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A Status Report for Sphagnum compactum, a Rare Moss Species in Southern Illinois

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Introduction

Sphagnum, commonly called peat moss, is one of the dominant genera of mosses in boreal peatlands. In general, peatlands are areas where plant annual production is greater than decomposition of organic matter. This means that organic matter accumulates as peat over long periods of time. Peat is the "accumulation of partially decayed organic matter" (Posa, Wijedasa, and Corlett, 2011). Much of this organic material consists of various moss, sedge, shrub, and tree species. Due to its diversity, *Sphagnum* moss has had numerous uses throughout history including dressings for soldiers in times of war and in the production of the Scotch whisky. In addition, peat contains significant amounts of carbon. Although peatlands only cover 3% of the Earth, roughly 30% of the world's carbon is stored in these ecosystems, making them very important for climate change (FAO, 2012).

Sphagnum compactum, the species of this study, also occurs in boreal regions, but can be found in warmer climates as well. *Sphagnum compactum* is generally found in areas that are highly acidic, sometimes disturbed, and often in wet environments (Amphlett and Payne, 2010). In addition, being a poor competitor, it is generally found in open areas with some exposed ground (Amphlett and Payne, 2010). *Sphagnum compactum* forms compact dense mats that are pale green, and often with yellow, orange, or brown hues. The growing apex, or capitulum, contains crowded, upward-pointing branches, and individual stems are usually so densely packed that the impression is of a smooth velvety surface rather than one of closely packed but individually distinct capitula" (Amphlett and Payne, 2010). The stems of the plant are usually black or dark brown and are circular (Amphlett and Payne, 2010). Patches of *Sphagnum compactum* are different from other *Sphagnum* species in that they generally grow isolated from other species of the genus, and these discrete patches are characteristic of its colonization to new areas (Amphlett and Payne, 2010).

This study aims to create a status report for *Sphagnum compactum* using the COSEWIC method (SRPR, 2017), which includes the taxonomy, description of species, distribution along with habitat, biology, threats, and protection. At this time, no literature exists that establishes the status of bryophytes in Illinois as being threatened or endangered, and very little literature exists regarding *Sphagnum compactum* in general. *Sphagnum compactum* is known from only a few localities in Illinois including Cook, Will, and Grundy counties in Northern Illinois (Snider, 1970), and Jackson county (Little Grand Canyon), and Pope county (Bell Smith Springs and Indian Kitchen) (Image 1 in Appendix). In addition, *S. compactum* may be a threatened or endangered species that should be protected. To fully discern whether or not *S. compactum* is a threatened species, however, the colonization and habitat requirements must be better understood. To do so, a variety of observations have been made that aim to understand the conditions in which *compactum* occurs in the Shawnee National Forest of Illinois. The Shawnee National Forest covers an area of 107,490.98 ha (USFS, 2008), and is found at the southern tip of Illinois. The forest exists at the most southern point of the Laurentide ice sheet, which last covered the area 190,000-130,000 years ago (Gemperline, 2013). As the ice sheet melted and calved, large portions of meltwater carved out large rock formations in the primarily sandstone bedrock of the region (Gemperline, 2013). Here, *Sphagnum compactum* can be found on some north facing sandstone cliff faces. Understanding why *compactum* occurs in these areas and not other north facing sandstone cliff faces within the forest will provide observation that relate to whether the species is threatened or endangered.

Methods

To discover the habitat requirements for *Sphagnum compactum* in southern Illinois, three sites throughout the Shawnee National Forest were sampled, and a variety of data points were gathered from each location. The sites included Little Grand Canyon (37°41’12” N, 89°23’48” W), Bell Smith Springs (37°31'20" N, 88°38'26" W), and Indian Kitchen (37°31’ 3”N, 88°32’20” W) with Rock Castle

Creek in Randolph county unable to be sampled for this study. Each of the sites are located off of trails that cut through the Shawnee National Forest, and are plotted via GPS coordinates in the Results section. Each site sampled had three different populations of *S. compactum* sampled identified by their height on the sandstone cliff face with a high population, an intermediate population, and a low population. At each of the sites, the first measurement taken was the cliff orientation. This was done with a compass recording the direction the cliff face was oriented. At this time, the coordinates and elevation were also recorded using a GPS and elevation meter, respectively. Shade as % canopy cover was recorded using a concave densiometer, where the amount of shade cover was calculated by counting the shaded boxes throughout the array of the densiometer. This value gave an estimate of shade for each of the three populations sampled at each site, and the values obtained were averaged for a mean value at each of the three sites sampled.

