X-RAY ASSESSMENT OF ELECTROFISHING INJURY OF COLORADO PIKEMINNOW

November 2002

John A. Hawkins

Larval Fish Laboratory
Colorado State University
Fort Collins, Colorado 80523

Final Report for the

Recovery Implementation Program for
Endangered Fishes of the Upper Colorado River Basin
U. S. Department of Interior, Fish and Wildlife Service
Lakewood, Colorado 80225

Recovery Program Project 64

Contribution 129 of the Larval Fish Laboratory, Colorado State University

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The objective of this study was to assess the occurrence and rate of electrofishing-caused injuries in endangered Colorado pikeminnow *Ptychocheilus lucius* caught by boat mounted, pulsed-DC electrofishing systems. Colorado pikeminnow captured by electrofishing during the Interagency Standardized Monitoring Program were examined for external injury and x-rayed in the field to assess vertebral injuries. Radiographs revealed that 12 of 46 Colorado pikeminnow x-rayed had vertebral compressions. Three fish (7%) had vertebral compressions considered acute injuries related to the electrofishing capture and nine fish (20%) had chronic (previous) or congenital abnormalities. Vertebral compressions affected 2–11 vertebrae but most fish (67%) had vertebral compressions of only two vertebrae. No fractured or misaligned vertebrae were observed. Injury type was determined by vertebra architecture (size, shape, and density) in each radiograph and was not validated with necropsy because all fish were released alive due to their endangered status. Three of 47 fish examined had external injuries that included bruises and associated muscle compaction, bleeding of the gills, and respiratory arrest. Respiratory arrest occurred due to extreme tetany after one fish was trapped under a live anode for 15-30 seconds resulting in prolonged exposure to tetanizing currents that stopped opercular movement. Another fish was bleeding from the gills after capture while in electrotaxis toward a cathode. Neither of these fish had observable vertebral damage. Information about the capture of the fish with bruises and muscle compaction was insufficient to relate the injury to observed electrofishing parameters but it was also the fish with compression of 11 vertebrae.

Fish with previous electrofishing captures showed no evidence of multiple injuries as would be expected if electrofishing caused high rates of non-lethal injuries in this long-lived species. I conclude that injuries other than vertebral compressions and inadequate handling procedures after capture may increase physiological shock and be of greater potential for increasing mortality than vertebral compressions. Following standard electrofishing guidelines and regular training of field crews should reduce or maintain injuries at low levels.

ACKNOWLEDGMENTS

I thank the following people for assistance with this project. Eric Bergersen, Colorado State University (CSU), Cooperative Fish and Wildlife Research Unit provided x-ray equipment. Joe VanCleave and the staff at CSU Veterinary Teaching Hospital assisted in x-ray procedure, technique, and film developing and James Brecht, DVM assisted in interpreting radiographic images. Bobby Compton and Jack Ruppert of CSU, Larval Fish Laboratory assisted in field x-ray procedures. Recovery Program sampling crew leaders Tom Chart, Utah Division of Wildlife Resources (UDWR, now with U.S. Bureau of Reclamation), Bill Elmblad, Colorado Division of Wildlife (CDOW), and Melissa Trammel (UDWR, now with SWCA, Inc.) and their assistants Rick Anderson, Caleb Chadwick, Kelley Crane, and Rob Martindale captured fish for our use and allowed us to monitor their capture techniques. X-ray technicians at Memorial Hospital in Craig, Colorado, Community Hospital in Grand Junction, Colorado and Rangely District Hospital in Rangely, Colorado assisted in developing x-ray films. Scott

Webb, Radiation Safety Officer, CSU, Environmental Health Services supervised x-ray safety procedures and certification. Tom Nesler and Rick Anderson (CDOW) provided field equipment. I appreciate the thoughtful review and comments of Tom Czapla, Doug Osmundson, and Larry Zeigenfuss; all with U.S. Fish and Wildlife Service. This study was funded by the Recovery Implementation Program for Endangered Fishes of the Upper Colorado River Basin. The Recovery Program is a joint effort of the U. S. Fish and Wildlife Service, U. S. Bureau of Reclamation, U. S. National Park Service, Western Area Power Administration, states of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, and the Colorado River Energy Distributors Association.

Disclaimer

Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the authors, the Fish and Wildlife Service, U. S. Department of Interior, or the Recovery Implementation Program.

Key Words: Colorado pikeminnow, Colorado River, electrofishing injury, Green River, endangered species, Interagency Standardized Monitoring Program (ISMP), radiograph, x-ray, vertebral compressions, Coffelt VVP-15, White River, Yampa River.

INTRODUCTION

The Colorado pikeminnow *Ptychocheilus lucius* is a federally listed, endangered species that occupies rivers in the Upper Colorado River Basin. Status and trends of their populations are currently monitored by annual abundance estimates (Osmundson and Burnham 1998; Osmundson 2002; T. Czapla, personal communication), and from 1986 to 2000 populations were monitored by an Interagency Standardized Monitoring Program (ISMP; USFWS 1987, McAda 2002). Both programs use boat electrofishing to capture adult Colorado pikeminnow. Although electrofishing is widely used to capture many species of fish, studies have demonstrated that electrofishing can reduce performance, injure, or kill some fish (Fredenberg 1992, Snyder 1992, Sharber et al. 1994; Dalbey et al. 1996; Thompson et al. 1997). Because of the unknown effects of electrofishing on individual animals and their populations, some researchers suggest that electrofishing be limited or eliminated in studies of rare species (Snyder 1995; Nielsen 1998). For rare species such as the Colorado pikeminnow it is important that negative effects on both individuals and the population are understood so that the benefits of electrofishing can be weighed against the potential costs (Carlson and Muth 1993). This is especially critical for Colorado pikeminnow that reside in large, turbid rivers where electrofishing is one of the most effective techniques for collecting fish.

