Remote Sensing of Vegetation Patterns of Big Meadow Bog:

Classifying high resolution UAV data to support Adaptive Management of Restoration.

Ian Manning, Dr. Nick Hill, Bill Livingstone, David Colville
NSCC Applied Geomatics Research Group, February 2018.

Paul Illsley (NSCC - AGRG Research Associate) facing-southeast towards Big Meadow Bog launches eBee SenseFly fixed-wing UAV with multispectral sensor from Brier Island Air Strip, October 2017. Photo by Ian Manning.

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Introduction

This paper presents and interprets results from various drone-based aerial surveys by the Nova Scotia Community College Applied Geomatics Research Group (AGRG). AGRG researchers used UAVs equipped with sensors that captured visible and infrared images to remotely track vegetation at Big Meadow Bog, prior to and following its hydrological restoration. The purpose of the restoration was to help in the recovery of the Endangered eastern mountain avens (Avens) (see Action Plan: Environment Canada 2016). The restoration of Big Meadow and the recovery of the Avens are interlinked as the former is the principal habitat of the latter. Big Meadow is a wetland peatland complex that developed over the past 2000 years (Spooner et al, 2017). The central raised bog (Leverin, 1948) is surrounded by fen that in turn is enveloped along the bog's long axis by sloping swamps (Figure 1). Each of these wetland types have distinctive vegetation. This report focuses on the central bog and its lagg zone which have been drastically altered by agricultural ditching (1958) and the disturbance and eutrophication resulting from thousands of nesting Herring Gulls (*Larus argentatus*) (from 1978 to present).

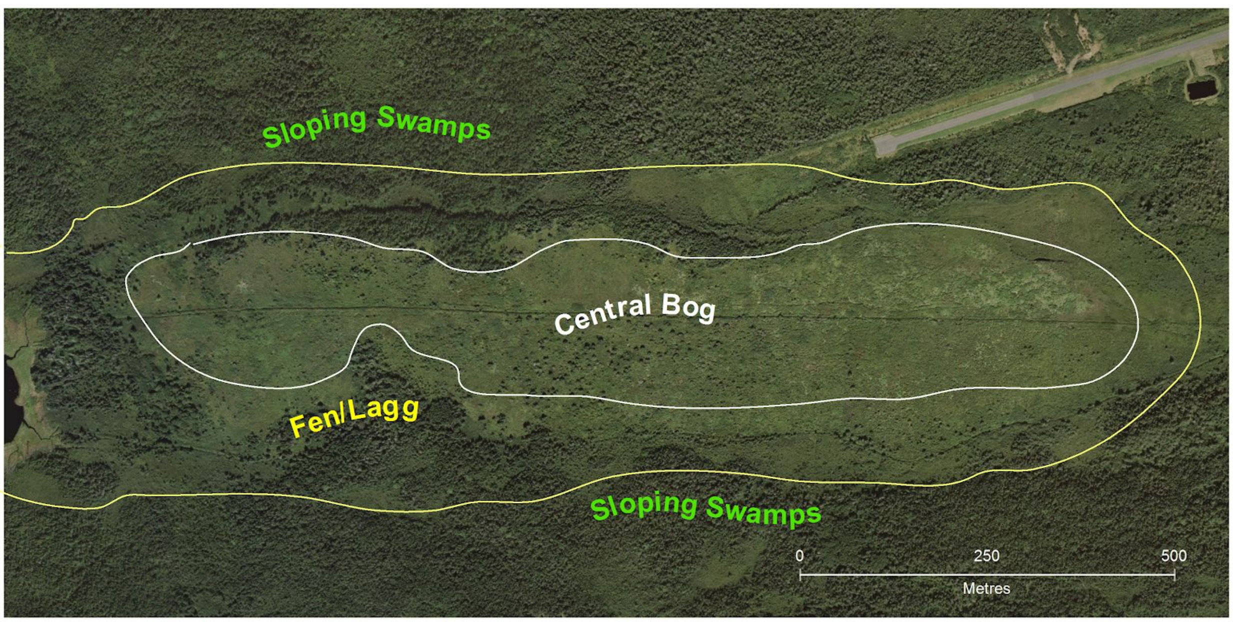

Figure 1. The three parts of Big Meadow Bog - Sloping swamps drain into the lagg/fen(green), the marginal fenn/lagg (yellow) receives water from swamp and central bog, and central raised bog (white) draining into marginal lagg. Central bog receives inputs from precipitation and atmospheric deposition. Background imagery provided by Nova Scotia Internal Services.

Recently, analyses of historic aerial photographs using a Geographic Information System (GIS) have led to an appreciation that there has been large scale successional changes in the bog that are driven by breeding gulls in Big Meadow and their shifting distributions over four decades (Toms, 2016; Hill et al., 2018ms). This report integrates that understanding and shows how historic gull movements have impacted current vegetation conditions. This report develops and tests classifications of the vegetation within the bog and lagg areas of Big Meadow Bog. The classification achieved can be used as a benchmark that can be compared to future states and used to track vegetation changes. These results demonstrate the effectiveness of the Maximum Likelihood Classification (MLC) technique for tracking shifts in gull disturbance, succession, and for monitoring the state of the lagg habitat of the Avens.

Data Collection

Over the last decade, Unmanned Aerial Vehicles (UAVs) have become an increasingly common research tool for wetland mapping (Madden et al, 2015). Research by the AGRG team of David Colville, Bill Livingstone, Paul Illsley and Ian Manning at the Nova Scotia Community College captured imagery used UAVs to help delineate vegetation and establish a high-resolution, pre-restoration baseline of vegetation types and distribution in Big Meadow Bog. Image collection surveys flown by UAVs can be flown safely at much lower altitudes than manned aircraft surveys, and as a result can capture imagery at much higher spatial resolutions (<5 cm per pixel). When used in analysis, these images can be used to identify environmental/ecological processes occurring at finer scales than would be possible from analysing air photos.

Several UAV surveys were completed by researchers from AGRG (Table 1) In total, three RGB benchmark datasets were collected from drone flights in 2016 (2) and 2017 (1); two additional multispectral datasets were collected in fall of 2017. On two occasions (23 August 2016 and 6 October 2017), flights at Big Meadow Bog resulted in incomplete surveys due to damaged equipment (23 August 2016) and sudden unexpected weather conditions (6 October 2017). These data provide a high resolution snapshot of conditions in Big Meadow Bog which can be used further down the road for tracking changes resulting from the restoration completed in fall of 2017.

Table 1 Dates and specifics of UAV surveys completed by AGRG Researchers at Big Meadow Bog, Brier Island, Nova Scotia, 2016-2017.

Date	**Platform - Sensor**	**Complete Coverage**
23 August 2016*	PrecisionHawk Lancaster - NIKON 1 S2 (RGB)	No
16 September 2016*	DJI Inspire - FC350 (RGB)	Yes
6 October 2017*	EBee Sensefly Parrot Sequoia (R, G, NIR, Red Edge)	No
13 October 2017	EBee Sensefly S.O.D.A (RGB)	Yes
13 October 2017	EBee Sensefly Parrot Sequoia (R, G, NIR, Red Edge)	Yes

* denotes acquisition with survey-grade GPS

The incomplete data collection was disappointing but unavoidable due to weather conditions. Incomplete image surveys (23 August 2016, 6 October 2017) served as useful resources for interpreting the imagery, as the slight difference in acquisition dates provided some clues to the identity of different vegetation types/features. While the image collected 6 October 2017 did not capture the bog in its entirety, it was collected using ground control, and was correctly registered in space. The image was closer in timing to the image captured in September 2016.

It is important to note that imagery captured in 2016 and 2017 were not directly comparable. Information collected in 2016 utilized a sensor that measured reflectance across three bands of visible wavelengths (red, green and blue). Multispectral imagery captured using the Sequoia Parrot sensor on 6 October and 13 October at Big Meadow Bog, captured imagery across four spectral bands: Red, Green, Red Edge and Near-Infrared (Table 2) The additional bands captured in the Red Edge and NIR bands provide value in analyzing vegetation. The temporal difference in data collection (16 September 2016 vs. 6 October 2017) also captured changes in phenology further complicating a comparison between the two dates. Surveys during the 2017 field season were delayed to October due to changes in the Federal rules surrounding the regulation of the UAV industry and the associated backlog in acquiring flight permissions from Transport Canada.

Table 2. Parrot Sequoia bands, associated wavelength, and detection application. Information from MicaSense Website (What spectral bands does the Sequoia camera capture?, 2016).

Band	Wavelength	Detection applications
Red	640 – 680 nm	biomass, plant stress
Green	530 – 570 nm	useful from identifying plants from other features, chlorophyll
Red Edge	730 – 740 nm	plant stress, chlorophyll/nutrient stress
Near Infrared	770 – 810 nm	plant vigor and type

The remainder of this report is separated into three sections, Data Analysis 2016, Data Analysis 2017, and Use of Remote Sensing in the Adaptively Managed Restoration. Both Data Analysis sections follow the same format, first showing examples of the imagery, then defining the classes for the image analysis. This is followed by discussing the vegetation height model created from the UAV surveys, showing the classified image of the bog generated from the image. Each section concludes with an accuracy assessment of the classification, and how the classified output and vegetation height model relate to historic patterns of herring gull nesting colonies in Big Meadow Bog. In the case of the imagery captured in 2017, the data is compared to GPS point locations of Avens data collected in September of 2018 to verify the results.

Analysis of 2016 Imagery

Data Preparation

After collecting the imagery, the first step of the process was to convert the raw images into a georeferenced format that could be fed into a GIS. Raw images were processed using the software package Agisoft PhotoScan (Agisoft, 2017) in combination with GPS positions captured with a survey-grade GPS. Outputs from this analysis included a high resolution air photo, and a 3D point cloud.

The images collected by the UAV surveys were of extremely high spatial resolution. For the image collected 16 September 2016, the resolution of the dataset was 2.9 cm/pixel. While this information was useful for interpretation, it had to be generalized before it could be used for image processing. High resolution imagery was generalized using the Segment Mean Shift technique. Segment Mean Shift is an image processing algorithm that groups pixels that are spatially coincident (neighbours) and spectrally similar (similar reflectance values) into segments or “super pixels” that represent distinct parts of the image. After the segmentation analysis is complete, the image segment becomes the base unit for image classification; in other words, the classification is completed on a per segment basis. The image was segmented into sections with an area of $2m^2$ (Figure 2).

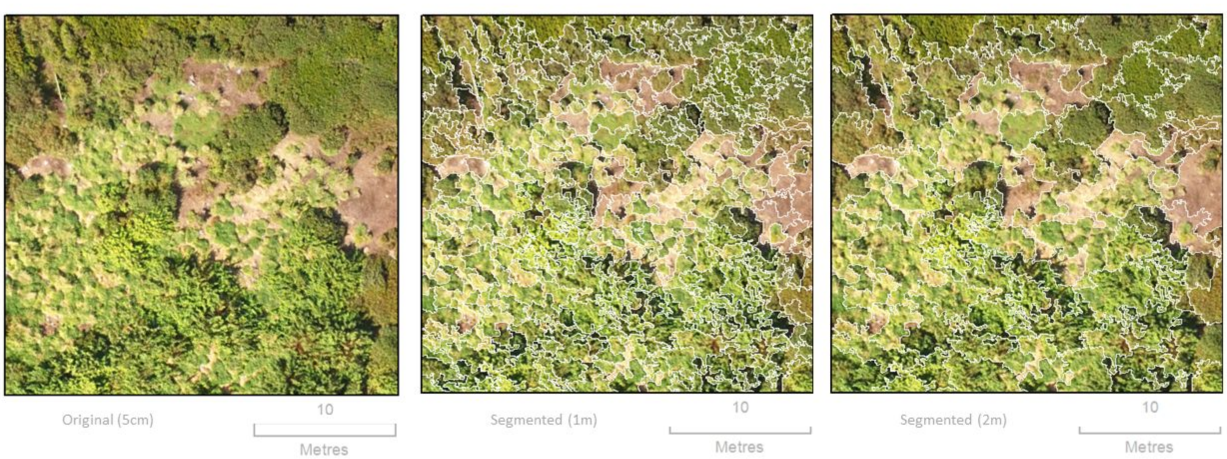

Figure 2. Example of image segmentation in Big Meadow Bog.

Past research at Big Meadow Bog has documented an increase in forested area and reduction in open area through analysis of historical air photos collected by the province of Nova Scotia (Toms, 2016). The goal of this analysis was to improve on that classification by further separating the vegetation into more discrete classes; for example, to attempt to differentiate the ecologically divergent open areas that are nutrient-enriched and gull occupied from the low, nutrient-poor, sedge/shrub of laggs. The former is an aberrant, degraded state and the latter is our goal habitat for healthy Avens.

The initial plan was to use existing vegetation survey data to classify the imagery. Percent cover data collected in 2015 for 70 quadrats across Big Meadow Bog were originally slated for use in classification process. While such an approach is conceptually elegant, AGRG (Colville, 2015) encouraged a simpler approach. The limitations of the MLC derived here support Colville's simpler approach.The overall approach taken was iterative and relied on linking patches of a vegetation dominant to colour signatures from remotely sensed imagery by interpreting the high resolution imagery. Researchers from AGRG tested this approach by: 1. Collecting training samples from the image (representative patches of homogeneous features); 2. Creating classification rules built on the training samples; 3. Using those rules created from the training samples to classify the image. High precision GPS data collected on 23 April 2017 by Dr. Nick Hill (Fern Hill) and Ian Manning (AGRG), helped to increase confidence in the identification of dominant features in Big Meadow Bog.

Permanent plot data, a three year Avens transplant study and the patterns of bog succession following gull disturbance provide an understanding of the desired habitat state of the avens and primary habitat in the lagg (bog margin) of Big Meadow, the desired habitat state of the central raised bog, and vegetation changes caused by gull destruction and eutrophication and the recovery succession following gull abandonment of bog zones. The main understandings of habitat are as follows:

1. **Healthy Lagg:** Avens occurs in greatest densities in the lagg zone of Big Meadow Bog in low shrub (<50cm height) that is typically dominated by Ericaceae with cover of fine sedge (e.g. *Tricophorum cespitosum* and *Carex exilis*) and Sphagnum moss. This desired lagg has also vegetation indicators of calcium availability (e.g. *Dasiphora fruticosa*) and pool areas that may further reduce intraspecific competition from shrubs (Figure 4).

2. **Healthy Bog:** The desired state of the raised bog is ombrotrophic, meaning that all nutrient input enters the bog via precipitation or atmospheric deposition. The original ombrotrophic raised bog has been modified by ditching at Big Meadow but a small area remains at the north, the "Remnant Heath" (Figure 3, Figure 5). This state is similar to the desired state of the lagg--low Ericaceae vegetation with fine sedge-- but with a lower water table, lower Sphagnum cover and different indicator plants for ombrotrophy (e.g. *Rubus chamaemoru*s and *Eriophorum vaginatum*).

3. **Gull Occupied:** Nesting gulls destroy vegetation of the Remnant Heath by perching on tussocks of "deergrass" (*Trichophorum cespitosum*). These areas are transformed to bare peat zones that later succeed to a short grass stage (90% *Holcus lanatus*)(Figure 3, Figure 5).

4. **Tall Shrubs/Cane:** The Gull Occupied stage rapidly succeeds from short grass to raspberry canes and shrub (70% *Rubus idaeus*) (Figure 5).

5. **Recovering Bog:** This Cane stage recovers to a swamp-like vegetation over 30 years through intermediate (e.g. 10-20 years) tall Rosaceae (e.g. *Photinia* spp.) shrubs, tall clonal herbs (*Calamagrostis canadensis* and *Chamerion angustifolia*) and then (20 to 30 years) to Ericaceae, black spruce (*Picea mariana*), ferns (Osmunda cinnamomea, *Dryopteris* spp) with Sphagnum.

6. **Gull Reinvasion:** In many areas, particularly in the middle of the bog, nesting gulls have returned to areas that they had previously occupied, then abandoned. This mixing of use pattern has led to a mosaic of vegetation types that defy the strict linear recovery succession laid out from 1-5. Exceptions to the proposed sequence in step 5 that do not fit this pattern of decreasing disturbance and nutrient availability, include areas of white spruce in the central bog, areas of weedy herbaceous cover around white spruce used as look outs by gulls, and a swathe of soft rush (*Juncus effusus*) in the central west to southwest.

Figure 3. RGB image of Big Meadow Bog, captured 16 September 2016 by staff of NSCC Applied Geomatics Research Group. Background imagery provided by Nova Scotia Internal Services.

