Impacts of a Small Dam Removal on the Endangered Watercress Darter

Brook L. Fluker, *Department of Biological Sciences, The University of Alabama, Box 870345,Tuscaloosa, AL 35487-0345*

Bernard R. Kuhajda, *Department of Biological Sciences, The University of Alabama, Box 870345,Tuscaloosa, AL 35487-0345*

R. Scot Duncan, *Biology Department, Birmingham-Southern College, Box 549022, 900 Arkadelphia Rd., Birmingham, AL 35254*

Elizabeth L. Salter, *Alabama Rivers Alliance, 2027 2nd Avenue North, Suite A, Birmingham, AL 35203*

Martin Schulman, *3612 North Woodridge Rd., Birmingham, AL 35223*

Abstract: Dam removals are typically well-planned events designed to restore sections of habitat to natural conditions within stream or river systems. In this paper, we document the deliberate but unplanned removal of a small dam that had created additional habitat for the federally-endangered watercress darter (*Etheostoma nuchale*) at Roebuck Spring in Birmingham, Alabama. On 19 September 2008, Birmingham city workers removed the dam without consulting U.S. Fish and Wildlife Service or the Alabama Department of Conservation and Natural Resources. This genetically-unique darter population was the largest of all native populations prior to dam removal. To determine the effects of the dam removal, we monitored basic water quality parameters and fish population characteristics for eight months following dam removal and compared these data to an ongoing study dating approximately 17 months prior to dam removal. Though no major changes in water quality were evident following this event, pre- and post-dam removal data were a valuable resource to ensure normal conditions were maintained during expedited restoration efforts. Destruction of the dam resulted in mortality of approximately 11,760 watercress darters, one of the largest documented losses of an endangered species. In addition, we observed a significant reduction in watercress darter abundance, increased mortality due to predation, and reduced reproduction potential the following spring, all of which could significantly impact this population's long-term viability. Our results show that long-term monitoring can play an important role in guiding restoration efforts following disastrous habitat alterations, but increased awareness and education of stakeholders and the local community should be essential components of any endangered species conservation plan.

Key words: watercress darter, dam removal, Roebuck Spring, water quality, restoration

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies 63:188–195

Dam removals are typically well-planned events designed to restore habitats to natural conditions within stream or river systems (Hart et al. 2002). Most dam removal studies involve pre-planned, carefully executed removals and subsequent ecological impact studies (Sethi et al. 2004, Doyle et al. 2005, Thomson et al. 2005). However, few studies have documented crisis management situations involving an unplanned and unexpected dam removal and the subsequent impacts on an endangered species.

The watercress darter (*Etheostoma nuchale*) (Figure 1A) is restricted to five springs in the upper reaches of the Black Warrior River in Jefferson County, Alabama. Due to its limited distribution and threats from urbanization in the greater Birmingham metropolitan area, *E. nuchale* was listed as federally endangered just five years after its discovery (Howell and Caldwell 1965, USFWS 1970). Throughout its range, the watercress darter is invariably associated with dense aquatic vegetation such as watercress (*Nasturtium officinale* R. Br.), aquatic moss (*Fontinalis* sp.), stonewort (*Chara* sp.), and green filamentous algae (*Spirogyra* sp.) in springs and spring runs where it forages on snails, crustaceans, and insect larvae (Howell and Caldwell 1965, Howell 1986, Stiles 2004). Gravid females have been collected from March to July and aquatic vegetation serves as the primary substrate for egg deposition (Stiles 2004).

Roebuck Spring, in the Village Creek watershed, supports the largest native population based on relative abundance and amount of suitable habitat (Fluker et al. 2008, 2009). It also represents a genetically-distinct unit for the species (Mayden et al. 2005, Fluker et al. 2008, 2009). Although this population is afforded some protection through agreements between the city of Birmingham and the U.S. Fish and Wildlife Service (USFWS) (Stiles 2004), Roebuck Spring has been impacted in recent decades by piping of the spring run (Figure 2A, 2B), poor surface water runoff practices, ground water contamination (Howell 1978), and high levels of polycyclic aromatic hydrocarbons (USFWS 1991). In order to create an additional 0.6 ha of habitat for the watercress darter following its discovery in Roebuck Spring in the late 1970s, an earthen dam was constructed just upstream of a tennis court maintained by the city of Birmingham (Figure 2B). Beaver dam construction on top of the earthen dam occasionally flooded or threatened to flood the

