Biological Soil Crust of The Palos Verdes Peninsula

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Biological soil crusts (BSC) are critical components of semi-arid and arid landscapes worldwide (Figure 1). In Southern California, studies examining BSC are limited. This study provides a preliminary assessment of the distribution, structure, and species composition of BSC in a coastal region of Southern California known as the Palos Verdes Peninsula (PVP). Biological soil crust is a micro-community of highly specialized organisms (cyanobacteria, fungi, diatoms, algae, lichens, bryophytes, etc.) that interact with one another and with surface soil particles to transform the upper portions of the soil matrix into a living cover (Belnap et al. 2001a; Belnap et al. 2001b). Biological soil crusts provide a suite of ecosystem services (nitrogen fixation, soil formation, nutrient traps, enhanced water absorption and retention, nurseries for other organisms, reduced soil erosion and loss, and a refuge for micro-biodiversity) and are vital to the maintenance and health of many soils worldwide.

Figure 1. BSC in Nevada, USA. 1. Overall view of Nevada BSC. 2. Close-up of Nevada BSC.

On the PVP, BSC was found to be a major component of its wildland soils. The cool, moist maritime climate and diverse topography of the PVP provide excellent conditions for BSC and the organisms that comprise it (Fig. 5, Fig. 6). Intact remnant coastal sage scrub (CSS) on the PVP contained the most BSC and was primarily found in the spaces between shrubs (Fig. 2, Fig. 3, Fig. 4). Canyon walls and coastal bluffs also contain BSC (Fig. 8, Fig. 9). Biological soil crust was found mainly on clay-rich soils; however, sandy sites such as Malaga Dunes, Linden

Figure 2. BSC on the soil surface within the Forrestal Nature Reserve. Additional photos show a close-up of BSC within a 5 cm x 5 cm quadrat, followed by a segment of that at 40x (penny for scale). Photos by the author.


Figure 3. Dormant BSC on soil between shrubs on the PVP. Photos by author.


Figure 4. Up close of BSC on the soil surface of the Forrestal Nature Reserve

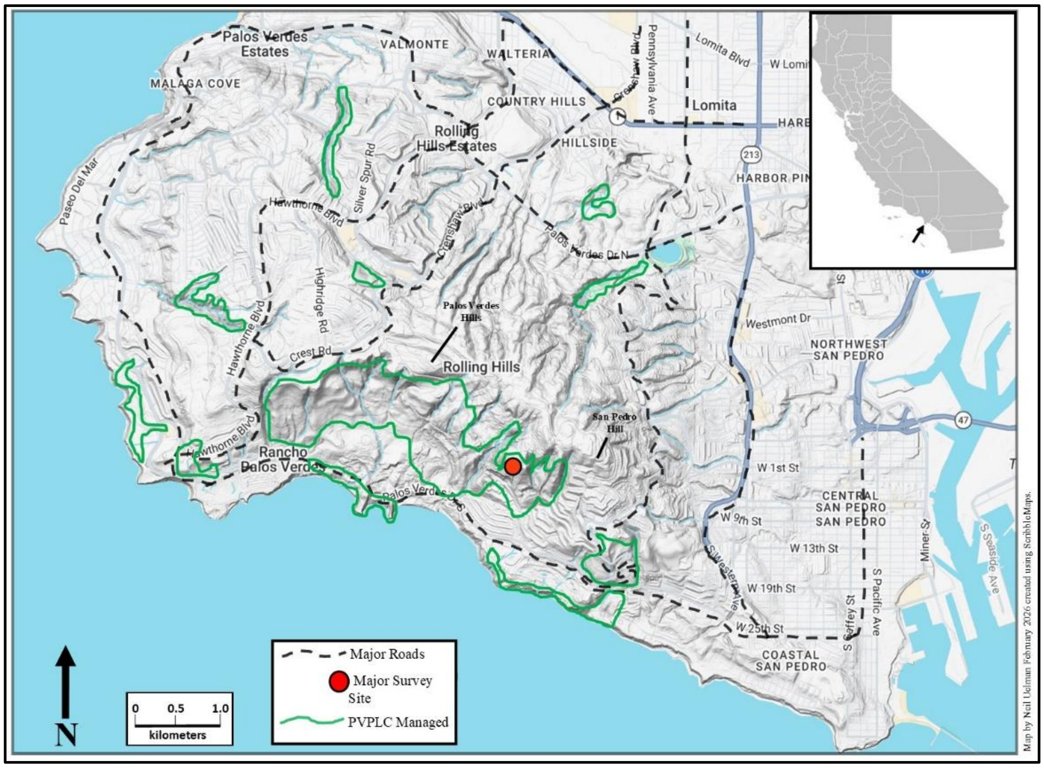

Figure 5. Location of the Palos Verdes Peninsula, California, and relationship to surrounding features. Map by author.

Figure 6. Palos Verdes Peninsula (San Pedro Channel facing side). Photo by the author.

H. Chandler Nature Preserve, and the Defense Fuel Supply Point also contained BSC (Fig. 17, Fig. 18, Fig. 19). The species composition was slightly different on sandy soils when compared to clay-rich soils. Late successional rugose BSC was found in remnant undisturbed habitat, and early successional BSC was found in areas that had experienced a disturbance (spur trails, landslides, roadcuts, etc.). The late successional BSC, when dry, has a roughened and dark gray appearance (Fig. 7, Fig. 10), while the early successional BSC, when dry, has a fuzzy and reddish orange color (Fig. 13). Lichens and mosses were the two types of organisms that dominated the outer surface of late successional BSC on the PVP (Fig. 12, Fig. 20, Fig. 23). In total, sixteen species of mosses were found to be present in the BSC, with ten of those species appearing to be restricted to the BSC (Table 1, Fig. 20). One of those ten moss species, *Tortula californica* E.B. Bartram, is a California Native Plant Society rare plant with a rank of 1B.2 (Fig. 20). Four species of liverworts were found in the BSC, and those liverworts were only encountered in sandy soil BSC (Table 1, Fig. 21). Lichens were present in BSC throughout the PVP (Fig. 12, Fig. 23). In total, 4 genera of lichens were found to be present (Table 1). Lichens were only found in the late-successional rugose BSC, and jelly lichens, as well as squamulose lichens, were the most frequently encountered. The third most common organism found in the BSC was cyanobacteria. Only 2 cyanobacterial genera were found, both of which were very common (Table 1, Fig. 25, Fig. 26) and are the foundational species of BSC. Cyanobacteria were observed in both early and late successional BSC. Terricolous algae were also observed in the BSC and were much more common on sandy soil BSC (Table 1, Fig. 24). Invertebrates were also encountered in the BSC on the PVP (Fig. 22).

