THE EFFECTS OF CRYPTOGAMIC SOIL CRUST ON THE POPULATION DYNAMICS OF ARABIS FECUNDA (BRASSICACEAE)

Prepared for:

The Montana Natural Heritage Program
State Library
1515 East Sixth Avenue
Helena, Montana 59620

Prepared by:

Peter Lesica
Division of Biological Sciences
University of Montana
Missoula, Montana 59812

and

J. Stephen Shelly
Montana Natural Heritage Program
State Library
1515 East Sixth Avenue
Helena, Montana 59620

January, 1991

THE EFFECTS OF CRYPTOGAMIC SOIL CRUST ON THE POPULATION DYNAMICS OF *ARABIS FECUNDA* (BRASSICACEAE)

Prepared for:

The Montana Natural Heritage Program
State Library
1515 East Sixth Avenue
Helena, Montana 59620

Prepared by:

Peter Lesica
Division of Biological Sciences
University of Montana
Missoula, Montana 59812

and

J. Stephen Shelly
Montana Natural Heritage Program
State Library
1515 East Sixth Avenue
Helena, Montana 59620

January, 1991

Abstract

At three sites in southwest Montana, _Arabis fecunda_ (Brassicaceae), a rare regional endemic, occurred more often than expected in cryptogamic soil crust than in bare soil. In two of four transects, small, young plants were underrepresented, and older, reproductive plants were overrepresented in crusts. In the other two transects, the distribution of life stage classes was independent of substrate. Measures of fecundity were independent of substrate in all four transects. These results demonstrate that the presence of soil crust is beneficial to populations of _A. fecunda_ at some sites and suggest that this relationship is more likely due to increased survival of older plants rather than enhanced recruitment.

Introduction

Cryptogamic soil crusts composed primarily of lichens, bryophytes and algae are common in arid and semi-arid regions of western North America. Soil crusts are often important contributors to nitrogen fixation (Snyder and Wullstein 1973, Rychert and Skujins 1974) and have been shown to reduce soil erosion (Booth 1941, Bailey et al. 1973). Soil crusts also improve water penetration into the soil (Loope and Gifford 1972, Brotherson and Rushforth 1983) and may increase soil water

retention (Booth 1941). Nonetheless, there is debate on the value of soil crusts in semi-arid grasslands, shrublands and woodlands. Some rangeland ecologists believe that crusts seal the soil surface, curtailing the establishment of vascular plant, especially grass, seedlings (Savory and Parsons 1980, Savory 1988). On the other hand, Nebeker and St. Clair (1980) and St. Clair et al. (1984) have shown that, under some circumstances, seedling establishment can be enhanced in soil crusts. Different types of crusts (i.e. pinnacled vs. flat) may have different properties, and this may be the source of the apparent contradictions in research results (J. Johansen, pers. comm.; see Brotherson and Rushforth 1983 for pictures of typical pinnacled crusts). Soil crusts are very sensitive to disturbance (Kleiner and Harper 1977, Anderson et al. 1982a, Brotherson et al. 1983) and recover slowly following disruption (Anderson et al. 1982b, Johansen and St. Clair 1986).

Arabis fecunda Rollins is a rosette-forming, short-lived perennial in the Mustard Family (Brassicaceae). This recently described species (Rollins 1984) is endemic to highly calcareous soils in the foothills of the Sapphire Range in Ravalli County and in the Pioneer Range in Beaverhead and Silver Bow counties in southwest Montana (Lesica 1985, Schassberger 1988). Plants bloom in early spring and disperse seed during early to mid-summer. The small (ca. 1 mm) seeds germinate readily without stratification (Lesica, unpublished data). Presumably most

germination occurs following late summer and autumn rains, but a second bout of germination may occur in the spring. Mortality of seedlings and first year plants is high (Lesica and Shelly, unpublished data). Plants generally grow for at least one year before blooming and then produce one or more inflorescences with 3-many flowers. Arabis fecunda is threatened by livestock trampling and competition with the aggressive exotic, Centaurea maculosa at the Ravalli County sites. It occurs in areas of historic mining activity in Beaverhead and Silver Bow counties (Schassberger 1988). Arabis fecunda is a candidate for listing as a threatened or endangered species by the U.S. Fish and Wildlife Service (USDI, Fish & Wildlife Service 1990) and is considered threatened in Montana (Lesica and Shelly 1991).

