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HUMAN TRAMPLING EFFECTS ON REGENERATION AND AGE STRUCTURES OF PINUS EDULIS AND JUNIPERUS MONOSPERMA

Alex S. Tonnesen1,2 and James J. Ebersole1,3

ABSTRACT.—We examined effects of human foot traffic on age structures and densities of seedlings and saplings of Pinus edulis (Colorado pinyon) and Juniperus monosperma (one-seed juniper) in a heavily used urban park, Garden of the Gods, Colorado. Age structures show no stand-destroying disturbances, but they do contain small peaks 85-95 yr ago (minimum age), which have been interpreted as responses to heavy grazing. For Pinus edulis reverse J-shaped age structures indicate a strongly reproducing population, while flat age structures of J. monosperma show low present reproduction. Young trees showed strong preferences for establishing under existing trees and shrubs and not among herbs or on bare soil. Pinus edulis seedling density was reduced by 73% in heavily trampled areas compared to lightly trampled areas. However, there were no differences in density when only the area protected by rocks, shrubs, or trees was considered. This indicates that direct effects such as physical damage and soil erosion kill young trees, and indirect effects, such as lower seed production, do not cause the lower densities in heavily trampled areas. Pinus edulis saplings and J. monosperma seedlings and saplings showed no differences in density across trampling intensities. In heavily trampled areas of Garden of the Gods Park, recent increases in use have apparently reduced Pinus edulis seedling establishment enough that long-term regeneration is threatened. Managers of all pinyon-juniper woodlands must recognize that in areas strongly impacted by foot traffic, and also presumably by similar disturbances such as vehicle traffic, sufficient regeneration likely does not occur to replace trees. The areal extent of severely disturbed areas should be limited, and managers should seek to avoid further degradation of less damaged areas.

Key words: pinyon-juniper woodland, Pinus edulis, Juniperus monosperma, trampling, disturbance, recreation ecology, management, age structure, seedling, microsite preference, regeneration.

Pinyon-juniper woodlands cover large areas of western North America and are important for wildlife, recreation, occasionally firewood (West 1988), and for Native American uses (Wasson 1987, Jebsen-Ross and Schwab 1995). Much of the research in pinyon-juniper woodlands has focused on expansion of the community and increases in tree density since the 1800s (Jameson 1962, Blackburn and Tueller 1970, Burkhardt and Tisdale 1976). Other research has studied disturbance to cryptogamic soil crusts in this community (Johansen and St. Clair 1986, Cole 1990, Beyer and Klopatek 1992, Belnap 1993). No study has addressed the effects of recreational disturbances upon age structures and recruitment of pinyons and junipers.

Here we examine effects of trampling from human foot traffic in a heavily used park adjacent to an urban area. In parts of the study site, trampling has removed most understory vegetation and caused substantial soil erosion. With such obvious effects on grasses and forbs, we focused on trees to determine if trampling has affected dominant plants of the ecosystem as well. Our results may apply to other pinyon-juniper woodlands and other disturbances, such as vehicle use, that remove herbaceous plant cover.

Specifically, our goals were to (1) determine how varying intensities of trampling have affected seedling and sapling densities of Pinus edulis Engelm. (Colorado pinyon) and Juniperus monosperma (Engelm.) Sarg. (one-seed juniper), (2) use age structures to determine the length of time this disturbance has affected tree establishment, and (3) predict future trends in these woodlands.

STUDY AREA

Garden of the Gods is a 553-ha city park on the edge of Colorado Springs, Colorado. The first portion of the park, including the study site, was established in 1909 (Colorado Springs
The park straddles transitions from plains to foothills and from grasslands to woodlands of *Pinus edulis* and *Juniperus monosperma*. *P. edulis* and *J. monosperma* reach their northeastern and northern limits, respectively, at Colorado Springs, with the exception of a few disjunct populations of *P. edulis* (Little 1971, Weber 1976). Mature *P. edulis* individuals substantially outnumber mature *J. monosperma* individuals even though *J. monosperma* is normally more common at lower elevations (Woodin and Lindsey 1954, Lajtha and Getz 1993). *Cercocarpus montanus* (mountain-mahogany) and *Quercus gambelii* (Gambel oak) are the most common shrubs of these woodlands.

The climate is semiarid with a 30-yr mean precipitation of 41 cm/yr recorded at a site 17 km to the east-southeast and 80 m lower. Winters are dry and mild with a mean January temperature of −2°C. Summers are warm (July mean temperature 22°C), with frequent thunderstorms that create a summer precipitation peak (NOAA 1993).

