

tiger salamanders in some areas. Active ground squirrel colonies probably are needed to sustain tiger salamanders because inactive burrow systems become progressively unsuitable over time. Loredó *et al.* (1996) found that burrow systems collapsed within 18 months following abandonment by or loss of the ground squirrels. Although the researchers found that California tiger salamanders used both occupied and unoccupied burrows, they did not indicate that the salamanders used collapsed burrows. Rodent control programs must be analyzed and implemented carefully in California tiger salamander habitat so the persistence of the animals is not threatened. One of the remaining Sonoma County California tiger salamander sites is currently occupied by cattle. Most owners of livestock seek to eliminate ground squirrel burrows because of the threat of cows (*Bos bos*) breaking their legs if they accidentally step into a burrow.

Mosquito Control

In addition to the use of western mosquitofish, a common chemical method of mosquito control in California involves the use of methoprene. Methoprene is an insect hormone mimic that increases the level of juvenile hormone in insect larvae and disrupts the molting process. Lawrenz (1984, 1985) found that methoprene (Altosoid SR-10) retarded the development of selected crustacea that had the same molting hormones (*i.e.*, juvenile hormone) as insects, and anticipated that the same hormone may control metamorphosis in other arthropods. Because the success of many aquatic vertebrates relies on an abundance of invertebrates in temporary wetlands, any delay in insect growth could reduce the numbers and density of prey available (Lawrenz 1984, 1985). The use of methoprene could have an indirect adverse effect on California tiger salamanders by reducing the availability of prey.

In more recent studies, methoprene did not cause increased mortality of gray treefrog (*Hyla versicolor*) tadpoles (Sparling and Lowe 1998). However, it caused reduced survival rates and increased malformations in northern leopard frogs (*Rana pipiens*) (Ankley *et al.* 1998) and increased malformations in southern leopard frogs (*R. utricularia*) (Sparling 1998). Blumberg *et al.* (1998) correlated exposure to methoprene with delayed metamorphosis and high mortality rates in northern leopard and mink (*R. septentrionalis*) frogs. Methoprene appears to have both direct

and indirect effects on the growth and survival of larval amphibians.

Road-Crossing Mortality

Although no systematic studies road-crossing mortality of the Sonoma County California tiger salamander have been conducted, it is known that significant numbers of California tiger salamanders in other portions of the species' range are killed by vehicular traffic while crossing roads (Hansen and Tremper 1993; S. Sweet, *in litt.*, 1993; J. Medeiros, pers. comm., 1993). For example, during a 1-hour period on a road bordering Lake Lagunita on the Stanford University campus, 45 California tiger salamanders were collected, 28 of which had been killed by cars (Twitty 1941). More recently, during one 15-day period in 2001 at a Sonoma County location, 26 road-killed California tiger salamanders were found (D. Cook, pers. comm., 2002). Overall breeding population losses of California tiger salamanders due to road kills have been estimated to be between 25 and 72 percent (Twitty 1941; S. Sweet, *in litt.*, 1993; Launer and Fee 1996). Mortality may be increased by associated roadway curbs and berms as low as 9 to 12 cm (3 to 5 in), which allow California tiger salamanders access to roadways but prevent their exit from them (Launer and Fee 1996; S. Sweet, *in litt.*, 1998). In a recent study along a 1.1 km (0.7 mi) high-vehicular-use (21,450 vehicles per day) section of the Trans-Canadian Highway in Alberta, Canada, Clevenger *et al.* (2001) recorded 183 road-killed tiger salamanders (*Ambystoma* species) in 30 days and concluded it was likely that very few of the local population had survived.

Hybridization With Non-native Salamanders

Hybrids between the California tiger salamander and the non-native tiger salamander (*Ambystoma tigrinum*) have been documented elsewhere in the range of *Ambystoma californiense* (Shaffer and Trenham 2002). Introduced salamanders may out-compete the California tiger salamander, or interbreed with the natives to produce hybrids that may be less fit and adapted to the California climate, or are not reproductively viable past the first or second generations (Bury and Lukenbach 1976; Shaffer *et al.* 1993). More recent evidence suggests that the hybrids are viable, and that they breed with California tiger salamanders (Shaffer and Trenham 2002). Over time, a population of a species could become genetically indistinguishable from a larger population of an introgressing species such that the true genotype (the

genetic constitution of an individual or group) of the lesser species no longer exists (Levin 2002). The loss of any breeding sites of the Sonoma County California tiger salamander due to hybridization with, or competition from, introduced species is of serious concern.

Livestock Grazing

Light-to-moderate livestock grazing is generally thought to be compatible with California tiger salamanders, provided the grazed areas do not also have intensive burrowing rodent control efforts (T. Jones, University of Michigan, *in litt.*, 1993, S. Sweet, pers. comm., 1998). By keeping vegetation shorter, grazing may make areas more suitable for ground burrowing rodents whose burrows are essential to Sonoma County California tiger salamanders. However, heavy grazing, or heavy use of certain pools and ponds for livestock watering, can clearly have adverse effects on the species. Melanson (*in litt.*, 1993) noted that, although vernal pool species continued to reproduce under a November-to-April grazing regime, California tiger salamanders were either absent or found in low numbers in portions of pools heavily trampled by cattle. Repeated trampling of pond edges by cattle can increase the surface area of a pond, and may increase water temperature and evaporation rate, thus reducing the amount of time the pond contains water (S. Sweet, pers. comm., 1998).

Reduction in water quality caused by livestock excrement may negatively affect the California tiger salamander by increasing nitrogen and silt levels. High nitrogen levels associated with bacterial blooms, lowered dissolved oxygen (Worthylake and Hovingh 1989), and silt have been associated with fatal fungal infections (Lefcort *et al.* 1997), as discussed earlier under Factor C.

However, grazing generally is compatible with the continued use of rangelands by the California tiger salamander as long as intensive control programs for burrowing rodents are not implemented on such areas, and grazing is not excessive (T. Jones, *in litt.*, 1993).

Population Size

The low numbers of Sonoma County California tiger salamander make it vulnerable to risks associated with small, restricted populations. The elements of risk that are amplified in very small populations include: (1) The impact of high death rates or low birth rates; (2) the effects of genetic drift (random fluctuations in gene frequencies) and inbreeding (mating among close relatives); and (3) deterioration in environmental quality