I examined each population as a whole. To do so, a 30 cm ruler was placed in the center of the population, and on the outside of the population to estimate the lateral extent of the population in centimeters. A core with an 8 cm diameter and depth of 15 cm was also taken in the center of each population, and the core was placed in a brown paper sack, labelled, and placed in a freezer. Community analysis was done both within the population and on the outside of the population. To do so, a colleague that is a bryophyte expert would name the genus and species of each plant found, and it would be recorded. If a plant was present that we could not identify, it was extracted, bagged, and identified in the laboratory.

Taxonomy

Sphagnum compactum is a member of the genus *Sphagnum* with approximately 200 species (Courteau, 2012). As a whole, the genus *Sphagnum* has been on earth since at least the Mesozoic, however, recent findings have suggested that the species of *Sphagnum* that are present today have recently diversified in the last 30 million years or so (Shaw et, al. 2010). Therefore, species like *compactum* are being heavily selected upon as they are still quite young in evolutionary time. *Sphagnum compactum* branched off early in the evolution of the genus (Shaw et, al. 2010). *S. compactum* is a sister taxon to fifteen species of *Sphagnum* and occupies a very isolated position in the genus. Specifically, no other species shares a branch with *compactum* once it branched off from the larger clade.

Description

Sphagnum compactum plants are moderate to large in size and are compact and dense. Plants can be found in a variety of different colors, however pale green, golden brown, and brownish white are the most common. In addition, a reddish color can be found when sampling in rocky habitats as well (Andrus, 2004). When found, *compactum* generally forms small, compact patches that are densely packed together much like a cushion. *Sphagnum compactum*, much like other *Sphagnum* mosses, can absorb a large amount of water and can therefore be found in a state of heavy saturation or very dry. The stems of the plant are brown, while stem leaves are found in a variety of colors, but are generally triangular-lingulate with a broad rounded apex and are 0.3-0.7 mm in size (Andrus, 2004). The branches of the plant are short, very compact, and are unranked. As for the branch fascicles, there are generally 4-6 branches per fascicle with 2-3 pendent and 2-3 spreading. That being said, in young clones there typically are no branches (Andrus, 2004). The branch leaves range from 1.4-3.0 mm and are semi- to fully squarrose, ovate, and have a toothed apex with no more than 6 teeth. Present on the convex surface are hyaline cells that contain five or more ringed pores that range from round to elliptic in shape (Andrus, 2004). On the concave surface there are numerous pseudopores with three ringed pores that occur in groups of three at adjacent cell angles. There are also chlorophyllous cells near the convex surface that are elliptical when viewed in transverse section (Andrus, 2004).

Distribution and Population

Contrasting from its peat-forming relatives found only in boreal landscapes of Canada and northern Eurasia, *Sphagnum compactum* is found in thirty states spanning the eastern and midwestern United States, and all Canadian provinces. Specifically, *compactum* can be found in Minnesota, Wisconsin, Iowa, Illinois, Missouri, Arkansas, Louisiana, Mississippi, Georgia, Florida, South Carolina, North Carolina, Virginia, West Virginia, Kentucky, Tennessee, Indiana, Ohio, Michigan, Pennsylvania, Vermont, Maine, Massachusetts, Connecticut, New Hampshire, Delaware, Montana, Washington, Oregon, and California (NRCS, 2017). Due to this widespread distribution, it can be said that *Sphagnum compactum* has a broad tolerance for climate.

When conditions are favorable for occurrence, *S. compactum* is generally found alone without populations of other *Sphagnum* species in close proximity. However, *compactum* does occur adjacent to a variety of other bryophyte species, with specific species being discussed in the “Habitat” section. *Sphagnum compactum* populations are also relatively small, with the diameter of the population rarely exceeding a few meters. Briefly, populations can be generally be found in open areas that receive intermediate levels of sunlight and are relatively moist. Again, the specifics of habitat requirements will be listed in the “Habitat” section.