Study sites are located on the strongly dipping portion of the Fountain Formation; they have eastern to southern aspects, flat to 3° slopes, and elevations of 1940 to 2000 m. Soils are of the Connerton series, deep, well-drained loams with gravel (Soil Conservation Service 1981). Surface runoff on study plots is medium to rapid, erosion hazard is moderate to high, and the sites have moderate to severe limitations for recreation (Soil Conservation Service 1981).

Over 1 million visitors per year visit this relatively small park (Colorado Springs Parks and Recreation Department 1994). Large numbers of people leave maintained trails, creating an obvious network of social trails and general trampling that very few areas have escaped. Areas close to trails, parking areas, and prominent rock outcrops retain little understory vegetation, and soil erosion is severe. In the most severely eroded areas, shrubs are on pedestals 0.5–1 m tall, and vertical-sided erosion gullies measuring up to 4 m deep have been cut. Trees in these areas, and even in areas moderately affected, commonly have partially exposed roots.

Invasive species and species resistant to trampling due to low stature (Liddle 1991), such as *Bouteloua* spp. (Ebersole unpublished data), make up most of the herbaceous cover remaining on heavily trampled sites. Areas with relatively dense herbaceous cover (40–75%) comprise approximately 5% of the pinyon-juniper community and are limited to areas that are farther from roads and trails and are blocked from easy access by very steep slopes or rock outcrops. These areas are dominated by plants less resistant to grazing (Risser et al. 1981) and presumably to human trampling due to their higher stature (Liddle 1991), such as *Andropogon gerardii* (big bluestem), *Schizachyrium scoparium* (little bluestem), and *Bouteloua curtipendula* (sideoats grama). Most of the pinyon-juniper community has received moderate levels of disturbance and has an understory of 12–35% cover.

**METHODS**

We considered 3 trampling intensities defined by cover of herbaceous vegetation: lightly trampled, >35% cover; moderately trampled, 11–35% cover; and heavily trampled, ≤10% cover. Areas with bedrock close to the surface and drainages were not sampled, and all plots had very similar soils.

Between August and October 1992, we estimated ages of 75–120 individuals of both *P. edulis* and *J. monosperma* within both moderately and heavily trampled areas. There was not enough lightly trampled area to sample. The largest possible rectangular plots, up to 20 m by 40 m, were placed in homogeneous areas; all trees with greater than 7-cm basal diameter were cored 15–20 cm above the ground; and rings were counted.

In cores without centers, distance to the center was determined and age adjusted using average inner ring width of cores with centers. No attempt was made to account for missing years or false rings. Since missing rings are common in pinyon and especially juniper, absolute ages are likely underestimates (Despain and Klemmedson 1987). However, we assumed missing rings occurred with approximately the same frequency in different trampling intensities. Ages were not adjusted for height of coring aboveground. They are an estimated 15–20 yr older than reported based on Tausch and West's (1988) findings that seedlings of *Pinus monophylla* (singleleaf pinyon) and *Juniperus osteosperma* (Utah juniper) 8–12 cm tall were 10–15 yr old.

Trees too small to core were grouped into 3 size classes: (1) seedlings (basal diameters <0.5
TABLE 1. Median, minimum, and maximum ages (yr) of small and large saplings of Pinus edulis and Juniperus monosperma determined by basal cross section. Samples were obtained 3 km south of the primary study site (see Methods).

<table>
<thead>
<tr>
<th></th>
<th>Small saplings</th>
<th>Large saplings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n Median Minimum Maximum</td>
<td>n Median Minimum Maximum</td>
</tr>
<tr>
<td>Pinus edulis</td>
<td>8 14.5 9 29</td>
<td>8 26.5 18 40</td>
</tr>
<tr>
<td>Juniperus monosperma</td>
<td>9 18 11 42</td>
<td>9 42 24 62</td>
</tr>
</tbody>
</table>

Ages of saplings were estimated by counting rings of similar-sized individuals cut at ground level within the same plant community, aspects, bedrock, and elevation 3 km south of Garden of the Gods. Seedlings were assumed to be ≤ 10 yr (Blackburn and Tueller 1970).

Microsite locations and densities of seedlings and saplings were determined from belt transects in October 1995. Ten plots, each 4 m by 20 m, were placed into each trampling regime: light, moderate, and heavy. All live seedlings and saplings were tallied by location: under trees, under shrubs, next to rocks, on bare soil, or within herbaceous vegetation. If normality assumptions were met, densities were compared with ANOVA; if not, Kruskal-Wallis tests were used. Homoscedasticity was not tested since P values are not affected by inequality of variance if sample sizes are equal (Scheffe 1959).

