ECOLOGICAL STUDIES AT NAVAJÓ NATIONAL MONUMENT

Part III

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INTRODUCTION

This report and the data contained therein has been compiled for the southwest region of the National Park Service and for their personnel of Navajo National Monument. The environmental contents of the report evaluate many of the relationships of the non-vascular plants found growing in the monument as well as their ecological relationships within the monument. The sampling and data collection is the result of two years' effort.

The reports contained herein comprise an updated data base and in most cases a primary data set. Each report is treated as an independent unit and results specific to that unit is contained only within that segment.

ECOLOGY OF LICHEN COMMUNITIES
IN NAVAJO NATIONAL MONUMENT

by

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INTRODUCTION

National Parks have been established in select regions of the United States to protect our national heritage and unique cultural and environmental areas. This program has been extremely successful and the United States has been the world leader in protecting and enhancing our natural environment. The Park Service has been particularly interested in protecting certain areas from degradation so that natural conditions are maintained for the enjoyment of future generations. This has become particularly difficult during the past several years due to increased population and the concommitant demands for resource development. Even when strict controls on development within the boundaries of National Parks are maintained, development in adjacent areas may impact the parks directly through such encroachments as industrial stack emissions, pollution of water resources or alteration of critical terrain which could increase erosion problems.

Such problems are on the horizon for a number of National Parks. The present study was undertaken in order to collect baseline data on the lichen communities of Navajo National Monument. Navajo National Monument will likely be impacted in the future by energy development in Northern Arizona. Lichens have been chosen for study since numerous investigations have shown that selected species are important biological monitors of air quality (Brodo, 1966; Fenton, 1964; Ferry, *et al.*, 1973; Hoffman, 1974;

Laundon, 1967; Marsh, 1979; Pyatt, 1970; Skye, 1979; Will-Wolf, 1980a, 1980b). Hence, an understanding of the ecology of lichen floras at this time has the potential of being very important for future monitoring of air quality changes in Navajo National Monument.

The present study represents an expansion of a study done in Navajo National Monument in 1979 by Nebeker. That pioneering study was floristic in nature and identified the lichens occurring on all substrates in the Monument. We have expanded this study in two ways. First, we continued floristic work and identified several additional species not found by Nebeker. Second, we performed the initial ecological work on the saxicolous and corticolous lichen communities of the Monument.

SITE DESCRIPTIONS.--Corticolous and saxicolous lichen communities were studied in two major areas of Navajo National Monument. Both of these were located at Betatekin Canyon. The slickrock habitat and Pinyon-Juniper community were sampled in the area surrounding the Monument headquarters. Populus tremuloides, Pseudotsuga menziesii, Quercus gambelii, and Navajo sandstone cliff faces were studied in the bottom of the canyon.

METHODS OF DATA COLLECTION.--Transects were established subjectively at all study sites in areas with sufficient density of trees or cliff faces to insure adequate study of lichen communities. Individual trees for determining the occurrence and distribution of corticolous lichens were selected using the quarter method (Phillips, 1959). This method is a proven plotless sampling technique in which points along a line transect are identified. The area around each point was divided into four quadrants and the nearest tree in each quadrant was sampled. Due to the probability of aspect-induced differences in corticolous lichen floras, north, south, east and west exposures on all trees were sampled separately.

Vertical cliffs at each of the study sites were selected on the basis of size and exposure. Quadrats on these substrates were placed each 100 cm throughout their length. In order to determine the influence of aspect on species distribution, north, south, east and west exposures on vertical cliff surfaces were sampled separately.

Frequency and estimated percent cover of both saxicolous and corticolous lichens were determined using 2 x 100 cm quadrats with 10 equal subquadrats. These quadrats were placed at measured intervals along established transect lines for saxicolous species and on each side of tree stems for corticolous species. Table 1 lists the total number of quadrats studied for each substrate type.

STATISTICAL METHODS.--Several statistical analyses were performed on the data collected. Stand similarity indices were calculated following the methods of Ruzicka (1958). Cluster analysis was then performed by comparing each stand to each other stand using arithmetic averages (Sneath and Sokal, 1973). This method has been used extensively in ecological studies because it introduces less distortion than other methods (Kaesler and Cairns, 1972).

The total number of species encountered on each substrate type was calculated. Shannon-Weaver diversity indices for each substrate type were also calculated.

An importance value for each species for the overall study was calculated by multiplying average frequency by average cover (Warner and Harper, 1975).

Niche breadths and niche overlaps for all lichen species were calculated following Colwell and Futuyma (1971). Cluster analysis on the basis of niche overlap was also performed (Jatkar, et al., 1979).

RESULTS AND DISCUSSION

The results of our overall cluster analysis of all stand types showed as expected that the floras of bark types are more closely correlated to each other than to the floras of rock substrates. In addition, since substrate types clustered at low levels of similarity, this analysis demonstrated that all of the substrate types examined are relatively unique from one another (Figure 4).

The substrate type with the greatest lichen species diversity was Navajo Sandstone cliff faces. The bark of *Pseudotsuga menziesii* demonstrated the highest diversity of lichen species of the various corticolous substrates sampled. Table 1 lists the total number of species encountered on each substrate together with a Shannon-Weaver diversity index for each substrate type.

The dominant species from all substrate types as determined by multiplying percent presence by average percent cover for all sites studied were *Aspicilia calcarea* (importance value of 1.21), *Lecidea tessellata* (importance value of 0.30), *Staurothele clopima* (importance value of 0.20) and *Candelariella deflexa* (importance value of 0.12).

The dominant species on rock substrates as determined by the same method were Aspicilia calcarea with an importance value of 14.86, Lecidia tessellata with an importance value of 3.63, Staurothela clopima with an importance value of 2.41, Lecanora frustulosa with an importance value of 1.14, Candelariella rosulans with an importance value of 0.67 and Acarospora fuscata with an importance value of 0.57.

The most important taxa on bark substrates were Caloplaca arizonica with an importance value of 0.01, Xanthoria species with an importance value of 0.01, Candelariella deflexa with an importance value of 0.01 and Parmelia subolivacea with an importance value of 0.01.

A listing of species encountered during this study according to broad substrate type together with their importance value is listed in Table 3.

Analysis of distribution by aspect of lichen species on all substrate types was performed. Several lichens show definite trends in distribution. These data are presented in Table 4.

Niche width and overlap measurements were performed. Table 3 presents the niche breadths of lichen species we studied. Lichens were then clustered on the basis of niche overlap. Several distinct species groups were evident from this analysis. The first was composed of species occurring exclusively on Navajo Sandstone cliff faces. Species included in this group were Acarospora fuscata, Acarospora *strigata*, *Aspicilia caesiocinerea*, *Buellia retrovertens*, *Caloplaca flavovirescens*, *Candelariella vitellina*, *Collema species*, *Encalyptra* species (moss), *Lecanora badia*, *Lecanora crenata*, *Lecanora christoi*, *Lecanora dispersa*, *Lecanora muralis*, *Lecanora novomexicana*, *Parmelia substygia*, *Physica endococcinea*, *Rhizocarpon disporum* and *Toninia caeruleonigricans*.

The second group was composed of species occurring on both sandstone cliff faces and horizontal slickrock exposures. Species included in this group were *Collema polycarpon*, *Grimmea* species (moss), *Staurothele clopima*, *Lecanora frustulosa*, *Aspicilia calcarea*, and *Lecidia tessellata*.

The third group included species which were identified only from the bark of *Pseudotsuga menziesii*. Species in this group are *Buellia punctata*, *Buellia* species, *Heterodermia pseudospeciosa*, *Cladonia pyxidata*, *Lecidia glomerulosa*, *Lecidia* species, *Lecanora caesiorubella*, *Lecanora chlarotera*, *Parmelia subolivacea*, *Physcia dubia*, and *Physconia grisea*.

The species *Xanthoparmelia lineola*, *Diploschistes actinostomus*, *Lepraria* species, *Candelariella deflexa*, and moss occurred on both stone and bark substrates. Most of these occurred at least on *Pseudotsuga* and cliff faces.

The last group was comprised of species occurring only on two or more separate bark substrates. Species in this group included *Caloplaca arizonica*, *Physconia pulverulenta*, *Xanthoria fallax*, *Lecanora hageni*, *Physcia stellaris*, *Usnea hirta* and *Xanthoria* species.

The lichens identified from Navajo National monument were dominated by crustose species over fruticose and foliose species by more than two to one. This ratio is not suprising when comparisons to similar studies in desert environments are made (Marsh and Nash, 1979). The unique morphological features of crustose lichens provide them with ideal adaptations for survival in harsh arid environments. Typically, the occurrence of fruticose and foliose species in dry environments is restricted to sheded, well protected areas where due to special microclimatic features humidity is significantly higher.

It is generally recognized that crustose lichens are more tolerant of airborne pollutants than are fruticose and foliose species (Fenton, 1964). Consequently, the identification of potential pollution indicators in desert environments can be a difficult and presently tentative task. This problem is further compounded by the fact that so few lichen related pollution studies have been performed in western North America. Therefore, most of the available data concerning pollution indicator species comes from research conducted in the eastern United States and Europe. In these latter areas, an abundance of fruticose and foliose species is often encountered.

Several features of the lichen flora in Betatekin canyon proper suggest that the selection of indicator species may be easier than in other arid regions for the following reasons. First, about thirty percent of the lichen flora in the canyon is composed of fruticose and foliose species. Second, unique topographical features of the canyon such as the presence of the narrow canyon walls and prolific vascular plant growth combine to yield an unusual microclimate with elevated humidity. Third, a diverse foliose corticolous lichen flora is present on Pseudotsuga menziesii. Several of these species occur in genera which are considered to be pollution intollerant (Laundon, 1967). Finally, sevaral large foliose lichens occur on sandstone walls along the trail in the canyon. Table 5 lists potential pollution indicator species by substrate type.

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Table 1. Listing of the number of transects studied and the number of species encountered by substrate type. Shannon-Wiener diversity indices are also recorded for each substrate type.

SUBSTRATE TYPE	NUMBER OF TRANSECTS STUDIED	NUMBER OF SPECIES	DIVERSITY INDEX
JUNIPERUS OSTEOSPERMA	212	3	1.500
PINUS EDULIS	92	4	1.290
POPULUS TREMULOIDES	72	6	1.383
PSEUDOTSUGA MENZIESII	128	19	3.580
QUERCUS GAMBELII	96	2	0.811
NAVAJO SANDSTONE CLIFF FACE	42	32	3.731
NAVAJO SANDSTONE SLICKROCK	16	9	1.814

Table 2. List of lichen species occurring on different substrates in Navajo National Monument, Arizona. Percent cover and percent frequency represent averages of all stands examined for each listed substrate.

SPECIES	PERCENT COVER	PERCENT FREQUENCY
	POPULUS TREMULOIDES	
Moss (pleuro)	0.556	0.011
Candelariella deflexa	0.097	0.017
Lecanora hageni	0.049	0.007
Xanthoria fallax	0.008	0.007
Physconia pulverulenta	0.004	0.001
Xanthoria sp.	0.003	0.001
	PSEUDOTSUGA MENZIESII	
Moss (pleuro)	0.296	0.009
Physcia dubia	0.113	0.006
Physconia grisea	0.091	0.004
Buellia sp.	0.081	0.009
Lecanora caesiorubella	0.067	0.006
Parmelia subolivacea	0.064	0.011
Diploschistes actinostomus	0.052	0.011
Heterodermia pseudospeciosa	0.052	0.010
Buellia punctata	0.039	0.006
Physconia pulverulenta	0.030	0.006

TABLE 2: CONTINUED

SPECIES	PERCENT COVER	PERCENT FREQUENCY
PSEUDOTSUGA MENZIESII: CONTINUED		
Caloplaca arizonica	0.029	0.005
Xanthoria fallax	0.027	0.011
Lecanora chlarotera	0.025	0.004
Cladonia pyxidata	0.023	0.002
Lepraria sp.	0.012	0.001
Lecanora hageni	0.011	0.004
Lecidia sp.	0.008	0.002
Lecidia glomerulosa	0.004	0.001
Candelariella deflexa	0.002	0.002
JUNIPERUS OSTEOSPERMA		
Caloplaca arizonica	0.019	0.004
Physcia stellaris	0.002	0.001
Xanthoria sp.	0.001	0.001
QUERCUS GAMBELII		
Caloplaca arizonica	0.064	0.016
Xanthoria sp.	0.020	0.011

TABLE 2: CONTINUED

SPECIES	PERCENT COVER	PERCENT FREQUENCY
NAVAJO SANDSTONE CLIFF FACE		
Erroded Lichen	5.07	0.30
Staurothele clopima	3.08	0.19
Acarospora fuscata	2.29	0.20
Lecanora muralis	1.20	0.06
Candelariella rosulans	1.18	0.11
Grimmia sp. (moss)	1.14	0.06
Aspicilia caesiocinerea	1.03	0.05
Aspicilia calcarea	0.91	0.05
Lecidia tessellata	0.82	0.07
Parmelia lineola	0.68	0.04
Physcia endococcinea	0.62	0.04
Diploschistes actinostomus	0.53	0.03
Lecanora frustulosa	0.48	0.03
Candelariella vitellina	0.35	0.04
Moss sp. (pleuro)	0.32	0.01
Caloplaca fraudans	0.26	0.03
Parmelia substygia	0.25	0.01
Lecanora novomexicana	0.11	0.01
Collema polycarpon	0.10	0.01
Lecanora dispersa	0.07	0.02
Encalyptra sp. (moss)	0.06	0.01

TABLE 2: CONTINUED

SPECIES	PERCENT COVER	PERCENT FREQUENCY
NAVAJO SANDSTONE CLIFF FACE: CONTINUED		
Toninia caeruleonigricans	0.06	0.01
Acarospora strigata	0.04	0.02
Caloplaca flavovirescens	0.04	0.02
Lecanora crenata	0.04	0.01
Lepraria sp.	0.03	0.01
Buellia retrovertens	0.02	0.01
Rhizocarpon disporum	0.02	0.01
Lecanora badia	0.02	0.01
Lecanora christoi	0.01	0.01
Tortula sp. (moss)	0.01	0.01
Collema sp.	0.01	0.01
PINUS EDULIS		
Parmelia subolivacea	0.179	0.035
Usnea hirta	0.052	0.022
Physcia stellaris	0.011	0.011
Xanthoria sp.	0.003	0.003
SLICKROCK		
Aspicilia calcarea	28.81	0.78
Erroded Lichen	11.35	0.53

TABLE 2: CONTINUED

SPECIES	PERCENT COVER	PERCENT FREQUENCY
	SLICKROCK: CONTINUED	
Lecidia tessellata	6.44	0.20
Lecanora frustulosa	1.80	0.08
Staurothele clopima	1.75	0.13
Grimmia sp. (moss)	1.22	0.04
Candelariella rosulans	0.17	0.06
Collema polycarpon	0.13	0.01
Caloplaca fraudans	0.03	0.01

Table 3. Lichen species encountered in Navajo National Monument listed with their importance values and niche breadths. Importance values were calculated by multiplying percent presence by average percent cover. Niche breadths were calculated after Colwell and Fatuyma (1971).

