INITIAL REPORT OF THE AIMWETLAB PROJECT: SIMULTANEOUS AIRBORNE HYPERSPECTRAL, LIDAR AND PHOTOGRAMMETRIC SURVEY OF THE FULL SHORELINE OF LAKE BALATON, HUNGARY

***András ZLINSZKY*[1], *Viktor TÓTH*[1], *Piroska POMOGYI*[2], *Gábor TIMÁR*[3]**

ABSTRACT:
Wetlands are valuable habitats under considerable threat from human activity. Lake shore wetlands are especially suitable for aerial surveys, and aerial photogrammetry, hyperspectral imaging or airborne laser scanning are the usual methods applied. Lake Balaton is a large shallow lake with wetlands in decline since the 1970's. In August 2010, a full photogrammetric, hyperspectral and ALS survey of the shores of Lake Balaton was completed. This initial report summarizes rationale, methodology, planned processing and expected outputs. Data collected with the three methods is planned to be evaluated to the level of dominant vegetation species and condition, and the accuracy of each method will be compared. A standard remote sensing procedure will be recommended for future surveys relying on the most suitable method. As a secondary data product, a digital elevation model of the shore region will be produced which should be interesting for geomorphological investigations.

Keywords: *Lidar and photogrametric survey, wetlands, Lake Balaton, vegetation species.*

1. INTRODUCTION

Shore areas of freshwater lakes are more and more in the focus of ecological and biogeosciences research. Ecosystem services provided by wetlands including (but not limited to) non-point pollution reduction, flood control, groundwater recharge and microclimatic effects. These areas are hotspots of biodiversity due to the wide variety of biotic and abiotic conditions within relatively low distances in space (*Vymazal, 2011*). Lake shores and especially shore wetlands are also under an ongoing threat from urban expansion, pollution, overexploitation and global change *(Schmieder, 2004*). These parameters lead to widespread efforts for monitoring condition and health of shore areas.

Research areas are the reed- (*Phragmites australis*) dominated wetland areas of Lake Balaton (12 km^2) and the full area of the Kis-Balaton wetland (70 km^2). Lake Balaton is a large (area 594 km^2) and relatively shallow lake (3.3 meters at mean water level) and thus is an important touristic destination. The management of the lake has to balance ecological needs and economic preferences. Large areas of shoreline have been built up by shorewalls, so the littoral areas which remain in their natural state are very important for maintaining ecological functions and species diversity. 90 % of the remaining natural shore is covered by reed-dominated wetlands, (*Virág, 1998*). These wetlands are gradually disintegrating since the 1970-s (*Kovács et al., 1989*) similarly to many other European lakes *(van der Putten, 1997*). Long-term datasets of the study area based on historic georeferenced maps starting from the 18th century (*Zlinszky and Molnar, 2009*) and aerial photographs starting from the 1950-s are available. During a previous study *(Zlinszky, 2007*) 73 sample areas were selected which are 200 meter stretches of shore sheltered from

[1] *Balaton Limnological Research Institute of the Hungarian Academy of Sciences, Tihany, Hungary*
[2] *Central Transdanubian Environmental and Water Authority, Székesfehérvár, Hungary*
[3] *Dept. of Geophysics and Space Science, Eötvös Loránd University, Budapest, Hungary*

direct human influence. Archive and present-day aerial images of these areas were used to study the long-term dynamics of reed stands and for concluding to find the global causes of the decline of reed all around Europe. The main conclusion of this preliminary study was that the main cause of reed decline on Lake Balaton is the artificially raised and stabilized water level.

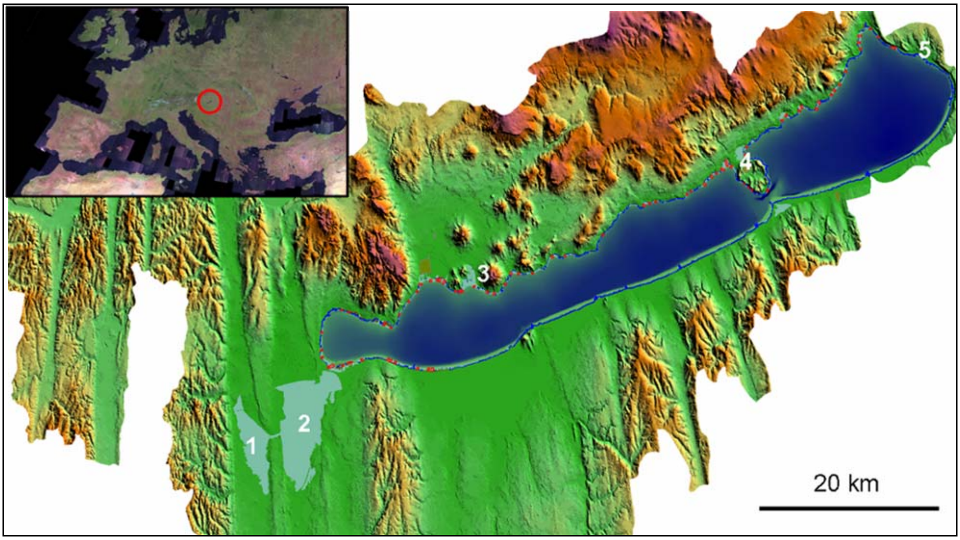

Fig. 1 Location of Lake Balaton and Kis-Balaton within the watershed of the Lake. Red circle on inset shows location of Lake Balaton within Central Europe. Red dots around Lake Balaton are sample sites of the long-term study. 1:Kis-Balaton reconstructed wetland (already flooded); 2: Planned extension of the Kis-Balaton wetland (not flooded yet); 3: Mesa hills of the Badacsony region; 4: Tihany peninsula; 5: Elevated cliffs on the NE shore. Elevation colouring is from 100 m. a.s.l. (green) to 500 m. a.s.l. (brown)

