Abstract— The objective of this paper is to spatially predict tree/shrub genera using generalized linear models (GLM), color-infrared (CIR) aerial images, ADS40 images, digital surface models (DSMs) and field samples. The present study was carried out in the framework of the Swiss Mire Protection Program, where extraction of forest parameters for description of present state of a mire ecosystem and as indicators for changes are of high importance. In a first step, high-quality DSMs were automatically generated from CIR aerial images for two test sites, both located in the Pre-alpine zone of Central Switzerland. In a second step, tree layers were then generated combining canopy height models derived from the DSMs and LiDAR DTM with a fuzzy classification of CIR aerial images. In a third step, on the basis of these tree layers, fractional tree/shrub covers were generated using explanatory variables derived from the DSMs and logistic regression models. Then tree genera were predicted for the pixel values (tree/shrub probability > 0.3) of the fractional covers using a multinomial regression model and additional spectral information as provided by Leica ADS40 data for one test site and CIR aerial images for the other test site. Overall, prediction of tree genera was less satisfactory when only using CIR aerial images. In contrary, up to six different tree genera were predicted with high accuracy using explanatory variables derived from ADS40 images. The study stresses the importance of high-resolution and high-quality DSMs and highlights the potential airborne remotes sensing data for ecological modeling purposes.

I. INTRODUCTION

This paper focuses on modeling fractional tree/shrub cover and prediction of tree/shrub genera in two mire ecosystems. The study was carried out in the framework of the Swiss Mire Protection Program which aims at conserving mire ecosystems of national importance and outstanding beauty in their present state. This implies no decrease of the mire area and no degradation of vegetation. A monitoring program based on a representative sample of 130 mires was set up in 1996 to examine the effectiveness of the conservation status [1, 2]. The monitoring also implies an assessment of shrub encroachment and increase of forest area exerting vehement impact on the non-forest areas of the mire biotopes. Shrub encroachment is a considerable danger for the biotope and accelerates a degradation of the mire area. Extraction of various forest related parameters (e.g. exact forest/shrub area, canopy height, trees/shrubs in open mire land, tree/shrub genera etc.) is essential to assess magnitude and consequences of this impact. However, such information is often difficult to acquire across mire ecosystems using traditional methods of field survey and aerial photograph interpretation. It is well known that obtaining different forest parameters, such as tree heights or stand composition through ground measurements or vegetation mapping is often not feasible in dense forest, too costly in terms of time and manpower, and also prone to errors [3]. Costs of forest sampling can be reduced substantially by estimating forest and tree parameters directly from high-resolution remotely sensed data.

Recent progress in three dimensional remote sensing mainly includes digital stereophotogrammetry, radar interferometry and LIDAR [4]. E.g. by subtracting DTM from the DSM canopy height models can be calculated. DSM can be obtained by means of photogrammetric methods or by LIDAR. Using digital photogrammetry, DSMs are based on ATE algorithms with image correlation. This method is widely used and has proven to provide both, reliable and accurate results [5]. DTM have been derived from manual photogrammetric or terrestrial measurements for a long time already [6]. Meanwhile several LIDAR systems are commercially available [7], enabling the derivation of DTMs from such data as well. A number of studies reveal the successful application of these methods to assess tree [8] and stand attributes (stand composition, tree height, crown diameter, basal area, and stem volume). Combining some of these attributes can be useful to evaluate growth estimations (including extent of forest area), to detect changes in the forest stands, and determination of tree/shrub genera [9, 10].

There is a growing need for sensitive tools to predict spatial and temporal patterns of plant species or communities [11]. Spatially explicit predictive modeling of vegetation is often used to construct current vegetation cover using information
on the relations between current vegetation structure and various environmental attributes [12]. E.g. [13, 14] point out that modern regression approaches have proven particularly useful for modeling spatial distribution of tree species and communities. Thus, high-resolution airborne remote sensing data in combination with regression analyses are also useful for modeling tree/shrub genera in mire environments.

The objective of this study is to develop a methodology for modeling a fractional tree/shrub cover and predicting tree/shrub genera using generalized linear models (GLM), airborne remote sensing data (analogue and digital) and field samples. A fractional cover approach for discrimination of tree area and species was chosen since the discrimination of tree/shrub pixels [15] into simple forest / non-forest categories results in a loss of information. The extracted forest parameters (area of forest, trees/shrubs in the open land and tree/shrub composition and genera) are indispensable to a range of protecting purposes as applied in the Swiss Mire Protection Program.