At many sites A. fecunda often occurs in soil with a low density of vascular plants but a relatively high cover of cryptogamic soil crust. Soil crusts at our study sites are similar to typical pinnacled crusts found in the steppe-deserts of southern Utah and Arizona (J. Johansen, personal communication). Common algae are Microcoleus vaginatus (Vauch.), Nostoc commune Vauch., N. muscorum C.A. Ag. and N. punctiforme (Kuetz.) Hariot. Common lichens include Collema tenax (Sw.) Ach., Catapyrenium lachneum (Ach.) R. Sant., Toninia caeruleonigricans (Lightf.) Th. Fr., Caloplaca tominii Savicz,C. jungermanniae (Vahl) Th.Fr. and Fulgensia bracteata (Hoffm.) Raanen. Patches of cryptogamic crust, typically 10-50 cm in

diameter, occur at the study sites interspersed in a matrix of bare mineral soil and rock.

During the course of a demographic monitoring study at three sites, we noticed that A. fecunda appeared to be disproportionately common in soil crust compared to bare soil. At two of the sites the crusts had been disrupted by livestock. The purpose of our study was to document any association between A. fecunda and the occurrence of soil crust and to begin to learn the causes of this association.

The Study Areas

We conducted our study at Birch Creek and Charley's Gulch in Ravalli County and at Lime Gulch in Beaverhead County. The Birch Creek site is on a steep, eroding, southeast-facing slope at 1430 m (T7N R19W S16). The Charley's Gulch site is on an eroding, southwest-facing slope at 1525 m (T6N R19W S19). At Hamilton, ca. 8 km southwest and 300 m lower, mean temperatures for July and January are 19.9° and -4.4° C respectively, and mean annual precipitation is 32 cm. Zonal vegetation surrounding the Ravalli County sites is foothills Agropyron-Festuca grasslands (Weaver 1980) with scattered Pinus ponderosa and Pseudotsuga menziesii. The effects of trampling and grazing by livestock are noticeable at both sites. The Lime Gulch site is on southeast and

northwest-facing slopes above the gulch at 1890 m (T5S R10W S14). At Divide, 18 km east and 240 m lower, mean temperatures are 17.4° and -7.2° C for July and January respectively, and mean annual precipitation is 31 cm. Vegetation is juniper woodland dominated by Juniperus scopulorum, Cercocarpus ledifolius and Agropyron spicatum. Effects of livestock grazing at this site are minimal. At all three sites A. fecunda occurs in soil with a relatively high cover of cryptogamic soil crust.

Methods

We estimated percent cover of soil crust, bare soil, rock and basal vegetation in transects using a point-frequency frame (Mueller-Dombois and Ellenberg 1974, p. 86). Each transect consisted of 12 1-m^2 plots with 20 pins per plot for a total of 240 sample points per transect. The diameter of each pin was 2 mm, approximately equal to the diameter of an A. fecunda taproot. Since few plants occurred on rock or amongst the base of other plants, we removed these points from subsequent analyses. We did not observe any correlation between the spacing of crust patches and that of the frequency pins.

For each A. fecunda plant in the plots we recorded whether it was rooted in bare soil or soil crust. Since A. fecunda plants at these sites had a median age of 2-3 years (Lesica and

Shelly, unpublished data), and crusts may take 14-20 years to develop (Anderson et al. 1982b), it seems likely that plants established in the crust rather than in bare soil before the crust formed. We also recorded size and number of rosette(s), number of inflorescences and number of fruits. For contingency tables, we classified each A. fecunda plant into one of three life stage classes:

I. Single sterile rosettes smaller than 2 cm diameter
II. Single sterile rosettes greater than 2 cm or multiple sterile rosettes
III. Plants with one or more fruiting inflorescences.

We chose these classes because they relate to age as well as size. Ongoing demographic monitoring studies at these same three sites showed that in 1990 an average of only 24% of those plants in Class I were more than one year old, while 66% and 89% in Class II and Class III respectively were more than one year old (Lesica and Shelly, unpublished data).