SPECIES	IMPORTANCE VALUE	NICHE BREADTH
ALL SUBSTRATE TYPES COMBINED		
Aspicilia calcarea	1.21	0.343
Erroded lichen	0.67	0.614
Lecidia tessellata	0.30	0.417
Staurothele clopima	0.20	0.663
Candelariella rosulans	0.12	0.496
Grimmia species (moss)	0.10	0.710
Lecanora frustulosa	0.09	0.516
Moss	0.07	0.517
Acarospora fuscata	0.05	0.386
Xanthoparmelia lineola	0.04	0.404
Lecanora muralis	0.02	0.386
Diploschistes actinostomus	0.02	0.410
Aspicilia caesiocinerea	0.02	0.343
Physcia endococcinea	0.01	0.386
Caloplaca fraudans	0.01	0.459
Collema polycarpon	0.01	0.699
Candelariella vitellina	0.01	0.386

TABLE 3: CONTINUED

SPECIES	IMPORTANCE VALUE	NICHE BREADTH
ALL SUBSTRATE TYPES COMBINED: CONTINUED		
Caloplaca arizonica	0.01	0.137
Parmelia substygia	0.01	0.126
BARK SUBSTRATES		
Moss	0.07	0.517
Caloplaca arizonica	0.01	0.137
Xanthoria species	0.01	0.138
Candelariella deflexa	0.01	0.496
Parmelia subolivacea	0.01	0.404
ROCK SUBSTRATES		
Aspicilia calcarea	14.86	0.343
Erroded lichen	8.21	0.614
Lecidia tessellata	3.63	0.417
Staurothele clopima	2.41	0.663
Grimmia species (moss)	1.18	0.710
Lecanora frustulosa	1.14	0.516
Candelariella rosulans	0.67	0.496
Acarospora fuscata	0.57	0.386
Lecanora muralis	0.30	0.386
Aspicilia caesiocinerea	0.26	0.343

TABLE 3: CONTINUED

SPECIES	IMPORTANCE VALUE	NICHE BREADTH
ROCK SUBSTRATES: CONTINUED		
Xanthoparmelia lineola	0.17	0.404
Physcia endococcinea	0.16	0.386
Caloplaca fraudans	0.14	0.459
Diploschistes actinostomus	0.13	0.410
Collema polycarpon	0.12	0.699
Candelariella vitellina	0.09	0.386
Moss	0.08	0.517
Parmelia substygia	0.06	0.126
Lecanora novomexicana	0.03	0.386
Lecanora dispersa	0.02	0.386
Encalyptra species (moss)	0.01	0.386
Toninia caeruleonigricans	0.01	0.386
Caloplaca flavovirescens	0.01	0.386
Lecanora crenata	0.01	0.386
Acarospora strigata	0.01	0.386
Lepraria species	0.01	0.462

Table 4. Distribution of lichen species by aspect on major substrate types in Navajo National Monument. The number on the top is average percent cover and the number below is average percent frequency.

SPECIES	NORTH	SOUTH	EAST	WEST
	CLIFF FACE			
Erroded Lichen	2.33 0.16	3.85 0.28	9.02 0.47	
Staurothela clopima		0.73 0.08	8.52 0.48	
Acarospora fuscata	6.54 0.58	0.33 0.03		
Lecanora muralis	3.32 0.13	0.27 0.03	0.01 0.01	
Candelariella rosulans	0.92 0.09	2.63 0.23		
Grimmia sp. (moss)	0.64 0.04	0.25 0.03	2.52 0.12	
Aspicilia caesiocinerea	0.62 0.03		2.47 0.12	
Aspicilia calcarea	0.76 0.05	1.50 0.08	0.47 0.03	
Lecidia tessellata	0.63 0.04	1.33 0.10	0.51 0.06	
Physcia endococcinea	1.85 0.13			
Diploschistes actinostomus	0.92 0.02	0.67 0.06		
Lecanora frustulosa	0.23 0.02		1.22 0.08	

TABLE 4: CONTINUED

SPECIES	NORTH	SOUTH	EAST	WEST
CLIFF FACE: CONTINUED				
Xanthoparmelia lineola	2.03 0.12			
Candelariella vitellina			1.06 0.12	
Moss sp. (pleuro)			0.97 0.03	
Caloplaca fraudans		0.54 0.08	0.23 0.04	
Parmelia substygia	0.74 0.03			
Lecanora novomexicana		0.32 0.03		
Collema polycarpon		0.08 0.01	0.22 0.03	
Lecanora dispersa		0.02 0.01	0.18 0.05	
Encalyptra sp. (moss)			0.19 0.02	
Toninia caeruleonigricans		0.17 0.01		
Acarospora strigata	0.02 0.02		0.11 0.03	
Caloplaca flavovirescens			0.11 0.02	
Lecanora crenata			0.11 0.03	
Lepraria sp.			0.08 0.01	

TABLE 4: CONTINUED

SPECIES	NORTH	SOUTH	EAST	WEST
CLIFF FACE: CONTINUED				
Buellia retrovertens	0.05 0.01			
Rhizocarpon disporum			0.06 0.01	
Lecanora badia			0.06 0.01	
Lecanora christoi			0.02 0.01	
Tortula sp. (moss)			0.03 0.01	
Collema sp.			0.03 0.01	
JUNIPERUS OSTEOSPERMA				
Caloplaca arizonica	0.019 0.004			
Physcia stellaris	0.002 0.001			
Xanthoria sp.	0.001 0.001			
PINUS EDULIS				
Parmelia subolivacea	0.130 0.022	0.008 0.003	0.027 0.008	0.014 0.003
Usnea hirta	0.046 0.049		0.005 0.003	
Physcia stellaris	0.011 0.011			
Xanthoria sp.	0.003 0.003			

TABLE 4: CONTINUED

SPECIES	NORTH	SOUTH	EAST	WEST
QUERCUS GAMBELII				
Caloplaca arizonica	0.020	0.019	0.013	0.013
	0.006	0.004	0.002	0.003
Xanthoria sp.	0.002		0.007	0.011
	0.001		0.005	0.004
POPULUS TREMULOIDES				
Moss (pleurolocular)	0.069	0.097	0.111	0.278
	0.001	0.003	0.004	0.003
Candelariella deflexa	0.024	0.001	0.003	0.069
	0.004	0.001	0.003	0.008
Lecanora hageni	0.007		0.042	
	0.001		0.006	
Xanthoria fallax			0.008	
			0.007	
Physconia pulverulenta			0.004	
			0.001	
Xanthoria sp.	0.003			
	0.001			
PSEUDOTSUGA MENZIESII				
Moss (pleuro)		0.034	0.197	0.065
		0.002	0.004	0.004
Physcia dubia	0.088			0.025
	0.002			0.004
Physconia grisea			0.027	0.064
			0.002	0.002
Buellia sp.	0.027	0.015	0.034	0.005
	0.005	0.001	0.002	0.002
Lecanora caesiorubella	0.004	0.027	0.023	0.014
	0.001	0.002	0.002	0.002

TABLE 4: CONTINUED

SPECIES	NORTH	SOUTH	EAST	WEST
	PSEUDOTSUGA MENZIESII:	CONTINUED		
Parmelia subolivacea	0.034 0.005	0.014 0.002		0.017 0.004
Diploschistes actinostomus		0.003 0.002	0.031 0.003	0.017 0.003
Heterodermia pseudospeciosa	0.012 0.002	0.001 0.001	0.026 0.005	0.013 0.002
Buellia punctata	0.001 0.001	0.034 0.004	0.005 0.002	
Physconia pulverulenta	0.002 0.002	0.002 0.001	0.019 0.003	0.008 0.001
Caloplaca arizonica			0.028 0.004	0.001 0.001
Xanthoria fallax	0.016 0.007	0.002 0.002		0.008 0.002
Lecanora chlarotera			0.008 0.002	0.017 0.003
Cladonia pyxidata			0.008 0.001	0.015 0.001
Lepraria sp.				0.011 0.001
Lecanora hageni	0.007 0.002	0.002 0.001		0.003 0.001
Lecidia sp.	0.008 0.002			
Lecidia glomerulosa				0.004 0.001
Candelariella deflexa			0.002 0.002	

Table 5. List of probable pollution sensitive lichen species occurring in Navajo National Monument according to substrate type.

	SUBSTRATES	
SPECIES	ROCK	BARK
Collema polycarpon	X	
Lecanora muralis	X	
Parmelia subolivacea		X
Physcia stellaris		X
Usnea hirta		X
Xanthoparmelia lineola	X	

Effects of Long Term Grazing on Cryptogam Communities in Navajo National Monument, Arizona

By

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INTRODUCTION

Throughout desert systems of western North America there is scant ground cover and rather extensive open areas between the plants. In these open areas, soils are often exposed to erosive impacts. When soils are unprotected, erosion can be extensive and soil losses can be great. Of primary importance in the protection of our desert soils are communities of non-vascular cryptogamic plants that grow upon or immediately beneath the soil surface. When well established and undisturbed such plants form a crust which plays an important role in soil stabilization (Fletcher and Martin 1942; Kleiner and Harper 1972; Kleiner and Harper 1977; and Anderson et al. 1978; Loope and Gifford 1972).

Algae are the primary components of these crusts but they are often accompanied by lichens and mosses (Anderson and Rushforth 1977; Kleiner and Harper 1972). Algae are the most effective in binding the soil particles (Anantani and Marathe 1974; Anderson and Rushforth 1977). Where cryptogam crusts are well developed the soil surface is almost always highly stable. Research has been done on several aspects of the biology of soil crusts and cryptogamic communities.

Ecological relationships have been studied by Anderson et al (1978) and Anderson and Harper (1978). Composition and taxonomy of crusts was studied by Anderson and Rushforth (1977). The role of such crusts in nitrogen fixation was studied by Rychert and Skujins (1974) and their effects on infiltration and sedimentation by Loope and

Gifford (1972). However, much is yet to be learned about the role of these crusts in the desert ecosystems.

The objective of this study was to evaluate the effects of long term grazing on the cryptogamic soil communities of the pinyon-juniper zone in northern Arizona (Navajo National Monument).

STUDY AREA

Navajo National Monument is located in northeastern Arizona and is the site of three large Anasazi Indian cliff dwellings. Betatakin Canyon, the site of the present study, is a side canyon of the larger Tsegi Canyon complex and has been described by Hack (1945). The major geological formation within the canyon is Navajo Sandstone, which forms sheer towering cliffs 200 m or more in height. The canyon floor consists of deep alluvial deposits of sandy Quarternary fill. Kayenta sandstone outcrops in the lower reaches of the canyon.

The annual temperatures recorded at Park headquarters at Betatakin canyon range from -23°C to 38°C with a mean of 10°C. The number of frost-free days in the area varies from 107 to 213, with an average of 155 days. Total annual precipitation ranges from 17 cm to 48 cm with a yearly mean of 29 cm. There is a single wet season, lasting from late summer to early fall.

A mature pinyon-juniper community occurs on the mesas and slopes above the canyon and extends onto the large areas of exposed slickrock along the canyon edges. Pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) are consistently the dominant overstory species of this community.

The understory is dominated by a variety of shrubs including big sagebrush (*Artemisia tridentata*); littleleaf mountain mahogany (*Cercocarpus intricatus*); cliffrose (*Cowania mexicana*); antelope bitterbrush (*Purshia tridentata*); cliff fendlerbush (*Fendlera rupicola*); and roundleaf buffaloberry (*Shepherdia rotundifolia*) (Brotherson et al. 1980).

METHODS

Sixteen (30 m) transects were placed perpendicular to the fenceline enclosing Navajo National Monument where topography vegetation and soil appeared equivalent. Eight transects were placed inside the monument boundary where grazing has been excluded for many years and another eight transects were placed outside the monument fence adjacent to those within the fence. Those located outside the monument boundary have been subject to the influence of grazing.

Ten quadrats (0.25 m^2) were distributed along the transects at 3 m intervals. Each quadrat was subdivided into four sections of equal size. Percent cover of vascular and non-vascular species were estimated using the ocular methods and cover classes proposed by Daubenmire (1959). The amount of non-vascular cover contributed by the general classes: lichens, mosses, algae, litter, soil and rock was also recorded (Anderson and Harper 1978). Frequency for all vascular and non-vascular species as well as the above listed general categories was also computed. This was done by noting the total number of quadrat sections of species or a general category occured within and then dividing by the total number of quadrat sections taken. The general importance of vascular plant life forms (trees, shrubs, grasses and forbs) was computed by numerically summing the average percent cover of all species falling into one of the life form groups. Differences between the grazed and non-grazed areas were determined using Students t-tests (Ott 1977).

