Colorado Division of Wildlife

Boreal Toad Research Progress Report

1999

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Preface

The Boreal Toad Recovery Team was formed in 1994, in response to reports of significant declines in boreal toad distributions in the Southern Rocky Mountains. These apparent declines resulted in an "Endangered" listing by Colorado and a "Status 2" species designation federally. The boreal toad is currently considered "warranted but precluded" for federal listing under the Endangered Species Act. The first Boreal Toad Recovery Plan was completed in 1997 under the direction of John Goettl; the Recovery Plan and Conservation Agreement have now been combined into one working document (Loeffler [ed.] 1998). Currently, the Recovery Team is coordinated by Chuck Loeffler, the Colorado Division of Wildlife (CDOW) Wildlife Manager for Reptiles, Amphibians, Mollusks, and Crustaceans.

This report represents boreal toad research sponsored by the CDOW in 1999 by several researchers and has been consolidated into a single document to make this information available to members of the Boreal Toad Recovery Team and other interested parties. The various sections of this report cover results of :

- Research conducted by the CDOW on habitat use, movements, and general life history aspects of boreal toads at the Climax Molybdenum Company mine near Empire, Colorado. This work was confounded in 1999 by a disease outbreak which was identified as chytridiomycosis; this topic will be covered also. Mark Jones is the principal investigator.

- Research conducted by the CDOW on boreal toad tadpole ecology. The principal investigator is Lauren J. Livo.

- Research conducted under a CDOW MOU with the University of Colorado at Boulder on the molecular genetic determination of management units within the Southern Rocky Mountain population of boreal toads. The principal investigator is Anna M. Goebel.

- Research conducted under a CDOW MOU with Colorado State University to develop a statistical/spatial habitat model for the boreal toad. The principal investigator is Andy Holland.

Funding for boreal toad research and recovery efforts in Colorado have been provided by Great Outdoors Colorado.

HENDERSON/URAD BOREAL TOAD STUDIES

SITE DESCRIPTION AND BACKGROUND

Research on population size, stability, movement, and habitat use has been conducted at the Henderson/Urad Mine since 1995. The Henderson Mine breeding locality consists of numerous ponds and wetlands in an area which is heavily disturbed due to molybdenum mining by the Climax Molybdenum Company. The mine is located west of Empire, Colorado at an elevational range of 10,000 to 10,500 feet. The specific breeding sites have been designated as follows: Power Alley, Hesbo, Treatment Pond, Donut, Anne’s Pond, and Upper Urad (Figure 1). In 1999, egg masses were located at two additional sites at the mine, with survival to metamorphosis at both.

Hesbo and 2-Pond were the main breeding locations in 1995 and 1996. Hesbo was the primary breeding site from 1997 to 1999. In 1995 and 1996 both sites were influenced by pre-treated mine effluent running through them at an elevated temperature of 19-21° C. Climax finished a new water treatment facility on the Urad side of the facility in 1997. As a result, 2-Pond is no longer an active breeding site and Hesbo has reduced water temperatures in the spring and no long term source of water. As a result of the changes in water supply to Hesbo, we had to pump water to the site once each week from July to September during the 1998 and 1999 seasons. In an attempt to remedy this situation, the Mine provided a backhoe to install a dam and water control structure and increase the depth of the channel in October 1998. Structural modifications were also made to Anne’s Pond in 1998. Even though Hesbo has the largest population of adult toads during breeding, this site did not recruit from 1995 to 1997. In 1998 and 1999, Lauren Livo removed Dyticid beetle larvae as part of her research, which resulted in substantial survival to metamorphosis in both years.

Power Alley is a beaver pond complex along the West Fork of Clear Creek and is the most natural breeding site in the area. It is not directly influenced by mine effluent and therefore the water temperature is colder than the previously mentioned sites and breeding occurs one to two weeks later. This site, however, has dried up during the last three years and desiccated the egg masses present.

Treatment is a man-made wetland complex which is dissected by the Urad Mill Road located north of the water treatment facility. Breeding activity is restricted to the pond(s) on the west side of the road. It does not have a large number of adults during breeding but produced 10,000-15,000 toadlets in each year from 1996 to 1999. Recruitment at this site is low as there is minimal overwinter refuge for toadlets.

Donut is a newer pond above the water treatment facility which serves as a catch basin for some of the upstream runoff. This site typically has 5-6 egg masses but because it is higher in elevation than the other sites, breeding occurs later making weather conditions post metamorphosis critical to toadlet survival and dispersal. In addition, there are few suitable hibernaculum close to this site. All toadlets froze in 1995 and 1996. We believe that some toadlets survived in 1997. Survival of toadlets was good in 1998 and 1999, presumably a result of increased vegetation and small mammal burrows on the islands.

Anne's Pond is a small wetland area south of Donut which, is fed by ground water and runoff. Because the average depth is less than 10 cm, the water temperature stays warm and tadpoles grow quickly. In 1996 this pond had several thousand tadpoles but dried up in July. At our request, the Henderson Mine personnel put in a water supply pipe to keep the water level constant, which resulted in successful recruitment in 1997 and 1998. In October, 1998 we used a backhoe to increase the main channel depth and added a side channel; these drain to a deep water thermal refuge. As a result of water levels decreasing too quickly in 1999 to successfully supplement water at this sight, all egg masses desicated.

Upper Urad is a large, man-made wetland area at the west end of the valley at an elevation of 10,500 ft. Due to the elevation, this is the last site for breeding activity each year. It produced toadlets in 1995 and 1996 but they froze in 1995 and were eaten by sand pipers in 1996. No successful reproduction occurred at this site from 1997 to 1999.

Figure 1 Site Map

MATERIALS AND METHODS

The Henderson/Urad breeding population was monitored by J. Goettl in 1995 and 1996. Data collected in 1995 was mostly exploratory in nature, as little was known about the status of these breeding sites and field techniques for radio telemetry were being refined. This project was transferred to M. Jones in 1997. Starting in 1996, all breeding sites were surveyed one time during daylight hours and one time at night each week during the period when toads were actively breeding. Each site was surveyed according to the protocols outlined in the Conservation Plan and Agreement (Loeffler [ed.] 1998). Each toad captured during the night surveys was sexed, weighed (± 0.1g), and measured (snout to urostyle length, ± 0.01mm). Each individual was then scanned for a PIT tag and if one was not found, a tag (AVID ITI-125S) was inserted dorsally. The tags were inserted by pinching the skin on the toads back (slightly off center and anterior), making a small incision using sterile scissors, inserting the sterile tag in a posterior direction using forceps, and closing the incision using surgical adhesive. All PIT tag numbers were recorded along with the other pertinent data on individuals and site. Water quality samples were taken at each breeding site a minimum of three times per year. Once in May, one time while tadpoles were present, and again during metamorphosis.

Twenty-nine toads (fifteen males and fourteen females) were radio tagged in May and June 1999 at Hesbo, Donut, and Anne's Pond with Holohil BD-2G radio transmitters weighing 2g each, with an expected battery life of six months. The radios were fixed to the toads using a waist harness constructed of plastic coated fishing leader material fastened with crimp collars inside 2mm vinyl tubing. An additional five toads (all males) were tagged during the summer as replacements for individuals killed by various predators (Jones et al 1999) or which lost their transmitters (Table 1).

Each radioed toad was located one time per week from May until they went into hibernation or were lost for various reasons. Toad locations were recorded in Universal Transverse Mercator (UTM) coordinates using a Trimble Pathfinder Basic Plus global positioning system (GPS) with an external antenna. Location files were downloaded to a computer, differentially corrected, and imported into ARC/INFO (ESRI 1997) for spatial analysis.