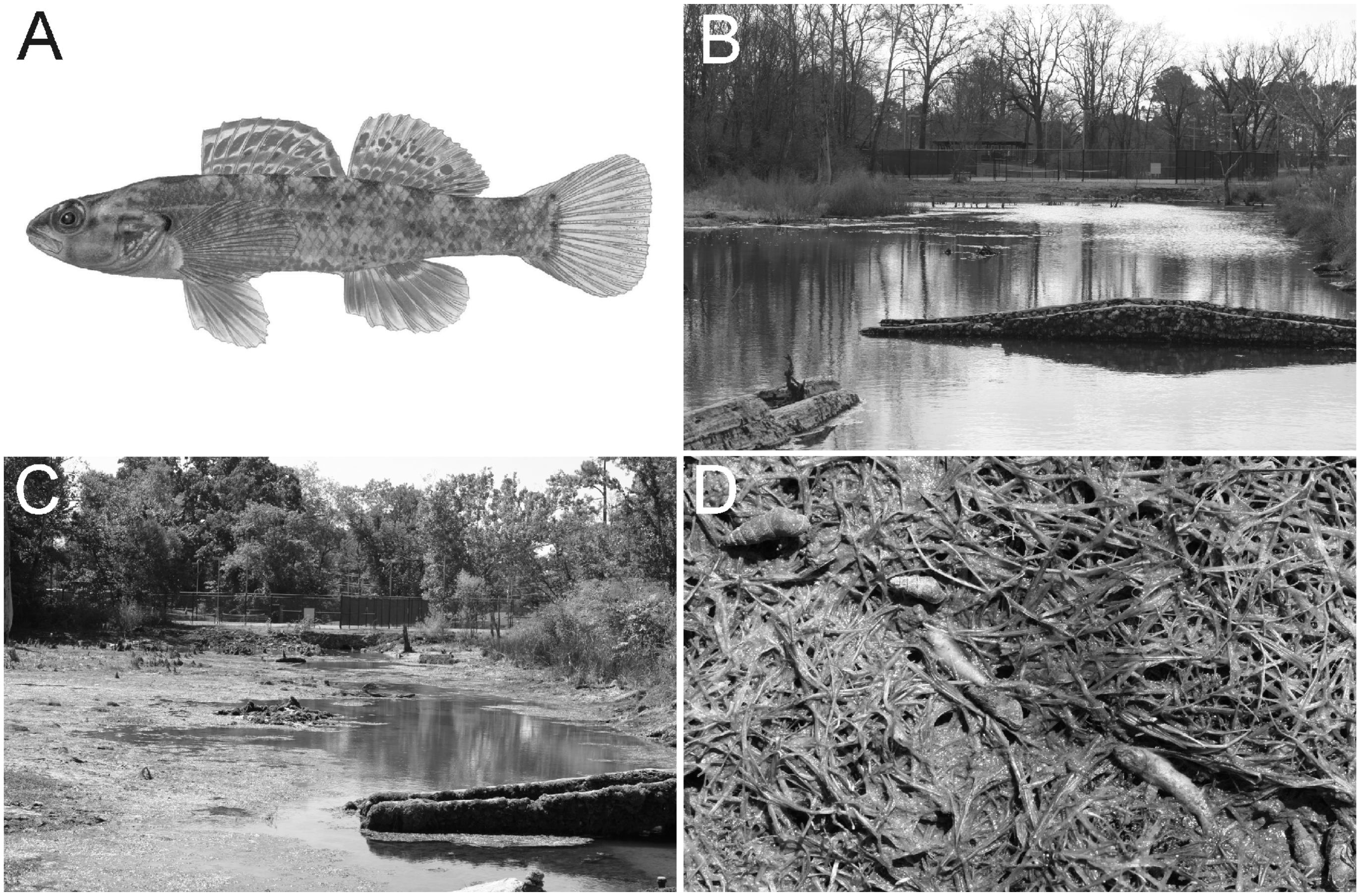

Figure 1. (A) Male watercress darter; illustration by J. R. Tomelleri. (B) View of the spring pool from the springhead facing downstream toward the earthen dam in January 2007 prior to dam removal. (C) Spring pool on 22 September 2008, three days after the dam removal. (D) Dead darters and snails in the decaying mats of aquatic vegetation on 22 September 2008.

city-maintained tennis courts, and while beaver dam removal was routinely performed by the city, the earthen dam had not been removed following its original construction.

On 19 September 2008, however, Birmingham city workers removed not only a beaver dam, but also the earthen dam without consulting with USFWS or Alabama Department of Conservation and Natural Resources (ADCNR). This action led to the rapid dewatering of much of the spring pool, causing severe changes to flow and vegetative characteristics. The upper half of the spring pool was reduced to a stream-like channel within a matter of hours and the dewatered area consisted of dense mats of decaying aquatic vegetation and deep, soft silt and mud (Figure 1B, 1C). Due to increased flow in the remaining channel, much of the benthic aquatic vegetation in the channel (primarily aquatic moss which lightly attaches to rock, silt, and mud in the spring pool) was scoured and carried away by the flushing action of the dam removal. Impacts to watercress darter were most evident in the spring pool where dead watercress darters were observed stranded in aquatic vegetation. Furthermore, the event led to an extreme concentration of the invasive exotic virile crayfish (*Orconectes virilis*), as most individuals survived the dewatering. Both *O. virilis* (Mayden and Burr 1981) and other *Orconectes* species (Taylor and Soucek 2010) have been shown to predate on small fishes.

