per kg one time, 5 days prior to spawning. After inspection for spawning characteristics (i.e., tubercles present and milt running in males, coloration, plumpness of females), as many adults as possible were spawned. Eggs from each female were fertilized with sperm from at least one male. Fertilized eggs were washed in bentonite clay solution to reduce adhesiveness and then were water hardened in Colorado River water.

Eggs were transported to 24-Road Fish Hatchery (hereafter termed 24-Road), Grand Junction, CO, and placed in incubation buckets with screened bottoms. Eggs from each female spawned were held in separate buckets. Buckets were held in 1.3 m-diameter tanks with recirculated 24-Road Fish Hatchery water (hereafter termed 24-Road water). Two samples of eggs from each spawn were collected, placed in Whirl-Pak bags, and stored frozen at -20°C until thawed for selenium and ICP analyses. After spawning, two fish from each site were sacrificed (euthanized with MS-222 [tricaine methanesulfonate]) to determine selenium concentrations in various tissues. Sacrificed fish were stored at -20°C until thawed for selenium analysis.

After spawning, adult fish from Adobe Creek and North Pond, along with Horsethief and brood stock fish, were held in the same earthen ponds at Horsethief for 60 days to determine the rate of selenium depuration from their tissues. Fish were captured at 30 and 60 days post spawning, identified by their PIT tag, measured for total length and weight, inspected for general

health, and muscle plugs were taken for selenium analysis. Two fish from each group held at the three exposure sites were sacrificed after spawning, after 30 days, and after 60 days in the depuration phase of the study for analysis of selenium concentrations in various tissues. The following samples were taken from each fish: muscle tissue from the dorsal area close to where muscle plugs were removed, liver, kidney, gonad, gall bladder, and gut contents (only two fish). The samples were placed in Whirl-Pak bags and stored frozen at -20°C until chemical analysis.

Informal observations of adult razorback sucker

Five adult male razorback sucker used in an electroshocking study (Muth and Ruppert 1996) were held at North Pond in a hoop net for 89 days (March 5 - June 2, 1995). The purpose of the informal observation was to determine if adult razorback sucker could survive in North Pond with selenium concentrations in water as high as 170 μg/L. This test was conducted prior to stocking the young adults in the reproduction study. Fish had limited access to bottom sediments and received a commercial fish diet (Silvercup, Nelson & Sons, Murray, UT) approximately every 7-10 days. Duplicate samples of the commercial fish food diet were collected for analysis of selenium concentrations. At 0, 30, 60, and 89 days of exposure, fish had muscle plugs collected as described previously. After 89 days of exposure, fish were sacrificed and stored frozen until selenium analysis of various tissues. The following samples were taken from each fish: muscle tissue from the dorsal area close to where muscle plugs were removed, liver, kidney, gonad, and gall bladder (no gut contents were available). The samples were placed in Whirl-Pak bags and stored frozen at -20°C until analysis of selenium concentrations.

Water and sediment sampling

Beginning in mid-April 1995, selected water quality characteristics were measured every week in situ at most of the 17 sample stations at the three test sites (Figures 3, 4, 5). In addition, water samples were collected at 17 stations every 30 days and analyzed for general water quality characteristics in the mobile laboratory. Water quality characteristics measured in situ at each site included pH, conductivity, salinity, air temperature, water temperature, and dissolved oxygen. Water quality measurements in water samples measured in the mobile laboratory included pH, conductivity, hardness, calcium, magnesium, alkalinity, and chloride. Two subsamples of each sample taken to the mobile laboratory were collected in polyethylene bottles. One sample was used for ammonia analysis and was acidified to a pH <2 with concentrated sulfuric acid. The other sample was used for analysis of nitrate, nitrite, sulfate, total suspended solids, volatile solids, and fixed solids and was stored in a refrigerator at 4°C. These subsamples were then shipped in a cooler with ice packs by overnight express to Yankton Field Research Station (FRS), SD, for analysis. All water quality characteristics were measured according to standard methods (APHA et al. 1995), except for the nitrogenous chemicals and chloride. Ammonia, nitrate, and nitrite were measured using ion-selective electrodes and following the procedures for low concentration measurements of the electrode manufacturer (Orion Research 1990, 1991; ATI Orion 1994). Chloride was measured by a modification of the APHA et al. (1995) method (Hach Company 1992).

Subsamples of water collected between May 1995 and June 1996 for water quality analyses from the 17 sample stations were taken for selenium analysis and ICP analysis of

inorganic elements. Samples for selenium analysis were collected monthly and those for ICP were collected bimonthly. Filtered and unfiltered water was collected for selenium analysis. Water was filtered through a 0.4 μm polycarbonate filter using a Geotech Filtration unit and 200 ml of filtered water samples was acidified with 2 ml of ultrapure HCl and stored frozen until analysis of selenium concentrations. Two-hundred ml of unfiltered water samples (but passed through a 25 μm filter bag) was acidified with 2 ml of ultrapure HCl and stored frozen until analysis of selenium concentrations. Samples for ICP analysis were filtered (0.4 μm) as described above and acidified with 2 ml of ultrapure HNO_3 and stored frozen. During the egg study, water samples were collected weekly from the prefiltered (25 μm filter bag) site waters for selenium analyses, and during the larval fish study for selenium and ICP analyses. The water was filtered (0.4 μm filter) and preserved as described above.

Sediment samples were collected in May 1995, October 1995, and April 1996 from each site where the adult fish were held. Sediment was collected by a petit ponar grab sampler, placed in a large plastic pan, thoroughly mixed, and large pieces of debris removed (plants, twigs, rocks, etc.). Three subsamples of the homogenized sediment were collected in polyethylene bottles, and stored in a freezer until analysis. One sample was analyzed for selenium, and a second sample was analyzed for inorganic elements by ICP analysis. A second portion of each of the samples collected in October 1995 and April 1996 was analyzed for total and inorganic carbon, for total, volatile, and fixed solids, and a third portion was examined for sediment texture.

Samples for carbon analysis were oven dried overnight at 105°C in a Fisher Isotemp oven. Dried samples were homogenized and ground in a CRC Micro-mill. Subsamples of about 30 mg each were wrapped in aluminum foil and bagged in Whirl-pak bags. The subsamples were sent to the Columbia Environmental Research Center (CERC), Columbia, MO, for analysis of total and inorganic carbon; organic carbon was determined by subtraction. Carbon analyses were accomplished with a Coulometrics Carbon model 5020 analyzer.

Total, volatile, and fixed solids were determined by standard methods (APHA et al. 1995). Briefly, subsamples were weighed in an aluminum drying pan and air-dried prior to oven drying and muffle furnace ignition. Total solids was determined by drying the sediment overnight in a Fisher Isotemp oven at 105°C. Constant weights were determined by loss of less than 4% or 50 mg, whichever was less. Fixed and volatile solids were determined by ignition at 550°C for 60 minutes in a Thermolyne model FA1730 muffle furnace and then allowed to cool overnight in the furnace before weighing.

Particle size determination of sediments was determined by standard methods (ASTM 1993). Samples were air-dried on fiberglass trays for 3-6 days, and large aggregates of dried sediment were crushed with a mortar and rubber-covered pestle. The dried sediment was sieved to remove particles >2.0 mm. Dried sediments were weighed, and stored at 4°C until analysis. Each sample was analyzed in duplicate. Hydrometer analyses were conducted in 1-L sedimentation cylinders or graduated cylinders using ASTM model 152H hydrometers following standard methods (ASTM 1990b). Briefly, sediment subsamples were dispersed overnight in 40 g/L sodium hexametaphosphate solution. A Hamilton Beach Scovill mechanical stirrer and a cup with baffles was utilized to further disperse the sample before hydrometer analysis. The results were plotted on graph paper and the percentage for the particle size of interest was interpolated from the graph. Particle sizes were classified according to the U.S. Geological Survey classification scheme, which is based on the Wentworth grade scale: sand 0.063 mm - 2.0 mm, silt 0.004 - 0.062 mm, and clay <0.004 mm (Guy 1969).

Inorganic element analyses

All samples collected for selenium analysis were analyzed at the Yankton FRS, SD, using a Perkin-Elmer model 3300 atomic absorption spectrophotometer equipped with a model MHS-10 hydride generator (AA-HG). The spectrophotometer was standardized with National Institute of Standards and Technology (NIST) standard reference material 3149 (water).

Water samples were digested using a persulfate digestion technique and total selenium determined by a modification of the method of Presser and Barnes (1984). Quality assurance/quality control measures included determination of limit of detection, procedural blanks for background equivalent concentration, percent relative standard deviation of triplicate sample preparation and analysis, recovery of elements from reference material, and recovery of digested-spiked sample solutions, and analysis-spiked samples at the AA-HG. The limit of detection (LOD) ranged from 0.5 to 3.9 μg/L (mean 1.4, SE 0.1, n=27). The procedure blanks had background concentrations less than the LOD, which indicated no contamination from reagents or sample handling. The percent relative standard deviation (triplicate sample preparation and analysis) ranged from 0 to 8.2% (mean 4.6, SE 2.1, n=27), which indicated consistent sample handling during preparation, digestion, and analysis. Recoveries of selenium from NIST reference material 1643c water and NIST reference material 1643d were within Columbia Environmental Research Center (CERC) recommended ranges, which indicated the digestion and analysis procedure accurately measured selenium concentrations. The digested-spiked sample solutions had percent recoveries ranging from 86 to 116% (mean 101, SE 8.4, n=27), which indicated the digestion procedure did not alter the amount of spiked selenium in the sample, i.e., suggested no loss of selenium in water samples during digestion procedure. Analysis of analysis-spiked samples analyzed for matrix suppression or enhancement had selenium recoveries ranging from 82 to 118% (mean 101, SE 9, n=27), which indicated no interference from other water components.

All sediment, fish, fish egg, zooplankton, brine shrimp, commercial fish food, tadpole, and aquatic plant samples were prepared for analyses of selenium concentrations by first lyophilizing the sample to a constant dry weight using a Virtis Vacu-Freezer. Fish samples were then homogenized with a food processor. Animal and plant tissue, fish food, and sediment samples were digested using a combination nitric acid wet digestion and magnesium nitrate dry ash technique (Pettersson et al. 1986). The dry ash procedure was accomplished in a Thermolyne model FA1730 muffle furnace. Total selenium was determined by a modification of the method of Presser and Barnes (1984). Quality control/quality assurance measures were the same as for water analyses, and the results are summarized in Table 1.

Analyses of water, sediment, zooplankton, and fish egg samples collected for ICP analysis of inorganic elements were performed at the Environmental Trace Substances Research Center (University of Missouri), Rolla, MO. The list of elements and LOD are given in Table 2. For water, the procedure blank had background equivalent concentrations less than the LOD for all elements except calcium, silicon in one blank, and antimony, calcium, and titanium in a second blank; the mean percent relative standard deviation (duplicate sample preparation and analysis) was 3.4%; the mean spike recovery was 97%; and the recovery of trace elements in Environmental Resources Associates reference water ERA9969TM was within recommended ranges except for arsenic, selenium, and thallium in one analysis, and aluminum, arsenic, and thallium in a second analysis.

Table 1. Mean (standard error in parentheses and number of samples in brackets) quality assurance and quality control measures for selenium analysis of sediment and biological samples.

Measure	Matrix					
	Sediment	Fish	Fish egg	Aquatic invertebrate	Brine shrimp	Fish food
Limit of detection (μg/g)	0.19 (0.11) [4]	0.12 (0.02) [20]	0.27 (0.14) [4]	0.16 (0.03) [19]	0.05	0.08 (0.01) [2]
%RSD[1]	5.7 (1.0) [4]	5.5 (0.5) [20]	6.2 (0.7) [4]	5.6 (0.5) [19]	4.8	6.2 (1.8) [2]
Reference material	0.44[2] (0.01) [4]	1.51[3] (0.04) [11] 1.39[4] (0.03) [9] 4.05[5] (0.06) [8]	1.23[4] (0.03) [4] 1.81[6] (0.01) [4]	1.51[3] (0.04) [11] 1.26[4] (0.03) [8] 4.05[5] (0.06) [8]	1.50[3] (-) [1] 3.90[5] (-) [1]	1.35[3] (0.05) [2] 4.0[5] (0) [2]
Digested spikes[7]	104 (3) [8]	99 (1) [39]	98 (3) [8]	97 (1) [38]	102 (2) [2]	104 (2) [4]
Analysis spikes[8]	102 (4) [4]	96 (2) [20]	98 (4) [4]	100 (2) [19]	97 (-) [1]	103 (2) [2]

[1] RSD: Percent relative standard deviation for triplicate preparation and analysis.
[2] National Research Council of Canada (NRCC) reference material BCSS-1 (marine sediment; 0.43 ± 0.06 [SD] μg/g).
[3] NRCC reference material DORM-1 (dogfish muscle tissue; 1.62 ± 0.12 [SD] μg/g).
[4] NRCC reference material DORM-2 (dogfish muscle tissue; 1.40 ± 0.09 [SD] μg/g).
[5] National Bureau of Standards (NBS) 50AT (Albacore tuna; 3.6 ± 0.4 [SD] μg/g).
[6] NBS 1566a (tissue; 2.21 ± 0.24 [SD] μg/g).
[7] % recovery of selenium from samples spiked with selenomethionine at the beginning of preparation for sample analysis.
[8] % recovery of selenium from digested samples spiked with selenite after sample preparation but before instrument analysis.

Table 2. Limit of detection for elements measured by inductively coupled argon plasma spectroscopy in water (μg/L), sediment (μg/g dw: dry weight), zooplankton (μg/g dw), and fish eggs (μg/g dw).

	Matrix			
Element	Water	Sediment	Zooplankton	Fish eggs
Ag	5	1	1	1
Al	30	8	7	6
As	20	7	4	3
B	6	6	1	1
Ba	0.4	0.1	0.1	0.1
Be	0.2	0.2	0.04	0.04
Bi	40	4	5	5
Ca	20	3	1	1
Cd	2	0.2	0.2	0.2
Co	3	0.8	0.5	0.4
Cr	7	2	2	2
Cu	5	1	1	1
Fe	5	1	0.8	0.8
K	700	100	175	190
Li	3	0.7	0.5	0.5
Mg	7	0.1	0.2	0.3
Mn	1	0.2	0.1	0.1
Mo	4	0.9	0.7	0.7
Na	30	10	14	11
Ni	6	4	1	1
P	40	6	6	5
Pb	7	5	4	4
Sb	30	6	9	10
Si	80	3	10	10
Sr	0.6	0.04	0.05	0.04
Ti	0.9	0.3	0.2	0.2
Tl	100	40	35	31
W	10	2	3	3
V	5	1	1	0.9
Zn	10	0.4	0.3	0.3

For sediments, the procedure blank had background equivalent concentrations less than the LOD for all elements except for silicon in one blank, the mean percent relative standard deviation (duplicate sample preparation and analysis) was 4.6%; the mean spike recovery was 97%, and the recovery of trace elements in National Bureau of Standards (NBS) reference sediment 2704 (Buffalo River sediment) was within recommended ranges except for aluminum, arsenic, barium, calcium, chromium, iron, magnesium, manganese, phosphorus, potassium, silicon, sodium, titanium, vanadium, and zinc in one analysis, and the same elements plus cobalt in a second analysis.

For zooplankton, the procedure blank had background equivalent concentrations less than the LOD for all elements, the mean percent relative standard deviation (duplicate sample preparation and analysis) was 6.0%, the mean spike recovery was 95%, the recovery of trace elements in NBS reference material 1566a (oyster tissue) was within recommended ranges except for aluminum, iron, phosphorus, silver, sodium, and vanadium, and the recovery of trace elements in National Research Council of Canada (NRCC) reference material TORT2 (lobster tomalley) was within recommended ranges except for arsenic, cobalt, lead, nickel, selenium, and vanadium.

For fish eggs, the procedure blank had background equivalent concentrations less than the LOD for all elements, the mean percent relative standard deviation (duplicate sample preparation and analysis) was 4.6%, the mean spike recovery was 98%, the recovery of trace elements in NBS reference material 1566a (oyster tissue) was within recommended ranges except for aluminum, iron, phosphorus, silver, sodium, and vanadium, and the recovery of trace elements in NRCC reference material DORM2 (dogfish muscle) was within recommended ranges except for aluminum, arsenic, copper, and manganese.

Muscle plugs from all the spawned fish and some unspawned fish were analyzed for selenium concentrations to ensure an adequate sample size for statistical analysis. Muscle plugs and larvae were prepared for analysis at CERC, and neutron activation analysis was performed at the University of Missouri Research Reactor (MURR), Columbia, MO.

Neutron activation was used for the analysis of selenium in muscle plugs and larvae because of the small sample mass. All sample preparation prior to neutron activation analyses and neutron activation method were described in Waddell and May (1995). Samples were transported to MURR for determination of the radionuclide ^{77m}Se (McKown and Morris 1978). Selenium standards and quality control samples were analyzed in the same manner as animal tissues. National Institute of Standards and Technology 1577 (bovine liver) standard reference material was analyzed by MURR as quality control checks on accuracy and precision. The recovery of selenium was within the NIST recommended range, and the percent relative standard deviation of multiple analyses ranged from 3.2 to 5.7%. Selenium values in μg were obtained by direct comparison of peak areas obtained for the samples to the average peak areas obtained for a set of standards. The limit of detection was 0.015 μg/g. Multiple muscle plugs from the same fish were not taken so no other quality assurance measures were evaluated.

Statistics

Data were analyzed using computer programs from Statistical Analysis System Institute, Inc (SAS 1990). Analysis of variance testing was used to determine treatment effects on percent survival (arcsine transformed values) and growth of razorback sucker larvae, and for

comparisons of residues in water, sediment, zooplankton, and muscle plugs (logarithmically transformed values) among sites and sample stations within sites. When significant differences (P=0.05 [probability {P} of a significant difference between measurement values at = 0.05]) were observed, means were compared by the Bonferroni (Dunn) multiple mean comparison test (Snedecor and Cochran 1967). Incremental growth of individual adult fish identified by PIT tag was calculated by subtracting the growth measurement at one sample period from the measurement at the previous sample period and dividing by the number of days between sample periods. Correlation analyses (Pearson product-moment correlation [r], SAS 1990) were used to test for relations among water quality characteristics, inorganic element concentrations, effects on fish, and tissue residue concentrations. Correlation analyses of the means with standard deviation and variance measures were conducted to determine if transformations were needed to meet the assumptions of normality and homogeneity of variance (M. Ellersieck, University of Missouri, Columbia, personal communication). The data for residues for water, sediment, zooplankton (except Ba, Ca, and Si), and muscle plugs, and water quality measures in the egg and larval fish studies were log10 transformed prior to correlation analysis.

Multiple regression analyses were used to test for relations among sediment characteristics and selenium concentrations in sediment, and among selenium concentrations in larvae, water, and zooplankton, and larval survival.

The predicted time-to-death and 95% confidence intervals were calculated for each test group of larvae and treatment using S-Plus statistical software (Mathsolf, Seattle, WA). The parametric proportional hazard regression model and Weibull distribution were used in the analysis. Both right and interval censoring of survival time data was accounted for in the statistical methodology. The predicted time-to-S%.mortality was calculated for S=50, 90, and 95%.

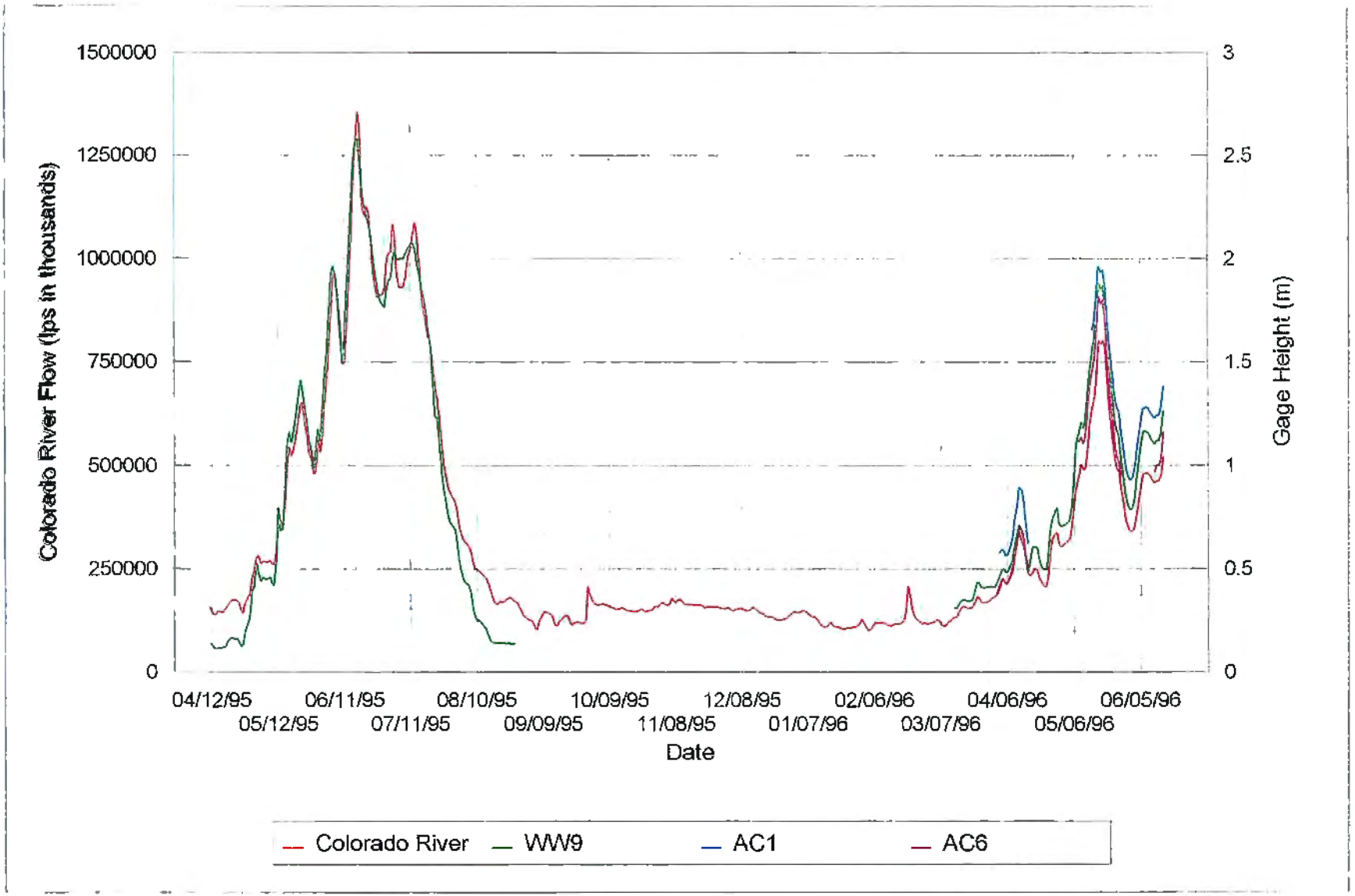
Results

Snow melt runoff in the upper Colorado River basin began approximately on May 1, 1995, and peaked on June 18, 1995 (Figure 6, Appendix A). Staff gage height at WW9 increased from a low of 0.12 m prior to May 1, 1995, to 2.59 m on June 18, 1995, at peak flow. No staff gage height information at Adobe Creek was recorded until April 1996.

Water quality

Water quality, characterized primarily by conductivity, varied over time at all the sites between May 3, 1995, and June 21, 1996 (Appendix B). This variation was partly due to flooding of the Colorado River during high runoff, which extended from mid-June to late-July in 1995 and from mid-May to late June in 1996. Water quality parameters at Horsethief matched closely with those in the Colorado River at stations WW1 and AC1, but water quality changes at Horsethief lagged behind those in the Colorado River by about 1-2 weeks. For example, the conductivity of the Colorado River at WW1 on August 7, 1995, was 509 µmhos/cm and increased 59% to 812 µmhos/cm on August 22, whereas a similar change in conductivity at Horsethief occurred on August 31. Likewise, when the conductivity in the Colorado River was decreasing in March 1996, changes in conductivity at Horsethief occurred about 2 weeks later. Water quality characteristics in samples measured in the mobile laboratory, such as hardness and

Figure 6. Flow (lps; liters per second) of the Colorado River (Crowfoot et al. 1996, 1997) and staff gage height (m) at Walter Walker State Wildlife Area and Adobe Creek.


Colorado River Flow (lps in thousands)
1500000
1250000
1000000
750000
500000
250000
0
Gage Height (m)
3
2.5
2
1.5
1
0.5
0
04/12/95
05/12/95
06/11/95
07/11/95
08/10/95
09/09/95
10/09/95
11/08/95
12/08/95
01/07/96
02/06/96
03/07/96
04/06/96
05/06/96
06/05/96
Date
Colorado River
WW9
AC1
AC6

alkalinity, followed changes in conductivity, being lowest during runoff and highest during low flow periods (Appendix C). During the period when adults were held at Horsethief, the range of values were 392-950 μmhos/cm conductivity, 148-324 mg/L hardness as $CaCO_3$, and 92-140 mg/L alkalinity as $CaCO_3$. The range of other water quality constituents also was narrow, i.e., chloride, nitrate, nitrite, solids, and sulfate (Appendix C).

Sample stations at the Adobe Creek site where the adults were held received mostly ground water infiltration from the river, but also inputs of irrigation water at station AC7 and pumped river water from station AC2. River water from the secondary channel (AC2) was used to maintain water levels in the area where the adult fish were held, and water from this channel was pumped from late August to early November 1995 and from late April to early June 1996. Flows into the adult holding area from AC7 were unexpected, but were monitored when flow was observed. Uncontrolled flooding of the Adobe Creek area occurred for about 1 week (~June 16-24, 1995) during high runoff flows in the Colorado River. Water quality characteristics at AC3, AC4, and AC5 were similar to those at HT because of pumped water from AC2, limited irrigation flows from AC7, and uncontrolled flooding. During the period when adults were held at Adobe Creek, the range of values were 418-1,110 μmhos/cm conductivity, 148-344 mg/L hardness as $CaCO_3$, and 75-189 mg/L alkalinity as $CaCO_3$ (Appendix D). There was no consistent pattern of higher or lower water quality values between the upstream station AC3 and the downstream station AC5, probably because the channel area was long and narrow. The highest values for water quality constituents occurred before the adults were stocked at Adobe Creek. Peak values were 1,680 μmhos/cm conductivity, 518 mg/L hardness as $CaCO_3$, and 300 mg/L alkalinity as $CaCO_3$. Nevertheless, during the period when adults were present, there was little difference in general water quality characteristics between Horsethief and Adobe Creek.

The stations at North Pond where adults were held (WW2 and WW3) received mostly upslope ground water from a cobble aquifer (Phillips 1986) and inputs of irrigation supply water from Independent Ranchman's Ditch via WW10. Flows from WW10 were used to maintain water levels in the area where the adult fish were held and occurred from late August to early November 1995 and from late April to early June 1996 (Appendix E). Uncontrolled flooding at North Pond occurred for about 1 week (~June 16-24, 1995) during high runoff flows in the Colorado River. Water quality characteristics were more variable at WW2 and WW3 than at the stations at Horsethief or Adobe Creek because of the mixture of upslope ground water, irrigation flows, and uncontrolled flooding (Appendix F). During the period when adults were held at North Pond, the range of values were 1,240-7,140 μmhos/cm conductivity, 364-2,160 mg/L hardness as $CaCO_3$, and 107-232 mg/L alkalinity as $CaCO_3$. There was a nine-fold variation in magnesium concentration (39-370 mg/L) and 11-fold variation in sulfate concentration (338-3,666 mg/L), which were greater than the six-fold variations of conductivity and hardness. Irrigation water inflow diluted some water quality characteristics (conductivity, hardness, magnesium, chloride, nitrate) at North Pond more than two-fold between July and early August 1995 compared to September -November 1995. In early May 1995, conductivities were as high as 12,390 μmhos/cm and then decreased three-fold in June and early July due to flooding from the Colorado River.

Selenium in water

There was no significant difference in selenium concentrations between filtered and

unfiltered water samples from the stations within the three sites where adults were held, and the data were combined within a sample station for further statistical analysis. Selenium concentrations in water at Horsethief ranged from 1.2 to 3.9 μg/L between July 1995 and June 1996 (Table 3). These values were similar to those in Colorado River samples collected at Walter Walker State Wildlife Area (WW1; 1.1-3.3 μg/L) and Adobe Creek (AC1; 0.8-4.2 μg/L) (Tables 4 and 5).

There was no significant difference in selenium concentrations at stations within a site where adults were held, i.e., no difference between HTi and HTo, among AC3, AC4, and AC5, or between WW2 and WW3, and hereafter the data were combined for further statistical analysis. The greatest difference in selenium concentrations between sample stations was 0.6 μg/L (HTi vs HTo) at Horsethief on October 18, 1995, 2.6 μg/L (AC3 vs AC4) at Adobe Creek on August 8, 1995, and 6.8 μg/L (WW2 vs WW3) at North Pond on March 11, 1996.

Selenium concentrations at the three sites were significantly different from each other. During the period when adults were present, selenium concentrations at Horsethief ranged from 1.2 to 3.9 μg/L (mean 2.2 μg/L), at Adobe Creek selenium concentrations ranged from 1.5 to 11.6 μg/L (mean 3.8 μg/L), and at North Pond selenium concentrations ranged from 3.8 to 19.6 μg/L (mean 9.5 μg/L).

The highest selenium concentrations at Adobe Creek occurred 2 weeks after irrigation water containing 11.4-12.4 μg/L selenium flowed from AC7 into Adobe near AC4 during September-October 1995 (Table 4). Selenium concentrations in the Adobe Creek site peaked at 9.8-11.6 μg/L on October 18, 1995, which were twice as high as those in August (3.3-5.9 μg/L). A similar two-fold increase in selenium concentrations occurred on June 11, 1996, after water containing 15 μg/L from AC7 flowed into the Adobe Creek site on April 25, 1996.

The highest selenium concentrations at the North Pond sites occurred on May 4, 1995, (115-133 μg/L) prior to stocking the adults and before dilution from river flooding or irrigation inflow via WW10 (Table 5). The 20-fold decrease in selenium concentrations in North Pond between May 4 and July 11, 1995, was due to flooding by the Colorado River. Some of the selenium in North Pond came from irrigation water containing 13.8 μg/L flowing from WW10 on September 11, 1995. However, most selenium probably came from the ground water as demonstrated by the elevated selenium concentrations at WW4 (adjacent to WW3, but outside and east of North Pond), whose only water source was ground water. When the Colorado River was at low flow, selenium concentrations at WW4 between September 1995 and April 1996 ranged from 54 to 138 μg/L. However, input of irrigation water into North Pond from WW10 continued to dilute the ground water inflow. Just prior to capture and removal of fish for spawning, selenium concentrations in North Pond had risen to 16-20 μg/L.

Selenium concentrations measured by AA-HG in water from Adobe Creek were significantly correlated with zinc concentration ($r=0.59$, $P=0.05$) measured by ICP in water. For North Pond, selenium measured by AA-HG in water was significantly correlated with each of nine elements measured by ICP (boron, calcium, potassium, lithium, magnesium, molybdenum, phosphorus, sodium, strontium; range $r=0.60$, $P=0.05$ to $r=0.88$, $P=0.0001$).

There was a significant positive correlation between selenium in water with several water quality characteristics at Horsethief including, from highest to lowest correlation coefficient (r), calcium (0.87, $P=0.0001$), hardness (0.86, $P=0.0001$), sulfate (0.86, $P=0.0001$), magnesium (0.82, $P=0.0001$), conductivity (0.80, $P=0.0001$), alkalinity (0.71, $P=0.0005$), and nitrate (0.63, $P=0.02$). At North Pond, the significant positive correlations were, from highest to

Table 3. Concentration of selenium (μg/L) measured by AA in filtered and unfiltered water samples from Horsethief Canyon State Wildlife Area (HT) sample stations near Grand Junction, Colorado, where adult razorback sucker were held. Water samples were collected at the inlet (i) and outlet (o) of the pond where the fish were held. Fish were moved from pond 1 to pond 6 as deemed necessary by The fish culturist.

Sample type	Date	Day of exposure	Station HTi	Station HTo
Filtered				
	05/03/95	-64	1.0	1.2
	06/06/95	-30	<1.0[1]	1.0
	07/10/95	4	<1.6	<1.6
	08/08/95	33	<2.8	<2.8
	09/12/95	68	3.0	3.0
	10/18/95	104	3.4	2.8
	11/14/95	131	3.7	3.3
	12/12/95	159	1.9	1.8
	01/09/96	187	-[2]	3.3
	02/12/96	221	2.6	2.5
	03/12/96	250	2.2	2.0
	04/16/96	285	2.0	1.2
	04/23/96	292	<2.2	<2.2
	05/21/96	.	<0.8	<0.8
	06/11/96	.	<1.2	1.4
Unfiltered				
	10/18/95	104	3.9	3.8
	02/12/96	221	2.0	2.3
	03/12/96	250	1.6	1.9
	04/16/96	285	1.4	1.8
	04/23/96	292	<1.6	<1.6
	05/21/96	.	0.7	0.7
	06/11/96	.	<1.6	-

[1]<: Below limit of detection.
[2]-: No sample.

Table 4. Concentration of selenium ($\mu g/L$) measured by AA in filtered and unfiltered water samples from Adobe Creek (AC) sample stations near Grand Junction, Colorado.

Sample type	Date	Day of exposure	Station						
			AC1	AC2	AC3	AC4	AC5	AC6	AC7
Filtered									
	05/03/95	-64	1.9	2.0	1.0	2.4	3.2	4.0	-[1]
	06/06/95	-30	<1.0[2]	<1.0	2.5	1.4	1.3	0.9	-
	07/10/95	4	<1.6	<1.6	3.7	2.0	3.2	2.3	-
	08/08/95	33	<2.8	<2.8	5.9	3.3	5.5	4.9	-
	09/12/95	68	3.9	3.8	7.5	6.4	8.1	8.8	12.2
	10/18/95	104	4.2	3.8	10.4	9.8	9.9	4.6	11.4
	11/14/95	131	2.9	2.9	3.4	3.4	3.4	3.0	-
	12/12/95	159	2.0	4.8	1.7	1.5	2.0	-	-
	01/09/96	187	2.2	3.2	3.4	2.1	4.3	3.9	-
	02/12/96	221	3.3	2.2	2.1	2.4	2.1	1.0	-
	03/12/96	250	3.3	2.5	2.8	1.9	1.8	<1.5	-
	04/16/96	285	<0.7	2.0	-	1.8	2.9	1.7	-
	04/23/96	292	-	-	1.9	1.9	1.8	-	-
	04/25/96	294	-	-	-	-	-	-	15.0
	05/21/96	.	<0.8	<0.8	2.5	<0.8	3.8	1.4	-
	06/11/96	.	<1.2	<1.2	4.5	5.9	9.7	9.1	10.7
Unfiltered									
	10/18/95	104	3.3	3.8	10.2	11.1	11.6	11.2	12.4
	02/12/96	221	2.9	2.6	2.7	2.2	1.8	-	-
	03/12/96	250	2.6	2.8	1.9	1.7	1.8	-	-
	04/16/96	285	1.5	1.6	1.7	1.6	1.5	0.7	-
	04/23/96	292	-	-	2.2	1.8	1.8	-	-
	04/25/96	294	-	-	-	-	-	-	12.0
	05/21/96	.	0.8	0.5	3.1	2.5	4.0	0.6	-
	06/11/96	.	<1.6	<1.6	3.9	6.3	10.9	10.1	12.6

[1] -: No sample.
[2] <: Below limit of detection.

Table 5. Concentration of selenium (μg/L) measured by AA in filtered and unfiltered water samples from Walter Walker State Wildlife Area (WW) sample stations near Grand Junction, Colorado.

Sample type and date	Day of exposure	Station									
		WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9	WW10
Filtered											
05/04/95	-63	1.9	133	115	126	79.6	69.1	62.1	12.3	3.1	-[1]
06/05/95	-31	1.1	26.5	26.3	3.9	1.2	2.3	1.8	<1.0[2]	<1.0	-
07/11/95	5	<1.6	6.5	5.9	<1.6	<1.6	<1.6	<1.6	<1.6	<1.6	-
08/07/95	32	<2.8	4.6	3.8	24.8	5.2	5.7	6.1	3.2	<2.8	-
09/11/95	67	2.8	5.3	5.8	66.5	6.8	5.5	5.6	7.4	3.5	13.8
10/17/95	103	3.3	8.3	7.1	74.5	13.1	10.4	14.8	12.5	7.8	-
11/13/95	130	2.2	4.5	5.8	54.2	18.2	8.0	11.7	12.1	12.1	-
12/11/95	158	2.0	9.8	16.0	92.0	23.5	14.6	69.7	33.6	21.1	-
01/10/96	188	2.0	6.6	8.5	73.5	25.8	16.6	71.5	45.5	2.3	-
02/13/96	222	2.6	5.2	5.6	134.6	57.6	22.0	42.2	52.7	40.9	-
03/11/96	249	<1.5	7.2	14.0	-	35.4	12.0	16.7	15.7	16.3	-
04/15/96	284	2.1	12.0	13.2	64.5	15.2	-	12.6	-	6.4	-
04/23/96	292	-	16.8	19.6	-	-	-	-	-	-	-
05/20/96	.	<0.8	12.9	11.4	4.9	1.7	1.4	<0.8	-	<0.8	-
06/10/96	.	<1.2	10.3	10.6	6.9	5.6	3.8	<1.2	-	1.8	-
Unfiltered											
10/17/95	103	3.3	7.1	7.3	58.3	10.6	9.2	16.1	15.8	8.6	-
02/13/96	222	2.8	5.9	5.6	137.7	58.9	21.6	41.1	24.0	36.9	-
03/11/96	249	3.0	10.3	13.3	75.2	41.3	19.3	21.6	22.1	20.0	-
04/15/96	284	1.3	13.6	13.6	65.4	15.5	12.5	13.5	-	7.4	-
04/23/96	292	-	16.3	18.6	-	-	-	-	-	-	-
05/20/96	.	<0.5	13.2	10.0	5.5	3.0	2.6	0.8	-	0.6	-
06/10/96	.	<1.6	8.2	-	5.2	5.4	3.0	<1.6	-	2.1	-

[1] -: No sample.

[2] <: Below limit of detection.

lowest correlation coefficient (r, all were P=0.0001), nitrate (0.86), hardness (0.78), magnesium (0.78), sulfate (0.76), chloride (0.75), conductivity (0.73), calcium (0.71), and nitrite (0.70). In contrast, there was a significant negative correlation between selenium in water and total dissolved solids (r=-0.64, P=0.004) and fixed solids (r=-0.56, P=0.03) at Horsethief, but not at North Pond. There were no positive correlations between selenium in water and water quality characteristics at Adobe Creek, but there was a significant negative correlation with nitrite (r= -0.47, P=0.0007), which is the opposite of the positive correlation for North Pond. The reason for this lack of a correlation at Adobe Creek between selenium and water quality characteristics or inorganic elements measured by ICP is unknown.

Other elements in water

Eight of the inorganic elements in water measured by ICP (antimony, boron, calcium, lithium, magnesium, phosphorus, sodium, strontium) were significantly higher at North Pond than at Adobe Creek, whereas one element (silicon) was higher at Adobe Creek than at North Pond (Table 6, Appendix G). Seven of these elements were the same ones found to be significantly correlated with selenium concentrations in water measured by AA-HG at North Pond (boron, calcium, lithium, magnesium, phosphorus, sodium, strontium); only antimony was not correlated to selenium concentrations in water.

Selenium in sediment

Selenium concentrations in sediment at Horsethief and Adobe Creek were not significantly different, but those at North Pond were significantly higher than those at the other two sites (Table 7). For each of the three sites where adult fish were held, selenium concentrations in sediments were not significantly different within a site, i.e., selenium concentrations were not different between HTi and HTo, among AC3, AC4, and AC5, or between WW2 and WW3. Selenium concentrations in North Pond sediment at WW3 collected in October 1995 were only 16-18% of those from the previous collection in May 1995 and in April 1996. The sediment samples from WW3 were reanalyzed and similar values obtained (Table 7). Station WW3 was located adjacent to station WW10 where irrigation source water entered North Pond (Figure 4). Flow from WW10 occurred 12 times between August 21 and October 11, 1995, which apparently delivered sufficient sediment from the irrigation ditch to change the selenium concentration in sediment at this station temporarily. In the absence of repeated flows from WW10 between November 4, 1995, and April 21, 1996, the selenium concentration in sediment at WW3 in April 1996 was similar to its concentration of a year earlier. The reason for the decreased selenium concentration at WW2 in April 1996 compared to the two earlier collections is unknown.

Other elements in sediment

Copper concentrations in sediment were 2-4 times higher at Horsethief than at Adobe Creek and North Pond (Table 8). The decrease in selenium concentrations at WW3 on October 17-18, 1995, compared to the earlier and later sampling at that station, seemed to parallel low concentrations of five elements (calcium, magnesium, manganese, sodium, strontium) in

Table 6. Mean (standard error in parentheses and number of samples in brackets) concentration of inorganic elements (mg/L) measured by ICP in water collected from three sites near Grand Junction, Colorado. For each element, an asterisk denotes a significant difference (P=0.05) between sites AC and WW (HT was not included because n=1).

	Site		
Element	HT	AC	WW
Ag	<0.005[1]	0.010 (-) [1][2]	<0.005
Al	<0.03	<0.03	0.05 (0.01) [2]
As	<0.02	<0.02	<0.02
B	0.035 (-) [1]	0.049 (0.003) [15]	0.129 (0.017)* [10]
Ba	0.124 (-) [1]	0.112 (0.007) [15]	0.096 (0.005) [10]
Be	<0.0002	<0.0002	<0.0002
Bi	<0.04	<0.04	<0.04
Ca	40.1 (-) [1]	67.9 (3.3) [15]	114.9 (18.2)* [10]
Cd	<0.002	<0.002	<0.002
Co	0.011 (-) [1]	0.004 (0) [8]	<0.003
Cr	<0.007	0.008 (0) [4]	0.034 (0.015) [8]
Cu	0.034 (-) [1]	0.006 (-) [1]	<0.005
Fe	0.023 (-) [1]	0.023 (0.002) [15]	0.019 (0.006) [9]
K	2.0 (-) [1]	3.3 (0.2) [15]	4.2 (0.6) [10]
Li	0.013 (-) [1]	0.023 (0.001) [15]	0.048 (0.005)* [10]

Table 6. Continued.

Element	Site		
	HT	AC	WW
Mg	11.0 (-) [1]	22.2 (1.3) [15]	99.7 (22.5) [10]
Mn	0.004 (-) [1]	0.032 (0.005) [15]	0.027 (0.006) [10]
Mo	0.005 (-) [1]	0.008 (0.001) [11]	0.009 (0.001) [10]
Na	20.8 (-) [1]	68.3 (5.7) [15]	294.4 (60.5)* [10]
Ni	0.007 (-) [1]	0.008 (0.001) [5]	<0.006
P	0.05 (-) [1]	0.06 (0.01) [8]	0.11 (0.02)* [9]
Pb	0.032 (-) [1]	0.026 (0.007) [7]	0.015 (0.003) [4]
Sb	<0.03	0.04 (0) [4]	0.05 (0)* [4]
Si	0.8 (-) [1]	1.3 (0.1) [15]	0.8 (0.4)* [4]
Sr	0.363 (-) [1]	0.665 (0.041) [15]	1.380 (0.258)* [10]
Ti	<0.0008	<0.0008	0.0015 (0.0005) [2]
Tl	0.20 (-) [1]	0.20 (0.06) [3]	<0.1
W	<0.01	0.01 (-) [1]	<0.01
V	<0.005	0.006 (0.001) [3]	<0.005
Zn	<0.01	0.02 (0) [9]	0.02 (0) [5]

Table 6. Continued.

[1]<: Below the limit of detection.
[2]The number of samples submitted for analysis was HT=1, AC=15, and WW=10. If the number of samples shown for a site and element is less than the number of samples submitted, concentrations in the other samples were below the limit of detection.

Table 7. Mean (standard error in parentheses) selenium concentration (μg/g dry weight) measured by AA in sediment from various stations at three sites near Grand Junction, Colorado. At Horsethief Canyon State Wildlife Area, sediment samples were collected from the inlet (i) and outlet (o) of ponds 1 and 6 when the fish were held in that pond (n=2).

Date	Day of exposure	Station									
		HTli	HTlo	HT6i	HT6o	AC3	AC4	AC5	WW2	WW3	WW3[1]
05/03-04/95	-64 to -63	-[2]	-	0.52	0.56	0.79	1.60	0.75	31.77	50.59	55.42
				(0.01)	(0)	(0.08)	(0.05)	(0.03)	(1.52)	(0.23)	(2.43)
10/17-18/95	103-104	0.12	1.37	-	-	0.95	1.43	2.10	30.12	8.16	7.17
		(0.01)	(0.01)			(0.04)	(0.06)	(0.07)	(1.99)	(0.74)	(0.35)
04/24-25/96	293-294	1.19	1.03	0.16	0.18	1.11	0.54	1.08	11.93	46.07	45.74
		(0.040	(0.08)	(0.010	(0.01)	(0.01)	(0.01)	(0.07)	(0.81)	(2.67)	(2.91)

[1]Samples reanalyzed.
[2]-: No sample.

Table 8. Concentration of inorganic elements (μg/g dry weight) measured by ICP in sediment from various stations at three sites near Grand Junction, Colorado.

Element	Date	Day of exposure	Station						
			HT1	HT6	AC3	AC4	AC5	WW2	WW3
Ag	10/17-18/95	103-104	-[1]	-	<1[2]	2	<1	<1	<1
	04/24-25/96	293-294	<1	<1	<1	<1	2	<1	<1
Al	10/17-18/95	103-104	-	-	9900	9770	12900	12700	12700
	04/24-25/96	293-294	10600	4910	4320	9070	8680	9860	11000
As	10/17-18/95	103-104	-	-	<7	<7	<8	<8	<8
	04/24-25/96	293-294	<7	<5	<6	<7	<7	<7	<8
B	10/17-18/95	103-104	-	-	<6	<6	<6	9	7
	04/24-25/96	293-294	<6	<6	<6	<6	<6	6	7
Ba	10/17-18/95	103-104	-	-	189	255	238	226	227
	04/24-25/96	293-294	150	146	147	260	218	227	185
Be	10/17-18/95	103-104	-	-	0.6	0.6	0.8	0.6	0.7
	04/24-25/96	293-294	0.7	0.5	0.3	0.6	0.6	0.6	0.5
Bi	10/17-18/95	103-104	-	-	<4	<4	<4	<4	5
	04/24-25/96	293-294	5	<4	6	<4	4	<4	<4
Ca	10/17-18/95	103-104	-	-	27700	33300	38400	57200	30900
	04/24-25/96	293-294	52600	24400	15500	32200	33000	46300	84300
Cd	10/17-18/95	103-104	-	-	0.6	0.8	0.8	1.2	0.8
	04/24-25/96	293-294	0.3	<0.2	<0.2	0.4	0.7	0.8	0.9
Co	10/17-18/95	103-104	-	-	6.1	6.8	8.3	7.9	6.6
	04/24-25/96	293-294	5.0	2.6	3.7	6.3	6.7	6.7	7.1
Cr	10/17-18/95	103-104	-	-	13	14	16	16	17
	04/24-25/96	293-294	11	4	5	11	12	14	14
Cu	10/17-18/95	103-104	-	-	16	17	21	20	16
	04/24-25/96	293-294	82	27	3	14	15	17	16
Fe	10/17-18/95	103-104	-	-	15100	15400	18600	16500	16500
	04/24-25/96	293-294	11400	4680	8630	14400	13300	15300	14100

Table 8. Continued.

Element	Date	Day of exposure	Station						
			HT1	HT6	AC3	AC4	AC5	WW2	WW3
K	10/17-18/95	103-104	-	-	2000	1900	2500	3000	3100
	04/24-25/96	293-294	2800	1540	590	1700	1800	2200	2500
Li	10/17-18/95	103-104	-	-	14	15	19	19	19
	04/24-25/96	293-294	13	5	8	14	15	17	18
Mg	10/17-18/95	103-104	-	-	7350	8120	9780	10600	8970
	04/24-25/96	293-294	6010	2970	3420	7570	7010	9700	11200
Mn	10/17-18/95	103-104	-	-	318	375	456	829	462
	04/24-25/96	293-294	312	197	191	348	341	494	1270
Mo	10/17-18/95	103-104	-	-	<0.9	<0.9	<0.9	3	1
	04/24-25/96	293-294	<0.9	<0.9	<0.9	<0.9	1	1	2
Na	10/17-18/95	103-104	-	-	1000	720	790	1570	910
	04/24-25/96	293-294	415	335	959	900	890	3340	5620
Ni	10/17-18/95	103-104	-	-	10	14	17	17	15
	04/24-25/96	293-294	10	4	6	10	10	15	14
P	10/17-18/95	103-104	-	-	580	644	685	771	700
	04/24-25/96	293-294	495	295	390	621	550	590	540
Pb	10/17-18/95	103-104	-	-	17	30	36	34	34
	04/24-25/96	293-294	22	14	17	28	29	34	29
Sb	10/17-18/95	103-104	-	-	<6	<6	<6	<6	6
	04/24-25/96	293-294	<6	<5	<6	<6	<6	6	<6
Si	10/17-18/95	103-104	-	-	2660	2820	3610	2940	2820
	04/24-25/96	293-294	3880	2580	822	2670	2460	2570	3110
Sr	10/17-18/95	103-104	-	-	109	121	145	541	164
	04/24-25/96	293-294	161	711	61	121	130	402	1080
Ti	10/17-18/95	103-104	-	-	102	94	105	133	111
	04/24-25/96	293-294	37	12	121	101	93	92	96

Table 8. Continued.

Element	Date	Day of exposure	Station						
			HT1	HT6	AC3	AC4	AC5	WW2	WW3
Tl	10/17-18/95	103-104	-	-	<40	<40	<40	<40	<40
	04/24-25/96	293-294	<40	<40	<40	<40	60	<40	<40
W	10/17-18/95	103-104	-	-	3	<2	<2	<2	<2
	04/24-25/96	293-294	<2	<2	<2	<2	<2	<2	<2
V	10/17-18/95	103-104	-	-	27	26	28	29	31
	04/24-25/96	293-294	17	6	16	22	23	26	25
Zn	10/17-18/95	103-104	-	-	70	93	115	113	92
	04/24-25/96	293-294	60	20	27	82	75	99	88

[1]-: No sample.
[2]<: Below limit of detection.

sediment from the same collection period. The largest difference in concentrations of elements in sediments among Horsethief, Adobe Creek, and North Pond was for selenium, which was elevated at North Pond (Table 7).

Sediment chemistry

Total carbon and percent organic carbon in sediments were similar at the Horsethief and Adobe Creek stations, but tended to be higher at the North Pond stations (Table 9). Combining all stations where adults were held and the two sediment sampling periods for selenium analysis (n=32), selenium sediment concentrations were positively correlated with several sediment constituents including inorganic carbon (r=0.70, P=0.0001), total carbon (r=0.80, P=0.0001), organic carbon (r=0.70, P=0.0001), and volatile solids (r=0.74, P=0.0001), and were negatively correlated with total solids (r=-0.72, P=0.0001) and fixed solids (r=-0.74, P=0.0001). Concentrations of total carbon, inorganic carbon, organic carbon, total solids, volatile solids, and fixed carbon in sediment were significantly correlated with each other.

Sediment particle size (clay, silt, and sand) was generally statistically different between or among stations within a site (Table 10). The statistical differences were due in part to the high variability of sediment composition, e.g., sediment from the inlet and outlet of Horsethief ponds varied within a pond as did inlets or outlets between ponds (Table 10). The only exception was the April 1996 sampling at WW2 and WW3 when there was no difference in sediment composition between the two stations in the content of clay, silt, and sand. Combining all stations where adults were held and the two sediment sampling periods for selenium analysis (n=32), selenium concentrations in sediment were positively correlated with silt (r=0.58, P=0.0005), negatively correlated with sand (r=-0.39, P=0.03), but not significantly correlated with clay (r=-0.12, P=0.50). The negative correlation between selenium concentration and sand content may explain the decrease in sediment selenium at WW2 in April 1996 in that the sand content at WW2 was increased compared to that in the October 1995 sample. Taking into account all the sediment measures, the best predictor of selenium concentration in sediment was total carbon content.

Selenium in biota

Aquatic food organisms were limited at Horsethief probably because of predation from cultured fish and their low abundance in the Colorado River, which was the source of pond water. Selenium concentrations in zooplankton samples from Horsethief were 3 µg/g or less (Table 11).

At Adobe Creek, selenium concentrations in zooplankton prior to stocking the adult fish ranged from 4.5 to 10.5 µg/g, and after stocking the fish, concentrations ranged from 13.7 to 55.6 µg/g. Selenium concentrations in zooplankton at Adobe Creek seemed to increase starting in late July and peaked in September 1995. This increase in selenium in zooplankton coincided with increasing waterborne concentrations of selenium in August and September, which was probably due to high selenium water entering the Adobe Creek site from AC7 in September (12.2 µg/L) (Table 4) and possibly from other earlier releases at AC that were undetected. There were no significant differences in selenium concentrations in zooplankton among AC3 (mean 26.4 µg/g), AC4 (mean 28.0 µg/g), and AC5 (mean 26.3 µg/g) for the period May 16, 1995, to May 19,

Table 9. Carbon and solids content of sediments from various stations at three sites near Grand Junction, Colorado.

Date	Measure	Station								
		HTli	HTlo	HT6i	HT6o	AC3	AC4	AC5	WW2	WW3
10/17-18/95	Carbon									
	Inorganic (µg/g)	14.3	15.9	-	-	6.6	9.0	10.2	16.4	8.0
	Organic (µg/g)	11.3	12.1	-	-	8.4	16.8	22.0	37.1	23.9
	Total (µg/g)	25.6	28.0	-	-	14.9	25.7	32.2	53.5	31.9
	% Inorganic[1]	1.43	1.13	-	-	0.66	0.90	1.02	1.64	0.80
	% Organic[1]	1.59	1.20	-	-	0.84	1.68	2.20	3.71	2.39
	Solids (%)									
	Total	56.4	58.7	-	-	66.2	59.0	47.2	21.5	47.2
	Volatile	3.6	4.0	-	-	1.9	4.0	5.1	11.4	5.1
	Fixed	96.4	96.0	-	-	98.1	96.0	94.9	88.6	94.9
04/24-25/96	Carbon									
	Inorganic (µg/g)	15.3	15.0	5.3	7.5	2.6	5.7	5.6	13.6	24.5
	Organic (µg/g)	10.8	11.4	3.0	4.5	8.6	10.2	5.9	17.4	23.2
	Total (µg/g)	26.1	26.4	8.4	12.1	11.2	15.9	11.5	31.0	47.7
	% Inorganic[1]	1.53	1.50	0.53	0.75	0.26	0.57	0.56	1.36	2.45
	% Organic[1]	1.08	1.14	0.30	0.45	0.86	1.02	0.59	1.73	2.32
	Solids (%)									
	Total	38.2	48.1	57.9	56.3	75.3	54.2	53.9	40.9	31.6
	Volatile	3.6	2.4	1.1	1.8	1.2	1.8	4.5	5.0	6.9
	Fixed	96.4	97.6	98.9	98.2	98.8	98.2	95.5	95.0	93.1

[1]Based on sample weight.

Table 10. Mean (standard error in parentheses) percent clay, silt, and sand in sediment from various stations at three sites near Grand Junction, Colorado. At Horsethief Canyon State Wildlife Area, sediments were collected from the inlet (i) and outlet (o) of ponds 1 and 6 when the fish were held in that pond (n=2). Within a site (HT1, HT6, AC, and WW), date, and texture measure, values with the same letter in common are not significantly different (P=0.05).

Date	Day of exposure	Texture	Station								
			HT1i	HT1o	HT6i	Ht6o	AC3	AC4	AC5	WW2	WW3
10/17-18/95	103-104	Clay	43.4a (0.5)	39.6a (0.9)	-[1]	-	9.8m (0.2)	13.8n (0.3)	21.8o (0.2)	14.6x (0.6)	18.8y (0.3)
		Silt	35.3a (1.1)	33.8a (1.4)	-	-	23.1m (0.2)	54.1n (0.3)	62.8o (0.2)	66.4y (0.8)	35.5x (0.9)
		Sand	21.1a (0.6)	26.4b (0.5)	-	-	66.7o (0.5)	31.3n (0.5)	14.9m (0.2)	18.2x (0.1)	45.4y (0.5)
04/24-25/96	293-294	Clay	36.3a (1.0)	30.8a (3.7)	7.3d (0.2)	24.4e (1.1)	2.5m (0.3)	7.1o (0.2)	4.5n (0.2)	14.8x (0.7)	16.4x (3.0)
		Silt	34.2b (1.2)	17.8a (3.2)	8.4d (0.4)	24.1e (1.7)	3.0m (0.4)	28.0o (0)	20.1n (0.7)	56.1x (1.7)	56.3x (5.5)
		Sand	29.1a (0.2)	46.2b (1.9)	84.1e (0.3)	51.1d (0.6)	94.4o (0.1)	63.9m (0.3)	75.0n (0.5)	25.7x (1.4)	25.6x (1.7)

[1]-: No sample.

Table 11. Concentration of selenium (μg/g dry weight) measurd by AA in zooplankton from various stations at three sites near Grand Junction, Colorado. At Horsethief Canyon State Wildlife Area, zooplankton were collected from the inlet (i) and outlet (o) of pond 6 where fish were held.

Date	Day of exposure	Station						
		HT6i	HT6o	AC3	AC4	AC5	WW2	WW3
05/16/95	-51	-[1]	-	6.6	6.6	9.6	43.4	66.5
06/13/95	-23	-	-	-	-	-	40.5	42.9
06/14/95	-22	-	-	4.5	-	4.9	81.3	77.7
06/15/95	-21	-	-	10.5	-	8.6	-	-
06/20/95	-16	3.0	3.0	-	-	-	-	-
07/21/95	15	<0.1[2]	<0.1	-	-	-	36.6	21.2
07/28/95	22	-	-	19.1	-	13.7	-	-
08/16/95	41	-	-	18.8	19.5	25.0	20.3	22.2
08/17/95	42	-	-	-	22.2	-	25.4	25.5
09/27/95	83	-	-	-	-	-	25.2	32.5
09/28/95	84	-	-	49.6	55.6	52.0	-	-
09/29/95	85	2.3	3.1	-	-	-	25.2	32.5
10/24/95	110	-	-	-	-	-	30.5	35.2
10/25/95	111	-	-	32.4	33.7	24.9	-	-
11/05/95	122	-	-	-	-	-	29.7	21.2
12/06/95	153	-	-	20.3	21.0	20.3	-	-
04/02-04/96	271-273	-	-	18.5	16.1	-	25.5	33.3
05/19/96	318	-	-	-	-	21.8	36.9	-

[1] -: No sample.
[2] <: Below limit of detection.

1996. The mean selenium concentration in zooplankton during the time period when adults were present was 28.5 µg/g (SE 3.5 µg/g, n=15). For the time period when adults were present, the correlation coefficient between selenium concentrations in zooplankton and water at Adobe Creek was r=0.58 (P=0.01, n=18). This correlation analysis used water concentrations measured about 1-2 weeks before zooplankton collections to account for the delay in selenium uptake from the water by aquatic organisms.

At North Pond, selenium concentrations in zooplankton prior to stocking the fish ranged from 40.5 to 81.3 µg/g, and after stocking the fish, concentrations ranged from 20.3 to 36.9 µg/g. The concentrations seemed to have decreased in late July due initially to flooding by the Colorado River and later to inputs of irrigation water, which lowered selenium concentrations in water from July 1995 to February 1996, after which concentrations started to rise in March 1996 (Table 5). There was no significant difference in selenium concentrations in zooplankton between WW2 (mean 28.8 µg/g) and WW3 (mean 27.3 µg/g) for the period May 16, 1995, to May 19, 1996. The mean selenium concentrations in zooplankton during the time period when adults were present was 27.1 µg/g (SE 1.6 µg/g, n=12). For the time period when adults were present, the correlation coefficient between selenium concentrations in zooplankton and water at North Pond was r=0.60 (P=0.02, n=15). This correlation analysis used water concentrations measured about 1-2 weeks between zooplankton collections to account for the delay in selenium uptake from the water by aquatic organisms.

Overall, when adults were present, selenium concentrations in zooplankton were significantly lower at Horsethief than at the other two sites, but concentrations in zooplankton from Adobe Creek and North Pond were not significantly different. However, prior to stocking the adults, selenium concentrations in zooplankton were significantly higher at North Pond than at Adobe Creek, but were not different among stations within Adobe Creek or North Pond. Apparently, input of high selenium water into Adobe Creek from AC7 caused selenium concentrations in zooplankton to increase sufficiently to match the selenium concentrations in zooplankton at North Pond. The decrease in water selenium concentrations and concomitant reduction of zooplankton selenium concentrations at North Pond was due to flooding by the Colorado River and input of irrigation water from WW10. Water entering North Pond from WW10 had lower selenium concentrations than ground water sources, which presumably was the source of high waterborne selenium concentrations in North Pond during May 1995 (115-133 µg/L).

Selenium concentrations in other aquatic macroinvertebrates collected at Horsethief were relatively low compared to those collected at Adobe Creek and North Pond, except for two samples of chironomids collected at Pond 6 in May 1995, which contained 8-14 µg/g (Table 12). Selenium concentrations in macroinvertebrates from the three sites, except for chironomids at Horsethief, were similar to those in zooplankton from the same sites. Using pooled data from all three sites during the time period when adults were present, the correlation between the combined zooplankton and macroinvertebrate data and water concentrations of selenium was r=0.55 (P=0.0001, n=57).

Prior to stocking adult razorback sucker, other fish collected at Adobe Creek contained whole-body selenium residues of 10-14 µg/g, whereas minnows from North Pond contained 82-119 µg/g (Table 12). After adults were stocked at these two sites and waterborne concentrations of selenium decreased due to flooding and irrigation water input, selenium concentrations in other fish species seemed to decrease slightly. Nevertheless, selenium concentrations in

Table 12. Concentration of selenium (μg/g dry weight) measured by AA in fish, aquatic invertebrates, tadpoles, and an aquatic plant at various stations at three sites near Grand Junction, Colorado. At Horsethief Canyon State Wildlife area, biota samples were collected from the inlet (i) and outlet (o) of ponds 1 and 6 when the fish were held in that pond. Standard error and number of samples are given in parentheses for those samples with more than one sample.

Date	Day of exposure	Tissue	Station									
			HTli	HTlo	HT6i	HT6o	AC3	AC4	AC5	AC6	WW2	WW3
11/23/94	-225	GSF[1]	-[2]	-	-	-	11.8 (1.1, 6)	-	-	-	-	-
		BBH[1]	-	-	-	-	14.1 (0.7, 3)	-	-	-	-	-
		WMF[1]	-	-	-	-	9.7 (0.2, 7)	-	-	8.2	-	-
		Tadpole	-	-	-	-	15.7 (0.3, 3)	-	-	-	-	-
		Tadpole gut	-	-	-	-	15.9	-	-	-	-	-
02/16/95	-140	Minnow[1]	-	-	-	-	-	-	-	-	104 (5, 9)	-
		Minnow[1] (dead)	-	-	-	-	-	-	-	-	119 (17, 2)	-
05/03/95	-64	Chironomid	-	-	13.6	8.0	-	-	-	-	-	-
06/14/95	-22	Water boatman	-	-	-	-	-	-	-	-	55.8	35.3
		Minnow[1]	-	-	-	-	-	-	-	-	87.4	82.0
06/20/95	-16	Water boatman	5.3	4.8	-	-	-	-	-	-	-	-
07/12/95	6	Minnow[1]	-	-	-	-	-	-	-	-	43.0	-
		Damselfly nymph	-	-	-	-	-	-	-	-	42.6	39.5
		Mayfly nymph	-	-	-	-	-	-	-	-	19.7	17.1
07/13/95	7	Aquatic plant	-	-	-	-	-	-	-	-	6.9	12.0
07/21/95	15	Mayfly	-	-	-	-	-	-	-	-	45.4	-
		Tadpole	-	-	-	-	-	-	-	-	47.6	34.6
		Water boatman	3.1	-	-	-	-	-	-	-	-	-

Table 12. Continued.

Date	Day of exposure	Tissue	Station									
			HTli	HTlo	HT6i	HT6o	AC3	AC4	AC5	AC6	WW2	WW3
07/28/95	22	Minnow[1]	-	-	-	-	6.9	-	6.4	-	-	-
		Tadpole	-	-	-	-	12.5	-	34.5	-	-	-
08/14/95	39	Chironomid	-	-	-	-	-	-	-	-	11.3[3]	25.8[3]
08/16/95	41	Tadpole	-	-	-	-	34.1	-	45.7	-	-	38.9
		Minnow[1]	-	-	-	-	-	-	11.1	-	-	22.3
08/17/95	42	Tadpole	-	-	-	-	-	-	-	-	-	38.9
		Minnow[1]	-	-	-	-	-	-	-	-	-	74.7
08/29/95	54	Water boatman	-	-	2.8	2.6	-	-	-	-	-	-
09/06/95	63	Chironomid	-	-	-	-	27.9[4]	45.4[4]	42.1[4]	-	-	-
09/27/95	83	Minnow[1]	-	-	-	-	-	-	-	-	93.4	26.5
09/29/95	85	Backswimmer	3.3	2.1	-	-	-	-	-	-	-	-
		Beetle larvae	2.3	3.5	-	-	-	-	-	-	-	-
10/25/95	111	Water boatman	2.1	-	-	-	-	-	-	-	-	-
04/22/96	291	Chironomid	-	-	-	-	34.0[5]	40.2[5]	37.8[5]	-	44.7[5]	-

[1]GSF: Green sunfish (*Lepomis cyanellus*), BLH: black bullhead (*Ameiurus melas*), WMF: western mosquitofish (*Gambusia affinis*), minnow (probably western mosquitofish).

[2]-: No sample.

[3]Collected by Hester-Denny sampler deployed 30 days (7/13/95-8/14/95).

[4]Collected by Hester-Denny sampler deployed 42 days (7/25/95-9/6/95).

[5]Collected by Hester-Denny sampler deployed 215 days (9/20/95-4/22/96).

chironomids collected by Hester-Dendy samplers, tadpoles, and minnows were elevated at North Pond (11-93 μg/g), as were concentrations in chironomids and tadpoles at Adobe Creek (12-46 μg/g).

Growth

No significant difference was found in weight or total length between female and male adults stocked at Horsethief or Adobe Creek in July 1995 (Table 13). Females stocked at North Pond were significantly longer (mean 427 mm ± SE 6) than males (mean 408 mm ± SE 6), but there was no difference in weight between the sexes. At spawning, females at Horsethief (mean 911 g ± SE 27) and Adobe Creek (mean 784 g ± SE 20), but not at North Pond (mean 808 g ± SE 30), were significantly heavier than males (Horsethief mean 814 g ± SE 26; Adobe Creek mean 718 g ± SE 19; North Pond mean 728 g ± SE 33). At spawning, there were no differences in length between females and males at Horsethief and Adobe Creek, whereas females at North Pond were significantly longer than males as was observed at stocking. Combining all fish at a site, length generally increased about 2-4% at the three sites between stocking and spawning, whereas weight increased by 15% at Horsethief, decreased by 2% at Adobe Creek, and increased by 3% at North Pond (Table 13). The greatest weight loss occurred at 69 days in the study and was 5.1% at Horsethief, 9% at Adobe Creek, and 5.6% at North Pond (Table 13). However, between day 69 and spawning (day 305), weight gains were 21.7% at Horsethief, 7.5% at Adobe Creek, and 9.2% at North Pond (Table 13). At spawning, females from Horsethief were significantly heavier than those from Adobe Creek and North Pond.

Based on incremental size changes in the same fish collected from a site, total length changed little (Table 14). The change in weight at 34 days of exposure was significantly less in fish at Adobe Creek compared to Horsethief and North Pond, although the magnitude of weight loss at all three sites was not large. The greatest loss of weight during the exposure period of the study occurred in fish at North Pond on day 69 when the average daily weight loss for the fish was 2.21 g/day. Fish at the three sites gained weight during two or more of the sample periods.

Selenium in tissues

Concentrations of selenium in muscle plugs from adults held at Horsethief did not change during the exposure or depuration periods (Table 15). Selenium concentrations in muscle plugs of fish held for 69 days of exposure and longer at Adobe Creek, and for 126 days and longer at North Pond were significantly higher than those in fish held at Horsethief. Selenium concentrations in muscle plugs at spawning (day 305) were significantly different among adults from the three sites, with fish from North Pond having 3.7 times and Adobe Creek 2.6 times the selenium present in muscle plugs of fish from Horsethief. Selenium concentrations in muscle plugs were 4.2 times higher in fish at Adobe Creek and 4.0 times higher in fish at North Pond at spawning compared to those at the time of stocking. For the exposure period from day 69 to 305, the correlation between selenium concentrations in muscle plugs pooled across site and sample date and the mean selenium concentration in water for the closest corresponding sample date was r=0.74 (P=0.006, n=12). For the same exposure period, the correlation between selenium concentration in muscle plugs and the mean selenium concentration in aquatic invertebrates for the closest corresponding sample date was r=0.65 (P=0.04, n=10). Day 69 was

Table 13. Mean (standard error in parentheses and number of samples in brackets) total length (mm) and weight (g) of adult razorback sucker held at three sites near Grand Junction, Colorado. For each day of exposure and measure, sites with the same letter are not significantly different (P=0.05).