Table 1. INSERT HERE

Central to the study of boreal toad biology is their use of various habitats and our ability to define their habitat requirements and preferences. This process involves defining the availability of individual habitat types within the study area and then determining the usage of these habitats. We can determine individual use of various habitats through our radio tracking activities; defining what is available is not as easy, and in almost all studies involving habitat selection, this is a subjective decision based on the researchers knowledge of the animals movement. By changing the spatial scale of what an investigator deems to be available to an animal or if habitat types are arranged in an aggregated pattern (Porter and Church 1997), the resultant conclusion about selection or preference for individual habitat types will also change. For this reason, we used two different spatial scales to define habitat availability. First, we combined all three study areas (Hesbo, Donut, and Upper Urad) because we know from our telemetry work during the last two years that toads can move from one end of the valley to the other and we have seen some interaction between study areas. For the second analysis, we defined availability of habitat types for each study area (because toads generally stayed within their respective area) by drawing a 300 m buffer around the pooled toad locations for each study site and calculating the availability of each habitat type within that polygon (Figure 2).

Habitat and slope coverages were developed in ARC/INFO starting with a photo interpreted CAD file obtained from the Henderson Mine and then ground truthing and making corrections by walking the perimeter of each habitat area with a GPS unit. Toad location data was overlaid on the habitat and slope coverages to assign habitat types to each location. The habitat categories were defined as aspen/conifer, road, spring, stream, lentic water (lake, reservoir, pond), and rock/grass. In addition, a photograph was taken at each toad location each week to verify the habitat classifications assigned in ARC/INFO. Only toads which had six or more habitat locations were included in the analysis. To test whether toads used a habitat category in greater or lesser proportion than its availability in the study area, a univariate t-test was used in SAS (1994) which tests whether the difference between the mean of the proportion of habitat availability and the mean of the proportion of habitat use equaled zero ($\propto$=0.05).

Home range analysis was conducted to quantify and evaluate the areas and habitats used by individual boreal toads. Home range estimates were produced on two temporal scales for each boreal toad. One estimate used all the radio-tracking locations and the other estimate only included post-breeding locations. An area used estimate was also calculated for each breeding site from pooled individual locations for that site. The minimum convex polygon and adaptive kernel (Worton 1989) methods were used to estimate the home ranges for all individuals that had six or more radio-tracking locations. **The program CALHOME (Kie et al. 1994) was used to calculate these estimates**.

Minimum convex polygon (MCP) is a common home range estimation method that assumes a uniform utilization distribution (Samuel and Garton 1985). With the MCP method, any area inside the polygon has an equal probability of containing a location. MCP is calculated by drawing a polygon around a specified percentage of the radio-tracking locations. Ninety-five percent of the locations were used for these estimates. MCP has the disadvantages of increasing the size of the home range estimate as the number of locations increases and not allowing for a precision estimate (White and Garrott 1990). MCP was useful, however, to get an idea about the minimum size and shape of home ranges and use areas. Many of the utilization distributions are linear between two core areas, MCP included these corridors in the estimates.

Figure 2. Map of designated study areas in the Henderson/Urad area, 1998.

The adaptive kernel method (Epanechnikov kernel) is a nonparametric method that uses point percentage contours to estimate a utilization distribution for the sample locations (Worton 1989). It delineates the smallest area that contains a specified percentage of the probability distribution. The adaptive kernel method was used in addition to the MCP in order to estimate areas of the home range where no locations were obtained such as foraging or nocturnal movements. This method was also chosen because it does not assume a normal or uniform distribution and is therefore capable of estimating home ranges for animals with core activity areas (Kie et al. 1994). This attribute was attractive because the radio-tracking locations for many individuals were not normally distributed. Many of the boreal toads studied appeared to move periodically to areas such as water sources or the breeding site but did not remain in these locations. A 95% point probability and the default grid size (30x30) were used. A bandwidth of 50 meters was chosen in these estimations. The bandwidth is the smoothing parameter that controls the amount of variation in the estimate (Worton 1989). A bandwidth of 50 meters was selected to allow the identification of core activity areas in even a relatively small home range. The goodness of fit of the bandwidth to the data is identified by a least square cross validation test (LSCV) (Kie 1994). The lower the LSCV score, the better the bandwidth and subsequently the polygon fit to the locations. For example, two core areas with a polygon around each of them would have a lower LSCV score than a larger polygon that encompasses both core areas.

Capture-recapture methods were used to estimate population numbers of males at each breeding site from 1995 to 1999. Only male boreal toads could be estimated as there was never a recapture of a female in the same year, indicating females breed and immediately leave the breeding site. The computer program Capture (White et al. 1978) was used for the analyses and White et al. 1978 should be referenced for a full description of procedures and model selection.

Movement was calculated by plotting sequential locations for each toad on a 3 m^2 cell digital elevation model in ARC/INFO. In this way, the extreme elevational unevenness of the terrain could be incorporated into the calculations. Total distance moved/time for each toad and average daily movement in meters was calculated. Differences between male and female movements were tested using the Mann-Whitney U test.

RESULTS and DISCUSSION

Breeding Site Monitoring: 1999

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Hesbo- Hesbo was monitored at night weekly from May 18 to June 15, 1999. Additional biweekly daylight surveys were conducted throughout the summer. The peak of breeding activity occurred on May 25 with 72 adults observed (65 male, 7 female). Night surveys were discontinued because all of the adults handled had been previously handled in 1999. Twenty-three egg masses were laid, resulting in approximately 20,000 tadpoles. During 1999, Lauren Livo continued dytiscid beetle larvae predation studies at this site.

Power Alley- Power Alley was night monitored weekly from May 18 to June 15, 1999. The most adults observed at this site was 33 males, no females were seen during monitoring. One egg masses were laid at this site which later desiccated.

Upper Urad- Upper Urad was night monitored weekly from June 22 to June 29, 1999. Seven adults including one gravid female was the highest number of toads observed on any occasion. One egg mass was deposited which fungused and died. No successful reproduction in 1999.

Donut- Donut was night monitored weekly from May 31 to June 22, 1999. Seventeen egg masses were deposited at this site, several died from fungus. Lauren Livo conducted tadpole ecology experiments at this site. Although some toadlets died from desiccation and exposure at this site, we believe survival was better than in previous years because many metamorphosed onto the islands, which are thickly vegetated and have suitable hibernaculum close to the edge of the water.

Treatment- Treatment was night monitored from June 15 to June 29, 1999. The greatest number of adults observed in one night was four. No egg masses were observed, but based on the groups of tadpoles observed on June 23, we suspect two egg masses were present. Monitoring was continued at this site throughout the summer with good survival to metamorphosis. It is still not known whether many survive the winter at this site as there are few suitable hibernacula and juveniles are not typically seen the following spring .

Anne's Pond- Anne's Pond was monitored from May 25 to June 29, 1999. The most adults observed in one night was 21, we checked a total of 7 females during the course of the active breeding period. Nineteen egg masses were laid, all of which dessicated because of our inability to keep water levels stable.

Other Breeding Sites

1- Pond- Boreal toads were first observed breeding in 1-Pond in 1998. Many juveniles were observed in June, 1999 indicating good over winter survival. In 1999, tadpoles were again observed at this site, probably from two egg masses. Most of the tadpoles metamorphosed and dispersed by September 29.