II. MATERIALS AND METHODS

A. Study Area

Models have been developed and tested for two representative mire ecosystems in the northern Pre-alpine zone of Switzerland. Both test sites are characterized by a permanent shrub encroachment in open mire land and few selective logging activities and cutting of shrubs as a result of conservation effort

The first test site “Walchwil” is located on a small plateau in the East of Lake of Zug (approx. 47°07' N and 8°32' E). The core of the mire has an area of approx. 2.61 km². The altitude varies from 900 m to 1000 m above sea level. The landscape is highly fragmented and characterized by pastures that are crossed by shrubs and bright broad-leaved woodland (see Fig. 1). The dominant vegetation types are moist and wet meadows and pastures, low sedge poor fen, bog forest and broad-leaved woodland and willow Carr.

The second test site “Breitmoos” is located in a small valley in the region of Appenzell (approx. 47°18’ N and 9°14’ E). The core of the mire has an area of approx. 1.1 km². The altitude varies from 900 m to 1100 m above sea level. The landscape is less fragmented and characterized by pastures, few shrubs and surrounded by mixed forest (see Fig. 1).

B. Remotely sensed Data

Three different data sets are available for test site “Walchwil”: 1. CIR (red, green, infrared, 8 bit) aerial images: 12 images (2 strips) of 2002, scale 1:5700 and an orthoimage that was generated with a spatial resolution of 0.5 m. 2. A digital surface model was generated automatically from the above images with a spatial resolution of 0.5 m. 3. National LiDAR data of the Swiss Federal Office of Topography (SWISSTOPO) was acquired in 2002 with leaves-off. From the raw data, both a DTM and DSM were generated by SWISSTOPO (as raw irregularly distributed points and regular grid; the first dataset was used in this study). The average density of the DSM data was 1-2 points / m² and the height accuracy (1 sigma) 0.5 m for open areas and 1.5 m for vegetation and buildings. The DTM has an average point density of 0.8 points / m² and height accuracy (1 sigma) of 0.5 m [16]. Four different data sets are available for test site “Breitmoos”: 1. CIR (red, green, infrared) aerial images: 4 images (1 strip) of 2005, scale 1:5600 and an orthoimage that was generated with a spatial resolution of 0.5 m (Fig. 2). 2. A digital surface model was generated automatically from the above images with a spatial resolution of 0.5 m. 3. National LiDAR data as already specified above. 4. Leica ADS40 images Level1 of 2005, scale 1:30000, RGB (16 bit), spatial resolution 0.25m. The orthoimage was generated using the above mentioned DSM (Fig. 2).
### C. Automatic Generation of Digital Surface Models

High-resolution DSM data is indispensable since accurate surface information in forested and open mire land is very important for modeling both fractional tree/shrub covers and tree/shrub genera. Thus, a matching method which is described in detail in [17, 18] was used. This method can simultaneously use any number of images (> 2). It is implemented in the operational, quasi-complete photogrammetric processing package Sat-PP which supports satellite and aerial sensors with frame and linear array geometry. The result was a regular grid DSM with 0.5 m spacing which was interpolated from a matching point cloud of similar density (ca. 15 million match points per stereo-pair). For both test sites the matching DSMs and the LiDAR DSMs and DTMs were co-registered, using a point cloud co-registration procedure described in Akca [19]. The difference matching DSMs minus LiDAR DTM gives the normalized DSMs (nDSM), i.e. the 3D objects in the scene and especially the canopy models. The modeled vegetation surface of a part of “Walchwil” is shown in Fig. 3.

![Image](image1)

**Figure 3.** Part of test site “Walchwil” illustrated by CIR aerial images and the corresponding DSM. Most challenging areas for the matching software are shadowed areas, forest clearings and small shrubs in the open mires.

### D. Tree Layers

In this study, a tree layer for each test site serves as basis (response variable) for the fractional modeling approach. In a first step, preliminary tree covers were calculated using canopy height models. Then potential woody areas were extracted according to the 3 m height definition of trees in the Swiss national Forest Inventory (NFI) [20]. In a second step, non-tree objects (buildings, rocks etc.) of the canopy covers were removed using normalized difference vegetation index (NDVI) information obtained from the CIR orthoimages. Separation was performed using a multi-resolution segmentation of the canopy cover and the NDVI values with a fuzzy classification [21]. To summarize, the resulting tree layers for the two test sites are a product of canopy model pixels with height values more than 3 m and spectral information of the CIR orthoimages. ori) was 3.4 m, showing a clear reduction of trees and other wooded plants from 1997 to 2002. The difference matching DSMs minus LiDAR DTM gives the normalized DSMs, i.e. the 3D objects in the scene and especially the canopy height models (Fig. 2).

