
Effects of Rock Climbing on Cliff Goldenrod
(Solidago sciaphila Steele) in Northwest Illinois

VICTORIA A. NUZZO
Native Landscapes, 1947 Madron Road, Rockford, Illinois 61107

ABSTRACT.—Solidago sciaphila is an endemic goldenrod, restricted to dolomite or sandstone cliffs in and near the driftless region of the upper Midwest. A demographic study of 544 genets on currently climbed, previously climbed and unclimbed dolomitic cliffs in NW Illinois indicated that position on the cliff face was the most significant factor affecting growth. Seventy percent of all plants grew within 3 m of the cliff top, an area that comprised only 18% of the cliff face. Within the upper cliff zone, rock climbing significantly reduced Solidago density. Cliffs that were actively climbed had few genets in the upper 3 m, averaging 3.2/m², while unclimbed cliffs and cliffs not climbed for 2 yr supported 14.2/m² and 12.0/m², respectively. Basal area/m² and flowering ramet production/m² were significantly lower, and inflorescence length nonsignificantly lower, on currently climbed cliffs, due to the lower genet density. In the lower cliff zone (>3 m from the top) genet density was low (0.2-2.1/m²) on all cliffs, regardless of climbing intensity. On climbed cliffs > 50% of flowering ramets were broken, significantly more than the 15% broken on unclimbed cliffs. Broken flowering ramets produced 22% of total inflorescence length on the currently climbed cliffs (compared to <5% on unclimbed and previously climbed cliffs), resulting in total inflorescence production statistically similar to, but lower than, that on unclimbed and previously climbed cliffs. Two years after cessation of climbing, Solidago in the upper zone of the previously climbed cliffs had similarly high density, basal area, ramet production and inflorescence production as on unclimbed cliffs. Climbing appeared to skew the population structure, favoring survival of large flowering genets and inhibiting survival of smaller nonflowering genets. This difference largely disappeared on cliffs unclimbed for 2 yr. To protect Solidago sciaphila, it is necessary to protect the entire cliff face, with highest priority given to the upper 3 m.

INTRODUCTION
Cliff goldenrod (Solidago sciaphila Steele) is a cliff endemic, restricted to dolomite and sandstone cliffs located primarily in the driftless region of Illinois, Iowa, Wisconsin and Minnesota (Thorne, 1953; Hartley, 1960; Salaman, 1963; Lammers, 1983; Gleason and Cronquist, 1991). The plant is listed as ‘threatened’ in Illinois (Herkert, 1991) and of special concern in Minnesota (Coffin and Pfannmuller, 1988), due to the rarity of cliff habitats that support this species. In Illinois a total of four populations are known (Herkert, 1991), the largest occurring on dolomitic cliffs above the Mississippi River, in the Mississippi Palisades State Park (Handel, 1994). The exposed cliffs are sparsely vegetated, and vascular species average only 5.8% total cover, with Solidago sciaphila contributing 36% of the total (Nuzzo, 1994). As on other dolomitic cliffs (Larson et al., 1989), vascular vegetation at the Mississippi Palisades is concentrated near the cliff top (Nuzzo, 1994).

Solidago sciaphila (hereafter referred to as Solidago) is a glabrous polycarpic perennial that forms a basal rosette from a branched caudex with a fibrous root system (Gleason and Cronquist, 1991). Basal leaves are largest and usually persistent, the blade measuring up to 15 cm × 8 cm, and tapering to the petiole. Genets produce one or more flowering ramets 4–8 (~11) dm in length. The inflorescence is an elongate, bracteate, rarely branched, terminal thryse, 1–2.5 dm long, with involucres (4–) 5–7 mm tall. Flowers are produced from late August through early October. No demographic studies have been conducted on this
goldenrod. The primary habitat is calcareous and sandstone cliffs and outcrops, where Solidago grows in crevices, pits and on ledges (Coffin and Pfannmuller, 1988; Handel, 1994). In addition, Solidago occasionally occurs in thin Sogn soil at bluff tops, and at the base of the cliff at the start of the talus slope (Handel, 1994).

Rock climbing is an increasingly popular activity (Berl and Chilman, 1980) that is believed to have a negative impact on cliff vegetation (Spear and Schiffman, 1979; NPS, 1990). Cliffs within the Mississippi Palisades State Park have been used for rock climbing for over 50 yr (Collett, 1991). No records have been kept of climber activity; estimated use intensity in 1988 ranged from 400–500 climber-days/year, in 1991 from 900–1200 climber-days/year, and in 1994 from 2000 to 2400 climber-days/year. One climber-day equates to one or more climbs, on the same or different route, on a given day. Two major climbing areas within the park were closed in 1991, due to the concern that climbing might damage cliff vegetation. This study was conducted in 1993 to assess the actual impact of current and prior rock climbing on Solidago sciaphila. The null hypothesis was that there were no significant differences in the density, size, or reproduction of Solidago sciaphila growing on currently climbed, previously climbed and never climbed cliffs.

