

## ASSESSMENT OF CRYPTOBIOTIC CRUST RECOVERY

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**ABSTRACT.**—Chlorophyll *a* and *b* analyses of cryptobiotic crusts from burned and unburned sites on the Snake River plain provided an estimate of crust recovery. In less than 3 years, chlorophyll *a* levels were approximately 50% of the unburned reference site. Chlorophyll *a/b* ratios indicated that the biotic composition of the recovering cryptobiotic crust consisted largely of eukaryotic algae and bryophytes.

*Key words:* cryptobiotic crusts, chlorophyll, fire recovery, Snake River plain.

Relatively undisturbed arid and semiarid landscapes can exhibit a soil surface cover of microphytes including mosses, lichens, algae, fungi, and cyanobacteria (Lange et al. 1992). Termed cryptogamic or microbiotic (Johansen 1993), cryptobiotic (Belnap et al. 1994), or microphytic crusts (Beymer and Klopatek 1991), these biological assemblages protect the soil from erosion (Harper and Marble 1988) and function in carbon cycling (Beymer and Klopatek 1991) and nitrogen cycling (Rychert et al. 1978).

There has been increasing interest in trying to assess recovery rates of cryptobiotic crusts after disturbance (e.g., overgrazing, fire, agriculture). Belnap (1993) found that the use of spectrophotometrically determined chlorophyll *a* as a measure of recovery of cryptobiotic crusts was both time-efficient and reliable. Chlorophyll *a* levels increased at rates of 1.0–2.6% per year after disturbance at various Utah sites.

Fire can destroy microbiotic crusts. Greene et al. (1990) observed reduction in coverage of soil crusts following fire. Soil erosion rate and the amount of bare soil surface per unit area increased, and a decline in aggregate stability in the 0–1 cm horizon was also observed. Johansen et al. (1982, 1993) observed significant reduction in the biomass of algal/cyanobacterial soil crusts after burning, although species diversity remained constant.

Recovery rates of soil crusts following fire can vary depending on the organisms involved and climatic conditions. In the lower Columbia Basin, Johansen et al. (1993) observed little

increase in algal/cyanobacterial density of soil crusts during the first 16 months following fire. It was also observed that immediately following fire the algal/cyanobacterial/moss crust, although dead, was still intact. Estimates of algal and cyanobacterial recovery time in terms of biomass and diversity range from 16 months to 5 years (Johnsen et al. 1982, 1993). Recovery appears to be highly dependent on precipitation patterns and composition of the crust, which are in turn influenced by soil characteristics and climate (Johansen et al. 1993).

This study is a preliminary attempt to estimate the recovery of cryptobiotic crusts on Idaho rangeland sites in the lower Snake River plains of Idaho following disturbance by fire. The use of chlorophyll determinations to provide both qualitative and quantitative estimations of cryptobiotic crust recovery was evaluated.

### MATERIALS AND METHODS

Cryptobiotic crust samples were collected nearly 3 years after the 1996 Kuna Butte fire (location: southwest of Boise, Idaho, Township 2 North, Range 1 West, Section 4). The lightning-caused fire began on 26 August 1996 and burned 5785 acres. The sampling area was formerly a Wyoming big sagebrush community similar to an adjacent unburned area. The burned area was dominated by cheatgrass (*Bromus tectorum*) and tumbled mustard (*Sisymbrium altissimum*). Most of the burned area still has good cover of perennial grasses, primarily Sandberg's bluegrass (*Poa secunda*) and

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TABLE 1. Chlorophyll concentrations: burned vs. unburned sites.

Site	Chlorophyll <i>a</i> (mg m <sup>-2</sup> )			Chlorophyll <i>b</i> (mg m <sup>-2</sup> )			<i>a/b</i> ratio		
	Mean <sup>a</sup>	Standard deviation	Coefficient of variation	Mean <sup>b</sup>	Standard deviation	Coefficient of variation	Mean <sup>c</sup>	Standard deviation	Coefficient of variation
Unburned	130.163	50.690	38.943	53.259	18.146	34.071	2.493	0.808	32.418
Burned	65.159	26.258	40.298	39.647	14.421	36.372	1.658	0.369	22.274

<sup>a</sup>t test, significantly different, *P* = 0.0020.<sup>b</sup>t test, not significantly different, *P* = 0.0797.<sup>c</sup>t test, significantly different, *P* = 0.0082.

bottlebrush squirreltail (*Elymus elymoides*) amongst the cheatgrass. The fire was high intensity, resulting in destruction of the biological crust. Trace amounts of moss were observed on the soil surface during sampling. Observations in the nearby Poen fire suggest that crust cover does not become visibly apparent until approximately 3–4 years following a high-intensity fire.

