1989/0081 NERC

Biological Report 80(40.26)
June 1989
Air Pollution and Acid Rain
Report No. 26

ACID PRECIPITATION STUDIES IN COLORADO AND WYOMING: INTERIM REPORT OF SURVEYS OF MONTANE AMPHIBIANS AND WATER CHEMISTRY

by

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Conducted in cooperation with:

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National Park Service
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Washington, DC 20240

Disclaimer

This research has been funded by the Fish and Wildlife Service as part of the National Acid Precipitation Assessment Program (NAPAP), and was subjected to NAPAP peer review in 1987. Funding was also supplied by the U.S. Forest Service (interagency agreement IAG-RM-6-97) and by the National Park Service. This report has not been submitted to these agencies peer or policy review, and therefore may not reflect the views of the Forest Service or National Park Service. Trade names are mentioned for information only. Such use does not constitute endorsement or recommendation by the Fish and Wildlife Service or the Federal Government.

Suggested citation:

Corn, P.S., W. Stolzenburg, and R.B. Bury. 1989. Acid precipitation studies in Colorado and Wyoming: interim report of surveys of montane amphibians and water chemistry. U.S. Fish Wildl. Serv. Biol. Rep. 80(40.26). 56 pp.

PREFACE

This project had its genesis in the late 1970's, when the senior author observed the extinction of several populations of leopard frogs in the mountains of Colorado. At the same time nearby, a well-studied population of chorus frogs had apparently suffered a precipitous decline, and anecdotal accounts suggested other amphibians in the mountains might be declining. In the early 1980's, William Lewis and Michael Grant of the University of Colorado observed declining pH in precipitation in the Front Range of Colorado. By 1985, numerous studies of the effects of acid precipitation on fish and amphibians had been conducted or were underway in eastern North America, so it seemed appropriate to determine the status of amphibians in the West. The initial hypothesis to be tested was that observed declines resulted from acid precipitation.

Although the preliminary results of this study do not show an association between amphibian declines and acid precipitation, this should not be a cause for complacency. Two species that were widespread and abundant are now scarce. The available evidence suggests that leopard frogs and boreal toads began to disappear at about the same time, but we have few clues as to the cause. When common species become rare in a short time and without a readily apparent mechanism, it is alarming. Greater effort is needed to discover the cause, and to devise management plans for recovering populations.

SUMMARY

Acid deposition may be detrimental or stressful to native populations of wildlife. Because many species of amphibians breed in shallow ponds created by spring rains or melting snow, they may be particularly vulnerable to the effects of acidification. From 1986 to 1988, we surveyed 105 locations in the central Rocky Mountains where amphibians had been recorded previously, and we found that two species of amphibians have experienced major losses. We found the northern leopard frog (*Rana pipiens*) at only 4 of 33 (12%) historically known localities, and the boreal toad (*Bufo boreas*) was present at 10 of 59 (17%) known localities. Three other species have not suffered region-wide declines. Tiger salamanders (*Ambystoma tigrinum*) and wood frogs (*Rana sylvatica*) were present at 45% and 69% of known localities respectively, and were observed at several localities where they had not been recorded previously. Chorus frogs (*Pseudacris triseriata*) suffered a catastrophic decline in population size in one population monitored since 1961, but regionally, this species was observed in 36 of 56 (64%) known localities and in another 19 localities where there were no previous records.

Complete water chemistry was recorded for 41 localities, and pH was measured at 110 sites in total. Acid neutralizing capacity, pH, specific conductivity, and cation concentrations were negatively correlated with elevation. However, in mountain ponds and lakes, pH was rarely less than 6.0 during the amphibian breeding season.

We tested the tolerance of embryos of the four species of frogs to low pH. The LC_{50} pH was 4.8 for chorus frogs, 4.4-4.7 for leopard frogs, 4.4-4.5 for boreal toads, and 4.2-4.3 for wood frogs. Survival of wood frog embryos declined when exposed to aluminum concentrations of 100 μg/L or greater, but boreal toad embryos survived exposure to aluminum concentrations of 400 μg/L.

Acid deposition does not appear to be a major factor in the decline of leopard frogs and boreal toads. However, we have not yet investigated effects of sublethal pH on growth and development of tadpoles. Pollution remains suspect, but other factors, including natural fluctuations in population size, may account for the observed declines.

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ACKNOWLEDGMENTS

This study was jointly funded in 1986-1988 by the U.S. Fish and Wildlife Service through the National Ecology Research Center - Leetown, and the U.S. Forest Service Rocky Mountain Forest and Range Experiment Station. The National Park Service, through Rocky Mountian National Park, supported field work in 1988. D. McCullough, T. Hendrickx, S. Yu, T. Williams, S. Olson, T. Esque, S. Haeger, S. Gillihan, R. Haberman, and J. Corn assisted with the field work. G. Hammerson kindly shared his list of locality records. We also thank F. Vertucci of the U. S. Forest Service, H. Bergman and R. Hockett of the University of Wyoming Red Buttes Laboratory, S. Workman of the Colorado State University Soils Analysis Laboratory, M. Noble and R. Cameron of the University of Colorado Mountain Research Station, D. Stevens of Rocky Mountain National Park, and the City of Boulder for their assistance. Figures 4-8 were drafted by J. Shoemaker. D. Pettus, K. Schreiber, F. Vertucci, R. Villella, and B. Woodward provided critical comments on the manuscript.

INTRODUCTION

Concern has been expressed recently about the status of populations of pond-breeding amphibians in the western United States. Declines of several species have been noted (Hayes and Jennings 1986; Stolzenburg 1989), and several causes have been proposed, including acid precipitation (Harte and Hoffman *in press*), droughts (Corn and Fogleman 1984), predation from introduced bullfrogs (Moyle 1973; Hammerson 1982a; Jennings 1987), predation from introduced fish (Hayes and Jennings 1986; Jennings 1987), and pollution from copper smelters (Hale and Jarchow 1987). Amphibians may be sensitive indicators of environmental degradation. They have a complex life cycle with aquatic larvae and terrestrial adults, so population declines may reflect events in either aquatic or terrestrial environments or may integrate across the boundary between environments. For this reason, amphibians are well suited for monitoring negative effects of pollution or habitat alterations (Niethammer et al. 1985).

Recently, Harte and Hoffman (*in press*) suggested that declines of tiger salamander (*Ambystoma tigrinum*) populations at high elevations in central Colorado resulted from episodic acidification (during snowmelt). However, most data on amphibian declines in the West are inferential, and there have been few documented cases. Also, proposed hypotheses do not account for widespread population declines in several species in the western United States.

Acid precipitation has already impacted fresh water ecosystems in large areas of eastern North America (Schindler 1988). Declines in fish populations are associated with lowered pH in lakes in the Adirondack Mountains and rivers in Nova Scotia (Haines 1986). The Environmental Protection Agency Western Lake Survey found that Western mountain systems are among the most sensitive to the effects of acidic deposition of any lakes in the world (Landers et al. 1987). About 16% of the lakes in the region have extremely low acid neutralizing capacities (<50 μeq/L).

In Rocky Mountain National Park, Colorado, current concentrations in precipitation of H^+, $SO_4^=$, and NO_3^- are 1/6, 1/3 to 1/5, and 2/3 respectively of concentrations found in the eastern United States (Galloway et al. 1984). The concentration of H^+ is similar to "background" levels, while the concentration of $SO_4^=$ is 2-5 times background, and the concentration of NO_3^- is 3-5 times levels found in remote sites (Galloway et al. 1984). Although direct evidence for acidification (defined as a decrease in acid neutralizing capacity) in Western surface waters is conflicting (Lewis 1982; Vertucci *in*

press), pulses of acidification associated with snowmelt have been detected in high elevation waters in both Colorado and Wyoming (Harte and Hoffman *in press*; Vertucci *in press*). The potential exists for episodic acidification of vernal ponds at snow melt, even at current deposition levels, due to the extreme geologic, edaphic, and hydrologic sensitivity of Western mountain aquatic ecosystems.

The distribution and breeding success of amphibian populations can be affected by low pH (Gosner and Black 1957; Karns 1984; Clark 1986a 1986b; Freda and Dunson 1986; Gascon and Planas 1986; Leuven et al. 1986). Aluminum is mobilized from sediments at low pH (Driscoll et al. 1980), and it is highly toxic to amphibians, depending on the speciation of the aluminum (Clark and Hall 1985; Clark and LaZerte 1985). However, evidence relating amphibian declines to acidification is lacking. Because breeding habitats in western North America are usually less acidic than in the East, Western amphibians may be less tolerant of acid conditions. Responses of several species of amphibians to low pH have been determined in the laboratory (see reviews by Pierce [1985] and Freda [1986]), but, aside from tiger salamanders (Harte and Hoffman *in press*), no Western species have been tested.

In 1986, the National Ecology Research Center (NERC) began investigating the status of montane amphibians in the Front and Park Ranges in northern Colorado and the Medicine Bow Mountains in Colorado and southeastern Wyoming. The research had three objectives:

(1) To document recent declines of any of the five species of montane amphibians in the region.

(2) To determine the water chemistry of amphibian breeding habitats, emphasizing trends in the breeding season (during and immediately after snowmelt) when pH is likely to be the lowest and when the most sensitive life stages (embryos and young larvae) are present.

(3) To measure the tolerance of selected species of Western amphibians to low pH and elevated levels of aluminum.

Research on these topics is continuing and may be expanded to include other areas of the western United States. The preliminary results of the first three years (1986-1988) of the study are presented here and will be useful to refine techniques and to generate hypotheses to test on a larger geographic scale.

This report also contains an archive of the data collected during 1986-1988. Such a summary of the results is often neglected, but it is important (Janzen 1986; McCune 1987). For example, while compiling localities where amphibians occurred in the past, we were hampered by the fragmentary and anecdotal nature of much of the existing

information. To our knowledge, there are no long-term monitoring sites for amphibian communities in western North America. All major data sets we located were three- to five-year studies at one or a few sites, generally representing a thesis problem. One notable exception was a census of a population of chorus frogs that has been carried out periodically since 1961 (Spencer 1964 pers. comm. [A.W. Spencer, Dept. of Biology, Fort Lewis College, Durango, CO 81301]; Matthews 1968). We hope to establish reference points so population trends can be better determined in the future, based on a detailed list of localities, amphibian populations, and basic water chemistry.

Amphibian Species

Five species of amphibians, including tiger salamanders, chorus frogs, boreal toads (*Bufo boreas*), leopard frogs (*Rana pipiens*), and wood frogs (*Rana sylvatica*), occur in all or parts of the study area. The tiger salamander occurs over most of the United States, and it is the only salamander present in Colorado and Wyoming. This species is present in both plains and mountain habitats to about 3,650 m (12,000 ft) (Hammerson 1982b). There is considerable intraspecific genetic variation present (Pierce and Mitton 1980), and populations are placed in three subspecies: *A. t. mavortium* on the plains, *A. t. nebulosum* in the mountains, and *A. t. melanostictum* in the plateau country west of the Continental Divide (Reese 1972).

Chorus frogs (Figure 1) are distributed over most of eastern and northern North America and, like tiger salamanders, occur throughout Colorado and Wyoming. All these regional populations belong to the subspecies *P. t. maculata*, but there are significant genetic and demographic differences between plains and mountain populations (Pettus and Angleton 1967; Matthews 1971).

Figure 1. Chorus frog, *Pseudacris triseriata*, from Larimer County, Colorado.

The boreal toad (Figure 2) is the only one of the five species restricted to western North America, and although it occurs in a variety of habitats in other areas, in Colorado and Wyoming it occurs only in the mountains above 2,400 m (8,000 ft). Variation has not been well studied in Rocky Mountain populations,

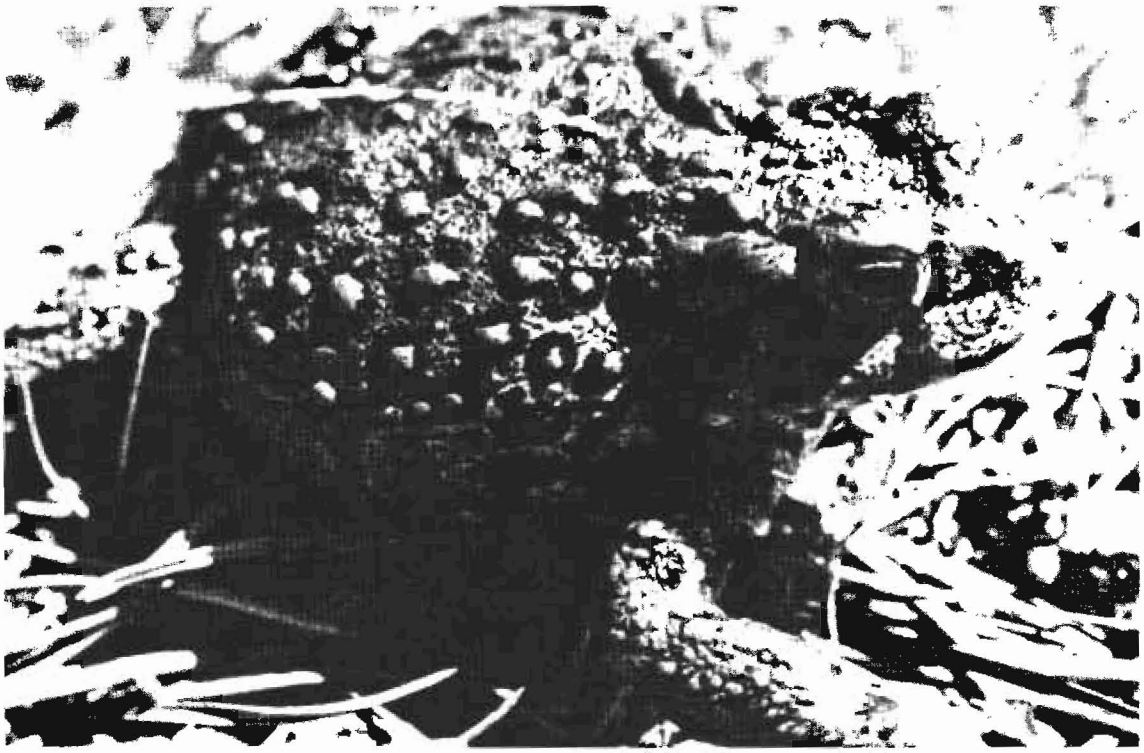

Figure 2. Boreal toad, *Bufo boreas*, from Trap Lake, Larimer County, Colorado.

which are all included in the subspecies *B. b. boreas*. The Rocky Mountain population of boreal toads has recently been listed as category 2 (listing as endangered or threatened may be appropriate) by the U.S. Fish and Wildlife Service (Drewry 1989).

Northern leopard frogs are distributed widely across North America from and eastward of the Great Basin, including most of Colorado and Wyoming below about 3,000 m (10,000 ft). No subspecies are recognized. Declines or extinctions of populations in Colorado have been observed recently in montane areas (Corn and Fogleman 1984) and plains habitats (Hammerson 1982a). The leopard frog is now on a candidate list of species of special concern by the State of Colorado (Livo 1986).

Wood frogs are common in the boreal forests of northern and eastern North America. In the Rocky Mountains, they are present only in disjunct, relict populations in the Never Summer Mountains, Park Range, and Medicine Bow Mountains in Colorado (Hammerson 1982b), the Medicine Bow Mountains in southern Wyoming, and the Big Horn Mountains in northern Wyoming (Dunlap 1977). The wood frog is classed as threatened by the State of Colorado because of its zoogeographic importance, limited distribution, and a lack of knowledge of its status (Haynes and Aird 1981).

METHODS

Amphibian Surveys

Status surveys determined the current presence or absence of amphibian species at known localities. We compiled a list of known localities using museum records (mainly the University of Colorado Museum [UCM] and the University of Wyoming Museum [UW]), published accounts, theses and dissertations, a file of visual observations maintained by Rocky Mountain National Park, and field notes of local herpetologists. Ideally, each locality should represent a breeding population, but given the nature of the information, it was not always possible to know if this was true. However, amphibians are usually most conspicuous during the breeding season, and most of the species we studied usually are not found long distances from water, so in most cases the known localities probably represent breeding populations.

Known localities were grouped in five general geographic areas: Boulder County, Colorado (Appendix A1), an area generally west and north of Nederland and south of Rocky Mountain National Park; Rocky Mountain National Park, Colorado (Appendix A2); Larimer County, Colorado (Appendix A3), with concentrations of localities near Red Feather Lakes and near Chambers Lake, north of the northwest corner of Rocky Mountain National Park; the Park Range in Colorado (Appendix A4), a small number of localities on the west side of North Park; and the Medicine Bow and Sherman mountains in southeastern Wyoming (Appendix A5).

We conducted field surveys from 1986 to 1988, beginning at snowmelt and continuing through early August of each year. Not all localities were searched in each year. Localities and the number of visits to each in each year are listed in Appendix A. A few localities were visited only once, but most were searched at least three times. Both daytime and nighttime searches were conducted during the breeding season. Searches later in the summer were conducted during the day. Daytime visits involved visual searches of shorelines and adjacent wetlands for adult amphibians, and shallow water for eggs or larvae (Figure 3). We occasionally used a dip net to search for larvae in water with dense emergent vegetation. If populations are small, adult amphibians may be difficult to detect, particularly after the breeding season. Larvae of all five species, in contrast, are conspicuous in shallow water, and daytime searches after the breeding season are reliable for detecting their presence.

Figure 3. Searching the shallow margin of Big Creek Lake (Jackson County, Colorado) for amphibian larvae.

