

Patterns in Estonian bogs as depicted in color kite aerial photographs

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Kite aerial photography (KAP) was conducted at three bogs in east-central and south-western Estonia to further investigate the possibilities of this technique for mire research. Color-visible and color-infrared photographs were acquired in all orientations with film and digital cameras. Individual objects can be identified in vertical photographs in the size range 10 to 30 cm, which allows for microstructural investigations. Color-visible photographs reveal distinct color and texture zones in the vegetation cover of bogs, and water pools form a strong contrast with emergent vegetation. The intricate patterns of emergent, floating and submerged vegetation are portrayed clearly, and the boundary is defined sharply between emergent and floating moss at pool margins. Distinct color and texture zones of plant cover represent specific vegetation communities. Color-infrared photographs depict active photosynthesis of floating and emergent moss (*Sphagnum* sp.) in narrow zones (1–2 m wide) at pool margins. The high level of photosynthesis in such narrow zones may have significant implications for development of bog morphology, biomass accumulation, methane emission, and other environmental factors. Numerous small water bodies are more abundant than anticipated and may be more common than is generally recognized on conventional airphotos or satellite images. Multi-view angle imagery displays considerable variations in reflectivity of bog cover materials for different viewing directions. Special lighting effects, such as sun glint and the hot spot, are more prominent in color-infrared pictures, because of darker shadows. Our field experience demonstrates that kite aerial photographs may provide a basis for microstructural mapping and analysis of complex bogs within a multi-scale approach to mire investigations.

Keywords: Aerial photography, kite, infrared, Estonia, bog.

Introduction

A raised (ombrotropic) bog presents a rather austere view for ground observation. It appears to be a haphazard collection of peaty hummocks,

muddy hollows and water-filled pools. The hummocks are vegetated mainly by moss (*Sphagnum* sp.), dwarf shrubs and pine trees — in short, a forbidding but picturesque landscape. As seen from above, however, mires display complex and

intricate patterns of vegetation and water bodies, which have resulted largely from organic evolution within the bog environment. For the “bird’s eye view” various techniques of remote sensing have been applied for mire research in Estonia. These techniques range from satellite imagery (Aaviksoo 1995; Aaviksoo et al. 2000) and conventional airphotos (Aaviksoo 1988) to high-resolution, near-surface aerial photography (Aaviksoo et al. 1997a; Aber and Aber 2001).

The scale and resolution terminology of Masing (1998) will be employed for purposes of this discussion. Satellite imagery (such as Landsat) provides moderate resolution (30 m pixels) that is appropriate for mesotope or mesostructural mapping and interpretation (1:10,000 to 1:100,000). Broad patterns of vegetation and water bodies can be recognized at this scale within larger bogs and in surrounding ecosystems. Conventional airphotos as well as the new high-resolution Ikonos satellite provide imagery appropriate for the microtope or conocomplex scale of study (1:1000 to 1:10,000). This scale is well suited for depicting vegetation and water environments within individual bogs at a resolution of 1–4 meters. To achieve the microstructural scale of imagery (> 1:1000), submeter resolution is necessary. Such very-high resolution may be obtained with small-format aerial photography (Warner et al. 1996; Light 2001).

Small-format aerial photography (SFAP) is based on low-height platforms such as ultra-light airplane, helicopter, model airplane, tethered hot-air blimp (Marzloff and Ries 1997), or kite (Aber et al. 1999). A variety of small-format (35 mm or 70 mm) film, compact digital, and video cameras has been utilized for all manner of environmental applications. Representative uses of SFAP range from mapping fossil forest beds in Arctic Canada (Bigras 1997), to rangeland management in the western United States (Quilter and Anderson 2000), to measuring dolphin body size in shallow coastal water of New Zealand (Chong and Schneider 2001).

Aber and Aber (2001) introduced kite aerial photography (KAP) for peatland research in Estonia as a means to acquire low-height, high-resolution, multi-view angle imagery for microstruc-

tural investigations. Advantages of KAP include high portability, rapid field setup and operation, low cost, small crew, and a range of suitable weather and site conditions. KAP represents a “micro-level” of observation within a multi-scale approach that involves ground study, conventional airphotos and satellite imagery. In this investigation, we expand the use of kite aerial photography for Estonian mire research to include color-visible and color-infrared photographs in film and digital formats. Our methodology combines visual interpretation of KAP images with ground observations of bog materials and conditions.

Spectral characteristics of Estonian mires

The surfaces of typical, raised bogs comprise an interdependent association of water, vegetation and peat. Open water can be found in pools and hollows, and water is bound in moss (*Sphagnum* sp.). Field layers of bog communities are represented mainly by graminoids (*Eriophorum* and *Trichophorum* sp.). In the shrub layer, *Calluna vulgaris* is most abundant, and Scots pine (*Pinus sylvestris*) is most common in the tree layer. A high bog water table creates a permanently moist environment. In the visible and near-infrared portions of the spectrum, these objects are relatively dark compared to most other land cover materials.

Mires are, thus, quite distinct in color-infrared airphotos and satellite images of Estonia (Peterson et al. 1998; Aber et al. 2001b). Eight bog habitat types were distinguished in the Alam-Pedja mire system using Landsat 5 TM (June) imagery (Aaviksoo et al. 2000). Photosynthetically active vegetation absorbs red (0.6–0.7 μm) light and strongly reflects near-infrared (0.7–1.0 μm) radiation (Colwell 1974). This distinctive spectral signature is the basis of numerous vegetation indices (Tucker 1979; Perry and Lautenschlager 1984), most of which are based on the ratio of near-infrared to red reflectivity and are utilized widely for regional and global measurements of vegetation cover and plant vigor (Lymburner et al. 2000).

