High cover, biomass and NDVI of biological soil crusts on Hayes Island, Franz Josef Land, Russia

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INTRODUCTION

Biological soil crusts (BSCs) are "…an intimate association between soil particles and cyanobacteria, algae, microfungi, lichens and bryophytes…which live within, or immediately on top of, the upper millimeters of soil" (Belnap and Lange 2003). They are common in sparsely vegetated landscapes where they help to stabilize and protect soils from erosion. BSCs have been most thoroughly studied in the arid deserts and semi-deserts of the world, but they are also common in sparsely vegetated Arctic landscapes, especially the "polar deserts" (Bliss & Gold 1999) and on dry and barren microhabitats such as frost boils in more continuously vegetated tundra areas (Kade et al. 2005). They fix nitrogen and improve site conditions for higher-plant seedling establishment. They also have a marked effect on the thermal and hydrological properties and reduce the susceptibility of soils to surface needle-ice cryoturbation (Bliss & Gold 1999). In the more arid parts of the High Arctic, such as northern Canada where they have been studied most intently, BSCs are a "common but locally restricted feature", occurring primarily in association with well-irrigated microhabitats beneath persistent snowbanks and in drainages (Bliss & Gold 1999). Our recent investigations at a High Arctic location on Hayes Island in the Franz Josef Land (FJL) archipelago (80.5 ˚N, 57.9˚E), Russia, indicate that BSCs are much more abundant in more oceanic parts of the High Arctic and actually dominate the total biomass of these landscapes.

Observations of the soil crusts were made during a joint U.S.-Russia expedition to Hayes Island, 6-13 Aug 2010, at two sites near the Krenkel hydrometeorological station in the northeast corner of the island (Walker et al. 2012) **(Fig. 1)**. The chief goals of the expedition were to 1) collect ground observation from the northernmost bioclimate subzone (Subzone A = polar desert of Russian authors) to help interpret satellite-derived spectral data that are being used to trace the trends of vegetation change in the Arctic, and 2) to establish the northernmost permafrost and active layer monitoring site in Russia. Here, we report the methods of biomass determination, site characteristics and preliminary assessment of BSC cover, biomass and NDVI at the two study sites.

GENERAL DESCRIPTION OF THE ISLAND AND STUDY SITES

Most of the Hayes Island is covered with sedimentary deposits consisting of unconsolidated sands, derived from alluvial marine sediments at lower elevations and sandstone bedrock and eluvium at higher elevations. The island has a maritime High Arctic climate caused by the moderating influence of the Barents Sea. The mean annual temperature is -12˚C and the range of mean monthly air temperatures is from -27˚C in February to 1˚C in July. Only July has a mean temperature above freezing. The absolute recorded extremes are -42˚C and 12˚C. Cloudiness, summer fog and frequent storms are typical. Mean annual precipitation is 282 mm with the maximum precipitation occurring during November to February.

From the air, most zonal sites on mesic gently sloping hills between drainages appear black, a consequence of the abundant black and dark-colored biological soil crusts that cover the soils **(Fig. 2)**. At the ground level, biological soil crusts cover more than half of the ground surface. Fruticose lichens cover about 5-15%; mosses 2-25%; and vascular plants 3-15%. The most common vascular plant nearly everywhere is the polar poppy, *Papaver dahlianum* ssp. *polare*, which is among a variety of cushion and mat forbs (including *Stellaria edwardsii, S. crassipes, Cochlearia groenlandica, Draba subcapitata, D. micropetala, Saxifraga cernua, S. cespitosa, S. oppositifolia, Cerastium arcticum,* and *C. regelii*). Graminioids (*Phippsia algida, Alopecurus borealis,* and *Poa abbreviata*) cover less than 1%. Common woody tundra plants such as *Dryas* and *Salix* are absent, as are all sedges (*Carex, Eriophorum, Kobresia*).

