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TURNING POPULATION TREND MONITORING INTO ACTIVE CONSERVATION: CAN WE SAVE THE CASCADES FROG (*RANA CASCADAE*) IN THE LASSEN REGION OF CALIFORNIA?

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Abstract.**—Monitoring the distribution, population size, and trends of declining species is necessary to evaluate their vulnerability to extinction. It is the responsibility of scientists to alert management professionals of the need for preemptive action if a species approaches imminent, regional extirpation. This is the case with *Rana cascadae* (Cascades Frog) populations near Lassen Peak. From 1993 to 2007, we conducted 1,873 amphibian surveys at 856 sites within Lassen Volcanic National Park and Lassen National Forest, California, USA. These surveys encompassed all *R. cascadae* habitats: ponds, lakes, meadows, and streams on those lands. We found frogs at only six sites during 14 years of surveys, and obtained one report of a single frog at one additional locality. These sites represented < 1% of the historically suitable habitat within the Lassen region. The number of *R. cascadae* in the Lassen area has declined since 1991, and one population is now extirpated. We found no evidence of reproduction in most of the populations, and reproduction at all but one of the other sites remained lower than the annual reproductive output of one breeding pair for > 12 years. Causes for the decline remain unclear, but introduced trout, disease, and pesticides are likely factors. We recommend that (1) additional protection for *R. cascadae* within 50 km of Lassen Peak; (2) investigation of the genetics of *R. cascadae* in California; (3) research into the role of possible causative factors in these declines; and (4) implementation of a feasibility study to captive breed and reintroduce *R. cascadae* in the Lassen area.**

Key Words.—amphibian; Cascades Frog; conservation; declining amphibian; Lassen; population status; *Rana cascadae*

INTRODUCTION

Scientists and managers often underestimate the vulnerability of small populations to extinction (Gilpin and Soulé 1986; Fagan and Holmes 2006). This shifts the timing of management intervention to the last moment, when the situation is critical and extinction or regional extirpations are likely. For example, the number of California Condors (*Gymnogyps californianus*) dropped to 27 before conservationists captured the surviving individuals for a captive breeding program (Snyder and Snyder 2000). Waiting until populations contain only a few individuals greatly reduces genetic diversity, and increases the financial costs of recovery. Models of extinction risk in vertebrates have demonstrated that population size and trends are the best predictors of extinction (O'Grady et al. 2004). In a review of 10 endangered vertebrate populations, Fagan and Holmes (2006) reported that once populations dropped below 50 individuals, they did not increase in abundance. To prevent extinction of vertebrate taxa, the World Conservation Union (IUCN [International Union for the Conservation of Nature, World Conservation Union]. 1987. Policy statement on captive breeding. Available from http://www.iucn.org/themes/ssc/publications/policy/captive_breeding.htm. (Accessed 17 February 2008). recommends close cooperation between scientists, land managers, and captive-breeding specialists when field surveys demonstrate that populations have fallen below 1,000 individuals in the wild. Once scientists document low population numbers and downward trends, they have a responsibility to communicate the risk, so that appropriate agencies can act before it is too late.

Rana cascadae (Cascades Frog) inhabits the mountains of Washington, Oregon, and northern California, USA. The southern-most part of the range occurs in the vicinity of Lassen Peak, where Fellers and Drost (1993) located no *R. cascadae* at 16 historic localities, and found that *R. cascadae* occupied only 2% of the suitable sites surveyed (1 of 50 sites). Since 1991, four large-scale surveys have been conducted to evaluate the occurrence of aquatic-breeding amphibians throughout the Lassen region (Fellers 1998; Koo, M.S., J.V. Vindum, and M. McFarland. 2004. Results of 02-CS-11050650-029, The 2003 California Academy of Sciences Survey: Amphibians and reptiles of the Lassen National Forest. California Academy of Sciences. 175

TABLE 1. Unpublished surveys conducted for *Rana cascadae* between 1993 and 2007.

