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Using Well Water to Increase Hydroperiod as a Management Option for Pond-Breeding Amphibians

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Abstract

*Drying of wetlands before the completion of larval development is a major factor controlling reproductive success of amphibians breeding in temporary ponds. For some endangered taxa, such drying can severely limit population viability and species survival. One way of reducing the impact of premature drying is to add water to temporary ponds via an outside source, but data on the value of this strategy are almost nonexistent. We tested whether water from nearby wells could be used to avoid pond drying and increase reproductive success for the endangered dusky gopher frog (*Rana sevosa*). During a 7-week period in 2001, we added over 366,000 L of water from nearby wells to the breeding site for this frog and were able to increase and maintain water levels until a heavy natural rainfall filled the pond basin. This avoided complete larval mortality and 130 metamorphic frogs were produced, the first successful reproduction since 1998. Our study provides an important initial step in evaluating the use of well water to increase the hydroperiod of breeding ponds for anurans; however, further studies should be undertaken before this method is used as a conservation tool to avoid larval mortality of imperiled amphibians.* (WILDLIFE SOCIETY BULLETIN 34(4):1022–1027; 2006)

Key words

amphibians, dusky gopher frog, hydroperiod, management, Rana sevosa*, reproductive success, well water.*

Timing and length of the breeding-site hydroperiod frequently play a significant role in metamorphic success in amphibians (Wilbur and Collins 1973, Pechmann et al. 1989, Rowe and Dunson 1995, Richter et al. 2003). In some cases, this relationship can be a strong determinant of population viability. For example, the highly imperiled dusky gopher frog (*Rana sevosa*) shows a strong relationship between hydroperiod and reproductive success, with a hydroperiod of at least 195 days required for successful metamorphosis of tadpoles (Richter et al. 2003). Because of this lengthy development period, successful production of metamorphs at the primary breeding site for this species occurred in only 3 of 7 years (Richter et al. 2003). Unsuccessful reproductive years often are marked by the pond filling to a moderate level of 40–60 cm (during which gopher frogs frequently lay eggs) followed by rapid drying in April or May and subsequent death of tadpoles before metamorphosis could occur. For example, in both 1996 and 1999 the breeding pond dried in March, only to refill within a few days to a few weeks (Richter et al. 2003). In such years a change in hydroperiod of only a few days might have meant the difference between complete mortality and successful reproduction.

For pond-breeding amphibians, several management alternatives may be considered when confronted with declining water levels and possible loss of an entire year's cohort of tadpoles, including moving the tadpoles to an off-site pond or raising the tadpoles in captivity (e.g., cattle tanks). Both of these options, however, require extensive handling of tadpoles and result in tadpoles undergoing metamorphosis in an artificial environment. Another approach is to maintain water levels in the existing pond via either a nearby well or by bringing in water from an outside source. Except for one unpublished attempt at the Savannah River Ecology Laboratory (D. Scott, Savannah River Ecology Laboratory, personal communication), we are not aware of any data regarding the merits of using this approach. Previous experiments (R. A. Seigel, Southeastern Louisiana University, unpublished data) indicated that dusky gopher frog tadpoles could be successfully raised in the laboratory using well water. Thus, when confronted with rapidly declining water levels at the breeding site for gopher frogs during the spring of 2001, we experimentally tested this procedure to maintain pond levels during drought conditions.

Materials and Methods

Study Species and Site

Dusky gopher frogs currently are confirmed from only 2 breeding sites in their former range (Richter et al. 2003, M. Sisson, Mississippi Museum of Science, personal communication). The species currently is listed as Critically Endangered on the Red List of the International Union for the Conservation of Nature and Natural Resources (2004) and Endangered under the United States Endangered Species Act (United States Fish and Wildlife Service 2001), but was not federally listed at the time of this study. The protocols used to conduct this study were approved by

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the Institutional Animal Care and Use Committee at Southeastern Louisiana University.