On 22 and 23 September 2008, parties from USFWS, ADCNR, and local universities met to determine how to begin the restoration process. Based on our sampling and observations, we determined that the combination of vegetation loss and the concentration of the virile crayfish was negatively impacting watercress darters. To counteract the concentration of the virile crayfish, we recommended that a crayfish removal program begin immediately and that the city install a temporary dam structure to slowly increase pool volume to near pre-dam removal levels until a permanent solution was determined. To avoid rapid decreases in dissolved oxygen (DO), which would be potentially fatal for

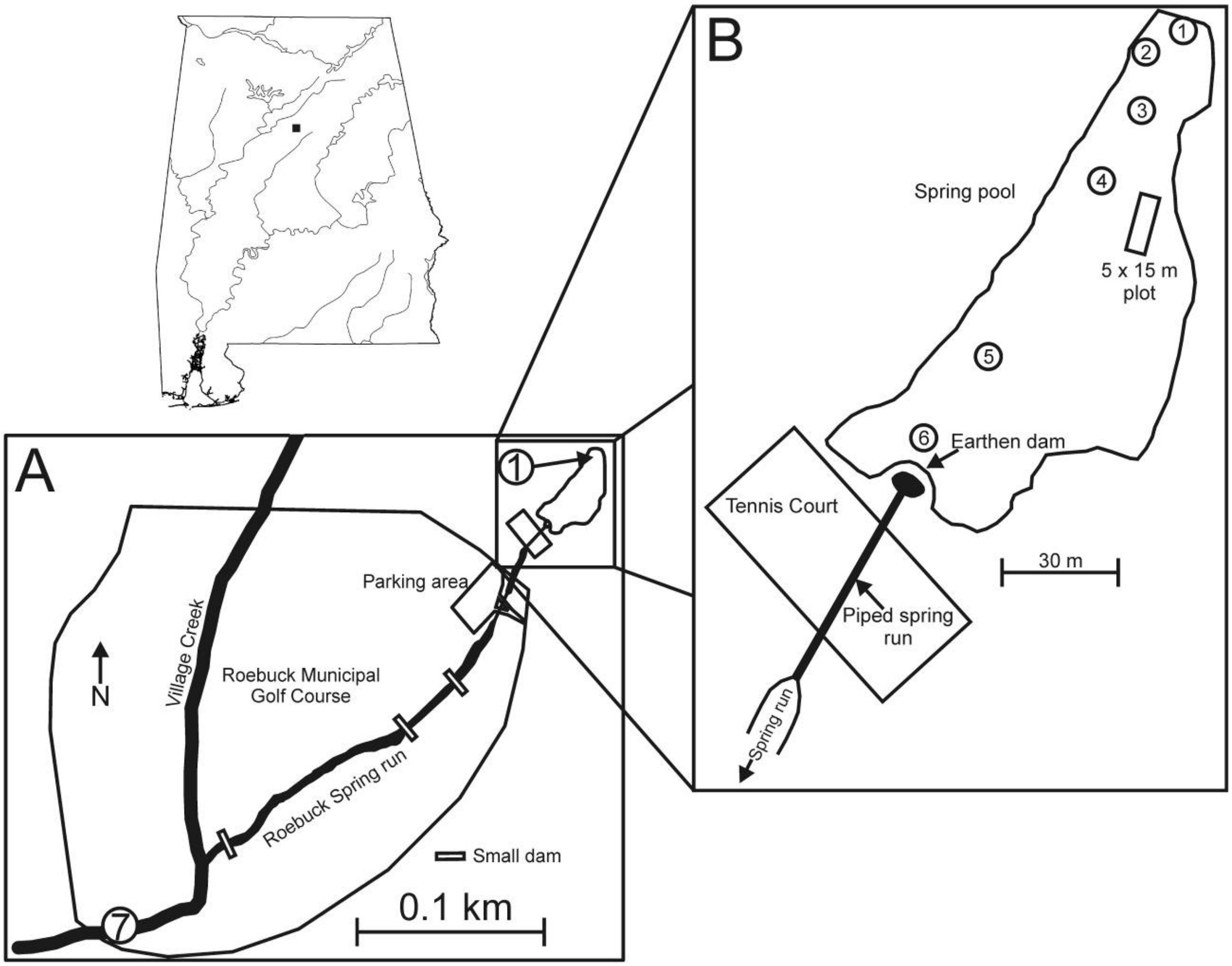

Figure 2. Diagram of study area in Village Creek and Roebuck Spring in Birmingham, Alabama. (A) Map of the entire Roebuck Spring complex showing water quality monitoring sites at the springhead (site 1) and Village Creek (site 7). (B) Map of the spring pool showing the dam of interest, study sites for fish and water quality monitoring, and the plot used in the fish kill investigation.

