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Fine-Scale Plant Species Identification in a Poor Fen and
Integration of Techniques and Instrumentation in a Classroom Setting

Honors Senior Thesis

Fall 2014-Spring 2015

Dylan Schiff

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Abstract

Refining carbon flux measurements in the carbon cycle is an ongoing challenge. This study attempted to identify plant species in Sallie's Fen, a nutrient-poor fen, at a fine scale in order to better model and understand carbon exchange between plants and the atmosphere in this type of ecosystem. A protocol for estimating percent cover of species in plots via ground measurements was developed. The next stage of this project was to compare these measurements with measurements derived from spectral images using ImageJ computer software. Statistical tests of the ground measurement data revealed that patterns of seasonal defoliation had a strong effect on the apparent species richness, evenness, and biodiversity of plants as seen aerially. The presence of *Sphagnum* mosses excluded the presence of other species, but the presence of other plants only excluded the visibility of *Sphagnum* since it resides in the understory of the layered community. A regression comparing percent cover of the vascular plant functional group and fractal dimensions from a digital camera was statistically significant, indicating that ground and aerial measurements agree and that spectral imaging can be used to save time in the field in place of ground measurements. Additionally, since ecosystem science is such an interdisciplinary field, it provides the perfect platform around which students can apply their scientific knowledge and understanding. Modifications to this project were suggested so that it can be carried out in a secondary school classroom setting while aligning with the Next Generation Science Standards.

Introduction

Peatlands are an important type of ecosystem because they contain large amounts of dead organic matter and a high carbon content. More specifically, these ecosystems act as a long-term storage pool of carbon, acting as a sink for carbon dioxide and as a source of methane (Bubier et al. 1997). Northern and temperate wetlands, such as peatlands, contribute approximately 25% of the world's global atmospheric methane (Bubier et al. 1993). It has difficult to obtain a more confident estimate of carbon flux in these ecosystems because of the variability of plant species diversity within and among wetland sites. Additionally, climate change is causing temperatures to warm, which is causing these wetlands to contribute different amounts of carbon to the atmosphere due to thawing permafrost and other changes to the ecosystem. In a world concerned with greenhouse gases, it is necessary to understand how these ecosystems are changing their carbon emissions.

It has been difficult to gain a general understanding of the changes in carbon because peatlands are highly variable. The microtopography within peatlands has significant effects on the spatial variability of thermal regime, hydrological regime, nutrient availability, and plant species distribution over short distances (Bubier et al. 1993). Hummock-hollow topography and changes in the position of the water table affect the spatial variability of aerobism versus anaerobism, which then affects the carbon flux of different plant species (Kenkel 1988). It has been found that hollows are generally capable of producing more methane than hummocks in poor fens due to aerobic conditions (Bubier et al. 1993). In addition to variability within peatlands, there is also variability among peatlands. The New Hampshire Natural Heritage

Inventory classified peatlands into 15 types, depending on communities of plant and moss species present, as well as dominant indicator species (Sperduto et al. 2000).

To complicate things even more, the different plant and moss species undergo photosynthesis and respiration at varying rates and are affected differently by changing environmental conditions (van Gaalen et al. 2007). Since distinguishing between species at fine scales (< 1m) has been challenging, estimating ecosystem-scale carbon emissions has been difficult. The differences between species' reflectance characteristics in remote sensing have been briefly investigated, and it was found that the normalized difference vegetation indexes (NDVI) for plant and moss species are statistically different from one another (Bubier et al. 1997). Additionally, unique near infrared (NIR) and visible region spectral reflectance curves have been found for different moss species, particularly *Sphagnum* moss (see Appendix A; Bubier et al. 1997). Although this information is known, application of this knowledge has not been explored to its utmost potential. To this point, only generalizations about species composition and ecosystem boundaries have been able to be identified using remote sensing. Expansion of this knowledge will play a very important role in the exploration of whether carbon flux can be better estimated over shorter distances in peatlands using remote sensing technologies.

The peatlands of southeastern New Hampshire are dwarf heath shrub-dominated, very poor fens (Sperduto et al. 2000). Such fens are oligotrophic, and the uppermost peat is poorly decomposed. They have hummock-hollow topography and lack tall shrubs and trees. The moss layer of very poor fens is dominated by *Sphagnum angustifolium*, *Sphagnum rubellum*, and *Sphagnum magellanicum*, and dominant vegetation include *Chamaedaphne calyculata* (leather leaf), *Kalmia angustifolia* (sheep laurel), *Vaccinium oxycoccos* (cranberry), and *Kalmia polifolia* (bog laurel). Other common species include *Eriophorum vaginatum* (tussock cottongrass), *Eriophorum virginicum* (tawny cottongrass), *Smilacina trifolia* (three-leaved Solomon's seal), and *Carex* sedges (see Appendix B; Sperduto et al. 2000). Additional species found at Sallie's Fen in particular include *Vaccinium corymbosum* (blueberry), *Pinus strobus* (eastern white pine), and *Solidago canadensis* (goldenrod). Lichen, leaf litter, and *Carex* litter were also included as separate observations.

Sphagnum moss species show a different spectral reflectance curve from that of vascular plants. NIR 2 is the dominant peak of all *Sphagnum* species, followed by peaks in NIR 1 and a less bright NIR 3 (Bubier et al. 1997). *Sphagnum* mosses, in particular, have a minor absorption in the spectral reflectance curve at 0.85 μm , which helps to distinguish them from other mosses, lichens, and vascular plants. *Sphagnum* species can be more difficult to discern from one another, and efforts have been made to distinguish between them. *Sphagnum magellanicum* is usually red or brownish-pink in color, but becomes green in shaded conditions. It grows in acidic environments, in hummocks at intermediate levels above the water table of poor fens (Bubier et al. 1997). *Sphagnum magellanicum* has turgid branches, cucullate leaves, and spiral-banded outer cortical cells (Vitt and Andrus 1977). *Sphagnum angustifolium* typically occurs in hollows below *Sphagnum magellanicum* and sits in water; therefore, the water table is most often at the

Sphagnum angustifolium surface. It is moderately smaller than other *Sphagnum* species and has two hanging branches per fascicle. Its stem leaves are triangular-ovate in shape, and its branch leaves have hyaline cells with one large pore (Vitt and Andrus 1977).

This project attempted to begin a long-term study to determine if peatlands can, in fact, be remotely-sensed at a finer scale. It is the ultimate goal of this study to be able to identify more confidently the carbon emissions in whole peatland ecosystems using near-remote sensing and spectral analysis techniques. It is the hope that this study will lead to a better understanding of how microtopography (hummock-hollow topography) and hydrology (water table positioning) impact fine-scale carbon emissions. Additionally, this particular component of the study investigated how techniques and practices used in the rudimentary stages of this study—such as the differentiation of plant species and the use of remote sensing—can be applied to and incorporated into a classroom setting based on the Next Generation Science Standards.

Methods

Field Site

Sallie's Fen is a temperate, mineral poor fen in Barrington, New Hampshire (see Appendix C). The New Hampshire Natural Heritage Inventory classifies Sallie's Fen as a *Chamaedaphne calyculata-Kalmia angustifolia* dwarf heath shrub bog/very poor fen (Sperduto et al. 2000). Such peatlands are oligotrophic-weakly minerotrophic mid-low elevation bogs and poor shrub fens. Sallie's Fen's coordinates are 43°12.5'N, 71°03.5'W. It has a surface area of 1.7 hectares and ranges in depth from 2 to 4.5 meters (Carroll and Crill 1997). It is surrounded by a mixed deciduous and coniferous hardwood forest. The peatland is fed by an ephemeral stream and receives approximately 1100 mm of precipitation per year (Treat et al. 2007). The pH of the fen ranges from 4.1 to 5.7, and the average annual temperature is 8.1°C (Treat et al. 2007). The site is dominated by bryophytes, particularly *Sphagnum* mosses. Previous studies have identified many species of *Sphagnum* in Sallie's Fen (Carroll and Crill 1997). Other vegetation present in the fen includes shrubs (*Chamaedaphne calyculata*), sedges (*Carex rostrata*), and cranberry (*Vaccinium oxycoccos*). Active biological production occurs from April through October, with senescence beginning in late August (Treat et al. 2007). Sallie's Fen has been the focus of gas exchange studies and methane flux research.

Fieldwork Methodology

Vegetation composition was collected using a 1-meter quadrat divided into five rows and five columns (25 cells). The columns were labeled A through E, and the rows were numbered 1 through 5 in order to label and refer back to individual cells. Each plot was oriented south, such that cell A1 was in the southeast corner of the plot. The corners of the plot were marked with flags for georeferencing with a Trimble GeoExplorer 6000 XT Global Positioning System (GPS) roving unit. Five plots were measured and photographed for this experiment. The plots were chosen based on their containing mixed vegetation with visible *Sphagnum* moss cover, accessibility from the main boardwalk, and lack of interference with other ongoing experiments

at Sallie's Fen. Percent cover of each species within each cell was identified and recorded. *Sphagnum magellanicum* and *Sphagnum angustifolium* were classified separately. Both were also either noted as being "dry" or "normal" based on hydrology, and in Plot 5, *Sphagnum magellanicum* was further classified red or brown-pink in color for further differentiation. Measurements of percent cover were taken between October 6 and November 4, 2014. Percent cover of vegetation composition for each cell in each plot was entered into an Excel spreadsheet.

Both a point-and-shoot (PS) Panasonic Lumix-GM1 camera and a near infrared (NIR) Tetracam ADC-Lites camera were used to photograph each plot. The Lumix camera utilized normal color spectra, while the Tetracam utilized the green, red, and near infrared spectra. All photographs were taken such that cell A1 was in the upper left-hand corner of the image. The Lumix camera was held above the plot by a user, while the Tetracam was placed on a platform that was then suspended above the plot by a pole rig made from PVC piping (see Appendix D). A display monitor was connected to the Tetracam to align the image properly before taking the photograph with a clicker. At least two photographs were taken with each camera per plot with the quadrat in place, and at least another two were taken with each camera per plot without the quadrat. A Teflon chip was used to normalize for entropy and to provide even data across light conditions for the Tetracam. Photographs of Plot 1 were taken with both cameras on October 6; Plots 2, 3, and 4 were photographed with the Lumix camera on October 31 and with the Tetracam on November 4; and Plot 5 was photographed with both cameras on November 4.