The Recovery Implementation Program responsible for monitoring Colorado pikeminnow populations identified the need to assess electrofishing effects on endangered fishes. This study was a preliminary assessment of electrofishing injury of Colorado pikeminnow caught during ISMP sampling with the goal of determining if electrofishing methods caused spinal injuries to Colorado pikeminnow. The objective was to identify the percent of Colorado pikeminnow with vertebral injuries after capture by electrofishing during ISMP.

METHODS

Colorado pikeminnow used in this analysis were captured by fishery biologists with Colorado Division of Wildlife (CDOW) and Utah Division of Wildlife Resources (UDWR) during ISMP sampling in 1996 (McAda et al. 1997). Adult and sub-adult Colorado pikeminnow were captured using standardized electrofishing methods that maintained consistency among researchers, rivers and years (USFWS 1987). Evaluation procedures were conducted in a manner that neither affected ISMP sampling nor harmed Colorado pikeminnow.

Sampling was conducted with outboard-powered, aluminum boats equipped with a 5-kilowatt generator and either VVP-15 or CPS electrofishing control units, both made by Coffelt Manufacturing. Anodes consisted of two stainless-steel spheres (23-cm or 28-cm diameter) mounted individually on fiberglass poles spaced 3.9 m apart and extended 2.4 m forward on each side of the bow. Cathodes were two, 7.6-m stainless steel cables suspended off each side of the boat. Electrode size, voltage and amperage were adjusted to maximize capture efficiency while attempting to minimize potential harm to fish. ISMP guidelines recommended only [pulsed] direct current with output not to exceed 300 volts or 12 amps, but usually at or below 6 amps.

Each electrofishing crew consisted of a boat driver and usually two netters positioned on the bow. The boat moved downstream under power at a constant speed that matched water velocity to maximize netting efficiency. Only shoreline or associated habitats (backwaters, eddies, tributary mouths) were sampled. Crews electrofished one side of the river until the entire reach was sampled and then returned upstream and sampled the other side either on the same or next day. If an endangered fish was captured, sampling was stopped until the requisite data were recorded and the fish released.

After each Colorado pikeminnow capture, the sampling crew reported the proximity of the fish to the nearest electrode (ft, later converted to m) and fish behavior (physiological state) when netted. Physiological states at capture included swimming, stunned, or tetany and represented the fish's ultimate response to the electrical field. Fish that were swimming when captured were generally swimming toward an electrode in electrotaxis. Stunned fish had lost equilibrium and stopped swimming and were in a state of narcosis or the beginning stages of tetany. Most stunned fish recovered immediately when removed from the electrical field. Fish captured in a tetanized state were immobilized and rigid due to sustained muscle contraction and often required longer to regain orientation and recover than stunned fish. The sampling crew was also queried about control-unit settings such as voltage, amperes, and pulse width.

At capture fish were placed in the boat live-well containing fresh river water, transported to shore, and then transferred to a 30-liter, plastic holding tank (food cooler) containing river water treated with 5–10 g/L salt (NaCl) solution to help the fish maintain osmotic balance. Prior to the x-ray procedure, fish were sedated in another cooler with the anesthetic Tricaine[1] (tricaine-methanesulfonate) with a dose of 200 mg/L via a treatment bath. The dilute solution was buffered with sodium bicarbonate ($NaHCO_2$) from baking soda to reduce respiratory stress and decrease physiological side effects of lowered blood pH caused by acidity of Tricaine (Summerfelt and Smith 1990). Approximately 200–250 mg $NaHCO_2$ per 100 mg Tricaine were added to obtain a pH similar to river water. Water was refreshed and treated as necessary to maintain good water quality. Fish were considered anesthetized when opercular rate (respiration) slowed, and they lost equilibrium, muscle tone, and reactivity to external stimuli. If a fish experienced an anesthetic overdose, evidenced by lack of opercular movement, procedures were stopped and the fish was revived immediately in fresh water.

Each fish was measured for total length, weighed, examined for external injuries, marked with a PIT tag, and x-rayed. Photographs were taken of their left, right, dorsal, and ventral aspects.

After the x-ray procedure, fish were returned to the holding tank and recovery was identified when the fish regained equilibrium. Fish were held an additional 15 minutes after they regained equilibrium and muscular control and were released at site of capture as soon as possible to reduce captivity stress. The goal was to perform all procedures and release the fish within 1 hour of capture.

Radiographs of fish were made with a portable, veterinary x-ray unit (MinXray™ Model X750-G) set up on shore near the capture site. A standard operating procedure

---

[1]Tricaine is the generic term for Finquel™ (often called by its trade name: MS-222™) which is a formulation of Tricaine Methanesulfonate registered with the U. S. Food and Drug Administration by Ft. Dodge Laboratories, Ft, Dodge, Iowa.

was followed for each x-ray exposure to insure suitable radiographs and to keep human exposure to limits “as low as reasonably achievable”. The x-ray unit was mounted under a heavy duty, photographic tripod to take a vertical x-ray with the fish and film cassette positioned on the ground. Power was supplied by a 110 volt (V), 3-kilowatt, Honda generator. Output of the x-ray unit was adjustable between 10 milliamp (mA) @ 75-kilovolt peak (kVp) to 15 mA @ 50kVp at 71-cm focal-film-distance. Total filtration was 3.0-mm aluminum including 0.5-mm aluminum collimator filtration.