the remaining watercress darters, our recommendations were to begin with a small increase in pool height (<0.3 m from the new base flow), followed by a period of stabilization, and then similar increases in pool height until pre-dam removal heights were achieved. On 26 September 2008, the city installed a temporary sandbag dam, raising the pool height approximately 15 cm. The pool remained at this level until 8 October 2008, when a second tier of sandbags was added raising the pool level another 20 cm. On 18–19 March 2009, city officials installed a box style dam to prevent beaver dam construction and the final pool elevation was set to the pre-dam removal level on 22 April 2009.

Because we had 1.5 years of water quality data on Roebuck Spring and had just finished a two-year study on this population of watercress darters prior to dam removal, we had the unique opportunity to evaluate the effects of this disastrous event. The purpose of this study was to determine the effects of the dam removal and subsequent restoration efforts on basic water quality parameters and the watercress darter population. In addition, we provide recommendations that may be useful in similar crisis management circumstances.

Methods

Water Quality Data Collection and Analyses

From April 2007 to May 2009, we measured temperature, DO, pH, alkalinity, and hardness monthly at Village Creek just below the confluence with the spring run (site 7; Figure 2A) and at the springhead (site 1; Figures 2A, B) with a Lamotte water monitoring kit (Lamotte Co., Chestertown, Maryland). Differences in water quality parameters before and after dam removal were assessed for each site with Mann-Whitney *U*-tests (data were non-normal in all cases; alpha = 0.05 for this and all tests). Our main concern following dam removal and throughout the pool restoration process was the possibility of low DO within the spring pool from rewatered decaying organic matter; a situation potentially lethal for watercress darter. To determine how pool restoration activities affected temperature and DO in the spring pool during the three weeks following the dam removal (29 September 2008 and 1, 3, and 10 October 2008), we measured these parameters at sites 1, 4, and 6 (Figure 2B) with a YSI Model 550 DO meter (YSI, Inc., Yellow Springs, Ohio).

Fish Sampling and Data Analyses

From October 2006 to August 2008 (pre-dam removal), fish were sampled quarterly with a 3- x 1.2-m seine with 4.7-mm mesh. Three sites within the spring pool were chosen to best reflect the range of habitats for watercress darters before dam removal: 1) shoreline habitat with little to no current (site 2; Figure 2B); 2) the main channel of spring run with moderate current (site 3; Figure 2B); and 3) a deeper section of the pool with little to no flow (site 4; Figure 2B). Each site was seined once and we recorded the total number and estimated relative size classes (in mm standard length [SL]) for all watercress darters collected. To prevent mortality from excessive handling, we classified individuals into size classes and obtained a range measurement for each size class. For any given season, we were able to identify three size classes corresponding to approximate age classes among all individuals captured in a collection. Although we had slight overlap in size classes between different seasons due to changes in group composition, our size classes typically ranged from 11 to 24 mm (small), 25 to 29 mm (medium), and >30 mm (large). Relative abundance was measured as catch per unit effort (CPUE) by dividing the total number of individuals captured by the number of seine efforts. Between October 2007 and February 2008, a beaver dam was constructed on top of the earthen dam, elevating water levels 0.3–0.6 m above levels from previous seasons. The elevated water levels decreased our collection efficiency by reducing our access to benthic aquatic vegetation (primarily aquatic moss) preferred by the watercress darter.

In order to assess the effects of the dam removal on watercress darters in the spring pool, we monitored three different habitat types near site 3 (Figure 2B) for eight months following the removal. Because sites 2 and 4 were dewatered or devegetated from scouring following dam removal, the three habitat types sampled near site 3 were chosen to emulate conditions at sites 2, 3, and 4 prior to dam removal. We used Mann-Whitney *U*-tests to evaluate differences in total CPUE and CPUE for each size class before and after dam removal. Because of post-removal loss of aquatic vegetation at site 3, we also monitored an additional site (site 5; Figure 2B) that retained more aquatic moss during this period. In conjunction with crayfish trapping by Carrol (2009) starting in October 2008, we also enumerated the number of crayfish captured with watercress darters after dam removal.

Mortality of watercress darters after the dam removal was estimated from counts obtained in a 5- x 15-m plot (Figure 2B) on 22 September 2008. This plot was located on a slightly sloping dewatered area on the east side of the former spring pool which was covered in decaying aquatic vegetation and was chosen because it best represented the majority of dewatered habitat present. These data were then used to estimate total mortality of the population by extrapolating darters found in the censused section to the total dewatered area of the spring pool as calculated by Buntin and Johnson (2008).