The corners of each plot were marked with flags, allowing for georeferencing through the use of an Earth-center, Earth-fixed Trimble GeoExplorer 6000 XT GPS roving unit. The unit was placed such that the internal sensor of the unit was over the flag at each corner of the quadrat for each plot. Coordinate fixes were taken at a sampling rate of one per second. The horizontal dilution of precision (HDOP) of the unit was set to 3.0 to ensure centimeter-level accuracy from trilateration after post-processing. Measurements were taken on November 21 (fixes for Plots 1 and 3), December 2 (an incomplete fix for Plot 2), December 3 (fixes for Plots 2, 4, and 5), and December 4 (a fix for one corner of Plot 4). Initial calibration had a carrier time of 45:00 minutes (at least 2700 fixes) in order to ensure a high confidence in the coordinates of the points gathered. Between 200 and 300 fixes were taken for each subsequent corner, as long as the carrier time did not reset and require recalibration. For each time the carrier time reset, the Trimble was left to recalibrate until the carrier time once again reached 45:00 minutes. Even with snow covering the fen on December 3 and 4, at least two flags from each of the remaining plots were exposed, allowing the quadrat to be placed down and used to collect accurate measurements for the corners where the flags were buried under the snow.

Labwork Methodology

The georeferenced quadrat corner coordinates were post-processed using GeoPathFinder Office. A Nation Geodetic Survey-regulated continuously-operating reference station (CORS) at Levitt Lane in Durham, New Hampshire, was used to correct for error. This base station was 12 kilometers from Sallie's Fen, and data was collected at a sampling rate of one fix per second.

Differential correction (DGPS) was then applied for carrier post-processing. The post-processed data was converted from the WGS 1984 geographic coordinate system to the NAD83 (2011) geographic coordinate system to match that of the data from the base station. The data was then exported to ArcMap, which was used to display post-processed points. Upon visual inspection of the post-processed data in ArcMap, a few points appeared to not follow the 1-meter square quadrat shape that was collected in the field. Information from ArcMap told that these points were skewed due to correction using an algorithmic code from the base station. These points were instead manually-corrected based off of other plot corners that were not adjusted by the algorithmic code and had a large number of fixes, allowing for high confidence in the accuracy of their positions.

Several statistical tests were applied to the collected data using JMP Pro 11 in order to compare percent cover of different species between cells and between plots. Bivariate linear fit regressions were plotted for each plant species against each *Sphagnum* species. Regressions were calculated for each of the plant species against a stack that combined all of the *Sphagnum* species together as a collective “moss stack.” Finally, all of the plant species were stacked and placed on a bivariate linear fit regression against the moss stack.

One-way ANOVA analyses and subsequent Tukey Tests with $\alpha=0.05$ were applied for each species to compare percent covers of a single species across the five plots. The Tukey Tests were reported as Connecting Letters Reports, in which plots assigned the same letters were similar in their composition and plots not connected by the same letter were significantly different from each other in terms of percent cover. Like with the bivariate linear fit regressions, stacks were created in order to explore patterns in functional type groups among the plants. The dry and normal *Sphagnum* mosses were stacked in order to identify trends in hydrology. Further, five species functional type groups were identified and stacked: mosses [*Sphagnum magellanicum* (normal), *Sphagnum magellanicum* (dry), *Sphagnum angustifolium* (normal), *Sphagnum angustifolium* (dry), and lichen]; ericaceous shrubs [*Kalmia angustifolia*, *Chamaedaphne calyculata*, *Vaccinium oxycoccos*, *Vaccinium corymbosum*, and *Vaccinium* (berry)]; vascular plants [*Carex rostrata* (live), *Solidago canadensis*, and *Eriophorum vaginaticum*]; litter [*Carex rostrata* (litter) and leaf litter]; and tree species [*Pinus strobus*]. One-way ANOVA analyses and Tukey Tests were applied for these stacks as well.

Shannon’s Index of Biodiversity [$Shannon's\ Index = -\sum p_i * \log(p_i)$] was calculated for each plot. A one-way ANOVA analysis and Tukey Test with $\alpha=0.05$ was performed on this data. Evenness was also calculated [$J' = \frac{H'}{H'_{max}}$, where H' is Shannon’s Index and $H'_{max} = -\sum \frac{1}{s} \ln \frac{1}{s}$].

Textural analysis of the point-and-shoot and Tetracam photos was analyzed in post-processing, and then was compared to measurements gathered from an Unmanned Aerial Vehicle (UAV), specifically an Aeronavis Droidworx MR6 Hexcopter. This drone includes autopilot, GPS tracking and stabilization, gimbles for rotor UAV, and the ability to switch out cameras or carry multiple cameras for fixed-wing UAV. The purpose of this comparison was to

investigate exactly what is in a particular fine-scale (1-meter) plot, in relation to a remotely-sensed image of the same plot.

Analyses included Entropy, Evenness, and Lacunarity. Entropy and evenness, which identify the diversity in the pixels, were estimated using Shannon's Index of Entropy and Simpson's Scale of Biodiversity. Each pixel was assigned a value between 0 and 255, where each value was a species. Shannon's Index of Entropy was calculated as the proportion of each species divided by the total in the plot, where the entire range of possible values spanned from 0 to 255 for an 8-bit, black-and-white image. This calculation accounted for richness and evenness. A separate evenness measurement was calculated for each plot by dividing entropy by the maximum entropy possible (the natural log of 255). In addition, the indices were calculated using the range of values from the Ikonos and Quickbird sensor (0-13 bits), as well as with the range (Max-Min) within each plot.

Lacunarity is a texture analysis technique that examines the extent and distribution of gaps in a dataset and identifies self-similarity across the landscape. Methods include semivariance, entropy, and crown delineation algorithms. Though usually used on binary data, the entire range of data was used based off of the mean and variance calculated on a moving window with spatial sizes of 1, 3, 5, 7, 11, 13, 15, 17, 21, and 51 (Malhi and Roman-Cuesta 2008). An Index of Translational Homogeneity (ITH) was calculated using the Lacunarity results by finding the x-intercept of the best fit of a linear regression as determined by the different moving window sizes. ITH is a measure of how self-similar gaps are as the scale widens across the image. It has been suggested that ITH is an index of average crown width. Fractal Dimension (FD) measures the complexity of the gaps in the landscape.

Results

Stacked bar graphs showing the percent cover distribution per plot by species and by functional group are shown in Appendix E. Many of the species found in lower abundances were only found in a few cells of select plots, while the more abundant species were found across all of the plots. The tree functional group, composed solely of *Pinus strobus*, was exclusively found in Plots 2 and 4. The litter functional group, comprised of *Carex rostrata* (litter) and leaf litter, was not found in Plot 1 since senescence had not yet begun for the season by the time data for that plot was collected.

Bivariate linear regressions were plotted for a number of species and species stacks. The only ones to have a statistically significant fit in the data were the regressions of stacked *Sphagnum magellanicum* versus *Carex rostrata* litter and stacked mosses versus stacked vascular plants. The relationship between stacked *Sphagnum magellanicum* and *Carex rostrata* litter was given by the equation $Carex\ rostrata\ (litter)\ Percent\ Cover = 10.693198 - 0.065279 * Sphagnum\ magellanicum\ Percent\ Cover$. This equation validates the idea that increased senescence of the *Carex rostrata* limits the amount of moss seen aerially. Mosses require sunlight, so increased litter initially diminishes net primary production. Once decomposed, the litter provides nutrients to the moss and sunlight attenuation decreases, benefitting the mosses. The relationship between

stacked mosses and stacked non-moss plants was given by the equation $Non\text{-}Moss\ Percent\ Cover = 4.7252304 - 0.016713 * Moss\ Percent\ Cover$. This relationship indicates that changes in moss cover do not greatly impact the presence of other plant species as a whole.

One-way ANOVA tests and corresponding Tukey tests with $\alpha=0.05$ were calculated for each of the species and species stacks. The following species were found to have statistically significant differences between plots: *Sphagnum magellanicum* (normal), *Sphagnum magellanicum* (dry), *Sphagnum angustifolium* (normal), *Sphagnum magellanicum* (dry), *Chamaedaphne calyculata*, *Kalmia angustifolia*, *Vaccinium oxycoccos*, *Carex rostrata* (litter), and leaf litter. Plots 1 and 3 were found to be statistically different for each of the *Sphagnum* species. Plot 1 was dominated by *Sphagnum magellanicum*, while Plot 3 was dominated by *Sphagnum angustifolium*. These plots were chosen purposely in order to determine whether aerial imaging could identify these species differently. Plot 1 had a higher abundance of dry *Sphagnum* species—the only to contain dry *Sphagnum angustifolium*, which is a hollow moss species that sits at the water table—which suggests a transition in the water table at this plot. For both *Chamaedaphne calyculata* and *Kalmia angustifolia*, Plots 1 and 4 were statistically different from Plots 2 and 3. Plots 1 and 4 were dominated by *Kalmia angustifolia*, while Plots 2 and 3 were dominated by *Chamaedaphne calyculata*. Plot 5 had a low amount of *Chamaedaphne calyculata* and no *Kalmia angustifolia*. *Vaccinium oxycoccos* was a dominant species in Plot 5 and was significantly different from the other four plots. *Carex rostrata* (litter) and leaf litter species were not found in Plot 1, but were similar across the other four plots.

Both of the stacked moss species [*Sphagnum magellanicum* (both normal and dry) and *Sphagnum angustifolium* (both normal and dry)] were found to have statistically significant differences between plots. The Tukey test performed on the stacked *Sphagnum magellanicum* species revealed a distribution identical to the Tukey test performed on the dry *Sphagnum magellanicum*: Plot 1 was found to be dominated by *Sphagnum magellanicum* and was statistically significantly different from the other plots. Stacked *Sphagnum angustifolium* was shown to have the same distribution as normal *Sphagnum angustifolium*: Plot 3 was dominated by the *Sphagnum angustifolium* species and was statistically different from the other four plots. As stated previously, Plots 1 and 3 were intentionally chosen in the field because upon initial observation, they showed differing moss species composition. The other three plots were selected because of their intermediate composition of both *Sphagnum* species, which was confirmed by performing these statistical tests.