		Day of exposure and date							
		0	34	69	126	231	305[1]	337[2]	371[3]
		7/6	8/9	9/13	11/9	2/22	5/6	6/7	7/11
Site	Measure	1995				1996			
HT	Total length	409a	408a	405a	407a	411a	418a	428a	422a
		(2)	(3)	(3)	(3)	(3)	(3)	(5)	(2)
		[56]	[36]	[30]	[48]	[46]	[45]	[6]	[36]
	Weight	742x	711x	704x	750x	809x	857x	888	812x
		(14)	(17)	(22)	(18)	(19)	(20)	(34)	(15)
		[56]	[36]	[30]	[48]	[46]	[45]	[2]	[36]
AC	Total length	409a	410a	409a	412ab	413a	419a	429	427ab
		(3)	(4)	(3)	(3)	(3)	(3)	(7)	(3)
		[36]	[20]	[23]	[23]	[25]	[32]	[6]	[25]
	Weight	764x	739x	695x	748x	756xy	747y	815	824x
		(16)	(22)	(15)	(11)	(17)	(15)	(37)	(19)
		[36]	[20]	[23]	[23]	[25]	[32]	[2]	[25]
WW	Total length	409a	410a	417a	420b	420a	426a	442a	437b
		(3)	(2)	(5)	(4)	(3)	(4)	(11)	(4)
		[36]	[46]	[11]	[15]	[23]	[24]	[3]	[20]
	Weight	748x	711x	706x	741x	733y	771y	914	773x
		(19)	(15)	(29)	(25)	(20)	(23)	(-)	(25)
		[36]	[46]	[11]	[15]	[23]	[24]	[1]	[20]

[1]Spawned and moved fish at AC and WW to reference site HT for depuration.
[2]32 days depuration.
[3]66 days depuration.

Table 14. Mean (standard error in parentheses and number of samples in brackets) daily incremental change in total length (mm/day) and weight (g/day) of adult razorback sucker held at three sites near Grand Junction, Colorado. For each day of exposure and measure, sites with the same letter are not significantly different (P=0.05).

		Day of exposure						
Site	Measure	34	69	126	231	305[1]	337[2]	371[3]
HT	Total length	0.04a (0.01) [36]	-0.20b (0.04) [28]	-0.17b (0.03) [22]	0.03b (0) [46]	0.10a (0.02) [45]	-0.36a (0.34) [6]	0.08a (0.01) [36]
	Weight	-1.08y (0.12) [36]	-1.00x (0.31) [28]	0.24x (0.23) [22]	0.56y (0.05) [46]	0.62y (0.09) [45]	-3.81y (0.50) [2]	-0.52y (0.17) [35]
AC	Total length	0.03a (0.02) [20]	-0.03a (0.03) [23]	0.04a (0.01) [23]	0a (0.01) [25]	0.08a (0.01) [32]	0.11a (0.05) [6]	0.13a (0.02) [25]
	Weight	-0.69x (0.11) [20]	-1.12x (0.12) [23]	0.48x (0.14) [23]	0.07x (0.06) [25]	-0.13x (0.05) [32]	0.34x (0.09) [2]	1.31x (0.15) [25]
WW	Total length	0.01a (0.02) [21]	-0.10ab (0.04) [18]	0.08a (0.02) [15]	0.03b (0.01) [23]	0.05a (0) [24]	-0.07a (0.01) [3]	0.13a (0.03) [20]
	Weight	-1.29y (0.13) [21]	-2.21y (0.46) [18]	0.41x (0.18) [15]	0.10x (0.06) [23]	0.38y (0.06) [24]	-0.03x (-) [1]	0y (0.27) [20]

[1]Spawned and moved fish at AC and WW to reference site HT for depuration.
[2]32 days depuration.
[3]66 days depuration.

Table 15. Mean (standard error in parentheses and number of samples in brackets) selenium concentration (μg/g dry weight) measure by neutron activation in muscle plugs from razorback sucker held at three sites near Grand Junction, Colorado, and from brood stock held at Horsethief Canyon State Wildlife Area. For each day of exposure, sites with the same letter are not significantly different (P=0.05).

	Day of exposure and date							
	0	34	69	126	231	305[1]	337[2]	371[3]
	7/6	8/9	9/13	11/9	2/22	5/6	6/7	7/11
Site	1995					1996		
HT	4.5a (0.2) [5]	4.7a (0.2) [5]	5.2a (0.4) [6]	4.7a (0.2) [9]	4.4a (0.1) [6]	4.5a (0.2) [6]	4.5a (0.2) [4]	4.5a (0.4) [2]
AC	3.9a (0.3) [8]	4.7a (0.2) [7]	7.4b (0.3) [6]	9.5b (0.5) [7]	10.6b (0.5) [5]	11.7b (0.4) [6]	11.5b (0.8) [4]	9.5ab (0.6) [2]
WW	4.1a (0.2) [7]	4.5a (0.7) [3]	6.3ab (0.3) [6]	9.5b (0.7) [7]	13.2b (1.0) [7]	16.6c (1.0) [6]	16.4b (2.3) [3]	14.2b (2.3) [2]
BS[4]	-[5]	-	-	-	-	5.1 (1.0) [14]	-	-

[1]Spawned and moved fish at AC and WW to reference site HT for depuration.
[2]32 days depuration.
[3]66 days depuration.
[4]BS: Brood stock.
[5]-: No sample.

selected as the beginning of the period because that was about the time when selenium concentrations in muscle plugs from fish at Adobe Creek and North Pond were becoming significantly higher than those of reference fish at Horsethief.

Selenium concentrations in muscle plugs of fish previously held at Adobe Creek decreased about 2% after 32 days of depuration and 19% after 66 days of depuration. Of the four fish sampled after 32 days of depuration at Adobe Creek, two (fish AC21 and AC28) had selenium concentrations that were 16-18% higher than those at spawning (Appendix H), suggesting that eggs containing high selenium concentrations might have been reabsorbed, thus adding to the muscle tissue burden of selenium (fish AC 21 did not spawn; AC28 did spawn but may not have released all of its eggs). Selenium concentrations in fish previously held at North Pond lost 1% of their selenium load at 32 days of depuration and 14% at 66 days of depuration. One of the three fish monitored did not spawn (fish WW12, Appendix H), yet it had a 6% loss of selenium after 32 days of depuration.

Part of the loss of selenium during depuration from fish previously held at Adobe Creek and North Pond might have been due to tissue dilution because the fish gained weight during the depuration period. Weight gain in fish from Adobe Creek sampled for muscle plugs was 1-2% at 32 days depuration and was 11-14% at 66 days depuration, whereas at North Pond it was 0% at 32 days depuration and 5-22% at 66 days depuration. These magnitudes of increase in body weight were comparable to those for decreased selenium concentrations in muscle plugs.

After 305 days of exposure at the test sites, selenium concentrations in muscle, liver, kidney, and gonad tissues were 2.5-4.4 times higher in fish from Adobe Creek and 4.6-8.4 times higher in fish from North Pond than in fish from Horsethief (Table 16). After 66 days of depuration, selenium concentrations in Adobe Creek fish decreased by 20% in muscle tissue and by 67% in the gonads. In North Pond fish the decreases in selenium concentrations were 38% in muscle and 72% in the gonads. Selenium concentrations in muscle plugs were significantly correlated with selenium in muscle (r=0.92, P=0.0001, n=17), liver (r=0.93, P=0.0001, n=12), kidney (r=0.78, P=0.0002, n=17), gonad (r=0.72, P=0.002, n=15), and gall bladder (r=0.82, P=0.01, n=8). Selenium concentrations in muscle tissue (measured by AA-HG) were 1.1 to 1.3 times higher in fish from Horsethief, 1.2 to 1.5 times for Adobe Creek, and 1.2 to 2.0 times for North Pond than in muscle plugs (measured by neutron activation).

Adult collection and spawning

The number of adults recaptured in April 1996 for spawning were 32 of 36 stocked at Adobe Creek, 24 of 36 at North Pond, and 45 at Horsethief. The missing adults at Adobe Creek and North Pond were assumed to have died during the 9-month exposure period or escaped capture efforts. For spawning, 14 females from Adobe Creek were available and 7 were spawned. From North Pond, 13 females were available and 5 were spawned. For Horsethief, 20 females were available and 7 were spawned. Several brood stock adults were spawned for other purposes, but larvae from these fish were used in the larval fish study.

Selenium in eggs

Mean selenium concentrations in eggs were 6.5 μg/g from Horsethief adults, 46.5 μg/g from Adobe Creek adults, and 37.8 μg/g from North Pond adults (Table 17, Appendix I).

Table 16. Mean (standard error in parentheses and number of samples in brackets) selenium concentration (μg/g dry weight) measured by AA in various tissues of razorback sucker held at three sites near Grand Junction, Colorado.

Site	Day of exposure[1]	Muscle	Liver	Kidney	Gonad	Gall bladder	Gut contents
HT	305	6.3	7.5	4.6	7.0	-[2]	-
		(0.3)	(1.1)	(1.0)	(0.4)		
		[4]	[2]	[4]	[2]		
	337	5.8	7.9	7.1	5.9	2.1	3.9
		(0.1)	(0.5)	(0.5)	(0)	(-)	(-)
		[2]	[2]	[2]	[2]	[1]	[1]
	371	6.0	6.8	6.1	5.1	2.0	-
		(0)	(0.4)	(0.2)	(0.7)		
		[2]	[2]	[2]	[2]		
AC	305	15.6	-	14.6	30.6	-	-
		(0.8)		(5.4)	(5.8)		
		[2]		[2]	[2]		
	337	13.5	17.6	20.3	27.5	3.6	-
		(1.0)	(1.1)	(2.6)	(7.9)	(-)	
		[2]	[2]	[2]	[2]	[1]	
	371	12.5	12.2	13.6	10.0	2.8	5.0
		(0.7)	(0.2)	(0.6)	(1.9)	(0)	(-)
		[2]	[2]	[2]	[2]	[2]	[1]
WW	305	29.2	52.1	38.7	45.5	4.8	-
		(4.2)	(19.1)	(15.8)	(3.1)	(-)	
		[3]	[2]	[3]	[2]	[1]	
	337	16.2	29.6	37.8	42.1	6.2	-
		(-)	(-)	(-)	(-)	(-)	
		[1]	[1]	[1]	[1]	[1]	
	371	18.0	23.7	30.1	12.9	4.8	-
		(1.3)	(-)	(5.1)	(1.1)	(-)	
		[2]	[1]	[2]	[2]	[1]	

[1]Spawned at day 305 and moved fish at AC and WW to reference site HT for depuration: Day 337 = 32 days depuration, day 371 = 66 days depuration.
[2]-: No sample.

Table 17. Mean (standard error in parentheses and number of samples in brackets) selenium concentration (μg/g dry weight) measured by AA, percent moisture, diameter (mm), and percent viability of eggs from razorback sucker held at three sites near Grand Junction, Colorado. Sites with lower case letters in common are not significantly different (P=0.05). For egg viability, there were no significant differences between the four sites (P=0.05).

Site	Selenium	% Moisture	Diameter	% Viable
HT	6.5a	87.2a	2.28b	31.8
	(0.2)	(0.5)	(0.05)	(5.2)
	[7]	[7]	[7]	[7]
AC	46.5b	89.1b	2.32b	43.8
	(4.6)	(0.2)	(0.02)	(7.7)
	[6]	[6]	[6]	[6]
WW	37.8b	87.7ab	2.17b	24.9
	(1.4)	(0.4)	(0.02)	(9.5)
	[5]	[5]	[4]	[3]
BS[1]	6.0a	66.7c	2.87a	30.6
	(0.7)	(0.2)	(0.02)	(3.6)
	[3]	[3]	[1]	[3]

[1]BS: Brood stock.

Selenium concentrations in eggs from adults held at Horsethief were significantly lower than those at Adobe Creek or North Pond, but those in eggs from Adobe Creek and North Pond were not significantly different from each other. Eggs from three brood stock held at Horsethief contained 6.0 μg/g. Selenium concentrations in eggs were correlated with selenium concentrations in muscle plugs of adults (r=0.85, P=0.0001, n=15). The equation describing this relation was: Egg selenium (μg/g)= -1.51 +2.66 (muscle plug selenium μg/g). Selenium concentrations in eggs were also highly correlated (r=0.97) with the mean selenium concentration in zooplankton from the three sites, and even though the correlation coefficient seemed important biologically, it was not statistically significant (P=0.16) due in part to the use of site means (n=3).

Other elements in eggs

Of the inorganic elements measured in eggs, only manganese and phosphorus had significant differences between sites. Manganese concentrations in eggs from fish at North Pond were significantly higher, whereas phosphorus concentrations were significantly lower, than in eggs from fish at Horsethief (Table 18). One fish from North Pond (fish WW12) had the highest aluminum, barium, calcium, copper, iron, magnesium, manganese, silicon, sodium, strontium, and titanium concentrations in muscle (for aluminum, barium, copper, iron, manganese, silicon, and titanium the reported values were 2 times higher than for other fish from North Pond), which contributed to the high mean values for eggs given in Table 18. If data from fish WW12 were removed from statistical consideration, the statistical differences for manganese, phosphorus, and selenium did not change. However, deleting fish WW12 from statistical analysis resulted in copper concentrations in eggs from fish at Horsethief (5.2 μg/g) to be significantly higher than those in eggs from adults at Adobe Creek (2.9 μg/g), but not in eggs from adults at North Pond (the mean copper concentration in eggs from North Pond fish would be reduced from 8.2 μg/g to 4.0 μg/g by removing fish WW12 from the dataset).

Insufficient data (i.e., inorganic element concentrations below the limit of detection in water measured by ICP) were available to determine if a significant correlation was present between inorganic elements measured in water and those in eggs. For the inorganic elements measured in zooplankton, only calcium had a significant correlation with calcium concentrations in eggs. For inorganic elements measured in sediment, only manganese and strontium concentrations had a significant correlation with the corresponding concentrations in eggs.

Egg characteristics

The percent moisture in eggs was about 20-22% higher in eggs from the young adults used in the study compared to eggs from brood stock (Table 17, Appendix I). Although the percent moisture of eggs from Horsethief was significantly lower than those from Adobe Creek, the difference was only 2%, the magnitude of difference was 10 times less than the difference between young adults and brood stock. The diameter of eggs from the young adults were significantly smaller (19 - 24%) than those of eggs from the brood stock (Table 17, Appendix I).

Table 18. Mean (standard error in parentheses and number of samples in brackets) concentration of inorganic elements (μg/g dry weight) measured by ICP in eggs collected from razorback sucker held at three sites near Grand Junction, Colorado. For manganese and phosphorus, sites with lower case letters in common were not significantly different (P=0.05); for the other elements, there were no significant differences between sites.

	Site		
Element	HT	AC	WW
Ag	2.0 (-) [1][1]	2.0 (-) [1]	2.0 (-) [1]
Al	474 (51) [7]	412 (43) [6]	606 (178) [5]
As	5.0 (-) [1]	<3[2]	13.5 (6.5) [2]
B	<1	<1	1.0 (0) [2]
Ba	2.1 (0.3) [7]	1.9 (0.2) [6]	3.7 (1.1) [5]
Be	<0.04	<0.04	<0.04
Bi	<5	<5	<5
Ca	956 (53) [7]	1,243 (193) [6]	1,095 (120) [5]
Cd	<0.2	<0.2	<0.2
Co	0.5 (-) [1]	<0.4	1.0 (-) [1]
Cr	<2	<2	<2
Cu	5.2 (0.3) [7]	2.9 (0.6) [6]	8.2 (4.3) [5]
Fe	160 (18) [7]	147 (15) [6]	242 (75) [5]
K	6,071 (292) [7]	6,000 (259) [6]	5,820 (541) [5]
Li	0.6 (0.1) [2]	<0.5	<0.5
Mg	592 (20) [7]	619 (20) [6]	641 (50) [5]

Table 18. Continued.

Element	Site		
	HT	AC	WW
Mn	3.3a (0.4) [7]	4.1ab (0.6) [6]	7.4b (1.3) [5]
Mo	0.8 (0.1) [4]	<0.7	<0.7
Na	1,284 (67) [7]	1,200 (57) [6]	1,156 (89) [5]
Ni	<1	2.0 (-) [1]	<1
P	9307a (89) [7]	9,110ab (72) [6]	8,762b (139) [5]
Pb	4.0 (-) [1]	<4	<4
Sb	<10	<10	<10
Si	28.1 (4.3) [7]	27.7 (7.3) [6]	33.6 (12.5) [5]
Sr	8.3 (0.4) [7]	8.3 (0.4) [6]	8.7 (1.0) [5]
Ti	11.8 (1.7) [7]	10.4 (1.0) [6]	15.9 (4.4) [5]
Tl	40 (-) [1]	<31	<31
W	<3	<3	<3
V	1.2 (0.2) [5]	0.9 (0.1) [2]	1.5 (0.3) [4]
Zn	74.2 (2.4) [7]	103.4 (17.7) [6]	84.2 (1.8) [5]

[1]The number of samples submitted for analysis was HT=7, AC=6, and WW=5. If the number of samples shown for a site and element is less than the number of samples submitted, concentrations in the other samples were below the limit of detection.

[2]<: All measurements were below the limit of detection.

Informal observations of adult razorback sucker

Selenium concentrations in muscle plugs from adults held in a hoop net for 89 days (March 5 to June 2, 1995) at North Pond, increased from 2.1 μg/g at stocking to 6.7 μg/g at 89 days (Table 19). After 89 days of exposure, selenium concentrations in tissues were 11.4 μg/g in muscle, 23.9 μg/g in liver, 27.5 μg/g in kidney, 4.5 μg/g in undeveloped gonad, and 9.1 μg/g in gall bladder (Table 20). Selenium concentrations in muscle plugs at day 89 were significantly correlated with concentrations in liver (r=0.87, P=0.05), but not with the other tissues (all n=5): muscle (r=0.80, P=0.11), kidney (r=0.13, P=0.83), gonad (r=0.67, P=0.22), and gall bladder (r=0.67, P=0.22). No gut contents were available because the stomachs were essentially empty. Due to holding in the hoop net, fish had limited access to natural food, and consequently, they were given weekly feedings of Silvercup brood stock feed, which contained 1.09 μg/g selenium.

During the exposure time period, selenium concentrations in filtered water collected from stations WW2 were 133 μg/L and from WW3 were 115 μg/L on May 4, 1995, and 26 μg/L on June 5, 1995 (Table 5). Selenium concentrations in sediment from WW2 were 32 g/g and from WW3 were 51-55 μg/g on May 4, 1995 (Table 7). Selenium concentrations in zooplankton from WW2 were 43 μg/g and from WW3 were 66 μg/g on May 16, 1995 (Table 11). Three months prior to stocking of razorback sucker, minnows collected on February 16, 1995, from North Pond contained 104 to 119 μg/g selenium, and shortly after removal of the adults, water boatmen collected on June 14, 1995, from North Pond contained 35 and 56 μg/g selenium (Table 12). Minnows collected from North Pond on June 14, 1995, contained 82 and 87 μg/g selenium.

Discussion

Water quality

High concentrations of cations and anions in water, as characterized by conductivity, at Horsethief and Adobe Creek probably did not adversely affect razorback sucker held at those sites. Tyus (1987) and Tyus and Karp (1990) reported that razorback sucker staged at Ashley Creek and Stewart Lake outlet in Utah in mid-April to May. During that time period at those two sites, Stephens et al. (1988) and Peltz and Waddell (1991) reported conductivities ranged from 1,510 to 2,550 μmhos/cm. These conductivities were higher than those observed in the present study when adults were present at Horsethief (range 392-950 μmhos/cm) and Adobe Creek (range 418-1,110 μmhos/cm) (Appendix C). The conductivities at Horsethief and Adobe Creek were similar to those at the two Colorado River stations, AC1 (range 305-940 μmhos/cm; Appendix D) and WW1 (range 266-934 μmhos/cm; Appendix F).

When adults were present at North Pond, conductivities (range 1,240 to 7,140 μmhos/cm; Appendix F) and salinities (range 0.5 to 5.5 μg/L) were elevated. Nelson and Flickinger (1992) reported that the acute toxicity of salinity to juvenile Colorado pikeminnow was 13.1 g/L, but for risk assessment purposes, they suggested that <9.7 g/L could be tolerated. For adult razorback sucker, 5.5 g/L salinity was probably not stressful, but it is unknown what concentration of conductivity or salinity may be stressful. Moreover, adults held at North Pond gained slightly more weight than adults held at Adobe Creek, which suggests that they were able to convert energy from their diet into growth and development of sex products, rather than using all their energy to compensate for potential stresses associated with osmoregulation and toxicants.

Table 19. Mean (standard error in parentheses) selenium concentration (μg/g dry weight) measured by neutron activation in muscle plugs of razorback sucker held in a hoop net in North Pond at Walter Walker State Wildlife Area near Grand Junction, Colorado, in 1995 (n=5).

Day of exposure and date			
0 3/5	32 4/6	60 5/4	89 6/2
2.1 (0.3)	2.4 (0.4)	3.1 (0.3)	6.7 (0.8)

Table 20. Mean (standard error in parentheses) selenium concentration (μg/g dry weight) measured by AA in various tissues of razorback sucker held in a hoop net in North Pond at Walter Walker State Wildlife Area near Grand Junction, Colorado, in 1995 (n=5).

Day of exposure	Tissue				
	Muscle	Liver	Kidney	Gonad	Gall bladder
89	11.4 (2.5)	23.9 (1.4)	27.5 (1.8)	4.5 (1.8)	9.1 (1.5)

Reduced growth is usually one of the first metabolic indications of chronic stress in fish (Rand and Petrocelli 1985).

Selenium and other elements in water

The similarity of selenium concentrations in filtered and unfiltered water samples in the present study was consistent with findings from investigations of flowing water systems at Kesterson Reservoir, CA (Fujii 1988, Moore et al. 1990). Similarly, Saiki et al. (1993) reported no difference in selenium concentrations between filtered and unfiltered water samples collected from seven riverine sites in the San Joaquin Valley, CA, where the waters contained up to 13 µg/L selenium. There was a potential for selenium concentrations in filtered and unfiltered water to be different because the Adobe Creek sites AC3-AC5 and North Pond sites WW2-WW3 were semi-static with little flow of water except from irrigation supply sources or pumped river water. For pond systems at Kesterson Reservoir, Fujii (1988) and Moore et al. (1990) reported that unfiltered water samples (reported as total selenium) had higher selenium concentrations than filtered samples (reported as dissolved selenium). Adams (1976) reported similar findings for Lake Erie and attributed the higher total selenium concentrations, compared to dissolved selenium, to the sorption of selenium on to suspended solids and selenium contained in plankton. Seiler (1996) also cautioned against assuming total (unfiltered) and dissolved (filtered) concentrations of selenium were similar, especially in highly productive waters where there may be large amounts of algae.

The maximum concentrations of selenium in river water collected at Horsethief (3.9 µg/L), Adobe Creek (AC1; 4.2 µg/L), and WWSWA (WW1; 3.3 µg/L) were higher than typical reference sites (defined as areas above irrigation influences) in the upper Colorado River. For example, Butler et al. (1996) reported that between 1987 and 1991 selenium concentrations were <1 µg/L (n=5) in the Gunnison River downstream from the Gunnison Tunnel near Montrose, CO, and between 1980 and 1992 they were ≤1 µg/L (n=22) in the Colorado River at Cameo, CO. However, the reaches of the Colorado and Gunnison rivers that are influenced by irrigation return flows from the Grand Valley and Uncompahgre Valley irrigation projects as well as private irrigation activities have elevated concentrations of selenium, other elements, and water quality characteristics (Butler et al. 1989, 1991, 1994, 1996). Consequently, the elevated selenium concentrations in water from Horsethief ponds, relative to reference areas in the upper Colorado and Gunnison rivers, suggests that adults at the Horsethief reference site were exposed to somewhat elevated selenium concentrations during the present study.

The elevated selenium concentrations in water at AC3-AC5 were due in part to inflow of irrigation return water via AC7, which contained >11 µg/L on two occasions. Selenium concentrations in water at the Adobe Creek site changed quickly due to the discharge of irrigation return flow from AC7 into the site. Selenium concentrations were low between November 14, 1995, and April 23, 1996, in the tertiary channel where the razorback suckers were held (AC3, AC4, AC5). However, after irrigation drainwater (AC7) containing 15 µg/L selenium flowed into the tertiary channel on April 25, 1996, selenium concentrations at AC5 increased from 1.8 µg/L on April 23 to 9.7 µg/L on June 11 (Table 4). A similar response was observed at AC3 and AC4 on June 11, 1996. The selenium concentrations in water from AC7 exceeded the USEPA chronic criterion of 5 µg/L (USEPA 1987) for the protection of aquatic life, and increased selenium concentrations in the confined area where adult razorback sucker

were held. In the same geographic area, water in Adobe Creek sampled near the interstate highway as part of the NIWQP in 1991-92 had a mean selenium concentration of 64 µg/L (Butler et al. 1994). Butler et al. (1989) noted that virtually all of the flow in Adobe Creek was irrigation return flow and drainage water. However, water from Adobe Creek did not enter the teritary channel where the adult razorback sucker were held.

The elevated concentrations of selenium in water at WW2 and WW3 were due in part to inflow of ground water from the underlying cobble aquifer (Phillips 1986). Water in the cobble aquifer sampled as part of the NIWQP in 1992 at a location about 5.5 km north of WWSWA had a selenium concentration of 175 µg/L (Butler et al. 1994). Water from the cobble aquifer comes to the surface in a marsh area adjacent to WW4, which has had a maximum selenium concentration of 138 µg/L. The WWSWA channel and North Pond have been identified by the U.S. Geological Survey as a discharge area for ground water (D. Butler, USGS, personal communication).

Water from Independent Ranchman's Ditch was used to maintain the water level in North Pond during the study. This water sampled at WW10, had a selenium concentration of 13.8 µg/L on September 11, 1995. Although the selenium concentration in water from WW10 exceeded the USEPA criterion of 5 µg/L for the protection of aquatic life (USEPA 1987), this water diluted the incoming ground water, which in May 1995 was the sole source of water for North Pond. Prior to the time that fish were stocked, North Pond had selenium concentrations of 115-133 µg/L.

The relatively low selenium concentration in North Pond water during the time when adult razorback sucker were present, compared to concentrations prior to stocking, were due to flooding of the Colorado River between June and July 1995. The consistently higher selenium concentrations at WW3 compared to WW2 may indicate that seepage of irrigation-derived ground water was greater on the west side of North Pond near WW3 (near a higher elevation, dry upland area) than on the east side near WW2 (near a lower elevation, marsh area).

Selenium concentrations in water at Adobe Creek and North Pond observed in the present study were typical of other surface waters in the Grand and Uncompahgre valleys that are influenced by irrigation activities. Selenium concentrations were 4-7 µg/L (median 5 µg/L, n=11) in the Colorado River at the CO-UT state line, 5-7 µg/L (median 6 µg/L, n=11) in the Gunnison River at Whitewater, and 8-25 µg/L (median 14 µg/L, n=20) in the Uncompahgre River at Delta, CO (Butler et al. 1994). However, selenium concentrations in water at Adobe Creek and North Pond, in addition to most waters in the irrigation-influenced areas of the Colorado, Gunnison, and Uncompahgre rivers, were elevated compared to uncontaminated aquatic ecosystems, which typically have <1 µg/L in the upper Colorado River (Butler et al. 1996) and in the U.S. (Maier and Knight 1994).

Some people have suggested that native fish in the Colorado River basin may have evolved in a selenium-rich environment because of the presence of high selenium soils derived from Mancos Shale (e.g., A. Archuleta, USFWS, written communication). To address the issue of background waterborne selenium concentrations in streams and water bodies in Mancos Shale areas in the Grand and Uncompahgre valleys with no irrigation activity (some areas had grazing activity that disturbed the soils), David Butler of the U.S. Geological Survey searched the area extensively and located seven areas for sampling (Butler and Osmundson 1999). At Wells Gulch at Fools Hill at Highway 50, west of Delta in the Gunnison River basin in an area with some grazing activity, selenium concentrations in water were <1 µg/L. At Cheney Reservoir in the

Uncompahgre River basin in an area with no grazing or irrigation, selenium concentrations in water were <1-1 µg/L, 2-2.4 µg/g in sediments composed almost exclusively from Mancos Shale, and 4.2 µg/g in aquatic invertebrates. At Little Salt Wash above Government Highline Canal in the Grand Valley in an area with no irrigation and minimal grazing activity, selenium concentrations in water during runoff events on February 20, 1996, (1.5 cfs) were 3 µg/L and on March 24, 1997, (0.99 cfs) were 1 µg/L. At Big Salt Wash above Government Highline Canal in the Grand Valley in an area with no irrigation activity, four selenium measurements in water ranged from 2 to 3 µ/L, but perennial flows were low, ranging from 0.08 to 0.14 cfs. At East Salt Creek downstream from Camp Gulch in the Grand Valley in an area with little irrigation activity, selenium concentrations in water were <1 µg/L during runoff events on December 4, 1995 (2.2 cfs) and February 16, 1996 (5.4 cfs). At West Salt Creek downstream below Prairie Canyon in the Grand Valley in an area with no irrigation and some grazing, selenium concentrations in water were <1 µg/L during runoff events on December 4, 1995 (0.99 cfs) and March 13, 1997 (5.3 cfs). In only one area with low flows (0.16-0.24 cfs) at West Salt Creek near S Road in the Grand Valley, selenium concentrations in water were elevated (9-10 µg/L) due to the presence of salt crusts. Because selenium concentrations in water draining high selenium soils were relatively low, i.e., ~1 µg/L, the hypothesis of aquatic environments with elevated selenium, i.e., selenium enriched, enhancing the possibility of selenium adaptation by native fish seems unlikely. These waterborne selenium concentrations are also lower than those in streams and rivers below areas influenced by irrigation activities.

At North Pond, the correlations observed between selenium measured by AA-HG and nine elements (boron, calcium, potassium, lithium, magnesium, molybdenum, sodium, phosphorous, and strontium) measured by ICP (r=0.60 to 0.88) were similar to those of Finger et al. (1994), who reported a strong relation between selenium, boron, cobalt, copper, lithium, and strontium in water in the middle Green River basin, UT. This correlation probably depends in part on the composition of the geologic material being leached by irrigation activities, i.e., elevated elements in soil will generally leach out in proportion to their concentration in soil depending on absorption coefficients. The lack of significant correlations between selenium concentrations in water and other inorganic elements at Horsethief and the single significant correlation with zinc at Adobe Creek suggest that irrigation drainwater probably had a much greater influence on concentrations of inorganic elements at North Pond than at Horsethief and Adobe Creek.

The reason for the inconsistent relation between water quality measures and selenium concentrations among the three test sites is unknown. Birkner (1978) reported no relation between selenium concentrations in water (0.3-15.9 µg/L) and water quality characteristics such as sulfate, hardness, and conductivity at 17 sites: 6 in Wyoming and 11 in Colorado. In contrast, Finger et al. (1994) reported a high correlation between selenium concentrations and specific conductance in water (r=0.90, based on log x log plot). Stephens et al. (1992) reported that correlation coefficients ranged from 0.35 to 0.91 for selenium concentrations in water and conductivity at four drains in the Stewart Lake area, UT, which suggested an inconsistent relation between waterborne selenium and conductivity.

Selenium and other elements in sediment and sediment chemistry

Selenium concentrations in sediment at Horsethief and Adobe Creek (except for one

value at Adobe Creek) were near national background concentrations of <1 μg/g (Maier and Knight 1994). The sediment selenium values observed at Horsethief and Adobe Creek were similar to those of Stephens et al. (1997) who listed a no effect concentration of <2 μg/g for effects of selenium on fish and wildlife, and Lemly (1995) who proposed a no hazard rating at <1 μg/g or a minimal hazard rating at 1-2 μg/g. In contrast, Presser et al. (1994) and Moore et al. (1990) used 0.5 μg/g as a reasonable selenium concentration in sediment to represent the threshold between uncontaminated, background conditions and environments with elevated selenium concentrations in sediments. Neither Lemly (1993a, 1995, 1996b) nor Maier and Knight (1994) proposed a toxic threshold for selenium concentrations in sediment.

The tertiary channel at Adobe Creek was diked to hold the adult fish for the present study. In June 1995 a water control structure was installed in the dike road at AC3 and an inactive beaver dam with 2-3 foot deep water was converted to a dike with an outflow water control structure at AC5 (D. Crabtree, USBR, personal communication). The one elevated selenium concentration in sediment collected at AC5 in October 1995 (2.1 μg/L) may have come from an area influenced by the beaver dam where selenium built up in the sediments could like have occurred. Nevertheless, the overall low selenium concentrations at Adobe Creek suggest that the 9-month duration of the present study may have been too short to allow for accumulation of selenium in the sediments. Consequently, selenium concentrations in sediments at the Horsethief and Adobe Creek sites (0.54 to 2.10 μg/g) were in the no hazard to minimal hazard ranges of Lemly (1995) and the "no effect" category of Stephens et al. (1997).

Selenium concentrations in sediment at North Pond probably accumulated over several years, perhaps more than 20 years. North Pond appears in aerial photos taken in 1973 and 1982 (T. Mathieson, Colorado Division of Wildlife, personal communication). One interesting observation during the present study was the decrease in selenium concentrations in sediment at WW3 on October 17, 1995, and the later increase on April 24, 1996. The decreased sediment selenium in October may have been due to deposition of sediment carried by water from Independent Ranchman's Ditch via an irrigation supply canal that delivered water to North Pond at WW10 near WW3. Twelve discharges were recorded between August 21 and October 10, whereas no water was delivered between November 3 and April 22, and apparently, selenium concentrations in sediment increased due to continued inflow of ground water. Discharge of ground water into North Pond has been measured (D. Butler, USGS, personal communication). The lowest selenium concentration in sediment observed in North Pond (7.17 μg/g) was above the high hazard value of >4 μg/g proposed by Lemly (1995) and the toxic threshold guideline value of >4 μg/g proposed by Stephens et al. (1997).

Selenium concentrations in sediment in the present study may have underestimated concentrations available to biota because they were thoroughly mixed at the time of sampling. Several investigators have reported that selenium accumulates in the top layer of sediments (Holland 1979, Cumbie 1984, Kiffney and Knight 1990, Oremland et al. 1990, Stephens 1996) and can contribute to selenium uptake in the aquatic food web (Peters et al. 1999) beginning with bacterivorous and algivorous predators (protozoa) (Sanders and Gilmour 1994). However, Zhang and Moore (1996) reported that selenium concentrations in sediments can be high in the surficial sediment or at lower depths and were associated with changes in organic carbon content in the sediment.

Accumulation of selenium in the top layer of sediments is generally the result of deposition of dead organic material from the water column and incorporation in the detrital food

chain (Weres et al. 1989, Bender et al. 1991, Graham et al. 1992). Graham et al. (1992) reported that in a pond study, selenium rapidly disappeared from the water column and correspondingly increased in sediments and biota, especially periphtyton. One component of the sediments is the detrital layer, which is partly composed of bacteria. Bender et al. (1991) reported selenium was rapidly removed from the water column by bacteria and cyanobacteria and incorporated into a detrital-like mat composed of anaerobically processed grass clippings. In their experiment initial selenium concentrations of 40 mg/L were undetectable after 27 days of microbial activity.

Ponds at Kesterson NWR, CA, had selenium concentrations in sediment of 5-10 μg/g, but surficial detrital material (decomposing organic matter) contained 40-130 μg/g (Presser et al. 1994). Bottom sediment from the main collective drain at Kesterson NWR, which was described as rich in organics, contained 92 μg/g in sediments, but 308 μg/g in detritus (Presser et al. 1994). Others have reported similar results (Saiki 1986, Saiki et al. 1993).

Selenium concentrations in sediment during 1987-1988 in areas of the Uncompahgre Valley affected by irrigation near Delta, CO, were 2.2-2.3 μg/g in the Uncompahgre River and 2.3-4.0 μg/g in the Gunnison River (Butler et al. 1991). During 1992, selenium concentrations in sediment in the Uncompahgre Valley ranged from 2.0 to 6.9 μg/g in creeks and 16 μg/g in Markley Pond (Butler et al. 1994). Selenium concentrations observed in sediments at North Pond (12-55 μg/g) were higher than those concentrations, but were similar to those reported for Sweitzer Lake (aka Garnet Mesa Reservoir) in 1987-1988 (9-41 μg/g; Butler et al. 1991), and Kesterson Reservoir, CA (aggregate geometric mean of 11.8 μg/g; Moore et al. 1990). Birkner (1978) reported selenium concentrations in sediment sampled during 1976-1977 were 6.5 μg/g at Sweitzer Lake and 15.4 μg/g at Desert Reservoir, near Grand Junction, CO, but only 1.2 μg/g at Mac Mesa Reservoir and 1.8 μg/g at Highline Reservoir. Barnhart (1957) reported that sediments at Sweitzer Lake had 10-40 μg/g selenium in 1956, but various canals and ditches in the Sweitzer Lake area had 1 to 25 μg/g.

Elevated selenium concentrations in sediment were reported in several creeks and washes in the Grand Valley (1.9 μg/g in Salt Creek, 6.3 μg/g in Reed Wash, 3.9 μg/g in Adobe Creek, 5.6 μg/g in Leach Creek, and 16 μg/g in Indian Wash; Butler et al. 1994, 1996). In a toxicity test with these five sediments, embryo-larvae of fathead minnow (*Pimphales promelas*) died within 24 hours of exposure (Butler et al. 1996). There was significant mortality of the amphipod *Hyallela azteca* in a toxicity test with sediments from Reed Wash and Adobe Creek, but not from Salt Creek, Leach Creek, or Indian Wash (Butler et al. 1996). In both toxicity tests, the cause of mortalities was unknown. Selenium concentrations in a variety of fish species collected from these washes and creeks (common carp *Cyprinus carpio*, roundtail chub *Gila robusta*, fathead minnow, speckled dace *Rhinichthys osculus*, white sucker *Catostomas commersoni*, bluehead sucker *Catostomus discobolus*, flannelmouth sucker *Catostomus latipinnis*) averaged 13.4 μg/g in Salt Creek, 11.4 μg/g in Reed Wash, 10.3 μg/g in Adobe Creek, 7.1 μg/g in Leach Creek, and 9.3 μg/g in Indian Wash (Butler et al. 1994).

The high copper concentration in sediments from Horsethief may have been from the use of copper sulfate, a common aquatic herbicide and algaecide used in some fish culture activities (Hansen et al. 1983). Copper sorbs readily to pond sediments (Reinert 1989). It has also been found to be elevated in sediments from fish culture ponds at the Gavins Point National Fish Hatchery, SD (A. Bullard, USGS, unpublished data).

No other elements seemed elevated to concentrations of concern in sediments other than selenium. A similar situation occurred at Kesterson Reservoir, CA, in that elements of concern

included arsenic, boron, chromium, molybdenum, and selenium in sediment, but only selenium concentrations were linked with adverse effects in fish and wildlife (Moore et al. 1990).

Even though selenium concentrations in sediment at Adobe Creek were near background concentrations, they were elevated compared to Horsethief, and sediment selenium was elevated at North Pond compared to Adobe Creek. These differences may have been due in part to elevated concentrations of organic carbon, which were highest at North Pond. Besser et al. (1989) reported higher selenium concentrations in sediments with high organic carbon than in sediments with lower organic carbon even though the two sediments had similar microbial activity, which is generally considered to be the mechanism of selenium entry into the sediments (Bender et al. 1991). Stephens et al. (1992) and Peltz and Waddell (1991) reported a positive relation between selenium concentrations in pond sediments at Ouray NWR, UT, and concentrations of organic material in sediments. As early as 1978, significant correlations between sediment selenium and the total carbon or organic content of sediment have been reported (Birkner 1978).

The significant correlations between selenium concentrations in sediment with various carbon fractions in the present study (r=0.70-0.80) were similar to high correlations for the same relations reported by Zhang and Moore (1996) for sediment from wetland ponds at Benton Lake NWR, MT (correlation coefficients ranged from 0.73 to 0.94). Zhang and Moore (1997) also reported high correlations between selenium concentrations in sediment and organic matter in sediment. However, they suggested that carbon content was not a primary controlling factor, but rather selenium inputs were a more important controlling factor for selenium accumulation in sediment. In the present study, the negative correlation between selenium concentration in sediment and sand content was similar to Besser et al. (1989) who reported that more selenium was sorbed to fine-textured, highly organic sediment than to sandy sediments.

Selenium in biota

Selenium concentrations in zooplankton and macroinvertebrates collected from Adobe Creek and North Pond were substantially above the proposed dietary toxic threshold concentration of 3 µg/g (Lemly 1993a, 1996b, Maier and Knight 1994). This threshold concentration was derived from examination of several laboratory and field investigations on a wide variety of fish species (Maier and Knight 1994 reviewed 5 studies, Lemly 1993a reviewed 11 studies, Lemly 1996b reviewed 1 additional study). Six additional studies supporting this proposed dietary toxicity threshold for fish were given in Hamilton et al. (1999). Even though selenium concentrations in water were below the current USEPA criterion of 5 µg/L at Adobe Creek for 12 of 13 months it was monitored, selenium concentrations in food organisms during the study (14 to 56 µg/g) exceeded the proposed dietary toxic threshold by a factor of 5 to 19 fold.

Selenium concentrations in zooplankton from Adobe Creek increased when waterborne selenium concentrations increased, and decreased when waterborne selenium concentrations decreased. Selenium concentrations in zooplankton at AC3-AC5 increased from 19-25 µg/g on August 16, 1995, to 50-56 µg/g on September 28, 1995 (6 weeks). This two-fold increase of selenium in zooplankton was similar to that observed at North Roadside Pond (17-24 µg/g on April 5, 1989 increasing to 31-40 µg/g on April 27, 1989), and at South Roadside Pond (12-13 µg/g on April 5, 1989 increasing to 40-53 µg/g on April 27, 1989) at Ouray NWR, UT (Stephens

et al. 1992). In a similar manner, selenium concentrations in zooplankton from North Pond decreased from 41-81 µg/g in June 1995 to 20-26 µg/g in July 1995.

Zooplankton can rapidly take up selenium from the water and accumulate it with no adverse effects on zooplankton reproduction except at very high selenium concentrations, i.e., >400 µg/L (Halter et al. 1980, Nassos et al. 1980, Reading and Buikema 1983, Salki et al. 1985, Foe and Knight 1986, Ingersoll et al. 1990). Similarly, Salki et al. (1985) found no effects on seasonal abundance of zooplankton exposed to selenium concentrations as high as 100 µg/L in large enclosures. However, two studies have reported adverse effects on invertebrates. Boyum and Brooks (1988) found that waterborne and dietary selenium exposure of daphnids reduced survival and greater reductions occurred in the waterborne exposure than in the combined water and dietary exposure. Dobbs et al. (1996) reported that rotifers biomass was reduced by exposure to 108 µg/L selenium in their three-trophic food chain experiments.

The likely sources of selenium residues in zooplankton at Adobe Creek and North Pond were water, aquatic plants such as algae, or both. Selenium in water is rapidly taken up by algae (Sandholm et al. 1973, Nassos et al. 1980, Foe and Knight 1986, Riedel et al. 1991, Besser et al. 1993) and aquatic plants (Allen 1991, Ornes et al. 1991). Typically, algae took up maximal concentrations in 3-24 hours, whereas floating plants took about 1 week to accumulate maximal concentrations. In those studies, neither algae nor aquatic plants exhibited adverse effects from selenium exposure except at high concentrations, i.e., ≥100 µg/L for algae (Foe and Knight 1986) or 1,250 µg/L for floating plants (Ornes et al. 1991). Part of the selenium taken up by zooplankton was probably waterborne organoselenium compounds released from living algae or necrosis of dead cells (Cutter 1986, 1989, 1991, 1992, Besser et al. 1994).

Even though waterborne selenium concentrations at Adobe Creek (<0.8-10.4 µg/L) and North Pond (4-20 µg/L) were lower than at Sweitzer Lake, CO (10-170 µg/L; Butler et al. 1991), selenium concentrations in zooplankton and other aquatic invertebrates from Adobe Creek (25-56 µg/g) at AC3-AC5 during September-October, 1995, and North Pond (25-35 µg/g) for the same time period were similar to or higher than those in aquatic invertebrates from selenium-contaminated Sweitzer Lake (27-30 µg/g; Butler et al. 1991). Birkner (1978) reported that a mixed-species sample of plankton collected in 1977 contained 42.5 µg/g selenium. Barnhart (1957) and Birkner (1978) suggested that the lack of reproduction of native fish such as flannelmouth sucker and stocked game fish such as channel catfish (*Ictalurus punctatus*) in Sweitzer Lake was probably due to adverse effects from selenium accumulated through the food chain.

Selenium concentrations in aquatic invertebrates from Adobe Creek and North Pond were also higher than those from other aquatic environments in the upper Colorado River, which may reflect differences between lentic and lotic environments, although Adobe Creek and North Pond were not entirely lentic, i.e., non-flowing. Aquatic invertebrates in the Uncompahgre River at Delta, CO, contained selenium concentrations of 4.1 µg/g, and in the Gunnison River at Delta, CO, were 5.6-6.8 µg/g (Butler et al. 1991), which exceed the proposed dietary toxicity threshold of 3 µg/g (Maier and Knight 1994, Lemly 1996b).

Butler et al. (1994) reported two examples of low selenium concentrations in water, but elevated concentrations in aquatic invertebrates from the Uncompahgre Valley: Horsefly Creek (<1 µg/L, 6.1 µg/g, respectively) and South Fork (<1 µg/L, 4.8 µg/g, respectively). Stephens et al. (1992) reported four examples from the Green River Valley, UT: Sheppard Bottom pond 5 (3-4 µg/L, 4.4-8.9 µg/g, respectively), Desilting Basin (3-5 µg/L, 3-9 µg/g, respectively), Big

Island Pond (2-5 µg/L, 5-6 µg/g, respectively), and Felters, Shoveler, and Pintail ponds (1-5 µg/L in adjacent waters, 6-11 µg/g, respectively). Birkner (1978) reported two examples from the Grand Valley: Mac Mesa Reservoir (2.2 µg/L, 7.7 µg/g, respectively), and Highline Reservoir (4.2 µg/L, 7.7 µg/g, respectively), as well as four other locations in Colorado and two in Wyoming. These examples from locations in the Uncompahgre, Grand, and Green river valleys were similar to the selenium loading study of Maier et al. (1998), which revealed that aquatic invertebrates exposed to low waterborne selenium concentrations can accumulate selenium residues that reach or exceed the proposed dietary toxicity threshold of 3 µg/g. Other examples of low waterborne selenium concentrations (<5 µg/L) associated with elevated selenium concentrations in food organisms above the proposed dietary toxic threshold (>3 µg/g) have been reported by Holland (1979), Schroeder et al. (1988), Peltz and Waddell (1991), Hamilton et al. (1996), and Lemly (1997b).

In aquatic ecosystems with elevated selenium concentrations in water, the amount accumulated in aquatic invertebrates may be variable due in part to the productivity of the water body. Butler et al. (1994) and Stephens et al. (1992) reported examples of moderate to high selenium concentrations in water and high selenium concentrations in aquatic invertebrates. In the Uncompahgre Valley, CO, examples include: Markley Pond (5 µg/L, 32 µg/g, respectively) and Loutsenhizer Arroyo (130 µg/L, 26 µg/g, respectively). In the Green River Valley, UT, examples include: Winter Storage Pond (8-9 µg/L, 37-42 µg/g, respectively), Drain J3 (58 µg/L, 37 µg/g, respectively), Stewart Lake (4-11 µg/L, 10-16 µg/g, respectively), North Roadside Pond (10-85 µg/L, 12-40 µg/g, respectively), and South Roadside Pond (39 µg/L, 12-53 µg/g, respectively). Birkner (1978) reported that Desert Reservoir in the Grand Valley had selenium concentrations of 12.5 µg/L in water and 31.3 µg/g in a mixed-species plankton sample. These elevated concentrations of selenium in aquatic invertebrates were comparable to those at Adobe Creek and North Pond.

The elevated selenium concentrations in chironomids (8.0-13.6 µg/g) collected at Horsethief ponds was similar to those reported in Montana by Zhang and Moore (1996). They found low selenium concentrations in water (0.94 -1.58 µg/L), but elevated selenium concentrations in chironomids (8.12 -10.4 µg/g).

Elements, other than selenium, measured by ICP in zooplankton are discussed in the section on the larval fish study.

Growth

Weight loss in adults at the three sites (Table 13) might be due to the time lag in fish adapting from the hatchery environment at Wahweap State Fish Hatchery, UT, to the hatchery ponds at Horsethief or to natural foraging at Adobe Creek and North Pond. Adults held at Horsethief had a 5% weight loss in the first 69 days of the study, but apparently adapted well to the hatchery ponds and feeding regime, and concomitantly had the greatest weight gain (15% compared to -2% at Adobe Creek and 3% at North Pond) of the three sites. The low weight gain in adults at Adobe Creek compared to those held at North Pond might be due to the difference in habitat between the two sites.

The slow growth of adult fish in the present study was consistent with the slow or negligible growth of adult razorback sucker reported by others. McAda and Wydoski (1980) reported that one adult razorback sucker had not grown after 1.5 years between captures, and a

second fish had grown about 2.3 mm/year over a 3.5 year period. Valdez et al. (1982) reported little or no change in length of five razorback sucker recaptured up to 1 year later. All of the razorback sucker collected by McAda and Valdez were considered to be old fish; no juveniles or sub-adults were collected (C. McAda and R. Valdez, personal communication). Other razorback sucker populations in the Colorado River basin also are presumed to be very old (McCarthy and Minckley 1987). Tyus (1987) reported slow growth (mean 2.2 mm/year) of 39 adults with recapture periods of 1 to 8 years. Roberts and Moretti (1989) found slow growth (mean 1.8 mm/year) in six adults recaptured after 1 year in the San Juan Arm of Lake Powell. Although not based on recapture of the same adults, the total length of adults in Lake Mohave increased by 5 mm/year up to 1964 (Minckley 1983), but thereafter (1965-1980s), there was no change (Marsh and Minckley 1991).

Growth is usually one of the first signs of contaminant stress in fish, especially in the early life stages (Rand and Petrocelli 1985). However, in the present study, it would not be expected to observe changes in adult growth during the relatively short exposure time period because razorback sucker are a slow growing, long-lived fish. Effects of selenium on the growth of adult fish are not well documented, whereas two of the well documented effects of selenium in the food chain is the elimination of fish species from aquatic ecosystems such as in Belews Lake, NC (Cumbie and Van Horn 1978, Lemly 1985); Martin Lake, TX (Garrett and Inman 1984, Sorensen 1988); Kesterson Reservoir, CA (Harris 1986, Vencil 1986); or the lack of reproduction as documented at Sweitzer Lake, CO (Barnhart 1957, Birkner 1978). Adverse effects have been reported on survival and growth of adult fathead minnow and bluegill (*Lepomis macrochirus*) exposed to a selenium concentration of 10 µg/L in experimental streams conducted by the USEPA at Monticello, MN, (Hermanutz et al. 1992, Schultz and Hermanutz 1990). However, Crane et al. (1992) reported no effects on growth of adult yellow perch (*Perca fluviatilis*) in a 288-day reproduction study where the fish were held in ponds treated with selenium concentrations of either 0, 2, 10 or 25 µg/L. Coyle et al. (1993) also reported no effects on adult bluegill exposed to selenium up to 10 µg/L in water and 32 µg/g in diet for 140 days.

Selenium in tissues

Selenium residues in adult razorback sucker tissue from the present study probably came primarily from food chain organisms, and secondarily from water and sediment exposure. Investigators have reported that adult razorback sucker feed on a variety of items including filamentous algae (Dill 1944, Marsh 1987), algae (Jonez and Sumner 1954, Banks 1964), zooplankton (Hubbs and Miller 1953, Minckley 1973, Allan and Roden 1978, Marsh 1987), diatoms (Marsh 1987), and other aquatic invertebrates (Banks 1964). Marsh (1987) noted that razorback sucker had both plankivorous and benthic feeding habits. Several investigators noted sediment, sometimes referring to it as ooze, detritus, or decaying organic matter, in the gut of razorback sucker (Dill 1944, Banks 1964, Vanicek 1967, Allan and Roden 1978, Marsh 1987).

At the time of stocking, selenium concentrations in muscle plugs from all the fish (range 3.9 to 4.5 µg/g) exceeded the 85th percentile (arbitrary point distinguishing "high" concentrations) in the National Contaminant Biomonitoring Program (NCBP) for the years 1971-1984 (Walsh et al. 1977, May and McKinney 1981, Lowe et al. 1985, Schmitt and Brumbaugh 1990). The NCBP has documented temporal and geographic trends in concentrations of persistent environmental contaminants, including selenium, in whole-body fish that may threaten

fish and wildlife. The 85th percentile concentrations of selenium in samples from the NCBP were 2.9 μg/g (reported as wet weight but converted to dry weight assuming 73% moisture [average of percent moisture in 1978-1981 and 1984 samples]) in 1972-1973; 3.0 μg/g (reported as wet weight, converted to dry weight assuming 73% moisture) in 1976-1977; 2.5 μg/g (reported as wet weight, converted to dry weight based on a mean moisture of 72% for 591 samples in the 1978-1981 collection) in 1978-1981; and 2.8 μg/g (reported as wet weight, converted to dry weight based on a mean moisture of 74% for 315 samples in the 1984 collection) in 1984, the last year of the program (Walsh et al. 1977, May and McKinney 1981, Lowe et al. 1985, Schmitt and Brumbaugh 1990).

Selenium concentrations in muscle plugs measured in the present study probably underestimate the concentrations in whole-body of fish. One report stated that fillets (i.e., muscle) had more selenium than whole body in bluegill and largemouth bass collected at a variety of sites in central California associated with irrigation drainage (Saiki et al. 1991), which was the opposite of the majority of the literature. In general, muscle contains less selenium than whole-body due to the relatively high amounts of selenium found in spleen, liver, kidney, heart, and other tissues, especially mature ovaries (Adams 1976, Sato et al. 1980, Lemly 1982, Hilton et al. 1982, Hilton and Hodson 1983, Kleinow and Brooks 1986, Lemly and Smith 1987, Hermanutz et al. 1992). Consequently, the estimated whole-body selenium concentrations in razorback sucker initially stocked in the present study would be about 6.5 to 7.5 μg/g (based on a conversion factor of 1.667 x muscle concentration=whole body concentration, Lemly and Smith 1987). Conversion factors were 2.355 based on data from Adams (1976) for rainbow trout (*Oncorhynchus mykiss*), and 1.745 from Lemly (1982) for bluegill and largemouth bass, both of which would have increased the converted values for razorback sucker. Thus, the razorback sucker used in the present study initially had selenium residues over two times higher than the 85th percentile of the NCBP.

Concentrations of selenium in muscle plugs in the present study seemed to be increasing at day 305 in fish at Adobe Creek and North Pond when fish were removed for spawning, which suggested that an equilibrium in selenium concentrations in muscle had not occurred. The adults at these two sites probably would have continued to accumulate selenium until an equilibrium was reached with selenium concentrations in their environment. Most other studies have reported equilibrium in selenium residues in whole-body or tissues were reached in 60 to 90 days (Gissel Nielsen and Gissel-Nielsen 1978, Sato et al. 1980, Lemly 1982, Besser et al. 1993), but others have estimated longer periods, i.e., >20 weeks (Adams 1976, Woock and Summers 1984). Equilibrium in whole-body selenium concentrations depends on a variety of factors including species, size, age, exposure route and concentration, chemical form, and many other factors. Because the present study used adults about 100 times heavier than the fish species in the studies cited above, it would probably take longer than 9 months for tissue residues to reach an equilibrium with selenium exposure in the water and diet. In fact, selenium concentrations increased in adults after an additional 9 months of exposure in the second reproduction study: 9.6 μg/g on July 11, 1996, to 16.2 μg/g on April 24, 1997, at Adobe Creek, and 14.2 μg/g on July 11, 1996, to 22.8 μg/g on April 24, 1997 (Hamilton et al. 2001).

Selenium concentrations in muscle plug tissue in razorback sucker from Adobe Creek and North Pond from 126 to 305 days of exposure (range 9.5 to 16.6 μg/g) exceeded the proposed guideline of Lemly (1996b) of 8 μg/g in skeletal muscle as the benchmark for probable reproductive failure. His value was based on a review of 17 laboratory and field studies of

selenium effects on various fish species. One study not reviewed by Lemly (1996b) also supports his proposed guideline of 8 μg/g for reproductive failure of fish. Cumbie and Van Horn (1978) reported reproductive failure of several fish species in Belews Lake, NC, at selenium concentrations of 10 μg/g or greater in skeletal muscle. In addition, Crane et al. (1992) reported no hatch of eggs from adult yellow perch exposed for 288 days to 25 μg/L in a pond system; fish contained 23 μg/g in muscle and 28 μg/g in gonads (reported as wet weight, converted to dry weight assuming 75% moisture).

Forty percent (18 of 45) of the wild adult razorback sucker sampled in the Green River, UT, by Waddell and May (1995) and Stephens and Waddell (1998) had selenium concentrations equal to or higher than those in the fish held at Adobe Creek (mean 11.7 μg/g at spawning) and North Pond (16.6 μg/g at spawning). It seems unusual that 40% of wild fish had higher selenium residues because the two groups of fish in the present study were held in elevated selenium environments for 9 months and had no opportunity to move to low selenium environments. The higher selenium in a substantial portion of the wild fish reported by Waddell and May (1995) and Stephens and Waddell (1998) suggested that some wild adults choose, or are forced, due to the lack of uncontaminated habitats, to use habitats with high selenium in water, food organisms, or both. It also suggested that wild razorback sucker can accumulate substantial amounts of selenium in their tissues without depurating selenium. Modde (1993) stated that "Based on the distribution of razorback sucker, it is likely that a significant portion of the remaining razorback sucker population in the middle Green River have been exposed to selenium contamination." Modde's statement was supported by information in Waddell and May (1995) and Stephens and Waddell (1998). Recently, Osmundson et al. (2000) reported that selenium concentrations were elevated in muscle plugs of Colorado pikeminnow sampled from the channel area at WWSWA, which has high selenium concentrations in water, sediment, food organisms, and fish (Butler et al. 1994, 1996). The maintenance of elevated selenium concentrations in some Colorado pikeminnow recaptured near WWSWA over a 3-year period suggested that they, similar to razorback sucker, maintain elevated selenium residues in tissue without depurating it.

Selenium concentrations in whole-body fish in the Colorado River basin, measured as part of the NCBP, have been among the highest in the nation (Walsh et al. 1977, Lowe et al. 1985, Schmitt and Brumbaugh 1990). They exceeded the 85th percentile in whole-body fish collected in 1972-1973 at 5 of 6 Colorado River basin stations (Green River at Vernal, UT [only upper basin station], and Colorado River at Imperial Reservoir, Lake Havasu, Lake Mead, Lake Powell, all AZ). Selenium concentrations in whole-body fish also exceeded the 85th percentile in 1978-1981 and 1984 at 6 of 7 stations (same five as above) plus Colorado River at Yuma, AZ.

Elevated selenium concentrations, exceeding the 85th percentile of the NCBP, in other fish species have been reported as part of the NIWQP and USFWS contaminants investigations in the upper Colorado, Dolores, Green, Gunnison, Uncompahgre, White, and Yampa rivers (Butler et al. 1991, 1994, 1996, Krueger 1988, 1991, Krueger et al. 1991, Stephens et al. 1988, 1992, Osmundson 1989, 1992, Peltz and Waddell 1991, Rose 1992, Waddell and Wiens 1992, 1994a, 1994b, Wiens and Waddell 1996). Elevated selenium concentrations have also been found in fish from Lake Powell (Bussey et al. 1976, Kidd and Potter 1978, Potter and Drake 1989, Waddell and Wiens 1993) and also in net plankton (Kidd and Potter 1978). These elevated concentrations in Lake Powell prompted Stanford and Ward (1991) to caution that "Relatively high [selenium] concentrations were observed in the larger fishes of Lake Powell (Potter and Drake 1989) and warrant further work, as selenium may inhibit egg production in squawfish

[Colorado pikeminnow] and other native fishes of the Colorado River."

High selenium concentrations in sediment at North Pond probably contributed to the high selenium concentrations in adults because other investigators have reported that the stomach contents of adults contained detritus or bottom ooze, plant debris, and benthic invertebrates (i.e., larvae of mayfly, caddis fly, midge), usually with associated sediment materials such as nondescript mud, clays, or silt (Dill 1944, Jonez and Sumner 1954, Banks 1964, Vanicek 1967, Allan and Roden 1978, Marsh 1987). Woock (1984) reported that golden shiners (*Notemigonus cryoleucas*) maintained in enclosures that allowed access to sediments, and presumably benthic food organisms, maintained high selenium concentrations in tissues even though they were exposed to clean water and clean water-column food organisms. Fish without access to sediments depurated selenium from their tissues (Woock 1984). Loss of selenium from fish tissue during a depuration phase of an exposure experiment has been reported to be independent of waterborne exposure concentration (Gissel Nielsen and Gissel-Nielsen 1978, Sato et al. 1980), but increased with dietary exposure concentration (Hilton and Hodson 1983). Loss of selenium also is faster in small, younger fish (Bennett et al. 1986) than in larger, older fish (Bertram and Brooks 1986).

In general, selenium was present in tissues, from highest to lowest, as follows: liver, kidney, ovary, whole body, muscle, and testes (Adams 1976, Sato et al. 1980, Hilton et al. 1982, Lemly 1982). Selenium concentrations in various tissues of razorback sucker in the present study were similar to those reported for other species, which suggested that the physiological storage of selenium in this species was similar to other fish species. The difference in tissue distribution and the magnitude of difference in selenium concentrations among tissues in the present study was similar to those reported by others in several fish species (Adams 1976, Hodson et al. 1980, Lemly 1982, Hilton and Hodson 1983, Sager and Cofield 1984). Elevated selenium concentrations in liver, kidney, ovaries, and testes have been linked with adverse pathological changes in those tissues (Sorensen et al. 1984, Sorensen 1986, 1988, 1991).

Our correlation between selenium concentrations in muscle plugs and muscle tissue ($r=0.92$, $P=0.0001$, $n=17$) was similar to that reported by Waddell and May (1995) who examined the relation in three areas (mid-dorsal, just behind the gill, and near the tail) of one razorback sucker, three common carp, and three flannelmouth sucker (for combined species and tissue locations, $r=0.97$). In the present study, all of the fish had higher selenium concentrations in muscle tissue measured by AA-HG than those in muscle plugs measured by neutron activation, whereas Waddell and May (1995) reported that four of seven fish had slightly lower selenium concentrations in muscle tissue than in muscle plugs. Neutron activation analyses have been documented to be accurate (a measure of the degree of conformity to the assumed or accepted value) and precise (the degree of agreement of repeated measurements) for the measurement of selenium in tissue (Pillay et al. 1974, McKown and Morris 1978, Dermelj et al. 1996).

Depuration of selenium from tissues

In the present study, razorback sucker from Adobe Creek and North Pond lost 14-19% of the selenium from their muscle tissue after 66 days of depuration, which suggested a slow loss of selenium. Depuration of selenium from tissues depends on several factors including cleanliness of the food and water in the depurating environment, age, size, metabolic activity, season for

poikilotherms, initial selenium load of various tissues, and other factors.

Besser et al. (1993) reported a 20-day half life of selenium residues in juvenile bluegill, although the authors thought the fish had not reached an equilibrium of selenium uptake before depuration was started, which could have lengthened the half life period. Kleinow and Brooks (1986) reported a 19-day half life for selenate and selenite, and a 27-day half life for selenomethionine in whole body of adult fathead minnow. They also reported that the half lives were longer in muscle tissue (33 days for selenate, 41 days for selenite, and 42 days for selenomethionine) than in whole body. The longer half life for selenomethionine was probably due to its incorporation into protein and tissue, which would require more metabolic work to eliminate. Others have reported half lives for selenium depuration of 28-30 days in various young fish (Gissel Nielsen and Gissel-Nielsen 1978, Sato et al. 1980, Hilton et al. 1982, Bennett et al. 1986), but Adams (1976) estimated a half life of 63 days in whole body of adult fathead minnows and muscle of rainbow trout, whereas Bertram and Brooks (1986) graphically showed a half life of about 49 days for adult fathead minnows exposed to selenium in the diet. In sub-adult bluegill and largemouth bass with elevated selenium concentrations in tissues, Lemly (1982) noted no significant decrease in selenium concentrations in muscle, liver, kidney, and spleen after 30 days depuration, which suggested a half life greater than 30 days. Similarly, Bryson et al. (1984) reported a half life of selenium residues in adult bluegill of about 60 days. Consequently, the slow depuration rate, i.e., >66 days, of selenium from muscle tissue in adult razorback sucker in the present study seemed realistic.

Two fish in the present study (AC21 and AC28) had increased selenium concentrations in muscle plugs after 30 days of depuration, which suggested that selenium may have been resorbed from another tissue and deposited in muscle. This increase in selenium concentration in muscle tissue may have been due to resorption of unexpelled eggs from the spawned fish (AC28) and the selenium load redistributed to the whole body. Likewise, the unstripped fish (AC21) may have begun to resorb its unspawned eggs, thus redistributing selenium from the resorbed eggs to muscle tissue. It seemed unusual that the three North Pond fish that spawned, then monitored during depuration, did not depurate a greater amount of selenium. Perhaps selenium from some unexpelled eggs were resorbed and offset any selenium that was depurated during the first 32 days of depuration. Hamman (1985) reported that of 70 hatchery-reared razorback sucker females stripped at 24-hour intervals, 16 ovulated all eggs after one stripping, 51 ovulated all eggs after two strippings, and 3 females ovulated all eggs after threes strippings.

The concept of depuration may be misleading in the natural environment because those measurements were on fish physically placed in a clean environment for the sole purpose of determining how fast their tissues can remove a contaminant. In the natural environment, fish may not be able to move to a clean environment. Sorensen (1988) reported that selenium tissue residues in fish from Martin Lake, TX, were only 25% lower after a 5-year period (1981-1986) following the drastic reduction of selenium inputs to the lake in 1978. In 1983, 4 years after selenium inputs to Martin Lake, TX, were stopped, selenium concentrations in ovary of redear sunfish were 20-24 μg/g (reported as wet weight, converted to dry weight assuming 75% moisture) (Sorensen and Bauer 1984), which is two times higher than the toxicity threshold of 10 μg/g in ovary or eggs. Likewise, Lemly (1997b) assessed selenium concentrations in five ecosystem components of Belews Lake, NC, 10 years after selenium inputs to the lake were stopped and found elevated selenium concentrations in sediment, benthic invertebrates, and fish that suggested a moderate hazard still existed. He also reported teratogenic deformities first

observed in 1992 (Lemly 1993c) were still presented at elevated levels in 1996.

Depuration does not seem to be occurring in endangered fish in the Colorado River near WWSWA, Grand Junction, CO, because Colorado pikeminnow recaptured over a 2 or 3-year period seemed to be conserving selenium concentrations in muscle plugs from year to year, i.e., if the selenium concentrations were elevated 1 year, they were elevated in subsequent years (Osmundson et al. 1999). Waddell and May (1995) and Stephens and Waddell (1998) did not collect muscle plugs from any adult razorback sucker that were recaptured, thus it is unknown if any changes in selenium concentrations have occurred over time (B. Waddell, USFWS, personal communication).

Spawning

If razorback suckers in the present study had been allowed to spawn naturally, no selenium effects on spawning behavior would have been expected. Behaviors associated with reproductive activities of fathead minnow (approach behavior, leading behavior, lateral display, tail-beating, vibrating, butting) were not altered in fish exposed to selenium concentrations up to 30,000 µg/L for 24 hours (Pyron and Beitinger 1989). Ogle and Knight (1989) reported no effects on number of spawns in fathead minnow exposed up to 30 µg/g selenium in the diet for 98 days. Hermanutz et al. (1992) reported no effect on the number of active nests for bluegill exposed to 10 µg/L selenium in experimental streams for 40 weeks. Others have also reported no effect of selenium exposure in water, diet, or both on fish spawning behavior (Coyle et al. 1993, Bryson et al. 1984). However, Ogle and Knight (1989) reported no spawning occurred in adults fed 40 µg/g selenium in the diet, which was similar to the concentration of selenium in zooplankton and aquatic invertebrates from North Pond.

We can not state whether natural spawning would have been successful or not in the present study because fish were induced to spawn by injection of hormones and hand stripping of eggs and milt. However, negative effects of selenium on fish reproduction in the upper Colorado River basin have been observed at Sweitzer Lake where few native or nonnative fish have been found to reproduce (Barnhart 1957, Birkner 1978). At Sweitzer Lake, schools of young fish were observed in the fall following earlier observations of spawning by fathead minnow, red shiner (*Cyprinella lutrensis*), and plains killifish (*Fundulus zebrinus*) (Barnhart 1957). Although flannelmouth sucker were abundant in the lake, no young fish were observed (Barnhart 1957).

Razorback suckers, some with low and some with high concentrations of selenium, have been collected at Razorback Bar, the best known spawning site in the Green River, UT (Stephens and Waddell 1998). Spawning of razorback sucker must have been somewhat successful because razorback sucker larvae have been collected from during several years of monitoring. During the 1992-1996 period 1,735 larvae were collected in the middle Green River and 440 larvae collected in the lower Green River (Muth et al. 1997). In 1994, 11 yearlings were captured in Leota Bottoms on the Green River (Modde and Wick 1997), and in 1993, 1 yearling was captured in the Yampa River (T. Modde, USFWS, written communication).

Selenium and other elements in eggs

Lemly (1996b) proposed a selenium toxic threshold of 10 µg/g in eggs or ovary of fish for reproductive failure based on a review of several studies. To assess the aquatic hazard of

selenium, Lemly (1995) used fish eggs as one of the five components and assigned a no hazard rating to selenium concentrations of <3 μg/g in eggs, minimal hazard at 3-5 μg/g, low at 5-10 μg/g, moderate at 10-20 μg/g, and high at >20 μg/g. These hazards are defined later in the section on hazard assessment. In the present study, mean selenium concentrations in eggs from razorback sucker at Adobe Creek were 46.5 μg/g and at North Pond were 37.8 μg/g, which were two times greater than Lemly's high hazard and almost four times higher than the proposed threshold for reproductive failure, i.e., lack of recruitment. Eggs from adults held at Horsethief had a mean selenium concentration of 6.5 μg/g, which falls in the low hazard category of Lemly (1995).