The Kis-Balaton was a wetland area directly upstream of Lake Balaton in historic times. The wetland was gradually drained in the 19th and 20th century, but after the large scale eutrophication of Lake Balaton, the artificial reconstruction of this wetland was initiated in 1984. A dyke system diverts the waters of the Zala river into two shallow basins (18 and 45 km^2, where phytoplankton and wetland vegetation facilitate the removal of nutrients (*Tatrai et al., 2000*).The whole Kis-Balaton area was regularly photographed and the dynamics of vegetation patches are very intensive since this area is newly flooded. The effect of the wetland on the water quality of the lake is still disputed, but the extension of the flooded area by a new basin is currently planned.

Lake Balaton and its surroundings are also of high interest to the geophysical and geomorphological research community. The surrounding landscape has high tectonic activity (*Tóth et al., 2008*) and the interpretation of fault patterns and activity has consequences that can be interpreted on a larger regional scale (*Fodor et al., 2005*). The time scale of processes leading to the formation of the lake is short enough to have implications relevant for ecology as well as geomorphology (*Cserny and Nagy-Bodor, 2000*).

Some surveys of shore macrophytes have been carried out by classical optical geodetic methods (*Kárpáti et al., 1987*), but the potential of remote sensing for wetland characterization and mapping have been recognized because of several reasons *(Wang et al., 2010*). Wetlands are influenced by many different abiotic factors and thus require an interdisciplinary approach, which is also needed for remote sensing.

While the condition of most key habitats on dry land can be followed trough botanical surveys of the dominant or indicative plant species, the difficult accessibility of the interior of wetlands often hinders the classical terrestrial approach. Airborne imaging has shown its potential for surveying wetlands, and aerial photography is a routine method used to produce basic data for shore ecology. The evolution of airborne digital surveying has produced a number of other methods suitable for more detailed investigation of shore communities, which were simultaneously used in this project in order to cross-validate them and to exploit the extended potential of a combined survey.

The use of aerial photography was the earliest to spread in wetland ecology, because this was the first available technology after classical geodetic surveys, and the technical resources for processing of film-based photographs were already widely available. Nowadays one of the main advantages of aerial photography is that image interpretation does not require detailed photogrammetric knowledge, images are relatively cheap to collect and not very sensitive to weather. Smaller surveys can be implemented through small-format DIY solutions including UAV-s (*Pereira et al., 2009; Verhoeven, 2009; Aber et al., 2010*). Georeferencing can be complicated and was first done with complex optical-mechanical systems (*Kraus and Waldhäusl, 1998*), but nowadays even minor GIS software packages have georeferencing modules, and free off-the-shelf solutions available. Georeferencing still requires the careful selection of ground control points, though nowadays this is more and more substituted by GPS and INS information. However, aerial photographs usually only allow the spatial extent of wetlands to be measured, and not the actual species composition *(Boar et al., 1989; Kovács et al., 1994; Ostendorp et al., 2003*). Most exceptions to this use stereoscopic viewing which needs much more expensive technology (*Dömötörfy et al., 1997; Sickel et al., 2004*). Although high-resolution satellite imagery can sometimes replace aerial surveys, the tendency of finer and finer spatial resolutions (*Bakó, 2010*) promises airborne applications beyond large-scale interpretation, the information visible on the images is getting closer and closer to what is visible in the field.

The potential of spectral information to aid image interpretation has been recognized early in the development of photography and has led to the shift from panchromatic (black and white) to colour and later colour infrared imaging. Normal camera film usually can only carry three or four different light-sensitive layers responding to different ranges of the spectrum of light, but the use of digital sensors in satellite imaging led to measurements in several tens of bands (multispectral) and the adaptation of similar instruments to aerial imaging has allowed up to several hundreds of bands (hyperspectral or, more correctly, imaging spectrometer data) sampling the spectra of each pixel (*Mather, 2006*). This means differentiation is possible between subtle shades of colour not recognizable to the human eye, and the spectral parameters of each image can be dealt with in a quantitative way, so the information available for each pixel facilitates mathematical classification. Off the shelf software are now available that can deal with this type of data, and a number of atmospheric and radiometric correction algorithms are included in addition to a vast rage of classification possibilities. Land cover categories identified on hyperspectral images can often easily be processed to the level of vector overlays automatically.

In case of wetlands, hyperspectral studies were first limited by the spatial resolution of the data, which was lower than for aerial photography. Imaging spectrometer applications first spread in the field of agriculture, where measuring ecophysiological and biochemical parameters allowed crop estimation and spatially accurate fertilizing *(LaCapra et al., 1996*). In wetlands, separation of vegetation categories that are very similar on true colour images *(Schmidt and Skidmore, 2003*) is possible, and hyperspectral sensors can even map submerged vegetation with considerable accuracy (*Pinnel et al., 2004*).