All of the one-way ANOVA and Tukey tests for the stacks divided by functional species types were found to have statistically significant differences between plots (Appendix E). The only tree species found in any of the plots was *Pinus strobus*, and it was seen in Plots 2 and 4. The Tukey test revealed that Plot 2 and Plot 4 were significantly different from each other, as well as from the other plots. The stacked vascular plants (live *Carex rostrata*, *Solidago canadensis*, and *Eriophorum vaginaticum*) were divided into three statistically different groups: Plots 1 and 2; Plot 3; and Plots 4 and 5. The stacked ericaceous shrubs (*Kalmia angustifolia*, *Chamaedaphne calyculata*, *Vaccinium oxycoccos*, *Vaccinium oxycoccos* berry, and *Vaccinium*

corymbosum) were also divided into three statistically different groups: Plots 1, 2, and 5; Plot 3; and Plot 4. The Tukey test for stacked mosses (all of the *Sphagnum* mosses and lichen) revealed three significantly different groups: Plot 1; Plots 3 and 4; and Plots 2 and 5. The stacked litter (*Carex rostrata* litter and leaf litter) was divided into four statistically different groups: Plot 5; Plot 4; Plots 2 and 3; and Plot 1.

A comparison of the Tukey tests between the stacked moss species and a stack of all of the non-moss species found that similar significantly different groups emerged. For the moss species, Plot 1 had the highest mean percent cover; Plots 3 and 4 were statistically similar and had a moderate percent cover for each plot; and Plots 2 and 5 were statistically similar and had the lowest mean percent cover. For the stacked non-moss species, Plots 2 and 5 were statistically similar and had the highest mean percent cover of the plots; Plots 1, 3, and 4 were statistically similar and had a lower mean percent cover. The plots with the higher vascular plant cover had lower moss cover, while plots with higher moss cover had a lower presence of vascular plants. Since percent cover was only measured based on the species as seen aerially, lots of moss was seen in the absence of vascular plants, while vascular plants were seen more when moss cover was lower. However, the presence of vascular plants does not exclude the presence of moss; rather, the moss resided in the understory and could not be seen from an aerial view.

Shannon's Index of Biodiversity and species evenness were calculated for each cell, as well as across plots (Appendix E). The one-way ANOVA for biodiversity was significant, and the subsequent Tukey Test showed that Plot 4 was significantly different from Plots 1 and 3, and that Plot 5 was also significantly different from Plot 1. Results from the one-way ANOVA for species evenness were significant, and the following Tukey Test indicated that Plot 4 was significantly different from Plots 1, 2, and 3. Plot 4 had a mean Shannon's Index of Biodiversity of 0.709 and Plot 5 had a mean Index of 0.669, while the Plots 1, 2, and 3 had Indices of 0.582, 0.619, and 0.616, respectively. The species evenness for Plot 4 was 2.500, and the other plots had statistically similar values ranging between 1.953 and 2.215.

The textural analysis provided several sets of data. The fractal dimension values for the point-and-shoot camera ranged from 1.803306 to 1.835006, and the Tetracam ranged from 1.810223 to 1.845119. Plots 1 and 4 had the highest fractal dimensions, indicating that the gaps among the pixels for those plots' images were the most complex and self-similar. The Index of Translational Invariance ranged from 4.915996 in Plot 2 to 5.198904 in Plot 4 for the point-and-shoot camera images, and from 4.605314 in Plot 5 to 5.290524 in Plot 4 for the Tetracam images. The textural analysis also provided a calculation of Shannon's Index of Entropy for the point-and-shoot camera, Tetracam, and UAV images. The average Shannon's Index of Entropy for the point-and-shoot camera was 5.12538; for the Tetracam was 4.39855; and for the UAV was 4.79505. Higher entropies correspond with more complex environments.

A series of bivariate linear regressions were performed in an attempt to link the ground and aerial measurements. The only comparison to result in a statistically significant P-value was a bivariate linear regression of vascular plant percent abundance and fractal dimensions from the point-and-shoot camera ($R^2=0.8976$, $P=0.0144$) (Appendix F).

Discussion

A large number and diverse group of findings came about from the statistical tests performed on the dataset. The bivariate linear regression for all mosses versus all other plants was a nearly horizontal linear fit ($Non\text{-}Moss\ Percent\ Cover = 4.7252304 - 0.016713 * Moss\ Percent\ Cover$) and was statistically significant. A comparison of the one-way ANOVAs and Tukey Tests for all mosses versus all other plants revealed opposite results: while Plots 2 and 5 were statistically similar and Plots 1, 3, and 4 were statistically similar for both moss and non-moss species, the moss species had the highest mean percent cover in Plots 1, 3, and 4, while the non-moss species had the highest mean percent cover in Plots 2 and 5. These tests suggest that the presence of plants excludes the presence of moss, and vice versa. However, percent cover measurements were recorded based on an aerial viewpoint, and moss can reside in the understory of a multi-layered community. It can also be buried beneath a layer of defoliated plant litter. Therefore, the presence of moss excludes the presence of plants, but the presence of plants does not necessarily exclude the presence of moss. As such, it is important to note that carbon flux measurements or other calculations performed using this dataset will only account for the plant species visible from an aerial stance, even though the community structure is realistically more complex and dynamic.

Additionally, patterns of seasonal defoliation were evident in the data and affected the percent cover of moss. *Carex rostrata* and leaves from the surrounding mixed hardwood forest began senescing partway through the data collection season. To represent this defoliation, *Carex rostrata* (litter) and leaf litter were classified separately from their non-defoliated counterparts. Since this process was not yet evident when percent cover was collected for Plot 1, the Tukey Test for these species revealed that Plot 1 was statistically significantly different from the other plots, as expected. The bivariate linear regression comparing *Carex rostrata* (litter) to stacked normal and dry *Sphagnum magellanicum* was statistically significant and revealed that an increase in *Carex rostrata* (litter) occurred along with a reduction in *Sphagnum magellanicum*. When more litter is present, less moss can be seen aurally since the litter covers the moss. Moss requires sunlight, so the defoliation of *Carex rostrata* initially diminishes the primary production as a result of increased light attenuation. However, once the litter is decomposed, the amount of sunlight reaching the moss increases, along with an increased supply of nutrients from the decomposed litter, benefitting the moss.

Plot 4 had the highest species biodiversity as measured by Shannon's Index of Biodiversity. There was Plot 5 had the next highest measure of biodiversity. Plots 1, 2, and 3 had statistically similar measures of biodiversity and were lower than Plots 4 and 5. Biodiversity is a measure that reflects both species richness and evenness. The tree functional group was absent from Plots 1, 3, and 5, and the litter functional group was absent from Plot 1. This reduced species richness lowered the biodiversity of those plots. When accounting for the species within the functional groups rather than the functional groups as a whole, Plots 4 and 5 had the most species richness. Additionally, Plot 4 had a significantly higher measure of evenness than the

other four plots. This factor suggests that in addition to there being more types of species present in Plot 4, there was also a more even distribution of those species present across the plot.

Stacking the normal and dry *Sphagnum* species together provided insight about the differences in the nature of the two species. When the normal and dry *Sphagnum magellanicum* were stacked, the results from the stacked one-way ANOVA and Tukey Test were similar to the results from the dry *Sphagnum magellanicum* analysis: Plot 1 had the highest mean and was significantly different from the other plots. Additionally, the other four plots were found to be statistically similar, but Plots 2 and 4 had higher mean percent cover of *Sphagnum magellanicum* than Plots 3 and 5. However, as described above, it is very possible that seasonal defoliation can explain the higher mean percent cover of *Sphagnum magellanicum* in Plot 1, since senescence of vascular plants began to occur between when data collection occurred for Plot 1 and Plot 2. The presence of litter excluded the presence of the moss from an aerial perspective, causing the percent cover measurements to be skewed once the defoliation process began.

A different conclusion can be drawn from the results found from stacking the normal and dry *Sphagnum angustifolium* species. The stacked *Sphagnum angustifolium* results were akin to those calculated for normal *Sphagnum angustifolium*: Plot 3 had the highest mean percent cover of *Sphagnum angustifolium* and was significantly different from the other four plots. Furthermore, Plots 4, 5, and 1 were statistically similar, and Plots 1 and 2 were statistically similar based on the Tukey Test. Only Plot 1 had the presence of dry *Sphagnum angustifolium*, and even so, its presence as a dry species in that plot was limited. *Sphagnum angustifolium* is a hollow species that sits at the water table; since the water table is at the moss's surface, it is uncommon to be dry. As such, no change was expected between the individual normal *Sphagnum angustifolium* tests and the stacked *Sphagnum angustifolium* tests. This hypothesis was supported, as the dry *Sphagnum angustifolium* measurements had a very small influence on the species as a whole, as indicated by the lack of difference when comparing results of the statistical tests.

Chamaedaphne calyculata had a very strong presence in Plots 2 and 3, a moderate presence in Plots 1 and 5, and a lower presence in Plot 4. This distribution may be attributed to the fact that *Chamaedaphne calyculata* is one of the first species to colonize a region that contains *Sphagnum* mosses. *Chamaedaphne calyculata* anchors and extends the *Sphagnum* bog mat and also recovers quickly in disturbed ecosystems as long as *Sphagnum* mosses remain established. This quality suggests that *Chamaedaphne calyculata* is an opportunistic, r-selected species. Once species in the vascular plant and tree functional groups take root, they reduce the visibility of the ericaceous shrubs as seen aerially.

The presence of *Kalmia angustifolia* excluded the presence of *Chamaedaphne calyculata*. Plots 1 and 4 were statistically significantly different from the other plots and had a high percent cover of *Kalmia angustifolia*, while Plots 2 and 3 were statistically significantly different from the other plots and had the highest percent cover of *Chamaedaphne calyculata*. *Kalmia angustifolia* is allelopathic, meaning its roots exude chemicals that inhibit the growth of other species. Many studies have investigated the effect of its allelopathy on coniferous species,

particularly black spruce trees, but not as much with other ericaceous shrubs (Mallik 1987). It is possible that the opposite presence of these two species can be attributed to the allelopathic nature of *Kalmia angustifolia*. *Chamaedaphne calyculata* is shade-intolerant, so while the presence of *Kalmia angustifolia* may reduce the presence of *Chamaedaphne calyculata*, the allelopathy toward conifers may ultimately benefit the likelihood of the reestablishment of *Chamaedaphne calyculata*.

A bivariate linear regression of Shannon's Index of Biodiversity and evenness revealed a strong linear relationship. Although biodiversity incorporates evenness in its calculation, it is interesting to note that the other factors included in Shannon's Index of Biodiversity does not lower the significance of the relationship by much. There was a significant positive correlation, both for a regression of individual cells and for the mean values for the five plots. This finding indicates that the more ecologically diverse plots show a more even distribution of species across those plots.