Midlines of belt transects were used for line-intercept sampling to determine areal proportions of the 5 microsites. Mean proportions of each microsite within each disturbance intensity were used to calculate expected numbers of seedlings and saplings assuming a random distribution. For chi-square tests rock, shrub, and tree counts were combined as sites protected from trampling, so that expected values met criteria of Koehler and Larntz (1980) for minimum expected frequencies.

RESULTS

Basal cross sections of saplings (Table 1) showed large variation in age, with J. monosperma generally older than Pinus edulis of similar size. Age structures (Fig. 1) are graphed with small and large saplings in the equivalent positions of 10–19 and 20–29 yr. Since saplings showed moderate to strong tendencies to be older than this (Table 1), age classes with mid-points of 35–65 yr will be substantially to slightly increased over the number obtained from cores, and the apparent number of trees 10–29 yr will be decreased (Fig. 1).

Under both trampling regimes Pinus edulis showed reverse J-shaped age structures, with moderately large numbers of young relative to older trees (Fig. 1). Age distributions of the 2 disturbance intensities do not differ significantly (P = 0.23). Since areas sampled differ between disturbance regimes, absolute densities cannot be inferred and compared from Figure 1.

J. monosperma age distributions were flatter than those for P. edulis (Fig. 1). Because many saplings are older than 29 yr (Table 1), in moderately trampled areas there are fewer individuals in the youngest age classes than in age classes around 85 yr. In heavily trampled areas J. monosperma seedlings appeared to be more abundant than individuals in older age classes, but saplings, after corrections from Table 1, were less abundant than individuals in age classes around 95 yr. Age structures in the 2 trampling regimes are different (P = 0.009) due to the larger number of seedlings and saplings and the fewer older trees in heavily disturbed areas (Fig. 1).

Absolute density of Pinus edulis seedlings was reduced 73% in heavily trampled areas compared to lightly trampled areas (Fig. 2, P = 0.02). Moderately disturbed areas showed intermediate P. edulis seedling densities although they were not significantly different from the 2 other trampling intensities. Densities of P. edulis saplings and of Juniperus monosperma seedlings and saplings combined did not differ among the 3 disturbance regimes (Fig. 2). When considering only sites protected by rocks and woody plants, trampling intensity does not change densities of seedlings and saplings (Table 3). Although the means for P. edulis seedlings suggest a trend, this is due to 1 high-density outlier in a lightly trampled area.
Fig. 1. Age structures of *Pinus edulis* and *Juniperus monosperma* under moderate and heavy trampling. Lengths of y-axes are proportional to sample size so bars of equal height represent the same relative frequency. In all graphs, seedlings and saplings are the left 3 bars as indicated in the first graph. Ages of destructive samples of seedlings (≤ 0.5 cm basal diameter), small saplings (basal diameter 0.5–7 cm and <50 cm tall), and large saplings (basal diameter 0.5–7 cm and ≥ 50 cm tall) are given in Table 1. *P. edulis* age distributions are not different (*P* = 0.23, two-sample Kolmogorov-Smirnov test for large sample sizes [Sokal and Rohlf 1995: 434]), and for *J. monosperma* they are different (*P* = 0.009).

*Pinus edulis* seedlings and saplings showed similar strong preferences for microsites, and these preferences were consistent across trampling intensities (Table 2). Fewer individuals than expected based on random distributions were found on bare soil; and more than expected were found in sites protected by rocks, shrubs, and trees. Because rock cover was very low, preferences were for sites under shrubs and trees. *J. monosperma* tended to show the same microsite preferences, although the rarity of young individuals made significance tests impossible (Table 2).

**DISCUSSION**

Reverse-J age distributions of *Pinus edulis* and the lack of fire scars on trees indicate no stand-destroying disturbances in the past 350 yr. Small peaks at 85–95 yr before sampling in
3 of 4 cases (Fig. 1) may be the result of over-grazing that reduced fine fuels and fire frequency as hypothesized by Burkhardt and Tisdale (1976), Miller and Wigand (1994), and Miller and Rose (1995).