### E. 1\textsuperscript{st} Model: Fractional Tree/Shrub Covers

Logistic regression is often used to predict probabilities for presence/absence of a specific vegetation type at each point [22]. Shrub/tree occurrence maps can be constructed by analysis of these probabilities’ actual occurrence. The logistic regression model is a special case of the generalized linear model (GLM) and is adapted for modeling such data [23]. The fractional shrub/tree cover of the open mire land is at first based on the tree layers, developed in section D, which means that pixels that were extracted as forest (according to the tree layers) are assigned the value 1, all others the value 0. These pixels serve as response variable (Y - that has to be binary) in the logistic regression model, assuming a binomial distribution. The result is a fractional tree/shrub cover, i.e. a probability for each pixel to belong to the class “tree/shrub”. The explanatory variable consists of five commonly used topographic parameters derived from normalized DSMs (slope, aspect, curvature, and local neighboring functions), see table 1 and for further details see [24]. Most of these parameters have successfully been applied for ecological modeling purposes in mires [1] or in biodiversity studies [25, 26]. Two fractional tree/shrub covers of both test sites were produced using the tree layers described in section D as response variables.

<table>
<thead>
<tr>
<th>Name</th>
<th>Derivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>curvature</td>
<td>curvature of the surface at each cell center (3x3 window)</td>
</tr>
<tr>
<td>plan</td>
<td>curvature of the surface perpendicular to the slope direction, referred to as the planform curvature (3x3 window)</td>
</tr>
<tr>
<td>prof</td>
<td>rate of change of slope for each cell, curvature of the surface in the direction of slope (3x3 window)</td>
</tr>
<tr>
<td>slope</td>
<td>rate of maximum change in z value from each cell</td>
</tr>
<tr>
<td>top</td>
<td>assessment of topographic position (4 classes: ridge, slope, toe slope and bottom), the resulting grid displays the most extreme deviations from a homogenous surface</td>
</tr>
</tbody>
</table>

### F. 2\textsuperscript{nd} Model: Stand Composition

Prediction of the tree/shrub genus is primarily based on the fractional tree/shrub covers - all pixels with a tree probability of less than 0.2 were skipped. For both test sites prediction of main tree genera was modeled: 1. Acer, 2. Betula, 3. Frangula, 4. Populus, 5. Salix, 6. Sorbus, 7. Picea abies and 8. Pinus silvestris for test site “Walchwil”; and 1. Abies alba, 2. Acer, 3. Betula, 4. Fagus, 5. Fraxinus, 6. Larix, 7. Picea abies, 8. Pinus silvestris for test site “Breitmoos”. For this second approach a multinomial regression model was chosen since tree genera are categorical data. For an optimal distinction between the different tree genera spectral information as provided by CIR...
aerial images (for test site “Walchwil”) and Leica ADS40 images (for test site “Breitmoos”) were used as explanatory variables together with the five previously used topographic parameters. The six spectral variables consist of original CIR and RGB channels, respectively and ratio mean of these channels). Altogether, 11 explanatory variables were used for each test site. To calibrate this model canopy closure was estimated and the dominant tree genus was recorded in 170 homogeneous areas in selected parts of the mire “Walchwil” in 2003 and 2005 of the mire “Breitmoos” with 120 homogenous areas, respectively. These records cover 10% of the mire areas and serve as reference data for the tree/shrub covers and for model calibration data for the prediction of the tree genera. Thus, tree genera from 170 and 120 field records of both test sites, respectively, were used as response variables. Subsequently, the predicted tree genera were extrapolated to the entire mire areas.

G. Validation Data

For validation of the fractional shrub cover approach, XY - coordinates and heights of 150 randomly sampled shrubs and trees (apex) and 150 non-tree objects (stones, grassland) in the open mire land for both test sites were obtained (DGPS and Tachymat) during field surveys in 2005 and 2006. Tree/shrub heights range from 1.8 m to 15 m. For validation of the second model 8 x 30 tree individuals (eight main tree genera) per test site were used which were selected by an expert in the mire area representing the eight dominant tree genera of the two test sites.