The textural analysis of the different camera images provided insight about the capability of using spectral imaging in place of with in combination with taking ground measurements. Of all the bivariate linear regressions comparing ground and aerial measurements, only the regression of percent cover of vascular plants and the fractal dimensions from the images taken by the digital point-and-shoot camera was statistically significant ($R^2=0.8976$, $P=0.0144$). This finding shows that aerial images from a point-and-shoot camera may be used in place of or in tandem with ground measurements, which can save time in the field.

Classroom Extension

The Next Generation Science Standards

The Next Generation Science Standards (NGSS) is an outline of the student performance expectations that should guide science educators in the development of their curricula, units, and lesson plans (*Next Generation Science Standards* 2013). The NGSS was developed in order to combat the below-par performance of U.S. students in science and mathematics in comparison to other first-world countries. In addition to improving the low achievements in science and mathematics, the NGSS is meant to give students the proper preparation in order to succeed in careers in the workforce and to allow students to achieve appropriate scientific and technological literacy (National Research Council 2012).

The NGSS is comprised of three dimensions—practices, crosscutting concepts, and disciplinary core ideas—which together form standards that can be incorporated into the classroom (National Research Council 2012). This framework model was developed to reflect the interconnected nature of science, both as it is practiced by scientists and as it is experienced in the world. The NGSS cooperates with the Common Core State Standards and focuses on students gaining an understanding of content and an understanding of the application of the content. As such, the concepts outlined by the NGSS build coherently from kindergarten through the end of secondary school, and science and engineering are integrated together along the way (*Next Generation Science Standards* 2013). The structure of the framework of the NGSS is also

intended to allow for easy, simultaneous integration of all three dimensions by science educators in the classroom.

The practices guide scientific inquiry and outline the scientific method. Knowledge of course material and skills come together to shape the implementation of investigations in the classroom. The eight essential classroom practices outlined by the NGSS are asking questions and defining problems; developing and using models; planning and carry out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information (National Research Council 2012). The scientific method is important for students to understand in that it is an approach used to investigate, model, and explain phenomena. Being able to carry out a scientific experiment and to understand these practices requires critical thinking, which helps students to acquire a meaningful set of knowledge that can then be combined with crosscutting concepts and disciplinary ideas to create a complete scientific understanding.

Crosscutting concepts are overarching ideas that apply to and bridge different fields of science and engineering (National Research Council 2012). These concepts provide students with a framework with which they can build scientific knowledge and relate information across disciplinary boundaries. Crosscutting concepts are important in the development of consistent standards, curricula, units, and lesson plans. The crosscutting concepts outlined by the NGSS include patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter; structure and function; and stability and change (National Research Council 2012). The development of the crosscutting concepts was included to facilitate students' understanding of science as integrated disciplines, comprehension of the phenomena within the disciplines as interconnected ideas, and recognition that the same concepts are relevant across different contexts. For this reason, the crosscutting concepts themselves are meant to be taught mutually, rather than in isolation from one another.

Disciplinary core ideas are content-focused and explore the systems and processes that underlie the different scientific fields. The fields are divided and arranged into four areas based on scientific domain: physical science; life science; earth and space science; and engineering, technology, and applications of science (National Research Council 2012). Each of these content areas is comprised of components that outline important core learning competencies that should be developed over the course of a student's education. The particular components outlined in the NGSS were chosen because they have broad importance over many scientific disciplines or are important in organizing the principles of a particular discipline; provide a tool for understanding or investigating complex ideas and solving problems; relate to life experiences, societal concerns, or technological knowledge; and are teachable and learnable over multiple grade levels in increasing depth or sophistication (National Research Council 2012). The intention of the organization of the disciplinary core ideas is to strengthen science proficiency in a coherent progression from kindergarten through the end of secondary school. Specified goals, called grade

band end points, are outlined for each component of each disciplinary core idea. Grade band end points are set for the end of grades 2, 5, 8, and 12 (National Research Council 2012).

Standards Covered in this Study

The study at Sallie’s Fen made use of a number of practices, crosscutting concepts, and disciplinary core ideas included in the NGSS. As this was a scientific study, the entire scientific method was covered, indicating that all of the practices were included in some fashion. The initial step was to ask a question and define a problem. For this study, that question was, “Can fine-scale plant species identification be done using remote sensing or satellite imagery?” This question is important in that being able to identify plant species at a fine scale using such technology can allow for more accurate carbon flux measurements for the whole fen, and can then potentially be applied to other ecosystems. Ground-based measurements and photographs were taken in order to carry out the investigation and to assess the accuracy of the computer models created using the remote sensing and satellite imagery. The data was analyzed through mathematics and computational thinking in the form of statistical analyses, computer programs, and algorithms. The results were interpreted in order to determine the effectiveness of the model. The writing of this paper then allowed for constructing explanations in regard to the original scientific question, evaluating the design solution of the experiment, deriving and defending a claim based on evidence, and communicating scientific information in multiple formats.

This study primarily explored the crosscutting concept of scale, since the question under investigation was whether plant species could accurately be identified at a finer scale. Structure and function were explored in that composition of the plots was determined both through ground observations and through remote sensing and satellite imagery. The long-term goal and big-picture purpose of this study was to more precisely model the carbon cycle—and specifically, more precisely measure carbon flux within Sallie’s Fen—which extends into the crosscutting concept of systems and system models.

The disciplinary core ideas investigated in this study came from a wide range of domains, supporting the integrative framework of the NGSS. Standards were incorporated from the physical sciences (PS), the life sciences (LS), and engineering, technology, and science (ETS). Cycles of matter and energy transfer in ecosystems (LS2.B) were the central, overarching focus of this study. Ecosystem dynamics, functioning, and resilience (LS2.C) were touched upon as well, in that spatial variability of plant species was considered. The study made extensive use of information technology and instrumentation (PS4.C) in the form of cameras, GPS units, and computer programs and software. Since this study relied heavily on engineering and, more so, technology to carry out the scientific investigation, it makes sense that there was a clear interdependence between science, engineering, and technology (ETS2.A) (*Next Generation Science Standards* 2013).

Incorporation in the Classroom

While this study may not lend itself directly to a classroom setting, modifications could be made to allow students to explore the sciences and to meet these same standards. A mini-unit was created in order to allow for a classroom-friendly experience that could allow secondary school students to apply their learning from a traditional unit studying ecosystem science and to

further their exploration in the field. This mini-unit is expected to take seven or eight 90-minute class periods, including a field trip to a local bog that extends throughout the school day. In the absence of a nearby bog, this mini-unit and corresponding field trip could be adapted for identifying tree species in a forest.

On day one, students are introduced to plant species identification, the concept of a dichotomous key, and percent cover. The carbon cycle and carbon flux is the focus of the second lesson. Day three provides an overview of GPS technology and the computer ImageJ. The day-long field trip is scheduled for the fourth day. Students travel to a local bog and work in teams to identify species and gather percent cover data. Additionally, teams take turns operating a handheld GPS taken into the field in order to georeference their plots. Two days are allotted to enter collected data into Excel; to calculate mean percent cover, Shannon's Index of Biodiversity, and evenness for the plots; to use an aerial image of the field trip location in ImageJ to calculate the same three parameters; and to analyze their data. Analysis will consist of a comparison of ground-based and aerial image calculations, a quantitative estimation of carbon flux using species abundance and carbon flux rates for the different species, and interpretation of differences in biodiversity and species abundance between plots. In the final day of the mini-unit, students will engage in a discussion in which they summarize their analyses and further their thinking by discussing the advantages and disadvantages of using ground-based measurements and measurements derived from aerial images, and how human activity and climate change may alter or affect biodiversity and species abundance. A formalized unit outline is provided in Appendix E. A detailed lesson plan for the first lesson is provided in Appendix F.

Many specific standards are addressed in this mini-unit, and like the disciplinary core ideas, span several topics. Physical science standard HS-PS4-5 indicates that students should be able to "communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy" (*Next Generation Science Standards* 2013). This unit makes use of GPS technology, so during one of the introductory lessons, students will gain an understanding of how GPS technology works. They will then handle a GPS and collect reference data in the field later in a subsequent lesson. Life science standard HS-LS2-2 states that students should "use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales" (*Next Generation Science Standards* 2013). Students estimate percent cover of different species and then calculate Shannon's Index of Biodiversity. Scaling differences are introduced when comparing individual plots versus the whole ecosystem. Life science standard HS-LS2-5 indicates student should be able to "develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere" (*Next Generation Science Standards* 2013). Students will be introduced to the carbon cycle and carbon flux, as the purpose of identifying percent cover and biodiversity during the field trip is to better understand the biosphere-atmosphere interface in the carbon cycle. Life science standard HS-LS2-7 dictates that students should "design, evaluate, and refine a solution for reducing the

impacts of human activities on the environment and biodiversity” (*Next Generation Science Standards* 2013). At the end of the mini-unit, students will be asked to further their thinking about ecosystem science by thinking about and discussing how climate change and human activity may affect percent cover and biodiversity. Like HS-LS2-5, earth and space science standard HS-EES2-6 investigates the carbon cycle, but requires students to “develop a quantitative model to describe the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere” (*Next Generation Science Standards* 2013). Students will analyze and interpret their data collected from the field trip in order to quantitatively represent carbon flux across the biosphere-atmosphere interface. The engineering, technology, and science standard HS-ETS1-4 requires students to “use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions with and between systems relevant to the problem” (*Next Generation Science Standards* 2013). After identifying the plant species and measuring percent cover in the field, students will calculate Shannon’s Index of Biodiversity. Furthermore, they will calculate the same parameters using a computer software program. As part of their discussion at the end of the mini-unit, students will discuss the advantages and disadvantages of using ground-based measurements versus measurements obtained from the computer simulation. It is evident that the standards covered in this lesson span several content areas, which is indicative of the interdisciplinary nature of environmental science and field research.

Conclusion

This study attempted to identify fine-scale plant species communities in Sallie’s Fen, a nutrient-poor fen in Barrington, New Hampshire, in order to refine carbon flux models for the site. Ground measurements identified percent cover of different species and functional groups as seen aerially. Photographs from three different types of cameras were used in order to identify whether spectral imaging can be used in place of or in conjunction with ground measurements. The ground measurements revealed that the presence of *Sphagnum* moss excluded the presence of other plant species, but the presence of other plant species only reduced the visibility of *Sphagnum* since it resides in the understory of a multi-layered community. As a result, carbon flux models developed using this data and protocol will be more simplified than the actual community since technique only accounts for the community’s canopy structure. It was also found that a textural analysis of the photographs taken by the digital point-and-shoot camera was statistically significantly correlated with the percent cover of the vascular plant functional group. Because of this correlation, images taken with the digital point-and-shoot camera can successfully identify fine-scale plant communities, thereby saving time in the field in comparison with making ground measurements.

