Overwintering Behavior of Adult Bullfrogs, *Rana catesbeiana*, in Northeastern Ohio[1]

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ABSTRACT. Many species of ranid anurans overwinter in aquatic habitats such as streams, ponds, and lakes, but little is known about their behavior or location when submerged. Six adult bullfrogs (*Rana catesbeiana*) at two small ponds (~0.25 hectares each) in Summit County, OH, were followed through a hibernation period in 1991/1992 by means of radio transmitters. The purpose of the investigation was to determine the bullfrog's hibernation sites and movements during the overwintering period. Two of the frogs were native to the study sites, and the remaining four were collected from Ottawa County, OH, shortly before the study began. During November and December, all six frogs left their release sites and moved from 33 to 96 m to overwintering areas. Five of the frogs overwintered in relatively shallow areas near small inlet streams in the NW corner of the ponds. The remaining frog overwintered 1-2 m off the west shore. Collectively, the six frogs were located 208 times and were nearly always submerged. Frogs moved about even during the coldest periods (mid-December through mid-February). They were seen floating at the water's surface or sitting on the bank on only 10 occasions. Bullfrogs that were observed submerged on the pond bottom were not buried or covered by silt. This study suggests that adult bullfrogs prefer relatively warm, shallow water for hibernacula and that they remain active throughout the hibernation period.

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INTRODUCTION

It is generally well known that many ranid anurans overwinter submerged in water (Martof 1953, Berger 1982, Bradford 1983, Cunjak 1986). However, little has been published on the behavior, habitat, and survival of these animals during winter submergence. Some authors suggest that frogs remain inactive in or on the mud at the bottoms of streams, ponds, and lakes throughout winter (Goin and Goin 1962, Hutchison and Dady 1964). This view is largely unsubstantiated because no published field studies exist for individual frogs during winter.

Overwintering under water, particularly in shallow ice-covered ponds and lakes, poses potentially lethal physiological problems, notably anoxia and freezing. In aerated water at low temperatures (<5° C) many frog species can maintain adequate oxygen uptake by means of cutaneous and possibly buccal respiration (Pinder 1987, Hutchison and Whitford 1966). However, unlike some freshwater turtles, frogs have only limited abilities to withstand anoxia (Penney 1987). Freshwater turtles are remarkably tolerant of anoxia. Painted turtles (*Chrysemys picta belli*) survive for up to six months at 3° C in nearly anoxic water (Ultsch and Jackson 1982a,b; Jackson and Ultsch 1982). This ability is related to a profound metabolic suppression (<5% of normoxic rate), elevated on-board glycogen stores, and tolerance of lactic acid. By contrast, laboratory studies suggest that frogs can only survive anoxia a few days to one week even at low water temperatures (Penney 1987). Consistent with this conclusion, Bradford (1983) documented high mortality associated with oxygen depletion in *Rana muscosa* overwintering in shallow lakes at high altitude (≤3,700 m). Some species of anurans overwinter on land beneath leaf litter and can survive freezing for several days (Schmid 1982, Storey and Storey 1988). However, anuran species that normally overwinter in water cannot survive freezing. It thus appears that movement to areas of high oxygen content and avoidance of freezing temperatures is required for survival of aquatic frogs. We therefore investigated individual adult bullfrogs, *Rana catesbeiana*, to determine if they remain inactive (torpid) during winter. Individuals are large enough to be equipped with radio transmitters. Bullfrogs are common residents of lakes, ponds, marshes, and sluggish portions of streams throughout Ohio (Walker 1946).