Difficulties of hyperspectral imaging include the need for absolutely clear skies and strong illumination, which can be difficult or even impossible to provide at certain climates and latitudes, and usually means that a hyperspectral airborne campaign needs relatively longer flight time allocation than other methods. The effectiveness and result of the classification process depends strongly on the amount and accuracy of ground truthing data collected (though this is true for all remote sensing methods). Ground thruths are mostly reference spectra measured on the different vegetation types in focus with a hand-held spectroradiometer, which are then used as endmembers for the classification algorithm e.g. (*Siciliano et al., 2008; Hunter et al., 2010*). The other approach is to survey areas of homogeneous vegetation on the ground, then use the spectra averaged from these pixels as endmembers in order to obtain a classified image after atmospheric correction, e.g (*Pengra et al., 2007; Wang et al., 2007*). Smaller-scale surveys where spectra can be collected during the actual duration of the flight itself are usually completed with the former, more explicit method; while surveys of large areas that are impossible to cover on the ground during a flight require the latter approach. Difficulties with this type of imaging include the high cost of airborne and ground spectrometers and the necessary software, and also the sheer amount of data that has to be managed and processed. The detailed spectral information collected is often affected by atmospheric noise, and large proportions of it can be redundant for the goal of a given survey. Comparative studies have found that classification accuracy depends more closely on spatial resolution than spectral resolution, as high spatial definition reduces the proportion of mixed pixels (*Belluco et al., 2006*). The spatial and spectral resolution of hyperspectral imaging continues to develop, and the size of the instruments now allows deployment from light aircraft or simultaneous use with other remote sensing systems such as LIDAR.

LIDAR, or more accurately Airborne Laser Scanning is classically a method for surveying geomorphology (*Wehr and Lohr, 1999*), and vegetation or buildings are considered “noise” and removed to produce surface models of the study area. Since water regime is the main driver of wetland vegetation dynamics (*Mitsch and Gosselink, 2003*), and elevation is one of the main determinants of inundation frequency and depth in shore zones, the potential of high resolution topographic data collected by LIDAR is well recognized in wetland ecology. In addition to this, the height of vegetation is revealed by recording several returns of each laser pulse, which allows for separation of different growth habits within the wetlands. The application of full wave form airborne laser scanning has provided very valuable information on vegetation structure in areas where vegetation seems impenetrable to passive optical imaging. Although this method is spreading in forestry, its applications as a standalone tool in wetland remote sensing remain rare (*Knight et al., 2009*). Vegetation height itself is not sufficient for outlining patches of different species or stages of stress, but vegetation density and structure can also be derived from LIDAR data if the point density is sufficient. The main strengths of LIDAR measurements are the ability to penetrate vegetation surfaces and represent three dimensional patterns. In forest environments, point densities available trough commercial instruments allow for identification of single trees and detailed mapping of forest parameters (*Jochem et al., 2011*). In wetland habitats dominated by a single species, vegetated and non-vegetated areas can be easily distinguished on the basis of canopy height (*Rosso et al., 2006*), while small changes in density, height or leaf cover are assumed to show stress and allow for identification of background variables associated with changes in condition. Changes in intensity of the reflected pulse are also useful for outlining inundated areas under the canopy (*Lang and McCarty, 2009*). While LIDAR instruments are also expensive and are not usually flown on low-cost aircraft, the relative independence from weather conditions compared to passive optical sensors means that flight campaigns are usually cheaper. The main drawback of LIDAR surveys is the lack of routine commercial software implementing processing steps. LIDAR datasets, especially full waveform data can also be very large and are on the border of the handling capacities of most desktop PC's.

Fusion of data collected by several different sensor types is a relatively new approach. Studies have shown that the simple visual interpretation of photogrammetric or multi-spectral images can be more accurate when they are draped over a terrain model created from LIDAR (*Gilvear et al., 2004*). The integration of LIDAR intensity with reflectance from passive optical methods can increase the effectiveness of vegetation classification (*Chust et al., 2008; Gilmore et al., 2008*). In addition to providing an opportunity for cross-calibration between different sensors, fusion of different measurement methods also opens up a broad range of applications for identifying the processes that create vegetation and geomorphologic patterns. The most obvious of these is that the elevation of the ground level above water level fluctuations is the main driver of species composition in wetlands, but it can also be assumed that vegetation stress identified by spectral properties will also show up in the vertical structure of a stand. Applying several different sensors to the same study area can measure independent and dependent variables together in a spatially explicit matter, and thus has a strong potential for drawing ecological conclusions.

As in all spatial ecological or geomorphological studies, the importance of the scale of observation should not be overlooked (*Alvarez-Cobelas and Cirujano, 2007*). When planning remote sensing campaigns, the size of the area that can be covered and the spatial and spectral resolution of the resulting data are essentially in trade-off. It has to be decided whether to survey a small sample of the area of interest in detail or to cover the whole area with the risk of compromising the data quality. It is very often not only the scale of the investigated ecological process determining the extent of the survey but rather the size of the ecological or geomorphological unit where the investigated process is present and the administrative extent of the area were any activity is planned to take place based on the results (e. g. a national park).

On a limited budget, it can also be difficult to balance the allocation of resources between aerial data acquisition and ground truthing. Ground truthing can be cumbersome and expensive, but the success of the survey can only be judged against a significant amount of ground truth data, and calibration-validation efforts always rely on some sort of reference. Modern pixel-based methods can be very successful even if limited ground truthing datasets are available (*Hunter et al., 2010*), and “ground truth” data can also be collected through remote sensing (*Artigas and Pechmann, 2010*), but the survey of field references during the flight itself remains one of the most difficult stages of an airborne campaign.