The primary breeding pond and the site of this study is known as Glen's Pond, located in a restored longleaf pine (*Pinus palustrus*) forest in the Desoto National Forest in southern Mississippi, USA. The pond was about 440 m in circumference, typically filled to a maximum depth of 1.1 m in midwinter, dried during the summer, and had high annual variation in hydroperiod length (Richter et al. 2003). Gopher frogs at this site bred from September to April, but most commonly from January to March, usually following heavy winter rains (Richter and Seigel 2002, Richter et al. 2003). Metamorphosis in successful years occurred mainly from late May to early August. Since 1996 the pond has been surrounded by a 525-m plastic-mesh drift fence with paired pitfall traps used to sample adults and metamorphs entering and exiting the pond. Details of the pond and the methods used to sample gopher frogs are found in Richter and Seigel (2002) and Richter et al. (2003).

Maintenance of Pond Water Levels Via Well Water

We used 3 sources of water to maintain water levels in Glen's Pond during 2001, 2 from wells situated at Glen's Pond and 1 from a well located off-site. The first well used was Glen's Pond Well #1, a shallow well (depth = 16 m) placed circa 50 m from Glen's Pond. We pumped water from this well into the pond via drip irrigation hoses at a maximum rate of approximately 18.9 L/minute. We placed the hoses approximately 0.5–1 m from any standing water in the pond to allow the well water to flow into Glen's Pond over the nearby ground surface. This allowed the water to aerate and created a more natural flow than would otherwise be the case. The second water source was a deep well (depth = 194 m) located at Harrison Experimental Research Station of the United States Forest Service, located approximately 8 km from Glen's Pond. We pumped water from this well into either new 1,892-L stainless steel holding tanks for transit to Glen's Pond or into a large (18,927-L) tanker truck supplied by the United States Army. The tanker truck had been used previously only for potable water transportation and contained no chemicals. We pumped water from the tanker truck into a new 1,892-L stainless steel holding tank for aeration and then pumped water through hoses to within 0.5–1 m of Glen's Pond as described above. Finally, because of the difficulty in transporting water from the Harrison Experimental Station, we had another well (Glen's Pond Well #2) dug circa 50 m from Glen's Pond on 23 May 2001. This well was deeper (depth = 42.7 m) than Glen's Pond Well #1 and had an increased flow rate of 102 L/minute. We introduced water from this well into the pond basin as described for Glen's Pond Well #1.

We measured pH and dissolved oxygen (DO) of pond water using an Oakton handheld meter. We measured water depth each morning by reading a standard depth gauge placed in the center of the pond and measured rainfall with a rain gauge placed within 50 m of the pond. We measured water quality between 0700 and 0900 hours each morning and again after we pumped water into the pond.

Effects of Well Water on Tadpole Survival

As a precautionary test to ensure that water from local wells was suitable for tadpole development, we compared the survival of a group of leopard frog (*R. sphenocephala*) tadpoles raised in Glen's Pond water to survival of leopard frog tadpoles raised in water from Glen's Pond Well #1. We used leopard frogs as the test species to avoid any unnecessary mortality among gopher frog tadpoles. We collected leopard frog tadpoles from Glen's Pond on 17 February 2001 when they were approximately 4–9 days old. For each group, we placed 4 randomly selected tadpoles in each of 20 3.8-L (32 × 17.5 × 9-cm) Tupperware© (Tupperware Corporation, Orlando, Florida) plastic containers. Ten containers held pond water and 10 held water from Well #1. All assignments to treatment conditions were made randomly, as were the locations of containers within the room. We maintained water and air temperatures from 18 to 22°C and set the light cycle to 11L:13D. We fed all tadpoles 0.6 g rabbit chow per container every 3–4 days with occasional addition of TetraMin® (Tetra Werke, Melle, Germany) fish flakes; we changed water every 3–5 days. We checked tadpoles for mortality or signs of abnormal development daily and immediately removed any dead tadpoles from the containers. We concluded the experiment after approximately 6 weeks, at which time tadpoles were showing signs of metamorphosis. All means are followed by ±1 standard error (SE). Alpha was set at 0.05 unless otherwise noted.