MATERIALS AND METHODS

Two bullfrogs were captured on 3 October 1991 at Seiberling Naturealm, Summit County, OH. The frogs (assigned no. 1 and 5) were taken to The University of Akron where they were anesthetized by immersion in tricaine methanesulfonate (1:10,000) buffered to pH 7-8. They were then placed into ice water and a Model T transmitter powered with a lithium battery (Mini-Mitter Co., Sunriver, OR) was inserted through a ventral incision into the abdominal cavity. The incision was sutured, and the frogs were allowed six days recovery in the laboratory before being released at their respective capture sites on 9 October 1991. Radiotransmitters were also implanted into four bullfrogs that were captured on 30 October 1991 at the Ottawa National Wildlife Reserve, Ottawa County, OH, under permit. These frogs were released 11 November 1991 at Seiberling Naturealm. Bullfrog nos. 1, 2, 3, and 4 were released into Seneca Pond, nos. 1 and 2 at the same site on the east shore, and nos. 3 and 4 at the same west shore site where several bullfrogs had previously been seen. Bullfrog nos. 5 and 6 were released into Echo Pond at the same north shore site. The frogs used in this study ranged in weight from 194 to 392 g and appeared in excellent health when released.

The bullfrogs were located with a Model CH-6 Receiver (Mini-Mitter Co.). Typically, the bullfrogs were under

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water and not visible. However, by walking the shoreline, occasionally wading short distances, and walking on the frozen ponds, the transmitters allowed us to approximate their locations by triangulation to within a 1.0 m^2 area. Care was taken not to disturb the frogs or their habitat. From late October until mid-April 1992, we tracked individuals and recorded air temperature 1.0 m above the ground. We also measured water temperature 2-3 cm below the surface 0.2 m from the north and west shorelines. Temperature was measured using a NBS certified Fisher brand thermometer (Fisher Scientific).

Study Site

Seiberling Naturealm is a 40 ha nature study and wildlife conservation preserve located in Summit County, OH. Within the preserve are Seneca Pond and Echo Pond, each with an area of 0.24-0.26 ha and a maximum depth of 3-4 m. The shorelines were surrounded by trees and brush, except for the west bank of Seneca Pond which was covered by grasses.

On 5 March 1992, the park service began draining Seneca Pond which resulted in a gradual fall in the water level. By 18 March, the water level had dropped 1-2 m and frogs 1, 3, and 4 were captured by hand. On 28 March the water was down 2-3 m and frog no. 2 was captured in a seine. All four frogs appeared in excellent condition; although sluggish, they kicked and vocalized when caught.

Water depths were determined by plumb line from a boat.

RESULTS

Air and Water Temperatures

In general, air and water temperatures gradually fell throughout October and November, were relatively low and stable from mid-December to early February, and then increased to early October values (Fig. 1). Water temperatures recorded at the four sites did not differ by