In this paper, we present a detailed initial report on the AIMWETLAB project, a simultaneous airborne hyperspectral, laser scanning and photogrammetric survey. Our objective is to summarize the rationale, methods, expected output and initial evaluation of the flight in order to provide a reference for fellow scientists planning further campaigns.

Research papers to be published later during the processing can not aim at including all methodological details, but we believe it is important to document these to promote access and use of this dataset for scientists interested.

2. MATERIALS AND METHODS

The survey was completed by the Airborne Research and Survey Facility (ARSF) of the Natural Environmental Research Council (NERC) of the UK based at Staverton Airport, Gloucester. The facility flies a Dornier Do-228 specially equipped with imaging and laser scanning equipment. The project was funded by a grant from the European Facility for Airborne Research (EUFAR), and was completed in a ten-day flight window between 16 and 26 August 2010. During this period the aircraft and crew were stationed at Sármellék airport, a former military air base now serving international traffic, located in the immediate vicinity of Lake Balaton. This proved ideal for logistics as the flight time was shared between several projects, so days of acceptable weather had to be exploited beyond the flight endurance of the plane. In many cases, after taking off in the morning and completing a five-hour flight, the aircraft would land for a quick refuel (facilitated by the sparse traffic at the airport) and be back on the study site to continue the survey in the afternoon.

The sensors carried by the aircraft are an AISA Eagle and Hawk imaging spectrometer system, a Leica ALS50-11 LIDAR system and an associated Leica RCD 105 digital camera.

AISA Eagle is a relatively compact imaging spectrometer with a spectral range of 400-970 nm in the visible and near infrared light spectrum with a maximum spectral resolution of 3.3 nm (subject to spectral binning in marginal light conditions) and 244 bands. The view angle range of the instrument is 37°.

AISA Hawk is an imaging spectrometer operating in the infrared and short wave infrared wavelengths with a range on 960 to 2450 nm and a spectral resolution of 6 nm adding up to 254 bands. The two imaging spectrometers are integrated to form a dual imaging system collecting pixels through the same pushbroom configuration. The view angle range of this sensor is 24°.

Leica ALS50 is a compact topographic laser scanning system operating in the near-infrared wavelength at a pulse frequency of up to 83 kHz. Multiple pulse capability allows for the exploitation of the pulse frequency at higher flight elevations. The instrument scans with a vibrating mirror, creating a sinusoidal point layout along the flight track. Up to four returns can be distinguished for each pulse.

The Leica RCD 105 camera is a medium-format digital imaging system designed to complement the ALS50 Lidar. It has a 39 megapixel CCD and was operated to collect true colour images.

The main focus of the survey was the wetland area around the shore of the lake and the Kis-Balaton reconstructed wetland slightly upstream. The selection of any sample sites instead of a full survey could have biased the results, so it was decided to do a complete survey of the shore of the lake and the whole area of Kis-Balaton. In order to keep flight times within reasonable constraints, it was obvious that the shoreline was only to be surveyed by single flight lines in most areas, which meant that the swath widths had to be set to correspond to the usual width of the wetland zone along the shore (**Fig. 2**). This is usually no more than 500 meters, but a fair margin had to be added to be able to cover curved stretches of the shore with straight flights.

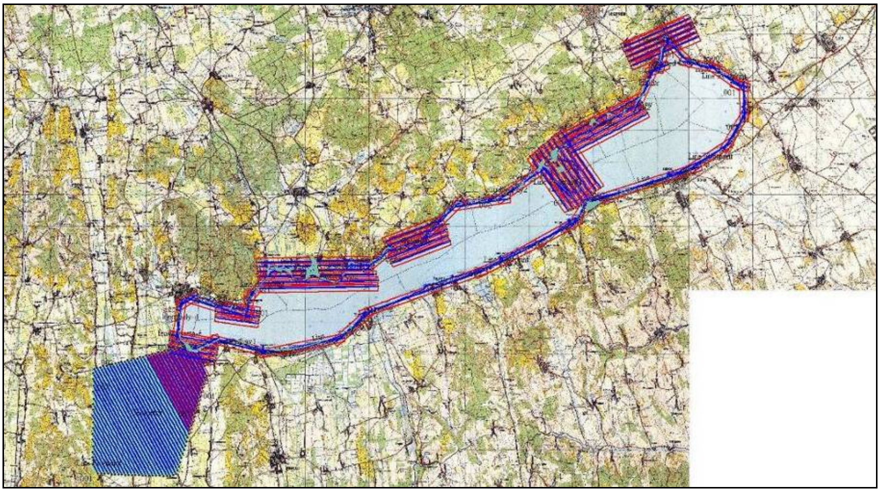

Fig. 2 Flight plan of the AIMWETLAB project overlain on a topographic overview map. Blue lines are flight lines, red and green rectangles outline imaged swaths. Strip overlap over Kis-Balaton is increased for full Hawk coverage

On fixed-wing aircraft, curves usually involve rolling the aircraft, so only straight flights can ensure horizontal position of the plane and a vertical camera axis. An Eagle/Hawk swath width of about 900 m could have been safely achieved with a flight elevation of 1000 m above ground level. However, multiple pulse in the air LIDAR surveying would provide almost twice the point density compared to single pulses, but only above an altitude of 1200 m AGL. The flight elevation was thus set to the lowest elevation where multiple pulses could be effectively used, adding up to a nominal LIDAR pulse density of 2.4 points/m^2, and an imaged and measured swath width of 1000 m. Eagle pixels were expected to be 0.75×0.75 m, and hawk pixels 1,5×1,5 m. With this elevation and swath width, the camera pixels have a ground size of 0,2×0,2 meters. As photogrammetric images mainly serve as interpretation aids and will not be evaluated using standard photogrammetric procedures (the camera is not a metric camera), they were only collected with a 30% overlap along track. Along-track overlap is not defined in case of the other two surveying systems, but flight lines overlap 30% across track where parallel blocks were flown. The fields of views of the two sensors are different, with Hawk measuring a much narrower angle than Eagle. During most of the survey, swath widths were calculated based on the field of view of Eagle with the intentional compromise that swaths will not have full Hawk coverage, only a narrower strip in the middle of the lines will be measured by Hawk. On Kis-Balaton, the overlap of the flight lines was increased to collect full Hawk coverage as well as Eagle, also adding up to a higher LIDAR point density.