Surveyors[1]	Survey Area[2]	Year Surveyed	Number of Surveys (or Survey Days)	Number of Unique Sites
NPS / USGS	LNF and LVNP	1993 - 2007	790	649
USFS / CDFG	LNF	2002	527	527
CAS	LNF	2003	80	80
USFS / SOU	LVNP	2004, 2007	470	365
Total			**1,873**	**856**

1. NPS - National Park Service, Point Reyes National Seashore; USGS – U.S. Geological Survey, Western Ecological Research Center; USFS – U.S. Forest Service, Pacific Southwest Research Station; CDFG - California Department of Fish and Game; CAS – California Academy of Sciences; SOU – Southern Oregon University.
2. LNF - Lassen National Forest, LVNP - Lassen Volcanic National Park.

p.; Welsh, H.W., and K.L. Pope. 2004. Impacts of introduced fishes on the native amphibians of northern California wilderness areas: Final Report to the California Department of Fish and Game, contract number P0010025 AM#1 with US Forest Service, Redwood Sciences Laboratory.; Stead, J.E., H.H. Welsh, and K.L. Pope. 2005. Survey of amphibians and fishes at all lentic habitats in Lassen Volcanic National Park: A report to the National Park Service. LVNP Study Number: LAVO-00717 contracted with Southern Oregon University and US Forest Service, Redwood Sciences Laboratory.). Annual surveys also took place at most of the known *R. cascadae* sites. Each of the four surveys reported extremely low numbers of *R. cascadae* populations; as well as low numbers of individuals within those populations.

Fellers and Drost (1993) speculated that the declines in the Lassen region resulted from a combination of local factors including: (1) the presence of non-native, predatory fish; (2) the loss of breeding habitat due to a five-year drought; and (3) the gradual loss of open meadows and associated aquatic habitats due to successional changes caused by fire suppression. Since then, numerous studies in the western United States have tried to identify the causes of amphibian declines, particularly in protected montane regions where declines have not been due to obvious habitat loss. Potential causative factors include the introduction of fish into historically fishless habitats (e.g., Knapp and Matthews 2000; Knapp 2005; Welsh et al. 2006), disease (e.g., Fellers et al. 2001; Briggs et al. 2005), the downwind drift of airborne pesticides from agricultural areas (e.g., Davidson 2004; Fellers et al. 2004), and synergy among these or other factors (e.g., Blaustein et al. 2003).

Perhaps because the results of *R. cascadae* surveys from 1993-2007 remain unpublished or were published in government reports from several different agencies, the precarious status of *R. cascadae* has not been fully appreciated. Management agencies have not completed management plans that address *R. cascadae*, the U.S. Fish and Wildlife Service (FWS) has not provided protection under the Endangered Species Act, and no one has petitioned the FWS to list the species. We used data from four unpublished reports and subsequent unpublished surveys to: (1) summarize the current status of *R. cascadae* in the Lassen region; (2) assess causes for the decline; (3) identify research needs; and (4) highlight the need for formal protection.

METHODS

Study Animal.—*Rana cascadae* is a montane frog endemic to the Pacific Northwest of the US where it is distributed throughout the Cascade Mountains of Oregon and Washington, and in three disjunct mountain ranges: the Olympic Peninsula of Washington, the Klamath-Siskiyou region of northwestern California, and the vicinity of Lassen Peak in north-central California. Populations of *R. cascadae* in Mount Rainier and Olympic National Parks in Washington appear to be doing well (Adams et al. 2001; Barbara Samora, pers. comm.; Christopher Pearl, pers. comm.). Some Oregon populations appear to be declining, but the species remains well distributed within its historic range within the state (Blaustein and Wake 1990, Christopher Pearl, pers. comm.). In the Trinity Alps of the Klamath-Siskiyou region, *R. cascadae* is relatively abundant (Welsh et al. 2006). Approximately half of the Trinity Alps Wilderness sites surveyed in 1999-2002 had *R. cascadae* present (Hartwell Welsh, unpubl. data). Two current studies found three populations with over 200 adult frogs each (Justin Garwood, Karen. Pope, and Sharon Lawler, unpubl. data).

The area historically occupied by *R. cascadae* around Lassen Peak includes public land managed by Lassen National Forest (47,500 km^2) and Lassen Volcanic National Park (500 km^2). Historic accounts and museum records indicate that *R. cascadae* was previously abundant in this area (Grinnell et al. 1930; Stebbins, R.C. 1951. Field notes on file at the Museum of Vertebrate Zoology, University of California, Berkeley, CA.). In the 1920s, Grinnell et al. (1930) visited Emerald Lake (Lassen Volcanic National Park) and reported finding “one frog for nearly every yard around

TABLE 2. High counts of each life history stage of *Rana cascadae* during 1993 - 2007 surveys in Lassen National Forest and Lassen Volcanic National Park, California. A single *Rana cascadae* was found at Butt Creek, an area not included in our surveys, in 1996. *R. cascadae* were first found in Warner Creek in 2002, so there were no counts from 1993-1999.