Two film cassettes were used to allow both ventral and lateral x-rays without changing film and to reduce time that fish were out of water. Each film cassette was 18 X 43 cm, Kodak, X-Omatic (KP 76015-C) with a Kodak, Lanex Medium, intensifying screen. X-ray film was Kodak, TMG RA. For each x-ray, the cassette was loaded with film, wrapped in a plastic bag, placed on the ground under the tripod, leveled with a small bubble level, and aligned with the collimator beam. During collimator alignment the tripod was covered with a canvas tarp to provide a dark environment for centering the collimator’s illuminated cross hairs on the film cassette. After alignment the tarp was opened before each x-ray exposure. Radiographic views included lateral (left side toward x-ray beam) and ventro-dorsal (ventral side toward x-ray beam) with head left (Morgan 1993). The ventro-dorsal view positioned the fish dorsal side down in order to locate the vertebrae close to the film to insure a diagnostic radiograph (Douglas and Williamson 1980).

A technique chart was created to determine the correct x-ray machine settings to produce a diagnostic radiograph (Morgan 1993). Initial technique was based on radiographs of a dead, surrogate fish (walleye, *Stizostedion vitreum*) of a size and mass similar to adult Colorado pikeminnow. Technique was refined by consulting x-ray technicians about the quality of field exposed radiographs. The technique chart specified the current (mA) and time (s) in milliampere-seconds (mAs) of each exposure based on thickness of the fish. Thicker fish had longer exposures. At 74 to 76 cm focal film distance, exposure was 12 mA @ 65 kVp and exposure time ranged from 0.25 to 0.5 seconds (s) for lateral views. For ventro-dorsal views, exposure was 11 mA @ 70 kVp for 0.45 to 0.9 s.

Each fish received an estimated exposure of 2.9 FRoentgen per x-ray as measured by a Qualified State Inspector by x-raying a dead, surrogate fish (walleye) with length, thickness, and mass similar to an adult Colorado pikeminnow. Estimated exposure to the operator was less than 0.6 FRoentgen per x-ray at a distance of 3 m. Both operator and assistant wore lead aprons during all exposures and each wore an exposure badge monitored by CSU Environmental Health Services.

Fish were immobilized by the anesthetic Tricaine to prevent movement during each x-ray procedure and restrained in the ventro-dorsal position by gently wedging them between adjustable, soft, styrofoam blocks[2]. Each radiograph was labeled with species, sample number, and date on lead-impregnated tape . Exposed film was removed and fresh film loaded into the cassettes inside a light-proof, photographer's, film-change bag. Exposed films were stored in light-proof film bags in a dry cooler and developed 1–3 days after exposure, either at local hospitals near each sampling site or at CSU Veterinary Teaching Hospital in Fort Collins.

---

[2]Styrofoam blocks used to position fish were floats known as "pull buoys" used by swimmers for training and were obtained from a sporting-goods store.

Developed radiographs were examined for abnormalities to the spine or associated bones. Spinal damage was described and severity classified using the criteria of Reynolds (1996):

0 ---- no spinal damage apparent,

1 ---- compression (distortion) of vertebrae only,

2 ---- misalignment of vertebrae, including compression,

3 ---- fracture of one or more vertebrae or complete separation of two or more vertebrae.

Radiographs were closely examined to determine if abnormal vertebrae were acutely injured by the ISMP electrofishing event. Acute vertebral injuries were distinguished from previous, healed vertebral injuries based on the architecture (size, shape, margin smoothness, and radiographic density) of injured vertebrae compared to adjacent uninjured vertebrae. Compressed vertebrae caused by the most recent ISMP electrofishing event (acute injuries) had irregular margins and a greater diameter and density than adjacent vertebrae. Compressed vertebrae of congenital or chronic (previous) origin had features characteristic of healing and regrowth including a smooth marginal surface and a diameter and density similar to proximal uninjured vertebrae. Based on radiographs only, it was not possible to distinguish between chronic and congenital injuries.

Location of abnormal vertebrae was identified by counting from the atlas (1st vertebra) and if the atlas was not clearly visible then the count started from the first pleural vertebra with an attached ventral rib (4th vertebra). Identification and counts of some vertebrae were assisted by locating attached neural spines or pleural ribs that were easily distinguished in radiographs. Counts included number of vertebrae anterior to abnormal vertebrae, number of abnormal vertebrae, and number of vertebrae posterior to abnormal vertebrae.

Percent of compression of abnormal vertebrae was calculated by comparing them to adjacent uninjured vertebrae. Average length of uninjured vertebrae was obtained from two uncompressed, proximal vertebrae on each side anterior and posterior to the abnormal vertebrae.

Capture histories of x-rayed fish were obtained from the Recovery Program PIT-tag database to identify whether fish had multiple vertebral injuries from repeated electrofishing captures and to examine growth of injured and uninjured fish that were later recaptured.

RESULTS

Forty seven Colorado pikeminnow were caught by ISMP electrofishing from the Colorado (n=21), White (n=13), and Yampa (n=13) rivers in May 1996. One of these was a recaptured fish handled the day before. Total length averaged 554 mm (SD, 89.95) and ranged 355 to 774 mm (Figure 1). Length frequency was similar to that of Colorado pikeminnow captured during ISMP in previous years (McAda et al. 1994a, 1994b, 1995, 1996). Conductivity ranged 175 to 400 FS/cm in the river and 350 to 480 FS/cm in flooded tributaries (Table 1). Secchi depth was 8 cm or less at several locations. Electrofishing settings were pulsed-DC set at 30 or 60 Hz with output from 150–390 V and 4–15 amps.