In the present reproduction study with razorback sucker, there seemed to be an incongruity in selenium concentrations in fish eggs from Adobe Creek (46.5 μg/g) and North Pond (37.8 μg/g) because North Pond had higher selenium concentrations in water (4-20 μg/L), sediment (7-55 μg/g), and fish muscle plugs (16.6 μg/g) than did Adobe Creek (water 1.5-12 μg/L), sediment (0.5-2.1 μg/g), and fish muscle plug (11.7 μg/g). However, North Pond had similar selenium concentrations in zooplankton (27.1 μg/g), and chironomids (11-45 μg/g) compared to Adobe Creek (zooplankton 28.5 μg/g, and chironomids 28-45 μg/g). The higher selenium concentrations in eggs of Adobe Creek fish may have been due to the substantially higher selenium concentrations in zooplankton at Adobe Creek during September 1995 (49.6-55.6 μg/g) compared to North Pond (25.2-32.5 μg/g). If razorback suckers begin deposition of egg yolks in the fall prior to spawning, the fall time period could be a critical time for deposition of selenium in eggs.

In the second reproduction study, North Pond adults had higher selenium concentrations in eggs (54.7 μg/g) than Adobe Creek adults (40.1 μg/g) (Hamilton et al. 2001). This relation in egg selenium between sites was consistent with the higher selenium concentrations at North Pond in water (3.2-17.1 μg/L), sediment (2.9-16 μg/g), zooplankton (39 μg/g), and fish muscle plugs (25.5 μg/g) compared to selenium concentrations at Adobe Creek in water (<0.7-4.5 μg/L), sediment (1.2-2.5 μg/g), zooplankton (18 μg/g), and fish muscle plugs (16.6 μg/g). Selenium concentrations in eggs in the second reproduction study followed the same pattern in zooplankton during September 1996 (20.0 μg/g at Adobe Creek and 33.9 μg/g at North Pond; Hamilton et al. 2001), which suggests September was a critical period for selenium deposition in eggs as hypothesized above.

If razorback sucker have a similar three-part reproductive cycle as rainbow trout (i.e., spawn in December, previtellogenesis December-March, endogenous vitellogenesis May-July, exogenous vitellogenesis July-December; Ng and Idler 1983), then for razorback sucker the cycle near Grand Junction, CO, would be spawn in May, previtellogenesis May-August, endogenous vitellogenesis August-December, exogenous vitellogenesis December-May. The vitellogenic phase of oocyte growth and protein incorporation can last 9 or more months (Tyler and Sumpter 1996). Vitellogenesis is the phase when selenoproteins are incorporated into oocytes in fish (Kroll and Doroshov 1991). Selenium in fish eggs is carried as part of the yolk precursor proteins, lipovitellin and phosvitin, and is incorporated into egg immunoglobulin and vitellogenin (Kroll and Doroshov 1991). These proteins are produced in the liver of fish (Ny and Idler 1983), and the liver of fish accumulates more selenium than most other tissues types in fish (Adams 1976, Lemly 1982, Sager and Cofield 1984).

Bryson et al. (1985) studied the uptake of selenium in the gonads of bluegill and reported that long-term exposure of fish was less important than exposure during the maturation of the

ovaries. Navas et al. (1997) also reported that a critical time for the development of high quality eggs was during vitellogenesis. They found that European sea bass (*Dicentrarchus labrax*) had higher quality eggs if females were fed a lipid-enriched diet during vitellogensis than if females were fed during previtellogenesis or prior to spawning. In an analogous manner, a critical exposure time of female razorback sucker in September 1995 (i.e., during endogenous vitellogenesis) could have occurred when selenium concentrations were higher in zooplankton from Adobe Creek (49.6-55.6 μg/g) than at North Pond (25.2-32.5 μg/g), and resulted in higher selenium concentrations in eggs in the present study.

The results of several studies reported adverse effects on fish species at selenium concentrations in eggs or ovaries that were half the concentration of those in razorback sucker held at Adobe Creek or North Pond (Cumbie and Van Horn 1978, Bryson et al. 1984, Gillespie and Baumann 1986, Schultz and Hermanutz 1990, Crane et al. 1992, Hermanutz et al. 1992, Nakamoto and Hassler 1992), whereas one study reported effects at similar selenium concentrations (Coyle et al. 1993).

Selenium concentrations in eggs of razorback sucker have also been reported to be elevated in the Green River. Hamilton and Waddell (1994) reported that selenium concentrations were 3.7, 4.7, and 10.6 μg/g in eggs (4.4, 7.1, and 32.0 μg/g, respectively, in muscle plugs) from three wild adult razorback sucker collected in 1992 from Razorback Bar in the Green River, UT. These selenium concentrations were similar to those reported in eggs of razorback sucker near Razorback Bar in 1988 (4.9 μg/g, Peltz and Waddell 1991), but lower than those in 1992 (28 μg/g, Waddell and Wiens 1992). This latter selenium concentration of 28 μg/g was comparable to those in fish from Adobe Creek and North Pond. Hamilton and Waddell (1994) concluded that the selenium concentrations in eggs of two razorback suckers (10.6 and 28 μg/g) were sufficiently elevated, i.e., exceeded the proposed toxic threshold of 10 μg/g (Lemly 1996b), to suspect reproductive problems may be contributing to the decline of razorback sucker in the upper Colorado River basin. The only other report of selenium concentrations in gonads from an endangered fish in the upper Colorado River basin was from a Colorado pikeminnow collected in 1982, which had 6.5 μg/g (Peltz and Waddell 1991). Kroll and Doroshov (1991) reported elevated and variable selenium concentrations in eggs (3.1-29.3 μg/g) of wild white sturgeon (*Acipenser transmontanus*) caught in the Sacramento River and San Francisco Bay, CA, which was similar to the wide variation reported by Peltz and Waddell (1991), Waddell and Wiens (1992), and Hamilton and Waddell (1994).

In the present study, the mean selenium concentration in eggs from fish at the Horsethief reference site was 6.5 μg/g (4.5 μg/g in muscle plug), whereas eggs from fish at Adobe Creek contained 46.5 μg/g (11.7 μg/g in muscle plug) and at North Pond contained 37.8 μg/g (16.6 μg/g in muscle plug). Because muscle plugs from the captive-held adults in the present study contained lower selenium concentrations than in 40% of the adults collected from the Green River (Waddell and May 1995, Stephens and Waddell 1998), and the selenium concentration in eggs from the captive adults was higher than in wild fish, it seems reasonable to assume that eggs from wild adults would probably contain elevated selenium concentrations, which would probably result in elevated selenium residues in larvae and reduced survival of larvae.

In comparing selenium concentrations in eggs, ovaries, and gonad tissue, one must be cautious. Lemly (1996b) proposed 10 μg/g as the toxic threshold for selenium concentrations in fish eggs and ovary, which he used as equivalent tissues. This assumption was supported by Schultz and Hermanutz (1990) who reported that for fathead minnow exposed to selenium in

experimental streams, eggs contained 15.6 μg/g selenium (±7.5 standard deviation, n=4), and ovaries contained 23.6 μg/g (±8.8 standard deviation, n=4) (reported as wet weight, converted to dry weight assuming 75% moisture). In the present study, selenium concentrations in gonads and eggs were similar for two of three adults (fish AC12 had 35.5 μg/g in eggs and 36.5 μg/g in gonads [3% difference]; AC19 had 43.3 μg/g in eggs, 24.8 μg/g in gonads [75% difference]; WW54 had 34.3 μg/g in eggs, 42.4 μg/g in gonads [24% difference]). However, it would be inappropriate to compare the selenium concentrations in gonads (Table 16) with those in eggs (Table 17) because different fish were used in the analyses.

Gillespie and Baumann (1986) reported what initially seemed to be conflicting evidence in that bluegill ovaries with low selenium concentration (3.3 μg/g) resulted in larvae with about the same selenium concentration (3.1 μg/g), but ovaries with high selenium concentration (46.5 μg/g) resulted in larvae with 39% less selenium (28.2 μg/g). However, R. Gillespie (written communication) stated that larvae were collected about 4 days post-hatch (larvae were collected at 140-150 hours post-fertilization and embryos hatched at about 48 hours, therefore larvae were 92-102 hours old at sampling, which would have allowed them to metabolize and depurate selenium from their tissue. Depuration of selenium in young, small fish can be rapid (Bennett et al. 1986). In a study where depuration was probably not a problem, Bryson et al. (1985) reported that selenium concentrations in ovaries were 14.8 μg/g and in newly hatched larvae were 17.0 μg/g.

Although 10 elements not including selenium (antimony, boron, calcium, potassium, lithium, magnesium, molybdenum, phosphorus, sodium, strontium) were significantly elevated in water at North Pond in the present study, they were not elevated in eggs from adults held at North Pond. Even though manganese was not significantly elevated in sediment, it was correlated to manganese concentrations in eggs ($r=1.0$, $P=0.01$, n=3), where it was significantly elevated. Nakamoto and Hassler (1992) reported that manganese accumulated in whole-body of bluegill collected from an area dominated by irrigation return flow near Kesterson Reservoir, CA, but not in gonads, which contrasts with the present study. Moller (1996) has presented a hypothesis that manganese and selenium accumulate in the liver of birds because they are components in liver enzymes important in the animals' antioxidant defense system. As mentioned earlier, yolk proteins are produced in the liver (Ng and Idler 1983), and because the liver is the site of manganese and selenium accumulation, manganese may be incorporated into the yolk proteins similar to selenium, which in turn is incorporated into the egg. The significance of manganese in fish eggs is unknown.

The concentrations of some elements in eggs in the present study and the second reproduction study (Hamilton et al. 2001) were similar to those reported by Wooch and Cofield (1983) for arsenic, copper, and zinc in gonads of bluegill, and by Bryson et al. (1984, 1985) for arsenic, copper, cadmium, and zinc in gonads of bluegill. Nakamoto and Hassler (1992) reported similar concentrations of arsenic, boron, beryllium, cadmium, chromium, copper, lead, manganese, molybdenum, nickel, strontium, vanadium and zinc in gonads of bluegill as in the present study. However, concentrations of aluminum, barium, iron, titanium, and thallium were substantially higher than in the present study than reported in Nakamoto and Hassler (1992), and therefore may reflect either a species difference, habitat or ecosystem difference due in part to geologic source rock, or a measurement error by the analytical laboratory. Overall, the magnitude of difference in manganese and phosphorous concentrations in eggs among adults held at the three sites was low (1.0-2.2) compared the 5.2-5.8 fold difference in selenium

concentrations between eggs from Horsethief fish and eggs from Adobe Creek or North Pond fish. Thus, selenium seemed to be the only element in eggs from adults from Adobe Creek and North Pond that was elevated to concentrations of concern compared to adults from Horsethief.

Egg characteristics

Although the difference in egg size seemed to be due to adult age in the present study, McFarlane and Franzin (1978) have reported that egg size, egg and larval survival, and adult longevity were reduced in white sucker from a lake with cadmium, copper, and zinc contamination compared to white sucker from a physically and chemically similar lake located nearby.

The difference in egg size and percent moisture in eggs between older brood stock and the young adults used in the present study suggested potential differences in fitness of the resulting larvae. The significant positive correlation between egg diameter and percent hatch suggested that larger eggs tend to have a higher percent hatch. In a similar manner, the significant negative correlation between egg diameter and either selenium concentrations in adult muscle plug or percent deformities of embryos suggested that smaller eggs had higher amounts of selenium and more deformities than did larger eggs. Based on studies with salmonids, older females (which typically are also larger) generally produce larger eggs and fry compared to younger females (Buss and McCreary 1960, Gall 1974, Pitman 1979, Kazakov 1981, Springate and Bromage 1985). Moreover, for females of the same age, larger eggs produced larger fry that had better swimming stamina than those from smaller eggs (Ojanguren et al. 1996). Larger fry hatched from larger eggs tend to have a faster growth rate than those from smaller eggs (Gall 1974, Pitman 1979), although one investigator reported no difference in growth rate between fry from larger or small eggs (Springate and Bromage 1985). Larger eggs produce fry with higher survival than those from smaller eggs (Bagenal 1969, Marsh 1986, Hutchings 1991), whereas others have reported no difference in survival (Springate and Bromage 1985), or decreased survival (Fowler 1972, Beacham and Murray 1985) due possibly to dissolved oxygen problems because large eggs have a lower surface to volume ratio for oxygen exchange. Still others have reported that larger eggs produced larger fry that had better burst swimming and predator avoidance (Taylor and McPhail 1985), and increased fitness (Hutchings 1991). Similar findings have been reported for non-salmonids (Baynes and Howell 1996, Marsh 1986).

The influence of the percent moisture in eggs on the fitness of the egg and resulting fry is unclear. Ojanguren et al. (1996) reported that percent moisture in eggs from brown trout (*Salmo trutta*) ranged from 55.3 to 61.4%, but this small range of variation (6%) was unrelated to female size. In the present study, the variation in moisture content of eggs between brood stock and test adults was over 20% difference, which seemed unusually large. Some might interpret the greater percent moisture in eggs from the first reproduction study as indicating a possible edematous condition due to selenium or possibly to inbreeding effects. Edema has been reported in newly hatched fish due to selenium exposure (Bryson et al. 1984, Gillespie and Baumann 1986, Woock et al. 1987, Pyron and Beitinger 1989, Schultz and Hermanutz 1990, Hermanutz et al. 1992), but not been reported in studies of inbreeding (Moav and Wohlfarth 1966, Kincaid 1976a, 1976b, Piper et al. 1982). However, in the second reproduction study with razorback sucker (Hamilton et al. 2001), the difference in percent moisture in eggs from young adults compared to brood stock was only 0.8 to 1.6%, which may not be biologically important. Because the same adults

were used in the second reproduction study as in the first, and selenium concentrations were higher in eggs in the second reproduction study than in the first, it seems reasonable to assume that if either inbreeding or selenium were the cause of the higher percent moisture in the first study, then high percent moisture in eggs should have occurred in the second reproduction study, which it did not.

The adults used in the present study were first time spawners, which may have produced eggs and resulting fry of lower quality than those produced by repeat spawners, such as the larger eggs produced by brood stock. Brooks et al. (1997) reviewed the literature and reported that females produce better quality eggs in their second season, survival of eyed eggs was better for second time spawners than first timers, and survival to hatch increased in successive spawning seasons.

Based on the above discussion, it seems reasonable to assume in the present study that the eggs and resulting fry from the older brood stock were probably higher quality than those produced by the young, first-time spawning, adults held at Horsethief, Adobe Creek, and North Pond. Nevertheless, the range of egg sizes measured in the present study (2.17-2.32 mm for young adults; 2.87 mm for brood stock) was similar to those reported by McAda and Wydoski (1985) for flannelmouth sucker (2.39 mm). Toney (1974) reported egg size in wild razorback sucker (perhaps as many as 40 fish) was 2.1 to 3.2 mm in diameter, but fish age was unknown. Also, some of the eggs measured by Toney (1974) may have not been fully mature, and therefore, smaller in size than mature eggs. Muth and Ruppert (1996) reported water-hardened eggs from razorback sucker (mean total length 575 mm) were 2.1 mm (range 2.1-2.3 mm), which is similar to the range of sizes in the current study.

Informal observations of adult razorback sucker

Adult razorback sucker held in the hoop net in North Pond had selenium concentrations in muscle plugs that were slightly less (6.7 µg/g at day 89) than in adults stocked later for the reproduction study (6.3 µg/g at day 69, but 9.5 µg/g at day 126). Based on graphic interpolation using the values for day 69 and 126, the predicted value for selenium residues in fish from the reproduction study would be 7.4 µg/g. However, the lower selenium concentrations in muscle plugs of the fish held in the hoop net may be due to the lower initial selenium concentration (2.1 µg/g) compared to the initial selenium concentration in adults in the reproduction study (4.2 µg/g).

The ratio of selenium concentrations in muscle tissue (measured by AA-HG) to those in muscle plugs (measured by neutron activation) in adults held in the hoop net ranged from 1.1 to 2.3, which was similar to those from free-ranging adults from North Pond analyzed in the reproduction study (ratio 1.2-2.0). The order of tissue accumulation of selenium, from highest to lowest, in adults held in the hoop net was similar to free-ranging adults in North Pond in the reproductive study with the exception of the gonads, which were undeveloped in the fish held in the hoop net.

EGG STUDY

This section of the report will describe the methods, results, and discussion of the egg study portion of the reproduction study.

Methods

Adult razorback sucker previously held for 9 months at either Horsethief, Adobe Creek, or North Pond and brood stock held at Horsethief were spawned on May 6 and 7, 1996. Eggs used in the study came from five spawns of Horsetheif adults, 6 spawns of Adobe Creek adults, and four spawns of North Pond adults. A detailed description of the spawning procedure is given in the Adult Study.

After the eggs were water hardened, a group of eggs from each spawn was transferred to the mobile laboratory for an egg study. The laboratory was housed at the CRFP garage in Grand Junction, CO. For each spawn (six each for Horsethief and Adobe Creek, and four for North Pond), six groups of 25 eggs were placed in incubator cups for percent survival and hatchability determinations. Eggs were randomly assigned to a hatching cup five eggs at a time until 25 eggs were placed in each cup. The eggs cups were suspended in 2-L glass beakers filled with 1.2 L of filtered (25 μm polypropylene bag filter, Filter Specialists, Inc., Michigan City, IN) water. Three groups from each spawn were placed on one of two tables in the mobile laboratory. Eggs on one table were held in 24-Road water, and eggs on the other table were held in site water collected from sites where the parents were located prior to spawning. The beakers were arranged in three rows on each table and their position was randomly assigned using a random numbers table.

Incubator cups and 2-L beakers were acid-cleaned before use and calibrated at the 600-ml and 1.2-L levels. The incubation cups were pint jars with the bottom removed and a polypropylene filter cloth (285 μm openings) glued with silicon adhesive to the bottom. They were suspended by a latex handle in beakers containing 1.2 L of filtered 24-Road water. After 2 hours the site water treatments had 50% of the water replaced with site water. Thereafter, 50% of the water (600 ml) was renewed daily. Oxygen concentrations in exposure water were supplemented by passing compressed air from an oil-less air compressor through air stones.

Test waters for the egg study were collected every day from each site as grab samples using two 19-L carboys. Water was prefiltered through 25 μm polypropylene filter bags to remove particulate matter and poured into large plastic buckets prior to use in water quality analyses and water renewal in exposure vessels. This water was sampled four times and analyzed for general water quality characteristics. During the egg study, water quality measurements include pH, conductivity, hardness, alkalinity, calcium, magnesium, and chloride. One filtered (0.4 μm) and one unfiltered water sample was collected from waters used in the renewals and analyzed for selenium concentrations.

Egg cups were gently removed once daily and placed in a petri dish with the same water as in the beaker, and examined using a dissecting scope to record the number of live and dead eggs, and the number and type of deformities. All dead eggs were removed daily. When the eggs began to hatch, the number of live and dead larvae, and the number and type of deformities were recorded daily and all dead larvae removed. The study was terminated at 4 days posthatch.

A checklist was maintained at the mobile laboratory during the egg study and each item on the checklist (i.e., lights, aeration, etc.) was checked daily to document test conditions. Temperature in exposure beakers was maintained at ambient air temperature and measured daily with a precision grade mercury thermometer. Ambient temperature in the mobile laboratory was maintained as close to 20°C as possible. Eggs and larvae were exposed under flourescent lighting (one cool-white bulb and one wide-spectrum bulb in each light fixture) to a photoperiod that existed at the time of testing in Grand Junction and approximated 12 hours light:12 hours

dark. Newly hatched larvae were not fed because of the short duration of the study.

Egg viability (i.e., number of eggs alive and developing) also was measured on groups of about 100 3-4 day-old eggs from each spawn maintained at 24-Road. A sample of eggs was removed from the incubation bucket and placed in a small petri dish marked into eight sections on the outside bottom. Two people independently counted the number of live and dead embryos in the same dish using dissecting microscopes set at 7x magnification. The eggs were reexamined by each person if their counts differed by more than 10%. The mean difference between the final count was 3.6% (SE 0.49). Eggs from seven spawns from Horsethief adults, six from Adobe Creek adults, four from North Pond adults, and three from brood stock adults were examined.

Egg diameter was determined on one set of 25 eggs from each of the seven spawns from Horsethief adults, six from Adobe Creek adults, four from North Pond adults, and three from brood stock adults. Eggs were held in a petri dish filled with 24-Road water so that the eggs would maintain their natural shape. The longest diameter was measured using a dissecting microscope fitted with a Reichert filar micrometer eyepiece. The micrometer was calibrated by determining the mean calibration constant for a 2.0 mm distance calibrated at the full scale, 50%, and 20% scale calibration distances.

Methods for water quality analysis, selenium analysis, and statistical analysis were the same as those described in the section on the Adult Study.

Results

The eggs and subsequent larvae held at 24-Road were treated with two different imprinting chemicals (morpholine and phenethyl alcohol [PEA]) at the same time that other larvae were being imprinted for other studies. Horsethief larvae were all imprinted with PEA, Adobe Creek larvae imprinted with morpholine, and North Pond larvae imprinted with both chemicals. Hatchery records stated that larvae from Adobe Creek looked anemic at the time of first feeding on May 21 (M. Montagne, USFWS, written communication).

In the egg study, for eggs from the five Horsethief spawns (females HT17, HT41, HT44, HT57, HT74), selenium concentrations in eggs ranged from 5.8 to 7.5 μg/g, egg diameters ranged from 2.0 to 2.4 mm, and selenium concentrations in adult muscle plugs at spawning ranged from 3.4 to 5.0 μg/g. For eggs from the six Adobe Creek spawns (females AC12, AC17, AC18, AC 19, AC20, AC28), selenium concentrations in eggs ranged from 35.5 to 65.1 μg/g, egg diameters ranged from 2.3 to 2.4 mm, and selenium concentrations in adult muscle plugs at spawning ranged from 10.3 to 12.9 μg/g. For eggs from the four North Pond spawns (females WW1, WW2, WW21, WW54), selenium concentrations in eggs ranged from 34.3 to 41.3 μg/g, egg diameters ranged from 2.1 to 2.2 mm, and selenium concentrations in adult muscle plugs at spawning ranged from 14.1 to 20.8 μg/g

Water quality characteristics were consistent within each water type during the egg study (Appendix J), but differed significantly among the four types (24-Road, HT, AC, WW) (Table 21). For each water characteristic, each water type was significantly different from each other except for alkalinity (significantly lower in 24-Road water than in the other three waters) and pH (significantly lower in 24-Road water than in AC and WW waters). In the exposure

Table 21. Mean (standard error in parentheses, n=4) water quality characteristics measured in test water collected from four stations and used in the egg study. For each measure, stations with the same letter are not significantly different (P=0.05).

	Station			
Measure	HT1	AC5	WW2	24-Road
pH	8.2ab (0)	8.4b (0)	8.4b (0.1)	8.1a (0.1)
Conductivity (μmhos/cm)	478b (6)	827c (34)	6,830d (388)	246a (4)
Hardness (mg/L as $CaCO_3$)	164b (2)	267c (3)	1,845d (143)	86a (2)
Calcium (mg/L)	47b (1)	69c (1)	195d (6)	26a (0)
Magnesium (mg/L)	12b (0)	23c (1)	330d (32)	5a (0)
Alkalinity (mg/L as $CaCO_3$)	102b (1)	112b (0)	124b (10)	73a (2)
Chloride (mg/L)	26b (1)	64c (1)	625d (49)	4a (0)

beakers, mean dissolved oxygen concentrations in the four waters ranged from 7.2 to 7.4 mg/L. The mean water temperature in the exposure beakers for the four water types ranged from 19.8 to 20.2°C, and the overall range was 17.0 to 22.5°C. Selenium concentrations (n=2) measured in water during the egg study were 1.1 μg/L at Horsethief, 7.4 μg/L at Adobe Creek, and 11.9 μg/L at North Pond. Although selenuim concentrations were not measured in 24-Road water during the egg study, they were <1 μg/L in the larval fish study.

Mean percent egg viability was 32% (SE 5) for Horsethief adults, 44% (SE 8) for Adobe Creek adults, 25% (SE 10) for North Pond adults, and 31% (SE 4) for brood stock. There was no significant difference in egg viability among the four groups. There was no difference in percent survival or percent hatch of eggs exposed in either 24-Road water or in site water (Table 22, Appendix L-P). Also, there were no differences in the percent deformities or in the percent mortality of deformed larvae among the three sites (Table 22, Appendix Q-S).

Within a site, there were significant differences in the number of deformities of eggs from Adobe Creek between the two water types tested, but not between the two water types tested with eggs from Horsethief or North Pond. There were more deformities in the Adobe Creek eggs exposed to Adobe Creek site water than in Adobe Creek eggs exposed to 24-Road water. Nearly twice the percentage of deformed larvae from Horsethief adults occurred where the eggs were held in site water (18%) compared to reference water (10%), but the differences were not significant. Some edemas in eggs did not appear until 8 or 9 days after spawning or until larvae hatched. Most deformed embryos either died or did not hatch. Hatched larvae that had deformities were counted as live even though biologically they most likely would not have lived in the natural environment.

There was a significant positive correlation between percent hatch and percent survival of eggs (r=0.97, P=0.0001, n=30) and between egg diameter and either percent hatch (r=0.41, P=0.03, n=30) or percent survival (r=0.45, P=0.01, n=30). There was a significant negative correlation between percent hatch and selenium concentrations in adult muscle plug (r= -0.40, P=0.05, n=24), and between egg diameter and either selenium concentrations in adult muscle plugs (r= -0.80, P=0.0001, n=24) or percent deformities in embryos (r= -0.40, P=0.03, n=30). There was a significant positive correlation between deformities in embryos and mortality of deformed embryos or larvae (r=0.46, P=0.01, n=30). In contrast, there was no correlation between percent hatch and with selenium concentrations in eggs (r= -0.17, P=0.36, n=30), or between percent survival and selenium concentrations in adult muscle plugs (r= -0.37, P=0.07, n=24) or in eggs (r= -0.11, P=0.58, n=30).

Discussion

Although selenium concentrations in eggs and water quality of the site waters differed significantly, it apparently did not affect the percent viability, percent hatch, or mortality of deformed embyros because there were no significant differences in those measures among the four test groups. The significant difference in the percentage of embryos with deformities for Adobe Creek eggs held in site water compared to reference water seemed unusual in that no differences were observed in the North Pond eggs, which were held in site water with several inorganic elements at higher concentrations than in Adobe Creek water. Dissolved oxygen concentrations and water temperature during the test were in the acceptable range of values for tests with eggs and embryos (Weber et al. 1989). It is unknown what effect the exposure to PEA

Table 22. Mean (standard error in parentheses and number of samples in brackets) of percent survival and hatch of eggs, percent of embryos with deformities, and percent mortality of deformed embryos and larvae in the egg study. Eggs were held in either reference water (R) from 24-Road or site water (S) during the egg study. Within a water quality, there were no significant difference among the three sites (P=0.05). Within a site, only % deformities in the AC site were significantly different (P=0.05) between the two water types.

Site	Water quality	Survival (%)	Hatch (%)	Embryos with deformities (%)	Mortality of deformed embryos and larvae (%)
HT	R	46	44	10	43
		(10)	(9)	(1)	(16)
		[5]	[5]	[5]	[5]
	S	66	65	18	68
		(11)	(11)	(5)	(8)
		[5]	[5]	[5]	[5]
AC	R	52	46	12a	47
		(6)	(7)	(2)	(14)
		[6]	[6]	[6]	[6]
	S	53	47	26b	80
		(6)	(5)	(4)	(6)
		[6]	[6]	[6]	[6]
WW	R	44	43	27	43
		(10)	(9)	(11)	(12)
		[4]	[4]	[4]	[4]
	S	40	37	20	49
		(8)	(7)	(11)	(18)
		[4]	[4]	[4]	[4]

and morpholine had on the eggs or embryos.

In the present study, the percent hatch of eggs from young adults (range 37-65%) and the percent survival of eggs and newly hatched larvae (range 40-66%) was in the range of results reported by others for razorback sucker. Hamman (1985) reported about 40% hatching success and survival of larvae. Muth and Ruppert (1996) reported that the mean percent egg hatch for control fish in their experiment was 26% (range 21-35%). Inslee (1982) reported a 23% hatch of eggs collected from 71 females. In recent years at Dexter NFH and Technology Center, NM, the overall average percent hatch of razorback sucker eggs has been about 50% and the survival of larvae has been about 35-40% (R. Hamman, USFWS, personal communication).

No effects were observed on egg survival or hatch in the present study and there was no significant correlation between hatch and selenium concentrations in eggs, or between survival and selenium concentrations in adult muscle plugs or eggs, which was similar to other selenium studies with fish. Crane et al. (1992) reported no effects on fertilization rate or time to first hatch in eggs from yellow perch exposed to 2 or 10 µg/L selenium in ponds for 288 days. However, they reported that no eggs hatched from the 25 µg/L treatment where selenium concentrations in adults were 23 µg/g in muscle and 28 µg/g in gonads (both reported as wet weight, converted to dry weight assuming 75% moisture). Gillespie and Baumann (1986) reported no effects on fertilization or hatch in bluegill eggs containing 27-32 µg/g selenium (reported as wet weight, converted to dry weight assuming 75% moisture). Woock et al. (1987) observed no effect on hatching success of eggs from adult bluegill exposed to selenium concentrations up to 30 µg/g in diet and 30 µg/L in water for 260 days. Ogle and Knight (1989) reported no effects on the number of eggs per spawn or percent hatch in fathead minnows exposed to selenium concentrations up to 30 µg/g in diet for 98 days. Coyle et al. (1993) reported no effects on the number of eggs per spawn or hatchability of eggs from adult bluegill exposed to selenium concentrations up to 10 µg/L in water and up to 33 µg/g in diet for 60 days.

In contrast, Hermanutz et al. (1992) reported that percent hatch was reduced in eggs of adult fathead minnows exposed to 10 µg/L selenium (72%) in an experimental stream for 1 year compared to those of adults in the reference stream (93%). Likewise, egg exposures to high selenium concentrations in water can affect the median hatch time of rainbow trout (10,000 µg/L) and lake trout (*Salvelinus namaycush*; 20,000 µg/L) (Klaverkamp et al. 1983), but concentrations up to 40,000 µg/L had no effect on hatch of fathead minnow eggs (Halter et al. 1980). Hodson et al. (1980) reported that exposure of fertilized rainbow trout eggs to 28 µg/L selenium in water caused a small (3.5%), but significant decrease in hatch. Saiki and Ogle (1995) reported that western mosquitofish (*Gambusia affinis*) (whole-body selenium >100 µg/g) from the San Luis Drain, CA, which contained 340-390 µg/L selenium, had a lower mean percentage of live births within broods and produced less fry than adults from a reference area with selenium concentrations of 0.4 µg/L in water and <1.6 µg/g in fish.

Deformities in eggs and larvae

The elevated percent of deformities in embryos and newly hatched larvae from Horsethief adults (10-18%), Adobe Creek adults (12-26%), and North Pond (20-27%) were higher than typical background levels. In large surveys of fish populations, Patten (1968) and Dahlberg (1970) reported deformity rates in various fish species at <1%, whereas Gabriel (1944) reported 2-3% in wild populations of *Fundulus*, and Gill and Fisk (1966) reported 3% in wild

Pacific salmon using x-ray analysis. Correspondingly, Bengtsson (1975) suggested that abnormality rates greater than 9 to 11% give rise to suspicion of a possible "man-made" effect. Physiological abnormalities in fish can take many forms including scoliosis, vertebral deformities, cranial deformities such as pugheadedness and deformed operculae, fin deformities including fin erosion, and genetic anomalies (Hickey 1973). Anomalies resulting in deformities can occur at several points during development including mutation or recombination of genes, during embryonic or larval development, or during the adult life stage. Most deformities develop during the sensitive early life stages of animals. Causes of deformities in fish can include incubation at inappropriate water temperature, low dissolved oxygen concentration, elevated salinity (for freshwater fish), exposure to X-irradiation or ultraviolet irradiation, diet deficiencies of vitamins such as vitamin C, mineral deficiencies, hormone-induced ovulation, and toxic substances such as pesticides (DDT, 2,4-dinitrophenol, oxadiazon, fenitrothion, toxaphene, Kepone, trifluralin, malathion, parathion, other organophosphate compounds), inorganic elements (cadmium, lead, selenium, zinc) (Bengtsson 1975, Hickey 1973, Sindermann 1979, Hiraoka and Okuda 1983, Lemly 1997a).

Teratogenesis is a well-documented biomarker of selenium toxicity in wild birds and fish at the embryo-larval stage (Ohlendorf et al. 1986, Hoffman and Heinz 1988, Hoffman et al. 1988, Lemly 1993c, 1997a, 1997b). Fish deformities include lordosis (concave curvature of lumbar and caudal regions of spine), kyphosis (convex curvature of thoracic region of the spine), scoliosis (lateral curvature of the spine), and head, mouth, gill cover, and fin deformities, in addition to edema, and brain, heart, and eye problems. Selenium-induced teratogenic deformities in fish larvae have been reported in laboratory studies (Goettl and Davies 1977, Bryson et al. 1984, Klauda 1986, Woock et al. 1987, Pyron and Beitinger 1989), experimental stream studies (Schultz and Hermanutz 1990, Hermanutz 1992, Hermanutz et al. 1992), artificial crossing experiments (Gillespie and Baumann 1986), and field investigations (Lemly 1993c, 1997a, 1997b, Saiki and Ogle 1995). Contaminated ecosystems may require long time periods for recovery from selenium contamination because 10 years after selenium inputs to Belews Lake, NC, were stopped, elevated incidences of deformed fry (3-6%) of four fish species were reported compared to a reference lake (High Rock Lake; 0% deformities in the same four species) (Lemly 1997b).

Lemly (1997a) stated that "In order to draw a conclusion of selenium-induced teratogenesis, the visual indicators and symptoms (deformities) must be corroborated with the presence of elevated concentrations of selenium in tissues." He goes on to state that selenium concentrations of 10-20 μg/g or greater in whole-body or 6-12 μg/g in muscle, would be sufficient to confirm the diagnosis. In the present study, there were 12-26% deformities in embryo-larvae from Adobe Creek adults and 20-27% in larvae from North Pond adults. Based on the teratogenesis rating of Lemly (1997a), and considering the elevated selenium concentrations in eggs (38-46 μg/g), muscle plugs (12-17 μg/g), and muscle tissue (13-29 μg/g) of adults from Adobe Creek and North Pond, an adverse impact on embryos would be expected from selenium exposure. The 10-18% deformities in embryo-larvae from Horsethief adults may indicate that this species may be sensitive to selenium exposure. Horsethief adults had selenium concentrations of 6.5 μg/g in eggs, 4.5 μg/g in muscle plugs, and 5.8-6.3 μg/g in muscle. The selenium concentrations in muscle were close to the low end of Lemly's (1997a) guideline of tissue residue as corroborative evidence for the diagnosis of selenium-induced teratogenesis.

Deformities can occur in fish during long-term exposures to selenium in the water. Goettl and Davies (1977) exposed rainbow trout from the fertilized egg to subadult stage to selenium in water during a 13.5-month study, and reported no deformities in the 60 µg/L treatment, whereas there were 16% deformities in the 130 µg/L treatment, 30% in the 260 µg/L treatment, 46% in the 490 µg/L treatment, and 100% in the 1,000 µg/L treatment. Deformities included small, pointed head, dark coloration, skin lesions, and bulbous anus. Klauda (1986) reported deformities (abnormal lower jaw, curved spine) in striped bass (*Morone saxatilis*) exposed to 90 µg/L selenium for 60 days. Selenium-induced deformities in fish would have to be preceeded by adverse pathological changes in tissues, which have been reported in fish (Sorensen et al. 1984, Sorensen 1986, 1988, 1991).

Alternatively, the high number of deformities observed in larvae in the present study may have been due to inbreeding effects. Dowling et al. (1996) reported that, based on mitochondrial DNA diversity, razorback sucker examined from the upper Colorado River seemed to be from a small population, were closely related, and possibly derived from a limited number of females. Spawning of closely related fish (i.e., brother-sister, mother-son, father-daughter) can result in reduced growth rate, lower survival, reduced feed conversion, reduced fertility, and increased numbers of deformed fry (Moav and Wohlfarth 1996, Ryman 1970, Kincaid 1976a, 1976b, Piper et al. 1982). However, Aulstad and Kittlesen (1971) reported that the amount of deformities in inbred siblings could vary greatly between matings. They found that only one out of nine different sib groups of rainbow trout had deformities, and that deformities were found in only 4 of a total of 53 inbreeding groups.

It should be noted that eggs used in the egg study were hand selected using "normal" appearance as the criterion. Criteria for use of fish and fish eggs in laboratory studies is that they are free of disease, uniform in size and age, have good nutrition, and holding conditions (temperature, water quality, photoperiod, uncrowded, minimal handling) (ASTM 1989). The guidelines further state that organisms should be free of signs of stress, physical damage, mortality, and external parasites, and that abnormal or injured individuals not used in tests, nor should organisms have abnormal behavior such as not eating, flashing, flipping, swimming erratically, emaciated, gasping at the surface, hyperventilating, hemorrhaging, producing excessive mucus, or exhibiting abnormal color. These types of guidelines were developed primarily for use with routinely tested organisms such as rainbow trout and fathead minnow with well-known culture procedures, past successful use in testing, and ease of handling. Consequently, toxicant concentrations that cause effects in razorback sucker eggs hand-selected according to standard testing guidelines (ASTM 1989) could tend to underestimate toxicant impact in the environment where a variety of environmental and organismal conditions would occur.

Deformities have been reported in threatened or endangered fish in the Colorado River basin or reared in hatcheries. Fin deformities were reported in razorback sucker larvae reared at the Colorado Division of Wildlife's Fish Research Hatchery, Bellvue, CO, in 1993, and again during a feeding study in 1994 (Martinez 1996). Martinez (1996) concluded that the fin deformities were a result of handling stress and not from genetic or nutritional sources, because siblings that were not used in the feeding test and handled substantially less did not have the deformities. The fin deformity was not observed in larvae in the egg study or larval fish study, in the larval fish held at 24-Road, or the second reproduction study (Hamilton et al. 2001).

Severson et al. (1992) also reported deformities in razorback sucker larvae in a study to

evaluate various feeds on larvae culture. They reported deformity rates between 0 and 83% in larvae fed different diet series for 127 days posthatch. The diet that had 0% deformities in one replicate also had 23% deformities in a second replicate. Spinal deformities included displaced vertebral columns, compressed spinal cords, and displaced musculature, which they speculated might have been due to vitamin deficiency associated with cold storage of the diets.

Deformities in razorback sucker larvae produced and reared at Dexter NFH and Technology Center, Dexter, NM, are apparently a problem that needs to be addressed (H. Williamson, USFWS, personal communication), and may be related to nutritional deficiencies (R. Barrows, USFWS, personal communication to H. Williamson). On the other hand, few deformities have been noted in razorback sucker larvae produced from wild adults spawned at Willow Beach National Fish Hatchery, AZ (C. Figiel, USFWS, personal communication).

Inbreeding

The young razorback sucker adults used in the reproduction studies in the present study and in the second reproduction study in 1996-1997 (Hamilton et al. 2001) came from a single mating in 1992, and thus the spawnings in 1996 and 1997 were of brother and sister. Progeny could have exhibited inbreeding effects such as reduced growth rate, lower survival, reduced feed conversion, reduced fertility, and increased numbers of deformed fry (Moav and Wohlfarth 1966, Ryman 1970, Kincaid 1976a, 1976b, Piper et al. 1982).

In the present reproduction study, the percent viability, percent hatch, and mortality of deformed embryos were not significantly different between embryos from the young adults held at the three sites and embryos from brood stock. This lack of difference in viability, hatch, and mortality suggests that inbreeding effects, if present, may have uniformly affected these measurements. On the other hand, the range of percent hatch and percent survival in the present study were similar to those reported for razorback sucker embryos and newly hatched larvae (Inslee 1982, Hamman 1985, Muth and Ruppert 1996), which suggests inbreeding did not affect viability, hatch, and mortality beyond the normal range of observation. The percent deformities of embryos and newly hatched larvae was not significantly different among the three groups of young adults, except there were more deformed embryos from Adobe Creek adults held in site water than in reference water, thus suggesting an effect from site water exposure for Adobe Creek larvae.

LARVAL FISH STUDY

This section of the report will describe the methods, results, and discussion of the larval fish portion of the reproduction study. Also included is information derived from informal observations of razorback sucker larvae held at 24-Road.

Methods

Adult razorback sucker previously held for 9 months at either Horsethief, Adobe Creek, or North Pond and brood stock held at Horsethief were spawned on May 6 and 7, 1996. A detailed description of the spawning procedure is given in the Adult Study.

Four sources of larvae, separated by parental exposure and individual spawn, were held at

24-Road for about 4 days before being transported to the mobile laboratory for the larval fish study. The four sources of larvae were adults from Horsethief, Adobe Creek, North Pond, and brood stock that had been held at Horsethief. The brood stock larvae were used as an additional reference group of test fish.

The study was conducted for 30 days to assess survival, growth, abnormal development, and whole-body residues of selenium in larvae produced by parents held at the test sites. The study was initiated with 5-day-old larvae from three spawns from each of the four sources. After the egg study was completed, the 2-L beakers were acid washed and recalibrated at the 800-ml and 1.6-L levels for use in the larval fish study. Larvae from one spawn were impartially distributed two at a time to eight exposure vessels until there were 10 larvae per beaker. The larvae were initially held in beakers containing 800 ml of filtered (25 μm polypropylene filter bag) 24-Road water. After 4 hours, an additional 800 ml of test water was added. Fifty percent of the water (800 ml) was renewed daily.

Four exposure beakers with larvae from each of the three spawns of the four sources (4 beakers x 3 spawns x 4 sources = 48 exposure beakers) were held on each of two tables in the mobile laboratory. The beakers were arranged in three rows on each table and their position randomly assigned based on a random numbers table. One set (two beakers termed replicate A and B) of larvae from each spawn and source were exposed to one of four treatments:

(1) reference food (brine shrimp) and reference water (24-Road),
(2) reference food and site water where adults were held [Colorado River water for Horsethief adults and brood stock],
(3) site food where adults were held [except larvae from Horsethief adults and brood stock adults, which were fed zooplankton collected from a wetland located adjacent to and east of the Horsethief ponds and whose only water source was effluent from the ponds; termed Horsethief east wetland] and reference water, and
(4) site food and site water.

The reference water treatments were held on one table and the site water treatments were held on the other table. A total of 60 larvae from each of the four adult sources were exposed to each treatment (2 replicates x 3 spawns x 10 fish/beaker).

Zooplankton were collected every other day from Horsethief east wetland (HTEW), Adobe Creek, and North Pond using modified light traps (Espinosa and Clark 1972). Light traps were set overnight and the trapped zooplankton were collected the following morning. The zooplankton were transported to and stored in the mobile laboratory in 3.8-L plastic jars filled with site water. Oxygen concentrations in the jars of zooplankton held in the laboratory were supplemented by bubbling compressed air from an oil-less air compressor through air stones.

Larvae were fed either 40 zooplankters or 40 brine shrimp (*Artemia* sp.) nauplii per live fish once daily after water renewal. For the site food, about half of the zooplankton sample was sieved through a U.S. Standard Sieve #40 to separate zooplankton <0.425 mm in size for feeding test fish that day. The concentration of zooplankters (number of organisms per ml) in the feeding solutions was determined by counting the number of zooplankters in three separate 1-ml samples taken with a Hensen-Stemple pipette. The zooplankton were anesthetized with 1 ml of alcohol and counted using a stereoscope microscope at 7-30x magnification and a counting wheel (Ward's, Rochester, NY). The number of organisms in three replicate counts were averaged and the volume calculated to feed 40 organisms per live fish in each exposure beaker.

Brine shrimp cysts (*Artemia* sp., Aquarium Products, Glen Burnie, MD, U.S.A.; source

Columbia, S.A.) were hatched in reconstituted seawater at 35 g/L salinity prepared by adding Instant Ocean seasalts to deionized water according to standard methods (ASTM 1992b). Jars containing the hatching media were aerated with air from an oil-less compressor, and the jars were held in a water bath at 25°C. One-day-old nauplii of brine shrimp were enumerated and fed at the same number of organisms per fish as described above. Aquatic invertebrates and brine shrimp not used for feeding were sieved from the media with a 153 µm nylon screen, placed in Whirl-Pak bags, and stored frozen for selenium and ICP analyses. A 2-ml subsample of live zooplankton was collected from each feeding solution, placed in a small vial, and preserved in 70% ethyl alcohol. The zooplankton in these archived samples were categorized as cladoceran, copepod, or other invertebrate type using a stereoscope microscope.

Test waters for the larval fish study were collected every day from each site as grab samples using two 19-L carboys. Water was prefiltered through 25 µm polypropylene filter bags to remove particulate matter and poured into large plastic buckets prior to use in water quality analyses and water renewal in exposure vessels. This water was sampled weekly and analyzed for general water quality characteristics. During the larval fish study, water quality measurements included pH, conductivity, hardness, alkalinity, calcium, magnesium, chloride, ammonia, nitrate, nitrite, sulfate, total suspended solids, volatile solids, and fixed solids. One filtered (0.4 µm) and one unfiltered water sample was collected at 3- to 7-day intervals from waters used in the renewals and analyzed for selenium concentrations. One water sample was collected for analysis of inorganic elements by ICP.

Water renewal in the larval fish study was accomplished by siphoning the water level down to the 800-ml calibration line using a siphon held inside a glass sleeve with the submerged end covered with a polypropylene filter cloth (285 µm openings) attached with a latex band. The sleeve was used to prevent larvae from being siphoned out of the beaker and restrict the loss of zooplankton fed the previous day. The siphon was held stationary in the beaker to minimize disturbance of larvae and to decrease the likihood of siphoning out small-sized zooplankton through the filter cloth. Exposure beakers were cleaned infrequently to remove any build-up of algae or other organisms on the walls using a small brush prior to water renewal. Oxygen concentrations in exposure water were supplemented by passing compressed air from an oil-less air compressor through air stones.

The number of live fish in each beaker were recorded daily and all dead fish removed. Observations of fish behavior and the amount of uneaten, live zooplankton were recorded daily. Dissolved oxygen concentration and water temperature were measured daily in two replicates (one replicate with reference food and one with site food) of each water type (24-Road, HT, AC, or WW) where live fish were present. After the 30-day exposure period, the surviving fish were anesthetized with MS-222 (tricaine methanesulfonate) and measured for total length to nearest mm using a measurement board and weight to nearest 0.0001 g using a 4-place analytical balance. Four fish from each treatment were collected as a composite sample, placed in Whirl-Pak bags, and stored frozen until analysis of selenium concentrations by neutron activation. Six of the 60 samples collected contained one (one sample), two (two samples), or three (three samples) fish because there were insufficient larvae in these beakers after 30 days of exposure. Because of a rapid die-off of larvae in site food treatments, one fish from each replicate of the three spawns in a treatment were collected (composite of six larvae) at day 6 for North Pond larvae, day 7 for Horsethief and Adobe Creek larvae, and day 12 for brood stock larvae. Samples were placed in Whirl-Pak bags and stored frozen until selenium analysis by neutron

activation.

A checklist was maintained at the mobile laboratory during the larval fish study and each item on the checklist (i.e., lights, aeration, etc.) was checked daily to document test conditions. Temperature in exposure beakers was maintained at ambient air temperature and measured daily with a precision grade mercury thermometer. Ambient temperature in the mobile laboratory was maintained as close to 20°C as possible. Fish were exposed under flourescent lighting (one cool-white bulb and one wide-spectrum bulb in each light fixture) to a photoperiod that existed at the time of testing in Grand Junction and approximated 12 hours light: 12 hours dark.

Methods for water quality analysis, selenium analysis, ICP analysis, and statistical analysis were the same as those described in the section on the Adult Study.

Informal observations of razorback sucker larvae

Larvae that were hatched (first hatching on May 12) and held at 24-Road (first feeding May 21, 9-days-old) since spawning, but not used in the larval fish study, were combined by adult exposure from all available spawns at Horsethief, Adobe Creek, or North Pond sites. The purpose of the informal observations of these larvae was to follow their survival, growth, and selenium residues after being held under hatchery culture conditions at 24-Road. This information was used in an informal comparison to survival, growth, and residue measurements in the formal exposure study in mobile laboratory. These three groups were reduced to 1,000 individuals per site on June 12 (larvae 31 day old), and held in three separate 1.3 m-diameter tanks at 24-Road. Fish were fed at 7% of body weight initially, and then the feeding rate was gradually reduced to 4%. Larvae were fed Biokyowa (250 μm size; BioProducts, Inc, Warrenton, OR) for the first week. During the second week, fish (17-days-old) were fed a mixture of Biokyowa and a larval fish food obtained from the Bozeman Fish Technology Center (USFWS, Bozeman, MT). The Bozeman diet was fed until fish were 89 days old, then it was mixed with a locally-produced, Tilapia-based (Tilapia sp.) diet (Mesa Feed and Farm Supply, Grand Junction, CO) and fed for 1 week. From age 96 to 134 days, fish were fed the Tilapia-based diet. A sample of the Bozeman diet, but not the Biokyowa diet or Tilapia-based diet, was collected for selenium analysis.

At 36, 78, 108, and 134 days of age, three 20-fish subsamples were collected at random, anesthetized with MS-222, and measured for total length and weight. During the growth measurements, deformities were noted such as scoliosis in the dorsal, caudal, and tail areas, missing eyes, deformed opercules and snouts, and missing tails. After 134 days, the fish were sacrificed and stored in 10% buffered formalin. Larvae from the same three brood stock spawns used in the larval fish study also were measured for total length and weight at the same time as the other larvae. At 134 days of age, three composite samples of 16-20 fish were collected from Horsethief, Adobe Creek, and North Pond larvae, and five composites from brood stock larvae for analysis of selenium concentrations. A composite sample of brood stock larvae was also collected at day 190 for analysis of selenium concentrations.

Results

Water quality characteristics were consistent within water types during the 30-day larval fish study (Appendix T), but differed significantly among the four water types (24-Road, HT,

Table 23. Mean (standard error in parentheses and number of samples in brackets) water quality characteristics measured in test water collected from four stations and used in the razorback sucker larvae study. For each measure, stations with the same letter are not significantly different (P=0.05).

Measure	Station			
	HT1	AC5	WW2	24-Road
pH	8.5b (0.1) [9]	7.9a (0.1) [9]	8.5b (0.1) [9]	7.9a (0.1) [8]
Conductivity (μmhos/cm)	424ab (13) [9]	939b (59) [9]	4,810c (250) [9]	237a (25) [8]
Hardness (mg/L as $CaCO_3$)	156a (4) [9]	313b (18) [9]	1,300c (68) [9]	68a (2) [8]
Calcium (mg/L)	44b (1) [9]	76c (4) [9]	143d (5) [9]	22a (0) [8]
Magnesium (mg/L)	11a (0) [9]	31a (3) [9]	229b (13) [9]	3a (0) [8]
Alkalinity (mg/L as $CaCO_3$)	102b (2) [9]	148c (14) [9]	111b (2) [9]	58a (3) [8]
Chloride (mg/L)	24ab (1) [9]	72b (6) [9]	425c (24) [9]	12a (7) [8]
Sulfate (mg/L)	87a (4) [8]	247a (15) [8]	2,080b (110) [8]	36a (1) [8]
Un-ionized ammonia (mg/L NH_3-N)	<0.01 (0) [8]	<0.01 (0) [8]	<0.01 (0) [8]	<0.01 (0) [7]

Table 23. Continued.

	Station			
Measure	HT1	AC5	WW2	24-Road
Nitrate (mg/L NO_3-N)	0.2a (0.1) [2]	0.1a (0.1) [2]	0.1a (0) [2]	0.1a (0.1) [2]
Nitrite (mg/L NO_2-N)	0.01a (0) [3]	0.01a (0) [3]	0.01a (0.01) [3]	0.01a (0) [3]
Total suspended solids (mg/L)	14.7c (2.4) [7]	5.4ab (1.4) [7]	8.8bc (3.0) [7]	0.4a (0.1) [7]
Volatile solids (mg/L)	3.0b (0.2) [7]	1.5a (0.2) [7]	3.0b (0.6) [7]	0.6a (0.2) [7]
Fixed solids (mg/L)	11.7b (2.2) [7]	3.9a (1.3) [7]	5.7ab (2.4) [7]	0.1a (0.1) [7]

AC, WW) (Table 23). North Pond water had the highest conductivity, hardness, calcium, magnesium, chloride, and sulfate, whereas Adobe Creek water had the highest alkalinity, and Horsethief water had the highest total suspended and fixed solids. Water from 24-Road had similar characteristics to that from Horsethief, except for calcium, alkalinity, and total suspended, volatile, and fixed solids, all of which were higher at Horsethief. In the exposure beakers, the mean dissolved oxygen concentrations in the four waters ranged from 7.3 to 7.4 mg/L. The mean water temperature in the exposure beakers for the four water types ranged from 20.1 to 20.4°C.

In the larval fish study, for larvae from the three Horsethief females (HT41, HT44, HT57), selenium concentrations in eggs were 6.6, 6.2, 5.8 μg/g, egg diameters were 2.3, 2.4, 2.4 mm, and selenium concentrations in adult muscle plugs at spawning were 5.0, 3.4, 4.6 μg/g, respectively. For eggs from the three Adobe Creek females (AC19, AC20, AC28), selenium concentrations in eggs were 43.4, 54.5, 38.0 μg/g, egg diameters were 2.4, 2.3, 2.3 mm, and selenium concentrations in adult muscle plugs at spawning were 12.9, 11.7, 11.5 μg/g, respectively. For eggs from the three North Pond females (WW2, WW21, WW54), selenium concentrations in eggs were 37.2, 35.3, 34.3 μg/g, egg diameters were 2.2, 2.2, 2.2 mm, and selenium concentrations in adult muscle plugs at spawning were 14.6, 17.3, 14.1 μg/g, respectively. For larvae from three brood stock spawns, female with PIT 7F7D133914 did not have selenium measured in eggs nor egg diameters measured, but the selenium concentration in muscle plug at spawning was 13.1 μg/g; female with PIT 7F7D163436 did not have the egg diameter measured, but the selenium concentration in eggs was 7.1 μg/g and in muscle plug at spawning was 13.8 μg/g; and female with PIT 7F7F365275 did not have selenium measured in eggs, but egg diameter was 2.9 mm and the selenium concentration in muscle plug at spawning was 2.6 μg/g.

Selenium and other elements in water and zooplankton

No significant difference in selenium concentration occurred between filtered and unfiltered water samples or between waters from stations within a site (i.e., between HTi and HTo; among AC3, AC4, and AC5; between WW2 and WW3), and consequently, the data were combined in statistical analysis. Mean selenium concentrations in water during the larval fish exposure were 0.9 μg/L (range 0.7-<1.5) for Horsethief, 5.5 μg/L (range 2.3-11.0) for Adobe Creek, and 10.7 μg/L (range 7.8-13.2) for North Pond, whereas concentrations were <1 μg/L for 24-Road water (Table 24). Waterborne selenium concentrations at the three sites were significantly different from each other during the period of the larval fish exposure. Just prior to the beginning of the exposure, selenium concentrations in water were <1.6 μg/L at Horsethief, 7.4 μg/L at Adobe Creek, and 11.9 μg/L at North Pond.

Waterborne concentrations of the inorganic elements that seemed to differ (n=1 per site) between the Adobe Creek and North Pond sites included antimony, boron, calcium, potassium, lithium, magnesium, sodium, and strontium (Table 25). Concentrations of the same elements in water were also found to be significantly different between the Adobe Creek and North Pond sites in the adult study.

For the Horsethief site, zooplankton were collected from the east wetland, which received effluent from the culture ponds. Mean selenium concentrations in zooplankton during the larval fish exposure were 5.6 μg/g (range 3.5-8.1 μg/g) at Horsethief east wetland, 20 μg/g (range

Table 24. Mean (standard error in parentheses, n=2) selenium concentration (μg/L) measured by AA in water collected from various stations at three sites near Grand Junction, Colorado, and used in the razorback sucker larvae study. Waters used in the study were 24-Road, HT1, AC5, and WW2; other waters were collected to determine the variability in concentrations at the location. Selenium concentrations in water at the three locations were significantly different from each other (P=0.05).

	Day of exposure[1]						
Station	-4	3-4	8	11	18	24-25	30
24-Road	<1.6[2] (-)	<1.5 (-)	<1.5 (-)	<1.5 (-)	<1.5 (-)	<1.6 (-)	<1.5 (-)
HT1	<1.6 (-)	0.7 (-)	0.8 (-)	0.8 (-)	<1.5 (-)	<1.2 (-)	<1.5 (-)
AC3	-[3]	2.8 (0.3)	-	-	-	4.2 (0.3)	-
AC4	-	2.5 (-)	-	-	-	6.1 (0.2)	-
AC5	7.4 (0.4)	3.9 (0.1)	3.4 (0.7)	2.6 (0.1)	2.4 (0.1)	10.4 (0.3)	10.4 (0.4)
WW2	11.9 (0.2)	13.1 (0.2)	12.0 (0.1)	11.1 (0.1)	10.8 (0.6)	9.2 (1.1)	8.1 (0.2)
WW3	-	10.7 (0.7)	-	-	-	10.6 (-)	-

[1]Water samples at HT and AC were collected on days 4 and 25, and at WW on days 3 and 24.
[2]<: Below limit of detection.
[3]-: No sample.

Table 25. Concentration of inorganic elements (mg/L) measured by ICP in water collected from Adobe Creek stations on 5/21/96 (day 3) and North Pond stations on 5/20/96 (day 4) near Grand Junction, Colorado, during the razorback sucker larvae study.

Element	Station				
	AC3	AC4	AC5	WW2	WW3
Ag	0.008	0.007	<0.005[1]	<0.005	<0.005
Al	<0.03	<0.03	<0.03	<0.03	<0.03
As	<0.02	<0.02	<0.02	<0.02	<0.02
B	0.061	0.059	0.055	0.290	0.290
Ba	0.133	0.093	0.111	0.074	0.072
Be	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Bi	<0.04	<0.04	<0.04	<0.04	<0.04
Ca	85.8	74.9	67.4	175	169
Cd	<0.002	<0.002	<0.002	<0.002	<0.002
Co	0.003	0.004	0.003	<0.003	<0.003
Cr	0.009	0.008	<0.008	0.022	0.010
Cu	<0.005	<0.005	<0.005	<0.005	<0.005
Fe	0.086	0.076	0.067	0.018	0.010
K	4.4	3.2	2.4	6.4	7.0
Li	0.026	0.029	0.028	0.100	0.100
Mg	29.5	27.8	26.9	295	287
Mn	0.110	0.089	0.067	0.075	0.058
Mo	0.010	0.009	0.009	0.018	0.017
Na	76.4	75.3	71.2	846	824
Ni	0.008	<0.006	0.008	<0.006	<0.006
P	0.10	0.08	0.09	0.18	0.17
Pb	<0.007	0.042	0.032	0.010	<0.007
Sb	0.04	<0.03	<0.03	0.08	0.08
Si	1.3	0.7	0.8	0.8	0.8
Sr	0.85	0.80	0.75	1.89	1.85
Ti	<0.0009	<0.0009	<0.0009	<0.0009	<0.0009
Tl	<0.1	0.2	0.2	<0.1	<0.1
W	0.01	<0.01	<0.01	<0.01	<0.01
V	0.007	<0.005	<0.005	<0.005	<0.005
Zn	0.01	0.02	0.02	<0.01	<0.01

[1]<: Below limit of detection.

Table 26. Mean (standard error in parentheses and number of samples in brackets) selenium concentration (μg/g dry weight) measured by AA in zooplankton collected from three stations near Grand Junction, Colorado, and used in the razorback sucker larvae study. Selenium concentration in zooplankton at the three sites were significantly different from each other at each time period (P=0.05).

	Day of exposure[1]					
Station	-36 to -45	2-6	7-12	13-18	19-24	25-30
HT east wetland	6.2 (1.0) [2]	4.6 (0.2) [4]	5.2 (0.2) [3]	4.8 (0.4) [5]	5.3 (0.3) [6]	7.4 (0.2) [6]
AC3	17.3 (1.2) [2]	22.6 (0.5) [4]	20.5 (0.5) [3]	19.3 (0.5) [5]	19.3 (1.5) [6]	18.4 (0.6) [6]
WW2	29.4 (3.9) [2]	36.1 (2.0) [3]	38.6 (2.2) [3]	38.2 (2.4) [4]	41.1 (1.2) [5]	40.8 (3.1) [5]

[1]Zooplankton samples were arbitrarily grouped into 6-day intervals for this table.

13-24 µg/g) at Adobe Creek, and 39 µg/g (range 30-48 µg/g) at North Pond (Table 26). Selenium concentrations in brine shrimp averaged 2.7 µg/g (range 2.5-2.8 µg/g, n=6). Selenium concentrations in zooplankton at the three sites were significantly different from each other at each collection period during the larval fish exposure. Just prior to the beginning of the exposure, mean selenium concentrations in zooplankton were 6.2 µg/g at Horsethief east wetland, 17 µg/g at Adobe Creek, and 29 µg/g at North Pond. When the zooplankton selenium data were pooled across the sites, the correlation coefficient between selenium concentrations in zooplankton and water was $r = 0.90$ ($P<0.0001$, n=68).

None of the inorganic elements measured in zooplankton by ICP had significant differences among locations (Table 27, Appendix U). Copper concentrations in zooplankton were the highest at Horsethief, intermediate at North Pond, and lowest at Adobe Creek. The highest concentrations of aluminum, iron, and vanadium in zooplankton occurred at Adobe Creek, whereas the highest concentrations of potassium, magnesium, manganese, and sodium in zooplankton occurred at North Pond. There was no consistent pattern among sites for the concentrations of these elements in zooplankton because sometimes Horsethief had intermediate concentrations compared to Adobe Creek and North Pond (aluminum, iron, potassium, vanadium), and other times Adobe Creek had intermediate concentrations compared to Horsethief and North Pond (magnesium, manganese).

Types of zooplankton

The types of zooplankton collected from the three sites and fed to razorback sucker larvae were predominantly cladocerans and copepods (Table 28). Cladocerans predominated at Horsethief east wetland and Adobe Creek, whereas copepods were predominant part of the time at North Pond. The ratio of cladocerans to copepods ranged from 0.14 to 72 at Horsethief east wetland, 0.05 to 61 at Adobe Creek, and 0.05 to 7 at North Pond. Although not quantified, razorback sucker larvae also fed on algae, zooplankton parts, and detritus. In the laboratory, algal and periphyton growth on the walls of test beakers was readily apparent, and the walls were brushed infrequently to remove the algal buildup, which also probably was a source of nutrition and inorganic elements, such as selenium, for the larvae. Some small food organisms and particles were also present in the site water treatments, which were filtered through 25 µm filter bags.

The number of live zooplankton in exposure beakers from feeding on the previous day was grossly quantified daily prior to feeding fresh zooplankton. No live brine shrimp were observed after about 3-4 hours following feeding. Nauplii of brine shrimp were cultured in 35 g/L salinity water. Placing them in freshwater (used as the test media) probably caused an osmotic shock, which lead to their death if not consumed within a few hours after being placed in the beakers. A few dead brine shrimp were observed on the bottom of some exposure beakers. Anywhere from a few (1 to 10 organisms) to many (>20 organisms) zooplankters were observed in the beakers prior to feeding for those treatments receiving site food collected from the Horsethief east wetland, Adobe Creek, and North Pond.

Selenium in larvae

Concentrations of selenium measured in larvae between days 6 and 12 of exposure were

Table 27. Mean (standard error in parentheses and number of samples in brackets) concentration of inorganic elements (μg/g dry weight) measured by ICP in zooplankton collected from three stations between 05/22/96 and 06/14/96 near Grand Junction, Colorado. For each element, sites with lower case letters in common are not significantly different (P=0.05).

	Station		
Element	HT east wetland	AC3	WW2
Ag	<1[1]	1.0 (-) [1][2]	<1
Al	1,637 (190)ab [4]	2,145 (424)b [4]	927 (153)a [4]
As	6.0 (1.0) [2]	6.5 (0.5) [2]	7.5 (1.5) [2]
B	2.4 (0.4) [4]	2.4 (0.4) [4]	2.4 (0.9) [3]
Ba	24 (4) [4]	29 (2) [4]	17 (2) [4]
Be	0.04 (0) [2]	0.07 (0.02) [3]	0.07 (-) [1]
Bi	<5	<5	<5
Ca	10,312 (1625) [4]	15,000 (1773) [4]	12,260 (3407) [4]
Cd	<0.2	0.2 (-) [1]	0.4 (0.1) [2]
Co	0.5 (0.1) [3]	0.7 (0.1) [4]	0.7 (0.1) [4]
Cr	1.5 (0.3) [4]	3.5 (0.5) [2]	1.0 (-) [1]
Cu	21 (3)a [4]	11 (0)b [4]	15 (2)ab [4]
Fe	814 (95)ab [4]	1,430 (256)b [4]	759 (79)a [4]
K	4,075 (718)a [4]	3,075 (433)a [4]	8,875 (131)b [4]
Li	1.6 (0.2) [4]	1.7 (0.4) [4]	1.2 (0.2) [4]
Mg	1,292 (40)a [4]	1,772 (91)b [4]	1,812 (55)b [4]
Mn	52 (5)a [4]	121 (11)b [4]	201 (8)c [4]

Table 27. Continued.

Element	Station		
	HT east wetland	AC3	WW2
Mo	1.0 (-)	1.0 (0)	1.3 (0.4)
	[1]	[4]	[3]
Na	1,222 (293)a	1,210 (263)a	3,105 (144)b
	[4]	[4]	[4]
Ni	1.5 (0.5)	1.0 (-)	1.8 (0.3)
	[2]	[1]	[4]
P	12,100 (471)	11,750 (494)	11,500 (58)
	[4]	[4]	[4]
Pb	<4	5.5 (0.5)	<4
		[2]	
Sb	<9	<9	<9
Si	207 (33)	195 (39)	119 (35)
	[4]	[4]	[4]
Sr	60 (9)	101 (14)	76 (15)
	[4]	[4]	[4]
Ti	26 (5)	44 (8)	23 (2)
	[4]	[4]	[4]
Tl	<35	<35	<35
W	<3	<3	<3
V	3.0 (0.4)ab	5.3 (0.9)b	2.3 (0.3)a
	[4]	[4]	[4]
Zn	92 (5)	114 (12)	178 (47)
	[4]	[4]	[4]

[1]<: Below than limit of detection.

[2]The number of samples submitted for analysis was 4. If the number of samples shown for a site and element is less than 4; concentrations in the other samples were below the limit of detection.

Table 28. Types of zooplankton fed to razorback sucker larvae. Zooplankton were collected from three stations near near Grand Junction, Colorado.

		Zooplankton type			
Station	Day	Cladoceran	Copepod	Other	Ratio[1]
HT east	1-2	326	301	-[2]	1.08
wetland	3-4	143	118	-	1.21
	5-6	16	117	-	0.14
	7-8	41	42	-	0.98
	9-10	300	54	-	5.56
	11-12	60	62	-	0.97
	13-14	143	30	-	4.77
	15-16	162	23	-	7.04
	17-18	255	26	-	9.81
	19-20	213	13	-	16.35
	21-22	223	34	-	6.56
	23	262	21	-	12.48
	23-24	340	15	-	22.67
	25-26	230	11	-	20.91
	27-28	251	7	-	35.86
	29-30	360	5	-	72.00
	31	216	44	-	4.91
AC3	1-2[3]	56	154	1 Ostracod	0.36
	3-4	140	5	-	28.00
	5-6	183	29	-	6.31
	7-8	188	22	-	8.55
	9-10	364	6	-	60.67
	11-12	113	20	-	5.65
	13-14	192	18	-	10.67

Table 28. Continued.

Station	Day	Zooplankton type			Ratio[1]
		Cladoceran	Copepod	Other	
AC3	15-16	273	34	-	8.03
	17-18	153	25	-	6.12
	19-20	4	85	-	0.05
	21-22	91	46	-	1.98
	23	155	120	-	1.29
	23-24	96	23	-	4.17
	25-26	47	87	-	0.54
	27-28	142	31	-	4.58
	29-30	37	55	-	0.67
	31	57	67	-	0.85
WW2	1-2	16	237	-	0.07
	3-4	13	113	1 Dipteran	0.12
	5-6	84	225	1 Dipteran 2 Ostracod	0.37
	7-8	151	39	1 Dipteran	3.87
	9-10	105	15	-	7.00
	11-12	198	43	-	4.60
	13-14	267	48	-	5.56
	15-16	57	45	1 Dipteran	1.27
	17-18	111	35	-	3.17
	19-20	78	167	-	0.47
	21-22	219	78	-	2.81
	23	203	201	-	1.01
	23-24	95	133	-	0.71
	25-26	13	248	-	0.05

Table 28. Continued.

Station	Day	Zooplankton type			Ratio[1]
		Cladoceran	Copepod	Other	
WW2	27-28	7	113	-	0.06
	29-30	10	111	-	0.09
	31	95	66	-	1.44

[1]Ratio of cladoceran to copepod.
[2]No other zooplankton type identified. Other items present in the zooplankton solution fed to razorback sucker larvae included algae, zooplankton parts, and detritus.
[3]On days 1 and 2, zooplankton were collected from AC5, and on days 3 through 31 they were collected from AC3.

Table 29. Mean (standard error in parentheses and number of samples in brackets) selenium concentration (μg/g dry weight) measured by neutron activation in razorback sucker larvae. Larvae were exposed for 30 days to either reference (RF) or site (SF) food and either reference (RW) or site (SW) water. For treatments RF/RW and RF/SW at 30 days of exposure (within column), values with a lower case letter in common are not significantly different (P=0.05). For each site at 30 days of exposure (within row), treatments with upper case letters in common are not significantly different (P=0.05). At days 6, 7, and 12, n=1.