We sampled one transect at each of the Ravalli County sites on May 29-30, 1990 and two transects at Lime Gulch, one on June 15 and the other on June 28, 1990.

We compared the distribution of plants among the life stage classes on soil and crust using contingency table analysis. Two-factor analysis of variance (ANOVA) was used to determine the

effect of rooting substrate, site and their interaction on components of fecundity: (1) fruits per inflorescence, (2) fruits per plant and (3) inflorescences per plant. Fecundity variables were log-transformed before analysis. Statistical calculations were performed on a microcomputer using SYSTAT (Wilkinson 1986).

Results

In all four transects cryptogamic soil crust was less common than bare soil, but more A. fecunda plants were rooted in crust (Table 1).

At Birch Creek and Lime Gulch South there was a significant difference in the distribution of A. fecunda life stage classes between bare soil and soil crust (Table 2). At both sites plants in Class I were proportionally underrepresented on soil crust. At Birch Creek both Class II and III were underrepresented on bare soil, while only Class II was underrepresented on bare soil at Lime Gulch South. These trends were not apparent at Charley's Gulch or Lime Gulch North, where significant associations were not detected (Table 2).

Whether a plant was rooted in bare soil or soil crust did not have a significant effect on any of the fecundity components (ANOVA, N=208, p>0.180). Site had a significant effect on all

three components ($p \leq 0.001$), while interaction effects were not significant ($p > 0.130$).

Discussion

Our results clearly demonstrate a strong positive association between the presence of cryptogamic soil crust and the occurrence of *Arabis fecunda* plants. There are two possible explanations for this phenomenon: (1) *A. fecunda* is able to establish and/or survive better in soil crust at the three sites and (2) *A. fecunda* establishes and survives with equal success in bare soil and in soil crust, but disturbances destroy soil crust and the plants growing in it, resulting in an increase in the amount of bare soil without *A. fecunda* in proportion to the amount of crust with plants. These two hypotheses are not mutually exclusive. However, the association between crust and *A. fecunda* was as strong at Lime Gulch as at the Birch Creek or Charley's Gulch, even though Lime Gulch former had much lower levels of disturbance. Thus, it is unlikely that disturbance can be an important cause of the *A. fecunda*-crust correlation.

At both Charley's Gulch and Lime Gulch North there was no evidence of differential survival of a life stage class between soil crust and bare soil. In these transects it appears that seedling establishment and survival of older plants are favored

equally in crust. At Birch Creek and Lime Gulch South, small non-reproductive plants were fewer than expected in soil crust. Since most plants in this life stage class are less than one year old, it appears that seedling establishment and survival was higher on bare soil. On the other hand, plants in the older, reproductive life stage class were more common than expected in soil crust. Results from these two transects suggest that survival of Arabis fecunda after the first year was enhanced for plants rooted in crust. Differential survival of older/larger plants may partially explain the observed association between A. fecunda and soil crust.

Cryptogamic soil crusts decrease permeability to water compared to bare soil (Loope and Gifford 1972, Brotherson and Rushforth 1983) and may, under some circumstances, reduce seedling establishment (St. Clair et al. 1984). Although St. Clair et al. (1984) found that soil crust enhanced establishment of two grasses in the greenhouse, Arabis fecunda has much smaller seeds than most grasses, and germinating seeds of A. fecunda may not possess the resources required to easily penetrate the crust.

Crusts increase soil fertility by adding to the organic matter (Fuller and Rogers 1952) and through nitrogen fixation (Snyder and Wullstein 1973, Rychert and Skujins 1974). The presence of crust is also correlated with deeper water penetration, probably due to the associated microtopographic

patterning (Loope and Gifford 1972, Brotherson and Rushforth 1983). In addition, soils covered with crust retain moisture for longer periods of time (Booth 1941). The improved water and nutrient relations associated with crust should be beneficial to plants once they have penetrated the crust and become established. The observed increase in survivorship of older/larger plants at Birch Creek and Lime Gulch South supports this hypothesis.