Proximity to the nearest electrode was reported for 40 Colorado pikeminnow. At capture, five fish touched an anode, 17 fish were one meter or less from an electrode, 16 fish were from 1 to 2 m, and two fish were from 2 to 3 m from an electrode. Physiological state at capture was observed for 42 fish; 64% were stunned (narcosis) by the electrical current, 24% were swimming toward an electrode (electrotaxis), and 12% were tetanized (tetany) when netted. The physiological response of fish to the electric field generally intensified as their mean distance from the anode decreased but for each physiological response, the range of distances varied widely and overlapped. Fish in electrotaxis were caught at a mean distance from the anode of 1.3 m (range 0–3 m; SD, 1.077), stunned fish were caught at 0.9 m (range 0–2.4 m; SD, 0.709), and tetanized fish were caught at 0.6 m (range 0–1.5 m; SD, 0.747). Fish that touched an anode exhibited a variety of responses to the electrical current: two were tetanized, two were stunned, and one was in electrotaxis (swimming).

Three of 47 fish examined had external injuries associated with electrofishing. One fish had several injuries within an area approximately 75-mm posterior to the insertion of the dorsal fin. These injuries included bruises (brands), three small puncture wounds, and lateral muscle compaction that gave a bulging appearance at the injury. The bruises were small and positioned along the dorsal surface unlike large, lateral-surface bruises typically seen on electofishing-injured trout. The punctures formed a triangle along the lateral surface and dorsal midline. Radiographs of this fish revealed Class-1 compressions in 11 vertebrae at the injury. This fish was captured while swimming toward an anode, but unfortunately the distance at capture was not reported.

Another fish had no visible injuries but was in respiratory arrest (not gilling) due to extreme tetany from prolonged exposure to tetanizing currents after being trapped under a live anode for 15-30 seconds while the boat was stuck in shallow water. The fish remained tetanized for several minutes but was resuscitated by moving it repeatedly through flowing water for about 10 minutes until it regained opercular movement. It was then held in flowing water for several more minutes until it regained orientation and respiration resumed at a normal rate. It is unlikely that this fish would have recovered without intervention. Radiographs revealed no abnormal vertebrae. The third fish with external injuries was caught while in electrotaxis toward a cathode and was bleeding from the gills. It had no other visible injuries and radiographs revealed no vertebral abnormalities. Three other fish were also captured while in electrotaxis toward a cathode: one was uninjured, one had acute vertebral injuries, and the other had minor congenital/chronic vertebral compressions. Even with the injuries described all fish regained orientation, behaved normally, and swam away at release.

An interesting observation on the White River was a Colorado pikeminnow found dead by an electrofishing crew in a reach that was electrofished the day before. The carcass was starting to exhibit rigor mortis, the skin and scales were in good condition but were starting to discolor, and the eyes were clear and natural, indicating fairly recent death within the past 24 hours. The fish had no signs of external injury and the cause of death was unknown, but it was not likely caused by angling because there were no signs of hooking injury and it was retrieved just downstream of Taylor Draw Dam in an area closed to fishing. Examination of the carcass at the Colorado Division of Wildlife, Fish Health Facility in Fort Morgan did not reveal cause of death (W. Elmblad, personal communication) and field radiographs revealed no vertebral injuries.

Another injury type observed in three fish from the White River was torn skin in the gular region between the mandible and isthmus along the interior margin of the mandible. The tears were 30– to 60–mm long and occurred on one or both sides and appeared severe enough to affect the respiratory efficiency due to leakage through the openings. There was no evidence that this injury was caused by the electrofishing event, but I have observed similar injuries on Colorado pikeminnow caught by electrofishing in other studies.

Forty-seven Colorado pikeminnow were x-rayed, including 46 caught by electrofishing and one found dead of unknown causes. Thirty-four of the 46 fish (74%) caught by electrofishing had no apparent vertebral injuries and 12 fish (26%) had Class-1 vertebral compressions. No vertebral misalignments (Class-2 injuries) or fractures (Class-3 injuries) were observed. Three fish (7%) had acute vertebral compressions attributed to the electrofishing event and nine fish (20%) had vertebral compressions classified as congenital or chronic in origin. Length of fish with vertebral compressions ranged 387–701-mm total length and was similar to that of non-injured fish (Figure 1; Table 2). Most fish (67%) had compressions that affected only two vertebrae (Table 2). None of the fish had multiple compressions. Compressed vertebrae were located from the 10^{th} to the 48^{th} vertebrae, but the majority of compressions occurred between the 16^{th} and 34^{th} vertebrae which is the area between the origins of the dorsal and anal fins (Table 2). Acute injuries affected 2–11 vertebrae and compressed them an average of 35% (SD, 15.39; range 18–48%) of original width. Congenital and chronic abnormalities affected from two to four vertebrae and compressed vertebrae an average of 23% (SD, 12.40; range 12–56%) of original width.

There were no clear relationships between the occurrence of compressed vertebrae and observed electrofishing events or physiological state at capture. Fish with compressed vertebrae (both congenital/chronic and acute) were captured at distances between 0 and 2.4 m from the nearest electrode and their physiological state at capture included: swimming (n=4), stunned (n=5), tetanized (n=1) and unknown (n=2). Only one fish with vertebral injuries had associated external injuries (bruises and muscle compaction) and it was the fish with the most extensive compressions (11 vertebrae).

Of the 46 fish caught by electrofishing and x-rayed, 19 were previously captured by either electrofishing (n=15) or trammel net (n= 4), 1–8 years prior to 1996. There was no evidence of multiple vertebral injuries in the radiographs of fish caught more than once by electrofishing.