Vegetation in the adjacent unburned area is Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) with an understory of bluebunch wheatgrass (*Pseudoroegneria spicata*) and Thurber's needlegrass (*Achnatherum thurberianum*). Sandberg's bluegrass and bottlebrush squirreltail are also present. The soil surface in the unburned area has a nearly complete cover of biological soil crust dominated by mosses (primarily *Bryum* spp.) and lichens. The soil of the sampling area is classified as a fine-silty, mixed, mesic Xerollic Haplargid. The texture is a silt loam.

Soil "cores" consisting of cryptobiotic crust plus soil were collected with sterile plastic petri dishes serving as coring devices (1 cm deep and 47 mm in diameter). Ten samples were collected from both the burned and unburned areas and kept on ice. Chlorophyll pigments were extracted with dimethylsulfoxide (DMSO) the same day (12 March 1999), following the procedures of Ronen and Galun (1984; 60°C for 50 minutes). Following filtration of the extracts through a Whatman #1 filter, absorbance readings at 750 nm, 665 nm, 648 nm, 435 nm, and 415 nm were made with a Spectronic 20 Genesys spectrophotometer.

Chlorophyll *a* (*C<sub>a</sub>*) and chlorophyll *b* (*C<sub>b</sub>*) concentrations were determined using the equations of Barnes et al. (1992):

$$C_a \text{ (in mg L}^{-1}\text{)} = 14.85 A_{665} - 5.14 A_{648}$$

$$C_b \text{ (in mg L}^{-1}\text{)} = 25.48 A_{648} - 7.36 A_{665}$$

Chlorophyll concentrations are expressed as mg m<sup>-2</sup>, extrapolated from the  $1.73 \times 10^{-3}$  m<sup>2</sup> soil core(s).

Statistical analyses were run with SAS for Windows, version 8 (SAS Institute, Inc. 1999).

## RESULTS AND DISCUSSION

Chlorophyll *a* concentrations, chlorophyll *b* concentrations, and chlorophyll *a/b* ratios are higher for the unburned than the burned site (Table 1). The burned site had chlorophyll *a* levels that are 50% of the unburned site. Mean chlorophyll *a* concentrations for both the burned (65 mg m<sup>-2</sup>) and control (130 mg m<sup>-2</sup>) sites were much higher than the levels determined by Belnap et al. (1994) with disturbed cryptobiotic soil crusts in Utah (approximately 10–50 mg m<sup>-2</sup>), but they are similar to endolithic microphytic chlorophyll *a* levels reported by Bell and Sommerfield (1987; 87 mg m<sup>-2</sup>) on the Colorado Plateau, and by Matthes-Sears et al. (1997; 73 mg m<sup>-2</sup>) in Ontario, Canada. Recovery of the cryptobiotic crust probably does not occur as a linear function; however, in less than 3 years, chlorophyll *a* values are approximately half recovered.

Chlorophyll *a/b* ratios may provide some indication of soil crust recovery after disturbance. Table 2 lists some chlorophyll *a/b* ratios from a variety of algae, plants, and lichens. Cyanobacteria (blue-green algae) lack chlorophyll *b* (Shoaf and Lium 1976). So, if the soil-stabilizing, nutrient-cycling, and nitrogen-fixing functions of cyanobacterial-lichen crusts represent the undisturbed ecological condition for arid and semiarid soil surfaces (Rychert et al. 1978, Buttars et al. 1998), higher chlorophyll *a/b* ratios may represent a useful assessment parameter. In this study the burned site exhibited a chlorophyll *a/b* ratio of 1.66, suggesting that cryptobiotic recovery after fire

TABLE 2. Chlorophyll *a/b* ratios found in literature.

Biocomponent	<i>N</i>	Mean <i>a/b</i>	<i>s</i>	$s_{\bar{x}}$	Range	Reference
Vascular plants	10	2.38	0.56	0.24	1.51–3.23	Barnes et al. (1992)
Moss	1	2.51				Sheridan and Rosentreter (1973)
Chlorophyta	7	3.00	0.87	0.29	1.89–4.16	Shoaf and Lium (1976)
Lichens, algae, and cyanobacteria (mixture)	1	3.69				Matthes-Sears et al. (1977)
Lichens	8	6.09	2.50	0.41	2.84–10.18	Barnes et al. (1992)

involves mainly eukaryotic algae and bryophytes. The chlorophyll *a/b* ratio for the reference site was 2.49, probably reflecting the predominant moss (*Bryum* spp.) cover, although a few lichens were present.