Methods

Study sites.—The study was conducted in extreme NW Illinois, within the Mississippi Palisades State Park (Sections 28 and 33, T25N, R3E, 4th PM, Carroll County), on vertical cliffs that parallel the E bank of the Mississippi River. Three cliff areas were selected for study. Two of the areas, Sentinel and Sun Buttress, are within the 21-ha Sentinel Nature Preserve, dedicated in 1991 to protect habitat for several state-listed species, including Solidago. Both areas contain cliff routes that were climbed continuously since the 1940s (Collett, 1991). In 1991 one route at Sentinel (estimated 25 climbs/year in 1990), and all routes at Sun Buttress (estimated 250 climbs/year in 1990) were closed to climbing; these closed routes are termed “previously climbed.” In 1993 two routes at Sentinel, termed “currently climbed,” averaged an estimated 75 and 250 climbs/year (R. LaFleur, pers. comm.). The third area, Squaw Point, lies 1 km N of the nature preserve, and was never or rarely climbed. The cliffs are composed of Silurian dolomite, with the upper 20–34 m (area studied) consisting of the Racine Formation, a pure dolomite that is medium-grained and light gray to white with gray mottings (Willman et al., 1975; Hynek, 1991). All cliffs included in this study have a general westerly exposure facing the Mississippi River; a 2–4 m wide expanse of bare rock at the top of a vertical slope; scattered red cedar (Juniperus virginiana) at or near the cliff edge; and deciduous forest at the cliff base. Despite these similarities, the cliffs are inherently variable with overhangs, fissures, narrow ledges and, due to differential weathering and exfoliation of the rock face, surface patterns that vary from smooth unfractured rock to vuggy (pock-marked), highly fractured rock within a short distance.

Data collection.—A total of 11, 1-m wide, belt transects were established, each located at the top of a real or potential climbing route; a potential route was defined as the most likely route a climber would use on an unclimbed cliff. To ensure a random sample, cliff faces were not examined for presence of Solidago before transect location. A 1-m-wide zone that centered on the top of each climbing route was delineated, and the midpoint of the transect was randomly established within this zone. Actual climbing routes were not consistently vertical, and therefore transects occasionally intersected, rather than overlapped, climbing routes. Cliff heights ranged from 5–21 m, and total number of transects/treatment and quadrats/cliff varied accordingly. Data were collected 15–17 September 1993 from a total of 185 quadrats: 42 currently climbed (two transects at Sentinel), 56 previously climbed (one transect at Sentinel and two at Sun Buttress), and 87 unclimbed (two transects each
at Sentinel, Sun Buttress and Squaw Point). Sampling was conducted 2 yr after routes were closed, and no precollection data were collected.

*Solidago* genet density was recorded within contiguous 1 m² quadrats in each belt, beginning at the top of each cliff. Data recorded for genets consisted of caudex class (single or multiple), basal rosette diameter in two directions (the first measured at the widest point, and the second at right angles to the first; d1 and d2, respectively), number of flowering ramets (broken and unbroken), and total inflorescence length/flowering ramet. Inflorescence length, rather than flowering ramet length, was recorded because the inflorescence covered from 10–90% of the ramet; thus, inflorescence length was considered a more accurate indicator of reproductive activity than flowering ramet length. *Solidago* typically has a narrow, unbranched, terminal thryse. When a branched thryse was encountered, the length of inflorescence on each branch was recorded and the measurements summed for total inflorescence length. Occasionally, flowering ramets were damaged during set-up or investigator movement on the cliff: these ramets were measured and recorded as unbroken.

Individual genets produce one or more rosettes: a solitary rosette was classified as a “single caudex” genet; genets with >=2 tightly clustered basal rosettes were classified as “multiple caudex” genets. In most cases branched caudices were visible below the basal leaves. However, caudices could not be seen for some densely clustered rosettes, and these plants, treated as multiple caudex genets, may have been separate individuals. The entire basal cluster, formed by one or more rosettes, was measured to determine basal area. Total basal area/genet was calculated by the formula $\pi[0.25(d1 + d2)]^2$. Plants smaller than 2 cm in diam were assigned an area of 1.8 cm². Only two seedlings were observed during data collection; both were assigned areas of 1.8 cm². Flowering genets often had small or no rosettes; those that lacked a rosette were assigned an area of 0.2 cm², based on a stem diam of 0.5 cm. Sterile genets were assigned to one of four size classes, based on basal area: class 1 (<=5 cm²), class 2 (5–50 cm²), class 3 (>50–179 cm²), or class 4 (>180 cm²). All flowering genets, regardless of basal area, were assigned to class 5.