Typical deciduous trees, such as maple and birch, have high near-infrared to red ratios of 13 to 16, and conifers, such as pine and spruce, have lower ratios of 8 to 11 (U.S. Geological Survey, online Digital Spectral Library, <http://spec lab.cr.usgs.gov/spectral-lib.html>). In sharp contrast, wetland vegetation has generally low near-infrared to red ratios; *Sphagnum* sp. has a ratio between 3 and 4 (Peterson and Aunap 1998). A further difference is the timing of maximum near-infrared to red ratios achieved during the growing season. In Estonia, deciduous trees achieve maximum ratio values during late spring and early summer (June–July); whereas maximum ratios for moss and other wetland plants are reached in late summer (August–September), as documented by Peterson and Aunap (1998). This seasonal phenology favors late summer as the optimum time for remote sensing of bog vegetation.

Water bodies and mud are other characteristic features of raised bogs. Water weakly scatters blue and green (0.4–0.6 μm) light and strongly absorbs longer wavelengths; wet soil and muddy areas have similar reflective properties. However, standing water creates intense specular (mirror) reflections at the oblique position opposite the sun. This phenomenon, known as sun glint, may aid for identification of small or shallow water bodies (Amsbury et al. 1994).

A further consideration for aerial photography is Estonia's relatively high latitude (58° N), which causes long shadows. At the autumnal equinox, the sun rises only 32° above the horizon at noon. Shadows play a dual role for interpretation of airphotos. Distinctive shadows may aid for identification of tall objects, such as pine trees. On the other hand, shadows may obscure low-lying features of interest. Shadows are more prominent in oblique views toward the sun and less prominent in views away from the sun. The darkness of shadows is wavelength dependent, as shorter wavelengths (blue light) are scattered more strongly in the atmosphere than are longer wavelengths. Shadows depicted on infrared photographs tend to be darker than for equivalent panchromatic pictures (Light 2001). In addition, image geometry and vegetation structure may affect illumination and cause bidirectional reflectance effects (Holopainen & Wang 1998a, 1998b; Pellikka 1998; Pellikka et al. 1998).



Fig. 1. Index map for Estonian mires (olive); adapted from GIS database compiled by Rivas (2002). Study sites in east-central and southwestern Estonia: A – Männikjärve and Teosaare bogs, B – Nigula Bog.

Field sites

Kite aerial photography was conducted at three sites in mid September, 2001, at the end of the summer growing season. Männikjärve Bog and Teosaare Bog are located in the Endla mire complex of east-central Estonia on the southern slope of the Pandivere Upland (Fig. 1). The Endla mire system (25,100 ha) arose as a result of terrestrialization of the ancient Great Endla Lake after the retreat and melting of the continental ice sheet. The mire system consists of seven bog massifs in different stages of development separated by rivers and minerotropic swampy forests. The third study site, Nigula Bog, is situated in the southwestern part of the country (Fig. 1).

Männikjärve — A bean-shaped, convex, raised bog (208 ha, maximum peat depth 7.3 m) is of limnogenic origin (Veber 1974). Peat formation started in the Boreal climatic period, and mire reached the ombrotrophic bog stage in the Sub-Boreal period (Veber 1974; Ilomets 1982a). It has a well-developed hollow-ridge-pool complex in the center and wooded bog margins. The convex shape, distribution of bog pines, and presence of *Chamaedaphne calyculata* prove that it belongs to the East-Estonian type of bogs. Since 1910, the Experimental Mire Station was opened at Tooma, and due to continuous research Männikjärve Bog is one of the best studied bogs

in Estonia (Kimmel 1998).

The development of the bog, its plant cover, growth and productivity of *Sphagnum* mosses, formation and development of bog microtopography, production and emission of bog gases, etc. have been studied in more detail by Ilomets (1982a, 1982b, 1988), Karofeld (1998), Karofeld & Toom (1999), Masing (1958, 1959, 1982, 1984), and Mets (1982). Bog plant cover has been classified using Landsat 5 TM imagery from June, 1995 into three classes: open bog, complex (hollow-ridge-pool) bog, and wooded bog in the context of 35 classification units. Supervised classification was utilized with *Erdas Imagine*, and overall accuracy was 85% (Aaviksoo 1995; Aaviksoo et al. 1997b).

Teosaare — A round-shaped, partly wooded bog (~ 100 ha, maximum peat depth > 6 m) has a concentric hollow system and numerous mud-bottom hollows. It is located adjacent to Männikjärve Bog, and their development is comparable in basic aspects (Veber 1974). Bog margins are influenced by artificial drainage, and a cleared and drained field lies within the bog. The field was created in the 1950s and utilized formerly for agricultural experiments; it is now abandoned, and birch and pine trees are invading.

Nigula — A typical West-Estonian type, plateau-like bog (2340 ha, maximum peat depth 7.0 m) has a sparse tree cover and an open, flat, central part divided into two massifs by mineral islands. Mire formation began as a result of infilling and overgrowing of an ancient lake, first in the western and thereafter in the eastern massif during the Boreal period (Pirrus 1963; Loopmann et al. 1988). Succession of plant communities, peat types, and growth dynamics of *Sphagnum* mosses were studied in more detail by Ilomets (1982a, 1982b, 1984). Formation and development of bog microtopography were investigated by Karofeld (1998), and palynological studies and paleoreconstructions were given by Koff (1997) and Klimanov et al. (1984, 1985).

Methodology

Kite aerial photography was conducted with three camera rigs at each site under favorable weather conditions—sunny to partly cloudy sky and wind

10–20 km/h (3–6 m sec⁻¹). In order to minimize shadows, all photography was done between 10 a.m. and 3 p.m. The KAP rigs each have radio control of camera position — pan and tilt, as well as shutter release. This allowed us to take pictures in all compass directions and in all tilt positions — vertical, low- and high-oblique. The capabilities of each camera system are detailed below.

Color-visible film camera — *Olympus Stylus Epic*, 35-mm, point-and-shoot camera. Fixed-focus, 35-mm lens and automatic light adjustment. *Kodak Elite* color-slide (diapositive), 200-speed film was utilized for its near-normal rendition of visible colors.