Results

Natural Hydroperiod and Reproduction in 2000–2001

Glen's Pond filled on 19 November 2000. A total of 36 gopher frog egg masses were deposited from 13 February to 15 March 2001, with almost all (33) laid from 5 to 15 March 2001. However, by mid-March 2001, water levels began to decline from their late-winter maximum of 72.1 cm, falling to 39.5 cm by 15 April 2001. The rate of decline averaged 1.53 cm/day from 1–15 April 2001, suggesting that the pond would dry completely (assuming no substantial rainfall and a linear rate of decline) by 11 May 2001. Even more alarming, previous data from this site (S. C. Richter, Southeastern Louisiana University, personal observation) showed that ranid tadpoles became stranded and died when pond levels declined to 16 cm, a level that would have been reached by 30 April (again assuming no substantial rainfall). This latter assumption was almost certainly correct; the area around Glen's Pond received only 5.28 cm of rain during April 2001 and only 1.27 cm during all of May 2001. Even the largest of these rainfall events (2.76 cm on 24 Apr 2001) raised the pond level only 5.2 cm, equivalent to about 3.5 days of additional time at the rate of drying of 1.5 cm/day. Since air temperatures increase rapidly during April and May at this site, the rate of water loss from both evaporation and transpiration increased to as high as 2.3 cm/day in

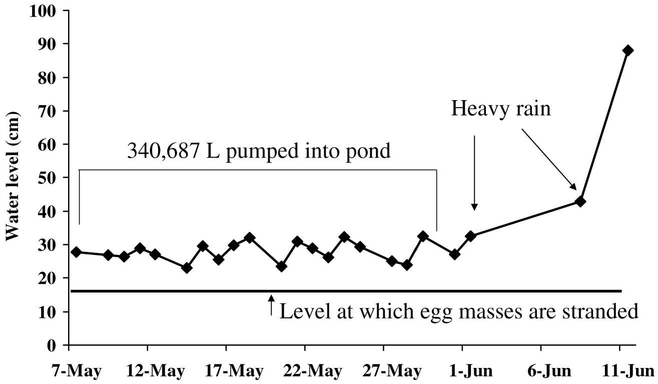

Figure 1. Water levels at Glen's Pond, southern Mississippi, USA, during May–Jun 2001, showing the impact of the prolonged drought and subsequent addition of well water. The level at which egg masses are stranded and will desiccate is shown by the horizontal line.

previous years (S. C. Richter, personal observation). Hence, it is certain that Glen's Pond would have dried completely by early to mid-May 2001 had other measures not been initiated. Since most gopher frog egg masses had been deposited from 60 to 90 days earlier (see above), there would have been complete mortality of these tadpoles.

Effects of Well Water on Tadpole Survival

Most tadpoles in both treatments developed normally through the stage of forelimb emergence. Out of 40 tadpoles in each treatment, only 1 tadpole died in the well-water group (2.5% mortality) compared with 9 deaths in the pond-water group (22.5% mortality). Using the mean number of deaths per tank as the dependent variable, there was no difference between the 2 groups (mean pond-water group mortality = 0.90 ± 0.433 [SE], mean well-water group mortality = 0.10 ± 0.100, $N = 20$ tanks per group; Mann–Whitney U test [using 0.5 added per tank to avoid zeros] = 66.5, $P = 0.101$). We found no deformities in either group.

Maintenance of Pond Water Levels Via Well Water

Initial attempts to maintain or raise the water levels in Glen's Pond via artificial means began on 16 April 2001, using water from Glen's Pond Well #1. These efforts were disappointing. Although soil surrounding the pond appeared saturated, water loss rates did not appear to diminish appreciably, and the pond declined from 40 cm on 17 April to 26 cm by 9 May, despite 4.09 cm of rainfall during that period. This likely was due to the low capacity of the well and associated pump, which, although theoretically capable of producing over 27,000 L/day, appeared to pump at a much lower rate than expected (the exact rate of pumping was not measured). To keep the pond from drying, a larger source of water was needed. Thus, from 9 to 14 May 2001, the United States Forest Service used a deep well at the nearby Harrison Experimental Station to fill 2 1,892-L stainless steel tanks, brought these tanks to Glen's Pond via a trailer, and pumped their contents into Glen's Pond using new fire hoses. Over a 6-day period, we pumped a total of 65,866 L of water into Glen's Pond, ranging from 3,785 to 26,119 L/day. Unfortunately, we found that even this rate of pumping was insufficient to maintain water levels over a long period. For each 1,892 L pumped, the water level in Glen's Pond rose only 0.5 cm, meaning that over 5,676 L/day was needed simply to maintain water levels at an evaporation rate of 1.5 cm/day (Fig. 1). Since the Forest Service could not provide transportation on weekends or keep up at least 3 trips per day indefinitely, an even larger source of water was needed.

