Burger, G.V., and J.G. Teer. 1981. Economic and socioeconomic issues influencing wildlife management on private land. Pages 252-278 *In:* R.T. Dumke, G.V. Burger, and J.R. March, eds. Proc. of symposium: wildlife management on private lands. LaCrosse Print. Co., LaCrosse, Wis.
Guynn, D.E., and J.L. Schmidt. 1984. Managing deer hunters on private lands in Colorado. Wildl. Soc. Bull. 12:12-19, 1984.
Holecek, D.F., and R.D. Westfall. 1977. Public recreation on private lands—the landowners perspective. Mich. Agric. Exp. Stn. Rep. No. 355. 12 pp.
Jackson, D.H. 1980. Wildlife management (or lack thereof) in a mixed economy. Western Wildlands. Summer. p. 2-10.
Kruckenburg, L.L. 1987. An overview of wildlife privatization and access in Wyoming. Proceedings of the Privatization of wildlife and public lands access symposium. Casper, Wyoming. 3-13 pp.
Langner, L.L. 1987. Hunter participation in fee access hunting. Trans. No. Amer. Wildl. and Nat. Resour. Conf. 52:475-481.
Leopold, A. 1930. The American game policy in a nutshell. Trans. Amer. Game Conf. 17:284-307.
Rounds, R.C. 1975. Public access to private land for hunting. Colorado Div. of Wildl. Report No. 2. 179 pp.
Steinbach, D.W., and C.W. Ramsey. 1988. The Texas "Lease System": History and Future. Proceedings, Recreation on rangelands: promise, problems, projections. Society for Range Manage. Corpus Christi, Texas p. 54-68.
Teer, J.G., and G.V. Burger, and C.Y. Deknatel. 1983. State-supported habitat management and commercial hunting on private lands in the United States. Trans. N. Amer. Wildl. and Natur. Resour. Conf. 48:445-456.
Thomas, J.W. 1984. Fee-hunting on the public's lands?—an appraisal. Trans. N. Amer. Wildl. and Natur. Resour. Conf. 49:455-468.
Train, R.E. 1978. Who owns American wildlife? Pages 275-278 *In:* Brokaw, H.P. (ed). Wildlife and America. Council on Environmental Quality. Superintendent of Documents, U.S. Govt. Printing Office. Washington, D.C. 532 pp.
Wiggers, E.P., and W.A. Rootes. 1987. Lease hunting: views of the nation's wildlife agencies. Trans. 52nd No. Amer. Wild. and Natur. Resour. Conf. 52:525-529.
Wigley, T.B., and M.A. Melchiors. 1987. State wildlife management programs for private lands. Wildl. Soc. Bull. 15:580-584.
Wright, B.A., and R.A. Kaiser. 1986. Wildlife administrator's perceptions of hunter access problems: a national overview. Wildl. Soc. Bull. 14:30-35.

Cryptogamic Soil Crusts in Arid Ecosystems

Jim Dunne

Observant travelers of desert and arid lands frequently notice the dark, lumpy surface crusts of the soil. These soil crusts are formed by cryptogamic plants which reproduce by means of spores; they do not produce flowers or seeds. Cryptogamic communities grow on or directly under the soil surface. A well-developed community forms a distinguishable, dark crust. These crusts are important because they stabilize and protect otherwise sparsely vegetated desert soils from the natural forces of water and wind erosion (Kleiner and Harper 1972). These biologically active crusts influence soil properties, such as moisture holding capacity, infiltration rate, organic matter content, texture (Fletcher and Martin 1948, Bond and Harris 1964), and fix atmospheric nitrogen (Sheilds et al. 1957).

Unfortunately, these crusts are fragile, and easily damaged or destroyed. Range management practices have generally ignored the importance of cryptogamic crusts, although livestock grazing and recreational use have impacted the soil crust over much of its range, degrading the health of desert ecosystems (Brotherson et al. 1983).

Cryptogamic crusts harbor many different species, and composition varies with region and substrate (Rogers and Lange 1971, Anderson and Rushforth 1976). Algae are usually the dominant genera. Lichens and mosses are also important components of crusts on rangelands (Brotherson et al. 1983).

Cryptogamic soil crusts are found world-wide in arid environments. In the United States, the most well-developed crusts are found on soils derived from gypsum in southern Utah and Nevada, and northern Arizona. Crusts can also be found in California, Colorado, New Mexico, Oregon, Washington, Wyoming, and throughout many of the plains states north into Canada (Anderson et al. 1982, Looman 1964). Cryptogams are common on rangelands of Australia, especially in the south (Rogers and Lange, 1971).

Development of cryptogamic crusts depends on the influences of soil characteristics, climate, competition from vascular plants, and the effects of animal and human disturbance. Managers of western rangelands should understand the ecology of cryptogams because they may have a greater effect on productivity than the plants which are currently emphasized in traditional range condition evaluation techniques.