Figure 7. Ground view of BSC in the hydrated state, showing a roughened appearance (Forrestal Nature Reserve). Photo by author.

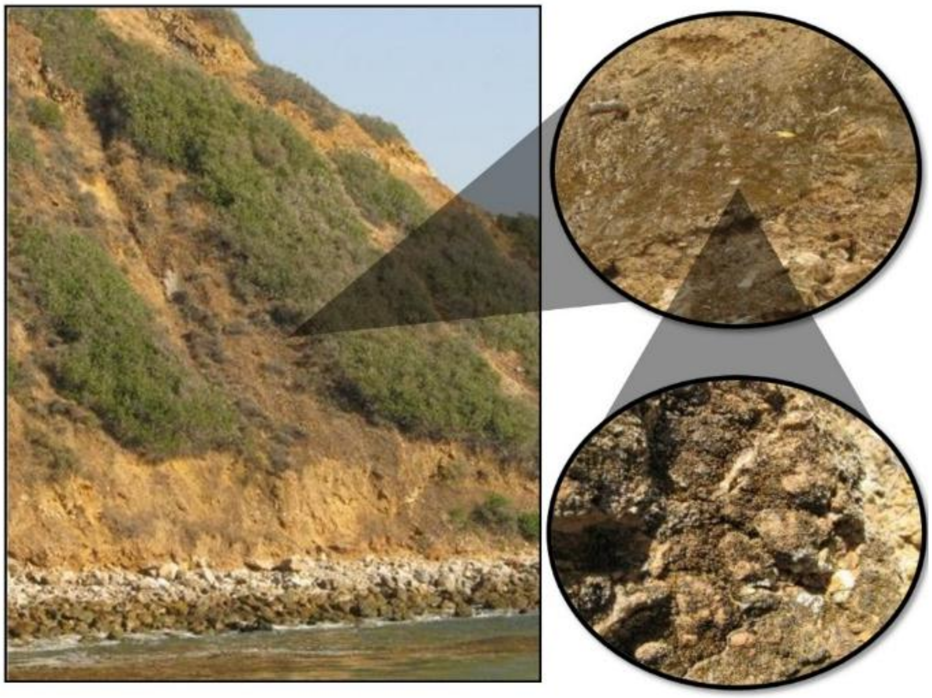

Figure 8. BSC on coastal bluffs. Photos by author.

Figure 9. BSC on canyon walls. Photos by author.

The surface of the late successional BSC was predominantly composed of cyanobacteria, mosses, and lichens, which matches observations of late successional BSC from Orange and Riverside Counties (Henandez & Sandquist 2010; Hernandez & Knudsen 2011). In the dormant state, the late-successional rugose BSC gave the soil surface a blackish gray color (Fig. 3, Fig. 4, Fig. 10). In addition, it had a fuzzy, roughened appearance due to slight changes in soil surface

Figure 10. Overall view of late successional BSC on the soil surface seen from above (1,4,5,6) and ground view (2,3) within the Forrestal Nature Reserve. Photos by the author.

topography and species composition. The overall fuzzy appearance is largely due to mosses on the BSC surface. Many mosses in the BSC possess leaf awns or awn-like extensions, and they produce abundant sporophytes, giving the surface a fuzzy appearance (Fig. 7). The thalli of various lichens in the late-successional BSC also contributed to its roughened appearance. The blackish-gray color of the dried late-successional BSC is a result of the desiccated state of cyanobacteria, cyanolichens, and mosses present within it. When the late successional BSC receives precipitation and becomes hydrated, the overall color changes from blackish gray to a greenish-black color (Fig. 11). The green color comes primarily from the rehydration of the mosses (*Bryum argenteum* (Hedw.), *Vinealobryum brachyphyllum* (Sull ex. Whipple) R.H. Zander, *Tortula brevipes* (Lesq.) M. Howe, etc.), phycolichens (*Placidium sp*. A. Massal, *Thalloidima spp*. A. Massal), and the blackish color from the cyanolichens (*Enchylium sp*. Ach. Gray) and cyanobacteria (*Microcoleus sp*. Desmazieres ex Gomont, *Nostoc sp*. Vaucher ex Bornet & Flahault).