In spite of the fact that older/larger plants appeared to be favored on soil crust in two of the transects, the three measured components of fecundity were not enhanced on crust. Furthermore, although there were more reproductive plants than expected on soil crust at Birch Creek, there was no evidence for increased individual fecundity. In fact, there was a tendency for measures of fecundity to be higher for plants in bare soil.
These results suggest that survivorship and fecundity are not tightly linked in _A. fecunda_.

Our study has shown that _Arabis fecunda_ occurs more commonly in soil crust than would be expected by chance. This association may occasionally be due to increased seedling establishment but is more likely due to enhanced survivorship of older plants. It seems clear that some populations of _A. fecunda_ benefit from the presence of soil crust.

Although Arabis fecunda is locally abundant, it occurs in only two relatively small and widely separate areas, and fewer than fifteen populations have been discovered. All of the Ravalli County populations are subjected to heavy grazing pressure from livestock. Trampling by livestock has been shown to destroy cryptogamic soil crusts in the shrub-steppe of southern Utah and northern Arizona (Brotherson et al. 1983, Johansen and St. Clair 1986), and we have observed destruction of soil crusts by cattle during the course of our long-term monitoring at the study sites. Soil crusts are slow to recover after disturbance; Johansen and St. Clair (1986) found that crusts in Utah had not fully recovered from the effects of livestock trampling after seven years, and Anderson et al.(1982b) estimated that recovery takes 14-20 years. Although livestock probably do not graze A. fecunda, they have a negative impact on some A. fecunda populations by trampling plants and destroying the beneficial soil crusts on steep slopes where mass soil slumping is easily induced. Over the long-term, trampling of its steep erodible habitat could lower A. fecunda density, thereby decreasing population viability of this rare species.

Acknowledgments

We are grateful to John Robbins and George Frost for permission to conduct this study on their land. Steve Forbes and Bruce McCune gave helpful advice on the manuscript. We thank Jeffrey Johansen and Bruce McCume for identifying algae and lichens. Funding for this study was provided by the U.S. Fish and Wildlife Service and Beaverhead National Forest.

Literature Cited

Anderson, D. C., K. T. Harper and R. C. Holmgren. 1982a. Factors influencing development of cryptogamic soil crusts in Utah deserts. Journal of Range Management 35: 180-185.

Anderson, D. C., K. T. Harper and S. R. Rushforth. 1982b. Recovery of cryptogamic soil crusts from Utah winter ranges. Journal of Range Management 35: 355-359.

Bailey, D., A. P. Mazurak and J. R. Rosowski. 1973. Aggregation of soil particles by algae. Journal of Phycology 9: 99-101.

Booth, W. E. 1941. Algae as pioneers in plant succession and heir importance in erosion control. Ecology 22: 38-46.

Brotherson, J. D. and S. R. Rushforth. 1983. Influence of cyptogamic crusts on moisture relationships of soils in Navajo National Monument, Arizona. Great Basin Naturalist 43: 73-78.

Brotherson, J. D., S. R. Rushforth and J. R. Johansen. 1983. Effects of long-term grazing on cryptogam crust cover in Navajo National Monument, Arizona. Journal of Range Management 36: 579-581.

Fuller, W. H. and R. N. Rogers. 1952. Utilization of the phosphorus of algal cells as measured by the Neubauer technique. Soil Science 74: 417-430.

Johansen, J. R. and L. L. St. Clair. 1986. Cryptogamic soil crusts: recovery from grazing near Camp Floyd State Park, Utah USA. Great Basin Naturalist 46: 632-640.

Kleiner, E. F. and K. T. Harper. 1977. Soil properties in relation to cryptogamic groundcover in Canyonlands National Park. Journal of Range Management 30: 202-205.

Lesica, P. 1985. Report on the conservation status of Arabis fecunda, a potential candidate species. Unpublished report submitted to the U.S. Fish and Wildlife Service, Office of Endangered Species, Denver, CO.

Lesica, P. and J. S. Shelly. 1991. Sensitive, threatened and endangered vascular plants of Montana. In preparation.

Loope, W. L. and G. F. Gifford. 1972. Influence of a soil microfloral crust on select properties of soils under pinyon-juniper in southeastern Utah. Journal of Soil and Water Conservation 27: 164-167.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, New York.