On 15 May 2001, with pond water levels at 25 cm, the Mississippi National Guard began using a large-capacity tanker truck to transport well water from the Harrison Experimental Station to Glen's Pond at a rate of 18,927 L/trip. On 6 days between 15 and 29 May, this provided approximately 283,905 L of well water at rates of 37,854–56,781 L/day. The Forest Service provided an additional 17,034 L of water during this period. Finally, construction of Glen's Pond Well #2 allowed for an increased flow rate of 146,880 L/day starting on 23 May 2001.

This large-scale pumping was successful at maintaining the water levels in Glen's Pond. Despite only 0.5 cm of rain between 11 and 29 May, water levels increased from 25.5 cm on 11 May to 32.5 cm on 29 May (Fig. 1). On 1 June Glen's Pond received its first substantial rainfall in over 35 days, when 4.27 cm of rain raised pond water levels by 6.5 cm. From 8 to 12 June, an even larger rainfall event of 43.3 cm from Tropical Storm Allison raised pond water levels from 31.5 cm to 88 cm, effectively ending any concerns about hydroperiod for the remainder of the larval development period, and we added no water after that point (Fig. 1).

Changes in Water Chemistry

Use of well water to maintain pond levels had mixed effects on water chemistry. Before we added water, pH in Glen's Pond varied from 3.1 to 6.0 (Fig. 2), whereas water from the 3 wells (as measured at the well sites) had pH levels of 7.5–8.3. After the introduction of well water, pH rose to as high as 8.1 on 18 May 2001. Conversely, changes in dissolved oxygen (DO) were fairly minor (Fig. 2), and we saw no major daily fluctuations in either DO or pH even on those days when a larger amount of water was added to the pond (Fig. 3).

Reproductive Success

We captured 130 individual metamorphic gopher frogs at the drift fence during 2001. Fourteen of these metamorphs were raised at the Harrison Experimental Station by G. Johnson and released at Glen's Pond. Thus, there were a total of 116 "natural" metamorphs during 2001. These were the first metamorphs seen since 1998 and only the third year with metamorphic success since we installed the complete drift fence in 1996. However, the number of metamorphs was lower than in either 1997 (221) or 1998 (2,248), despite a comparable number of egg masses in 1998. The mean snout–vent length (SVL) of the "natural" 2001 metamorphs was 33.9 ± 0.26 mm ($N = 114$), which was larger than the mean SVL for the metamorphs reared in the lab (30.5 ± 0.49 mm, $N = 10$; $F = 15.7$, df = 1, 122, $P < 0.001$) and within the range of sizes found in 1997 (35.7 ± 0.09 mm; N

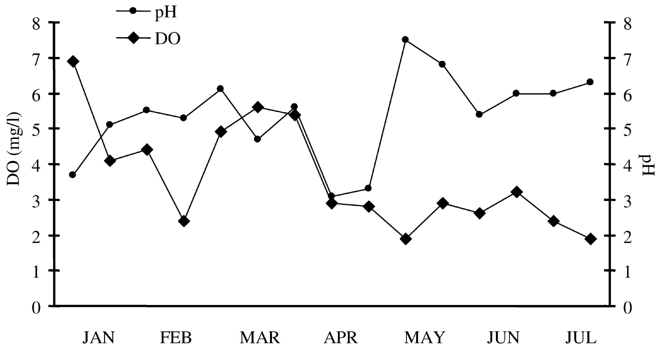

Figure 2. Comparison of dissolved oxygen (DO) and pH levels at Glen's Pond, southern Mississippi, USA, before and after the addition of well water (indicated by an arrow) from Jan 2001 to Jul 2001.

$= 221$) and 1998 (29.8 $\pm$ 0.05 mm; $N = 2{,}248$; Richter and Seigel 2002).