Lake origin was recorded as either geologic or man-made, and lake type was recorded as drainage (having a permanent outlet), semidrainage (having an outlet only in years with high water [Pennak 1969]), or as a beaver pond. At each locality, the lake or pond dimensions were measured with a rangefinder or were measured on topographic maps for larger lakes. Water depth was characterized as < 1 m, 1-2 m, or > 2 m. The substrate was characterized as predominantly organic matter, silt, sand, gravel, or boulders. The area covered by emergent vegetation was estimated, the presence or absence of emergent vegetation and shallow water on the north shoreline was noted, and the nearest distance to a forest edge was measured.

We estimated numbers of male chorus frogs at two localities in Larimer County (Lily Pond and Matthews Pond) in all three years, and at two localities in Rocky Mountain National Park (Horseshoe Park #1 and Horseshoe Park #3) in 1988. Frogs were collected at night and usually were released the same night or the next day at the latest. Each frog was given a unique mark by toe-clipping, and we measured snout-vent length to the nearest 0.1 mm with dial calipers. Population sizes were estimated

using either the modified Lincoln-Peterson method, Lincoln-Peterson weighted-mean method, or the Jolly method (Begon 1979). The method used depended on the number of times a population was sampled. If more than one method was applicable, the estimate with the smallest standard error was used.

Reproduction by wood frogs was monitored at several ponds in Larimer County and Wyoming by counting numbers of egg masses. Female wood frogs in the Rocky Mountains probably deposit their entire clutch in one egg mass (Corn and Livo *in press*), so twice the number of egg masses provides a direct measure of effective population size (Merrell 1968). Only a few ponds (Matthews Pond, Upper Gravel Pit, Evans Creek, Spur Ponds) were monitored in all three years.

Water Chemistry

We collected water samples in high-density polyethylene bottles and kept them cold until processed. Water samples were taken from a subset of 33 localities in May 1987 (Appendix B). We measured pH in the laboratory using a variation of the technique described by Turk (1986) within 24 hours of collection with a Beckman meter and Orion 9162 electrode. Three successive aliquots of each sample were used, and the meter was allowed to come to a stable reading before rinsing the electrode with the sample water and measuring the next aliquot. Only the pH of the final aliquot was used. Additional analyses were performed by the Soils Testing Laboratory, Colorado State University. Acid neutralizing capacity (μeq HCO_3) was determined by Gran titration. Anions (NO_3^-, $SO_4^=$, Cl^-, and F^-) were measured using an ion chromatograph following standard methods. Cations were determined with an ICP (Ca^{++}, Mg^{++}) and atomic spectrophotometer (Na^+ and K^+). Silicon (SiO_2), total aluminum , and phosphorus were determined with ICP. We also collected 5 water samples at weekly intervals beginning 29 April from both Matthews Pond and Lily Pond (Larimer Co.). These were analyzed in the same manner to provide a profile of water chemistry during the breeding season.

In 1988, we measured pH at 78 sites in Rocky Mountain National Park using a Beckman model 21 portable pH meter and Orion Ross 8156 electrode. The technique was the same as described above. We also measured pH over a 24-hour period at Lily Pond and Glacier Basin, and Bierstadt Lake in Rocky Mountain National Park. Water was collected from four stations equally spaced around the perimeter of each pond. We used separate one-way analysis of variance to test for differences between stations and time of day at pond. Weekly water samples were again collected at Lily Pond and Matthews, and additional weekly samples were collected at Trap Lake (Larimer Co.), two ponds in Horseshoe Park in Rocky Mountain National Park (Horseshoe Park #1 and Fan Lake), and Lost Lake (Boulder Co.). Additional water samples were collected from a few other sites (Appendix B). Analysis of water samples collected in 1988 was done by the U.S. Forest Service.

Amphibian Tolerance to Low pH and Aluminum

We tested the tolerance of leopard frog, wood frog, chorus frog, and boreal toad embryos to low pH. Also, wood frog and boreal toad embryos were exposed to elevated concentrations of aluminum. Wood frogs and leopard frogs were tested at the University of Wyoming's Red Buttes Laboratory in 1987, and boreal toads and chorus frogs were tested at the Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service in Fort Collins in 1988. The change in laboratories was made mainly for convenience, and although test conditions differed somewhat between years (see below), low ion strength water was used in both years.

We collected egg masses and adult leopard frogs from a series of active beaver ponds on the North Fork of Lodgepole Creek (Albany County, Wyoming). Wood frog egg masses were collected from two glacial pothole ponds in the vicinity of Long Lake (Carbon County, Wyoming). Boreal toad eggs were collected from Lost Lake (Boulder Co.), and adult chorus frogs were collected from Spur Ponds (Albany County, Wyoming).

In 1987, embryos were tested in soft water generated by passing well water through a high-capacity reverse osmosis (RO) system. RO water was then remixed with well water to achieve the following water chemistry (ion concentrations in mg/L): pH 6.7, Ca^{++} 0.7, Mg^{++} 0.3, Na^{+} 1.13, K^{+} 3.47, Cl^{-} 1.8. Test levels of pH were achieved by adding sulfuric acid (H_2SO_4). For the experiments involving aluminum, a stock solution with an aluminum concentration of 10 mg/L was prepared using aluminum chloride, and test concentrations were prepared by diluting the stock solution. Aluminum speciation was not determined, but Freda and McDonald (*in press*) found little organic complexation in similar test media. Most of the aluminum added should have remained as inorganic aluminum, which is the most toxic form to aquatic organisms (Driscoll et al. 1980; Clark and LaZerte 1985). We tested embryos in 1988 in artificial soft water (Freda and Dunson 1985), using RO distilled water as the base and with nominal levels of calcium, sodium, and potassium of 1 mg/L. Measured ion concentrations were (mg/L): Ca^{++} 0.9, Mg^{++} 0.0, Na^{+} 1.09, K^{+} 1.05, Cl^{-} 3.90, and pH 6.7.

One female (A) and four male (1-4) leopard frogs from Lodgepole Creek were collected, and matings (pA1-pA4) between the female and each male were performed in the laboratory. The female had already ovulated, so eggs were stripped and fertilized using sperm suspensions in the control medium. Groups of 24-44 fertilized embryos from each mating were placed in each test solution. Three additional leopard frog egg masses (pB, pC, and pD) were collected, divided into groups numbering 88-145 embryos, and placed in each test solution. Leopard frog embryos were exposed to the control and pH 5.7, 5.0, 4.4, and 4.0 solutions. Three wood frog egg masses were collected (sA, sB, and sC), divided into groups of 26-86 embryos, and exposed to the control and pH 5.0, 4.6, 4.3, and 4.0 solutions. We exposed 40-88 additional wood frog embryos from each mating to Al concentrations of 50, 100, and 300 μg/L, at pH 5.0 and 4.6.

Eggs from three boreal toad egg strings (bA, bB, and bC) were exposed to the control and pH 5.2, 4.9, 4.6, 4.3, and 4.0 solutions. Ten to 20 eggs from bA and bB were exposed to aluminum concentrations of 50, 100, 200, and 400 μg/L at pH 4.6 and 4.9, and 14-23 eggs from bC were exposed to 100, 200, 400, and 800 μg/L Al at pH 4.9. Laboratory matings were made between two female and three male chorus frogs, but fertilization was successful in only one case (mating tA1). Nine to 19 embryos were tested in the control solution and at pH 5.2, 4.9, 4.6, 4.3, and 4.0.

Each group of embryos was tested in 400 ml of solution in individual polyethylene containers, placed in a water bath at 20 °C in 1987 and at room temperature in 1988. All solutions were replaced daily, until embryos were near hatching. Variation in hatching success at each pH was assessed using the *G*-test (log likelihood ratio) for goodness of fit (Sokal and Rohlf 1981). We calculated the LC_{50} pH for each mating using maximum likelihood probit estimation (Hewlett and Plackett 1979; Wilkinson 1988).

Hatching success of wood frog and boreal toad embryos was high at all levels of Al; therefore, 20 embryos that had hatched without deformities from each group of wood frogs were placed in fresh solution and allowed to develop to feeding stage (stage 25; Gosner 1960). All surviving boreal toad embryos were followed to stage 25. Cumulative survival at each Al concentration was obtained by multiplying the proportion of embryos that survived to hatching by the proportion surviving between hatching and stage 25. A two-way analysis of variance (pH and Al) was run using the rank of cumulative survival. Separate nonparametric analysis of variance tested survival between each level of Al.

RESULTS

Amphibian Surveys

We identified 105 separate localities where at least one amphibian species had been recorded previously. Tiger salamanders had been recorded at the fewest localities (22). We found salamanders at 10 (45%) known localities (Figure 4). Tiger salamanders were also found at 11 localities that did not have previous records. Salamanders were the most difficult species to sample because larvae may have been present in deeper water that we did not search effectively.

Fifty-nine known localities of boreal toads were searched in 1986-1988. Boreal toads were found at only 10 (17%) of known localities (Figure 5). Toads were observed at an additional two localities where they had not been recorded previously. Outside of Rocky Mountain National Park we observed only four breeding populations: Trap Lake (Larimer Co.) in 1986 and 1987, Big Creek Lake (Park Range) in 1987, Slack-Weiss Reservoir (Park Range) in 1988, and Lost Lake (Boulder County) in 1987 and 1988. The greatest number of egg strings observed in these populations was three at Lost Lake in 1988. At Trap Lake a few hundred tadpoles were seen in 1986, and adult toads were present in the breeding season in 1987, but only one egg string was deposited and it had zero hatching success. No toads were observed at Trap Lake in 1988. No breeding populations were observed in Wyoming, where only one adult toad was located in three years of field work. Populations inside Rocky Mountain National Park appear to be surviving better than those on the outside. Boreal toads were present at only 10% (5/48) of known sites outside the Park and 45% (5/11) of known sites inside the Park. In 1988, we verified breeding only at Glacier Basin in the Park, however, adult toads were observed at Poudre Lake, Lost Lake, and Spruce Lake. Most of these probably represent successful breeding populations, but additional observations are necessary.

There were 56 known localities of chorus frogs searched in 1986-1988. We found chorus frogs at 36 (64%) of these (Figure 6) and at an additional 19 localities without previous records. Localities with chorus frogs present comprised either breeding choruses or ponds with tadpoles present later in the season. We did not verify whether all breeding choruses successfully produced offspring.

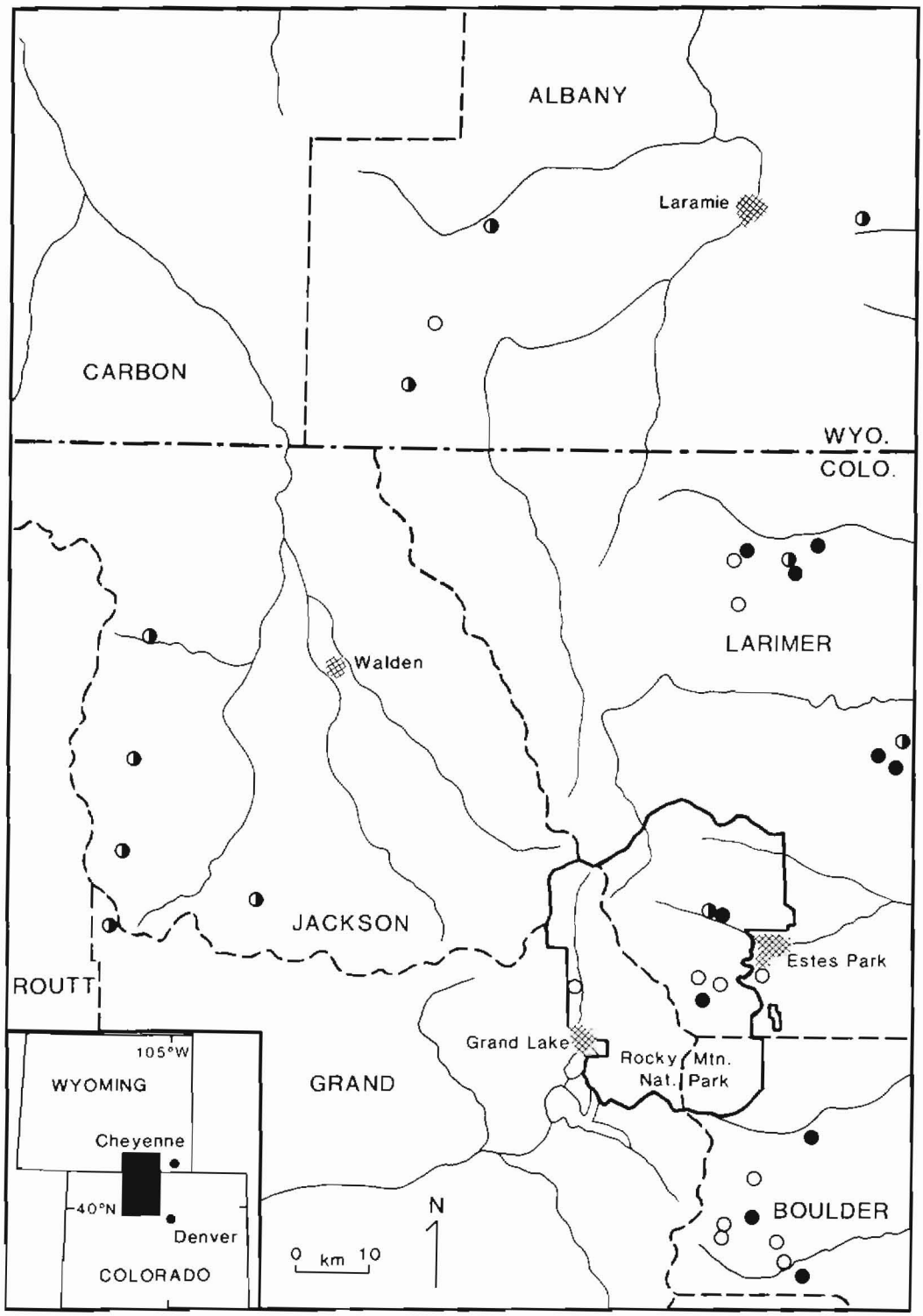

Figure 4. Occurrence of tiger salamanders in 1986-1988. Unshaded circles are known localities where we did not find salamanders, filled circles are known localities where salamanders were still present, and half-filled circles are "new" localities.

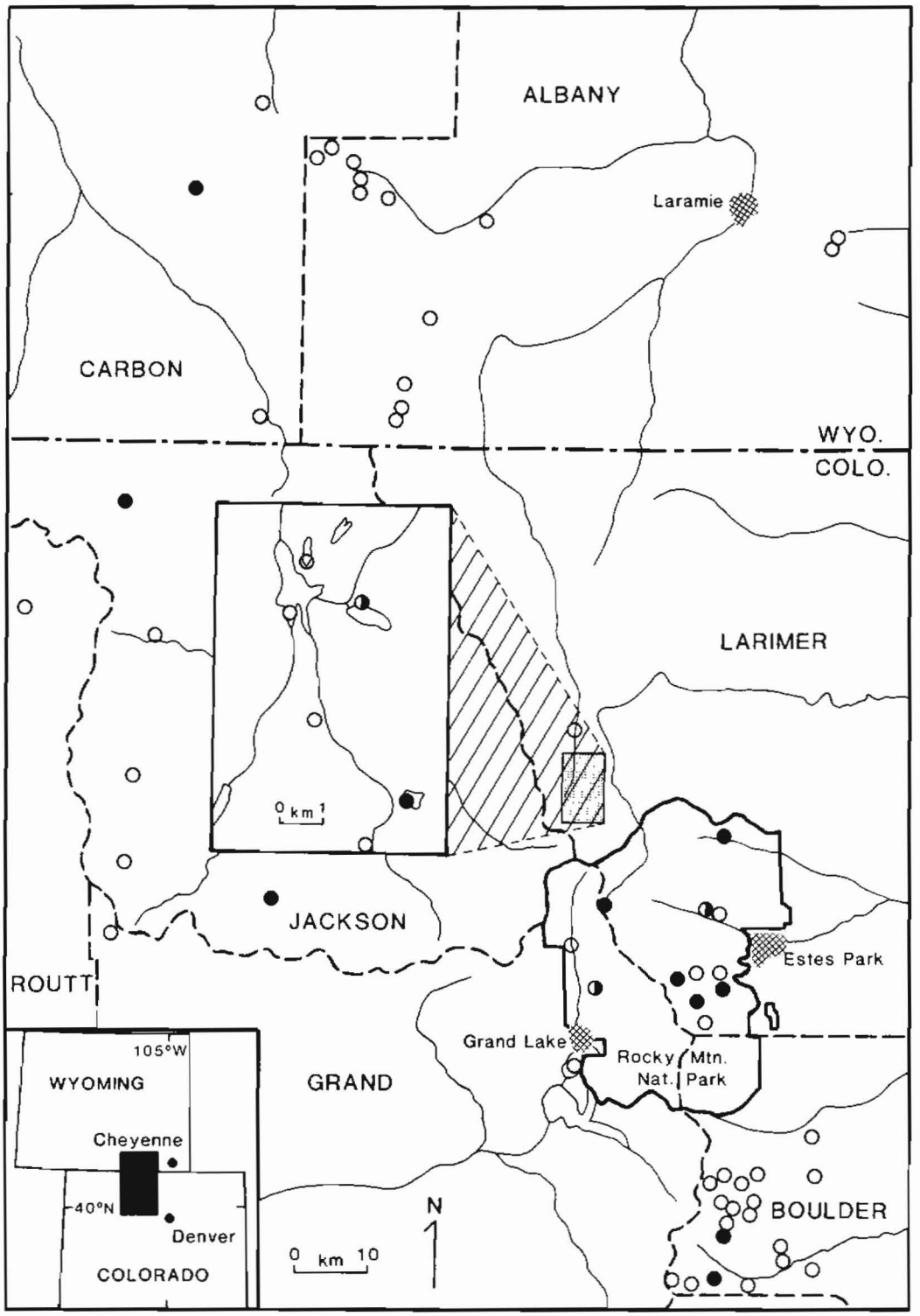

Figure 5. Occurrence of boreal toads in 1986-1988. Unshaded circles are known localities where we did not find toads, filled circles are known localities where toads were still present, and half-filled circles are "new" localities.