John's Pond- John's Pond is a small catch basin by the domestic water treatment plant on the Henderson side of the mine. Breeding was first observed at this site in 1998. In 1999, tadpoles from one egg mass were observed on June 30. Most metamorphosed and dispersed by September 29.

Lower Urad Lake- This was the second year we observed breeding in Lower Urad Lake. On June 23, two egg masses were observed in the north west cove. On subsequent visits it appeared that one of these disappeared and the other produced approximately 100 tadpoles. It didn't appear like any of these survived to metamorphosis.

Climatic conditions each year have a major impact on survival and recruitment. Spring storms frequently kill egg masses and early fall freezing conditions either directly kill toadlets or negatively impact dispersal to suitable hibernaculum. On may 25, 1999 two male and one female adult toad were found dead following a snowstorm. Summer drought can dry breeding ponds before metamorphosis can occur (Anne's Pond 1999). In 1999, several egg masses that were deposited late succumbed to fungus, presumably the result of elevated water temperature. Breeding sites at higher elevations are more susceptible to negative climatic conditions. In addition, cooler than average summer temperatures slow tadpole development which makes fall conditions critical to timely metamorphosis and dispersal. Water level fluctuation resulting in desiccation of egg masses is also very common. In 1997, 1998, and 1999 all egg masses in the main pool at Power Alley desiccated due to the water level dropping prior to hatch. We have been able to mitigate this situation in a number of cases by artificially manipulating water level or by moving egg masses to stable sites which resulted in substantial recruitment that otherwise would not have occurred.

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Variation in yearly recruitment causes natural fluctuations in populations through the absence of sequential year classes. These short term fluctuations are tempered by the fact that boreal toads are relatively long lived. Long term research is needed to define possible long term fluctuations and to distinguish between natural and anthropogenically caused declines (Pechmann et al. 1991).

Habitat Use and Movement

Locational data was collected on a total of 26 radio tagged boreal toads (Table 1) which had six or more contacts and was used to calculate movement and habitat use. It should be noted that major heterogeniety between individual toads was observed in both habitat use and movement data. As defined earlier, habitat availability was defined using two spatial scales. First, preference was determined using the entire Upper Urad drainage as available habitat. Next, preference was based on available habitat using a 300 m buffer around the pooled toad locations at each of the three study areas (Figure 2).

Of the 388 toad locations recorded (study areas combined), 34. 5% were on 0-20% slope (12.3% of total study area), 23.4% were on 21-40% slope (12.6% of total), 22.4% were on 41-60% slope (28.9% of total), and 19.6% were found on 61-80% slopes (45.2% of total). No toad locations were recorded on slopes >80%; slopes of this magnitude comprised only 0.5% of the study area. The use of all slope categories except 41-60% by boreal toads was significantly out of proportion to availability in the Urad drainage (0-20%, P<0.003; 21-40%, P<0.04; 41-60%, P<0.47; 61-80%, P<0.00).   This analysis using the entire drainage included more high gradient slope areas (the area was delineated by timberline) which were not used by telemetered toads and therefore not in individual toad's home ranges (Figure 3.). As a result, I feel that the slope analysis on a site-specific basis is more meaningful.

Figure 3. Use of various slope categories in 1998 by boreal toads using the entire Urad valley as available habitat

Of the 136 toad locations in the Donut study area (300 m buffer), 68.4% were on 0-20% slopes (23.2% of total study area), 26.5% were on 21-40% slopes (16.2% of total), 5.2% were on 41-60% slopes (29.7% of total), and 0.0% were on 61-80% slopes (40.0% of total). There were no slopes greater than 80% in the Donut study area**.** Of the 197 toad locations recorded in the Hesbo study area (300 m buffer) in 1998, 14.7% were on 0-20% slopes (10.7% of total study area), 23.4% were on 21-40% slopes (20.8% of total), 28.9% were on 41-60% slopes (32.1% of total), and 32.9% were found on 61-80% slopes (36.4% of total). No toad locations were recorded on slopes >80%; slopes of this magnitude comprised only 0.01% of the study area. Of the 55 toad locations in the Urad study area, 21.8% were on 0-20% slopes (15.7% of total study area), 16.4% were on 21-40% slopes (19.5% of total), 41.8% were on 41-60% slopes (36.5% of total), and 20.0% were on 61-80% slopes (28.4% of total). There were no slopes greater than 80% in the Urad study area**.** When slope data was analyzed on a site-specific basis, boreal toads generally used slopes in proportion to their availability. The only exceptions were 0-20% slopes were used more than expected ($P<0.00$) and 40-60% slopes were used less than expected ($P<0.02$), based on availability at the Donut site.

The primary objective of this analysis was to show that slope is not a deterrent to toad movement and that boreal toads commonly frequent upland habitats not associated with the relatively flat wetland areas. The use of upland habitats by boreal toads tends to vary depending on the availability of wetland areas in close proximity to the breeding site (loeffler [ed.] 1998). This can be seen in Figure 4 which shows upland habitats being used extensively after breeding in the Hesbo study area; this site has little wetland areas surrounding the breeding site. In contrast, Figure 5 shows toads in the Donut study area using lower gradient slopes which contain ponds and wetlands relatively close to the breeding site. The Upper Urad study site (Figure 6) contains both wetlands around the breeding site and numerous springs in the upland areas. Bartelt and Peterson (1994) conducted similar radio telemetry studies on the Targhee National Forest in which they quantified use of various habitat components. They found that boreal toads occupied terrestrial habitats 90 percent of the time and their daily movements were significantly influenced by the distribution of suitable cover (usually shrubs). As pointed out by Dodd (1996), these types of data may be helpful in directing attention to the importance of upland habitats in the conservation of amphibian populations which depend upon isolated wetlands for breeding.

Figure 4. Use of various slope categories in 1998 by boreal toads using a 300 m buffer around the pooled locations in the Hesbo study area as available habitat.

Figure 5. Use of various slope categories in 1998 by boreal toads using a 300 m buffer around the pooled locations in the Donut study area as available habitat.

Figure 6. Use of various slope categories in 1998 by boreal toads using a 300 m buffer around the pooled locations in the Urad study area as available habitat.

The habitat areas were defined as conifer/aspen, river, spring seep, lake (lentic water), road, and rock. For the combined study areas (N=388), conifer/aspen contained 10.3% of the toad locations and represented 54.2% of the available habitat showing avoidance of this habitat ($P<0.00$). The spring seep category contained 3.1% of the toad locations and represented 0.4% of the available habitat; this use was not significantly out of proportion with availability. The lake category had 11.1% of the locations and represented 2.2% of the habitat, showing significant selection ($P<0.01$). Areas defined as road contained 2.1% of the locations and represented

2.0% of the habitat and therefore were used randomly. Rocky areas were selected for (P<0.00) since they contained 73.5% of the locations and only represented 41.2% of the habitat (Figure 7).

Figure 7. Use of habitat categories in 1998 by boreal toads using the entire Urad valley as available habitat.

Habitat use in each study area was then analyzed separately by defining the available habitat as everything within a 300 m buffer drawn around the pooled toad locations for each site. For the Hesbo study area (N=197), the conifer/aspen category contained 7.1% of the toad locations and represented 65.2% of the available habitat showing avoidance of this habitat (P<0.00). The spring seep category contained 3.1% of the toad locations and represented 1.5% of the available habitat; this use was not significantly out of proportion with availability. The lake category had 17.3% of the locations and represented 5.5% of the habitat, showing significant selection (P<0.03). Areas defined as road contained 2.0% of the locations and represented 2.5% of the habitat and therefore this category was used randomly. Rocky areas were selected for (P<0.00) since they contained 70.6% of the locations and only represented 24.9% of the habitat (Figure 8). It should be noted, however, that the majority of the rocky areas in the Hesbo study site were actually rock outcroppings within the upland conifer/aspen habitat type.