Site 1 (zonal sandy loam site, Fig. 3a) was located on a gentle west-facing slope at an elevation of 30 m with relatively abundant vascular plant cover. Biological soils crusts covered 48 ± 5% of the surface (measured with to an optical point sampling device described below). Mean active layer depth was 34 cm on 11 Aug. The soil was on average 61% sand and 7% clay. The soil pH was 6.0 to 6.5. Volumetric soil moisture was 38 ± 3%, and soil conditions were saturated with small pools of water on the surface during sampling. Small patterned-ground features formed by seasonal frost cracking (non-sorted polygons 10-15 cm in diameter) were common. The cracks between polygons were protected habitats for small mosses, lichens and forbs **(Fig. 3b)**.

Site 2 (sandy site, Fig. 4 and 2a) was located on a flat sandy marine terrace at about 10 m elevation. The depth of thaw averaged 33 cm on Aug 12. The surface geomorphology was composed of large flat-centered ice-wedge polygons 20-25 m in diameter and small nonsorted polygons 10-20 cm in diameter. Compared to Site 1, Site 2 was better drained and had conspicuously less moss cover and more crust cover. The soil was on average 81% sand and 3% clay. Volumetric soil moisture was 33 ± 3%. Soil pH at this site ranged from 5.2 to 5.6.

Methods

The vegetation, soil, and spectral properties of the land surface were described using methods from in Walker et al. (2012). Only plant cover, biomass and NDVI are reported here. NDVI is the normalized difference vegetation index, a spectral measurement that is indicative of vegetation chlorophyll content or productivity potential. At each site, plant cover was measured along five 50-m transects using a Buckner optical point sampling device, which has a telescope with cross hairs that sights vertically down on the plant canopy (100 points/transect, 500 points total at each site).

Biomass was sampled using a 20 x 50-cm clip-harvest frame in the center of each relevé. In previous expeditions to the Yamal Peninsula, we did not determine the biomass of biological soil crusts because they normally are a small component of he biomass and because of the difficultly of separating the crusts from the substrate. At the Hayes Island, the crusts are extraordinarily abundant and thick, and relatively easy to separate. The vegetation and top 2 cm of soil were removed intact from each 20 x 50 cm biomass plot using a serrated bread knife. The slices of soil with attached vegetation and soil crusts were divided in half and placed intact into two gallon-size Ziploc bags. Replicate samples of crusts were sent to the Komarov Botanical Institute in St. Petersburg for determination of the primary readily identifiable components. The aboveground vascular plants, mosses and lichens were removed by fingers or clipped with scissors from the soil slices and sorted according to plant functional types (mosses, lichens, graminoids, forbs) and live and dead components. Small representative "cookies" containing the BSC biomass were cut from the remaining intact slices of soil with a 5-cm diameter (19.6 cm^2 area) lid from a 300 ml Edge® shaving-lotion can. Five cookies were cut from each 20 x 50-cm plot if possible. Excess mineral was removed from the bottom of each cookie, leaving a thickness of about 0.5 cm. We then quickly agitated the cookie sample in a Waring blender to detach the organic material from the sand. We then added water to separate the heavy sand from the lighter crust material, decanted the water and lighter organic fraction, removed the water by filtering, and then ashed the organic to determine its mass (described more fully in on-line Appendix S6 of Walker et al., 2012). Extrapolation to the area of the biomass plots was determined by multiplying the mean biomass on each cookie times the number of cookies per m^2.

Ground measurements of NDVI were obtained using a hand-held PS-2 portable spectrometer manufactured by Analytical Spectral Devices, Inc., Boulder CO. Measurements were made 100 points along each transect. Because of instrumental problems and very wet conditions, only three transects were sampled at Site 1 and two at Site 2. Five biomass plots were sampled and Site 1 and four at Site 2.

Results and discussion

***Composition of the BSCs*:**

The primary identified lichen components of the BSCs were *Protopannaria pezizoides, Lecidea ramulosa, Baeomyces rufus, Lepraria gelida, Ochrolechia inaequatula, Ochrolechia frigida,* and *Pertusaria* cf. *coriacea*. Common small bryophytes included in the crusts were *Polytrichastrum alpinum, Orthothecium chryseon, Bryum rutilans* and *Anthelia juratzkana*. Other unidentified components included lichen prothalli and algal crusts **(Table 1)**.