This project was also adapted into a curriculum that can be implemented in a secondary classroom. This curriculum was composed of seven lessons that can be incorporated as a full unit or as individual investigations. The curriculum allowed for fun, hands-on scientific inquiry while aligning with the Next Generation Science Standards. Six standards were covered across four

content areas, highlighting the interdisciplinary nature of science and research. The curriculum consisted of an introduction to ecosystem science, gathering of data using technology and scientific instrumentation, and an analysis and synthesis of the data. The development of this curriculum accounted for curricular, time, and resource limitations often found in secondary classrooms. The purpose of this classroom extension was to inspire educators to develop curricula that better reflect the interdisciplinary nature of science. Hopefully students exposed to such curricula will be more engaged in the coursework and recognize the importance of scientific inquiry.

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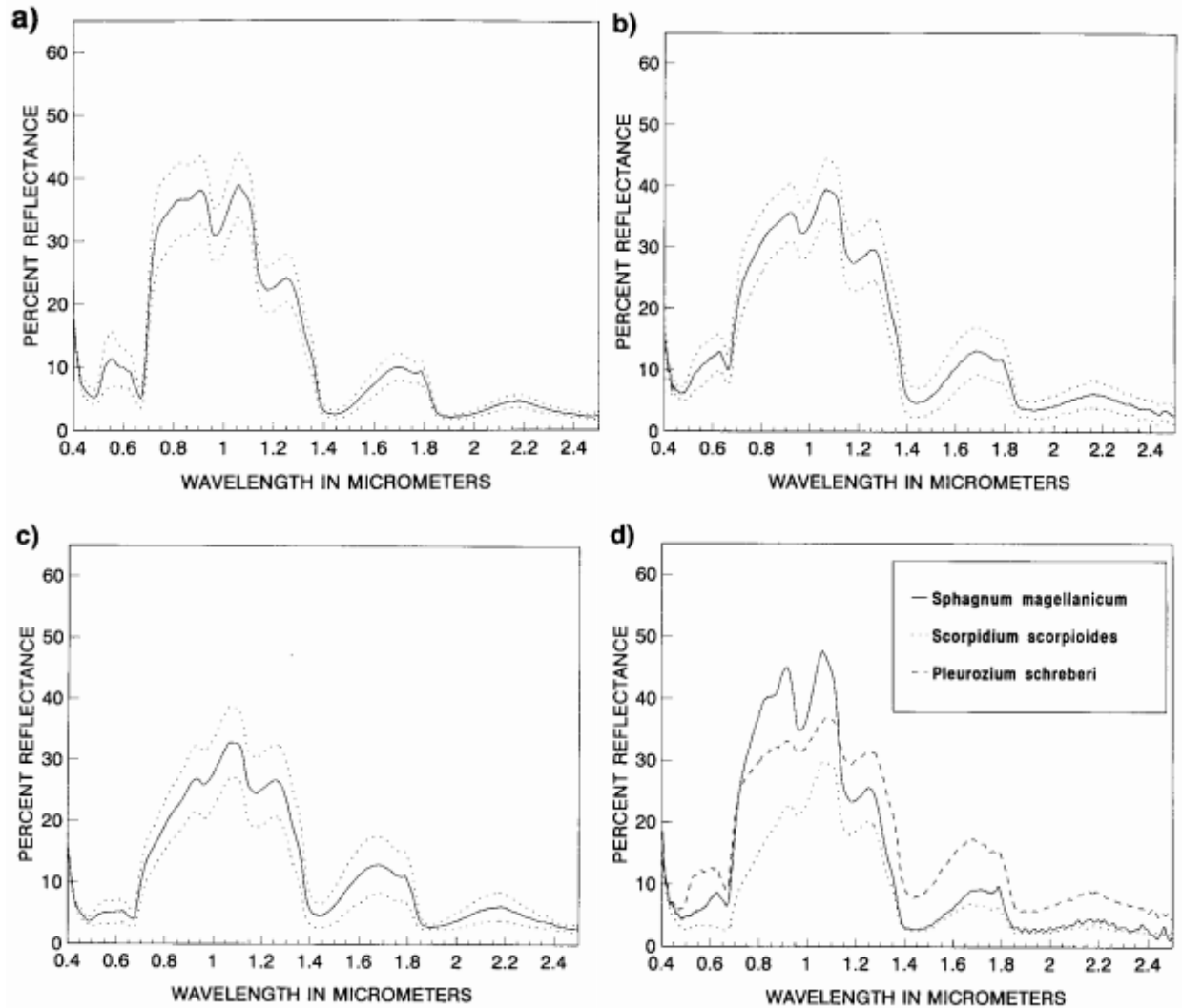
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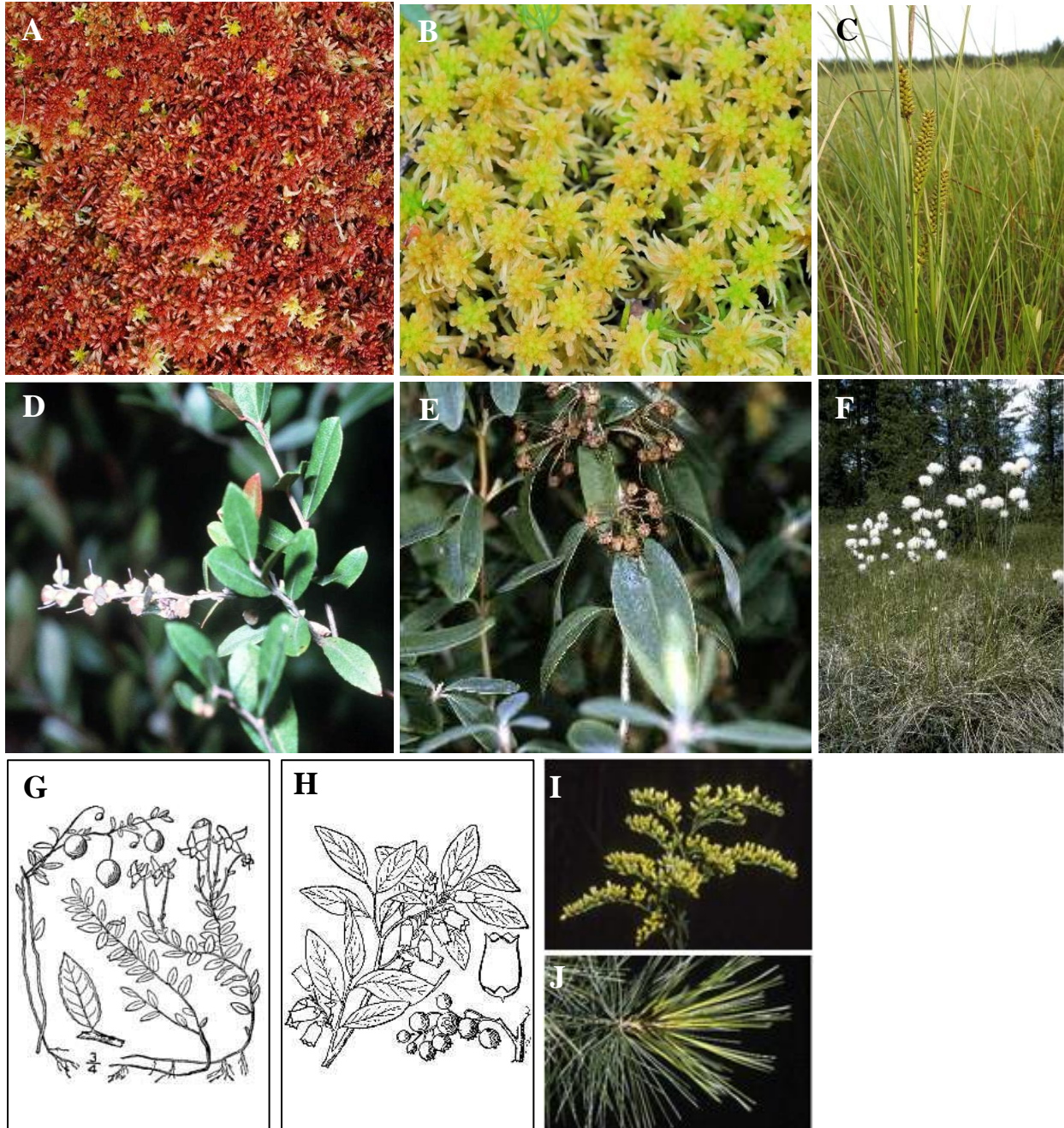
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Appendix

Appendix A (Figure 1): Spectral reflectance curves for (a) *Sphagnum* mosses, (b) feather mosses, and (c) brown mosses. The spectral reflectance curve of *Sphagnum magellanicum* is represented as the solid line in graph (d). These unique spectral reflectance curves were used to distinguish between species at Sallie's Fen. Image taken from Bubier et al. (1997).



Appendix B (Figure 2): Plant species identified at Sallie's Fen. Moss species included (a) *Sphagnum magellanicum* (Schou 2003) and (b) *Sphagnum angustifolium* (Schou 2003). Plants and shrubs identified included (c) *Carex rostrata* (Cameron 2014), (d) *Chamaedaphne calyculata* (Mohlenbrock 1989), (e) *Kalmia angustifolia* (Mohlenbrock 1995), (f) *Solidago canadensis* (Mohlenbrock 1995), (g) *Vaccinium oxycoccos* (Britton and Brown 1913), (h) *Vaccinium corymbosum* (Britton and Brown 1913), (i) *Eriophorum vaginatum* (Mohlenbrock 1995), and (j) *Pinus strobus* (Mohlenbrock 1995). Lichen, leaf litter, and *Carex rostrata* litter were also included as observations.