RESULTS AND CONCLUSIONS

The Navajo National Monument fenceline boundary provided an excellent opportunity to evaluate the effects of grazing on the cryptogamic crust communities of the pinyon-juniper zone in northeastern Arizona. Cover and frequency characteristics of the vascular and non-vascular communities are presented in Table 1-7. Our results demonstrate significant impacts upon the vascular and non-vascular cryptogamic communities with the non-vascular community suffering the greatest damage (Table 1-4). Data on the cryptogamic community show strong differences between the paired grazed and non-grazed areas. The areas subject to grazing support significantly less cryptogamic cover including algae, lichens, and mosses (Table 1 and 2). The lichens and mosses were shown to be the most heavily impacted by grazing. The algae were much more tolerant of grazing disturbance. This also has been shown by Anderson et al. (1978). When individual species of mosses and lichens were considered the above patterns repeated themselves with almost all identifiable species showing reduced numbers as well as reduced importance in the areas subject to grazing pressure (Table 3 and 4).

Percent of exposed soil in the grazed areas showed significant increases over non-grazed areas. This was due to the decreased importance of the cryptogamic crust communities in these areas. Although rock cover was significantly higher in the non-grazed areas this was not due to grazing but to the presence of somewhat more slickrock in the non-grazed sites.

The vascular plant and litter cover categories showed no significant differents between the paired areas (Table 1 and 2). However when examined species by species and by plant life form categories (Tables 5-7) differences were detected. The species slenderbush eriogonum (*Eriogonum microthecum*), slender gilia (*Gilia leptomeria*), and sandhill muhly (*Muhlenbergia pungens*) showed average cover values to be greater in the grazed areas while the species pricklygilia (*Leptodactylon pungens*), brittle pricklypear (*Opuntia fragilis*), Indian rice grass (*Oryzopsis hymenoides*), and longtongue muttongrass (*Poa longiligula*) had higher cover values in the non-grazed areas (Tables 5 and 6). Analysis by life form indicated little or no differences in cover between the two areas for trees, shrubs and forbs. Grasses on the other hand had nearly two and a half times more cover in the non-grazed than in the grazed areas (Table 7). The frequency values also confirm the above conclusions (Tables 6 and 7).

Trends discussed in this study suggest that cryptogamic communities on our western ranges are reduced by domestic grazers. Mosses and lichens appear to be more susceptable to impact than algae. Both the total cover of the cryptogamic community and the number of species involved are decreased under grazing. Realizing the need for present and continued care of our rangelands as well as a need to keep them in good condition, new and improved management practices which consider the health of the cryptogamic crusts should be a positive contribution in rangeland protection. Management techniques favoring the health of cryptogamic crusts are not well worked out. However, Anderson and Harper (1978) indicated that such management practices are possible and should take into account the timing of grazing use to avoid the season of low precipitation, high temperature and the incidence of torrential rains. They reason that this is the time period when the cryptogamic crusts are in an inactive state and thus are the most succeptable to disturbance. Further, it appears that periods of rest enhance the reestablishment of cryptogamic cover and therefore management schemes should provide for such periods. Future research should include analyses of cryptogamic community health and their association to present day established grazing systems.

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Table 1. Percent mean cover values for grazed versus non-grazed areas in Navajo National Monument.

Cover Category	Grazed Mean	Grazed sd	Non-grazed Mean	Non-grazed sd	Significance level
Algae	13.8	15.5	32.7	18.3	0.05
Moss	1.1	1.1	6.8	5.6	0.025
Lichen	2.5	3.0	14.1	9.0	0.01
Vascular Plants	21.4	11.2	26.0	18.5	NS
Litter	30.2	12.3	26.2	11.6	NS
Soil	41.3	20.5	14.7	10.1	0.01
Rock	0.1	0.2	11.3	16.7	0.05

Table 2. Percent mean frequency values for grazed versus non-grazed areas in Navajo National Monument.

Frequency Category	Grazed Mean	Grazed sd	Non-grazed Mean	Non-grazed sd	Significance level
Algae	51.9	39.4	83.4	15.6	0.05
Moss	15.3	15.3	52.8	24.6	0.005
Lichen	21.6	24.3	62.5	25.2	0.01
Vascular Plants	77.4	24.9	70.6	26.7	NS
Litter	96.9	5.9	97.2	6.2	NS
Soil	85.6	6.2	65.3	36.3	0.1
Rock	0.6	1.8	19.4	24.0	0.05

Table 3. Percent mean cover values for cryptogamic species growing on grazed and non-grazed soils in Navajo National Monument.

	Grazed		Non-grazed	
Species	Mean	sd	Mean	sd
<u>Moss</u>				
Bryum sp.	0.1	0.2	0.6	1.0
Grimmia ovalis			0.1	0.2
Grimmia sp.			0.4	0.7
Tortula ruralis	1.0	1.1	6.3	6.2
<u>Lichens</u>				
Acrospora chloroplana			0.1	0.1
Candelaria sp.			0.3	0.5
Colemia sp.	1.4	2.6	8.1	12.4
Colemia tenax	0.4	0.7	0.8	1.4
Fulgensia sp.			0.4	0.5
Lecanora crenulata			1.2	2.2
Lecanora sp.			0.4	1.2
Lecidea decipiens			0.1	0.1
Lecidea sp.			1.3	2.8
Lecidea tessellata			0.2	0.5
Lepraria sp.			0.1	0.1
Lichen sp. 1	0.2	1.0	1.3	1.3
Lichen sp. 2	0.1	0.1	0.2	0.3
Lichen sp. 3	0.1	0.1	0.1	0.1

Table 3: Continued

	Grazed		Non-grazed	
Species	Mean	sd	Mean	sd
Lichens continued:				
Lichen sp. 4	0.1	0.2	1.0	1.2
Toninia caerulonigricans			0.1	0.2
Usnea sp.			0.1	0.1
Xanthoria elegans			0.1	0.2

Table 4. Percent mean frequency values for cryptogamic species growing on grazed and non-grazed soils in Navajo National Monument.

	Grazed		Non-grazed	
Species	Mean	sd	Mean	sd
		Moss		
Bryum sp.	0.9	1.9	5.3	5.7
Grimmia ovalis			1.6	3.5
Grimmia sp.			6.3	10.2
Tortula ruralis	14.4	15.9	45.6	23.3
		Lichens		
Acrospora chloraplana			1.6	3.5
Candelaria sp.			4.7	9.6
Colemia sp.	13.1	23.4	28.8	40.5
Colemia tenax	7.5	12.5	13.1	18.7
Fulgensia sp.	0.9	1.9	5.6	6.9
Lecanora crenulata			4.7	8.9
Lecanora sp.			3.1	8.8
Lecidea decipiens			0.6	1.8
Lecidea sp.			11.6	20.6
Lecidea tessellata			6.3	12.7
Lepraria sp.			0.3	0.9
Lichen sp. 1	1.9	2.9	16.9	15.7
Lichen sp. 2	0.3	0.9	2.5	4.0
Lichen sp. 3	0.3	0.9	0.9	2.7

Table 4: Continued

Species	Grazed		Non-grazed	
	Mean	sd	Mean	sd
	<u>Lichens</u> continued:			
Lichen sp. 4	0.3	0.9	12.2	22.0
Toninia caerulongricans			1.6	2.7
Usnea sp.			0.3	0.9
Xanthoria elegans			1.6	3.5

Table 5. Percent mean cover values for vascular plant species growing on grazed and non-grazed areas in Navajo National Monument.

	Grazed		Non-grazed	
Species	Mean	sd	Mean	sd
Androsace septentrionalis	0.4	1.2	0.1	0.2
Artemisia frigida	0.5	1.1	0.4	0.5
Artemisia tridentata	2.7	3.4	3.9	6.8
Astragalus corvallarius	0.1	0.2	0.1	0.2
Aster arenosus	0.4	1.1	0.9	1.5
Bouteloua gracilis	2.0	4.0	3.5	4.7
Chrysothamnus nauseosus	0.4	1.1		
Delphinium nelsonii			0.2	0.5
Descurainia pinnata	0.2	0.4	0.4	0.4
Echinocereus triglochidiatus			0.1	0.2
Epilobium hormanii			0.3	0.5
Eriogonum alatum	0.1	0.2		
Eriogonum microthecum	2.7	3.7	1.5	2.8
Fendlera rupicola	0.2	0.6	0.2	0.5
Fritillaria atropurpurea			0.1	0.1
Gilia leptomeria	2.1	2.4	0.9	1.1
Heterotheca villosa	2.5	3.7	3.6	6.8
Juniperus osteosperma	2.9	4.1	1.7	3.4
Mentzelia albicaulis	0.1	0.2		
Leptodactylon pungens	0.9	2.1	2.0	2.6

Table 5: Continued

Species	Grazed		Non-grazed	
	Mean	sd	Mean	sd
Muhlenbergia pungens	1.4	3.4	0.6	1.6
Opuntia fragilis	0.2	0.3	2.8	4.9
Opuntia polycantha	0.1	0.2	0.4	1.1
Oryzopsis hymenoides	0.8	1.5	1.4	1.8
Penstemon comarrhenus	0.2	0.3	0.1	0.2
Penstemon eatonii	0.1	0.2		
Pinus edulis	4.4	5.6	4.6	5.5
Poa longiligula	0.2	0.2	4.5	5.5
Stephanomeria tenuifolia	0.1	0.2		
Stipa comata	0.1	0.2	0.5	1.0
Tradescantia occidentalis	0.3	0.5	0.4	1.1
Xanthocephalum sarothrae			0.2	0.5
Xucca angustissima			0.1	0.2
Unknown seedlings	0.8	0.8	0.1	0.1

Table 6. Percent mean frequency values for vascular plant species growing on grazed and non-grazed areas in Navajo National Monument.

	Grazed		Non-grazed	
Species	Mean	sd	Mean	sd
Androsace septentrionalis	1.9	5.3	2.5	5.3
Artemisia frigida	2.8	4.5	2.2	2.5
Artemisia tridentata	11.6	16.4	5.6	9.0
Astragalus convallarius	0.6	1.8	0.6	1.8
Aster arenosus	1.9	3.7	4.7	8.9
Bouteloua gracilis	11.9	18.5	15.0	15.7
Chrysothamnus nauseosus	0.6	1.8		
Delphinium nelsonii			1.9	3.7
Descurainia pinnata	0.2	1.9	7.2	6.6
Echinocereus triglochidiatus			0.9	1.3
Epilobium hormanii			1.9	3.5
Eriogonum alatum	0.9	1.3		
Eriogonum microthecum	12.8	17.5	5.9	10.3
Fendleria rupicola	1.6	4.4	0.3	0.9
Fritillaria atropurpurea			0.3	0.9
Gilia leptomeria	15.3	12.2	10.0	7.9
Heterotheca villosa	11.3	15.4	8.8	18.0
Juniperus osteosperma	7.8	6.7	4.7	6.9
Mentzelia albicaulis	0.6	1.8		
Leptodactylon pungens	2.5	7.1	9.4	10.6

Table 6: Continued

Species	Grazed		Non-grazed	
	Mean	sd	Mean	sd
Muhlenbergia pungens	4.4	10.5	3.1	8.8
Opuntia fragilis	4.4	6.8	13.1	19.8
Opuntia polycantha	0.6	1.8	1.3	3.5
Oryzopsis hymenoides	8.1	3.9	7.2	10.1
Penstemon comarrhenus	1.9	2.9	1.6	3.0
Penstemon eatonii	0.6	1.8		
Pinus eduhs	12.2	14.5	9.4	9.7
Poa longiligula	1.6	1.3	15.6	17.0
Stephanomena tenuifolia	0.6	1.8		
Stipa commata	1.3	3.5	3.1	4.6
Tradescantia occidentalis	3.8	8.8	1.9	3.7
Xanthocephalum sarothrae			0.3	0.9
Xucca angustissima			0.3	0.9
Unknown seedlings	21.3	21.8	1.6	3.5

Table 7. Percent sum cover and frequency values for vascular plant life form types growing on grazed and non-grazed areas in Navajo National Monument.

	Cover		Frequency	
Life form	grazed	non-grazed	grazed	non-grazed
Trees	7.3	6.3	20.0	14.1
Shrubs	7.4	9.0	35.6	37.1
Grasses	4.5	10.5	27.3	44.0
Forbs	6.9	7.5	40.9	43.6

INFLUENCE OF CRYPTOGAMIC CRUSTS ON MOISTURE RELATIONSHIPS OF SOILS IN NAVAJO NATIONAL MONUMENT ARIZONA

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Cryptogamic crusts are non-vascular plant communities which grow on or immediately beneath the soil surface. Such communities are often important components of desert ecosystems. They are of immense importance in several ecosystems in western North America (Anderson and Harper 1978) as well as in the deserts of the Middle East (Evenari et al. 1971). Until recently scant attention had been given them and little was known concerning the roll they play in native ecosystems. Studies of the past decade indicate that they exert a significant impact on reducing soil erosion (Evenari et al. 1971; Loope and Gifford 1972; Kleiner and Harper 1972; Kleiner and Harper 1977; Anderson and Harper 1978; and Anderson et al. 1978). Fletcher and Martin (1948) found that mold and algae crusts increase the tensile strength of soil. The algae appear to be the most effective in binding the surface soil particles (Durrell and Shields 1961) because of the thick gelatinous sheaths that enclose the trichomes of several algal species (Anderson and Rushforth 1977). Such gelatinous sheaths add strength and aggregating qualities to the surface 1 or 2 millimeters of soil upon which they grow (Anantani and Marathe 1974).