Discussion

Amphibian populations are declining worldwide (reviewed in Alford and Richards 1999). Many declines are the direct result of human activities (e.g., Delis et al. 1996), whereas other causes are not as obvious, including infectious disease, introduction of exotic species, and pollutants (Lips 1998, Kiesecker et al. 2001, Lips et al. 2005). Climatic variables, including drought, have been linked to some declines and extirpations of amphibian populations (Fellers and Drost 1993, Pounds et al. 1999, Lips et al. 2005). For many regions of the world and for many species, baseline data of amphibian species abundances and distributions are not available (e.g., Young et al. 2001). However, population size can decrease dramatically in amphibians due to single years of reproductive failure (Stewart 1995, Grafe et al. 2004). Typically these annual declines are compensated by immigration from nearby ponds (e.g., Greenberg 2001) or by reproductive success in other years (e.g., Caldwell 1987). When populations become isolated, as is true for dusky gopher frogs at Glen's Pond, the effects of annual reproductive failure escalate and can result in extinction of such isolated populations. When there are only a limited number of populations, such a local extinction may be unacceptable. In fact, *R. sevosa* appears susceptible to extinction following complete reproductive failure from 4 to 5 consecutive years of low rainfall (Richter et al. 2003).

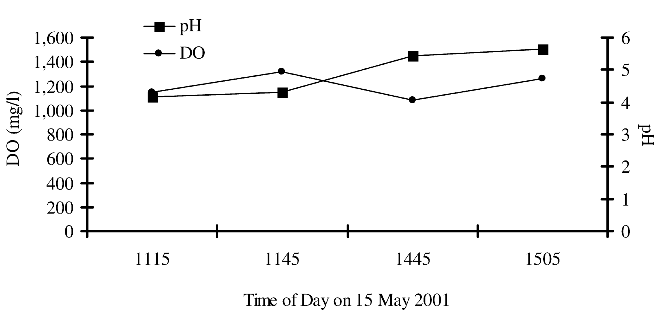

Figure 3. Diel patterns of dissolved oxygen (DO) and pH levels for a typical day (15 May 2001) when large amounts of well water (37,854 L) were added to Glen's Pond, southern Mississippi, USA.

Causes for lack of reproductive output during dry years range from no pond forming and thus no reproduction to an abbreviated hydroperiod (i.e., wasted reproductive effort). Our data show that well water can be used to maintain pond levels in a natural setting, at least long enough to "bridge" brief periods of drought. Although only a modest number of metamorphs (116) was produced, this is clearly many more than would have emerged had the pond been allowed to dry naturally. In addition, we speculate that an earlier addition of water would have avoided the pond reaching near-critical levels and might have resulted in a higher number of metamorphs. Thus, this method has at least the potential for being useful in a conservation setting. However, this does not mean that this method should be applied widely at this stage.

Conservation and management programs for imperiled taxa frequently make use of manipulative techniques to maximize population viability, including habitat alterations, control of predator populations, and reintroductions or translocations (Dodd and Seigel 1991, Denton et al. 1997, Knapp and Matthews 1998, Seigel and Dodd 2000). However, such programs frequently are criticized as being "halfway technologies" (i.e., methods that give the appearance of solving a conservation problem without addressing the underlying causes; Frazer 1992, Meffe 1992, Myers 1994). In a recent paper, one of us (R. A. Seigel) suggested that manipulative conservation projects should be 1) examined with strong skepticism and 2) treated as experimental until results are published and replicated (Seigel and Dodd 2001). The experiment described above is, thus, only a first step toward evaluating the utility of using well water to maintain pond levels for imperiled species of amphibians. For example, although we found no differences in the survival of leopard frog tadpoles reared from just after hatching to near metamorphosis in well water versus pond water, we caution that we did not measure postmetamorphic survival, nor did we test for differences in performance (e.g., endurance, sprint speed) between the 2 water sources. Such tests might be a useful complement to our preliminary findings and should be conducted before using this method on a larger scale or more frequently. In addition, although we were successful in producing metamorphs at Glen's Pond that were as large as or larger than those produced in "normal" years, we do not know if the alteration in water quality noted above may have influenced tadpole survival or behavior. We were especially concerned about the effects of pH, which showed the most dramatic changes after well water was introduced. However, we found no evidence of either tadpole mortality or mortality of aquatic insects during the period of well-water pumping, and information from several experts on tadpole biology indicated that pH levels as high as 8.0 do not represent a significant mortality risk for tadpoles (A. Braswell, North Carolina Museum of Natural Sciences; W. Dunson, Pennsylvania State University; B. Pierce, Baylor University; and R. D. Semlitsch, University of

Missouri, personal communications). Finally, effects of introduction of well water on the rest of the aquatic community (e.g., amphibians that benefit from shorter hydroperiods) remain unknown.