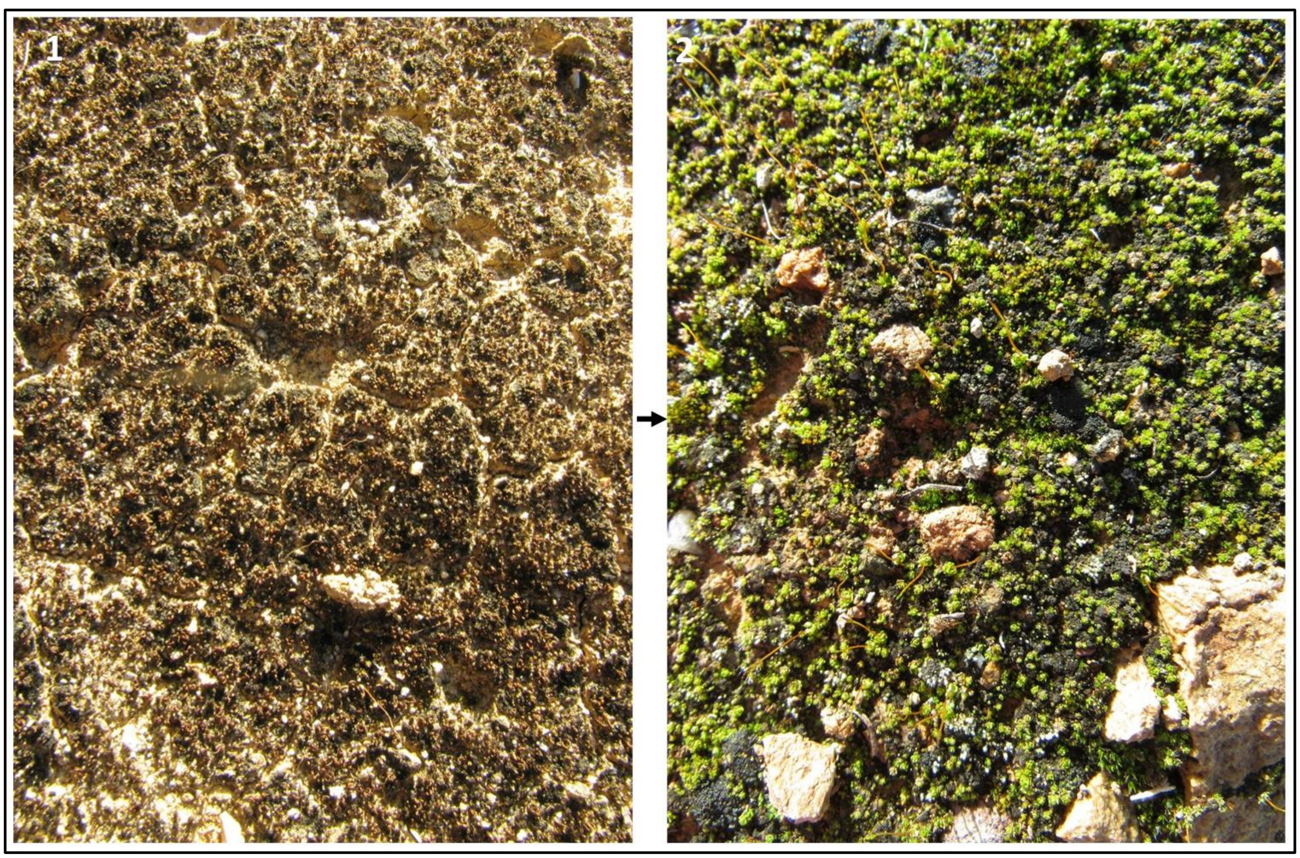

Figure 11. PVP BSC from the desiccated state to the hydrated state. Photos by the author.

Figure 12. Up close of BSC (40x) showing mosses (white arrow) and a cyanolichen (red arrow). Photo by the author.

Numerous moss species and lichen genera were observed, as well as two cyanobacterial genera (Table 1). Late-successional rugose BSC on the PVP appears to be acting as a refugium for these minute soil-surface dwellers.

Early successional BSC was also observed on the PVP. It occurred in recently disturbed areas (Fig. 13). Disturbance causes fragmentation of the BSC (Fig. 14), eventually leading to its disappearance from sites. Where disturbance had been removed, the BSC began to reform as early successional BSC (Fig. 15). The overall form of the early successional BSC is flat (Belnap et al. 2001b) and has a fuzzy appearance. The early successional stage of BSC on the PVP consisted primarily of cyanobacteria (*Microcoleus sp*.) and only a few ruderal moss species (*Vinealobryum vineale* R.H. Zander (R.H. Zander), *Bryum argenteum*, and *Funaria hygrometrica* Hedw. These moss species give the BSC its fuzzy appearance and color. The BSC of this early successional stage, when desiccated, gave the soil surface a reddish tan color (Fig. 13). When hydrated, this early successional BSC is mostly light green and lacks the blackish color seen in the late successional BSC. This is due to the absence of cyanolichens and additional cyanobacteria, such as *Nostoc*, which are not typical of early successional BSC.

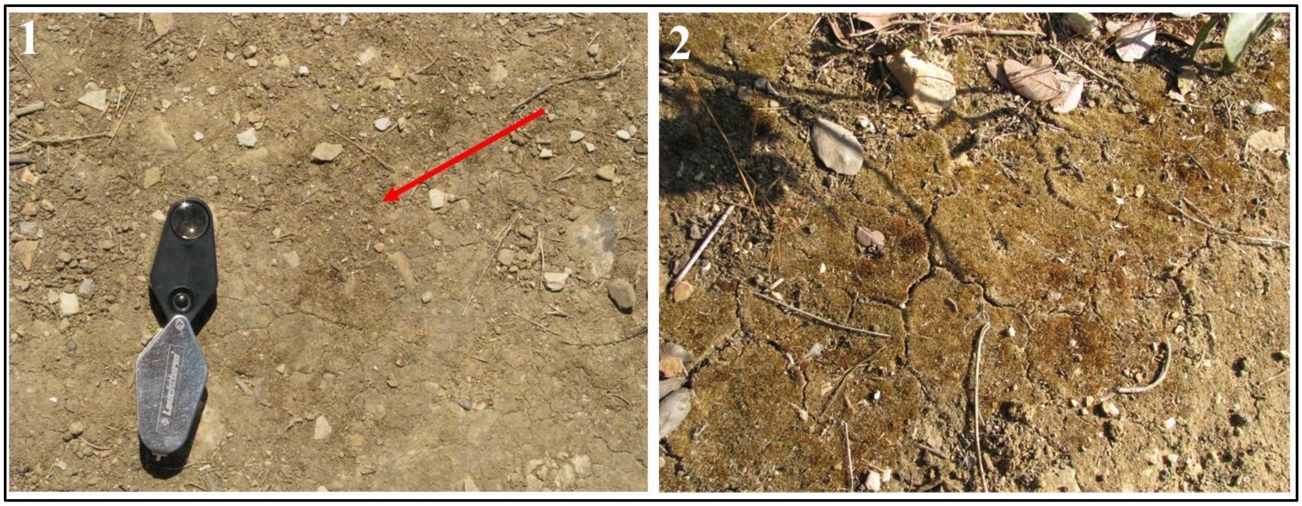

Figure 13. 1. Early successional BSC desiccated (red arrow) forming on the PVP; 2. Early successional BSC fully formed and desiccated on the PVP. Photos by the author.