The flight pattern (**Fig. 2**) was basically adapted to follow the shore and the boundaries of the wetlands on the lake. Some large wetlands near the shore but cut off from the open water by roads or railways were also included in the survey.

Because of the irregularities of the shoreline, some areas could be more economically surveyed by flying a block of parallel lines than by fitting straight flight lines to the curves of the shore. These areas were (from East to West): the narrow bay of Fűzfő which has a large wetland outside the boundary of the lake; the system of bays and coves from Almádi to Balatonfüred; the Tihany peninsula, where less flight time was required by this solution than for a flyaround of the shore, and where extending the flight lines to meet the southern shore created a welcome opportunity for cross-georeferencing; the bay and peninsula of Zánka and Szepezd; the mesa hills and low-lying wetlands around Badacsony and Szigliget; the point of Györök; and the Zala river mouth. In order to share time optimally between this and the other parallel projects, the full study area was surveyed in blocks of a few hours mostly in the early afternoons of suitable days in the flight window. This means that solar illumination was sometimes lower than optimal, and this was compensated by a spectral binning of 2 on the Eagle sensor.

A total of 78 ground truthing polygons of 10×10 meter were surveyed using differential GPS. The device used was a Leica GS20, with the following properties and settings:

Coverage:	**Max accuracy**
Mask angle	10°
DOP filter	PDOP 10
Minimum satellites	4
Logging	static and moving,1 sec
Min. no.of positions:	5

Vegetation height, water depth, dominant vegetation, performance of reed, dominant species and the abundance of the 18 most dominant macrophyte and tree genera was recorded along with notes of any changes or structural parameters. The reference quadrats were selected to include homogeneous but monodominant areas of each dominant species and mixed but homogeneous stands of several species together. In order to collect homogeneous endmember spectra of each dominant macrophyte, several 10×10 meter areas were searched through in the field and all specimens of sub-dominant macrophytes removed by hand clipping. Using this method, homogeneous areas of *Phragmites australis* (healthy, stressed and completely dry stands separately)*, Typha latifolia, Thyha angustifolia, Carex sp.* were produced. Five 1×1 meter quadrats were clipped completely and the number of plants and the height and number of leaves on each was counted and recorded.

A point-based ground truthing dataset was also collected, collecting data in at least three points of a transect perpendicular to the shore on each site. The height the upper (*Phragmites*, *Typha*) and lower canopy was recorded together with the estimation of shoot density of the upper and lower canopy. Vegetation density at both levels of canopy was estimated by a series of zenith-facing digital photographs. These images were taken by mounting a self-timed AGFA DC-600uw compact camera on a pole, pushing it through at least a meter of undisturbed vegetation and holding it exactly on the water surface as the images were taken. Images were previously calibrated to different densities of *Phragmites* and Typha.

Several hundreds of spectroradiometer spectra were collected using and OceanOptics USB 2000 Miniature Fiber Optic Spectrometer in the initial tests and an ASD FieldSpec 3 during the flight. These were also arranged in sets of at least five points along a transect. Both instruments only measure in the visible and near infrared spectrum (400-950 nm), but have a spectral resolution under 2 nm. Readings were taken as averages of 15 single measurements and geo-tagged using DGPS. Measurements of dark current and a white spectralon reference (in case of the ASD instrument) and downwelling radiance (in case of the OceanOptics) were collected between each measurement cycle.

At each point where spectra were measured during the flight, 3 samples from the uppermost fully emerged leaves were collected for chlorophyll content, and further 3 samples for nutrient measurements. Leaves were sampled with a 9 mm diameter cork borer and tissue samples were wrapped in aluminium foil and placed on ice in a cooler box during transport. At the laboratory, samples were stored in fridge under -20 °C until the measurements. The leaves for nutrient content prior measurements were dried at 60 °C for a week (T-6, Heraeus, USA), weighted (OHAUS Explorer, Ohaus Corp., USA) and later ground in Eppendorf vials with metal ball bearings in a mill (MM220, Retsch, Germany). Nitrogen content was determined spectrophotometrically using the phenol hypochlorite method *(Mackereth et al., 1978*). Soluble reactive P content of the pore water was measured using modified Murphy-Riley molybdenum blue spectrophotometric assay(*Murphy and Riley, 1962; Mackereth et al., 1978*). Sulphide content was determined by measuring the blue colour formation by N, N'-diethyl-D-phenylenediamine in the presence of iron (III) ions. The intensity of the colour was determined spectrophotometrically at 670 nm (UV-VIS 1601, Shimadzu, Japan) against a standard sodium sulphide solution. Chlorophyll was determined according to the procedure of Wellbrun (1994) were followed (*Wellburn, 1994*). Plant tissues was placed an eppendorf vial with metal ball bearings and grounded (MM220, Retsch, Germany). The chlorophyll content was extracted from the grounded sample with 80% (v/v) acetone the colour intensity was determined spectrophotometrically (UV-VIS 1601, Shimadzu, Japan).