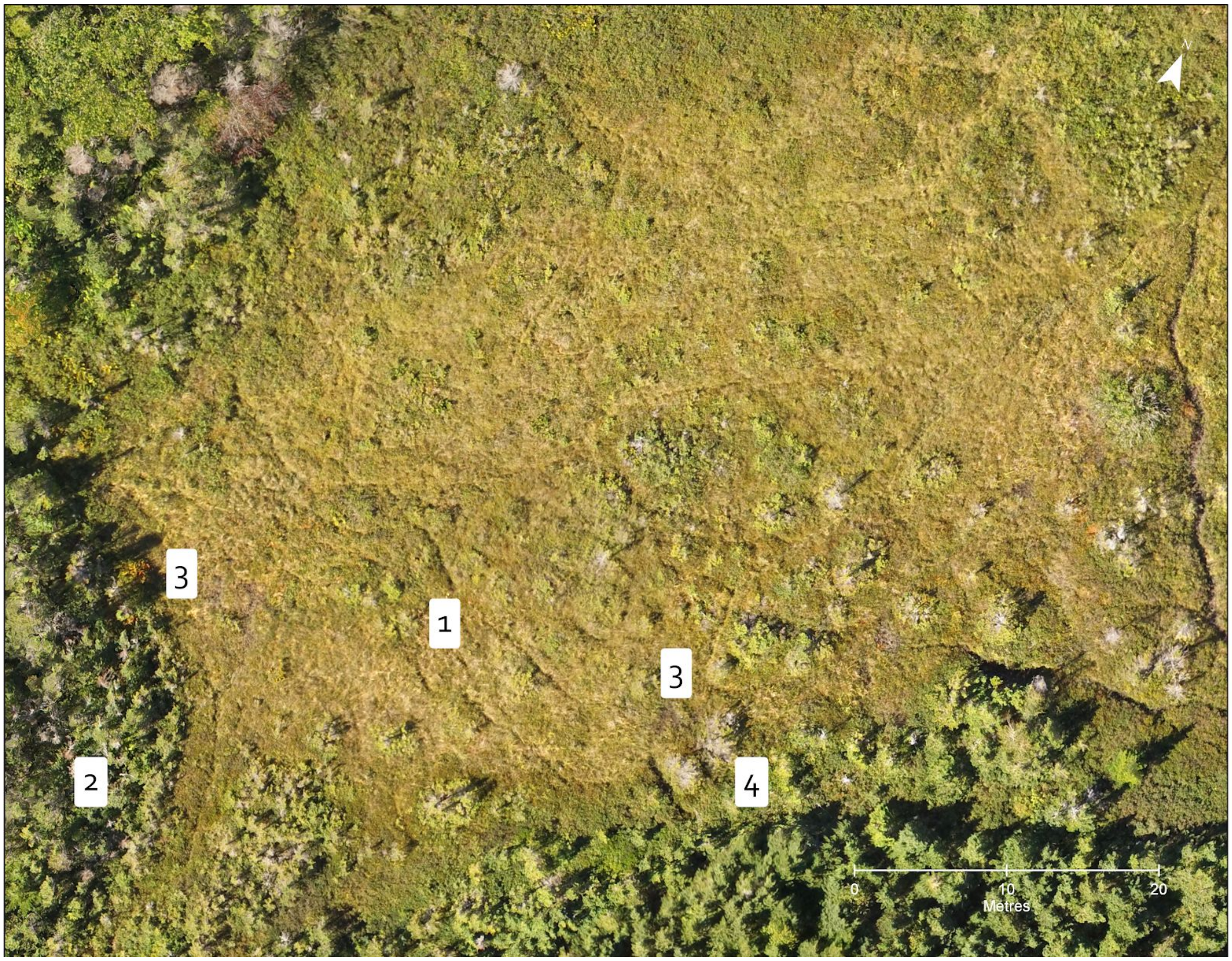

Figure 4. RGB image of Runway Bog, image captured 16 September 2016 at Big Meadow Bog, Brier Island. Image shows 1. Healthy avens habitat 2. Swamp draining into runway bog, 3. Shallow open water (predominately dry after historically dry summer) and 4. Ericaceous heath (low shrub).

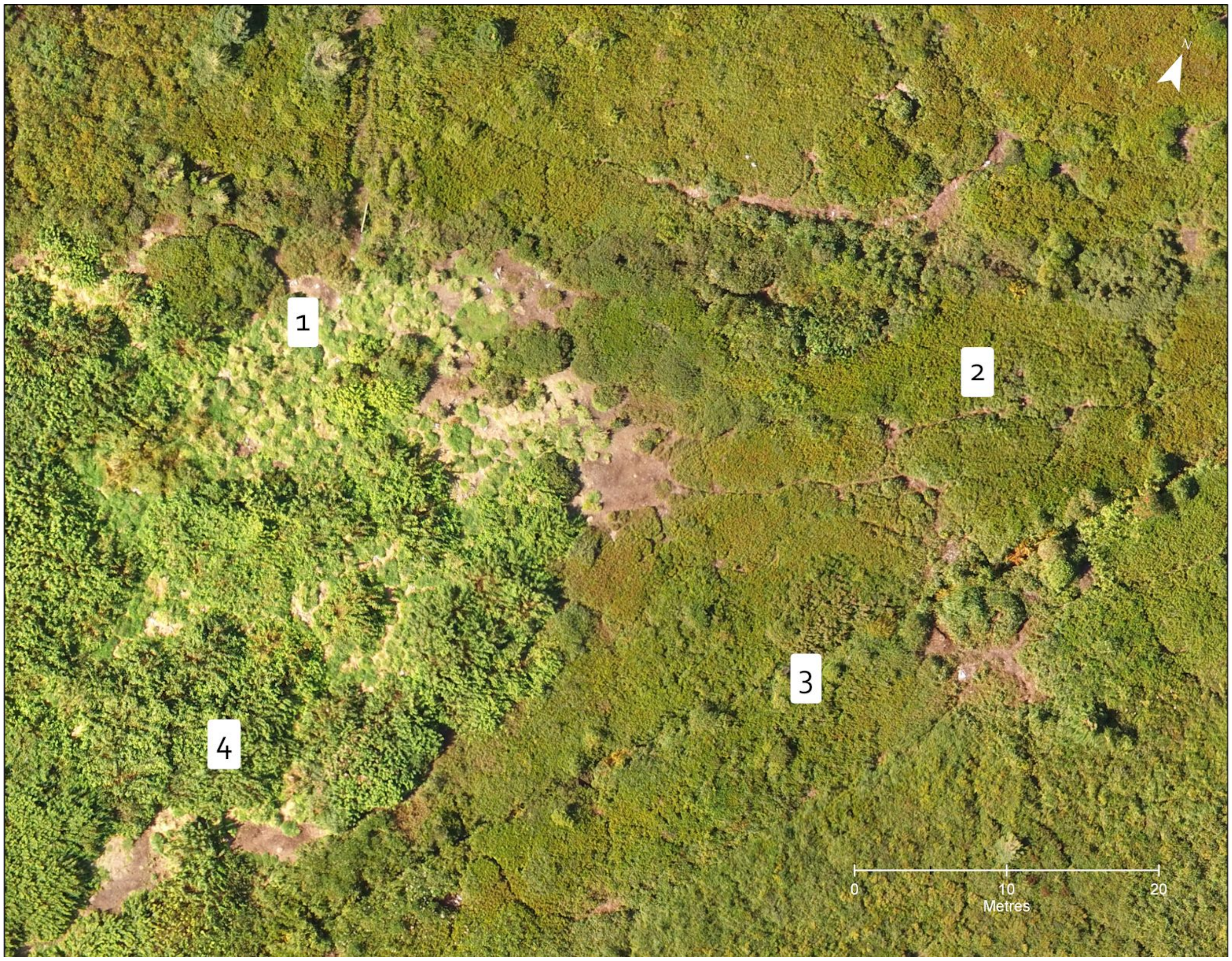

Figure 5. RGB image of leading edge of gull breeding area, image captured 16 September 2016 at Big Meadow Bog, Brier Island. Image shows 1. Active Gull Area dominated by gull grass 2. Remnant heath (deep green) 3. Pre-restoration drainage ditch and 4. Raspberry.

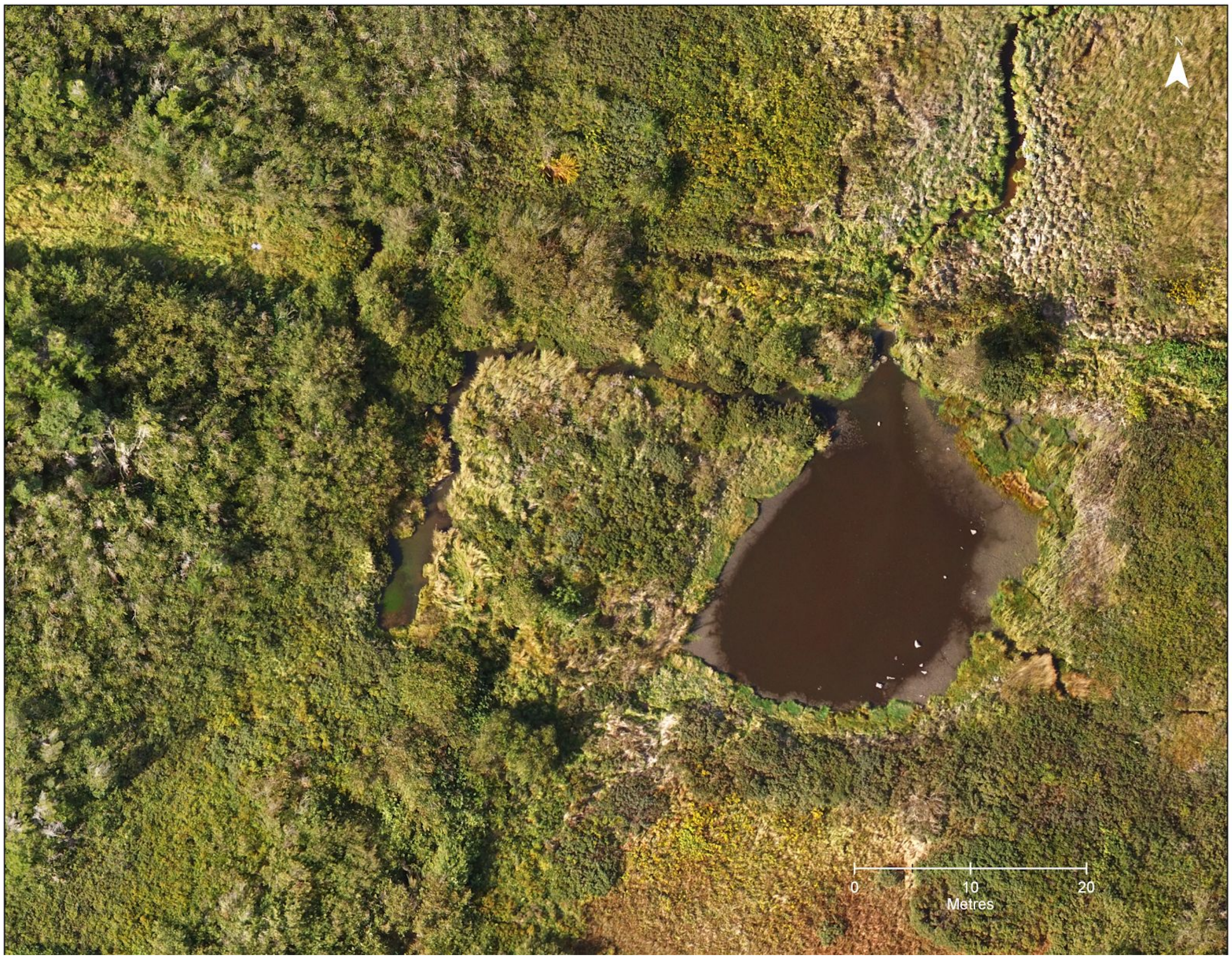

Figure 6. Jimmy's Pond, a waterbody of significant cultural heritage to Brier Island prior to restoration by East Coast Aquatics, Big Meadow Bog, Brier Island, Nova Scotia. Image captured 16 September 2016.

Building on this knowledge of succession patterns, a series of classes/categories were created that were spectrally separable in the RGB imagery. In some cases, a vegetation class (ex. Active Gull/Spruce) was a composite of multiple vegetation types or features that in combination are indicative of a specific ecological narrative (Table 3). Representative samples of each class were identified and used to train the image analysis model.

Table 3. Class definitions with component classes (if used) and descriptions for classifying UAV imagery at Big Meadow Bog from 2016 imagery.

Class	Component Class(es)	Description
Sedges / Rushes	--	Sedges and rushes indicating healthy lagg including *Trichophorum cespitosum*
Low Shrub	--	Low shrubby ericaceous vegetation representing remnants of healthy bog community.
Active Gull	Bare Soil Gull Grass (H. lanatus) Gull Grass Dead (H. lanatus)	Soil exposed by nesting gulls Green grass in gull nesting areas Dead grass in gull nesting areas
Herbaceous Disturbed	Fireweed (*E. angustifolium)* Cinnamon Fern (*O. cinnamomea*) Goldenrod (*Solidago spp.*)	Herbaceous vegetation that follows gull disturbance, weedy.
Tall Shrub/ Cane	Blackberry (*R. alleghaniensis*) Raspberry (*R. Idaeus*)	Shrubby vegetation indicative of disturbance/nutrient increase that follows gull occupation.
Trees	Spruce (*P. mariana, glauca*) Dead Spruce (from gulls/flooding) White Birch (*B. papyrifera*)	Spruce that grow in ditched bog/swamp Spruce tree dead from gulls/water Deciduous tree found in bog
Shadow	Shadow	Areas unable to classify due to shadow

After collecting representatives of each class across the study area (50 segments representing each component class), the imagery was analysed using a technique called Maximum Likelihood Classification (MLC). MLC is considered a “supervised classification” technique. In a supervised classification, the user creates “training areas”, areas of a known type that are used to create a set of rules to distinguish between classes. The rules were then applied to the remainder of the image to divide the image into component classes.

Early classification results were promising in identifying areas occupied by gulls, the classification showed an overabundance of some cover types notably fireweed. It was thought that by introducing elevation as a variable to the classification, that it might be possible to improve the model. To reduce the amount of mixing in the classes, a vegetation height model was created from the images captured during the UAV survey. During the UAV image processing workflow a high-resolution point cloud was created. This high resolution point cloud was used as the starting point to build a vegetation height model for Big Meadow Bog.

To use the elevation data in the classification model, the information had to be translated from a 3D point cloud to a 2D raster (image). A summary workflow (Table 4) explains this process. In this particular case, the point cloud was exported from the software as LAS files, LAS files were referenced via a LASD format (Esri) and converted using the LASD to Raster tool in ArcGIS Pro to create raster datasets representative of the ground (DEM) and the tops of vegetation (DSM). Finally, a vegetation height model (VHM) was created by subtracting the finalized DEM from the DSM (Figure 7). The VHM was also broken into three classes of vegetation height (low, medium and tall) to better symbolize the distribution of vegetation heights across the study area (Figure 8).

Table 4. Generalized workflow used to convert 3D point cloud data from UAV images into a vegetation height model used for analysis in GIS.

