

m (10 to 30 ft) (Van Auken *et al.* 1979). Applying the “three tree height” general rule, and using the average value of 6.6 m for tree height, we estimated that a buffer width of at least 20 m (66 ft) is needed around a core habitat area to protect the vegetative community from edge effects. Based on this rule, 7 acres is necessary to protect a 33-acre core area. We recognize that the “three tree height” approach described by Harris (1984) was based on the distance that effects of storm events (“wind-throw”) from a surrounding clear-cut “edge” will penetrate into an old-growth forest stand. Since the effects of edge on woodland/grass land mosaic communities have not been well studied, the “three tree height” recommendation is considered to be the best available peer-reviewed science to protect woodland areas from edge effects (Dr. Kathryn Kennedy, Center for Plant Conservation, pers. comm. 2003). The Texas Parks and Wildlife Department is also in general agreement about the need for some type of buffer as a means of addressing edge effects, but currently has not specific recommendations on appropriate size for such a buffer (John Herron, Texas Parks and Wildlife Department, pers. comm. 2003).

Animal communities also should be buffered from impacts associated with edge effects or disturbance from adjacent urban development. Edges can act as a barrier to dispersal of birds and mammals (Yahner 1988; Hansson 1998). Invertebrate species are affected by edges. Mader *et al.* (1990) found that carabid beetles and lycosid spiders avoided crossing unpaved roads that were even smaller than 3 m (9 ft) wide. Saunders *et al.* (1990) suggested that as little as 100 m (328 ft) of agricultural fields may be a complete barrier to dispersal for invertebrates and some species of birds. In general, for animal communities, species need buffers of 50 to 100 m (164 to 328 ft) or greater to ameliorate edge effects (Lovejoy *et al.* 1986; Wilcove *et al.* 1986; Laurance 1991; Laurance and Yensen 1991; Kapos *et al.* 1993; Andren 1995; Reed *et al.* 1996; Burke and Nol 1998; Didham 1998; Suarez *et al.* 1998).

Nonnative fire ants are known to be harmful to many species of invertebrates and vertebrates. In coastal southern California, Suarez *et al.* (1998) found that densities of the exotic Argentine ant (*Linepithema humile*), which has similar life history and ecological requirements to the red imported fire ant (Dr. Richard Patrock, University of Texas at Austin, pers. comm. 2003), are greatest near disturbed areas. Native ant communities tended to be more

abundant in native vegetation and less abundant in disturbed areas. Based on the association of the Argentine ant and distance to the nearest edge in urban areas, core areas may only be effective at maintaining natural populations of native ants when there is a buffer area of at least 200 m (656 ft) (Suarez *et al.* 1998).

Information on the area needed to maintain populations of animal species, including cave crickets, found in Central Texas is lacking. As discussed above, animal communities should be buffered by areas of 50 to 100 m (164 to 328 ft) or greater to ameliorate edge effects, and by areas of 200 m (656 ft) to buffer against the effects of fire ants. From this data, we determined that a buffer of 100 m (328 ft), in addition to the 50 m (164 ft) cave cricket foraging area, would, at a minimum, protect the cave cricket foraging area from the effects of edge and nonnative species invasions.

Fragmentation

Haskell (2000) examined the effect of habitat fragmentation by unpaved roads through otherwise contiguous forest in the southern Appalachian Mountains and found reduced soil macroinvertebrate species abundance up to 100 m (328 ft) from the road and declines in faunal richness up to 15 m (50 ft) from the road. Haskell (2000) pointed out that “these changes may have additional consequences for the functioning of the forest ecosystem and the biological diversity found within this system. The macroinvertebrate fauna of the leaf litter plays a pivotal role in the ability of the soil to process energy and nutrients.” Haskell further points out that these changes may in turn affect the distribution and abundance of other organisms, particularly plants. Changes in abundance in litter dwelling macroinvertebrates may also affect ground-foraging vertebrate fauna (Haskell 2000).

Invertebrate biomass per unit area has been found to be less in small fragmented habitats, which may result in reduced food available for cave crickets. Burke and Nol (1998), working in southern Ontario, Canada, found a greater biomass of leaf litter invertebrates in large (≥ 20 ha (49 ac)) than in smaller forested areas. Zanette *et al.* (2000) in New South Wales, Australia, reported that the biomass of ground dwelling invertebrates was 1.6 times greater in large (> 400 ha (988 ac)) than in smaller (~ 55 ha (136 ac)) forested areas.

Dispersal

The ability of individuals to move between preferred habitat patches is essential for colonization and population viability (Eber and Brandl 1996; Fahrig and Merriam 1994; Hill *et al.* 1996; Kattan *et al.* 1994; Kindvall 1999; Kozlov 1996; Kuussaari *et al.* 1996; Turner 1996). Patch shapes allowing connection with the highest number of neighboring patches increase the likelihood that a neighboring patch will be occupied (Fahrig and Merriam 1994; Kindvall 1999; Kuussaari *et al.* 1996; Tiebout and Anderson 1997). If movement among populations is restricted and a population is isolated, the habitat patch size must be large enough to ensure that the population can survive (Fahrig and Merriam 1994).

It is likely that many cave systems are connected throughout the subsurface geologic formation even though this may not be readily apparent from surface observations. The extent to which listed species use interstitial spaces and passages is not known. Troglotic species may retreat into these small interstitial spaces where the physical environment is more stable (Howarth 1983) and may spend the majority of their time in such retreats, only leaving them during temporary forays into the larger cave passages to forage (Howarth 1987). During several karst invertebrate surveys conducted in Bexar County caves, Service biologists have observed that troglotes, including listed species, were not found when temperature and humidity in the cave was low. Upon returning to the same cave once environmental conditions returned to optimal, the listed species and other troglotes were observed.

Small voids (inaccessible to humans) and interstitial spaces can also provide subsurface corridors for movement of listed species and cave crickets between and among caves and karst features. Cores drilled around and between occupied caves have led to discovery of additional void space that was hydrologically, but not physically connected to the humanly-accessible portion of an occupied cave. Listed species were found in this void space.

Summary

The conservation of the endangered karst invertebrates depends on a self-sustaining karst ecosystem; surface and subsurface drainage basins to maintain adequate levels of moisture; and a viable surface animal and plant community for nutrient input and protection of the subsurface from adverse impacts. The area needed to conserve such an