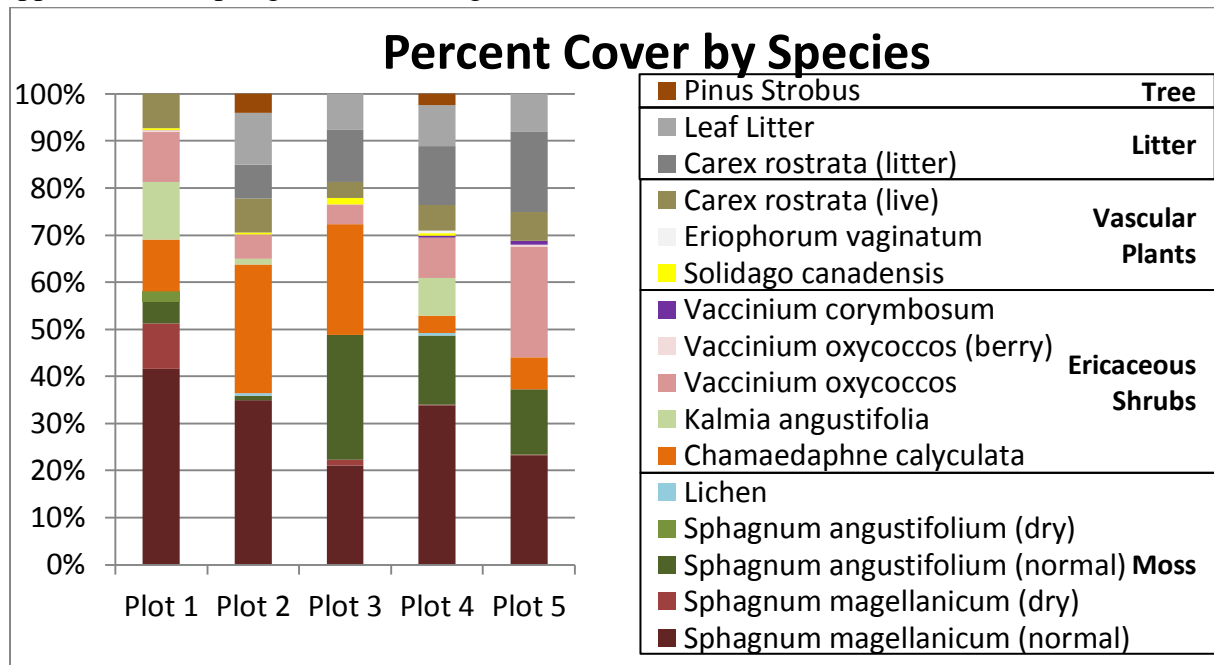
Appendix C (Figure 3): Aerial map of the study site, Sallie's Fen in Barrington, New Hampshire. The five one-meter by one-meter plots are identified.



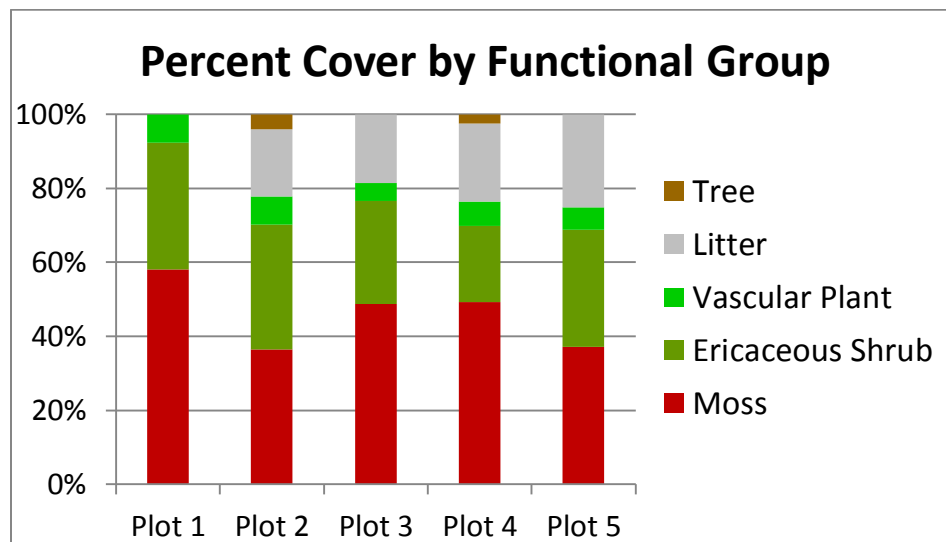
Appendix D (Figure 4): Pole Mapping Rig. Example of a pole rig, which is suspended above the plot under observation for photographing for mapping (gclout01 2003). In addition to being suspended on the pole rig, the camera was connected to a display monitor to ensure that the whole plot was in the scope of the picture. Additionally, a clicker was attached to the camera such that the user at the ground could take the photograph, rather than take continuous photographs as the camera was adjusted into place.



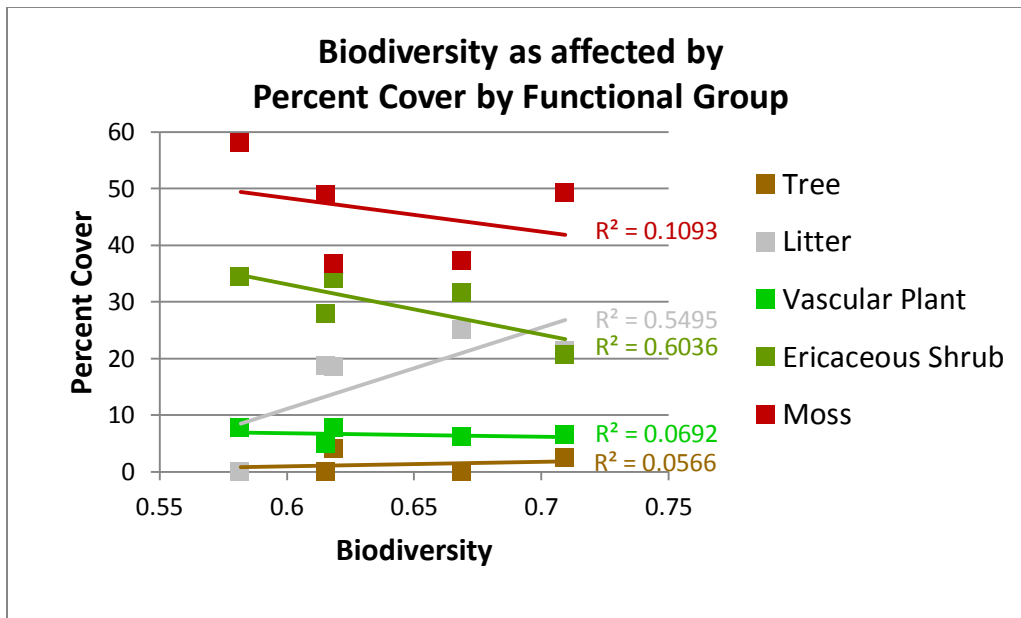
Appendix E: Graphs generated from ground measurement data.



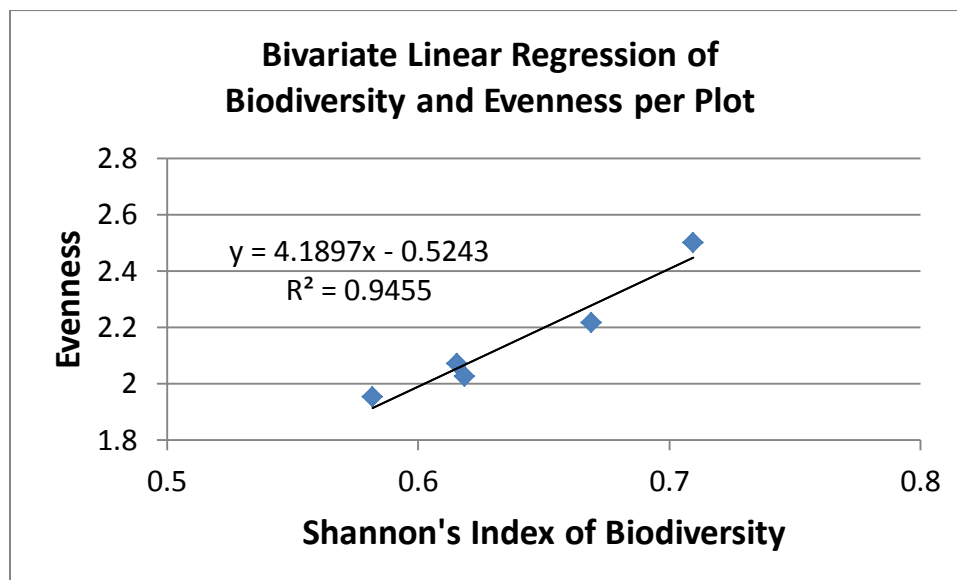
(Figure 5) Percent cover by species per plot. *Sphagnum magellanicum* (normal) was very prevalent in all of the plots, dominating Plot 1. *Sphagnum angustifolium* (normal) dominated Plot 3. Leaf litter and *Carex rostrata* litter were not seen in Plot 1. *Pinus strobus* was only seen in Plots 2 and 4. Within plots, the presence of *Kalmia angustifolia* possibly reduces the abundance of *Chamaedaphne calyculata* due to allelopathy.



(Figure 6) Percent cover of each functional group by plot. Mosses were the most abundant functional group for all of the plots. Ericaceous shrubs were also prominent. The abundance of vascular plants was roughly the same across all of the plots. Litter was not found in Plot 1 since senescence had not yet begun, indicating patterns of seasonal defoliation. The tree functional group was only found in two plots.

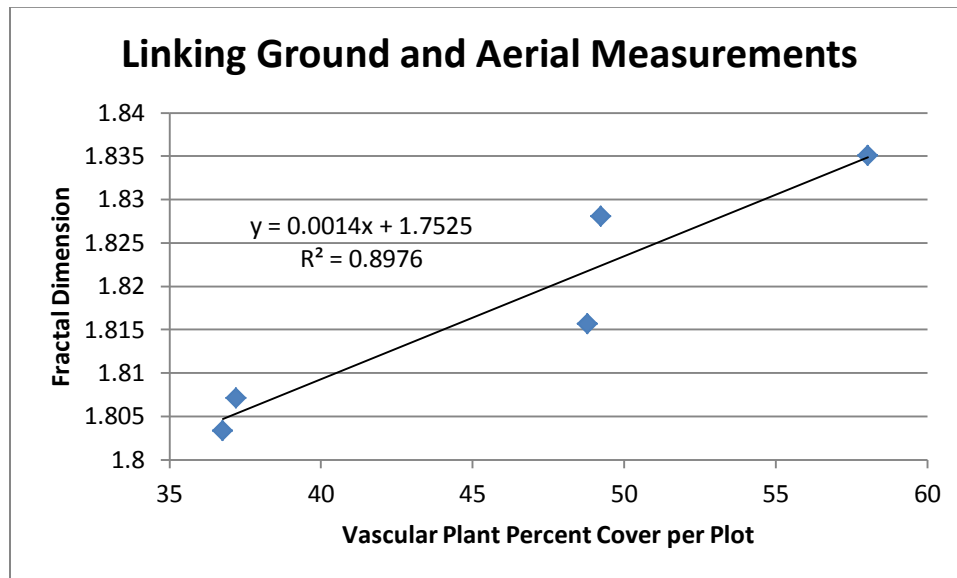


(Figure 7) Biodiversity versus mean percent cover of functional groups. Increases in litter abundance coincide with increases with biodiversity and decreases in the abundance of other functional groups. Although these linear regressions are not significant, the relationships between biodiversity and many of the species within the functional groups are significant.