Habitat

The habitat for *Sphagnum compactum* is fairly well understood. In general, *compactum* is found in open areas where bare ground is present and occurs best in areas that are wet, acidic, and often disturbed (Amphlett and Payne, 2010). However, specific colonization requirements in southern Illinois are not well understood. Particularly, no literature on why *Sphagnum compactum* favors north-facing sandstone cliffs in the Shawnee National Forest is available. To discover the exact habitat of *S. compactum* in Illinois, a range of environmental characteristics essential to the establishment of *Sphagnum compactum* were developed by carrying out field observations. Essentially, environmental measurements were taken and averages in addition to ranges were calculated to show the lower and upper limits in which *S. compactum* could establish in addition to conditions most common when established populations were found.

Slope orientation was by far the most consistent measurement. As previously stated, *S. compactum* is only found on north-facing sandstone cliffs, and this held true for all populations and sites. Elevation was also standard for the region with the average elevation for Little Grand Canyon of 116 meters, Bell Smith Springs 137 meters, and Indian Kitchen 149 meters (Table 1 in Appendix). For shade, the Little Grand Canyon site had the lowest average shade values from the three populations at 51.7% with a range of 31%, Bell Smith Springs had an average of 74.3% with a range of 26%, and Indian Kitchen had an average of 69.3% and range of 12%. In total, the average shade from all nine populations was 65.1% with a range of 57% (Table 2 in Appendix).

The next measurement taken was population depth. This is important to see both approximately how well established the population is in the area, and if the population is expanding outward. For the Little Grand Canyon, measurements were only taken from the intermediate and highest populations due to weather conditions. The intermediate population had a measure of 4.5 cm depth in the center of the population and 3.8 cm depth at the periphery. The highest population also had a center depth measure of 4.5 cm, and a periphery of 6.7 cm. This equates to an average center population depth of 4.5 cm, and average periphery population depth of 5.25 cm. Bell Smith Springs showed a center depth of 7 cm and peripheral depth of 4.5 cm for the high population. For the intermediate population, the center depth was 7.5 cm and peripheral was 4.5 cm with the low population having a center depth of 10 cm, and peripheral depth of 8 cm. When averaged, the center population had a depth of 8.16 cm with the peripheral depth average being 5.67 cm. As for Indian Kitchen, the lowest population center depth was 12 cm with a 7 cm periphery depth, the intermediate population measured 7 cm in the center and 4.5 cm in the periphery, and the highest population measured 6.5 cm in the center and 5 cm in the periphery. An average center depth at Indian Kitchen measured 8.5 cm whereas the average periphery depth measured 5.5 cm (Table 3 in Appendix).

Community measurements were the final parameter that was examined. For the Little Grand Canyon site, *Dicranum scoparium*, *Thuidium delicatulum*, *Atrichum angustatus*, *Polytrichum ohioense*, *Hedwigia ciliata*, *Cladina rangiferina* were found. Bell Smith Springs had a much smaller community including *Polytrichum ohioense*, *Cladina mitis*, *Dicranum scoparium*, and *Brachythecium sp*. Indian Kitchen contained *Dicranum scoparium*, *Bartramia pomiformis*, *Polytrichum ohioense*, *Thuidium delicatulum*, *Atrichum angustatus*, and *Cladina sp.*. When extrapolating these results, it shows that *Hedwigia* and *Cladina rangiferina* were site specific to Little Grand Canyon. Likewise, *Cladina mitis* and *Brachythecium* were site specific to Bell Smith Springs, and *Bartramia pomiformis*, Dicranum scoparium, and *Cladina sp.* were site specific to Indian Kitchen. Further, *Dicranum scoparium*, *Poytrichum ohioense*, *Thuidium* and *Atrichum* were found at multiple sites with *Dicranum scoparium* and *Polytrichum ohioense* being found at every site (Table 3 in Appendix).