Day of exposure	Site	Treatment			
		RF/RW	RF/SW	SF/RW	SF/SW
7	HT	7.3	7.9	8.8	8.6
7	AC	32.1	32.8	69.0	70.6
6	WW	39.7	46.9	28.3	44.5
12	BS[1]	7.2	6.8	8.1	9.6
30	HT	3.3aX (0.2) [6]	5.1aY (0.3) [6]	-[2]	-
	AC	7.7bX (0.3) [6]	12.7bY (1.2) [6]	-	-
	WW	9.7bX (0.9) [6]	15.2bY (0.8) [5]	-	-
	BS	3.6aX (0.2) [6]	5.2aXY (0.3) [6]	5.4XY (0.5) [6]	6.9Y (0.6) [5]

[1]BS: Brood stock.
[2]No live fish.

similar to those measured in eggs (Table 29). After 30 days of exposure in both the reference food-reference water and reference food-site water treatments, larvae from brood stock and from Horsethief adults had less selenium than larvae from Adobe Creek and North Pond adults. However, in both reference food treatments there was no difference in selenium concentrations between larvae from brood stock and Horsethief adults or between larvae from Adobe Creek adults and North Pond adults. Insufficient larvae were available in the site food treatments to measure or compare selenium concentrations in larvae from adults held at Horsethief, Adobe Creek, and North Pond. However, significantly more selenium was found in larvae from adults held at Horsethief, Adobe Creek, and North Pond and exposed to the reference food-site water treatment than those exposed to the reference food-reference water treatment. This difference between treatments indicates that larvae accumulated selenium from exposure to water, from algae or periphyton growing on beaker walls, or from small organisms that were not removed by a filter bag during site water filtering. At 30 days of exposure, significantly more selenium was found in larvae from brood stock in the site food-site water treatment than in the reference food-reference water treatment.

Larvae from Adobe Creek adults and North Pond adults had substantially lower selenium concentrations at 30 days of exposure than at 7 days of exposure (Table 29). For example, larvae from Adobe Creek adults exposed to the reference food-reference water treatment had 32.1 μg/g selenium at day 7, which decreased to 7.7 μg/g at day 30. This decrease suggested that larvae were depurating selenium from their tissues down toward the selenium concentrations in food organisms, i.e., brine shrimp with 2.7 μg/g selenium.

Selenium concentrations in larvae from Horsethief adults and brood stock were not significantly correlated with either waterborne or zooplankton concentrations of selenium. However, based on multiple regression analysis, selenium concentrations in these larvae were significantly associated with median zooplankton selenium concentrations and the mean waterborne selenium concentrations (two variable model, r^2=0.99, P=0.0006). For the combined four groups of larvae in the reference food-reference water and reference food-site water treatments, selenium concentrations in larvae were significantly correlated with mean waterborne selenium concentrations (r=0.87, P=0.001).

Growth and condition

After 30 days of exposure in the reference food-reference water treatment, larvae from brood stock were significantly heavier and longer than larvae from adults held at the three sites (Table 30). However, based on condition factor, there were no differences among larvae from the four sources. In the reference food-site water treatment, larvae from brood stock were significantly longer than larvae from the other adults, and heavier than those from Horsethief and North Pond adults. Insufficient larvae were available from the site food treatments after 30 days to compare length and weight measurements.

Survival

Good survival occurred among razorback sucker larvae in all four groups in the reference food (brine shrimp; 2.7 μg/g)-reference water (24-Road; <1 μg/L) treatment (Figures 7 and 8, Table 31, Appendix U-X). In this treatment, survival of larvae from brood stock (89%) and

Table 30. Mean (standard error in parentheses) total length (mm), weight (g), and Fulton-type condition factor (K) of razorback sucker larvae. Larvae were exposed for 30 days to either reference (RF) or site (SF) food and either reference (RW) or site (SW) water. For each measure and treatment, values with a lower case letter in common are not significantly different (P=0.05).

		Treatment			
Measure	Site	RF/RW	RF/SW	SF/RW	SF/SW
Total length	HT	11b (0.2)	11b (0.2)	-[1]	-
	AC	11b (0.1)	11b (0.2)	12[2]	-
	WW	11b (0.2)	11b (0.2)	-	-
	BS[3]	12a (0.1)	12a (0.1)	12 (0.1)	-
Weight	HT	0.0074b (0.0003)	0.0064b (0.0001)	-	-
	AC	0.0071b (0.0001)	0.0067ab (0.0004)	0.0080[2]	-
	WW	0.0071b (0)	0.0066b (0.0004)	-	-
	BS	0.0086a (0.0004)	0.0081a (0.0001)	0.0076 (0.0003)	-
Condition factor	HT	0.48a (0.02)	0.48ab (0.02)	-	-
	AC	0.49a (0.01)	0.54b (0.01)	0.46[2]	-
	WW	0.50a (0.02)	0.52b (0.02)	-	-
	BS	0.45a (0.01)	0.43a (0.01)	0.43 (0.3)	-

[1]No live fish.
[2]n=1.
[3]BS: Brood stock.

Table 31. Percent survival of razorback sucker larvae exposed to either reference (RF) or site (SF) food and either reference (RW) or site (SW) water.

	Treatment and site															
	RF/RW				RF/SW				SF/RW				SF/SW			
Day	HT	AC	WW	BS[1]	HT	AC	WW	BS	HT	AC	WW	BS	HT	AC	WW	BS
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	97	100	100	100	100	100	100	100	100	100	100
3	100	100	97	100	100	97	100	100	100	97	98	100	100	100	93	100
4	100	100	97	100	100	97	98	100	97	92	87	100	100	88	90	100
5	100	98	97	100	100	93	95	100	92	77	57	100	92	82	73	100
6	100	98	97	100	98	88	92	100	62	67	17	98	80	80	38	100
7	100	93	93	100	98	88	84	100	38	50	0	98	56	75	6	98
8	98	91	93	100	98	86	82	100	25	38	0	97	22	51	2	97
9	98	91	91	100	98	83	80	100	15	27	0	90	14	46	2	93
10	98	91	91	100	98	81	79	100	6	19	0	88	8	24	2	87
11	98	91	91	98	98	79	75	100	2	9	0	85	2	7	2	82
12	98	90	89	98	98	77	71	97	2	6	0	82	2	4	2	77
13	98	86	89	98	96	77	69	97	2	6	0	80	0	4	2	75

Table 31. Continued.

	Treatment and site															
	RF/RW				RF/SW				SF/RW				SF/SW			
Day	HT	AC	WW	BS	HT	AC	WW	BS	HT	AC	WW	BS	HT	AC	WW	BS
14	98	86	89	98	96	77	69	97	0	2	0	78	0	2	2	70
15	98	86	88	96	96	77	69	97	0	2	0	76	0	2	2	64
16	96	86	88	95	96	77	67	95	0	2	0	74	0	2	2	63
17	91	86	88	95	96	73	67	93	0	2	0	72	0	2	2	57
18	91	86	88	95	96	71	67	89	0	2	0	68	0	2	2	55
19	91	86	88	95	93	71	60	87	0	2	0	68	0	2	2	55
20	91	86	88	93	93	71	60	87	0	2	0	66	0	2	2	55
21	91	86	88	93	93	69	60	87	0	2	0	66	0	2	2	53
22	91	86	84	93	93	69	58	87	0	2	0	64	0	2	2	53
23	91	86	82	93	93	69	58	87	0	2	0	64	0	2	2	51
24	89	86	82	91	93	69	56	86	0	2	0	64	0	2	0	49
25	89	86	80	89	93	69	56	86	0	2	0	64	0	2	0	49
26	87	86	78	89	91	69	54	86	0	2	0	64	0	2	0	49
27	87	86	78	89	91	69	54	86	0	0	0	64	0	2	0	49
28	87	84	78	89	89	68	54	86	0	0	0	62	0	2	0	49

Table 31. Continued.

	Treatment and site															
	RF/RW				RF/SW				SF/RW				SF/SW			
Day	HT	AC	WW	BS	HT	AC	WW	BS	HT	AC	WW	BS	HT	AC	WW	BS
29	87	84	76	89	89	66	54	86	0	0	0	62	0	2	0	44
30	87	84	75	89	89	66	54	86	0	0	0	62	0	2	0	42

[1]BS: Brood stock.

Figure 7. Percent survival of razorback sucker larvae from four groups of adults (●: Brood stock, ○: Horsethief Canyon State Wildlife Area, ■: Adobe Creek, and □: North Pond at Walter Walker State Wildlife Area) exposed to A: Reference food and reference water, B: Reference food and site water, C: Site food and reference water, or D: Site food and site water.

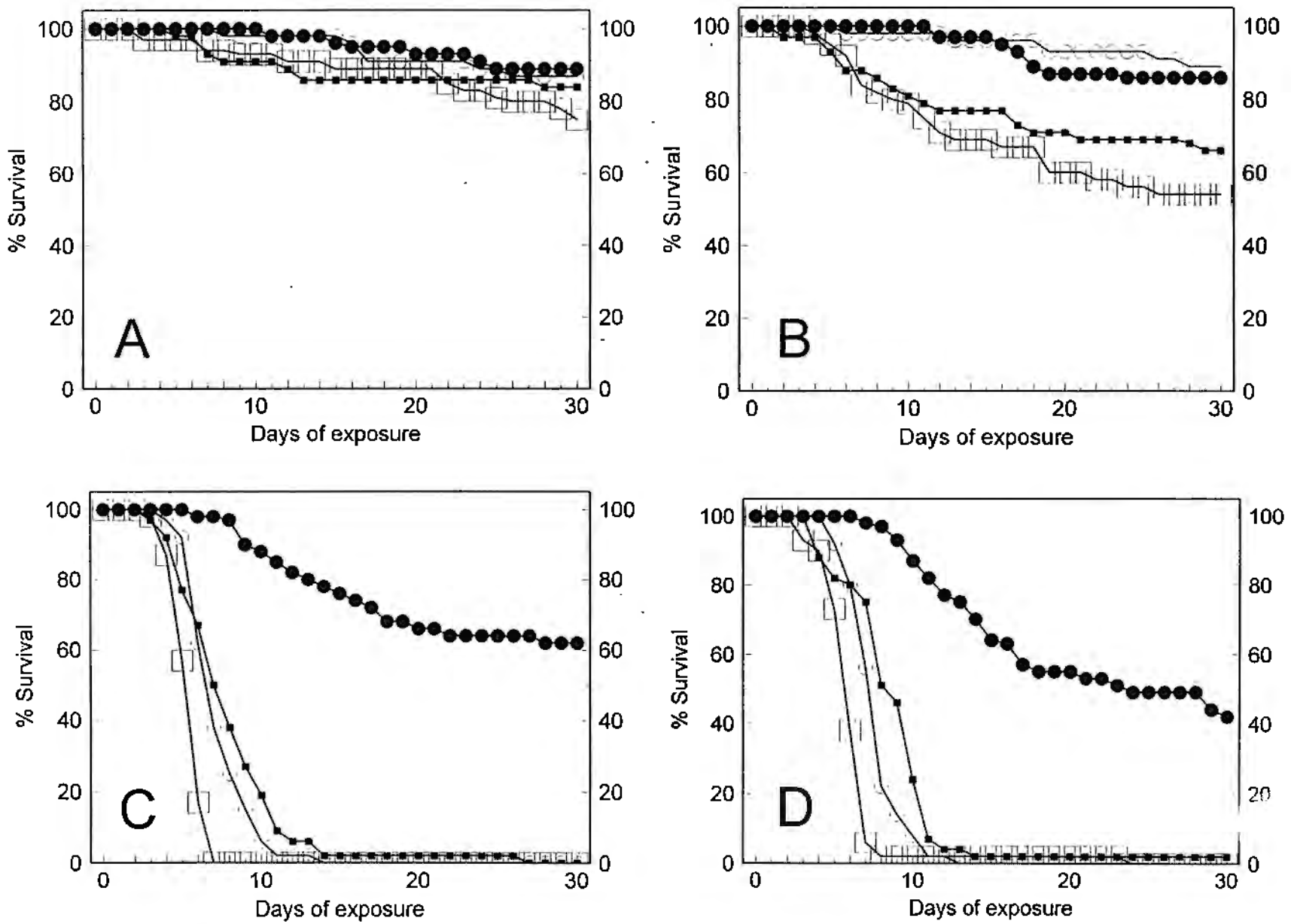
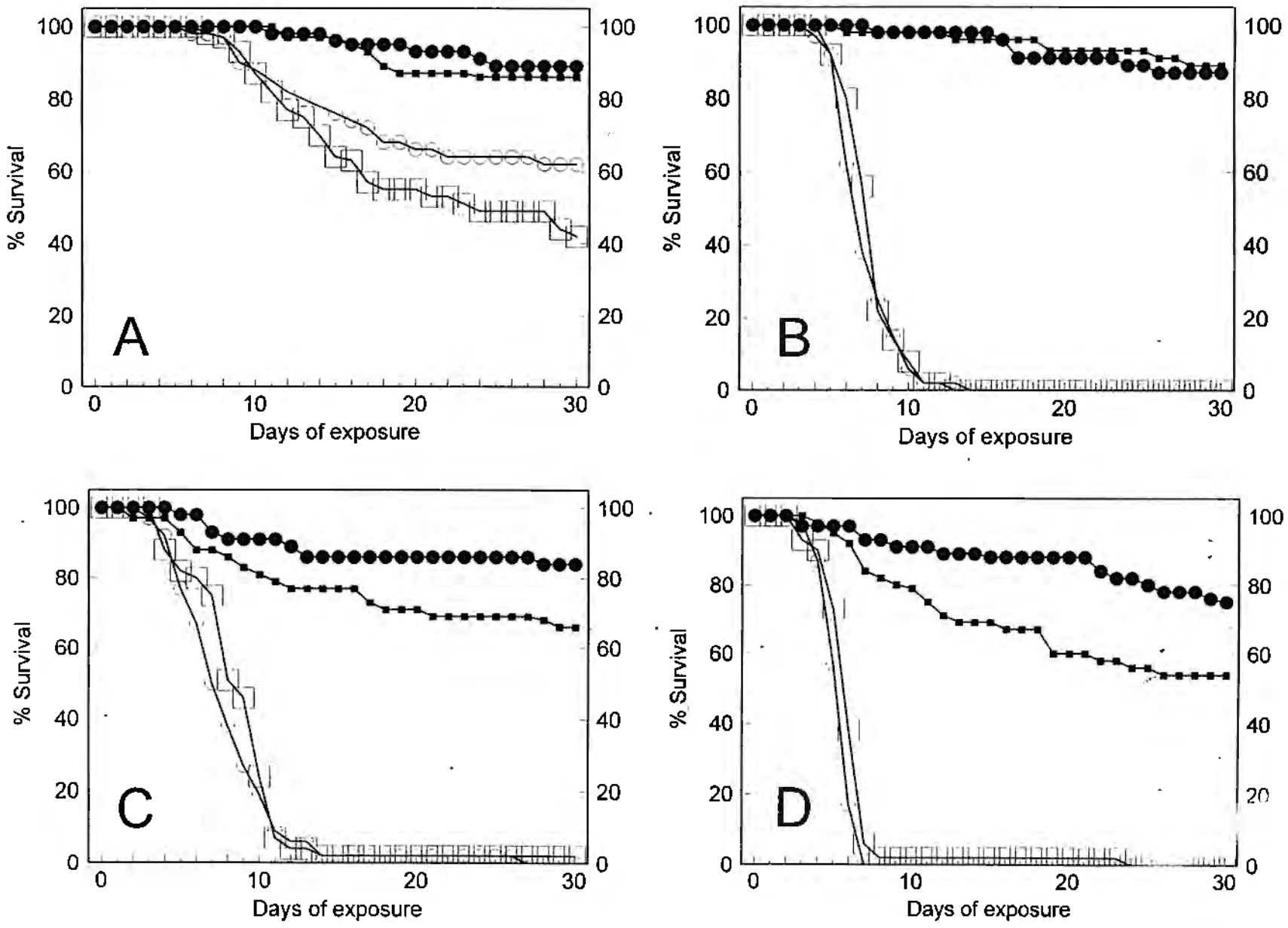

A
B
C
D
% Survival
Days of exposure
0
10
20
30
40
60
80
100

Figure 8. P :ent survival of razorback sucker larvae from four groups of adults (A: Brood :ck, B: Horsethief Canyon State Wildlife Area, C: Adobe Creek, and D: North 'ond at Walter Walker State Wildlife Area) exposed to ●: Reference food and reference water, ○: Site food and reference water, ■: Reference food and site water, or □: Site food and site water.


A
B
C
D
% Survival
Days of exposure
0
10
20
30
40
60
80
100

Horsethief adults (87%) was higher than those from Adobe Creek adults (84%) or North Pond adults (75% after 30 days of exposure (Table 31, Figure 7A). This high survival of larvae suggested that the reference food and reference water treatment was adequate to maintain razorback sucker larvae.

In the reference food-site water treatment, survival of larvae from Horsethief adults (89%) and brood stock (86%) was higher than that of larvae from Adobe Creek adults (66%) or North Pond adults (54%) after 30 days of exposure (Table 31, Figure 7B). This 21 to 28% reduction in survival of Adobe Creek and North Pond larvae exposed to site water compared to those in reference water suggested that elements in site water were toxic to larvae after 6 days of exposure when increased mortality began to occur. Selenium concentrations during the first 6 days were 3.9-7.4 μg/L in Adobe Creek site water, and 11.9-13.1 μg/L in North Pond site water (Table 24), which may have allowed selenium bioaccumulation in algae and periphyton growing on beaker walls thus leading to a dietary exposure.

After 14 days of exposure to the site food-reference water treatment, survival of larvae from brood stock (78%) was higher than those from Horsethief (0%), Adobe Creek (2%), and North Pond (0%) adults (Table 31, Figure 7C). The sharp decline in survival of larvae from young adults held at the three sites started at about 5-6 days of exposure and occurred more rapidly in larvae from North Pond adults than in those from Horsethief or Adobe Creek adults. Selenium concentrations in zooplankton during that time period were 4.6 μg/g at Horsethief east wetland, 22.6 μg/g at Adobe Creek, and 36.1 μg/g at North Pond (Table 26). Larvae from brood stock also were fed the site food diet from the Horsethief east wetland, but their survival was 62% after 30 days of exposure.

After 14 days of exposure to the site food-site water treatment, survival of larvae from brood stock (70%) was higher than those from Horsethief (0%), Adobe Creek (2%), and North Pond (2%) adults (Table 31, Figure 7D). The sharp decline in survival in larvae from young adults held at the three sites started at about 5-6 days of exposure and occurred more rapidly in larvae from North Pond adults than in those from Horsethief or Adobe Creek adults. This mortality pattern in North Pond larvae was similar to that observed in the site food-reference water treatment. Selenium concentrations in zooplankton during that time period (days 2-6) were 4.6 μg/g at Horsethief east wetland, 22.6 μg/g at Adobe Creek, and 36.1 μg/g at North Pond (Table 26). After 30 days of exposure, survival of larvae from brood stock was lower in the site food-site water treatment (42%) compared to the reference food-site water treatment (62%).

The four treatments for the larvae discussed above are grouped by adult source in Figure 7. Larvae from brood stock survived well in both reference food treatments (86-89%), but their survival was reduced in site food-reference water treatment (62%) and further reduced in the site food-site water treatment (42%) (Figure 8A). Larvae from Horsethief adults survived well in both reference food treatments (87-89%) but no larvae survived after 13 days in either site food treatment (Figure 8B). Both brood stock larvae and Horsethief larvae received the same site food, but their survival was substantially different in the site food treatment.

Larvae from Adobe Creek adults survived well in the reference food-reference water treatment (84%), but their survival was reduced in reference food-site water treatment (66%), which suggested elements in site water caused the mortality, although selenium accumulation in algae and periphyton growing on beaker walls may have contributed to the mortality (Figure 8C). Survival of these larvae in both site food treatments decreased rapidly (50-75% at 7 days), which suggested elements in site food caused the mortality. Survival of larvae from North Pond adults was 75% in the reference food-reference water treatment, but was reduced to 54% in the

reference food-site water treatment, which suggested elements in site water caused the mortality (Figure 8D), and possibly due to selenium accumulated in algae and periphyton from beaker walls. Survival of North Pond larvae in either site food treatment decreased rapidly (< 6% at 7 days), similar to that of larvae from Horsethief and Adobe Creek adults.

Prior to death, many of the larvae were swimming erratically or laying lethargic on the bottom of the exposure beaker. All larvae observed with scoliosis swam erratically. After death, many of the larvae were fed upon by copepods.

Combining the four groups of larvae, a significant negative correlation occurred between survival of larvae and selenium concentrations in larvae (r= -0.55, P=0.10), which suggested a concentration response. A significant negative correlation occurred between survival of larvae and selenium in zooplankton (r= -0.70, P=0.003), but not survival and selenium in water (r= -0.24, P=0.37). Based on multiple regression analysis and combining the four groups of larvae, survival was significantly associated with selenium in zooplankton (one-variable model, r^2=0.46, P=0.03) with this same variable plus selenium concentrations in larvae (two-variable model, r^2=0.92, P=0.001).

The predicted time-to-death of razorback sucker larvae for 50, 90, and 95% mortality are given in Table 32. At each mortality level, there were no significant differences in the predicted time-to-death among larvae in the reference food-reference water treatment. Nevertheless, Figure 9 shows a trend of highest survival in larvae from Horsethief adults and brood stock, intermediate survival in larvae from Adobe Creek adults, and lowest survival in larvae from North Pond adults. For each predicted mortality interval in the reference food-site water treatment, larvae from Horsethief adults had the longest predicted time to mortality, which was similar to larvae from brood stock, whereas larvae from North Pond adults had the shortest predicted time to mortality (Figure 9). For the site-food-water treatments, brood stock larvae had the longest predicted time to mortality, Horsethief and Adobe Creek larvae had intermediate survival times, and North Pond larvae had the shortest survival time (Table 32).

A significant decrease within each predicted mortality interval occurred in predicted time to mortality between reference food treatments and site food treatments for larvae from brood stock, Horsethief, and Adobe Creek adults (Table 32). There was a significant decrease within each predicted mortality interval in predicted time to mortality among each of the four treatments for larvae from North Pond adults. Differences in mortality of larvae from brood stock, Horsethief, and Adobe Creek adults were associated with food source, whereas for larvae from North Pond adults, differences among treatments were associated with both water and food sources. Time to mortality for North Pond larvae fed site food was longer in the site water treatment than in the reference water treatment, which suggested an antagonistic interaction between site food and site water that allowed the larvae to live slightly longer than those in the reference water treatment.

Informal observations of razorback sucker larvae

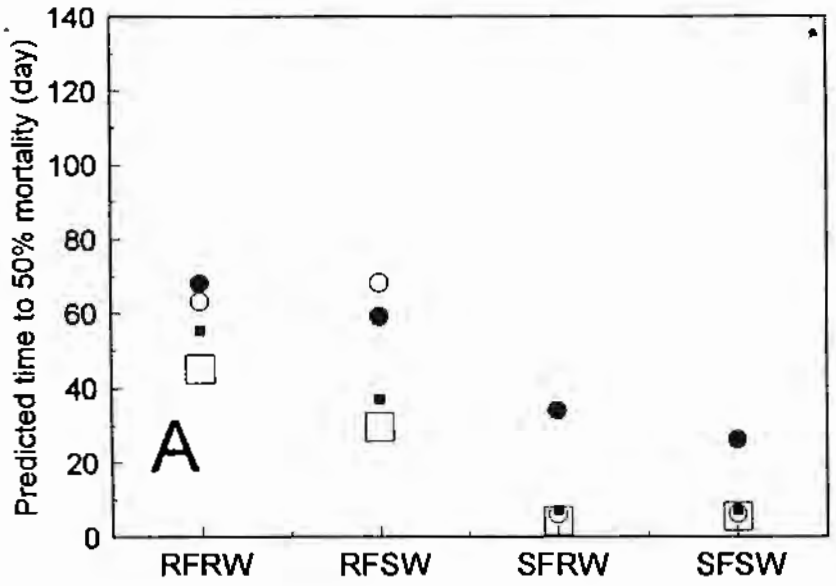
The survival of larvae cultured at 25-Road Hatchery between 31 and 134 days of age was 93% for brood stock and Horsethief larvae, 94% for Adobe Creek larvae, and 64% for North Pond larvae (Appendix Z). Part of the reduced survival of fish, especially in the North Pond larvae, may have been due to the loss of weak fish through slots in the tank drain (M. Montagne

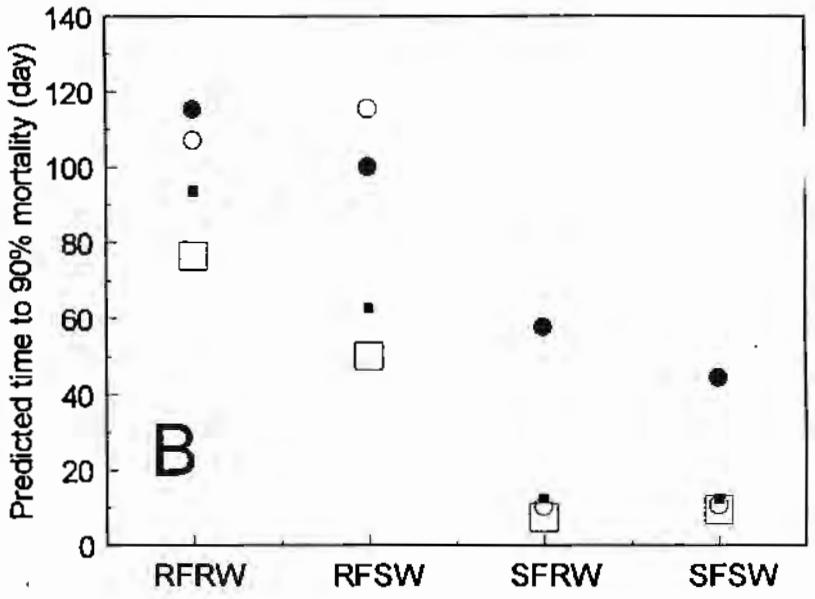
Table 32. M (95% confidence intervals in parentheses) of predicted time (days) to 50, 90, and 95% mortality of razorback sucker larvae. Larvae were exposed for 30 days in an on-site test to either reference (RF) or site (SF) food and either reference (RW) or site (SW) water. For each predicted mortality and site (within rows), values with a lower case letter in common are not significantly different (P=0.05). For each predicted mortality and treatment (within column), values with upper case letters in common are not significantly different (P=0.05). For the RF/RW treatment and each predicted mortality, there was no significant difference between locations (P=0.05).

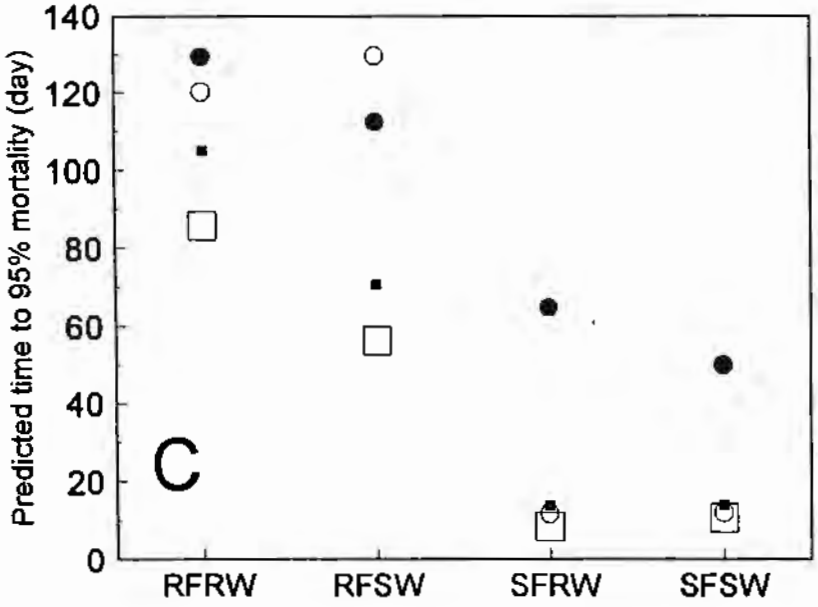
Predicted mortality	Site	Treatment			
		RF/RW	RF/SW	SF/RW	SF/SW
50%	HT	63.2aX (45.7-87.5)	68.2aX (48.0-96.9)	6.1bY (5.5-6.9)	6.3bYZ (5.7-7.1)
	AC	55.3aX (41.5-73.7)	37.1aYZ (30.4-45.2)	7.3bY (6.6-8.2)	7.3bY (6.6-8.2)
	WW	45.1aX (35.9-56.8)	29.6bZ (25.1-34.9)	4.4cZ (4.0-4.9)	5.6dZ (5.0-6.2)
	BS[1]	68.1aX (47.9-96.7)	59.1aXY (43.6-80.1)	34.0bX (28.3-40.9)	26.2bX (22.6-30.4)
90%	HT	107.0aX (77.2-148.4)	115.4aX (81.1-164.2)	10.4bY (9.3-11.6)	10.7bYZ (9.6-12.0)
	AC	93.6aX (70.1-124.8)	62.8aYZ (51.5-76.5)	12.4bY (11.1-13.9)	12.4bY (11.1-13.9)
	WW	76.4aX (60.6-96.2)	50.1bZ (42.4-59.1)	7.5cZ (6.7-8.4)	9.4dZ (8.4-10.5)
	BS	115.2aX (81.0-163.9)	100.0aXY (73.7-135.8)	57.6bX (47.9-69.2)	44.3bX (38.2-51.4)
95%	HT	120.1aX (86.6-166.6)	129.5aX (91.0-184.4)	11.7bY (10.4-13.1)	12.0bYZ (10.7-13.4)
	AC	105.0aX (78.7-140.1)	70.5aYZ (57.8-85.9)	13.9bY (12.5-15.6)	13.9bY (12.4-15.6)
	WW	85.7aX (68.0-108.1)	56.2bZ (47.6-66.4)	8.4cZ (7.5-9.4)	10.6dZ (9.5-11.8)
	BS	129.3aX (90.8-184.0)	112.3aXY (82.7-152.5)	64.6bX (53.7-77.7)	49.8bX (42.9-57.7)

[1]BS: Brood stock.

Figure 9. Mean predicted time (days) to mortality of razorback sucker larvae from four groups of adults (●: Brood stock, ○: Horsethief Canyon State Wildlife Area, ■: Adobe Creek, and □: North Pond at Walter Walker State Wildlife Area) at mortality levels: 50% (A), 90% (B), or 95% (C). Fish were exposed to reference food and reference water (RF/RW), reference food and site water (RF/SW), site food and reference water (SF/RW), or site food and site water (SF/SW).


Predicted time to 50% mortality (day)
140
120
100
80
60
40
20
0
A
RFRW
RFSW
SFRW
SFSW


Predicted time to 90% mortality (day)
140
120
100
80
60
40
20
0
B
RFRW
RFSW
SFRW
SFSW


Predicted time to 95% mortality (day)
140
120
100
80
60
40
20
0
C
RFRW
RFSW
SFRW
SFSW

and F. Pfeifer, written communication, 1999). During fish culture, feed plugged th slots in the drain pipes, and consequently, the current drains were switched to drains with slight larger slots through which an undetermined number of weak fish probably were lost. There as no note in the daily records when the slot changes occurred.

Larvae from adults held at Horsethief, Adobe Creek, and North Pond were significantly shorter than those from brood stock at 36 days of age (Table 33). Larvae from North Pond also had the lowest weight and lowest condition factor at day 36. At 78 days of age, larvae from North Pond adults were significantly smaller, and at 108 days of age significantly shorter in length than larvae from the brood stock. However, by 134 days of age, there were no significant differences in size of fish among the four groups.

Anesthetization with MS-222 at 36 days of age, as part of the procedure for measuring total length and weight of larvae, resulted in the mortality of 29 of 60 (48%) larvae sampled from North Pond adults, 19 (32%) from Horsethief adults, 6 (10%) from Adobe Creek adults, and 5 (8%) from brood stock. Typically, only 1-2 fish out of about 60 may die during the anesthetization and measurement process. Because two highly experienced personnel (K. Buhl and M. Ehlers, USGS) anesthetized and measured these fish, the mortalities seemed higher than normal. During growth sampling on day 78, there were four mortalities of Horsethief larvae, none of Adobe Creek larvae, eight of North Pond larvae, and one of brood stock larvae. On day 108, there were two mortalities of brood stock larvae, but none of Horsethief, Adobe Creek, or North Pond larvae. No mortalities occurred at day 134 sampling.

There were few deformities observed in fish at day 36 sampling. At day 78 sampling, deformities in the dorsal, caudal, and tail areas were recorded, as well as missing eyes (right, left, or both), and deformed opercules (Table 34). For the larvae from Horsethief, Adobe Creek, and North Pond adults, the total number of deformities seemed to increase over time, and seemed to differ among sites (Table 34). For example, dorsal and opercule deformities seemed most prominent in larvae from North Pond adults and brood stock. Deformed snouts seemed to be unique to larvae from North Pond adults. Caudal, dorsal, and tail deformities seemed to be the least in larvae from Adobe Creek compared to other larvae. At 134 days of age larvae from North Pond adults had 2.2 times more total deformities than those from Horsethief adults, 3.5 times more than from Adobe Creek adults, and 1.8 times more than from brood stock.

The larvae from three brood stock females were held separately, and consequently, the number of deformities were determined during growth measurements for each spawn (Table 34). There seemed to be an inconsistent pattern of deformities in that dorsal deformities were low and opercule deformities were high for two brood stock (PIT 3436 and PIT 5275). Conversely, dorsal deformities were high and opercule deformities were low in the other brood stock (PIT 3914). This inconsistent pattern was further confounded in that two brood stock had elevated selenium in muscle plugs (PIT 3436 had 13.8 μg/g and PIT 3914 had 13.1 μg/g), whereas the third brood stock (PIT 5275) had low selenium (2.6 μg/g). The brood stock with the highest selenium in muscle plug (PIT 3436) also had 7.1 μg/g in eggs (no selenium measures were made in eggs from PIT 3914 or PIT 5275).

The number of deformities recorded on growth data sheets may reflect observation bias in that (1) deformed larvae might have been easier to collect for the growth sampling, (2) the skill of the observers in identifying abnormalities might have improved at later sampling times, and (3) the abnormalities were more obvious in older, larger larvae than in younger, smaller larvae. Nevertheless, the deformed snouts observed in larvae from North Pond adults might be a

Table 33. ' ı (standard error in parentheses) total length (mm), weight (g), and Fulton-type ıdition factor (K) of razorback sucker larvae from adults held at three sites near and Junction, Colorado, and held at 24-Road for 134 days post hatch. Larvae were ɛld in hatchery water and fed a commercial fish food. For each measure and time period, values with lower case letters in common are not significantly different (P=0.05).

		Age (days)			
Measure	Site	36	78	108	134
Total length	HT	14b (0.4)	34a (0.4)	54ab (2)	64 (2)
	AC	14b (0.2)	31a (0.2)	54ab (1)	65 (2)
	WW	12b (0.1)	26b (1)	48b (1)	63 (2)
	BS[1]	17a (0.6)	35a (1)	56a (1)	68 (2)
Weight	HT	0.018ab (0.002)	0.45ab (0.02)	2.17 (0.15)	3.40 (0.18)
	AC	0.019ab (0.001)	0.35bc (0.01)	2.02 (0.15)	3.40 (0.36)
	WW	0.007b (0)	0.21c (0.03)	1.92 (0.10)	3.75 (0.20)
	BS	0.034a (0.004)	0.51a (0.04)	2.18 (0.17)	3.68 (0.37)
Condition factor	HT	0.62a (0.03)	1.03 (0.02)	1.19ab (0.13)	1.12 (0.02)
	AC	0.63a (0.01)	1.04 (0.05)	1.20ab (0.02)	1.13 (0.01)
	WW	0.40b (0.01)	1.01 (0.02)	1.38b (0.03)	1.22 (0.04)
	BS	0.66a (0.04)	1.00 (0.02)	1.13a (0.03)	1.06 (0.04)

[1]BS: Brood stock.

Table 34. Percent deformities in razorback sucker larvae from adults held at three sites near Grand Junction, Colorado, and held at 24-Road for 134 days post hatch. The deformities in larvae from three spawns of brood stock (identified by the last four PIT numbers) are summarized in the BS section, but given at the bottom of table for individual spawns (n=60 for HT, AC, and WW; n=120 for brood stock (BS); and n=40 for individual BS females).

Site	Age (days)	Caudal deformity	Dorsal deformity	Tail Deformity	Total scoliosis	Eye deformity	Opercule deformity	Deformed snout	Total deformities
HT	78	3	2	2	7	5	3	0	15
	108	0	0	12	12	8	7	0	27
	134	7	0	5	12	17	18	0	43
AC	78	2	0	0	2	12	2	0	15
	108	0	2	0	2	8	5	0	13
	134	0	2	2	5	12	13	2	27
WW	78	0	15	0	17	7	8	0	30
	108	0	8	0	8	13	47	0	60
	134	10	12	20	43	8	82	53	95
BS	78	3	11	0	14	1	28	0	42
	108	0	8	0	9	0	20	0	27
	134	3	11	0	13	3	39	8	52
BS (3436)	78	5	2	0	8	0	55	0	57
	108	0	5	0	5	0	22	0	25
	134	3	8	0	10	3	62	5	72
BS (3914)	78	2	22	0	25	0	2	0	27
	108	0	18	0	18	0	3	0	20
	134	3	15	0	18	3	3	3	22
BS (5275)	78	2	8	0	10	2	27	0	40
	108	0	3	0	3	0	35	0	37
	134	5	10	0	12	3	52	18	60

delayed eff stress that did not appear until a certain stage of development was reached.

In on, it was noted by various observers that larvae from North Pond adults did not school i tank as did larvae from the other two groups or brood stock, nor did they exhibit a fright r se when a person approached the tank (R. Krueger [three observations], USFWS; B. Osm n [one observation], USFWS; P. von Guerard [one observation], USGS; D. Butler [on rvation], USGS; written communications, 1999). One author (K. Holley) noted that lar from Adobe Creek adults had a predominance of missing eyes and darker coloration, and larvae from North Pond adults had blunt snouts, bent or humped backs, and bent caudal regions, whereas larvae from Horsethief adults seemed similar in behavior to those from brood stock and both groups looked "normal." In contrast, hatchery personnel routinely cultured the larvae on a daily basis, along with many tanks of brood stock larvae, and did not record any observational data on different schooling behavior among groups (M. Montagne and F. Pfeifer, USFWS, written communication). One observer visited the hatchery intermittently to observe the larvae in various tanks and noted that the North Pond fish swam at random and did not school as larvae in other tanks (K. Holley [12-15 observations], USFWS, written communication).

Mean selenium concentrations in larvae from all adult sources after 134 days of culturing at 24-Road ranged from 0.94 to 0.98 μg/g (Table 35). One sample of brood stock larvae sampled after 190 days of culture at the hatchery contained 0.96 μg/g of selenium. The Bozeman diet, which was fed to larvae age 9 to 96 days old, contained 1.95 μg/g selenium (triplicate sample preparation and analysis).

Discussion

Razorback sucker larvae used in the present study were 5-day-old at the start of the exposure, which seemed to be the appropriate age for initiating a dietary and waterborne test. Tyus and Severson (1990) started their feeding studies with razorback sucker larvae at 5-days posthatch, and Papoulias and Minckley (1992) started their feeding study with razorback sucker larvae at 7-days posthatch. Papoulias and Minckley (1992) reported that within 1 day of stocking (age 8 days posthatch) larvae had phytoplankton, diatoms, and detritus in their stomachs, and that the following day (age 9 days posthatch) these same food items plus rotifers, nauplii, cladocerans, invertebrate eggs, and chironomids were found in larvae stomachs. Minckley and Gustafson (1982) reported that 9 day-old razorback sucker larvae fed on ground aquarium fish food (Tetramin). Toney (1974) reported that razorback sucker larvae 6 days posthatch swam to the surface and fed on baby food, i.e., strained beef liver. In the studies by Papoulias and Minckley (1992) and Minckley and Gustafson (1982) it is possible that razorback sucker larvae would have started feeding earlier if the studies had been started at an earlier age or food was presented to the larvae at an earlier age.

Water quality

Dissolved oxygen and water temperature during the test were in the acceptable range of values for tests with fish (Weber et al. 1989). Water quality characteristics differed significantly among the four test waters, but those differences probably did not contribute to observed mortality of larval fish in the study, especially for waters from 24-Road, Horsethief, and Adobe Creek, which were all close to conditions in various segments of the Colorado River (e.g., WW1

Table 35. Mean (standard error in parentheses and number of samples in brackets) nium concentration (μg/g dry weight) measured by AA in juvenile razorback su r from adults held at three sites near Grand Junction, Colorado, and held at 24-Road for 134 days post hatch.

Site	Selenium
HT	0.94
	(0.03)
	[3]
AC	0.94
	(0.03)
	[3]
WW	0.98
	(0.02)
	[3]
BS[1]	0.98
	(0.03)
	[5]

[1]BS: Brood stock.

and AC1, Appendix B). Razorback sucker are routinely spawned and cultured at Dexter NFH and Technology Center, Dexter, NM, and water quality characteristic there were 2,350 mg/L as $CaCO_3$ hardness, 3,710 μmhos/cm conductivity, and 3,570 mg/L total dissolved solids (R. Hamman, USFWS, personal communication). Pimentel and Bulkley (1983) reported that the total dissolved solids preference (measured as conductivity) of Colorado pikeminnow, bonytail, and humpback chub ranged from 3,610 to 5,106 μmhos/cm. Considering the culture activities at Dexter NFH, and assuming razorback sucker have a similar preference to conductivity as the three endangered fish tested by Pimentel and Bulkley (1983) in the Colorado River basin, then the water quality from Horsethief and Adobe Creek probably would not adversely affect larvae in the present study. The information in Pimentel and Bulkley (1983) was taken from Bulkley et al. (1981), who used razorback sucker juveniles in other tests (temperature preference, swimming tests, and blood analysis), but there was no mention of why razorback sucker were not used in the total dissolved solids testing.

Concentrations of conductivity or salinity were elevated in North Pond water, but it is unknown what concentrations are stressful to the razorback sucker larvae. Nelson and Flickinger (1992) reported that the 96-hour LC50 for salinity to Colorado pikeminnow ranged from 11.8 to 14.7 g/L. The maximum salinity at station WW8 or WW8b was 2.0 g/L and the associated conductivity was 17,020 μmhos/cm during the 1995-1997 period when several fish species including Colorado pikeminnow were collected from this area (Mourning 1995, Lloyd 1996, Scheer 1997). In the present study with razorback sucker larvae, conductivity of test water was 24,060 μmhos/cm, which calculates to 2.8 g/L salinity based on the salinity/conductivity relation at WW8b. If razorback sucker have a similar sensitivity to salinity as Colorado pikeminnow, then stress due to elevated conductivity in the treatments with water from North Pond would not be expected.

Selenium and other elements in water

Waterborne concentrations of inorganic elements at Horsethief were not elevated sufficiently to have caused direct toxicity from waterborne exposure based on the results of studies with other fish. Waterborne selenium concentrations that cause direct toxic effects generally have to be in the 47 to >100 μg/L range (Goettl and Davies 1977, Hodson et al. 1980, Hamilton et al. 1986, Hunn et al. 1987). However, Woock et al. (1987) has reported that low (relative to chronic waterborne toxicity thresholds) waterborne selenium exposure to 10 μg/L in addition to dietary selenium exposure (13 μg/g) can increase mortality and the incidence of deformities in fish above that present in dietary only exposures.

This scenario may have occurred in the present study. Exposure of razorback sucker larvae from Adobe Creek and North Pond adults to site water (and reference food) caused increased mortality compared to the reference water (and reference food) treatment. This increased mortality in the site water treatment compared to the reference water treatment suggested that some component of the site water, either water quality characteristics or inorganic elements contributed to the increased mortality. In the exposures with Adobe Creek larvae exposed to the Adobe Creek water, the site water had water quality characteristics (e.g., hardness, alkalinity) that were very similar to Colorado River water, which suggested that the water quality characteristics were probably acceptable to the larvae. The only inorganic element in the Adobe Creek water that was elevated to a concentration of concern was selenium, which

averaged 5.5 µg/L.

There was a greater magnitude of difference in mortality in North Pond larvae between reference water and site water treatments (Figure 8D) than observed in Adobe Creek larvae exposed to Adobe Creek water or reference water (Figure 8C), suggesting there was an incremental increase in a stressor. Although there was a difference in water quality characteristics (conductivity, hardness, calcium, magnesium, alkalinity, chloride, sulfate) between North Pond water and Adobe Creek water, it seems unlikely that the change in water quality would have caused the incremental increase in mortality. North Pond water had water quality characteristics (i.e., hardness, conductivity) that were lower than characteristics reported to cause adverse effects in Colorado pikeminnow (Nelson and Flickinger 1992). Consequently, water quality characteristics of North Pond water were probably not harmful to the larvae. The only inorganic element in North Pond water that was elevated to a concentration of concern was selenium, which averaged 10.7 µg/L -- an incremental increase of two-fold higher than that in Adobe Creek site water. The selenium concentration in North Pond water was similar to that used by Woock et al. (1987), who reported an increase in mortality and deformities in larval bluegill over that from dietary selenium exposure alone.

The elevated hardness at Adobe Creek and North Pond water treatments probably would have reduced the toxicity of some elements known to be affected by hardness such as cadmium, chromium III, copper, lead, nickel, silver, and zinc (USEPA 1998, 1999). Selenium toxicity, however, is minimally affected by changes in hardness or salinity (Palawski et al. 1985, Hamilton and Buhl 1990, USEPA 1998, 1999).

Selenium concentrations at Adobe Creek, 4 days before the larval fish study was started and during the last 5 days, and at North Pond during the 30-day period, exceeded the USEPA criterion of 5 µg/L for the protection of aquatic life (USEPA 1987). This criterion was based on bioaccumulation of selenium through the food chain, and the resulting dietary selenium toxicity. The general consensus is that dietary exposure to selenium is more toxic to fish than waterborne exposure, and that waterborne concentrations of selenium between 2 and 5 µg/L can cause bioaccumulation of selenium in the food chain to toxic concentrations (Maier and Knight 1994, Lemly 1996b, Skorupa 1998, Hamilton and Lemly 1999). However, in natural aquatic situations the two exposure routes are inseparable. The selenium concentrations in water at the three sites in the present study were elevated sufficiently to allow selenium to be bioaccumulated to concentrations above the dietary toxic threshold. This accumulation from water to algae and periphyton growing on the exposure beaker walls probably occurred, which in turn may have contributed to the dietary selenium exposure. This scenario could lead to the possibly incorrect impression that low waterborne selenium exposure (5.5 µg/L in Adobe Creek water and 10.7 µg/L in North Pond water) contributed directly to the increased mortality observed in the site water treatments compared to reference water treatments.

Selenium and other elements in zooplankton

The selenium concentrations in zooplankton in the present study, including zooplankton collected from Horsethief east wetland (4.6 to 7.4 µg/g), exceeded the dietary toxicity threshold of 3 µg/g proposed by Lemly (1993a, 1996b) and Maier and Knight (1994) based on their review of several laboratory and field studies. This threshold for selenium-sensitive fish species was similar to the dietary toxic threshold for birds (3-8 µg/g based on reproductive impairment) and

mammals (3 μg/g based on reduced longevity) (USDOI 1998). As early as 1980, Hilton et al. (1980) speculated that selenium in the diet in excess of 3 μg/g might be toxic to rainbow trout. They also reported that rainbow trout needed dietary selenium concentrations between 0.15 and 0.38 μg/g to maintain maximal plasma glutathione peroxidase activity (enzyme important in the oxidative stress defense system of animals), and homeostasis was maintained up to 1.25 μg/g in the diet. Sharma and Singh (1984) described selenium as a paradox because it is essential in the diet of animals at about 0.1 μg/g, but toxic at >1 μg/g. Lakin (1973) reported that dietary selenium in animals must meet a minimal concentration of 0.04 μg/g, was beneficial up to 0.1 μg/g, but was toxic above 4 μg/g. These three reports suggest that the difference between essential concentrations and toxic concentrations can be as little as 10 fold.

The high copper concentrations in zooplankton from Horsethief east wetland match the elevated copper concentrations in sediments from Horsethief ponds, which were the water source for the wetland. In the present study, copper concentrations in zooplankton (11-21 μg/g) probably did not contribute to toxic effects in razorback sucker larvae because they were about 32 times lower than those reported by Lanno et al. (1985) to be toxic to 12-g rainbow trout exposed to a copper-supplemented commercial diet containing 665 μg/g copper, or about 17 times lower than those reported by Mount et al. (1994) to be toxic to swim-up rainbow trout fed copper-exposed brine shrimp containing >350 μg/g copper.

Vanadium was not as elevated in zooplankton in the present study (2.3-5.3 μg/g) as in a study at Ouray NWR, UT, where vanadium was suggested as potentially contributing to the toxicity to razorback sucker larvae fed zooplankton collected from Sheppard Pond 3 (8.4 μg/g vanadium) and North Roadside Pond (9.5 μg/g vanadium) (Hamilton et al. 1996). No toxic threshold has been proposed for vanadium, but Hilton and Bettger (1988) reported that vanadium toxicity to juvenile rainbow trout was between 1.2 μg/g in their control treatment and 10 μg/g, which was their next higher treatment concentration.

The concentrations of iron, magnesium, manganese, potassium, and sodium in zooplankton in the present study were similar to concentrations reported in *Daphnia* sp. and nauplii of brine shrimp used in fish culture (Watanabe et al. 1983), and therefore probably did not cause toxic effects in razorback sucker larvae. The aluminum concentration in zooplankton in the present study was similar to background concentrations in aquatic invertebrates (Wren and Stephenson 1991), and therefore probably did not cause toxic effects.

Selenium was the only inorganic element in zooplankton from Adobe Creek and North Pond in the present study that exceeded concentrations reported to be toxic to fish. Selenium in zooplankton from Horsethief east wetland also exceeded the proposed selenium dietary toxic threshold for selenium-sensitive fish species. Selenium concentrations of ≥4.6 μg/g in food organisms from Horsethief east wetland adversely affected survival of razorback sucker larvae after 5-6 days of exposure. This same selenium concentration of ≥4.6 μg/g also adversely affected survival of razorback sucker larvae after 6-8 days of exposure in the second reproduction study conducted a year later (Hamilton et al. 2001).

Brine shrimp

In the present study, fish that received the reference food treatment were fed 1-day-old nauplii of brine shrimp (*Artemia* sp.). A systematic survey of eight strains of *Artemia* by the

International Study on *Artemia* (ISA) reported that the source of the *Artemia* can have a major influence on the suitability for fish culture (Leger et al. 1986). They concluded that the reasons for the difference between a poor-quality and a variable-quality *Artemia* strain were complex, and due in part to a lack of knowledge of the nutritional requirements of the test fish species being cultured in the ISA study. The analysis of the ISA *Artemia* strains for amino acids, inorganic elements, pesticides, caloric content, and carotenoids yielded no data that could be related to the test fish species growth and survival during culture testing. Leger et al. (1986) acknowledged that *Atremia* could not be used as a complete substitute for natural zooplankton or other food organisms, which have meet with limited success.

Brine shrimp used in the present study contained about 2.7 μg/g selenium, which was close the proposed dietary threshold of 3 μg/g. This selenium concentration apparently was not toxic to the razorback sucker larvae because no abnormal mortality and altered growth were observed. However, that does not necessarily mean that long-term feeding of fish at that selenium concentration is safe.

It might be possible that long-term feeding of brine shrimp with 2.7 μg/g of selenium could be toxic. Most laboratory studies are too short in duration to determine the adverse effects of long-term (>12 months) exposures on fish. We are not aware of any studies conducted of a long-term period (>1 year) where fish were exposed to dietary selenium at low concentrations (2-4 μg/g).

Selenium concentrations in brine shrimp used in the present study seemed to be elevated compared to other studies. Analysis of brine shrimp (Aquarium Products, Glen Burnie, MD, source Columbia, S.A.) used in culture at the Yankton FRS had selenium concentrations of 3.0 μg/g in 1992 (reported as wet weight, converted to dry weight assuming 88.4% moisture measured in 1996), 2.4 μg/g in 1993 (reported as wet weight, converted to dry weight assuming 88.4% moisture), and 2.7 μg/g in 1996 (present study). Coyle et al. (1993) also used brine shrimp from Aquarium Products and reported selenium concentrations of 2.7 μg/g. Olney et al. (1980) reported that nauplii contained selenium concentrations of 1.0 μg/g from Italy, 2.1 μg/g from Utah, and 0.8 μg/g from San Pablo Bay, CA, and below detection from Brazil. Petrucci et al. (1995) reported that adult brine shrimp and nauplii from Italy contained selenium concentrations of 0.4-1.7 μg/g. Cowgill et al. (1987) reported that cysts contained 0.6 μg/g from Brazil, S.A., 1.7 μg/g from Columbia, S.A., and 0.2-2.0 μg/g from San Francisco Bay, CA. Interestingly, cysts in six cans from the same lot of brine shrimp from San Francisco Bay had a 10-fold variation in selenium concentration (0.19, 0.43, 0.48, 0.90, 1.20, 1.96 μg/g), which the authors concluded indicated the actual geographic location of the collections were different. We do not know why brine shrimp from Columbia, S.A., seem to have higher selenium concentrations than brine shrimp from other locations.

Although the concentrations of inorganic elements in brine shrimp were not measured in the present study, they were measured in the second reproduction study with razorback sucker (Hamilton et al. 2001). In that study, concentrations of elements in brine shrimp were similar to concentrations of cobalt, chromium, copper, iron, manganese, molybdenum, nickel, vanadium and zinc in brine shrimp nauplii reported by Cowgill et al. (1987) (same source of cysts as in present study: Columbia, S.A.). Olney et al. (1980) and Petrucci et al (1995) also reported somewhat similar concentrations of inorganic elements in brine shrimp nauplii from other sources such as Australia, Brazil, Italy, California, and Utah.

Selenium interacts with several inorganic elements in fish, birds, and mammals (Diplock

1976, Whanger 1981, Marier and Jaworski 1983, Sorensen 1991). These interactions can be additive, antagonistic, or synergistic, and in some cases the interaction is reversed, i.e., antagonistic changed to synergism. In general, selenium toxicity is alleviated by antimony, arsenic, bismuth, cadmium, copper, germanium, lead, mercury, silver, tellurium, tin, and tungsten (Diplock 1976, Levander 1977, Howell and Hill 1978, Whanger 1981, Marier and Jaworski 1983), whereas chromium, cobalt, fluorine, molybdenum, nickel, tellurium, uranium, vanadium, and zinc apparently have no effect on selenium toxicity (Hill 1975, Ewan 1978).

Of the elements measured by ICP in nauplii of brine shrimp in the second reproduction study (Hamilton et al. 2001), arsenic and boron concentrations were elevated compared to concentrations in zooplankton, whereas concentrations of aluminum, barium, iron, manganese, silicon, strontium, titanium, and vanadium were lower than in zooplankton. The possible effects of higher concentrations of boron or lower concentrations of aluminum, barium, iron, manganese, silicon, strontium, titanium, and vanadium in brine shrimp compared zooplankton cannot be discounted, but the available literature strongly suggests that arsenic was a factor.

The arsenic concentration in brine shrimp nauplii in the second reproduction study was 24 μg/g (Hamilton et al. 2001). Arsenic concentrations in brine shrimp nauplii varied widely between sources of brine shrimp cysts. Cowgill et al. (1987) reported 9.7 μg/g in Brazilian brine shrimp, 11.0-19.5 μg/g in San Franciscan brine shrimp, and 15.7 μg/g in Columbian brine shrimp, whereas Petrucci et al. (1995) reported 0.9-3.1 μg/g in Italian brine shrimp.

Arsenic concentrations in brine shrimp nauplii in the second reproduction study were not elevated sufficiently to cause dietary toxicity (Cockell et al. 1991), but may have ameliorated the toxic stress of dietary selenium. Arsenic compounds have been reported to protect against the toxicity of a variety of forms of selenium including selenite, selenocystine, and selenomethionine (Levander 1977). The protective effect of arsenic against selenium toxicity has been observed in rats, dogs, swine, cattle, and birds (Levander 1977). In general, arsenic exposure in water or diet protects against dietary selenium toxicity (Moxon 1938, Dubois et al. 1940, Klug et al. 1949, 1950, Levander and Argrett 1969, Thapar et al. 1969, Howell and Hill 1978, Hoffman et al. 1992), but combined arsenic and selenium water borne exposure does not (Cabe et al. 1979, Frost 1981).

Dubois et al. (1940) and Klug et al. (1949) reported that the toxicity of selenite, selenocystine, selenomethionine, and seleniferous grain was reduced in rats by exposure to arsenic as either arsenate or arsenite, but not as arsenic sulfide. Klug et al. (1950) reported that selenium residues increased in liver (28%), kidney (141%), and muscle (52%) in rats exposed for 12 weeks to arsenic in water and selenium in the diet, compared to exposure to only selenium in the diet. Klug et al. (1950) also reported that arsenic protected against selenium-induced mortality, reduced growth, and reduced feeding, and concluded that arsenic counteracts selenium toxicity in some way other than increasing elimination. Howell and Hill (1978) also reported increased selenium residues in liver of chicks exposed to dietary selenium and either arsenic, tin, or tellurium compared to selenium exposure alone, and the interaction of these elements with selenium reduced selenium toxicity compared to selenium alone exposures. Levander and Argrett (1969) also reported that arsenic protected against selenosis in rats, and that selenium residues were increased in carcass compared to animals in the selenium alone exposure. Others have concluded that arsenic exposure increased the excretion of selenium in bile in short-term (1-10 hours) injection experiments (Diplock 1976, Levander 1977, Whanger 1981, Marier and Jaworski 1983). In a reciprocal manner, selenium has been reported to reduce arsenic-induced

teratogenic deformities in hamsters (Holmberg and Ferm 1969).

Selenium residues in razorback sucker larvae from Horsethief or brood stock adults after 7-12 days of exposure to the reference food (brine shrimp) treatment and reference water (24-Road) treatment were elevated at 7.2-7.3 μg/g. Similarly, selenium residues in razorback sucker larvae from Horsethief or brood stock adults after 7-12 days of exposure in the reference food treatment and the Horsethief site water treatment were elevated at 6.8-7.9 μg/g. Accordingly, survival of larvae was very similar between the same food treatments (but with the different water treatments): 98-100%. Similar selenium residues in razorback sucker larvae from Horsethief or brood stock adults were present at 30 days of exposure: 3.3-3.6 μg/g in the reference food and reference water treatment and 5.1-5.2 μg/g in the reference food and site water treatment. Accordingly, survival was very similar between the food treatments (but with the different water treatments): 86-89%. This same scenario occurred in the second reproduction study with razorback sucker larvae (Hamilton et al. 2001).

The similarity in survival at 7-12 days of exposure was due to the use of the same reference food (brine shrimp). Nevertheless, selenium concentration in brine shrimp (2.7 μg/g) was near the selenium dietary toxic threshold (3 μg/g; Maier and Knight, Lemly 1996b), and whole-body residues were above the whole-body adverse effect threshold (4-5 μg/g based on Hilton et al. 1980, Hamilton et al. 1986, Hunn et al. 1987, Ogle and Knight 1989, Hamilton and Wiedmeyer 1990, Hamilton et al. 1990, Cleveland et al. 1993, Lemly 1993b, Hamilton 2001). Considering that the whole-body selenium residues were elevated, selenium concentrations in food were relatively close to the selenium dietary toxicity threshold, arsenic concentrations were elevated in brine shrimp, and survival was good suggests that the selenium residue in larvae fed reference food (brine shrimp) was somehow inactivated from having a toxic effect similar to the counteraction of selenium toxicity by arsenic reported by others (Klug et al. 1950, Levander and Argrett 1969, Howell and Hill 1978).

The same counteraction of selenium toxicity by arsenic probably occurred at day 30 in larvae from Horsethief, Adobe Creek, North Pond, and brood stock fed brine shrimp and held in 24-Road water. Survival of larvae was relatively high in the brine shrimp treatment (75-89%) compared to other food treatments (0-62%), yet whole-body residues were elevated (up to 9.7 μg/g, Table 29). Nevertheless, survival followed a concentration response: lowest survival (75%) was in North Pond larvae with the highest selenium residue (9.7 μg/g), intermediate (84%) in Adobe Creek larvae with the intermediate selenium residue (7.7 μg/g), and highest in Horsethief and brood stock larvae (87-89%) with the lowest selenium residues (3.3-3.6 μg/g).

In the absence of the protective effect of elevated arsenic (6.0 μg/g in HTEW zooplankton), a different survival pattern was present in the Horsethief site food treatments with either reference water (24-Road) or site water (Horsethief). Selenium residues in razorback sucker larvae from Horsethief or brood stock adults after 7-12 days of exposure to the Horsethief site food treatment and reference water (24-Road) treatment were elevated at 8.1-8.8 μg/g. Similarly, selenium residues in razorback sucker larvae from Horsethief or brood stock adults after 7-12 days of exposure in the Horsethief site food treatment and the Horsethief site water treatment were elevated at 8.6-9.6 μg/g. Survival was very similar between the same food treatments (but with the different water treatments) within the same adult source: 38-56% for larvae from Horsethief adults and 82-85% for larvae from brood stock. The similarity in survival within an adult source was due to the use of the same site food (Horsethief). The selenium concentration in Horsethief site food (4.6 μg/g) was above the selenium dietary toxic threshold

(3 μg/g; Maier and Knight 1994, Lemly 1996), and whole-body residues were above the whole-body adverse effect threshold (4-5 μg/g based on Hilton et al. 1980, Hamilton et al. 1986, Hunn et al. 1987, Ogle and Knight 1989, Hamilton and Wiedmeyer 1990, Hamilton et al. 1990, Cleveland et al. 1993, Lemly 1993b, Hamilton 2001). Considering that the whole-body residues were elevated, selenium concentrations in food were above the selenium dietary toxicity threshold, arsenic concentrations in zooplankton from Horsethief east wetland were low (6.0 μg/g), and survival was lower than in the reference food treatments suggests that the selenium residue in larvae fed the site food was not inactivated due to the absence of arsenic. This same scenario occurred in the second reproduction study with razorback sucker larvae (Hamilton et al. 2001).

The relatively low arsenic concentrations compared to selenium concentrations in invertebrates in the present study was similar to collections of invertebrates from the Grand and Gunnison valleys. Butler et al. (1994) reported low arsenic concentrations compared to selenium concentrations in aquatic invertebrates collected from several locations in the upper Colorado River basin: 2.4 μg/g arsenic & 6.1 μg/g selenium at Horsefly Creek, 0.9 μg/g arsenic & 26 μg/g selenium at Loutsenhizer Arroyo, 1.5 μg/g arsenic & 4.8 μg/g selenium at Smith Fork, 0.5 μg/g arsenic & 2.0 μg/g selenium at North Fork Gunnison River at Paonia, 3.5 μg/g arsenic & 11 μg/g selenium at Indian Wash, 1.4 μg/g arsenic & 32 μg/g selenium at Markley Pond. Butler et al. (1991) also reported similar results for five other locations in the upper Colorado River basin. In only one composite sample of aquatic invertebrates from Happy Canyon, Spring, and Dry creeks in the Uncompahgre River basin was the arsenic concentration substantially greater (9.1 μg/g) than the selenium concentration (2.8 μg/g) (Butler et al. 1991). In most locations in the Grand and Gunnison valleys the amount of arsenic in food organisms seemed to be too low compared to selenium concentrations to alleviate selenium toxicity.

Zooplankton

Dabrowski (1984) reviewed the literature on feeding of fish larvae and stated that zooplankton were the natural food of fish larvae. He further stated that "zooplankton can be used as a model for the formulation of artificial feed," and went on to discuss problems in the culture of fish larvae associated with formulating nutritionally adequate, artificial dry diets, and rearing intensive mono-cultures of live invertebrates for feeding fish. In the present study, we collected and fed live zooplankton from the general biogeographical area where the last riverine population of razorback sucker occur, which suggests that the composition of zooplankton was probably similar to what wild larvae would have encountered. In addition, although not counted as food, some algae and detrital material was present in the rations of zooplankton fed to razorback sucker larvae, and algae and periphyton that grew on the walls of the exposure beakers also were a food source for the larvae.

The zooplankton fed in the present study were predominantly cladocerans and copepods, whose ratio (cladoceran/copepod) varied greatly between collections, i.e., Horsethief east wetland 0.97 to 72, Adobe Creek 0.05 to 61, and North Pond 0.05 to 7. This wide variation in the ratios of the cladocerans to copepods was similar to that reported by Grabowski and Hiebert (1989) for backwaters near Island Park, Jensen, and Ouray on the Green River. The wide range in these ratios may reflect changes in water temperature, light intensity, time of placement or retrieval of light traps, seasonal community structure, water flow, or other unknown factors.

Razorback sucker larvae seem to be opportunistic feeders and are capable of using zooplankton, benthic organisms, algae, and detritus as food, sometimes selectively and other times in proportion to the abundance of the item. Marsh and Langhorst (1988) found that stomachs of razorback sucker larvae in Arizona Bay backwater in Lake Mohave, CA-AZ, contained *Bosmina* (Cladoceran) 55%, rotifers 53%, and copepoda 45% of the time. They also reported larvae exhibited a positive selection for cladocerans, especially *Bosmina*, and strong negative selection for rotifers. In a more detailed report of their research with razorback sucker larvae, Langhorst and Marsh (1986) reported that larvae used all available habitats (limnetic, benthic, and macrophytic) as evidenced by the presence in larvae stomachs of *Macrothrix*, a cladoceran associated with vegetation. Gut analysis of razorback sucker larvae stocked into, and collected 1 week later, from a backwater in the Salt River, AZ, indicated that chironomid larvae were the dominant food (J. Brooks, USFWS, personal communication, cited in Bestgen 1990). Papoulias and Minckley (1992) reported that razorback sucker larvae (7 days post hatch) were eating sessile diatoms, phytoplankton, and detritus the first day after stocking in ponds, were eating rotifers, nauplii, cladocerans, insect eggs, and chironomids by 8 days post hatch. Muth (1995) examined gut contents of razorback sucker larvae collected in low velocity habitats of the middle and lower Green River, UT, and reported similar items were consumed including rotifers, chironomid larvae, filamentous and colonial algae, diatoms, and organic debris. From a fish culture standpoint, Toney (1974) reported that razorback sucker larvae actively fed on small amounts of baby food and strained beef liver for the first 2 weeks after hatch, and after placement in an outside raceway, they "gorged themselves" on Cladocera and blackfly larvae.

From a caloric standpoint, aquatic invertebrates, including cladocerans and copepods, have similar energy content as nauplii of brine shrimp (5.32 kcal/g, Hamilton and Buhl 1999; source was Columbia, S.A.), which were used as reference food in the present study. Driver et al. (1974) reported that the caloric values (kilocalories/gram:kcal/g) measured by calorimeter for 33 species of aquatic invertebrates ranged from 3.70 to 6.97 kcal/g (the calculated mean using the mean value for the reported ranges was 5.52 kcal/g, SE ±1.01). Driver (1981) later reported that the caloric values for 24 species of aquatic invertebrates ranged from 3.68 to 6.27 kcal/g dry weight with a mean of 5.22 kcal/g. Cummins and Wuycheck (1971) reported that the caloric content was 4.30-6.28 kcal/g for cladocerans, 5.33-7.38 kcal/g for copepods, and 5.47 kcal/g (grand mean) for all aquatic invertebrates in their study.

Watanabe et al. (1983) assessed the nutritional values of live organisms used for mass propagation of fish and reported that the essential fatty acid (EFA) contents, but not mineral content, of live food organisms determined the chief nutritional value for fish larvae. They reported that the EFA content in two cladocerans, *Moina* and *Daphnia*, made them suitable as food organisms for fish larvae. From a calculated energy content standpoint, the energy content of *Moina* (5.1 kcal/g) and *Daphnia* (4.3 kcal/g) was similar to that of other common live culture foods such as brine shrimp (4.4 kcal/g from San Francisco Bay, 4.7 kcal/g from South America, 4.2 kcal/g from Canada), a rotifer (*Brachionus plicatilis*; 4.7-5.4 kcal/g), and two marine copepods (4.1-5.2 kcal/g). Schauer et al. (1980) used a wet oxidation technique to measure energy content of five geographic strains of brine shrimp (Australia, Brazil, Italy, San Francisco Bay, and Utah) and reported values ranging from 5.4 to 6.0 kcal/g with a mean of 5.6 kcal/g (reported as J/g; J x 0.239=cal). Because the caloric content of brine shrimp and freshwater aquatic invertebrates were similar, the use of brine shrimp in the present study as a reference food organism and field-collected zooplankton seemed appropriate. However, some

investigators have reported that natural food organisms either alone or in combination with brine shrimp nauplii were better for culturing fish than brine shrimp nauplii alone (Colesante 1989, Mason et al. 1992, Ronnestad et al. 1998, Shields et al. 1999). Brine shrimp have been used as substitutes for natural food organisms in a dietary toxicity study with rainbow trout (Mount et al. 1994).

In the present study, larvae were fed 40 organisms/fish (250 organisms/L or 25 organisms per L per fish). Papoulias and Minckley (1990) reported in their laboratory study that 30 to 60 nauplii of brine shrimp per fish per day was sufficient to maintain high survival and no reduced growth, whereas 12 or less nauplii per fish per day resulted in substantial mortality and reduced growth. Papoulias and Minckley (1992) reported high larval survival (77, 90, and 67%) in ponds with zooplankton densities of 43, 24, and 12 organisms/L, respectively. In a feeding study where 5 day-old razorback sucker larvae were fed 20, 40, or 80 nauplii of brine shrimp per fish per day for 20 days, survival was 95% or better in all treatments (Hamilton et al. 1996). They also tested 24-day old razorback sucker and confirmed that as little as 20 nauplii per fish per day would maintain a high survival rate (97%).

Likewise, Marsh and Langhorst (1988) concluded that nutritional factors such as type, number, or size of available foods did not affect survival or growth of razorback sucker larvae in Lake Mohave, which had 1.55 zooplankton/L (reported as 1,554 zooplankton/m^3) or in Arizona Bay backwater, which had 0.38 zooplankton/L (reported as 377 zooplankton/m^3). In contrast, Papoulias and Minckley (1990, 1992) suggested that at those low zooplankton densities, larval survival might be reduced in Lake Mohave, but not at the more common densities reported for Lake Mead (25-41 zooplankton/L), Lake Havasu (83 zooplankton/L), or Lake Mohave (29-45 zooplankton/L) (Papoulias and Minckley 1992). However, Papoulias and Minckley (1990, 1992) failed to acknowledge that Marsh and Langhorst (1988) reported that razorback sucker larvae were abundant and growing (>20 mm total length) in the Arizona Bay backwater site, which had 0.38 zooplankton/L. Larvae at that site only disappeared after the berm isolating the backwater from the main lake was breached allowing predators to enter, after which all larvae disappeared in 30 days. The organism densities in the field studies by Papoulias and Minckley (1992) and Marsh and Langhorst (1988) encompassed all possible sizes, whereas the zooplankton used in the present study were preselected to be <0.425 mm, which would have represented only a portion of the various sizes present in a field situation and presumably available to larval fish.