(Figure 8) Bivariate linear regression of biodiversity and evenness. More biodiverse plots show more evenness of the species across the plots. This distribution could be due to patterns of succession as the community matures. *Sphagnum* mosses form the base of the community. *Chamaedaphne calyculata* is an opportunistic species that anchors the moss mat. *Kalmia angustifolia* can use allelopathy to outcompete the *Chamaedaphne calyculata*. Tree species become present late in succession. In addition, species abundance in the biodiversity calculation only relied on the species present in the uppermost layer of the multilayered community.

Appendix F (Figure 9): Linking ground and aerial measurements. Bivariate linear regression of vascular plant abundance and fractal dimensions from the textural analysis of the point-and-shoot camera. This comparison was statistically significant ($R^2=0.8976$, $p=0.0144$), indicating that ground and aerial measurements can be linked. Knowing this relationship, it is possible to collect images over a larger span of the site and more confidently estimate percent cover. Collecting data using point-and-shoot cameras saves time and money in comparison with collecting data using ground observations.



Appendix G (Figure 10): Mini-unit outline for a classroom-friendly adaptation of the fieldwork and research done for this project.

Context and Rationale: After completing a traditional unit on ecosystems (which introduces concepts of carrying capacity, biodiversity, energy flow, nutrient cycles, and human influence on ecosystems), it is important for students to apply their knowledge. This series of lessons allows students to further their exploration of ecosystem science through data collection, working with technological instrumentation, and interpreting their data.

Lesson	Learning Objective	General Description
1	<p>Be able to identify and distinguish between plant and moss species.</p> <p>Successfully estimate percent cover of plant species in a plot.</p> <p>STANDARD USED: HS-LS2-2</p>	<p>Students will be introduced to plant (or tree) species found in a local fen, bog, or forest (depending on field trip destination) and identification of those species using a dichotomous key via PowerPoint. Samples of plants will then be supplied for groups, and groups will identify species using a dichotomous key.</p> <p>Students will be introduced to percent cover and Shannon's Index of Biodiversity as a continuation of the PowerPoint. Students will then have a handout with which they estimate the percent cover of different "species" within a plot. Using their estimates, they must then calculate Shannon's Index of Biodiversity.</p>
2	<p>Be able to draw and label components of the carbon cycle and the links that connect the different pools.</p> <p>Understand how carbon flux from the biosphere to atmosphere occurs via plant respiration.</p> <p>STANDARD USED: HS-LS2-5</p>	<p>A PowerPoint will be used to give an overview of the components of the carbon cycle. Further, we will discuss how carbon flux occurs across earth's spheres and the links that connect the spheres. The presentation will conclude with understanding that different species have different respiration rates, so plant species identification and percent cover can be used to estimate carbon flux. Students will then be asked to draw a picture that illustrates the carbon cycle.</p>
3	<p>Be able to understand how GPS works.</p> <p>Be able to understand how to use computer program to analyze data.</p> <p>STANDARD USED: HS-PS4-5</p>	<p>Students will learn about GPS technology via YouTube videos about how GPS works. The video "How Does GPS Work (2005)" https://www.youtube.com/watch?v=0n0T992ccik introduces the concept. The video "How Does GPS Work?" https://www.youtube.com/watch?v=vfzAL5L29Y can be used to further explore the technology. Students will then be provided step-by-step instructions on how to operate a handheld field GPS. Students will work in groups to try operating the GPS.</p> <p>Students will then be exposed to the computer software ImageJ, which will be used to analyze data collected during the field trip.</p>

4	<p>Collect plant species and percent cover data in a field trip.</p> <p>Collect GPS points for plots.</p>	<p>Students will take a field trip to a local bog or fen (or a nearby forest), depending on availability and distance. Students will be divided into six groups to identify plant species and percent cover in five predetermined plots. Groups will take turns measuring the plot corner coordinates using the GPS. Additionally, teams will collaborate to complete a plot, then will rotate to other plots in order to compare values gathered by other teams. Teams will have access to a dichotomous key and the teacher as field resources. A worksheet for recording species identification and percent cover will be provided to be filled out in the field.</p>
5	<p>Enter plant species and percent cover data into computer.</p> <p>Compute quantitative measurements in computer program ImageJ.</p> <p>STANDARD USED: HS-ETS1-4</p>	<p>Students will enter plant species and percent cover data into an Excel spreadsheet, then will calculate mean percent cover, biodiversity, and evenness for the plots.</p> <p>Students will also use the computer program ImageJ to calculate mean percent cover, biodiversity, and evenness using an aerial (satellite) image.</p>
6	<p>Analyze results from computer program in context of plant species biodiversity and abundance.</p> <p>Quantitatively estimate carbon flux.</p> <p>STANDARD USED: HS-EES2-6</p>	<p>Students will analyze the results from the Excel spreadsheet and computer program. Students will quantitatively estimate carbon flux using carbon flux rates for different species and species abundances.</p> <p>Students will compare values from the two in order to determine whether ground and aerial image calculations provide similar results. They will also be asked to create a short write-up in which they identify which species are more abundant and how biodiversity differs between plots.</p>
7	<p>Be able to discuss and synthesize results regarding biodiversity and abundance.</p> <p>Be able to apply knowledge in context of ecosystem change and human activity.</p> <p>STANDARD USED: HS-LS2-7</p>	<p>Students will engage in a discussion in which they discuss their write-ups. Topics will include species abundance and biodiversity as seen in the field trip; advantages of using ground-based measurements versus measurements derived from aerial images; and how this ecosystem may change in the context of climate change due to human activity.</p>

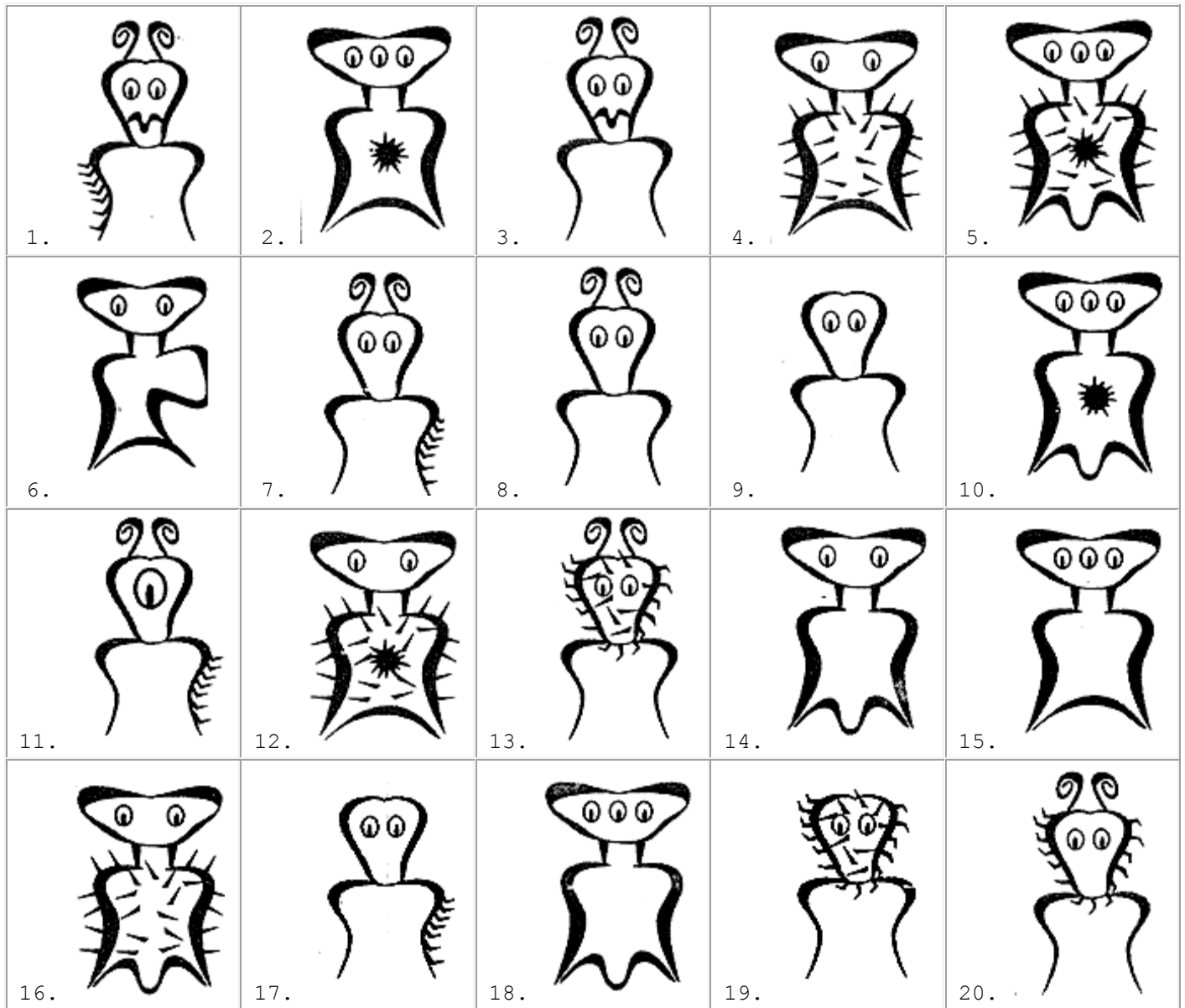
Appendix H (Figure 11): Detailed lesson plan for Day 1 of mini-unit.