Chlorophyll *a* degradation to phaeophytin *a* occurs for a variety of reasons including extraction with solvents, air pollution, and exposure to air (oxidation). The state of degradation of chlorophyll *a* can be measured by the absorbancy at 435/415 nm ratio (Ronen and Galun 1984). The mean A 435/415 in this study was 0.933 for the unburned site ( $s$  0.065,  $s_{\bar{x}}$  0.070) and 0.898 for the burned site ( $s$  0.032,  $s_{\bar{x}}$  = 0.40). This is very similar to the degradation noted by Belnap et al. (1994). Based upon the mixtures tested by Ronen and Galun (1984), just under 50% of the chlorophyll *a* has been degraded. Freezing and thawing, characteristic of the spring climate, would tend to reduce chlorophyll *a/b* ratios due to the greater effect on chlorophyll *a* (Barnes et al. 1992). However, in this study the A 435/415 ratios are nearly identical; therefore, chlorophyll *a/b* ratios and chlorophyll *a* concentrations for the burned and reference sites can be compared unambiguously.

This study represents the first analysis of chlorophyll *a* in cryptobiotic crusts from the Snake River plain. The crust recovery rate estimated from this study reflects crust assemblage and climatic differences from other sites (Belnap 1993). Recovery rates may be site specific. Selective sampling primarily of moss- and lichen-covered sites would provide important additional information on in situ chlorophyll *a/b* ratios.

Monitoring chlorophyll *a* and *b* concentrations can provide 2 important indicators of cryptobiotic crust recovery. Chlorophyll *a* levels are an estimate of cryptobiotic crust biomass, while chlorophyll *a/b* ratios are an indicator of how the biotic composition of the

cryptobiotic crust is changing. Temporal studies exhibiting higher or increasing ratios would suggest development or return of cyanobacteria and lichens as components of the crust.

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## THE EFFECT OF FLOODING ON NORTHERN BOBWHITES

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*Key words:* *Colinus virginianus*, *flooding*, *mortality*, *Northern Bobwhite*.

Effects of flooding on mammals (Yeager and Anderson 1944) and reptiles (Stickel 1948) have been documented, and Northern Bobwhites (*Colinus virginianus*) have been known to drown (Schorger 1946, Mullan and Applegate 1969). However, on landscape and population scales, the implications of mortality from extensive flooding are undocumented for birds. We document mortality of bobwhites, possibly by drowning, because of flooding in east central Kansas.

From 31 October through 2 November 1998, 21 cm of rain fell in Lyon County, Kansas (Kansas Precipitation Report <ftp://oz.oznet.ksu.edu>). Water levels in all rivers and streams in the area overflowed their banks for the 3rd time in the decade (1993, 1995, 1998). The Cottonwood and Neosho rivers and their tributaries flooded a minimum area of 130 km<sup>2</sup> of Lyon County. During this period we observed the effects of flooding on Northern Bobwhites.

We conducted research on 12 independent 259-ha parcels of private and public land. Study areas were separated by at least 1.6 km. Distances between study areas were small enough to eliminate confounding climate and habitat heterogeneity effects on the population and yet large enough to avoid bobwhite interchange between study sites. Study areas were located in eastern Lyon County, western Osage County, and western Coffee County, Kansas. All study areas (1) were composed of habitat that was representative of east central Kansas and (2) allowed no hunting of bobwhites. Additionally, 5 of the 12 study areas were entirely or partially within the floodplain of the Cottonwood and Neosho rivers (termed floodplain study areas, FSA). The remaining 7 study areas were considered to be outside the

floodplain in upland areas (termed upland study areas, USA).

Bobwhites were captured 1 October–1 December 1998 using bait-traps (Stoddard 1931) and night-lighting (Labisky 1968). Upon capture, birds were sexed, aged (Rosene 1969), and weighed to the nearest gram. From each covey we randomly selected 3 birds that were fitted with a necklace-type radio-transmitter weighing <6 g (Burger et al. 1995). Birds weighing <150 g were not radio-marked to avoid stress from radio-collars weighing >5% of body mass (Samuel and Fuller 1994). All other birds captured in the covey were leg-banded. We immediately released all birds at the capture location. Radio-tagged individuals were located 5–7 times per week by homing (White and Garrott 1990) until death, radio failure, or 31 January. We recorded individual locations as Universal Transverse Mercator (UTM) coordinates with a resolution of 1.00 ha (Exum et al. 1982).

We monitored bobwhite survival during the period of flooding (31 October–1 December 1998). Survival rates were calculated with staggered entry additions, and all assumptions were met (Kaplan and Meier 1958, Pollock et al. 1989). We allowed birds to adjust to radio-collars for 7 days before they were included in survival analysis. We right-censored birds when fate was unknown or there was radio failure or loss, emigration from the study area, or survival beyond 31 January. Additionally, we estimated cause-specific mortality rates, classifying mortality agents as flooding or natural mortality. Both survival and mortality rates were calculated within the staggered entry survival model between treatments with log-rank tests ( $P \leq 0.10$ ; Pollock et al. 1989).

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