After analyzing the results obtained from the observations, a habitat profile for *Sphagnum compactum* in the Shawnee National Forest of southern Illinois was created. In short, *S. compactum* can be found on north-facing sandstone cliffs in southern Illinois where the average canopy cover is 65% and average elevation is 134 meters. Further, when *S. compactum* is established the depth of the center of the population spans 4.5-12 cm and periphery ranges from 3.8-8.0 cm with an average center and periphery depth of 7.1 cm and 5.4 cm respectively. Lastly, *S. compactum* occurs when both *Dicranum* *scoparium* and *Polytrichum ohioense* are present, however populations have been found containing other bryophytes as well.

Biology

As for biology, *Sphagnum compactum* reproduces via spores on monoicous (bisexual) plants (Andrus, 2004). Thus, both male and female sexual organs are found on a single plant. However, male and female reproductive organs are found in different areas of the plant. There are two distinct generations that make up a single life cycle for *Sphagnum compactum*; the gametophyte and sporophyte generation. Since *S. compactum* is a bryophyte, the gametophyte phase is the dominate phase rather than the sporophyte being the dominant phase as in most vascular plants (Temsch, 2004).

In the gametophyte phase, the plant has abundant chlorophyll, bears leaves, and is sexually active (Temsch, 2004). This generation is the haploid generation, and arises from a bud in the protonema which is a juvenile stage beginning by the germination of a spore created in the sporophyte phase (Temsch, 2004). Due to the fact that the gametophyte phase can undergo sexual reproduction, sex organs are developed in this phase. For males, antheridia form whereas archegonia form in females. As discussed earlier, these organs are found on the same plant, but grow on different branches (Temsch, 2004). Generally, antheridia grow near the base of the leaves on short side branches, and appear to be small spheres. Each antheridium produces thousands of sperm called antherozoids that are able to move, so once sperm are mature, they are released and swim to an egg (Temsch, 2004). Therefore, a water film must be present for sexual reproduction to occur. Archegonia, on the other hand, grow on their own or in small clusters generally not exceeding five on short side branches, and look like a bud in appearance (Temsch, 2004). Each archegonium contains a single egg that is found at the bottom of a canal. Once maturation has occurred, the cells surrounding the canal form a mucus that enables the antherozoids to meet the egg. Only a single sperm will fuse with the egg, and this will form a diploid zygote that will eventually become the sporophyte (Temsch, 2004).

Once the sporophyte is formed, tissue from the base of the archegonia nourishes and guards the sporophyte while it develops. When the sporophyte matures, a mass of spores form in a bulb like sporangium that is found above the plant that acts as a dispersing agent for spores found within (Temsch, 2004). According to Richard Andrus from Bryophyte Flora of North America, spores are generally 25-35 um, and the sporangium generally matures in the summer months (BFNA, 2004). When the sporangium opens, spores are thrust up to 20 centimeters with the wind carrying them further. It is important to note that spores are part of the haploid gametophyte generation, and are formed by meiosis of one diploid sporocyte, which in turn creates four haploid spores (Temsch, 2004). These spores then have the potential to serve as reproductive agents and grow into young gametophyte plants that will soon be ready to reproduce again.

However, spores seem to be rare in *S. compactum* populations. In the nine populations studied, spores have only been found once, and were not present on all plants in the population. Instead, fragmentation of *compactum* plants is likely the driver for colonization. Spores do play a part, however it is a relatively small part compared to that of much more common plant fragments. These fragments essentially break off of the main plant and are able to establish in another area and grow into mature gametophytes. This is done by asexual reproduction, and is very common in peat forming mosses as well (Rydin, Hakan, and Jeglum 2006).

Threats

The largest threat to *Sphagnum compactum* is human contact. As previously stated, in southern Illinois *Sphagnum compactum* is generally found in areas that are adjacent to hiking trails. This is not to say that the moss is not found other places, but given that *compactum* is found in open, sometimes disturbed environments, trails are a prime location for the moss to be found. This creates several issues. The most potent of these being humans mistaking the moss as bare ground and stepping on it. To the untrained eye, *Sphagnum compactum* looks similar to tree litter on top of soil. Given that *Sphagnum* is not a vascular plant, it is very inconspicuous and hard to identify especially when walking at a brisk pace. In addition, the weight of a human being is enough to severely damage the plant. To exasperate the issue, the patches are not very large, so a foot print of damage could potentially damage one tenth of the population in a given area.