III. RESULTS

A. Fractional shrub/tree covers

The predicted shrub/tree cover strata (as shown in table 2) were validated using a pixel-to-pixel comparison to the 150 randomly sampled field measurements. For this validation the corresponding pixel clusters (5x5 window) of the measured 150 tree/shrub samples and 150 non-tree samples, respectively were used. Table 2 presents the correspondence between the pixels of randomly sampled shrubs/trees that are > 1.8 m and the modeled individual shrub/tree cover strata trained on the tree layers as an overview. Several statistical measures are used, namely: correct classification rate (CCR), consumer’s accuracy, producer’s accuracy, kappa coefficient and correlation coefficient ($r^2$). The kappa coefficient is a widely used measure for assessing the accuracy of classification of remotely sensed data [27]. The accuracies for five different tree/shrub cover strata based on the tree layers are given for test site “Walchwil” and for test site “Breitmoos” in brackets. Best correspondence between the model and the field samples are obtained for stratum 30-100%.

![Figure 4](image)

Fig. 4 visualizes the fractional covers in a typical part of the mire “Walchwil” where small shrubs and single trees are well present. Small single trees and shrub encroachment are not detected by the tree layer.

![Table II](image)

<table>
<thead>
<tr>
<th>Shrub/tree cover stratum</th>
<th>10-100%</th>
<th>20-100%</th>
<th>30-100%</th>
<th>40-100%</th>
<th>50-100%</th>
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</thead>
<tbody>
<tr>
<td>CCR</td>
<td>0.916</td>
<td>0.958</td>
<td>0.963</td>
<td>0.951</td>
<td>0.938</td>
</tr>
<tr>
<td></td>
<td>(0.923)</td>
<td>(0.967)</td>
<td>(0.972)</td>
<td>(0.958)</td>
<td>(0.943)</td>
</tr>
<tr>
<td>Consumer's acc.</td>
<td>0.818</td>
<td>0.949</td>
<td>0.975</td>
<td>0.979</td>
<td>0.986</td>
</tr>
<tr>
<td></td>
<td>(0.792)</td>
<td>(0.956)</td>
<td>(0.985)</td>
<td>(0.978)</td>
<td>(0.991)</td>
</tr>
<tr>
<td>Producer's acc.</td>
<td>0.958</td>
<td>0.916</td>
<td>0.901</td>
<td>0.875</td>
<td>0.821</td>
</tr>
<tr>
<td></td>
<td>(0.934)</td>
<td>(0.924)</td>
<td>(0.912)</td>
<td>(0.881)</td>
<td>(0.834)</td>
</tr>
<tr>
<td>Kappa</td>
<td>0.818</td>
<td>0.901</td>
<td>0.912</td>
<td>0.889</td>
<td>0.852</td>
</tr>
<tr>
<td></td>
<td>(0.802)</td>
<td>(0.911)</td>
<td>(0.923)</td>
<td>(0.883)</td>
<td>(0.856)</td>
</tr>
<tr>
<td>$r^2$</td>
<td>0.824</td>
<td>0.902</td>
<td>0.911</td>
<td>0.892</td>
<td>0.859</td>
</tr>
<tr>
<td></td>
<td>(0.832)</td>
<td>(0.909)</td>
<td>(0.924)</td>
<td>(0.891)</td>
<td>(0.864)</td>
</tr>
</tbody>
</table>

B. Prediction of Stand Composition: Tree Genus

Since the prediction of the stand composition is primarily based on the occurrence of trees/shrubs – therefore the most accurate thresholds (probability of > 0.3 or 30%-100% stratum) of the fractional covers were used. Prediction for each test site was validated with 240 field samples of eight different tree genera belonging to 4 groups: single trees, group of trees, trees at forest border, and trees within forest.

1) CIR aerial images for test site “Walchwil” - A first test of predicting the eight main tree genera revealed no satisfactory results, especially between deciduous trees. E.g. it was not possible to predict Acer, Frangula, Populus although they are the dominant genera in several parts of the mire. Good prediction was only obtained for Betula pubescens, Picea abies and Pinus silvestris. Detailed accuracies for each group of tree individuals are given in table 3. An independence test revealed that the classification of these tree individuals depends on their group affiliation.

![Table III](image)

TABLE III. OVERVIEW OF PREDICTED ACCURACIES FOR EACH GROUP OF TREE INDIVIDUALS (BETULA, PINUS SILVESTRIS AND PICEA ABIES) OF TEST SITE “WALCHWIL” USING CIR AERIAL IMAGES.
Best accuracies are obtained for tree individuals that are located at the forest border. Highest gamma values are obtained for both trees in groups and at the forest border.

