

and its residues were detected in significant quantities in mountain yellow-legged frogs and foothill yellow-legged frogs throughout the Sierra Nevada up to an elevation of 3,660 m (12,000 ft) (Cory *et al.* 1970). The origin of this DDT is primarily attributed to agriculture in the Central Valley (Cory *et al.* 1970). DDT residues likely from agriculture in the Central Valley still appeared in Pacific treefrog larvae collected in the Sierra Nevada in the late 1990s (Sparling *et al.* 2001), more than 25 years after the use of DDT was banned in the United States. Levels of this toxicant in the mountain yellow-legged frog and foothill yellow-legged frog were significantly higher in the central Sierra Nevada, from the Tuolumne Meadows area of Yosemite National Park, north to Sonora Pass in the Stanislaus National Forest. The origin of DDT at these locations is attributed to two massive applications administered directly to this national forest and national park for pest control (Cory *et al.* 1970, 1971).

Snow core samples from the Sierra Nevada contain a variety of contaminants from industrial and automotive sources, including hydrogen ions that are indicative of acidic precipitation, nitrogen and sulfur compounds (NH<sub>4</sub>, NO<sub>3</sub>, SO<sub>2</sub>, and SO<sub>4</sub>), and heavy metals (lead, iron, manganese, copper, and cadmium) (Laird *et al.* 1986). The pattern of recent frog extinctions in the southern Sierra Nevada corresponds with the pattern of highest concentration of air pollutants from automotive exhaust, possibly due to increases in nitrification (or other changes), caused by those pollutants (Jennings 1996). The effects of contaminants on amphibians need further research (Hall and Henry 1992; Briggs *et al.* 2002). However, the correlative evidence between areas of pesticide contamination in the Sierra Nevada and areas of amphibian decline, along with evidence of an adverse physiological effect from pesticides on amphibians in the Sierra Nevada, indicates that contaminants may present a risk to the mountain yellow-legged frog and may have contributed to the species' decline (Jennings 1996; Sparling *et al.* 2001; (Davidson *et al.*, 2002).

It has been suggested that contamination from wind-borne pesticides originating from upwind agriculture, and other contaminants originating from metropolitan areas, may compromise amphibian immune systems (Carey 1993; Carey *et al.* 1999; Daszak *et al.* 1999; Angermann *et al.* 2002). An effort to test the hypothesis that contaminants originating in the San

Joaquin Valley are suppressing the mountain yellow-legged frog's immune system, thereby making it more vulnerable to disease, is underway (Briggs *et al.* 2002).

Laboratory studies have documented sublethal effects on mountain yellow-legged frog embryos at pH 5.25 (pH represents acidity on a negative scale, with 7 being neutral and lower numbers indicating increased acidity). Survivorship of mountain yellow-legged frog embryos and tadpoles was negatively affected as acidity increased (at approximately pH 4.5 or lower), with embryos being more sensitive to increased acidity than tadpoles (Bradford and Gordon 1992; Bradford *et al.* 1992). Acidic deposition has been suggested as contributing to amphibian declines in the western United States (Blaustein and Wake 1990; Carey 1993; Alford and Richards 1999). Other studies, however, do not support this hypothesis as a contributing factor to amphibian population declines in this area (Bradford and Gordon 1992; Bradford *et al.* 1992; Corn and Vertucci 1992; Bradford *et al.* 1994a, 1994b).

Acid precipitation has been postulated as a cause of amphibian declines at high elevations in the Sierra Nevada because waters there are low in acid neutralizing capacity, and, therefore, are susceptible to changes in water chemistry caused by acidic deposition (Byron *et al.* 1991; Bradford *et al.* 1994b). Near Lake Tahoe, at an elevation of approximately 2,100 m (6,900 ft), precipitation acidity has been documented to have increased significantly (Byron *et al.* 1991). In surface waters of the Sierra Nevada, acidity increases and acid neutralizing capacities decrease during snow melt and summer storms, though rarely does pH dip below 5.6 (Nikolaidis *et al.* 1991; Bradford and Gordon 1992; Bradford *et al.* 1998). The mountain yellow-legged frog breeds shortly after snow melt, thereby exposing its early life stages, which are most sensitive to acidification, to these conditions (Bradford and Gordon 1992). However, the hypothesis of acidic deposition as a cause of mountain yellow-legged frog declines has been rejected by field experiments that failed to show differences in water chemistry parameters between occupied and unoccupied mountain yellow-legged frog sites (Bradford *et al.* 1994b).

Extreme pH in surface waters of the Sierra Nevada is estimated at 5.0, with most high elevation lakes having a pH of greater than 6 (Bradford *et al.* 1992, 1998). Caused by oxidation of pyrite found in metamorphic and granitic rocks, a small number of lakes in the

Sierra Nevada (approximately 10) are naturally acidic (Bradford *et al.* 1998). Bradford *et al.* (1998) found mountain yellow-legged frog tadpoles to be sensitive to naturally acidic conditions, and that their distribution was significantly related to lake acidity; they were not found in lakes with a pH less than 6. By contrast, the distribution of adult mountain yellow-legged frogs was not significantly related to natural lake acidity or other chemical or physical parameters. Though acidity may have an influence on mountain yellow-legged frog abundance or distribution, it is unlikely to have contributed to this species' decline, given the rarity of lakes acidified either by natural or anthropogenic sources (Bradford *et al.* 1998).

The last century has included some of the most variable climate reversals documented, at both the annual (extremes and high frequency of El Niño (associated with severe winters) and La Niña (associated with milder winters) events) and near-decadal scales (periods of 5 to 8 year drought and wet periods) (USDA 2001b). These events may have negative effects on Sierra Nevada mountain yellow-legged frogs. Severe winters (El Niño) would force longer hibernation times and could stress mountain yellow-legged frogs by reducing the time available for them to feed and breed. Alternately, during mild winters (La Niña), precipitation is reduced. This reduction in precipitation could reduce available breeding habitat and lead to stranding and death of frog eggs and tadpoles. It could also lead to increased exposure to predatory fish by forcing frogs into fish-containing waters if fishless waters dry out.

In California, prolonged droughts are a regular occurrence to which native amphibians have adapted; even severe droughts are not expected to result in widespread population declines (Drost and Fellers 1996). However, an increase in the frequency, magnitude, and duration of droughts caused by global warming may have compounding effects with respect to populations of mountain yellow-legged frogs already in decline. In situations where other factors have resulted in the isolation of mountain yellow-legged frogs to marginal habitats, localized mountain yellow-legged frog population crashes or extirpations due to droughts may exacerbate their isolation and preclude their recolonization or immigration from other populations (Bradford *et al.* 1993; Drost and Fellers 1996).

Changes in climate that occur faster than the ability of endangered species to adapt could cause local extinctions (U.S. Environmental Protection Agency