In addition, trails serve as other threats as well. Trails inevitably hamper natural environmental processes. For example, areas where trails are present will act as flat areas in which water and tree litter can pool rather than moving down the backslope region of the cliff face. Water pooling naturally increases the infiltration rate of that area and decreases filtration in other areas where pooling is not present. Essentially, however minimalistic they are intended to be, trails inevitably disrupt natural processes. The presence of trails in a landscape that has been free of unnatural foot traffic for millennia can be an environmental disaster for a species like *S. compactum*.

Protection

As discussed earlier, *Sphagnum compactum* is a rare moss in southern Illinois, known from four sites, with only three able to be sampled for this study. As of right now, the only populations that have been discovered in southern Illinois are found on north-facing sandstone cliffs in the Shawnee National Forest. As discussed, the observations showed that the environmental window is relatively narrow for occurrence. So narrow, that *S. compactum* is only found on four sandstone cliff faces in the national forest. This begs the question, should *compactum* be considered threatened or even endangered, and if so, what steps should be taken to protect it?

When examining propagule transfer and the environmental requirements that enable colonization, protection becomes warranted. As discussed in the "Biology" section, spores are ejected up to 20 cm and more commonly plant fragments form that rely on wind to transfer them from one location to another. That being said, to colonize a new area within the forest, those fragments/spores will have to be delivered to an area that meets all of the environmental conditions for colonization. As discussed in the "Habitat" section, these conditions are quite rare. Further, literature notes that one potential contributor of colonization is a disturbed habitat. Disturbance does not have a specific definition, but in this area of the country the largest disturbance to an area is human caused disturbance in the form of clear cutting for trails or naturally occurring disturbances such as coal seems or open areas in the soil left from a tree that was naturally removed. There is a casual relationship at best with the former, as it is true that most *compactum* found was near a trail, but that is most likely a sampling bias as we rarely moved off the trail for a considerable amount of time. However, the latter provides a good explanation as to why *S. compactum* is so rare.

Given the environmental conditions that have to be met for *S. compactum* to colonize, *compactum* should be more readily found throughout the forest. However, when adding the disturbance component to the environmental conditions and noting that the topography in the region creates a difficult environment for wind to travel for a long distance, the rarity of c*ompactum* begins to become rational. The observations done to discover the habitat requirements backs up this hypothesis. In each of the sites that were surveyed, only one sandstone cliff face contained *Sphagnum compactum*, however there were several populations that were found on each cliff face. Specifically, there was a population that was high on the cliff, one at an intermediate height, and one that was low on the cliff. This shows that after one population has colonized, fragments and spores are able to travel along that cliff face due to wind acting as a dispersing agent. However, populations ended abruptly. One could hypothesize that the fragmented plants and spores did not germinate due to environmental conditions being inadequate for establishment. Further, wind as a dispersal agent was ineffective in transporting them to a location in which colonization was favorable.

In addition, one must remember that capsules carrying spores are rarely found in *S. compactum* populations. Rather, as discussed in the "Biology" section, fragments of *S. compactum* plants are more likely the drivers behind colonization. Further, if *S. compactum* has two dispersal methods, the species is certainly not limited by propagule transfer, so why are more populations not present? The answer may be relatively straight forward. Spores are quite small and easily carried by wind, but spores, as mentioned previously are very rare. *S. compactum* fragments being the main drivers of dispersal significantly reduces the range in which *compactum* can spread. Plant fragments are inherently much larger than spores and will be exponentially more difficult to transfer via wind. This being the case, regardless of how many fragments and spores are produced the dispersal agent is unable to carry *compactum* to a location in which establishment is possible which is why so few populations are found.

However, *S. compactum* seems to be very robust when established. Depth measurements taken at the center and peripheral of populations were indicative of long established populations and lateral expansion. Throughout the nine populations sampled, there was not a single population that showed signs of a recent colonization. All but one population was much deeper in the center than in the periphery showing evidence of long standing populations. As stated previously, due to the strict environmental characteristics and given level of habitat disturbance needed for colonization it is unlikely that populations will readily establish. In addition, being that it is not an issue of propagule emission, but one of propagule transfer, protection for *compactum* is very necessary. Further, funds allocated to *compactum* protection will not be wasted due to the resilience of populations once established. Frankly, environmental conditions will not be the driver for habitat destruction, but human intervention will.