2) RGB ADS40 images for test site “Breitmoos”. A first test of predicting the eight main tree genera revealed only partly satisfactory results. However, it was possible to distinguish between deciduous trees Betula, Fagus, Fraxinus or Acer, Betula, Fagus with high accuracy but not between Fraxinus and Acer. Good prediction was also obtained for the four main coniferous tree genera Abies alba, Larix, Picea abies and Pinus silvestris. Detailed accuracies for each group of tree individuals are given in table 4. An independence test revealed that the classification of the tree individuals does not depend on their group affiliation. Overall, best accuracies and highest gamma values are obtained for tree individuals that are located in the forest and at the forest border, respectively.

<table>
<thead>
<tr>
<th>Tree individuals belonging to</th>
<th>Overall accuracy</th>
<th>kappa</th>
<th>gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single tree</td>
<td>0.738</td>
<td>0.573</td>
<td>0.903</td>
</tr>
<tr>
<td>Group</td>
<td>0.833</td>
<td>0.706</td>
<td>0.963</td>
</tr>
<tr>
<td>Forest border</td>
<td>0.91</td>
<td>0.751</td>
<td>0.965</td>
</tr>
<tr>
<td>Forest</td>
<td>0.833</td>
<td>0.739</td>
<td>0.894</td>
</tr>
</tbody>
</table>

IV. DISCUSSION AND CONCLUSION

This study highlights the potential of combining airborne remote sensing data with generalized linear models to extract various forest related parameters such as canopy height models, forest/shrub area, and tree/shrub genera. The first objective of this study was to develop a methodology for deriving fractional tree/shrub. Combining remote sensing data with regression analysis on sub-pixel level as it is performed in many studies for land cover mapping [13, 28] seems also to be appropriate for fractional shrub/tree cover mapping in mire biotopes. The usage of standard explanatory variables as already applied in other studies [1, 26] derived from the DSMs proved to be a good approach for modeling fractional covers. With a fractional cover approach, also subtle changes of tree/shrub area can be detected before reaching a discrete threshold value. Shrub/tree classifications based on the continuous data can be adjusted retrospectively. This may be an advantage also for mire habitat management. In the present study, for both test sites, highest correspondence between the model and the field data are obtained when using the fractional shrub/tree cover strata of 30-100%. However, this validation is based on shrubs/trees > 1.8 m. It has to be kept in mind that accuracies for the strata may vary when considering also shrubs/trees < 1.8 m for validation. But detailed visual stereo image interpretation confirmed that most real small shrubs and trees are then extracted in the open mire area when using this stratum. The exact detection of the shrubs/trees in open mire land is substantial for assessing shrub encroachment and tree growth. Since shrub encroachment often starts in areas where small shrubs or group of small trees have established themselves, this approach may be helpful for finding potential areas of encroachment over the entire area. These regions are high risk areas for the biotope and accelerate degradation of the mire area. The second objective was a prediction of tree genera for the two test sites. The use of CIR aerial image information only produced partly satisfactory results for test site “Walchwil”. Reliable distinction was only possible for Betula, Pinus silvestris and Picea abies. Distinction for further deciduous trees failed due limited spectral information of the CIR images. This modeling approach clearly shows the limits of the RC30 sensor. Another reason was that Acer, Frangula, Populus are often partly covered or mixed with other tree genera. Much better prediction is obtained by the use of RGB ADS40 images for test site “Breitmoos”. Distinction was possible between four coniferous tree genera and also among deciduous trees. Problems only occurred for a Fraxinus and Acer, where distinction was only partly possible. However, the present study shows that ADS40 provides the spectral information needed for detection of stand composition and tree species. Mean ratio of the RGB channels in combination with DSM parameters are the most appropriate explanatory variables for the model.

Finally, accuracy of the tree layers, the fractional tree/shrub covers and the tree composition maps strongly depend on the accuracy of the DSM data. Thus, DSMs derived from newly developed, high-quality matching methods are indispensable. The usage of a dense and accurate DSM is an absolute prerequisite in order to be able to derive accurate topographic parameters which in turn are used to derive the fractional tree/shrub covers and to model tree genera [29]. LiDAR DTM as applied for this study have smaller point density that the DSM, and during the vegetation season, due also to partial canopy penetration or LiDAR flight with leaves off, are less accurate for modeling vegetation canopy. Regarding the matching DSM, a larger side overlap could reduce occlusions and lead to better modeling of small openings between trees, while increasing the number of image rays per measurement leading to higher accuracy and reliability.

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