Color-visible digital camera — *Canon Digital Elph* (Ixus), 1200 by 1600 CCD pixel array with autofocus and automatic light adjustment. The lens is equivalent to a 40-mm focal length. We employed a 96-MB memory card, which can hold more than 100 high-resolution images.

Color-infrared film camera — *Canon EOS RebelX*, 35-mm, full-featured, SLR camera with zoom lens. The lens was set to 35-mm focal length, and a yellow filter was employed to eliminate blue light from reaching the film. *Kodak color infrared* (EIR) film was utilized for capturing images in the green, red, and near-infrared spectrum.

KAP with the panchromatic (color-visible) cameras is a straightforward operation, as each camera has automatic sensing and control of light conditions. Color-infrared photography is another matter, however, as camera light meters do not register infrared radiation, and color-infrared film has no speed rating. Empirical light settings for our color-infrared camera rig were utilized based on previous field testing (Aber et al. 2001a). In this case, a shutter speed of 1/250 and *f*-stop of 9.5 were set manually for each flight. Note: infrared film is sensitive only to near-infrared radiation ($\leq 0.9 \mu\text{m}$) and does not respond to longer thermal-infrared (heat) wavelengths.

Survey markers were placed at study sites and the locations of markers were determined with GPS equipment. The number of survey markers varied from three to more than ten per study site. The sizes and locations of markers provided controls for measuring image scale and orientation. The camera rigs were manoeuvred through a

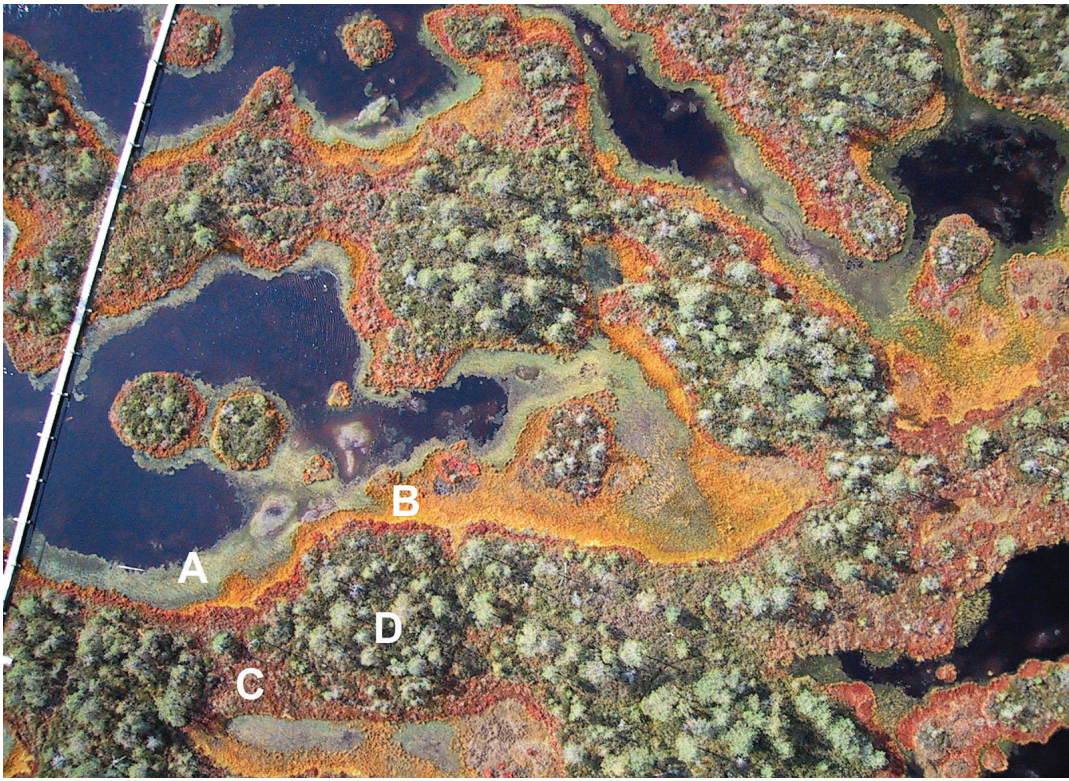


Fig. 2. Closeup vertical picture of pools and hummocks in the central portion of Männikjärve Bog. A = *Sphagnum cuspidatum* floating in water, B = *S. cuspidatum* at pool shore (barely emergent), C = *S. rubellum* above water table, D = Scots pine trees on hummocks along with dwarf shrubs — *Empetrum nigrum*, *Chamaedaphne calyculata*, *Andromeda polifolia* and *Calluna vulgaris*. The boardwalk is 60 cm wide.

height range of 50–150 m and placed in various positions relative to survey markers to acquire views from different vantages. Field observations were undertaken to identify dominant mosses and other plant species growing in the study sites.

Results

Color-visible photography — Panchromatic, vertical photographs reveal distinct color zones in the plant cover of mires, and dark-toned water pools form a strong contrast with emergent vegetation. Where submerged or floating in pools, *Sphagnum cuspidatum* appears silvery or pale green in color, but where barely emergent at pool margins it is bright yellowish orange. In slightly higher and drier positions, *S. magellanicum* and *S. rubellum* have a distinctive red to reddish-brown color. The color zonation of these mosses

was quite distinct in Männikjärve Bog (Fig. 2) and also was apparent in Teosaare and Nigula bogs (Fig. 3). The higher portions of hummocks are mostly green in color, reflecting pine, heather, and various other dwarf shrubs.

Scots pine trees are tall enough to cast distinctive shadows. However, dwarf shrubs, grass clumps, and moss mounds also provide sufficient relief to create small shadows. These small shadows affect the visible roughness or texture of vegetation surfaces. Emergent vegetation generally has a “lumpy” texture; whereas, floating or submerged vegetation appears smooth (Fig. 2). Marked differences in color and texture define the sharp boundary between floating and emergent vegetation at the margins of pools.