Finally, P. Pomogyi collected a detailed set of geo-tagged ground photography during the 2010 summer survey of the shore. Although not a quantitative dataset, this collection of about ten thousand images collected satisfies scientific criteria, provides detailed coverage of the whole shoreline and will be an important source of information for interpretation of species composition and stand health.

3. PLANNED PROCESSING AND EVALUATION

The dynamics of reed stands on Lake Balaton were investigated through a 50-year series of georeferenced aerial images and 72 constant sample sites where the reed-water boundary was digitized at a scale of 1:100 (*Zlinszky, 2007*). Aerial photogrammetric images will be processed in the same way to ensure full continuity with this dataset. Georeferencing will be completed automatically in batch (most probably using ER Mapper 7) based on positions from GPS and angles from IMU data supplied by the pre-processing team. The reed-water boundary will be hand-digitized and areas of each sample site will be compared with the area of the previous years. In addition to this, the ground truth polygons will be used as references to identify the characteristic texture of stressed and healthy *Phragmites*, and *Carex* and *Typha* vegetation.

The high spatial resolution of the images will most probably be sufficient for visual interpretation of these categories, and categorization by hand-digitizing will be tested. The patches of homogeneous vegetation identified on the aerial images will also serve to extend the ground-surveyed polygons to the boundaries of these patches in order to provide more ground truth pixels for hyperspectral processing (**Fig. 3**).

Hyperspectral data cubes will be pre-processed to the level of radiance by ARSF DAN. The orientation and position information will also be supplied along with the data. A correction of timing errors which would otherwise lead to minor positioning errors will also be completed by DAN on a strip-by-strip basis.

Fig.3 Cutout of a raw aerial photograph collected during the AIMWETLAB campaign showing the Zala river entering the lake. Different macrophyte and tree species can be identified: *Phragmites:* Grey-green, *Typha:* Full vivid green, *Populus:* Light grey-green trees, *Salix:* Yellowish green trees

Hpyerspectral data needs atmospheric correction, which will be completed using atcorr software or the FLAASH module in ENVI. Local meteorological data and Microtops sun photometer data collected during the flight will be used to determine the correct input parameters. The ground truth spectral library, including the spectra of very dark (tarmac/soil) and very light (white dolomite gravel/concrete) surfaces will be used to determine the success of the atmospheric correction. After this stage, azgcorr software (provided with the data by ARSF) will be used for geometric correction and orthorectification of the hyperspectral strips.

After a Minimum Noise Fraction filtering, several different classification algorithms will be tested, including Minimum Noise Fraction, Spectral Angle Mapper and Support Vector Machines. Output maps will include ecological maps such as the dominant species (including the mixing ratio in mixed pixels), the abundance of the main macrophytes separately, and the health of reed stands according to the categorization of the Hungarian National Standard (*Virág, 1998*). Endmembers of classification will be selected from the averages of pixels corresponding to the homogeneous areas outlined on the ground (and possibly extended based on the photogrammetric images) and also from the ground truth spectra.

Results will be validated against a selection from the ground truth quadrat pixels, the photographic database in case of species composition, and against the long-term historic dataset in case of the vegetation stress map. Sites were a decrease of area can be identified from the aerial images will be considered stressed sites, and the correlation with remotely sensed spectral or spatial stress symptoms will be investigated. (**Fig. 4**)

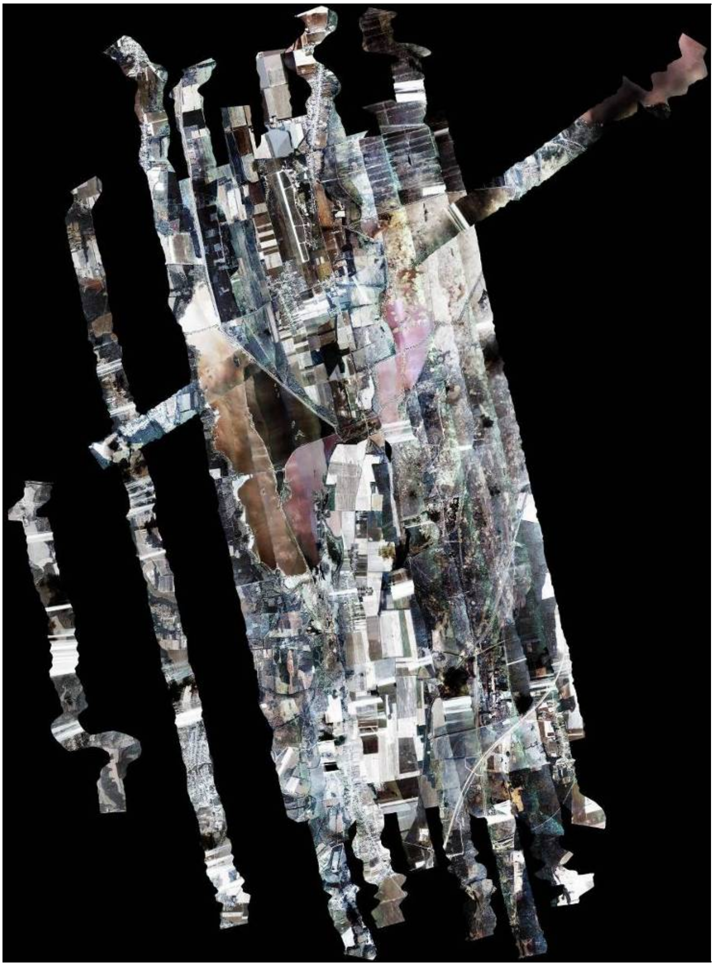

Fig. 4 Mosaic of raw AISA Eagle swaths collected over Kis-Balaton, (band assignment represents near true colour) showing overlap and layout of strips collected during one flight day

The fusion approach will also be tested on a pseudo-dataset including the most relevant spectral bands (simulating a programmable hyperspectral sensor such as CASI) and rasters of parameters derived from LIDAR to investigate the accuracy of classification of this dataset.