Research focusing on the biology of cryptogamic crusts has also been done in several other areas. These studies include taxonomy (Ali and Sandhu 1972; Anderson and Rushforth 1978); nitrogen fixation (MacGregor and Johnson 1971; Reddy and Gibbons 1975); land reclamation (Singh 1950); soil fertility (Schields and Durrell 1964); reproduction, growth and habitat relations (Evenari et al. 1971; Anderson et al. 1978); and moisture (Booth 1941; Loope and Gifford 1972).

The objective of our study was to investigate the influence of cryptogamic crusts in the pinyon-juniper woodlands of northeastern

Arizona on water permeability, infiltration, runoff, and potential sediment production.

STUDY AREA

Navajo National Monument is located in northeastern Arizona and is the site of three large Anasazi Indian cliff dwellings. Betatakin Canyon, the site of the present study, is a side canyon of the larger Tsegi Canyon complex and has been described by Hack (1945). The major geological formation within the canyon is Navajo Sandstone, which forms sheer towering cliffs 200 m or more in height. The canyon floor consists of deep alluvial deposits of sandy Quarternary fill. Kayenta sandstone outcrops in the lower reaches of the canyon.

The annual temperatures recorded at park headquarters at Betatakin canyon ranges from -23°C to 38°C with a mean of 10°C. The number of frost-free days in the area varies from 107 to 213, with an average of 155 days. Total annual precipitation ranges from 17 cm to 48 cm with a yearly mean of 29 cm. There is a single wet season, lasting from late summer to fall.

METHODS

Cryptogamic crusts were sampled in the pinyon-juniper (<u>Pinus edulis</u>-<u>Juniperus osteosperma</u>) community which borders Betatakin canyon in Navajo National Monument, Arizona. Crust conditions were sampled in pairs where varying conditions in habitat (slope, exposure, soil texture, etc.) could be kept to a minimum. Pairs consisted of sites where crusts were intact and undisturbed and sites where the crusts had been heavily disturbed or destroyed. Pairs were always located within a meter of each other.

Water permeability was measured by using a thin walled aluminum cylinder 65 mm in diameter. The cylinder was gently turned into the crust or soil of adjacent sites and 50 ml of water was ponded above the core inside of the cylinder . Percolation into the core was measured as the number of seconds needed for the ponded water to disappear into the core.

Water infiltration and runoff were assessed by raining 1.5 liters of water onto the crust or adjacent soil surface through a perforated 80 mm diameter disk. The perforations were evenly spaced on a 0.5 cm grid. The disk was placed at a distance of 1.2 meters above the ground surface. Total delivery time for the water to be dispensed onto the crust or soil surface was 20 seconds. Once the water had disaopeared into the crust or soil surface infiltration was immediately measured as total depth of penetration. Five depth measurements were taken for each area and averaged.

Runoff was measured by recording the across slope and down slope spread of water rained onto study sites. The area of spread was computed from these measurements via the formula which computes the area of an ellipse.

Soil movement was assessed by estimating the amount of soil moved during a measured rain. The following index was used: 1 = no appreciable movement; 2 = moderate movement; and 3 = heavy movement.

All runoff and soil movement measurements were replicated five times during the third week of August 1980. Significant differences in the paired measurements were assessed through the use of students-t statistic.

RESULTS

Average values for all measurements taken during this study are given in Table 1. Six soil moisture characteristics were assessed relative to being influenced by the presence of cryptogamic crusts on the soil surface. As can be seen from this table all but one of the measured characteristics showed significant differences due to the presence of the crusts on the soil surface.

Infiltration measurements on the paired study sites indicated that well developed cryptogamic crusts significantly increased the depth of water penetration. This was also demonstrated by Loope and Gifford (1972). Downslope movement of water was significantly greater on the sites which exibited no crust development. The differences in total area of surface spread were also significant. These differences are probably best explained by the micro-topographic changes which develop at the soil surface under the influence of cryptogamic crust growth. Well developed crusts are associated with a type of pedestle formation which looks something like a convoluted coral surface. Hills and valleys a few centimeters in relief develop across broad crusted areas. The small valleys run in all directions and cause a pooling and/or ponding effect of the water as it hits the soil surface. This ponding effect decreases runoff and across surface movement. With reduced surface movement areas of spread are decreased and more water is held in place allowing for deeper penetration (more runin and less runoff).

Well developed crust areas also showed significantly less (almost none) soil movement (Table 1). These data support the findings of several other studies (Fletcher and Martin 1948; Loope and Gifford 1972; Kleiner and Harper 1977; and Anderson et al. 1978). Cryptogamic crusts appear to have a protective influence on the soil in four major ways. First, they bind the soil surface particles with the intertwining growth of algal and fungal filaments. Second, the moss and lichen constituents of cryptogam crusts aid in stabilizing the soil by covering the surface with thalli and penetrating the soil surface with rhizoids (Anderson et al. 1978). Third, the irregularities of a well developed cryptogamic crust surface tend to break up microwind patterns and thus reduce windborn soil movement (Brady 1974). And fourth, with less water movement as shown on our study, there will also be significantly less soil movement.

Well developed crusts also influenced permeability of water into the soil. Percolation rates were significantly reduced or impeded by crust cover. The highest percolation rates (most rapid penetration by water) occurred on soils with no cryptogamic cover (Table 1). In general where cryptogamic cover was high greater resistance to percolation occurred. Loope and Gifford (1972) also noted this and suggested that when moisture was added before permeability trials were begun this resistance by crusts was increased by a factor of 2.

Data from several studies indicate that high cryptogamic crust cover is associated with high silt in the soil surface (Evenari et al. 1971; Loope and Gifford 1972; and Anderson et al. 1978). Evenari et al. (1971) have presented data which indicate that soils high in silt often have low permeability rates and high runoff. They suggest that soils with high levels of silt in the upper layers will hsow high initial infiltration rates but as more wetting occurs the percolation rates decrease rapidly and eventually an almost impenetratable crust can be formed. Beneath such a sealed surface air caught in the voids of the lower layers would have a difficult time escaping and such entrapped air could further retard infiltration.

It appears then that at least three factors tend to reduce water penetration rates in soils with cryptogam crusts. The effect of high levels of silt in the soil and its resultant swelling and sealing action when mixed with water (Evenari et al. 1971). The wetting action of the water on the geletinous sheaths of the algal filaments causing the filament to swell and tightly bind the surface soil particles (Anatani and Marathe 1974, and Durrell and Shields 1961). And finally air can be trapped beneath the sealed surface to further impede water penetration.

Evenari et al. (1971) also indicated from their research on micro-watershed irrigation projects, that as the farm areas receive runoff water ladened with silt from the watersheds and as the silt is deposited on the soil surface, evaporation from the irrigated fields was reduced to as little as 7.4 mm over a 7 month period. This kind of reduction in an area of desert with annual evaporation values from 1700-2700 mm would be highly important relative to moisture retention in the subsurface layers of the soil.

Since cryptogamic crusts tend to seal the soil surface as shown by our data and the data of others, and since the crusts also increase the depth of moisture penetration because of their microtopographic relations the effects they appear to have on reducing moisture stress in desert ecosystems could prove to be extremely valuable. Coupled with the above is the fact that the crust communities tend to grow on areas of soil surface with high silt levels. These elevated silt levels at the soil surface undoubtedly further reduce water losses by evaporation. This being the case, cryptogamic crusts may be just as important in their role in water conservation in desert systems as they are in preventing soil erosion.

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Table 1. Relationships of cryptogamic crusts growing on the soil in Navajo National Monument to measured moisture parameters.

Characteristic Measured	Crust Mean	Crust sd	Non-Crust Mean	Non-Crust sd	Significance Level
Water penetration (inches)	2.15	0.53	1.27	0.27	.05
Down slope spread (inches)	27.60	5.41	37.60	1.67	.001
Across slope spread (inches)	18.60	4.28	18.00	2.55	NS
Area of spread (sq. inches)	1617.29	471.50	2130.00	338.77	.001
Soil movement*	1.00	0.00	2.60	0.89	.01
Permeability (seconds)					
Moss	15.40	3.90	238.00	87.90	.001
Lichen and algae	48.00	14.50	31.00	8.10	.001

* Soil movement was assessed as follows: 1 = no movement, 2 = moderate movement, 3 = heavy movement.

LICHENS OF NAVAJO NATIONAL MONUMENT

By

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November 1981

LIST OF LICHEN SPECIES COLLECTED IN NAVAJO NATIONAL MONUMENT, 1975-1981

We have been collecting and identifying lichens in Navajo National Monument since 1975. During this time, we have studied the lichen species on a wide variety of substrate types. A total of 88 species have been identified from these studies. These species are listed in the following pages together with a notation of the substrate upon which they occurred. An explanation of the abbreviation of substrate type is listed at the end of the species list.

LICHENS OF NAVAJO NATIONAL MONUMENT

Lichens	Substrate
Acarospora fuscata (Schrad.) Arn.	Ns
A. strigata (Nyl.) Jatta	Ns
Aspicilia caesiocinerea (Nyl.) Hue	Ns
A. calcarea (L.) Mudd.	Ns
Bacidia umbrina (Ach.) Bausch	Ns
Buellia lepidastra (Tuck.) Tuck.	Ns
B. punctata (Hoffm.) Mass	Jo, Pm
B. retrovertens Tuck.	Ns
B. zahlbruckneri J. Stein.	W, Jo
Caloplaca arizonica Magn.	Jo, Qg, Fr.
C. cerina (Ehrh.) Th. Fr.	Qg
C. durietzii Magn.	Jo, W
C. epithallina Lynge	Parasite
C. ferruginea (Huds.) Th. Fr.	Cm
C. flavovirescens (Wulf.) Dalla Torre & Sarnth.	Ns
C. fraudans (Th. Fr.) Oliv.	Ns
C. holocarpa (Hoffm.) Wade	Qg, Fr, Jo
C. jungermanniae (Vahl) Th. Fr.	Moss on Ns
C. microphyllina (Tuck.) Hasse	W, Jo
C. pinicola Magn.	Jo
C. trachyphylla (Tuck.) Zahlbr.	Ns
Candelariella deflexa (Nyl.) Zahlbr.	Pt
C. rosulans (Mull. Arg.) Zahlbr.	Ns
C. vitellina (Ehrh.) Mull. Arg.	Ns
Cladonia pyxidata (L.) Hoffm.	S

Lichens	Substrate
Collema polycarpon Hoffm.	Ns
C. tenax (Sw.) Ach.	S
Dermatocarpon hepaticum (Ach.) Th. Fr.	S
D. lachneum (Ach.) A. L. Sm.	S
D. miniatum (L.) Mann.	Ns
D. plumbeum (B. de Lesd.) Zahlbr.	Ns
Diploschistes actinostomus (Pers.) Zahlbr.	S, Ns
D. scruposus (Schreb.) Norm	S
Endocarpon wilmsoides Zahlbr.	Ns
Fulgensia fulgens (Sw.) Elenk.	S
Heterodermia pseudospeciosa (kurok) W. Culb	Pm
Lasalia papulosa (Ach.) Llano	Ns
Lecanora badia (Hoffm.) Ach.	Ns
L. chlarotera Nyl.	Qg, Pm
L. chloropolia (Erichs.) Almb.	Qg
L. christoi W. Web.	Ns
L. crenulata (Dicks.) Nyl.	Ns
L. dispersa (Pers.) Somm.	Ns
L. frustulosa (Dicks.) Ach.	Ns
L. hagenii (Ach.) Ach.	Jo, Pm
L. lentigera (G. Web.) Ach.	S
L. muralis (Schreb.) Rabenh.	Ns
L. novomexicana Magn.	Ns
L. pinniperda Korb.	Ci
L. saligna (Schrad.) Zahlbr.	Ci
Lecidea auriculata Th. Fr.	S
L. crenata (Tayl.) Stizenb.	S

Lichens	Substrate
L. decipiens (Hedw.) Ach.	S
L. novomexicana (B. de Lesd.) W. Web.	S
L. russellii Tuck.	S
L. tessellata (Ach.) Florke	Ns
Lecidella glomerulosa (DC.) Choisy	Jo, Qg, Pm
L. viridans (Flot.) Korb.	Ns
Lepraria membranacea (Dicks.) Vain.	S
Parmelia elegantula (Zahlbr.) Szat.	Qg
P. olivacea (L.) Ach.	trees
P. subolivacea Nyl.	Cm, Pe, Qg, Ci
Peltigera canina (L.) Willd.	S
Pertusaria saximontana Wetm.	W
Physcia aipolia (Ehrh.) Hampe	Qg
P. biziana (Mass.) Zahlbr.	Qg, Jo
P. ciliata (Hoffm.) Du Rietz	Jo
P. dubia (Hoffm.) Lett.	Pm
P. stellaris (L.) Nyl.	Cm, Pe, Qg
Physconia grisea (Lam.) Poelt	Fr, M
P. pulverulenta (Schreb.) Poelt	Pm
Phizoplaca chrysoleuca (Sm.) Leuck. & Poelt	Ns
R. melanophthalma (Ram.) Leuck. & Poelt	Ns
Rinodina achraea (Ach.) Arn.	Jo
R. exigua (Ach.) S. Gray	Jo
R. pyrina (Ach.) Arn.	Pm
Sarcogyne clavus (Ram.) Kremp.	Ns
Staurothele clopima (Wahlenb. ex Ach.) Th. Fr.	Ns

Lichens	Substrate
Torinia caeruleonigricans (Lightf.) Th. Fr.	S
T. tristis (Th. Fr.) Th. Fr.	S
Usnea hirta (L.) Wigg	Pe, Pm
Xanthoparmelia conspersa (Ach.) Hale	Ns
X. cumberlandia (Gyel.) Hale	Ns
X. plittii (Gyel.) Hale	Ns
Xanthoria elegans (Link) Th. Fr.	Ns
X. fallax (Hepp.) Arn.	Qg, Fr.
X. parietina (L.) Th. Fr.	trees
X. polycarpa (Ehrh.) Oliv.	Ci, Fr, Qg

Ci - *Cercocarpus intricatus* S. Wats.