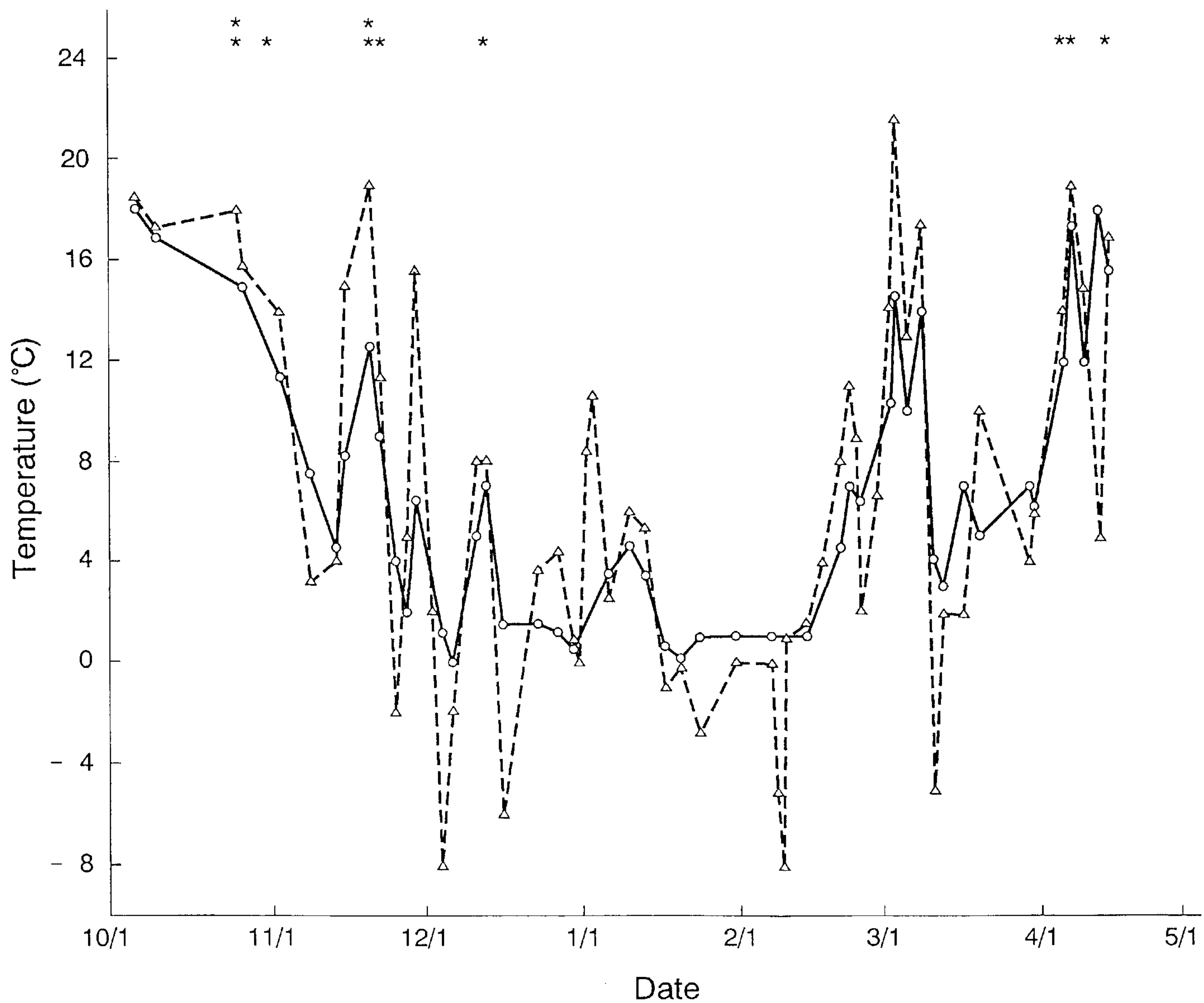

FIGURE 1. Air (dashed line and triangles) and water temperatures (solid line and circles) taken 1 m above the ground and 2-3 cm below the water's surface, respectively. Temperatures are the mean values taken at Seneca Pond and Echo Pond. * indicates days when bullfrogs with radio transmitters were seen, either floating at the water's surface or on shore. Ice covered the ponds from 23 December to 30 December and from 17 January to 22 January.

more than 2° C and were averaged. The gradual decline in temperatures was interrupted by a brief warming period during which three of the bullfrogs were seen on shore. During December, temperatures briefly increased to 7-8° C and one bullfrog was observed floating at the water's surface. The rapid warming that occurred in late February and early March was followed by several weeks of relatively low temperatures. Spring emergence from the pond bottoms did not occur until early April.

Telemetry

Telemetered frogs were located 208 times and were nearly always submerged. On only 10 occasions were individuals seen floating, near the shore, or sitting on the bank (Fig. 1). Movements correlated with temperature (Figs. 1,2). The greatest distances traveled were during October to late November and from late February to mid-April. During January and most of February, when temperatures were lowest, there was minimal activity. These mid-wintering sites were 33 to 96 m from the original release sites.

From 11 October to 15 November frog no. 1 remained at its release site and was typically submerged 1-2 m offshore in an area of cattails (measured water depth = 0.5 m, Fig. 3a). On 22 November the frog was found across the pond 1-2 m from the west shoreline, 96 m from its release site. This distance assumes that the frog swam near the shoreline, as opposed to swimming directly across the pond. The new location was also in a region of cattails 0.5 m deep. Frog no. 1 occasionally moved within a 10-12 m stretch of the shore throughout the remainder of the study. On 18 March, the frog was captured 0.2 m offshore while lying on the bottom in 0.5 m deep water.