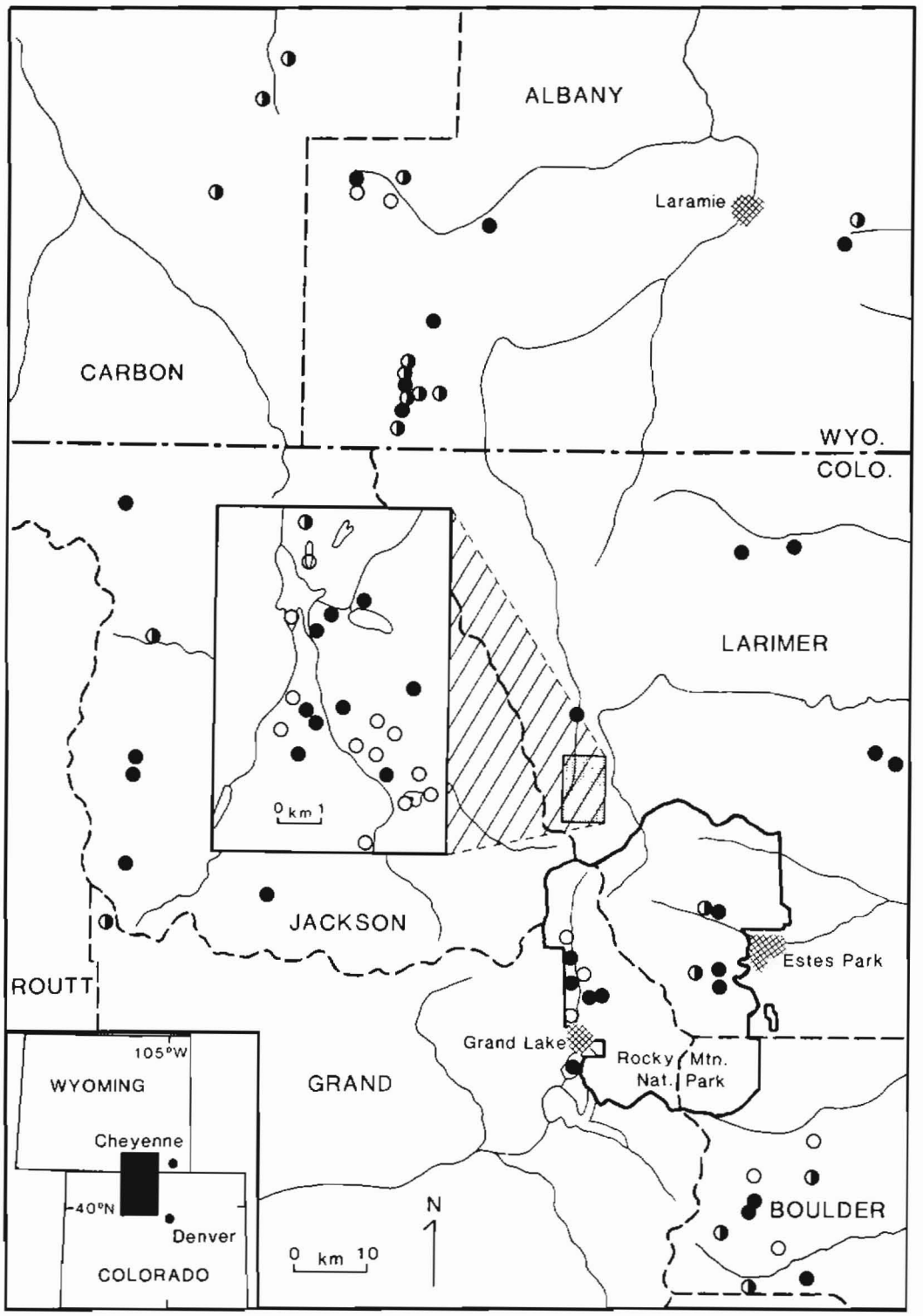

Figure 6. Occurrence of chorus frogs in 1986-1988. Unshaded circles are known localities where we did not find chorus frogs, filled circles are known localities where chorus frogs were still present, and half-filled circles are "new" localities.

We found 33 localities with previous records of leopard frogs, and four of these had leopard frogs present in 1986-1988 (Figure 7). Leopard frogs were not found at any localities where they had not been recorded previously. This represented the greatest decline of the five species studied. Leopard frogs were only found in the Park Range and in the Sherman Mountains in Wyoming. Most of the populations studied by Corn and Fogleman (1984) in the Red Feather Lakes area of Larimer County were resurveyed in this study, and there has been no recolonization of populations that went extinct in the 1970's.

Wood frogs have the most restricted distribution and occupy the narrowest range of habitats of the species studied, so a priori they might be considered to be most susceptible to population declines. However, wood frogs were still present in 20 of 29 (69%) known localities (Figure 8), and we found wood frogs at nine localities where they had not previously been recorded. This includes a slight range extension into the Ryan Park area on the west slope of the Medicine Bow Mountains, Wyoming.

No trends in wood frog populations could be identified by counting numbers of egg masses (Table 1). Numbers of egg masses varied considerably, both between years and among populations. The comparatively small numbers of egg masses observed, however, do not represent any recent declines of wood frogs. Both Bagdonas (1971) and Haynes and Aird (1981) reported similar numbers. Wood frogs in the Rocky Mountains apparently have small populations compared to wood frogs in eastern North America, where communal deposition of hundreds of egg masses has been noted (Seale 1982; Waldman and Ryan 1983).

The estimated sizes of chorus frog populations were also relatively small and showed considerable temporal variability (Table 2). The population at Matthews Pond declined between 1986 and 1987 and was stable between 1987 and 1988, while at Lily Pond numbers of chorus frogs were stable between 1986 and 1987 but increased in 1988. Despite this increase, there are currently fewer than 10% of the number of chorus frogs at Lily Pond than the maximum number estimated in the past (Figure 9).

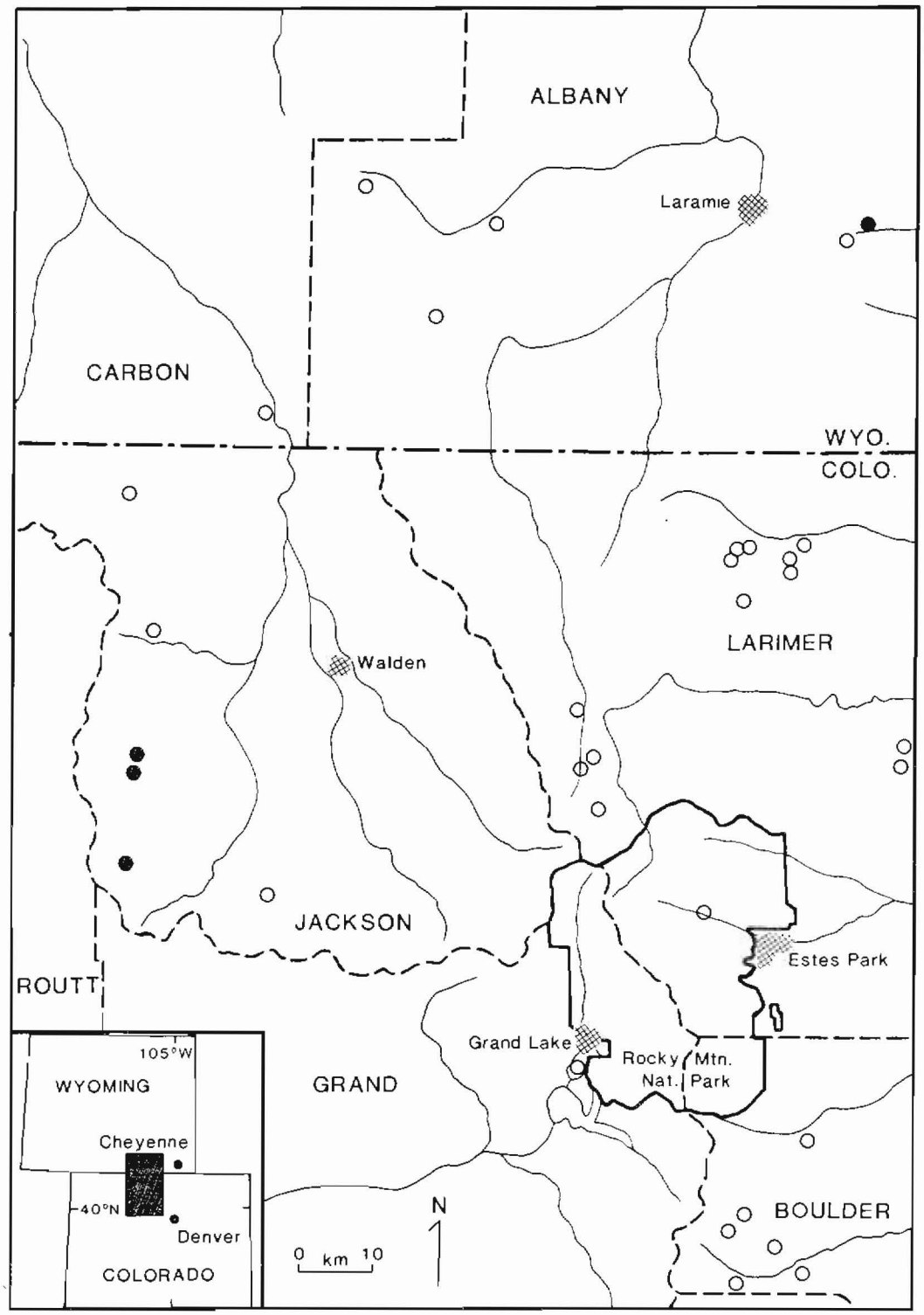

Figure 7. Occurrence of leopard frogs in 1986-1988. Unshaded circles are known localities where we did not find leopard frogs, filled circles are known localities where leopard frogs were still present, and half-filled circles are "new" localities.

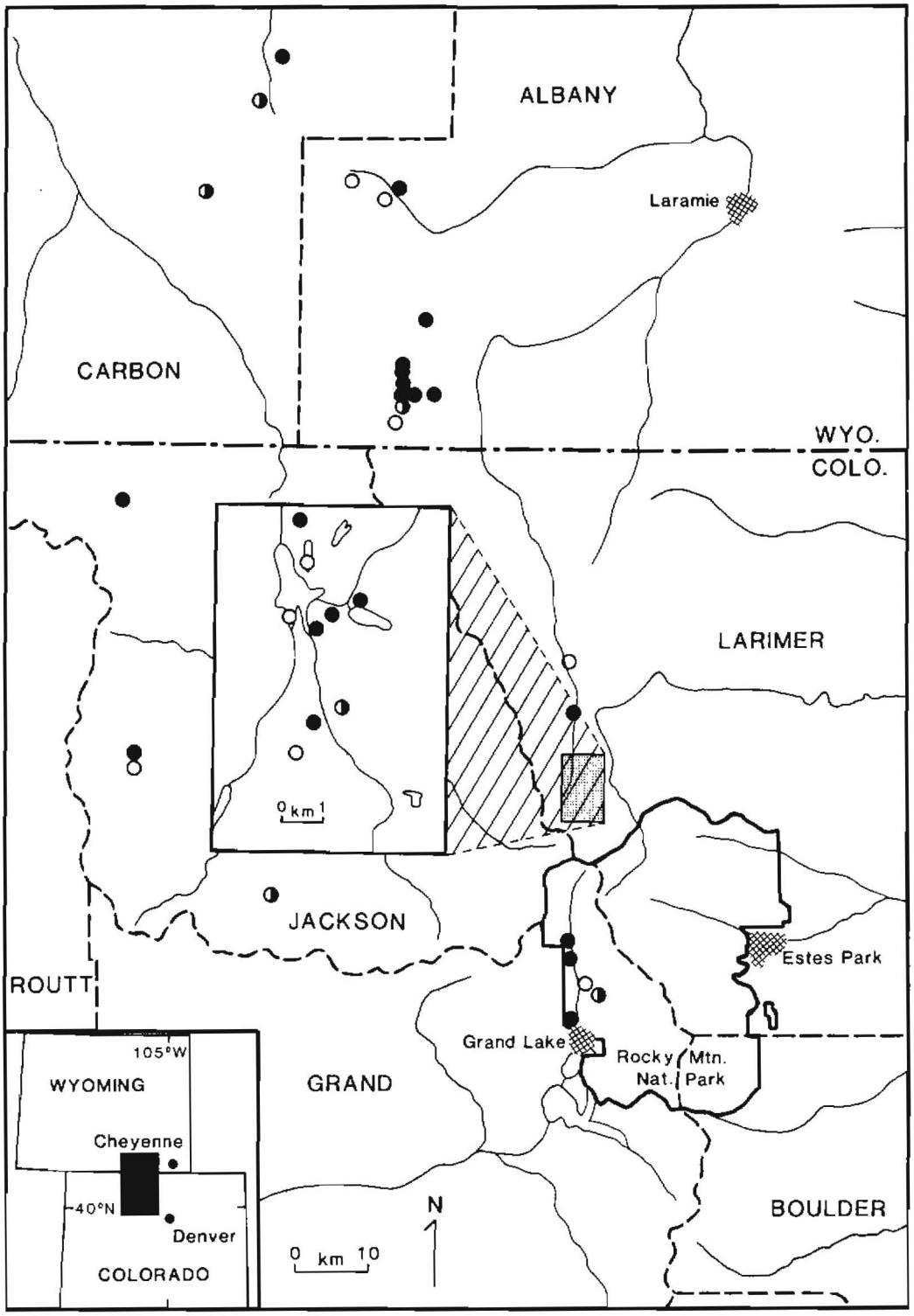

Figure 8. Occurrence of wood frogs in 1986-1988. Unshaded circles are known localities where we did not find wood frogs, filled circles are known localities where wood frogs were still present, and half-filled circles are "new" localities.

Table 1. Number of wood frog egg masses observed in 1986, 1987, and 1988 at localities in Colorado and Wyoming.

Location	Year		
	1986	1987	1988
Chambers Lake area, Larimer Co., Colorado			
Matthews Pond	19	38	18
Upper Gravel Pit	3	8	17
Spruce Bog	-	28	-
Fox Park area, Albany Co., Wyoming			
Evans Creek West	0	5	1
Evans Creek East	-	24	6
Fox Park	3	3	-
Spur Ponds	0	9	4
Long Lake area, Carbon Co., Wyoming			
Pond #1	9	-	-
Pond #2	4	-	-
Pond #3	-	5	-
Pond #4	-	8	-
Pond #5	-	5	-
Pond #6	-	8	-
Pond #7	-	22	-

Table 2. Estimated numbers of male chorus frogs breeding in four populations in the mountains of northern Colorado.

Population	Year	Number marked	N_{est}	95% C.I.
Chambers Lake area (Roosevelt National Forest)				
Matthews Pond	1986	79	99[a]	69 - 129
Matthews Pond	1987	31	36[b]	15 - 57
Matthews Pond	1988	40	46[b]	26 - 66
Lily Pond	1986	33	41[b]	17 - 65
Lily Pond	1987	23	39[c]	14 - 64
Lily Pond	1988	66	106[b]	62 - 150
Rocky Mountain National Park				
Horseshoe Park #1	1988	77	137[b]	74 - 200
Horseshoe Park #3	1988	72	128[c]	49 - 207

[a]Jolly estimate; [b]Lincoln-Peterson weighted-mean estimate; [c]Lincoln-Peterson modified estimate

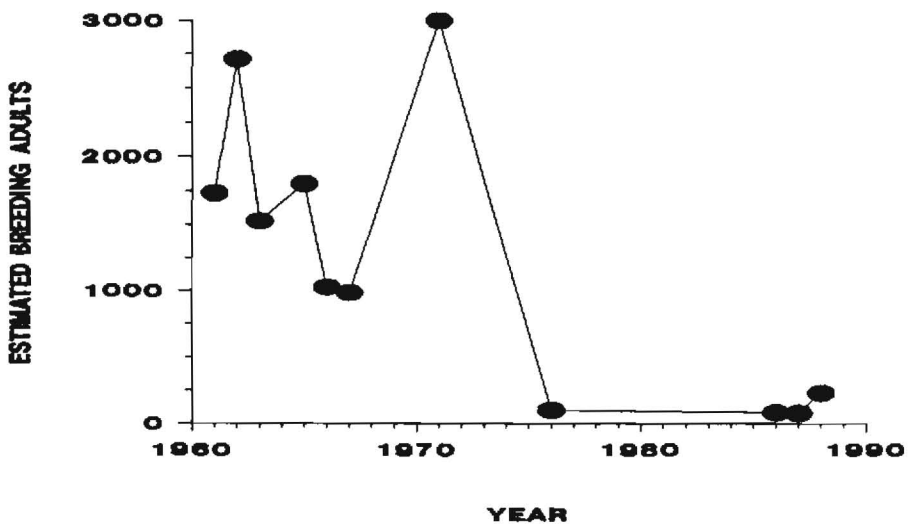

Figure 9. Estimated numbers of adult chorus frogs present at Lily Pond, Larimer County, Colorado. Data are from Spencer (1964; pers. comm.), Matthews (1968), and double the number of males in Table 2.