Cm - *Cowania mexicana* D. Don

Fr - *Fendlera rupicola* Gray

Jo - *Juniperus osteosperma* (Torr.) Little

M - Moss

Ns - Navajo sandstone

Pe - *Pinus edulis* Engelm

Pm - *Pseudotsuga menzeisii* (Mirb.) Franc.

Pt - *Populus tremuloides* Michx.

Qg - *Quercus gambellii* Nutt.

S - Soil

W - Wood

REFERENCE PHOTOGRAPHS TAKEN OF PERMANENT PLOTS IN NAVAJO NATIONAL MONUMENT

Jack D. Brotherson and Samuel R. Rushforth

Permanent plot No. 1. Plot is located 3 feet west of where the lower boundry fence in Batatakin Canyon meets the Navajo sandstone cliffs at its south end. The plot is located 4.5 feet above ground level. Marking Blue tipped marker rod is located directly beneath plot.

Permanent plot No. 2. Plot is located 21 feet west of where the lower boundry fence in Batakin Canyon meets the Navajo sandstone cliffs at its south end. The plot is located at 5 feet above ground level. Blue tipped marker rod is located directly beneath plot.

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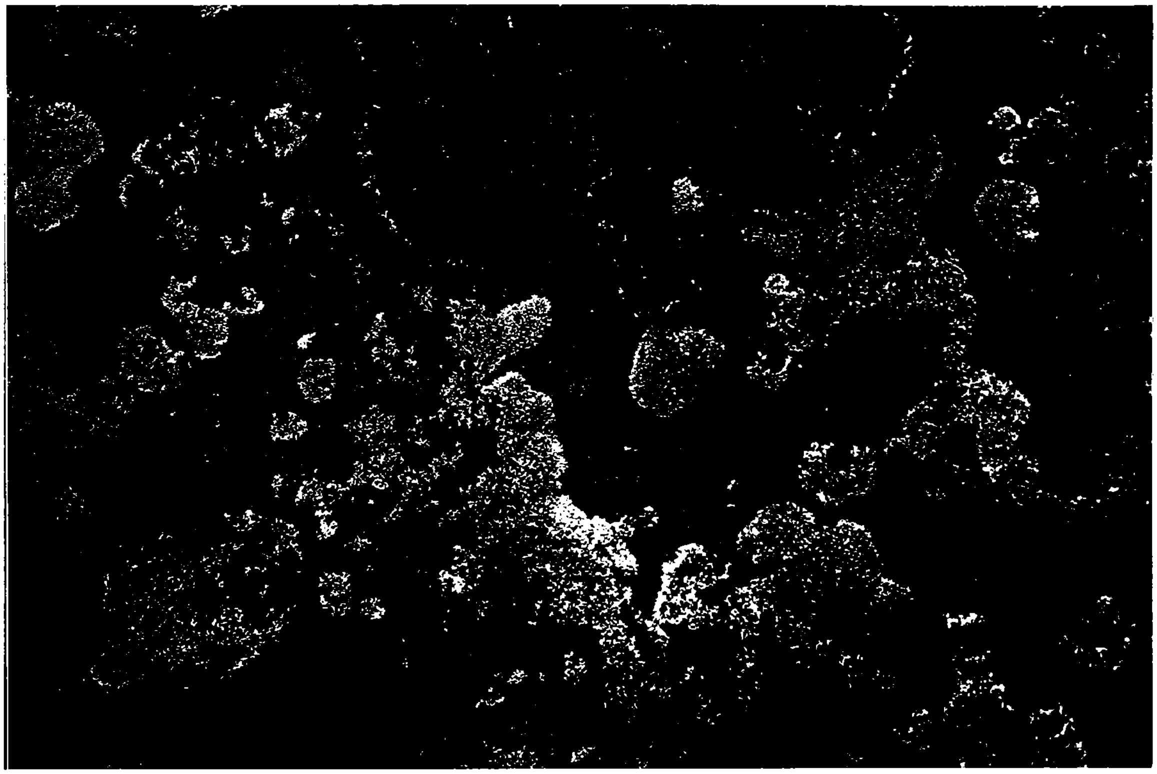

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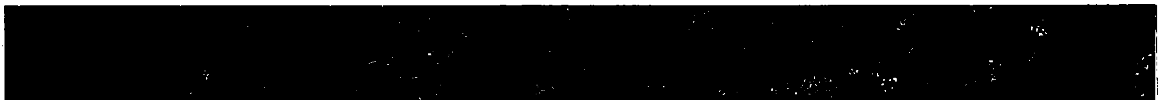
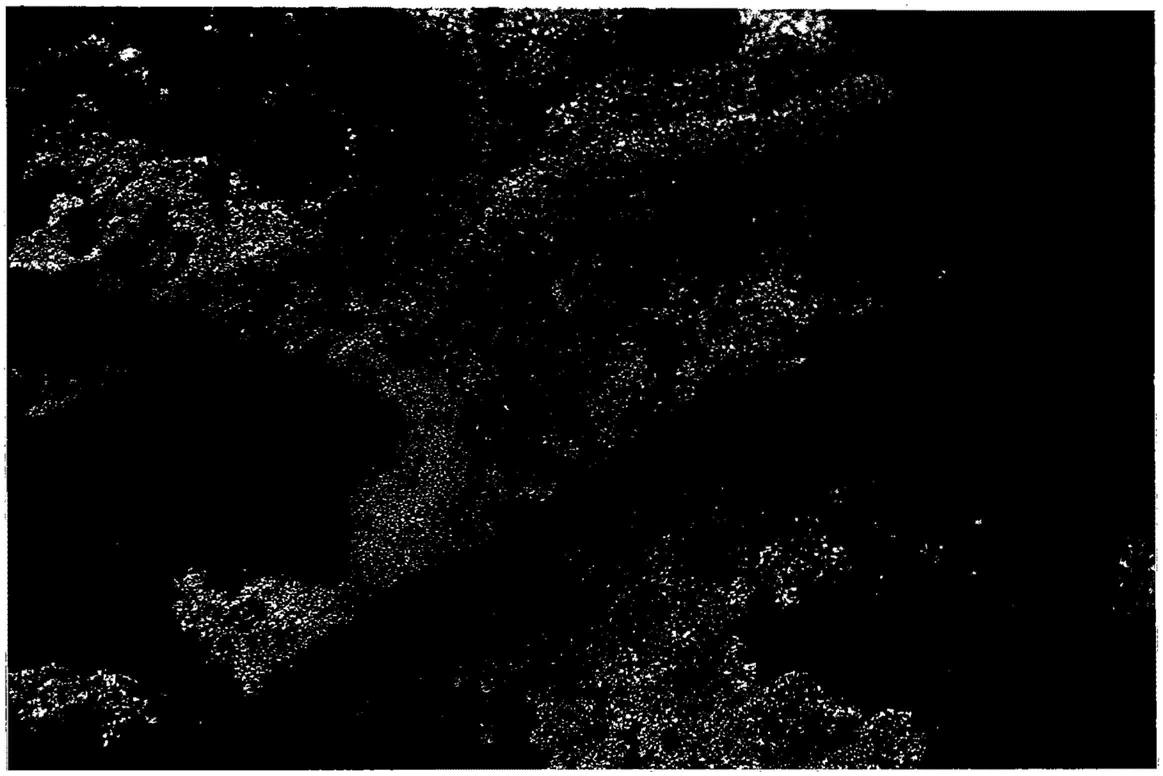
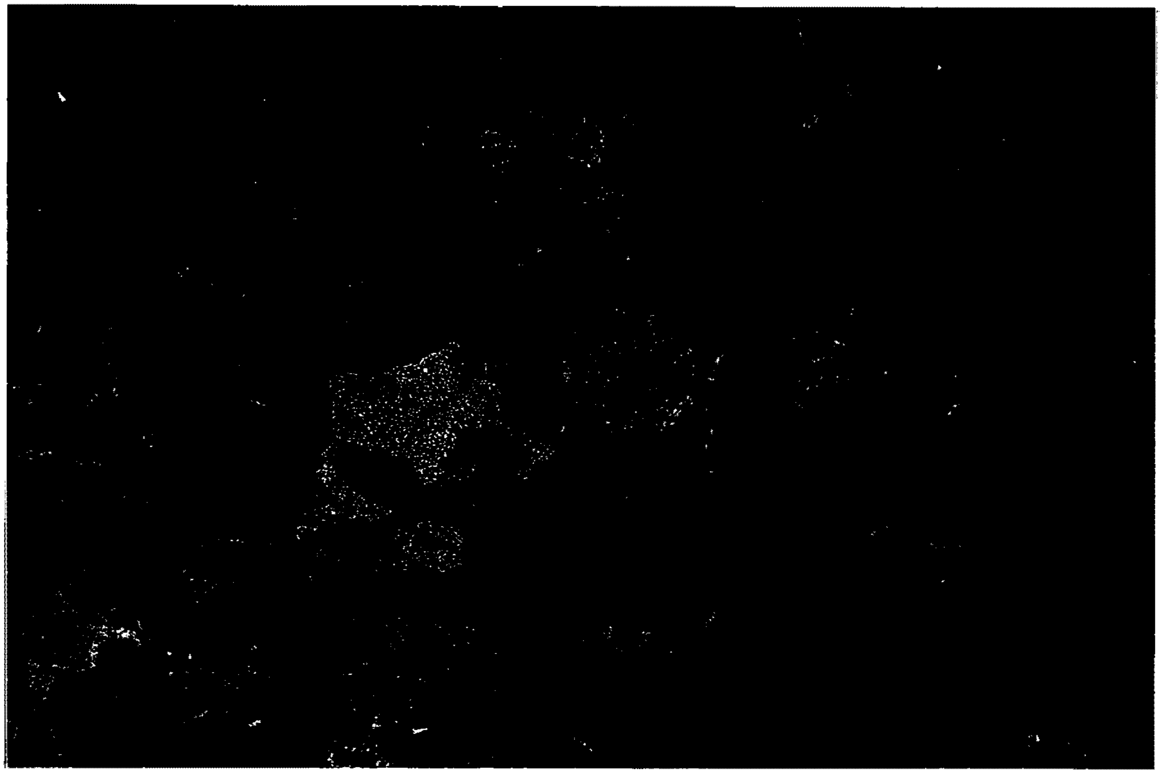


Permanent plot No. 3. Plot is located up drainage area from 3rd major bend in trail. The plot is 21 feet up toward the cliff face. Blue tipped marker rod is located at base of second rock below plot

Permanent plot No. 4. Plot is on slickrock 100 yards North of over look station information stand. Blue tipped marker rod is at base of pinyon tree. The plot is 3 feet west of the rod.





Permanent plot No. 5. Plot is located at point in trail which exits Betatabin canyon where "A" frame stand with rope dangling. The plot is 16 feet southwest of "A" frame on sandstone. Its located 2 feet above the ground level. Blue tipped marker rod is located in slit of sandstone directly below plot.

Permanent plot No. 5. Photograph depicts the Blue tipped marker placement directly below the plot.

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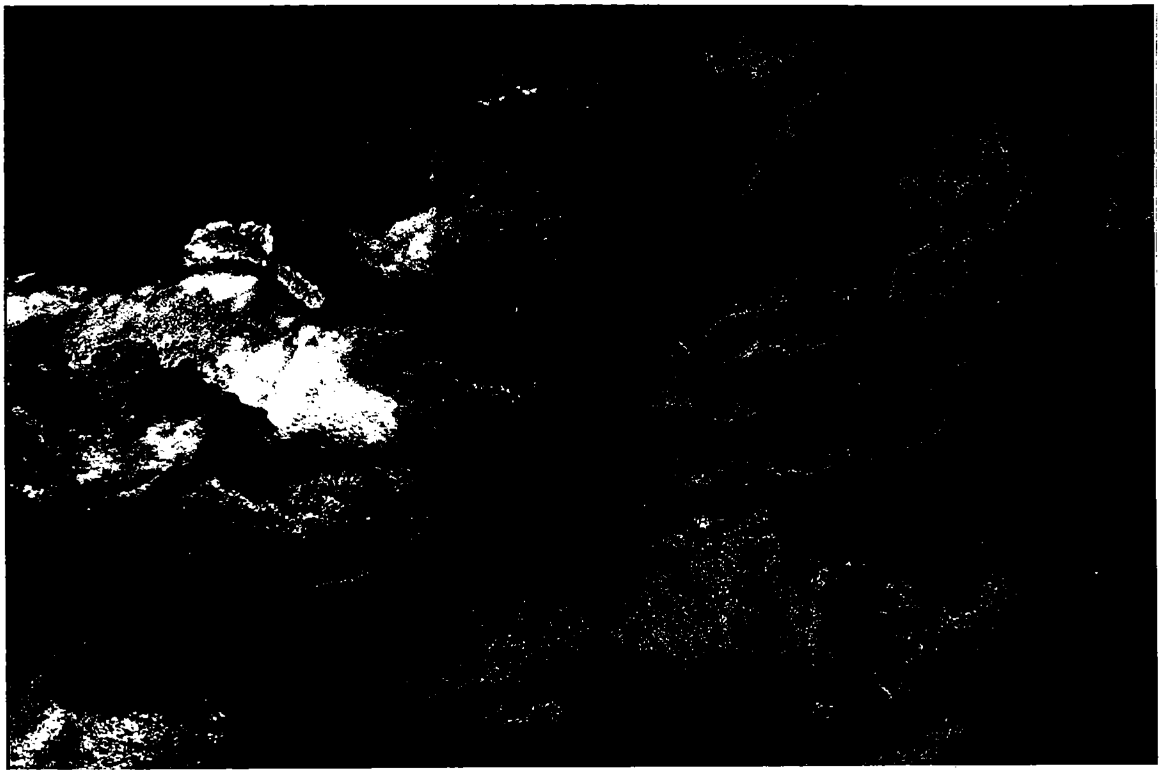