Population	Life History Stage	High Count 1993 - 1999	High Count 2000 - 2007
Crumbaugh Creek	Adult	3	0
	Subadult	0	0
	Larvae	0	0
	Egg Masses	0	0
Juniper Lake and ponds	Adult	3	2
	Subadult	6	1
	Larvae	0	0
	Egg Masses	0	0
Warner Creek	Adult	-	1
	Subadult	-	2
	Larvae	-	0
	Egg Masses	-	0
Carter Meadow	Adult	10	9
	Subadult	25	5
	Larvae	8	14
	Egg Masses	2	13
Colby / Willow Creeks	Adult	8	3
	Subadult	11	1
	Larvae	25	0
	Egg Masses	1	0
Old Cow Creek / Cutter Meadow	Adult	-	2
	Subadult	-	10
	Larvae	-	15
	Egg masses	-	23

the lake." Fellers and Drost (1993) reported significant *R. cascadae* population declines in this part of the range.

Study Area and Field Surveys.—Our study area included all *R. cascadae* habitat on public lands within a 50-km radius of Lassen Peak (6,360 km^2; Fig. 1), along with a very limited amount of private land where we had permission to conduct surveys. This area includes the entire range of *R. cascadae* within the southern isolate as depicted in standard field guides (e.g., Stebbins 2003; Olson 2005). To assess the status of *R. cascadae*, we used data sets from four extensive amphibian surveys in the Lassen area subsequent to the work of Fellers and Drost (1993). Herpetologists from the California Academy of Sciences, Southern Oregon University, USDA Forest Service (USFS), and U.S. Geological Survey (USGS) carried out this research (Table 1). Some of these surveys were exhaustive in their attempt to visit every habitat (ponds, lakes, wet meadows, and streams) used by *R. cascadae*. Unmapped habitat features were surveyed when located. Surveys conducted by these four groups were entirely independent, and some of the surveys overlapped a subset of sites. All surveys used the same technique; visual encounter surveys (VES) to locate amphibians (Crump and Scott 1994; Fellers and Freel 1995). Trained field crews walked the shoreline and wadeable parts of ponds, lakes, streams, and meadows and recorded the presence, species, life stage, and relative abundance of all amphibians encountered. Dip nets were used to sample larvae and capture adults. Crews searched under banks and submerged woody debris along the shore for hidden animals.

We defined a site as a discrete pond, lake, meadow, or stream segment. There was no minimum distance between sites. Occasionally, it was difficult to determine whether two adjacent ponds should be considered one or two sites. In unusually dry years the ponds might be discrete water bodies, while in particularly wet years, the ponds might merge together, at least at the beginning of the season. This situation was rare and we used our best judgment to decide what would occur in a typical year. Different habitats received unique site designations; hence, a stream