Airborne laser scanning data is pre-processed by the ARSF Data Analysis Node to link recorded signal travel times and intensities to the position and attitude data of the IMU and GPS and the corresponding angle of the scanning mirror. A basic filtering is also applied to flag points that most probably result from atmospheric or secondary echoes. To correct for some minor errors in the scanning angle calibration, a roll correction is applied to each flight line based on minimizing errors of fit in the overlapping parts of the strips.

After these pre-processing steps performed by the ARSF Data Analysis Node, LIDAR data will be processed using the OPALS software package developed by the Institute of Photogrammetry and Remote Sensing of the Technical University of Vienna. After viewing and visual quality control of each flight strip, simple elevation threshold filters will be applied to remove points that are a result of multiple echos (visible as outliers below the data) or atmospheric reflections (visible as points above the rest of the point cloud). After this, Opals packages will be used to create a vegetation and water mask in order to outline areas that are smooth enough to be used as reference areas for correction of elevation differences between overlapping strips. After calculating full 12-parameter affine transformations for the pairwise transformation of overlapping strips to minimize differences, a global optimum will be applied to the dataset to correct fine-georeferencing errors. Last echos will be selected and a building mask will be applied before moving planes interpolation to create a high resolution Digital Elevation Model of the ground surface of the whole shoreline and the Kis-Balaton region. The highest points of the dataset will be used to interpolate a surface model and the surface and elevation model will be subtracted to calculate vegetation canopy height. Zones of plants characterized by different heights (including trees) will be outlined through edge detetection filtering.

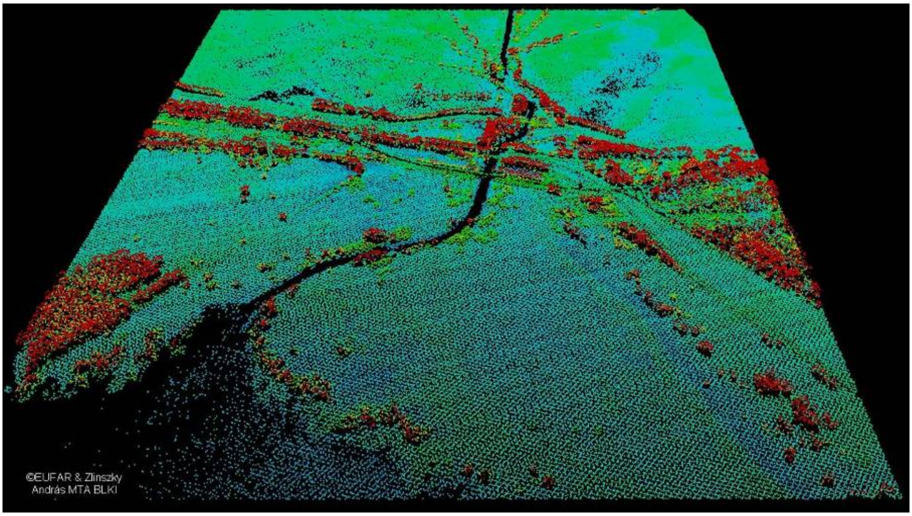

Fig. 5 Cutout of LIDAR point cloud of the Zala river mouth, coloured to represent elevation above ground level. Blue points are the lowest (ca. 105 m a.s.l.), green points are higher, red points are the highest (up to 125 m. a.s.l). Void (black) areas are open water.

Aggregations in the ground hits are a signal of inhomogeneous growth caused by stress; these will be located using the excentricity parameter. The intensities of ground echoes will also be mapped on a raster basis, as low intensities signal the presence of water. An inundation map of the studied areas will be created based on this. Patterns will be investigated and compared with the ground truth polygons to validate the effectiveness of the mapped parameters in predicting vegetation height and density, inundation, species composition and stress. Raster maps of vegetation height, ground elevation, echo intensity, vegetation density and ground point excentricity will be exported to act as pseudo-channels in fusion with the hyperspectral image data (**Fig. 5**).

Finally, the classification accuracies of the three methods used will be cross-validated. The effectiveness of each method for returning vegetation species composition, health and extent maps will be assessed in addition to the amount of work necessary to produce a result. This is in order to find the most effective method for use in the future.