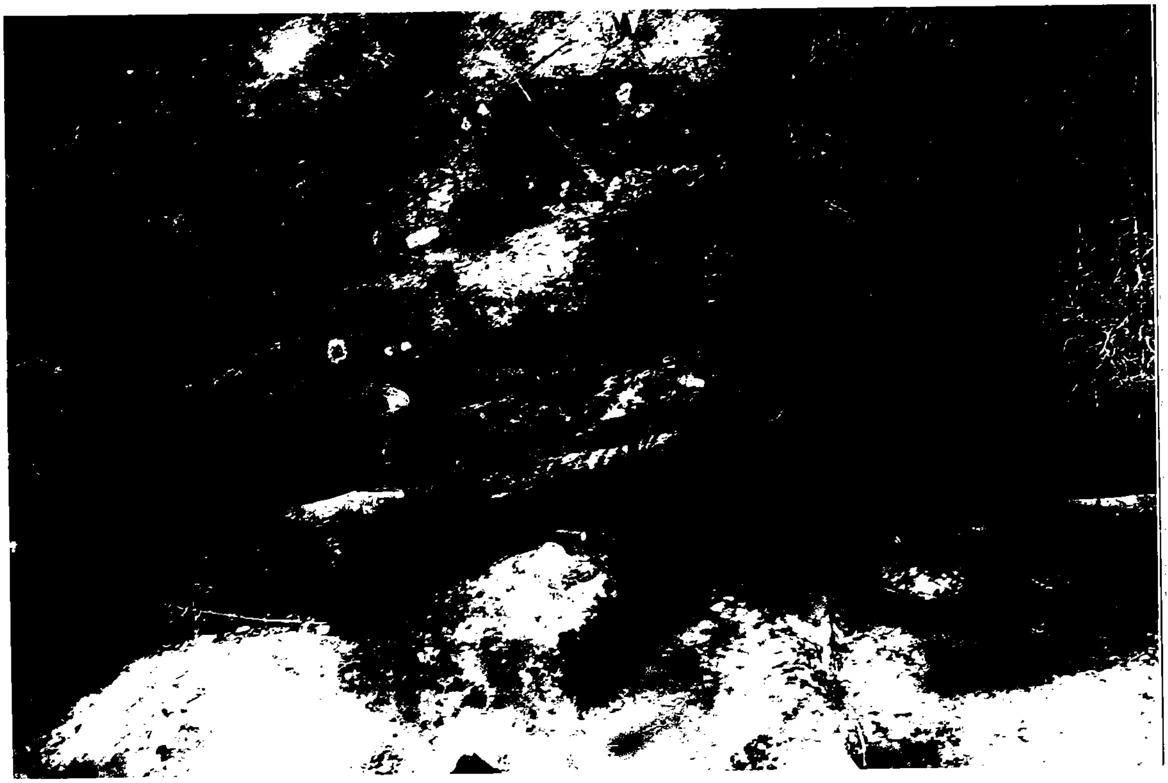

SUBAERIAL ALGAE OF
NAVAJO NATIONAL MONUMENT
ARIZONA[1]

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Running title: JOHANSEN ET AL.--SUBAERIAL ALGAE IN ARIZONA

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ABSTRACT

Samples from soils and other xeric substrates in Navajo National Monument, Navajo County, Arizona were collected in 1978. After culturing in distilled water for three days these samples were analyzed for algae. Thirty algal taxa were identified. Five species of filamentous Cyanophyta comprised the majority of the biomass. Diatoms were ubiquitous in the soils although low in density. Diatom floras were very similar throughout the monument. Well developed algal crusts were common in those sites where grazing and excessive litter were absent.

INTRODUCTION

Cryptogamic soil crust communities in arid regions of the world have received attention from several workers (Ali and Sandhu, 1972; Anantani and Marathe, 1974a, 1974b, Bischoff and Bold, 1963; Cameron, 1964; Chantanachat and Bold, 1962; Durrell, 1959; Fletcher and Martin, 1948; Forest and Weston, 1966; Hayek and Hulbary, 1956). Such communties are variable in composition. Those best developed form crusted hummocks composed of as many as 30 to 40 species of various cryptogams including lichens, mosses and algae (Anderson and Rushforth, 1976). Under some circumstances such crusts do not develop, but algae may still be present and bind soil particles (Durrell and Shields, 1961). Algal binding and crust formation protect the soils from heavy summer rains and persistent winds (Anderson and Rushforth, 1976). In addition to reducing erosion and consequent leaching of minerals, nitrogen fixation by some of the blue-green algae also contributes to overall soil quality (Macgregor and Johnson, 1971; Rychert and Skujins, 1974; Shields and Durrell, 1964; Snyder and Wullstein, 1973). When crusts are disturbed by grazing or heavy human traffic the binding of the soil is decreased and soil erosion increases (Anderson, Harper and Rushforth, in press; Loope and Gifford, 1972).

Cryptogamic crusts are very widespread and important in arid regions of western North America and have been under investigation in our laboratory for several years. Anderson *et al*. (1976; in press) examined soil crusts throughout Utah, and discussed taxonomy, distribution, and the effects of grazing and soil quality on crust development. The present study is a continuation of our cryptogamic research and deals with the algal component of the soils and subaerial substrates of Navajo National Monument, Navajo County, Arizona.

Navajo National Monument is located in northeastern Arizona about 16 km north and west of Black Mesa and Arizona Highway 160. The principal sites of the monument are three large Indian "cliff dwellings" of the Anasazi culture. These cliff dwellings are located in three separate canyons. Betatakin and Keet Seel Canyons are part of the Tsegi Canyon complex while Inscription House is located about 32 km west of Betatakin in Nitsin Canyon. All three units lie in country dominated by pinyon-juniper communities (*Pinus edulis*, *Juniperus osteosperma*) growing in soil pockets associated with sandstone slickrock (Fig. 1). Within the region there exist many deep-cut canyons with high-walled sandstone cliffs often reaching heights of 300 m above the streambeds. Springs and seeps are often encountered in these canyons, creating unique habitats which develop plant and animal communities foreign to the overall pinyon-juniper type. Aspen (*Populus tremuloides*), Gambel oak (*Quercus gambelii*), and Douglas-fir (*Pseudotsuga menziesii*) communities are present in Betatakin Canyon; oak and mixed weed communities (Fig. 2) are present in Keet Seel; and a large, heavily grazed, annual weed community (Fig. 3) exists in the Inscription House segment (Brotherson *et al.*, 1978; Brotherson *et al.*, in review). The soils of Navajo National Monument are essentially all derived from the Navajo Sandstone formation.

Even so, many environmental subtypes exist, providing different habitats for the development of cryptogams.

Materials and Methods

Soil Samples from the communities discussed above were obtained during the summer of 1978 by scooping approximately 200 g of soil into collection boxes. In addition mosses, lichens, and evident cryptogamic crusts (Fig. 4-6) growing on soils, rocks and trees in the monument were also collected. These samples were subsequently moistened for 36 hours with distilled water in order to hydrate prominent living algae. Permanent diatom slides were later prepared using standard acid oxidation techniques and Naphrax mountant (St. Clair and Rushforth, 1976). All species were studied and identified using a Zeiss RA research microscope with Nomarski interference and phase-contrast accessories.

Results and Discussion

A total of thirty algal taxa were found in the soil and rock substrates of the monument. Ten of these were blue-green algae (Cyanophyta, Fig. 7-17, 19, 20), one was a green algae (Chlorophyta, Fig. 18), and nineteen were diatoms (Bacillariophyta, Fig. 21-41). These taxa are listed in Table 1 together with pertinent descriptive data. The algae most prevalent in crusted soils were all filamentous blue-green species; *Anabaena variabilis*, *Microcoleus vaginatus*, *Nostoc muscorum*, *Phormidium tenue*, and *Scytonema myochrous* (Table 2). These algae, particular *M. vaginatus*, were chiefly responsible for binding the soil and producing crusts.

The best developed crusts were those in the pinyon-juniper communities of Betatakin (Fig. 1). These soils have been protected from grazing for many years and the crusts here often contain mosses and lichens in addition to algae. The oak, fir, and aspen communities of Betatakin are covered with excessive litter which retards crust production. Due to overgrazing, crusts were absent in the Keet Seel and Inscription House areas and serious erosion problems were evident (Fig. 3). However, some crusts were found in the slickrock above Inscription House where soil pockets in the rock were not subjected to grazing.

The most surprising find of this study was the widespread distribution of diatoms in the xeric habitats in the monument (Table 3). Though not a major part of the algal biomass, diatoms were found in every sample taken. The uncrusted soils of Keet Seel contained few blue-green and green algae, yet hosted a diverse diatom flora. Likewise, the lichens on the oaks in Keet Seel had diatoms associated with them, including Hannaea arcus, which was not seen elsewhere in the monument. The mosses and lichens on rock surfaces also supported diatom assemblages. Soils from the heavily grazed area of Inscription House had a very depressed diatom population with only four frustules being seen after extensive examination of samples. All uncrusted soils of Betatakin, though poor in filamentous algae, contained numerous diatoms.

Hantzschia amphioxys was the most abundant diatom, with Navicula mutica var. cohnii being nearly as abundant (Table 3).

Navicula mutica, Pinnularia borealis, and Caloneis bacillum were also important. The presence of two centric planktonic diatoms, Cyclotella comta and Stephanodiscus astraea var. minutula, was somewhat surprising, though these taxa have been reported from arid soils elsewhere (Anderson and Rushforth, 1976). It is interesting to note that neither of these species was observed in the aquatic habitats of the monument.

The close similarity of diatom floras in the soils of the monument is good evidence that the diatoms encountered in the samples represent living communities, not incidental contaminants. Upon examining moistened crusts, living diatoms were rare. However, numerous frustules were found approximately one centimeter below the soil surface. It is likely that the diatoms migrate to the soil surface under favorable conditions. More work is planned to test this hypothesis. The discovery that algae grow in arid soils which show no evidence of crusting or binding has stimulated our interest in such soils, and research on the various uncrusted soil types in arid western North America is planned. Furthermore, we are currently studying the effects of grazing and compaction by humans on cryptogamic communities.

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Table 1. Algal taxa observed in collections from selected terrestrial environments of Navajo National Monument. Pertinent descriptive information for each species is included.

CYANOPHYTA

Anabaena variabilis Kütz. (Fig. 12): cells 4 um wide by 2-4 um long; heterocysts 7 um wide by 6 um long.

Chlorogloea fritschii Mitra (Fig. 9): cells 4-6 um in diameter.

Chroococcus rufescens (Kütz.) Naeg. (Fig. 7): colony 10-25 um in diameter; cells 3-11 um in diameter.

Chroococcus turgidus (Kütz.) Naeg. (Fig. 8): colony 18-20 um wide by 20-25 um long; cells 6-13 um in diameter.

Lyngbya limnetica Lemm. (Fig. 10): cells 1-3 um wide by 1.6-6 um long.

Microcoleus vaginatus (Vauch.) Gomont (Fig. 19, 20): colonial sheath 20-32 um wide; trichomes 2.5-8 um wide; cells 2-9 um long.

Nostoc commune Vauch. (Fig. 13, 14): colony microscopic; cells 4-5 um wide by 4-6 um long; heterocysts 6-8 um in diameter; akinetes 6 um wide by 8 um long.

Nostoc muscorum C. A. Ag. (Fig. 15): colony microscopic; cells 2.5-4 um in diameter; heterocysts 6 um in diameter.

Phormidium tenue (Menegh.) Gomont (Fig. 11): cells .7-2.5 um wide by 2-3 um long.

Scytonema myochrous (Dillw.) C. A. Ag. (Fig. 16, 17): filaments 12-15 um wide; trichomes 6-12 um wide; cells 3-12 um long; heterocysts 10-12 um wide by 7.5-10 um long.

CHLOROPHYTA

Table 1. Continued.

Unknown coccoid green alga (Fig. 18): cells spherical, 6-15 um in diameter.

BACILLARIOPHYTA

Achnanthes linearis W. Sm. (Fig. 24): valve 2.5 um wide by 9 um long; striae 24 in 10 um in the center to about 30 in 10 um near the ends.

Achnanthes microcephala (Kütz.) Grunow: valve 3.5 um wide by 18 um long; striae 26-30 in 10 um, becoming finer towards the ends.

Caloneis bacillum (Grun.) Cl. (Fig. 36): valve 3.5-4.5 um wide by 14-24 um long; striae 20-22 in 10 um.

Cyclotella comta (Ehr.) Kütz. (Fig. 22): valve 30 um in diameter; striae 10 in 10 um.

Cymbella turgida (Greg.) Cl.: valve 10 um wide by 33 um long; striae 8-9 in 10 um.

Denticula elegans f. *valida* Pedic. (Fig. 40, 41): valve 4-6 um wide by 24-30 um long; costae 3-4 in 10 um; striae 20 in 10 um.

Diatoma vulgare Bory (Fig. 26): valve 12 um wide by 29 um long; costae 7 in 10 um; striae unresolved.

Hannaea arcus (Ehr.) Patr.: valve 6 um wide; striae 12 in 10 um (identified from broken specimens).

Hantzschia amphioxys (Ehr.) Grunow (Fig. 37-39): valve 6-9 um wide by 29-35 um long; fibulae 6-9 in 10 um; striae 21-25 in 10 um.

Melosira roeseana Rabh. (Fig. 21, 25): frustule 12-19 um in diameter by 16-24 um long; striae 7-9 in 10 um.

Navicula mutica Kütz. (Fig. 27, 28): valve 6-9 um wide by 20-29 um long; striae 18-20 in 10 um.