Figure 8. Use of habitat categories in 1998 by boreal toads using a 300 m buffer around the pooled locations in the Hesbo study area as available habitat.

For the Donut study area (N=136), the conifer/aspen category contained 17.7% of the toad locations and represented 43.9% of the available habitat showing avoidance of this habitat ($P<0.00$). The spring seep category contained 4.4% of the toad locations and represented 0.1% of the available habitat; this use was not significantly out of proportion with availability. The lake category had 6.2% of the locations and represented 2.9% of the habitat and therefore was used randomly. Areas defined as road contained 2.9% of the locations and represented 4.2% of the habitat and therefore this category was used in proportion to availability. Rocky areas were selected for ($P<0.01$) since they contained 68.4% of the locations and only represented 48.8% of the habitat (Figure 9).

Figure 9. Use of habitat categories in 1998 by boreal toads using a 300 m buffer around the pooled locations in the Donut study area as available habitat.

The only habitat categories which were used in the Urad study area were aspen/conifer and rocky areas, although all other habitat types were present. The conifer/aspen category contained 3.6% of the toad locations but represented 60.5% of available habitat, showing significant (P<0.00) under-utilization of this habitat. Rocky areas contained 96.4% of the total toad locations but only represented 34.1% of the available habitat showing significant (P<0.00) selection for these areas (Figure 10). It should be noted that rocky areas in the Upper Urad study were found both around the breeding site and as rock outcroppings in upland aspen/conifer areas.

Our data shows that the toads do indeed use a wide variety of habitat types and that there was high variability between individuals in habitat selection. The activity and subsequent use of habitats by ectotherms is closely tied to their body temperatures (Huey 1991) which may explain the disproportionately high use of rocky areas. Toads were commonly found basking in rocky areas, but they were always within a couple of meters of a burrow or vegetative shelter.

Figure 10. Use of habitat categories in 1998 by boreal toads using a 300 m buffer around the pooled locations in the Urad study area as available habitat.

Movement was calculated for each toad weekly on a 3 m^2 digital elevation model in ARC/INFO as previously described. Three hundred thirty four individual weekly movement measurements were calculated for 33 toads. The average distance moved per day for all telemetered toads was 8.9 m (SD=135.0). Male toads moved an average of 14.1 m per day (SD=67.1, N=11) and females moved an average of 6.3 m per day (SD=14.3, N=22). There was much greater variability between male average daily movement increments than female, Figure 11. The minimum average distance moved per day was 0.06 m by a female, which was tracked for 90 days, and the maximum average daily movement was 767.0 m by a male monitored for a total of 70 days. The maximum distance traveled by any telemetered toad during the summer of 1998 was 1,397.6 m by a female monitored 112 days. Due to individual heterogeneity, it could not be shown that daily movement by female boreal toads was significantly different than males (Z=-0.4874, P=0.626).

Boreal toad movement patterns are highly variable between individuals. Female toads which we radio tagged at a breeding site left the location immediately after egg deposition and generally moved further away from the breeding site quicker than did males. Again habitat use heterogeneity among females was observed with some finding suitable summer locations within 400 to 600 m from the breeding wetland while other individuals moved further into upland habitats.

Figure 11. Comparison of male and female boreal toad daily movement increments (male=113, female=205) at the Henderson/Urad study site in 1998.

Home Range Estimates

As with movement, there were major differences (heterogeneity) between individual toad home range sizes. As expected, the adaptive kernel method (AK) provides larger estimates than minimum convex polygon (MCP). We can probably assume that we are missing movements when we only locate individuals once per week. Therefore, I feel that the AK method is probably more useful in terms of recommending construction setbacks or designating critical habitat. The mean home range area in 1998 for telemetered boreal toads in the Henderson population was 46,185 m^2 (min.=1,893, max.=474,000, SD=121,710) using the AK method and 23,894 m^2 (min.= 461, max.=240,700, SD=56,960) with the MCP (Table 2). The mean area used by males was 72,869 m^2 using the AK method and 37,122 m^2 using the MCP approach. The mean area used by females was 34,325 m^2 using the AK method and 18,015 m^2 using the MCP approach (Figure 12). The mean home range area excluding the breeding site 43,558 m^2 (min.=379, max.=474,100, SD=124,847) using the AK method and 22,806 m^2 (min.= 101, max.=240,700, SD=58,413) with the MCP. The mean area used by males was 70,296 m^2 using the AK method and 36,131 m^2 using the MCP approach. The mean area used by females was 31,675 m^2 using the AK method and 16,884 m^2 using the MCP approach. Cumulative home range estimates were also calculated for all telemetered toads at each site for 1997 and 1998 (Table 3).

Although home range size was not significantly different between sexes using either method at α=0.05 (Z=-1.61, P=0.11 for AK; Z=-2.06, P=0.08 for MCP) as a result of high variability, I feel that the are some general tendencies which warrant discussion. In general, females move further from the breeding site after breeding (possibly because they do not return to breed each year) and set up a fairly discreet home range. In general, males don't go as far from their breeding site (possibly because they return each year) but may move around quite a bit, which increases their home range size. Males often return to the breeding site or other wetland in the vicinity several times during the summer and then return to upland habitats. Females seem to be more inclined to take up residence in an upland area which contains a spring or wet area and seldom return to the breeding area during the summer. The same toads (both sexes) were observed repeatedly in different areas in the same burrows or general areas they were previously recorded at, ie. the toads would move to a different area 10 to 50 meters away and then return to the same exact place a week or two later. Other authors have also noted distinct home range areas in anuran populations (Brattstrom 1962; Campbell 1976; Parker and Gittins 1979; Bartelt and Peterson 1994). Plots of the calculated home ranges for each toad may be found in appendix 2.

Table 2. Home range estimates for radio telemetered toads in the Henderson Mine area in 1998.

Year	Site	Tag Number	Sex	Locations	Adaptive Kernel (m^2)	Minimum Convex Polygon (m^2)	LSCV Score
1998	Donut	386	F	13	8158	10730	-638500
1998	Urad	476	F	14	10310.00	3829.00	-25209.00
1998	Urad	487	F	8	3629	554	-3344.6
1998	Urad	490	F	11	10460	1768	-20998
1998	Hesbo	572	F	22	2473.00	620.70	-108980.00
1998	Hesbo	574	F	23	15500.00	8916.00	-1069300.00
1998	Hesbo	576	F	10	7826.00	1383.00	-227720.00
1998	Hesbo	577	F	11	11990.00	7444.00	-832840.00
1998	Urad	578	F	12	10160.00	15450.00	-975960.00
1998	Hesbo	579	F	22	4384.00	460.80	-342640.00
1998	Hesbo	580	F	20	12460.00	6659.00	-292150.00
1998	Hesbo	581	F	10	14130.00	9275.00	-2696300.00
1998	Hesbo	582	F	8	7533.00	8068.00	-302510.00
1998	Hesbo	583	F	19	11140.00	3593.00	-378940.00
1998	Donut/Urad	588	F	17	474100.00	240700.00	-43008500.00
1998	Donut	590	F	7	2387.00	802.00	-2077.40
1998	Hesbo	771	F	6	4988.00	828.90	-16287.00
1998	Hesbo	773	F	10	6229.00	3182.00	-45520.00
1998	Donut	350	M	15	2628	630.7	-5244.8
1998	Hesbo	471	M	10	1893.00	538.60	-588.54
1998	Hesbo	482	M	14	31070	35190	-1940500
1998	Donut	585	M	18	36310.00	28400.00	-11331000.00
1998	Hesbo/Donut	587	M	11	459500.00	195000.00	-10066000.00
1998	Donut	589	M	18	20040.00	13560.00	-303660.00
1998	Donut	592	M	18	19350.00	12420.00	-1792100.00
1998	Donut	919	M	17	12160.00	11240.00	-1141300.00
Mean Home Range					46184.92	23893.95	
Mean Male					72868.88	37122.41	
Mean Female					34325.39	18014.63	

Table 3. Cumulative boreal toad home range estimates by site from the Henderson study area.