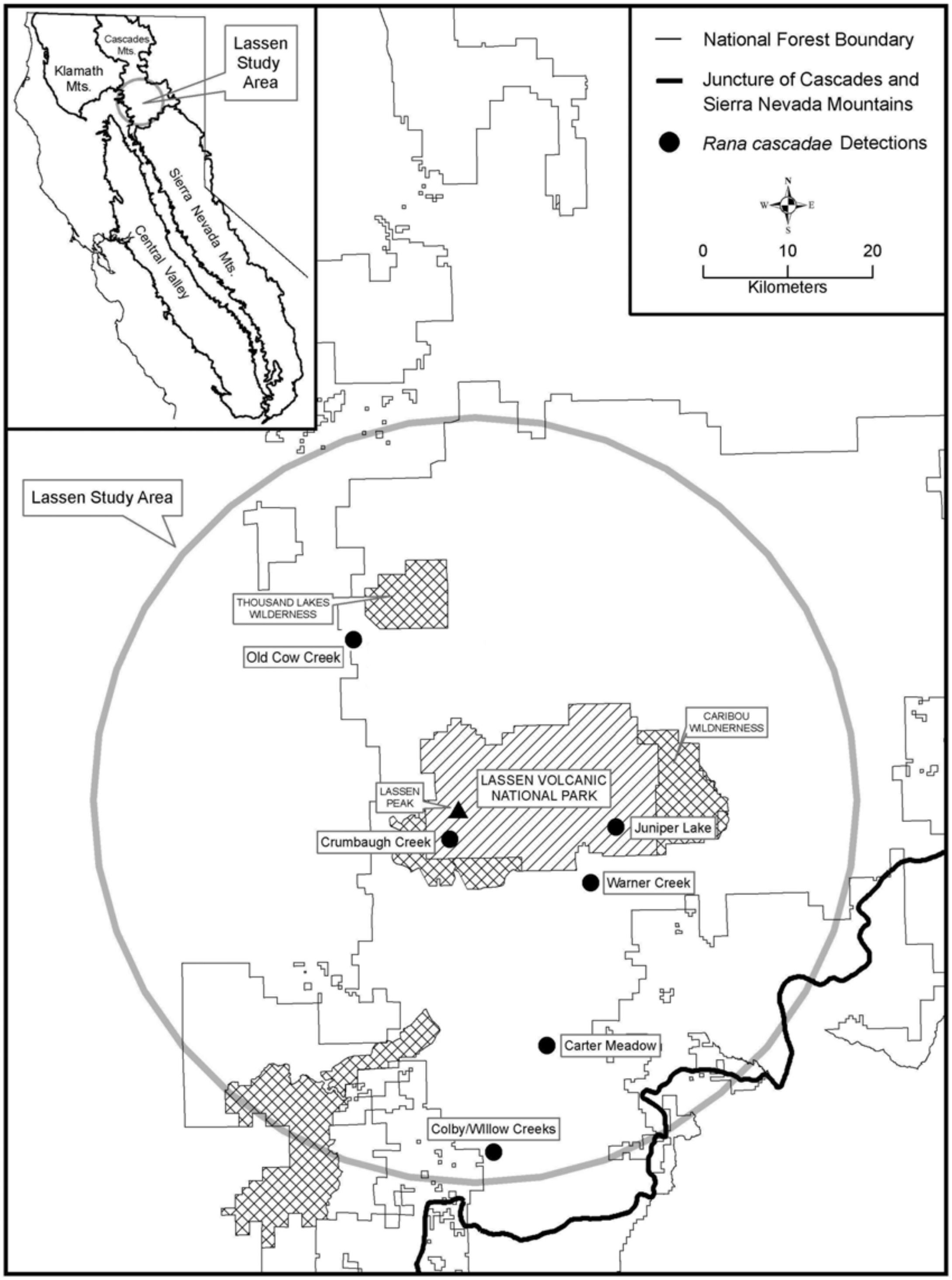

FIGURE 1. Map of California showing key geographic areas: Cascades Mountains, Sierra Nevada, Klamath-Siskiyou region, and the Central Valley of California, USA.

flowing into a lake would be two sites. We analyzed data using exact binominal tests (Quantitative Skills: Consultancy for Research and Statistics. Simple interactive statistical analysis. Available from http://www.quantitativeskills.com/sisa/distributions/binomial.htm [Accessed 17 February 2008]) with an $\alpha = 0.05$ to evaluate statistical significance.

TABLE 3. Distance (km) between populations of *Rana cascadae* in the Lassen region of California, USA.

	Crumbaugh Creek	Juniper Lake	Warner Creek	Carter Meadow	Colby / Willow Creeks
Rumbaugh Creek	-	-	-	-	-
Juniper Lake	14.1	-	-	-	-
Warner Creek	15.4	4.2	-	-	-
Carter Meadow	25.5	26.1	21.0	-	-
Colby / Willow Creeks	35.7	38.7	33.8	12.9	-
Old Cow Creek / Cutter Meadow	28.3	37.7	37.6	53.1	61.1

RESULTS

Surveys.—From 1993 to 2007, we conducted 1,873 surveys for *R. cascadae* at 856 unique sites (Table 1). We located frogs at only six sites within the study area (Table 2, Fig. 1). This number is < 1% of the sites suitable for *R. cascadae* within the Lassen area. The total number of adult and subadult *R. cascadae* detected in the Lassen area declined significantly from 1993-2007 (exact binomial test, $P < 0.0001$, Table 2). For two of the sites (Carter Meadow and Colby / Willow Creeks) the number of frogs present in the 1990s allowed for site-specific statistical analysis; both sites showed a significant decline (Carter: $P = 0.0038$; Colby / Willow: $P = 0.0026$; Table 2).

No *R. cascadae* were found along Crumbaugh Creek since 1994, even though we conducted 10 field surveys at or near that site since we found the last *R. cascadae. R. cascadae* are probably extirpated at that location. Juniper Lake is a 232 ha lake with 10 mapped ponds or small lakes within 1.0 km of its edge. Two of the ponds had adult or subadult *R. cascadae* on at least one occasion between 1993 and 2007. The ponds are 180 m and 290 m from the shore of Juniper Lake, and 2.1 km from each other. We consider Juniper Lake and the adjacent ponds to represent a single population and refer to them as one site. Similarly, Colby Creek (4.7 km long) and Willow Creek (5.8 km long) are short stream segments that flow together just before joining a larger tributary. *Rana cascadae* occurred along the lower 2 km of Colby Creek and the lower 4 km of Willow Creek. The most distant frogs were 3.3 km apart (straight-line distance). We treat frogs in these two confluent creeks as one population. The Old Cow Creek population is 5.0 km from Cutter Meadow, but frogs occur in drainages that flow within 1.3 km of each other in an area with relatively flat terrain. We consider these two sites as a single population that we call Old Cow Creek.