Input Dataset	Resolution	Action	Output	Output Resolution
UAV Point Cloud	--	LASD To Raster (Binning MAX)	DSM	1m
UAV Point Cloud	--	LASD To Raster (Binning MIN)	DEM1	2m
DEM1	2m	Filter (Low Pass)	DEM2	2m
DEM2	2m	Resample (Cubic)	DEM3	1m
DEM3/DSM	1m	Minus	VHM	1m

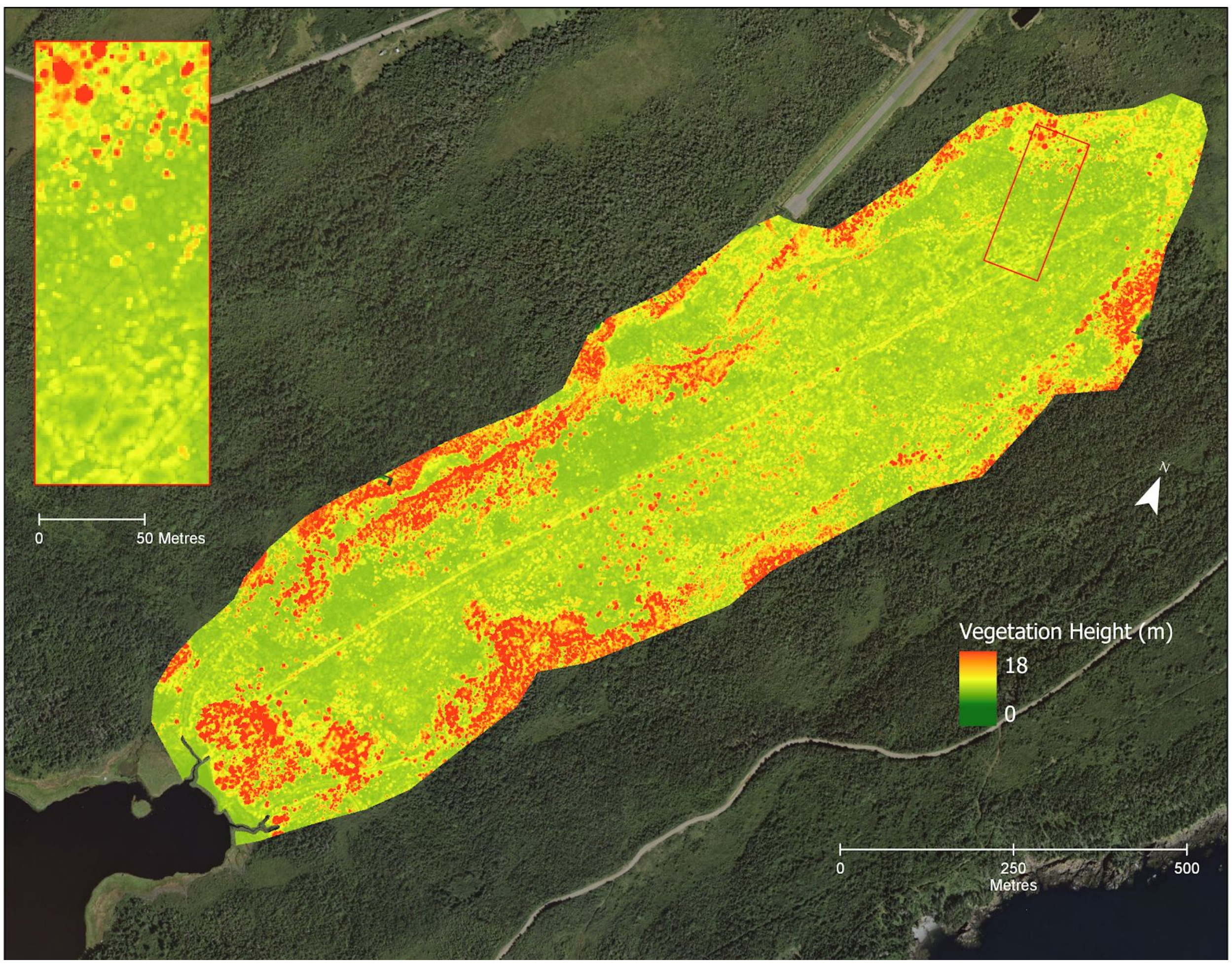

Figure 7. Vegetation Height Model (DSM-DEM) generated from gridded 3D image point cloud derived from UAV survey completed 16 September 2016 by AGRG. Background imagery provided by Nova Scotia Internal Services.

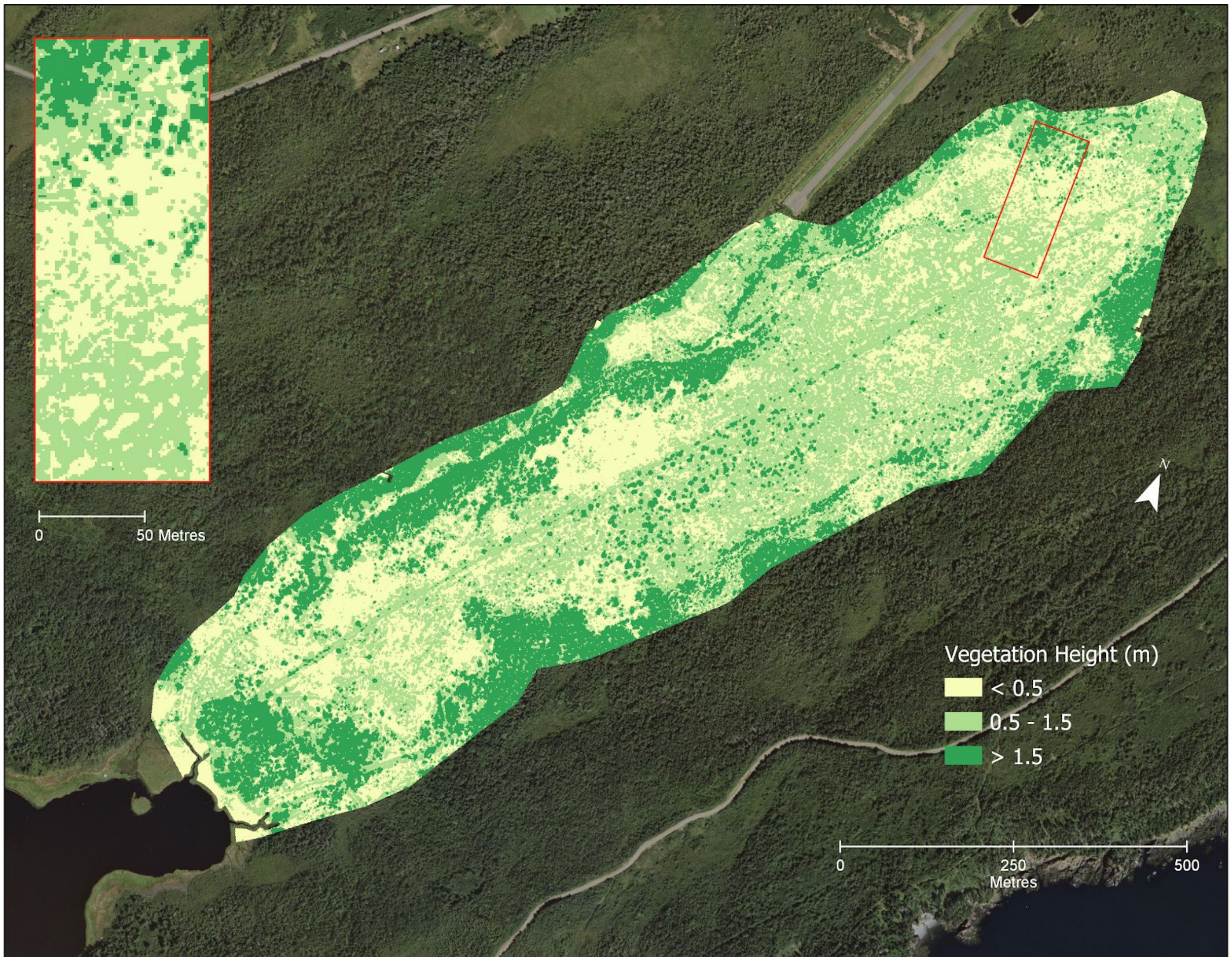

Figure 8.Vegetation Height Model (DSM-DEM) symbolized in three vegetation height classes, generated from gridded 3D image point cloud derived from UAV survey completed 16 September 2016 by AGRG. Background imagery provided by Nova Scotia Internal Services.

The VHM (Figure 8) clearly shows that the zones containing the lowest vegetation are found within the central raised portion of the bog. Taller vegetation is found growing in the swamps flanking the bog's northwest and southeast borders. Taller vegetation can also be found scattered along the central drainage ditch, and throughout the southern portion of the bog (Figure 8). These results were consistent with our expectations as results showed taller vegetation around the drainage ditches; the greater abundance of taller trees in the southern portion of bog were consistent with research from historical photographs that showed trees followed the increased nutrient loads from gull colonization of Big Meadow beginning in the southern portion of the bog, trending northward (Toms, 2016).

Classification Results

An iterative process of testing inputs to the classification was used. The earlier hypothesis that a useful classification of vegetation could be made by linking reflectance to species or guild dominants (e.g. black spruce, evergreen ericads, rosaceae shrubs, gull grass, raspberry, etc.) was foregone when the approach grossly overrepresented fireweed (*Chamerion angustifolium*) and all but left out others. This led to further changes to the workflow including the recognition of dominant vegetation classes in particular areas and the development and incorporation of a more refined elevation dataset (Vegetation Height Model) described in methods (Table 4). The classification of the image was based on a two-step approach:

1. Linking of dominant vegetation patches to color output
2. Vegetation Height Model built from high-resolution image point cloud (3D).

The Maximum Likelihood Classification (Figure 9) was created using the segmented image and vegetation height data. Simply comparing the classified output, with our knowledge of on the ground conditions showed promising results. In the classified image, the east and west of the bog, the slopes of the swamp are covered in spruce trees matching our understanding of on the ground conditions. Areas of the wetland complex deemed “ideal Avens habitat” (Hill, 2015) including Runway Bog and Brad’s Bog, are classified as a mix of low ericaceous shrub and sedge/rush (Figure 9) which agrees with earlier report to NSDNR (Hill, 2015) . Sections classified as tall shrub/ cane are found throughout the bog, and are concentrated in the northern section of the raised bog, mirroring the more recent pattern of gull nesting in the area. Active gull areas are predicted as being both in the north and the south of the bog (near Big Pond). While there is gull activity in the north, the erroneous prediction of gulls in the south is a confusion that supports the mechanism of the model. There were large areas of dried exposed soil in the southwest from the first stage of restoration in Spring 2016 and this should produce a spectral signature similar to that of the gull destroyed areas (low elevation, high spectral reflectance). Comparing the on the ground survey with the classified image revealed that the low shrub category was overrepresented in the classified image.

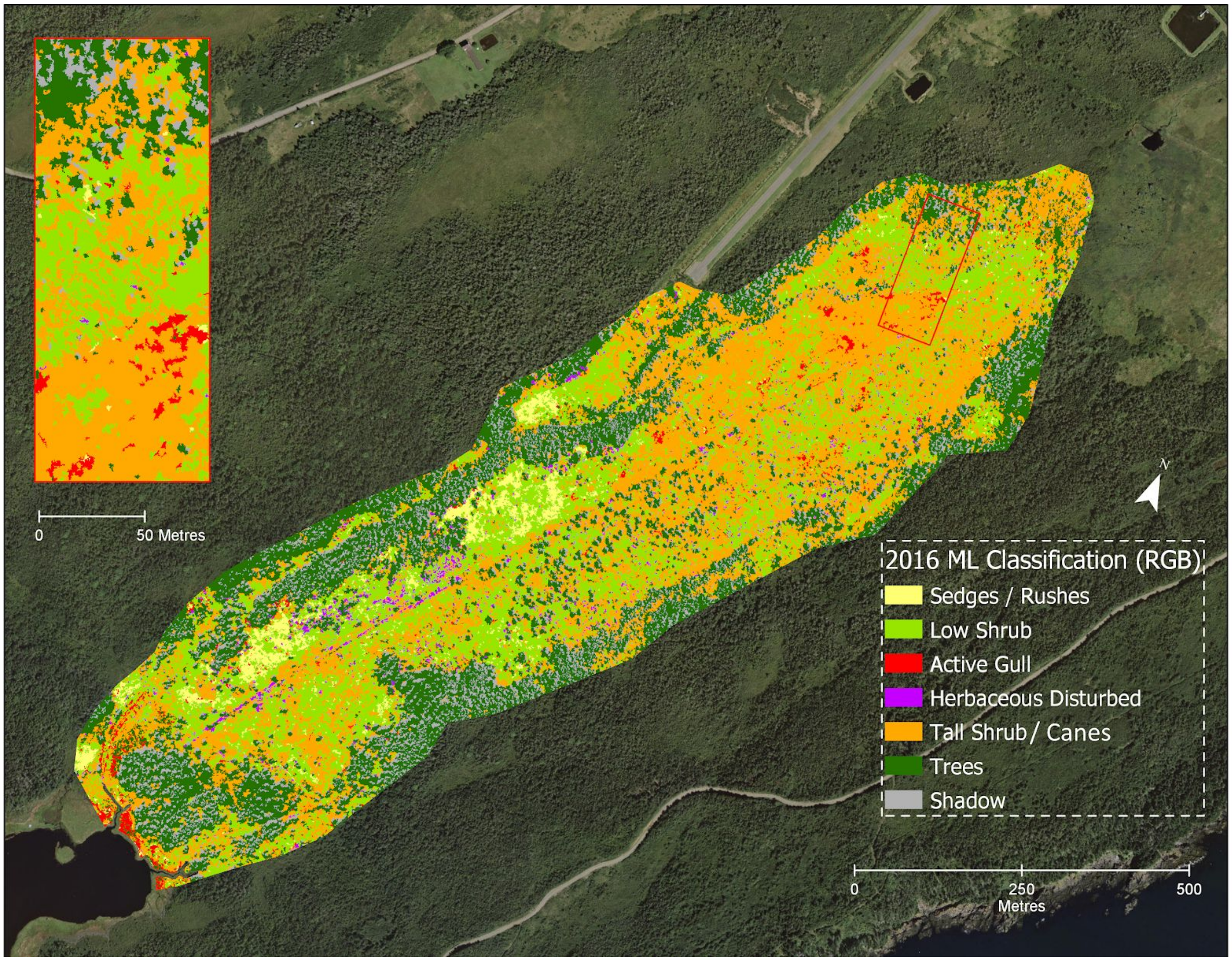

Figure 9. Maximum Likelihood Classification of Big Meadow Bog generated from UAV aerial photography mission completed on 16 September 2016 by the NSCC AGRG. Background imagery provided by Nova Scotia Internal Services.

To check the accuracy of the classification, random points were generated within the boundary of Big Meadow Bog. Points were generated using the Create Accuracy Assessment Points tool in ArcGIS Pro (Esri, 2018). An equal amount (25) of sample points were created for each class in the image. Points were generated within the main boundary of Big Meadow Bog but excluded from areas used to generate training samples from which the classification was based. Each random point was assigned to one of seven classes via careful interpretation of the high-resolution RGB imagery. The point feature class contained two fields, one containing the classified result, and a second containing the ground-truthed interpretation. Once completed, the point feature class was analysed using the Create Confusion Matrix tool in ArcGIS Pro (Esri, 2018), creating a confusion matrix that shows how the classification performed across the image (Table 5).

Table 5.Confusion matrix for MLC classification of Big Meadow Bog for RGB UAV image captured 16 September 2016 by AGRG.

	Sedges / Rushes	Low Shrub	Active Gull	Herbaceous Disturbed	Tall Shrub / Cane	Trees	Shadow	Reference Total	User Accuracy
Sedges / Rushes	**21**	1	0	2	1	0	0	25	0.84
Low Shrub	5	**6**	0	5	9	0	0	25	0.24
Active Gull	4	1	**15**	2	3	0	0	25	0.6
Herbaceous Disturbed	1	5	2	**11**	5	0	1	25	0.44
Tall Shrub / Cane	2	3	0	2	**15**	1	2	25	0.6
Trees	0	0	2	0	5	**14**	4	25	0.56
Shadow	0	0	0	0	1	3	**21**	25	0.84
Classified Total	33	16	19	22	39	18	28	175	0
Producer Accuracy	0.636	0.375	0.789	0.5	0.385	0.778	0.75	0	0.589

The confusion matrix (Table 5) describes the accuracy of the classification. At a glance, the cells highlighted in black show the number of ground truthed areas correctly classified for each class. Values off the diagonal are misclassified points. The table shows three different types of accuracy measure, user accuracy (UA), producer accuracy (PA) and overall accuracy (OA). Each measure tells us something different about the accuracy of the classification.

User accuracy (UA) describes how often the classification shown on the map is correct. This number is calculated by dividing the total number of correctly classified points, by the count of points belonging to that classification (in this case, 25 for each). UA is sensitive to errors in commission (inclusion). In this example, the sedge/rush class has a UA of 84%.

Producer accuracy (PA) is calculated in a similar way to UA, however it is sensitive to errors of omission. PA is calculated by dividing the total number of correctly classified points for a particular class by the sum of all ground-truthed points in that class. In the case of this example, the sedge/rush class has a PA of 63.6%. This value is lower because, 12 areas that were human-verified as sedge/rush were erroneously placed in other classes.

Overall Accuracy (OA) is the total number of correctly classified sites (sum of black cell) divided by the total number of reference sites (175) expressed as a percentage. While OA is a useful measure, it doesn’t capture the variation in accuracy between different classes. For this reason, UA, PA and OA are typically all reported as error measures.

Overall the accuracy of the classification (58.9%) was quite good, but varied between classes. The classification of the RGB imagery did an excellent job at classifying sedges/rushes (UA = 84%, PA = 63.6%), shadow (UA = 84%, PA = 75%), trees (UA = 60%, PA = 77.8%) and active gull areas (UA = 60%, PA = 78.9%). This is somewhat unsurprising, as each of these features were relatively distinctive in visible colour and/or height. While the classification was good for these classes, it was less reliable for others. The low shrub class (UA = 24% PA = 37.5%) showed that the classification overestimated the amount of low shrubs in the study area. The tall shrub/cane class (UA = 60%, PA = 38.5%) was also poorly classified, and was likely due to the heterogeneous nature of the tall shrub/cane areas due to the revisiting of gulls.

As an additional way of examining the classified output, the classified raster of the bog was restricted to the boundary of the bog, removing built up areas, salt marsh and the runway. Each class was reported in terms of total hectares, and percent of bog area (Table 6). The bog was dominated by three main cover types, tall shrub/cane (mainly rose family), trees, and low shrub (intact or recovering bog featuring Ericaceae). The shadow classification occupied about five hectares, which was tightly associated with taller features on the landscape, notably trees and tall shrub/cane classes. Active gull nesting areas occupied less than one hectare, with a similar footprint occupied by the herbaceous disturbed stage.Table 6 provides an overall benchmark state of the bog, provided the hydrological restoration succeeds, increasing waterlogging and decreasing gull activity and eutrophication, we should see reductions in the tall shrub/canes, herbaceous disturbed, active gulls sites, and an increase in the low shrub class.