Year	Site	Tag Number	Sex	Locations	Adaptive Kernel (m^2)	Minimum Convex Polygon (m^2)	LSCV Score
1998	Hesbo	all* from hesbo	all	185	128700	98360	-16099000
1998	Donut	all	all	84	78750	25230	-1413800
1998	Upper Urad	all	all	43	62660	34570	-378510
1997	Hesbo	all	all	114	71940	44570	-18203000
1997	Donut/Ann's Pond	915 and 919		23	32350	15000	-626370
Mean					74880	43546	

* Excludes toad 587

Figure 12. Comparison of home range sizes for male and female telemetered toads at the Henderson Mine in 1998.

Breeding Site Population Estimates

UPDATED***

Boreal toads at theUrad/Hendersonbreeding sites were PIT tagged during 1995 to 1999 breeding site monitoring activities. Monitoring begins in mid-May and continues until no new individuals are found at each site. Males typically persist at the breeding site for several weeks after breeding activity ceases. As stated in methods, the program Capture (White et al. 1982) was used to estimate the number of males at each site for each year monitored.

Listed below is a brief description of each possible model selection, see White et al. 1982 for complete descriptions.

Model M_o : Population estimation with constant probability of capture.

Model M_h : Population estimation with variable probability of capture by animal.

Model M_b : Population estimation with behavioral response to capture.

Model M_{bh} : Population estimation with behavioral response and heterogeneity.

Model M_t : Population estimation with time specific changes in probability of capture.

Model M_{th} : Population estimate under time variation and individual heterogeneity in capture probabilities.

Model M_{tb} : Population estimation under time variation and behavioral response to capture.

Model M_{tbh} : Population estimate under time variation, behavioral response, and heterogeneity.

Table 3. Population estimates for male boreal toads at the breeding sites in the Urad/Henderson area from 1995 to 1999.

Site	Year	Model	Estimate	SE	95% CI
Hesbo	1995	M_{bh}	141	1.57	141 to 148
Hesbo	1996	M_b	119	4.79	114 to 134
Hesbo	1997	M_t	120	2.52	117 to 127
Hesbo	1998	M_t	120	2.73	117 to 128
Hesbo	1999	M_t	94	3.55	90 to 104
2 Pond	1995	M_t	32	0.95	32 to 36
2 Pond	1996	M_o	6	0.91	4 to 8
Power Alley	1996	M_{th}	61	6.72	54 to 82
Power Alley	1997	M_{tb}	80	5.10	80 to 113
Power Alley	1998	M_{tb}	80	0.66	80 to 80
Power Alley	1999	M_t	53	4.22	49 to 66
Upper Urad	1996	M_{tb}	41	0.26	40 to 41
Upper Urad	1997	M_o	34	7.59	27 to 59
Upper Urad	1998	M_h	29	5.27	23 to 44
Donut	1997	M_{th}	19	4.32	16 to 37
Donut	1998	M_t	44	6.29	37 to 63
Donut	1999	M_t	15	2.19	14 to 24
Anne's Pond	1998	M_b	33	0.44	33 to 33
Anne's Pond	1999	M_t	26	1.79	25 to 33

In all cases, the estimate derived from the Capture model (Table 3.) was nearly the same as the total number handled at each site indicating we had PIT tagged and handled close to the entire breeding population of males each year at each site. Based on the 1996 estimates, the male breeding population in the Henderson/Urad metapopulation was approximately 227, 233 in 1997, 306 in 1998, and 188 in 1999. There was not enough tags implanted at all sites to calculate estimates, especially in 1998 when breeding occurred at a small scale at several new locations. This type of work is critical in defining what is natural fluctuation in breeding numbers over time due to dominant year classes and identifying declines due to other causes such as disease.

OK to HERE*****

Female Returns

As stated earlier, the number of female boreal toads in the Henderson/Urad area is difficult to estimate because they were never recaptured again in the same year, and only rarely in subsequent years. **Table____** lists all females which returned to breed from 1995 to 1999. During this time we pit tagged a total of 86 unique females and had 10 returns. This is fairly conclusive evidence that it is unusual for females to breed in consecutive years, although it does occur. Six hundred nineteen unique males were tagged during this same time period .

Other evidence which indicates that females generally don't breed every year is breeding site sex ratios. Our data and work conducted by Campbell in 1976 indicate that male:female capture rates during breeding are skewed toward male dominance, even though sex ratios observed after breeding approximate 50:50. From 1995 to 1999 a total of 92 individual females (all years and all sites combined) were handled in comparison to 221 males in 1995, 223 males in 1996, 209 males in 1997, 306 males in 1998, and 177 males in 1999 (all sites combined). The yearly male:female sex ratios were 20:1 in 1995, 32:1 in 1996, 10:1 in 1997, 8:1 in 1998, and 9:1 in 1999. More research needs to be conducted on the biology, physiology, and population dynamics of female boreal toads as this information may be a key link in recovery efforts. Trends in population size and breeding success at all known boreal toad breeding sites is being monitored on an ongoing basis. It is obvious that not all sites recruit every year and this fluctuation is natural. In most cases, individual breeding sites recruit in one out of three years at best. Females may also show the high degree of breeding site fidelity exhibited by males **(Jones et al 1998)** as only one female returned to a different site than originally tagged even though they routinely traveled the length of the Urad valley as documented by our radio tracking activities.

Table ?????. Returns of PIT tagged female boreal toads from 1995 to 1999 at the Henderson Mine study area.

Tag Number	Site(s)	Year	SV length (mm)	Weight (g)
17325635	Hesbo	1996	85.00	43
	Hesbo	1997	78.83	52
17579122	Annes Pond	1996	85.00	79
	Annes Pond	1998	83.91	82
28365802	Hesbo	1998	70.86	45
	Hesbo	1999	76.52	55
11098104	Hesbo	1995	85.00	75
	Hesbo	1996	75.00	65
11360034	Annes Pond	1998	78.97	71
	Annes Pond	1999	76.41	68
14893850	Hesbo	1997	75.60	49
	Hesbo	1998	76.46	54
15585598	Hesbo	1996	87.00	72
	Hesbo	1999	85.00	65
16298110	Hesbo	1997	77.91	65
	Hesbo	1999	79.60	81
16576774	Donut	1996	80.00	64
	Upper Urad	1997	82.90	67
15520298	Power Alley	1995	70.00	40
	Power Alley	1997	75.41	41

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APPENDIX 1. Boreal toad radio telemetry contact locations in the Henderson/Urad study area, 1998.

35 pages of maps

APPENDIX 2. Home range estimates for boreal toads in the Henderson/Urad study area, 1998.