*Statistical design.*—The research design was a two-way analysis of variance, with climbing intensity (never climbed, previously climbed, or currently climbed) and location (upper 3 m or the remainder of the cliff) as the categorical variables. This approach tested for significant differences attributable to climbing relative to location on the cliff surface, and allowed an assessment of *Solidago* recovery once climbing stopped. All values were compiled on a square meter basis and transformed to improve normality. Basal area was increased by 0.5 and then square root transformed, and all other values were increased by 1, and log transformed to base 10 (Zar, 1984). Significant differences between means were determined by a least significant difference (LSD) test. On a per genet basis, Kruskal-Wallis and Mann-Whitney tests were performed on mean values within each climbing treatment or each location; the scarcity of plants on the currently climbed cliff limited more detailed testing. Simple linear regression and chi square analysis (using Yates correction when df = 1) were also conducted. Analyses were conducted with Systat (Wilkinson, 1990).

**Results**

A total of 544 genets was recorded, 310 on unclimbed cliffs (within 87 m²), 208 on previously climbed cliffs (56 m²), and 26 on currently climbed cliffs (42 m²). Genet density ranged from 0–63 plants/m², and basal area from 0.2–829.6 cm².

*Results expressed per m².*—Position on the cliff face was the most significant factor affecting *Solidago* growth, and was consistent at all sites and treatments (Table 1). The upper 3 m of each cliff, which comprised 18% of the study area, supported 70% of all plants. Within this zone *Solidago* grew at a mean density of 14.2/m², compared to a mean of 0.8/m² in the
### Table 1.—Summary tables of two-way ANOVA for *Solidago sceaphila* density, rosette area, flowering ramet density, and inflorescence length, per m²

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density (#/m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>1.464</td>
<td>0.732</td>
<td>6.814</td>
<td>0.001</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>9.348</td>
<td>9.348</td>
<td>87.030</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>0.364</td>
<td>0.182</td>
<td>1.693</td>
<td>0.187</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>19.226</td>
<td>0.107</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sterile genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>1.643</td>
<td>0.822</td>
<td>8.407</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>7.457</td>
<td>7.457</td>
<td>76.299</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>0.435</td>
<td>0.217</td>
<td>2.223</td>
<td>0.111</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>17.495</td>
<td>0.098</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertile genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>0.231</td>
<td>0.115</td>
<td>3.676</td>
<td>0.027</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>1.851</td>
<td>1.851</td>
<td>58.937</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>0.170</td>
<td>0.085</td>
<td>2.704</td>
<td>0.070</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>5.621</td>
<td>0.031</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Basal area (cm²/m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>790.097</td>
<td>395.049</td>
<td>5.000</td>
<td>0.008</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>5992.534</td>
<td>5992.534</td>
<td>75.849</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>347.204</td>
<td>173.602</td>
<td>2.197</td>
<td>0.114</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>14,142.169</td>
<td>79.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sterile genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>797.936</td>
<td>398.968</td>
<td>7.091</td>
<td>0.001</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>2452.608</td>
<td>2452.608</td>
<td>43.589</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>194.209</td>
<td>97.104</td>
<td>1.726</td>
<td>0.181</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>10,071.652</td>
<td>56.266</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertile genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>88.530</td>
<td>44.265</td>
<td>1.063</td>
<td>0.348</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>2361.662</td>
<td>2361.662</td>
<td>56.693</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>107.128</td>
<td>53.564</td>
<td>1.286</td>
<td>0.279</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>7456.574</td>
<td>41.657</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ramet density (#/m²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>0.691</td>
<td>0.346</td>
<td>4.421</td>
<td>0.013</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>5.519</td>
<td>5.519</td>
<td>70.589</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>0.518</td>
<td>0.259</td>
<td>3.316</td>
<td>0.039</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>13.994</td>
<td>0.078</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbroken genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>0.990</td>
<td>0.495</td>
<td>7.454</td>
<td>0.001</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>3.996</td>
<td>3.996</td>
<td>60.146</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>0.612</td>
<td>0.306</td>
<td>4.607</td>
<td>0.011</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>11.893</td>
<td>0.066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken genets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>0.017</td>
<td>0.008</td>
<td>0.387</td>
<td>0.679</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>0.823</td>
<td>0.823</td>
<td>38.420</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>0.036</td>
<td>0.018</td>
<td>0.850</td>
<td>0.429</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>3.834</td>
<td>0.021</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