In vertical digital images, pixel resolution is in the range 2.5 to 6 cm, depending on height of the camera above the ground. A rule of thumb in

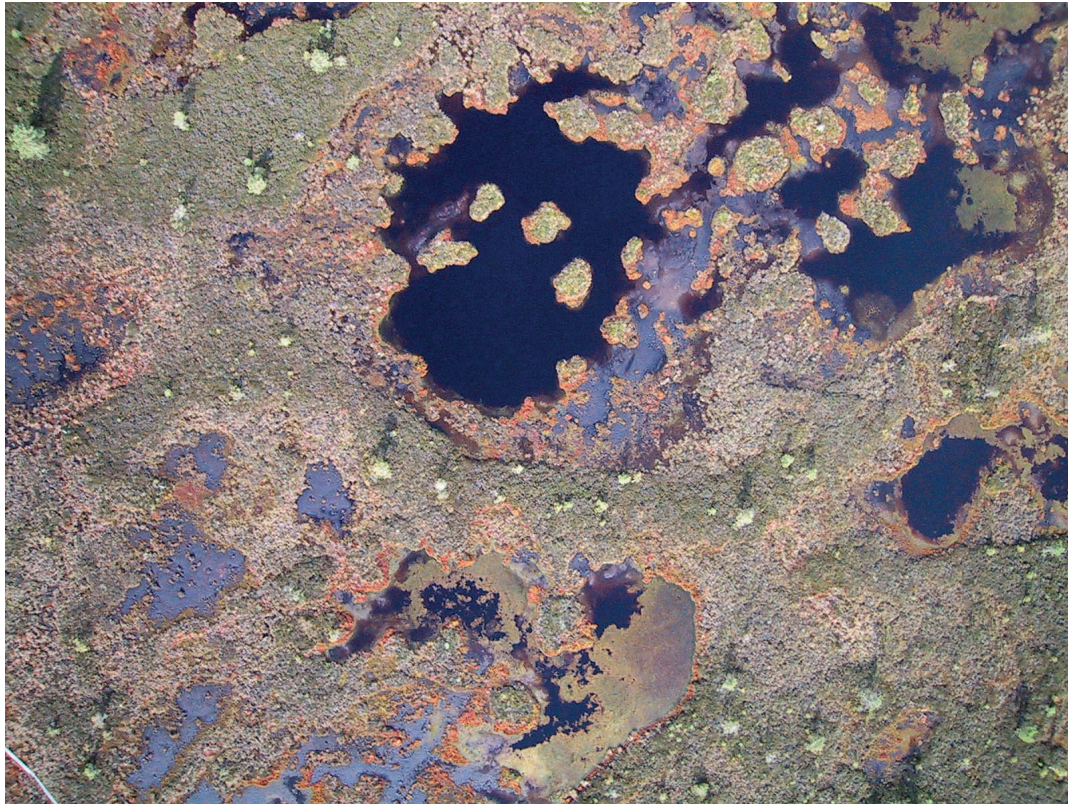


Fig. 3. Vertical view in eastern portion of Nigula Bog. *Sphagnum cuspidatum* forms a silvery green “mat” floating in parts of some pools. The reddish-brown zones include *S. magellanicum* and *S. rubellum*. Heather covers much of the mottled green surface along with a few small pines (note shadows). A portion of the boardwalk (approx. 40 cm wide) is visible in lower left corner.

airphoto interpretation is that positive recognition of objects requires a ground resolution three to five times smaller than the object size (Hall 1997). This means that individual objects can be identified in the digital photographs in the size range 10 to 30 cm. Our film photographs have about the same resolution in practice.

Oblique photographs provide side views, which are particularly helpful for identification of taller objects, such as trees, within and around mires. Such photographs reveal distinct forest zones on mineral islands within bogs (Fig. 4). These zones display marked differences in tree density, color, foliage, and species. Side views aid in recognizing subtle topography of emergent islands and other geomorphic features associated with mires. Oblique views also typically depict a larger ground area than do vertical views, and so

provide better displays of overall bog structure, surface cover, and relationships to surrounding features.

Kite aerial photography allowed us to acquire images in all orientations (vertical, low- and high-oblique) and in all directions relative to the sun. In oblique views, best lighting is achieved at azimuth angles roughly 110–160° from the sun (Fig. 5). In such views, the ground is illuminated well and shadows are distinct but not dominant. Oblique views directly away (180°) from the sun may include the so-called “hot spot” or opposition effect (Fig. 6), which is the point in direct alignment between the sun, camera, and ground (Lynch & Livingston 1995). In vicinity of the hot spot, no shadows are visible and the picture appears to be “overexposed” or saturated. These conditions are visually distracting and may cause difficulty

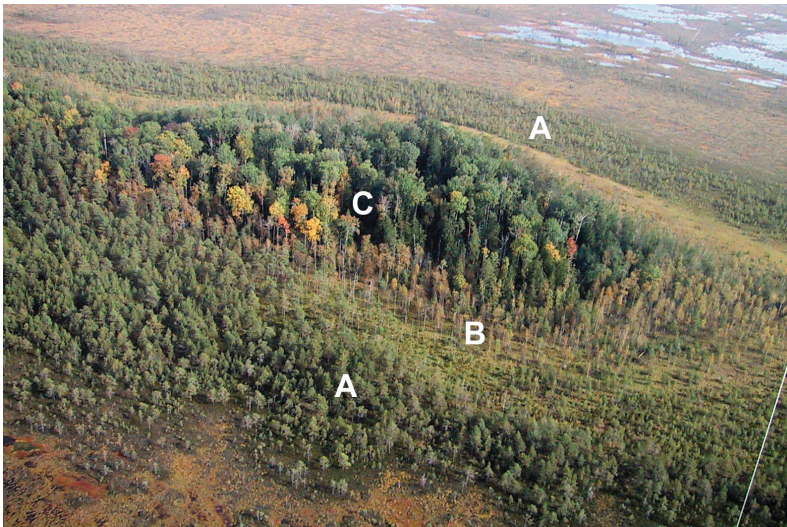


Fig. 4. Low-oblique view over Salupeaksi, a tree-covered “mineral” island (a drumlin), in the middle of Nigula Bog. Notice the marked forest zones of the island. A = pine, B = birch (partly bare), C = ash, elm, maple and other deciduous hardwoods, some of which are displaying fall colors. Kite line crosses the lower right corner of photograph.