Table 6. Percent of Big Meadow Bog, belonging to each image class from the classification completed on 2016 UAV imagery (RGB).

Class	**Area (ha)**	**Percent Area (%)**
Sedges / Rushes	1.71	2.67
Low Shrub	16.42	25.69
Active Gull	0.98	1.54
Herbaceous Disturbed	0.84	1.32
Tall shrub/ Cane	22.07	34.53
Trees	16.9	26.45
Shadow	4.99	7.81

Gull Impacts on Vegetation

The disturbance and eutrophication of Big Meadow Bog by herring gulls is the second main derangement of the bog after loss of surface water table brought about by ditching, although it too may be a consequence of the ditching if gulls nested in the bog because its surface had dried out. Brad Toms of MTRI delineated areas of the bog suspected to be the locations of the nesting herring gull colony (Toms, 2016). These areas were interpreted from historic air photos captured in 1978, 1988, 2001, 2011 and 2015 (Figure 10). Mapping the extent of these boundaries shows a shift in gull nesting over time. Note the difference in the gull footprint from 2011 to 2015 (Figure 10), the gull nesting northeastern boundary has extended and the southeastern retreated in just four years. It is important to realize while this data shows the general trend of a northern shift, it does not effectively capture smaller shifts in gull nesting patterns occurring on an annual basis.

Figure 10. Suspected locations of herring gull nesting colonies from 1978-2015 as derived from historic air photos (Toms, 2016). As time advances suspected herring gull nesting colonies shift northward. Background imagery provided by Nova Scotia Internal Services.

Historic gull nesting areas (Figure 10) were cross referenced with the vegetation height model created from the UAV flight captured in 2016 (Figure 8).. The purpose of this analysis was to determine if sites occupied earlier by gulls, would have a greater proportion covered in advanced stages of succession/taller vegetation. Results from the analysis show that former gull nesting patterns influence present day vegetation in the bog. In the vegetation height analysis (Table 7, illustrated by Figure 11), the first areas occupied by gulls have the greatest percent cover of both extremes of vegetation height: the low (<0.5m) and the high (>1.5m). Although the percentage values involved in the tallest vegetation type are much lower (maximum value = 10% versus 53 and 66% against the smallest and medium respectively), there is a 5-fold difference over time which is in keeping with our successional analysis that follows long-term abandoned patches that consist of 30% tree cover, 30 years after gull damage. Similarly, research has shown an increase in cover of ericads over time which may be represented here in the smallest vegetation class. It is telling that the medium height vegetation shows the opposite trend and is greatest in the recent gull areas (2011 and 2015; Table 7, Figure 11). This may reflect the large zones of “canes” (70% *Rubus idaeus*; maximum heights 80cm) that follow gull disturbances and are commonly found in close proximity to active gull areas.

Table 7. Historic gull nesting sites (Toms, 2016) in Big Meadow Bog, and area/percentage of 2016 vegetation heights (Figure 8) for each area.

Air Photo Year	Area of Gull Occupation (ha)	Veg height < 0.5 m (ha) (% of total)	Veg height 0.5 m - 1.5m (ha) (% of total)	Veg. height > 1.5m (ha) (% of total)
1978	2.90	1.55 (53.37)	1.06 (36.52)	0.29 (10.12)
1988	11.02	5.4 (49.02)	4.42 (40.13)	1.2 (10.85)
2001	13.40	6.15 (45.87)	6.08 (45.4)	1.17 (8.72)
2011	11.57	3.42 (29.56)	7.62 (65.88)	0.53 (4.56)
2015	11.32	4.16 (36.75)	6.95 (61.38)	0.21 (1.87)

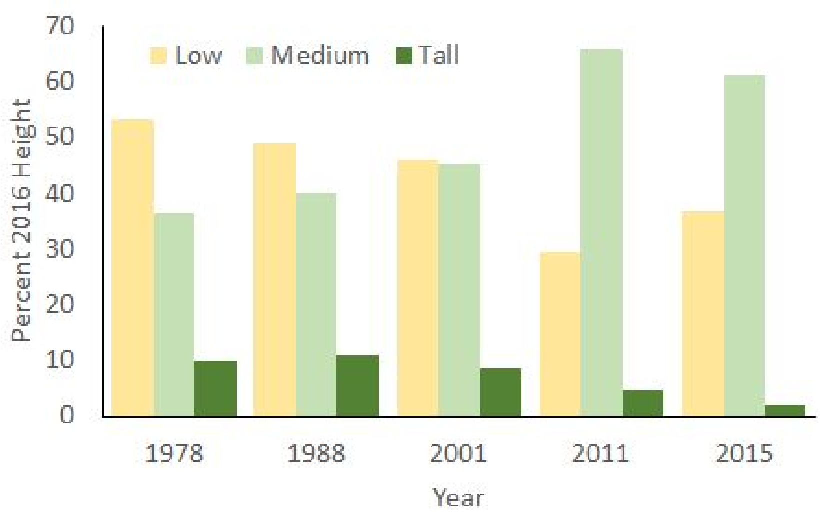

Figure 11. Historic gull nesting sites (Toms, 2016) in Big Meadow Bog broken down by percentage of 2016 vegetation heights (Figure 8) for each area.

The same analysis was completed using the classified UAV mosaic captured in September 16 2016 (Figure 9). The classified raster dataset was restricted to the zones of historic gull occupation delineated by MTRI (Toms, 2015). The results were consistent with the data collected during on the ground vegetation surveys of patches currently used by gulls and those abandoned for one, two or three decades (Hill et al, 2017). In the current analysis, there is an increase with increasing age of first gull occupancy in the percent cover of trees, shadow (associated with taller vegetation), low ericaceous shrub and sedges/rushes (Table 8, Figure 12). With the increase in age of first occupancy, there are many areas that become abandoned and go through the succession from grass to canes to shrub and thence to smaller ericad shrub and trees.

Table 8. Historic gull nesting sites in Big Meadow Bog (Toms, 2016), and area/percentage of 2016 vegetation classes for each area.

Air Photo Year	Total Area (Ha)	Area in hectares and percent total area						
		Sedges / Rushes	Low Shrub	Active Gull	Herbaceous Disturbed	tall shrub/ Cane	Trees	Shadow
1978	2.90	**0.37 (12.74)**	**1.37 (47.27)**	0.04 (1.21)	**0.1 (3.35)**	0.63 (21.71)	0.32 (11.07)	0.08 (2.65)
1988	11.02	1.08 (9.84)	5.08 (46.14)	0.11 (0.97)	0.19 (1.75)	2.9 (26.33)	**1.29 (11.74)**	**0.36 (3.22)**
2001	13.40	1.16 (8.65)	6.09 (45.49)	0.15 (1.09)	0.36 (2.66)	3.9 (29.08)	1.38 (10.33)	0.36 (2.69)
2011	11.57	0.08 (0.71)	3.88 (33.52)	0.27 (2.35)	0.13 (1.14)	6.28 (54.26)	0.74 (6.4)	0.19 (1.63)
2015	11.32	0.42 (3.72)	3.64 (32.17)	**0.33 (2.93)**	0.09 (0.82)	**6.39 (56.52)**	0.35 (3.13)	0.08 (0.71)

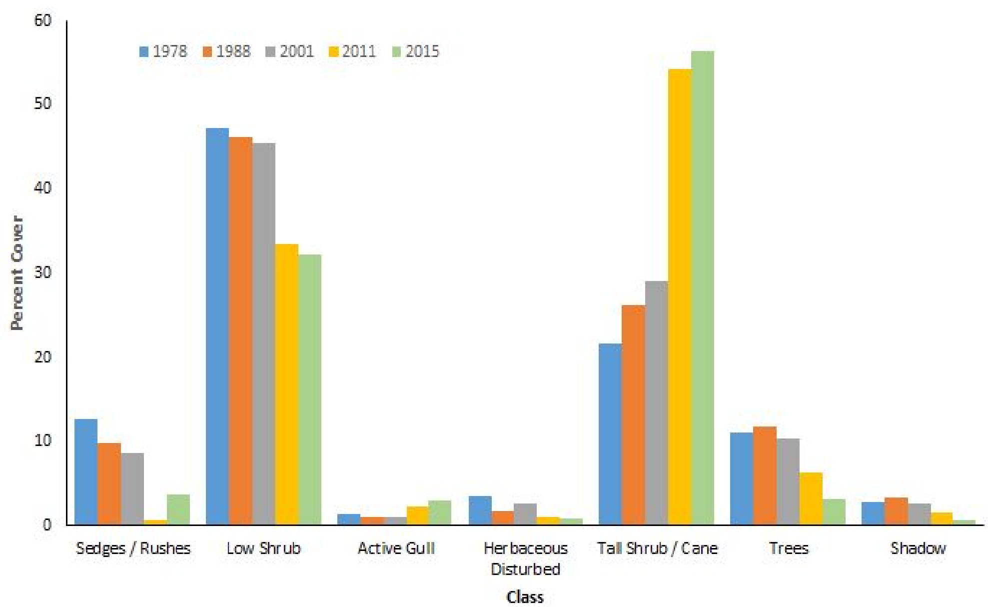

Figure 12. Historic gull nesting sites in Big Meadow Bog (Toms, 2016), and percent area of 2016 vegetation classes for each geography.

Analysis of 2017 Imagery

Data Preparation

Following the data analysis for the imagery collected in 2016, a similar approach was applied to the data collected on 6 October 2017. This data was collected with the Sensefly eBee fixed-wing UAV with the MicaSense Parrot Sequoia multispectral sensor. This sensor measures reflectance values in four different wavelengths (Red, Green, Infrared and Near Infrared).

After visually inspecting different composites, of the imagery it was decided to use an image composite consisting of bands 1 (red), 2 (green), and 4 (near infrared) displayed in the RGB channels. This composite was chosen as it allowed for very clear discrimination between different features of interest (Figure 13, Figure 14, Figure 15, Figure 16).

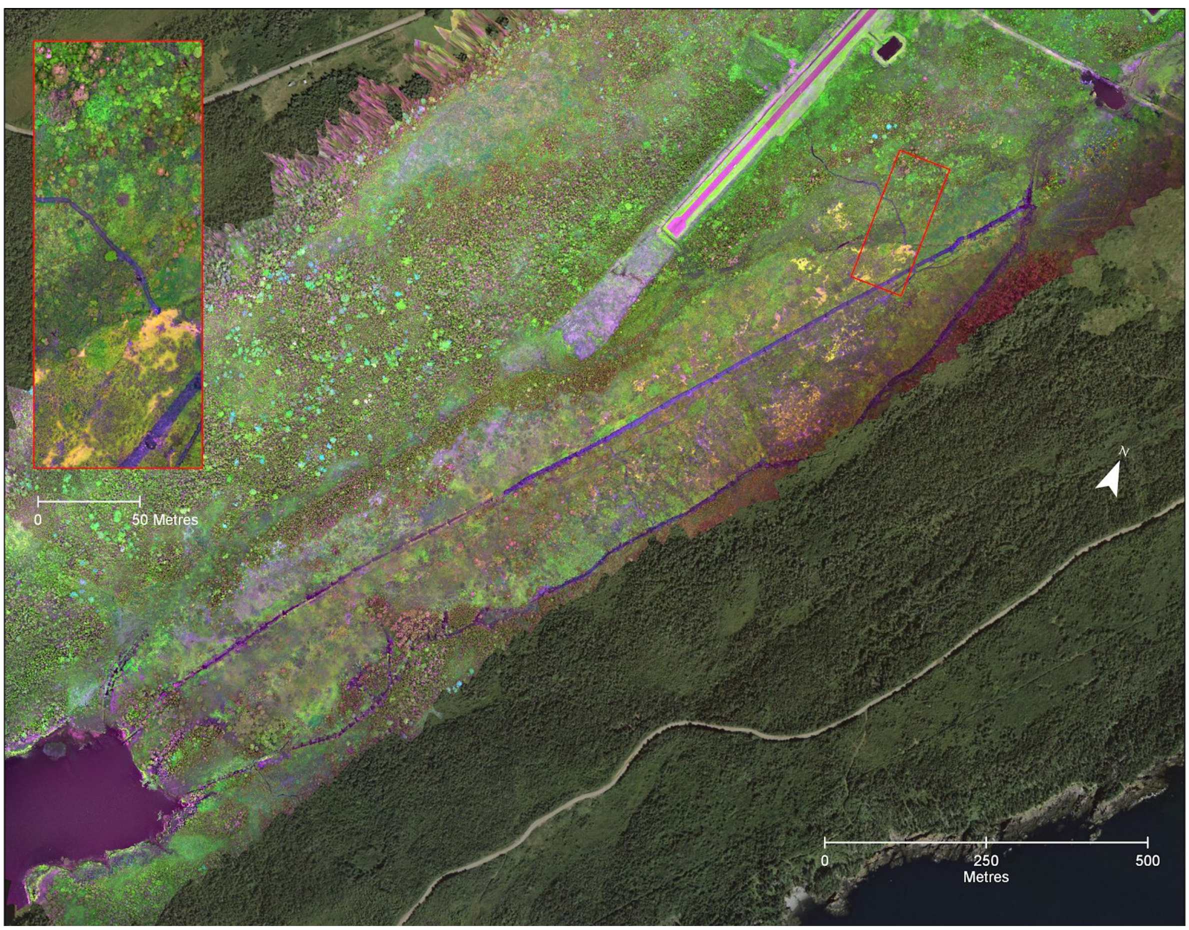

Figure 13. Composite Red, Green and Near Infrared image of Big Meadow Bog, captured 6 October 2017 at Big Meadow Bog, Brier Island by staff of NSCC Applied Geomatics Research Group. Background imagery provided by Nova Scotia Internal Services.

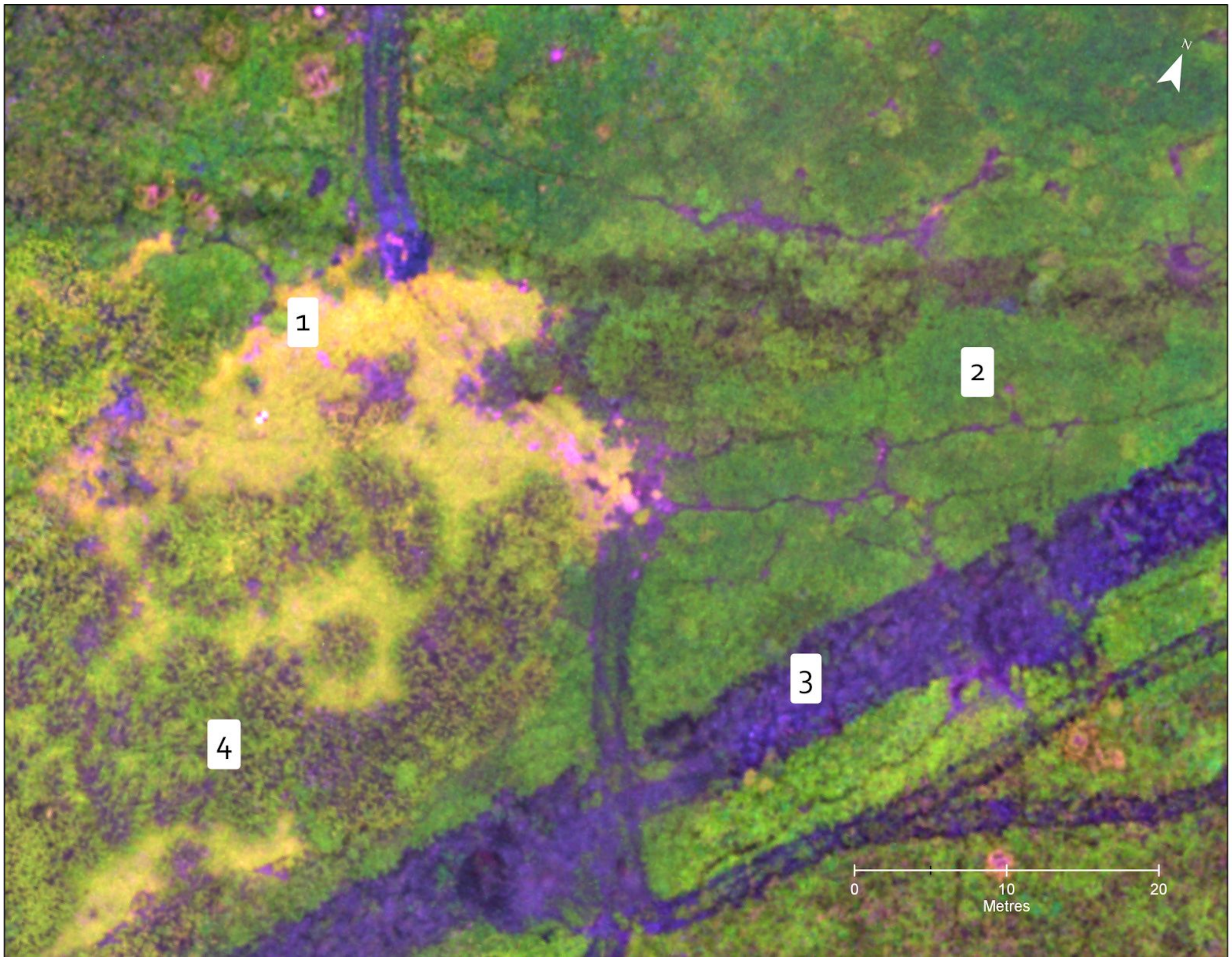

Figure 14. Composite image of red, green and near infrared bands captured 6 October 2017 at the northwest of Big Meadow Bog, Brier Island (note the central ditch in purple). Composite image shows 1. Active Gull Area dominated by gull grass (yellow) 2. Remnant heath (deep green) 3. Recently filled drainage ditch (purple) and 4. Raspberry (purple and green within gulled area).