Title of lesson: Plant Species, Percent Cover, and Biodiversity
Grade Level: Secondary school
Time: 90 minutes
Topic of Main Idea: This lesson introduces the basic concepts that serve as the foundation for collecting data in the upcoming fieldtrip. Students will have already been introduced to the ideas of species biodiversity and scale. Students will use a dichotomous key to identify species, estimate the percent cover of species, and understand how to calculate species biodiversity using percent cover.
Objectives: By the end of the lesson, students will be able to use a dichotomous key, identify and distinguish between plant species using a dichotomous key, estimate percent cover, and calculate biodiversity of species using percent cover.
Standards Used: HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.
<p>Materials:</p> <ul style="list-style-type: none"> • PowerPoint presentation • Computer • Projector • Pamishan Creatures Activity and Dichotomous Key • Plant samples corresponding with plant species found at fieldtrip location and Dichotomous Key • Percent Cover/Shannon's Index worksheet
Activity: Students will be introduced to biodiversity through the plant species found at a local bog (which later in the mini-unit will serve as the fieldtrip destination) via a PowerPoint presentation ("Plant Species, Percent Cover, and Biodiversity"). This PowerPoint will lead into an introduction of how to use a dichotomous key in order to distinguish between species. After the slide about "Dichotomous Keys," students will then be given a worksheet and asked to use a dichotomous key to classify the Pamishan creatures. The next slide on the PowerPoint is an aerial view of the fieldtrip location, to give students a setting for where the plant species for the next activity will be found. An assessment will be given in which students identify plant samples corresponding to plant species found at the fieldtrip location (assessment 1). Once the class successfully identifies the plant species, students will be introduced by continuing PowerPoint to measuring percent cover and calculating Shannon's Index of Biodiversity using percent cover. A worksheet will then be provided to have the students practice estimating percent cover and calculating Shannon's Index of Biodiversity (assessment 2).
Assessment: (1) Students will be asked to identify plant species samples corresponding to species found at the fieldtrip location at their tables using a dichotomous key. The teacher will assess students based on observation of their ability to successfully identify species. (2) Students will be given a worksheet to practice estimating percent cover and calculating Shannon's Index of Biodiversity. This activity will contain 100-cell grids that are color-coded, such that each color represents a different species. Students will have to estimate the percent cover of each species. Then using their percent cover values, students will calculate H' .
Homework: None.
Modifications: Paraprofessionals will be given the lesson plan ahead of time so that they can

best modify any aspect of the lesson for their special needs student, the blind, and/or the deaf. For students that need presentation accommodations, have another student share class notes so that they can pay attention to the presentation rather than having to multitask with listening and writing notes down. For students that require setting accommodations, this lesson heavily relies on group collaboration. Even for the percent cover worksheet, students can work in groups and discuss their process. Students will have use of a calculator for the percent cover worksheet to accommodate students with response modifications. Students who are colorblind can have the percent cover worksheet adapted such that “species” are distinguished by texture or pattern (dots, stripes, etc.) instead of by color. There will 3-minute breaks between activities to accommodate students that have difficulty focusing their attention for long periods of time. Each activity will have an allotted completion time, so advanced students that finish the activities early will not be “waiting” for other students to finish, and students that take longer to complete the assignment can be brought up to speed.

Taxonomy, Classification, and Dichotomous Keys

Help! Scientists have discovered quite a few new creatures on planet Pamishan. They need your help to identify and classify them. Use the dichotomous key on the next page to identify these creatures.



A Key to New Pamishan

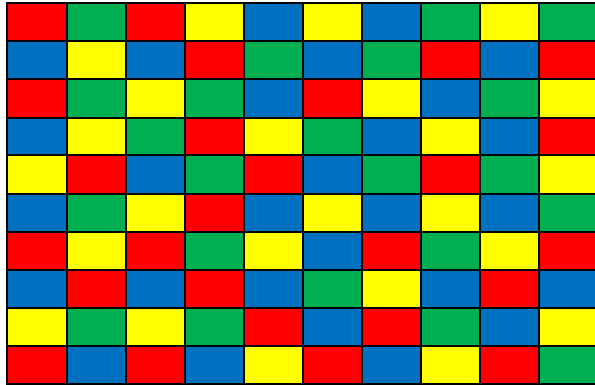
1. a. The creature has a large wide head.....go to 2
b. The creature has a small narrow head.....go to 11
2. a. It has 3 eyesgo to 3
b. It has 2 eyesgo to 7
3. a. There is a star in the middle of its chest.....go to 4
b. There is no star in the middle of its chestgo to 6
4. a. The creature has hair spikes*Broadus hairus*
b. The creature has no hair spikes.....go to 5
5. a. The bottom of the creature is arch-shaped*Broadus archus*
b. The bottom of the creature is M-shaped*Broadus emmus*
6. a. The creature has an arch-shaped bottom*Broadus plainus*
b. The creature has an M-shaped bottom.....*Broadus tritops*
7. a. The creature has hairy spikesgo to 8
b. The creature has no spikes.....go to 10
8. a. There is a star in the middle of its body*Broadus hairystarus*
b. There is no star in the middle of its bodygo to 9
9. a. The creature has an arch shaped bottom*Broadus hairyemmus*
b. The creature has an M shaped bottom*Broadus kiferus*
10. a. The body is symmetrical*Broadus walter*
b. The body is not symmetrical.....*Broadus anderson*
11. a. The creature has no antennaego to 12
b. The creature has antennaego to 14
12. a. There are spikes on the face*Narrowus wolfus*
b. There are no spikes on the facego to 13
13. a. The creature has no spike anywhere*Narrowus blankus*
b. There are spikes on the right leg*Narrowus starboardus*
14. a. The creature has 2 eyes.....go to 15
b. The creature has 1 eye.....*Narrowus cyclops*
15. a. The creature has a mouth.....go to 16
b. The creature has no mouth.....go to 17
16. a. There are spikes on the left leg*Narrowus portus*
b. There are no spikes at all*Narrowus plainus*
17. a. The creature has spikesgo to 18
b. The creature has no spikes*Narrowus georgia*
18. a. There are spikes on the headgo to 19
b. There are spikes on the right leg.....*Narrowus montanian*
19. a. There are spikes covering the face*Narrowus beardus*
b. There are spikes only on the outside edge of head .*Narrowus fuzzus*

Dichotomous Key for Plant Species at Sallie's Fen

1. a. The plant is a moss.....go to 2
b. The plant is not a moss.....go to 4
2. a. The moss is not growing in a mat.....Lichen
b. The moss is growing in a mat.....go to 3
3. a. The moss is red.....*Sphagnum magellanicum*
b. The moss is green.....*Sphagnum angustifolium*
4. a. The plant is a tree.....*Pinus strobus*
b. The plant is not a tree.....go to 5
5. a. The plant is a vascular plant.....go to 6
b. The plant is an ericaceous shrub.....go to 8
6. a. The plant has small yellow flowers.....*Solidago canadensis*
b. The plant does not have small yellow flowers....go to 7
7. a. The leaves look like grass.....*Carex rostrata*
b. The leaves are at/near the base of the plant....*Eriophorum vaginatum*
8. a. There is more than leaf per node.....*Kalmia angustifolia*
b. There is one leaf per node along the stem.....go to 9
9. a. The edge of the plant's leaves have teeth.....*Chamaedaphne calyculata*
b. The edge of the plant's leaves are smooth.....go to 10
10. a. The bark peels easily or hangs off.....*Vaccinium corymbosum*
b. The bark is thin and smooth.....*Vaccinium oxycoccos*

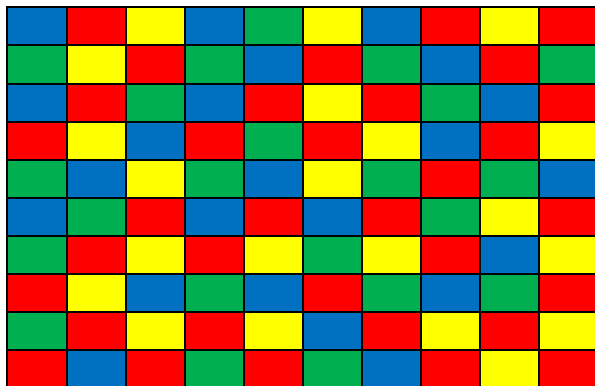
Percent Cover and Shannon's Index of Biodiversity

Each color represents a different species. Count up how many boxes are of each color. Translate this value into a percentage, considering there are 100 boxes. This percentage is percent cover. Then calculate Shannon's Index of Biodiversity [$H' = \text{negative sum of } (p_i * \ln p_i)$], where p_i is percent cover as a decimal and \ln is the "natural log" function on your calculator.



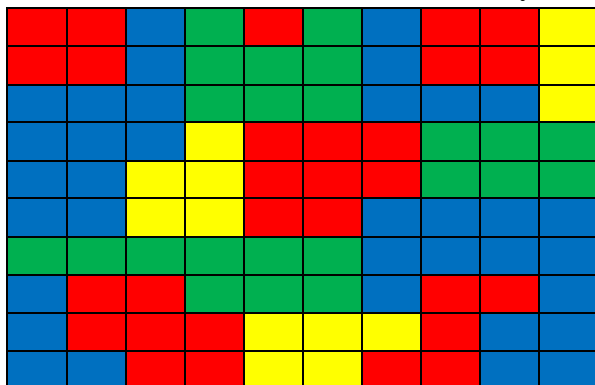
Red _____ boxes, _____ %
 Blue _____ boxes, _____ %
 Green _____ boxes, _____ %
 Yellow _____ boxes, _____ %
 Shannon's Index of Biodiversity: $H' =$ _____

Estimate the percent cover for each color, without counting. Once you have an estimate, count up the number of boxes of each color and see how close you came. There are still 100 boxes.



Red _____ % estimated, _____ % actually
 Blue _____ % estimated, _____ % actually
 Green _____ % estimated, _____ % actually
 Yellow _____ % estimated, _____ % actually
 H' from estimated percent cover = _____
 H' from actual percent cover = _____

Often times, species will be grouped together. This is called **aggregation**. Even though the colors are aggregated, when you estimate percent cover, you still need to consider each box. Estimate the percent cover of each color. Once you have an estimate, count up the number of boxes of each color and see how close you came. There are still 100 boxes.



Red _____ % estimated, _____ % actually
 Blue _____ % estimated, _____ % actually
 Green _____ % estimated, _____ % actually
 Yellow _____ % estimated, _____ % actually
 H' from estimated percent cover = _____
 H' from actual percent cover = _____