***Cover of BSCs*:**

Measured cover of BSCs at Site 1 (sandy loam zonal site) was 45% **(Table 2)**. Of these 38% were black crusts, 4% white crusts, and 3% gray crusts. Cover of other plant functional types on Site 1 included 2% graminoids, 8% forbs, 17% bryophytes, 12% fruticose and foliose lichen, 0.4% litter and algae, and 17% bare soil and stones. Measured cover of BSCs at Site 2 (sandy site) was 53%: 44% were black crusts, 1% white crusts, and 8% gray crusts. Cover of other cover components on Site 2 included 1% graminoids, 8% forbs, 9% bryophytes, 20% fruticose and foliose lichens, 1% litter and algae, and 16% bare soil.

***NDVI*:**

Mean NDVI was 0.4 ± 0.01 at Site 1 and 0.57 ± 0.05 at Site 2 **(Table 2)**. These values are extraordinarily high for such an extreme northerly site. The comparable mean value at the Isachsen zonal site along the NAAT was 0.27. These values also exceeded those of all subzone B and C sites along the NAAT (0.27 to 0.36) and were comparable to the subzone D values (0.39 to 0.48). The BSCs clearly contribute a major component to the NDVI values as evidenced by the much higher NDVI values at Site 2 which had higher BSC biomass but much lower biomass of of non-BSC components. However, the wet conditions at Krenkel undoubtedly also contributed to the high hand-held NDVI readings at Krenkel. In a study of desert soil crusts (Karnieli et al. 2001, cited in Belanap and Lange 2003) reported an NDVI of 0.32 for wet crusts following a rain event, triple that of dry desert soil crusts at the same site.

***Biomass of BSCs*:**

BSC biomass for Site 1 was estimated at 95 ± 29 g m^{-2}. This was about 31% of the total aboveground biomass. At the sandy Site 2, the BSC biomass was 218 ± 40 g m^{-2}, about 83% of the total aboveground biomass. If the BSCs are included in the calculations of total aboveground biomass, the total biomass values of the two sites are comparable, 305 g m^{-2} for Site 1 and 263 g m^{-2} for Site 2. These biomass values are considerably higher than values recorded at the northernmost (bioclimate subzone A) site at Isachsen along the North America Arctic Transect (NAAT, Walker et al. 2012), where total biomass values averaged 171 g m^{-2}, but BSCs were not included in that total.

Conclusions

This first study of BSCs from subzone A adds to earlier studies of BSCs in the High Arctic (Bliss and Gold 1999, Yoshitake et al. 2010). Black BSCs are a dominant portion of the total biological cover and biomass on zonal and nonzonal sites on Hayes Island. The BSCs also contribute to the relatively high NDVI of this extreme maritime site. The differences in BSC cover, biomass and NDVI between the more continental and the more maritime portions of the High Arctic need to be considered in panarctic evaluations of trends in biomass and NDVI along the Arctic climate gradient. More detailed studies are needed to assess BSC's total biological composition and effects on soil temperature, active layer depth and permafrost conditions at these extreme sites.

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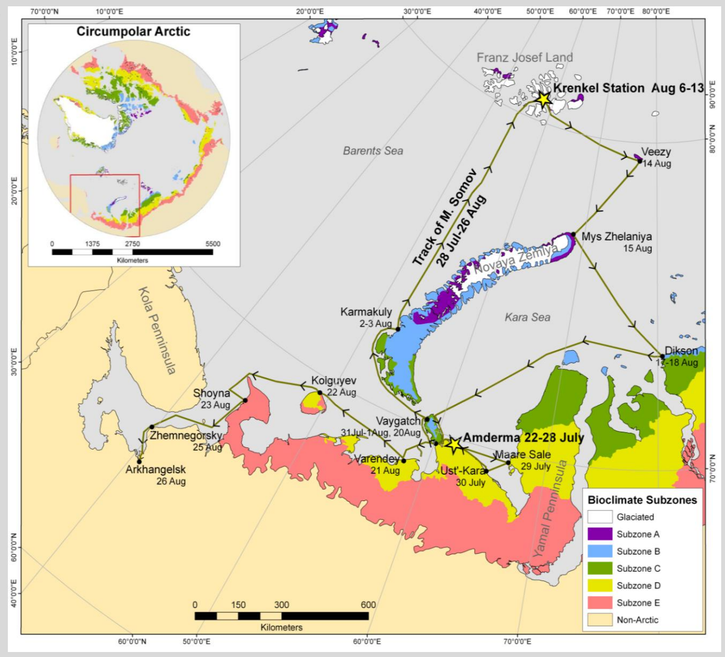