Frog no. 2 was found at its release site from 13 November to 22 November (Fig. 3b). However, the signal had disappeared from the area on 25 November and was not located until 17 February 45 m away near the NW corner. Thus, the frog's location was not known for

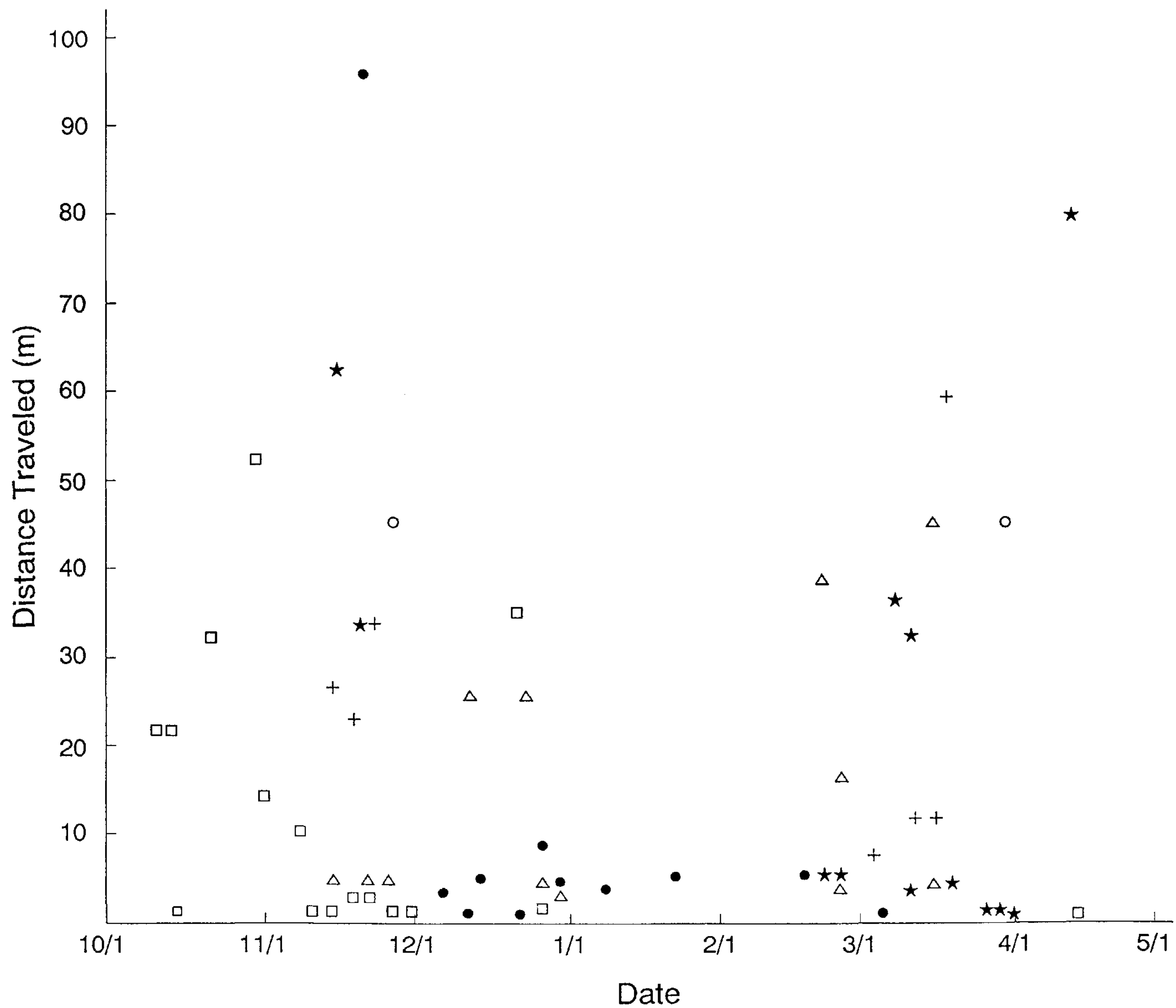

FIGURE 2. Distance traveled by six adult bullfrogs tracked by telemetry. Distances were measured between consecutive locations. Times when there was no movement between observations (0.0 m) are not indicated. Symbols represent individual frogs (• no. 1, o no. 2, + no. 3, Δ no. 4, ❑ no. 5, ★ no. 6). Note that the greatest activity occurred during October to late November and from late February to mid-April.