Feeding densities in the present study were higher than wild larvae would encounter naturally. Razorback sucker larvae in the present study were initially fed either 250 organisms/L, which was 17 times greater than the 15 organisms/L, which included all possible sizes, reported by Cooper and Severn (1994) for Sheppard Bottom pond 3 at Ouray NWR, UT. Grabowski and Hiebert (1989) reported higher zooplankton concentrations in backwaters (seasonal average 0.4-1.5 zooplankton/L) than in river sections (0.04-1.0 zooplankton /L) near Island Park, Jensen, and Ouray on the Green River in 1987-1988. They reported high concentrations of 16.6 zooplankton/L in a Jensen backwater (seasonal average 4.1 zooplankton/L) and 15.1 zooplankton/L in an Ouray backwater (seasonal average 5.2 zooplankton/L).

By using a high density of zooplankton and preselecting small sizes in the present study, the likelihood that razorback sucker larvae would successfully consume food was increased compared to natural occurrences. This approach also reduced the energy cost to larvae to search and capture prey. In natural wetlands fish would have unlimited access spatially to food

organisms, but low food density would require larvae to forage over greater areas, which could in turn cost them more energy and subject them to greater predation pressure or competition from other species.

The size of zooplankton (<0.425 mm) fed to larvae in the present study seemed to be the appropriate size range. Langhorst and Marsh (1986) reported that razorback sucker larvae 11-14 mm total length selected smaller plankton to feed on compared to sizes available in the plankton population at large. They found size selection was especially notable for *Daphnia*, which averaged 0.66 to 0.86 mm in length, in larvae stomachs. The selected *Daphnia* were about half the average size (1.42 to 1.60 mm) in plankton samples. Papoulias and Minckley (1992) found that razorback sucker larvae exhibited prey-size selection, based on body width, and consumed prey from 0.1 to 0.4 mm.

By selecting small-sized zooplankton for feeding in the present study, we may have inadvertently selected zooplankton with elevated inorganic residues compared to larger-sized invertebrates. For example, van Hattum et al. (1991, 1996) reported that invertebrate size, rather than species or sex, explained most of the variation in inorganic element accumulation in aquatic invertebrates. Timmermans et al. (1989) and Farag et al. (1998) also reported that small-sized aquatic invertebrates had higher concentrations of inorganic elements than larger-sized invertebrates. Consequently, Farag et al. (1998) concluded that early life stages of fish may be exposed to larger doses of inorganic elements that larger older life stages. In the present study, the small-sized zooplankton fed to razorback sucker larvae were the appropriate size due to morphological considerations, but small-sized invertebrates may have presented a greater dose of inorganic elements, including selenium, to the razorback sucker larvae.

Selenium in larvae

The whole-body toxic threshold for selenium-induced adverse effects, i.e., mortality of juveniles and reproductive failure, in a selenium-sensitive fish proposed by Lemly (1996b) was 4 μg/g, whereas Maier and Knight (1994) proposed 4.5 μg/g as the concentration above which adverse affects occur in fish and wildlife. These values were derived from a review of several laboratory and field studies where selenium was the toxicant of concern. Hamilton et al. (2000a) cited three additional studies that documented whole-body selenium concentrations of 3.6 to 5.5 μg/g in juvenile fish were associated with adverse effects. Information in the selenium literature linking whole-body residues of 4 μg/g or higher with adverse effects in fish seems sufficient to suggest that a tissue-based selenium criterion should be used for the protection of aquatic life rather than a water-based criterion (Hamilton 2001).

At day 7 and 12 larvae from brood stock and Horsethief adults had higher selenium residues than at day 30. The initially high residues apparently decreased due to depuration and tissue dilution as fish grew. Investigations have reported decreases in selenium residues in fish due to tissue dilution from growth (Bennett et al. 1986) or due to depuration of initially high selenium residues in larvae while being fed food with a low selenium concentration (Birkner 1978). An interesting example is given in Birkner (1978) who conducted a 90-day study with juvenile fathead minnow that initially had a whole-body selenium concentration of 13.9 μg/g. After 90 days of exposure, fish fed zooplankton with selenium concentrations of 1.2 μg/g had whole-body residues of 5.0-5.7 μg/g, those fed zooplankton with 5.7 μg/g had a whole-body residue of 5.2-7.0 μg/g, and those fed zooplankton with 11.8 μg/g had a whole-body residue of

10.3-11.0 μg/g. Thus, fish depurated selenium from their initial whole-body residue to close to the concentration in their food. Selenium residues in razorback sucker larvae from Horsethief after 7 days of exposure to the brine shrimp or HTEW food treatments and the 24-Road or Horsethief water treatments were elevated at 7.3-8.8 μg/g. However, survival was very different between the two food treatments within the same water treatment: 98-100% in the brine shrimp food treatment, but 38-56% in the HTEW food treatment. The elevated whole-body residues in larvae fed the brine shrimp food treatment (7.3-7.9 μg/g), but lack of adverse effects on survival of larvae suggested that something counteracted the toxic effects that should have been manifested by the selenium tissue residues. Whole-body residues above 4-5 μg/g have been associated with adverse effects (Hilton et al. 1980, Hamilton et al. 1986, Hunn et al. 1987, Ogle and Knight 1989, Hamilton and Wiedmeyer 1990, Hamilton et al. 1990, Cleveland et al. 1993, Lemly 1993b, Hamilton 2001). The difference may be due in part to the selenium concentrations in food at 7 days of exposure, which were 2.7 μg/g in brine shrimp and 4.6 μg/g in zooplankton from HTEW. More likely, the elevated arsenic concentrations in brine shrimp (24 μg/g; Hamilton et al. 2001) inactivated the toxic effect of the elevated selenium residues in larvae much like the counteraction of selenium toxicity by arsenic (Klug et al. 1950, Levander and Argrett 1969, Howell and Hill 1978). This same scenario occurred in the second reproduction study with razorback sucker larvae (Hamilton et al. 2001).

The high whole-body selenium residues in razorback sucker larvae from Adobe Creek (32-71 μg/g) and North Pond (28-47 μg/g) adults at days 6 and 7 in the present study were similar to those reported by others. Bennett et al. (1986) reported whole-body selenium residues of 52 μg/g in 17-day old fathead minnow larvae fed rotifers containing 46 μg/g selenium for 9 days, and 61 μg/g in 9-day old larvae fed rotifers with 91 μg/g for 7 days. Dobbs et al. (1996) reported whole-body selenium residues of 47 μg/g in fathead minnow larvae fed rotifers containing 40-47 μg/g selenium for 7 days.

After 30 days of exposure in the present study, larvae from brood stock (residue 3.6 μg/g) and Horsethief (residue 3.3 μg/g) adults exposed to the reference food-reference water treatment had selenium residues below the toxic threshold (4 μg/g), and concomitantly, no adverse effects on growth and survival. However, those selenium residues were higher than those typically reported in control fish from laboratory studies or in reference fish from field studies, which were ≤2 μg/g (Hamilton et al. 2000a).

Selenium residues in razorback sucker larvae from brood stock after 30 days of exposure to the brine shrimp or HTEW food treatments and the 24-Road or Horsethief water treatments were elevated at 3.6-6.9 μg/g. However, survival was very different between the two food treatments within the same water treatment: 86-89% in the brine shrimp food treatment, but 42-62% in the HTEW food treatment. The elevated whole-body residues in larvae fed the brine shrimp food treatment (3.6-5.2 μg/g), but lack of adverse effects on survival of larvae suggested that something counteracted the toxic effects that should have been manifested by the selenium tissue residues. The difference may be due in part to the selenium concentrations in food at 30 days of exposure, which averaged 2.7 μg/g in brine shrimp and 5.6 μg/g in zooplankton from HTEW. More likely, the elevated arsenic concentrations in brine shrimp (24 μg/g; Hamilton et al. 2001) inactivated the toxic effect of the elevated selenium residues in larvae much like the counteraction of selenium toxicity by arsenic (Klug et al. 1950, Levander and Argrett 1969, Howell and Hill 1978). This same scenario occurred in the second reproduction study with razorback sucker larvae (Hamilton et al. 2001).

Selenium residues in larvae from Adobe Creek (7.7 μg/g) and North Pond (9.7 μg/g) adults were still elevated after 30 days in the reference food-reference water treatments, which were depurating conditions similar to the study conducted by Birkner (1978). Although larvae from Adobe Creek and North Pond adults depurated selenium, there was a trend for reduced survival throughout the 30-day exposure (Figure 6A). This trend for reduced survival suggested that even if selenium residues were depurated to 7.7-9.7 μg/g, adverse effects in razorback sucker larvae may have continued to occur. The poor survival of larvae observed during the informal observation period conducted at 24-Road confirmed that long-term adverse effects occurred in the larvae from Adobe Creek and North Pond adults under depurating conditions.

At 30 days of exposure, the increased selenium residues in larvae from Horsethief (5.1 μg/g), Adobe Creek (12.7 μg/g), and North Pond (15.2 μg/g) adults in the reference food-site water treatment compared to the reference food-reference water treatment (3.3, 7.7, 9.7 μg/g, respectively) revealed that larvae were accumulating selenium from the site water exposure. Selenium uptake in fish from water exposure can occur via the gill and epithelium (Hodson et al. 1986). Selenium uptake in larvae in the site water treatments may have come from dietary uptake of algae, periphyton, and detritus growing on the walls or bottom of the exposure beakers. Selenium is readily accumulated from water into algae (Nassos et al. 1980, Foe and Knight 1986, Riedel et al. 1991, Besser et al. 1993), periphyton (Graham et al. 1992), and detritus (Bender et al. 1991). Algae, periphyton, and detritus are consumed by razorback sucker larvae (Papoulias and Minckley 1992). In the present study, larvae in the site water treatments probably accumulated selenium residues indirectly via a dietary exposure route in Adobe Creek and North Pond site water treatments.

Growth

In the present study, the only consistent difference in growth was between brood stock larvae and larvae from the younger adults held at Horsethief, Adobe Creek, and North Pond. This difference was consistent with the reports that larvae from large eggs are larger at hatch and remain larger for up to 324 days posthatch than larvae from small eggs (Buss and McCreary 1960, Gall 1974, Pitman 1979, Kazakov 1981, Springate and Bromage 1985).

Growth is the culmination of many biochemical phenomena that occur in a somewhat regulated pattern, and reduced growth may occur when contaminant intoxication induces biochemical changes that interfere with normal growth processes (Mehrle and Mayer 1985). In general, growth of fish is a sensitive indicator of contaminant stress from long-term, chronic exposures, and changes in growth usually occur before reductions in survival occur (Rand and Petrocelli 1985). However, some studies with selenium exposure in the water, diet, or both have reported inconsistent results: (1) reduced growth occurred in the same treatments (exposure concentration and duration) where reductions in survival occur (Hilton et al. 1980, Klauda 1986), (2) reduced survival occurred before reduced growth (Hunn et al. 1987, Woock et al. 1987, Hamilton et al. 1990 [San Luis Drain diet], Crane et al. 1992, Hermanutz et al. 1992, Cleveland et al. 1993), (3) reduced growth occurred before reduced survival (Hilton and Hodson 1983, Ogle and Knight 1989, Hamilton et al. 1990 [selenomethionine diet]), or (4) no effects occurred on growth or survival, but other pathological effects or reproductive effects occurred (Hodson et al. 1980, Coyle et al. 1993). The inconsistency between these studies was probably due to differences in species, age, exposure route and duration, selenium form, and other factors.

Survival

Razorback sucker larvae in the present study probably did not die from starvation because Papoulias and Minckley (1990) reported that the point of irreversible starvation, and subsequent mortality, was between 19 and 23 days, whereas the median time to 50% mortality for unfed larvae was between 24 and 25 days. In the site food treatments of the present study, nearly complete mortality occurred in 5 to 12 days, which is substantially less than the period when irreversible starvation could have influenced later mortality or the median time to 50% mortality of unfed larvae reported by Papoulias and Minckley (1990).

The process of yolk sac absorption probably was not associated with the observed mortality beginning at day 6 of the study. Minckley and Gustafson (1982) reported that hatching in razorback sucker occurred at 131 hours of development, and yolk sac absorption occurs at 311 hours of development – a difference of 180 hours = 7.5 days posthatch. The current study was started with 5-day-old fish and the mortality occurred at 6 days of exposure [total 11 days]. Assuming that the larvae used in the present study had similar development to those examined by Minckley and Gustafson (1982), the larvae in the present study would have been feeding for at least 3-4 days (11 – 7.5 = 3.5 days), which is probably sufficient time to incur toxicity from dietary selenium in very small larval fish. The actual amount of time of feeding in the present study was probably longer because Minckley and Gustafson (1982) conducted their study in 14°C water, whereas in the present study the holding temperature at 24-Road for egg development and first 4 days posthatch was about 24°C and the first 6 days in the mobile laboratory was about 21°C. At the lower temperatures of Minckley and Gustafson (1982), development would have taken longer than in the present study, whereas at the higher temperatures in the present study development would have been shorter and the time at first feeding earlier than suggested by Minckley and Gustafson (1982). Consequently, yolk sac absorption probably did not have an influence on larval mortality.

In the present study, the time frame of nearly 100% mortality in exposures receiving site food was similar to Bryson et al. (1984) who reported that juvenile bluegill collected from Hyco Reservoir, NC, experienced 97% mortality within a week after being fed plankton, which contained 45 μg/g selenium. Selenium concentrations in the diet at concentrations close to the proposed selenium dietary toxic threshold of 3 μg/g have been documented to cause adverse effects in young fish usually following 30-60 days of exposure. For example, Hamilton et al. (1990) reported that 5.3 μg/g selenium in the diet reduced growth of chinook salmon (*Oncorhynchus tshawytscha*), Cleveland et al. (1993) reported that 6.5 μg/g selenium in the diet reduced survival of bluegill, and Lemly (1993b) reported that 5.1 μg/g selenium in the diet (and 4.8 μg/L selenium in the water) reduced survival of bluegill held under winter stress conditions.

The time frame of mortality in the present study was also similar to another study with razorback sucker larvae where larvae were fed zooplankton with different concentrations of selenium collected from sites at Ouray NWR, UT (Hamilton et al. 1996). In one test initiated with 5-day-old larvae, rapid mortality in larvae began 5-10 days after feeding zooplankton containing selenium concentrations of 3.5 to 25.7 μg/g. These selenium concentrations, as well as those reported by Hamilton et al. (1990; 5.3 μg/g), Cleveland et al. (1993; 6.5 μg/g), and Lemly (1993b; 5.1 μg/g) indicate that the selenium concentration in zooplankton from Horsethief east wetland (4.6 μg/g) was sufficiently elevated during the first week of exposure to cause the reduced survival, which started at day 5. In the second reproduction study with razorback sucker

larvae, selenium concentrations of 4.6 μg/g or greater were also linked with a sharp decline in survival of razorback sucker larvae at about 6-8 days of exposure (Hamilton et al. 2001).In addition, waterborne exposure to site water (tested with reference food) contributed to the reduced survival of the larvae (Figures 7B, 8C, 8D). Other studies have also reported that combined water and dietary exposures of fish to selenium was additive (Bertram and Brooks 1986, Woock et al. 1987). However, the magnitude of the effect of site food (tested with reference water) on mortality (Figure 7C) was much greater than that contributed by exposure to site water (tested with reference food) (Figure 7B). This prominence of adverse effects from dietary sources over waterborne sources has also been stated in review papers (Maier et al. 1988, Maier and Knight 1994, Lemly 1996b).

In the present study, because (1) zooplankton types, feeding density, and energy content seemed appropriate for proper nutrition of the larvae, (2) the time frame of mortality precluded the influence of starvation, and matched those in studies of dietary selenium toxicity with fish, (3) selenium concentrations, but not other inorganic elements, were elevated in zooplankton above well-documented selenium dietary toxic thresholds, (4) the significant negative correlation between larval survival and selenium concentrations in zooplankton, and (5) selenium residues in larvae were above whole-body concentrations linked with reduced survival in young fish reported in other studies, it seems reasonable to assume that a diagnostic pattern has been formed that leads to the conclusion that dietary selenium was the primary cause of the reduced survival of larvae (discussed further in the section on hazard assessment).

Likewise, because (1) brine shrimp have been documented as a suitable food organism in larval fish culture, (2) selenium concentrations in brine shrimp were near well-documented selenium dietary toxic threshold, (3) arsenic concentrations were probably elevated in brine shrimp [documented in the second reproduction study, Hamilton et al. 2000a], (4) arsenic counteracts selenium toxicity and allows selenium residues to accumulate in animals above those in selenium alone exposures but without having a toxic effect, and (5) selenium residues in Horsethief and brood stock larvae fed brine shrimp and exposed to 24-Road water were near whole-body concentrations linked with reduced survival in young fish reported in other studies, and (6) reduced survival did not occur in Horsethief and brood stock larvae fed brine shrimp and exposed in 24-Road water, it seems reasonable to assume a diagnostic pattern has been formed that leads to the conclusion that dietary arsenic counteracted selenium toxicity thus allowing good survival of larvae fed brine shrimp.

Delayed mortality

In the present study, a significant delay in mortality, based on the predicted time to death, occurred in razorback sucker larvae fed site food and held in site water from North Pond compared to larvae fed site food, but held in reference water. This delayed mortality was similar to that of razorback sucker larvae held in water from Sheppard Bottom pond 1 and fed food organisms from either North Roadside Pond or South Roadside Pond compared to larvae fed food organisms from Sheppard Bottom pond 1 at the Ouray NWR, UT (Hamilton et al. 1996). The same delayed mortality, based on the predicted time to death, occurred in razorback sucker larvae tested in 1997 using the same waters and site food organisms as in the present study (Hamilton et al. 2001).

If a typical concentration-response relation was present in the current study, larvae fed

zooplankton from North Pond and held in North Pond water should have died sooner than larvae receiving the same food, but held in reference water. However, the delayed mortality (1.2 days at the 50%, 1.9 days at 90%, and 2.2 days at the 95% predicted mortality level) suggested an interaction between inorganic contaminants in the site food (zooplankton) and site water was occurring. The average selenium concentration in zooplankton from North Pond (39 μg/g) was about 12 times higher than the proposed dietary toxic threshold (3 μg/g), and because the waterborne route of selenium exposure is a lesser contributor to toxicity than dietary selenium exposure, it seems reasonable that this high dietary selenium concentration should have killed the larvae in the same time period regardless of waterborne selenium concentrations. Nevertheless, the delayed mortality in the present study (1.2 - 2.2 days) was probably not significant from a biological standpoint.

The delayed mortality observed in the present study, as well as the two other studies (Hamilton et al. 1996, 2001), may have been due to selenium interacting with other elements. Selenium interacts with a variety of other inorganic elements including antimony, arsenic, cadmium, cobalt, copper, germanium, lead, mercury, silver, tellurium, tin, and tungsten (Diplock 1976, Levander 1977, Howell and Hill 1978, Whanger 1981, Marier and Jaworski 1983, Sorensen 1991). These interactions can be additive, antagonistic, or synergistic, and in some cases the interaction has been reported to be reversed, i.e., antagonism changed to synergism, by altering exposure conditions. It is not known if interactions between selenium and other elements occurred in the present study, but an interaction was suggested by the slight, but significant, longer predicted time to death in North Pond larvae receiving the site food and site water treatment compared to those receiving the site food and reference water treatment. A typical concentration-response in survival seems to have been present in the reference food-reference water treatment because there was a shorter predicted time to death occurred for larvae from Adobe Creek adults (55 days) or North Pond adults (45 days) than for larvae from Horsethief adults (63 days) or brood stock adults (68 days). Larvae from Adobe Creek or North Pond adults had more selenium deposition in the egg from which they hatched, and under clean food and clean water conditions should have had a shorter predicted time to death than larvae from Horsethief or brood stock adults. The same concentration-response occurred in the reference food-site water treatment.

It has been suggested that the delayed mortality of larvae fed food from either Adobe Creek or North Pond compared to larvae fed food from Horsethief argues against a concentration response related to selenium concentrations in food (Recovery Program reviewer, written communication). They suggested that perhaps the food organisms at Horsethief had a more toxic species of selenium, and therefore, was more toxic to larvae than the species of selenium in food organisms at Adobe Creek or North Pond. Investigators have reported that algae and bacteria contain several seleno–analogues of sulphur amino acids incorporated mostly into protein, but also in amino acid fractions of extracts (Wrench 1978, Foda et al. 1983, Bottino et al. 1984). The forms reported include selenocysteic acid, selenomethionine, selenocystine, selenocysteine, Se-methyl selenocysteine, selenoxide form and selenone form of Se-methyl selenocysteine, Se-methyl selenomethionine, and hydrogen selenide. In spite of several organic selenium components being identified in plants and bacteria, only two organic forms of selenium have been tested with fish to determine their toxicity: selenomethionine (Sandholm et al. 1973, Woock et al. 1987, Ogle and Knight 1989, Hamilton et al. 1990, Besser et al. 1993, Cleveland et al. 1993, Coyle et al. 1993) and selenocystine (Bryson et al. 1985). In one test comparing

selenomethionine and selenocystine, the investigators found that accumulation of selenomethionine in fish was similar to accumulation from selenium-laden natural zooplankton, and both had higher accumulation than from selenocystine (Bryson et al. 1985). The greater effect from exposure to selenomethionine compared to selenocystine was probably due to the greater ability of fish to digest selenomethionine than selenocystine (Bell and Cowey 1989). The limited toxicological information on the toxicity of various forms of organic seleno-compounds does not seem to support a suggestion of differential seleno-compounds in Horsethief zooplankton versus zooplankton from Adobe Creek and North Pond.

There is a narrow range of selenium concentrations between nutritionally optimal (i.e., 0.3 μg/g) and potentially toxic dietary exposures (i.e., 2 μg/g) to vertebrate animals, about a 7-to 10-fold range (Wilber 1980, NRC 1989). This small range of selenium concentrations between homeostasis and toxicity suggests that the range between sublethal effects and lethal effects also would be rather small, possibly over a range of selenium concentrations spanning 2-3 μg/g. Thus, a readily apparent concentration-response would not be expected unless the exposure concentrations were, for example, 2, 3, 4, 5, 6, 7, and 8 μg/g, and there were sufficient replicates to identify small statistical differences. Similar to the results of the present study, nine other studies have reported no concentration-response in exposures of fish to dietary selenium (Hilton et al. 1980, Bryson et al. 1984, Bennett et al. 1986, Woock et al. 1987, Coughlan and Velte 1989, Ogle and Knight 1989, Hamilton et al. 1990, Cleveland et al. 1993, and Coyle et al. 1993). In contrast, only two studies have reported a concentration response (Goettl and Davies 1977, Hamilton et al. 1990), and three studies have reported a partial concentration response limited in part by the experimental design (Geottl and Davies 1978, Hilton et al. 1980, Lemly 1993b). Consequently, the majority of dietary selenium studies with fish do not report a concentration response, which is similar to the present study and the second reproduction study (Hamilton et al. 2001).

It should be noted that larvae used in the larval fish study were from exposed adults, and were hand selected using the criterion in ASTM (1989). Criteria for use of fish in laboratory studies is that they are free of disease, uniform in size and age, have good nutrition and holding conditions (temperature, water quality, photoperiod, uncrowded, minimal handling) (ASTM 1989). The guidelines further state that organisms should be free of signs of stress, physical damage, mortality, and external parasites, and that abnormal or injured individuals not used in tests, nor should organisms have abnormal behavior such as not eating, flashing, flipping, swimming erratically, emaciated, gasping at the surface, hyperventilating, hemorrhaging, producing excessive mucus, or showing abnormal color. These types of guidelines were developed primarily for use with routinely tested organisms such as rainbow trout and fathead minnow with well-known culture procedures, past successful use in testing, and ease of handling. Consequently, toxicant concentrations that cause effects in razorback sucker larvae hand-selected according to standard testing guidelines (ASTM 1989) could tend to underestimate toxicant impact in the environment where a variety of environmental and organismal conditions would occur.

Informal observations of razorback sucker larvae

Most of the mortality of larvae from North Pond adults occurred in the first 30 days of the observation period (June 12-July 13), and was greater than in larvae from Adobe Creek, in

spite of the similar magnitude of elevated selenium concentrations in eggs of adults held at these two sites (Adobe Creek 46.5 μg/g, North Pond 37.8 μg/g). However, selenium concentrations in gonads were higher in fish from North Pond (45.5 μg/g) than in fish from Adobe Creek (30.6 μg/g). The importance of the mortality associated with the change in drain slot size, and the inadvertent loss of larvae was unclear because the date when the slot size was changed was not recorded in the daily records at 24-Road.

Growth

The greater total length and weight of larvae from brood stock at 42 days of age compared to larvae from first-time spawners was consistent with the reports that larvae from large eggs hatch into larger larvae and remain larger for a period of time after hatch than larvae from small eggs (Buss and McCreary 1960, Gall 1974, Pitman 1979, Kazakov 1981, Springate and Bromage 1985). At 140 days of age, there were no differences in total length or weight, which was inconsistent with the reports that differences due to egg size remain in fry up to 324 days post hatch (Pitman 1979, Springate and Bromage 1985, Ojanguren et al. 1996).

At 84 days of age, the significant reduction in total length and weight of larvae from North Pond adults compared to larvae from Horsethief and Adobe Creek adults suggested a stress was transferred from the parents to the egg because larvae from all three parental exposures were hatched and cultured in the same water, and larvae were fed the same food. The disappearance of growth differences at 140 days of age among the three groups may be due to mortality removing smaller, weak larvae from North Pond adults.

The consequence of reduced growth in early life stages of fish is that swimming performance is reduced and susceptibility to predation is increased (Bams 1967, Taylor and McPhail 1985), and feeding efficiency is reduced (Gunn and Noakes 1987). Functions that promote fish survival also are related to body size (reviewed by Ojanguren et al. 1996). For example, sensory systems develop rapidly during early life stages and visual acuity increases with fish size, enabling large fry to better detect predators and food and resist starvation, thus allowing them access to a wider range of prey and increase the likelihood of finding appropriate food. Consequently, razorback sucker larvae with reduced growth, may be less fit to survive the rigors of competition and predation, especially with nonnative fish. Predation on larval and juvenile razorback sucker by invertebrates and fish has been reported (Marsh and Langhorst 1988, Marsh and Brooks 1989, Horn et al. 1994, Modde and Wick 1997).

Deformities

Deformities in larvae were elevated in larvae from adults from Horsethief (43%), Adobe Creek (27%), North Pond (95%), and brood stock (52%) compared to typical background deformities rates of <1-3% (Gabriel 1944, Gill and Fisk 1966, Patten 1968, Dahlberg 1970). The amounts of deformities in razorback sucker larvae were also higher than the range of 9 to 11% suggested by Bengtsson (1975) as abnormal and probably due to a "man-made" effect. Two of the three brood stock had elevated selenium muscle plugs (13.1 and 13.8 μg/g), but the third female did not (2.6 μg/g), whereas the average selenium concentration in eggs was 6.0 μg/g.

Deformities have been observed in fish larvae hatched from eggs with high selenium concentrations (Gillespie and Baumann 1986, Woock et al. 1987, Pyron and Beitinger 1989,

Schultz and Hermanutz 1990, Crane et al. 1992, Hermanutz 1992, Hermanutz et al. 1992, Coyle et al. 1992). Fish larvae exhibiting these characteristics were not expected to survive in natural systems, except in predator-free situations (Hermanutz 1992, Lemly 1993c). Deformities have even been documented in selenium-tolerant western mosquitofish from the San Luis Drain, CA, where waterborne concentrations were 340-390 µg/L, and fish had over 100 µg/g selenium (Saiki and Ogle 1995). Lemly (1993c) documented selenium-induced deformities in 19 species of fish from Belews Lake, NC, and reported that selenium residues were similar in normal-appearing fish and abnormal fish. Later, Lemly (1997a) developed a teratogenic index for selenium-induced deformities in larval fish. He documented deformities in larval fish in Belews Lake, NC, 10 years after selenium inputs to the lake were stopped, and concluded selenium in sediment was being recycled into the aquatic food chain (Lemly 1997b).

Hermanutz (1992) reported that selenium-induced teratogenesis in fathead minnow, where adults were exposed to selenium in an outdoor stream and allowed to spawn, could persist beyond the embryo-larval stage in a predator-free environment. Lemly (1993c) also reported selenium-induced deformities in adult and juvenile fish in Belews Lake, NC, during a period when predators were not present in the lake. The results of these two studies were similar to the persistence of deformed razorback sucker larvae from Adobe Creek and North Pond adults that were held from hatching to 134 days of age at 24-Road.

Deformed snouts, i.e., pugheadedness, were observed in larvae from North Pond adults, but not in larvae from Horsethief or Adobe Creek adults. Pugheadedness can be caused by genetic anomalies causing a germinal defect during embryo development, oxygen deficiency, varying levels of temperature and oxygen, varying levels of temperature and salinity, X-irradiation, endocrine disturbances, selenium exposure, or mixtures of environmental contaminants (Hickey 1973, Hickey et al. 1977, Slooff 1982, Lemly 1993c, 1997a).

The lack of schooling in larvae from North Pond adults that was observed by one fishery biologist and four non-fishery biologists, but not noted in daily observations of personnel who cultured the fish, has been observed in razorback sucker and in other fish exposed to selenium. Lack of schooling behavior was also observed in razorback sucker exposed to a waterborne mixture of nine inorganic elements, including selenate and selenite, simulating Ashley Creek (Hamilton et al. 2000b). The observation was made after 21 days of exposure to the high treatment, and by 60 days of exposure, 95% mortality had occurred in larvae in that treatment. Coughlan and Velte (1989) noted nonschooling and corneal cloudiness in one or both eyes in striped bass that were fed red shiners (*Cyprinella lutrensis*) containing selenium concentrations of 38.6 µg/g. Abnormal swimming in fish exposed to selenium has been reported (Ellis et al. 1937, Hilton et al. 1980, Woock et al. 1987). Opaqueness of eye lens was noted in adult bluegill exposed to dietary selenium (Woock et al. 1987), and reported in fish fed a diet containing 13.1 µg/g selenium appeared oblivious to other fish or obstacles in the tank, which suggested the fish were blind (Hilton et al. 1980). Cloudy eye lens or cornea were reported to be one of five categories of abnormalities associated with selenium exposed fish (Lemly 1993c, 1997a, 1997b), and has been induced by selenium exposure in fish as early as 1937 (Ellis et al. 1937). Eye problems including bulging and blindness have been reported in razorback sucker (Valdez et al. 1982, Minckley 1983, Bozek et al. 1984). Cloudy eyes probably would cause partial or complete blindness, and concomitantly the loss of schooling and the appearance of abnormal swimming behavior. Abnormal schooling or swimming behavior tends to make fish more susceptible to predation (Atchison et al. 1987).

The nearly 3-6 fold higher number of eye deformities in larvae from young adults held at 24-Road for 134 days post hatch, compared to larvae from brood stock may have resulted from the larvae being more susceptible to stress. Eggs from adults held at Adobe Creek and North Pond had selenium concentrations of 46.5 and 37.8 μg/g, respectively, which were 2-fold higher than the high hazard category of Lemly (1995) for selenium concentrations in fish eggs. Eggs from young adults held at Horsethief had selenium concentrations of 6.5 μg/g, which place them in the low hazard category of Lemly (1995). If razorback sucker are a sensitive fish species to selenium exposure, then perhaps the larvae from young adults held at Horsethief had sufficient selenium residues from eggs to cause eye deformities, which have been documented as a symptom of selenium stress. Alternatively, the higher incidence of eye deformities in larvae from young adults compared to brood stock larvae may have been due to the effects of inbreeding, although eye deformities have not been documented as occurring in inbred fish (Aulstad and Kittlesen 1971, Kincaid 1976b, Piper et al. 1982).

Selenium in larvae

At 134 days of age, razorback sucker larvae had selenium concentrations (0.94-0.98 μg/g) that were similar to background concentrations reported in control fish from laboratory studies and reference fish from field studies (<2 μg/g, Hamilton et al. 2000a). The selenium concentrations in these larvae were about a third of those in the larval fish study after 30 days of exposure to the reference food/reference water treatment (3.3 μg/g in Horsethief larvae and 3.6 μg/g in brood stock larvae). These results reveal that the longer the larvae were fed clean food and held in clean water, the lower their selenium residues would be due to metabolic elimination of selenium. Birkner (1978) reported that fish reduced initially elevated selenium concentrations in whole body when fed food with lower selenium concentrations, whereas Bennett et al. (1986) reported that selenium concentrations in larval fish decreased as fish grew, i.e., tissue addition diluted whole body selenium concentrations. However, selenium-induced teratogenic deformities derived from parental selenium deposited in the egg, as manifested by the deformed snout of larvae from adults held at North Pond, do not seem to be reversible when the selenium exposure is reduced or eliminated.

Inbreeding

The young razorback sucker adults used in the present study and in the second reproduction study in 1996-1997 (Hamilton et al. 2001) came from a single mating in 1992, and thus the spawnings in 1996 and 1997 were of brother and sister. Progeny could have exhibited inbreeding effects such as reduced growth rate, lower survival, reduced feed conversion, and reduced fertility (Moav and Wohlfarth 1966, Ryman 1970, Kincaid 1976a, 1976b, Piper et al. 1982).

During the informal razorback sucker larvae study at 24-Road, mortality of larvae during length and weight measurement at day 36 was 48% for North Pond larvae, 32% for Horsethief larvae, 10% for Adobe Creek larvae, and 8% for brood stock. This difference in mortality suggested that North Pond and Horsethief larvae were weak and had a difficult time withstanding the anesthetization and handling. If the effects of inbreeding were uniform across spawns, then a similar amount of mortality should have occurred during measurements of Adobe Creek larvae.

Survival of larvae between 31 and 134 days of age during the observation period at 24-Road was highest in brood stock and Horsethief larvae (93%) and Adobe Creek larvae (94%), and lowest in North Pond larvae (64%), which suggested an effect from parental exposure and probably not inbreeding. Early growth of larvae held at 24-Road was comparable among larvae from young Horsethief or Adobe Creek adults and larvae from brood stock, but not larvae from North Pond adults.

Studies with rainbow trout have revealed that inbreeding can result in increased numbers of deformed fry (Kincaid 1976b, Piper et al. 1982). Aulstad and Kittlesen (1971) reported that the amount of deformities in inbred rainbow trout siblings could vary greatly between matings. They found that only one out of nine different sib groups of rainbow trout had a curved-spine deformity, and that this deformity was found in only 4 out of a total of 53 inbreeding groups. The lack of significant differences in survival and growth of larvae held at 24-Road suggested that these possible effects of inbreeding were not observed.

The deformities recorded during growth measurements of the larvae held at 24-Road seemed to vary among holding sites: dorsal and opercule deformities seemed most prominent in larvae from North Pond and brood stock; caudal, dorsal, and tail deformities seemed to be the least in Adobe Creek larvae compared to other larvae; and deformed snouts seemed to be unique to North Pond larvae. These differences in types and frequencies of deformities suggest an effect from exposure of the young adults and not inbreeding.

There were nearly 3-6 fold higher numbers of eye deformities in the larvae from young adults, compared to larvae from brood stock, held at 24-Road for 134 days post hatch during the informal observation period. The eye deformities may have been due to inbreeding or possibly selenium exposure. Although eye deformities have not been reported as occurring in inbred fish (Aulstad and Kittlesen 1971, Kincaid 1976b, Piper et al. 1982), other reports have linked eye deformities in fish to selenium exposure (Ellis et al. 1937, Woock et al. 1987, Lemly 1993c, 1997a, 1997b).

In the second reproduction study (Hamilton et al. 2001), deformities in embryos and newly hatched larvae were recorded by type rather than by individual fish, and therefore, no quantitation of deformities was possible. However, from a semi-quantitative and qualitative viewpoint, larvae from brood stock had the most deformities recorded, followed by larvae from North Pond adults (about two-thirds of the notations for brood stock larvae), Adobe Creek adults (half the notations as for North Pond larvae), and the least deformities were in Horsethief larvae (a third of the notations as for Adobe Creek larvae). This difference in the type and frequency of deformities suggests an effect from parental exposure of the young adults rather than inbreeding effects.

The lack of obvious inbreeding effects in the present study with razorback sucker, except for the possibility of eye deformities, may be due to "family effects" as discussed by Kandl and Thompson (1996). They reported the family linage of eastern mosquitofish significantly affected survival of individuals under environmental stress, regardless of the inbreeding coefficient of the individual. Nevertheless, possible effects from inbreeding may have occurred in the first and second reproduction studies with razorback sucker.

HAZARD ASSESSMENT

Lemly (1995) presented a protocol for aquatic hazard assessment of selenium, which was

formulated primarily in terms of the potential for food-chain bioaccumulation and reproductive impairment in fish and aquatic birds. The protocol incorporated five ecosystem components including water, sediment, benthic invertebrates, fish eggs, and bird eggs. Each component was given a numeric score based on the degree of hazard: 1, no identifiable hazard; 2, minimal hazard; 3, low hazard; 4, moderate hazard; 5, high hazard. The final hazard characterization was determined by adding the individual scores and comparing the total to the following evaluation criteria: 5, no hazard; 6-8, minimal hazard; 9-11, low hazard; 12-15, moderate hazard; 16-25, high hazard. Lemly (1996a) modified his protocol for use with four ecosystem components due to the difficulty in collecting residue information for all five components in an assessment. He adjusted the final ecosystem-level hazard assessment to the following four-component evaluation criteria: 4, no hazard; 5-7, minimal hazard; 8-10, low hazard; 11-14, moderate hazard; 15-20, high hazard.

Lemly (1995) defined five categories of hazards as follows: (1) high hazard denotes an imminent, persistent toxic threat sufficient to cause complete reproductive failure in most species of fish and aquatic birds; (2) moderate hazard indicates a persistent toxic threat of sufficient magnitude to substantially impair, but not eliminate reproductive success; some species will be severely affected whereas others will be relatively unaffected; (3) low hazard denotes a periodic or ephemeral toxic threat that could marginally affect the reproductive success of some sensitive species, but most species will be unaffected; (4) minimal hazard indicates that no toxic threat is identified, but concentrations of selenium are slightly elevated in one or more ecosystem components (water, sediment, invertebrates, fish eggs, bird eggs) compared to uncontaminated reference sites; (5) no hazard denotes that no toxic threat is identified and selenium concentrations are not elevated in any ecosystem component. The following hazard rating table is based on Lemly (1996a):

		Hazard				
		None	Minimal	Low	Moderate	High
Ecosystem component	Water (µg/L)	<1	1-2	2-3	3-5	>5
	Sediment (µg/g)	<1	1-2	2-3	3-4	>4
	Benthic invertebrate (µg/g)	<2	2-3	3-4	4-5	>5
	Fish eggs (µg/g)	<3	3-5	5-10	10-20	>20

These protocols have been used to assess the selenium hazard to aquatic ecosystems at Ouray NWR, UT, the Animas, LaPlata, and Mancos rivers in the San Juan River basin, and three Wildlife Management Areas in Nevada (Lemly 1995, 1996a, 1997c). Although the original protocol was published in 1995, apparently no critiques have been published pointing out any deficiencies in the protocol (D. Lemly, USFS, personal communication).

Present study

The information from the present study was used with the four-component hazard assessment (Table 36). The final hazards were moderate at Horsethief and high at Adobe Creek and North Pond. It is interesting to note that even though sediments at Adobe Creek were ranked as a minimal hazard because selenium concentrations were low, selenium concentrations in water, invertebrates, and fish eggs ranked as high hazards. The outcome of the hazard assessment protocol coincides with the observations in the razorback sucker larvae study with larvae from adults held at Adobe Creek and North Pond, but not at Horsethief. The nearly complete mortality during the first week of exposure of razorback sucker larvae fed zooplankton containing 4.6 μg/g selenium from Horsethief east wetland suggested that the protocol may be conservative. This selenium concentration in zooplankton from Horsethief east wetland (4.6 μg/g) was also the same as that linked with a sharp decline in survival of razorback sucker larvae in the second reproduction study (Hamilton et al. 2001).

It should be noted that the selenium values used in the protocol for water, sediment, chironomids, and fish eggs came from the hatchery ponds at Horsethief, whereas the zooplankton used in the larval fish study came from Horsethief east wetland, which received effluent only from the hatchery ponds. The sediments in Horsethief east wetland also were probably rich in organic material, and thus probably contained a large reservoir of selenium available to the wetland ecosystem, whereas the ponds were lined with clay. These incongruities, (i.e., [1] the use of zooplankton in the lab test and benthic invertebrates in the protocol, and [2] use of water, sediment, chironomid, and fish egg values from the hatchery pond source) may have caused the hazard estimate from the protocol to be lower than the actual outcome of the toxicity test with razorback sucker larvae.

The protocol specifies use of selenium concentrations in benthic invertebrates, but not water-column invertebrates such as zooplankton, as the dietary component of the protocol. The proposed dietary threshold for adverse effects from selenium in sensitive aquatic organisms was 3 μg/g (Maier and Knight 1994, Lemly 1993a; 1996b), but the dietary source or type, i.e., water-column organisms, benthic organisms, plant material, detritus, or prepared diet, was not specified. It seems reasonable that if the dietary toxic threshold is 3 μg/g, then in the protocol, the high hazard should be associated with a value closer to 3 μg/g rather than >5 μg/g.

In the present study, several inorganic elements were measured in water, zooplankton, sediment, and fish eggs, but only selenium was elevated to concentrations reported to cause adverse effects in fish. This scenario has occurred in other contaminant investigations. For example, Sorensen (1988) stated that "Fish kills [at Belews Lake, NC, and Martin Lake, TX] were considered a direct result of selenium release into the main basin of the lakes because several hundred analyses for metals, metalloids, physiochemical parameters, and pesticides provided essentially negative results except for sufficiently high levels of selenium in the water (about 5 μg/L) to warrant concern." Lemly (1985) reviewed information in 10 studies of potential causes for the cause of fishery problems at Belews Lake, and of the 16 inorganic elements of concern, only selenium was present at elevated concentrations in water and fish. Saiki and Lowe (1987) measured several inorganic and organic chemicals in water and biota collected from Kesterson Reservoir area, CA, and concluded only selenium was elevated sufficiently to be of concern to fisheries resources. Nakamoto and Hassler (1992) measured 20

Table 36. Hazard assessment of selenium in the razorback sucker reproduction study.

Site and environmental component	Selenium concentration[1]	Evaluation by component		Totals for the site	
		Hazard	Score	Score	Hazard
Horsethief					
Water	<1-3.8	Moderate	4		
Sediment	0.2-1.4	Minimal	2	14	Moderate
Invertebrate	8.0-13.6	High	5		
Fish egg	6.5	Low	3		
Adobe Creek					
Water	1.5-11.6	High	5		
Sediment	0.5-2.1	Minimal	2	17	High
Invertebrate	27.9-45.4	High	5		
Fish egg	46.5	High	5		
Walter Walker					
Water	3.8-19.6	High	5		
Sediment	7.2-55.4	High	5	20	High
Invertebrate	11.3-44.7	High	5		
Fish egg	37.8	High	5		

[1]Selenium concentrations in µg/L for water, µg/g for sediment, benthic invertebrate, and fish eggs.

trace elements in fish from the Merced River and from Salt Slough, San Joaquin Valley, CA, which carried primarily irrigation return flows, and concluded only selenium was present at toxic concentrations. Gillespie and Baumann (1986) concluded that in studies of Hyco Reservoir, NC, selenium was the element causing the deformities and reduced survival of bluegill larvae and not other elements (arsenic, cadmium, copper, lead, mercury, zinc) present in female bluegills. Bryson et al. (1984) concluded that selenium was the only element elevated sufficiently in zooplankton collected from Hyco Reservoir, NC, and not other elements (arsenic, cadmium, copper, mercury, or zinc), to cause the 97% mortality of juvenile bluegill after 1 week of dietary exposure. Montgomery Watson (1998) concluded that selenium was the major element of concern associated with phosphate mining activities in the Blackfoot River watershed of southeastern Idaho and not other elements (cadmium, manganese, nickel, vanadium, zinc). Skorupa (1998) reviewed 12 environmental case studies of clearly confirmed or highly probable selenium poisonings in nature, even though other inorganic elements were present.

Comparison with environmental conditions

The validity of extrapolating laboratory results, such as the egg study and larval fish study in the present investigation, to field situations had been questioned because of the lack of environmental realism with single-species tests (Cairns 1983, Kimball and Levin 1985). Yet, most investigators acknowledge that ecosystem studies require more subjective scientific judgments that laboratory test, are prohibitively expensive to conduct, lack theoretical basis to explain and relate the confounding morass of data collected, and lack of standardized protocols for conducting ecosystem studies. In contrast, several investigators have independently reviewed numerous laboratory and field studies of a wide variety of chemical contaminants and concluded that laboratory-derived information is a good predictor of ecosystem effects (Slooff et al. 1986, Arthur 1988, Emans et al. 1993, Sprague 1997). Sprague (1997) also reviewed several reports and concluded that ambient toxicity tests were good indicators of field effects.

Using the species of concern, similar conditions such as water quality, temperature, photoperiod, and relevant biological endpoints that can be linked to population level effects enhances achieving comparability between laboratory and field studies (Kenaga 1982). The present study incorporated these concerns in the experimental design by evaluating the effects on adults, eggs, and larvae of endangered razorback sucker exposed to water, sediment, and food organisms at three sites in aquatic locations in their current range in the upper Colorado River.

Extrapolating the results of the present study to the potential hazard in the field is a practical need in implementing the actions necessary to the recovery of endangered razorback sucker. Although single species testing has been questioned when used to evaluate the hazard to a community or ecosystem (Cairns 1983), this approach is appropriate when assessing the hazard of selenium in its various forms and combined with other inorganic elements from a source (i.e., irrigation activities) to specific organisms of concern (i.e., federally-listed endangered fishes). Razorback sucker were tested because they were endangered and indigenous to the upper Colorado River basin, not because they were considered the "most sensitive" species, which is the goal of most toxicity testing (Cairns 1986).

Comparing the biological effects concentration (BEC) with the expected (or measured) environmental concentrations (EEC) is a basis principle in evaluating the hazard of toxicants to aquatic life (Kimerle et al. 1979). The BEC/EEC quotient has been referred to as the margin of

uncertainty. In the early stages of hazard evaluation (i.e., acute toxicity tests) neither the BEC nor EEC is a precise value, but rather are values with wide confidence intervals due to variability associated with the BEC and EEC (Mount 1981). For example, the BEC will vary with the species and life stage tested, organism health, genetic constitution, route of exposure, water quality, and acclimation. The EEC will vary depending on water quality of the receiving water, mixing characteristics (flow rate, input rate, etc.), degradation (photo, biological, or chemical), and seasonal changes. Many of these concerns were specifically addressed in the experimental design of the present study, thus removing a substantial amount of uncertainty in the BEC and EEC values.

To evaluate the hazard of selenium in the present study, the margin of uncertainty was calculated by comparing the BEC (4.6 μg/g dietary selenium concentration causing adverse effects on razorback sucker larvae) with the EEC measured in potential food organisms of razorback sucker larvae collected from various aquatic locations in the upper Colorado River basin including the Green River. Margins of uncertainty of one [BEC/EEC=1] using field study-derived data indicate a high potential for environmental hazard, whereas higher margins (i.e., >1) indicate low potential (OECD 1989). Other examples of uncertainty factor include 10 for good quality chronic toxicity data, 100 for limited or poor chronic data, and 1000 for no chronic data (OECD 1989). The U.S. Environmental Protection Agency recommends similar safety factors (USEPA 1984), and there is international, national, and federal support of uncertainty (safety) factors in hazard assessments (Dourson and Stara 1983).

Several studies have reported selenium concentrations >4.6 μg/g in aquatic invertebrates in aquatic habitats in the upper Colorado River basin (Barnhart 1957, Birkner 1978, Butler et al. 1991, 1994, 1996, Peltz and Waddell 1991, Stephens et al. 1992, Waddell and Wiens 1994a, Hamilton et al. 1996, Wiens and Waddell 1996), and other reports have reported selenium concentrations in aquatic invertebrates greater than the dietary selenium threshold of 3 μg/g (Osmundson 1989, 1992). Consequently, the BEC/EEC ratio would be less than one for several locations in the upper Colorado River basin, which suggests that adverse effects on razorback sucker recruitment is probably occurring.

Assessing the hazard of selenium to razorback sucker using either the selenium hazard assessment protocol suggested by Lemly (1995, 1996a) or the BEC/EEC ratio (USEPA 1984, OECD 1989) indicates that selenium probably adversely affecting the survival of razorback sucker larvae. Other reports have suggested adverse effects from selenium were occurring in aquatic organisms in the Colorado River basin (reviewed in Hamilton 1998, 1999). Based on selenium concentrations measured in water, sediment, invertebrates, and fish given in published NIWQP reports of studies in the Green River and upper Colorado River basins, and biological effects measured in the present study and the second reproduction study (Hamilton et al. 2001), selenium contamination is adversely affecting razorback sucker. Recovery of razorback sucker should include addressing selenium contamination issues in the upper Colorado River basin, in addition to on-going efforts to address other factors contributing to the decline of endangered fish in the upper Colorado River basin such as stream alteration (dams, irrigation withdrawals, dewatering, channelization), loss of habitat (spawning sites, and backwater nursery areas), changes in flow regime, blockage of migration routes, water temperature and clarity changes, competition with and predation by introduced species, parasitism, and changes in food base.

UNCERTAINTIES

As with any field study, there are a variety of uncertainties that are present because of the inherent variability's associated with field studies compared to lab studies, which are generally conducted under highly controlled conditions (USEPA 1992). In field studies site characteristics can vary between sites and between locations within a site during the course of a study including physical environment (e.g., atmospheric and water temperature, hydrologic conditions, water quality, habitat variables such as sediments, plant, invertebrate, and fish communities), organisms behavior, exposure to stressors such as exposure concentration and duration, mixtures of organic and inorganic chemicals, interaction of physical and chemical stressors, and interactions with other ecological components (USEPA 1992). The variation in these kinds of site differences combined with the lack of standard methods for field studies results in uncertainties in the interpretation of results from field studies. However, USEPA (1992) acknowledges that professional judgment based on scientific expertise is needed for the interpretation of scientific data, particularly from field studies, which is frequently difficult and complex, conflicting or ambiguous, or incomplete.

Some uncertainties in the present study that were suggested during a meeting to review the study reports with the Biology Committee included (1) identifying potentially confounding factors, (2) potential effects from inbreeding, (3) whether deformities are an accurate measure of effect, (4) genetic adaptation of fish to selenium in specific areas, (5) selenium dietary threshold of 4.6 μg/g, (6) unexplained interaction/synergistic effects, (7) variation in study results between years, (8) no consistent quantitative response of fish to selenium concentrations, (9) application of "worst-case" situations at Adobe Creek and North Pond to the wild, (10) variability of zooplankton concentration and composition among years and sites, and (11) use of brine shrimp nauplii as a reference treatment for zooplankton treatments. Below is a brief discussion of uncertainties associated with the above 11 items.

1. Identifying potentially confounding factors. The major confounding factor was the use of inbred fish for the study [discussed below]. Other factors of lesser importance are (1) possible interactions between inorganic elements in water, diet, and water and diet [discussed below], (2) differences in the three sites such as water quality, habitat, and chemical, physical, and biological composition [inherent in all field studies], (3) use of brine shrimp as a reference treatment for field collected zooplankton used as selenium treatments [discussed in "Brine shrimp" section in the Larval Fish study discussion and below], and (4) differences in zooplankton composition within sites, among sites, and between years [discussed below].
2. Influence of inbreeding on the results of the Egg and Larvae Fish studies. All the fish used were progeny of a single spawn of two adult razorback sucker (female: PIT 7F7F19036C, and male: PIT 7F7D055802). The young razorback sucker adults used in the reproduction studies in 1996 (this study) and 1997 (Hamilton et al. 2001) came from a single mating in 1992, and thus the spawnings in 1996 and 1997 were of brother and sister. Progeny could have exhibited inbreeding effects such as reduced growth rate, lower survival, reduced feed conversion, reduced fertility, and increased numbers of deformed fry (Moav and Wohlfarth 1966, Ryman 1970, Kincaid 1976a, 1976b, Piper et al. 1982). The potential effects from inbreeding were discussed previously in sections

titled "Inbreeding" in the Egg study discussion and in the Larval Fish study discussion. Briefly, the lack of significant differences in percent viability, percent hatch, and mortality of embryos between embryos from young adults and brood stock, and the similarity of percent hatch and percent survival reported by other investigators for razorback sucker, suggest that inbreeding was not a major factor in the Egg study. Likewise in the Larval Fish study, inbreeding effects did not seem to be a major factor on measures of growth, survival, or deformities. However, the 3-6 folder higher numbers of eye-deformities in larvae from young adults compared to larvae form brood stock may have been due to inbreeding effects. The seemingly lower quality of larvae from the young adults was considered in part due to smaller sized eggs for first-time spawned fish compared to the higher quality, larger eggs from brood stock that had been spawned multiple times. However, the lower quality of the larvae from the young adults may have been a result of inbreeding. The uncertainty associated with the influence of inbreeding on the results of the Egg study and the Larval Fish study seems low to moderate.

3. Use of deformities as an accurate measure of selenium effects. Several factors were mentioned in the discussion section of the Egg study that causes deformities. Several papers were cited in the "Deformities in eggs and larvae" section of the Egg study to show that selenium could be responsible for the observed deformities. Deformities by themselves do not indicate that selenium or other specific stresses caused the deformities. However, the observed deformities in the present study coincided with elevated selenium residues in eggs, larvae, adult muscle plugs, and adult muscle tissue thus corroborating the likely possibility that selenium caused the deformities as suggested by Lemly (1997a). The uncertainty associated with the use of deformities as an accurate measure of selenium effects would be high in the absence of corroborating data, but low in the present study because of the substantial amount of corroborating data.
4. Possibility of genetic adaptation of fish to selenium in specific areas, i.e., the Colorado River basin. This aspect of the study was discussed in the "Selenium and other elements in water" section of the Adult study discussion. Although it may be possible for short-lived, rapid reproducing fish to evolve to a chronic selenium stress, no evidence was found in the literature that any animal, i.e., invertebrate, reptile, amphibian, fish, bird, or mammal, has adapted to chronic selenium exposure. The uncertainty associated with a possible genetic adaptation by fish in the Colorado River basin to long-tern selenium stress, while a popular supposition, seems low.
5. Selenium dietary threshold of 4.6 μg/g. This value was associated with reduced larval survival in both the first study using larvae from young adults and in the second reproduction study with larvae from brood stock conducted a year later (Hamilton et al. 2001). The occurrence of similar reduced survival in two different studies with different sources of razorback sucker larvae conducted a year a part suggests that there is a consistent sensitivity in razorback sucker larvae to dietary selenium. This value also coincides with several published papers, which were discussed in the "Selenium and other elements in zooplankton" section in the Larval Fish study discussion. The general consensus is that the threshold for dietary effects is about 3 μg/g (Lemly 1993a 1996b, Maier and Knight 1994). The uncertainty associated with adverse effects from dietary selenium occurring at 4.6 μg/g in food organisms seems low.
6. Unexplained interactions/synergistic effects. In any field study, a wide variety of

interactions are possible between stressors and ecological components (USEPA 1992). Although many inorganic elements were measured in water, sediment, and invertebrates in the present study, it is possible that other unmeasured elements may have contributed to interactions that affected the results. Likewise, the toxicological literature is incomplete concerning interactions between inorganic elements, thus interactions may have occurred between measured elements that have not yet been documented in the literature. Many water quality and sediment characteristics were measured, but the measurements were not exhaustive, and the literature is incomplete concerning interactions between water quality and sediment characteristics and chemical stressors such as inorganic elements, thus interactions between these variables may have influenced the results. No measurements were made of potential organic stressors, nor habitat differences, invertebrate community differences, and other ecological components, which may have aided in the interpretation of the results of the study. In spite of the possible shortage of information on chemical, physical, or biological stressors, ecosystem components, and possible interactions, the available information from the study seems consistent with the available literature, especially concerning selenium interactions and effects. One example of the literature aiding in explaining a seemingly odd result was the discussion of the interaction of arsenic and selenium in the "Brine shrimp" section of the Larval Fish study discussion. The uncertainty associated with interactions/synergistic effects seems low to moderate.

7. Variation in study results between years. Several study results that were consistent between years including (1) adults accumulated selenium in muscle plugs and eggs relative to the amount in food organisms at the location where they were held [the one exception in 1996 was Adobe Creek adults, but the possibility of a three-part reproduction cycle was discussed as a likely explanation in the "Selenium and other elements in eggs" section of the Adult study discussion], (2) eggs with elevated selenium had no effects on percent hatch or percent survival after hatch, (3) 4.6 μg/g selenium in zooplankton caused reduced survival of razorback sucker larvae from young adults in 1996 and from brood stock in 1997, (4) rapid mortality of larvae in 4-6 days after exposure to Horsethief water and zooplankton from Horsethief east wetland in 1996 and 1997 [consistent with results in the Ouray study conducted in 1994], (5) delayed mortality of larvae receiving the North Pond water and food treatments in both 1996 and 1997 [consistent with the Ouray study; suggested a synergistic interaction], and (6) similar hazard assessment ranking in 1996 and 1997. Overall, there was a consistent response of adults and larvae to selenium exposure in 1996 and 1997. The uncertainty associated with variation in study results between years seems low.
8. Lack of a consistent quantitative response of fish to selenium concentrations in water, diet, or both. A few study results showed a concentration response including (1) selenium accumulation in razorback sucker larvae after 30 days of exposure in 1996 [larvae starting with elevated selenium from parental transfer through egg yolk from Adobe Creek or North Pond adults depurated selenium to concentrations in their food for the Adobe Creek and North Pond treatments], (2) a significant negative correlation occurred between survival of larvae and selenium concentrations in larvae ($r = -0.55$, $P=0.10$) in 1996 [survival followed a concentration response: lowest survival (75%) was in North Pond larvae with the highest selenium residue (9.7 μg/g), intermediate (84%) in

Adobe Creek larvae with the intermediate selenium residue (7.7 µg/g), and highest in Horsethief and brood stock larvae (87-89%) with the lowest selenium residues (3.3-3.6 µg/g)], and (3) in 1997 survival followed a concentration response [lowest survival (52%) in larvae fed North Pond zooplankton and with whole-body residues of 16.0 µg/g, intermediate survival (72%) in larvae fed Adobe Creek zooplankton and with whole-body residues of 12.0 µg/g, and highest survival (81-83%) in larvae fed brine shrimp or zooplankton from HTEW and with whole-body residues of 5.2 µg/g]. The lack of a concentration response in the majority of published selenium studies was discussed in the "Delayed mortality" section of the Larval Fish study discussion (9 studies had no concentration response, 3 had a partial response and 2 had a concentration response). Thus, results from the 1996 study and the 1997 study place them in the partial response category. The uncertainty associated with the presence of limited concentration responses in the studies seems low.

9. Application of "worst-case" situations at Adobe Creek and North Pond to the wild. One objective of the study experimental design was to exposure adult razorback sucker to environmental concentrations of selenium that would cause accumulation of elevated selenium in adult tissue, which was achieved for adults held at Adobe Creek and North Pond. For the 1996 study, selenium concentrations in muscle plugs from adults held at Adobe Creek and North Pond for 9 months were lower than 40% of the wild razorback sucker adults sampled from the Green River (Waddell and May 1995, Stephens and Waddell 1998). For the 1997 study, selenium concentrations in muscle plugs from adults held at Adobe Creek and North Pond for 9 months in 1996, followed by 60 days depuration and a second 9-month exposure, were lower than 33% of the wild razorback sucker adults sampled from the Green River (Waddell and May 1995, Stephens and Waddell 1998). Although holding fish for one 9-month exposure in the 1996 study and a second 9-month exposure in the 1997 study may seem like a worst-case situation, the exposure failed to cause the adults to accumulate selenium comparable to those in wild fish, which have opportunities to move about the Green River. One uncertainty present is the length of time the wild adults accumulated selenium compared to the relatively rapid accumulation by adults held at Adobe Creek and North Pond. There are no studies differentiating between the chronic effects of relatively rapid (i.e., 9 months) verse slow (i.e., several years) accumulation of selenium in fish. The selenium accumulation in muscle plugs from adults held at Adobe Creek and North Pond apparently was not a worst-case situation because 33-40% of wild fish have higher selenium residues in muscle plugs. The uncertainty associated with the comparison of the worst-case situation in the present study with possible effects in wild fish seems low.
10. Variability of zooplankton concentration and composition among years and sites. The ratio of cladocerans to copepods was different between sites within a year, different at the same site between years, and different within a site over a 30-day period. This type of variation in zooplankton composition was similar to that reported by Grabowski and Hiebert (1989) for backwaters near Island Park, Jensen, and Ouray on the Green River. The zooplankton used in the Larval Fish studies were native to the area where razorback sucker have been historically found in the upper Colorado River, and therefore, were probably appropriate to use in the study. Natural variation in invertebrate communities would be expected spatially and temporally in aquatic ecosystems. Razorback sucker are

opportunistic feeders using whatever food source is presence, sometimes selecting certain organisms and other times selectively avoiding certain organisms, as discussed in the "Zooplankton" section in the Larval Fish study discussion. The uncertainty associated with the variability of zooplankton concentration and composition within sites, among sites, and among years seems low.

11. Use of brine shrimp nauplii as a reference for zooplankton treatments. We assumed that zooplankton from Horsetheif east wetland would be the reference treatment because (1) the wetland was located on the south side of the Colorado River and away from the majority of irrigation operations, which occur on the north side of the river, (2) some irrigation occurred near the wetland, but it was down gradient from the wetland, (3) the up-gradient side of the wetland was undisturbed land, and (4) the water source of the wetland was the Colorado River, and it was the same water used at the Horsethief Fish Facility where adult endangered fish were held. The brine shrimp nauplii treatment was added as an additional reference treatment for comparison to the HTEW diet treatment. Subsequent chemical analysis revealed elevated selenium in zooplankton from HTEW and high mortality in larvae receiving the diet, whereas slightly elevated selenium in brine shrimp, but low mortality probably due to antagonistic interactions between selenium and elevated arsenic in brine shrimp. Other potential differences between brine shrimp and zooplankton were addressed in the discussion section of Larval Fish study such as caloric content, food size, and food density, but no differences were found in the literature to suspect a substantial difference between the two diet types. The uncertainty associated with the use of brine shrimp as a reference treatment for zooplankton treatment is low.

Overall, the most prominent uncertainties in the study were the possible effects of inbreeding on the results of the Egg and Larval Fish studies and the use of brine shrimp nauplii as the reference treatment for the zooplankton treatments. The discussion section of these two studies addresses inbreeding concerns and concludes that the effects observed were more likely related to exposure than inbreeding. The discussion sections also address concerns about the nutritional comparability of the two diet types and concludes that the two diets were probably similar. Although the results of the field study may seem difficult and complex, conflicting or ambiguous, or incomplete to some readers, it is the professional judgment of the first author of this report, based on 26 years of research experience including 17 years of selenium research experience, that selenium was the primary stressor in the study and that the effects observed are consistent with the selenium literature.

One additional uncertainty is the comparison of information in the present study with information presented in three reports investigating the effects of selenium and other elements on razorback sucker larvae, flannelmouth sucker, and fathead minnow by Beyers and Sodergren (1999, 2001a, 2001b). Those reports seem incomplete and less than scientifically rigorous. Some of the problems include: (1) inadequate information or citations of analytical chemistry methods precludes drawing conclusions about residues measured in various types of samples, (2) there were little or no quality assurance/quality control information given for chemical analyses, (3) comparisons were made between larvae of different fish species tested at different ages (up to 30 days difference in age), (4) many exceptions to cited test methods (ASTM 1992a, 1990a) were made, but not noted, and seriously conflicted with the methods, (5) control water contained

>5 µg/L selenium, which exceeded the USEPA criterion (USEPA 1987), (6) growth of razorback sucker was substantially lower than reported by others for similar aged larvae (Papoulias and Minckley 1990, 1992, Marsh and Langhorst 1988) thus casing doubt on statements about growth effects, (7) inappropriate storage of site exposure water in Beyers and Sodergren (2001a) probably allowed the loss of selenium during storage (USEPA guidelines for use of site waters in toxicity tests is given in Lewis et al. 1994 and Weber 1993), and (8) little discussion of how the results of the studies relate to the selenium literature. In Beyers and Sodergren (2001a) the statement is made that "Larval razorback sucker studied in this investigation were not strongly negatively affected by exposure to site waters with dissolved selenium concentrations ≤20.3 µg/L and corresponding dietary selenium concentrations ≤21.8 µg/g," which is substantially different than the selenium literature (Lemly 1986, Maier et al. 1987, 1988, Maier and Knight 1994, Lemly 1996b, Skorupa et al. 1996, Skorupa 1998, Hamilton and Lemly 1999, Lemly 1999), yet the conclusion is not discussed. These concerns preclude discussing the results of Beyers and Sodergren (1999, 2001a, 2001b) relative to those in the present study.

CONCLUSIONS

1. Selenium was elevated in water, food-chain organisms, and sediments at North Pond, and elevated in adult tissues including eggs. Selenium was sufficiently elevated in food organisms collected from to cause reduced survival of razorback sucker larvae.
2. Selenium was elevated in water and food-chain organisms at Adobe Creek, and elevated in adult tissues including eggs. Selenium was sufficiently elevated in food organisms collected from Adobe Creek to cause reduced survival of razorback sucker larvae.
3. Although selenium was substantially elevated in eggs from adults held at Adobe Creek and North Pond, percent hatch and percent survival of eggs and newly hatched larvae was not different than that of reference eggs and newly hatched larvae.
4. Selenium was elevated sufficiently in food-chain organisms collected from Horsethief east wetland to cause reduced survival of razorback sucker larvae.

RECOMMENDATIONS

Selenium concentrations in water, food organisms, fish, and fish eggs should be taken into consideration in making management decisions.