Figure 14. Spur trail showing disturbance and fragmentation of the BSC. Photos by the author.

Figure 15. Early successional BSC forming (black arrow) on the soil of an old spur trail after disturbance has been removed. Photos by the author.

BSC was surveyed throughout the PVP. In total, BSC was found in forty locations throughout the PVP. BSC was commonly encountered in thin-soil habitats, consistent with observations of BSC elsewhere in southern California (Magney and Knudsen 2006). These thin soil habitats were found along coastal bluffs, canyon walls, historical road cuts, and in many nature reserves (Three Sisters, Portuguese Bend, Forrestal, George F Canyon, and Alta Vicente). Portions of the coastal bluffs contained large coverings of BSC, especially on more north-facing bluffs (Fig. 8). The BSC of these coastal bluffs gives the soil surface a brownish-black and gray color in the summer and a greenish-black color in the wet season. The coastal bluffs of Bluff Cove, Christmas Cove, Abalone Cove, Sacred Cove, Lunada Bay, and Malaga Cove were found to contain coverings of BSC. Surveys conducted in off-trail areas of remnant intact CSS, throughout the PVP Nature Preserve, often found BSC on the soil surface between shrubs. Canyon walls of riparian areas throughout the PVP also contained BSC (Fig. 9). Lunada Canyon contained extensive BSC coverage along portions of its walls. Biological soil crust was also observed on the sandy soils of Linden H. Chandler Nature Preserve, Malaga Dunes, and the Defense Fuel Support Point in San Pedro (Fig. 16, Fig. 17, Fig. 18). Overall, BSC was found throughout the PVP in coastal bluff scrub, CSS, canyon riparian, and sandy soil sites. However, in these areas it was distributed sporadically. The sporadic nature of the PVP BSC is consistent with studies of BSC in CSS in Orange County (Hernandez and Sandquist 2011; Hernandez and

Knudsen 2012). The distribution of BSC on the PVP has been greatly reduced due to habitat loss, invasion by non-native plants, altered fire regimes, and extensive soil surface disturbance from historical and present land uses (e.g., agriculture, cattle grazing, spur trails, etc.).

Figure 16. BSC hydrated on sandy soil at the Linden H. Chandler Preserve.

Figure 17. Close-up of hydrated BSC on sandy soil at the Linden H. Chandler Preserve.

Figure 18. Desiccated BSC on sandy soil at the Defense Fuel Support Point in San Pedro. Photo by author.

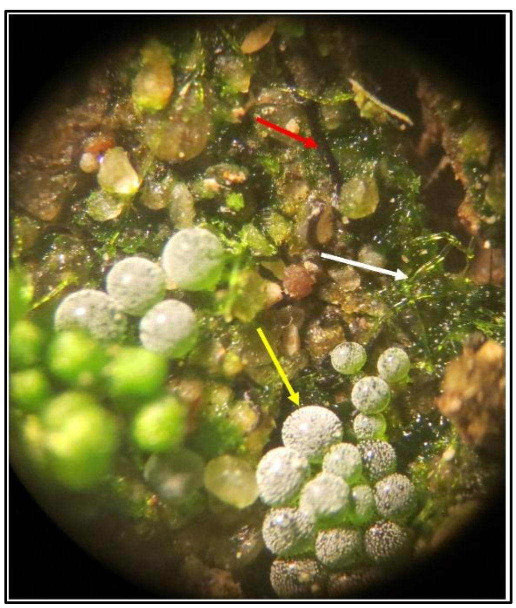

Figure 19. Organisms encountered in sandy soil BSC on the PVP: filamentous cyanobacteria (red arrow), terrestrial alga (white arrow - possibly the genus *Vaucheria*), terrestrial alga (yellow arrow – possibly the genus *Botrydium*). Photo by author.

Biological soil crusts dominated by bryophytes are a common component of semi-arid wildlands, especially along the coast, where marine fog is abundant (Rosentreter and Belnap 2001). Mosses were found to be a major component of BSC throughout the PVP (Fig. 20). A list of species encountered in the BSC is provided in Table 1. All the mosses encountered in the BSC on the PVP were acrocarpous mosses. Of the sixteen moss species found within the BSC, ten appeared to be restricted to it. The two dominant moss families encountered in the BSC were Pottiaceae and Bryaceae. The most common species encountered in the BSC on the PVP were *Vinealobryum vineale, Vinealobryum brachyphyllum, Trichostomopsis australasiae* Hook & Grev. (R.H. Zander)*, Tortula brevipes* (Lesq.) M. Howe*, Aloina aloides* var*. ambigua* (Bruch & Schimp) E.J. Craig, and *Bryum argenteum*. Four species of liverworts were observed in the BSC on the PVP (Fig. 21). However, the liverworts were only encountered in late successional BSC on more sandy soils, such as soils of the Linden H. Chandler Preserve, Malaga Dunes, and the Defense Fuel Support Point in San Pedro. No hornworts were observed in the BSC on the PVP.

Southern California possesses a rich lichen flora from its coastline to its deserts (Hasse 1913; Nash et al. 2002; Knudsen 2005; Magney and Knudsen 2006; Knudsen et al. 2013; Tucker 2012). Maritime habitats of California, especially along southern California's coastline, host a high lichen diversity due to the strong influence of Pacific Ocean fog (Magney and Knudsen 2006; Sharnoff 2014). Lichens were found to be abundant components of late-successional BSC at the FNR study sites and throughout the PVP. Lichen genera observed in the BSC of the study sites are listed in Table 1. Cyanolichens appeared to be the most abundant type of lichen in the BSC of the FNR and throughout the PVP. These cyanolichens (hydrated & desiccated) contributed to the dark color observed in late-successional BSC on the PVP. They also imparted a gelatinous feel to the BSC surface when hydrated. The most encountered lichen genera were *Endocarpon* and *Enchylium* (Fig. 23), representing the lichen families Verrucariaceae and Collemataceae. The genus *Thalloidima spp*. (Fig. 23) was also observed, but infrequently.