Fifteen of the 46 x-rayed fish were later recaptured between 1997 and 2002. Fish with no vertebral injury (n=10) grew an average of 17.2 mm/year (SD, 12.74; range 2.8–41.5; Table 3). Four fish with congenital or chronic injuries grew 15.6 mm/year (SD, 6.30; range 8.3–23.4) and the one recaptured fish with acute injuries grew 9.9 mm/year after 2 years at large.

DISCUSSION

The acute injury rate of Colorado pikeminnow attributed to electrofishing (7%) was much lower than that reported for salmonids collected in the wild with similar equipment. Sharber and Carothers (1988) observed vertebral compressions in 43-67% of rainbow trout *Oncorhynchus mykiss* captured with a VVP-15 and Fredenberg (1992) reported spinal injuries in 18-98% of rainbow trout collected with a VVP-15. The acute injury rate of Colorado pikeminnow was also much lower than the injury rate of razorback sucker *Xyrauchen texanus* shocked using similar equipment (VVP-15) in laboratory settings. Eight razorback suckers had a 50% rate of injury during a laboratory study of electrofishing effects on gametes (Muth and Ruppert 1996). However, Colorado pikeminnow injury rate was greater than that of wild roundtail chub *Gila robusta* which showed no evidence of vertebral injury after electrofishing capture from the Colorado River with equipment and techniques similar to ISMP (Cowdell and Valdez 1994). All spinal injuries of Colorado pikeminnow in this study were spinal compressions (Class-1 injury) and none of the injured vertebrae were fractured (Class 2) or misaligned (Class 3), suggesting that Colorado pikeminnow were less susceptible to electrofishing injury than trout which typically experience severe Class 2 and Class 3 injuries (Hollender and Carline 1994; Dalbey et al. 1996; Thompson et al. 1997).

Because of their protected status, fish in this study were not necropsied to confirm their injury classification. Necropsy would allow examination for spinal hemorrhages often associated with acute vertebral injury and whether injured vertebrae were calcified, indicating healed previous injury. However, a low rate of acute injury for Colorado pikeminnow was supported by the lack of multiple injuries in recaptured fish. In addition, a low rate of acute injury was supported by a relatively low congenital/chronic injury rate (20%) for Colorado pikeminnow. With repeated electrofishing, non-lethal acute injuries should accumulate in the population as chronic injuries (Kocovsky et al. 1997). Colorado pikeminnow live over 12 years (Hawkins 1991) and their populations are shocked annually. In this study, the rate of congenital and chronic injuries in Colorado pikeminnow was relatively low and similar to the upper range of background (congenital) abnormalities observed in wild salmonids (0-16%; Gill and Fisk 1966; Hollender and Carline 1994; Sharber and Carothers 1998).

This study lacked an unshocked reference group of fish necessary to confidently distinguish acute injuries from injuries of previous origin. In an attempt to collect a reference group of unshocked fish, other studies have used alternative capture techniques such as angling or netting in areas never electrofished (Hollender and Carline 1994; Thompson et al. 1997). An unshocked reference group from the wild was not considered reliable because most reaches in the upper Colorado River Basin have been electrofished annually for over 15 years and it is likely that some portion of the Colorado pikeminnow population is electrofished without being captured. An alternative would be to x-ray a group of fish before and after exposure to electrofishing. Unshocked hatchery fish may provide the best source for control fish or use in before and after treatment studies.

All Colorado pikeminnow, including those with acute compressions, actively swam away at release suggesting that vertebral compressions did not affect mobility. There was also evidence that even severe vertebral injuries did not result in delayed mortality as evidenced by the recapture of the one fish with both severe external injuries (bruises, punctures, and muscle compaction) and the most numerous (11) vertebral compressions. Growth of this acutely injured fish was less than the average growth of uninjured fish, although it was within the range observed for uninjured fish; however, evaluation of growth affects was limited by the small number of recaptured fish. Immediate mortality was not observed in any fish captured but it is likely that the one fish that experienced respiratory arrest was injured severely enough to cause mortality if it had not been resuscitated.

Physiological response of fish to the electrical field did not follow established theory that fish become increasingly incapacitated as they move closer to the anode. Proximity is considered important because there is evidence that the closer a fish is to an electrode, the greater its potential for injury (Snyder 1992). Fish in this study were captured at a range of distances from the anodes and their physiological state was not related to the distance; but, the relationship was potentially confounded by the inability to accurately observe fish location at all times prior to capture. Observations of fish location in this study may not accurately portray how close some fish were to an electrode before capture because their trajectory and location prior to netting was often obscured by turbidity and influenced by the moving boat, flowing water, and fish depth. This might explain why some tetanized fish were captured more than 2 m from an anode. However, this explanation does not account for fish observed swimming all the way to and touching an anode without experiencing tetany. Because the area immediately adjacent to the anode has the highest voltage gradient, fish that are extremely close or touch the anode should experience tetany (Snyder 1995).

Fish that touched an anode in this study (whether tetanized or not) were not injured at a greater rate than fish that did not touch an anode. However, the harmful effects of extreme tetany were observed in the fish that was in respiratory arrest after prolonged contact with a live anode. Without resuscitation this fish would have probably suffocated, “a common result of excess exposure to high, tetanizing power densities near the electrodes” (Snyder 1995).