lower zone, on the never climbed cliffs (Table 2). On the previously climbed cliffs densities were similarly high in the upper zone (12.0/m²), and slightly higher in the lower zone (2.1/m²), while on the currently climbed cliffs *Solidago* densities averaged only 3.2/m² and 0.2/m² in the upper and lower zones, respectively (Table 2). Because genets were denser
in the upper zone, mean basal area/m², mean flowering ramet density/m² and mean inflorescence length/m² were also significantly higher in this location (Tables 1 and 2).

Climbing treatment had a significant impact on Solidago density; significantly fewer genets (both sterile and fertile) grew on the currently climbed cliffs than on the previously or never climbed cliffs, in the upper zone. As would be expected, the lower density resulted

### Table 1.—Continued

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflorescence length (cm/m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All ramets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>1.426</td>
<td>0.713</td>
<td>2.192</td>
<td>0.115</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>19.175</td>
<td>19.175</td>
<td>58.945</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>1.028</td>
<td>0.514</td>
<td>1.580</td>
<td>0.209</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>58.228</td>
<td>0.325</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unbroken ramets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>2.324</td>
<td>1.162</td>
<td>3.788</td>
<td>0.024</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>17.163</td>
<td>17.163</td>
<td>55.960</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>1.289</td>
<td>0.644</td>
<td>2.101</td>
<td>0.125</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>54.901</td>
<td>0.307</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Broken ramets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>2</td>
<td>0.182</td>
<td>0.091</td>
<td>1.544</td>
<td>0.216</td>
</tr>
<tr>
<td>Position</td>
<td>1</td>
<td>1.098</td>
<td>1.098</td>
<td>55.960</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Intensity × position</td>
<td>2</td>
<td>0.006</td>
<td>0.003</td>
<td>0.047</td>
<td>0.954</td>
</tr>
<tr>
<td>Error</td>
<td>179</td>
<td>10.551</td>
<td>0.059</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2.—Solidago sciaphila mean values per m² in upper (within 3 m of cliff top) and lower (>3 m from top) zones of never climbed, previously climbed, and currently climbed cliffs. n = number of quadrats in each location. Different letters indicate statistically different means (P < 0.05)

<table>
<thead>
<tr>
<th>Upper zone of cliff</th>
<th>Lower zone of cliff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never climbed n = 18</td>
</tr>
<tr>
<td>Genet density (#/m²)</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>14.2(a)</td>
</tr>
<tr>
<td></td>
<td>Sterile genets</td>
</tr>
<tr>
<td></td>
<td>Fertile genets</td>
</tr>
<tr>
<td>Basal area (cm²/m²)</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>Sterile genets</td>
</tr>
<tr>
<td></td>
<td>Fertile genets</td>
</tr>
<tr>
<td>Flowering ramet density (#/m²)</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>Unbroken ramets</td>
</tr>
<tr>
<td></td>
<td>Broken ramets</td>
</tr>
<tr>
<td>Inflorescence length (cm/m²)</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>Unbroken ramets</td>
</tr>
<tr>
<td></td>
<td>Broken ramets</td>
</tr>
</tbody>
</table>
in significantly lower basal area on a m² basis (328.6 compared to 678.0 and 793.6 cm²/m²) on currently climbed, previously climbed, and never climbed cliffs, respectively) and lower flowering ramet density (2.0 compared to 8.8 and 6.3/m² on the same cliffs, respectively: Table 2). These differences reflect the relative lack of sterile genets on the currently climbed cliffs. In the upper zone, fertile genet density on currently climbed cliffs was only half that recorded on the other cliffs (1.0/m² vs. 2.1/m²). However, mean basal area of fertile genets (221.5 cm²/m², 278.9 cm²/m² and 308.6 cm²/m²), and mean inflorescence length (34.2 cm/m², 72.2 cm/m² and 45.1 cm/m²) on currently climbed cliffs were lower than, but not significantly different from, the previously climbed and never climbed cliffs, respectively (Table 2).