Predator communities and boreal toad breeding sites

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Abstract—I studied aquatic predators of tadpoles in 25 montane ponds along the Front Range of Colorado, including six ponds with current or historical records of breeding by boreal toads (*Bufo boreas*). Pond temperatures were positively correlated both with diversity of animals and with expected impact from predators of tadpole. Ponds used as boreal toad breeding sites had significantly fewer predaceous diving beetles (*Dytiscus* sp.) and tiger salamanders (*Ambystoma tigrinum*) than ponds without records of boreal toad reproduction. These findings suggest that successful boreal toad reproduction depends on sites that are sufficiently warm but that do not include abundant populations of important predators of tadpoles.

Introduction

Within the past 20 years, boreal toads (*Bufo boreas*) have undergone unexplained population declines in distribution and abundance in Colorado (Corn et al., 1989; Carey, 1993). Because of these declines, the Colorado Division of Wildlife listed this species as endangered in 1993 (Goettl, 1997). Surveys in 1994-1995 along the Front Range of Colorado documented boreal toads at sites that range in elevation from 2390 m to 3640 m, a range similar to the historical elevational range (Livo and Yackley, 1997). In contrast, the current elevational range of breeding sites (2840 to 3280 m) may be somewhat contracted relative to the historical elevational range of breeding sites (2630 to 3350 m) (Livo and Yackley, 1997).

Boreal toad distribution was recently studied in Rocky Mountain National Park, Colorado (Corn et al., 1997). For sites occupied by at least one amphibian species, they found no significant differences between sites occupied by toads versus sites not occupied by toads in terms of physical habitat parameters, including elevation, pond pH, pond area, and pond structural and vegetational characteristics. These findings suggest that one or more biotic factors, such as the presence of particular predators, may be important in shaping the current distribution of occupied boreal toad sites. Although predation on eggs, tadpoles, or metamorphosed toads has not been suggested as a direct cause of population declines in this species in Colorado, with the reduced abundance of boreal toads, natural predation events now may be a threat to small remanent populations (Corn, 1993).

My surveys and others conducted by the Colorado Division of Wildlife of boreal toad breeding sites frequently revealed sharp declines in boreal toad tadpole numbers prior to metamorphosis. Because of noxious compounds in the skin, tadpoles in the genus *Bufo* are generally regarded as unpalatable to many predators (Voris and Bacon, 1966; Kruse and Stone, 1984; Hews and Blaustein, 1985; Peterson and Blaustein, 1991). However, in laboratory trials, several aquatic predators consumed boreal toad tadpoles: predaceous diving beetle larvae (*Dytiscus* sp.), various adult diving beetles (*Dytiscus dauricus*, *Agabus tristis*, *Rhantus binotatus*, and *Graphoderus occidentalis*), medium and large dragonfly larvae (family Aeshnidae), and tiger salamander larvae (*Ambystoma tigrinum*) (Livo, 1998; Jones et al., in press). Backswimmers (Notonectidae) were noted as predators of boreal toad tadpoles in the Pacific Northwest (Kiesecker et al., 1996).

Two aquatic predators, *Dytiscus* sp. and *Ambystoma tigrinum*, are of particular interest. In laboratory experiments, boreal toad tadpoles were significantly more vulnerable to predation by *Dytiscus* larvae than were chorus frog (*Pseudacris triseriata*) tadpoles, a hylid anuran broadly sympatric with *Bufo boreas* in the southern Rocky Mountains but which shows little evidence of population declines (Livo, 1998; Corn et al., 1989; Corn et al., 1997). Similarly, *Bufo boreas* tadpoles were significantly more vulnerable to predation by *Dytiscus* larvae than tadpoles of another hylid anuran, *Pseudacris regilla* (Peterson and Blaustein, 1992). *Dytiscus* larvae consume boreal toad tadpoles at several boreal toad breeding sites (pers. obs.), and *Bufo boreas* tadpoles reared in sections of pools with greater densities of *Dytiscus* larvae metamorphose at smaller body sizes than do tadpoles in sections of pools with reduced densities of *Dytiscus* larvae (Livo, unpublished data).

The second predator, *Ambystoma tigrinum* larvae, readily consumes *Bufo boreas* tadpoles in a laboratory setting and its geographic range overlaps broadly with that of *Bufo boreas* (Livo, 1998). There are historical records of *Ambystoma tigrinum* larvae present at the same site as *Bufo boreas* larvae. However, within the past 10 years, there have been no reports in Colorado of these two species reproducing in the same pond at the same time despite the broad overlap of their geographic ranges, lack of evidence of decline of *Ambystoma tigrinum*, and regular surveys of *Bufo boreas* breeding sites (Corn et al., 1989; Corn et al., 1997) (Colorado Division of Wildlife, unpublished data).

Boreal toad tadpoles must reach metamorphosis in a single season and do not overwinter as tadpoles (Fetkavich and Livo, 1998). Consequently, the thermal environment probably excludes successful reproduction by boreal toads at cold ponds. Cold pond temperatures are also expected to limit occupation by predators of boreal toad tadpoles.

If temperature and predator gradients have a role in determining which ponds can be occupied successfully by boreal toads, then there may be detectable differences between ponds currently occupied by boreal toads and those not occupied by boreal toads. In particular, all other things being equal, sites with current boreal toad populations may contain lower densities of important tadpole predators compared to sites that lack boreal toads.

The purpose of this study was to test the hypothesis that, within the elevational range occupied by boreal toads, there is a predator gradient associated with pond temperatures, and further, that successful boreal toad reproduction is excluded both from ponds that are too cold as well as from ponds with high potential impact from aquatic predators. If trapping data and selected physical parameters from a series of montane ponds can be used to discriminate between ponds used as breeding sites by boreal toads and those without records of breeding, logistic regression procedures may also serve to identify ponds that could be considered for use as boreal toad restoration sites.

Methods

Between 25 June and 31 August 1998, I sampled aquatic predator communities in 26 montane ponds in Boulder, Clear Creek, Gilpin, and Larimer counties, Colorado (Figure 1). Ponds ranged in elevation between 2450 and 3180 m. Each pond was sampled twice, first in late June or July, and a second time in August. Geographically proximate ponds were grouped together and sampled on the same dates. Sampling dates for proximate groups of ponds were randomly assigned. Results were pooled for the two sampling periods. One shallow pond was discarded from the analysis because a strong wind on the second sampling date blew several of the traps out of the water.

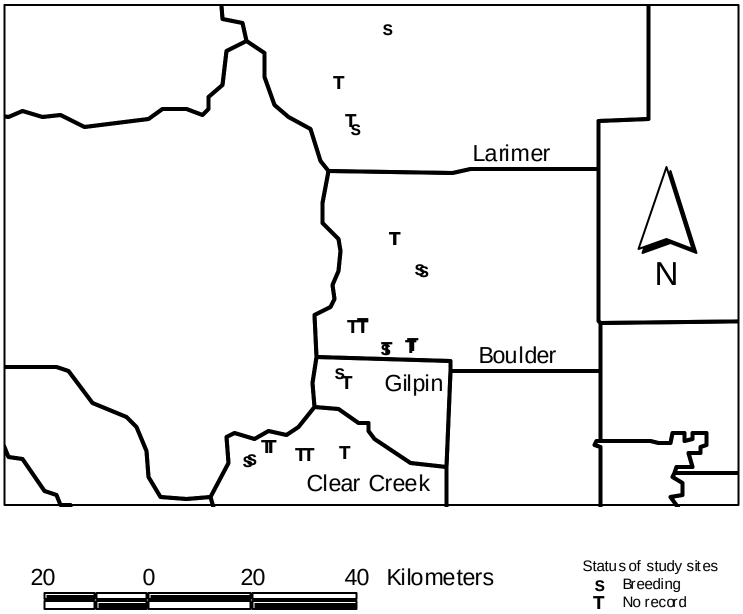

Figure 1. Study sites; circles represent *Bufo boreas* breeding sites and triangles represent sites with no record of *Bufo boreas* breeding.