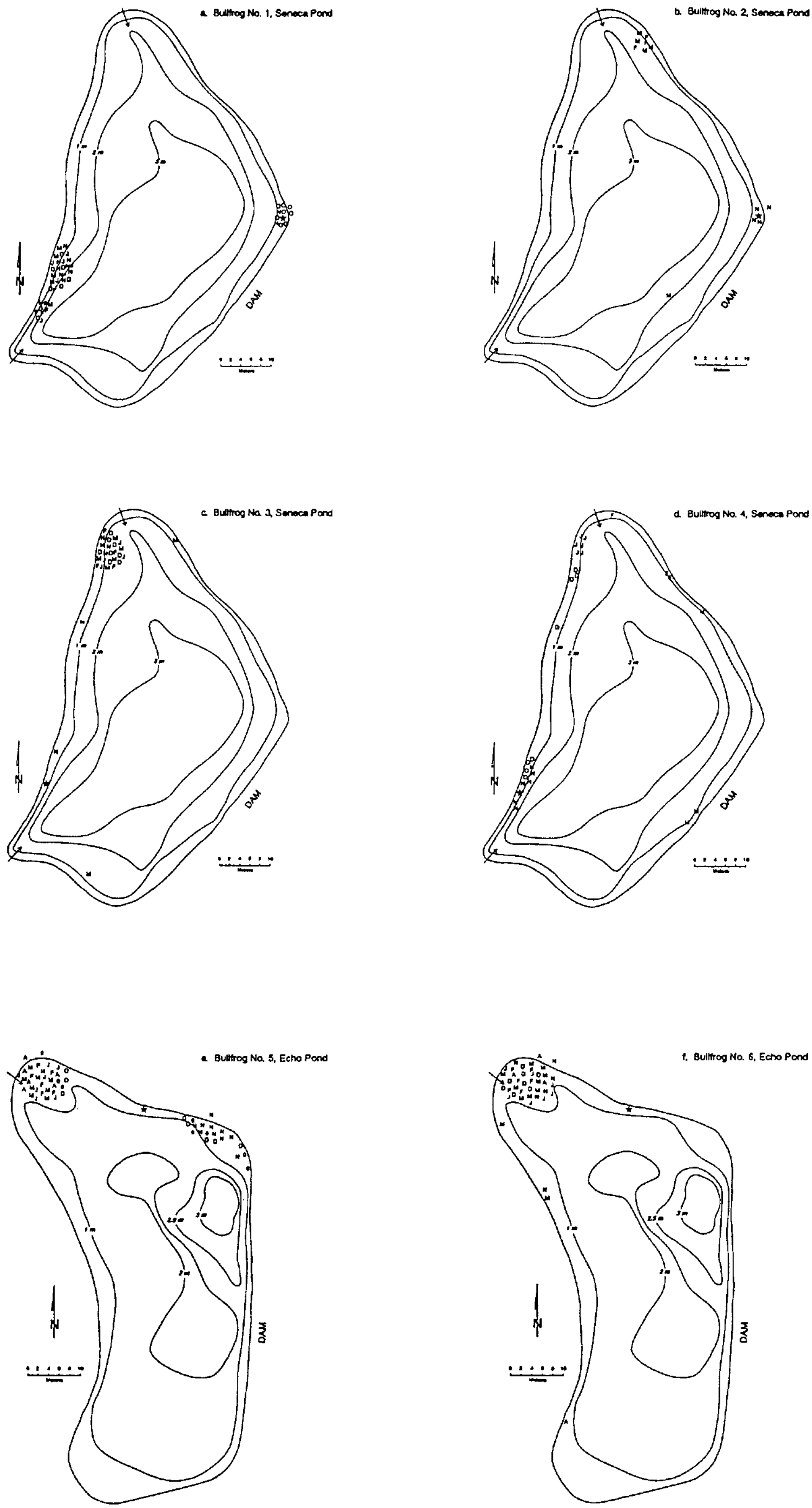

FIGURE 3. Approximate locations of individual bullfrogs at the two study sites, Seneca Pond and Echo Pond. Symbols indicate the months when the animals were located (O = Oct., N = Nov., D = Dec., J = Jan., F = Feb., M = Mar., A = Apr.). Arrows show locations of the small inlet streams. Stars indicate original release sites. Depth contours are in m.