If we treat Juniper Lake and the two immediately adjacent ponds as one site, the Colby and Willow Creeks as one site, and the Old Cow Creek / Cutter Meadow areas as one site, we identified six *R. cascadae* populations within the isolated Lassen portion of the species' range. In 1996, a single *R. cascadae* was seen in Butt Creek, Lassen National Forest (Melanie McFarland, unpubl. data). Though we have not observed *R. cascadae* there on five of our own surveys, we consider that observation to be valid, in which case it would represent another small population, 28 km (straight-line distance) from the Colby and Willow Creek locality. We first found *R. cascadae* along Warner Creek in 2002. We conducted one survey along Warner Creek prior to this observation (1998), and three subsequent; 2002, 2006, and 2007. Warner Creek is an unusually complex habitat with lots of woody debris and side-pools. It is not surprising that a few frogs could be overlooked; however, it is unlikely that a large population would go undetected.

On 15 occasions, field crews from two different agencies visited *R. cascadae* sites during the same field season. Biologists conducting field work were not aware of the number of *R. cascadae* found by the other survey, or that other surveys took place. Of the 15 repeat surveys, seven resulted in identical counts for adult frogs, four differed by one, and three differed by two. These repeat counts show that field surveys were comparable in detecting the presence and relative abundance of frogs. For example, Juniper Lake is a large lake with an 8.1 km perimeter. The USGS surveyed it on 17 Aug 2006 and the USFS conducted a survey on 25 Aug 2006. On both occasions, they located and photographed one adult female *R. cascadae.* Subsequent comparisons of the photographs showed that both surveys found the same frog. Additionally, the frog was within 100 m of the same point on both surveys. Neither survey crew found *R. cascadae* at the two ponds adjacent to Juniper Lake. A 2007 survey of Juniper Lake and adjacent ponds detected one adult *R. cascadae* at one of the two ponds. Photographs showed that the frog was the same individual found in Juniper Lake during the 2006 surveys. The frog moved at least 180 m between 2006 and 2007.

Since our surveys began in 1993, we have found no more than ten adult *R. cascadae* at any of the six populations. Also, the number of eggs, larvae, and recent metamorphs located on any one occasion exceeded the reproductive output of one pair of frogs only twice. We found two egg masses at Carter Meadow in 1996 and 13 in 2007. It is not known whether *R. cascadae* can lay multiple clutches per year like some other *Rana* (e.g., *R. clamitans*, Wells 1976; *R. catesbeiana*, Emlen 1977).

Discussion

Rana cascadae was once a common frog in the Lassen area. Grinnell et al. (1930) reported this species at eight sites and described the frog as abundant. *Rana cascadae* no longer occur at any of these sites today. Collection records from the Museum of Vertebrate Zoology (MVZ, University of California, Berkeley) show that, in the 1970s, *R. cascadae* was numerous at sites such as Dersch Meadows, where 48 frogs were collected on 30 June 1974. *R. cascadae* is no longer present in that meadow. Fellers and Drost (1993) surveyed 50 sites within LVNP and found only two frogs at one site (Crumbaugh Creek), but this species has not been found there since 1994.

The 1,873 surveys spanning 1993-2007 located six populations of *R. cascadae*, but their small population size make long-term viability unlikely. Our surveys were exhaustive; in many cases they included all known habitat for this frog and included all mapped ponds, lakes, wet meadows, and streams on public lands within our study area. While there could be a few small populations that went undetected (e.g., Butt Creek), it is unlikely that any large *R. cascadae* populations exist in the Lassen area.

There are several questions raised by our work: (1) How viable are the remaining populations of *R. cascadae* in the Lassen area; (2) Why have they declined; (3) What research needs remain; and (4) What management actions will benefit this species?