Fig. 1 a) Location of the Krenkel Station, Hayes Island, Franz Josef Land, Russia with reference to the bioclimate zonation of western Arctic Russia and the route of the 2010 Joint Russia-U.S. expedition. Subzones are from the Circumpolar Arctic Vegetation Map (Walker et al. 2005). **b) Landsat image of Hayes Island.** Krenkel Station and the expedition camp are in the upper right corner of the map. Colored lines show the routes of the helicopter- and ground-reconnaissance transects. Sites 1 and 2 are sites of permafrost boreholes and measurements of vegetation, soils, spectral properties, and active-layer thickness. The "Coral Reef" is a site of lush lichen-rich vegetation that was not sampled, but shown in **Fig. 8**. Note the "Hydrogeographers" ice cap, stream channels filled with snow and the numerous linear snow beds that form on the leeward side of volcanic dikes. Inset shows location within the Franz Josef Land archipelago. (Base map: Pan sharpened false-color infrared composite image (bands, 4, 3, 2), Landsat ETM+ Path 202, Row 101, July 3, 2001. Maps by Shalane Frost).

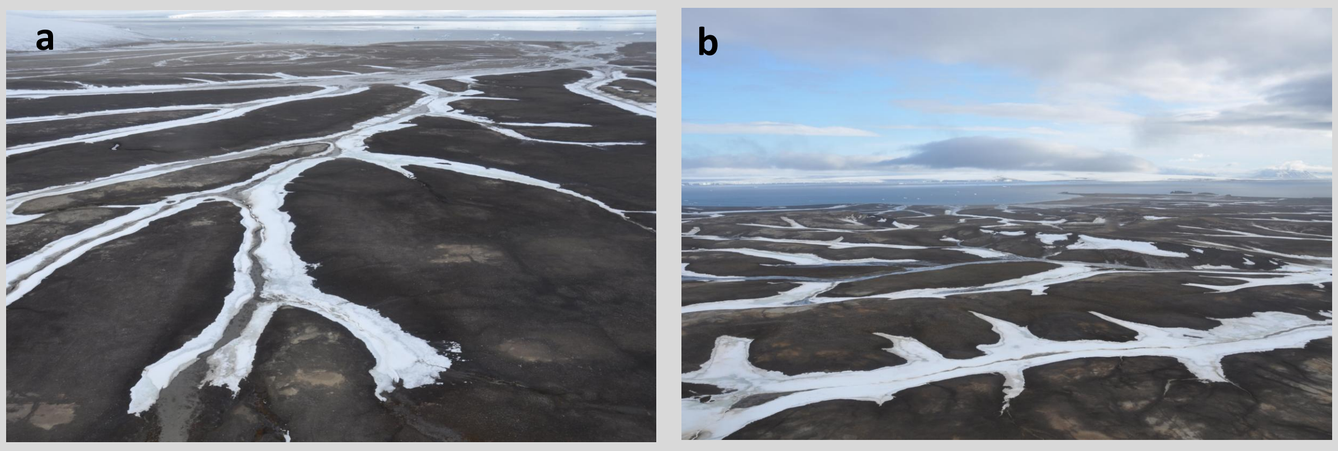

Fig. 2. Dark-colored surfaces caused by the abundant biological soil crusts (see Fig. 1b) a) Sandy alluvial-marine terraces near Site 2 (location on Fig. 1b). View is toward the northern coast of the Hayes Island, the island's small ice cap (upper left) and glacier-covered Salisbury Island in the distance. Deep snow still lies in the stream drainages. **b) Gentle rolling topography typical of much of interior part of Hayes Island.** Most of the island is covered by sandy soils derived from unconsolidated sandstones, which outcrop along stream channels and hill tops. View is toward the south side of the island and Hall Island in the distance. Photos taken by D.A. Walker during helicopter reconnaissance of the island, 6 Aug 2010.