over 2.5 months. During this time we walked most of the perimeter of the pond many times in an effort to locate the signal. While it is possible that the frog was too far into the pond to pick up a signal, it is more likely that frog no. 2 was actually in the NW corner west of its 17 February location. Tracking in this region was not done because of thick undergrowth and soft mud. The NW corner of the pond was relatively shallow (<1 m deep) with cattails and a small inlet stream. Frog no. 2 remained close to the NW corner through 9 March, but it was not found again until captured in a seine on 28 March.

Four days after its release bullfrog no. 3 had moved north and was submerged near the west shore (Fig. 3c). It then returned to near its release site on 20 November. On 22 November the frog was located near the NW corner where it remained, with some movement, until 13 March. On 18 March the frog was captured by hand 0.65 m from shore in 0.8 m deep water approximately 59 m from the NW corner.

Frog no. 4 was similar to frogs 2 and 3 in that it left its release site and overwintered in the NW corner of Seneca Pond (Fig. 3d). Furthermore, like no. 3, it also explored the west shoreline before settling near the inlet stream. On 16 December the frog was close to the NW corner. It then returned, but by 30 December it was in the NW corner. No further movement occurred through 17 February. However, between 17 February and 26 February the frog progressively moved eastward. On 3 March the frog had apparently left the area and was relocated off the NE shore on 9 March. On 16 March the frog was found near the SE shore and was captured two days later in the same area while resting on the bottom in 0.5 m deep water.

There was considerable movement by frog no. 5 along the north shore of Echo Pond during October, November, and December (Fig. 3e). On 12 October the frog was near the NE corner but had returned to the release site the following day, and on 14 October it was seen motionless on the bottom within 0.2 m of the shoreline. On 22 October it was in the NW corner, but on 31 October the frog was again submerged near the NE corner. It stayed within a 5 m stretch of the north shore from 8 November to 16 December. On 23 December the frog was once again in the NW corner and was observed motionless on the bottom within a few cm of the shoreline. When touched, the frog immediately swam away. Frog no. 5 remained in the NW corner, typically near cattails in water <1 m deep.

Frog no. 6 spent most of the study period in the NW corner of Echo Pond (Fig. 3f). Four days after its release, it was in an area of cattails near the west shore, which was 61.5 m from the original release site, assuming that the frog swam along the northern and western shorelines. On 20 November the frog was on the bank in the NW corner and on subsequent days was submerged there. On 14 February a hole was chopped through the ice, where the frog was found resting on the bottom 2 m from shore (water depth, 0.6 m). When prodded, the frog swam away. One week later frog no. 6 was found once again submerged in the NW corner where it remained through 6 March. On 9 March the frog was submerged near the west shore 37 m away but returned to the NW corner by 13 March. From 13 March to 8 April some movement between areas of cattails occurred. On 13 April the frog was found 80 m south submerged near cattails (water depth = 0.5 m).

DISCUSSION

This study conclusively documents movement by adult bullfrogs in ponds during the fall and winter seasons, confirming our hypothesis that hibernating aquatic frogs are not torpid. All six frogs left their original release sites in November or December. Presumably these movements were accomplished by swimming near the shoreline, as opposed to hopping on the banks. Willis et al. (1956) reported that large bullfrogs in Missouri farm ponds were rarely seen once air and water temperature fell below about 15° C; however, bullfrogs could be collected by seining. Similar findings were reported by Martof (1953) in a study of green frogs (*Rana clamitans*) along a stream in Michigan. Once air temperature fell below about 15.5° C, the frogs left the banks for the stream bottom. In our study of large bullfrogs, surface water temperatures were well below 15° C throughout November and December, and it is highly unlikely that the frogs would have ventured onto land except during the brief warm spell in late November (Fig 1).