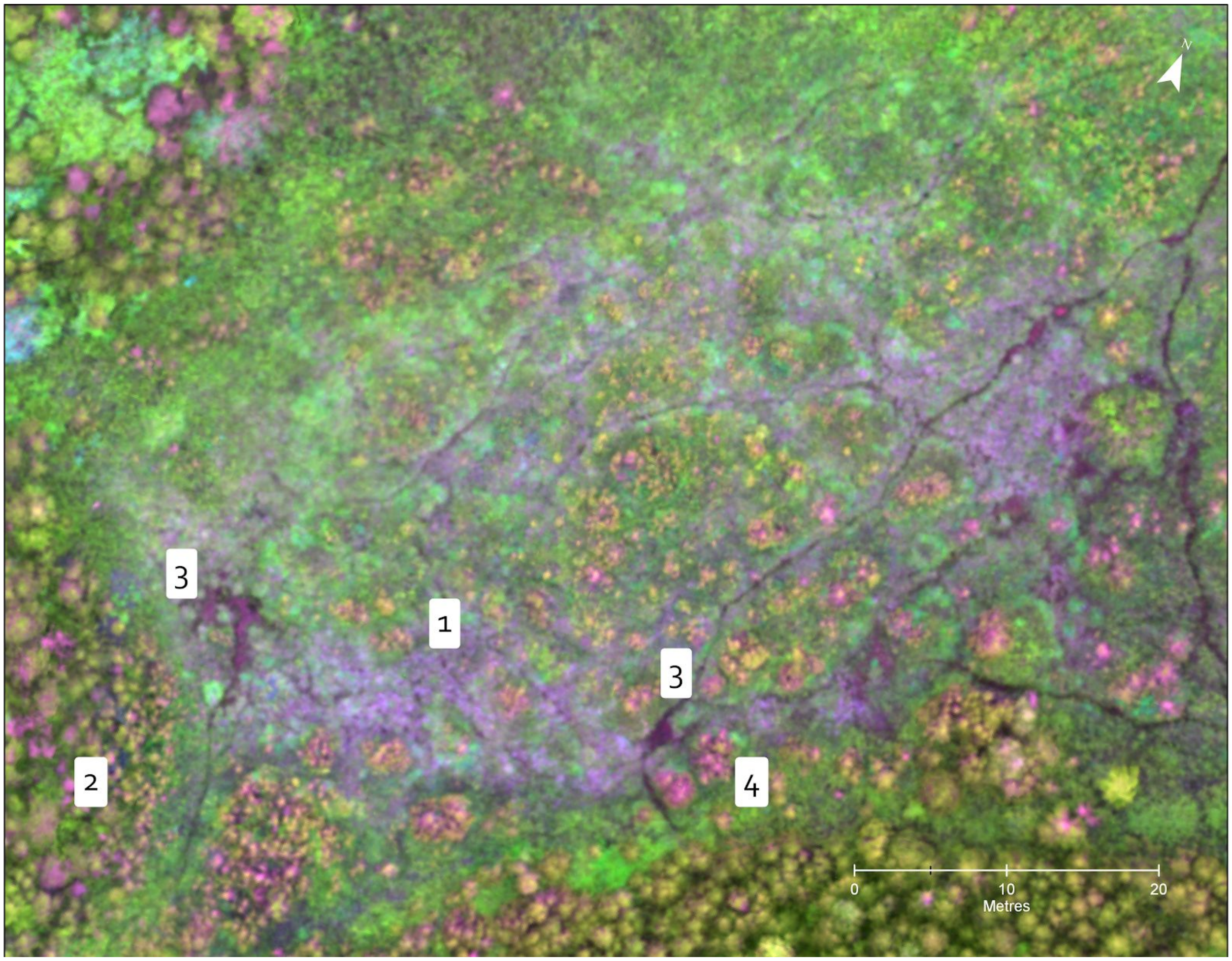

Figure 15. Composite image of red, green and near infrared bands captured 6 October 2017, of Runway Bog, Big Meadow Bog, Brier Island. Composite image shows 1. Healthy avens habitat 2. Swamp draining into runway bog (dead spruce = pink, live = green) 3.shallow open water and 4. Ericaceous heath (low shrub).

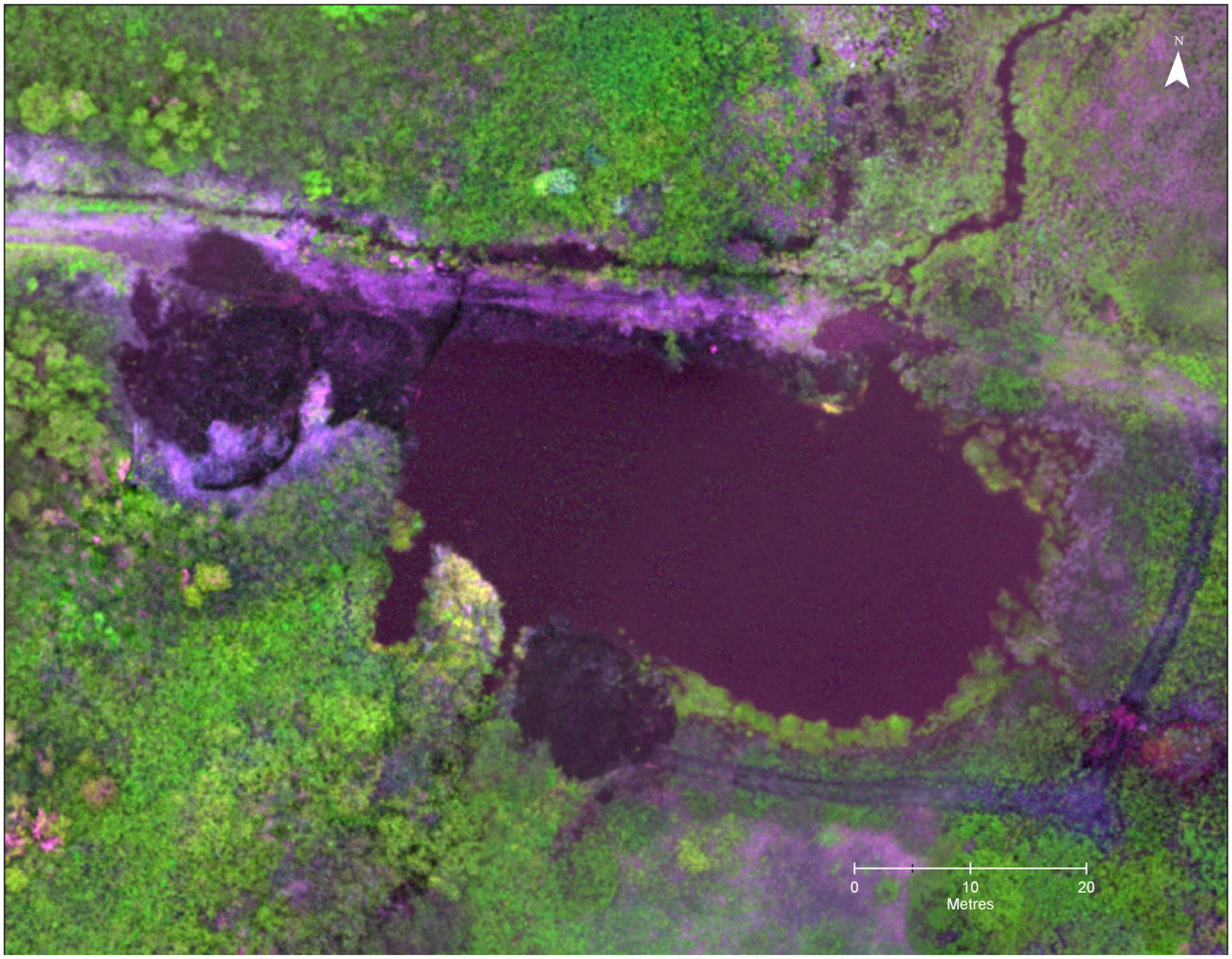

Figure 16. Composite image of Jimmy's Pond, a pond of significant cultural heritage to Brier Island following restoration by East Coast Aquatics, Big Meadow Bog, Brier Island, Nova Scotia. Image captured 6 October 2017.

Each of these images provides strong visual contrast: the purple of the exposed earth versus the green of the surrounding vegetation (Figure 13), the yellow of the gull grass against the deep green of the remnant heath (Figure 14, Figure 15), the pale purple of sedge in the avens lagg (Figure 15), and the dark purple of water in Jimmy's Pond (Figure 16). The next question was to see how it stacked up against the analysis of the RGB imagery collected in 2016.

When it came time to analyze the multispectral data, the classes used with the imagery captured in 2016 were re-used with some modifications due to differences in what could be discerned from the imagery (Table 9). The imagery captured in Fall 2017 was captured after a summer with much greater precipitation than 2016. More water present combined with digging of new ponds through the restoration process necessitated the creation of a water class. The soil disturbance from ditching also resulted in a lot of exposed soils/dessicated vegetation along the central drainage ditch in the bog (Figure 17).

Table 9.Class definitions with component classes (if used) and descriptions for classifying UAV imagery at Big Meadow Bog from 2016 imagery.

Class	Component Class(es)	Description
Sedges / Rushes	--	Fine sedges of healthy lagg but also soft rush of post-gull recovery areas .
Low Shrub	--	Low shrubby ericaceous vegetation representing remnants of healthy bog community.
Active Gull	Gull Grass (Holcus. lanatus)	Soil exposed by nesting gulls Green grass in gull nesting areas
Herbaceous Disturbed	Fireweed (*Chamerion angustifolium)* Cinnamon Fern (*Osmunda cinnamomea*)	Herbaceous vegetation that follows gull disturbance, weedy.
tall shrub/ Cane	Blackberry (*Rubus alleghaniensis*) Raspberry (*R. Idaeus*) Chokeberry (Photinia spp.)	Shrubby vegetation indicative of disturbance/nutrient increase that follows gull occupation.
Trees	Spruce (*P. mariana, glauca*) Dead Spruce (from gulls/flooding) White Birch (*B. papyrifera*)	Spruce that grow in ditched bog/swamp Spruce tree dead from gulls/water Deciduous tree found in bog
Water	--	Water found in new ponds created along central drainage ditch and existing ponds in the Big Meadow Area ie. Jimmy's Pond, Lily Ponds
Shadow	Shadow	Areas unable to classify due to shadow
Bare Soil	Wet Soil Dry Soil	Exposed soil wetted by recent exposure by machinery or puddling Exposed soil dried by environment

Figure 18. Central drainage ditch following restoration. Feature characterized by mixture of dried peat, soil, raspberry and unidentified dessicated vegetation. Image captured 6 October 2017 by Ian Manning (AGRG).

The same analysis complete on the 2016 imagery, was completed on the imagery from 2017. The 3D point cloud generated in the UAV image processing workflow was gridded to datasets representing high and low elevations. The two datasets were differenced to create a normalized height model representing vegetation heights in the bog (Table 10, Figure 19). The VHM was broken into three classes of vegetation height (low, medium and tall) to better symbolize the distribution of vegetation heights across the study area (Figure 20).

Table 10. Summary workflow of methodology used to convert 3D point cloud data from UAV images into vegetation height model used for analysis in GIS from multispectral image collected 16 October 2017 at Big Meadow Bog.

Input Dataset	**Input Resolution**	**Action**	**Output**	**Output Resolution**
UAV Point Cloud	--	LASD To Raster (Binning MAX)	DSM	1m
UAV Point Cloud	--	LASD To Raster (Binning MIN)	DEM1	2m
DEM1	2m	Filter (Low Pass)	DEM2	2m
DEM2	2m	Resample (Cubic)	DEM3	1m
DEM3/DSM	1m	Minus	CHM	1m

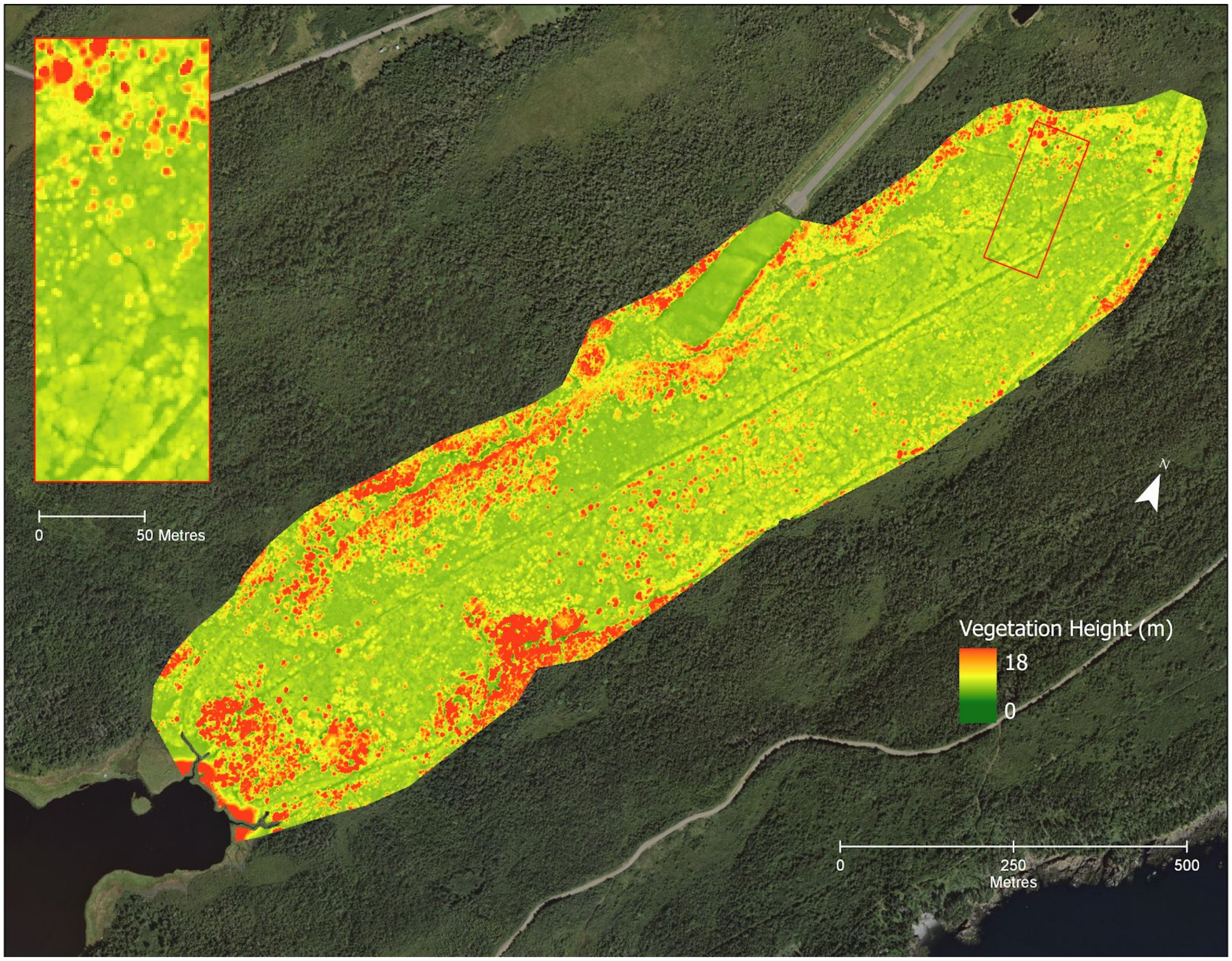

Figure 19. Vegetation Height Model (DSM-DEM) generated from gridded 3D image point cloud derived from UAV survey completed 6 October 2017 by AGRG. Background imagery provided by Nova Scotia Internal Services.