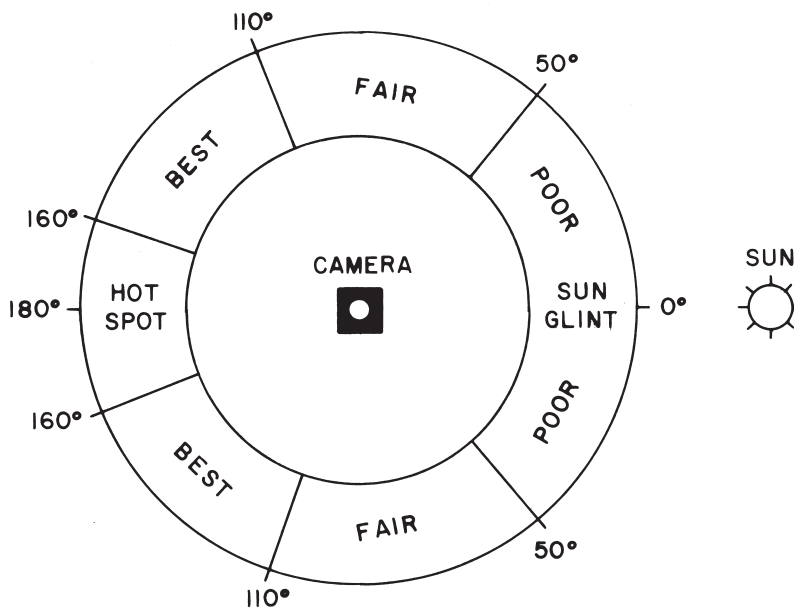


Fig. 5. Azimuthal (plan) diagram of lighting conditions for oblique kite aerial photography relative to the sun position.

for identifying ground features.

In views toward the sun, shadows become excessive at azimuth angles less than about 50° (Fig. 5). This leads to high-contrast images with poor color definition of objects. Sun glint (mirror reflection) from water bodies may appear in views directly toward the sun (Fig. 7). While sun glint renders much of the scene obscure, it does highlight water bodies regardless of water depth or turbidity. Quite small water pools are revealed

by sun glint. This may be useful for identifying shallow, muddy or small water bodies that are not readily apparent in vertical views.

Color-infrared photography — Color-infrared, vertical photographs display high contrast between bright pink-red active vegetation and other dark objects. These images reveal the importance of photosynthesis in moss zones at the perimeter of pools (Figs. 8 & 9). Vegetation on hummocks is considerably darker in general; pine

Fig. 6. Late morning view over Teosaare Bog toward the north. The bright zone in left center is an example of the “hot spot” or opposition effect, which is the point in direct alignment between the sun, camera, and ground. Survey markers are visible along the right side of view and toward the left center; two people are standing near lower right edge of scene.

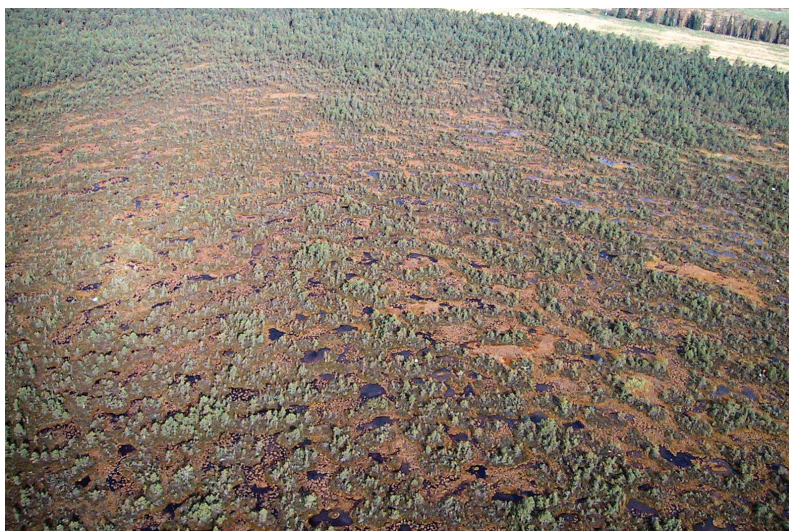
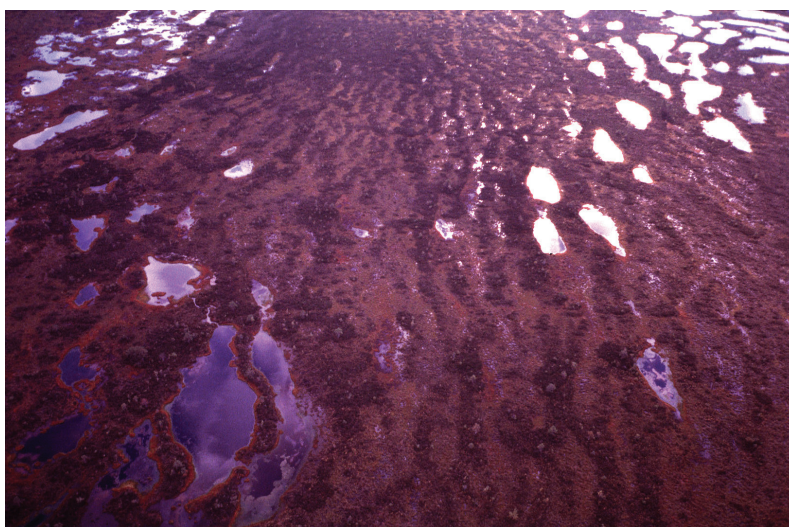


Fig. 7. Early afternoon southward view toward the sun over the western portion of Nigula Bog. Lakes in the background are highlighted by sun glint; lakes in foreground display reflections of sky and clouds. Overall the image has high brightness contrast and poor definition of colors.



trees are purple in color, while heather, grass and dwarf shrubs are barely depicted. Water absorbs all infrared radiation within a few cm of penetration, so water bodies normally appear dark blue to black in color-infrared photographs. In this case, floating or barely submerged *Sphagnum cuspidatum* appears as a pale purple color within the pools; whereas, emergent *S. cuspidatum* gives the brightest pink color. *S. magellanicum* and *S. rubellum* are depicted in bright red color. The distribution of highly active vegetation is limited to narrow zones, 1–2 m wide, around pools;

whereas most of the emergent bog surface displays quite low levels of vegetation activity.