Cryptogamic Crust Development

Soil characteristics that are influential in crust development are surface rock, texture, and chemistry. Large areas of exposed rock do not favor extensive cryptogamic

Ackowledgements
J.W. Bartolome provided criticism and comments on this paper, and I extend my thanks to him. Also, Cindi Jones, Amy Beaton Dunne, Lenny Brennan, Bill Block, Marc Liverman, and *Rangelands* reviewers gave necessary critiques.

crust formation, although pockets of well-developed crust formed as 'cryptogamic islands' on Utah slickrock. Soil texture has an important effect: the finer the texture, the greater the diversity and cover of lichens, mosses, and algae. Soil crusts in Utah do not form as extensively on soils with higher percentages of sand. Moderate to very well-developed crust formed on soils that averaged 50% sand, 35% silt, and 15% clay. Lightly developed crust formed on soils which average 60% sand, 26% silt, and 14% clay. Finally, soil chemistry influences crust formation because saline soils tend to support more cryptogamic crust. Not only are cryptogams salt tolerant, but they experience less competition for light and moisture from vascular plants on saline sites (Anderson et al. 1982).

Climate has basic influences on crust development. Since cryptogamic crusts form slowly, the environment must remain stable enough to allow that development (Loomin 1964). Temperature and moisture fluctuations influence all biological activity, including cryptogamic development. Results of laboratory and field experiments showed that nitrogen fixation in cryptogamic crusts was limited by soil water potentials below Ç13 bars (approximate wilting point) and had an optimal temperature range of 51 to 61 degrees F (Rychert and Skujins 1974).

Competition from vascular plants also influences crust development. Increased vascular plant cover limits available moisture and nutrients while over-topping plants reduce the amount of light reaching the cryptogams. Some shrubs within the Great Basin Desert may chemically inhibit the formation of cryptogamic crusts (Rychert and Skujins 1974). Shrub cover has changed in much of the Intermountain region. Competition between cryptogams and vascular plants will change during succession.

Constant heavy use of rangeland by hooved animals, vehicles, or hikers prevents cryptogamic crust formation. An extreme view was expressed by Mack and Thompson (1982:764): "It appears that herbivorous mammals are incompatible with maintenance of steppe where cryptogams (particularly crustose lichens) occupy a significant fraction of the soil surface." Far western and Intermountain arid lands did not support large populations of native ungulates (Baker 1976), and the soil-holding crust was not subjected to the pressure of present livestock grazing regimes. The effects of moderate intensities of livestock use on cryptogamic crust development are poorly documented. Moderately grazed pastures in Southeastern Oregon were quantitatively rated as showing fair to good cryptogamic crust development (Bartolome et al. 1988).

Ecological Role

The ecological role of cryptogamic crusts is not well-understood. Most evidence explains how the crust interacts with soil properties. Crusts not only cover the soil, but the algal filaments, fungal mycelia, and exudates firmly bind and cement sandy soil particles, thus stabilizing the soil (Anderson et al. 1982). Over time, the crust and soil stability are enhanced by the addition of organic material as the community grows.

Soil structure is enhanced by the continuous addition of organic material by crusts, including trapped wind blown particles. This process reduces the relative percent of sand, increases nutrients (Kleiner and Harper 1977), increases the cation exchange complex (Anderson et al. 1982), and increases ability of the soil to hold water.

Soil organic and inorganic nitrogen can be increased by the decomposition of cryptogams and nitrogen fixation (Shields et al. 1957). Also, more available phosphorus and organic carbon are present in soils with well-developed crusts than in less developed ones (Anderson et al. 1982). Nitrogen fixation by cryptogams could be the primary way soils get nitrogen (MacGregor and Johnson 1971). The nitrogen-fixing blue-green algae living in association with lichens are able to remain active for relatively long periods of time, only limited by desiccation and extreme cold (Henriksson and Simu 1971).

The microclimate of the crust is beneficial to plant growth because favorable moisture conditions persist and the dark color of well-developed crusts retains heat longer than light, desert soils without crust development. Infiltration of water into the soil is increased by cryptogamic crusts (Loope and Gifford 1972).

Cryptogamic Crust and Succession

The role of cryptogamic crusts in plant succession is not well known. Booth (1941) studied algae and lichens in secondary succession on eroded land. He concluded that cryptogams were important as pioneers on denuded lands. They added organic matter, fixed nitogen, increased water infiltration, stabilized soil particles with algal filaments, and increased moisture content of the upper inch of the soil. In effect, the crust prepares the microenvironment for future seral stages of higher plants.

Looman (1964) described a late seral stage where the overtopped cryptogamic crust became a mere remnant of its past cover in an area that had been protected from grazing for several years. He also presented data for an aspen-grassland community that was monitored for more than 50 years. Protection increased height of the vascular plants, which soon over-topped the crust. Observed changes included decreased light, increased moisture due to the increasing amount and density of the mulch, and the increasing density of the vascular community. Within 7 years, most of the cryptogamic community had disappeared. As aspen encroached into the grassland, the cryptogams were shaded out. Yet when the aspens grew old and died, leaving openings in the canopy, cryptogams slowly reappeared.