Results

Water Quality Monitoring

Temperature, pH, and DO were not significantly different following dam removal at sites 1 or 7, yet alkalinity at site 7 and hardness at sites 1 and 7 showed a significant decrease following dam removal (Table 1). During pool restoration, temperature and DO within the spring pool averaged 16.9, 17.6, and 17.8 C and 5.6, 5.6, and 6.3 mg/L for sites 1, 4, and 6, respectively.

Fish Sampling

Using estimates from sites 2, 3, and 4 prior to dam removal and the three modified sites near site 3 following dam removal, total CPUE dropped 46% following dam removal and the ratio of CPUE for small:medium:large size classes before and after dam removal was 16:15:1 and 2:4:1 respectively (Table 2, Figure 3). Total CPUE

Table 1. Pre- and post-dam removal averages, with standard deviation in parentheses, for catch per unit effort (CPUE) and water quality variables at sites measured throughout the study. Results from Mann-Whitney *U*-tests are shown for each comparison. Significant comparisons ($P < 0.05$) are indicated with an asterisk.

	Site/variable	Pre-removal	Post-removal	*P*-value
Springhead (sites 2,3,4)	CPUE small	19.3 (11.4)	4.0 (3.5)	0.005*
	CPUE medium	17.8 (6.7)	11.3 (4.6)	0.053
	CPUE large	1.2 (0.8)	2.6 (1.9)	0.173
	CPUE total	38.3 (14.9)	17.8 (8.5)	0.017*
Springhead (site 1)	Temperature	16.7 (0.6)	16.3 (0.4)	0.088
	pH	7.1 (0.2)	7.1 (0.2)	0.635
	DO	5.3 (0.3)	5.6 (0.3)	0.105
	Alkalinity	200.0 (17.4)	176.0 (33.4)	0.078
	Hardness	190.3 (17.0)	167.0 (21.1)	0.008*
Village Creek (site7)	Temperature	19.2 (4.5)	16.4 (3.2)	0.122
	pH	7.5 (0.3)	7.3 (0.3)	0.164
	D.O.	8.5 (0.7)	8.8 (0.9)	0.236
	Alkalinity	199.7 (30.9)	172.2 (24.4)	0.025*
	Hardness	199.4 (29.0)	171.1 (13.6)	0.002*

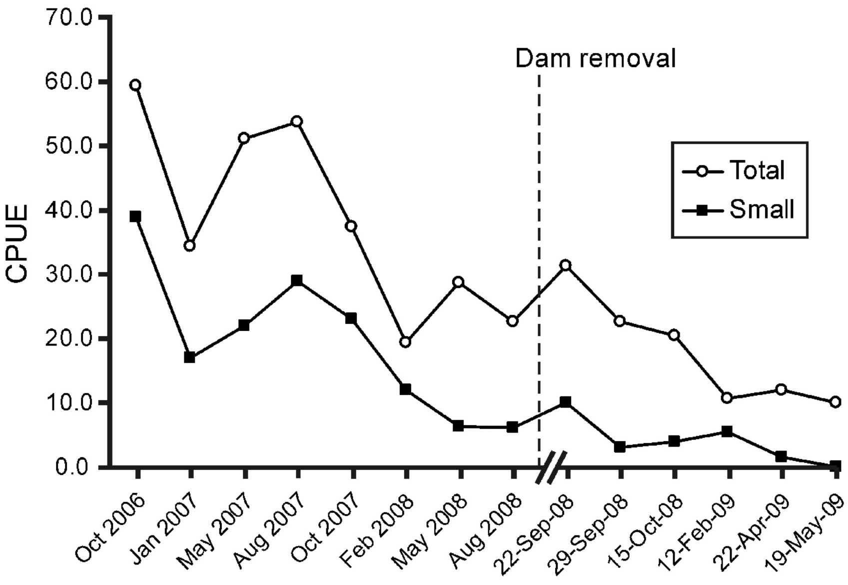

Figure 3. Total size class and small catch per unit effort (CPUE) throughout the study period. The dashed line indicates dam removal.

Table 2. Number and size classes of watercress darters captured during each season prior to and eight months after dam removal (dashed line). Total = *n* darters captured, effort = *n* seining efforts, CPUE = total catch per unit effort, % small = the proportion of small individuals relative to the whole catch, and crayfish = the number of crayfish captured with darters.