Results expressed per genet.—Of the 544 plants, 98 (18%) were fertile and 446 (82%) were sterile. Position on the cliff face had a significant effect on basal area of sterile, but not fertile, genets (Table 3). Climbing treatment had no significant effect on sterile genet basal area. Sterile genets in the upper zone averaged 38.5 cm² (across all climbing treatments), nearly half the basal area of genets in the lower zone, which collectively averaged 78.2 cm². The smaller average basal area is likely due to higher density in the upper zone.

Fertile genet basal area was highly variable, ranging from 0.2-660.5 cm². Although no significant differences in basal area were detected due to position or climbing treatment (Table 3), fertile genets growing on the currently climbed cliffs were 1.5–2.5 times larger than fertile genets on the previously and never climbed cliffs (Table 4). Only 10 fertile genets were recorded on the currently climbed cliffs, each with a basal rosette. Fertile genets were more numerous on both previously climbed and never climbed cliffs; a total of 44 fertile genets, 38 with basal rosettes, were recorded on the never climbed cliffs, and a total of 44 fertile genets, 39 with basal rosettes, were recorded on the previously climbed cliffs (upper and lower zones combined). Excluding the eleven genets that lacked a basal rosette, the remaining fertile genets had an average basal area of 159 cm² on the never climbed cliffs, and 154 cm² on the previously climbed cliffs, still smaller than the 232 cm² average fertile genet size on the currently climbed cliffs (upper and lower zones combined).

Individual genets usually produced 1–4 flowering ramets, although one individual had 22 separate ramets that produced 132 cm of inflorescence (maximum total inflorescence length produced by a single genet was 148 cm). Position on the cliff, but not climbing treatment, had a significant effect on the number of flowering ramets produced by fertile genets (Table 3). Across all treatments, fertile genets in the upper zone produced an average of 3.2 flowering ramets, compared to an average of 2.1 in the lower zone. However, climbing treatment became significant and cliff position nonsignificant, when flowering ramets were separated into broken and unbroken ramets; significantly more broken ramets were present on the currently climbed cliffs, and significantly more unbroken flowering ramets were present on the never climbed and previously climbed cliffs (Table 3). On the currently climbed cliffs an average of 0.8–2.0 broken flowering ramets/genet was recorded in the upper and lower zones, significantly higher than the 0–0.7 recorded in the same zones on the never climbed and previously climbed cliffs (Table 4). Flowering ramet breakage was even higher in the lower zone of the currently climbed cliffs, where broken ramets outnumbered unbroken ramets 2 to 1 (Table 4).

On all cliffs, ca. one third of broken flowering ramets produced inflorescences, which originated from axillary buds below the breakage point. On the never climbed and previously climbed cliffs, broken flowering ramets contributed very little to total inflorescence production (2–5%). In contrast, on the currently climbed cliffs broken flowering ramets contributed significantly to total inflorescence length, particularly in the lower zone, where broken flowering ramets produced 63% of the total inflorescence length (Table 4).
Table 3.—Summary tables of Mann-Whitney tests for effects of cliff position, and Kruskal-Wallis tests for climbing intensity, on mean rosette area, flowering ramet density and inflorescence length, per Solidago sciaphila genet

<table>
<thead>
<tr>
<th></th>
<th>Mann-Whitney</th>
<th>df</th>
<th>Kruskal-Wallis</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>All genets (n = 544)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>2.698</td>
<td>0.26</td>
</tr>
<tr>
<td>Position</td>
<td>8.268</td>
<td>1</td>
<td>—</td>
<td>0.004</td>
</tr>
<tr>
<td><strong>Fertile genets (n = 98)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>2.478</td>
<td>0.29</td>
</tr>
<tr>
<td>Position</td>
<td>0.006</td>
<td>1</td>
<td>—</td>
<td>0.94</td>
</tr>
<tr>
<td>Total ramet density</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>1.519</td>
<td>0.47</td>
</tr>
<tr>
<td>Position</td>
<td>8.062</td>
<td>1</td>
<td>—</td>
<td>0.005</td>
</tr>
<tr>
<td>Unbroken ramet density</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>7.711</td>
<td>0.021</td>
</tr>
<tr>
<td>Position</td>
<td>3.76</td>
<td>1</td>
<td>—</td>
<td>0.053</td>
</tr>
<tr>
<td>Broken ramet density</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>15.858</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Position</td>
<td>2.26</td>
<td>1</td>
<td>—</td>
<td>0.13</td>
</tr>
<tr>
<td><strong>Sterile genets (n = 446)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>2.127</td>
<td>0.34</td>
</tr>
<tr>
<td>Position</td>
<td>9.039</td>
<td>1</td>
<td>—</td>
<td>0.003</td>
</tr>
<tr>
<td>Total inflorescence length</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>1.527</td>
<td>0.47</td>
</tr>
<tr>
<td>Position</td>
<td>1.773</td>
<td>1</td>
<td>—</td>
<td>0.18</td>
</tr>
<tr>
<td>Unbroken inflorescence length</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>4.26</td>
<td>0.12</td>
</tr>
<tr>
<td>Position</td>
<td>1.765</td>
<td>1</td>
<td>—</td>
<td>0.18</td>
</tr>
<tr>
<td>Broken inflorescence length</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climbing intensity</td>
<td>—</td>
<td>2</td>
<td>13.482</td>
<td>0.001</td>
</tr>
<tr>
<td>Position</td>
<td>0.182</td>
<td>1</td>
<td>—</td>
<td>0.67</td>
</tr>
</tbody>
</table>