Cyanobacteria are the backbone and a crucial component in the formation of BSC (Belnap 1992; Belnap 1994; Belnap 2003). Cyanobacteria are often pioneer species that, through biological activities, stabilize the soil surface, thereby allowing colonization by other BSC-associated organisms (Belnap 1994; Li et al. 2001; Belnap 2003). Two types of cyanobacteria were encountered in the BSC on the PVP. They were only identified to the genus level and are listed in Table 1. The most common cyanobacteria was a filamentous species that appeared to belong to the genus *Microcoleus*. *Microcoleus* is known for creating gelatinous sheaths on and within the first few millimeters of the soil surface, which creates the very foundation on which BSC can form (Belnap 2001c). The sheaths of this filamentous cyanobacterium appear on the soil surface following rain events (personal observation, Fig. 26). *Microcoleus* was observed in early and late successional BSC. The second genus encountered was *Nostoc*. *Nostoc* was found only in late-successional BSC and was very common. It would form mucilaginous spheres (< 2 mm) on the surface of the late successional BSC following rain (Fig. 25). It was observed in the study sites of the FNR and throughout the PVP.

Figure 20. Mosses seen in PVP BSC (hydrated except 5 & 12). 1. *Aloina bifrons*; 2. *Aloina aloides* var. *ambigua*; 3. *Trichostomopsis australasiae*; 4. *Vinealobryum brachyphyllus*; 5. *Tortula inermis*; 6. *Tortula brevipes*; 7. *Vinealobryum vineale*; 8. *Crossidium seriatum*; 9. *Tortula californica*; 10. *Funaria hygrometrica*; 11. *Bryum argenteum*; 12. *Bryum lanatum*. Photos by the author.

Figure 21. Liverworts seen in PVP BSC (hydrated). 1. *Riccia nigrella*; 2. *Targioina hypophylla*; 3. *Sphaerocarpos texanus*; 4. *Riccia lamellosa*. Photos by the author.

Figure 22. Arthropods seen in PVP BSC. 1. Mite; 2. Pseudoscorpion; 3. Springtail. Photos by the author.

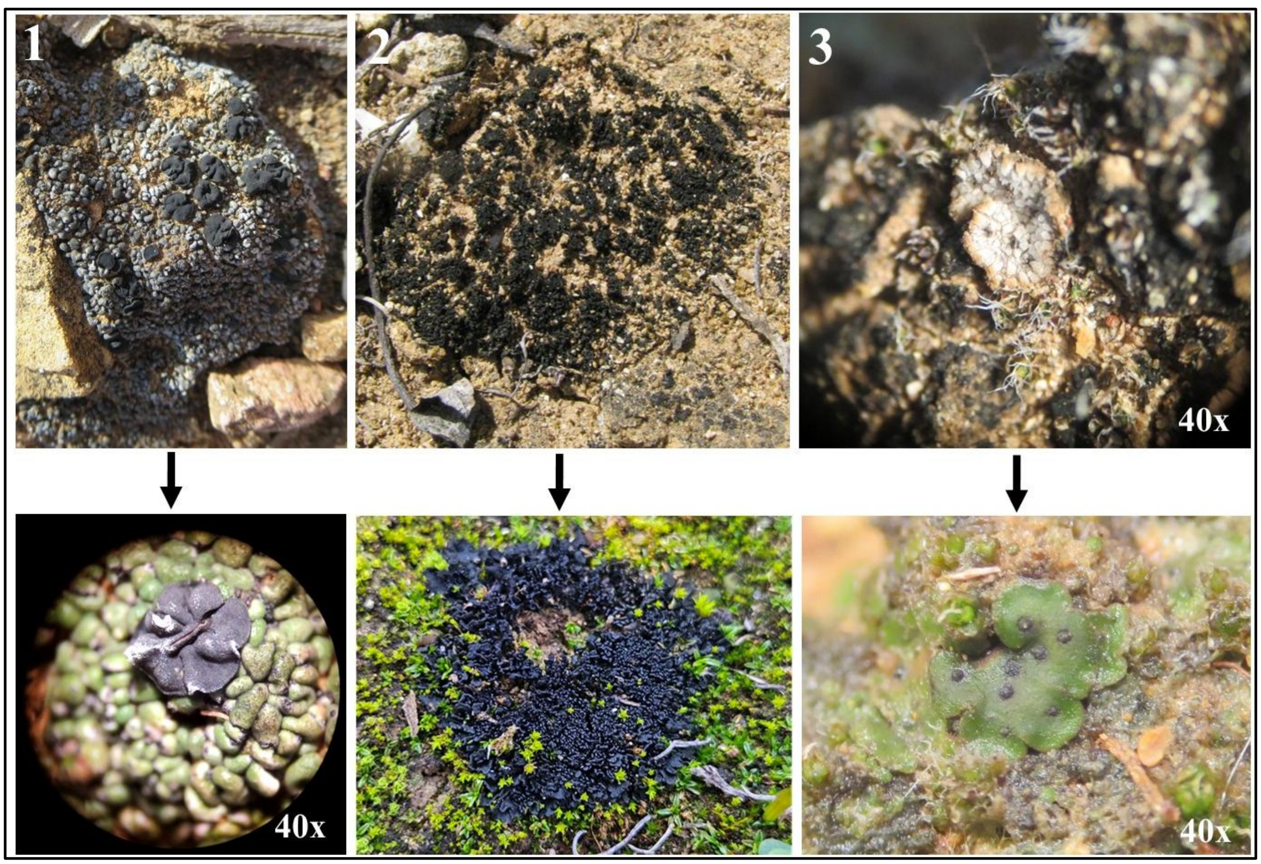

Figure 23. Lichens seen in PVP BSC (desiccated to hydrated). 1. *Thalloidima* spp.; 2. *Enchylium* ssp.; 3. *Endocarpon* ssp. Photos by the author.