Water Chemistry

Complete water chemistry data were collected from 33 localities in 1987 and from 8 additional localities in 1988 (Appendix B). We measured pH at 7 other localities in 1987 and at 70 additional sites in Rocky Mountain National Park in 1988. Linear regression of 118 measurements (8 locations were measured in both years), showed that pH declined at higher elevations (Figure 10: $r^2 = 0.228$, $Y = 10.26 - 0.001X$). Part of the explanation for the relatively low coefficient of determination (23%) may be due to a significant difference between years ($P = 0.02$) in the relationship between pH and

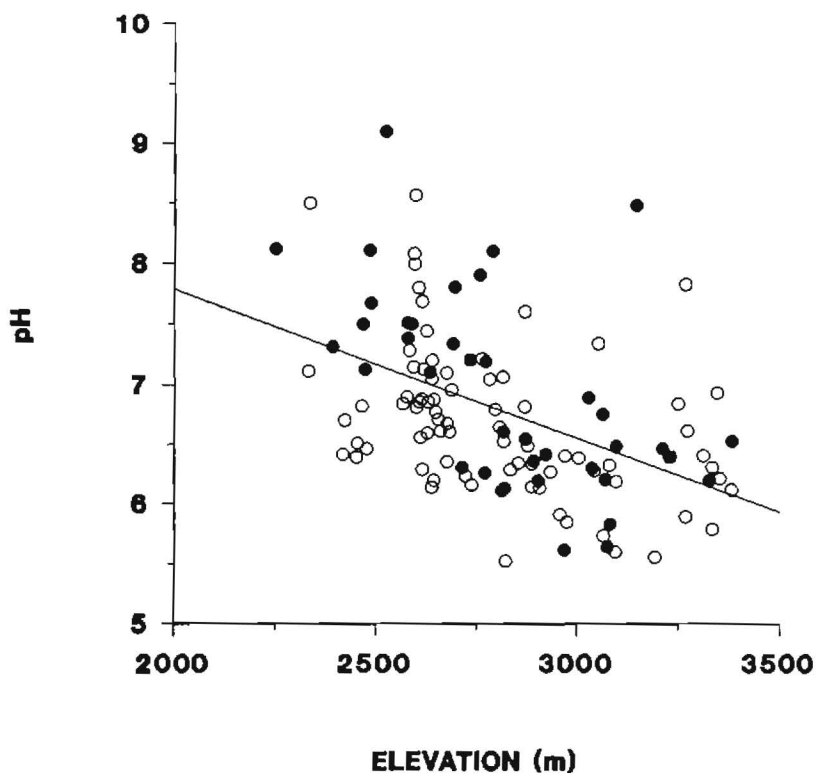

Figure 10. pH versus elevation for 1987 (filled circles) and 1988 (open circles).

elevation. Similar to pH, acid neutralizing capacity, specific conductivity, and cation concentrations were all highest in low elevation localities.

Declines of amphibian populations were unrelated to both pH and elevation (Figure 11). There were 59 localities with known amphibian populations where we measured pH. Neither pH ($P = 0.67$) nor elevation ($P = 0.55$) was significantly different at 41 localities where at least one amphibian species was missing versus 18 localities where all known species were observed.

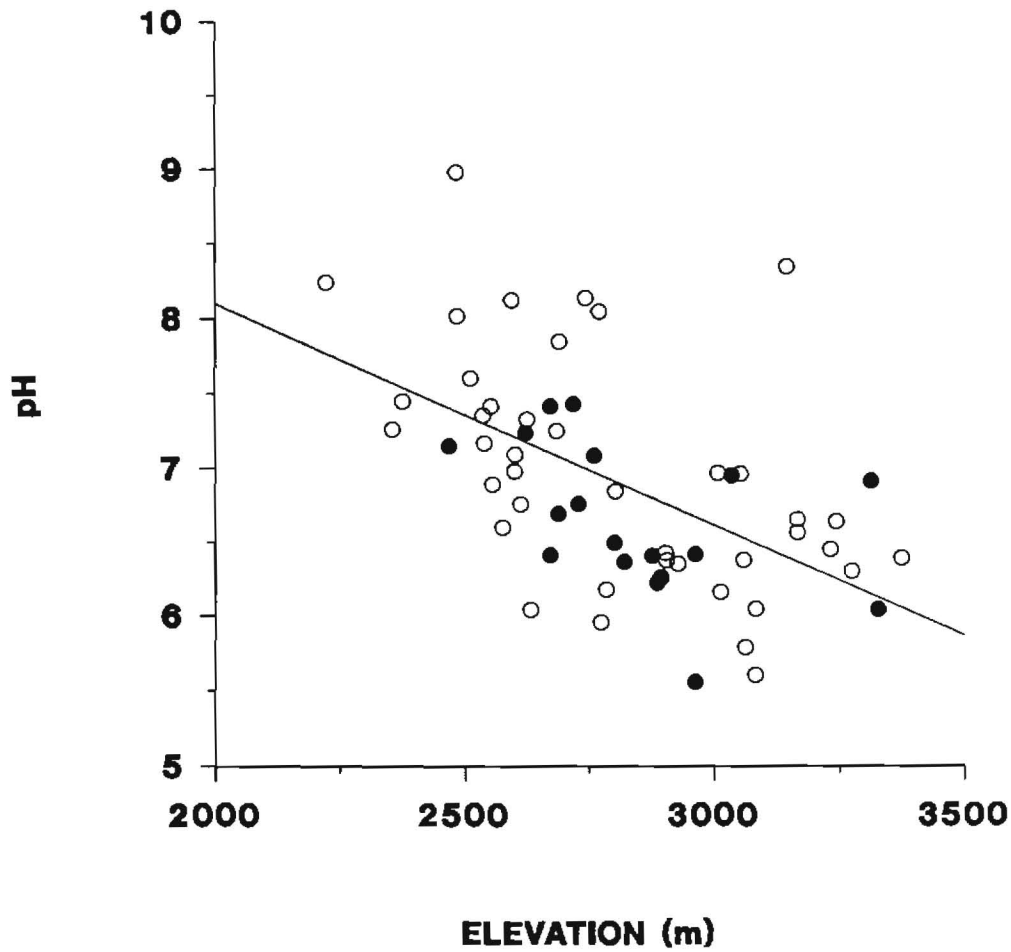

Figure 11. pH versus elevation at localities where no absenses of known amphibians were observed (filled circles), or at least one known amphibian was missing (open circles).

Few regional trends in water chemistry were apparent, but generally higher sulfate and nitrate concentrations were found in Boulder County localities. Moderate levels of total aluminum were found at a few Wyoming localities.

There was no discernible trend of increasing pH or acid neutralizing capacity over time at Lily Pond or Matthews Pond in 1987, or Horseshoe Park #1, Fan Lake, or Lost Lake in 1988. We began collecting water samples at all these sites some time after most snowmelt had taken place. At Lily Pond, Matthews Pond, and Trap Lake in 1988, water samples were collected when the first open water appeared (Figure 12). Both pH and acid neutralizing capacity were lowest at the beginning of snowmelt and increased during the spring. There were significant positive correlations between acid neutralizing capacity and the Julian date at Lily Pond ($n = 7, r = 0.93, P = 0.002$) and Trap Lake

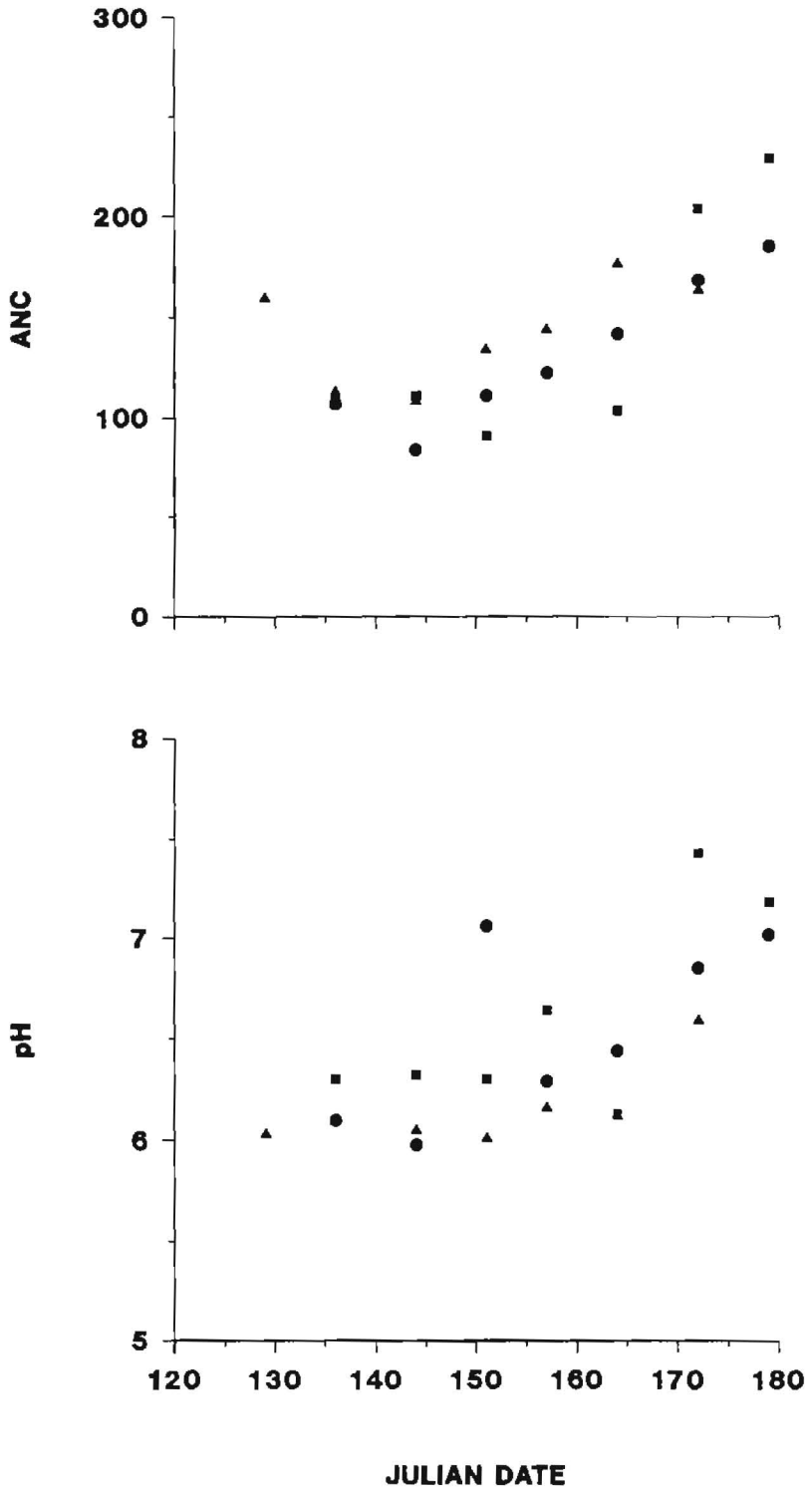

Figure 12. Trends in acid neutralizing capacity (top) and pH (bottom) following snowmelt at three localities near Chambers Lake, Larimer County, Colorado: Matthews Pond (triangles), Lily Pond (squares), and Trap Lake (circles).

(n = 7, r = 0.79, P = 0.03), suggesting some acidification early during snowmelt. However, none of the correlations between pH and date were statistically significant.

The potential for acidification during snowmelt was supported by the observation that pH varied significantly (P = 0.052) among the four measuring stations at Lily Pond (Table 3). Station 3 consistently had the lowest pH, and this station was located next to a remnant snowbank in the pond. No spatial variation was observed at Bierstadt Lake or Glacier Basin, where there was no snow left on the ground. At these two sites, but not at Lily Pond, pH varied significantly over a 24-hour period. The lowest readings were taken early in the morning at both sites.

Table 3. Variation in pH over 24 hours at three amphibian breeding habitats in northern Colorado. For each pond, the mean pH (n = 4) is listed for each station and time of day.

	Station (Time)				
Variable	1 (07:00)	2 (13:00)	3 (18:00)	4 (24:00)	P
Lily Pond (Roosevelt National Forest), elevation 2896 m, 4-5 June					
Station	6.18	6.19	6.04	6.16	0.052
Time of Day	6.20	6.12	6.14	6.10	0.560
Bierstadt Lake (Rocky Mountain National Park) elevation 2800 m, 13-14 June					
Station	6.56	6.53	6.54	6.56	0.232
Time of Day	6.50	6.52	6.61	6.57	0.006
Glacier Basin (Rocky Mountain National Park) elevation 2680 m, 13-14 June					
Station	6.78	6.79	6.83	6.86	0.883
Time of Day	6.65	6.82	7.04	6.83	< 0.001

Amphibian Tolerance to Low pH and Aluminum

Hatching success of leopard frog embryos was near 100% at pH 5.0 and above, but was reduced at pH 4.4 and was zero at pH 4.0 (Table 4). Hatching success at pH 4.4 of offspring of the four males mated to female A ranged from 3 to 22% ($\bar{x}$ = 13%), but differences among males were not significant (G = 5.56, 3 df, P = 0.14). Hatching success at pH 4.4 of offspring from different females (egg masses pB, pC, and pD, and offspring from matings pA1-pA4 lumped) was unequal among females (G = 99.97, 3 df, P < 0.001). The LC_{50} pH for each mating was: pA1 4.5, pA2 4.7, pA3 4.6, pA4 4.5, pB 4.4, pC 4.5, pD 4.5.

Table 4. Hatching success (percent hatching) of amphibian embryos.

Mating		pH								
♀	♂	4.0	4.3	4.4	4.6	4.9	5.0	5.2	5.7	6.6
Leopard Frog (*Rana pipiens*)										
A	1	0		22.2			100		96.1	97.0
A	2	0		3.2			90.0		87.1	100
A	3	0		11.8			96.9		94.9	97.7
A	4	0		15.6			100		100	100
B (egg mass)		0		55.7			97.9		98.5	98.4
C (egg mass)		0		7.8			100		100	100
D (egg mass)		0		15.2			99.1		100	100
Wood Frog (*Rana sylvatica*)										
A (egg mass)		0	67.6		88.5		100			81.2
B (egg mass)		0	44.6		100		97.7			100
C (egg mass)		0	88.3		97.3		90.2			90.5
Boreal Toad (*Bufo boreas*)										
A (egg mass)		0	5.0		100	100		100		100
B (egg mass)		0	15.0		80.0	95.0		100		100
B (egg mass)		0	4.8		72.7	88.2		100		100
Chorus Frog (*Pseudacris triseriata*)										
A	1	0	0		0	50.0		92.8		94.7

Hatching success of wood frog embryos was more variable than hatching success of leopard frog embryos (Table 4). There was significant variation in hatching success among the embryos from the three egg masses at pH 6.7 (G = 14.7, 2 df, P = 0.001), pH 4.6 (G = 8.01, 2 df, P = 0.02), and pH 4.3 (G = 30.2, 2 df, P < 0.001). Some of this variation might have been due to temperature. Wood frog embryos are relatively intolerant of high temperatures (Bagdonas and Pettus 1976). All three groups had zero success at pH 4.0. The departure from the control hatching success was at pH 4.3. Percent hatching varied from 45 to 88% ($\bar{x}$ = 67%), but the LC_{50} pH was 4.3 for egg masses sA and sB and 4.2 for egg mass sC.

No boreal toad embryos survived more than a few hours at pH 4.0. Mean hatching success was 8% at pH 4.3, and 84% at pH 4.6 (Table 4). The LC_{50} pH was 4.4 for egg masses bA and bB and 4.5 for egg mass bC. There were no significant differences in hatching success among egg masses at any pH.

The one group of chorus frogs tested had zero hatching success below pH 4.6 (Table 4) and an LC_{50} pH of 4.8. Chorus frogs may be the least tolerant of the four species to low pH, but the sample size of one mating makes this conclusion tentative.

Wood frog embryos were relatively tolerant of all aluminum concentrations until hatching. Mean survival was 81% at 300 μg/L Al at pH 4.6, and 60% at pH 5.0. Survival at 50 and 100 μg/L Al was >90% at both levels of pH. Cumulative survival to stage 25 (Table 5) was near zero at 300 μg/L Al and appeared to decline at 100 μg/L Al. While the differences in cumulative survival varied significantly among aluminum concentrations (F = 17.2, P < 0.001), there was no difference between cumulative survival at pH 4.6 and 5.0 relative to aluminum concentration (F = 0.49, P = 0.49), and no significant interaction between pH and aluminum concentration (F = 0.14, P = 0.94). When runs at both pH's were combined, there was no difference between cumulative survival at 0 and 50 μg/L Al (P = 1.0), but survival declined significantly between 50 and 100 μg/L Al (P = 0.025) and between 100 and 300 μg/L Al (P = 0.003).

Embryos of boreal toads appeared to tolerate higher aluminum concentrations than wood frogs (Table 5). Statistical tests were not run because of the small sample size. There was considerable variation in survival of toad embryos among levels of aluminum, but survival was high at 400 μg/L Al at both pH 4.6 and 4.9. The only zero survival was observed at 800 μg/L Al.

Table 5. Cumulative survival (%) of wood frog and boreal toad embryos to stage 25.