Special lighting effects are often accentuated in color-infrared photographs compared to equivalent color-visible pictures. This is apparent for shadows, sun glint, and the hot spot. Shorter wavelengths are scattered more strongly in the atmosphere than are longer wavelengths, and so shadows are illuminated by blue-rich light. However, blue light is excluded for color-infrared photographs, so shadows appear quite dark to black (Light 2001). Color-infrared images dis-

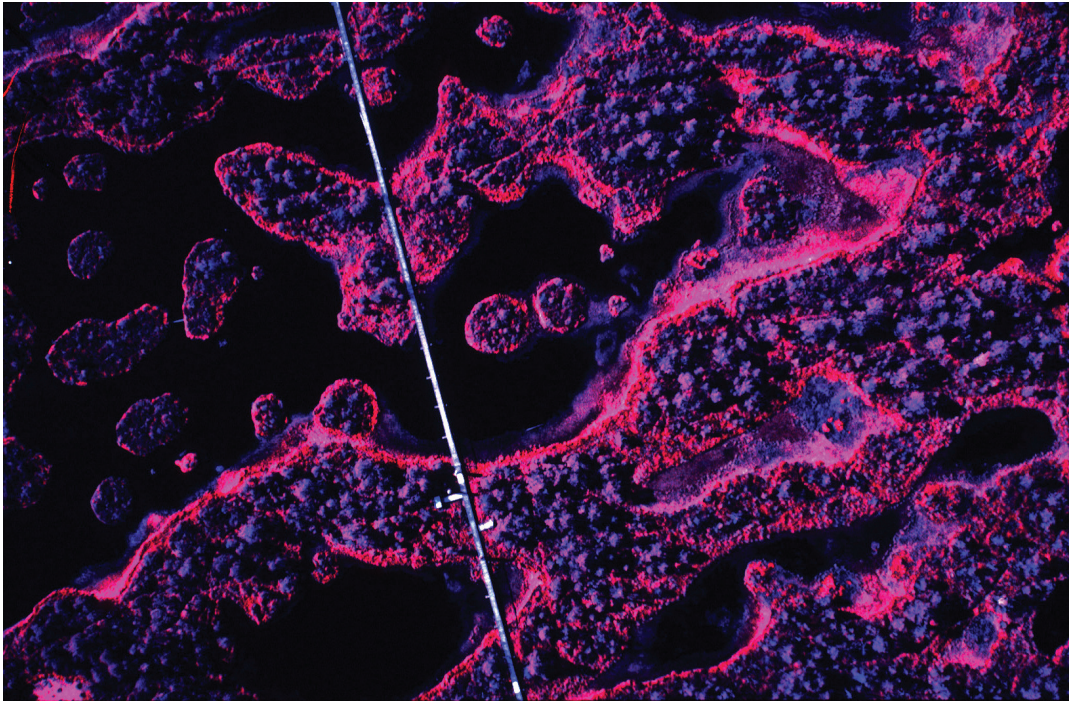


Fig. 8. Vertical view over the boardwalk in the western portion of Männikjärve Bog. Active moss photosynthesis is concentrated at the margins of pools, as shown by bright pink-red in the color-infrared picture. Compare with Fig. 2.

play high brightness contrast (Fig. 10). The enhancement of shadows contributes to stronger sun-glint and hot-spot effects (Figs. 11 & 12).

Discussion

Our results indicate that kite aerial photography has potential for microstructural investigations and analysis of mires. The civilian imagery interpretability rating scale has ten rating levels (0–9). The resolution of vertical digital kite aerial photographs (2.5 to 6 cm) provides for interpretability ratings of 7 or 8 (Leachtenauer et al. 1997). Level 7 includes such tasks as recognizing individual railroad ties (sleepers) and detecting tree stumps and rocks in forest clearings and meadows. At level 8 it is possible to identify a survey marker set in a paved surface and to recognize individual pine seedlings or individual water lilies on a pond. The ground resolution of vertical kite aerial photographs is an order of magnitude more detailed than conventional airphotos. On

this basis, the areas viewed by vertical KAP (approx. 1 ha) could be used as training sites for improved interpretation of conventional airphotos and satellite images.

Vertical kite aerial photographs may be used either singly or in stereo-pairs for accurate spatial measurements based on photogrammetric techniques (Warner et al. 1996). Field survey markers could be utilized for geometric correction of KAP images, which then could be mosaiced and employed as a quickly renewable layer in a GIS database.

