

the higher end of range (that is, nearer 250 individuals) suggested by Pavlik (1996) to be viable, we do not have the data to support that contention. Therefore, on the basis of our review of information available to us, and after soliciting input from a botanist with expertise in the Edwards Plateau (Dr. Kathryn Kennedy, Center for Plant Conservation, pers. comm. 2002), we consider a minimum viable population size for individual plant species composing a typical oak/juniper woodland found in central Texas to be 80 individuals per species. This estimate is based on a habitat type that, as a whole, is fairly mature, and on knowledge that the species are relatively long-lived and reproductively successful.

On the basis of an analysis of recorded densities, corrected for nonreproductive individuals, we then calculated the area needed to support 80 mature reproductive individuals per species for the 24 species reported by Van Auker *et al.* (1980). Based on our calculations, the four highest area requirements to maintain at least 80 mature individuals were for species that occur at lower densities. These included 80 ha (198 ac) for *Condalia hookeri*, and approximately 32 ha (79 ac) for each of *Ptelea trifoliata*, *Ungnadia speciosa*, and *Bumelia lanuginosa*. Our calculations indicate that the area needed to maintain the 7 species with the highest average dominance values (*Juniperus ashei*, *Quercus fusiformis*, *Quercus texana*, *Acacia greggii*, *Rhus virens*, *Berberis trifoliata*, and *Ulmus crassifolia*) is approximately 13 ha (33 ac). This number would maintain 80 reproductive individuals for 15 of the 24 species. Nine of the species are rarer in the community and all have importance values of less than 1.0. The area needed to maintain these nine species ranges from approximately 20 to 80 ha (49 to 198 ac), with 7 of them in the 26 ha to 32 ha (65 to 79 ac) range.

Most literature found for Central Texas native grasslands was descriptive and not quantitative in its treatment of species composition and dispersion. No literature was located that provided grassland species area curves or quantitative species density tables for the Central Texas area. Two papers by Lynch (1962, 1971) examined species on an 8-acre tract over time, with 123 species, but a high species turnover. High species turnover can be indicative of a habitat area which is too small; however, pre- and post-drought conditions may also have affected this situation. Robertson *et al.* (1997), in a slightly more mesic grassland habitat, found that a 4 ha (10 ac) site captured

most of the species diversity (100 species) present even in much larger patches, although it does not address population sizes and persistence in isolation, and an increase to a 6 ha (14 ac) tract increased species representation to 140. One paper on a grassland in a more westerly and drier location in Central Texas recorded 157 taxa in a 16 ha (40 ac) enclosure studied between 1948 and the mid-1970's (Smeins and Merrill 1976).

Primary recruitment of new individuals of grass species in grasslands is from seedling establishment. Many grass species use wind to disperse their seeds and dispersal distances may be small. The process of expansion through rhizomes (underground stems) is slow and clonal, which reduces genetic variability. Seed dispersal, soil texture, and suitable soil moisture profiles at critical times are important factors for maintaining viability (Coffin *et al.* 1993).

As described above, we have reviewed the available information concerning grasslands and grassland species in Central Texas. The information is of a relatively general nature, and we did not find specific information addressing the role that grasslands or grass species might play in contributing, directly or indirectly, to karst ecosystems. While grassland communities and species may be important to maintaining the karst community, we lack adequate information to credibly estimate surface habitat patch size requirements for grass species in relation to karst ecosystems.

The presence of surface vegetation communities is important for maintaining the humid conditions, stable temperatures, and natural airflow in cave and karst environments. Vegetation also plays an important role in water quality. Since soil depth is shallow over the limestone plateau, water collects as sheet flow on the surface following rain and enters the subsurface environment through cave openings, fractures, and solutionally-enlarged bedding planes. This direct, rapid transport of water through the karst allows for little or no purification (Veni 1988), allowing contaminants and sediments to enter directly into the subsurface environment. As a result, karst features and karst dependent invertebrates are vulnerable to the adverse effects of pollution from contaminated ground and surface water. Maintaining stable environmental conditions and protecting groundwater quality and quantity requires managing a healthy vegetation community to avoid threats from surface and subsurface drainage to the karst

environment needed by the karst dependent species. This includes not only the cave entrances accessible to humans, but also sinks, depressions, fractures, and fissures, which may serve as subsurface conduits into caves and other subsurface spaces used by the invertebrates.

### Buffer Areas

To maintain a viable vegetative community, including woodland and grassland species, a buffer area is needed to shield the core habitat from impacts associated with edge effects or disturbance from adjacent urban development (Lovejoy *et al.* 1986; Yahner 1988). In this context, edge effects refer to the adverse changes to natural communities (primarily from increases in invasive species and pollutants, and changes in microclimates) from nearby areas that have been modified for human development.

The changes caused by edge effects can occur rapidly. For example, vegetation 2 m (6.6 ft) from a newly created edge can be altered within days (Lovejoy *et al.* 1986). Edges may allow invasive plant species to gain a foothold where the native vegetation had previously prevented their spread (Saunders *et al.* 1990; Kotanen *et al.* 1998; Suarez *et al.* 1998; Meiners and Steward 1999). When plant species composition is altered as a result of an edge effect, changes also occur in the surface animal communities (Lovejoy and Oren 1981; Harris 1984; Mader 1984; Thompson 1985; Lovejoy *et al.* 1986; Yahner 1988; Fajer *et al.* 1989; Kindvall 1992; Tschamtkke 1992; Keith *et al.* 1993; Hanski 1995; Lindenmayer and Possingham 1995; Bowers *et al.* 1996; Hill *et al.* 1996; Kozlov 1996; Kuussaari *et al.* 1996; Turner 1996; Mankin and Warner 1997; Burke and Nol 1998; Didham 1998; Suarez *et al.* 1998; Crist and Ahern 1999; Kindvall 1999). Changes in plant and animal species composition as a result of edge effects may unnaturally change the nutrient cycling processes required to support cave and karst ecosystem dynamics. To minimize edge effects, the core area must have a sufficient buffer area.

One recommendation for protecting forested areas from edge effects that are in proximity to clear-cut areas is use of the "three tree height" approach (Harris 1984) for estimating the width of the buffer area needed. We used this general rule to estimate the width of buffer areas needed to protect the habitat core areas. The average height of native mature trees in the Edwards woodland association in Texas ranges from 3 to 9