Hikers are the main threat to *S. compactum* populations and given the relatively small size of each population, humans pose a significant threat if and when they step on the populations. Humans pose such a threat because one misplaced step can cause permanent damage to existing populations. Further, the lack of new populations shows that the colonization extinction ratio is very small. This means that colonization events are much rarer than extinction events. In addition, the fact that there are only four known populations in southern Illinois compounds this problem. Humans pose a great threat to *S. compactum* populations and given the low recruitment to new populations, damage inflicted by humans could cause an extinction event. Given the low colonization extinction ratio, this could cause the entire species to become extinct in southern Illinois. In fact, because of the lack of new populations found, the strict environmental conditions for colonization, and the small size of existing populations, I propose that *Sphagnum compactum* should be added to the Illinois Endangered Species list.

However, the protection of *compactum* does not have to be one riddled with costs and intensive labor. Given that, if left alone, *compactum* is robust once it establishes, practitioners could place a fence around the population with signage discussing the moss and provide education to those hiking the trail in threats to *compactum*. The fence should be metal in construction with posts placed as far apart as possible as to not disturb the population as it grows. This, paired with signage that discusses the reasoning behind the fence, will be enough to deter humans from stepping on and damaging the population. Further, when creating new hiking trails in the national forest, the proximity to *S. compactum* populations must be taken into consideration. Building hiking trails next to populations increases the risk of damage to populations, and should be avoided. In addition, given that *compactum* faces extraordinary odds for establishing in an area, practitioners could manually spread fragments from *compactum* to areas that meet the environmental conditions in an attempt to create more populations in the area. This would be effective in growing the number of populations and could remove the list from the proposed endangered list if successful.

Appendix

Table 1: Shade (as canopy cover), elevation in meters, and slope orientation for low, intermediate, and high populations at Little Grand Canyon, Bell Smith Springs, and Indian Kitchen. Included are averages and ranges for the shade and elevation measurements.

Site:	Populations:	Shade:	Elevation (m):	Slope Orientation:
Little Grand Canyon	Low:	58	112.77	N
	Intermediate:	64	115.82	N
	High:	33	118.87	N
	Average:	51.67	115.82	
	Range:	31	6.1	
Bell Smith Springs	Low:	69	127.66	N
	Intermediate:	90	138.66	N
	High:	64	145.16	N
	Average:	74.33	137.16	
	Range:	26	17.5	
Indian Kitchen	Low:	74	146.30	N
	Intermediate:	62	149.35	N
	High:	72	152.4	N
	Average:	69.33	149.35	
	Range:	12	6.1	