			Aluminum (μg/L)						
Species	pH	Mating	0	50	100	200	300	400	800
Wood Frog (*Rana sylvatica*)									
	4.6	A	88.5	79.1	89.9		12.8		
		B	100	100	75		0		
		C	97.3	98.1	50.5		0		
	5.0	A	100	96.6	83.1		0		
		B	97.7	100	80		9.5		
		C	90.2	96.7	90.8		0		
Boreal Toad (*Bufo boreas*)									
	4.6	A	100	85.0	80.0	80.0		75.0	
		B	80.0	70.0	50.0	40.0		30.0	
	4.9	A	100	80.0	35.0	90.0		85.0	
		B	95.0	80.0	80.0	90.0		100	
		C	88.2		60.0	28.6		34.8	0

DISCUSSION

Our status surveys suggest that amphibians in the mountains of northern Colorado and southern Wyoming have undergone major declines. Leopard frogs and boreal toads were present at only a small percentage of known localities, and tiger salamanders, chorus frogs, and wood frogs were present at 45-69% of known localities.

Before discussing potential causes of population declines, we need to evaluate the reliability of the data because the records used to build the list of known localities for each species have serious limitations. Museum records do not necessarily represent breeding populations. Although we regard most of the records used as representing legitimate populations, mistakes that inflate the number of known localities will also inflate the observed rate of decline. There is also the problem of how to treat localities that provide marginal habitat, where breeding may occur but is rarely successful. This may happen with high-elevation populations of boreal toads (Baxter 1952; Campbell 1970). No potentially marginal populations were deleted because data on reproductive success of individual populations are rare. Another problem is that the records are combined over a period of about 50 years, and this ignores natural processes of extinction and recolonization. A final problem with museum records is that they are likely to be incomplete. Not all species inhabiting a locality may be represented in collections, as most areas are not sampled systematically.

Sizes of amphibian populations are highly variable. The population of chorus frogs at Lily Pond declined and rebounded several times before reaching its current low level. Bragg (1960) observed similar large fluctuations of several species in Oklahoma over a 25-year period. The survey methods we used might miss very small populations, counting as absent a species that may soon reestablish a large population.

Our data supply some help in sorting out real declines from the "noise" in the system. One approach is to compare the percent of known localites occupied to the percent of "new" localities (relative to number of known localities). "New" localities are those where species were present in 1986-1988 but had not been recorded previously. These probably represent a mixture of localities colonized or recolonized since the last time a locality was searched, and populations that existed but were never recorded. Regardless, a large percentage of "new" localities suggests that a species is not in decline, and that a low percentage of known localities occupied (e.g., 45% of tiger salamander localities) probably is an artifact of the sampling methods employed.

Tiger salamanders, chorus frogs, and wood frogs have combined percentages of known localities occupied and "new" localities that equal or approach 100% of the original number of known localities (Figure 13). These species are probably not in decline. Rather, some local populations may be extinct but nearby populations or newly established colonies are viable. Boreal toads and leopard frogs have a low percentage

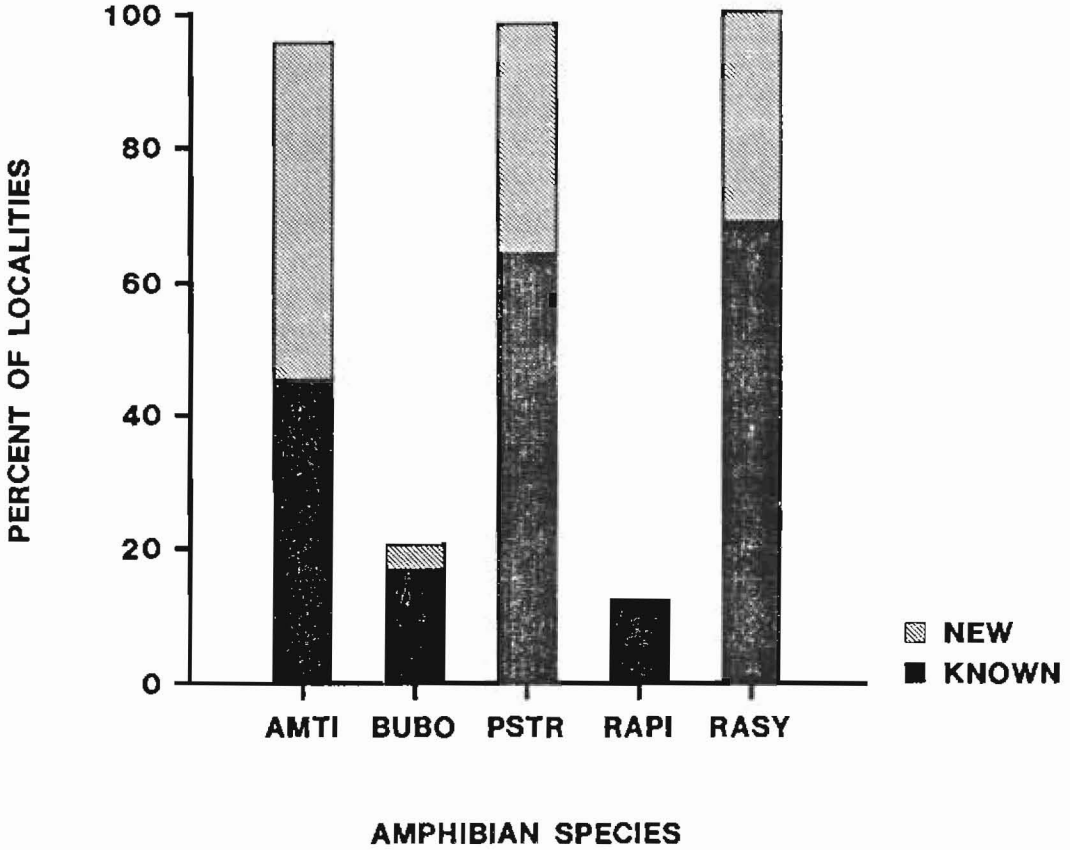

Figure 13. Percent of known and "new" locations occupied by tiger salamanders (AMTI), boreal toads (BUBO), chorus frogs (PSTR), leopard frogs (RAPI), and wood frogs (RASY).

of known localities occupied and low percentages of "new" localities (0% for leopard frogs), which indicates that these two species have declined severely. Extinction of leopard frog populations at some of the localities we surveyed have already been documented (Corn and Fogleman 1984). And, although we observed several breeding populations of boreal toads, the numbers found of this once abundant amphibian are not encouraging. The largest number of boreal toad egg masses observed in any population was three, with total reproductive failure in 1987 at Trap Lake, Larimer County, and in 1988 at Horseshoe Park, Rocky Mountain National Park. Boreal toads have also declined in northern New Mexico where they occur in a few localities (Carey 1987), and populations in the Rocky Mountains in central Colorado and Utah appear to have

declined since the mid-1970's (Stolzenburg 1989; C. Carey [Dept. Organismal, Environmental, and Population Biology, Univ. Colorado, Boulder, CO 80309] pers. comm.).

Has acid precipitation contributed to the declines of leopard frogs and boreal toads? We did collect evidence that some amphibian breeding habitats may undergo acidification during snowmelt, and high elevation habitats (> 2800 m) had lower pH and acid neutralizing capacity, hence greater susceptibility to acidification, than did low elevation sites (< 2800 m). However, the declines we observed do not match up well with sensitivities of habitats to acidification. The two species that appear to have declined occupy opposite ends of the elevation gradient. Boreal toads were most abundant in the high-elevation, sensitive habitats (Campbell 1970), but leopard frogs were most common in the lower elevation lakes with high pH and acid neutralizing capacity (Pennak 1969; Corn and Fogleman 1984). Chorus frogs, which did not decline and are possibly the least tolerant to acid of the species we tested, were common at all elevations.

It is unlikely that acid precipitation has affected leopard frog populations in Colorado and Wyoming, because they did not occupy sensitive habitats, and embryos do not suffer mortality until the pH drops below 5. Similarly, although boreal toads inhabit areas sensitive to acidification, we found no evidence that sufficient acidification has occurred to affect boreal toad reproduction. We found few localities with breeding season pH less than 6.0; in the laboratory, boreal toad embryos displayed no mortality until pH dropped below 4.9.

It is also doubtful that amphibian populations in the areas surveyed have been affected by elevated aluminum concentrations. The lowest pH measured was probably not low enough to mobilize aluminum bound in the sediments, and Freda et al. (*in press*) reported that if dissolved organic compounds are present most of the aluminum is complexed in non-toxic forms. At non-lethal pH, presence of organic compounds greatly increases embryonic tolerance to aluminum. At low pH, the organic compounds are toxic, but labile aluminum increases embryonic survival (Freda and McDonald *in press*; Freda et al. *in press*). This suggests that aluminum is not a significant threat to most amphibian populations. However, sensitivity to aluminum seems to vary widely among species, and western mountain waters can have appreciable aluminum concentrations and low organic carbon (Appendix B). We found that wood frog and boreal toad embryos tolerated higher aluminum concentrations than have been reported for wood frogs and American toads (*Bufo americanus*) in Canada (Clark and Hall 1985; Clark and LaZerte 1985). Our results should be interpreted cautiously because we did not determine the aluminum species to which embryos were exposed. We also did not test leopard frogs for sensitivity to aluminum, although most known localities of leopard frogs were lower elevation sites with relatively high pH. Mobilization of aluminum is not likely at these localities. However, our studies should be replicated and extended, with more complete

analysis of aluminum speciation, before concluding that Western amphibians are tolerant of high concentrations of aluminum.

If acid precipitation has not caused amphibian declines, then what has? Numerous possibilities remain to be investigated, including lethal and sublethal effects of other anthropogenic pollutants, extreme weather conditions, natural population fluctuations, introduced vertebrate predators, ecological succession of amphibian habitats, disease, and other factors acting alone or synergistically. Research into some of these possibilities is planned, and a broader survey of amphibian populations in the western United States may suggest additional hypotheses and explanations.

Because both leopard frogs and boreal toads were once widespread and abundant in our study area, the decline of both species and our inability to provide a reasonable explanation are alarming. Even if the declines represent natural fluctuations in the populations of both species, the related concepts of ecological crunches (Wiens 1977) and extinction vortexes (Gilpin and Soule 1986) suggest that our concern is justified. Variable environments periodically turn hostile and produce periods of intense selection pressure (ecological crunches) with associated declines in population size. If populations are too small, random demographic variation then makes extinction a common event. The effects of anthropogenic stresses, such as acidification, may be magnified if they occur during these crunches.

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Appendix A1. Known amphibian localities in Boulder County, Colorado. Ownership is in parentheses after the locality name (A-RNF = Arapaho-Roosevelt National Forest, Boulder = City of Boulder Municipal Watershed). Species abbrviations are: AMTI - tiger salamander; BUBO - boreal toad; PSTR - chorus frog; RAPI - leopard frog; RASY - wood frog.

Giggey Lake (private) 1.2 km S and 3 km E of Nederland, T1S R73W S20-21, 2591 m, Lat 39.95°N, Lon 105.47°W. USGS Quad Name: Tungsten

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1947 (BS/FC[1])	breeding
BUBO	(UCM[2])	no
PSTR	(UCM)	breeding
RAPI	(UCM)	no

Number of Visits, 1986: 0; 1987: 3; 1988: 0

Barker Reservoir (private) 0.8 km E of Nederland, T1S R72W S17, 2494 m, Lat 39.97°N, Lon 105.50°W. USGS Quad Name: Tungsten

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1967 (UCM)	no
BUBO	(UCM)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 3; 1988: 0

Eldora Lakes (private) 1.2 km S of Eldora, T1S R73W S29, 2856 m, Lat 39.94°N, Lon 105.57°W. USGS Quad Name: Nederland

Species	Years Observed	Observed 1986-1988
AMTI		no
BUBO	1948 (UCM)	no
PSTR		breeding
RAPI	1948 (UCM)	no

Number of Visits, 1986: 0; 1987: 3; 1988:0

Lost Lake (A-RNF) 4 km W of Eldora, T1S R74W S24, 2987 m, Lat 39.95°N, Lon 105.62°W. USGS Quad Name: Nederland

Species	Years Observed	Observed 1986-1988
AMTI		no
BUBO	1960 (UCM), 1961 (BS/FC)	breeding
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 2; 1988: 15

Jenny Lake (A-RNF) 1.6 km S and 7.9 km W of Eldora, T1S R74W S28, 3328 m, Lat 39.94°N, Lon 105.66°W. USGS Quad Name: East Portal

Species	Years Observed	Observed 1986-1988
AMTI		no
BUBO	1968 (Campbell 1970)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

King Lake (A-RNF) 0.8 km S and 10 km W of Eldora, T1S R74W S20, 3475 m, Lat 39.94°N, Lon 105.69°W. USGS Quad Name: East Portal

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1968 (Campbell 1970)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 1; 1988: 0

[1]Biological Surveys Collection, U.S. Fish and Wildlife Service, Ft.Collins, Co.

[2]University of Colorado Museum, Boulder

Muskee Lake (private) 3 km N and 1 km E of Nederland, T1S R73W S1, 2499 m, Lat 39.99°N, Lon 105.50°W. USGS Quad Name: Nederland

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1939 (Meyers 1939), 1941 (Hamilton 1949), 1947, 1948 (UCM), 1954 (Ten Broek 1954), 1963 (Reese 1969)	no
BUBO	1931 (Johnson 1932)	no
PSTR	1947 (BS/FC, UCM)	no
RAPI	1931 (Johnson 1932), 1947 (BS/FC), 1952 (Maslin 1959)	no

Number of Visits, 1986: 0; 1987: 3; 1988: 0

Rainbow Lakes (A-RNF) 5 km N and 5.9 km W of Nederland, T1N R73W S32, 3109 m, Lat 40.01°N, Lon 105.58°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1939 (Myers 1939)	no
BUBO	1939 (Myers 1939), 1947, 1957, 1963 (UCM),1968 (Campbell 1970)	yes
PSTR		breeding
RAPI	(UCM)	no

Number of Visits, 1986: 1; 1987: 3; 1988: 0

North Rainbow Lakes (A-RNF) 5.9 km N and 6.2 km W of Nederland, T1N R73W S29, 3182 m, Lat 40.01°N, Lon 105.58°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1901, 1903, 1904 (AMNH[3])	no
BUBO	1902 (AMNH)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

[3]American Museum of Natural History, New York

[4]Mark Noble, Mountain Research Station, University of Colorado, Nederland, Co 80466

Moraine Ponds (A-RNF/Boulder) 7.5 km N and 4.4 km W of Nederland, T1N R73W S21, 22, 27, 3048 m, Lat 40.02°N, Lon 105.56°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1932 (Oder 1932)	yes
BUBO	1932 (Oder 1932), 1955 (Maslin 1959), 1963 (UCM)	no
PSTR	1963 (UCM)	yes
RAPI	1932 (Oder 1932), 1947 (BS/FC)	no

Number of Visits, 1986: 2; 1987: 3; 1988: 0

Como Creek (A-RNF) 4.1 km S and 3.1 km W of Ward, T1N R73W S22, 3048 m, Lat 40.03°N, Lon 105.54°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1967-1969 (Campbell 1970)	no
PSTR	(Noble[4])	breeding
RAPI		no

Number of Visits, 1986: 2; 1987: 0; 1988: 0

North Boulder Creek Pond (Boulder) 3.8 km S and 6.6 km W of Ward, T1N R73W S17, 3292 m, Lat 40.04°N, Lon 105.58°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	(UCM)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 1; 1987: 0; 1988: 0

Albion Townsite (Boulder) 3.1 km S and 7.5 km W of Ward, T1N R73W S18, 3353 m, Lat 40.04°N, Lon 105.59°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1935 (UCM), 1968 (Campbell 1970)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 1; 1987: 3; 1988: 0

Lefthand Reservoir (private) 0.6 km S and 5.4 km W of Ward, T1N R73W S9, 3243 m, Lat 40.09°N, Lon 105.57°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1966-1969 (Campbell 1970)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 1; 1987: 3; 1988: 0

Red Rock Lake (A-RNF) 1.0 km N and 2.8 km W of Ward, T1N R73W S2, 3048 m, Lat 40.08°N, Lon 105.54°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1939 (Myers 1939), 1946, 1947 (Hamilton 1949), 1948 (UCM)	no
BUBO	1907 (CM[5]), 1913, 1927 (Maslin 1959), 1968 (Campbell 1970)	no
PSTR	1958 (UCM)	no
RAPI		no

Number of Visits, 1986: 2; 1987: 3; 1988: 0

Long Lake (A-RNF) 6.9 km W of Ward, T1N R73W S5, 3207 m, Lat 40.08°N, Lon 105.58°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	(UCM)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 1; 1987: 3; 1988: 0

Lake Isabelle (A-RNF) 0.4km S and 9.1 km W of Ward, T1N R73W S7, 3313 m, Lat 40.07°N, Lon 105.61°W. USGS Quad Name: Ward

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1947 (UCM)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 3; 1988: 0

Gold Lake (private) 1.2 km N and 5 km E of Ward, T1N R72W S3, 2627 m, Lat 40.09°N, Lon 105.45°W. USGS Quad Name: Gold Hill

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1968 (Campbell 1970)	no
PSTR		breeding
RAPI		no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

Minnie Lake (private) 6.1 km N and 3.4 km E of Ward, T2N R72W S16, 2666 m, Lat 40.13°N, Lon 105.47°W. USGS Quad Name: Raymond

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1954, 1955 (Ten Broek 1955), 1957 (UCM)	breeding
BUBO	1957 (UCM)	no
PSTR	1957 (UCM)	no
RAPI	1957 (UCM, CM)	no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

[5]Carnegie Museum of Natural History, Pittsburg, Pa

Appendix A2. Known amphibian localities in Rocky Mountain National Park, Colorado.