Colorado pikeminnow have died during electrofishing in other studies and examination and x-rays of the carcasses have not revealed injuries or spinal abnormalities in those fish. For example, a Colorado pikeminnow died after being electrofished from a flooded tributary during ISMP sampling on the Yampa River in 1995 (W. Elmblad, personal communication). The electrofishing unit was operating unusually and the operator noticed a Colorado pikeminnow swimming at the surface about 5 m from the cathode. The fish turned belly-up and died. It had no external injuries and x-ray and necropsy at the Colorado Division of Wildlife, Fish Health Facility, in Fort Morgan did not reveal internal injuries. The boat’s cathode was later found to be corroded and not fully functional and was suspected to have caused an unusual electrical event.

Only one fish was observed bleeding at the gills during this study, but other researchers and I have observed gill-bleeding in Colorado pikeminnow following electrofishing (W. Elmblad, personal communication). In this study, there was no link between gill-bleeding and spinal injury. Snyder (1995) suggested that bleeding was not associated with spinal injuries or tetany and the long-term effects of gill-bleeding on survival were unknown. Interestingly, the bleeding fish captured in this study was in apparent electrotaxis toward a cathode which is an unusual response and indicates potential equipment malfunction. This reinforces the need to check equipment regularly for polarity and proper functioning.

It was unknown if other internal organs or tissues were damaged as a result of electrofishing because fish were not killed and necropsied. But even necropsy has failed to reveal the cause of death for many Colorado pikeminnow examined by fish-health experts. Vertebral injuries may not be related to other injuries and non-vertebral injuries may be of greater concern to the performance or survival of injured fish. General observations previously discussed of fish killed in other studies or severely injured after electrofishing suggest that injuries may independently or in accumulation with other stressors induce physiological shock resulting in death soon after the capture event. Although injury may increase the potential for physiological shock, other environmental stressors associated with capture and handling may have an equal or larger role in fish survival. Kelsch and Shields (1996) noted that water quality has an important role in fish survival. Poor water quality would include high water temperatures; rapid, extreme temperature changes as fish are transferred from site water to live-well water; or insufficient oxygen content of live-well water that may contain many other fish. All of these are potential characteristics of conditions found in backwater habitats where Colorado pikeminnow have been reported dying after capture. Most of these conditions are controllable by observant field crews but improved handling procedures should be established and taught.

For common species, some mortality from electrofishing is acceptable given the benefits obtained from using the technique especially since many studies would be impossible without electrofishing as a capture technique. Schill and Beland (1995) recommended that some level of harm at the individual level was acceptable as long as the harm does not cause population-level effects. For rare species, the same caveat applies but even more care is required because harm to even a few individuals may cause population affects that influence the survival of the species. This study provided evidence of injury to Colorado pikeminnow caught by electrofishing although the rate and severity of injury was much lower than reported in the literature for salmonids. The injuries observed did not appear to affect survival based on the recapture several years later of the fish with the most severe vertebral injury. Injuries not related to vertebral injury may have greater potential for harm and when combined with poor handling practices likely increase the potential for death. I recommend increased vigilance and training to reduce or maintain low injury rates. Electrofishing crews should be trained in the most recent electrofishing techniques that reduce injury and fish handling procedure should be improved and institutionalized.

CONCLUSIONS

- Colorado pikeminnow captured by electrofishing had both external and vertebral injuries related to electrofishing, but the rate of injury was low.
- Vertebral injuries consisted of only compressions; no fractures or misalignments were observed.
- Other injuries such as extreme tetany, bleeding gills, or increased physiological stress due to poor handling conditions probably have a greater influence on fish survival than vertebral compressions.

RECOMMENDATIONS

- Require electrofishing certification for crews working within the Upper Colorado River Basin.
- Provide regular, formal training to crews for safe and effective electrofishing techniques to reduce potential injuries to fish.
- Establish a protocol to check electrofishing equipment for proper operation, polarity, and output.
- Establish and improve fish handling protocols to minimize handling stress and train crews in fish-resuscitation techniques.
- Researchers should document and photograph external injuries in Colorado pikeminnow.
- Use hatchery-reared fish for controlled studies to determine the rate of background environmental abnormalities in vertebrae of unshocked Colorado pikeminnow and for studies that examine radiographs of individual fish before and after electrofishing.

LITERATURE CITED

Carlson, C. A. and R. T. Muth. 1993. Endangered species management. Pages 355-381 *in* C. C. Kohler and W.A. Hubert, editors. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Cowdell, B. R., and R. A. Valdez. 1994. Effects of pulsed DC electroshock on adult roundtail chub from the Colorado River, Colorado. North American Journal of Fisheries Management 14:659-660.

Dalbey, S. R., T. E. McMahon, and W. Fredenberg. 1996. Effect of electrofishing pulse shape and electrofishing-induced spinal injury on long-term growth and survival of wild rainbow trout. North American Journal of Fisheries Management 16: 560–569.

Douglas, S. W. and H. P. Williamson. 1980. Principles of veterinary radiography, Third Edition. Lea and Febinger, Philadelphia, Pennsylvania.

Fredenberg, W. 1992. Evaluation of electrofishing-induced spinal injuries resulting from field electrofishing surveys in Montana. Montana department of Fish, Wildlife and Parks, Boseman, Montana.

Gill, C.D. and D.M. Fisk. 1966. Vertebral abnormalities in sockeye, pink, and chum salmon. Transactions of the American Fisheries Society 95: 177–182.

Hawkins, J. A. 1992. Age and growth of Colorado squawfish from the Upper Colorado River Basin, 1978-1990. Master's thesis. Colorado State University, Fort Collins.

Hollender, B.A. and R.F. Carline. 1994. Injury to wild brook trout by backpack electrofishing North American Journal of Fisheries Management 14: 643–649.

Kelsch, S.W. and B. Shields. 1996. Care and handling of sampled organisms. Pages 121-144 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, second edition. American Fisheries Society, Bethesda, Maryland.