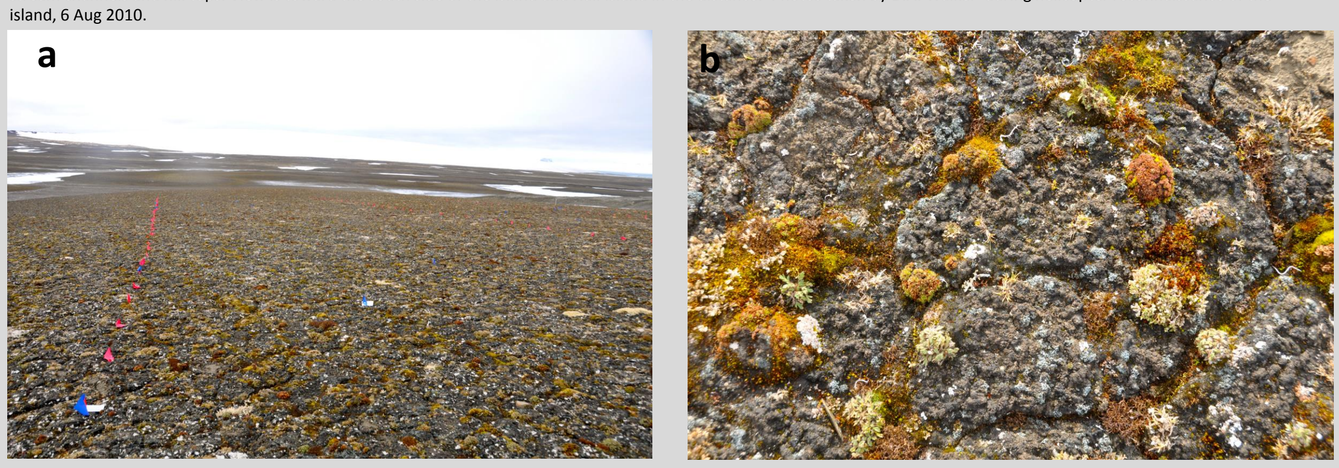

Fig. 3. Site 1. (sandy loam site). The site is on a gentle west-facing slope at an elevation of 30 m, with relatively abundant plant cover. Mean active layer thickness was 34 cm on 11 Aug. **a) Landscape view.** The red flags mark one of the transects for measuring plant cover, NDVI, and LAI. The blue flags mark the corners and center (location of the biomass harvest) of one of he 5 x 5 m relevés. **b) Close up view of soil surface covered by biological soil crusts.** Most of the soil surface is covered by dark-colored crusts. Larger vascular plants, mosses and fruticose lichens are concentrated in the cracks between small nonsorted polygons. Dominant vascular plants are *Papaver polare, Stellaria edwardsii, S. crassipes, Draba micropetala, Saxifraga cespitosa,* and *Phippsia algida.* Mosses include *Cirriphyllum cirrosum, Orthothecium chryseum, Polytrichum alpinum,* and *Ditrichum flexicaule*. Non-crustose lichens include *Cetrariella delisei, Cetraria islandica, Thamnolia subuliformis, Flavocetraria cucullata, Stereocaulon alpinum,* and *S. rivulorum.* Photos by D.A. Walker.