Biological soil crusts host a diverse array of microarthropods (Belnap 2001c; Neher et al. 2009). The microarthropod component of the BSC on the PVP is greatly understudied. Three microarthropods were observed from late successional BSC samples from the FNR (Fig. 22): a mite (class Arachnida), a springtail (class Collembola), and a pseudoscorpion (order Pseudoscorpiones). More research is needed regarding the microarthropods of BSC on the PVP.

Research on BSC has shown that it contains a large diversity of both single-celled and filamentous algae (Flechtner et al. 1998; Hawkes and Flechtner 2002; Smith et al. 2004; Flechtner et al. 2008; Wu et al. 2011). Information on algae associated with the BSC on the PVP is lacking. During this survey, free-living algae were observed within the BSC of the PVP (Fig. 24). The genera *Vaucheria* A.P.de Candolle and *Asterosiphon* P.J.L. Dangeard were found in the BSC. The genus *Botrydium* Wallroth was also found in the BSC of sandy soil sites on the PVP.

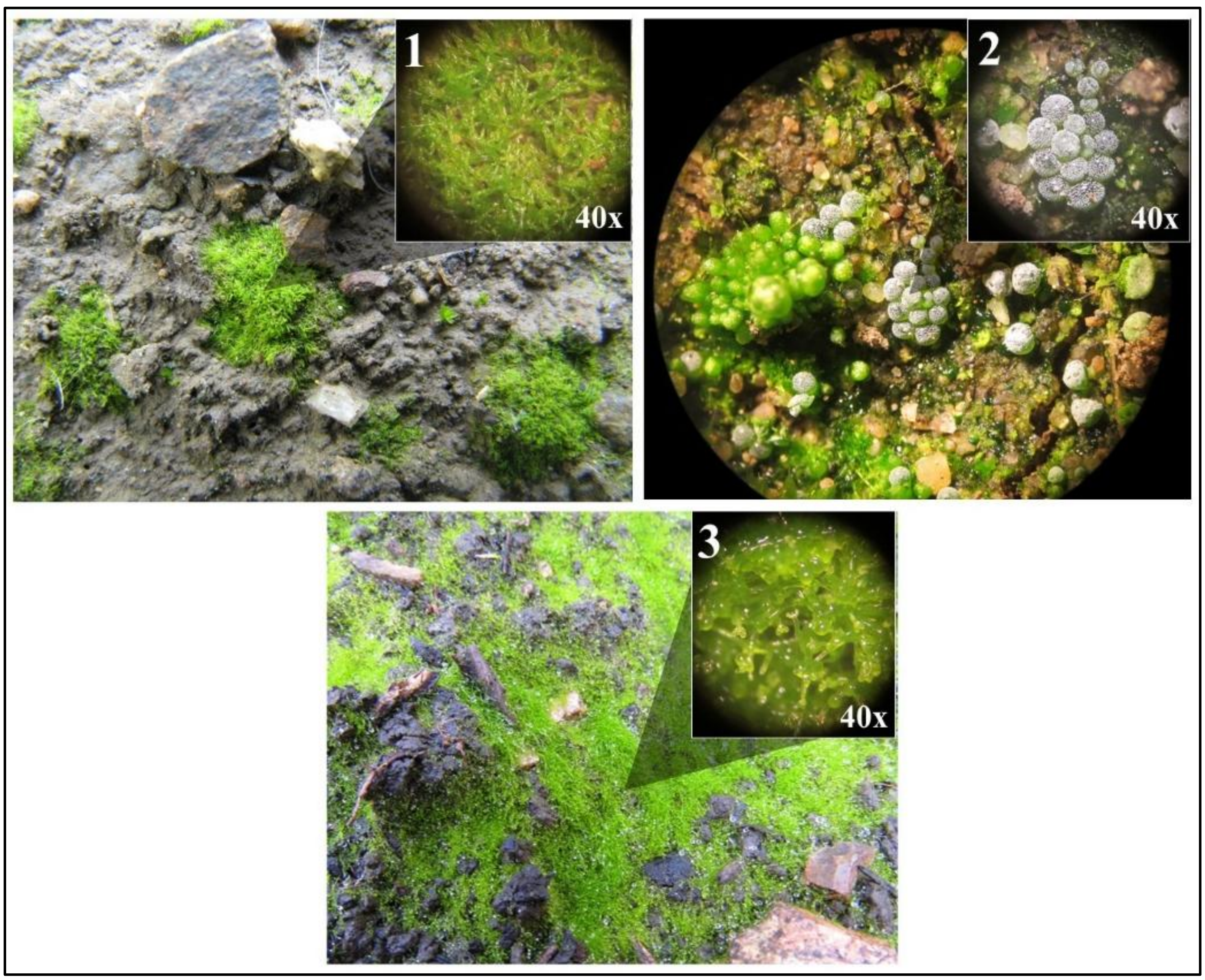

Figure 24. Terricolous algae seen in PVP BSC (hydrated). 1. *Asterosiphon* spp.; 2. *Botrydium* ssp.; 3. *Vaucheria* spp. Photos by the author.

Microfungi were also observed in BSC on the PVP and appeared during good rain years (Fig. 27). Little is known about microfungi within BSC, and no information is present about microfungi in BSC of the PVP. More research is needed on this.

There is much work left to do regarding the BSC of the PVP and the species that reside within it. No doubt, further exploration of the BSC on the PVP will yield many new discoveries and provide essential information for its conservation.