4. EXPECTED RESULTS

Digital elevation model of the shore area (500-1000 m from the shore), the Tihany peninsula, the mesa hills of Badacsony and Szigliget, and the Kis-Balaton reconstructed wetland will be produced from the LIDAR point cloud. The planned spatial resolution is 1×1 meter, with elevation errors in the range of 5 cm. Lake Balaton lies in a tectonically very complicated setting, and the development of the lake is not resolved in full detail. The geomorphology of the shore areas is an important source of information, but is difficult to study because man-made structures change the landscape and vegetation obscures morphologic features. Since LIDAR DEM-s allow for the masking of vegetation and buildings, the topography of the immediate surroundings of the lake can be studied in a virtual environment in high detail without the obscuring effects mentioned. Special care was taken during the planning of the flight to include features of interest to tectonic geomorphology in the surveyed area, which are the elevated shore cliffs around the eastern and southwestern edge of the lake, the mesa hills of the Badacsony area and the geyser domes of the Tihany peninsula. Masking of buildings will most probably allow observation of shore abrasion features created during the maximum Holocene extent of the lake, which can provide information on differential uplift rates. Volcanological studies will benefit from exact elevation models of landscape features including the Tihany peninsula and the Badacsony region.

The DEM of the shoreline will also serve as a basis for shore erosion studies in comparison with previous maps, and can be a basis for planning shore protection measures. The water level of the lake has been extremely high in the last years, and combined with storm seiche surges, has caused severe flooding of some resorts especially on the southern shore. Accurate elevation data from this model will serve flood risk assessment. Several wetland areas exist outside the official boundary of the lake, but in very close vicinity of it, often only separated by a road or railway embankment. The flight plan was also adjusted to include a reasonable number of these. The ecological and hydrological connection of these wetlands is unknown as they were not yet so much in focus of research as the wetlands actually inside the lake. The elevation range of these areas derived from the DEM will determine if they were originally part of the lake itself and how they are connected now.

The DEM of Kis-Balaton will also be a basis for identifying geomorphological marks of historic and prehistoric flood extents. Surveying the elevation of the dyke and channel system will serve as an important follow-up of the surveys conducted during the planning and building of the system. Since a large part of the mapped area is currently under reconstruction as a wetland and awaits flooding, the most important purpose of the DEM of the Kis-Balaton region will be forecasting of flooding extents and patterns.

Hyperspectral information will be used to create detailed vegetation maps of the whole shoreline. The extent and distribution of main vegetation types will be assessed based on this, and the structure of species distribution in wetland habitats surveyed. Currently, *Phragmites* wetlands on Lake Balaton have a high conservation status as key habitats, but stands of other wetland macrophytes are not officially protected, and are often damaged by shore residents. If maps of habitat structure previously unrevealed by classical aerial photography prove that *Carex* and *Typha* belong to the natural zonation of the shore, perhaps these areas will also be conserved. The distribution of different plant associations will be compared to historic data to evaluate the succession of these habitats. If *Phragmites, Typha* and *Carex* are found to follow each other in a temporal and not only in a spatial sequence, perhaps predictions on the future of the wetlands can be made, which should influence shore development planning.

Both LIDAR and Hyperspectral data will be used to measure the extent of stressed wetland vegetation on the lake. Since long-term studies show that the main cause of wetland die-back is the stabilized and raised water level, this map can serve as ground data for determining if the water level should be lowered.

Rare habitats of key interest will be identified based on the combination of LIDAR elevation data and spectral vegetation maps. These include *Alnus* wetland forests, wet meadows, large *Carex* zones, and wetland areas dominated by *Salix* shrubs.

Finally, through evaluation of the accuracy of these three mainstream remote sensing methods for the detection of reed stress, a standard protocol for reed wetland health monitoring will be proposed. Based on this step-by-step protocol, conservation authorities could hire local remote sensing operators to survey wetland stress using the single most effective method of the three tested here, and process it with only basic ecological background knowledge and more focused ground truthing. The accuracy and credibility of these local surveys would be backed up by the fact that the comparative evaluation of most mainstream methods was once completed in a full survey of a large lake involving a leading scientific airborne operator.

5. PRELIMINARY DISCUSSION

Although the survey has not yet produced scientific results at this stage, some preliminary evaluation is already possible. It was high time to complete this survey, since monitoring of Lake Balaton wetlands was previously only based on aerial images, a comprehensive cross-validation of these methods was not yet performed in a full survey of a major lake (as far as the authors are aware) and will allow subsequent surveys to focus on the most effective method. The applications of these methods to wetland mapping are very promising and especially in case of LIDAR still a subject of methodological experimentation worldwide.

In retrospect to the completed flights and ground truthing, the flight window of ten days was on the margin of sufficiency under the weather conditions we experienced, and could have led to missing areas with a little less luck.

Although the ground truthing was extensive and detailed, the use of a full range spectroradiometer would probably have added to the accuracy of the atmospheric correction and the classification. The distribution of sample quadrats surveyed could have been more homogeneous along the lake, and including submerged macrophyte patches would have further extended the scientific potential of the survey. In order to obtain a statistically sound calibration to vegetation parameters, more quadrats should have been harvested and plants counted and weighed. The LIDAR point density might be on the margin of applicability for vegetation surveys, but this was the price for full coverage of the lake shore and Kis-Balaton. This survey was planned to balance between development of methodology (which would have required a more detailed survey of smaller extent) and effective data collection for conservation (which would not necessarily have needed all three surveying methods). The cooperation between scientists of very diverse backgrounds through the common language of GIS proved to be efficient, and the operating team of the aircraft understood the scientific requirements and was committed to producing the best data possible. The support of the European Facility for Airborne Research has allowed a unique large-scale survey involving the cutting edge of remote sensing technology. Chances for setting up such an expensive and complicated project in the future are low, but this survey can serve as a benchmark to identify methods and sites of interest for smaller scale airborne or terrestrial surveys.

The authors are open to further exploitation of this dataset through cooperations with other scientific disciplines.

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