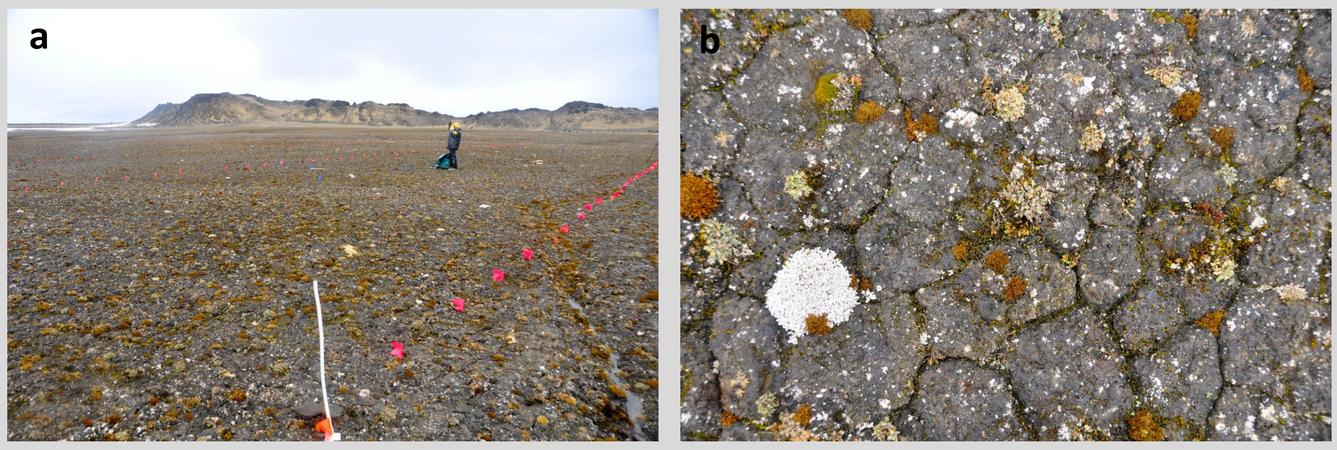

Fig. 4. Site 2. (sandy site). a) Landscape view. Dominant vascular plant species are *Papaver dahlianum* ssp. *polare, Stellaria edwardsii, S. crassipes,* and *Phippsia algida.* The red flags mark one of the transects for measuring plant cover, NDVI, and LAI. The blue flags mark the corners and center (location of the biomass harvest) of one of he 5 x 5 m relevés. **b) Close up view of soil surface with small nonsorted polygons and dark biological soil crusts.** The large white lichen is *Stereocaulon alpinum.* Note the small cushion forms of the vascular plants, lichens and mosses. Photos by D.A. Walker.

Table 1. Partial composition of the biological soil crusts.

Dominant crustose lichen:
Protopannaria pezizoides
Lecidea ramulosa
Baeomyces rufus
Lepraria gelida
Ochrolechia inaequatula
Ochrolechia frigida
Pertusaria cf. *coriacea*

Common small bryophytes included in the crusts:
Polytrichastrum alpinum
Orthothecium chryseon
Bryum rutilans
Anthelia juratzkana

Other unidentified components included lichen prothalli and algal crusts.

Table 2. Summary of cover (%), Leaf area index (LAI) and normalized different vegetation index (NDVI) for Sites 1 and 2, broken down by plant functional type. Values represent means for five 50-m point sample transects (100 points per transect, 500 points total. Cover measurements were determined using an Buckner optical sampling device. LAI was determined with a LiCOR 2000 LAI-2000 Plant Canopy Analyzer, and NDVI was measured with an Analytical Spectral Devices, Inc. PS-2 spectroradiometer.

							Biological soil crusts				
Site	Graminoid	Forb	Bryophyte	Lichen	Litter & alga	Bare soil & rock	black crust	white crust	gray crust	Percent of total cover	NDVI
1	1.6	8.4	16.7	12.2	0.4	17.4	37.6	4.0	3.2	44.8	0.398±0.014
2	0.8	8.0	9.0	19.5	1.0	15.6	43.6	1.4	8.3	53.3	0.569±0.047

Table 3. Summary of biomass (g m^-2), for Sites 1 and 2, broken down by plant functional type. Values represent means of five 20 x 50-cm biomass harvest plots.

Site	Graminoid		Forb		Bryophyte		Lichen	Soil Crust	Total	Percent soil crust of total
	Live	Dead	Live	Dead	Live	Dead				
1	0.2	0.4	5.9	41.4	43.8	84.3	34.1	95.0	305.30	0.31
2	0.2	0.8	3.7	11.2	11.2	9.6	8.5	218.0	263.14	0.83

Fig. 5. The "Coral Reef". Some areas are not covered in biological soil crusts. Spectacular fruticose-lichen communities develop on the well drained gentle south-facing slopes. They are able to thrive because of the present-day lack of reindeer on the island. The brown lichens are mainly *Cetrariella delisei* and *Cetraria islandica.* The white lichens are *Stereocaulon alpinum* and *S. rivulorum.* The yellow lichens are mainly *Flavocetraria cuculllata.* Photos by D.A. Walker.

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