Glacier Gorge (including Blue and Black lakes) Larimer County, 10.5 km S and 9.5 km W of Estes Park, T4N R74W S26 35 36, 3170 m, Lat 40.28°N, Lon 105.65°W. USGS Quad Name: McHenrys Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1957 (RMNP[6], UCM)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Bear Lake (including Nymph Lake) Larimer County, 7 km S and 10.6 km W of Estes Park, T4N R74W S14, 2925 m, Lat 40.31°N, Lon 105.65°W. USGS Quad Name: McHenrys Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1979 (Roselund and Stevens 1986)	breeding
BUBO	1933 (UCM) 1954 (RMNP)	yes
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 5

Glacier Basin (Glacier Creek, Boulder Brook, and Sprague Lake) Larimer County, 5.5 km S and 7 km W of Estes Park, T4N R73W S7 8 18, 2680 m, Lat 40.32°N, Lon 105.61°W. USGS Quad Name: Longs Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1941 (RMNP), 1951 (UCM)	breeding
PSTR	1972 (RMNP)	breeding
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 6

[6]Rocky Mountain National Park, wildlife observations file

[7]National Museum of Natural History, Washington, D. C.

Hallowell Park Larimer County, 3.8 km S and 7.2 km W of Estes Park, T4N R73W S6, 2555 m, Lat 40.33°N, Lon 105.61°W. USGS Quad Name: Longs Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1955 (RMNP)	no
BUBO	1955 (RMNP)	no
PSTR	1956 (RMNP)	breeding
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 2

Spruce Lake Larimer County, 3.4 km S and 13.8 km W of Estes Park, T4N R74W S4, 2950 m, Lat 40.35°N, Lon 105.68°W. USGS Quad Name: McHenrys Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1979 (RMNP)	yes
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 2

Cub Lake Larimer County, 2.9 km S and 10 km W of Estes Park, T4N R74W S2, 2630 m, Lat 40.35°N, Lon 105.65°W. USGS Quad Name: McHenrys Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1972 (UCM)	no
BUBO	1953 (RMNP)	no
PSTR		breeding
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Mary's Lake (private) Larimer County, 3.1 km S and 0.5 km W of Estes Park, T4N R73W S2, 2450 m, Lat 40.35°N, Lon 105.52°W. USGS Quad Name: Longs Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1895 (USNM[7])	no
BUBO		no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Sheep Lakes Larimer County, 3.4 km N and 8.2 km W of Estes Park, T5N R73W S18, 2590 m, Lat 40.40°N, Lon 105.62°W. USGS Quad Name: Estes Park

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1955 (RMNP)	breeding
BUBO	1955 (RMNP)	no
PSTR	(UCM)	breeding
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 6

Horseshoe Park Larimer County, 3.5 km N and 9.4 km W of Estes Park, T5N R74W S13, 2600 m, Lat 40.41°N, Lon 105.63°W. USGS Quad Name: Trail Ridge

Species	Years Observed (Source)	Observed 1986-1988
AMTI		breeding
BUBO		breeding
PSTR		breeding
RAPI	1974 (Corn)	no

Number of Visits, 1986: 0; 1987: 0; 1988: 7

Lost Lake Larimer County, 14.5 km N and 6.9 km W of Estes Park, T6N R73W S8, 3260 m, Lat 40.51°N, Lon 105.60°W. USGS Quad Name: Pingree Park

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1975 (Stevens[8])	yes
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Poudre Lake Larimer County, 18.8 km N and 1.5 km E of Grand Lake, T5N R75W S4, 3275 m, Lat 40.42°N, Lon 105.81°W. USGS Quad Name: Fall River Pass

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	(UCM)	yes
PSTR		no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 0; 1988: 2

[8]David Stevens, Biologist, Rocky Mountain National Park, Estes Park, Co 80517

Colorado River (near Timber Creek) Grand County, 15 km N and 1.9 km W of Grand Lake, T5N R75W S8, m, Lat 40.39°N, Lon 105.84°W. USGS Quad Name: Fall River Pass

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1980 (Haynes and Aird 1981)	no
PSTR	1980 (Haynes and Aird 1981)	no
RAPI		no
RASY	1980 (Haynes and Aird 1981)	yes

Number of Visits, 1986: 0; 1987: 0; 1988: 2

Never Summer Ranch Grand County, 13 km N and 2.8 km W of Grand Lake, T5N R76W S25, 2710 m, Lat 40.37°N, Lon 105.85°W. USGS Quad Name: Grand Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1980 (Haynes and Aird 1981)	breeding
RAPI		no
RASY	1980 (Haynes and Aird 1981)	breeding

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Onahu Creek (above U.S. highway 34) Grand County, 7.2 km N and 1.6 km W of Grand Lake, T4N R76W S12, 2680 m, Lat 40.32°N, Lon 105.84°W. USGS Quad Name: Grand Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1980 (Haynes and Aird 1981)	no
RAPI		no
RASY	1960 (RMNP)	no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Onahu Creek (below U.S. highway 34) Grand County, 6.9 km N and 1.9 km W of Grand Lake, T4N R76W S12, 2670 m, Lat 40.32°N, Lon 105.84°W. USGS Quad Name: Grand Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1980 (Haynes and Aird 1981)	no
BUBO		no
PSTR	1980 (Haynes and Aird 1981)	breeding
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Green Mountain Trail Grand County, 6.2 km N of Grand Lake, T4N R75W S17-18, 2800 m, Lat 40.31°N, Lon 105.80°W. USGS Quad Name: Grand Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1980 (Haynes and Aird 1981)	breeding
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 0; 1988: 2

Big Meadows Grand County, 6.2 km N and 1.1 km E of Grand Lake, T4N R75W S17, 2870 m, Lat 40.31°N, Lon 105.78°W. USGS Quad Name: Grand Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		yes
PSTR	1980 (Haynes and Aird 1981)	breeding
RAPI		no
RASY		breeding

Number of Visits, 1986: 0; 1987: 0; 1988: 2

Harbison Ditch Grand County, 0.9 km N and 1.2 km W of Grand Lake, T4N R75W S31, 2645 m, Lat 40.27°N, Lon 105.84°W. USGS Quad Name: Grand Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1980 (Haynes and Aird 1981)	no
RAPI		no
RASY	1959 (RMNP), 1980 (Haynes and Aird 1981)	breeding

Number of Visits, 1986: 0; 1987: 0; 1988: 2

Shadow Mountain Lake Grand County, 1 km S and 1 km W of Grand Lake, T3N R75-76W S6-7, 18-19,12-13, 24, 2550 m, Lat 40.13°N, Lon 105.84°W. USGS Quad Name: Shadow Mountain

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1961 (BS/FC)	no
PSTR	1961 (BS/FC)	breeding
RAPI	1961 (BS/FC)	no
RASY		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Appendix A3. Known amphibian localities in Larimer County, Colorado. Ownership is in parentheses after the locality name (A-RNF = Arapaho-Roosevelt National Forest).

Stratton Park (private) 1.5 km N and 10 km W of Bellvue, T8N R71W S24, 2134 m, Lat 40.64°N, Lon 105.29°W. USGS Quad Name: Poudre Park

Species	Years Observed (Source)	Observed 1986-1988
AMTI		yes
BUBO		no
PSTR		no
RAPI	1963 (BS/FC)	no

Number of Visits, 1986: 0; 1987: 1; 1988: 0

Buckhorn Mountain (private) 2.5 km S and 11.9 km W of Bellvue, T8N R71W S35, 2499 m, Lat 40.61°N, Lon 105.32°W. USGS Quad Name: Buckhorn Mountain.

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1963 (BS/FC)	breeding
BUBO		no
PSTR	1963 (BS/FC)	breeding
RAPI	(UCM)	no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

Stove Prairie (private) 15.6 km W of Bellvue, T8N R71W S29, 2195 m, Lat 40.61°N, Lon 105.35°W. USGS Quad Name: Poudre Park

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1962 (BS/FC)	breeding
BUBO		no
PSTR	1963 (BS/FC)	breeding
RAPI		no

Number of Visits, 1986: 0; 1987: 1; 1988: 0

Dowdy Lake (A-RNF) 2.8 km E of Red Feather Lakes, T10N R73W S27, 2478 m, Lat 40.79°N, Lon 105.55°W. USGS Quad Name: Red Feather Lakes

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		no
RAPI	1974 (Corn and Fogleman 1984)	no

Number of Visits, 1986: 0; 1987: 3; 1988: 0

West Lake (A-RNF) 0.9 km S and 2 km E of Red Feather Lakes, T10N R73W S34, 2499 m, Lat 40.79°N, Lon 105.56°W. USGS Quad Name: Red Feather Lakes

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1950 (UCM)	no
BUBO		no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 4; 1988: 0

Prairie Divide (A-RNF) 8.1 km N and 8.8 km E of Red Feather Lakes, T11N R72W S32, 2365 m, Lat 40.88°N, Lon 105.48°W. USGS Quad Name: Cherokee Park

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1976 (Corn)	breeding
BUBO		no
PSTR	1975 (BS/FC)	breeding
RAPI	1976 (Corn and Fogleman 1984)	no

Number of Visits, 1986: 1; 1987: 4; 1988: 0

Raspberry Ponds (A-RNF/private) 5 km N and 6.9 km E of Red Feather Lakes, T10N R72W S7, 2408 m, Lat 40.84°N, Lon 105.50°W. USGS Quad Name: Red Feather Lakes

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1974, 1980 (Corn)	breeding
BUBO		no
PSTR		no
RAPI	1974, 1980 (Corn and Fogleman 1984)	no

Number of Visits, 1986: 1; 1987: 2; 1988: 0

Deer Stop (A-RNF) 5.8 km N and 6.6 km E of Red Feather Lakes, T10N R73W S12, 2438 m, Lat 40.84°N, Lon 105.51°W. USGS Quad Name: Red Feather Lakes

Species	Years Observed (Source)	Observed 1986-1988
AMTI		yes
BUBO		no
PSTR		no
RAPI	1974 (BS/FC, Corn and Fogleman 1984)	no

Number of Visits, 1986: 1; 1987: 2; 1988: 0

Creedmore Lake #1 (A-RNF) 6.2 km N of Red Feather Lakes, T10N R73W S4, 2521 m, Lat 40.85°N, Lon 105.59°W. USGS Quad Name: Red Feather Lakes

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1979 (Corn)	no
BUBO		no
PSTR		no
RAPI	1977, 1979 (BS/FC, Corn and Fogleman 1984)	no

Number of Visits, 1986: 1; 1987: 3; 1988: 0

Creedmore Lake #2 (A-RNF) 6.6 km N and 0.3 km E of Red Feather Lakes, T10N R73W S4, 2536 m, Lat 40.85°N, Lon 105.58°W. USGS Quad Name: Red Feather Lakes

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		no
RAPI	1979 (Corn and Fogleman 1984)	no

Number of Visits, 1986: 1; 1987: 3; 1988: 0

Creedmore Lake #3 (A-RNF) 6.9 km N and 0.8 km E of Red Feather Lakes, T10N R73W S4, 2530 m, Lat 40.85°N, Lon 105.58°W. USGS Quad Name: Red Feather Lakes

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1979 (Corn)	breeding
BUBO		no
PSTR	1979 (Corn)	breeding
RAPI	1979 (Corn and Fogleman 1984)	no

Number of Visits, 1986: 1; 1987: 3; 1988: 0

Trap Park (A-RNF) 2.4 km N and 16.3 km E of Gould, T7N R75W S29, 3200 m, Lat 40.55°N, Lon 105.82°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1961 (BS/FC)	no
PSTR	1961, 1962 (BS/FC, Spencer 1964), 1964 (BS/FC)	no
RAPI		no
RASY		no

Number of Visits, 1986: ; 1987: 3; 1988: 1

Trap Meadow (A-RNF) 3.8 km N and 17.8 km E of Gould, T7N R75W S21, 3036 m, Lat 40.56°N, Lon 105.81°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964), 1966 (Tordoff et al. 1976)	no
RAPI		no
RASY		no

Number of Visits, 1986: 2; 1987: 5; 1988: 5

Trap Lake (A-RNF) 3.7 km N and 17.3 km E of Gould, T7N R75W S21, 3048 m, Lat 40.56°N, Lon 105.81°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1961, 1962 (BS/FC, UCM)	breeding
PSTR	1961-1963 (Spencer 1964; BS/FC), 1966 (Tordoff et al. 1976)	no
RAPI	1964 (BS/FC)	no
RASY		no

Number of Visits, 1986: 3; 1987: 6; 1988: 6

Spencer 15 (A-RNF) 4.4 km N and 17.5 km E of Gould, T7N R75W S21, 3094 m, Lat 40.56°N, Lon 105.81°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964)	no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 2

Spencer 16 (A-RNF) 4.2 km N and 16.8 km E of Gould, T7N R75W S20, 3042 m, Lat 40.56°N, Lon 105.82°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964)	breeding
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 1

Spencer 14 (A-RNF) 4.6 km N and 16.7 km E of Gould, T7N R75W S20, 3124 m, Lat 40.57°N, Lon 105.82°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964)	no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

Spencer 12&13 (A-RNF) 5.4 km N and 16.9 km E of Gould, T7N R75W S16, 3048 m, Lat 40.57°N, Lon 105.°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964)	no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

Spencer 21 (A-RNF) 6.5 km N and 17.3 km E of Gould, T7N R75W S9, 2920 m, Lat 40.57°N, Lon 105.82°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964)	breeding
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

Spencer 11 (A-RNF) 5.5 km N and 16.3 km E of Gould, T7N R75W S17, 2972 m, Lat 40.58°N, Lon 105.83°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964)	no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

[9]David Pettus, Department of Biology, Colorado State University, Ft. Collins, Co 80523

Spencer 10 (A-RNF) 5 km N and 15.9 km E of Gould, T7N R75W S17, 2972 m, Lat 40.57°N, Lon 105.83°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964)	no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 0

Mosquitos (A-RNF) 6.1 km N and 15.5 km E of Gould, T7N R75W S17, 3001 m, Lat 40.57°N, Lon 105.84°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964), 1965-1966 (Tordoff et al. 1976), 1977 (Corn)	breeding
RAPI		no
RASY		yes

Number of Visits, 1986: 0; 1987: 2; 1988: 1

Lily Pond (A-RNF) 5.4 km N and 15 km E of Gould, T7N R75W S18, 2896 m, Lat 40.57°N, Lon 105.84°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1961 (BS/FC)	no
PSTR	1961-1963 (Spencer 1964; BS/FC), 1965-1970 (Matthews 1967; Tordoff 1971), 1973 (Hoppe 1975), 1977 (Corn)	breeding
RAPI		no
RASY	1962 (UCM, BS/FC), 1966-1970 (Bagdonas 1971)	yes

Number of Visits, 1986: 5; 1987: 5; 1988: 5

Sylvatica Pond (A-RNF) 4.8 km N and 14.5 km E of Gould, T7N R75W S19, 3018 m, Lat 40.56°N, Lon 105.85°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964), 1966 (Tordoff et al. 1976)	breeding
RAPI		no
RASY	1965 (Pettus[9])	no

Number of Visits, 1986: 0; 1987: 2; 1988: 2

Three Story Marsh (A-RNF) 5 km N and 14 km E of Gould, T7N R75W S18, 2972 m, Lat 40.57°N, Lon 105.86°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964), 1966 (Tordoff et al. 1976)	no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 1

Slash Pond (A-RNF) 5.8 km N and 14.7 km E of Gould, T7N R75W S18, 2944 m, Lat 40.57°N, Lon 105.85°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964), 1966 (Tordoff et al. 1976)	breeding
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Spencer 7 (A-RNF) 6.2 km N and 14.8 km E of Gould, T7N R75W S18, 2871 m, Lat 40.55°N, Lon 105.85°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1961-1963 (Spencer 1964)	no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988: 1

Nancy Pond (private) 8.5 km N and 15.7 km E of Gould, T7N R75W S5, 2743 m, Lat 40.6°N, Lon 105.83°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		yes
PSTR	1978 (Pettus)	breeding
RAPI		no
RASY	1978 (Pettus)	breeding

Number of Visits, 1986: 0; 1987: 4; 1988: 0

Upper Gravel Pit (private) 8.3 km N and 15.1 km E of Gould, T7N R75W S5, 2774 m, Lat 40.6°N, Lon 105.84°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1966 (Tordoff et al. 1976)	breeding
RAPI		no
RASY	1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 3; 1987: 4; 1988: 1

Chambers Lake (A-RNF) 8 km N and 14.3 km E of Gould, T7N R75W S6, 2804 m, Lat 40.6°N, Lon 105.85°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1915 (Maslin 1959), 1950, 1958 (UCM), 1961, 1963 (BS/FC), 1972 (UCM)	no
PSTR	1950 (UCM), 1961, 1962 (BS/FC)	no
RAPI	1961, 1962 (BS/FC)	no
RASY	(UCM)	no

Number of Visits, 1986: 0; 1987: 1; 1988: 0

Matthews Pond (A-RNF) 7.8 km N and 14.8 km E of Gould, T7N R75W S7, 2804 m, Lat 40.6°N, Lon 105.84°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR	1965 (Pettus)	breeding
RAPI		no
RASY	1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 6; 1987: 6; 1988: 6

Lost Lake (A-RNF) 9.4 km N and 14.6 km E of Gould, T7N R75W S6, 2804 m, Lat 40.61°N, Lon 105.85°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1961 (BS/FC)	no
PSTR	1962 (BS/FC)	no
RAPI	1961 (BS/FC)	no
RASY	1966-1970 (Bagdonas 1971)	no

Number of Visits, 1986: 0; 1987: 3; 1988: 0

Spruce Bog (A-RNF) 10.7 km N and 14.5 km E of Gould, T8N R75W S31, 2804 m, Lat 40.62°N, Lon 105.85°W. USGS Quad Name: Chambers Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		breeding
RAPI		no
RASY	1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 0; 1987: 4; 1988: 0

Tunnel (A-RNF) 16 km N and 14.1 km E of Gould, T8N R75W S7, 2618 m, Lat 40.67°N, Lon 105.85°W. USGS Quad Name: Boston peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1958 (UCM)	no
PSTR	1980 (Hammerson[10])	breeding
RAPI	1958 (UCM)	no
RASY	1958 (UCM)	breeding

Number of Visits, 1986: 0; 1987: 3; 1988: 1

Lily Pond Lake (A-RNF) 3.1 km N and 23.8 km W of Rustic, T9N R76W S24, 2591 m, Lat 40.73°N, Lon 105.86°W. USGS Quad Name: Boston Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		no
RAPI		no
RASY	(Maslin 1959)	no

Number of Visits, 1986: 0; 1987: 3; 1988: 0

[10]Goeffrey Hammerson, The Nature Conservancy, 55 High Street, Middletown, Ct 06457

Appendix A4. Known amphibian localities in the Park Range, Colorado. Ownership is in parentheses after the locality name (RNF = Routt National Forest).