Navicula mutica var. *cohnii* (Hilse) Grunow (Fig. 29): valve 5-8 um wide by 9-21 um long; striae 18-20 in 10 um.

Table 1. Continued.

Navicula mutica var. undulata (Hilse) Grunow (Fig. 30): valve 6 um wide by 13-19 um long; striae 16 in 10 um.

Navicula tripunctata (O. F. Müll.) Bory (Fig. 32): valve 7 um wide by 31 um long; striae 12-14 in 10 um.

Navicula tripunctata var. schizonemoides (V. H.) Patr. (Fig. 33): valve 7 um wide by 36 um long; striae 11-12 in 10 um.

Navicula species (Fig. 31): valve 3-4 um wide by 15-18 um long; striae 20-22 in 10 um in the center, becoming finer towards the ends.

Pinnularia appendiculata (C. A. Ag.) Cl. (Fig. 35): valve 4.5-6 um wide by 21-32 um long; striae 16-19 in 10 um.

Pinnularia borealis Ehr. (Fig. 34): valve 7-8 um wide by 29-43 um long; striae 4-5 in 10 um.

Pinnularia microstauron (Ehr.) Cl.: valve 11 um wide by 54 um long; striae 11 in 10 um.

Stephanodiscus astraea var. minutula (Kütz.) Grunow (Fig. 23): valve 18 um in diameter; striae 12 in 10 um.

Table 2. Distribution of Soil Non-diatoms in Navajo National Monument.

Species	Betatakin	Keet Seel	Inscription House
<u>Cyanophyta</u>			
Anabaena variabilis	Cu*		c
Chlorogloea fritschii	c		R
Chroococcus rufescens	u		c
C. turgidus	r		cR
Lyngbya limnetica	c		
Microcoleus vaginatus	Cu		Cr
Nostoc commune			c
N. muscorum	C		C
Phormidium tenue			C
Scytonema myochrous	C		Cr
<u>Chlorophyta</u>			
Chlorococcum humicola	cu	ut	r

*C = Crusted Soil; U = Uncrusted Soil; R = Rock; T = Tree; Upper case letters represent common to abundant taxa and lower case letters represent rare to infrequent taxa.

Table 3. Distribution of Soil Diatoms in Navajo National Monument.

Species	Betatakin	Keet Seel	Inscription House
<u>Bacillariophyta</u>			
Achnanthes linearis	cu*		u
A. microcephala	r	u	
Caloneis bacillum	cur		cur
Cyclotella comta	cu		
Cymbella turgida			r
Denticula elegans f. valida	cr	u	cu
Diatoma vulgare	cu		
Hannaea arcus		t	
Hantzschia amphioxys	CUR	UT	CUR
Melosira roeseana	r	u	c
Navicula mutica	cU	u	cur
N. mutica var. cohnii	Cur	U	CUR
N. mutica var. undulata			c
N. tripunctata			u
N. tripunctata var. schizonemoides	r		
Navicula species 1	cur	u	u
Pinnularia appendiculata	ur	u	u
P. borealis	cUr		cur
P. microstauron			r
Stephanodiscus astraea var. minutula			c

*C = Crusted Soil; U = Uncrusted Soil; R = Rock; T = Tree; All soil diatoms were rare to infrequent. Upper case letters represent relative frequency 20% or above and lower case letters represent relative frequency less than 20%.

Fig. 1-6. Collecting sites and cryptogamic crusts in Navajo National Monument, Arizona. 1. Cryptogamic soil crusts in pinyon-juniper slickrock community of Betatakin. 2. Mixed weed and oak communities of Keet Seel. 3. Annual weed community in heavily eroded Nitsin Canyon, Inscription House. 4. Algal crust. 5. Lichen crust. 6. Moss crust.


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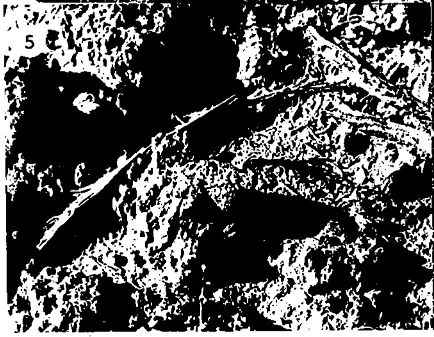
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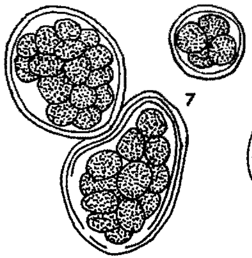
Fig. 7-18. Algae of xeric substrates in Navajo National Monument. All illustrations are drawn to the same scale. 7. *Chroococcus rufescens*. 8. *Chroococcus turgidus*. 9. *Chlorogloea fritschii*. 10. *Lyngbya limnetica*. 11. *Phormidium tenue*. 12. *Anabaena variabilis*. 13, 14. *Nostoc commune* 15. *Nostoc muscorum*. 16, 17. *Scytonema myochrous*. 18. Unknown coccoid green alga.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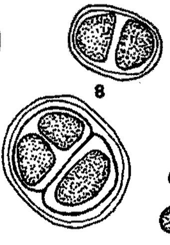
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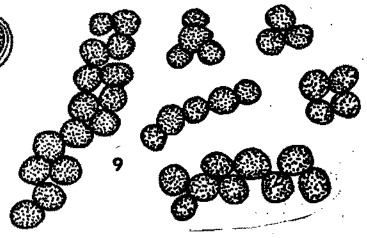
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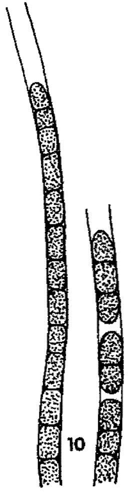
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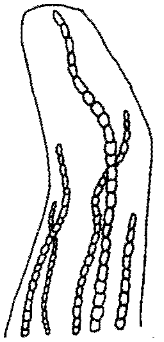
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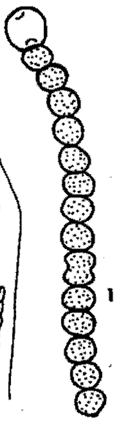
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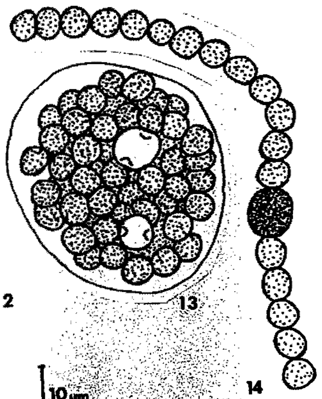
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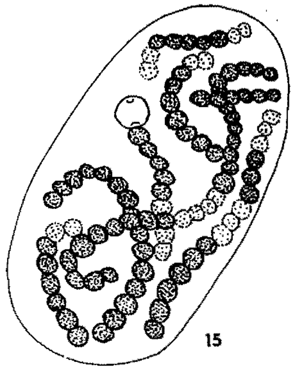
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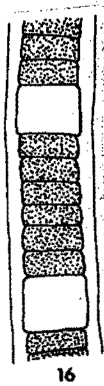
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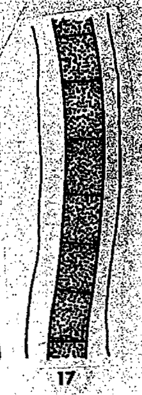
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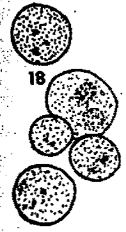
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Fig. 19-41. Algae of xeric substrates in Navajo National Monument. All diatom micrographs are enlarged to the same magnification. 19, 20. *Microcoleus vaginatus*. 21. *Melosira roeseana*. 22. *Cyclotella comta*. 23. *Stephanodiscus astraea* var. *minutula*. 24. *Achnanthes linearis*. 25. *Melosira roeseana*. 26. *Diatoma vulgare*. 27, 28. *Navicula mutica*. 29. *Navicula mutica* var. *cohnii*. 30. *Navicula mutica* var. *undulata*. 31. *Navicula species*. 32. *Navicula tripunctata*. 33. *Navicula tripunctata* var. *schizonemoides*. 34. *Pinnularia borealis*. 35. *Pinnularia appendiculata*. 36. *Caloneis bacillum*. 37-39. *Hantzschia amphioxys*. 40, 41. *Denticula elegans* f. *valida*.

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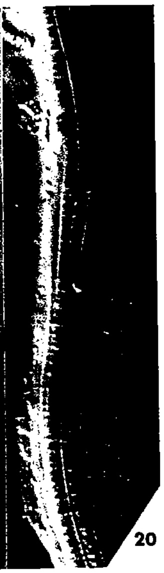

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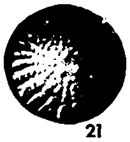

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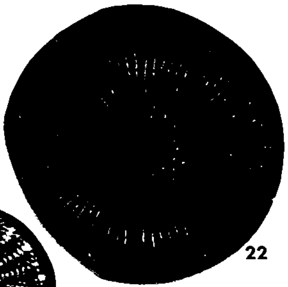

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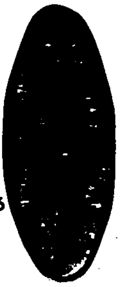

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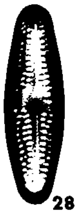

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TERRESTRIAL CHRYSOPHYTE CYSTS FROM NAVAJO NATIONAL MONUMENT, ARIZONA, AS SEEN IN SCANNING ELECTRON MICROSCOPY

by

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INTRODUCTION

One of the prominent characteristics of the class Chrysophyceae is the production of silicious cysts. These cysts, often called statospores, are formed endogenously and have a single small opening which is closed at maturity by a plug. They are mostly spherical to ellipsoidal in shape and may be smooth, sculptured, or variously ornamented with warts, spines or arms. Wall ornamentation is thought to be species specific (Hibberd, 1977). In fact, some species are delimited by their cysts (Wujek, 1976), though many workers feel that knowledge of the vegetative stage is also essential for taxonomy (Bourrelly, 1957).

Ultrastructure work on these cysts has so far been scarce. Details of ultrastructure and stages of formation of statospores were described over 50 years ago by use of the light microscope (Hibberd, 1977). Scanning electron microscopy (SEM) has been used to study cysts of *Mallomonas* (Cronberg, 1973), *Dinobryon* (Sheath *et al*., 1975), *Ochromonas* (Hibberd, 1977) and *Chrysococcus* (Nicholls, 1981). Though cysts are thought to be species specific, most extant chrysophytes are described in their vegetative state. Nygaard (1956) named many fossil species from cysts, giving them form genera classifications. Correlating these fossil cysts with living chrysophytes is an important task which is currently in progess (Nicholls, 1981).

Chrysophytes are most commonly found in cold and unpolluted fresh waters, such as alpine or subarctic-arctic lakes and streams (Pienaar, 1980). They also occur in brackish to marine waters. Terrestrial cryophilic chrysophytes are rare but have been noted in the literature (Hoham, 1980). In a recent review of soil algae, members of Chrysophyceae were not mentioned as being found in any soil type (Starks _et al_., 1981).

The presence of chrysophyte cysts in the desert soils of Utah and northern Arizona was observed in several studies conducted by the author. Cysts were seen in northern Utah at several sites and in soils and drip walls of Navajo National Monument, Arizona. This paper will present the preliminary results of SEM study of these terrestrial chrysophyte cysts.

MATERIALS AND METHODS

A sample from Keet Seel drip wall, Navajo National Monument, Arizona was collected 26 August 1977 and returned under refrigeration to Brigham Young University. The sample was cleaned in boiling nitric acid and the cleaned material mounted in Hyrax for diatom study. A portion of the cleaned material was suspended in distilled water and stored in a small glass vial. Material from this vial was later air-dried on a coverslip affixed to an aluminum SEM stub. The stub was then sputter coated with gold-palladium and examined in a JEOL JSM-35 scanning electron microscope.

RESULTS AND DISCUSSION

Chrysophyte cysts were abundant in the diatom slides from Keet Seel. They appear as heavily silicified spheres. The collar on some species was often visible in the light microscope. Most statospores, however, were smooth with no collar or neck.

At least three species were seen in the SEM study. The variation observed may indicate more than three taxa, but based on preliminary observation of available material, cysts will be divided into three classifications in this paper. Descriptions of the cysts follow, together with a discussion of morphology and taxonomy.

Chrysophyte species 1 (Fig. 1-6).

Cyst spherical, smooth, lacking any ornamentation, 7.9-8.8 um in diameter; shallow depression at mouth of pore 0.9-1.4 um in diameter; pore circular, 0.45-0.58 um in diameter; cyst wall 0.3-0.4 um thick; inner portion of cyst wall smooth.

This statospore is characterized by its simple structure. The cyst is spherical and smooth, though one cyst was seen which had some texture (Fig. 4). The pore was also the simplest of the three different cysts observed, being circular and lacking a collar. One specimen was seen with an occluded pore (Fig. 6). This pore may have been closed by the original plug, which is thought to be partly silicified (Hibberd, 1977) and thus could conceivably weather the acid cleaning. Alternatively, it may have been clogged with detritus.

This taxa is the most abundant chrysophyte in the Keet Seel sample. It is also the most common in the desert soils so far observed. It resembles the cysts of _Uroglena_ _americana_ and _U_. _conradii_ var. _gallica_ (Bourrelly, 1957). However, _Uroglena_ is a relatively large, multicellular colony and it seems unlikely that members of this genus could survive in terrestrial habitats.