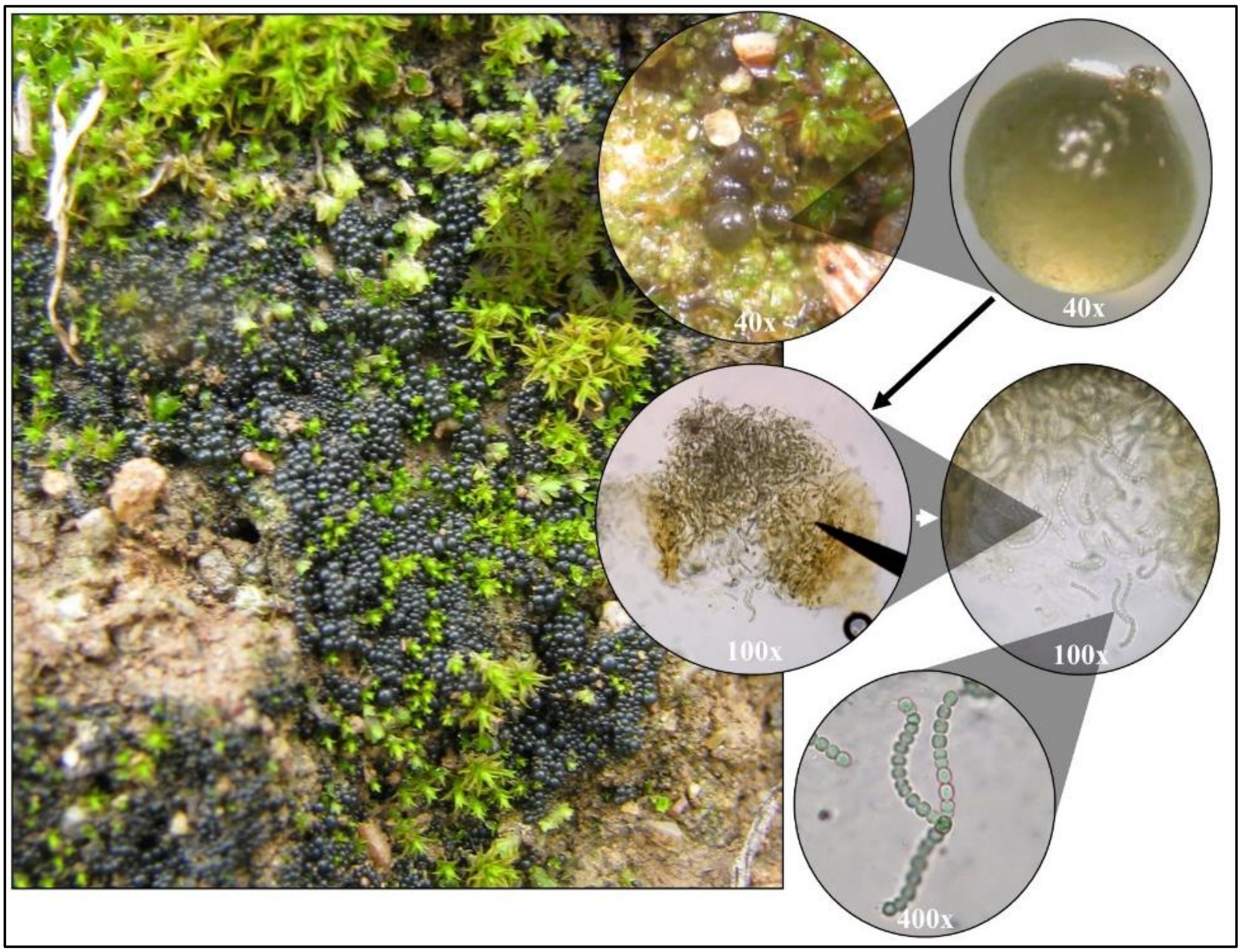

Figure 25. *Nostoc* sp. seen in PVP BSC (hydrated). Photos by the author.