The complicated patterns of emergent, floating and submerged vegetation are portrayed clearly in kite aerial photographs, and the boundary is defined sharply between emergent and floating moss around pools. Distinct color and texture zones represent specific vegetation communities. In the authors' experience, these vegetation zones are most prominent in late summer, when moss and other wetland plants reach their maximum growth phase and color definition. On this basis, we recommend September as the opti-

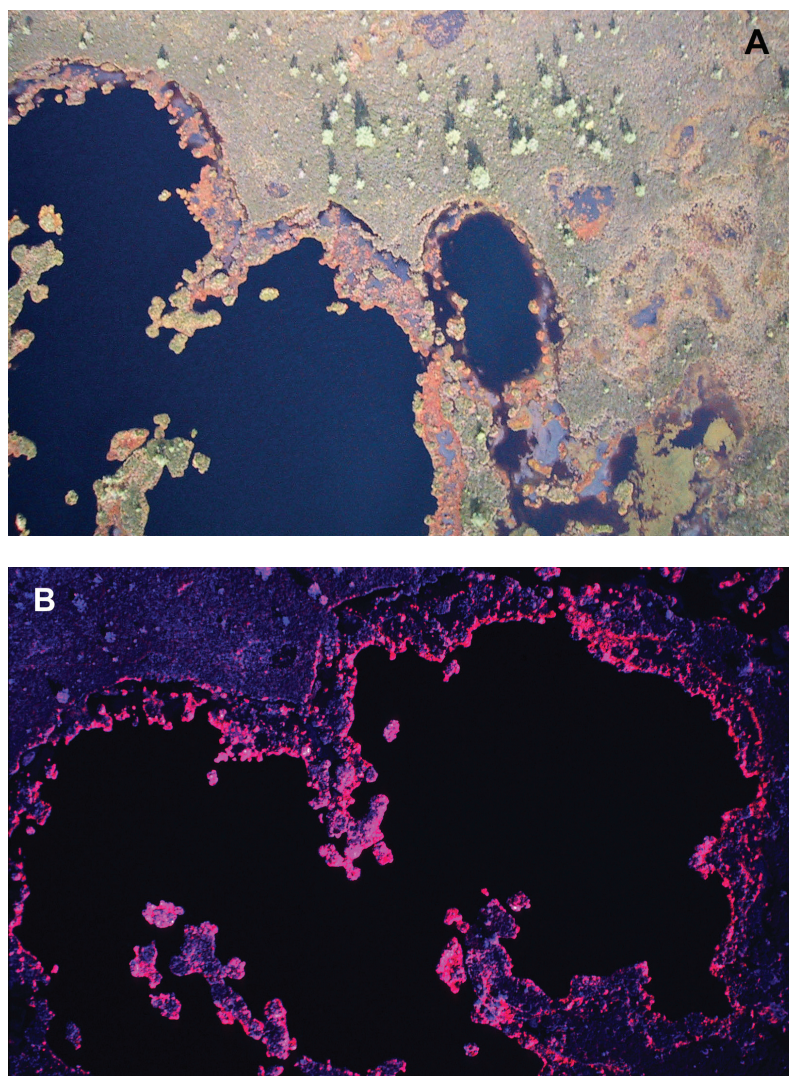


Fig. 9. Color-visible (A) and color-infrared (B) vertical views over the eastern portion of Nigula Bog. In A, the reddish-brown zone represents *Sphagnum magellanicum* and *S. rubellum* growing around pools. This same zone is bright pinked in B, but the rest of the emergent bog displays dark violet-purple color of minimal photosynthetic activity.

imum time of year for remote sensing of Estonian mires for purposes of ecological mapping and analysis. With further study, it may be possible to create an interpretation key for Estonian bog vegetation in late summer based on color-visible and color-infrared airphotos.

A direct comparison of color-visible and color-infrared images favors the visible portion of the spectrum for revealing overall variations and details for all types of land cover in bogs. The natural colors and relative ease of interpretation are advantages for color-visible imagery in both vertical and oblique views. Color-infra-

red photographs are, in contrast, more difficult and costly to acquire. Nonetheless, color-infrared emphasizes the photosynthetically active moss zone, which is a narrow strip at the margins of pools and hollows. Vertical color-infrared images are preferred to oblique views, as the latter tend to display excessive brightness contrast.

Mires are normally rather dark features in most false-color satellite images. The reason for this is apparent from examination of color-infrared KAP. The zone of active photosynthesis is distributed in narrow strips or clumps (1–2 m

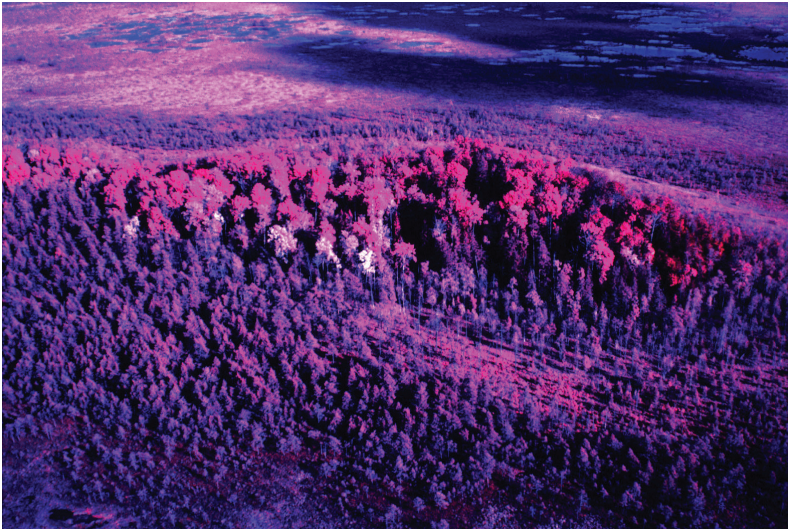


Fig. 10. Low-oblique, color-infrared view over Salupeaksi in the middle of Nigula Bog. Note dark shadows within the deciduous forest (center) and dark cloud shadow in the background. Compare with Fig. 4.