We also found that bullfrogs voluntarily move even during the coldest periods. Frog no. 5 was seen lying on the bottom next to the shore on 23 December, but by 27 December it had moved approximately 5 m out into deeper water. From 17 February to 26 February, frog no. 4 gradually moved eastward around the NW corner of Seneca Pond. When a hole was cut through the ice on 14 February and frog no. 6 was touched, it immediately swam away, but voluntarily returned within 10 days. Finally, some movement by frog no. 1 occurred between 16 December and 17 December.

The ability of some ranid species to be active at low water temperature is well established. Emery et al. (1972) used scuba gear to observe *Rana pipiens* in an ice covered pond in Canada. The authors found frogs resting in small shallow pits excavated into the mud at a water temperature of 2.5° C. They reported seeing undisturbed frogs lift up and rotate within the pits, as if to circulate water for gas exchange. Furthermore, when the investigators picked up and released frogs, they swam slowly back to the bottom. Cunjak (1986) also reported slow swimming ability of *R. pipiens* at near freezing temperatures. *R. pipiens* kept 48-72 hours in the laboratory at 1.5° C can right itself (Licht 1991). Juvenile *R. catesbeiana* cease motor activity between 0 and 1° C (Lotshaw 1977). The ability to swim at low water temperatures is apparently utilized by adult *R. catesbeiana* during winter.

An obvious question is why the frogs moved during our study. It is noteworthy that all six frogs selected overwintering sites that were quite similar. The two frogs in Echo Pond went to the NW corner, despite the fact that one frog was native to Echo Pond and the other was introduced in November. In Seneca Pond, all three introduced frogs left the areas where they had been released and overwintered in the NW corner. Finally, the single native telemetered frog in Seneca Pond also left its original location, but overwintered next to the western shoreline.

The fact that the NW corners were chosen by five frogs strongly suggests favorable environmental conditions in these areas.

The NW corners were relatively shallow (<1 m), contained algae and cattails, and were fed by small streams. Furthermore, the northern shore should receive the most sunlight during the fall and winter seasons. Also, the western banks of the ponds (particularly Seneca) gradually sloped upward forming a natural drainage area, whereas the eastern banks were relatively low level earthen dams. During the study period, we observed that ice consistently formed last and melted first along the northern and western shorelines. This was especially evident in the NW corners near the inlet streams. Consequently, it is likely that the northern and western shorelines were the warmest, both because of direct solar radiation and because of runoff and seepage of water into the ponds. More light, higher temperature, and less ice cover would also favor higher dissolved O_2 levels. Future studies of thermal and dissolved O_2 gradients are needed to verify their importance to overwintering behavior in bullfrogs.

Overwintering in shallow water may also allow for the use of temperature as a cue for spring emergence and breeding. Five of the six frogs in this study chose sites near inlet streams. These streams carry soil deposits into the ponds, creating shallow regions. They are also major sources for water entering the ponds. Martof (1953), as well as earlier investigators, have commented on the close association between high temperatures and rainfall and the effectiveness of warm spring rains in causing frogs to emerge in spring. Ultsch and Lee (1983) located wintering snapping turtles buried in mud in the shallow inlet stream of a small pond in Connecticut. The authors also pointed out the possible importance of higher temperature in the shallow inlet as a cue for spring emergence.

In summary, adult bullfrogs moved to relatively shallow water to overwinter and even during the coldest months maintained some activity. We did not observe frogs burrowing into the mud, as do freshwater turtles (Ernst 1972, Ultsch and Lee 1983). It thus appeared that the frogs actively avoided conditions that could interfere with cutaneous gas exchange. The ability to move during winter is also beneficial in that the frogs can respond to thermal gradients, escape predators, and avoid unfavorable conditions such as freezing or falling water levels.

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