Slack-Weiss Reservoir (RNF) Jackson County, 32.5 km S and 6 km W of Walden, T5N R80W S3, 2745 m, Lat 40.43°N, Lon 106.36°W. USGS Quad Name: Buffalo Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		breeding
BUBO	1968 (UCM)	breeding
PSTR	1968 (UCM)	breeding
RAPI	1968 (UCM)	no
RASY		breeding

Number of Visits, 1986: 0; 1987: 1; 1988: 1

Dumont Lake (RNF) Grand County, 9 km S and 17 km E of Steamboat Springs, T5N R82W S8, 2920 m, Lat 40.40°N, Lon 106.63°W. USGS Quad Name: Mount Werner

Species	Years Observed (Source)	Observed 1986-1988
AMTI		breeding
BUBO	(KU[11])	no
PSTR		breeding
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 0; 1988: 3

Colorado Creek (RNF) Jackson County, 28 km S and 27 km W of Walden, T6N R82W S21, 2740 m, Lat 40.47°N, Lon 106.60°W. USGS Quad Name: Rabbit Ears Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		breeding
BUBO	1958 (UCM)	no
PSTR	1958 (UCM)	breeding
RAPI	1958 (UCM)	yes
RASY		breeding

Number of Visits, 1986: 0; 1987: 1; 1988: 1

Burns Reservoir (RNF) Jackson County, 17 km S and 27 km W of Walden, T7N R82W S16, 2620 m, Lat 40.58°N, Lon 106.60°W. USGS Quad Name: Teal Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1946 (UCM), 1975 (Engmann[12])	no
PSTR	1946 (UCM), 1980 (Haynes and Aird 1981)	breeding
RAPI	(MVZ), 1975 (Engmann)	breeding
RASY	1946 (UCM)	no

Number of Visits, 1986: 0; 1987: 1; 1988: 0

Newcomb Creek (RNF) Jackson County, 15 km S and 25 km W of Walden, T7N R82W S10, 2640 m, Lat 40.60°N, Lon 106.59°W. USGS Quad Name: Teal Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		breeding
BUBO		no
PSTR	1946 (UCM)	breeding
RAPI	(MVZ[13]), 1980 (Haynes and Aird 1981)	breeding
RASY	1980 (Haynes and Aird 1981)	breeding

Number of Visits, 1986: 0; 1987: 1; 1988: 0

Lone Pine Creek (private) Jackson County, 2.5 km N and 22 km W of Walden, T9N R81W S18, 2650 m, Lat 40.75°N, Lon 106.55°W. USGS Quad Name: Pitchpine Mountain

Species	Years Observed (Source)	Observed 1986-1988
AMTI		breeding
BUBO	1980 (Haynes and Aird 1981)	no
PSTR		breeding
RAPI	1980 (Haynes and Aird 1981)	no
RASY		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

[11] University of Kansas Museum of Natural History, Lawrence

[12] Richard Engmann, Denver Wildlife Research Center, Building 16, P. O. Box 25266, Denver Federal Center, Denver, Co 80225

[13] Museum of Vertebrate Zoology, University of California, Berkeley

Big Creek Lakes (RNF) Jackson County, 21 km N and 27.5 km W of Walden, T11N R82W S16, 2740 m, Lat 40.92°N, Lon 106.61°W. USGS Quad Name: Pearl

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1950 (UCM), 1980 (Haynes and Aird 1981)	breeding
PSTR	1950 (UCM), 1980 (Haynes and Aird 1981)	breeding
RAPI	1950 (UCM), 1980 (Haynes and Aird 1981)	no
RASY	1950 (UCM), 1980 (Haynes and Aird 1981)	breeding

Number of Visits, 1986: 0; 1987: 1; 1988: 2

Seedhouse (RNF) Routt County, 33 km N and 3.7 km E of Steamboat Springs, T10N R84W S34-35, 2500 m, Lat 40.79°N, Lon 106.78°W. USGS Quad Name: Farwell Mountain

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	(UCM)	no
PSTR		no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 0; 1988: 1

Appendix A5. Known amphibian localities in Wyoming. Ownership is in parentheses after the locality name (MBNF = Medicine Bow National Forest).

Happy Jack (MBNF) Albany County, 7 km S and 15 km E of Laramie, T15N R72W S24, 2499 m, Lat 41.26°N, Lon 105.41°W. USGS Quad Name: Ragged Top Mountain

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1946 (UW[14]), 1950 (Baxter 1952)	no
PSTR	1949 (UMMZ[15])	breeding
RAPI	1947 (UW), 1950 (Baxter 1952)	no

Number of Visits, 1986: 0; 1987: 3; 1988 0

Summit (MBNF) Albany County, 8.1 km S and 12.5 km E of Laramie, T15N R72W S35, 2682 m, Lat 41.24°N, Lon 105.43°W. USGS Quad Name: Sherman Mountains

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1946 (UW)	no
PSTR		no
RAPI		no

Number of Visits, 1986: 0; 1987: 2; 1988 0

North Lodgepole Creek (MBNF) Albany County, 3.5 km S and 16.5 km E of Laramie, T15N R71W S7, 2500 m, Lat 41.28°N, Lon 105.39°W. USGS Quad Name: Ragged Top Mountain

Species	Years Observed (Source)	Observed 1986-1988
AMTI		breeding
BUBO		no
PSTR		breeding
RAPI	1950 (Baxter 1952)	breeding

Number of Visits, 1986: 0; 1987: 4; 1988

Heidrich Creek (MBNF) Albany County, 4.5 km S of Foxpark, T12N R78W S4, 2774 m, Lat 41.05°N, Lon 106.16°W. USGS Quad Name: Foxpark

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1948 (UW)	no
PSTR		breeding
RAPI		no
RASY		breeding

Number of Visits, 1986: 0; 1987: 2; 1988 0

Bear Creek (MBNF) Albany County, 3.0 km S of Foxpark, T13N R78W S33, 2774 m, Lat 41.05°N, Lon 106.15°W. USGS Quad Name: Foxpark

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1961 (BS/FC)	no
PSTR		breeding
RAPI		no
RASY		breeding

Number of Visits, 1986: 0; 1987: 2; 1988 0

Woods Creek (MBNF) Albany County, 0.4 km S and 5 km E of Foxpark, T13N R77W S19, 2713 m, Lat 41.07°N, Lon 106.09°W. USGS Quad Name: Woods Landing

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		breeding
RAPI		no
RASY	1948 (UW)	breeding

Number of Visits, 1986: 0; 1987: 4; 1988 1

[14] University of Wyoming Museum, Laramie

[15] University of Michigan Museum of Zoology, Ann Arbor

Evans Creek West (MBNF) Albany County, 0.9 km S of Foxpark, T13N R78W S28, 2755 m, Lat 41.06°N, Lon 106.15°W. USGS Quad Name: Foxpark

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		breeding
RAPI		no
RASY	1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 1; 1987: 3; 1988 1

Evans Creek East (MBNF) 0.6 km S and 0.8 km E of Foxpark, T13N R78W S27, 2750 m, Lat 41.06°N, Lon 106.14°W. USGS Quad Name: Foxpark

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		breeding
RAPI		no
RASY	1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 0; 1987: 5; 1988 1

Fox Creek (MBNF) Albany County, Foxpark, T13N R78W S21, 2755 m, Lat 41.06°N, Lon 106.16°W. USGS Quad Name: Foxpark

Species	Years Observed (Source)	Observed 1986-1988
AMTI		breeding
BUBO	1950 (Baxter 1952)	no
PSTR	1950 (Baxter 1952)	breeding
RAPI		no
RASY	1950 (Baxter 1952), 1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 1; 1987: 4; 1988 0

Spur Ponds (MBNF) Albany County, 0.8 km N and 0.3 km E of Foxpark, T13N R78W S21, 2743 m, Lat 41.08°N, Lon 106.15°W. USGS Quad Name: Foxpark

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		breeding
RAPI		no
RASY	1965 (AMNH), 1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 0; 1987: 3; 1988 1

Railroad Pond (MBNF) Albany County, 1.7 km N and 0.4 km E of Foxpark, T13N R78W S15, 2758 m, Lat 41.07°N, Lon 106.15°W. USGS Quad Name: Foxpark

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		breeding
RAPI		no
RASY	1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 1; 1987: 3; 1988 1

Strain Creek (MBNF) Albany County, 2.9 km S and 1.2 km E of Albany, T14N R78W S25-26, 2719 m, Lat 41.15°N, Lon 106.11°W. USGS Quad Name: Lake Owen

Species	Years Observed (Source)	Observed 1986-1988
AMTI	1949 (UW, Baxter 1952)	no
BUBO	1949 (UW, Baxter 1952)	no
PSTR	1949 (UMMZ, Baxter 1952)	breeding
RAPI	1950 (Baxter 1952)	no
RASY	1950 (Baxter 1952)	yes

Number of Visits, 1986: 2; 1987: 4; 1988 0

Porter Lake (private) 11.9 km E of Centennial, T15N R77W S1, 2256 m, Lat 41.29°N, Lon 105.99°W. USGS Quad Name: Millbrook

Species	Years Observed (Source)	Observed 1986-1988
AMTI		yes
BUBO	1948 (UW) 1949-1950 (Baxter 1952)	no
PSTR	1948 (UW) 1950 (Baxter 1952)	breeding
RAPI	1948 (UW) 1950 (Baxter 1952)	no
RASY		no

Number of Visits, 1986: 0; 1987: 4; 1988 0

Hanging Lake (MBNF) Albany County, 5.2 km N and 3.1 km W of Centennial, T16N R78W S20, 2768 m, Lat 41.34°N, Lon 106.18°W. USGS Quad Name: Centennial

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1950 (Baxter 1952)	no
PSTR	1950 (Baxter 1952)	no
RAPI		no
RASY	1950 (Baxter 1952)	no

Number of Visits, 1986: 0; 1987: 3; 1988 0

Little Laramie River (MBNF) Albany County, 5.8 km N and 1.9 km W of Centennial, T16N R78W S16, 2774 m, Lat 41.35°N, Lon 106.17°W. USGS Quad Name: Centennial

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		breeding
RAPI		no
RASY	1966-1970 (Bagdonas 1971)	breeding

Number of Visits, 1986: 0; 1987: 4; 1988 0

Trails Divide Pond (MBNF) Albany County, 5.6 km N and 7.2 km W of Centennial, T16N R79W S14, 3040 m, Lat 41.34°N, Lon 106.23°W. USGS Quad Name: Centennial

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1936 (Blake 1945), 1947 (UW)	no
PSTR	1946, 1947 (UW)	breeding
RAPI		no
RASY	1946, 1947 (UW)	no

Number of Visits, 1986: 0; 1987: 2; 1988 0

Swastika Lake (MBNF) Albany County, 5 km N and 7.2 km W of Centennial, T16N R79W S23, 3048 m, Lat 41.34°N, Lon 106.23°W. USGS Quad Name: Centennial

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1936 (Blake 1945), 1947 (UCM)	no
PSTR	1940 (UW), 1947 (UCM)	no
RAPI	1947 (UCM)	no
RASY		no

Number of Visits, 1986: 0; 1987: 2; 1988 0

Mill Pond Lake (MBNF) Albany County, 6.2 km N and 8.8 km W of Centennial, T16N R79W S14, 3353 m, Lat 41.35°N, Lon 106.24°W. USGS Quad Name: Centennial

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1946 (UW), 1949-1951 (Baxter 1952)	no
PSTR		no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 4; 1988 0

Glacier Ponds (MBNF) Albany County, 6.2 km N and 14.4 km W of Centennial, T16N R79W S18, 3353 m, Lat 41.34°N, Lon 106.30°W. USGS Quad Name: Medicine Bow Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1948 (UW)	no
PSTR		no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 3; 1988 0

South Gap Ponds (MBNF) Albany County, 7.8 km N and 12.9 km W of Centennial, T16N R79W S8, 3353 m, Lat 41.34°N, Lon 106.30°W. USGS Quad Name: Medicine Bow Peak

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1947 (UW)	no
PSTR		no
RAPI		no
RASY		no

Number of Visits, 1986: 0; 1987: 3; 1988 0

Six Mile Gap (MBNF) Carbon County, 3.8 km S and 20 km W of Foxpark, T12N R80W S4, 2317 m, Lat 41.04°N, Lon 106.40°W. USGS Quad Name: Elkhorn Point

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	1940 (UW)	no
PSTR		no
RAPI	1940 (UW)	no
RASY		no

Number of Visits, 1986: 0; 1987: 1; 1988 0

South Brush Creek (MBNF) Carbon County, 2 km N and 2 km E of Ryan Park, T16N R81W S22, 2615 m, Lat 41.32°N, Lon 106.49°W. USGS Quad Name: Phantom Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	(UK)	yes
PSTR		breeding
RAPI		no
RASY		breeding

Number of Visits, 1986: 0; 1987: 4; 1988 0

Turpin Reservoir Ponds (MBNF) Carbon County, 12.5 km N and 8.5 km E of Ryan Park, T17N R80W S17, 2896 m, Lat 41.44°N, Lon 106.39°W. USGS Quad Name: Turpin Reservoir

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO	(UK)	no
PSTR		breeding
RAPI		no
RASY		breeding

Number of Visits, 1986: 0; 1987: 5; 1988 0

Long Lake (MBNF) Carbon County, 22.5 km S and 3.5 km E of Elk Mountain, T18N R80W S27, 2750 m, Lat 41.49°N, Lon 106.36°W. USGS Quad Name: Sand Lake

Species	Years Observed (Source)	Observed 1986-1988
AMTI		no
BUBO		no
PSTR		breeding
RAPI		no
RASY	1978 (UW)	breeding

Number of Visits, 1986: 1; 1987: 6; 1988 0

Appendix B1. Water chemistry characteristics of amphibian localities in the mountains of Colorado and Wyoming.

