

karst features acting as sources and the majority of karst features acting as sinks, but Helf *et al.* (1995) recommends that “even sink populations should be protected because their emigrants can “rescue” source populations that experience local decimation.” These studies suggest that it is important to protect the geological features that connect caves and maintain habitat corridors among caves.

Other Surface Animals

Many central Texas caves with endangered invertebrate species are frequented by mammals and several species of reptiles and amphibians (Reddell 1967). Although there are no studies establishing the role of mammals in central Texas cave ecology, the presence of a large amount of animal materials (such as scat, nesting materials, and dead bodies) indicates they are probably important. An important source of nutrients for the cave species may be the fungus, microbes, and/or other trogloliths and trogloliths that grow or feed on feces (Elliott 1994b; Gounot 1994).

For predatory trogloliths (such as the listed Bexar County invertebrates), invertebrates that accidentally occur in the caves may also be an important nutrient source (Hopper 2000). Documented accidental species include snails, earthworms, terrestrial isopods (commonly known as pillbugs or potato bugs), scorpions, spiders, mites, collembola (primitive wingless insects that are commonly known as springtails), thysanura (commonly known as bristletails and silverfish), harvestmen (commonly known as daddy-long-legs), ants, leafhoppers, thrips, beetles, weevils, moths, and flies (Reddell 1965; 1966; 1999).

Vegetation Community

Surface vegetation is an important element of the karst habitat for several reasons, including its role in providing nutrients from: (1) Direct flow of plant material into the karst with water; (2) habitat and food sources provided for the animal communities that contribute nutrients to the karst ecosystem (such as cave crickets, small mammals, and other vertebrates); and possibly, (3) roots that extend into subsurface areas. Surface vegetation also acts as a buffer for the subsurface environment against drastic changes in the temperature and moisture regime and serves to filter pollutants before they enter the karst system (Biological Advisory Team 1990; Veni 1988). In some cases, healthy native plant communities also help control certain exotic species (such as fire ants) (Porter *et al.* 1988) that may

compete with or prey upon the listed species and other species (such as cave crickets) that are important nutrient contributors (Elliott 1994a; Helf, *in litt.* 2002).

Tree roots have been found to provide a major energy source in shallow lava tubes and limestone caves in Hawaii (Howarth 1981). Jackson *et al.* (1999) investigated rooting depth in 21 caves on the Edwards Plateau to assess the belowground vegetational community structure and the functional importance of roots. They observed roots penetrating up to 25 m (82 ft) into the interior of 20 of the caves, with roots of 6 tree species common to the plateau penetrating to below 5 m (16.4 ft).

Along with providing directly and indirectly nutrients to the karst ecosystem, a healthy vegetative community may also help control the spread of exotic species. The red imported fire ant (*Solenopsis invicta*) is an aggressive predator, which has had a devastating and long-lasting impact on native ant populations and other arthropod communities (Vinson and Sorenson 1986; Porter and Savignano 1990) and is a threat to the karst invertebrates (Elliott 1994b; USFWS 1994). Fire ants have been observed building nests both within and near cave entrances, as well as foraging in caves, especially during the summer. Shallow caves inhabited by listed karst invertebrates are especially vulnerable to invasion by fire ants and other exotic species. In addition to preying on cave invertebrate species, including cave crickets, fire ants may compete with cave crickets for food (Elliott 1994a; Helf *in litt.* 2002). Helf (*in litt.* 2002) states that competition for food between fire ants and cave crickets (*Ceuthophilus secretus*) may be a more important interaction than predation. The presence of fire ants in and around karst areas could have a drastic detrimental effect on the karst ecosystem through loss of both surface and subsurface species that are critical links in the food chain.

The invasion of fire ants is known to be aided by “any disturbance that clears a site of heavy vegetation and disrupts the native ant community” (Porter *et al.* 1988). Porter *et al.* (1991) state that control of fire ants in areas greater than 5 ha (12 ac) may be more effective than in smaller areas since multiple queen fire ant colonies reproduce primarily by “budding,” where queens and workers branch off from the main colony and form new sister colonies. Maintaining large, undisturbed areas of native vegetation may also help sustain the native ant communities (Porter *et al.* 1988; 1991).

Listed species, and their associated prey items, have adapted to native vegetation, with its associated nutrients, surface foliage, and subsurface roots. Before 1860, Bexar County native vegetation consisted of an approximate equal mix of areas with woody and grassland plants (Del Weniger 1988). In more recent times, exotic species have often replaced native plants. The effects on listed invertebrates of replacement of native with exotic vegetation have not been reported.

Woodland-Grassland Community

Because of the various roles played by surface vegetation in maintaining the cave and karst ecosystem, including the listed karst invertebrate species that are part of the ecosystem, we examined the best available scientific information to estimate the surface vegetation needed to support ecosystem processes. The woodland-grassland mosaic community typical of the Edwards Plateau is a patchy environment composed of many different plant species. Van Auken *et al.* (1980) studied the woody vegetation of the Edwards and Glen Rose formations in the southern Edwards Plateau in Bexar, Bandera, and Medina counties. They encountered a total of 24 species of plants on the Edwards or Glen Rose geologic formations, two of the principal, cave-containing rock units of the Edwards Plateau.

To maintain natural vegetation communities over the long term, enough individuals of each plant species must be present for successful reproduction. The number of reproductive individuals necessary to maintain a viable or self-reproducing plant population is influenced by needs for satisfactory germination (Menges 1995), genetic variation (Bazzaz 1983; Menges 1995; Young 1995), and pollination (Groom 1998; Jennersten 1995; Bigger 1999). Pavlik (1996) stated that long-lived, self-fertilizing, woody plants with high fecundity would be expected to have minimum viable population sizes in the range of 50–250 reproductive individuals. Fifty reproductive individuals is a reasonable minimum figure for one of the dominant species of the community (*Juniperus ashei*) based on reproductive profiles (Van Auken *et al.* 1979; Van Auken *et al.* 1980; Van Auken *et al.* 1981). This figure would likely be an underestimate for other woody species present in central Texas woodlands, however, because these other species are more sensitive to environmental changes and do not meet several of the life-history criteria needed for the lowest minimal viable population size. Although these species may require population sizes at