***Population Viability*.**—The small size of, and lack of connectivity between the current populations of *R. cascadae* in the Lassen area greatly reduces their long-term viability, potentially leading to a genetic bottleneck (Young and Clarke 2000). Potential connectivity exists between Juniper Lake and Warner Creek, which are 4.2 km apart (straight-line) or 6.1 km along a creek (297 m difference in elevation; Fig. 1). In a mark-recapture study conducted in the Trinity Alps Wilderness, Garwood and Pope (unpubl. data) found connectivity via dispersal of frogs among populations that were 5 km apart (straight-line). Garwood (pers. comm.) found that frogs moved up to 1.6 km between breeding and wintering sites, often traversing dry rocky habitats that appeared completely unsuitable for frogs. While frogs may travel between Warner Creek and Juniper Lake on occasion, the distances and topographic barriers between all other populations probably preclude connectivity via frog dispersal (Table 3, Fig. 1).

Even if dispersal and gene flow exists between sites up to 10 km apart, our highest count for any site (Carter Meadow 1999) is incredibly low (10 adult frogs). Haig et al. (1993) examined a similar-sized population of red-cockaded woodpeckers (*Picoides borealis*) in South Carolina and concluded that inbreeding depression and stochastic environmental events placed the population's existence and future survival at risk. They estimated that the woodpeckers had a 68-100% chance of extinction within 200 years. Li and Jiang (2004) reported that the critically endangered Przewalski's Gazelle (*Procapra przewalskii*) consisted of only four subpopulations around Qinghai Lake in China. They predicted that the gazelle would become extinct within 200 years if no management measures were taken. Similar conclusions have been reached for many small populations of invertebrates (Schtickzelle et al. 2005) and plants (Richards et al. 2003). The future of *R. cascadae* in the Lassen area looks bleak. The loss of nearly all populations and the precarious nature of those few remaining raise two important questions: What has caused these losses, and can we reverse the trend? We address both these questions below.

***Trout*.**—Brook Trout (*Salvelinus fontinalis*), Brown trout (*Salmo trutta*), and Rainbow Trout (*Oncorhynchus mykiss*) have been introduced throughout the range of *R. cascadae*. These introductions occurred in formerly fishless lakes and streams where *R. cascadae* were once abundant. Non-native trout impact both the distribution and abundance of *R. cascadae* in the Klamath-Siskiyou region of northwestern California. Welsh et al. (2006) found that *R. cascadae* distribution negatively correlates with fish distribution, and *R. cascadae* larvae occurred 3.7 times more frequently in lakes without trout. Trout may negatively affect *R. cascadae* in the Lassen area, approximately 150 km east of the Klamath-Siskiyou region, but two lines of evidence suggest that trout are not the primary cause of amphibian declines there.

The timing of trout introductions at LVNP does not correlate with the decline of *R. cascadae* in that area. Fish stocking at LVNP began by 1928 and continued through the 1970s. Stocking was gradually phased-out starting in 1968, and by 1980 all stocking within LVNP had been terminated (Al Denniston, pers. comm.). The decline of *R. cascadae* in LVNP was first noticed in the late 1980s (Al Denniston, pers. comm.), almost ten years after fish stocking in the park had ceased. In 1974, frogs were still abundant at some localities (MVZ records). Perhaps because some of the habitats occupied by *R. cascadae* do not support fish, *R. cascadae* seem to have fared relatively well through decades of regular fish stocking, only to decline later.

The second line of evidence is that trout are less widely distributed in the Lassen region than in other mountainous regions where ranid frog populations are still viable (Knapp and Matthews 2000; Welsh et al. 2006). Welsh et al. (2006) found trout in 85% of the lakes in their Klamath-Siskiyou study area compared with 16% of the lakes in LVNP. If fish were the primary factor causing *R. cascadae* declines in the Klamath-Siskiyou region, we would expect greater declines in that area, but that is not the case.

***Disease and Pathogens*.**—Fungi, viruses, bacteria, parasitic worms, and protozoans are potential causes of amphibian declines throughout the world (Blaustein et al. 1994; Berger et al. 1998; Bosch et al. 2001; Daszak et al. 2003). Chytridiomycosis, a newly discovered fungal disease in amphibians, has been implicated in amphibian die-offs in Mountain Yellow-legged Frogs (*Rana muscosa*) in parts of the Sierra Nevada 200-300 km SE of Lassen Peak (Briggs et al. 2005). *Batrachochytrium dendrobatidis* (the fungus that causes chytridiomycosis) has not been found in *R. cascadae* in Washington (Steven Wagner, pers. comm.), but it is present in central Oregon (Jefferson County) and northern California (Siskiyou county) (Michael Adams, pers. comm.). Limited sampling has detected the fungus in *R. cascadae* at three of our study sites (Carter Meadow, Colby Creek, and Old Cow Creek; Karen Pope, unpubl. data), as well as, in the Trinity Alps where *R. cascadae* populations remain stable.