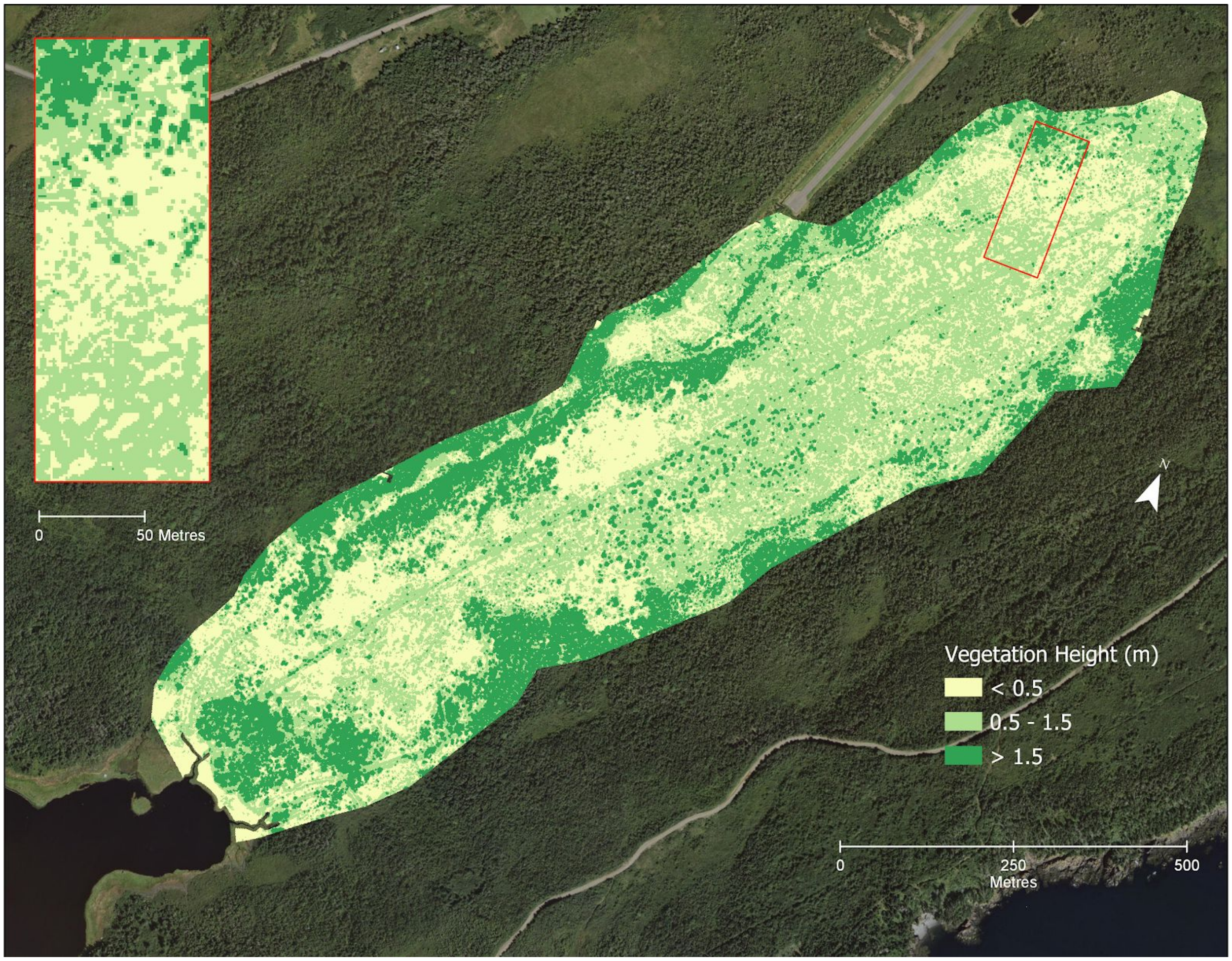

Figure 20. Vegetation Height Model (DSM-DEM) symbolized in three vegetation height classes, generated from gridded 3D image point cloud derived from UAV survey completed 6 October 2017 by AGRG. Background imagery provided by Nova Scotia Internal Services.

Classification Results

Similar to the results from the classified imagery captured in 2016, the classified imagery from 2017 (Figure 21)showed promising results at first inspection. Like the 2016 classification, the 2017 image captured the surrounding swamp draining into Big Meadow very accurately. Where the 2016 image overrepresented low shrub, the image from 2017 showed a greater than anticipated abundance of the herbaceous class, particularly in the northwest portion of the bog. Visible in the 2017 imagery is the extensive soil disturbance from infilling of the central drainage ditch, and associated pools of water from the digging of borrow pits.

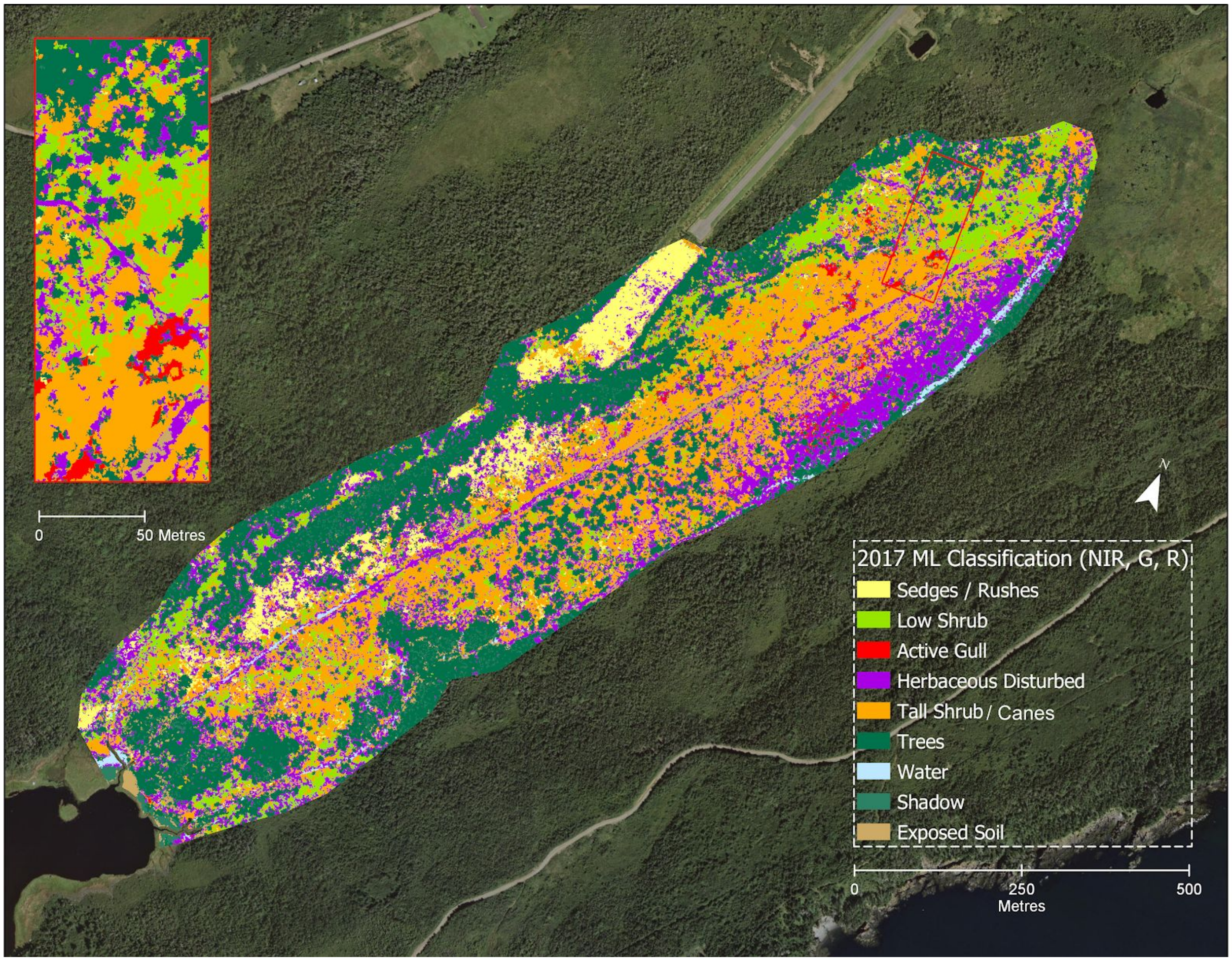

Figure 21. Maximum Likelihood Classification of Big Meadow Bog using NIR/G&R imagery for a UAV flight on 6 October 2017. This differs from Figure 9 due to the addition of the bare soil,and water classes and the input imagery type (multispectral vs. RGB). (NSCC AGRG bog imagery with background imagery provided by Nova Scotia Internal Services).

Following the same workflow used to assess the classification from 2016, the accuracy of the 2017 classification was checked. Random points were generated within the boundary of Big Meadow Bog excluding the areas used to train the classifier. The cover type at each random point was identified from the high resolution imagery, and cross referenced against the classified raster. The validated point data was then converted into a confusion matrix (Table 11) to better explain the results of the classification.

Table 11 .Confusion matrix for ML classification of Big Meadow Bog for Multispectral (NIR G&R) UAV image captured 16 October 2017 by AGRG.

	Sedges / Rushes	Low Shrub	Active Gull	Herbaceous Disturbed	Tall Shrub / Cane	Trees	Water	Shadow	Bare Soil	Classified Total	User Accuracy
Sedges / Rushes	13	2	0	9	1	0	0	0	0	25	0.52
Low Shrub	4	12	0	2	6	1	0	0	0	25	0.48
Active Gull	0	0	23	0	0	2	0	0	0	25	0.92
Herbaceous Disturbed	3	3	0	9	4	3	0	1	2	25	0.36
Tall Shrub / Cane	1	2	1	5	16	0	0	0	0	25	0.64
Trees	3	1	0	0	2	18	0	1	0	25	0.72
Water	0	0	0	1	0	0	15	5	4	25	0.6
Shadow	0	0	0	0	4	4	5	10	2	25	0.4
Bare Soil	4	0	0	3	1	3	3	1	10	25	0.4
Reference Total	28	20	24	29	34	31	23	18	18	225	--
Producer Accuracy	0.46	0.6	0.96	0.31	0.47	0.58	0.65	0.56	0.56	--	0.56

Overall the accuracy of the classification of the multispectral imagery (56%) was similar to that of the RGB imagery (58.9%). The classification of the multispectral imagery was most accurate in classifying active gull areas (UA = 92%, PA = 96%), trees (UA = 72%, PA = 58%), tall shrub/ cane (UA = 64%, PA = 47%) and water (UA = 60%, PA = 65%). The accuracy of other classes was much lower including that for herbaceous disturbed (UA = 36%, PA = 31%), shadow (UA 40%, PA = 56%) and bare soil (UA = 40%, PA= 56%).

The lower accuracies of the shadow classification from 2017 can be attributed to the inclusion of points representing tall shrub/cane (4), trees (4) and water (5) in the areas classified as water. This is not surprising, as many pools of water exist on the border of the bog, and larger shadows are associated with taller features on the landscape (tall shrub and trees). There were also larger shadows in the 2016 flight due to weather conditions, that led to a more accurate shadow classification. The low accuracies for the herbaceous disturbed class are due to a high amount of mixing between the classes, and also the general level of disturbance in the bog from restoration activities (note the amount of area classified as herbaceous disturbed occuring along the central drainage ditch (Figure 21)).

The accuracy assessment of the 2016 classified image was compared against the accuracy assessment of the 2017 classified image (Table 12). The 2017 image classification outperformed 2016 for the low shrub, active gull and tall shrub/cane classes. The 2016 classified image was more accurate for the sedge/rush class, herbaceous disturbed and shadow class. The 2016 and 2017 classified images performed similarly with the tree classification, however the higher UA and lower PA in 2017 suggests that the classifier missed classifying fewer trees but had a higher tendency to erroneously group other features within this class.

Table 12. Comparison of accuracies between the 2016 (RGB) and 2017 (NIR,G,R) classified images. Note that water and bare soil classes were not included in the 2016 classification.

Class	2016		2017	
	UA	PA	UA	PA
Sedges / Rushes	0.84	0.64	0.52	0.46
Low Shrub	0.24	0.38	0.48	0.60
Active Gull	0.60	0.79	0.92	0.96
Herbaceous Disturbed	0.44	0.50	0.36	0.31
Tall Shrub / Cane	0.60	0.39	0.64	0.47
Trees	0.56	0.78	0.72	0.58
Shadow	0.84	0.75	0.40	0.56
Water	--	--	0.60	0.65
Bare Soil	--	--	0.40	0.56

The classified output was clipped to a boundary of the bog. It should be noted that the boundary of the bog was slightly altered (smaller) than the boundary used to clip the 2016 imagery (Figure 9, Figure 21), to create a comparison of the two years of image classification (Table 13), the 2016 imagery was clipped to the reduced boundary from the 2016 imagery. Differences in class definitions reduce the usefulness of comparing the classified outputs from 2016 and 2017. The differences in values are indicative of the different results of the classifiers. The classification run on the RGB imagery predicted more ericaceous vegetation (low shrub) and less disturbed herbaceous vegetation than the classification from 2017. These results are due to land clearing in the area south of the runway, and disturbance along the central drainage ditch in Big Meadow Bog.

Table 13. Percent of Big Meadow Bog, belonging to each image class from the classification completed on 2017 UAV imagery compared with the results from 2016.

Class	2017		2016		Change (2017 - 2016)	Percent
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	
Sedges / Rushes	3.26	5.5	1.7	2.87	1.56	2.63
Low Shrub	5.85	9.87	15.86	26.75	-10.01	-16.88
Active Gull	0.48	0.81	0.97	1.64	-0.49	-0.83
Herbaceous Disturbed	12.17	20.53	0.84	1.42	11.33	19.11
Tall Shrub/ Cane	15.68	26.45	20.86	35.18	-5.18	-8.73
Trees	19.08	32.18	14.68	24.76	4.4	7.42
Shadow	1.26	2.13	4.37	7.37	-3.11	-5.24
Water	0.47	0.79	--	--	--	--
Bare Soil	1.04	1.75	--	--	--	--

Gull Impacts on Vegetation

Following the same workflow used with the 2016 data, the vegetation height model (Figure 20) was summarized within each of the zones delineating herring gull colonies from old airphotos (Toms, 2015). The summarized data shows the percentage of each gull zone that is covered with each class of vegetation height (Table 14). Results were consistent with the expected trends. Areas with the highest percentage of vegetation under 0.5m were found in areas that were recently host to nesting gulls and areas that been clear of gull activity for some time. This relative abundance of vegetation below 0.5m includes recovering bog, pristine bog not compromised by gull inputs, and areas actively used by gulls that have yet to succeed to shrubby vegetation. Greater proportions of tall vegetation (>1.5m) were found in areas that had been invaded by gulls at earlier dates.

Table 14. Historic gull nesting sites (Toms, 2016) in Big Meadow Bog, and area/percentage of 2017 vegetation heights for each area. Table coded to show maximum area (green) and minimum area (red) for each height class.

Air Photo Year	Area of Gull Occupation (hectares)	Vegetation height < 0.5 m (ha) (% of total)	Vegetation height 0.5 m - 1.5m (ha) (% of total)	Vegetation height > 1.5m (ha) (% of total)
1978	2.9	1.71 (58.97)	0.9 (31.03)	0.29 (10)
1988	11.02	6.24 (56.62)	3.52 (31.94)	1.25 (11.34)
2001	13.4	10.77 (80.37)	2.17 (16.19)	0.48 (3.58)
2011	11.57	8.84 (76.4)	2.55 (22.04)	0.19 (1.64)
2015	11.32	5.33 (47.08)	5.75 (50.8)	0.24 (2.12)

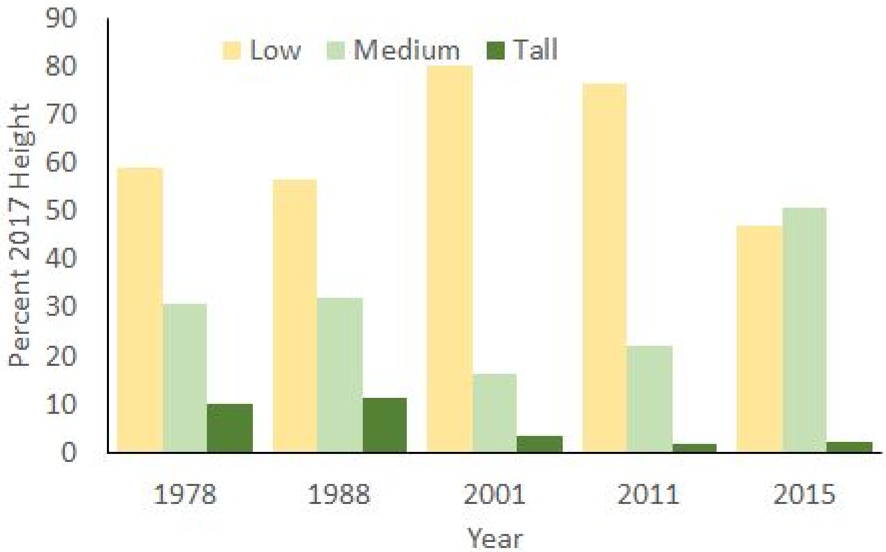

Figure 22. Historic gull nesting sites (Toms, 2016) in Big Meadow Bog broken down by percentage of 2017 vegetation heights (Figure 8) for each area.