As would be expected, inflorescence length/genet was significantly related to number of flowering ramets, with 19% of the increase in inflorescence length due to the increase in flowering ramet density ($r^2 = 0.19, F = 22.758, P = 0.0001, df = 97$). The low $r^2$ value reflects the inflorescence production from broken ramets, particularly on the currently climbed cliffs. Basal area was not a significant factor for inflorescence length once ramet density was in the equation, reflecting the lack of a basal rosette on 12% of fertile genets.

Size class distributions.—On all cliffs, regardless of location, smaller nonflowering genets (class 1 and 2) were most numerous and large nonflowering genets (class 4) were least
Table 4.—Mean values per *Solidago sciuophila* genet, in upper and lower zones of never climbed, previously climbed and currently climbed cliffs. Number of genets in each location is indicated in parentheses. \( n \) = number of quadrats in each location

<table>
<thead>
<tr>
<th></th>
<th>Upper zone of cliff</th>
<th>Lower zone of cliff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never climbed</td>
<td>Previously climbed</td>
</tr>
<tr>
<td>Fertile genets</td>
<td>( n = 18 )</td>
<td>( n = 9 )</td>
</tr>
<tr>
<td>Basal area (cm(^2))</td>
<td>(38)</td>
<td>(19)</td>
</tr>
<tr>
<td>All ramets</td>
<td>2.97</td>
<td>4.16</td>
</tr>
<tr>
<td>Unbroken ramets</td>
<td>2.50</td>
<td>3.42</td>
</tr>
<tr>
<td>Broken ramets</td>
<td>0.47</td>
<td>0.74</td>
</tr>
<tr>
<td>Inflorescence length (cm/genet)</td>
<td>Total</td>
<td>21.45</td>
</tr>
<tr>
<td></td>
<td>Unbroken ramets</td>
<td>20.24</td>
</tr>
<tr>
<td></td>
<td>Broken ramets</td>
<td>1.21</td>
</tr>
<tr>
<td>Sterile genets</td>
<td>(217)</td>
<td>(92)</td>
</tr>
<tr>
<td>Basal area (cm(^2))</td>
<td>37.0</td>
<td>40.3</td>
</tr>
<tr>
<td>All genets</td>
<td>(255)</td>
<td>(111)</td>
</tr>
<tr>
<td>Basal area (cm(^2))</td>
<td>55.9</td>
<td>55.0</td>
</tr>
</tbody>
</table>

Numerous (Fig. 1). Fertile genets (class 5) outnumbered large sterile genets (class 4) by a factor of 3 or more. Fertile genets comprised 15–17% of the *Solidago* population in the upper zone, and 11–26% in the lower zone, on the never and previously climbed cliffs, respectively. In contrast, the few fertile plants present on the currently climbed cliffs comprised 32% of the population in the upper zone, and 57% in the lower zone.

*Caudex* type.—*Solidago* genets initiate growth as a single caudex, and over time can develop branched or multiple caudices. Caudex type is significantly related to genet size class (\( \chi^2 = 130.212, \text{df} = 4, P < 0.0001 \)), and single caudex genets are most abundant in the smaller size classes, while multiple caudex genets are most frequent in the larger size classes (Fig. 2). This pattern was similar regardless of climbing intensity (\( \chi^2 = 3.555, \text{df} = 2, P = 0.17 \)), or location on cliff (\( \chi^2 = 1.56, \text{df} = 1, P = 0.21 \)). Multiple caudices were noticeably absent from genets \(<180 \text{ cm}^2\) (size class 1–3) on the currently climbed cliff (Fig. 1), where they comprised only 23% of the total population, compared to 40–42% of the population on the previously and never climbed cliffs.