Site(s)	Date	Small	Medium	Large	Total	Effort	CPUE	% Small	Crayfish
Sites 2,3,4	Oct 2006	117	53	8	178	3	59.3	66	–
	Jan 2007	51	51	1	103	3	34.3	50	–
	May 2007	66	83	4	153	3	51.0	43	–
	Aug 2007	87	74	0	161	3	53.7	54	–
	Oct 2007	69	40	3	112	3	37.3	62	–
	Feb 2008	36	19	3	58	3	19.3	62	–
	May 2008	19	63	4	86	3	28.7	22	–
	Aug 2008	18	45	5	68	3	22.7	26	–
Site 3	22 Sep 2008	30	48	16	94	3	31.3	32	–
	29 Sep 2008	9	49	10	68	3	22.7	13	67
	15 Oct 2008	12	39	10	61	3	20.3	20	36
	12 Feb 2009	16	15	1	32	3	10.7	50	13
	22 Apr 2009	3	16	5	24	2	12.0	13	0
	19 May 2009	0	28	2	30	3	10.0	0	17

was significantly different following dam removal and examination of each size class revealed a significant reduction in the small size class following dam removal, yet no differences were found for medium and large size classes (Table 1, Figure 3). Although there was a steady decrease in total and small class CPUE throughout the entire study period (Figure 3), our sampling efficiency was hampered from February 2008 to August 2008 by elevated water levels caused by beaver dam construction. Therefore, sampling efficiency was much higher before and after this period of elevation, likely resulting in more accurate CPUE estimates during these normal or low water periods. Immediately following dam removal, we observed slight increases in total and small class CPUE on 22 September 2008. However, total and small size class CPUE showed a steady decline throughout the entire sampling period to their lowest points (10.0 and 0 respectively) on 19 May 2009 (Figure 3). Crayfish captured with watercress darters at the three modified sites immediately following dam removal were nearly all large adults, decreasing from 67 on 29 September 2008 to zero on 22 April 2009 and the slight increase to 17 observed on 19 May 2009 were all juveniles (Table 2). Following dam removal (September 2008–May 2009), total CPUE at our supplemental site 5 averaged 46.3 and the ratio of CPUE of small:medium:large size classes was 3:8:1.

Fish Kill Investigation

On 22 September 2008, three days after dewatering, we observed a large number of dead watercress darters, mosquito fish (*Gambusia affinis*), and snails stranded in soft sediments and exposed aquatic vegetation (Figure 1D). Buntin and Johnson (2008) determined the total surface area of the impounded spring pool was 5165 m^2 prior to dam removal and the wetted area was 2225 m^2 following dam removal. Therefore their estimate yielded a dewatered area of 2940 m^2, an area reduction of 56.9% of the spring pool habitat previously available to watercress darters. Our survey of a 5- x 15-m plot (Figure 2) yielded 107 intact watercress darters which were preserved in formalin and cataloged into the University of Alabama Ichthyological Collection (UAIC 15568.01). The estimated number of dead watercress darters in the plot was most likely higher because there were many (approximately 200) carcasses that had decayed to the point that extracting whole bodies was impossible. Using an estimate of 300 dead watercress darters within the plot, extrapolation of our census data to the entire dewatered area yielded an estimated 11,760 dead watercress darters within the spring pool.

Discussion

Effects on Water Quality

We suspect there were rapid short-term changes in water quality immediately following the earthen dam removal, but we found no alarming long-term changes. We found significant reductions in alkalinity and hardness at sites 1 and 7, yet levels by May 2009 were comparable to pre-removal levels. The relative consistency in overall water quality probably reflects the constant input of thermally-stable groundwater.

Having pre-dam removal water quality data for Roebuck Spring provided much needed baseline information to ensure that normal levels were maintained during the restoration process. Our results show that the incremental approach to water level increases in the spring pool maintained desirable DO levels (>5.0 mg/L) for most pond fishes (Boyd 1979).

Impacts to the Watercress Darter Population

Based our findings, an estimated 11,760 watercress darters were killed by removal of the dam, making this one of the largest documented losses of a federally-endangered species (see Jones et al. 2001, USFWS 2005). There are several unknown factors that could make our results an under- or overestimate of mortality for watercress darters. Darters may have been concentrated in the survey area prior to dam removal or had escape routes blocked, which would result in an overestimate. Conversely, darters in this area may have had better access to escape routes as water levels dropped or carcasses may have been hidden under decaying aquatic vegetation during our survey, which would result in an underestimate. Finally, watercress darters in the vicinity of the dam during removal may have been washed out of the spring pool through the piped run. Any of the above events could have altered the density of watercress darters over the dewatered area and therefore the overall mortality estimate for the darters following dam removal. However, our density estimate from the sample plot (4 darters/m^2) is similar to density estimates of watercress darters from Seven Springs, where Duncan et al. (2010) found densities to be 1.6, 3.4, and 5.9 darters/m^2 for non-vegetated, combined vegetated, and aquatic moss habitats, respectively. Considering that our density estimate was similar to natural densities in similar habitat types in another spring (4 darters/m^2 in Roebuck Spring vs. an average of 3.4 darters/m^2 in Seven Springs), we believe this is a reasonable estimate. Further evidence suggests that this may be an underestimate because our investigation was conducted three days after dam removal, giving time for decomposition and scavenging of carcasses, and the majority of the dewatered area had the densest stands of aquatic vegetation prior to dam-removal. Additionally, our estimate only includes the initial mortality due to the stranding of watercress darters in aquatic vegetation, but we believe there was a continued decrease in the darter population due to the scarcity of habitat, as well as high levels of predation from crayfish that survived the dewatering event in high numbers. We hypothesize that the destruction of aquatic vegetation eliminated much of the food source for watercress darters in the spring pool, which decreased the amount of energy available for gamete production, in turn resulting in fewer progeny in spring 2009. This was evidenced by the extremely low proportion of small individuals found during April and May 2009 (peak spawning period for watercress darters; Stiles 2004). Even when we include post-removal data from our supplemental site 5 with site 3, the proportion of small individuals was only 28% of the entire catch compared to 48% for sites 2, 3, and 4 during the pre-removal period.