Preference of young pinyons and junipers for microsites protected by woody plants has been found by others (Phillips 1909, Tausch et al. 1981, Welden et al. 1990, Miller and Rose 1995) and is likely caused here by (1) reduced soil surface temperatures compared to bare soil and soil under grasses (Burkhardt and Tisdale 1976); (2) frost heaving of seedlings being more common on bare soil (Heidmann 1976); (3) protection under woody plants from direct injury of trampling; (4) scrub jays avoiding caching P. edulis seeds in open areas (Balda 1987; pinyon jays are uncommon in Garden of the Gods); and (5) perhaps defecation of juniper seeds by birds perched in trees. Lack of density differences among trampling regimes within protected sites (Table 3) indicates that direct effects such as soil erosion and physical injury from foot traffic reduce densities of young trees. If indirect effects such as decreased seed production in heavily trampled areas were important, then protected sites of heavily trampled areas would presumably show lower densities.

The sharp decrease in density of Pinus edulis seedlings caused by trampling and the lack of density differences for P. edulis saplings (Fig. 2) imply trampling has limited seedling establishment only recently. Apparently, the marked growth in users and subsequent trampling in Garden of the Gods over the last decades (personal observation, Beidleman written communication) has substantially increased seedling mortality.

Management Implications

In pinyon-juniper woodlands with heavy human trampling, and presumably similar disturbances caused by heavy vehicle use, loss of understory vegetation is obvious. Erosion rates are also greatly increased, by approximately 10–35 times relative to undisturbed areas (Wilcox 1994). In addition to these more obvious effects, this study provides strong evidence that in heavily trampled areas insufficient regeneration occurs to replace trees as they die. Managers must realize that these heavily impacted areas are sacrifice areas not being used sustainably. It is important to limit the
Table 2. Pinus edulis and Juniperus monosperma observed and expected seedling and sapling frequencies by microsite. There were ten 4 X 20 m plots in each trampling intensity. To meet minimum expected frequencies for $\chi^2$, 2 sizes of Pinus edulis saplings were combined; and rock, shrub, and tree microsites were considered together as protected sites (data are also given by original 5 microsites). J. monosperma seedlings and saplings were combined, and no statistical tests were done due to small expected frequencies.

<table>
<thead>
<tr>
<th>Microsite</th>
<th>Average % cover</th>
<th>P. edulis seedlings</th>
<th>P. edulis saplings</th>
<th>J. monosperma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Obs</td>
<td>Exp</td>
<td>$\chi^2$</td>
<td>Obs</td>
</tr>
<tr>
<td>Bare</td>
<td>31.4</td>
<td>3</td>
<td>12.9</td>
<td>30.73</td>
</tr>
<tr>
<td>Herb</td>
<td>36.9</td>
<td>12</td>
<td>15.1</td>
<td>0.00</td>
</tr>
<tr>
<td>RST(^a)</td>
<td>31.4</td>
<td>37</td>
<td>12.9</td>
<td>4.36</td>
</tr>
<tr>
<td>Rock</td>
<td>5.7</td>
<td>4</td>
<td>0.9</td>
<td>0.36</td>
</tr>
<tr>
<td>Shrub</td>
<td>21.6</td>
<td>13</td>
<td>2.3</td>
<td>0.04</td>
</tr>
<tr>
<td>Tree</td>
<td>23.6</td>
<td>20</td>
<td>9.7</td>
<td>0.05</td>
</tr>
<tr>
<td>Total</td>
<td>52</td>
<td>6</td>
<td>9.2</td>
<td>0.00</td>
</tr>
</tbody>
</table>

\(^a\)Rock, shrub, and tree microsites combined.

Table 3. Densities (no./m\(^2\), $\bar{x} \pm s_p$, $n = 10$) of Pinus edulis and Juniperus monosperma seedlings and saplings in protected sites (rock, shrub, and tree microsites combined). Significance of Kruskal-Wallis tests for differences among trampling regimes is given.

<table>
<thead>
<tr>
<th>Trampling intensity</th>
<th>P. edulis seedlings</th>
<th>P. edulis saplings</th>
<th>J. monosperma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>0.31 ± 0.162</td>
<td>0.12 ± 0.024</td>
<td>0.06 ± 0.019</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.052 ± 0.018</td>
<td>0.040 ± 0.015</td>
<td>0.048 ± 0.018</td>
</tr>
<tr>
<td>Heavy</td>
<td>0.023 ± 0.016</td>
<td>0.018 ± 0.013</td>
<td>0.025 ± 0.019</td>
</tr>
</tbody>
</table>

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areal extent of these heavily impacted areas by controlling use, and managers should also seek to prevent lightly and moderately impacted areas from deteriorating further. Pinus edulis and Juniperus monosperma are not only the most visually dominant species of this community, but they also hold soil in place, modify the environment for many other plant species (West 1984), and provide food and cover for many animals (Sedgwick and Ryder 1987). Their substantial reduction or loss would markedly reduce the biological and recreational values of these woodlands.

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