**Discussion**

*Solidago* showed a distinct preference for the upper part of each cliff. Regardless of overall cliff height, which ranged from 5 to 21 m, the majority of plants clustered in the upper 3 m, mirroring findings by Larson *et al.* (1989) and Nuzzo (1994) for cliff face flora in general. Within this narrow zone, rock climbing produced a substantial decline in *Solidago* density, which averaged 3.2/m\(^2\) on the currently climbed cliffs, one quarter the density recorded on the other cliffs. Fertile as well as sterile genets were reduced, with a consequent reduction in flowering ramets, which averaged just 2.0/m\(^2\) on the currently climbed cliffs, compared to 6.3–8.0/m\(^2\) on the never and previously climbed cliffs.
Solidago occurs almost exclusively on bare rock, rooted in fissures and pits, both of which are used for hand- and foot-holds by rock climbers. The lack of Solidago genets in the upper part of the currently climbed cliffs implies that rock climbing excludes Solidago from favorable habitat, presumably by climber use of the crevices Solidago roots in, and possibly by direct abrasion by ropes. Fertile genets were fewer but larger on the currently climbed cliffs.
than on the previously or never climbed cliffs. The size of fertile genets was only slightly dependent on total density ($r^2 = 0.05$, df = 97, $F = 4.521$, $P = 0.04$). Because large flowering genets are highly noticeable, it is likely that these plants were intentionally avoided by climbers. All routes on the currently and previously climbed cliffs are moderately difficult cliffs rated at 5.9–5.12 (Yosemite Decimal System); climbers who ascend to the top of these cliffs have the proficiency to avoid vegetated crevices and noticeable plants. Additionally, crevices and narrow ledges are often designated “off route” on difficult cliffs, and therefore will be intentionally avoided.

Climbing activity is heaviest near the base of the cliff, and decreases with cliff height, as less skilled climbers often come off the cliff before reaching the top. At the Mississippi Palisades, Solidago density was consistently low (0.2–2.1/m$^2$) on all cliffs in this lower zone, and no differences in density were detected between climbing treatments. Solidago densities are naturally low farther down the cliff, and presumably climbers have fewer encounters with, and consequently lower impact on, Solidago genets.

Very few genets were recorded in size class 2 or 3 (diam 3–15 cm) on the currently climbed cliffs. These smaller, nonflowering plants were likely unintentionally injured by climbers. Genets in the smallest size class (<5 cm$^2$), while still infrequent on the currently climbed cliffs, comprised 35% of the population, approximately the same as on the never climbed cliffs (30%). This may indicate that plants <5 cm$^2$ are less prone to trampling because they are so small. However, if this smallest size class represents the current year’s seedlings, then the very low density represents the current year’s climber-induced mortality, relative to the other cliffs.

The data imply a climbing-induced skewing of the age structure, in addition to a reduction of Solidago density. This is suggested by (1) the disproportionate abundance of fertile genets, and (2) the complete absence of multiple caudex genets in the three smaller size classes, on the currently climbed cliffs. While genet age was not determined in this study, the lack of multiple genets may imply younger plants in the smaller size classes; Zedler et al. (1983) determined that the number of apices in the composite Cirsium rhodophyllum increased with age cohort. Regardless of age, the absence of small multiple caudex genets may signify that climbing favors survival of single caudex genets; that small genets do not live long enough to develop multiple rosettes; or that climbing stimulates basal expansion over caudex expansion. As the factors that promote development of multiple caudices in this species are unknown, no direct conclusions can be made regarding the paucity of multiple rosette genets on the currently climbed cliffs.

It was hypothesized that flowering ramets would be broken during climbing, by setup of the route (which includes tossing ropes over the cliff edge) and/or by climbers brushing against flowering ramets. This hypothesis is supported as over half of the flowering ramets were broken on the currently climbed cliff, compared to 15% or less on the previously and never climbed cliffs, where ramets were naturally damaged by wind and falling debris. Despite the increased breakage, average inflorescence length/fertile genet on the currently climbed cliffs was comparable to that recorded on the other cliffs. Apparently, the loss of the primary inflorescence was compensated by production of additional, usually smaller, inflorescences from axillary buds. Similar net increases in flowerhead production following damage to the primary apex of herbaceous composites were hypothesized by Inouye (1982) and Zedler et al. (1983).