Locality	Elev. meters	Date	pH	ANC µeq/L	Electrical Conduct. µS/m	Ca^{++} mg/L	Mg^{++} mg/L	Na^{+} mg/L	K^{+} mg/L	NH_4^{+} mg/L	Cl^{-} mg/L	F^{-} mg/L	$SO_4^{=}$ mg/L	NO_3^{-} mg/L	SiO_2 mg/L	Total P mg/L	Total Al mg/L
Boulder County, Colorado																	
Muskee Lake	2499	5/29/87	7.4	294	39	3.9	1.1	2.01	0.45	<0.01	0.2	0.09	2.8	0.03	12.0	<0.01	0.26
Giggey Lake	2591	5/26/87	7.4	1068	154	15.9	5.5	6.27	1.50	0.06	11.8	0.36	2.6	<0.02	13.8	0.03	<0.09
Minnie Lake	2666	5/29/87	7.8	709	111	9.9	2.4	4.73	5.29	0.15	9.1	0.84	2.4	<0.02	1.3	0.04	<0.09
Eldora Lakes	2818	5/26/87	6.1	107	18	1.2	0.5	0.41	0.95	0.19	0.2	0.12	0.6	<0.02	0.4	0.04	<0.09
Moraine Ponds	3048	5/27/87	6.4	76	17	1.4	0.4	0.85	0.33	0.09	0.2	0.06	2.0	<0.02	2.1	0.01	<0.09
Red Rock Lake	3048	5/28/87	6.8	275	32	3.5	0.9	1.15	0.35	0.06	0.2	0.07	0.8	<0.02	0.6	0.02	<0.09
Rainbow Lakes	3109	5/27/87	5.9	145	26	3.0	0.3	1.12	0.28	0.01	0.1	0.08	3.2	0.63	2.2	<0.01	<0.09
Long Lake	3207	5/28/87	6.5	105	21	2.2	0.3	0.70	0.39	0.05	0.2	0.03	2.6	0.56	4.3	0.01	<0.09
Left Hand Res.	3242	5/28/87	6.5	87	20	1.6	0.4	1.17	0.28	0.12	0.2	0.06	3.1	<0.02	0.9	0.03	<0.09
Albion Townsite	3353	5/27/87	6.5	111	22	2.4	0.3	0.60	0.19	0.05	0.1	0.07	3.3	0.12	2.2	<0.01	<0.09
Larimer County, Colorado																	
Prairie Divide	2365	5/27/87	7.4	2918	313	27.7	9.3	22.06	10.42	0.08	3.8	4.40	4.2	<0.02	16.6	0.02	<0.09
West Lake	2499	5/27/87	8.1	571	68	7.1	1.9	2.94	0.89	0.08	0.8	0.25	2.9	<0.02	1.3	0.02	<0.09
Creedmore L #1	2521	5/27/87	9.0	1853	217	7.5	8.2	27.15	3.37	0.01	8.2	4.90	0.7	<0.02	1.4	0.01	<0.09
Lily Pond Lake	2591	5/27/87	7.4	425	44	3.8	1.4	1.70	1.85	0.17	0.1	0.15	0.2	<0.02	0.1	0.03	<0.09
Tunnel	2618	5/27/87	7.0	312	40	3.8	1.2	2.21	0.96	0.06	0.2	0.12	2.1	<0.02	13.6	0.01	0.93
Spruce Bog	2804	5/27/87	6.6	256	36	4.4	0.9	1.37	0.5	0.09	0.4	0.15	0.8	<0.02	1.7	0.02	0.22
Trap Lake	3048	5/27/87	6.8	157	20	2.2	0.3	1.13	0.46	0.10	0.1	0.07	0.8	<0.02	5.6	0.04	<0.09
Trap Park	3200	5/27/87	6.5	150	22	2.2	0.4	1.15	0.77	0.01	0.2	0.03	1.1	<0.02	11.0	0.01	0.09
Albany and Carbon counties, Wyoming																	
Porter Lake	2256	5/28/87	8.1	7566	725	87.1	40.6	20.36	0.71	0.04	0.8	1.15	32.9	<0.02	27.4	<0.01	<0.09
Lodgepole Creek	2500	5/06/87	7.2	903	103	17.8	1.6	2.52	2.00	0.06	0.9	1.30	5.7	<0.02	10.5	0.02	<0.09
Ryan Park	2591	5/28/87	7.3	212	26	3.5	0.6	0.75	0.22	0.01	0.4	0.03	1.3	<0.02	6.4	<0.01	0.25
Woods Creek	2713	5/28/87	7.4	1770	198	28.6	4.2	4.33	1.09	0.01	7.8	0.18	1.3	0.05	15.4	0.11	0.11
Long Lake #1	2750	5/18/87	-	150	28	3.0	0.9	0.65	0.75	0.06	0.7	0.02	1.0	<0.02	1.9	0.13	0.34
Long Lake #2	2750	5/18/87	-	154	26	2.5	1.0	0.73	0.30	0.04	0.5	0.02	0.8	<0.02	0.8	0.11	0.20
Long Lake #3	2713	5/28/87	6.4	278	39	5.0	1.4	0.78	1.22	0.13	0.4	0.09	0.6	<0.02	3.1	0.03	0.25
Strain Creek	2728	5/28/87	7.9	1593	159	23.3	4.0	3.27	0.11	0.03	0.6	0.17	0.7	<0.02	20.7	<0.01	<0.09
Evans Creek East	2758	5/28/87	7.3	1043	104	15.0	2.2	2.91	0.27	0.06	0.2	0.12	0.7	<0.02	8.5	0.01	<0.09
Hanging Lake	2768	5/28/87	8.1	1816	189	20.5	9.6	2.52	0.40	0.05	5.6	0.19	1.4	<0.02	3.4	<0.01	<0.09
Little Laramie	2774	5/28/87	7.2	698	72	9.7	3.2	0.39	0.97	0.10	0.3	0.12	0.3	<0.02	0.5	0.02	<0.09
Turpin Reservoir	2896	5/28/87	6.3	61	12	1.3	0.4	0.44	0.12	0.05	0.2	0.04	0.5	<0.02	0.4	0.02	<0.09
Mill Pond Lake	3139	5/28/87	8.4	723	75	9.0	3.2	0.3	0.26	0.06	0.2	<0.02	1.0	0.05	1.6	<0.01	<0.09

(continued)

Appendix B1. Concluded.

Locality	Elev. meters	Date	pH	ANC µeq/L	Electrical Conduct. µS/m	Ca^{++} mg/L	Mg^{++} mg/L	Na^{+} mg/L	K^{+} mg/L	NH_4^{+} mg/L	Cl^{-} mg/L	F^{-} mg/L	$SO_4^{=}$ mg/L	NO_3^{-} mg/L	SiO_2 mg/L	Total P mg/L	Total Al mg/L
Park Range, Colorado																	
Dumont Lake	2920	6/25/88	6.4	110	-	1.58	0.43	0.48	0.49	0.02	0.04	-	0.07	<0.01	1.14	0.01	0.06
Rocky Mountain National Park, Colorado																	
Bierstadt Lake	2865	6/22/88	6.8	121	-	2.33	0.65	1.32	0.84	0.07	0.47	-	-	<0.01	2.78	0.02	0.27
Bierstadt Pond	2865	6/22/88	6.1	86	-	1.98	0.49	1.10	0.30	0.11	0.26	-	-	<0.01	5.05	0.02	0.49
Lost Lake	3260	6/22/88	7.0	134	-	2.39	0.34	1.31	0.38	0.16	0.24	-	1.49	0.03	4.96	0.02	0.38

Appendix B2. Spring water chemistry (weekly measurements) at selected amphibian localities in 1987 and 1988.

Locality	Elev. meters	Date	pH	ANC µeq/L	Electrical Conduct. µS/m	Ca^{++} mg/L	Mg^{++} mg/L	Na^{+} mg/L	K^{+} mg/L	NH_4^{+} mg/L	Cl^{-} mg/L	F^{-} mg/L	$SO_4^{=}$ mg/L	NO_3^{-} mg/L	SiO_2 mg/L	Total P mg/L	Total Al mg/L	Total Organic Carbon µeq/L
Larimer County, Colorado																		
Matthews Pond	2804	4/29/87	-	119	24	1.9	0.6	0.68	1.51	0.11	0.5	0.02	1.6	<0.02	4.1	0.03	0.16	-
		5/06/87	5.9	159	26	2.7	0.6	0.83	1.24	0.12	0.5	0.06	1.4	0.15	3.4	0.03	0.24	13
		5/14/87	6.1	150	29	2.6	0.7	0.8	1.69	0.10	0.5	0.02	0.8	<0.02	1.0	0.05	0.15	18
		5/21/87	-	146	27	2.4	0.7	0.71	1.52	0.01	0.4	0.08	1.0	<0.02	0.6	0.15	0.14	18
		5/27/87	6.2	166	27	2.5	0.7	0.69	1.45	0.03	0.4	0.12	0.8	<0.02	0.5	0.04	0.13	29
		5/08/88	6.0	159	-	1.89	0.65	0.51	1.57	0.14	0.23	0.01	1.23	<0.01	3.32	0.02	<0.01	-
		5/15/88	6.1	113	-	1.92	0.58	0.68	1.31	0.02	0.45	0.01	1.42	<0.01	3.42	0.02	0.13	-
		5/23/88	6.0	108	-	2.40	0.66	0.99	1.14	0.01	0.64	-	1.72	<0.01	4.11	0.02	0.16	-
		5/30/88	6.0	133	-	2.79	0.74	1.11	1.22	0.03	0.63	-	1.46	<0.01	3.79	0.02	0.20	-
		6/05/88	6.2	143	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		6/12/88	6.1	176	-	3.44	0.94	1.16	1.76	0.11	0.81	-	1.09	<0.01	1.95	0.02	0.19	-
		6/20/88	6.6	163	-	3.48	0.93	1.41	1.90	0.03	1.04	-	0.95	0.19	1.15	0.01	0.12	-
Lily Pond	2896	4/29/87	-	90	17	1.2	0.3	0.50	1.64	0.10	0.6	0.02	0.7	0.09	3.0	0.01	0.11	-
		5/06/87	5.9	79	16	1.3	0.3	0.72	0.67	0.11	0.3	0.08	0.7	<0.02	5.3	0.02	0.19	9
		5/14/87	6.2	119	25	1.8	0.4	1.36	1.01	0.05	0.6	0.03	0.8	<0.02	4.2	0.15	0.20	15
		5/21/87	-	112	21	1.5	0.3	1.24	0.89	0.03	0.3	0.13	1.0	<0.02	7.3	0.11	0.12	14
		5/27/87	6.5	132	21	1.5	0.3	1.38	1.04	0.12	0.3	0.09	1.0	<0.02	7.4	0.02	0.11	13
		5/15/88	6.1	107	-	1.52	0.34	0.84	1.16	0.23	0.37	0.01	1.28	0.57	3.02	0.02	0.02	-
		5/23/88	6.0	84	-	1.49	0.32	0.91	0.81	0.05	0.24	-	0.99	0.13	8.11	0.03	0.09	-
		5/30/88	7.1	111	-	1.64	0.32	1.28	0.98	0.01	-	-	-	-	10.19	0.03	0.08	-
		6/05/88	6.3	122	-	1.75	0.32	1.31	1.01	0.01	0.27	-	1.11	0.07	11.41	0.03	0.08	-
		6/12/88	6.4	141	-	1.79	0.36	1.53	1.14	0.05	0.26	-	1.01	<0.01	11.09	0.12	0.09	-
		6/20/88	6.8	168	-	1.95	0.39	1.80	1.49	0.01	0.34	-	0.75	0.05	9.97	0.02	0.05	-
		6/27/88	7.0	185	-	2.05	0.42	1.98	1.56	0.01	0.24	-	0.67	<0.01	11.71	0.03	0.15	-
Trap Lake	3048	5/15/88	6.3	110	-	2.02	0.33	0.85	0.39	0.01	0.39	<0.01	1.82	<0.01	5.91	0.02	0.17	-
		5/23/88	6.3	111	-	2.34	0.37	0.95	0.37	0.01	0.28	-	1.77	0.07	5.76	0.04	0.07	-
		5/30/88	6.3	91	-	1.93	0.29	0.80	0.45	0.01	0.28	-	1.36	0.07	5.16	0.02	0.10	-
		6/05/88	6.6	122	-	2.27	0.29	0.93	0.53	<0.01	0.31	-	1.06	0.14	6.06	0.03	0.07	-
		6/12/88	6.1	103	-	2.24	0.43	1.36	0.53	0.09	0.08	-	0.81	<0.01	10.94	0.13	0.16	-
		6/20/88	7.4	203	-	3.07	0.32	1.37	0.96	0.01	0.15	-	1.33	<0.01	5.95	0.03	0.02	-
		6/27/88	7.2	229	-	3.26	0.36	1.46	1.06	<0.01	0.16	-	1.25	<0.01	4.62	0.03	0.05	-

(continued)

Appendix B2. Concluded.

Locality	Elev. meters	Date	pH	ANC µeq/L	Electrical Conduct. µS/m	Ca^{++} mg/L	Mg^{++} mg/L	Na^{+} mg/L	K^{+} mg/L	NH_4^{+} mg/L	Cl^{-} mg/L	F^{-} mg/L	$SO_4^{=}$ mg/L	NO_3^{-} mg/L	SiO_2 mg/L	Total P mg/L	Total Al mg/L	Total Organic Carbon µeq/L
Rocky Mountain National Park, Colorado																		
Horseshoe Park	2600	5/05/88	7.6	1218	-	12.60	4.61	4.27	2.63	0.01	0.48	0.69	<0.01	<0.01	13.16	0.02	<0.01	-
#1		5/12/88	7.7	1225	-	12.60	4.53	3.20	3.19	0.01	0.56	0.72	<0.01	<0.01	13.91	0.02	<0.01	-
		5/19/88	7.6	1572	-	16.20	6.28	4.20	3.46	0.01	-	-	-	-	14.45	0.07	0.04	-
		5/25/88	8.0	2159	-	25.60	9.16	4.86	3.94	0.02	0.45	-	0.14	0.03	15.17	0.05	<0.01	-
		6/01/88	7.6	1502	-	18.40	6.26	3.20	2.52	0.12	0.12	-	0.14	<0.01	15.04	0.04	0.06	-
		6/08/88	7.2	2017	-	22.40	7.52	5.04	4.09	0.03	0.17	-	0.30	0.14	17.10	0.03	0.24	-
		6/16/88	7.1	1472	-	18.20	5.84	3.91	2.13	0.02	0.11	-	0.15	<0.01	13.01	0.02	0.04	-
Horseshoe Park	2600	6/01/88	6.9	491	-	4.57	1.34	3.22	0.93	0.03	0.33	-	0.20	0.07	18.53	0.09	0.05	-
#3		6/08/88	6.9	626	-	6.48	1.82	3.60	0.38	<0.01	0.50	-	0.14	0.07	18.62	0.09	0.07	-
		6/16/88	6.4	721	-	8.03	2.20	3.62	0.84	0.01	0.34	-	<0.01	<0.01	21.16	0.15	0.03	-
Fan Lake	2600	5/05/88	7.6	186	-	2.57	0.85	1.47	0.55	0.01	0.33	0.12	3.11	<0.01	6.03	0.02	0.10	-
		5/12/88	7.1	150	-	2.06	0.69	1.51	0.49	0.02	0.34	0.12	2.96	0.04	5.22	0.02	0.04	-
		5/19/88	7.0	134	-	2.02	0.64	1.04	0.51	0.01	0.34	0.08	2.11	0.33	4.52	0.02	0.13	-
		5/25/88	6.7	125	-	2.77	0.88	1.26	0.61	0.01	0.37	-	2.29	0.20	5.31	0.02	0.03	-
		6/03/88	6.9	140	-	2.19	0.68	1.05	0.42	0.01	0.28	-	2.33	0.14	4.88	0.02	0.04	-
		6/08/88	7.0	105	-	1.77	0.59	0.86	0.40	0.01	0.22	-	2.18	0.49	4.28	0.01	0.11	-
		6/16/88	6.5	87	-	1.83	0.54	0.85	0.36	<0.01	0.16	-	1.49	0.46	4.15	0.01	0.10	-
Boulder County, Colorado																		
Lost Lake (inlet)	2987	5/25/88	7.0	319	-	6.98	1.41	1.53	0.54	0.01	-	-	-	-	6.59	0.02	<0.01	-
(outlet)		5/25/88	7.0	336	-	7.10	1.43	1.71	0.71	0.02	-	-	-	-	7.00	0.02	<0.01	-
(inlet)		6/01/88	7.4	325	-	3.80	0.69	1.46	0.48	0.03	0.29	-	-	0.07	4.49	0.02	0.34	-
(outlet)		6/01/88	7.4	332	-	6.52	1.32	1.43	0.47	0.03	0.28	-	-	0.03	6.38	0.02	0.02	-
(outlet)		6/08/88	7.3	263	-	5.96	1.19	1.34	0.46	0.01	-	-	-	-	6.12	0.02	<0.01	-
(outlet)		6/15/88	7.3	276	-	5.69	1.14	1.76	0.66	0.01	0.80	-	6.29	<0.01	5.41	0.01	0.09	-
(outlet)		6/22/88	7.4	300	-	-	-	1.53	0.45	0.09	0.14	-	-	<0.01	-	0.02	-	-

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. Biological Report 80(40.26)	2.	3. Recipient's Accession No.

4. Title and Subtitle
Acid Precipitation Studies in Colorado and Wyoming: Interim Report of Surveys of Montane Amphibians and Water Chemistry

5. Report Date June 1989

6.

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
National Ecology Research Center
U.S. Fish and Wildlife Service
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Fort Collins, CO 80526-2899

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
U.S. Department of the Interior
Fish and Wildlife Service
Research and Development
Washington, DC 20240

13. Type of Report & Period Covered
Interim, 1986-88

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Surveys for amphibians were conducted in the Rocky Mountains of northern Colorado and southern Wyoming from 1986 to 1988. The northern leopard frog (Rana pipiens) was present at only 12% of historically known localities, and the boreal toad (Bufo boreas) was present at 17% of known localities. Chorus frogs (Pseudacris triseriata) suffered a catastrophic decline in population size in one population monitored since 1961, but regionally, this species was observed in 64% of known localities. Tiger salamanders (Ambystoma tigrinum) and wood frogs (Rana sylvatica) were present at 45% and 69% of known localities respectively. Acid neutralizing capacity, pH, specific conductivity, and cation concentrations in water at amphibian localities were negatively correlated with elevation. However, in mountain ponds and lakes, pH was rarely less than 6.0 during the amphibian breeding season. In laboratory tests of the tolerance of embryos to acid, the LC50 pH was 4.8 for chorus frogs, 4.4-4.7 for leopard frogs, 4.4-4.5 for boreal toads, and 4.2-4.3 for wood frogs. Survival of wood frog embryos declined when exposed to aluminum concentrations of 100 µg/L or greater, but boreal toad embryos survived exposure to aluminum concentrations of 400 µg/L.

17. Document Analysis a. Descriptors
Acidification, amphibia, frogs, salamanders, toads

b. Identifiers/Open-Ended Terms
Acid rain, boreal toad (Bufo boreas), chorus frog (Pseudacris triseriata), northern leopard frog (Rana pipiens), tiger salamander (Ambystoma tigrinum), wood frog (Rana sylvatica)

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Release unlimited	Unclassified	viii + 56
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

☆ U.S. GOVERNMENT PRINTING OFFICE: 1989--676-041/5097 Region #8