Blaustein et al. (2005) found that *R. cascadae* larvae in the laboratory were susceptible to infection by *B. dendrobatidis*, but it did not reduce survival of infected larvae. This is not surprising since Fellers et al. (2001) noted that infected *R. muscosa* larvae appeared healthy and had large fat bodies. Even in adult anurans, the effect of *B. dendrobatidis* varies. Some infected species decline to extinction (*Litoria rheocola* and *Taudactylus acutirostris*; McDonald and Alford 1999), others decline and then recover to previous densities (*Litoria genimaculata*; McDonald et al. 2005), and some species are largely unaffected (*Bufo marinus*, Berger 2001; *R. catesbeiana*, Daszak et al. 2004). Research on the susceptibility of recently metamorphosed *R. cascadae* suggests that recent metamorphs are highly susceptible to *B. dendrobatidis* (Garcia et al. 2006).

The relatively sudden decline of *R. cascadae* in the Lassen area is compatible with a disease hypothesis, and the decline may involve *B. dendrobatidis*. Because chytridiomycosis was first described in frogs in 1998 (Berger et al. 1998), and was first reported in the United States in 2001 (Fellers et al. 2001), well after the initial decline of *R. cascadae*, it is not possible to evaluate the role of chytridiomycosis. While *B. dendrobatidis* is present in *R. cascadae*, it is not known whether the fungus is recently introduced, or a native pathogen that is now having an increased impact on amphibians, perhaps due to changes in environmental stressors (see Morehouse et al. 2003; Weldon et al. 2004; Morgan et al. 2007).

***Pesticide Drift*.**—There has been increasing concern that pesticides used in the Central Valley of California (Fig. 1) move with the prevailing winds into the montane areas immediately to the east (Fellers et al. 2004). Several studies have measured pesticide concentrations in both the environment and in frog tissue in California (LeNoir et al. 1999; Sparling et al. 2001; Angermann et al. 2002; Fellers et al. 2004). The regions of California that have suffered the greatest amphibian declines, and the non-agricultural areas where environmental pesticide concentrations are the highest, are the central and southern portion of the Sierra Nevada (Sparling et al. 2001). This mountain range lies immediately south of our study area. Studies suggesting that pesticides may have played a role in the decline of *R. muscosa* in the Sierra Nevada (e.g., Fellers et al. 2004) may not explain the decline in the Lassen area because pesticide residue concentrations in *Pseudacris* (= *Hyla*) *regilla* (Pacific Chorus Frog) from this area were similar to coastal reference sites where pesticide concentrations were lowest (Sparling et al. 2001).

***Synergistic Effects*.**—None of the causative factors discussed above (trout, disease, pesticides) provide a compelling explanation for the observed decline. It is possible, and perhaps likely, that a combination of these or other factors interacted to cause the declines. For example, UV radiation can interact with contaminants and enhance their impact on amphibians (Blaustein et al. 2003). Stress from low concentrations of pesticides increase susceptibility to chytridiomycosis (Taylor et al. 1999; Gilbertson et al. 2003; Davidson 2004). Relyea and Mills (2001) demonstrated synergistic effects between carbaryl and olfactory cures of a predator. Carbaryl was 2-4 times more lethal to *Hyla versicolor* (Gray Treefrog) larvae when raised with olfactory cues from a native predator (*Ambystoma maculatum*, Spotted Salamander).

Global climate change is a confounding factor that may interact with any of the factors noted above. Global warming affects amphibians directly [e.g., causing earlier breeding (Blaustein et al. 2001; Gibbs and Breisch 2001)], and indirectly [e.g., lowering pond depth and hence exposing eggs to higher levels of UV radiation (Kiesecker et al. 2001)]. Juan Parra and William Monahan (unpubl. data) have developed climate models for the period from 1900 to 1940 and compared that period to current climate patterns. They found that during the driest quarter of the year, there is currently less precipitation compared to the historic period in northeastern California, a region that encompasses our study area in the northern Sierra Nevada and southern Cascade Mountains. Parra and Monahan found only moderate change in precipitation for the wettest quarter of the year. Because amphibians are dependent on water, these changes in climate are of concern, but we cannot yet determine whether climate contributes to declines of *R. cascadae*. A challenge to understanding the cause(s) of amphibian declines is the difficulty of deciphering the contributions of multiple stressors and determining which one(s) have significant effects (Sih et al. 2004).