While no conclusion can be made about the different use intensities, it appears that climbing impact occurs with relatively few climbs. The two currently climbed cliffs differed in estimated annual use by a factor of 3 (approximately 75 and 250 climbs/year) but had similarly low Solidago densities. This similarity may result from the cumulative impact of 50
yr of climbing, or may indicate that the majority of impact results from the first few climbs, with relatively minor additional impact from successive climbs. The currently climbed cliffs reflect *Solidago* presence after 50 yr of climbing. It appears that once climbing activity ceases, *Solidago* can substantially recover within 2 yr, as indicated by the similarity of previously climbed and never climbed cliffs. This conclusion assumes that the cliffs supported comparable numbers of *Solidago* before closure of the three previously climbed routes. Sampling was not conducted before closure, and additional study is needed to support this conclusion.

*Solidago* plants were clustered in the upper 3 m of all cliffs, regardless of climbing history. A second clustering was apparent on most cliffs at approximately 8–14 m below the cliff top, possibly indicating presence of a stratigraphic seam of more fractured rock; *Solidago* density increases with fracture abundance (Nuzzo, 1994). Two of the three previously climbed cliffs showed much higher *Solidago* density and cover in this midcliff location than the other cliffs. While this higher abundance may be due to greater fracturing of the rock face on these specific cliffs (fractures were not measured in this study), it may also indicate that *Solidago* responds positively to release from climbing pressure. The increased growth in this location made the lower zone of the previously climbed cliffs similar to the upper zone of the currently climbed cliff, and dissimilar to the other lower zones (Table 2). Further study is needed to determine if the locally greater growth resulted from more favorable growing conditions, or release from climbing pressure.

*Solidago* grows on both exposed (high sun and wind) and protected (shaded, less windy) rock surfaces. Although this study focused on the very harsh environment of exposed cliff faces, *Solidago* appears to have similar or greater abundance on protected cliffs and rock faces; the specific name *sciaphila* indicates shade loving (Fernald, 1970). Additional study is needed to determine if *Solidago* responds similarly to climbing on both shaded and exposed cliffs. *Solidago* was noticeably absent from forest immediately adjacent to the cliffs, where the deeper soil and competitive presence of other species may be limiting factors for this goldenrod, and from the relatively level rock of the cliff top, where visitor trampling eliminates virtually all plant growth.

On the exposed cliffs, *Solidago* basal cover increases with increased fracturing of the rock surface (Nuzzo, 1994), possibly because fractures provide locations for plants to root in, or because fractures provide increased moisture for plants rooted in them (Ashton and Webb, 1977). *Solidago* is most abundant just below the cliff top, mirroring the habitat preference of other cliff species, for example, *Thuja occidentalis* L. and *Polypodium virginianum* (Larson, 1989; Larson et al., 1990; Bartlett et al., 1990). Damage to this portion of the cliff face would have a substantial detrimental impact on *Solidago*, as the majority of the population is restricted to this narrow band. Damage results from any trampling at the cliff edge, whether by climbing activity or hiking (Taylor et al., 1993). At the Mississippi Palisades, hiking trails lead to the top of the cliffs at Sun Buttress and Sentinel. Vegetation is virtually absent in these locations, due to years of visitor trampling on the cliff top. Larson (1990) investigated visitor trampling impact on one cliff edge species (*Thuja occidentalis*), and determined that while individual trees responded positively with increased growth, seedling survival was virtually zero; he therefore concluded that regulation of human activities along the cliff edge was necessary to ensure survival of the species. In addition to trampling on the cliff top, visitors impact the upper 0.5–1 m of the cliff face by sitting on the edge of the cliff and stepping on small ledges. Below this zone, all human impact is due to climbing activity.

Protecting the cliff edge habitat favored by *Solidago sciaphila* requires limiting visitor access, both to the level cliff top and to the upper cliff face. Less critical but still necessary
is to protect the cliff face >3 m below the cliff edge, where 30% of Solidago grows, particularly in crevices and pits. Plants in the lower cliff zone tend to be larger, and may be critical seed sources for repopulation if plants growing at the cliff edge are severely damaged.

Acknowledgments.—Ron LaFleur and Richard Collins contributed greatly to this project, providing climbing equipment and setting up all routes, for which I am most grateful. I would also like to thank Jean Haskell for providing field and office assistance, Richard Nordheim for statistical advice, Dennis Kolata for determining cliff stratigraphy, and two anonymous reviewers for insightful critiques of an earlier version of this paper. Funding for this project was provided by The Access Fund. The Illinois Department of Conservation and The Illinois Nature Preserves Commission provided permission for this study to be conducted in the Sentinel Nature Preserve within the Mississippi Palisades State Park.

LITERATURE CITED