Succession is influenced by suppression of seed germination by cryptogamic crust. One study compared germination of blue panicgrass, Lehmann lovegrass, corn, and sunflower seeds on two soil surface types—bare and a cryptogamic crust (McIlvanie 1942). Seeds easily germinated on the bare soil, but rarely on the crust. Seeds on the crust were prevented from coming into contact with mineral soil. They dried out and died. The successional pattern is altered when the crust is broken because it becomes a source of microsites for alien grass establishment (Mack and Thompson 1982).

Cryptogamic Crust on Western Rangelands

Utah ecologists D.C. Anderson, J.D. Brotherson, K.T. Harper, and S.R. Rushforth have studied the effects of livestock grazing on cryptogamic crusts for two decades. Most of the information compares protected areas to areas with heavy season-long use. Although the crust persists under natural erosive forces, the hooves of livestock (or the vibram soles of hiking boots) restrict cryptogams in Intermountain rangelands. The scientists's results repeatedly show that livestock reduces the cover and diversity of crust compared to complete protection, while protection increased infiltration and decreased sedimentation, erosion, head-cutting of secondary stream channels, and pedestaled bunchgrasses (Kleiner and Harper 1972, Brotherson et al. 1983).

Although the conflicts are well-documented, and should be a matter of concern for the general health of desert ecosystems, land managers have not effectively addressed the problem (Anderson et al. 1982). Public and private land managers need more demonstrations of practical possibilities for manipulating livestock to protect critical cryptogamic habitat, a neglected but important part of arid ecosystems.

Literature Cited

Anderson, D.C., and S.R. Rushforth. 1976. The cryptogam flora of desert soil crusts in Southern Utah, U.S.A. Nova Hedwigia 28:691-729.

Anderson, D.C., K.T. Harper, and R.C. Holmgren. 1982. Factors influencing development of cryptogamic soil crusts in Utah deserts. J. Range Manage. 35(2):180-185.

Baker, H.G. 1976. Invasion and Replacement in California and neotropical grasslands. pp. 368-384 *In:* J.R. Wilson, ed., Plant Relations in Pastures. Canberra, Australia: CSIRO.

Bartolome, J.W., B.H. Allen, and H.F. Heady. 1988. Changes in Vegetation. p. 36-53 *In:* H.F. Heady, ed., The Vale Rangeland Rehabilitation Program: An Evaluation. Resour. Bull. PNW-RB-157. Portland, OR: USDA Forest Service, Pacific Northwest Research Station; U.S. Dept. of the Interior, BLM.

Bond, R.D., and J.R. Harris. 1964. The influence of the microflora on physical properties of soils. Aust. J. Soil Res. 2:111-122.

Booth, W.E. 1941. Algae as pioneers in plant succession and their importance in erosion control. Ecology 22(1):38-46.

Brotherson, J.D., S.R. Rushforth, and J.R. Johnson. 1983. Effects of long term grazing on cryptogamic crust cover in Navajo National Monument, Ariz. J. Range Manage. 36(5):579-581.

Fletcher, J.E., and W.P. Martin. 1948. Some effects of algae and molds in the rain-crust of desert soils. Ecology 29(1):95-100.

Henriksson, E., and B. Simu. 1971. Nitrogen fixation by lichens. Dikos 22:119-121.

Kleiner, E.F., and K.T. Harper. 1972. Environment and community organization in grasslands of Canyonlands National Park. Ecology 53(2):299-309.

Kleiner, E.F., and K.T. Harper. 1977. Soil properties in relation to cryptogamic ground cover in Canyonlands National Park. J. Range Manage. 30(3):203-205.

Looman, J. 1977. Ecology of lichen and bryophyte communities in Saskatchewan. Ecology 45(3):481-491.

MacGregor, A.H., and D.E. Johnson. 1971. Capacity of desert algal crusts to fix atmospheric nitrogen. Soil Sci. Soc. Amer. Proc. 35:843-844.

McIlvanie, S.K. 1942. Grass seedling establishment, and productivity—overgrazed vs. protected range soils. Ecology 23(2): 228-231.

Mack, R.N., and J.N. Thompson. 1982. Evolution in Steppe with few large, hooved mammals. The American Naturalist. 119(6):757-773.

Rogers, R.W., and R.T. Lange. 1971. Lichen populations on arid soil crusts around sheep watering places in Southern Australia. Oikos 22:93-100.

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

Shields, L.M., C. Mitchell, and S. Drouet. 1957. Alga- and lichen-stabilized surface crusts on soil nitrogen sources. Amer. J. Bot. 44:489-498.