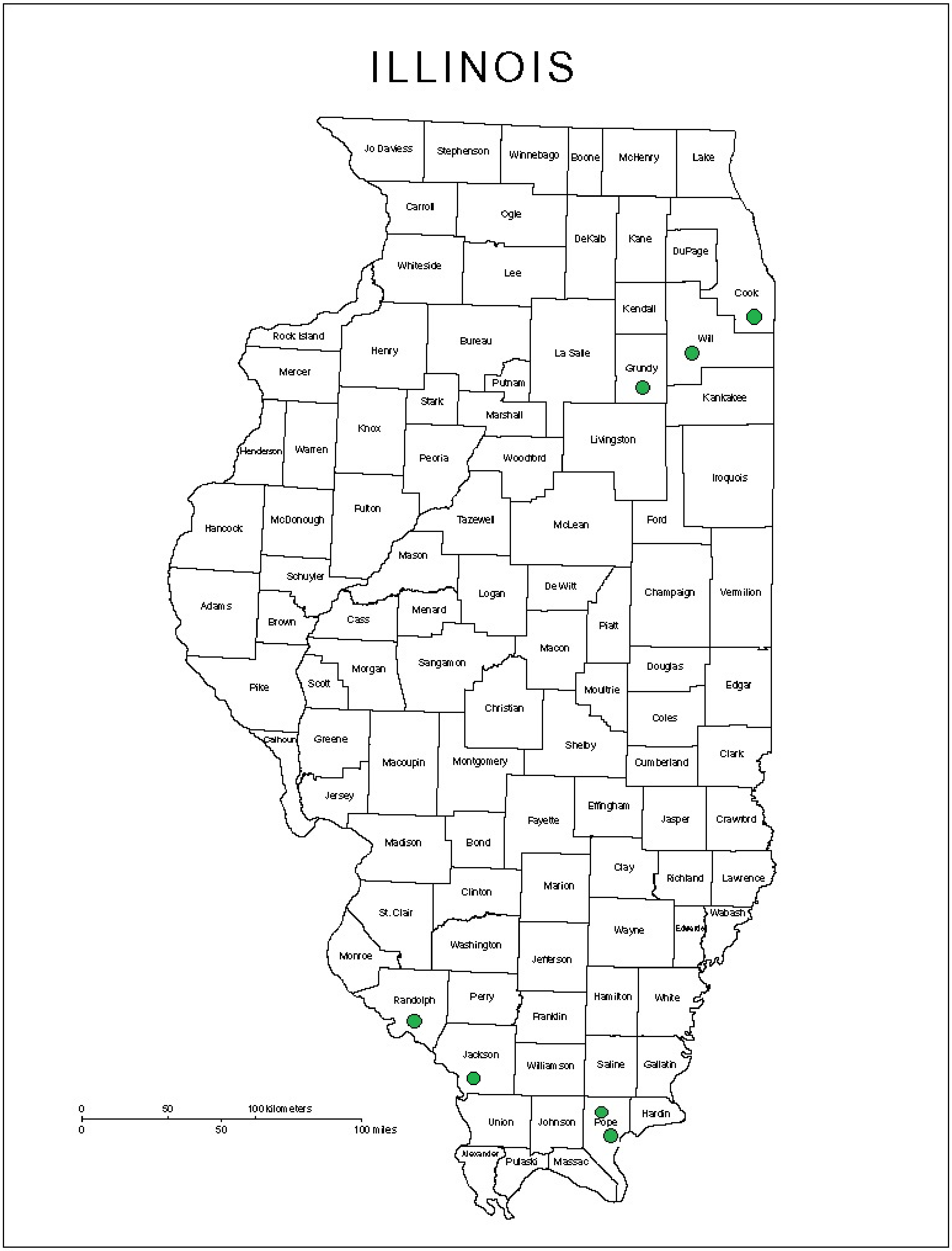
Table 2: Population Depth in centimeters for both the center and periphery of low, intermediate, and high populations with the average center and periphery depth measurements documented as well.

Site:	Populations:	Population Depth (cm): Center	Population Depth (cm): Periphery
Little Grand Canyon	Low:	N/A	N/A
	Intermediate:	4.5	3.8
	High:	4.5	6.7
	Average:	4.5	5.25
Bell Smith Springs	Low:	10	8
	Intermediate:	7.5	4.5
	High:	7	4.5
	Average:	8.16	5.67
Indian Kitchen	Low:	12	7
	Intermediate:	7	4.5
	High:	6.5	5
	Average:	8.5	5.5

Table 3: Community analysis for Little Grand Canyon, Bell Smith Springs, and Indian Kitchen. Total community and site specific community documented with *indicating flora shared by one other site and **indicating flora shared by all other sites.

Site:	Total Community:	Site Specific Community
Little Grand Canyon	*Dicranum scoparium***	*Hedwigia cilata*
	*Thuidium delicatulum**	*Cladina rangiferina*
	*Atrichum angustatus**	
	*Polytrichum ohioense***	
	Hedwigia cilata	
	Cladina rangiferina	
Bell Smith Springs	*Polytrichum ohioense***	*Cladina mitis*
	Cladina mitis	*Brachythecium sp.*
	*Dicranum scoparium***	
	Brachythecium sp.	
Indian Kitchen	*Dicranum scoparium***	*Bartramia pomiformis*
	Bartramia pomiformis	*Cladina sp.*
	*Polytrichum ohioense***	
	*Thuidium delicatulum**	
	*Atrichum angustatus**	
	Cladina sp.	
***indicates shared by one other population**		
****indicates shared by all populations**		

Image 1: Map of Illinois with green dots being placed in areas in which *S. Compactum* has been found.



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