RECOMMENDATIONS

Our surveys of 1,873 site surveys suggest that *R. cascadae* is on the brink of extirpation in the Lassen area (Table 2). Although research exists on the possible causes for the decline, there is insufficient evidence to implicate any one factor. The proximal causes of the decline are as much of a mystery today as they were in the early 1990s. Because there remains a paucity of information needed to identify the causes of this decline, we provide recommendations for the conservation of this at-risk species.

Protection.—*Rana cascadae* within a 50 km radius of Lassen Peak would benefit from additional protection. This would (1) restrict habitat alterations; (2) stimulate funding for research on the causes of declines; and (3) provide support for either captive breeding or repatriation of wild frogs. Limited research and no effort to augment or restore populations have taken place since Fellers and Drost (1993) documented the decline of this frog. Thus, it seems likely that the attention and funding associated with formal listing would reduce the likelihood that *R. cascadae* will be extirpated in the Lassen area.

Genetics.—Monsen and Blouin (2003) included California populations in their range-wide evaluation of *R. cascadae* genetic diversity. Their data suggested that the California populations were sufficiently distinct from frogs in Oregon and Washington to warrant designation as a Distinct Population Segment (DSP); however, their limited sampling in California may have prevented identification of significant genetic differences between populations in the Lassen and Klamath-Siskiyou regions. Case (1978) provided electrophoretic evidence that distinct differences exist between *R. cascadae* from these two regions; however, a more detailed genetic evaluation *R. cascadae* in California and southern Oregon is needed to determine the boundaries of genetic differentiation.

Causative Factors.—Introduced trout, disease, and contaminants may be the strongest contributors to the decline of *R. cascadae*. While it is unlikely that trout are the primary cause of the declines, *R. cascadae* are susceptible to fish predation and tend to avoid fish-containing waters for reproduction (Welsh et al. 2006; Karen Pope, unpubl. data). In the Trinity Alps Wilderness, *R. cascadae* populations increased significantly after fish removal (Karen Pope, unpubl. data). Therefore, removal of non-native fish from waters near remnant frog populations could restore habitat for frogs to recolonize.

Little data exist on the role of disease and contaminants. Biologists have yet to determine (1) the range of chytridiomycosis in California; (2) the susceptibility of *R. cascadae* to chytridiomycosis; and (3) the role of chytridiomycosis in the declines. The Lassen area is part of only a few contaminants studies (e.g., Sparling et al. 2001; Cowman 2005). These suggested that pesticides in the Lassen area are less problematic than in the southern Sierra Nevada. However, recent research suggests that the breakdown products (e.g., oxons) of some of the most commonly used pesticides greatly reduce survival in other native *Rana* (Sparling and Fellers 2007). Other research demonstrated an order of magnitude difference in LC_{50}s (= concentration that is expected to be lethal to 50% of a group of organisms during the exposure period) among different genera of native frogs in California (Don Sparling, pers. comm.). Similar experiments need to be conducted with *R. cascadae* to evaluate the impact of ambient concentrations of contaminants.

Specific causes of decline in the Lassen region need to be investigated. Are there unique predators, parasites, pathogens, or contaminants in the Lassen region that may be affecting the survival or fecundity of *R. cascadae*?

Captive Breeding and Repatriation.—We view captive breeding and repatriation of wild frogs as last resort efforts in the conservation of wild populations (Snyder et al. 1996), but *R. cascadae* may be at that point. Amphibians are good candidates for captive breeding because they have high fecundity, require less space, and are generally more economical to raise than many other species (Bloxam and Tonge 1995; Trenham and Marsh 2002). There are, however, potential problems with maintaining genetic diversity and preventing the introduction of pathogens into wild populations (Bloxam and Tonge 1995). The International Union for the Conservation of Nature and Natural Resources (IUCN) endorses captive breeding as a proactive conservation measure that should be initiated before species reach critically low numbers (IUCN 1987). Dodd (2005) noted that the chance of success greatly increased when reintroductions (1) were preceded by habitat restoration; (2) included a long-term commitment; and (3) were part of a multifaceted approach including genetic and life history research. If a captive breeding program is initiated for *R. cascadae*, we recommend first running trials with *R. cascadae* collected from the Klamath-Siskiyou region due to their geographic proximity and because those populations are relatively large and can better tolerate the removal of animals for a breeding program.

A combination of habitat protection, research, and active management is needed to prevent the continued decline of *R. cascadae* in the Lassen region. At this stage, management and research professionals must collaborate to preserve the genetic diversity and viability of *R. cascadae*.

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