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Appendix A. Average gage height (m) at one station at Walter Walker State Wildlife Area (WW) and two stations at Adobe Creek (AC) near Grand Junction, CO, and average flow (lps) of the Colorado River at the Colorado-Utah state line.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
04/12/95	0.15	-[1]	-	165,239
04/13/95	0.14	-	-	146,682
04/14/95	0.12	-	-	142,151
04/15/95	0.13	-	-	151,496
04/16/95	0.13	-	-	151,496
04/17/95	0.13	-	-	150,363
04/18/95	0.13	-	-	150,646
04/19/95	0.13	-	-	159,991
04/20/95	0.16	-	-	165,371
04/21/95	0.17	-	-	173,583
04/22/95	0.18	-	-	178,963
04/23/95	0.17	-	-	178,963
04/24/95	0.17	-	-	178,963
04/25/95	0.16	-	-	174,716
04/26/95	0.13	-	-	153,761
04/27/95	0.14	-	-	146,965
04/28/95	0.21	-	-	172,451
04/29/95	0.24	-	-	184,910
04/30/95	0.28	-	-	196,520
05/01/95	0.41	-	-	234,465
05/02/95	0.42	-	-	248,906
05/03/95	0.54	-	-	283,170
05/04/95	0.49	-	-	286,002
05/05/95	0.45	-	-	267,029
05/06/95	0.47	-	-	272,693
05/07/95	0.46	-	-	272,126

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
05/08/95	0.46	-	-	270,711
05/09/95	0.47	-	-	275,808
05/10/95	0.44	-	-	267,312
05/11/95	0.43	-	-	264,764
05/12/95	0.55	-	-	300,160
05/13/95	0.81	-	-	399,270
05/14/95	0.69	-	-	368,121
05/15/95	0.70	-	-	359,626
05/16/95	0.89	-	-	419,092
05/17/95	1.11	-	-	506,874
05/18/95	1.17	-	-	549,350
05/19/95	1.12	-	-	529,528
05/20/95	1.18	-	-	543,686
05/21/95	1.26	-	-	577,667
05/22/95	1.33	-	-	611,647
05/23/95	1.42	-	-	654,123
05/24/95	1.37	-	-	656,954
05/25/95	1.28	-	-	608,816
05/26/95	1.21	-	-	577,667
05/27/95	1.13	-	-	535,191
05/28/95	1.08	-	-	523,865
05/29/95	0.98	-	-	484,221
05/30/95	1.07	-	-	489,884
05/31/95	1.19	-	-	566,340
06/01/95	1.13	-	-	538,023
06/02/95	1.27	-	-	580,499
06/03/95	1.44	-	-	656,954
06/04/95	1.55	-	-	722,084

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
06/05/95	1.73	-	-	801,371
06/06/95	1.93	-	-	883,490
06/07/95	1.97	-	-	971,273
06/08/95	1.92	-	-	954,283
06/09/95	1.81	-	-	917,471
06/10/95	1.64	-	-	841,015
06/11/95	1.51	-	-	750,401
06/12/95	1.59	-	-	753,232
06/13/95	1.83	-	-	841,015
06/14/95	2.05	-	-	962,778
06/15/95	2.26	-	-	1,059,056
06/16/95	2.47	-	-	1,197,809
06/17/95	2.57	-	-	1,294,087
06/18/95	2.59	-	-	1,362,048
06/19/95	2.50	-	-	1,319,572
06/20/95	2.33	-	-	1,132,680
06/21/95	2.25	-	-	1,110,026
06/22/95	2.22	-	-	1,132,680
06/23/95	2.19	-	-	1,118,522
06/24/95	2.12	-	-	1,050,561
06/25/95	2.02	-	-	976,937
06/26/95	1.92	-	-	934,461
06/27/95	1.86	-	-	911,807
06/28/95	1.82	-	-	917,471
06/29/95	1.79	-	-	917,471
06/30/95	1.77	-	-	928,798
07/01/95	1.85	-	-	991,095
07/02/95	1.90	-	-	1,016,580

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
07/03/95	1.92	-	-	1,022,244
07/04/95	1.99	-	-	1,090,205
07/05/95	2.04	-	-	1,067,551
07/06/95	2.00	-	-	962,778
07/07/95	2.01	-	-	934,461
07/08/95	2.01	-	-	937,293
07/09/95	2.01	-	-	937,293
07/10/95	2.04	-	-	965,610
07/11/95	2.05	-	-	1,005,254
07/12/95	2.08	-	-	1,027,907
07/13/95	2.09	-	-	1,059,056
07/14/95	2.06	-	-	1,093,036
07/15/95	1.99	-	-	1,064,719
07/16/95	1.93	-	-	991,095
07/17/95	1.87	-	-	928,798
07/18/95	1.82	-	-	883,490
07/19/95	1.75	-	-	849,510
07/20/95	1.66	-	-	821,193
07/21/95	1.61	-	-	801,371
07/22/95	1.44	-	-	741,905
07/23/95	1.24	-	-	693,767
07/24/95	1.24	-	-	665,450
07/25/95	1.15	-	-	622,974
07/26/95	0.99	-	-	557,845
07/27/95	0.89	-	-	506,874
07/28/95	0.83	-	-	475,726
07/29/95	0.76	-	-	450,240
07/30/95	0.73	-	-	436,082

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
07/31/95	0.72	-	-	427,587
08/01/95	0.70	-	-	416,260
08/02/95	0.63	-	-	390,775
08/03/95	0.54	-	-	356,794
08/04/95	0.49	-	-	334,141
08/05/95	0.45	-	-	319,982
08/06/95	0.44	-	-	317,150
08/07/95	0.43	-	-	311,487
08/08/95	0.40	-	-	297,329
08/09/95	0.32	-	-	271,277
08/10/95	0.28	-	-	255,986
08/11/95	0.26	-	-	250,605
08/12/95	0.26	-	-	250,039
08/13/95	0.25	-	-	242,960
08/14/95	0.23	-	-	237,296
08/15/95	0.22	-	-	231,067
08/16/95	0.19	-	-	219,740
08/17/95	0.16	-	-	199,918
08/18/95	0.15	-	-	182,645
08/19/95	0.15	-	-	172,451
08/20/95	0.15	-	-	166,787
08/21/95	0.15	-	-	177,264
08/22/95	0.15	-	-	173,017
08/23/95	0.15	-	-	174,150
08/24/95	0.15	-	-	178,680
08/25/95	0.15	-	-	183,211
08/26/95	0.15	-	-	186,043
08/27/95	0.15	-	-	178,963

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
08/28/95	0.15	-	-	174,433
08/29/95	-	-	-	173,583
08/30/95	-	-	-	163,672
08/31/95	-	-	-	150,646
09/01/95	-	-	-	140,735
09/02/95	-	-	-	137,337
09/03/95	-	-	-	133,090
09/04/95	-	-	-	132,524
09/05/95	-	-	-	127,143
09/06/95	-	-	-	111,003
09/07/95	-	-	-	107,321
09/08/95	-	-	-	130,541
09/09/95	-	-	-	141,019
09/10/95	-	-	-	150,930
09/11/95	-	-	-	149,797
09/12/95	-	-	-	149,514
09/13/95	-	-	-	144,983
09/14/95	-	-	-	140,452
09/15/95	-	-	-	118,648
09/16/95	-	-	-	115,250
09/17/95	-	-	-	129,126
09/18/95	-	-	-	131,674
09/19/95	-	-	-	139,603
09/20/95	-	-	-	141,585
09/21/95	-	-	-	140,452
09/22/95	-	-	-	123,462
09/23/95	-	-	-	118,082
09/24/95	-	-	-	124,312

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
09/25/95	-	-	-	126,860
09/26/95	-	-	-	126,860
09/27/95	-	-	-	123,745
09/28/95	-	-	-	123,179
09/29/95	-	-	-	128,276
09/30/95	-	-	-	211,811
10/01/95	-	-	-	193,122
10/02/95	-	-	-	178,114
10/03/95	-	-	-	171,035
10/04/95	-	-	-	166,787
10/05/95	-	-	-	168,486
10/06/95	-	-	-	168,486
10/07/95	-	-	-	169,336
10/08/95	-	-	-	167,353
10/09/95	-	-	-	165,938
10/10/95	-	-	-	163,672
10/11/95	-	-	-	161,124
10/12/95	-	-	-	159,142
10/13/95	-	-	-	155,744
10/14/95	-	-	-	158,009
10/15/95	-	-	-	160,841
10/16/95	-	-	-	159,708
10/17/95	-	-	-	156,876
10/18/95	-	-	-	154,611
10/19/95	-	-	-	154,044
10/20/95	-	-	-	152,345
10/21/95	-	-	-	151,213
10/22/95	-	-	-	151,496

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
10/23/95	-	-	-	153,478
10/24/95	-	-	-	158,009
10/25/95	-	-	-	155,744
10/26/95	-	-	-	151,496
10/27/95	-	-	-	153,195
10/28/95	-	-	-	155,177
10/29/95	-	-	-	152,629
10/30/95	-	-	-	163,389
10/31/95	-	-	-	163,672
11/01/95	-	-	-	162,256
11/02/95	-	-	-	171,601
11/03/95	-	-	-	173,583
11/04/95	-	-	-	168,769
11/05/95	-	-	-	167,353
11/06/95	-	-	-	167,637
11/07/95	-	-	-	185,193
11/08/95	-	-	-	175,565
11/09/95	-	-	-	173,017
11/10/95	-	-	-	180,662
11/11/95	-	-	-	180,662
11/12/95	-	-	-	173,866
11/13/95	-	-	-	168,486
11/14/95	-	-	-	169,902
11/15/95	-	-	-	168,486
11/16/95	-	-	-	169,052
11/17/95	-	-	-	167,920
11/18/95	-	-	-	167,070
11/19/95	-	-	-	167,070

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
11/20/95	-	-	-	166,787
10/21/95	-	-	-	166,221
11/22/95	-	-	-	160,557
11/23/95	-	-	-	164,522
11/24/95	-	-	-	163,955
11/25/95	-	-	-	163,106
11/26/95	-	-	-	162,540
11/27/95	-	-	-	163,672
11/28/95	-	-	-	162,823
11/29/95	-	-	-	158,575
11/30/95	-	-	-	159,142
12/01/95	-	-	-	159,142
12/02/95	-	-	-	160,557
12/03/95	-	-	-	159,991
12/04/95	-	-	-	155,460
12/05/95	-	-	-	153,478
12/06/95	-	-	-	158,009
12/07/95	-	-	-	157,443
12/08/95	-	-	-	158,858
12/09/95	-	-	-	158,292
12/10/95	-	-	-	155,177
12/11/95	-	-	-	154,328
12/12/95	-	-	-	154,328
12/13/95	-	-	-	157,726
12/14/95	-	-	-	163,672
12/15/95	-	-	-	158,009
12/16/95	-	-	-	154,044
12/17/95	-	-	-	148,664

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
12/18/95	-	-	-	148,098
12/19/95	-	-	-	143,567
12/20/95	-	-	-	139,320
12/21/95	-	-	-	139,603
12/22/95	-	-	-	139,603
12/23/95	-	-	-	137,337
12/24/95	-	-	-	134,789
12/25/95	-	-	-	131,391
12/26/95	-	-	-	130,825
12/27/95	-	-	-	132,807
12/28/95	-	-	-	133,939
12/29/95	-	-	-	134,789
12/30/95	-	-	-	139,886
12/31/95	-	-	-	145,549
01/01/96	-	-	-	150,080
01/02/96	-	-	-	150,930
01/03/96	-	-	-	148,947
01/04/96	-	-	-	149,514
01/05/96	-	-	-	152,912
01/06/96	-	-	-	154,894
01/07/96	-	-	-	149,514
01/08/96	-	-	-	146,116
01/09/96	-	-	-	141,585
01/10/96	-	-	-	138,753
01/11/96	-	-	-	138,470
01/12/96	-	-	-	131,674
01/13/96	-	-	-	124,595
01/14/96	-	-	-	116,100

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
01/15/96	-	-	-	114,118
01/16/96	-	-	-	114,118
01/17/96	-	-	-	118,931
01/18/96	-	-	-	127,143
01/19/96	-	-	-	118,082
01/20/96	-	-	-	114,118
01/21/96	-	-	-	114,118
01/22/96	-	-	-	113,268
01/23/96	-	-	-	110,436
01/24/96	-	-	-	107,605
01/25/96	-	-	-	110,436
01/26/96	-	-	-	113,268
01/27/96	-	-	-	110,436
01/28/96	-	-	-	114,684
01/29/96	-	-	-	113,268
01/30/96	-	-	-	116,383
01/31/96	-	-	-	121,197
02/01/96	-	-	-	133,373
02/02/96	-	-	-	124,595
02/03/96	-	-	-	114,684
02/04/96	-	-	-	106,472
02/05/96	-	-	-	107,038
02/06/96	-	-	-	115,817
02/07/96	-	-	-	124,312
02/08/96	-	-	-	123,462
02/09/96	-	-	-	124,595
02/10/96	-	-	-	124,595
02/11/96	-	-	-	124,878

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
02/12/96	-	-	-	120,914
02/13/96	-	-	-	118,082
02/14/96	-	-	-	116,383
02/15/96	-	-	-	117,516
02/16/96	-	-	-	120,630
02/17/96	-	-	-	121,763
02/18/96	-	-	-	122,046
02/19/96	-	-	-	125,444
02/20/96	-	-	-	127,427
02/21/96	-	-	-	151,779
02/22/96	-	-	-	213,510
02/23/96	-	-	-	191,706
02/24/96	-	-	-	154,611
02/25/96	-	-	-	137,337
02/26/96	-	-	-	132,807
02/27/96	-	-	-	129,409
02/28/96	-	-	-	122,896
02/29/96	-	-	-	123,745
03/01/96	-	-	-	122,329
03/02/96	-	-	-	121,197
03/03/96	-	-	-	124,028
03/04/96	-	-	-	124,312
03/05/96	-	-	-	126,011
03/06/96	-	-	-	132,240
03/07/96	-	-	-	130,258
03/08/96	-	-	-	118,648
03/09/96	-	-	-	116,949
03/10/96	-	-	-	115,817

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
03/11/96	-	-	-	126,577
03/12/96	-	-	-	128,842
03/13/96	-	-	-	134,223
03/14/96	0.32	-	-	138,470
03/15/96	0.32	-	-	138,753
03/16/96	0.34	-	-	150,080
03/17/96	0.35	-	-	159,991
03/18/96	0.36	-	-	164,522
03/19/96	0.36	-	-	162,540
03/20/96	0.35	-	-	157,726
03/21/96	0.36	-	-	160,841
03/22/96	0.36	-	-	162,256
03/23/96	0.40	-	-	170,752
03/24/96	0.44	-	-	186,326
03/25/96	0.44	-	-	185,193
03/26/96	0.42	-	-	173,583
03/27/96	0.42	-	-	173,866
03/28/96	0.42	-	-	173,583
03/29/96	0.42	-	-	174,716
03/30/96	0.42	-	-	179,813
03/31/96	0.42	-	-	185,193
04/01/96	0.42	-	-	186,892
04/02/96	0.44	-	0.38	194,821
04/03/96	0.47	0.58	0.40	211,245
04/04/96	0.50	0.60	0.45	229,368
04/05/96	0.51	0.60	0.46	230,500
04/06/96	0.49	0.57	0.44	218,890
04/07/96	0.50	0.58	0.45	222,288

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
04/08/96	0.52	0.61	0.48	233,332
04/09/96	0.55	0.66	0.52	247,491
04/10/96	0.62	0.75	0.58	283,170
04/11/96	0.67	0.81	0.63	319,982
04/12/96	0.72	0.91	0.71	342,636
04/13/96	0.69	0.89	0.70	322,814
04/14/96	0.65	0.84	0.66	308,655
04/15/96	0.56	0.73	0.58	279,206
04/16/96	0.49	0.63	0.50	242,960
04/17/96	0.56	-	-	236,730
04/18/96	0.61	-	-	244,942
04/19/96	0.62	-	-	255,419
04/20/96	0.62	-	-	251,738
04/21/96	0.56	-	-	235,314
04/22/96	0.52	-	-	225,120
04/23/96	0.51	-	-	214,360
04/24/96	0.51	-	-	210,112
04/25/96	0.56	-	-	234,465
04/26/96	0.69	-	-	294,497
04/27/96	0.76	-	-	328,477
04/28/96	0.78	-	-	336,972
04/29/96	0.81	-	-	342,636
04/30/96	0.72	-	-	314,319
05/01/96	0.72	-	-	305,824
05/02/96	0.72	-	-	314,319
05/03/96	0.73	-	-	317,150
05/04/96	0.74	-	-	322,814
05/05/96	0.75	-	-	328,477

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
05/06/96	0.85	-	-	370,953
05/07/96	0.95	-	-	413,428
05/08/96	1.11	-	-	450,240
05/09/96	1.16	-	1.12	475,726
05/10/96	1.22	-	1.15	506,874
05/11/96	1.19	-	1.11	495,548
05/12/96	1.22	-	1.15	495,548
05/13/96	1.37	-	1.30	540,855
05/14/96	1.47	-	1.39	605,984
05/15/96	1.57	1.66	1.47	642,796
05/16/96	1.62	1.71	1.53	665,450
05/17/96	1.76	1.84	1.67	724,915
05/18/96	1.90	1.97	1.83	807,035
05/19/96	1.86	1.94	1.79	798,539
05/20/96	1.88	1.96	1.81	807,035
05/21/96	1.80	1.89	1.73	787,213
05/22/96	1.58	1.68	1.50	688,103
05/23/96	1.46	1.57	1.37	628,637
05/24/96	1.37	1.48	1.26	583,330
05/25/96	1.24	1.36	1.13	532,360
05/26/96	1.18	1.29	1.05	495,548
05/27/96	1.16	1.28	1.03	495,548
05/28/96	1.05	1.17	0.96	453,072
05/29/96	0.96	1.10	-	416,260
05/30/96	0.87	1.01	-	376,616
05/31/96	0.82	0.96	-	356,794
06/01/96	0.79	0.94	-	345,467
06/02/96	0.80	0.95	-	345,467

Appendix A. Continued.

Date	Average gage height			Colorado River flow
	WW9	~AC1	~AC6	
06/03/96	0.85	0.99	-	356,794
06/04/96	0.96	1.09	-	390,775
06/05/96	1.03	1.16	-	421,923
06/06/96	1.12	1.23	-	453,072
06/07/96	1.18	1.29	-	484,221
06/08/96	1.18	1.29	-	487,052
06/09/96	1.17	1.29	-	487,052
06/10/96	1.15	1.27	-	481,389
06/11/96	1.13	1.25	-	470,062
06/12/96	1.11	1.24	0.98	461,567
06/13/96	1.13	1.25	1.01	467,231
06/14/96	1.13	1.25	1.01	467,231
06/15/96	1.17	1.29	1.05	481,389
06/16/96	1.28	1.40	1.18	529,528

[1]-: No measurement.

Appendix B. Water quality characteristics measured on-site near the inlet (i) and outlet (o) of ponds when fish were held in that pond at Horsethief Canyon State Wildlife Area, Adobe Creek, and Walter Walker State Wildlife Area near Grand Junction, Colorado.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
HT2i	05/03/95	-64	20.0	15.0	8.58	600	<1.0[3]	8.5
HT6i	05/03/95	-64	15.0	16.1	8.64	660	<1.0	10.0
	05/11/95	-56	12.0	15.5	8.90	610	<1.0	9.8
	05/19/95	-48	17.0	17.1	9.12	590	<1.0	8.9
	05/24/95	-43	20.0	17.9	8.63	580	<1.0	7.1
	06/01/95	-35	27.0	19.5	8.64	560	<1.0	9.1
	06/06/95	-30	16.0	18.1	8.25	560	<1.0	6.7
	06/12/95	-24	≈30.0[4]	22.0	8.15	580	<1.0	6.5
HT1i	06/19/95	-17	24.0	20.0	8.82	410	<1.0	8.6
	06/26/95	-10	29.0	23.5	8.65	430	<1.0	7.1
	07/05/95	-01	25.0	23.8	8.62	400	<1.0	7.2
	07/10/95	04	27.0	24.1	8.27	390	<1.0	6.9
	07/17/95	11	31.0	27.0	8.53	380	<1.0	7.6
	07/24/95	18	34.5	25.8	8.61	380	<1.0	7.9
	07/31/95	25	30.5	25.8	8.58	390	<1.0	7.3
	08/08/95	33	27.0	23.4	8.66	430	<1.0	6.7
HT6i	08/23/95	48	28.0	23.0	8.51	230	1.2	7.6
	08/31/95	56	31.0	24.3	8.60	710	<1.0	9.1
	09/07/95	63	26.0	23.6	8.22	820	<0.5	7.8
	09/12/95	68	12.0	20.0	8.42	880	0.5	7.5
HT1i	09/21/95	77	18.0	18.4	8.55	1,030	0.5	8.4
	09/27/95	83	28.0	16.9	8.67	1,010	0.5	9.9
	10/05/95	91	10.0	13.8	8.27	950	0.5	9.4
	10/12/95	98	17.0	13.5	8.90	900	0.5	9.6
	10/18/95	104	20.0	14.2	8.77	880	0.5	-[5]
	10/31/95	117	-	12.8	8.74	910	1.0	10.7

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
HT1i	11/07/95	124	-	8.4	8.60	800	0.5	11.3
HT6i	11/14/95	131	3.0	6.9	8.71	840	0.5	11.7
	11/16/95	133	5.0	11.6	8.67	670	0.5	9.8
	11/30/95	147	6.0	5.1	8.47	810	0.5	11.9
	12/06/95	153	13.0	8.0	8.52	810	0.5	11.1
	12/11/95	158	4.0	4.3	8.47	830	0.5	11.5
	12/19/95	166	-2.0	3.1	8.43	860	0.5	12.5
	01/09/96	187	<-2.0	1.9	8.61	900	0.5	13.0
	01/19/96	197	5.0	2.8	8.46	870	0.5	14.1
	01/25/96	203	0.0	2.0	8.80	890	0.5	13.3
	02/02/96	211	4.0	3.2	8.64	860	0.5	14.3
	02/08/96	217	8.0	4.5	8.74	820	0.5	12.9
	02/12/96	221	-4.0	3.9	8.60	840	0.5	11.4
	02/20/96	229	12.0	8.0	8.40	890	0.5	11.3
	02/29/96	238	7.0	6.3	8.93	930	0.5	12.0
	03/07/96	245	15.0	6.8	8.78	920	0.5	11.5
	03/12/96	250	16.0	9.6	8.62	920	0.5	10.6
	03/21/96	259	23.0	13.8	8.63	890	0.5	10.4
	03/28/96	266	20.0	12.0	8.50	800	0.5	10.0
	04/04/96	273	17.0	14.5	8.71	750	0.5	9.2
	04/10/96	279	20.0	16.5	8.69	720	0.5	10.5
	04/16/96	285	4.0	11.6	8.82	670	<0.5	9.8
	04/26/96	295	23.0	13.8	8.81	640	<0.5	8.8
	05/02/96	301	25.0	14.2	8.41	520	<0.5	9.4
	05/21/96	320	25.0	18.1	8.59	400	<0.5	7.6
	05/31/96	330	27.0	20.0	-	440	<0.5	7.9
	06/07/96	337	31.5	22.5	8.98	460	<0.5	8.9

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
HT6i	06/11/96	341	22.0	20.3	8.79	400	<0.5	7.7
	06/21/96	351	30.0	22.5	8.70	410	<0.5	7.4
HT2o	05/03/95	-64	20.0	15.8	8.64	600	<1.0	8.9
HT6o	05/03/95	-64	15.0	15.7	8.85	610	<1.0	11.4
	05/11/95	-56	12.0	15.5	8.78	610	<1.0	9.5
	05/19/95	-48	17.5	17.2	9.08	590	<1.0	9.6
	05/24/95	-43	20.0	18.6	8.65	570	<1.0	7.4
	06/01/95	-35	26.0	20.6	8.57	550	<1.0	8.5
	06/06/95	-30	18.0	18.2	8.11	560	<1.0	6.5
	06/12/95	-24	≈30.0[4]	22.1	8.09	580	<1.0	6.5
HT1o	06/19/95	-17	23.0	21.2	8.83	410	<1.0	8.6
	06/26/95	-10	30.0	23.6	8.58	430	<1.0	7.2
	07/05/95	-01	24.0	23.3	8.55	390	<1.0	7.3
	07/10/95	04	27.0	24.1	8.43	400	<1.0	6.9
	07/17/95	11	31.0	27.0	8.57	380	<1.0	7.8
	07/24/95	18	32.0	24.8	8.56	380	<1.0	8.0
	07/31/95	25	30.5	24.7	8.67	400	<1.0	7.4
	08/08/95	33	28.0	23.8	8.49	430	<1.0	6.8
HT6o	08/23/95	48	28.0	26.0	8.57	210	1.0	9.2
	08/31/95	56	31.0	25.1	8.73	700	<1.0	8.6
	09/07/95	63	26.0	23.6	8.13	820	<0.5	7.8
	09/12/95	68	12.0	20.2	8.43	880	0.5	7.3
HT1o	09/21/95	77	18.0	18.7	8.45	1,020	0.5	8.4
	09/27/95	83	27.0	18.3	8.54	1,030	0.5	9.5
	10/05/95	91	10.0	13.4	8.19	960	0.5	9.1
	10/12/95	98	18.0	13.6	8.64	900	0.5	9.6
	10/18/95	104	20.0	15.0	8.68	860	0.5	-

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
HT6o	10/31/95	117	-	13.7	8.71	890	1.0	10.8
	11/07/95	124	-	8.2	8.69	810	0.5	11.1
	11/14/95	131	2.0	6.7	8.51	850	0.5	11.7
	11/30/95	147	9.0	5.0	8.34	810	1.0	12.0
	12/06/95	153	15.0	7.4	8.44	830	0.5	11.2
	12/11/95	158	2.0	4.6	8.31	820	0.5	11.4
	12/19/95	166	-2.0	3.8	8.27	840	0.5	12.5
	01/09/96	187	<-2.0	0.2	8.58	950	0.5	13.8
	01/19/96	197	4.0	0.7	8.29	840	0.5	13.9
	01/25/96	203	0.0	1.0	8.87	920	0.5	13.4
	02/02/96	211	8.0	2.8	8.58	870	0.5	14.5
	02/08/96	217	6.0	2.3	9.28	790	0.5	13.2
	02/12/96	221	-4.0	3.4	8.64	850	0.5	11.8
	02/20/96	229	12.0	7.6	8.26	900	0.5	11.2
	02/29/96	238	12.0	6.1	9.18	940	0.5	12.3
	03/07/96	245	15.0	7.1	8.91	910	0.5	11.4
	03/12/96	250	16.0	9.7	8.55	920	0.5	10.6
	03/21/96	259	24.0	14.0	8.95	890	0.5	10.0
	03/28/96	266	27.0	11.5	8.35	810	0.5	10.4
	04/04/96	273	19.0	13.8	8.82	760	0.5	9.5
	04/10/96	279	22.0	17.0	8.94	710	0.5	10.3
	04/16/96	285	4.0	11.6	8.82	670	<0.5	9.8
	04/26/96	295	20.0	14.3	8.64	630	<0.5	9.2
	05/02/96	301	26.0	15.0	8.25	510	<0.5	9.3
	05/21/96	320	21.0	18.5	8.70	410	<0.5	7.7
	05/31/96	330	28.0	19.5	-	450	<0.5	7.8
	06/07/96	337	29.0	22.4	9.08	460	<0.5	9.2

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
HT6o	06/11/96	341	22.0	20.0	8.67	400	<0.5	7.7
	06/21/96	351	34.0	23.0	8.67	400	<0.5	7.5
AC1	05/03/95	-64	17.0	11.4	8.13	550	<1.0	9.3
	05/11/95	-56	17.0	11.7	8.05	580	<1.0	9.4
	05/19/95	-48	17.0	11.9	7.98	480	<1.0	9.5
	05/24/95	-43	14.0	12.8	7.16	420	<1.0	5.9
	05/31/95	-36	22.5	13.2	7.81	460	<1.0	8.7
	06/06/95	-30	16.0	13.2	7.37	450	<1.0	8.4
	06/12/95	-24	28.0	17.6	7.90	420	<1.0	7.3
	06/26/95	-10	27.0	15.2	8.11	310	<1.0	8.8
	07/05/95	-01	22.5	13.8	7.64	330	<1.0	9.1
	07/10/95	04	18.0	15.5	7.73	300	<1.0	8.4
	07/17/95	11	22.0	17.3	7.89	320	<1.0	8.8
	07/24/95	18	26.0	20.2	7.89	500	<1.0	6.8
	07/31/95	25	28.0	18.0	8.06	440	<1.0	8.2
	08/08/95	33	21.0	18.4	7.90	540	<1.0	7.9
	08/23/95	48	21.0	21.0	7.79	920	1.0	7.4
	08/31/95	56	24.0	21.2	8.49	860	<1.0	8.0
	09/07/95	63	22.0	20.8	8.31	1,090	<0.5	9.3
	09/12/95	68	7.0	17.2	7.40	940	0.5	7.8
	09/21/95	77	13.0	15.6	8.52	980	1.0	9.2
	09/27/95	83	20.0	14.9	8.20	1,050	0.5	10.1
	10/05/95	91	6.0	11.5	7.10	940	0.5	9.1
	10/12/95	98	10.0	12.2	7.48	930	0.5	9.0
	10/18/95	104	9.0	10.7	8.48	890	0.5	10.5
	10/31/95	117	-	10.8	8.60	890	0.5	11.2

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC1	11/07/95	124	-	7.1	8.50	840	<0.5	10.7
	11/14/95	131	<-2.0	6.1	8.47	860	0.5	10.8
	11/30/95	147	4.0	4.7	8.63	820	0.5	12.8
	12/06/95	153	14.0	8.0	8.47	810	0.5	12.4
	12/11/95	158	<-2.0	4.2	8.58	830	0.5	11.7
	12/19/95	166	<-2.0	2.4	8.41	880	1.0	13.1
	01/09/96	187	<-2.0	0.5	8.76	850	1.0	12.7
	01/19/96	197	4.0	1.1	7.99	920	0.5	13.4
	01/26/96	204	-4.0	0.7	8.37	1,030	0.5	13.3
	02/02/96	211	-2.0	1.9	8.47	900	1.0	13.1
	02/08/96	217	6.0	4.1	8.16	920	0.5	12.1
	02/12/96	221	3.0	3.3	8.33	940	0.5	11.6
	02/20/96	229	13.0	5.8	8.05	950	0.5	11.0
	02/29/96	238	6.0	4.2	8.44	910	0.5	12.2
	03/07/96	245	7.0	5.1	8.33	890	0.5	11.2
	03/12/96	250	13.0	7.9	8.43	890	0.5	10.5
	03/21/96	259	27.0	8.3	8.50	730	0.5	11.0
	03/28/96	266	23.0	7.8	8.30	740	0.5	10.2
	04/04/96	273	21.0	11.3	8.30	610	<0.5	9.3
	04/12/96	281	15.0	8.7	8.07	490	<0.5	9.5
	04/16/96	285	0.0	7.9	7.94	600	0.5	10.5
	04/26/96	295	21.0	12.5	8.16	560	0.5	9.1
	05/02/96	301	19.0	10.7	8.18	520	<0.5	9.3
	05/21/96	320	17.0	12.8	7.94	350	<0.5	8.4
	05/31/96	330	19.5	14.0	-	520	<0.5	8.7
	06/07/96	337	22.0	15.0	8.24	380	<0.5	8.6
	06/11/96	341	18.0	15.2	8.03	390	<0.5	8.4

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC2	06/21/96	351	26.5	16.6	8.13	380	<0.5	8.7
	05/03/95	-64	19.0	11.5	8.14	550	<1.0	9.4
	05/11/95	-56	17.0	11.4	7.87	570	<1.0	9.3
	05/19/95	-48	19.0	12.0	8.09	470	<1.0	9.5
	05/24/95	-43	15.0	11.2	7.33	390	<1.0	9.3
	05/31/95	-36	24.0	12.3	7.77	460	<1.0	9.5
	06/06/95	-30	14.5	13.2	7.42	360	<1.0	8.8
	06/12/95	-24	28.0	13.6	8.23	340	<1.0	9.1
	06/26/95	-10	27.0	14.3	7.94	300	<1.0	9.0
	07/05/95	-01	21.0	13.1	8.31	320	<1.0	9.3
	07/10/95	04	20.0	15.2	7.70	300	<1.0	8.7
	07/17/95	11	24.0	17.0	7.99	310	<1.0	9.0
	07/24/95	18	25.0	16.4	8.50	360	0.0	8.6
	07/31/95	25	24.0	18.6	7.88	430	<1.0	8.2
	08/08/95	33	22.0	18.3	8.39	540	<1.0	8.0
	08/23/95	48	22.0	21.0	7.99	870	1.0	7.2
	08/31/95	56	27.0	21.0	8.44	870	<1.0	8.0
	09/07/95	63	22.0	20.9	8.08	1,080	0.5	8.7
	09/12/95	68	8.0	17.2	7.92	940	0.5	7.7
	09/21/95	77	14.0	15.5	8.53	980	<0.5	9.1
	09/27/95	83	21.0	15.5	7.18	1,100	1.0	8.8
	10/05/95	91	5.0	11.5	7.24	940	0.5	9.1
	10/12/95	98	10.0	12.3	7.69	920	0.5	9.0
	10/18/95	104	9.0	10.5	8.42	900	0.5	10.5
	10/31/95	117	-	11.4	8.54	950	0.5	11.3
	11/07/95	124	-	7.0	8.48	840	0.5	10.6
	11/14/95	131	<-2.0	6.1	8.45	860	0.5	10.8

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC2	11/30/95	147	3.0	4.6	8.54	820	0.5	12.5
	12/06/95	153	16.0	7.8	8.61	820	0.5	12.5
	12/11/95	158	<-2.0	4.0	8.32	840	0.5	11.7
	12/19/95	166	<-2.0	2.2	8.39	890	0.5	13.3
	01/09/96	187	<-2.0	0.6	8.44	840	1.0	13.0
	01/19/96	197	5.0	1.4	7.90	910	0.5	13.3
	01/26/96	204	-4.0	0.4	8.24	1,040	0.5	12.9
	02/02/96	211	-2.0	1.8	8.45	900	0.5	13.4
	02/08/96	217	2.0	3.8	8.18	920	0.5	12.1
	02/12/96	221	5.0	3.3	8.14	940	0.5	11.6
	02/20/96	229	11.0	5.7	8.19	950	0.5	10.8
	02/29/96	238	11.0	3.8	8.44	920	0.5	12.1
	03/07/96	245	6.0	5.1	8.29	890	0.5	10.8
	03/12/96	250	13.0	7.6	8.45	900	0.5	10.6
	03/21/96	259	22.0	8.3	8.51	730	0.5	11.0
	03/28/96	266	22.0	8.2	8.24	740	0.5	10.2
	04/04/96	273	16.0	11.6	8.24	600	<0.5	9.6
	04/12/96	281	16.0	8.6	7.97	480	<0.5	9.6
	04/16/96	285	0.0	7.7	7.84	600	0.5	10.6
	04/26/96	295	19.0	12.0	8.19	570	0.5	9.0
	05/02/96	301	20.0	11.3	8.13	510	<0.5	9.3
	05/21/96	320	18.0	11.6	8.02	300	<0.5	9.4
	05/31/96	330	22.0	14.0	-	510	<0.5	8.7
	06/07/96	337	24.0	15.1	8.23	370	<0.5	8.6
	06/11/96	341	20.0	15.1	8.34	380	<0.5	8.5
	06/21/96	351	26.0	15.9	8.17	340	<0.5	8.5
AC3	05/03/95	-64	18.0	16.2	7.69	1,680	<1.0	10.8

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC3	05/11/95	-56	17.0	13.1	7.55	1,680	1.0	5.8
	05/19/95	-48	17.0	14.3	7.46	1,630	1.0	2.1
	05/24/95	-43	13.0	14.9	7.19	1,490	1.0	1.9
	05/31/95	-36	23.5	20.1	7.39	1,820	1.0	2.9
	06/06/95	-30	15.0	16.8	7.32	1,540	1.0	2.6
	06/12/95	-24	29.0	20.3	7.71	770	<1.0	4.4
	06/26/95	-10	27.5	17.9	7.82	500	<1.0	6.0
	07/05/95	-01	23.0	16.0	8.12	350	<1.0	8.9
	07/10/95	04	20.0	20.5	7.02	550	<1.0	5.7
	07/17/95	11	24.0	21.3	7.51	540	<1.0	5.9
	07/24/95	18	25.0	24.1	7.72	710	<1.0	6.2
	07/31/95	25	25.5	23.8	7.29	610	<1.0	4.5
	08/08/95	33	25.0	23.0	7.55	730	<1.0	5.1
	08/23/95	48	22.0	23.0	7.45	750	<1.0	3.9
	08/31/95	56	28.0	22.6	7.78	940	<1.0	3.0
	09/07/95	63	22.0	22.7	8.07	890	0.5	6.4
	09/12/95	68	8.0	19.9	7.11	1,000	0.5	2.4
	09/21/95	77	15.0	17.7	8.44	1,050	1.0	6.4
	09/27/95	83	23.0	17.0	7.94	1,060	0.5	8.8
	10/05/95	91	4.5	12.5	7.10	1,050	1.0	5.8
	10/12/95	98	10.0	12.0	7.55	1,060	0.5	7.5
	10/18/95	104	5.0	10.5	8.00	1,110	0.5	9.4
	10/31/95	117	-	12.3	7.70	1,190	1.0	7.5
	11/07/95	124	-	6.7	7.64	1,230	1.0	6.6
	11/14/95	131	<-2.0	5.3	7.84	880	1.0	7.3
	11/30/95	147	5.0	4.4	8.05	990	0.5	8.2
	12/06/95	153	14.0	8.4	7.96	950	1.0	9.4

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC3	12/11/95	158	<-2.0	3.4	7.90	940	1.0	8.6
	12/19/95	166	<-2.0	4.3	8.30	990	1.0	11.2
	01/09/96	187	<-2.0	0.5	9.05	1,030	1.0	13.9
	01/19/96	197	3.0	2.9	8.14	860	0.5	17.5
	01/26/96	204	-4.0	3.2	8.96	940	0.5	18.6
	02/02/96	211	-3.0	1.1	9.07	920	1.0	>20.0
	02/08/96	217	2.0	3.2	8.12	680	0.5	18.3
	02/12/96	221	2.0	4.4	8.36	820	0.5	13.7
	02/20/96	229	13.0	7.2	8.41	910	0.5	13.8
	02/29/96	238	4.0	5.4	8.18	880	1.0	13.3
	03/07/96	245	11.0	6.4	8.13	930	0.5	10.4
	03/12/96	250	15.0	9.4	9.05	930	0.5	10.2
	03/21/96	259	17.0	10.0	8.67	840	0.5	9.4
	03/28/96	266	17.0	11.3	8.80	810	0.5	11.3
	04/04/96	273	19.0	16.9	8.61	770	0.5	8.8
	04/12/96	281	15.0	11.9	7.67	670	0.5	6.2
	04/16/96	285	0.0	11.8	8.54	740	0.5	8.8
	04/26/96	295	19.0	16.1	8.12	840	0.5	6.4
	05/02/96	301	20.0	15.1	8.26	740	<1.0	7.1
	05/21/96	320	18.0	18.1	7.57	1,040	1.0	3.8
	05/31/96	330	22.0	17.5	-	1,170	1.0	5.1
	06/07/96	337	24.5	21.1	7.60	1,140	1.0	4.8
	06/11/96	341	21.0	22.2	7.57	1,000	1.0	5.2
	06/21/96	351	28.0	22.4	7.63	950	1.0	4.0
AC4	05/03/95	-64	19.0	18.3	7.57	1,430	1.0	6.5
	05/11/95	-56	17.0	15.3	7.53	1,600	1.0	6.4
	05/19/95	-48	19.0	16.3	7.88	1,440	1.0	7.7

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC4	05/24/95	-43	14.0	16.7	7.18	1,600	1.0	5.9
	05/31/95	-36	23.0	21.1	7.61	1,730	1.0	7.9
	06/06/95	-30	15.0	16.9	7.43	950	<1.0	6.9
	06/12/95	-24	28.0	18.7	7.77	800	<1.0	3.4
	06/26/95	-10	27.0	18.5	7.90	350	<1.0	7.1
	07/05/95	-01	22.0	13.2	8.25	340	<1.0	9.0
	07/10/95	04	20.0	19.0	7.55	420	<1.0	6.4
	07/17/95	11	24.5	21.4	7.80	480	<1.0	4.7
	07/24/95	18	24.0	22.6	7.91	630	0.0	4.2
	07/31/95	25	24.0	23.8	7.67	610	<1.0	3.0
	08/08/95	33	22.0	23.1	7.69	730	<1.0	2.8
	08/23/95	48	22.0	23.0	7.19	750	<1.0	1.4
	08/31/95	56	27.0	22.9	7.70	830	<1.0	2.8
	09/07/95	63	22.0	22.5	7.77	840	<0.5	3.2
	09/12/95	68	7.0	19.5	7.62	1,010	0.5	2.4
	09/21/95	77	14.0	18.3	8.20	1,030	1.0	3.5
	09/27/95	83	21.0	16.0	7.05	1,090	0.5	5.5
	10/05/95	91	5.0	12.6	7.44	1,050	1.0	4.6
	10/12/95	98	10.0	11.9	7.55	1,070	0.5	7.7
	10/18/95	104	10.0	10.7	7.92	1,100	0.5	6.4
	10/31/95	117	-	11.5	7.91	1,140	1.0	8.9
	11/07/95	124	-	6.0	8.09	1,260	1.0	8.9
	11/14/95	131	<-2.0	3.9	8.05	1,000	1.0	7.1
	11/30/95	147	5.0	2.7	8.20	1,040	1.0	10.6
	12/06/95	153	15.0	7.8	8.61	970	0.5	9.7
	12/11/95	158	<-2.0	3.9	7.99	1,000	1.0	8.4
	12/19/95	166	<-2.0	2.8	8.30	1,040	1.0	12.0

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC4	01/09/96	187	<-2.0	0.0	8.53	860	1.0	12.4
	01/19/96	197	5.0	0.7	8.04	1,490	1.0	16.5
	01/26/96	204	-2.0	0.2	8.22	950	0.5	13.0
	02/02/96	211	-2.0	0.1	8.59	950	1.0	15.1
	02/08/96	217	3.0	0.7	8.43	930	0.5	12.5
	02/12/96	221	6.0	1.9	8.01	980	0.5	12.0
	02/20/96	229	12.0	6.8	8.19	920	0.5	11.8
	02/29/96	238	6.0	4.7	8.52	900	0.5	12.1
	03/07/96	245	10.2	6.3	8.34	930	0.5	10.2
	03/12/96	250	13.0	9.0	8.42	940	0.5	11.3
	03/21/96	259	18.0	10.3	8.53	830	0.5	10.8
	03/28/96	266	23.0	10.1	8.39	840	0.5	10.2
	04/04/96	273	19.0	15.1	8.27	860	0.5	8.1
	04/12/96	281	15.0	13.4	7.71	770	0.5	5.2
	04/16/96	285	0.0	11.7	8.03	800	0.5	8.3
	04/26/96	295	19.0	16.0	8.02	840	0.5	7.4
	05/02/96	301	20.0	14.9	8.04	800	<0.5	8.8
	05/21/96	320	18.0	19.4	7.37	1,010	1.0	3.6
	05/31/96	330	22.0	20.0	-	1,000	0.5	6.5
	06/07/96	337	23.5	21.9	7.90	1,060	1.0	5.9
	06/11/96	341	20.5	22.4	7.79	790	0.5	5.4
	06/21/96	351	25.0	23.2	8.52	620	0.5	6.0
AC5	05/03/95	-64	18.0	18.0	7.54	1,500	1.0	9.3
	05/11/95	-56	18.0	17.0	7.59	1,650	1.0	9.0
	05/19/95	-48	19.0	18.0	7.76	1,380	1.0	11.4
	05/24/95	-43	15.0	17.5	7.44	1,520	1.0	8.6
	05/31/95	-36	24.0	20.1	7.63	1,760	<1.0	9.6

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC5	06/06/95	-30	16.0	16.4	7.44	1,320	1.0	6.2
	06/12/95	-24	27.0	18.3	7.93	800	<1.0	4.8
	06/26/95	-10	28.0	21.2	7.82	380	<1.0	6.9
	07/05/95	-01	21.0	14.1	8.22	340	<1.0	8.9
	07/10/95	04	22.0	19.3	7.69	450	<1.0	5.5
	07/17/95	11	24.0	23.0	7.64	510	<1.0	5.4
	07/24/95	18	26.5	23.4	7.78	620	<1.0	4.1
	07/31/95	25	23.0	24.6	7.41	600	<1.0	3.2
	08/08/95	33	20.0	22.8	7.85	630	<1.0	4.2
	08/23/95	48	24.0	24.0	7.25	730	<1.0	2.7
	08/31/95	56	28.0	24.8	7.71	800	<1.0	4.2
	09/07/95	63	22.0	23.0	7.79	880	<0.5	4.8
	09/12/95	68	8.0	19.4	7.72	1,010	0.5	3.6
	09/21/95	77	14.0	18.8	7.95	1,020	1.0	3.3
	09/27/95	83	21.0	15.4	7.28	1,100	0.5	5.6
	10/05/95	91	8.0	13.3	7.22	1,030	1.0	6.2
	10/12/95	98	12.0	12.0	7.53	1,060	0.5	8.3
	10/18/95	104	10.0	11.3	8.40	1,080	0.5	-
	10/31/95	117	-	10.2	7.84	1,120	1.0	9.1
	11/07/95	124	-	6.1	7.98	1,250	1.0	9.7
	11/14/95	131	<-2.0	5.3	7.77	960	1.0	8.2
	11/30/95	147	4.0	4.9	7.76	1,060	1.0	10.4
	12/06/95	153	14.0	7.5	7.82	1,130	1.0	9.8
	12/11/95	158	<-2.0	3.5	8.04	1,020	1.0	10.4
	12/19/95	166	<-2.0	3.3	8.33	1,020	1.0	12.7
	01/09/96	187	<-2.0	0.0	8.66	1,050	1.0	9.4
	01/19/96	197	3.0	1.2	8.17	920	0.5	14.3

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC5	01/26/96	204	-2.0	0.9	8.16	1,020	0.5	13.4
	02/02/96	211	-2.0	1.1	8.39	920	0.5	12.4
	02/08/96	217	4.0	1.4	8.10	820	0.5	12.6
	02/12/96	221	6.0	3.1	7.69	860	0.5	11.5
	02/20/96	229	12.0	7.3	8.32	910	0.5	12.3
	02/29/96	238	7.0	6.1	8.38	940	0.5	12.3
	03/07/96	245	-	6.3	8.73	930	0.5	11.1
	03/12/96	250	15.0	9.1	8.67	930	0.5	12.7
	03/21/96	259	18.0	12.8	8.23	910	0.5	10.2
	03/28/96	266	19.0	9.9	8.56	840	0.5	10.5
	04/04/96	273	21.0	13.8	8.21	890	<0.5	8.5
	04/12/96	281	13.0	14.1	7.76	760	0.5	6.7
	04/16/96	285	1.0	11.5	8.20	810	0.5	10.6
	04/26/96	295	22.0	16.4	8.09	840	0.5	7.6
	05/02/96	301	23.0	15.6	8.47	730	0.5	13.1
	05/21/96	320	20.0	19.4	7.58	900	1.0	7.2
	05/31/96	330	21.5	21.0	-	1,030	0.5	10.4
	06/07/96	337	25.0	22.1	8.86	1,060	1.0	10.1
	06/11/96	341	21.0	21.8	7.98	640	<0.5	5.8
	06/21/96	351	23.5	22.9	8.68	620	<0.5	8.4
AC6	05/03/95	-64	18.0	20.1	7.59	1,540	1.0	6.9
	05/11/95	-56	18.0	17.0	7.61	2,120	1.0	6.5
	05/19/95	-48	19.0	17.9	7.73	1,620	1.0	3.7
	05/24/95	-43	18.0	14.7	7.26	1,000	<1.0	3.2
	05/31/95	-36	25.0	22.8	7.50	2,090	1.0	4.5
	06/06/95	-30	16.0	14.2	7.76	420	<1.0	7.7
	06/12/95	-24	27.0	16.3	8.22	530	<1.0	6.8

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC6	06/26/95	-10	28.0	16.9	7.92	360	<1.0	7.3
	07/05/95	-01	21.0	14.4	8.31	340	<1.0	8.8
	07/10/95	04	22.0	18.5	7.71	410	<1.0	6.8
	07/17/95	11	24.0	18.7	7.80	390	<1.0	7.0
	07/24/95	18	26.0	21.3	7.77	540	<1.0	8.3
	07/31/95	25	23.0	25.3	7.83	700	<1.0	5.5
	08/08/95	33	20.0	22.1	7.69	740	<1.0	4.9
	08/23/95	48	26.0	25.0	7.27	1,100	<1.0	7.2
	08/31/95	56	28.0	24.6	7.70	910	<1.0	7.3
	09/07/95	63	23.0	23.3	7.73	930	<0.5	6.2
	09/12/95	68	8.0	18.9	7.67	1,020	0.5	5.3
	09/21/95	77	14.0	20.3	7.84	1,210	1.0	8.0
	09/27/95	83	21.0	16.4	7.36	1,080	0.5	7.4
	10/05/95	91	8.0	12.6	7.43	1,050	0.5	7.8
	10/12/95	98	12.0	12.0	7.64	1,060	0.5	9.1
	10/18/95	104	15.0	12.1	8.25	1,060	0.5	-
	10/31/95	117	-	16.7	7.43	3,450	3.0	≥20
	11/07/95	124	-	10.8	7.37	3,980	2.5	7.1
	11/14/95	131	-1.0	5.3	7.65	1,360	1.0	7.9
	11/30/95	147	4.0	5.1	7.36	3,630	2.5	4.9
	12/06/95	153	14.0	12.6	7.29	4,000	5.0	8.0
	12/11/95	158	<-2.0	5.8	7.35	3,790	2.0	1.8
	12/19/95	166	<-2.0	5.6	7.50	4,130	2.5	3.8
	01/09/96	187	<-2.0	0.2	7.74	2,940	1.5	5.7
	01/19/96	197	3.0	6.6	7.19	3,390	2.0	6.7
	01/26/96	204	3.0	4.4	7.32	3,630	2.0	5.0
	02/02/96	211	-1.0	5.7	7.54	3,560	2.0	9.1

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC6	02/08/96	217	5.0	5.8	7.46	3,470	2.0	6.3
	02/12/96	221	6.0	3.9	7.30	3,430	2.0	6.1
	02/20/96	229	13.0	9.1	7.45	3,520	2.0	6.2
	02/29/96	238	8.0	8.5	7.80	3,940	2.5	9.2
	03/07/96	245	4.0	9.1	7.79	3,090	2.0	6.6
	03/12/96	250	15.0	10.0	7.71	3,290	2.0	5.6
	03/21/96	259	20.0	12.6	7.82	3,730	2.5	8.6
	03/28/96	266	20.0	12.8	7.71	3,720	2.5	7.8
	04/04/96	273	20.0	19.1	7.85	3,830	2.5	7.3
	04/12/96	281	15.0	13.6	7.58	3,390	2.0	7.9
	04/16/96	285	2.0	11.1	7.54	3,540	2.0	7.8
	04/26/96	295	20.0	16.8	8.14	830	0.5	9.1
	05/02/96	301	23.0	15.8	8.48	850	0.5	12.6
	05/21/96	320	20.0	14.1	7.75	420	0.5	7.9
	05/31/96	330	21.5	21.5	-	2,250	1.5	8.9
	06/07/96	337	25.0	22.5	7.69	2,420	2.0	7.7
	06/11/96	341	21.0	21.4	7.94	700	<0.5	6.4
	06/21/96	351	25.0	21.3	8.08	650	<0.5	7.3
AC7	08/31/95	56	30.0	22.8	8.37	840	<1.0	9.4
	09/07/95	63	24.0	23.0	8.21	940	<0.5	10.7
	09/12/95	68	12.0	19.1	7.79	1,010	0.5	9.9
	09/21/95	77	14.0	18.1	8.35	1,040	1.0	9.3
	09/27/95	83	21.0	15.9	7.99	1,090	0.5	12.3
	10/05/95	91	10.0	12.6	7.90	1,050	1.0	9.7
	10/12/95	98	13.0	12.3	7.91	1,060	0.5	11.6
	10/18/95	104	19.0	11.6	8.90	1,080	0.5	-
	10/31/95	117	NS[6]	NS	NS	NS	NS	NS

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
AC7	11/07/95	124	NS	NS	NS	NS	NS	NS
	11/14/95	131	NS	NS	NS	NS	NS	NS
	11/30/95	147	NS	NS	NS	NS	NS	NS
	12/06/95	153	NS	NS	NS	NS	NS	NS
	12/11/95	158	NS	NS	NS	NS	NS	NS
	12/19/95	166	NS	NS	NS	NS	NS	NS
	01/09/96	187	NS	NS	NS	NS	NS	NS
	01/19/96	197	NS	NS	NS	NS	NS	NS
	01/26/96	204	NS	NS	NS	NS	NS	NS
	02/02/96	211	NS	NS	NS	NS	NS	NS
	02/08/96	217	NS	NS	NS	NS	NS	NS
	02/12/96	221	NS	NS	NS	NS	NS	NS
	02/20/96	229	NS	NS	NS	NS	NS	NS
	02/29/96	238	NS	NS	NS	NS	NS	NS
	03/07/96	245	NS	NS	NS	NS	NS	NS
	03/12/96	250	NS	NS	NS	NS	NS	NS
	03/21/96	259	NS	NS	NS	NS	NS	NS
	03/28/96	266	NS	NS	NS	NS	NS	NS
	04/04/96	273	NS	NS	NS	NS	NS	NS
	04/12/96	281	NS	NS	NS	NS	NS	NS
	04/16/96	285	NS	NS	NS	NS	NS	NS
	04/26/96	295	25.0	14.9	8.53	800	0.5	9.6
	05/02/96	301	25.0	14.7	8.57	680	<1.0	9.7
	05/21/96	320	NS	NS	NS	NS	NS	NS
	05/31/96	330	NS	NS	NS	NS	NS	NS
	06/07/96	337	27.5	23.7	9.83	510	<0.5	8.9
	06/11/96	341	21.0	21.3	8.58	540	<0.5	8.9

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW1	06/21/96	351	23.0	22.7	9.05	520	<0.5	9.4
	05/04/95	-63	13.0	10.2	8.18	540	<1.0	9.3
	05/11/95	-56	17.0	12.3	8.11	560	<1.0	9.2
	05/19/95	-48	24.0	13.4	8.12	450	<1.0	9.5
	05/23/95	-44	20.0	13.8	8.05	380	<1.0	9.2
	06/01/95	-35	17.0	13.0	7.78	390	<1.0	9.3
	06/05/95	-31	20.0	12.7	7.33	350	<1.0	9.3
	06/12/95	-24	21.0	12.7	7.70	340	<1.0	9.3
	06/19/95	-17	19.0	11.7	7.87	290	<1.0	9.5
	06/26/95	-10	22.0	13.2	7.77	280	<1.0	9.3
	07/05/95	-01	18.0	12.4	7.54	310	<1.0	9.3
	07/11/95	05	26.0	14.9	8.16	270	<1.0	8.9
	07/17/95	11	25.5	15.7	7.63	300	<1.0	9.1
	07/24/95	18	23.0	16.7	7.33	340	0.0	8.8
	08/01/95	26	24.0	18.3	8.56	410	<1.0	8.4
	08/07/95	32	19.0	17.9	8.75	510	<1.0	8.7
	08/22/95	47	23.0	21.0	8.19	810	<1.0	8.5
	08/31/95	56	25.0	20.6	8.50	760	<1.0	7.7
	09/07/95	63	20.0	19.7	7.39	1,000	1.0	8.0
	09/11/95	67	17.0	17.5	8.51	930	0.5	7.9
	09/21/95	77	8.0	14.5	7.45	1,000	1.0	8.7
	09/26/95	82	17.0	12.9	8.56	1,040	0.5	9.3
	10/05/95	91	12.0	12.1	8.64	930	<0.5	9.3
	10/12/95	98	22.0	13.5	8.68	900	<0.5	9.8
	10/17/95	103	-	11.5	9.33	880	0.5	10.2
	11/01/95	118	-	10.5	8.39	830	0.5	9.6
	11/07/95	124	-	8.4	8.59	800	<0.5	11.3

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW1	11/13/95	130	-1.0	5.2	8.48	800	0.5	11.3
	11/30/95	147	12.0	5.7	8.67	790	0.5	13.0
	12/07/95	154	2.0	6.1	8.42	780	0.5	11.3
	12/12/95	159	2.0	4.4	8.33	820	0.5	11.4
	12/19/95	166	5.0	2.8	8.49	870	0.5	13.5
	01/10/96	188	<-2.0	1.2	8.12	920	0.5	13.2
	01/19/96	197	-3.0	1.7	8.30	990	0.5	13.5
	01/25/96	203	5.0	0.9	8.61	930	<1.0	13.4
	02/02/96	211	4.0	1.8	8.51	900	0.5	13.8
	02/09/96	218	9.0	4.0	8.35	920	0.5	12.1
	02/13/96	222	3.0	2.4	8.27	880	0.5	12.0
	02/20/96	229	11.0	5.4	8.24	960	1.0	10.9
	02/29/96	238	4.0	2.7	8.48	960	0.5	12.2
	03/07/96	245	16.0	5.9	8.49	870	0.5	11.3
	03/11/96	249	15.0	6.7	8.72	920	0.5	12.3
	03/21/96	259	14.0	7.4	8.55	750	0.5	10.9
	03/28/96	266	16.0	7.7	8.31	750	0.5	9.9
	04/04/96	273	18.0	10.7	8.36	590	<0.5	9.6
	04/12/96	281	12.0	8.3	8.06	480	<0.5	9.9
	04/15/96	284	4.0	6.5	8.06	560	0.5	10.4
	04/26/96	295	13.0	11.6	8.39	550	0.5	9.0
	05/02/96	301	17.0	10.4	8.29	510	<0.5	9.5
	05/20/96	319	16.0	11.4	8.40	280	<0.5	9.3
	05/31/96	330	16.0	13.7	8.58	470	<0.5	8.8
	06/07/96	337	19.5	14.4	8.20	340	<0.5	8.6
	06/10/96	340	22.0	14.3	8.54	350	<0.5	8.6
	06/21/96	351	24.5	15.0	8.25	320	<0.5	8.7

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW2	05/04/95	-63	14.0	14.9	8.51	12,390	7.0	12.6
	05/11/95	-56	18.0	17.8	8.85	12,750	8.0	16.5
	05/19/95	-48	22.0	22.7	8.76	7,320	4.5	13.9
	05/23/95	-44	19.0	20.9	9.25	8,680	5.0	12.3
	06/01/95	-35	20.5	19.8	9.09	9,990	6.0	10.4
	06/05/95	-31	23.0	20.3	9.06	4,390	2.0	11.6
	06/12/95	-24	24.0	20.5	9.62	6,560	4.0	11.7
	06/19/95	-17	22.0	16.5	8.02	1,020	<1.0	6.3
	06/26/95	-10	24.0	22.6	9.34	2,990	2.0	12.1
	07/05/95	-01	20.0	21.8	9.14	3,090	2.0	9.4
	07/11/95	05	29.0	24.8	9.06	3,410	2.0	4.0
	07/17/95	11	25.0	25.7	9.08	3,060	2.0	10.1
	07/24/95	18	25.0	24.6	8.70	3,280	2.5	6.5
	08/01/95	26	24.0	24.5	8.70	3,640	2.0	3.0
	08/07/95	32	18.0	23.7	8.66	3,840	2.0	2.5
	08/22/95	47	21.0	24.0	7.84	2,040	1.0	4.7
	08/31/95	56	24.0	23.7	7.90	1,540	1.0	4.4
	09/07/95	63	23.0	23.4	7.89	1,550	1.0	3.6
	09/11/95	67	13.0	20.5	7.87	1,420	1.0	2.2
	09/21/95	77	9.0	17.1	7.94	1,300	1.0	3.9
	09/26/95	82	21.0	16.5	8.27	1,310	1.0	8.1
	10/05/95	91	15.0	15.7	8.31	1,280	1.0	6.8
	10/12/95	98	24.0	16.6	8.30	1,310	1.0	9.8
	10/17/95	103	-	16.5	8.48	1,310	1.0	9.4
	11/01/95	118	-	12.0	8.00	1,260	1.0	8.9
	11/07/95	124	-	10.4	8.05	1,250	1.0	10.4
	11/13/95	130	3.0	5.6	8.18	1,270	1.0	9.6

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW2	11/30/95	147	12.0	8.8	8.52	1,300	1.0	11.0
	12/07/95	154	2.0	6.3	8.31	1,400	1.0	10.4
	12/12/95	159	9.0	4.8	8.12	1,460	1.0	9.7
	12/19/95	166	8.0	5.0	8.44	1,460	1.0	13.6
	01/10/96	188	<-2.0	1.7	7.87	1,710	1.0	14.8
	01/19/96	197	-2.0	1.7	7.68	1,800	1.0	15.1
	01/25/96	203	3.0	3.4	7.96	2,040	1.5	14.9
	02/02/96	211	4.0	4.1	8.24	2,160	1.0	>20.0
	02/09/96	218	7.0	5.4	7.91	2,560	1.5	15.2
	02/13/96	222	3.0	2.6	8.02	2,880	2.0	12.3
	02/20/96	229	8.0	7.3	8.27	3,400	2.5	9.9
	02/29/96	238	3.0	4.2	8.49	3,820	2.5	14.2
	03/07/96	245	16.0	9.0	8.26	4,030	2.5	12.2
	03/11/96	249	18.0	8.4	7.96	4,390	3.0	9.2
	03/21/96	259	17.0	11.5	8.05	5,390	3.0	9.8
	03/28/96	266	16.0	11.3	8.07	5,820	4.0	9.0
	04/04/96	273	20.0	17.7	8.23	6,970	4.0	11.7
	04/12/96	281	13.0	10.6	7.93	7,590	4.0	8.9
	04/15/96	284	4.0	7.3	8.13	7,100	4.5	9.5
	04/26/96	295	17.0	13.4	7.99	8,990	5.5	7.0
	05/02/96	301	18.0	14.1	8.16	9,470	6.0	8.4
	05/20/96	319	20.0	19.2	8.95	6,180	4.0	7.1
	05/31/96	330	19.0	20.0	8.75	4,200	2.5	8.0
	06/07/96	337	22.0	22.7	8.67	4,390	3.0	3.7
	06/10/96	340	23.0	22.9	8.11	4,580	3.0	2.3
	06/21/96	351	28.0	23.8	8.22	4,250	3.0	3.9
WW3	05/04/95	-63	12.0	15.3	8.52	12,270	7.0	13.5

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW3	05/11/95	-56	19.0	18.2	8.81	12,070	7.0	16.3
	05/19/95	-48	20.0	21.1	8.64	6,480	4.0	13.4
	05/23/95	-44	20.0	20.3	9.08	8,790	5.0	11.3
	06/01/95	-35	20.0	19.7	8.87	9,460	6.0	14.3
	06/05/95	-31	20.5	18.6	8.91	4,100	2.0	11.3
	06/12/95	-24	24.0	20.6	9.81	6,550	4.0	12.4
	06/19/95	-17	20.0	16.5	7.96	840	<1.0	7.3
	06/26/95	-10	24.5	22.3	9.27	2,950	2.0	11.6
	07/05/95	-01	20.0	20.7	9.07	2,620	1.5	8.4
	07/11/95	05	30.0	25.4	9.27	3,370	2.0	5.5
	07/17/95	11	24.0	25.3	8.91	2,980	2.0	7.9
	07/24/95	18	24.5	24.7	8.45	3,320	2.5	6.8
	08/01/95	26	23.0	24.0	8.84	3,670	2.0	4.4
	08/07/95	32	17.0	23.7	8.60	4,000	2.5	2.9
	08/22/95	47	22.0	23.0	7.76	2,030	1.0	4.4
	08/31/95	56	23.0	23.5	7.91	1,540	1.0	4.6
	09/07/95	63	21.0	22.5	7.85	1,360	1.0	3.6
	09/11/95	67	15.0	21.1	7.86	1,510	1.0	3.4
	09/21/95	77	10.0	18.0	7.81	1,380	1.0	4.8
	09/26/95	82	22.0	16.0	8.25	1,270	1.0	7.9
	10/05/95	91	13.0	15.7	8.22	1,220	0.5	7.8
	10/12/95	98	27.0	16.2	8.19	1,260	1.0	8.9
	10/17/95	103	-	15.3	8.37	1,350	1.0	11.5
	11/01/95	118	-	11.8	8.18	1,270	1.0	9.8
	11/07/95	124	-	10.0	8.22	1,260	1.0	11.2
	11/13/95	130	4.0	6.3	8.17	1,240	1.0	10.2
	11/30/95	147	14.0	7.7	8.43	1,340	1.0	12.7

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW3	12/07/95	154	2.0	5.6	8.19	1,430	1.0	10.3
	12/12/95	159	10.0	4.9	8.10	1,460	1.0	10.6
	12/19/95	166	7.0	4.8	8.39	1,460	1.0	13.9
	01/10/96	188	0.0	1.4	8.16	1,820	1.0	>20.0
	01/19/96	197	-1.0	1.1	7.83	2,020	1.0	>20.0
	01/25/96	203	3.0	1.5	8.26	2,270	1.5	>20.0
	02/02/96	211	6.0	2.8	8.31	2,260	1.5	>20.0
	02/09/96	218	10.0	3.9	8.13	2,510	1.5	>20.0
	02/13/96	222	4.0	3.8	7.95	2,860	2.0	14.8
	02/20/96	229	10.0	7.5	8.04	3,600	2.5	11.6
	02/29/96	238	2.0	4.5	8.50	3,860	2.5	15.1
	03/07/96	245	14.0	8.1	8.34	4,210	2.5	13.6
	03/11/96	249	18.0	9.1	8.32	4,600	3.0	15.4
	03/21/96	259	15.0	11.8	8.25	5,010	3.5	13.1
	03/28/96	266	18.0	11.9	8.16	5,340	4.0	12.7
	04/04/96	273	22.0	18.8	8.28	6,810	4.0	14.6
	04/12/96	281	12.0	12.5	7.95	7,220	4.5	9.6
	04/15/96	284	5.0	8.6	8.12	7,140	5.0	10.7
	04/26/96	295	18.0	15.3	8.08	8,590	5.0	11.2
	05/02/96	301	20.0	14.6	8.24	8,740	5.5	13.9
	05/20/96	319	19.0	19.6	8.71	5,580	4.0	8.1
	05/31/96	330	19.5	20.6	8.80	3,820	2.5	10.3
	06/07/96	337	21.0	22.4	8.76	4,160	3.0	7.2
	06/10/96	340	24.0	23.3	8.40	4,440	3.0	4.3
	06/21/96	351	27.0	23.3	8.15	4,240	3.0	6.1
WW4	05/04/95	-63	14.0	11.4	7.76	10,810	5.0	9.4
	05/11/95	-56	18.0	15.5	7.95	11,000	6.0	9.9

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW4	05/19/95	-48	23.0	21.6	7.84	2,780	2.0	6.7
	05/23/95	-44	20.0	19.7	7.80	1,560	1.0	5.2
	06/01/95	-35	19.0	17.1	7.41	2,590	2.0	1.9
	06/05/95	-31	20.0	16.9	7.40	1,180	<1.0	5.8
	06/12/95	-24	21.5	18.0	7.65	1,270	1.0	2.3
	06/26/95	-10	24.5	17.9	7.81	380	<1.0	7.3
	07/05/95	-01	19.0	15.9	7.71	460	<1.0	7.8
	07/11/95	05	29.0	18.7	8.57	410	<1.0	9.2
	07/17/95	11	26.0	19.0	7.45	410	<1.0	5.8
	07/24/95	18	21.5	20.8	7.42	1,300	1.0	3.3
	08/01/95	26	22.0	17.5	7.65	4,440	2.5	2.8
	08/07/95	32	18.0	19.3	7.96	8,980	5.0	7.3
	08/22/95	47	20.0	27.0	8.29	6,740	4.0	12.7
	08/31/95	56	23.0	19.2	7.77	7,870	5.0	5.3
	09/07/95	63	20.0	20.3	7.75	9,890	6.0	4.9
	09/11/95	67	15.0	15.0	8.20	11,120	7.0	4.9
	09/21/95	77	7.0	9.8	7.54	9,160	5.0	5.9
	09/26/95	82	16.0	12.4	8.27	10,540	6.0	9.9
	10/05/95	91	11.0	11.0	8.24	6,820	4.0	9.9
	10/12/95	98	22.0	14.1	8.16	8,840	5.5	12.4
	10/17/95	103	-	10.2	8.65	9,760	6.0	11.5
	11/01/95	118	-	7.9	7.82	7,420	4.5	7.9
	11/07/95	124	-	11.3	7.91	5,960	4.0	12.9
	11/13/95	130	-2.0	1.4	7.68	6,830	4.0	10.0
	11/30/95	147	12.0	4.7	7.46	8,980	5.0	11.6
	12/07/95	154	3.0	3.7	7.91	10,120	8.0	9.4
	12/12/95	159	2.0	2.3	7.41	8,300	5.5	9.3

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW4	12/19/95	166	4.0	1.4	7.27	8,920	5.0	10.0
	01/10/96	188	-2.0	0.7	7.53	7,090	4.0	5.0
	01/19/96	197	-3.0	0.5	7.89	11,280	7.5	6.7
	01/25/96	203	5.0	0.6	7.88	11,240	7.0	5.9
	02/02/96	211	4.0	1.7	7.76	10,810	6.0	8.4
	02/09/96	218	9.0	1.0	7.71	11,080	6.5	7.5
	02/13/96	222	2.0	0.0	7.49	10,530	6.0	8.7
	02/20/96	229	8.0	4.2	7.76	7,300	5.5	9.9
	02/29/96	238	3.0	2.3	8.45	10,590	7.5	16.2
	03/07/96	245	16.0	8.0	8.36	8,880	5.0	15.1
	03/11/96	249	13.0	5.2	8.23	7,720	5.0	11.1
	03/21/96	259	15.0	11.1	8.34	8,850	5.5	9.5
	03/28/96	266	15.0	10.6	7.90	7,590	4.0	8.3
	04/04/96	273	22.0	17.4	7.95	7,020	5.5	11.2
	04/12/96	281	10.0	10.0	7.98	7,010	4.5	8.5
	04/15/96	284	2.0	8.4	8.21	8,790	5.0	9.3
	04/26/96	295	15.0	12.6	7.82	9,830	6.0	5.6
	05/02/96	301	17.0	14.6	7.96	9,980	6.5	7.1
	05/20/96	319	16.0	16.7	7.74	1,190	1.0	4.9
	05/31/96	330	15.0	17.0	7.72	5,020	3.5	4.1
	06/07/96	337	19.5	19.3	7.76	3,370	2.0	2.9
	06/10/96	340	21.0	20.3	7.56	2,420	1.5	2.6
	06/21/96	351	21.0	21.4	7.71	2,040	1.0	4.2
WW5	05/04/95	-63	15.0	15.2	8.85	11,070	7.0	17.2
	05/11/95	-56	18.0	18.8	8.90	10,210	6.0	>20.0
	05/19/95	-48	24.0	21.5	7.97	1,770	1.0	7.3
	05/23/95	-44	21.0	19.3	8.23	1,230	1.0	6.0

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW5	06/01/95	-35	18.0	18.0	7.61	810	1.0	8.1
	06/05/95	-31	18.5	15.2	7.64	680	<1.0	7.6
	06/12/95	-24	20.2	15.9	7.84	670	<1.0	8.2
	06/26/95	-10	23.0	15.8	7.85	350	<1.0	7.8
	07/05/95	-01	18.5	15.0	7.70	400	<1.0	8.5
	07/11/95	05	26.5	19.4	8.27	340	<1.0	9.4
	07/17/95	11	25.5	19.3	8.39	360	<1.0	10.5
	07/24/95	18	21.5	18.5	7.54	630	1.0	7.1
	08/01/95	26	22.5	21.4	8.29	3,760	2.0	14.9
	08/07/95	32	17.0	22.2	8.55	5,810	3.5	14.0
	08/22/95	47	22.0	24.0	8.05	7,140	4.0	5.8
	08/31/95	56	25.0	23.1	8.23	7,260	4.0	8.6
	09/07/95	63	21.0	22.5	8.13	4,100	3.0	6.0
	09/11/95	67	15.0	19.5	8.42	6,700	4.0	6.8
	09/21/95	77	10.0	15.8	7.96	4,850	4.5	7.8
	09/26/95	82	19.0	16.9	8.18	3,310	2.0	8.4
	10/05/95	91	14.0	17.4	8.27	5,850	3.5	7.5
	10/12/95	98	24.0	18.8	8.12	6,240	4.0	9.4
	10/17/95	103	-	15.9	8.26	7,260	4.0	10.3
	11/01/95	118	-	13.1	8.04	7,760	6.0	7.9
	11/07/95	124	-	10.7	8.02	8,260	5.0	11.1
	11/13/95	130	1.0	6.6	7.94	7,710	5.0	10.9
	11/30/95	147	11.0	8.4	8.08	8,790	5.0	11.4
	12/07/95	154	2.0	6.9	7.99	9,170	6.5	8.6
	12/12/95	159	5.0	5.8	7.94	8,680	5.0	8.0
	12/19/95	166	5.0	6.2	8.09	8,580	5.0	11.3
	01/10/96	188	-1.0	3.6	7.47	9,300	5.5	8.4