Following the same workflow completed for the 2016 classified imagery, the classified imagery from 2017 was clipped to the boundaries of gull-occupied areas from historic air photos. The area of each gull inhabited zone was shown and expressed as a percentage of the total gull occupied area (Table 15).

Table 15.Historic gull nesting sites in Big Meadow Bog (Toms, 2016), and area/percentage of 2017 vegetation classes for each area.

		Area in hectares and percent total area								
Air Photo Year	**Total Area (Ha)**	**Sedges / Rushes**	**Low Shrub**	**Active Gull**	**Bare Soil**	**Herbaceous Disturbed**	**Tall shrub/ Cane**	**Trees**	**Water**	**Shadow**
1978	2.90	**0.547 (18.86)**	**0.424 (14.62)**	0.002 (0.07)	0.064 (2.21)	**0.341 (11.76)**	1.142 (39.38)	**0.378 (13.04)**	0 (0)	**0.001 (0.03)**
1988	11.02	1.349 (12.24)	1.603 (14.55)	0.019 (0.17)	0.303 (2.75)	0.697 (6.33)	5.799 (52.63)	1.209 (10.97)	**0.024 (0.22)**	0.014 (0.13)
2001	13.40	1.595 (11.91)	1.874 (13.99)	0.041 (0.31)	0.399 (2.98)	0.911 (6.8)	7.23 (53.97)	1.34 (10)	0.002 (0.01)	0.003 (0.02)
2011	11.57	0.182 (1.57)	1.064 (9.2)	0.263 (2.27)	0.772 (6.67)	0.161 (1.39)	**7.805 (67.47)**	1.32 (11.41)	0 (0)	0 (0)
2015	11.32	0.486 (4.29)	0.835 (7.38)	**0.346 (3.06)**	**0.816 (7.21)**	0.122 (1.08)	6.544 (57.83)	1.029 (9.09)	0 (0)	0.001 (0.01)

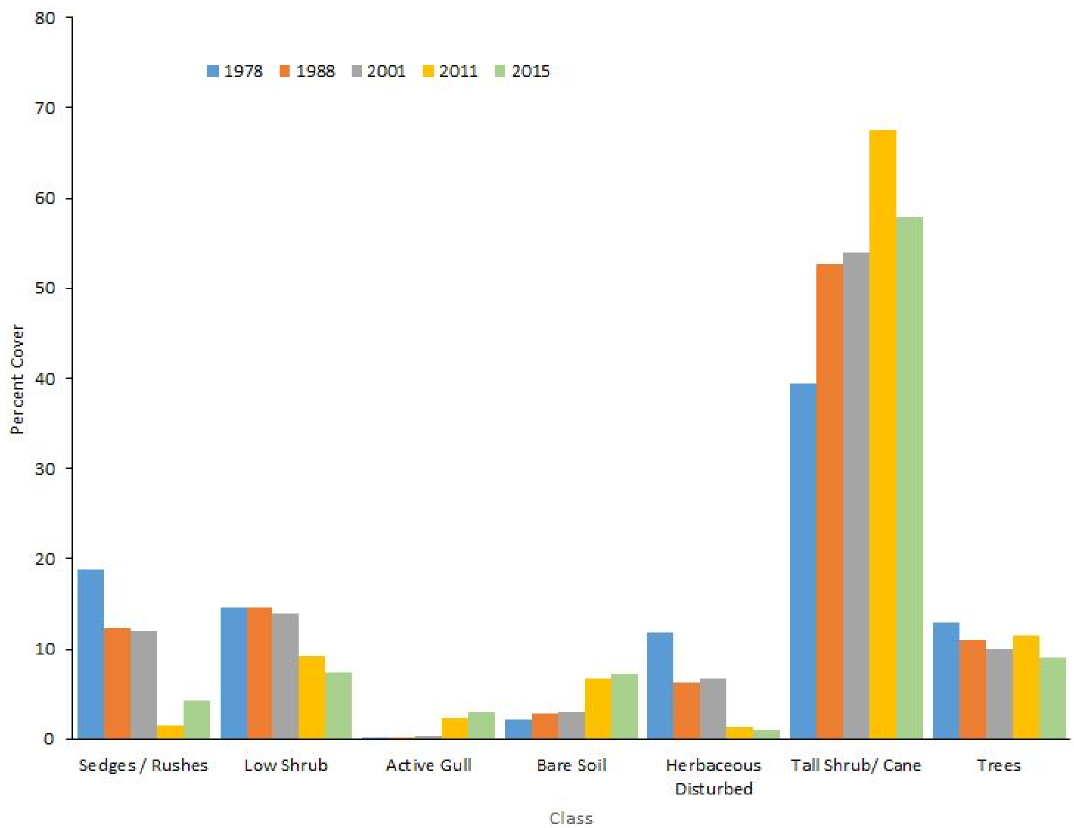

Figure 23. Historic gull nesting sites in Big Meadow Bog (Toms, 2016), and percent area of 2017 vegetation classes for each geography.

The 2017 ML classification applied to the historic gull areas suggests a positive outcome consistent with the 2016 analysis (Figure 12). Areas with earlier records of gull occupation showed a greater proportion of sedge/rush habitat, low shrub habitat, herbaceous disturbed, treed habitat and shadow (associated strongly with treed habitat). Areas more recently occupied by gulls had a greater proportion of active gull areas, bare soil, and tall shrub/cane (Table 15, Figure 23). The amount of bare soil (which was included in the active gull classification in 2016) was higher than normal due to the presence of heavy machines in the bog/associated travel corridors and the large amount of soil disturbance associated with infilling the central and western drainage ditches.

The areas first occupied by gulls (e.g. 1978 and 1988) have little bare soil, more low shrub and sedge/rushes and less tall rose-type shrub. We also see more “Herbaceous Disturbed”, a category that takes in disparate vegetation types (e.g. *Chamerion angustifolium* versus *Osmunda cinnamomea*); ground level work (Hill et al., 2018ms) suggests that this may an increase in fern cover with succession after gull disturbance, although this could also be related to the machine disturbance in the bog.

Relating 2017 UAV Imagery Products to Avens Survey Data

Each application of the MLC can be thought of as a test of its utility, given the understanding that there are accuracy concerns for different categories. The application of the 2017 MLC to the historic gull zones, showed its usefulness over various categories: bare soil, low shrub, sedge/rush and tall Rosaceae. We reasoned that cross-referencing the many Avens locations with the vegetation height model, and classified image would serve as a rapid test of model applicability at a local scale (e.g. 10m) over the lagg zones where Avens occurs. This test would not be circular as the model was not trained at such a fine level in the lagg. Given our understanding of Avens habitat from the transplant study (Poirier thesis, 2016, and work on-going), we knew Avens was more associated within the lagg with low vegetation with a high sedge to shrub ratio. We also had observed and confirmed using transects that Avens occurrence was negatively correlated with shrub height.

Avens point location data collected in September 2017 by Brad Toms of MTRI were cross-referenced with the outputs from the 2017 multispectral remote sensing products by AGRG. The GPS locations provided by Toms (n = 619) were overlaid on the digital products. Because of unsuitable flight conditions (Table 1) the UAV survey did not include areas on the southern boundary of Big Meadow that are known suitable avens habitat (Beauty Bog, Brad's Bog), which reduced the sample size of the analysis. Other Avens point locations collected by Toms included other areas of Brier Island and Long Island. A total of 282 surveyed Avens locations fell within the boundary of the October 6 datasets.

The classified output and estimated vegetation height were extracted for each of the 282 point locations that fell within the boundary of the 2017 datasets. The frequency of point locations occuring in each 10 cm vegetation height bin (Figure 24) and image class (Figure 25) were charted. Results were consistent with existing knowledge of Avens habitat, avens point locations were found in locations with low vegetation height and overwhelmingly within areas classified as sedges/rush, and low shrub (Figure 24, Figure 25).

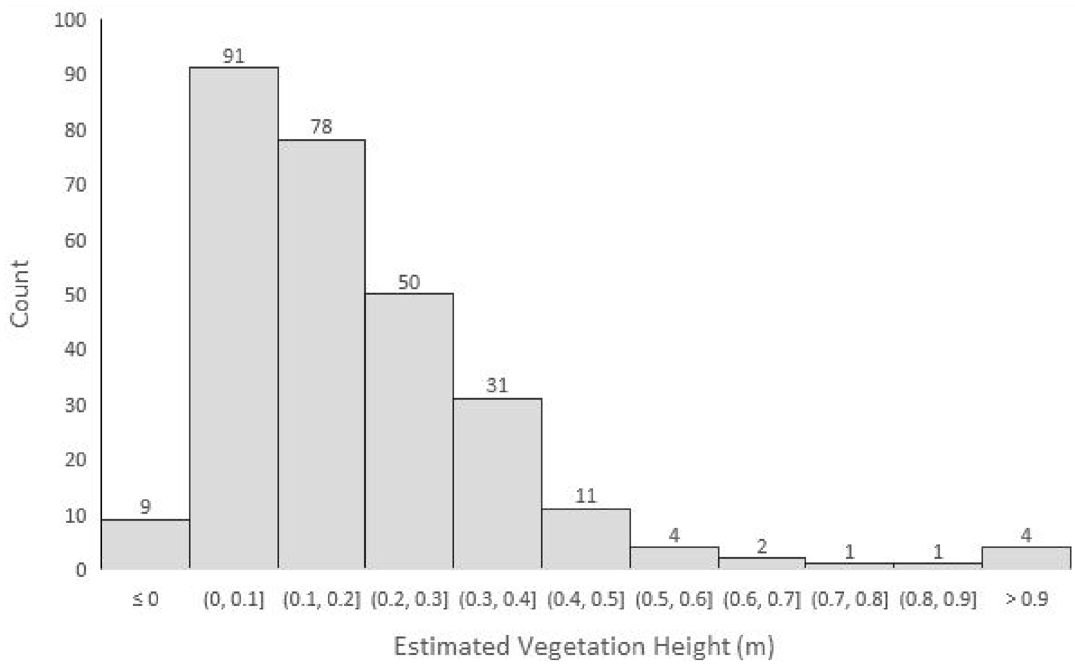

Figure 24. The estimated vegetation height derived from 2017 UAV flight (Figure 19) cross-referenced against locations of Avens collected in September 2017 by Brad Toms (MTRI). n=282.

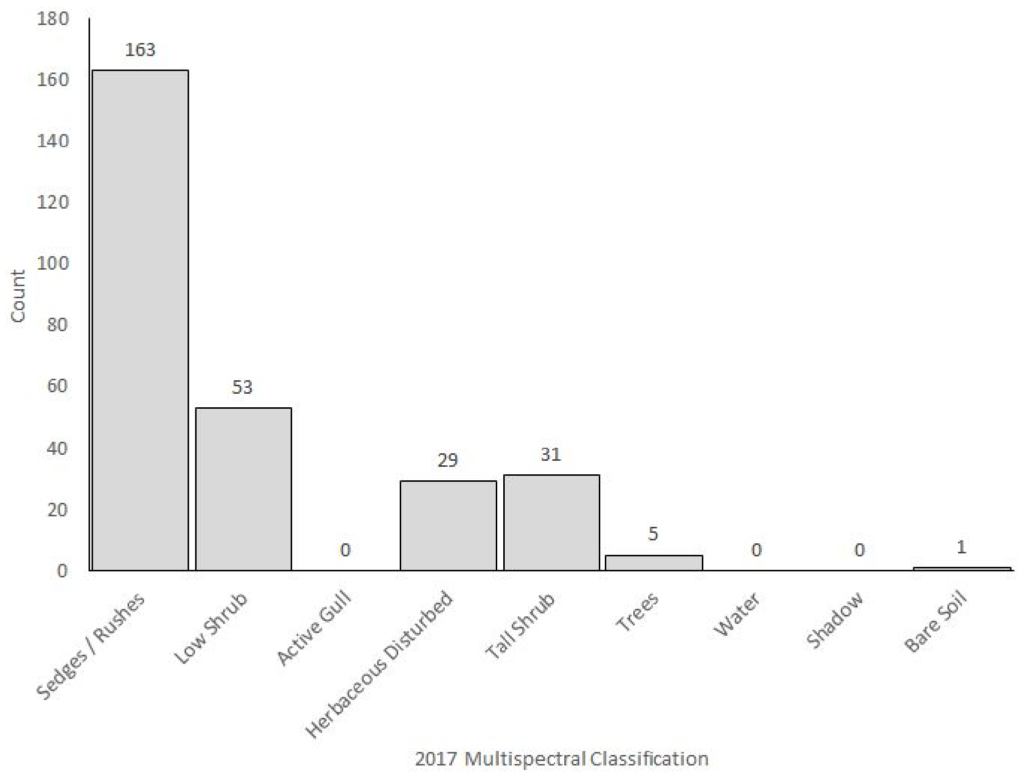

Figure 25. Predicted vegetation class derived from 2017 UAV flight (Figure 21) cross-referenced against locations of Avens collected in September 2017 by Brad Toms (MTRI). n=282.

This cross-referencing of known Avens locations with outputs generated by remote sensing upheld the usefulness of both derived datasets. According to the MLC, 57% of the Avens occurred in areas classified as sedge/rush and 19% in low shrub, habitats that have been reported as the primary Avens determinants (Figure 25). While this is 76% of the total, it is significant that no Avens were associated by the model with Active Gull and we know that Avens does persist under tall woody vegetation, although it does not flower and the transplant study has shown low survival in such areas (Poirier, 2016). The skewed curve of vegetation heights of avens point locations (Figure 24) suggests an affinity for low vegetation areas, an outcome consistent with observations of Avens (Hill, 2015).

Use of Remote Sensing in the Adaptively Managed Restoration

Adaptive management of the restoration will be responsive to the dynamics in hydrology, chemistry and vegetation; changes in these states are feedbacks for management. The image classifications (Figure 9, Figure 21) completed for 2016 and 2017 used two different types of imagery as input (RGB and NIR & RG). Each imagery input achieved different degrees of success at classifying the vegetation. The classified output of the RGB imagery captured in 2016 proved to be excellent in identifying the areas of sedge/rush, and the active gull areas. Multispectral imagery capture in October 2017, was also effective at classifying active gull areas and pools. Remote sensing data has also shown promise for identifying suitable avens habitat (Figure 24, Figure 25).

In this section, we'll examine the potential of the remote sensing datasets described above to help guide adaptive management. These include the detection and monitoring of negative habitat features and processes that should diminish in the course of restoration (1. gull disturbance areas, 2. observer disturbance from paths in sensitive habitats) as well as positive features and processes that should increase following the restoration (3 Avens lagg features: 3A pools in lagg, 3B low shrub in lagg; 4. flooding-induced death of competitive woody vegetation; 5. Low shrub, ombrotrophic raised bog).

Negative Features and Processes (1 & 2)

<u>1) Gull disturbance areas (High resolution images)</u>

Areas currently occupied by gulls are easy to discern from the high resolution aerial imagery (Figure 26). These areas are characterized by the presence of gull grass, gull feathers and guano, dead gulls and bare soil. With the drainage ditches blocked by East Coast Aquatics in

2017, water levels will increase throughout the bog, in hopes of making the bog a less desirable location for nesting gulls.

Figure 26. Part of Big Meadow Bog actively occupied by nesting gulls. Image shows gull grass (1), dead gulls (2) and bare soil (3). Image captured 06 September 2016 at Big Meadow Bog, Brier Island, Nova Scotia.

Expectation: Increased water table discourages gull nesting. Gull density in Big Meadow Bog diminishes and bare earth, gull grass and raspberry decrease in cover. Succession after gull abandonment of these areas leads to phases of shrub vegetation (Rosaceae then Ericaceae dominated) which is reduced as Sphagnum proliferates and influences waterlogging and nutrient availability.

Alternative: Increased water levels insufficient or too localized. Gull nesting in bog continues to create disturbance and eutrophication.

2. Observer Disturbances: Footpaths, machine tracks

Restoration and research in Big Meadow Bog comes at an ecological cost. Disturbance from researchers accessing wet sites creates well-worn footpaths in the bog that are visible from the air. Access paths from excavators and bulldozers also damage the ecosystem. Damage from All-Terrain-Vehicles (ATVs) is also evident (Figure 27).