Other management alternatives to well-water pumping should be considered and evaluated to salvage tadpoles when the breeding pond is nearing the level when tadpoles would suffer unacceptable mortality. In the case of gopher frogs at Glen's Pond, few options were available in 2001. Although moving all of the tadpoles in the pond to a nearby fish hatchery was possible, this would have entailed either moving large numbers of morphologically similar leopard frog tadpoles or trying to separate them from gopher frogs on an individual basis, something not thought to be feasible at the time. We concluded that allowing tadpoles to undergo metamorphosis in their native pond was less manipulative then moving them to a distant site. A second possibility was to have reared tadpoles in cattle tanks near Glen's Pond. Cattle tanks have been widely used to rear amphibian larvae (e.g., Morin 1981, Skelly et al. 2002) and currently are being used successfully at Glen's Pond as a "hedge" against reproductive failure (J. Pechmann, East Carolina University, personal communication). Cattle tanks have the advantages of isolating larvae from events occurring in the natural breeding site (e.g., disease, avian predators) and at low densities (<25 per tank for gopher frogs) can produce similar-sized metamorphs compared to natural sites (J. Pechmann, personal communication). However, cattle tanks require high levels of maintenance and it also would take a large number of cattle tanks to produce a sizable number of metamorphs, even at low rates of mortality. Thus, we view cattle tanks as complementary to the addition of well water rather than as a substitute.

In addition to the effectiveness of management strategies, costs need to be considered when prioritizing approaches for endangered taxa (Saterson et al. 2004). Two obvious constraints on use of well water are availability of suitable subsurface water and the expense of digging the well. The expense is linked directly to the depth of drilling. At Glen's Pond a well of only about 42 m was sufficient to maintain water levels without additional supplements and this well cost less than $4,000 to construct. A gasoline generator and pump raised total costs to about $6,000. Obviously, a deeper well or one located in a more remote area would add significantly to the costs, but these prices are not extreme when one considers that the well can be used for many years and can also be used to fill cattle tanks at the same time.

Our data indicate that use of water from an appropriate outside source has the potential for increasing the reproductive success of critically endangered amphibians. Although we do not go as far as to recommend this as a proven conservation method, we suggest that this technique has sufficient promise that additional experimental tests are warranted, especially examining the effect of outside water on performance of larval amphibians and how this method works in different habitats.

Acknowledgments

This research was supported by funding from the Section 6 Program of the Endangered Species Act, and we are grateful to the United States Fish and Wildlife Service, the Mississippi Department of Wildlife, Fisheries, and Parks, and the United States Forest Service. We especially thank L. LaClaire, B. Jones, and T. Mann. Additional financial support for this research was provided by the Department of Biological Sciences of Southeastern Louisiana University. The Southern Research Station at the Harrison Experimental Forest allowed us use of lab space and their cabin facility, and we thank G. Johnson, R. Doudrick, and K. Mansfield. We also thank R. Smith and D. Tyrone of the United States Forest Service for their cooperation and assistance. The Mississippi Army National Guard arranged the deliveries of water through the Environmental Section of the Facilities Management Office and the trucks were provided by the Directorate of Logistics. Colonel B. Lee of the Mississippi Army National Guard deserves our special thanks for his efforts. We also thank the many graduate students and volunteers who helped with the project, especially N. Anderson, B. Horne, C. Kennedy, T. Lorenz, J. R. Lee, N. Seigel, B. Seigel, and S. Woltman. Comments on this manuscript were provided by J. Caldwell, C. Elliott, and J. Pechmann. Collecting permits were provided by the Mississippi Department of Wildlife, Fisheries, and Parks.

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Associate Editor: Perry.