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW5	01/19/96	197	-2.0	2.9	7.68	8,390	6.0	8.3
	01/25/96	203	2.0	4.6	7.79	9,830	6.0	12.1
	02/02/96	211	0.0	2.8	7.84	7,200	4.0	14.6
	02/09/96	218	9.0	4.5	8.02	7,640	5.0	14.4
	02/13/96	222	4.0	5.9	7.72	9,450	6.0	14.5
	02/20/96	229	10.0	8.1	8.03	8,860	5.5	12.4
	02/29/96	238	5.0	5.2	8.43	7,560	5.5	11.6
	03/07/96	245	18.0	9.0	8.18	8,640	5.0	11.6
	03/11/96	249	18.0	9.1	8.26	8,620	5.5	11.5
	03/21/96	259	15.0	10.7	8.30	9,630	5.5	12.4
	03/28/96	266	20.0	12.0	8.14	9,310	5.5	10.4
	04/04/96	273	20.0	16.5	8.39	9,550	6.0	11.9
	04/12/96	281	12.0	12.5	8.18	9,200	5.5	8.3
	04/15/96	284	4.0	9.3	8.37	8,570	5.0	10.5
	04/26/96	295	16.0	14.7	8.40	8,710	5.5	9.6
	05/02/96	301	18.0	15.1	8.33	8,630	5.0	8.5
	05/20/96	319	21.0	17.4	8.05	820	1.0	7.5
	05/31/96	330	18.0	19.2	8.51	2,760	2.0	11.1
	06/07/96	337	21.0	22.5	8.25	3,150	2.0	6.5
	06/10/96	340	24.0	22.7	7.91	2,560	1.5	4.1
	06/21/96	351	26.0	21.6	8.08	1,660	1.0	6.5
WW6	05/04/95	-63	15.0	15.3	8.07	10,430	6.0	6.6
	05/11/95	-56	14.0	17.9	8.52	10,410	6.0	12.3
	05/19/95	-48	22.0	18.2	7.96	980	<1.0	7.3
	05/23/95	-44	21.0	17.9	8.08	980	<1.0	7.2
	06/01/95	-35	17.0	15.5	7.41	980	1.0	7.9
	06/05/95	-31	17.0	13.5	7.38	450	<1.0	8.1

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW6	06/12/95	-24	20.3	14.5	7.68	440	<1.0	8.5
	06/26/95	-10	23.0	16.0	7.80	310	<1.0	7.8
	07/05/95	-01	17.5	14.8	7.76	370	<1.0	8.7
	07/11/95	05	26.0	18.2	8.30	350	<1.0	8.5
	07/17/95	11	24.0	18.5	7.77	350	<1.0	9.1
	07/24/95	18	21.5	17.9	7.55	490	0.5	7.7
	08/01/95	26	22.0	21.1	8.14	2,160	1.0	9.7
	08/07/95	32	18.0	21.2	8.56	7,550	4.5	12.5
	08/22/95	47	22.0	26.0	8.29	6,870	4.0	7.8
	08/31/95	56	24.0	21.8	8.18	7,460	4.0	8.7
	09/07/95	63	20.0	21.3	8.20	6,460	4.0	6.7
	09/11/95	67	14.0	17.6	8.09	6,990	4.0	4.2
	09/21/95	77	8.0	11.9	8.19	4,000	3.0	7.8
	09/26/95	82	18.0	16.4	8.31	4,670	3.0	6.6
	10/05/95	91	11.0	16.5	8.36	5,370	3.0	8.8
	10/12/95	98	20.0	18.5	8.25	5,710	3.5	11.6
	10/17/95	103	-	16.5	8.57	7,160	4.0	16.6
	11/01/95	118	-	11.7	8.06	6,100	4.0	7.6
	11/07/95	124	-	14.2	8.12	5,170	3.0	8.8
	11/13/95	130	0.0	4.4	7.88	4,370	3.0	9.3
	11/30/95	147	14.0	7.4	8.11	5,880	4.0	10.9
	12/07/95	154	2.0	6.3	7.98	7,780	5.0	8.3
	12/12/95	159	4.0	5.1	7.72	7,180	4.5	7.9
	12/19/95	166	6.0	3.7	8.07	6,580	4.0	11.8
	01/10/96	188	-1.0	0.5	7.54	8,460	5.0	8.9
	01/19/96	197	-2.0	1.2	7.75	6,780	4.0	9.6
	01/25/96	203	3.0	2.5	7.86	7,890	5.0	16.2

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW6	02/02/96	211	1.0	1.5	8.00	7,260	4.0	14.4
	02/09/96	218	6.0	2.0	8.64	5,890	3.5	8.3
	02/13/96	222	3.0	1.5	7.80	6,800	4.0	10.5
	02/20/96	229	10.0	7.3	8.07	7,400	5.0	8.9
	02/29/96	238	3.0	2.8	8.35	6,420	4.5	13.5
	03/07/96	245	16.0	11.9	8.30	8,000	5.5	16.3
	03/11/96	249	16.0	7.9	8.16	7,350	5.0	10.6
	03/21/96	259	19.0	11.2	8.32	8,150	5.0	16.5
	03/28/96	266	14.0	12.3	8.09	5,940	4.0	9.9
	04/04/96	273	18.0	19.3	8.38	8,420	5.5	13.2
	04/12/96	281	11.0	11.4	8.03	6,350	4.0	7.0
	04/15/96	284	5.0	8.6	8.33	6,770	4.0	10.2
	04/26/96	295	16.0	13.2	8.26	7,750	4.5	8.6
	05/02/96	301	17.0	15.5	8.32	6,720	4.0	7.2
	05/20/96	319	18.0	17.0	8.05	830	1.0	7.9
	05/31/96	330	18.0	18.8	8.30	1,980	1.5	8.1
	06/07/96	337	20.0	21.8	8.17	2,400	1.5	6.1
	06/10/96	340	22.0	20.5	7.87	1,590	1.0	4.5
	06/21/96	351	25.0	19.7	8.09	830	1.0	7.3
WW7	05/04/95	-63	15.0	15.9	8.01	10,290	6.0	6.3
	05/11/95	-56	13.0	17.4	8.35	9,940	6.0	10.4
	05/19/95	-48	21.0	17.1	7.78	880	<1.0	7.4
	05/23/95	-44	23.0	13.9	7.78	480	<1.0	7.8
	06/01/95	-35	16.0	13.4	7.14	640	<1.0	7.4
	06/05/95	-31	19.5	13.2	7.45	390	<1.0	8.5
	06/12/95	-24	20.5	13.7	7.02	380	<1.0	8.6
	06/26/95	-10	23.0	13.5	7.89	290	<1.0	8.9

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW7	07/05/95	-01	17.3	12.6	7.86	310	<1.0	9.3
	07/11/95	05	22.5	15.2	8.22	280	<1.0	8.8
	07/17/95	11	21.5	15.6	7.36	290	<1.0	8.8
	07/24/95	18	21.0	15.9	7.45	390	<1.0	8.0
	08/01/95	26	21.0	18.1	7.91	1,150	<1.0	7.8
	08/07/95	32	18.0	22.1	8.38	4,660	3.0	11.3
	08/22/95	47	20.0	23.2	8.19	6,730	4.2	7.4
	08/31/95	56	22.0	18.8	8.05	7,940	6.0	5.3
	09/07/95	63	23.0	21.8	8.42	6,920	4.0	12.8
	09/11/95	67	10.0	14.5	7.66	5,880	4.0	3.6
	09/21/95	77	10.0	14.1	8.46	4,420	3.0	8.5
	09/26/95	82	16.0	14.4	8.22	5,140	3.0	8.2
	10/05/95	91	12.0	14.4	8.44	5,890	4.0	9.4
	10/12/95	98	19.0	16.2	8.53	5,290	3.0	10.7
	10/17/95	103	18.0	13.9	9.06	6,090	4.0	10.9
	11/01/95	118	-	14.5	8.46	6,250	4.0	15.1
	11/07/95	124	-	12.0	8.22	6,390	4.0	14.1
	11/13/95	130	<-2.0	4.4	8.14	6,680	6.0	9.8
	11/30/95	147	11.0	9.0	7.49	8,640	5.0	11.0
	12/07/95	154	3.0	6.8	7.89	7,660	4.5	10.4
	12/12/95	159	1.0	5.4	7.90	7,030	4.0	8.9
	12/19/95	166	2.0	5.9	7.63	7,710	4.5	15.0
	01/10/96	188	<-2.0	3.1	7.81	7,390	6.0	8.2
	01/19/96	197	-1.0	2.7	7.32	7,840	5.0	10.2
	01/25/96	203	4.0	4.1	8.58	7,820	5.0	10.8
	02/02/96	211	4.0	2.8	7.91	7,120	4.0	13.2
	02/09/96	218	11.0	5.9	7.69	6,770	4.0	14.1

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW7	02/13/96	222	-2.0	0.8	8.11	7,070	6.0	10.4
	02/20/96	229	10.0	7.3	7.91	7,180	4.5	13.5
	02/29/96	238	1.0	3.0	8.97	7,160	5.0	11.5
	03/07/96	245	14.0	9.0	8.57	6,480	4.0	15.3
	03/11/96	249	10.0	6.4	8.58	7,290	4.5	7.7
	03/21/96	259	11.0	8.9	8.51	8,660	5.0	8.8
	03/28/96	266	16.0	9.2	8.42	8,590	6.0	9.3
	04/04/96	273	16.0	14.4	8.95	8,150	5.0	10.2
	04/12/96	281	7.0	9.1	7.86	2,230	2.0	7.9
	04/15/96	284	2.0	8.3	8.65	6,170	4.0	10.6
	04/26/96	295	11.0	12.4	8.29	4,540	3.0	4.5
	05/02/96	301	17.0	13.6	8.18	4,730	3.0	7.0
	05/20/96	319	19.0	13.2	8.14	340	<0.5	8.7
	05/31/96	330	20.5	18.0	-	2,080	1.0	6.7
	06/07/96	337	22.0	18.1	7.88	810	0.5	6.8
	06/10/96	340	19.0	17.8	7.90	700	<0.5	6.6
	06/21/96	351	23.0	16.7	7.71	430	<0.5	7.5
WW8	05/04/95	-63	17.0	15.7	8.03	3,400	2.0	6.8
	05/11/95	-56	20.0	17.4	8.05	4,560	3.0	7.5
	05/19/95	-48	NS	NS	NS	NS	NS	NS
	05/23/95	-44	NS	NS	NS	NS	NS	NS
	06/01/95	-35	17.0	13.2	7.22	520	<1.0	7.9
	06/05/95	-31	16.0	12.8	7.19	360	<1.0	8.6
	06/12/95	-24	19.8	13.0	7.57	340	<1.0	8.7
	06/26/95	-10	23.0	13.2	8.07	280	<1.0	9.2
	07/05/95	-01	17.3	12.5	7.37	320	<1.0	9.3
	07/11/95	05	23.5	15.1	8.20	270	<1.0	8.9

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW8	07/17/95	11	21.5	15.5	7.26	290	<1.0	9.1
	07/24/95	18	21.0	16.5	7.09	370	<1.0	7.6
	08/01/95	26	21.0	21.1	8.02	1,140	<1.0	7.3
	08/07/95	32	16.0	22.9	8.47	2,240	1.0	11.1
	08/22/95	47	21.0	25.0	8.40	4,500	3.0	6.4
	08/31/95	56	21.0	21.6	8.41	6,420	4.5	5.3
	09/07/95	63	22.0	21.7	8.38	7,470	4.5	7.0
	09/11/95	67	10.0	18.0	8.17	6,930	4.0	3.4
	09/21/95	77	13.0	14.5	8.61	5,000	3.0	7.8
	09/26/95	82	15.0	14.3	8.38	5,150	3.0	8.5
	10/05/95	91	13.0	12.4	8.77	4,610	3.0	9.0
	10/12/95	98	21.0	15.6	8.46	5,850	3.5	10.0
	10/17/95	103	17.0	12.1	9.04	5,970	3.5	9.9
	11/01/95	118	-	13.4	8.23	5,650	4.5	11.4
	11/07/95	124	-	8.0	8.60	2,740	1.5	12.1
	11/13/95	130	<-2.0	4.3	8.57	4,800	3.0	12.3
	11/30/95	147	11.0	5.6	8.42	6,510	4.0	18.3
	12/07/95	154	3.0	5.9	7.93	7,320	4.5	10.5
	12/12/95	159	1.0	4.8	8.02	7,570	5.0	12.5
	12/19/95	166	5.0	5.0	8.05	7,600	4.5	13.8
	01/10/96	188	-2.0	0.5	8.22	7,520	5.0	14.9
	01/19/96	197	-1.0	1.2	7.47	7,520	4.5	16.2
	01/25/96	203	7.0	1.4	8.16	7,830	6.0	15.5
	02/02/96	211	3.0	2.3	7.94	6,970	4.0	18.2
	02/09/96	218	10.0	4.9	7.78	5,680	3.5	>20.0
	02/13/96	222	-1.0	1.9	8.18	7,520	5.5	14.4
	02/20/96	229	10.0	7.4	8.06	9,040	5.0	13.5

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW8	02/29/96	238	2.0	2.2	8.64	7,620	5.0	15.0
	03/07/96	245	17.0	7.2	8.29	7,580	4.5	13.0
	03/11/96	249	10.0	7.2	8.45	8,330	5.0	12.3
	03/21/96	259	12.0	9.7	8.50	7,770	4.5	11.7
	03/28/96	266	14.0	9.9	8.54	6,460	4.0	11.9
	04/04/96	273	21.0	15.1	8.49	4,320	3.0	10.2
	04/12/96	281	NS	NS	NS	NS	NS	NS
	04/15/96	284	NS	NS	NS	NS	NS	NS
	04/26/96	295	14.0	13.9	8.17	3,490	2.0	7.5
	05/02/96	301	17.0	14.8	8.33	2,980	2.5	7.9
	05/20/96	319	NS	NS	NS	NS	NS	NS
	05/31/96	330	22.0	20.0	-	1,330	1.0	8.4
	06/07/96	337	NS	NS	NS	NS	NS	NS
	06/10/96	340	NS	NS	NS	NS	NS	NS
	06/21/96	351	NS	NS	NS	NS	NS	NS
WW9	05/04/95	-63	21.0	18.3	8.17	1,260	<1.0	8.3
	05/11/95	-56	19.0	12.8	7.70	590	<1.0	9.3
	05/19/95	-48	20.0	15.0	7.89	620	<1.0	7.6
	05/23/95	-44	16.0	13.0	7.29	430	<1.0	7.8
	06/01/95	-35	16.0	13.4	7.57	510	<1.0	8.2
	06/05/95	-31	16.0	12.4	7.02	380	<1.0	8.4
	06/12/95	-24	19.8	13.1	7.36	360	<1.0	8.4
	06/26/95	-10	23.0	13.5	7.61	290	<1.0	8.9
	07/05/95	-01	16.5	12.5	7.34	320	<1.0	9.1
	07/11/95	05	20.3	15.3	8.23	270	<1.0	8.7
	07/17/95	11	22.0	15.8	7.20	300	<1.0	8.7
	07/24/95	18	20.0	16.0	7.07	370	<1.0	7.6

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW9	08/01/95	26	21.0	20.9	8.12	1,300	1.0	7.8
	08/07/95	32	18.0	19.2	8.15	1,010	<1.0	7.3
	08/22/95	47	26.0	30.0	8.44	4,750	3.0	12.1
	08/31/95	56	19.0	18.6	7.92	6,840	4.5	3.4
	09/07/95	63	21.0	22.4	8.41	7,890	4.5	10.0
	09/11/95	67	10.0	16.2	7.60	4,930	3.0	2.3
	09/21/95	77	11.0	15.7	8.75	5,230	3.0	8.7
	09/26/95	82	14.0	13.4	7.79	5,330	4.0	6.4
	10/05/95	91	11.0	13.3	8.39	4,570	3.0	8.9
	10/12/95	98	19.0	14.8	8.57	5,960	3.5	8.6
	10/17/95	103	13.0	9.3	9.15	5,710	3.5	8.1
	11/01/95	118	-	11.3	8.39	880	<1.0	10.4
	11/07/95	124	-	10.3	8.22	3,480	2.0	13.7
	11/13/95	130	2.0	5.3	8.23	2,080	1.0	12.1
	11/30/95	147	12.0	5.9	8.14	5,510	3.5	>20.0
	12/07/95	154	2.0	5.8	7.88	4,580	3.0	10.8
	12/12/95	159	2.0	3.9	8.41	5,530	3.0	12.5
	12/19/95	166	3.0	3.4	7.93	7,400	4.0	>20.0
	01/10/96	188	-2.0	1.5	8.94	910	1.0	13.2
	01/19/96	197	0.0	2.4	8.11	7,650	4.5	18.4
	01/25/96	203	2.0	1.6	8.91	8,410	5.0	>20.0
	02/02/96	211	2.0	1.9	8.01	6,260	5.0	19.9
	02/09/96	218	13.0	6.9	7.88	5,730	3.5	>20.0
	02/13/96	222	-4.0	1.4	8.45	7,280	4.0	13.8
	02/20/96	229	12.0	7.8	7.94	8,190	5.0	16.1
	02/29/96	238	3.0	5.4	8.39	7,110	5.0	18.1
	03/07/96	245	3.0	3.6	8.66	7,860	5.5	13.9

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW9	03/11/96	249	7.0	4.8	8.80	5,450	3.0	8.1
	03/21/96	259	12.0	10.3	9.32	6,190	4.0	12.6
	03/28/96	266	12.0	7.8	8.87	820	0.5	11.4
	04/04/96	273	14.0	13.4	7.96	1,030	1.0	9.7
	04/12/96	281	8.0	8.6	8.06	800	0.5	8.9
	04/15/96	284	1.0	8.1	8.32	1,480	1.0	10.2
	04/26/96	295	11.0	11.3	8.60	570	0.5	9.0
	05/02/96	301	15.0	10.5	8.34	690	0.5	9.1
	05/20/96	319	20.0	13.1	8.26	340	<0.5	8.5
	05/31/96	330	20.0	19.5	-	1,280	1.0	8.4
	06/07/96	337	22.0	19.8	8.35	1,000	1.0	8.3
	06/10/96	340	17.5	20.4	7.85	820	0.5	6.2
	06/21/96	351	22.0	16.5	7.72	410	<0.5	7.4
WW10	08/22/95	47	27.0	21.0	7.67	1,080	0.5	4.5
	09/07/95	63	22.0	20.3	7.88	990	0.5	7.2
	09/21/95	77	10.0	13.3	8.16	1,160	1.0	9.1
	09/26/95	82	22.0	15.2	8.17	1,110	1.0	8.0
	10/04/95	90	17.0	12.0	7.20	1,060	0.5	8.5
	10/05/95	91	NS	NS	NS	NS	NS	NS
	10/12/95	98	NS	NS	NS	NS	NS	NS
	10/17/95	103	NS	NS	NS	NS	NS	NS
	11/01/95	118	NS	NS	NS	NS	NS	NS
	11/07/95	124	NS	NS	NS	NS	NS	NS
	11/13/95	130	NS	NS	NS	NS	NS	NS
	11/30/95	147	NS	NS	NS	NS	NS	NS
	12/07/95	154	2.0	5.2	8.27	1,530	1.0	9.8
	12/12/95	159	NS	NS	NS	NS	NS	NS

Appendix B. Continued.

Station	Date	Day of exposure	Air temp. (°C)	Water temp. (°C)	pH	Cond.[1] (µmhos/cm)	Salinity (g/L)	D.O.[2] (mg/L)
WW10	12/19/95	166	NS	NS	NS	NS	NS	NS
	01/10/96	188	NS	NS	NS	NS	NS	NS
	01/19/96	197	NS	NS	NS	NS	NS	NS
	01/25/96	203	NS	NS	NS	NS	NS	NS
	02/02/96	211	NS	NS	NS	NS	NS	NS
	02/09/96	218	NS	NS	NS	NS	NS	NS
	02/13/96	222	NS	NS	NS	NS	NS	NS
	02/20/96	229	NS	NS	NS	NS	NS	NS
	02/29/96	238	NS	NS	NS	NS	NS	NS
	03/07/96	245	NS	NS	NS	NS	NS	NS
	03/11/96	249	NS	NS	NS	NS	NS	NS
	03/21/96	259	NS	NS	NS	NS	NS	NS
	03/28/96	266	NS	NS	NS	NS	NS	NS
	04/04/96	273	NS	NS	NS	NS	NS	NS
	04/12/96	281	NS	NS	NS	NS	NS	NS
	04/15/96	284	NS	NS	NS	NS	NS	NS
	04/26/96	295	NS	NS	NS	NS	NS	NS
	05/02/96	301	NS	NS	NS	NS	NS	NS
	05/20/96	319	NS	NS	NS	NS	NS	NS
	05/31/96	330	NS	NS	NS	NS	NS	NS
	06/07/96	337	NS	NS	NS	NS	NS	NS
	06/10/96	340	NS	NS	NS	NS	NS	NS
	06/21/96	351	NS	NS	NS	NS	NS	NS

[1]Cond. = conductivity (µmhos/cm) corrected to 25°C.
[2]D.O. = dissolved oxygen.
[3]<: Below limit of detection.
[4]Thermometer broke.
[5]-: No data.
[6]NS: No sample collected due to no water flow.

Appendix C. Water quality characteristics in water collected from Horsethief Canyon State Wildlife Area near Grand Junction, CO, in the inlet (i) and outlet (o) of ponds 1 and 6 when fish were present. Characteristics were measured in a mobile laboratory at Grand Junction, Colorado (pH, conductivity, hardness, calcium, magnesium, alkalinity, and chloride) or at Yankton, South Dakota (sulfate, nitrate, nitrite, total suspended solids, volatile solids, and fixed solids).

Measure	Date	Day of exposure	Pond	Station HTi	Station HTo
pH					
	05/03/95	-64	6	8.4	8.6
	06/06/95	-30	6	8.2	8.2
	07/10/95	4	1	8.2	8.0
	08/08/95	33	1	8.3	8.3
	09/12/95	68	6	8.0	8.0
	10/18/95	104	1	8.6	8.5
	11/14/95	131	6	8.6	8.5
	12/11/95	158	6	8.2	8.3
	01/09/96	187	6	8.3	8.3
	02/12/96	221	6	8.4	8.4
	03/12/96	250	6	8.5	8.5
	04/16/96	285	6	8.5	8.5
	05/21/96	320	6	8.4	8.4
	06/11/96	341	6	8.7	8.7
Conductivity[1] (µmhos/cm)					
	05/03/95	-64	6	660	600
	06/06/95	-30	6	560	560
	07/10/95	4	1	390	400
	08/08/95	33	1	430	430
	09/12/95	68	6	880	880
	10/18/95	104	1	880	860
	11/14/95	131	6	840	850
	12/11/95	158	6	830	820
	01/09/96	187	6	900	950
	02/12/96	221	6	840	850
	03/12/96	250	6	920	920
	04/16/96	285	6	670	670
	05/21/96	320	6	400	410
	06/11/96	341	6	400	400

Appendix C. Continued.

Measure	Date	Day of exposure	Pond	Station HTi	Station HTo
Hardness (mg/L as $CaCO_3$)					
	05/03/95	-64	6	220	220
	06/06/95	-30	6	186	184
	07/10/95	4	1	153	152
	08/08/95	33	1	160	160
	09/12/95	68	6	324	324
	10/18/95	104	1	324	324
	11/14/95	131	6	276	276
	12/11/95	158	6	264	268
	01/09/96	187	6	268	272
	02/12/96	221	6	264	264
	03/12/96	250	6	272	272
	04/16/96	285	6	228	226
	05/21/96	320	6	148	150
	06/11/96	341	6	146	148
Calcium (mg/L)					
	05/03/95	-64	6	58	59
	06/06/95	-30	6	48	47
	07/10/95	4	1	42	42
	08/08/95	33	1	45	45
	09/12/95	68	6	88	88
	10/18/95	104	1	86	86
	11/14/95	131	6	74	73
	12/11/95	158	6	70	70
	01/09/96	187	6	71	72
	02/12/96	221	6	70	70
	03/12/96	250	6	71	71
	04/16/96	285	6	60	60
	05/21/96	320	6	43	44
	06/11/96	341	6	42	42

Appendix C. Continued.

Measure	Date	Day of exposure	Pond	Station HTi	Station HTo
Magnesium (mg/L)					
	05/03/95	-64	6	18	18
	06/06/95	-30	6	16	16
	07/10/95	4	1	12	11
	08/08/95	33	1	12	12
	09/12/95	68	6	25	25
	10/18/95	104	1	27	27
	11/14/95	131	6	22	23
	12/11/95	158	6	22	23
	01/09/96	187	6	22	22
	02/12/96	221	6	22	22
	03/12/96	250	6	23	23
	04/16/96	285	6	19	19
	05/21/96	320	6	10	10
	06/11/96	341	6	10	10
Alkalinity (mg/L as $CaCO_3$)					
	05/03/95	-64	6	28	128
	06/06/95	-30	6	118	119
	07/10/95	4	1	110	111
	08/08/95	33	1	107	106
	09/12/95	68	6	138	136
	10/18/95	104	1	140	138
	11/14/95	131	6	129	128
	12/11/95	158	6	127	127
	01/09/96	187	6	134	134
	02/12/96	221	6	130	130
	03/12/96	250	6	136	136
	04/16/96	285	6	129	129
	05/21/96	320	6	105	105
	06/11/96	341	6	93	92

Appendix C. Continued.

Measure	Date	Day of exposure	Pond	Station HTi	Station HTo
Chloride (mg/L)					
	05/03/95	-64	6	52	52
	06/06/95	-30	6	38	38
	07/10/95	4	1	16	16
	08/08/95	33	1	21	21
	09/12/95	68	6	56	58
	10/18/95	104	1	58	58
	11/14/95	131	6	65	66
	12/11/95	158	6	65	65
	01/09/96	187	6	74	75
	02/12/96	221	6	81	80
	03/12/96	250	6	86	86
	04/16/96	285	6	60	60
	05/21/96	320	6	22	22
	06/11/96	341	6	23	22
Sulfate (mg/L)					
	05/03/95	-64	6	148	151
	06/06/95	-30	6	122	116
	07/10/95	4	1	68	67
	08/08/95	33	1	90	89
	09/12/95	68	6	250	256
	10/18/95	104	1	245	260
	11/14/95	131	6	203	200
	12/11/95	158	6	186	173
	01/09/96	187	6	197	197
	02/12/96	221	6	194	196
	03/12/96	250	6	201	209
	04/16/96	285	6	163	158
	05/21/96	320	6	79	75
	06/11/96	341	6	77	78

Appendix C. Continued.

Measure	Date	Day of exposure	Pond	Station HTi	Station HTo
Nitrate (mg/L NO_3-N)					
	05/03/95	-64	6	-[2]	-
	06/06/95	-30	6	-	-
	07/10/95	4	1	1.2	1.0
	08/08/95	33	1	<0.1	<0.1
	09/12/95	68	6	<0.1	<0.1
	10/18/95	104	1	0.4	0.4
	11/14/95	131	6	-	-
	12/11/95	158	6	0.1	0.1
	01/09/96	187	6	0.4	0.4
	02/12/96	221	6	0.3	0.3
	03/12/96	250	6	0.2	0.2
	04/16/96	285	6	<0.1	<0.1
	05/21/96	320	6	-	-
	06/11/96	341	6	0.1	0.1
Nitrite (mg/L NO_2-N)					
	05/03/95	-64	6	-	-
	06/06/95	-30	6	-	-
	07/10/95	4	1	-	-
	08/08/95	33	1	-	-
	09/12/95	68	6	<0.01	<0.01
	10/18/95	104	1	<0.01	<0.01
	11/14/95	131	6	-	-
	12/11/95	158	6	<0.01	<0.01
	01/09/96	187	6	0.01	<0.01
	02/12/96	221	6	<0.01	<0.01
	03/12/96	250	6	<0.01	<0.01
	04/16/96	285	6	<0.01	<0.01
	05/21/96	320	6	0.02	0.02
	06/11/96	341	6	<0.01	<0.01

Appendix C. Continued.

Measure	Date	Day of exposure	Pond	Station HTi	Station HTo
Total suspended solids (mg/L)					
	05/03/95	-64	6	48	43
	06/06/95	-30	6	23	20
	07/10/95	4	1	25	33
	08/08/95	33	1	16	16
	09/12/95	68	6	28	28
	10/18/95	104	1	15	12
	11/14/95	131	6	8	6
	12/11/95	158	6	11	12
	01/09/96	187	6	13	9
	02/12/96	221	6	35	32
	03/12/96	250	6	28	24
	04/16/96	285	6	40	37
	05/21/96	320	6	-	-
	06/11/96	341	6	14	21
Volatile solids (mg/L)					
	05/03/95	-64	6	-	-
	06/06/95	-30	6	-	-
	07/10/95	4	1	-	-
	08/08/95	33	1	7.6	7.2
	09/12/95	68	6	6.0	7.0
	10/18/95	104	1	2.6	2.6
	11/14/95	131	6	1.3	1.0
	12/11/95	158	6	1.7	2.0
	01/09/96	187	6	3.0	2.6
	02/12/96	221	6	4.5	5.0
	03/12/96	250	6	4.7	4.0
	04/16/96	285	6	6.5	5.5
	05/21/96	320	6	-	-
	06/11/96	341	6	3.3	4.3

Appendix C. Continued.

Measure	Date	Day of exposure	Pond	Station HTi	Station HTo
Fixed solids (mg/L)					
	05/03/95	-64	6	-	-
	06/06/95	-30	6	-	-
	07/10/95	4	1	-	-
	08/08/95	33	1	8.4	8.4
	09/12/95	68	6	21.6	21.0
	10/18/95	104	1	12.4	9.6
	11/14/95	131	6	6.7	5.3
	12/11/95	158	6	9.3	9.8
	01/09/96	187	6	10.0	6.2
	02/12/96	221	6	31.0	26.7
	03/12/96	250	6	23.7	11.8
	04/16/96	285	6	34.0	32.0
	05/21/96	320	6	-	-
	06/11/96	341	6	10.3	16.7

[1]Conductivity (μmhos/cm) corrected to 25°C.
[2]-: No data.

Appendix D. Water quality characteristics in water from Adobe Creek stations near Grand Junction, CO. Characteristics were measured in a mobile laboratory at Grand Junction, Colorado (pH, conductivity, hardness, calcium, magnesium, alkalinity, and chloride) or at Yankton, South Dakota (sulfate, nitrate, nitrite, total suspended solids, volatile solids, and fixed solids).

Measure	Date	Day of exposure	Station						
			AC1	AC2	AC3	AC4	AC5	AC6	AC7
pH	05/03/95	-64	7.9	7.9	7.8	7.7	7.9	7.8	NS[1]
	06/06/95	-30	7.8	7.9	7.6	7.7	7.7	7.8	NS
	07/10/95	4	7.6	7.8	7.6	7.5	7.4	7.5	NS
	08/08/95	33	7.9	7.9	7.6	7.4	7.5	7.3	NS
	09/12/95	68	8.0	8.0	7.2	7.1	7.1	7.1	7.6
	10/18/95	104	8.2	8.1	7.8	7.6	7.7	8.1	8.1
	11/14/95	131	8.3	8.3	7.8	7.7	7.9	7.5	NS
	12/11/95	158	8.2	8.2	7.9	7.8	8.0	7.2	NS
	01/09/96	187	8.1	8.1	8.2	8.2	8.0	7.2	NS
	02/12/96	221	8.3	8.2	8.1	8.0	7.9	7.5	NS
	03/12/96	250	8.3	8.3	8.1	8.3	8.4	7.7	NS
	04/16/96	285	8.0	8.0	8.1	8.0	8.2	7.6	NS
	05/21/96	320	7.5	7.8	7.5	7.4	7.6	7.7	NS
	06/11/96	341	8.1	8.1	7.8	7.8	8.0	7.9	8.5
Conductivity[2] (µmhos/cm)	05/03/95	-64	550	550	1,680	1,430	1,500	1,540	NS
	06/06/95	-30	450	360	1,540	950	1,320	420	NS
	07/10/95	4	300	300	550	420	450	410	NS
	08/08/95	33	540	540	730	730	630	740	NS
	09/12/95	68	940	940	1,000	1,010	1,010	1,020	1,010
	10/18/95	104	890	900	1,110	1,100	1,080	1,060	1,080
	11/14/95	131	860	860	880	1,000	960	1,360	NS
	12/11/95	158	830	840	940	1,000	1,020	3,790	NS
	01/09/96	187	850	840	1,030	860	1,050	2,940	NS
	02/12/96	221	940	940	820	980	860	3,430	NS
	03/12/96	250	890	900	930	940	930	3,290	NS
	04/16/96	285	600	600	740	800	810	3,540	NS
	05/21/96	320	350	300	1,040	1,010	900	420	NS
	06/11/96	341	390	380	1,000	790	640	700	540

Appendix D. Continued.

Measure	Date	Day of exposure	Station						
			AC1	AC2	AC3	AC4	AC5	AC6	AC7
Hardness	05/03/95	-64	200	204	500	470	470	530	NS
(mg/L as $CaCO_3$)	06/06/95	-30	162	142	518	448	456	152	NS
	07/10/95	4	116	114	212	148	166	150	NS
	08/08/95	33	188	188	232	248	232	300	NS
	09/12/95	68	364	368	292	292	296	320	288
	10/18/95	104	336	336	336	336	336	348	332
	11/14/95	131	288	288	312	324	332	516	NS
	12/11/95	158	268	268	300	336	328	1,420	NS
	01/09/96	187	256	252	260	264	328	1,000	NS
	02/12/96	221	288	292	256	304	284	1,240	NS
	03/12/96	250	280	280	280	280	288	1,152	NS
	04/16/96	285	202	202	236	248	248	1,190	NS
	05/21/96	320	128	114	344	332	304	130	NS
	06/11/96	341	142	144	324	268	232	240	204
Calcium	05/03/95	-64	56	54	112	115	115	131	NS
(mg/L)	06/06/95	-30	42	40	121	105	106	42	NS
	07/10/95	4	34	32	56	41	46	42	NS
	08/08/95	33	53	53	62	66	61	77	NS
	09/12/95	68	98	99	78	78	78	83	75
	10/18/95	104	88	87	88	88	88	90	87
	11/14/95	131	76	75	82	85	86	125	NS
	12/11/95	158	70	70	78	86	84	312	NS
	01/09/96	187	67	66	67	70	86	230	NS
	02/12/96	221	74	75	66	76	70	274	NS
	03/12/96	250	70	72	71	72	72	251	NS
	04/16/96	285	55	55	62	63	64	253	NS
	05/21/96	320	37	34	89	85	76	37	NS
	06/11/96	341	40	40	77	65	60	62	54

Appendix D. Continued.

Measure	Date	Day of exposure	Station						
			AC1	AC2	AC3	AC4	AC5	AC6	AC7
Magnesium (mg/L)	05/03/95	-64	15	17	54	44	44	49	NS
	06/06/95	-30	14	10	52	45	47	11	NS
	07/10/95	4	8	8	18	11	12	11	NS
	08/08/95	33	14	14	19	20	19	26	NS
	09/12/95	68	29	29	24	24	25	27	24
	10/18/95	104	28	29	28	28	28	30	28
	11/14/95	131	24	24	26	27	28	50	NS
	12/11/95	158	23	23	26	29	29	156	NS
	01/09/96	187	22	21	23	22	28	103	NS
	02/12/96	221	25	25	22	28	27	135	NS
	03/12/96	250	26	24	25	24	26	128	NS
	04/16/96	285	16	16	20	22	21	136	NS
	05/21/96	320	9	7	30	29	28	9	NS
	06/11/96	341	10	11	32	26	20	21	17
Alkalinity (mg/L as $CaCO_3$)	05/03/95	-64	145	149	300	261	256	253	NS
	06/06/95	-30	105	102	293	239	236	106	NS
	07/10/95	4	81	75	124	92	93	89	NS
	08/08/95	33	99	98	101	120	101	131	NS
	09/12/95	68	155	154	122	122	120	133	114
	10/18/95	104	147	148	147	147	147	152	145
	11/14/95	131	137	138	147	151	153	223	NS
	12/11/95	158	129	134	145	155	152	526	NS
	01/09/96	187	130	130	128	131	161	442	NS
	02/12/96	221	140	141	125	144	134	474	NS
	03/12/96	250	142	140	136	136	136	434	NS
	04/16/96	285	115	115	129	132	131	450	NS
	05/21/96	320	83	82	189	174	143	85	NS
	06/11/96	341	87	85	160	113	99	102	85

Appendix D. Continued.

Measure	Date	Day of exposure	Station						
			AC1	AC2	AC3	AC4	AC5	AC6	AC7
Chloride (mg/L)	05/03/95	-64	36	36	158	154	150	160	NS
	06/06/95	-30	24	12	140	112	115	18	NS
	07/10/95	4	14	14	34	20	23	20	NS
	08/08/95	33	34	34	50	50	50	61	NS
	09/12/95	68	54	52	102	103	104	108	110
	10/18/95	104	60	60	114	114	115	118	115
	11/14/95	131	73	72	78	86	89	123	NS
	12/11/95	158	64	64	76	85	83	320	NS
	01/09/96	187	73	72	70	70	92	211	NS
	02/12/96	221	84	85	78	87	83	280	NS
	03/12/96	250	82	84	87	86	88	246	NS
	04/16/96	285	41	41	58	64	64	272	NS
	05/21/96	320	18	15	76	78	71	19	NS
	06/11/96	341	24	24	79	60	42	45	33
Sulfate (mg/L)	05/03/95	-64	126	121	395	290	350	445	NS
	06/06/95	-30	110	94	572	484	562	447	NS
	07/10/95	4	56	55	133	82	95	84	NS
	08/08/95	33	128	132	206	181	167	239	NS
	09/12/95	68	311	316	224	231	204	245	231
	10/18/95	104	256	254	248	257	240	258	242
	11/14/95	131	185	207	233	237	250	486	NS
	12/11/95	158	204	202	202	232	230	1,570	NS
	01/09/96	187	184	185	196	193	233	1,010	NS
	02/12/96	221	222	220	194	232	226	1,290	NS
	03/12/96	250	214	219	215	227	229	1,140	NS
	04/16/96	285	130	128	174	182	186	1,440	NS
	05/21/96	320	70	54	216	225	223	68	NS
	06/11/96	341	82	80	238	216	179	194	153

Appendix D. Continued.

Measure	Date	Day of exposure	Station						
			AC1	AC2	AC3	AC4	AC5	AC6	AC7
Nitrate	05/03/95	-64	-[3]	-	-	-	-	-	NS
(mg/L NO_3-N)	06/06/95	-30	-	-	-	-	-	-	NS
	07/10/95	4	2.2	2.3	1.0	1.3	1.1	1.3	NS
	08/08/95	33	0.5	0.5	0.1	0.1	0.1	0.1	NS
	09/12/95	68	0.3	0.3	<0.1	<0.1	<0.1	<0.1	<0.1
	10/18/95	104	0.8	0.8	0.2	0.1	0.2	0.2	0.5
	11/14/95	131	-	-	-	-	-	-	NS
	12/11/95	158	0.3	0.3	0.1	0.1	0.1	<0.1	NS
	01/09/96	187	0.8	0.7	0.7	0.8	0.7	0.2	NS
	02/12/96	221	0.6	0.6	0.2	0.2	0.2	<0.1	NS
	03/12/96	250	0.5	0.4	0.1	<0.1	<0.1	<0.1	NS
	04/16/96	285	0.5	0.5	<0.1	<0.1	<0.1	0.1	NS
	05/21/96	320	-	-	-	-	-	-	NS
	06/11/96	341	0.4	0.4	<0.1	<0.1	0.2	0.2	0.5
Nitrite	05/03/95	-64	-	-	-	-	-	-	NS
(mg/L NO_2-N)	06/06/95	-30	-	-	-	-	-	-	NS
	07/10/95	4	-	-	-	-	-	-	NS
	08/08/95	33	-	-	-	-	-	-	NS
	09/12/95	68	0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	10/18/95	104	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	11/14/95	131	-	-	-	-	-	-	NS
	12/11/95	158	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NS
	01/09/96	187	<0.01	<0.01	<0.01	<0.01	0.01	0.01	NS
	02/12/96	221	0.01	0.01	<0.01	<0.01	<0.01	0.01	NS
	03/12/96	250	0.01	<0.01	<0.01	<0.01	<0.01	0.01	NS
	04/16/96	285	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	NS
	05/21/96	320	0.02	0.02	0.02	0.02	0.02	0.02	NS
	06/11/96	341	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Appendix D. Continued.

Measure	Date	Day of exposure	Station						
			AC1	AC2	AC3	AC4	AC5	AC6	AC7
Total suspended solids (mg/L)	05/03/95	-64	520	658	6	29	17	65	NS
	06/06/95	-30	193	421	37	137	44	91	NS
	07/10/95	4	103	179	19	60	18	43	NS
	08/08/95	33	86	89	20	10	23	37	NS
	09/12/95	68	92	86	12	20	16	68	32
	10/18/95	104	14	15	16	7	8	5	37
	11/14/95	131	33	36	9	15	8	39	NS
	12/11/95	158	10	9	16	11	7	21	NS
	01/09/96	187	27	11	7	4	10	18	NS
	02/12/96	221	51	48	18	10	11	16	NS
	03/12/96	250	96	97	62	10	11	14	NS
	04/16/96	285	215	189	8	7	8	24	NS
	05/21/96	320	-	-	-	-	-	-	NS
	06/11/96	341	70	80	7	2	6	23	8
Volatile solids (mg/L)	05/03/95	-64	-	-	-	-	-	-	NS
	06/06/95	-30	-	-	-	-	-	-	NS
	07/10/95	4	-	-	-	-	-	-	NS
	08/08/95	33	7.2	6.8	3.2	3.0	3.2	4.4	NS
	09/12/95	68	7.5	8.0	1.0	2.0	2.0	9.2	0.8
	10/18/95	104	1.8	1.7	1.8	0.8	1.0	0.6	3.2
	11/14/95	131	2.2	2.8	1.3	1.7	1.2	6.3	NS
	12/11/95	158	1.3	1.6	2.0	1.4	1.0	3.0	NS
	01/09/96	187	2.4	1.1	1.4	0.9	2.6	7.5	NS
	02/12/96	221	4.8	5.3	3.7	1.4	2.0	7.3	NS
	03/12/96	250	8.5	8.5	7.0	1.4	1.6	4.3	NS
	04/16/96	285	21.0	16.5	2.0	1.3	1.4	4.8	NS
	05/21/96	320	-	-	-	-	-	-	NS
	06/11/96	341	6.5	8.0	2.2	1.1	1.6	3.2	1.2

Appendix D. Continued.

Measure	Date	Day of exposure	Station AC1	AC2	AC3	AC4	AC5	AC6	AC7
Fixed solids	05/03/95	-64	-	-	-	-	-	-	NS
(mg/L)	06/06/95	-30	-	-	-	-	-	-	NS
	07/10/95	4	-	-	-	-	-	-	NS
	08/08/95	33	79.2	82.0	17.2	7.0	19.6	32.8	NS
	09/12/95	68	85.0	78.0	11.0	18.4	14.0	58.4	31.6
	10/18/95	104	12.2	12.9	14.4	6.2	7.2	4.6	34.0
	11/14/95	131	31.2	33.4	7.8	13.4	7.3	32.7	NS
	12/11/95	158	8.8	7.6	14.2	9.6	6.0	17.7	NS
	01/09/96	187	24.1	10.1	5.4	3.5	7.0	10.5	NS
	02/12/96	221	46.0	42.7	14.7	8.8	9.0	9.0	NS
	03/12/96	250	87.5	88.5	55.0	8.2	9.4	9.7	NS
	04/16/96	285	194	173	6.3	5.5	6.2	19.0	NS
	05/21/96	320	-	-	-	-	-	-	NS
	06/11/96	341	64.0	72.0	5.2	1.3	4.9	19.6	6.4

[1]NS: No sample collected due to no water flow at AC7.
[2]Conductivity (μmhos/cm) corrected to 25°C.
[3]-: No data.
[4]<: Below limit of detection.

Appendix E. Water flow from Independent Ranchman's Ditch via WW10 to North Pond at Walter Walker State Wildlife Area near Grand Junction, CO.

Date water on	Date water off
8/21/95	8/22/95
8/24/95	8/25/95
8/28/95	8/29/95
8/31/95	9/1/95
9/6/95	9/7/95
9/10/95	9/11/95
9/12/95	9/13/95
9/15/95	9/18/95
9/25/95	9/26/95
9/28/95	9/29/95
10/3/95	10/4/95
10/10/95	10/11/95
10/19/95	10/20/95
10/24/95	10/27/95
11/2/95	11/3/95
4/22/96	4/24/96
4/30/96	5/2/96
5/6/96	5/8/96
5/15/96	5/17/96
5/28/96	6/2/96
6/5/96	6/7/96

Appendix F. Water quality characteristics measured in water from Walter Walker State Wildlife Area stations near Grand Junction, CO. Characteristics were measured in a mobile laboratory at Grand Junction, Colorado (pH, conductivity, hardness, calcium, magnesium, alkalinity, and chloride) or at Yankton, South Dakota (sulfate, nitrate, nitrite, total suspended solids, volatile solids, and fixed solids).

Measure	Date	Day of exposure	Station									
			WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9	WW10[1]
pH												
	05/04/95	-63	7.8	8.5	8.5	7.8	8.8	8.0	8.0	7.9	7.9	NS[2]
	06/05/95	-31	7.4	9.1	8.9	7.7	7.9	7.8	7.9	8.0	7.9	NS
	07/11/95	5	8.2	9.0	9.2	8.2	8.0	8.0	7.8	8.1	7.8	NS
	08/07/95	32	8.0	8.1	8.2	7.7	8.2	8.1	8.0	8.0	7.9	NS
	09/11/95	67	8.0	7.4	7.4	7.5	8.1	7.9	7.7	8.2	8.0	NS
	10/17/95	103	8.3	7.8	7.8	7.8	8.1	8.2	8.1	8.2	8.0	7.9
	11/13/95	130	8.4	8.0	8.0	7.7	8.1	8.0	8.0	8.3	8.2	NS
	12/12/95	159	8.2	7.9	7.9	7.6	7.8	7.8	7.7	8.0	7.9	NS
	01/10/96	188	8.2	7.9	8.1	7.4	7.6	7.7	7.4	7.7	8.0	NS
	02/13/96	222	8.2	7.6	8.0	7.6	7.8	7.8	7.7	8.0	8.0	NS
	03/11/96	249	8.3	7.8	8.1	7.8	8.1	8.1	7.8	8.1	7.8	NS
	04/15/96	284	8.1	7.9	8.0	7.8	8.2	8.2	8.2	NS	8.0	NS
	05/20/96	319	7.8	8.6	8.4	7.6	7.8	7.9	7.8	NS	7.8	NS
	06/10/96	340	8.1	8.0	8.2	7.6	7.8	7.8	7.8	NS	7.9	NS
Conductivity[3] (µmhos/cm)												
	05/04/95	-63	540	12,390	12,270	10,810	11,070	10,430	10,290	3,400	1,260	NS
	06/05/95	-31	350	4,390	4,100	1,180	680	450	390	360	380	NS
	07/11/95	5	270	3,410	3,370	410	340	350	280	270	270	NS
	08/07/95	32	510	3,840	4,000	8,980	5,810	7,550	4,660	2,240	1,010	NS
	09/11/95	67	930	1,420	1,510	11,120	6,700	6,990	5,880	6,930	4,930	NS
	10/17/95	103	880	1,310	1,350	9,760	7,260	7,160	6,090	5,970	5,710	1,060
	11/13/95	130	800	1,270	1,240	6,830	7,710	4,370	6,680	4,800	2,080	NS
	12/12/95	159	820	1,460	1,460	8,300	8,680	7,180	7,030	7,570	5,530	NS
	01/10/96	188	920	1,710	1,820	7,090	9,300	8,460	7,390	7,520	910	NS
	02/13/96	222	880	2,880	2,860	10,530	9,450	6,800	7,070	7,520	7,280	NS
	03/11/96	249	920	4,390	4,600	7,720	8,620	7,350	7,290	8,330	5,450	NS
	04/15/96	284	560	7,100	7,140	8,790	8,570	6,770	6,170	NS	1,480	NS
	05/20/96	319	280	6,180	5,580	1,190	820	830	340	NS	340	NS
	06/10/96	340	350	4,580	4,440	2,420	2,560	1,590	700	NS	820	NS

Appendix F. Continued.

Measure	Date	Day of exposure	Station WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9	WW10[1]
Hardness (mg/L as $CaCO_3$)												
	05/04/95	-63	192	3,580	3,400	3,300	3,160	2,960	2,900	940	362	NS
	06/05/95	-31	138	1,380	1,190	410	210	154	144	138	148	NS
	07/11/95	5	104	835	850	130	124	109	106	104	106	NS
	08/07/95	32	178	960	970	2,460	1,500	1,950	1,280	620	308	NS
	09/11/95	67	342	408	416	3,680	1,800	1,740	1,520	1,700	770	NS
	10/17/95	103	316	376	376	2,700	1,920	1,860	1,560	1,610	1,610	356
	11/13/95	130	276	364	364	2,500	2,260	1,760	1,800	1,260	996	NS
	12/12/95	159	260	428	444	3,060	2,500	2,080	2,060	2,140	1,940	NS
	01/10/96	188	256	520	532	1,820	2,600	1,980	2,440	1,960	256	NS
	02/13/96	222	272	900	840	3,380	2,660	1,900	2,000	2,160	2,140	NS
	03/11/96	249	272	1,460	1,400	2,520	2,500	2,160	2,040	2,240	1,940	NS
	04/15/96	284	186	2,160	2,120	2,800	2,360	1,860	1,740	NS	490	NS
	05/20/96	319	98	1,600	1,620	368	250	240	120	NS	120	NS
	06/10/96	340	124	1,220	1,200	870	690	448	216	NS	252	NS
Calcium (mg/L)												
	05/04/95	-63	51	296	296	392	264	272	272	140	73	NS
	06/05/95	-31	35	131	125	85	53	44	41	40	40	NS
	07/11/95	5	31	92	92	36	34	32	31	32	32	NS
	08/07/95	32	50	98	98	301	189	221	176	112	69	NS
	09/11/95	67	94	85	86	448	212	208	180	204	128	NS
	10/17/95	103	82	82	82	344	244	224	184	196	200	96
	11/13/95	130	74	82	82	332	280	216	216	168	142	NS
	12/12/95	159	70	96	104	408	308	256	256	264	244	NS
	01/10/96	188	66	99	106	264	332	264	312	244	68	NS
	02/13/96	222	72	173	155	440	336	244	244	264	264	NS
	03/11/96	249	72	234	211	340	300	244	236	264	237	NS
	04/15/96	284	51	256	252	340	264	216	204	NS	85	NS
	05/20/96	319	32	172	176	72	54	52	34	NS	35	NS
	06/10/96	340	36	360	340	128	110	37	50	NS	56	NS

Appendix F. Continued.

Measure	Date	Day of exposure	Station									
			WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9	WW10[1]
Magnesium (mg/L)												
	05/04/95	-63	16	690	646	564	608	554	540	143	44	NS
	06/05/95	-31	12	256	213	48	19	11	10	9	12	NS
	07/11/95	5	7	147	151	10	9	7	7	6	6	NS
	08/07/95	32	13	174	176	415	250	340	204	83	33	NS
	09/11/95	67	26	48	49	622	309	297	260	289	109	NS
	10/17/95	103	27	42	42	447	318	316	267	272	270	28
	11/13/95	130	22	39	39	406	379	297	306	204	156	NS
	12/12/95	159	21	46	45	496	421	350	345	360	323	NS
	01/10/96	188	22	66	65	282	430	321	404	328	21	NS
	02/13/96	222	22	114	110	554	442	314	338	365	360	NS
	03/11/96	249	22	213	212	406	425	377	352	384	328	NS
	04/15/96	284	14	370	362	474	413	321	299	NS	68	NS
	05/20/96	319	4	284	287	46	28	27	8	NS	8	NS
	06/10/96	340	8	78	85	134	101	86	22	NS	27	NS
Alkalinity (mg/L as $CaCO_3$)												
	05/04/95	-63	120	162	159	480	188	237	250	180	140	NS
	06/05/95	-31	107	131	149	175	125	112	107	105	107	NS
	07/11/95	5	81	115	107	90	86	80	80	80	80	NS
	08/07/95	32	96	142	146	484	245	298	256	184	129	NS
	09/11/95	67	149	149	153	616	340	351	315	283	195	NS
	10/17/95	103	147	147	148	468	340	328	313	300	277	171
	11/13/95	130	132	145	144	444	371	341	351	243	217	NS
	12/12/95	159	164	153	158	485	396	369	385	361	323	NS
	01/10/96	188	134	161	180	351	431	372	445	340	132	NS
	02/13/96	222	139	202	195	512	417	335	375	347	339	NS
	03/11/96	249	140	232	223	386	363	338	372	345	311	NS
	04/15/96	284	115	207	213	407	307	289	299	NS	149	NS
	05/20/96	319	81	104	120	147	115	112	84	NS	84	NS
	06/10/96	340	82	122	122	259	220	171	120	NS	132	NS

Appendix F. Continued.

Measure	Date	Day of exposure	Station									
			WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9	WW10[1]
Chloride (mg/L)												
	05/04/95	-63	35	1,220	1,220	1,050	1,200	1,120	1,140	306	94	NS
	06/05/95	-31	16	470	370	94	37	20	18	16	17	NS
	07/11/95	5	12	278	276	19	18	14	13	13	12	NS
	08/07/95	32	36	340	400	870	540	730	440	178	77	NS
	09/11/95	67	59	134	138	1,150	630	620	540	620	250	NS
	10/17/95	103	63	139	141	810	640	660	530	550	540	102
	11/13/95	130	74	145	147	770	780	600	640	450	318	NS
	12/12/95	159	76	152	147	920	820	680	690	700	630	NS
	01/10/96	188	85	163	177	570	820	630	760	630	88	NS
	02/13/96	222	104	252	250	1,000	850	610	680	660	640	NS
	03/11/96	249	99	416	408	770	850	710	700	720	610	NS
	04/15/96	284	38	700	710	890	830	660	600	NS	145	NS
	05/20/96	319	16	550	560	91	58	54	18	NS	18	NS
	06/10/96	340	22	430	410	260	206	124	46	NS	56	NS
Sulfate (mg/L)												
	05/04/95	-63	112	6,640	6,480	5,320	5,880	5,280	5,240	148	420	NS
	06/05/95	-31	57	2,320	2,020	454	144	111	61	58	71	NS
	07/11/95	5	49	1,350	1,310	68	64	51	51	52	52	NS
	08/07/95	32	113	1,630	1,520	4,210	2,470	3,140	2,000	874	343	NS
	09/11/95	67	264	391	404	5,900	3,060	3,060	2,690	3,150	809	NS
	10/17/95	103	246	358	378	4,370	3,020	3,490	2,720	2,690	2,780	246
	11/13/95	130	195	339	338	3,720	3,470	2,790	3,330	2,150	1,610	NS
	12/12/95	159	185	406	421	4,930	1,980	3,480	3,820	3,700	3,450	NS
	01/10/96	188	183	526	568	2,520	3,920	3,120	4,080	3,540	171	NS
	02/13/96	222	194	1,060	1,020	5,020	3,960	3,010	3,280	3,590	3,450	NS
	03/11/96	249	204	2,140	1,940	4,000	3,990	3,570	3,630	4,120	3,160	NS
	04/15/96	284	108	3,520	3,670	4,610	4,000	3,330	3,010	NS	834	NS
	05/20/96	319	42	2,700	2,840	439	272	240	65	NS	63	NS
	06/10/96	340	64	2,380	1,930	1,130	932	536	174	NS	220	NS

Appendix F. Continued.

Measure	Date	Day of exposure	Station									
			WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9	WW10[1]
Nitrate (mg/L)												
	05/04/95	-63	-[4]	-	-	-	-	-	-	-	-	NS
	06/05/95	-31	-	-	-	-	-	-	-	-	-	NS
	07/11/95	5	2.52	2.21	2.31	1.49	1.66	2.51	2.51	2.44	2.67	NS
	08/07/95	32	0.32	0.80	0.56	6.11	1.29	1.73	0.97	0.39	0.25	NS
	09/11/95	67	0.28	0.01	0.01	10.40	0.06	0.04	0.08	0.05	0.16	NS
	10/17/95	103	0.41	0.05	0.04	37.30	1.45	0.97	1.18	0.88	0.18	0.70
	11/13/95	130	-	-	-	-	-	-	-	-	-	NS
	12/12/95	159	0.23	0.07	0.25	20.70	2.21	1.02	3.30	1.44	0.68	NS
	01/10/96	188	0.71	0.16	0.15	29.80	7.44	4.30	9.16	5.91	0.86	NS
	02/13/96	222	0.42	0.05	0.09	37.70	15.10	4.13	4.72	5.07	2.84	NS
	03/11/96	249	0.27	0.22	0.32	16.10	12.80	1.39	1.52	2.17	0.54	NS
	04/15/96	284	0.35	0.71	0.80	16.60	1.06	0.25	0.25	NS	0.27	NS
	05/20/96	319	-	-	-	-	-	-	-	NS	-	NS
	06/10/96	340	0.20	0.09	0.08	0.14	0.06	0.07	0.15	NS	0.09	NS
Nitrite (mg/L)												
	05/04/95	-63	-	-	-	-	-	-	-	-	-	NS
	06/05/95	-31	-	-	-	-	-	-	-	-	-	NS
	07/11/95	5	-	-	-	-	-	-	-	-	-	NS
	08/07/95	32	-	-	-	-	-	-	-	-	-	NS
	09/11/95	67	0.012	0	0	0.255	0.015	0.009	0.029	0.011	0.007	NS
	10/17/95	103	0.008	0.007	0.003	0.134	0.140	0.103	0.060	0.059	0.023	0.011
	11/13/95	130	-	-	-	-	-	-	-	-	-	NS
	12/12/95	159	<0.001	<0.001	0.002	0.057	0.154	0.083	0.216	0.098	0.063	NS
	01/10/96	188	0.003	0.001	0.003	0.066	0.246	0.117	0.464	0.137	0.009	NS
	02/13/96	222	0.014	0.011	0.008	0.182	0.225	0.155	0.255	0.196	0.161	NS
	03/11/96	249	0.016	0.030	0.030	0.376	0.241	0.120	0.107	0.152	0.054	NS
	04/15/96	284	0.014	0.058	0.055	0.213	0.060	0.025	0.080	NS	0.012	NS
	05/20/96	319	0.017	0.022	0.021	0.032	0.027	0.028	0.020	NS	0.019	NS
	06/10/96	340	0.008	0.008	0.007	0.016	0.005	0.002	0	NS	0	NS

Appendix F. Continued.

Measure	Date	Day of exposure	Station WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9	WW10[1]
Total suspended solids (mg/L)												
	05/04/95	-63	540	2	4	10	10	47	62	122	238	NS
	06/05/95	-31	148	6	33	15	41	53	74	73	80	NS
	07/11/95	5	156	6	15	32	37	73	126	201	137	NS
	08/07/95	32	65	10	7	56	108	125	108	66	109	NS
	09/11/95	67	127	5	3	22	56	105	62	58	24	NS
	10/17/95	103	12	3	5	12	71	50	31	85	66	NS
	11/13/95	130	29	6	2	23	8	77	76	46	37	NS
	12/12/95	159	11	13	2	21	45	227	173	7	25	NS
	01/10/96	188	17	32	2	20	87	25	144	8	11	NS
	02/13/96	222	32	4	2	21	36	61	67	11	18	NS
	03/11/96	249	99	11	2	47	58	83	91	26	57	NS
	04/15/96	284	283	8	5	18	55	39	73	NS	145	NS
	05/20/96	319	-	-	-	-	-	-	-	NS	-	NS
	06/10/96	340	75	8	11	40	75	77	45	NS	107	NS
Volatile solids (mg/L)												
	05/04/95	-63	-	-	-	-	-	-	-	-	-	NS
	06/05/95	-31	-	-	-	-	-	-	-	-	-	NS
	07/11/95	5	-	-	-	-	-	-	-	-	-	NS
	08/07/95	32	6.0	2.4	1.6	17.6	20.0	23.5	23.0	15.5	14.0	NS
	09/11/95	67	11.0	1.0	0.4	3.5	12.0	16.5	13.0	12.0	3.0	NS
	10/17/95	103	1.2	0.8	1.4	2.0	9.0	10.5	5.4	10.3	13.5	1.7
	11/13/95	130	2.6	0.9	0.8	3.2	1.4	7.0	8.5	6.5	5.7	NS
	12/12/95	159	1.2	1.7	0.4	2.2	4.0	23.0	18.0	1.7	4.3	NS
	01/10/96	188	1.5	8.7	1.2	3.3	12.0	4.0	19.0	1.3	1.9	NS
	02/13/96	222	3.1	1.3	0.8	3.0	5.6	10.0	10.0	2.2	3.8	NS
	03/11/96	249	7.3	2.2	1.0	6.5	8.0	10.0	10.5	4.3	8.5	NS
	04/15/96	284	27.0	2.0	2.2	6.0	8.0	6.5	13.0	NS	17.0	NS
	05/20/96	319	-	-	-	-	-	-	-	NS	-	NS
	06/10/96	340	8.0	2.6	3.0	9.5	12.0	13.0	6.0	NS	15.0	NS

Appendix F. Continued.

Measure	Date	Day of exposure	Station									
			WW1	WW2	WW3	WW4	WW5	WW6	WW7	WW8	WW9	WW10[1]
Fixed solids (mg/L)												
	05/04/95	-63	-	-	-	-	-	-	-	-	-	NS
	06/05/95	-31	-	-	-	-	-	-	-	-	-	NS
	07/11/95	5	-	-	-	-	-	-	-	-	-	NS
	08/07/95	32	59.2	8.0	5.2	38.8	88.0	101	85.0	51.0	95.3	NS
	09/11/95	67	116.0	4.2	2.8	18.5	44.5	89.0	49.5	46.5	21.0	NS
	10/17/95	103	11.0	1.8	3.4	9.6	62.5	39.0	25.2	75.0	53.0	10.7
	11/13/95	130	26.0	5.4	1.1	19.4	6.9	70.0	68.0	39.5	31.7	NS
	12/12/95	159	9.3	11.6	1.7	19.2	41.0	204	155	5.6	21.0	NS
	01/10/96	188	15.6	23.3	0.8	17.0	75.5	21.0	125	6.7	9.6	NS
	02/13/96	222	29.1	2.4	1.5	17.7	30.4	51.0	57.5	8.8	14.0	NS
	03/11/96	249	91.7	8.8	1.4	40.5	50.0	73.5	81.0	21.3	49.0	NS
	04/15/96	284	256	6.3	3.0	12.0	47.0	33.0	60.0	NS	128	NS
	05/20/96	319	-	-	-	-	-	-	-	NS	-	NS
	06/10/96	340	66.7	5.0	8.4	31.0	63.5	64.5	39.3	NS	92.5	NS

[1]WW10 was sampled on 10/4/95.
[2]NS: No sample collected at WW8 due to flooding or at WW10 due to intermittent flow.
[3]Conductivity (μmhos/cm) corrected to 25°C.
[4]-: No data.
[5]<: Below limit of detection.

Appendix G. Concentration of inorganic elements (mg/L) in water collected from various sample stations near Grand Junction, Colorado.

Element	Date	Day of exposure	Station							
			HT	AC3	AC4	AC5	AC7	WW2	WW3	WW10
Ag	07/10-11/95	4-5	<0.005[1]	<0.005	<0.005	<0.005	-[2]	<0.005	<0.005	-
	09/11-12/95	67-68	-	<0.005	<0.005	0.010	0.007	<0.005	<0.005	-
	10/04/95	90	-	-	-	-	-	-	-	<0.005
	11/13-14/95	130-131	-	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
	01/09-10/96	187-188	-	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
	03/11-12/96	249-250	-	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
Al	07/10-11/95	4-5	<0.03	<0.03	<0.03	<0.03	-	<0.03	0.06	-
	09/11-12/95	67-68	-	<0.03	<0.03	<0.03	<0.03	<0.03	0.04	-
	10/04/95	90	-	-	-	-	-	-	-	<0.03
	11/13-14/95	130-131	-	<0.03	<0.03	<0.03	-	<0.03	<0.03	-
	01/09-10/96	187-188	-	<0.03	<0.03	<0.03	-	<0.03	<0.03	-
	03/11-12/96	249-250	-	<0.03	<0.03	<0.03	-	<0.03	<0.03	-
As	07/10-11/95	4-5	<0.02	<0.02	<0.02	<0.02	-	<0.02	<0.02	-
	09/11-12/95	67-68	-	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-
	10/04/95	90	-	-	-	-	-	-	-	<0.02
	11/13-14/95	130-131	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	-
	01/09-10/96	187-188	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	-
	03/11-12/96	249-250	-	<0.02	<0.02	<0.02	-	<0.02	<0.02	-
B	07/10-11/95	4-5	0.035	0.031	0.025	0.023	-	0.180	0.170	-
	09/11-12/95	67-68	-	0.053	0.057	0.068	0.057	0.091	0.100	-
	10/04/95	90	-	-	-	-	-	-	-	0.063
	11/13-14/95	130-131	-	0.059	0.055	0.055	-	0.069	0.078	-
	01/09-10/96	187-188	-	0.048	0.047	0.056	-	0.096	0.100	-
	03/11-12/96	249-250	-	0.057	0.052	0.054	-	0.200	0.210	-

Appendix G. Continued.

Element	Date	Day of exposure	Station							
			HT	AC3	AC4	AC5	AC7	WW2	WW3	WW10
Ba	07/10-11/95	4-5	0.124	0.138	0.085	0.044	-	0.103	0.066	-
	09/11-12/95	67-68	-	0.131	0.129	0.125	0.119	0.096	0.112	-
	10/04/95	90	-	-	-	-	-	-	-	0.140
	11/13-14/95	130-131	-	0.102	0.140	0.104	-	0.072	0.094	-
	01/09-10/96	187-188	-	0.102	0.099	0.106	-	0.109	0.116	-
	03/11-12/96	249-250	-	0.146	0.115	0.109	-	0.100	0.094	-
Be	07/10-11/95	4-5	<0.0002	<0.0002	<0.0002	<0.0002	-	<0.0002	<0.0002	-
	09/11-12/95	67-68	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	-
	10/04/95	90	-	-	-	-	-	-	-	<0.0002
	11/13-14/95	130-131	-	<0.0002	<0.0002	<0.0002	-	<0.0002	<0.0002	-
	01/09-10/96	187-188	-	<0.0002	<0.0002	<0.0002	-	<0.0002	<0.0002	-
	03/11-12/96	249-250	-	<0.0002	<0.0002	<0.0002	-	<0.0002	<0.0002	-
Bi	07/10-11/95	4-5	<0.04	<0.04	<0.04	<0.04	-	<0.04	<0.04	-
	09/11-12/95	67-68	-	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	-
	10/04/95	90	-	-	-	-	-	-	-	<0.04
	11/13-14/95	130-131	-	<0.04	<0.04	<0.04	-	<0.0	<0.04	-
	01/09-10/96	187-188	-	<0.04	<0.04	<0.04	-	<0.04	<0.04	-
	03/11-12/96	249-250	-	<0.04	<0.04	<0.04	-	<0.04	<0.04	-
Ca	07/10-11/95	4-5	40.1	51.0	38.5	45.2	-	80.8	80.7	-
	09/11-12/95	67-68	-	77.5	70.3	72.0	68.6	81.9	85.1	-
	10/04/95	90	-	-	-	-	-	-	-	86.9
	11/13-14/95	130-131	-	78.6	76.3	79.2	-	80.0	78.5	-
	01/09-10/96	187-188	-	68.3	68.2	82.0	-	114	105	-
	03/11-12/96	249-250	-	68.8	69.4	73.2	-	230	213	-

Appendix G. Continued.

Element	Date	Day of exposure	Station							
			HT	AC3	AC4	AC5	AC7	WW2	WW3	WW10
Cd	07/10-11/95	4-5	<0.002	<0.002	<0.002	<0.002	-	<0.002	<0.002	-
	09/11-12/95	67-68	-	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	-
	10/04/95	90	-	-	-	-	-	-	-	<0.002
	11/13-14/95	130-131	-	<0.002	<0.002	<0.002	-	<0.002	<0.002	-
	01/09-10/96	187-188	-	<0.002	<0.002	<0.002	-	<0.002	<0.002	-
	03/11-12/96	249-250	-	<0.002	<0.002	<0.002	-	<0.002	<0.002	-
Co	07/10-11/95	4-5	0.011	<0.003	<0.003	<0.003	-	<0.003	<0.003	-
	09/11-12/95	67-68	-	<0.003	0.004	0.006	0.006	<0.003	<0.003	-
	10/04/95	90	-	-	-	-	-	-	-	<0.003
	11/13-14/95	130-131	-	0.005	0.003	<0.003	-	<0.003	<0.003	-
	01/09-10/96	187-188	-	0.005	<0.003	0.004	-	<0.003	<0.003	-
	03/11-12/96	249-250	-	0.003	<0.003	0.005	-	<0.003	<0.003	-
Cr	07/10-11/95	4-5	<0.007	<0.007	<0.007	<0.007	-	0.010	0.010	-
	09/11-12/95	67-68	-	0.008	<0.007	<0.007	0.010	<0.007	0.008	-
	10/04/95	90	-	-	-	-	-	-	-	<0.007
	11/13-14/95	130-131	-	<0.007	<0.007	<0.007	-	0.010	<0.007	-
	01/09-10/96	187-188	-	<0.007	<0.007	0.009	-	0.010	0.010	-
	03/11-12/96	249-250	-	<0.007	0.008	0.009	-	0.010	0.020	-
Cu	07/10-11/95	4-5	0.034	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
	09/11-12/95	67-68	-	<0.005	<0.005	<0.005	0.005	<0.005	<0.005	-
	10/04/95	90	-	-	-	-	-	-	-	<0.005
	11/13-14/95	130-131	-	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
	01/09-10/96	187-188	-	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
	03/11-12/96	249-250	-	<0.005	0.006	<0.005	-	<0.005	<0.005	-

Appendix G. Continued.