Kocovsky, P. M., C. Gowan, K. D. Fausch, and S. C. Riley. 1997. Spinal injury rates in three wild trout populations in Colorado after eight years of backpack electrofishing. North American Journal of Fisheries Management 17: 308–313.

McAda, C. M. 2002. Subadult and adult Colorado pikeminnow monitoring; summary of results, 1986-2000. Recovery Program Project 22, U. S. Fish and Wildlife Service, Grand Junction, Colorado.

McAda, C. W., J. W. Bates, J. S. Cranney, T. E. Chart, W. R. Elmblad, and T. P. Nesler. 1994a. Interagency Standardized Monitoring Program: summary of results, 1986–1992. Final Report. Recovery Implementation Program for the Endangered

Fishes of the Upper Colorado River Basin, U. S. Fish and Wildlife Service, Denver, Colorado.

McAda, C. W., J. W. Bates, J. S. Cranney, T. E. Chart, M. A. Trammell, and W. R. Elmblad. 1994b. Interagency Standardized Monitoring Program: summary of results, 1993. Annual Report. Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin, U. S. Fish and Wildlife Service, Denver, Colorado.

McAda, C. W., W. R. Elmblad, T. E. Chart, K. S. Day, and M. A. Trammell. 1995. Interagency Standardized Monitoring Program: summary of results, 1994. Annual Report. Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin, U. S. Fish and Wildlife Service, Denver, Colorado.

McAda, C. W., T. E. Chart, M. A. Trammell, K. S. Day, P. A. Cavalli, and W. R. Elmblad,. 1996. Interagency Standardized Monitoring Program: summary of results, 1995. Annual Report. Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin, U. S. Fish and Wildlife Service, Denver, Colorado.

McAda, C. W., W. R. Elmblad, K. S. Day, M. A. Trammell, and T. E. Chart. 1997. Interagency Standardized Monitoring Program: summary of results, 1996. Annual Report. Recovery Implementation Program for the Endangered Fishes of the

Upper Colorado River Basin, U. S. Fish and Wildlife Service, Denver, Colorado.

Morgan, J. P. 1993. Techniques of veterinary radiography. Fifth Edition. Iowa State University Press, Ames, Iowa. 482 pp.

Muth, R. T. and J. B. Ruppert. 1996. Effects of two electrofishing currents on captive ripe razorback suckers and subsequent egg-hatching success. North American Journal of Fisheries Management 16: 473-476.

Nielsen, J. L. 1998. Electrofishing California's endangered fish populations. Fisheries 23:6-12.

Osmundson, D. O. 2002. Dynamics of the upper Colorado River populations of Colorado pikeminnow. Draft report. U.S. Fish and Wildlife Service Grand Junction, Colorado.

Osmundson, D. O. and K. P. Burnham. 1998. Status and trends of Colorado squawfish in the Upper Colorado River. Transactions of the American Fisheries Society 127:957–970.

Reynolds, J. B. 1996. Electrofishing. Pages 221–251 *in* Fisheries techniques, (2^{nd} Edition) B. R. Murphy and D. W. Willis, editors. American Fisheries Society, Bethesda, Maryland.

Schill, D. J. and K. F. Beland. 1995. Electrofishing studies: a call for population perspective. Fisheries 20:28–29.

Sharber, N.G. and S. W. Carothers. 1988. Influence of electrofishing pulse shape on spinal injuries in adult rainbow trout. North American Journal of Fisheries Management 8: 117–122.

Sharber, N.G., S. W. Carothers, J. P. Sharber, J. C. De Vos, Jr, and D. A. House. 1994. Reducing electrofishing-induced injury of rainbow trout. North American Journal of fisheries Management 14:340–346.

Snyder, D. E. 1992. Impacts of electrofishing on fish. Report of Colorado State University, Larval Fish Laboratory to U. S. Department of Interior, Bureau of Reclamation, Salt Lake City.

Snyder, D. E. 1995. Impacts of electrofishing on fish. Fisheries 20:26–27.

Summerfelt, R. C. and L. S. Smith. 1990. Anesthesia, surgery, and related techniques. Pages 213–272 *in* Methods of fish biology, C. B. Schreck and P. B. Moyle, editors. American Fisheries Society, Bethesda, Maryland.

Thompson, K.G., E.P. Bergersen, and R. B. Nehring. 1997. Injuries to brown trout and rainbow trout induced by capture with pulsed direct current. North American

Journal of Fisheries Management 17: 141–153.

USFWS (U. S. Fish and Wildlife Service). 1987. Interagency Standardized Monitoring Program Handbook. U. S. Fish and Wildlife Service, Grand Junction, Colorado.

Table 1.—Sample location, date, discharge, and conductivity during adult Colorado pikeminnow ISMP, 1996. Agencies conducting sampling included Colorado Division of Wildlife (CDOW) and Utah Division of Wildlife Resources (UDWR).

Sample location						
River	km	Reach	Date	Agency	Discharge (m^3/s)	Conductivity (FS/cm)
Colorado	247–212	Loma - Stateline	May 7–8	CDOW	413	310 – 370
	109–79	Moab-Potash	May 9–10	UDWR	479–513	350 – 400
Yampa	129–112	Maybell-Sunbeam	May 14	CDOW	320	175
	169–153	Above Juniper Springs	May 15–16	CDOW	337–351	130 – 175
	87–79	Lily Park	May 30	CDOW	194	—
White	167–153	Taylor Draw-Rangely	May 28–31	CDOW	45–51	340

Table 2.—Location and characteristics of compressed vertebrae observed in radiographs of Colorado pikeminnow captured during ISMP electrofishing, 1996.