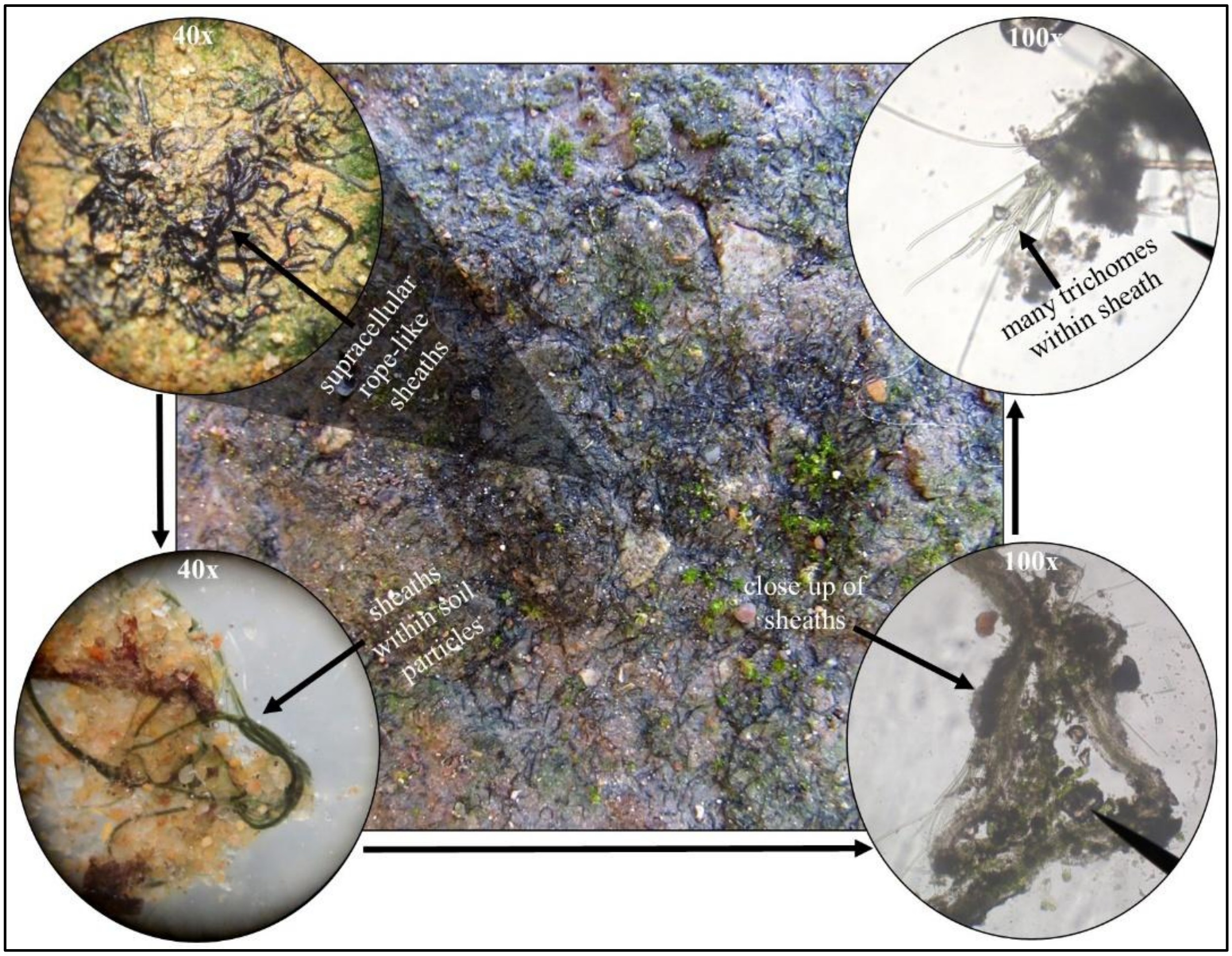

Figure 26. *Microcoleus* sp. seen in PVP BSC (hydrated). Photos by the author.

Figure 27. Fungi observed in BSC on the PVP. 1. Possibly *Pulvinula* sp.; 2. Possibly *Clavarias* sp.; 3. Possibly *Contumyces* sp.

Table 1. Bryophytes, lichens, algae, and cyanobacteria found in BSC on the PVP, common name, abundance in the BSC, BSC successional stage (late (L), early (E)), and remarks. Abundance ratings are R = rare; U = uncommon; C = common.

Species and Common Name	**Abundance in BSC**	**BSC Successional Stage**	**Remarks**
BRYOPHYTES:			
Bryaceae			
Bryum argenteum Hedw. silvery bryum	**C**	**E**	
Bryum lanatum (P. Beauvois) Hampe. silvergreen bryum Moss	**U**	**L**	Appears restricted to BSC.
Gemmabryum caespiticium (Hedwig) J.R. Spence tufted thread-moss	**C**	**E/L**	
Funaruaceae			
Funaria hygrometrica Hedw. bonfire moss	**C**	**E**	
Pottiaceae			
Aloina bifrons (De Not.) Delgad. aloe-moss	**U**	**L**	Appears restricted to BSC.
Aloina aloides var. ambigua (Bruch & Schimp) E.J. Craig common aloe-moss	**C**	**L**	

Table 1 cont.

Crossidium squamiferum (Viv.) Jur. screw-moss	**U**	**L**	Appears restricted to BSC.
Crossidium seriatum Crum & Steere. common screw-moss	**U**	**L**	Appears restricted to BSC.
Microbryum davallianum (Sm.) R.H. Zander. *smallest pottia*	**U**	**L**	Appears restricted to BSC.
Tortula atrovirens (Sm.) Lindb. tongue-moss	**U**	**L**	Appears restricted to BSC.
Trichostomopsis australasiae (Hook & Grev.) R.H. Zander *syn = Didymodon australasiae* beard-moss	**C**	**L**	Appears restricted to BSC.
Tortula brevipes (Lesq.) M. Howe screw-moss	**C**	**L**	
Tortula californica E.B. Bartram california tortula	**U**	**L**	Appears restricted to BSC (CNPS 1B.2).
Tortula inermis (Brid)	**U**	**L**	Appears restricted to BSC.
Vinealobryum brachyphyllum (Sull. ex. Whipple) R.H. Zander *syn = Didymodon brachyphyllus*	**C**	**L**	Appears restricted to BSC.
Vinealobryum vineale (R.H. Zander) R.H. Zander *syn = Didymodon vinealis* soft-tufted beard-moss	**C**	**E/L**	

Table 1 cont.

Ricciaceae			
Riccia lamellosa Raddi white-rim crystalwort	**U**	**L**	Sandy soil BSC.
Riccia nigrella DC. black crystalwort	**U**	**L**	Sandy soil BSC.
Sphaerocarpaceae			
Sphaerocarpos texanus Austin texas balloonwort	**C**	**L**	
Targioniaceae			
Targioina hypophylla L. orobus-seed liverwort	**C**	**L**	
LICHENS:			
Collemataceae			
Enchylium spp. (Ach.) Gray jelly lichens	**C**	**L**	
Ramalinaceae			
Thalloidima spp. A. Massal. bruise lichens	**U**	**L**	Appears restricted to BSC.
Verrucariaceae			

Table 1 cont.

Endocarpon ssp. Hedw. chalice lichens	**C**	**L**	Appears restricted to BSC.
Placidium spp. A. Massal earthscale lichens	**U**	**L**	Appears restricted to BSC.
ALGAE:			
Botrydiaceae			
Asterosiphon spp. P.J.L. Dangeard	**C**	**L**	
Botrydium spp. Wallroth	**C**	**L**	Sandy soil BSC.
Vaucheriaceae			
Vaucheria spp. A.P.de Candolle	**U**	**L**	
CYANOBACTERIA:			
Microcoleaceae			
Microcoleus spp. Desmazieres ex Gomont	**C**	**E/L**	
Nostocaceae			
Nostoc spp. Vaucher ex Bornet & Flahault	**C**	**L**	Appears restricted to BSC
Totals: **Families - 13** **Genera - 29** **Species - 20**			

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