Recovery and Management Implications

The incremental approach to raising water levels during spring pool restoration quickly diluted the the virile crayfish population and began habitat restoration for the aquatic vegetation, thus providing relief for the surviving and concentrated watercress darters. From October 2008 to April 2009, Carroll (2009) captured and removed *O. virilis* from Roebuck Spring, resulting in a significant decrease in crayfish catch rate throughout the study period. With the installation of the permanent dam structure, water levels within the spring pool stabilized and aquatic vegetation showed signs of rapid recovery. Recovery of the watercress darter will be a much slower process that is dependent on re-establishment of the epiphytic food base. Thus, the highest conservation priorities for the Roebuck Spring population are ensuring that a major disturbance of this magnitude does not happen again and determine the effect and duration of reduced reproduction within the spring pool. We are concerned about the long-term effects of this massive take on the health of this population of watercress darters due to a potential genetic bottleneck, which would lower the genetic diversity of future generations. Concern is compounded by recent microsatellite data (Fluker et al. 2008) demonstrating that watercress darters from Roebuck Spring possessed the lowest levels of genetic variation relative to all other native populations prior to dam removal. Because the new dam is a barrier to upstream migration for watercress darters, we support the suggestions of Duncan et al. (2008) to transplant a minimum of 300 individuals annually from downstream sections of the spring run into the spring pool to ensure genetic continuity and potentially mediate the effects of a genetic bottleneck.

This catastrophic event could have been easily prevented through education and public awareness. Because a disturbance of this magnitude can easily occur at springs containing watercress darters which have earthen or large beaver dams forming impoundments (Thomas and Tapawingo springs), simple policies need to be implemented to prevent or to better prepare for such events in the future. We recommend that long-term monitoring continue not only for the Roebuck Spring population, but for all watercress darter populations. Monitoring should be standardized to include water quality data, crayfish and predator abundance, and vegetative characteristics of the springs, all of which will be vital in the long-term recovery planning for the species. Stakeholders need to have annual meetings with the USFWS and ADNCR to review the status of the population and to share new information as it becomes available. An information sheet about watercress darters and what is necessary for its management and preservation should be distributed to the stakeholders, especially those that play an essential role in the protection of Roebuck Spring. It would be beneficial to all parties involved to draft an incident protocol outlining detailed instructions on when and whom to contact in case of an emergency. Obvious signage at watercress darter sites would increase the public's awareness and may help prevent or limit future catastrophes. In addition, engagement with the community could spark a sense of pride regarding the continued existence of this unique fish so close to a large urban area.

Acknowledgments

We wish to thank Micah G. Bennett, J. Heath Howell, Grey Hubbard, Ashley Hudson, Jake Rudolph, and Lauren Vest for field assistance. Eric Spadgenske provided chronological details and field assistance. This project was supported by a section 6 grant from the ADCNR and USFWS, additional funding from the USFWS, the University of Alabama, and Birmingham-Southern College.

Literature Cited

Boyd, C. E. 1979. Water quality in warmwater fish ponds. Alabama Agricultural Experiment Station, Auburn University, Auburn.

Buntin, M. and P. Johnson. 2008. Investigation of a gastropod kill in Roebuck Spring at Roebuck-Hawkins Park, Jefferson County, Alabama. Alabama Department of Conservation and Natural Resources Report, Montgomery.

Carroll, K. 2009. Trapping and removal of invasive Northern crayfish, *Orconectes virilis*, from Roebuck Springs, Alabama: an effort in protecting the endangered watercress darter. Senior Thesis. Birmingham-Southern College, Birmingham.

Doyle, M. W., E. H. Stanley, C. H. Orr, A. R. Selle, S. A. Sethi, and J. M. Harbor. 2005. Stream ecosystem response to small dam removal: lessons from the heartland. Geomorphology 71:227–244.