For each sample, I placed eight aquatic traps around the perimeter of the pond. The traps were Ranger Products 25 x 25 x 43-cm collapsible funnel traps with 3-cm openings and 1.6-mm mesh. To minimize trap mortality, I positioned each trap so that the openings were submerged but at least part of the upper surface of the trap was above water. Unbaited traps remained in place for 24 hours to collect both diurnal and nocturnal animals. I made the following assumptions regarding the trapping: 1) traps sampled non-overlapping areas of a pond, 2) organisms already present in the traps had no effect on the likelihood that subsequent organisms would enter the trap, 3) organisms small enough to escape through the trap mesh are not important tadpole predators, and 4) the trap openings were sufficiently large to allow passage of the largest of aquatic tadpole predators. A Stowaway Boxcar® temperature logger collected temperature data at 15-minute intervals; these data were used to calculate mean pond temperature for the 24 hour period.

I used U.S. Geological Survey 1:24,000 topographic maps to determine pond elevations; measurements in English units were converted to metric prior to use in the analysis. I estimated pond length and width with a rangefinder; for ponds with one or more axis >75 m, I measured pond length and width from a USGS 1:24,000 topographic map. Pond perimeter was calculated as an elipse with the length and width estimating the major and minor axes.

Trap contents were emptied into plastic containers for sorting. I identified trap contents at least to family level. Vertebrates caught in the traps were measured and released. Coleoptera larvae and adults were preserved in the field in alcohol as were selected voucher specimens of other invertebrate taxa. Specimens were deposited in the C. P. Gillette Museum of Arthropod Diversity, Colorado State University, Ft. Collins, Colorado.

I estimated diversity at the family level for each pond using the Shannon-Wiener diversity index (Smith, 1974), but excluded any trapped *Bufo boreas* tadpoles from these calculations. Previous laboratory trials indicated that different predator groups differed in their likely impact on boreal toad tadpole populations (Livo, 1998; Jones et al., in press). To obtain an estimate of the potential effect of predators in a pond, I tallied predators by group (such as *Dytiscus* larvae, Notonectidae, and so on), then multiplied these numbers by a daily consumption rate factor for that group (Table 1). This variable was termed “predator impact.” Except for notonectids, I based consumption rates on the mean number of tadpoles consumed per predator per day from laboratory trials (Livo, 1998; Livo, unpubl. data). Notonectid consumption rates were estimated from another study (Cronin and Travis, 1986). All other animals (excluding *Bufo boreas* tadpoles) in the traps were tallied as non-predators.

Table 1. Estimated daily rates of consumption of *Bufo boreas* tadpoles by selected predators.

Predator group	**Estimated consumption rates**
Dytiscus larvae	6.4
Dytiscid (non-*Dytiscus*) larvae	0.25
Small adult Coleoptera	0.25
Medium and large adult Coleoptera	0.5
Anisoptera larvae	4.0
Notonectidae	3.7
Ambystoma tigrinum	6.3

I used the SAS logistic regression procedure to discriminate between two classes of ponds: those with current or historical records of breeding by boreal toads, and those with no such record.

Results

The five variables used in the logistic regression procedure were elevation in meters (mean = 2779 ± S.E. 41 m, *n* = 25), mean pond temperature (mean = 15.3 C ± S.E. 0.6 C, *n* = 25), diversity (mean = 22 ± S.E. 3, *n* = 25), total number of *Dytiscus* sp. (mean = 6.4 ± 2.1, *n* = 25), and total number of *Ambystoma tigrinum* (mean = 7.6 ± 4.0, *n* = 25).

Compared to other logistic regression analyses with different and/or more variables, this analysis produced among the best categorization of sites with among the lowest scores for the Akaike's Information Criterion (AIC = 29.554 for Intercept Only, = 21.718 for Intercept and Covariates). Using these variables, the logistic regression procedure correctly classified 23 of the 25 ponds (92 percent). One of six “breeding” sites was incorrectly classified as a “no record” site, whereas one of 19 “no record” sites was classified as a “breeding” site. In *t*-tests comparing the variables used in the logistic regression procedure, only elevation differed significantly between ponds with boreal toad breeding and those without records of breeding (Table 2). Figure 2 illustrates the distribution of predicted probabilities that specific ponds are boreal toad breeding sites versus those predicted to have no record of boreal toad breeding.

Table 2. Variable means, associated Chi Square values, and comparison between boreal toad breeding sites and sites without record of boreal toad breeding.

Predictor	Parameter estimate (± SE)	$\chi 2$	Breeding (means, n = 19) (±SE)	Non-breeding (means, n = 6) (±SE)	*t*
Dytiscus	-0.18 ± 0.20	0.5	4.67 ± 2.12	6.95 ± 2.64	0.46
Ambystoma tigrinum	-0.11 ± 0.15	0.49	0.50 ± 0.50	9.79 ± 5.20	1.78
Mean temperature	1.79 ± 2.84	2.85	17.13 ± 0.60	14.75 ± 0.78	-1.64
Elevation	0.01 ± 0.01	3.23	2930 ± 84	2731 ± 42	-2.26*
Diversity	-0.047 ± 0.09	0.27	24.6 ± 5.3	21.2 ± 3.87	-0.44
Overall model $\chi 2 = 17.836$, df = 5, $p < 0.01$ * $p < 0.05$					

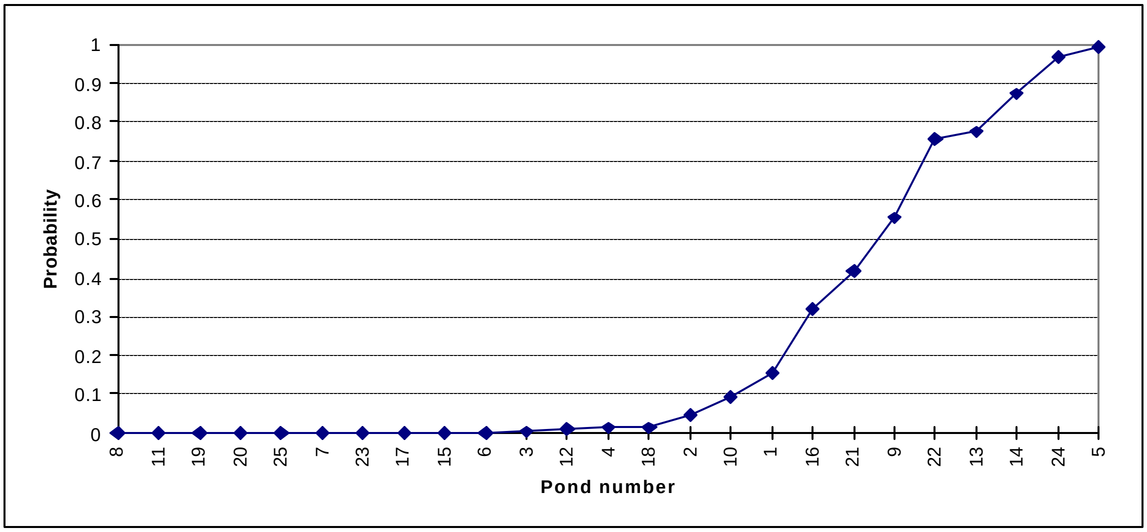

Figure 2. Distribution of predicted probabilities for pond status (ponds with a probability score > 0.5 are expected to be boreal toad breeding sites, whereas ponds with a probability score < 0.5 are expected to have no record of boreal toad breeding. Pond numbers are displayed along the x-axis.