This cyst probably could be assigned to a genus in the Ochromonadales, either in Ochromoadaceae or Phaeocystaceae. The Ochromonadaceae encompasses many unicellular species which could conceivably swim in the interstitial water in sandy soils during periods of wetness. Another attractive possibility is that this cyst (as well as the others) belongs in the Phaeocystaceae. This family has members which form palmelloid, mucilage producing unicells or colonies, producing flagellated cells only during zoosporulation (Bourrelly, 1957). Mucilage production is an important adaptation for many soil algae of arid regions. Mucus layers retard desication, and nearly all cyanophytes which inhabit these soils are mucilage producers

(Anderson and Rushforth, 1976; Johansen, 1980). Another reason that this family is attractive is that it may explain why living chrysophytes were not observed. Algae of this group could easily be misidentified as chlorococcalean algae, which were noted as being present in earlier studies.

Chrysophyte species 2 (Fig. 7-10).

Cyst spherical to slightly oval, evenly textured, 6.8-7.3 (8.4) um in diameter; collar present around opening, consisting of raised portion with outer diameter 2.0-2.5 um; neck on collar very short to 1.6 um long; pore circular, 0.74-1.0 um in diameter.

This statospore is characterized by its even texture and raised collar and neck. More than one species may be grouped here. A large (8.4 um in diameter) cyst nearly lacking the collar and neck (Fig. 7) is quite likely different from the other collared specimens observed. One specimen had a very long and pronounced neck (Fig. 10a) with a hooked end (Fig. 10b, c). The specimen in Fig. 9 appears to have had a portion of its neck broken off. The break is about the same width as the extended portion of the neck in Fig. 10. Also, there does not appear to be any breaks on the collar in the Fig. 10 specimen. These evidences support the conclusion that the extended neck with hooked end is characteristic, and not just a fragment left from a larger neck structure.

If this is so it is separate from the specimens in Fig. 7 and 8.

This group of statospores were less common than species 1. The collar can be seen in the light microscope when cysts are mounted in Hyrax. The organism(s) also probably belongs in either Ochromonadaceae or Phaeocystaceae for the reasons given previously under discussion of species 1.

Chrysophyte species 3 (Fig. 11-13).

Cyst spherical, evenly textured, 7.3-8.1 um in diameter; shallow depression at mouth of pore spirally star-shaped, outer reach of points up to 2.3 um in diameter; pore circular, 0.58-0.78 um in diameter.

This statospore is characterized by the even texture (similar to that of an orange) and the star-shaped depression at the opening. The depression structure can be obliterated by erosion (Fig. 12).

This species was also rarer than species 1. Because its texture is similar to that of species 2, the two taxa cannot be differentiated unless the pore is seen by electron microscopy. This cyst likely belongs in Ochromonadaceae or Phaeocystaceae for reasons given previously under discussion of species 1.

ACKNOWLEDGEMENTS

The author wishes to thank Richard Wahrer for assistance on the SEM. Thanks are also due to Dr. Elenor Cox and Dr. Greta Fryxell for advice and encouragement.

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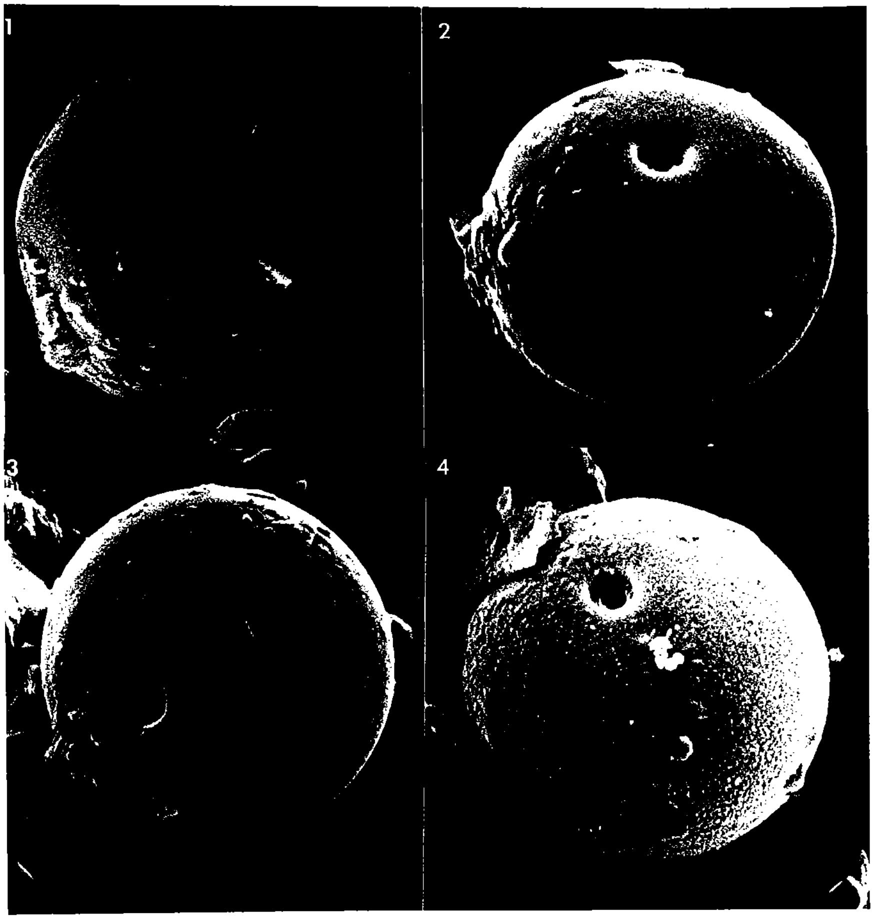
Figures 1-4. Chrysophyte species 1, Note the smooth walls and simple circular depression at the opening. Fig. 1. Cyst 8.0 um in diameter (X8600); Fig. 2. Cyst 8.7 um in diameter (X7800); Fig. 3. Cyst 8.8 um in diameter (X7800); Fig. 4. Cyst 8.1 um in diameter (X8600), note the slight texture present on the wall.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Figures 5-6. Chrysophyte species 1. Fig. 5. Broken cyst with wall thickness 0.3-0.4 um, 7.9 um in diameter (X8600); Fig. 6. Occluded pore 1.1 um in diameter (X18,000).

Figures 7-8. Chrysophyte species 2. Fig. 7. Cyst with reduced collar, 8.4 um in diameter (X8600); Fig. 8. Cyst 7.3 um in diameter (X9400).

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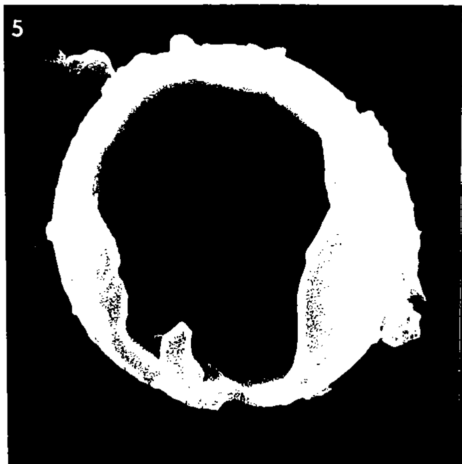

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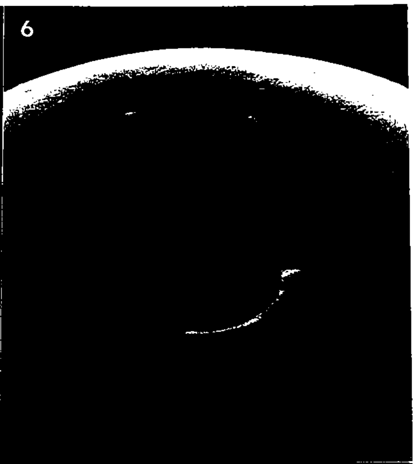

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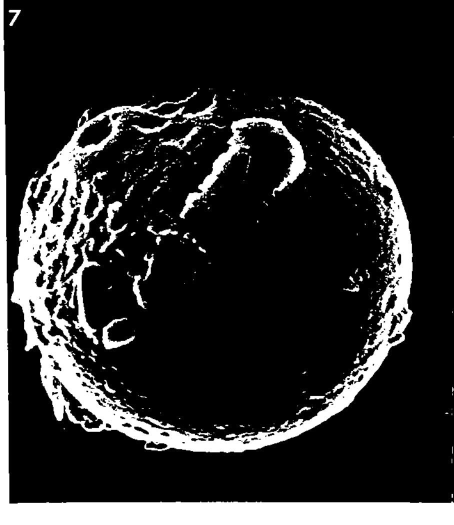

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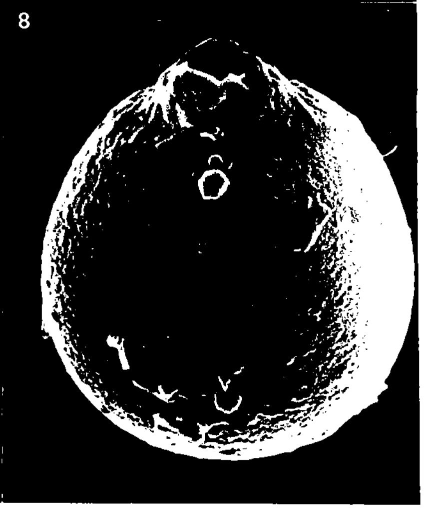
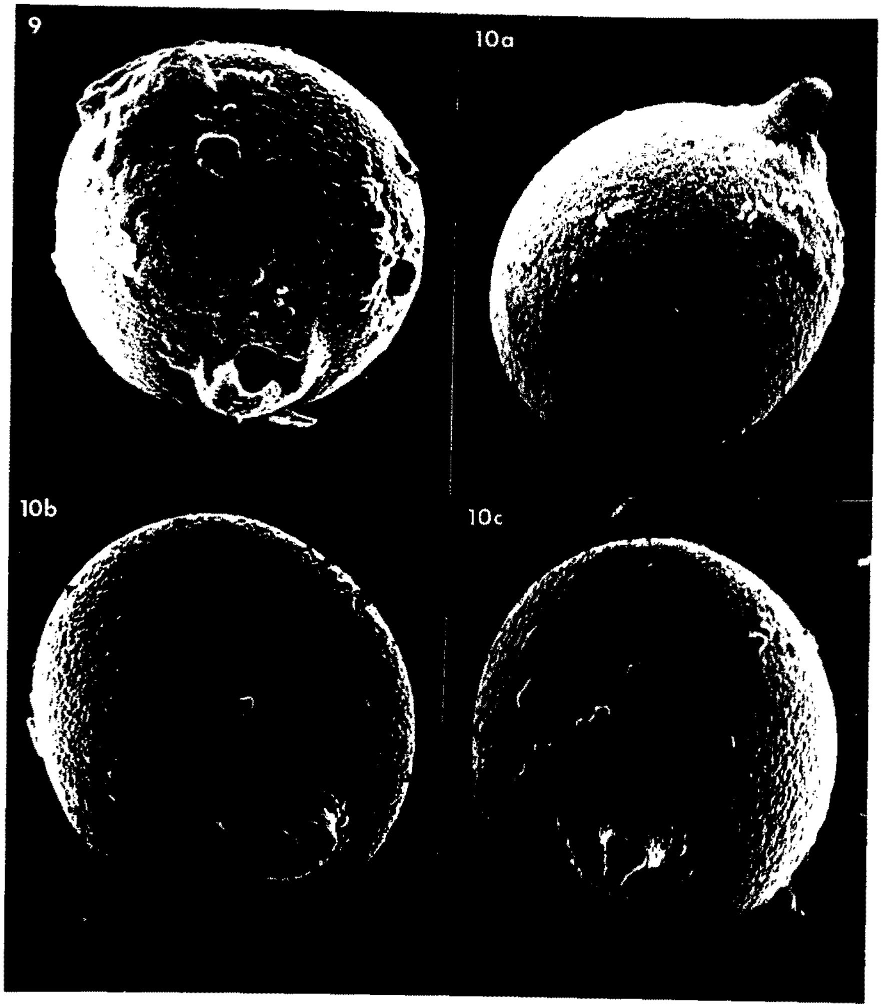


Figures 9-10. Chrysophyte species 2. Fig. 9. Cyst 7.3 um in diameter (X9400), note the break visible on the collar; Fig. 10. Cyst 7.2 um in diameter, 9.5 um long including the neck, a) showing extended neck (X8600), b, c) showing hooked neck and pore (X10,000).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Figures 11-13. Chrysophyte species 3, note the spirally star-shaped depression at the opening. Fig. 11. Cyst 8.0 um in diameter (X8600); Fig. 12. Partially eroded cyst 7.3 um in diameter (X7800); Fig. 13. Cyst 8.1 um in diameter, pore 0.78 um in diameter, a) X7800, b) X18,000.

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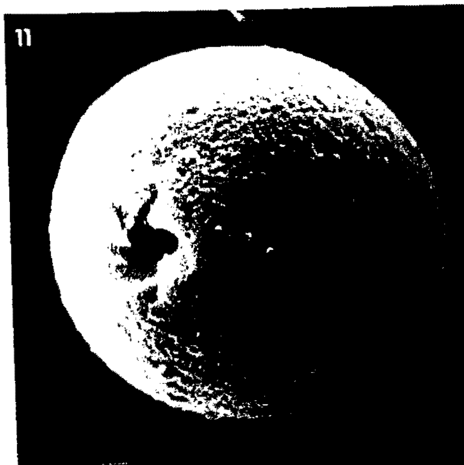

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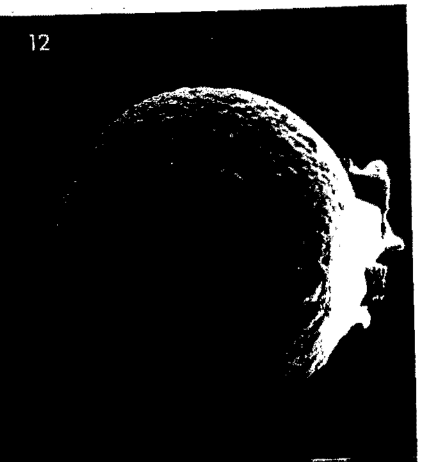

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