Duncan, R. S., C. Elliot, B. L. Fluker, and B. R. Kuhajda. 2010. Habitat use of the watercress darter (*Etheostoma nuchale*): an endangered fish in an urban landscape. American Midland Naturalist. 164(1): in press.

———, B. R. Kuhajda, B. L. Fluker, L. Davenport, W. M. Howell, K. R. Marion, and R. A. Stiles. 2008. Science-based recommendations for the near- and long-term survival of the watercress darter (*Etheostoma nuchale*) in Roebuck Springs, Birmingham, Alabama. U. S. Fish and Wildlife Service Report, Jackson, Mississippi.

Fluker, B. L., B. R. Kuhajda, and P. M. Harris. 2008. Status and distribution survey and genetics of the endangered watercress darter, *Etheostoma nuchale*. U. S. Fish and Wildlife Service Report, Jackson, Mississippi.

———, ———, and ———. 2009. Status and distribution survey and genetics of the endangered watercress darter, *Etheostoma nuchale*. U. S. Fish and Wildlife Service Report, Jackson, Mississippi.

Hart, D. D., T. E. Johnson, K. L. Bushaw-Newton, R. J. Horwitz, A. T. Bednarek, D. F. Charles, D. A. Kreeger, and D. J. Velinsky. 2002. Dam removal: challenges and opportunities for ecological research and river restoration. BioScience 52:669–681.

Howell, W. M. 1978. A proposal to determine the geographic distribution of the rare and endangered watercress darter, *Etheostoma nuchale* (Pisces: Percidae), Contract No. 14-16-0009-77-044. U. S. Fish and Wildlife Service Report, Jackson, Mississippi.

———. 1986. Watercress darter. Pages 5–6 *in* R. H. Mount, editor. Vertebrate animals in Alabama in need of special attention. Alabama Agricultural Experiment Station, Auburn University, Auburn.

——— and R. D. Caldwell. 1965. *Etheostoma* (Oligocephalus) *nuchale*, a new darter from a limestone spring in Alabama. Tulane Studies in Zoology 12(4):101–108.

Jones, J. W., R. J. Neves, M. A. Patterson, C. R. Good, and A. DiVittorio. 2001. A status survey of freshwater mussel populations in the Upper Clinch River, Tazewell County, Virginia. Banisteria 17:20–30.

Mayden, R. L. and B. M. Burr. 1981. Life history of the slender madtom, *Noturus exilis*, in southern Illinois (Pisces: Ictaluridae). Occasional Papers of the Museum of Natural History University of Kansas 93:1–64.

———, K. E. Knott, J. P. Clabaugh, B. R. Kuhajda, and N. J. Lang. 2005. Systematics and population genetics of the coldwater (*Etheostoma ditrema*) and watercress (*Etheostoma nuchale*) darters, with comments on the gulf darter (*Etheostoma swaini*) (Percidae: subgenus *Oligocephalus*). Biochemical Systematics and Ecology 33:455–478.

Sethi, S. A., A. R. Selle, M. W. Doyle, E. H. Stanley, and H. E. Kitchel. 2004. Response of unionid mussels to dam removal in Koshkonong Creek, Wisconsin (USA). Hydrobiologia 525:157–165.

Stiles, R. A. 2004. Watercress darter, *Etheostoma nuchale*. Pages 192–193 *in* R. E. Mirarchi, J. T. Garner, M. F. Mettee and P. E. O'Neil, editors. Alabama wildlife, volume 2, imperiled aquatic mollusks and fishes. The University of Alabama Press, Tuscaloosa.

Taylor, C. A. and D. J. Soucek. 2010. Re-examining the importance of fish in the diets of stream-dwelling crayfishes: implications for food web analyses and conservation. American Midland Naturalist 163:280–293.

Thomson, J. R., D. D. Hart, D. F. Charles, T. L. Nightengale, and D. M. Winter. 2005. Effects of removal of a small dam on downstream macroinvertebrate and algal assemblages in a Pennsylvania stream. Journal of the North American Benthological Society 24(1):192–207.

U.S. Fish and Wildlife Service (USFWS). 1970. Endangered and threatened wildlife and plants; determination of *Etheostoma nuchale* (watercress darter) to be an endangered species. Federal Register 35(199):16047.

_____. 1991. An investigation of contaminant impacts to watercress darter, *Etheostoma nuchale*, habitat at Roebuck Spring, Thomas Spring, and Glenn Spring, Jefferson County, Alabama. U.S. Fish and Wildlife Service, Daphne, Alabama.

_____. 2005. Pre-assessment screen and determination, South Canadian River, Canadian and Grady Counties, Oklahoma. *http://www.fws.gov/southwest/es/oklahoma/envqual.htm*