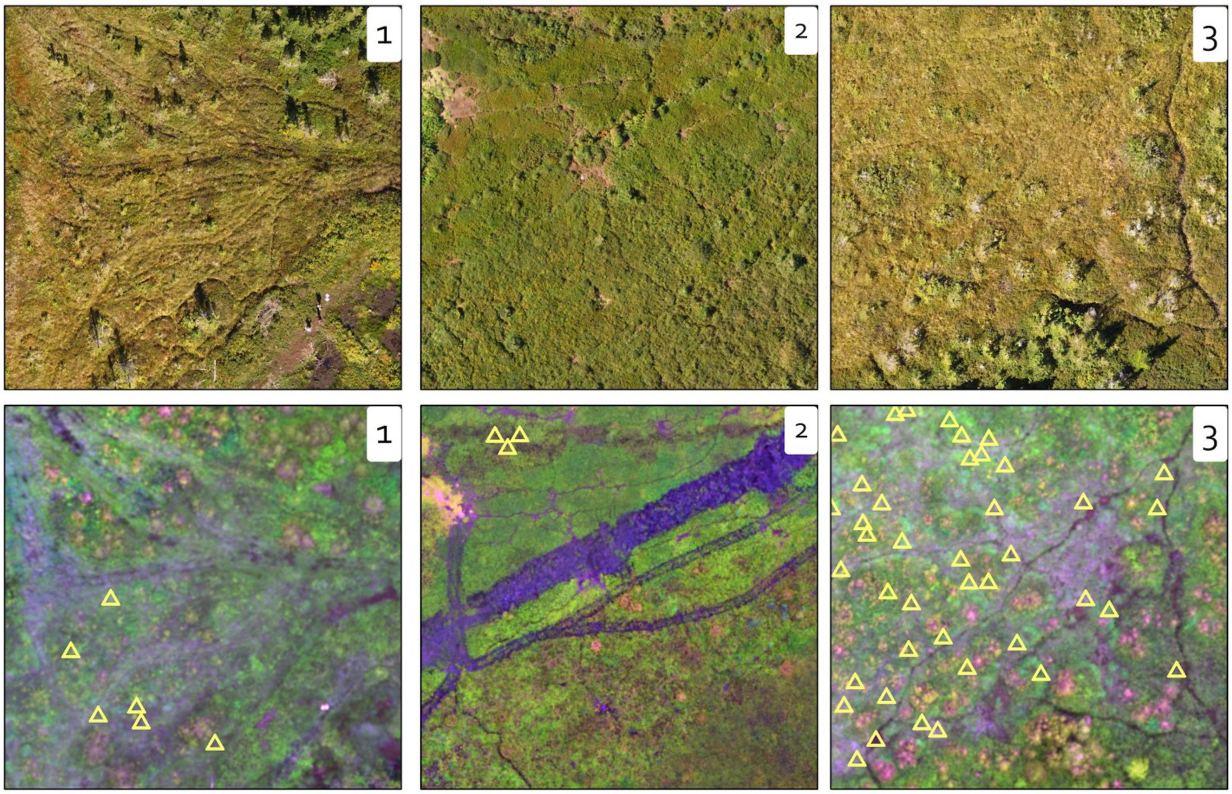

Figure 27. Three different types of disturbance in Big Meadow Bog, Brier Island, Nova Scotia from three different sources. Top imagery captured 16 September 2016 (RGB), bottom imagery captured 06 October 2017 (Near Infrared, Green, Red) overlaid with yellow triangles representing the locations of avens plants. Frames show: 1. ATV damage in Bog South West corner 2.) Machine tracks from excavation of drainage ditch, and 3. Researcher footpaths in Runway Bog.

Expectation: As active restoration efforts gear down, the bog well be accessed less, and machinery traffic from official means will reduce significantly. Boardwalk construction should reduce impact on sensitive areas.

Alternative: Boardwalk activity increases disturbance in the bog due to increase in accessibility. In this scenario, adaptive action is required to ensure harm is reduced as much as possible. This may take the form of signs, physical barriers or other techniques.

Positive Features and Processes (3, 4 & 5)

3). Lagg Features and Processes

3A). Avens Habitat - Pools

Restoration by blocking drainage ditches restored the pools (Lily Ponds) to Big Meadow and created new pools (Figure 28) along the drainage ditches from excavation borrow pits. The creation of new pools is a positive feature in the main raised bog (central ditch area) and in the lagg (at the southwest ditch and all along the eastern ditch). These pools can be used by waterfowl and East Coast Aquatics is monitoring the return of the Lily Ponds, favourite former duck hunting areas, in the southern laggs. All pools will also provide heterogeneity of habitat and increase the diversity of plant (e.g. bladderworts), insect (e.g. caddis fly larvae) and amphibian life (e.g. yellow-spotted and blue-spotted salamanders). The edges of the pools in the lagg are valuable as habitat for rare plants: the Eastern Mountain Avens, the livid sedge (*Carex livida*), and *Sphagnum carolinianum* (det. Richard Andrus). In addition to detecting the pool outlines (Figure 28), remote sensing should be able to detect algal blooms that are the result of active gull enrichment or high nutrient loads from former nestings.

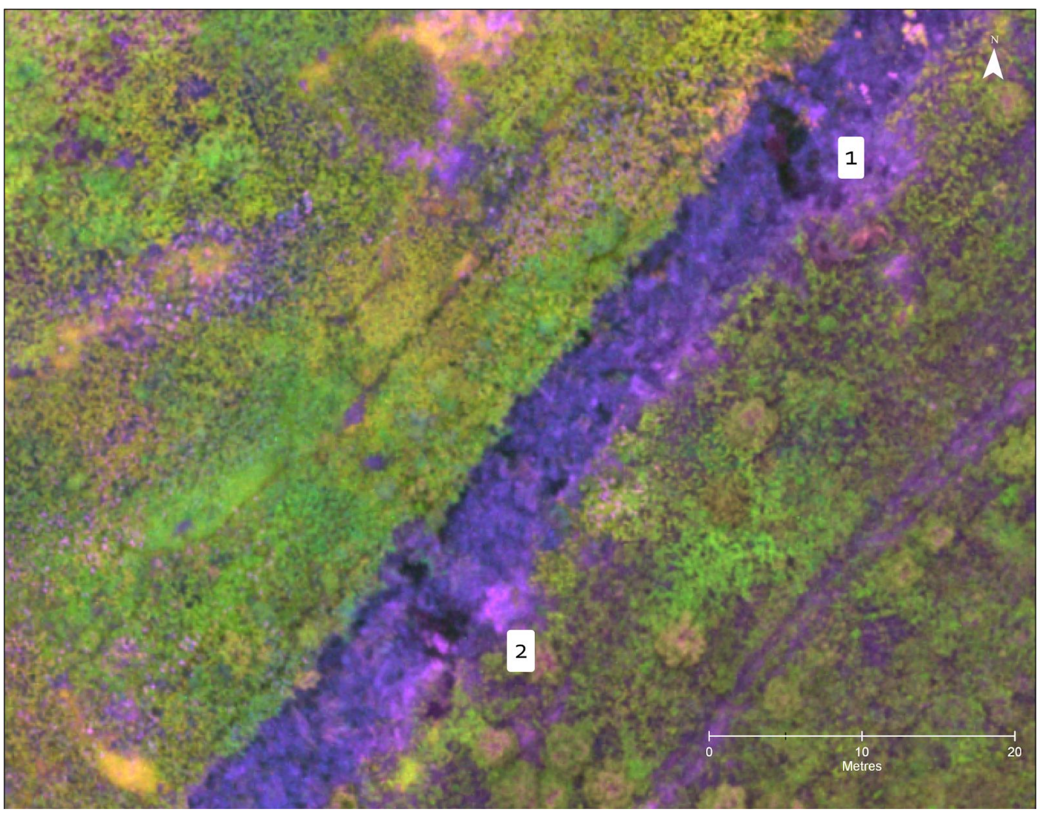

Figure 28. Pools created by East Coast Aquatics along the Big Meadow Bog central drainage ditch. Marker 1 shows depression mostly filled with water while Marker 2 shows less accumulated water. Image captured 6 October 2017.

Expectation: Pool habitat is created by ditching and is maintained. Over time, pools gradually become clearer as nutrient load decreases and gull densities diminish due to waterlogging of nesting habitat

Alternative: Pools fill in with shrub, or become eutrophic and colonized by green algae.

3B). Low shrub, open Avens habitat

Avens occurs mainly in the lagg fens at Big Meadow Bog. Furthermore, it is associated with low-stature vegetation such as sedges (e.g. Trichophorum cespitosum) and low shrubs (Figure 24, Figure 25). There has been a substantial loss of this habitat at Big Meadow (Toms, 2015). We expect to see a reversal of this ditching induced trend following the ditch blocking as waterlogging inhibits the growth of trees and tall shrubs and restricts aerobic rooting to surface layers. Remote sensing can help identify the type habitat for the Avens. The multispectral image Runway Bog (a lagg fen) suggested that Avens (yellow crosses) was associated with the interface of the purple and green areas. These may indicate edge zones between areas with too much shade, or water.

This observation suggested that the 2017 MLC might have the power to classify Avens habitat (see Avens section: pp.35-37, Figures 24 & 25). The MLC application was tested and its utility for identifying the condition of Avens habitats was upheld.

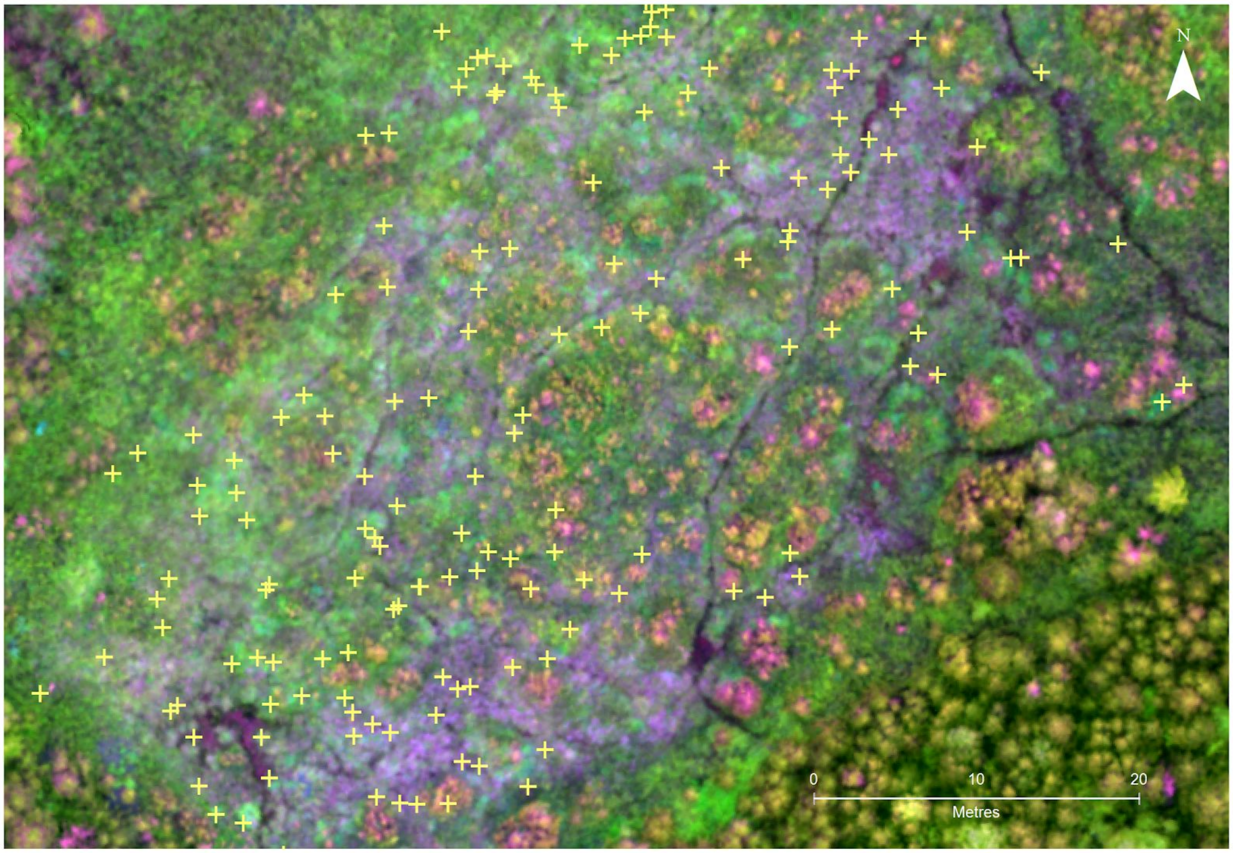

Figure 29. Multispectral image of runway bog (NIR, R, G) captured 6 October 2017 overlaid with locations of Avens (yellow crosses) collected by Brad Toms in September 2017. Image show association between Avens and the interface of shrubs (green) and open habitat (purple).

Expectation: Increase in low biomass Avens habitat in the lagg and rand of Big Meadow Bog as waterlogging from ditch blocking preferentially stresses tall shrubs and trees.

Alternative: Decrease in above Avens habitat in lagg. This could arise if residual nutrient loads from previous gull stages, increase shrub growth despite the waterlogging stress.

The transplantation study showed that a shift in vegetation brought about by gulls in the south of the Big Meadow Bog-lagg area 1 (BM1) was associated with death of all nine transplants. Furthermore a 90% loss of Avens in BM1 overall may be related to an increase in woody growth that relates to low water tables through that lagg area. This research (Figure 25, Figure 24) show that we can classify Avens habitats in the lagg using the MLC 2017 generated for the whole bog. Multispectral images (like Figure 29 can be generated for each lagg area and used to track the condition of these areas with outputs that track vegetation height and classification of the area.

4. Flooding-induced death of competitive woody vegetation

Trees and shrubs are sensitive to flooding and soil anoxia (Kozlowski, 1984, Keddy and Toner, 1997). After the drainage ditches were plugged, the water levels in the bog will rise, causing trees and shrubs to die. Remote sensing can detect the change in vegetation health (Figure 30). Change in the number of tree deaths over time could be a good indicator for restored hydrology. Aerial imagery can capture differences in phenology of flood-stressed trees and shrubs (e.g. Big Lily Pond) as well as dead crowns of trees and tall shrubs.

Figure 30. Imagery captured 16 September 2016 shows a healthy spruce (left with red highlight) and a dead spruce tree (right with yellow highlight). Gulls were the cause of death in this case but imagery can just as well pick out flood killed trees and shrubbery.

Expectation: Trees and shrubs not adapted to withstand long-term flooding and associated soil anoxia will die, and show-up on imagery as light gray deadwood.

Alternative: If an aerated surface layer persists in the central bog, tree and shrub growth could resume if nutrient loads remain high.

5) Low shrub, Bake Apple habitat in central raised bog.

Gulls destroyed ombrotrophic heathland where Jonesberry (Rubus chamaemorus) persisted (Figure 31). Retrospective study of gull abandoned patches showed that there has been a succession from eutrophic weedy stages to a tall Ericaceae and black spruce dominated swamp-like vegetation.

Waterlogging from the ditch blocking should kill the spruce (Figure 30) and favour Sphagnum moss. Sphagnum mosses may further this shift to nutrient-demanding vegetation such as Ericaceae, sedges, orchids and the signature Jonesberry.

Figure 31. Area of remnant low shrub bog habitat at northern extent of Big Meadow Bog. Note the intrusion of herring gull nesting areas interspersed throughout the heath.

Expectation: Spread of ombrotrophic bog (low nutrient and low biomass raised bog): southward from North Remnant Heath as well as along edges at the southeast and southwest of Big Meadow Bog inwards.

Alternative: Remnant Heath decreases in area. In this scenario, adaptive action is required.

Summary

The use of remotely sensed imagery captured by UAVs has provided detailed benchmark imagery of Big Meadow Bog prior to and during restoration. The multispectral images provide contrast to immediately visualize water, bare earth, gull zones, low vegetation and trees. The estimated vegetation height models produced from the UAV flights provide another immediate output that can be used to track bog restoration into the future.

The classified image generated from the 2016 RGB imagery was particularly effective at identifying areas of sedge/rush and active gull areas. The classified output from the multispectral imagery collected in 2017 was extremely effective at identifying the active gull areas. The accuracy ratings for both years of analysis reflect the challenge of classifying vegetation in Big Meadow Bog which may relate to the four decades of shifting gull colonies within the bog and associated vegetation complexes.

Comparing the vegetation height model and classified image outputs restricted to boundaries of historic gull occupations showed expected patterns of succession and vegetation height. Areas first invaded had a higher proportion of tall vegetation. Areas that were more recently invaded had higher proportions of medium height vegetation, corresponding to the flush of tall shrub/canes following the nutrient flush provided by nesting gulls.

A comparison of point locations of avens plants collected in 2017 were cross-referenced against the vegetation height model and classified image generated from the 2017 flights. The results were most rewarding. This was an independent test of both remote-sensing derivations. Given what we knew of the Avens and its habitat preferences, each test had the potential to refute or indict the utility of these techniques. The results of this analysis confirmed the results of our GIS analysis with great correspondence between the vegetation height layers/image classification and our knowledge of Avens habitat preferences.

We have shown that remote sensing can play a major role in the adaptive management of Big Meadow Bog. It can be used to monitor active gull zones, the health of restored pools, the restoration of the raised bog, and quantify recovery of the Avens habitat. Remote sensing is not a substitute for on the ground work, but an excellent complement to field studies. Remote sensing can be used to test large-scale patterns across the study area with a reduction in labor. These technologies will help guide the adaptive management of Big Meadow Bog restoration and the recovery of the eastern mountain avens.

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