Element	Date	Day of exposure	Station							
			HT	AC3	AC4	AC5	AC7	WW2	WW3	WW10
Fe	07/10-11/95	4-5	0.023	0.010	0.026	0.028	-	<0.005	0.007	-
	09/11-12/95	67-68	-	0.027	0.030	0.031	0.021	0.010	0.010	-
	10/04/95	90	-	-	-	-	-	-	-	0.022
	11/13-14/95	130-131	-	0.030	0.021	0.018	-	0.009	0.020	-
	01/09-10/96	187-188	-	0.016	0.016	0.018	-	0.005	0.065	-
	03/11-12/96	249-250	-	0.017	0.025	0.029	-	0.021	0.027	-
K	07/10-11/95	4-5	2.0	4.1	2.9	3.1	-	2.2	1.0	-
	09/11-12/95	67-68	-	4.2	3.3	3.7	3.1	4.2	4.8	-
	10/04/95	90	-	-	-	-	-	-	-	3.3
	11/13-14/95	130-131	-	2.8	2.5	2.7	-	3.6	3.7	-
	01/09-10/96	187-188	-	2.7	2.5	3.8	-	3.9	3.9	-
	03/11-12/96	249-250	-	2.8	4.1	3.8	-	7.6	6.6	-
Li	07/10-11/95	4-5	0.013	0.015	0.013	0.014	-	0.048	0.048	-
	09/11-12/95	67-68	-	0.028	0.027	0.031	0.032	0.034	0.034	-
	10/04/95	90	-	-	-	-	-	-	-	0.031
	11/13-14/95	130-131	-	0.026	0.023	0.025	-	0.035	0.033	-
	01/09-10/96	187-188	-	0.024	0.024	0.028	-	0.045	0.048	-
	03/11-12/96	249-250	-	0.024	0.024	0.026	-	0.075	0.077	-
Mg	07/10-11/95	4-5	11.0	15.9	10.7	12.1	-	136	136	-
	09/11-12/95	67-68	-	23.8	23.5	24.1	23.7	46.7	48.3	-
	10/04/95	90	-	-	-	-	-	-	-	26.4
	11/13-14/95	130-131	-	25.1	25.5	26.7	-	38.1	38.2	-
	01/09-10/96	187-188	-	21.4	21.9	26.2	-	58.1	63.4	-
	03/11-12/96	249-250	-	24.7	25.0	26.4	-	215	217	-

Appendix G. Continued.

Element	Date	Day of exposure	Station							
			HT	AC3	AC4	AC5	AC7	WW2	WW3	WW10
Mn	07/10-11/95	4-5	0.004	0.074	0.026	0.032	-	0.036	0.047	-
	09/11-12/95	67-68	-	0.065	0.055	0.043	0.003	0.020	0.033	-
	10/04/95	90	-	-	-	-	-	-	-	0.004
	11/13-14/95	130-131	-	0.025	0.023	0.020	-	0.008	0.010	-
	01/09-10/96	187-188	-	0.023	0.024	0.025	-	0.007	0.033	-
	03/11-12/96	249-250	-	0.021	0.009	0.009	-	0.059	0.013	-
Mo	07/10-11/95	4-5	0.005	0.008	0.007	0.006	-	0.010	0.009	-
	09/11-12/95	67-68	-	0.012	0.009	0.009	0.010	0.009	0.009	-
	10/04/95	90	-	-	-	-	-	-	-	0.009
	11/13-14/95	130-131	-	<0.004	<0.004	<0.004	-	0.009	0.008	-
	01/09-10/96	187-188	-	0.005	<0.004	0.006	-	0.008	0.007	-
	03/11-12/96	249-250	-	0.010	0.009	0.008	-	0.015	0.010	-
Na	07/10-11/95	4-5	20.8	34.5	21.9	24.5	-	420	416	-
	09/11-12/95	67-68	-	79.9	80.6	83.9	89.5	146	154	-
	10/04/95	90	-	-	-	-	-	-	-	88.8
	11/13-14/95	130-131	-	74.6	74.8	77.9	-	127	127	-
	01/09-10/96	187-188	-	69.0	67.4	83.6	-	170	201	-
	03/11-12/96	249-250	-	81.6	82.4	87.8	-	585	598	-
Ni	07/10-11/95	4-5	0.007	<0.006	<0.006	<0.006	-	<0.006	<0.006	-
	09/11-12/95	67-68	-	<0.006	<0.006	0.010	0.009	<0.006	<0.006	
	10/04/95	90	-	-	-	-	-	-	-	0.007
	11/13-14/95	130-131	-	<0.006	0.006	<0.006	-	<0.006	<0.006	-
	01/09-10/96	187-188	-	0.010	<0.006	0.007	-	<0.006	<0.006	-
	03/11-12/96	249-250	-	<0.006	0.008	<0.006	-	<0.006	<0.006	-

Appendix G. Continued.

Element	Date	Day of exposure	Station							
			HT	AC3	AC4	AC5	AC7	WW2	WW3	WW10
P	07/10-11/95	4-5	0.05	<0.04	<0.04	<0.04	-	0.16	0.12	-
	09/11-12/95	67-68	-	<0.04	0.08	0.09	0.06	0.05	0.06	-
	10/04/95	90	-	-	-	-	-	-	-	0.08
	11/13-14/95	130-131	-	0.05	<0.04	0.04	-	<0.04	0.14	-
	01/09-10/96	187-188	-	<0.04	<0.04	0.04	-	0.04	0.07	-
	03/11-12/96	249-250	-	0.06	0.05	0.04	-	0.16	0.15	-
Pb	07/10-11/95	4-5	0.032	<0.007	0.010	<0.007	-	<0.007	<0.007	-
	09/11-12/95	67-68	-	0.010	0.037	0.063	0.058	0.020	<0.007	-
	10/04/95	90	-	-	-	-	-	-	-	0.033
	11/13-14/95	130-131	-	<0.007	<0.007	<0.007	-	0.010	<0.007	-
	01/09-10/96	187-188	-	0.025	<0.007	<0.007	-	<0.007	0.009	-
	03/11-12/96	249-250	-	<0.007	0.009	0.029	-	0.020	<0.007	-
Sb	07/10-11/95	4-5	<0.03	<0.03	0.04	<0.03	-	0.04	0.05	-
	09/11-12/95	67-68	-	0.04	<0.03	<0.03	<0.03	<0.03	<0.03	-
	10/04/95	90	-	-	-	-	-	-	-	<0.03
	11/13-14/95	130-131	-	<0.03	<0.03	<0.03	-	<0.03	<0.03	-
	01/09-10/96	187-188	-	<0.03	<0.03	<0.03	-	<0.03	<0.03	-
	03/11-12/96	249-250	-	<0.03	0.03	0.04	-	0.05	0.05	-
Se	07/10-11/95	4-5	<0.05	<0.05	<0.05	<0.05	-	<0.05	<0.05	-
	09/11-12/95	67-68	-	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-
	10/04/95	90	-	-	-	-	-	-	-	<0.05
	11/13-14/95	130-31	-	<0.05	<0.05	<0.05	-	<0.05	<0.05	-
	01/09-10/96	187-188	-	<0.05	<0.05	<0.05	-	<0.05	<0.05	-
	03/11-12/96	249-250	-	<0.05	0.05	0.05	-	<0.05	<0.05	-

Appendix G. Continued.

Element	Date	Day of exposure	Station							
			HT	AC3	AC4	AC5	AC7	WW2	WW3	WW10
Si	07/10-11/95	4-5	0.83	1.1	0.8	2.1	-	<0.08	<0.08	-
	09/11-12/95	67-68	-	1.8	0.9	0.3	2.0	1.40	1.40	-
	10/04/95	90	-	-	-	-	-	-	-	1.1
	11/13-14/95	130-131	-	1.4	1.5	1.4	-	<0.08	0.10	-
	01/09-10/96	187-188	-	2.2	1.1	2.1	-	<0.08	0.20	-
	03/11-12/96	249-250	-	1.0	1.0	1.0	-	<0.08	<0.08	-
Sr	07/10-11/95	4-5	0.363	0.433	0.320	0.378	-	0.822	0.826	-
	09/11-12/95	67-68	-	0.795	0.791	0.808	0.802	0.874	0.897	-
	10/04/95	90	-	-	-	-	-	-	-	0.922
	11/13-14/95	130-131	-	0.769	0.762	0.801	-	0.946	0.939	-
	01/09-10/96	187-188	-	0.630	0.642	0.767	-	1.41	1.34	-
	03/11-12/96	249-250	-	0.689	0.680	0.710	-	2.92	2.83	-
Ti	07/10-11/95	4-5	<0.0008	<0.0008	<0.0008	<0.0008	-	<0.0009	0.0020	-
	09/11-12/95	67-68	-	<0.0009	<0.0009	<0.0009	<0.0009	<0.0009	0.0010	-
	10/04/95	90	-	-	-	-	-	-	-	<0.0009
	11/13-14/95	130-131	-	<0.0009	<0.0009	<0.0009	-	<0.0009	<0.0009	-
	01/09-10/96	187-188	-	<0.0009	<0.0009	<0.0009	-	<0.0009	<0.0009	-
	03/11-12/96	249-250	-	<0.0009	<0.0009	<0.0009	-	<0.0010	<0.0009	-
Tl	07/10-11/95	4-5	0.2	<0.1	<0.1	<0.1	-	<0.1	<0.1	-
	09/11-12/95	67-68	-	<0.1	0.2	0.3	0.4	<0.1	<0.1	-
	10/04/95	90	-	-	-	-	-	-	-	0.2
	11/13-14/95	130-131	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	-
	01/09-10/96	187-188	-	<0.1	<0.1	<0.1	-	<0.1	<0.1	-
	03/11-12/96	249-250	-	<0.1	<0.1	0.1	-	<0.1	<0.1	-

Appendix G. Continued.

Element	Date	Day of exposure	Station							
			HT	AC3	AC4	AC5	AC7	WW2	WW3	WW10
W	07/10-11/95	4-5	<0.01	<0.01	<0.01	<0.01	-	<0.01	<0.01	-
	09/11-12/95	67-68	-	<0.01	<0.01	0.01	0.01	<0.01	<0.01	-
	10/04/95	90	-	-	-	-	-	-	-	<0.01
	11/13-14/95	130-131	-	<0.01	<0.01	<0.01	-	<0.01	<0.01	-
	01/09-10/96	187-188	-	<0.01	<0.01	<0.01	-	<0.01	<0.01	-
	03/11-12/96	249-250	-	<0.01	<0.01	<0.01	-	<0.01	<0.01	-
V	07/10-11/95	4-5	<0.005	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
	09/11-12/95	67-68	-	<0.005	<0.005	0.005	<0.005	<0.005	<0.005	-
	10/04/95	90	-	-	-	-	-	-	-	<0.005
	*11/13-14/95	130-131	-	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
	01/09-10/96	187-188	-	<0.005	<0.005	<0.005	-	<0.005	<0.005	-
	03/11-12/96	249-250	-	<0.005	0.006	0.007	-	<0.005	<0.005	-
Zn	07/10-11/95	4-5	<0.01	0.01	<0.01	<0.01	-	<0.01	<0.01	-
	09/11-12/95	67-68	-	0.02	0.03	0.03	0.01	0.02	0.02	-
	10/04/95	90	-	-	-	-	-	-	-	0.01
	11/13-14/95	130-131	-	0.02	0.03	0.02	-	<0.01	<0.01	-
	01/09-10/96	187-188	-	0.01	0.01	<0.01	-	<0.01	0.01	-
	03/11-12/96	249-250	-	<0.01	<0.01	<0.01	-	0.02	0.01	-

[1]<: Below limit of detection.
[2]-: No sample.

Appendix H. Concentration of selenium ($\mu g/g$ dry weight) in muscle plugs from razorback sucker held at three sites near Grand Junction, Colorado, and from brood stock held at Horsethief Canyon State Wildlife Area.

			Day of exposure and date							
Site	Fish no.	Sex	0 7/6	34 8/9	69 9/13	126 11/9	231 2/22	305[1] 5/6	337[2] 6/7	371[3] 7/11
			1995				1996			
HT	12	F	4.4	4.0	5.1	4.7	-[4]	-	-	-
	16	F	4.0	4.9	5.5	4.9	-	-	-	-
	17	F	5.0	4.8	-	5.3	5.0	4.5	4.9	4.9
	19	F	4.7	5.3	5.8	5.1	-	-	-	-
	25	F	4.2	4.3	6.4	4.8	4.0	4.8	-	-
	41	F	-	-	5.0	4.6	4.2	5.0	4.8	-
	44	F	-	-	3.6	3.6	4.4	3.4	3.9	-
	57	F	-	-	-	4.4	4.5	4.6	-	-
	74	F	-	-	-	4.5	4.3	4.6	4.3	4.1
AC	12	F	2.7	4.0	-	6.6	11.1	12.4	-	-
	19	F	5.0	4.7	7.6	9.8	12.2	12.9	-	-
	20	F	3.8	-	-	9.7	10.4	11.7	10.1	-
	21	F	3.9	4.8	6.7	-	9.1	10.3	12.1	10.2
	22	F	4.4	6.0	8.2	11.2	-	-	-	-
	23	F	3.2	4.2	7.6	9.7	-	11.3	10.3	8.9
	26	M	4.4	4.7	6.2	10.1	-	-	-	-
	28	F	4.1	4.6	8.3	9.5	10.4	11.5	13.4	-
WW	1	F	5.0	-	6.9	11.2	17.3	20.8	20.7	16.6
	2	F	3.4	-	6.0	9.2	13.0	14.6	12.9	-
	3	M	4.3	4.8	6.7	10.8	14.6	16.4	-	-
	12	F	3.7	-	-	10.6	-	16.7	15.7	11.9
	17	F	4.6	-	5.8	-	9.1	-	-	-
	21	F	4.2	-	7.4	9.8	14.6	17.3	-	-
	33	M	3.8	3.2	5.3	5.9	11.7	-	-	-
	54	F	-	5.6	-	8.9	12.1	14.1	-	-

Appendix H. Continued.

Site	Fish no.	Sex	Day of exposure and date: 0 7/6 (1995)	34 8/9 (1995)	69 9/13 (1995)	126 11/9 (1995)	231 2/22 (1996)	305[1] 5/6 (1996)	337[2] 6/7 (1996)	371[3] 7/11 (1996)
BS	1	F (0404)[5]	-	-	-	-	-	3.6	-	-
	2	M (320E)	-	-	-	-	-	5.2	-	-
	3	F (3914)	-	-	-	-	-	13.1	-	-
	4	F (3436)	-	-	-	-	-	13.8	-	-
	5	F (OC6B)	-	-	-	-	-	6.3	-	-
	6	F (253C)	-	-	-	-	-	-[6]	-	-
	7	M (4F7E)	-	-	-	-	-	2.7	-	-
	8	F (706D)	-	-	-	-	-	4.3	-	-
	9	F (081D)	-	-	-	-	-	2.5	-	-
	10	F (275F)	-	-	-	-	-	3.5	-	-
	11	F (5275)	-	-	-	-	-	2.6	-	-
	12	M (5964)	-	-	-	-	-	3.5	-	-
	13	M (607A)	-	-	-	-	-	3.2	-	-
	14	M (6363)	-	-	-	-	-	3.8	-	-
	15	M (6D7B)	-	-	-	-	-	3.3	-	-

[1]Spawned and moved fish at AC and WW to reference site HT for depuration.
[2]32 days depuration.
[3]66 days depuration.
[4]-: No sample.
[5]The last four PIT numbers are given for brood stock.
[6]Hybrid not sampled.

Appendix I. Mean (standard error in parentheses) selenium concentration (μg/g dry weight), percent moisture, diameter (mm), and percent viability of eggs from razorback sucker held at three sites near Grand Junction, Colorado.

Site	Fish number	Selenium	Moisture (%)	Diameter	Viable (%)
HT	17	7.5	87.8	2.28 (0.01)	43.6 (0.1)
	25[1]	6.1	86.8	2.26 (0.02)	32.2 (3.0)
	41	6.6	87.8	2.28 (0.02)	12.0 (1.6)
	44	6.2	88.5	2.41 (0.01)	49.6 (0.8)
	57	5.8	87.3	2.43 (0.02)	37.9 (3.7)
	66	6.2	87.2	2.30 (0.02)	30.1 (2.3)
	74[1]	6.8	84.5	2.02 (0.03)	16.3 (0)
AC	12	35.5	90.1	2.29 (0.01)	35.7 (2.9)
	17	42.5	88.2	2.32 (0.02)	21.1 (2.2)
	18	65.1	88.9	2.38 (0.01)	60.2 (1.4)
	19	43.4	88.9	2.35 (0.02)	59.1 (1.1)
	20	54.5	89.2	2.29 (0.01)	24.6 (0.4)
	23[1]	28.2	85.5	-[3]	-
	28	38.0	89.4	2.31 (0.02)	61.8 (0.4)
WW	1	41.3	89.0	2.11 (0.01)	-
	2	37.2	88.0	2.20 (0.01)	12.2 (2.0)
	12	40.9	87.9	-	-
	21	35.3	86.4	2.17 (0.02)	43.6 (2.5)
	54	34.3	87.3	2.20 (0.02)	18.9 (1.8)
BS	0404[4]	4.6	67.0	-	-
	3436	7.1	66.6	-	36.0 (1.5)
	3914	-	-	-	32.0 (2.0)
	5275	-	-	2.87 (0.02)	23.7 (0)
	706D	6.2	66.4	-	-

[1]Eggs not used in egg study, and values not included in Table 16.
[2]Eggs spontaneously broke during fertilization when the fish was spawned on two different days. Value not included in mean calculation for Table 16.
[3]-: No sample.
[4]The last four PIT numbers are given for brood stock.

Appendix J. Water quality characteristics measured in dilution water used in the egg study.

Measure	Date	Day of exposure	Station HT1	AC5	WW2	24-Road
pH						
	05/08/96	2	8.1	8.4	8.6	8.3
	05/09/96	3	8.2	8.4	8.3	8.1
	05/10/96	4	8.1	8.3	8.5	8.0
	05/13/96	7	8.2	8.4	8.4	7.8
Conductivity (µmhos/cm)						
	05/08/96	2	470	790	6,080	240
	05/09/96	3	480	850	6,780	250
	05/10/96	4	470	910	7,910	250
	05/13/96	7	490	760	6,560	250
Hardness (mg/L as $CaCO_3$)						
	05/08/96	2	166	258	1,590	87
	05/09/96	3	170	272	1,670	88
	05/10/96	4	162	272	1,890	87
	05/13/96	7	160	266	2,230	81
Calcium (mg/L)						
	05/08/96	2	49	68	184	26
	05/09/96	3	47	69	188	26
	05/10/96	4	46	71	200	26
	05/13/96	7	45	67	208	25

Appendix J. Continued.

Measure	Date	Day of exposure	Station HT1	AC5	WW2	24-Road
Magnesium (mg/L)						
	05/08/96	2	11	21	275	5
	05/09/96	3	13	24	292	6
	05/10/96	4	11	23	338	5
	05/13/96	7	12	24	416	4
Alkalinity (mg/L as $CaCO_3$)						
	05/08/96	2	104	112	137	76
	05/09/96	3	104	112	140	76
	05/10/96	4	102	113	124	74
	05/13/96	7	99	111	97	67
Chloride (mg/L)						
	05/08/96	2	27	63	534	4
	05/09/96	3	27	67	562	4
	05/10/96	4	24	65	652	4
	05/13/96	7	26	63	752	4

Appendix K. Percent survival of razorback sucker eggs and newly hatched larvae from adults held at Horsethief Canyon State Wildlife Area near Grand Junction, CO. Eggs and newly hatched larvae were held in either reference water (24-Road) or site water in the egg study.

		Fish number and replicate																	
		HT44			HT17			HT41			HT57			HT66			HT25		
Day of exposure	Date	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Reference water																			
1	5/7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	5/8	100	100	96	88	76	88	92	88	80	92	88	100	88	84	84	88	84	84
3	5/9	100	100	96	80	68	68	80	80	68	92	84	96	88	84	84	88	76	72
4	5/10	88	92	88	76	56	64	48	52	56	84	68	96	88	84	76	84	76	72
5	5/11	88	88	88	72	52	56	48	52	52	84	64	88	88	84	76	.[1]	.	.
6	5/12	84	84	88	40	28	40	44	48	48	52	32	60	68	32	44	.	.	.
7	5/13	84	84	88	24	28	32	40	48	36	48	32	52	60	20	36	.	.	.
8	5/14	80	84	88	24	28	32	36	48	36	44	28	52	56	16	32	.	.	.
9	5/15	80	84	88	24	28	32	36	48	36	44	28	52	56	16	32	.	.	.
Site water																			
1	5/7	-[2]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	5/8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3	5/9	100	100	96	88	76	80	96	100	100	96	100	96	92	96	96	76	80	92
4	5/10	92	92	92	68	68	68	96	96	96	92	88	92	88	96	96	72	76	88
5	5/11	92	92	88	68	64	56	92	96	96	88	88	92	88	96	96	.	.	.

Appendix K. Continued.

Day of exposure	Date	Fish number and replicate																
		HT44			HT17			HT41			HT57			HT66			HT25		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
6	5/12	92	92	88	60	60	48	88	96	96	88	88	92	88	96	88	.	.	.
7	5/13	88	80	84	60	32	36	72	88	88	76	88	88	52	76	72	.	.	.
8	5/14	88	80	80	28	28	28	72	88	88	76	88	88	48	64	52	.	.	.
9	5/15	88	80	80	28	28	28	72	88	88	76	88	88	48	64	48	.	.	.

[1].: Testing discontinued to make room for spawn WW4.
[2]-: Eggs stocked at 2 days post spawn.

Appendix L. Percent survival of razorback sucker eggs and newly hatched larvae from adults held at Adobe Creek near Grand Junction, CO. Eggs and newly hatched larvae were held in either reference water (24-Road) or site water in the egg study.

Day of exposure	Date	Fish number and replicate																	
		AC12			AC28			AC17			AC19			AC20			AC18		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Reference water																			
1	5/7	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	5/8	92	88	92	80	92	100	80	84	72	92	88	96	92	80	84	88	88	96
3	5/9	92	72	84	76	92	96	76	72	64	84	88	96	84	76	76	88	88	96
4	5/10	92	72	84	76	80	88	52	56	64	80	88	96	80	72	68	84	88	92
5	5/11	80	60	56	72	80	88	48	56	56	76	68	68	80	64	60	80	80	76
6	5/12	80	60	52	72	72	76	36	56	44	68	48	52	80	64	60	76	76	76
7	5/13	72	44	48	52	72	76	36	16	36	68	48	52	80	64	52	72	76	76
8	5/14	52	44	36	52	68	76	36	16	36	60	32	48	80	64	52	60	68	64
9	5/15	52	44	36	52	68	76	36	16	36	60	32	48	80	64	52	60	68	64
Site water																			
1	5/7	100	100	100	100	100	100	-[1]	-	-	-	-	-	-	-	-	-	-	-
2	5/8	76	84	60	84	88	92	100	100	100	100	100	100	100	100	100	100	100	100
3	5/9	76	72	56	80	88	88	84	92	96	100	100	100	84	84	92	88	96	100
4	5/10	64	68	56	76	80	88	76	96	92	96	96	100	72	72	80	88	96	96
5	5/11	64	64	52	72	80	76	76	92	88	96	88	92	68	68	64	84	84	96

Appendix L. Continued.

Day of exposure	Date	Fish number and replicate																
		AC12			AC28			AC17			AC19			AC20			AC18		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
6	5/12	28	52	36	64	76	60	52	68	68	84	64	80	68	60	52	64	52	76
7	5/13	28	36	36	64	76	60	52	64	64	84	64	72	64	60	52	64	52	68
8	5/14	28	36	16	64	76	60	44	64	64	60	60	72	60	60	52	48	48	44
9	5/15	28	36	16	64	76	60	44	64	64	56	60	72	60	60	52	48	48	44

[1]-: Eggs stocked at 2 days post spawn.

Appendix M. Percent survival of razorback sucker eggs and newly hatched larvae from adults held at Walter Walker State Wildlife Area near Grand Junction, CO. Eggs and newly hatched larvae were held in either reference water (24-Road) or site water in the egg study.

		Fish number and replicate											
		WW2			WW54			WW21			WW1		
Day of exposure	Date	a	b	c	a	b	c	a	b	c	a	b	c
Reference water													
1	5/8	100	100	100	100	100	100	100	100	100	-[1]	-	-
2	5/9	100	100	100	92	100	96	96	96	76	-	-	-
3	5/10	64	80	60	80	92	92	84	56	64	100	100	100
4	5/11	32	36	28	60	88	84	64	52	56	84	72	92
5	5/12	32	32	16	56	80	84	64	52	48	56	64	68
6	5/13	32	32	16	56	76	84	64	52	48	44	52	32
7	5/14	32	28	12	52	72	84	56	48	44	36	52	32
8	5/15	32	28	12	52	72	84	56	48	44	36	52	32
9	5/16	32	28	12	52	72	84	56	48	44	36	52	32
10	5/17	-	-	-	-	-	-	-	-	-	36	52	32
11	5/18	-	-	-	-	-	-	-	-	-	32	48	24
Site water													
1	5/8	100	100	100	100	100	100	100	100	100	-	-	-
2	5/9	92	100	100	92	88	100	76	92	72	-	-	-
3	5/10	72	56	76	72	76	80	52	72	32	100	100	100
4	5/11	20	20	32	68	72	72	48	72	32	84	68	92
5	5/12	20	20	32	56	72	68	36	68	20	48	40	60
6	5/13	20	20	28	52	68	60	36	68	16	40	28	56
7	5/14	20	20	28	52	68	60	36	68	16	36	24	56
8	5/15	20	20	28	52	68	60	36	68	12	36	24	56
9	5/16	20	20	28	52	68	60	36	68	12	36	24	56
10	5/17	-	-	-	-	-	-	-	-	-	36	24	56
11	5/18	-	-	-	-	-	-	-	-	-	36	24	56

[1]-: Spawn WW4 occurred 2 days after other spawns.

Appendix N. Percent hatch of razorback sucker eggs from adults held at Horsethief Canyon State Wildlife Area near Grand Junction, CO. Eggs were held in either reference water (24-Road) or site water in the egg study.

Day of exposure	Date	Fish number and replicate																	
		HT44			HT17			HT41			HT57			HT66			HT25		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Reference water																			
1	5/7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	5/8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	5/9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	5/10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	5/11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.[1]	.	.
6	5/12	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	.	.	.
7	5/13	0	76	40	16	0	4	16	20	32	16	8	44	68	0	24	.	.	.
8	5/14	76	80	80	20	28	28	36	48	36	36	28	44	68	16	28	.	.	.
9	5/15	80	80	80	20	28	28	36	48	36	36	28	44	68	16	28	.	.	.
Site water																			
1	5/7	-[2]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	5/8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	5/9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	5/10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	5/11	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	.	.	.
6	5/12	0	0	56	0	0	0	4	28	4	16	0	0	0	0	0	.	.	.

Appendix N. Continued.

Day of exposure	Date	Fish number and replicate																
		HT44			HT17			HT41			HT57			HT66			HT25		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
7	5/13	80	76	84	24	20	20	72	88	60	76	88	88	44	56	44	.	.	.
8	5/14	80	76	84	28	24	28	72	88	88	76	88	88	44	64	48	.	.	.
9	5/15	80	76	84	28	24	28	72	88	88	76	88	88	44	64	48	.	.	.

[1].: Testing discontinued to make room for spawn WW4.
[2]-: Eggs stocked at 2 days post spawn.

Appendix O. Percent hatch of razorback sucker eggs from adults held at Adobe Creek near Grand Junction, CO. Eggs were held in either reference water (24-Road) or site water in the egg study.

Day of exposure	Date	Fish number and replicate																	
		AC12			AC28			AC17			AC19			AC20			AC18		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Reference water																			
1	5/7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	5/8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	5/9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	5/10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	5/11	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5/12	0	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	5/13	36	44	16	52	52	52	0	8	4	28	8	0	68	48	36	16	64	8
8	5/14	52	44	36	52	52	52	24	8	28	48	20	32	80	60	52	56	64	56
9	5/15	52	44	36	52	56	56	24	8	28	48	20	40	80	64	52	56	64	56
Site water																			
1	5/7	0	0	0	0	0	0	-[1]	-	-	-	-	-	-	-	-	-	-	-
2	5/8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	5/9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	5/10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	5/11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix O. Continued.

Day of exposure	Date	Fish number and replicate																	
		AC12			AC28			AC17			AC19			AC20			AC18		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
6	5/12	24	16	8	32	20	8	4	0	0	4	8	0	0	4	0	8	0	16
7	5/13	28	36	16	64	60	52	36	20	56	24	40	64	48	56	40	48	36	44
8	5/14	28	36	16	64	60	52	44	44	64	28	40	64	60	60	52	48	44	44
9	5/15	28	36	16	64	60	52	44	44	64	28	40	64	60	60	52	48	44	44

[1]-: Eggs stocked at 2 days post spawn.

Appendix P. Percent hatch of razorback sucker eggs from adults held at Walter Walker State Wildlife Area near Grand Junction, CO. Eggs were held in either reference water (24-Road) or site water in the egg study.

Day of exposure	Date	Fish number and replicate											
		WW2			WW54			WW21			WW1		
		a	b	c	a	b	c	a	b	c	a	b	c
Reference water													
1	5/8	0	0	0	0	0	0	0	0	0	-[1]	-	-
2	5/9	0	0	0	0	0	0	0	0	0	-	-	-
3	5/10	0	0	0	0	0	0	0	0	0	0	0	0
4	5/11	0	0	0	0	0	0	0	0	0	0	0	0
5	5/12	0	0	0	0	0	0	0	0	0	0	0	0
6	5/13	0	0	0	0	4	4	0	4	0	0	0	0
7	5/14	20	24	12	16	64	84	24	44	36	0	0	0
8	5/15	32	28	12	44	72	84	56	44	44	0	0	0
9	5/16	32	28	12	44	72	84	56	44	44	4	40	12
10	5/17	-	-	-	-	-	-	-	-	-	32	48	16
11	5/18	-	-	-	-	-	-	-	-	-	32	48	16
Site water													
1	5/8	0	0	0	0	0	0	0	0	0	-	-	-
2	5/9	0	0	0	0	0	0	0	0	0	-	-	-
3	5/10	0	0	0	0	0	0	0	0	0	0	0	0
4	5/11	0	0	0	0	0	0	0	0	0	0	0	0
5	5/12	0	0	0	0	0	0	0	0	0	0	0	0
6	5/13	0	0	0	24	4	0	0	20	8	0	0	0
7	5/14	12	20	28	44	64	60	24	64	12	0	0	0
8	5/15	16	20	28	44	64	60	32	64	12	4	0	20
9	5/16	16	20	28	44	64	60	32	64	12	20	16	52
10	5/17	-	-	-	-	-	-	-	-	-	36	16	52
11	5/18	-	-	-	-	-	-	-	-	-	36	16	52

[1]-: Spawn WW4 occurred 2 days after other spawns.

Appendix Q. Percent deformity and mortality of deformities (in parentheses) of razorback sucker eggs and newly hatched larvae from adults held at Horsethief Canyon State Wildlife Area near Grand Junction, CO. Eggs and newly hatched larvae were held in either reference water (24-Road) or site water in the egg study.

		Fish number and replicate																	
		HT44			HT17			HT41			HT57			HT66			HT25		
Day of exposure	Date	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Reference water																			
5	5/11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.[1]	.	.
6	5/12	4 (0)	0	4 (0)	16 (0)	0	8 (0)	8 (0)	0	12 (0)	8 (0)	4 (0)	16 (0)	12 (0)	12 (0)	8 (0)	.	.	.
7	5/13	4 (0)	0	4 (0)	16 (100)	0	8 (100)	8 (50)	0	16 (75)	8 (0)	4 (0)	16 (0)	12 (67)	12 (100)	8 (100)	.	.	.
8	5/14	4 (0)	4 (0)	8 (0)	16 (100)	4 (0)	12 (67)	8 (100)	0	16 (75)	12 (0)	8 (50)	16 (0)	12 (67)	12 (100)	12 (100)	.	.	.
9	5/15	4 (0)	4 (0)	8 (0)	20 (80)	4 (0)	12 (67)	8 (100)	0	16 (75)	12 (0)	8 (50)	16 (0)	12 (67)	12 (100)	12 (100)	.	.	.
Site water																			
5	5/11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.	.	.
6	5/12	0	0	0	16 (50)	0	0	0	4 (0)	0	0	0	8 (0)	0	0	0	.	.	.
7	5/13	4 (100)	8 (100)	4 (100)	16 (50)	16 (75)	12 (67)	20 (80)	12 (67)	12 (67)	12 (100)	4 (0)	8 (50)	40 (90)	28 (71)	16 (100)	.	.	.
8	5/14	4 (100)	12 (67)	4 (100)	16 (75)	28 (43)	24 (67)	20 (80)	16 (50)	24 (33)	12 (100)	4 (0)	8 (50)	44 (82)	28 (71)	20 (80)	.	.	.
9	5/15	4 (100)	12 (67)	4 (100)	16 (75)	28 (43)	24 (67)	20 (80)	16 (50)	24 (33)	12 (100)	4 (0)	8 (50)	44 (82)	28 (71)	20 (100)	.	.	.

[1].: Testing discontinued to make room for spawn WW4.

Appendix R. Percent deformity and mortality of deformities (in parentheses) of razorback sucker eggs and newly hatched larvae from adults held at Adobe Creek near Grand Junction, CO. Eggs and newly hatched larvae were held in either reference water (24-Road) or site water in the egg study.

		Fish number and replicate																	
		AC12			AC28			AC17			AC19			AC20			AC18		
Day of exposure	Date	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Reference water																			
5	5/11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5/12	12 (0)	8 (0)	12 (0)	24 (0)	8 (0)	16 (0)	12 (0)	28 (0)	0	4 (0)	16 (0)	0	0	0	8 (0)	16 (0)	4 (0)	16 (0)
7	5/13	12 (33)	8 (100)	12 (33)	24 (100)	8 (0)	16 (0)	12 (0)	28 (57)	0	4 (0)	16 (0)	0	0	0	8 (100)	16 (25)	4 (0)	16 (0)
8	5/14	24 (100)	8 (100)	16 (100)	24 (100)	8 (0)	16 (0)	12 (0)	28 (57)	0	8 (50)	16 (25)	0	0	0	12 (67)	16 (75)	8 (100)	16 (75)
9	5/15	24 (100)	8 (100)	16 (100)	24 (100)	8 (0)	16 (0)	12 (0)	28 (57)	0	8 (50)	16 (25)	4 (0)	0	4 (0)	12 (67)	16 (75)	8 (100)	16 (75)
Site water																			
5	5/11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5/12	36 (100)	12 (100)	12 (100)	8 (100)	4 (100)	16 (100)	24 (100)	24 (100)	20 (100)	12 (100)	24 (100)	12 (100)	12 (0)	8 (100)	12 (100)	20 (100)	32 (100)	20 (100)
7	5/13	36 (100)	12 (100)	12 (100)	8 (100)	4 (100)	16 (100)	24 (100)	28 (100)	24 (100)	12 (100)	24 (100)	12 (100)	12 (33)	8 (100)	16 (75)	36 (56)	32 (100)	32 (87)
8	5/14	36 (100)	12 (100)	20 (100)	8 (100)	24 (17)	20 (80)	32 (100)	28 (100)	28 (86)	36 (67)	36 (67)	12 (100)	16 (25)	8 (100)	20 (60)	36 (56)	36 (89)	56 (93)
9	5/15	36 (100)	12 (100)	24 (83)	8 (100)	24 (17)	20 (80)	32 (100)	28 (100)	28 (86)	36 (78)	36 (67)	12 (100)	16 (25)	8 (100)	20 (60)	36 (56)	36 (89)	56 (93)

Appendix S. Percent deformity and mortality of deformities (in parentheses) of razorback sucker eggs and newly hatched larvae from adults held at Walter Walker State Wildlife Area near Grand Junction, CO. Eggs and newly hatched larvae were held in either reference water (24-Road) or site water in the egg study.

		Fish number and replicate											
		WW2			WW54			WW21			WW1		
Day of exposure	Date	a	b	c	a	b	c	a	b	c	a	b	c
Reference water													
4	5/11	0	0	0	0	0	0	0	0	0	0[1]	0	0
5	5/12	0	8 (50)	20 (60)	24 (0)	24 (33)	24 (0)	8 (0)	8 (0)	20 (40)	28 (100)	16 (0)	32 (75)
6	5/13	0	8 (50)	20 (60)	24 (0)	24 (50)	24 (0)	8 (0)	8 (0)	20 (40)	40 (100)	16 (75)	56 (100)
7	5/14	4 (0)	8 (100)	20 (80)	24 (17)	28 (57)	24 (0)	8 (0)	8 (0)	20 (60)	48 (100)	16 (75)	56 (100)
8	5/15	4 (0)	8 (100)	20 (80)	24 (17)	28 (57)	24 (0)	8 (0)	8 (0)	20 (60)	68 (71)	16 (75)	72 (78)
9	5/16	4 (0)	8 (100)	20 (80)	24 (17)	28 (57)	24 (0)	8 (0)	8 (0)	20 (60)	68 (71)	36 (33)	76 (74)
10	5/17	-	-	-	-	-	-	-	-	-	68 (71)	36 (33)	76 (74)
11	5/18	-	-	-	-	-	-	-	-	-	68 (71)	36 (44)	76 (84)
Site water													
4	5/11	0	0	0	0	0	0	0	0	0	0	0	0
5	5/12	0	0	0	12 (100)	0	12 (33)	12 (100)	4 (100)	16 (75)	36 (100)	28 (100)	32 (100)
6	5/13	0	0	0	24 (67)	0	12 (100)	12 (100)	8 (50)	16 (100)	44 (100)	40 (100)	36 (100)
7	5/14	0	0	0	24 (67)	4 (0)	12 (100)	12 (100)	12 (33)	16 (100)	48 (100)	40 (100)	36 (100)
8	5/15	0	0	0	28 (57)	4 (0)	16 (75)	16 (75)	12 (33)	16 (100)	64 (75)	40 (100)	36 (100)
9	5/16	0	0	0	28 (57)	4 (0)	16 (75)	16 (75)	12 (33)	16 (100)	64 (75)	44 (91)	40 (90)
10	5/17	-	-	-	-	-	-	-	-	-	64 (75)	44 (91)	40 (90)
11	5/18	-	-	-	-	-	-	-	-	-	64 (75)	44 (91)	44 (82)

[1]-: Spawn WW4 occurred 2 days after other spawns.

Appendix T. Water quality characteristics measured in dilution water used in the razorback sucker larvae study.

Measure	Date	Day of exposure	Station HT1	AC5	WW2	24-Road
PH						
	05/13/96	-4	8.2	8.4	8.4	7.8
	05/19/96	2	8.6	7.9	8.8	8.1
	05/21/96	4	8.4	7.6	8.6	-
	05/23/96	6	8.6	8.0	8.6	8.0
	05/27/96	10	8.4	7.8	8.6	7.8
	05/30/96	13	8.1	7.9	8.6	7.8
	06/03/96	17	8.3	8.0	8.6	8.1
	06/06/96	20	8.6	8.3	8.4	8.1
	06/11/96	25	8.7	8.1	8.2	7.9
	06/14/96	28	8.7	8.0	8.3	7.7
	06/17/96	31	8.5	8.0	8.2	7.3
	06/20/96	33	8.6	8.0	8.2	8.0
Conductivity (µmhos/cm)						
	05/13/96	-4	490	760	6,560	250
	05/19/96	2	420	900	5,650	230
	05/21/96	4	400	900	6,180	-
	05/23/96	6	400	970	4,820	220
	05/27/96	10	400	1,060	4,840	210
	05/30/96	13	410	1,090	3,650	200
	06/03/96	17	480	1,110	4,380	200
	06/06/96	20	500	1,090	4,870	220
	06/11/96	25	400	680	4,730	210
	06/14/96	28	410	640	4,190	410
	06/17/96	31	440	630	4,260	330
	06/20/96	33	410	610	4,330	310

Appendix T. Continued.

Measure	Date	Day of exposure	Station HT1	AC5	WW2	24-Road
Hardness (mg/L as $CaCO_3$)						
	05/13/96	-4	160	266	2,230	81
	05/19/96	2	152	292	1,610	76
	05/21/96	4	148	304	1,600	-
	05/23/96	6	154	358	1,270	72
	05/27/96	10	152	350	1,340	68
	05/30/96	13	160	354	1,000	68
	06/03/96	17	176	380	1,200	68
	06/06/96	20	172	318	1,240	66
	06/11/96	25	146	238	1,310	65
	06/14/96	28	148	222	1,110	62
	06/17/96	31	154	218	1,140	60
	06/20/96	33	151	227	1,160	62
Calcium (mg/L)						
	05/13/96	-4	45	67	208	25
	05/19/96	2	43	72	160	24
	05/21/96	4	43	76	172	-
	05/23/96	6	45	92	147	23
	05/27/96	10	42	83	146	22
	05/30/96	13	45	82	124	22
	06/03/96	17	50	92	126	22
	06/06/96	20	48	65	138	22
	06/11/96	25	42	60	142	22
	06/14/96	28	42	59	131	21
	06/17/96	31	46	60	133	19
	06/20/96	33	43	60	130	21

Appendix T. Continued.

Measure	Date	Day of exposure	Station HT1	AC5	WW2	24-Road
Magnesium (mg/L)						
	05/13/96	-4	12	24	416	4
	05/19/96	2	11	27	294	4
	05/21/96	4	10	28	284	-
	05/23/96	6	10	31	219	4
	05/27/96	10	11	35	237	3
	05/30/96	13	12	36	168	3
	06/03/96	17	12	43	215	3
	06/06/96	20	13	38	218	3
	06/11/96	25	10	21	232	2
	06/14/96	28	10	18	190	2
	06/17/96	31	10	17	196	3
	06/20/96	33	11	19	203	2
Alkalinity (mg/L as $CaCO_3$)						
	05/13/96	-4	99	111	97	67
	05/19/96	2	102	131	102	63
	05/21/96	4	105	143	104	-
	05/23/96	6	108	200	113	59
	05/27/96	10	104	169	112	56
	05/30/96	13	103	162	110	56
	06/03/96	17	107	210	109	57
	06/06/96	20	103	120	111	56
	06/11/96	25	93	99	123	42
	06/14/96	28	93	95	118	73
	06/17/96	31	96	97	130	86
	06/20/96	33	106	99	121	94

Appendix T. Continued.

Measure	Date	Day of exposure	Station HT1	AC5	WW2	24-Road
Chloride (mg/L)						
	05/13/96	-4	26	63	752	4
	05/19/96	2	22	66	528	4
	05/21/96	4	22	71	550	-
	05/23/96	6	22	79	408	5
	05/27/96	10	24	84	428	5
	05/30/96	13	24	86	326	4
	06/03/96	17	28	91	392	5
	06/06/96	20	29	90	400	5
	06/11/96	25	24	47	424	14
	06/14/96	28	24	37	368	58
	06/17/96	31	26	38	376	28
	06/20/96	33	22	38	378	16
Sulfate (mg/L)						
	05/13/96	-4	-	-	-	-
	05/19/96	2	-	-	-	-
	05/21/96	4	79	223	2,700	35
	05/23/96	6	77	251	2,100	36
	05/27/96	10	80	270	2,080	36
	05/30/96	13	88	286	1,630	36
	06/03/96	17	102	276	1,980	37
	06/06/96	20	94	295	1,960	34
	06/11/96	25	77	179	2,030	34
	06/14/96	28	100	194	2,190	41
	06/17/96	31	110	193	2,200	41
	06/20/96	33	101	204	2,260	41

Appendix T. Continued.

Measure	Date	Day of exposure	Station			
			HT1	AC5	WW2	24-Road
Un-ionized ammonia (mg/L NH_3-N)						
	05/13/96	-4	-	-	-	-
	05/19/96	2	-	-	-	-
	05/21/96	4	0.02	0.01	0.02	0.08
	05/23/96	6	0.02	0.00	0.01	0.02
	05/27/96	10	0.01	0.01	0.02	0.03
	05/30/96	13	0.02	0.01	0.02	0.08
	06/03/96	17	0.01	0.01	0.02	0.12
	06/06/96	20	0.01	0.01	0.02	0.14
	06/11/96	25	0.01	0.01	0.03	0.19
	06/14/96	28	0.01	0.01	0.01	0.23
	06/17/96	31	0.01	0.01	0.01	0.17
	06/20/96	33	0.01	0.02	0.01	0.25
Nitrate (mg/L NO_3-N)						
	05/13/96	-4	-	-	-	-
	05/19/96	2	-	-	-	-
	05/21/96	4	-	-	-	-
	05/23/96	6	-	-	-	-
	05/27/96	10	-	-	-	-
	05/30/96	13	-	-	-	-
	06/03/96	17	0.2	<0.1	0.1	<0.1
	06/06/96	20	-	-	-	-
	06/11/96	25	0.1	0.2	0.1	0.2
	06/14/96	28	-	-	-	-
	06/17/96	31	-	-	-	-
	06/20/96	33	<0.1	0.1	0.1	0.2

Appendix T. Continued.

Measure	Date	Day of exposure	Station			
			HT1	AC5	WW2	24-Road
Nitrite (mg/L NO_2-N)						
	05/13/96	-4	-	-	-	-
	05/19/96	2	-	-	-	-
	05/21/96	4	0.02	0.02	0.02	0.02
	05/23/96	6	-	-	-	-
	05/27/96	10	-	-	-	-
	05/30/96	13	-	-	-	-
	06/03/96	17	0.01	<0.01	<0.01	<0.01
	06/06/96	20	-	-	-	-
	06/11/96	25	<0.01	<0.01	<0.01	<0.01
	06/14/96	28	-	-	-	-
	06/17/96	31	-	-	-	-
	06/20/96	33	<0.01	0.01	<0.01	0.02
Total suspended solids (mg/L)						
	05/13/96	-4	-	-	-	-
	05/19/96	2	-	-	-	-
	05/21/96	4	-	-	-	-
	05/23/96	6	14.6	3.4	5.2	0.3
	05/27/96	10	26.3	10.5	25.5	0.9
	05/30/96	13	17.0	3.8	10.5	0.4
	06/03/96	17	15.3	10.3	6.0	0.3
	06/06/96	20	8.7	1.7	2.8	0.3
	06/11/96	25	13.7	6.4	3.6	0.8
	06/14/96	28	7.3	2.0	7.7	0.0
	06/17/96	31	16.2	4.2	5.8	0.4
	06/20/96	33	12.7	4.0	3.7	0.0

Appendix T. Continued.

Measure	Date	Day of exposure	Station HT1	AC5	WW2	24-Road
Volatile solids (mg/L)						
	05/13/96	-4	-	-	-	-
	05/19/96	2	-	-	-	-
	05/21/96	4	-	-	-	-
	05/23/96	6	2.8	1.1	2.2	0.1
	05/27/96	10	4.3	2.2	6.0	0.9
	05/30/96	13	2.7	1.2	3.5	0.0
	06/03/96	17	2.3	2.0	2.3	0.7
	06/06/96	20	2.7	1.7	1.5	0.7
	06/11/96	25	3.3	1.6	2.8	0.8
	06/14/96	28	2.7	1.0	2.7	1.3
	06/17/96	31	2.7	0.5	1.0	0.1
	06/20/96	33	2.7	0.3	0.3	0.0
Fixed solids (mg/L)						
	05/13/96	-4	-	-	-	-
	05/19/96	2	-	-	-	-
	05/21/96	4	-	-	-	-
	05/23/96	6	11.8	2.3	3.0	0.1
	05/27/96	10	22.0	8.2	19.5	0.0
	05/30/96	13	14.3	2.5	7.0	0.4
	06/03/96	17	13.0	8.3	3.7	0.0
	06/06/96	20	6.0	0.0	1.2	0.0
	06/11/96	25	10.3	4.9	0.8	0.0
	06/14/96	28	4.7	1.0	5.0	0.0
	06/17/96	31	13.5	3.8	4.8	0.3
	06/20/96	33	10.0	3.7	3.3	0.3

[1]-: No data.

Appendix U. Concentration of inorganic elements (μg/g dry weight) in zooplankton collected from various sites near Grand Junction, Colorado. Samples were collected at Horsethief Canyon State Wildlife Area and Adobe Creek on 5/22/96 (day 5), 5/30/96 (day 13), 6/5/96 (day 19), and 6/13/96 (day 27); and at North Pond at Walter Walker State Wildlife Area on 5/25/96 (day 8), 6/4/96 (day 18), 6/7/96 (day 21), and 6/14/96 (day 28) of the razorback sucker larvae study.

Element	Day of exposure	Site		
		HT	AC	WW
Ag	5/8	<1[1]	<1	<1
	13/18	<2	1	<1
	19/21	<1	<1	<2
	27/28	<1	<1	<1
Al	5/8	1,360	1,390	1,380
	13/18	1,280	2,140	711
	19/21	1,840	3,330	790
	27/28	2,070	1,720	827
As	5/8	<5	<4	6
	13/18	<5	<4	9
	19/21	7	6	<6
	27/28	<5	7	<3
B	5/8	1.9	2.0	4.1
	13/18	2.0	2.0	1.0
	19/21	2.0	3.8	<2
	27/28	3.7	2.0	2.0
Ba	5/8	32.2	30.5	15.0
	13/18	19.0	26.9	13.6
	19/21	16.0	34.3	21.3
	27/28	30.8	24.6	19.3

Appendix U. Continued.

Element	Day of exposure	Site		
		HT	AC	WW
Be	5/8	<0.03	<0.04	0.07
	13/18	<0.03	0.05	<0.04
	19/21	0.04	0.12	<0.06
	27/28	0.04	0.05	<0.03
Bi	5/8	<5	<5	<5
	13/18	<5	<5	<5
	19/21	<5	<5	<9
	27/28	<5	<5	<5
Ca	5/8	10,700	18,700	3,640
	13/18	11,400	17,200	10,100
	19/21	5,750	11,100	18,700
	27/28	13,400	13,000	16,600
Cd	5/8	<0.3	<0.2	0.6
	13/18	<0.4	<0.2	0.3
	19/21	<0.2	0.2	<0.3
	27/28	<0.2	<0.2	<0.2
Co	5/8	0.6	0.5	0.8
	13/18	<0.6	0.9	0.7
	19/21	0.4	1.0	0.9
	27/28	0.6	0.6	0.6
Cr	5/8	0.9	<2	1.0
	13/18	1.0	3.0	<2
	19/21	2.0	4.0	<3
	27/28	2.0	<2	<2

Appendix U. Continued.

Element	Day of exposure	Site		
		HT	AC	WW
Cu	5/8	14	11	20
	13/18	30	11	14
	19/21	20	11	13
	27/28	21	11	13
Fe	5/8	671	1,020	973
	13/18	635	1,400	596
	19/21	942	2,160	712
	27/28	1,010	1,140	757
K	5/8	4,600	2,700	8,900
	13/18	5,800	4,300	9,100
	19/21	2,500	3,000	8,500
	27/28	3,400	2,300	9,000
Li	5/8	1.9	1.0	1.9
	13/18	2.0	2.1	1.0
	19/21	1.0	2.8	1.0
	27/28	1.6	1.0	0.8
Mg	5/8	1,210	1,750	1,750
	13/18	1,270	1,820	1,700
	19/21	1,290	1,980	1,950
	27/28	1,400	1,540	1,850
Mn	5/8	62.4	119	202
	13/18	42.8	115	223
	19/21	57.0	152	189
	27/28	45.0	98	190

Appendix U. Continued.

Element	Day of exposure	Site		
		HT	AC	WW
Mo	5/8	<0.8	1.0	<0.8
	13/18	<0.8	1.0	1.0
	19/21	<0.7	1.0	2.0
	27/28	1.0	0.9	0.8
Na	5/8	1,300	1,360	2,680
	13/18	2,010	1,820	3,180
	19/21	670	1,100	3,290
	27/28	910	560	3,270
Ni	5/8	1	<1	2
	13/18	2	<1	2
	19/21	<1	1	2
	27/28	<1	<1	1
P	5/8	12,700	12,300	11,400
	13/18	12,600	12,800	11,600
	19/21	10,700	10,600	11,600
	27/28	12,400	11,300	11,400
Pb	5/8	<4	<4	<4
	13/18	<4	6	<4
	19/21	<4	5	<7
	27/28	<4	<4	<4
Sb	5/8	<4	<10	<4
	13/18	<4	<10	<10
	19/21	<10	<10	<20
	27/28	<10	<10	<10

Appendix U. Continued.

Element	Day of exposure	Site		
		HT	AC	WW
Se	5/8	<8	27	44
	13/18	<7	26	42
	19/21	10	33	44
	27/28	20	28	42
Si	5/8	160	100	170
	13/18	150	230	190
	19/21	230	280	50
	27/28	290	170	68
Sr	5/8	66.7	140	47
	13/18	64.7	100	53
	19/21	34.8	77	110
	27/28	73.9	88	93
Ti	5/8	17	31	28
	13/18	16	41	20
	19/21	35	68	20
	27/28	35	37	22
Tl	5/8	<40	<30	<40
	13/18	<40	<30	<30
	19/21	<30	<30	<60
	27/28	<30	<30	<30
W	5/8	<2	<3	<2
	13/18	<2	<3	<3
	19/21	<3	<3	<5
	27/28	<3	<3	<3

Appendix U. Continued.

Element	Day of exposure	Site		
		HT	AC	WW
V	5/8	3.0	3.5	3.4
	13/18	2.0	5.5	2.0
	19/21	3.1	7.7	2.0
	27/28	3.8	4.6	2.0
Zn	5/8	81	91	313
	13/18	107	97	162
	19/21	89	128	140
	27/28	92	140	96

[1]<: Below limit of detection.

Appendix V. Percent survival of razorback sucker larvae exposed to reference food (brine shrimp) and reference water (24-Road) in the larval fish study.

	Fish number and replicate																							
	HT44		HT41		HT57		AC28		AC19		AC20		WW2		WW54		WW21		BS1[1]		BS2[2]		BS3[3]	
Day	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100	100	90	100	100	90	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	100	100	100	90	100	100	90	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	100	90	100	90	100	100	90	100	100	100	100	100	100	100	100
6	100	100	100	100	100	100	100	100	100	100	90	100	90	100	100	90	100	100	100	100	100	100	100	100
7	100	100	100	100	100	100	100	100	90	100	70	100	90	100	89	90	100	89	100	100	100	100	100	100
8	89	100	100	100	100	100	100	100	79	100	70	100	90	100	89	90	100	89	100	100	100	100	100	100
9	89	100	100	100	100	100	100	100	79	100	70	100	90	100	89	90	89	89	100	100	100	100	100	100
10	89	100	100	100	100	100	100	100	79	100	70	100	90	100	89	90	89	89	100	100	100	100	100	100
11	89	100	100	100	100	100	100	100	79	100	70	100	90	100	89	90	89	89	100	100	100	90	100	100
12	89	100	100	100	100	100	100	100	79	100	70	89	90	100	89	90	89	78	100	100	100	90	100	100
13	89	100	100	100	100	100	100	100	79	100	70	67	90	100	89	90	89	78	100	100	100	90	100	100
14	89	100	100	100	100	100	100	100	79	100	70	67	90	100	89	90	89	78	100	100	100	90	100	100
15	89	100	100	100	100	100	100	100	79	100	70	67	90	100	89	80	89	78	100	100	100	90	89	100
16	89	100	100	100	89	100	100	100	79	100	70	67	90	100	89	80	89	78	100	100	89	90	89	100
17	89	89	100	78	89	100	100	100	79	100	70	67	90	100	89	80	89	78	100	100	89	90	89	100
18	89	89	100	78	89	100	100	100	79	100	70	67	90	100	89	80	89	78	100	100	89	90	89	100

Appendix V. Continued.

	Fish number and replicate																							
	HT44		HT41		HT57		AC28		AC19		AC20		WW2		WW54		WW21		BS1[1]		BS2[2]		BS3[3]	
Day	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
19	89	89	100	78	89	100	100	100	79	100	70	67	90	100	89	80	89	78	100	100	89	90	89	100
20	89	89	100	78	89	100	100	100	79	100	70	67	90	100	89	80	89	78	100	100	89	90	89	89
21	89	89	100	78	89	100	100	100	79	100	70	67	90	100	89	80	89	78	100	100	89	90	89	89
22	89	89	100	78	89	100	100	100	79	100	70	67	90	100	89	80	89	56	100	100	89	90	89	89
23	89	89	100	78	89	100	100	100	79	100	70	67	90	100	78	80	89	56	100	100	89	90	89	89
24	89	78	100	78	89	100	100	100	79	100	70	67	90	100	78	80	89	56	100	100	89	79	89	89
25	89	78	100	78	89	100	100	100	79	100	70	67	90	100	78	80	78	56	100	100	78	79	89	89
26	78	78	100	78	89	100	100	100	79	100	70	67	79	100	78	80	78	56	100	100	78	79	89	89
27	78	78	100	78	89	100	100	100	79	100	70	67	79	100	78	80	78	56	100	100	78	79	89	89
28	78	78	100	78	89	100	100	89	79	100	70	67	79	100	78	80	78	56	100	100	78	79	89	89
29	78	78	100	78	89	100	100	89	79	100	70	67	79	100	78	80	78	44	100	100	78	79	89	89
30	78	78	100	78	89	100	100	89	79	100	70	67	79	100	78	70	78	44	100	100	78	79	89	89

[1]: BS1 = spawn 9601, 7F7F365275; BS2 = spawn 9602, 7F7D133914; BS3 = spawn 9603, 7F7D163436.

Appendix W. Percent survival of razorback sucker larvae exposed to reference food (brine shrimp) and site water in the larval fish study.

	Fish number and replicate																							
	HT44		HT41		HT57		AC28		AC19		AC20		WW2		WW54		WW21		BS1[1]		BS2[2]		BS3[3]	
Day	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	80	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	80	100	100	100	100	100	100	100	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	100	80	100	100	100	100	100	90	100	100	100	100	100	100	100	100
5	100	100	100	100	100	100	100	100	100	80	90	90	80	100	100	90	100	100	100	100	100	100	100	100
6	100	100	100	90	100	100	90	100	100	80	90	70	80	100	90	90	100	90	100	100	100	100	100	100
7	100	100	100	90	100	100	90	100	100	80	90	70	69	100	79	90	89	79	100	100	100	100	100	100
8	100	100	100	90	100	100	90	100	100	80	79	70	69	100	79	90	89	67	100	100	100	100	100	100
9	100	100	100	90	100	100	90	100	100	80	56	70	69	100	79	90	89	56	100	100	100	100	100	100
10	100	100	100	90	100	100	90	100	100	80	45	70	69	100	79	90	89	45	100	100	100	100	100	100
11	100	100	100	90	100	100	90	100	100	69	45	70	69	100	79	79	78	45	100	100	100	100	100	100
12	100	100	100	90	100	100	90	100	100	69	45	58	69	100	67	79	67	45	90	90	100	100	100	100
13	100	89	100	90	100	100	90	100	100	69	45	58	69	100	67	79	56	45	90	90	100	100	100	100
14	100	89	100	90	100	100	90	100	100	69	45	58	69	100	67	79	56	45	90	90	100	100	100	100
15	100	89	100	90	100	100	90	100	100	69	45	58	69	100	67	79	56	45	90	90	100	100	100	100
16	100	89	100	90	100	100	90	100	100	69	45	58	69	100	67	79	44	45	90	90	100	89	100	100
17	100	89	100	90	100	100	90	100	89	57	45	58	69	100	67	79	44	45	90	90	100	78	100	100
18	100	89	100	90	100	100	90	100	78	57	45	58	69	100	67	79	44	45	90	68	100	78	100	100
19	89	89	100	90	100	89	90	100	78	57	45	58	69	78	67	79	33	34	90	68	100	78	89	100

Appendix W. Continued.

	Fish number and replicate																							
	HT44		HT41		HT57		AC28		AC19		AC20		WW2		WW54		WW21		BS1[1]		BS2[2]		BS3[3]	
Day	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
20	89	89	100	90	100	89	90	100	78	57	45	58	69	78	67	79	33	34	90	68	100	78	89	100
21	89	89	100	90	100	89	90	100	78	46	45	58	69	78	67	79	33	34	90	68	100	78	89	100
22	89	89	100	90	100	89	90	100	78	46	45	58	57	78	67	79	33	34	90	68	100	78	89	100
23	89	89	100	90	100	89	90	100	78	46	45	58	57	78	67	79	33	34	90	68	100	78	89	100
24	89	89	100	90	100	89	90	100	78	46	45	58	46	78	67	79	33	34	90	68	100	67	89	100
25	89	89	100	90	100	89	90	100	78	46	45	58	46	78	67	79	33	34	90	68	100	67	89	100
26	78	89	100	90	100	89	90	100	78	46	45	58	46	78	67	67	33	34	90	68	100	67	89	100
27	78	89	100	90	100	89	90	100	78	46	45	58	46	78	67	67	33	34	90	68	100	67	89	100
28	78	78	100	90	100	89	90	100	78	46	45	47	46	78	67	67	33	34	90	68	100	67	89	100
29	78	78	100	90	100	89	90	89	78	46	45	47	46	78	67	67	33	34	90	68	100	67	89	100
30	78	78	100	90	100	89	90	89	78	46	45	47	46	78	67	67	33	34	90	68	100	67	89	100

[1]: BS1 = spawn 9601, 7F7F365275; BS2 = spawn 9602, 7F7D133914; BS3 = spawn 9603, 7F7D163436.

Appendix X. Percent survival of razorback sucker larvae exposed to site food and reference water (24-Road) in the larval fish study.

	Fish number and replicate																							
	HT44		HT41		HT57		AC28		AC19		AC20		WW2		WW54		WW21		BS1[1]		BS2[2]		BS3[3]	
Day	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	90	90	100	90	100	100	100	100	100	100	100	100	100	100
4	100	90	100	90	100	100	100	90	100	100	80	80	80	90	80	90	90	90	100	100	100	100	100	100
5	90	70	100	90	100	100	80	80	80	100	50	70	50	50	40	60	70	70	100	100	100	100	100	100
6	40	20	90	30	90	100	70	80	70	80	40	60	10	0	10	40	20	20	100	100	90	100	100	100
7	10	10	70	0	90	50	20	50	70	80	40	40	0	0	0	0	0	0	100	100	90	100	100	100
8	0	0	23	0	79	50	0	12	70	80	40	27	0	0	0	0	0	0	100	100	90	100	100	90
9	0	0	0	0	56	37	0	0	58	80	27	0	0	0	0	0	0	0	80	80	90	100	100	90
10	0	0	0	0	22	12	0	0	23	80	13	0	0	0	0	0	0	0	80	70	90	100	100	90
11	0	0	0	0	11	0	0	0	23	34	0	0	0	0	0	0	0	0	70	60	90	100	100	90
12	0	0	0	0	11	0	0	0	12	23	0	0	0	0	0	0	0	0	70	50	90	90	100	90
13	0	0	0	0	11	0	0	0	12	23	0	0	0	0	0	0	0	0	58	50	90	90	100	90
14	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	58	50	90	79	100	90
15	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	58	50	90	67	100	90
16	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	58	50	90	67	100	79
17	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	47	50	90	67	100	79
18	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	100	79

Appendix X. Continued.

	Fish number and replicate																							
	HT44		HT41		HT57		AC28		AC19		AC20		WW2		WW54		WW21		BS1[1]		BS2[2]		BS3[3]	
Day	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
19	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	100	79
20	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	100	67
21	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	100	67
22	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	89	67
23	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	89	67
24	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	89	67
25	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	89	67
26	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	23	50	90	67	89	67
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	50	90	67	89	67
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	50	79	67	89	67
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	50	79	67	89	67
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	50	79	67	89	67

[1]: BS1 = spawn 9601, 7F7F365275; BS2 = spawn 9602, 7F7D133914; BS3 = spawn 9603, 7F7D163436.

Appendix Y. Percent survival of razorback sucker larvae exposed to site food and site water in the larval fish study.

	Fish number and replicate																							
	HT44		HT41		HT57		AC28		AC19		AC20		WW2		WW54		WW21		BS1[1]		BS2[2]		BS3[3]	
Day	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
3	100	100	100	100	100	100	100	100	100	100	100	100	100	90	90	90	90	100	100	100	100	100	100	100
4	100	100	100	100	100	100	100	100	90	100	70	70	100	90	80	90	90	90	100	100	100	100	100	100
5	70	90	100	100	90	100	100	90	90	90	60	60	80	70	70	70	80	70	100	100	100	100	100	100
6	50	70	80	100	90	90	100	90	90	90	50	60	50	40	20	40	40	40	100	100	100	100	100	100
7	20	60	40	70	60	70	80	90	90	90	50	50	0	13	0	13	0	13	100	100	90	100	100	100
8	0	0	13	23	48	47	34	56	90	79	25	25	0	13	0	0	0	0	100	90	90	100	100	100
9	0	0	0	0	48	35	23	56	79	79	12	25	0	13	0	0	0	0	80	90	90	100	100	100
10	0	0	0	0	24	23	11	22	45	56	0	12	0	13	0	0	0	0	50	80	90	100	100	100
11	0	0	0	0	0	12	0	0	22	22	0	0	0	13	0	0	0	0	40	70	90	100	100	90
12	0	0	0	0	0	12	0	0	11	11	0	0	0	13	0	0	0	0	30	60	90	90	100	90
13	0	0	0	0	0	0	0	0	11	11	0	0	0	13	0	0	0	0	30	60	90	79	100	90
14	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	48	90	79	100	90
15	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	48	67	67	100	90
16	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	48	67	67	100	79
17	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	48	67	45	89	79
18	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	36	67	45	89	79

Appendix Y. Continued.

	Fish number and replicate																							
	HT44		HT41		HT57		AC28		AC19		AC20		WW2		WW54		WW21		BS1[1]		BS2[2]		BS3[3]	
Day	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b	a	b
19	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	36	67	45	89	79
20	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	36	67	45	89	79
21	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	36	67	45	89	67
22	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	36	67	45	89	67
23	0	0	0	0	0	0	0	0	11	0	0	0	0	13	0	0	0	0	15	36	56	45	89	67
24	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	15	36	56	34	89	67
25	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	15	36	56	34	89	67
26	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	15	36	56	34	89	67
27	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	15	36	56	34	89	67
28	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	15	36	56	34	89	67
29	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	15	24	45	34	89	56
30	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	15	24	45	34	78	56

[1]: BS1 = spawn 9601, 7F7F365275; BS2 = spawn 9602, 7F7D133914; BS3 = spawn 9603, 7F7D163436.

Appendix Z. Percent survival of razorback sucker held at 24-Road from hatch until 134 days of age and fed a commercial fish food.

Date	Age (day)	Site			
		HT	AC	WW	BS[1]
6/12	31	100	100	100	100
6/13	32	100	100	99	99
6/14	33	100	100	98	99
6/15	34	100	100	95	99
6/16	35	99	99	93	98
6/17	36	99	99	92	98
6/18	37	99	99	91	98
6/19	38	99	99	90	97
6/20	39	98	98	88	97
6/21	40	98	98	87	97
6/22	41	98	98	86	97
6/23	42	98	97	85	97
6/24	43	98	97	82	97
6/25	44	98	97	82	96
6/26	45	98	96	81	96
6/27	46	98	96	79	96
6/28	47	98	96	78	96
6/29	48	98	96	78	96
6/30	49	98	96	78	96
7/1	50	98	96	77	96
7/2	51	98	95	76	96
7/3	52	97	95	75	95

Appendix Z. Continued.

Date	Age (day)	Site			
		HT	AC	WW	BS[1]
7/4	53	97	95	73	95
7/5	54	97	95	73	95
7/6	55	97	95	73	95
7/7	56	97	95	71	95
7/8	57	97	95	71	95
7/9	58	97	95	70	95
7/10	59	97	95	70	95
7/11	60	97	95	69	95
7/12	61	96	95	69	94
7/13	62	96	95	68	94
7/14	63	96	95	68	94
7/15	64	96	95	68	94
7/16	65	96	95	67	94
7/17	66	96	95	67	94
7/18	67	96	95	67	94
7/19	68	96	94	66	94
7/20	69	96	94	66	94
7/21	70	96	94	66	94
7/22	71	96	94	66	94
7/23	72	96	94	66	94
7/24	73	96	94	66	94
7/25	74	96	94	66	94
7/26	75	96	94	66	94

Appendix Z. Continued.

Date	Age (day)	Site			
		HT	AC	WW	BS[1]
7/27	76	96	94	66	94
7/28	77	96	94	66	94
7/29	78	96	94	66	94
7/30	79	96	94	65	93
7/31	80	96	94	65	93
8/1	81	96	94	65	93
8/2	82	96	94	65	93
8/3	83	96	94	65	93
8/4	84	96	94	65	93
8/5	85	96	94	65	93
8/6	86	96	94	65	93
8/7	87	96	94	65	93
8/8	88	96	94	65	93
8/9	89	96	94	65	93
8/10	90	96	94	65	93
8/11	91	96	94	65	93
8/12	92	96	94	65	93
8/13	93	96	94	65	93
8/14	94	96	94	65	93
8/15	95	96	94	65	93
8/16	96	96	94	65	93
8/17	97	96	94	65	93
8/18	98	96	94	65	93

Appendix Z. Continued.

Date	Age (day)	Site			
		HT	AC	WW	BS[1]
8/19	99	96	94	65	93
8/20	100	96	94	65	93
8/21	101	95	94	65	93
8/22	102	95	94	64	93
8/23	103	95	94	64	93
8/24	104	95	94	64	93
8/25	105	95	94	64	93
8/26	106	95	94	64	93
8/27	107	95	94	64	93
8/28	108	95	94	64	93
8/29	109	95	94	64	93
8/30	110	95	94	64	93
8/31	111	95	94	64	93
9/1	112	95	94	64	93
9/2	113	94	94	64	93
9/3	114	94	94	64	93
9/4	115	94	94	64	93
9/5	116	94	94	64	93
9/6	117	94	94	64	93
9/7	118	94	94	64	93
9/8	119	94	94	64	93
9/9	120	94	94	64	93
9/10	121	94	94	64	93

Appendix Z. Continued.

Date	Age (day)	Site			
		HT	AC	WW	BS[1]
9/11	122	94	94	64	93
9/12	123	94	94	64	93
9/13	124	94	94	64	93
9/14	125	94	94	64	93
9/15	126	94	94	64	93
9/16	127	94	94	64	93
9/17	128	94	94	64	93
9/18	129	93	94	64	93
9/19	130	93	94	64	93
9/20	131	93	94	64	93
9/21	132	93	94	64	93
9/22	133	93	94	64	93
9/23	134	93	94	64	93

[1]: Combined survival of brood stock larvae were calculated from spawns 9601A, 9601C, 9602A, 9602C, 9603A, and 9603C, which were the same spawns used for growth measurements.