Sample	Fish total length (mm)	Total Number of vertebrae	Median location of injured vertebrae [a]	Location of injured vertebrae	Number of vertebrae injured	Percent compression of injured vertebrae	Injury Type
411	487	48	33.5	33–34	2	39	acute
213	584	48	31	26–36	11	48	acute
312	701	[b]	30	29–31	3	18	acute
208	540	48	17.5	16–19	4	56	congenital/chronic
211	387	47	13.5	13–14	2	30	congenital/chronic
216	420	47	10.5	10–11	2	40	congenital/chronic
206	477	47	17.5	17–18	2	31	congenital/chronic
311	552	48	22	21–23	3	27	congenital/chronic
414	557	47	25.5	25–26	2	31	congenital/chronic
307	602	48	47.5	47–48	2	[c]	congenital/chronic
415	624	48	31.5	31–32	2	12	congenital/chronic
306	685	48	33.5	33–34	2	35	congenital/chronic
Minimum	387	47	10.5		2	12	
Maximum	701	48	47.5		11	56	
Average	551	48	26		3	33.4	
SD	96.9	0.50	10.46		2.57	12.49	

[a] Number of vertebrae from the atlas (1st vertebra).
[b] Unable to count all vertebrae because radiograph incomplete.
[c] Compression affected penultimate and ultimate vertebrae that were not comparable to adjacent vertebrae due to different shape and size.

Table 3.—Growth of recaptured Colorado pikeminnow with different vertebral injuries after initial capture during ISMP electrofishing in 1996.

Fish PIT tag	Length in 1996 (mm)	Length at recapture (mm)	Date of Capture in 1996	Date of recapture	Days at large	Annual growth
acute injury						
1F5-B06-5B25	584	604	05/10/96	05/15/98	735	9.9
congenital/chronic injury						
1F7-33D-7938	557	565	05/29/96	05/14/97	350	8.3
7F7-B08-5C0A	685	732	05/15/96	09/22/99	1225	13.9
7F7-B13-056F	602	636	05/15/96	05/21/98	736	16.8
1F7-338-486E	420	468	05/10/96	05/26/98	746	23.4
						mean growth = 15.6 (SD, 6.299)
no injury						
7F7-D07-191D	669	680	05/14/96	04/24/00	1441	2.8
7F7-D0F-3527	630	635	05/09/96	05/12/97	368	4.9
1F4-A44-341F	542	575	05/29/96	04/22/02	2154	5.6
1F4-136-3733	638	674	05/28/96	04/26/02	2159	6.1
1F4-359-3312	563	610	05/16/96	05/19/99	1098	15.6
203-70E-0714	509	594	05/29/96	05/25/00	1457	21.2
1F7-435-1523	441	549	05/28/96	06/01/01	1830	21.5
1F7-437-2115	555	621	05/07/96	05/25/99	1113	21.6
1F4-359-5075	580	733	05/29/96	04/16/01	1783	31.2
1F4-14D-1E35	504	544	05/29/96	05/15/97	351	41.5
						mean growth = 17.2 (SD, 12.737)

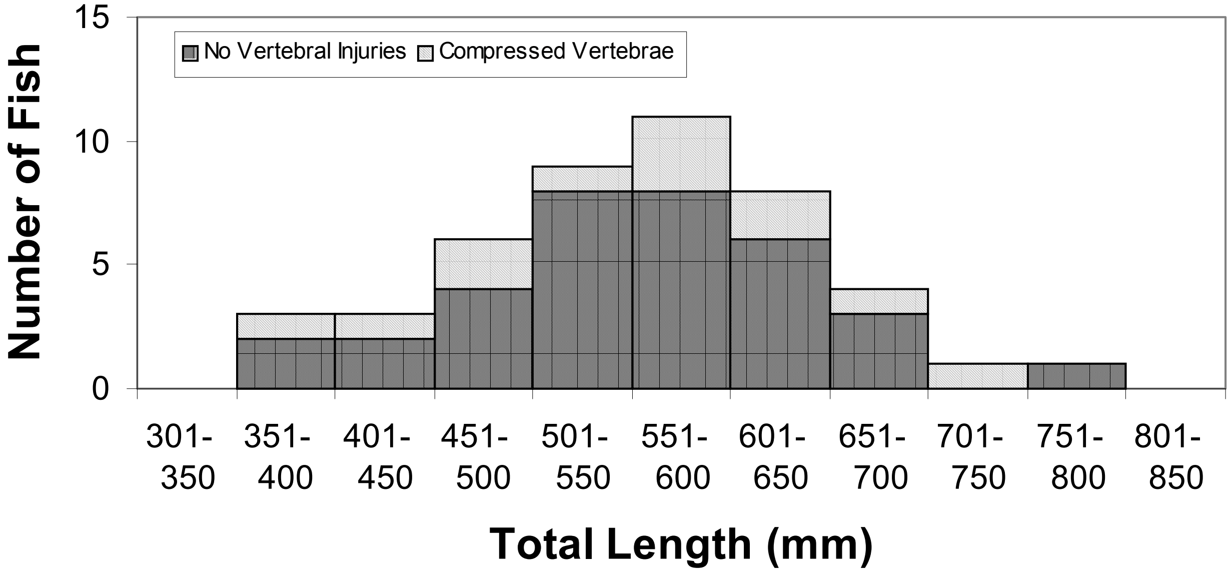

Figure 1.—Length-frequency of x-rayed Colorado pikeminnow captured by electrofishing and size of fish with vertebral compressions.