There was a highly significant correlation betwen mean pond temperature and total diversity ($r = 0.641$, $p < 0.001$, df $= 23$). However, there were no significant correlations among other variables used in the logistic regression (Table 3).

Although predator impact scores were not used in the logistic regression, there was a significant correlation between mean pond temperature and predator impact score ($r = 0.464$, $p < 0.05$, df = 23). With respect to correlations between pond perimeter and tallies of individual predators, only the number of odonate larvae was significantly correlated ($r = 0.477$, $p < 0.05$, df = 23), although correlations approached significance for the tally of large Coleoptera ($r = 0.392$, $p = 0.053$, df = 23) and Notonectids ($r = 0.390$, $p = 0.055$, df = 23).

Excluding the six coldest ponds (all with mean pond temperatures < 14.5 C), I compared the total number of individuals of *Dytiscus* sp. plus *Ambystoma tigrinum* in *Bufo boreas* breeding ponds versus those ponds with no record of breeding. In this comparison, *Bufo boreas* breeding ponds had significantly fewer of these predators (mean total in breeding ponds = 5.167 ± 4.792 S.E., mean total in non-breeding ponds = 24.462 ± 25.644 S.E., $t = 2.616$, $df = 17$, $p < 0.05$) (Figure 3). However, there was no significant difference between boreal toad breeding ponds and ponds without record of boreal toad breeding when these ponds were compared with the generalized predator impact scores (mean predator impact score for breeding ponds = 82.69 ± 124.38 S.E., mean predator impact score in non-breeding ponds = 168.87 ± 168.87 S.E., $t = 0.763$, $df = 17$, $p > 0.05$).

Table 3. Correlation matrix for variables used in logistic regression (probabilities in parentheses).

	Mean pond temperature	Elevation (m)	Number of *Dytiscus* sp.	Number of *Ambystoma tigrinum*	Total diversity

Mean pond temperature	1.00	00.12 (0.580)	0.365 (0.072)	0.108 (0.609)	0.641*** (0.0006)
Elevation (m)		1.00	-0.011 (0.958)	-0.093 (0.659)	-0.345 (0.091)
Number of *Dytiscus* sp.			1.00	-0.114 (0.586)	0.179 (0.392)
Number of *Ambystoma tigrinum*				1.00	0.192 (0.358)
Total diversity					1.00
***p < 0.001					

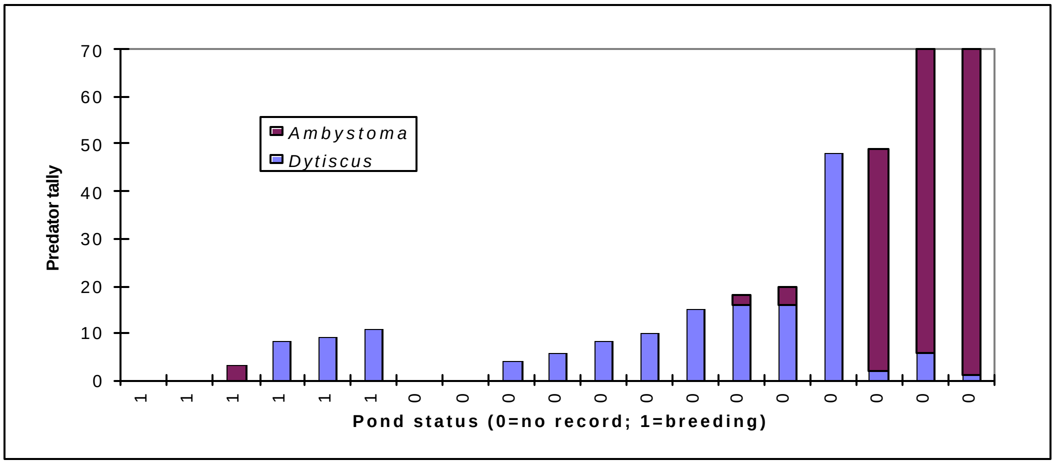

Figure 3. Comparison of total numbers of *Ambystoma tigrinum* and *Dystiscus* larvae and adults in boreal toad breeding ponds (pond status = 1) and ponds with no record of boreal toad breeding (pond status = 0).

Discussion

Although predation has not been suggested as a cause of the widespread geographic decline in boreal toad populations, the results of this study indicate that predator communities do play a role in shaping the distribution of breeding sites for boreal toads. The logistic regression procedure served to successfully discriminate between most ponds considered boreal toad breeding sites and ponds without record of breeding by boreal toads. With respect to the abundance of *Dytiscus* sp. and *Ambystoma tigrinum*, when cold ponds were excluded, ponds with current or historical records of breeding by boreal toad had significantly lower scores for these predators than ponds that lacked current records.

Some caution is necessary in interpreting the results of this study because of uncertainty with the historic record. There were insufficient sites to have a third category comprised entirely of historical sites, so these sites were grouped with sites having current breeding reports. Because boreal toad populations have declined, some ponds identified in this study as having no record of boreal toad breeding may have been used in the past by toads. Tadpoles tend to be difficult to identify to species, and there was little pressure for biologists in past decades to make comprehensive notes concerning the presence or identity of tadpoles at various sites. Consequently, the distribution of ponds used as breeding sites by boreal toads is certainly underrepresented compared to the distribution of adult toads as documented through both museum specimens and literature reports. Further, other ponds identified as having record of occupation by boreal toads in the past may now have altered thermal or biotic characteristics. Finally, at least two of the ponds currently used as breeding sites by boreal toads are of recent anthropogenic origin, so predator populations may be artifically low at these sites.

Tadpole vulnerability to predation is not constant through time, and at large body sizes, tadpoles may escape predation by some gape-limited predators such as notonectids. However, larger tadpoles may represent preferred prey items by other predators such as birds, which were not considered in this analysis. Further, some predators may persist in a pond for relatively short periods of time, whereas others are present throughout the time tadpoles are present.

Predator abundances noted for boreal toad breeding sites in this study may actually represent the higher end of the spectrum. Boreal toads in Colorado often select temporary pools and other ephemeral sites in which to breed, and these sites may have especially low predator abundances. However, the traps used in this study require a minimum pond depth of approximately 18 cm, resulting in the exclusion from this study of several small, shallow pools used as breeding sites by boreal toads.

Finally, the results of this study may enhance the ability of wildlife mangers to assess a series of potential restoration sites and identify those with the highest probability of successful survival of tadpoles. The logistic regression procedure identified a pond (Bald Mountain Spring, pond 14) without record of boreal toad breeding as a predicted breeding site. Compared to the other ponds without boreal toad breeding records, this pond might represent a suitable restoration site for boreal toads, although other features of the local environment must be considered (e.g., hibernacula may not be available, predators of metamorphosed toads may be limiting, and so on). Aquatic trapping programs such as those conducted for this study could be implemented in areas being considered for restoration efforts, such as Grand Mesa in western Colorado. Most habitat evaluations associated with reintroduction efforts concentrate on features important to the survival of adult animals. Adult survival obviously remains an important consideration. However, this study emphasizes the need to consider habitats from the tadpoles' point of view, because any successful reestablishment of a species requires adequate survival of all stages in its life history.

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