Nebeker, G. T. and L. L. St. Clair. 1980. Enhancement of seed germination and seedling development by cryptogamic soil crusts. Botanical Society of America Miscellaneous Publication Series No. 158, p.81.

Rollins, R. C. 1984. Studies in the Cruciferae of western North America II. Contributions to the Gray Herbarium 214: 1-18.

Rychert, R. C. and J. Skujins. 1974. Nitrogen fixation by blue-green algae-lichen crusts in the Great Basin Desert. Soil Science Society Proceedings 38: 768-771.

Savory, A. 1988. Holistic resource management. Island Press, Washington D.C.

Savory, A. and S. D. Parsons. 1980. The Savory Grazing Method. Rangelands 2: 234-237.

Schassberger, L. A. 1988. An update of the report on the conservation status of <u>Arabis</u> <u>fecunda</u>, a candidate threatened species. Unpublished report submitted to the U.S. Fish and Wildlife Service, Office of Endangered Species, Denver, CO.

Snyder, J. M. and L. H. Wullstein. 1973. The role of desert cryptogams in nitrogen fixation. American Naturalist 90: 257-265.

St. Clair, L. L., B. L. Webb, J. R. Johansen and G. T. Nebeker. 1984. Cryptogamic soil crusts: enhancement of seedling establishment in disturbed and undisturbed areas. Reclamation and Revegetation Research 3: 129-136.

U.S. Department of Interior, Fish and Wildlife Service. 1990. Endangered and threatened wildlife and plants; review of plant taxa for listing as endangered or threatened species; notice of review. Federal Register 55 (35): 6184-6229.

Weaver, T. 1980. Climates of vegetation types of the Northern Rocky Mountains and adjacent plains. American Midland Naturalist 103: 392-398.

Wilkinson, L. 1986. SYSTAT: The system for statistics. SYSTAT Inc., Evanston, IL.

Table 1. Number of frequency pin hits (percent cover) for bare soil and cryptogamic soil crust and the number of Arabis fecunda plants rooted in each of the two substrates. Chi-square values are for the null hypothesis that the distribution of A. fecunda is independent of substrate.

Study Site	Percent Soil Crust	Percent Bare Soil	A. fecunda in Crust	A. fecunda in Soil	X^2	p
Birch Creek	57 (33%)	114 (67%)	83 (63%)	48 (37%)	26.89	<0.001
Charley's Gulch	76 (47%)	86 (53%)	124 (77%)	38 (23%)	30.10	<0.001
Lime Gulch North	95 (45%)	116 (55%)	208 (69%)	93 (31%)	29.77	<0.001
Lime Gulch South	73 (34%)	139 (66%)	162 (57%)	114 (43%)	28.27	<0.001

Table 2. Contingency tables and their associated probabilities for three *Arabis fecunda* life stage classes (see Methods) and two rooting substrates for four transects at the three study sites. The null hypothesis is that the distribution of classes is independent of substrate.

Birch Creek

Size Classes	Soil Crust	Bare Soil	Total	
I	4 (5%)	13 (27%)	17	
II	57 (69%)	29 (60%)	86	X^2=14.72, p=0.001
III	22 (26%)	6 (13%)	28	
Total	83 (100%)	48 (100%)	131	

Charley's Gulch

Size Classes	Soil Crust	Bare Soil	Total	
I	16 (13%)	8 (21%)	24	
II	55 (44%)	13 (34%)	68	X^2=2.04, p=0.360
III	53 (43%)	17 (45%)	70	
Total	124 (100%)	38 (100%)	162	

Lime Gulch North

Size Classes	Soil Crust	Bare Soil	Total	
I	60 (29%)	22 (24%)	82	
II	99 (48%)	50 (54%)	149	X^2=1.16, p=0.561
III	49 (23%)	21 (22%)	70	
Total	208 (100%)	93 (100%)	301	

Lime Gulch South

Size Classes	Soil Crust	Bare Soil	Total	
I	23 (14%)	31 (27%)	54	
II	117 (72%)	65 (57%)	182	X^2=8.35, p=0.015
III	22 (14%)	18 (16%)	40	
Total	162 (100%)	114 (100%)	276	