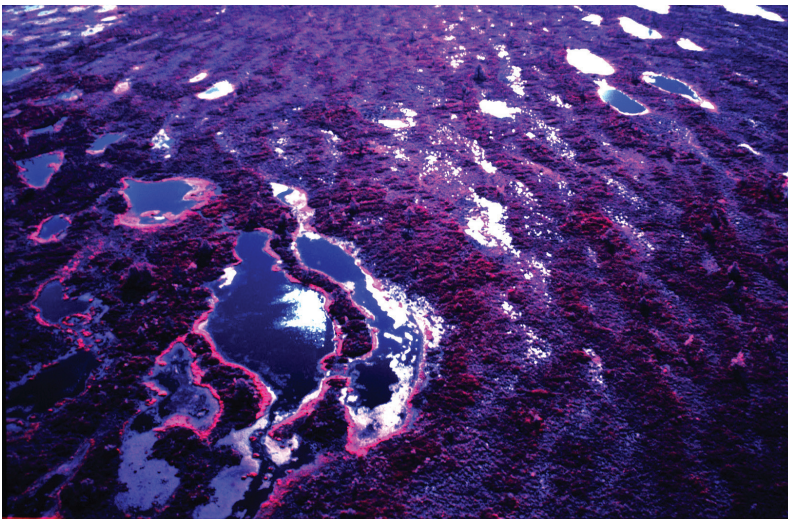


Fig. 11. Color-infrared view of sun-glint over the western portion of Nigula Bog. Note the extreme brightness contrast. Compare with Fig. 7.

wide) at the margins of pools and hollows. Such narrow zones are “lost” in the lower resolution of satellite images. The active-zone of high near-infrared reflection is “blended” with adjacent water, mud, and hummock reflections to create an average low value. Our results suggest that while plant activity is low overall in late summer, bogs contain narrow zones within and around pools which support a high level of photosynthesis. This finding may have significant implications for accumulation of peat biomass, bog microtopography, methane flux, and related environmental factors.

It is exactly the zone of high photosynthesis that represents the boundary between yellow peat of hollows dominated by *S. cuspidatum* and brown hummock peat composed of *S. fuscum* and *S. rubellum*. Spatial interplay between ridges and hollows during the Holocene is a basic attribute of raised bogs in Estonia. Expansion of hollows/pools takes place generally during cool/wet climatic intervals; whereas, ridges are stable or increasing during warm/dry periods (Karofeld 1998). Frenzel and Karofeld (2000) demonstrated at Männikjärve Bog that ridges are sinks for methane and hollows/pools are sites of methane emis-



Fig. 12. Color-infrared picture over Teosaare Bog showing an enhanced hot-spot effect at scene center. Compare with Fig. 6.

sion. Gradual changes in ridge-hollow distribution, thus, affect methane flux within the bog system. Kite aerial photography offers a convenient means to acquire imagery at submeter resolution for detailed mapping of the boundary between the yellow hollow/pool and reddish-brown hummock zones of active moss in raised bogs of Estonia (see Figs. 2 & 3).

As a general reaction, we are impressed by the amount of open water present in our study sites. Sun-glint views highlight very small water pools that would have escaped detection in other views. The amount of surface water was surprising, particularly in the case of Teosaare Bog. The impact of marginal drainage ditches and a former agricultural field are apparently less than we had anticipated. On this basis, we suggest that the number and area of water pools in bogs is often underestimated from conventional airphotos and satellite images.

The phenomenon of bidirectional reflectance, also known as multi-view angle (MVA) reflectance, is the variation in reflectivity depending on

the location of the sensor in relation to the ground target and sun position (Asner et al. 1998). In conventional remote sensing, the camera or scanner looks straight down (or nearly so) to capture a vertical (nadir) view of the Earth's surface. However, oblique vantages may prove useful in some situations. Considerable theoretical analysis has been conducted on MVA reflectance (Nilson and Kuusk 1989; Schaaf and Strahler 1994), and extensive field research has been done to understand the effects of MVA reflectance (Ranson et al. 1994). Manned-space photography has demonstrated the value of multiple vantages and different sun angles for discriminating geologic features (Lulla et al. 1993).

Mires represent ideal natural laboratories for further field investigations of multi-view angle reflectance, and kite aerial photography offers an inexpensive and quick means to acquire MVA imagery in all orientations — nadir and oblique. Such images could be utilized to confirm or refine theoretical models of MVA reflectance for the surface materials common in bogs — water,

mud, moss, dwarf trees. The hot-spot position is normally avoided as it creates overexposure or saturation of the image. Likewise, the sun-glint position is also avoided in most applications, but it can be used to advantage for identifying small water bodies. In general, we find that color-infrared images are more susceptible than are color-visible pictures to special lighting effects seen in MVA images, because of darker color-infrared shadows. Color-infrared photographs also tend to accentuate special lighting effects, because the manual (fixed) setting of camera light functions does not compensate for brightness variations at different viewing angles.

Kite aerial photography has several other potential applications in mire research. It is a promising technique for determination of Natura 2000 sites. Because of its low cost and simplicity, it can be employed when quick investigation is needed of ephemeral conditions. Examples include damage from wind storms, extent of floods, pollution effects, forest clearing, etc. The results of KAP for selected sites within a bog may be extrapolated across the bog massif, although one should be cautious for broader generalization to surrounding mires, which may be quite different in character.

Conclusions

Kite aerial photography reveals distinct late-summer vegetation zones in Estonian mires. Marked differences in image color and texture allow detailed mapping and identification of submerged and emergent moss as well as other plant cover. Color-visible images are most effective for depicting the general types and distribution of vegetation, mud, and water at submeter resolution. Color-infrared photographs highlight active photosynthesis, which is concentrated in narrow zones (1–2 m wide) around pools. The high level of photosynthesis at the pool-shore interface may have important consequences for peat biomass accumulation, evolution of hummock-hollow morphology, methane emission, and other environmental factors. KAP revealed many more (small) water bodies than we had anticipated, and so we suggest that the number and area of water

pools in ombrotropic bogs is often underestimated from conventional airphotos and satellite images. Color-infrared photographs have darker shadows and higher brightness contrast than do color-visible pictures, which enhances special lighting effects — sun glint and the hot spot. Kite aerial photography has many potential applications for mire research at the microstructural level, could serve as a quickly renewable map layer in a GIS database, and may lead to improved interpretation of conventional airphotos and satellite images.

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TIIVISTELMÄ:

Viron soiden pinnanmuodot värillisten leijailmakuvien valossa

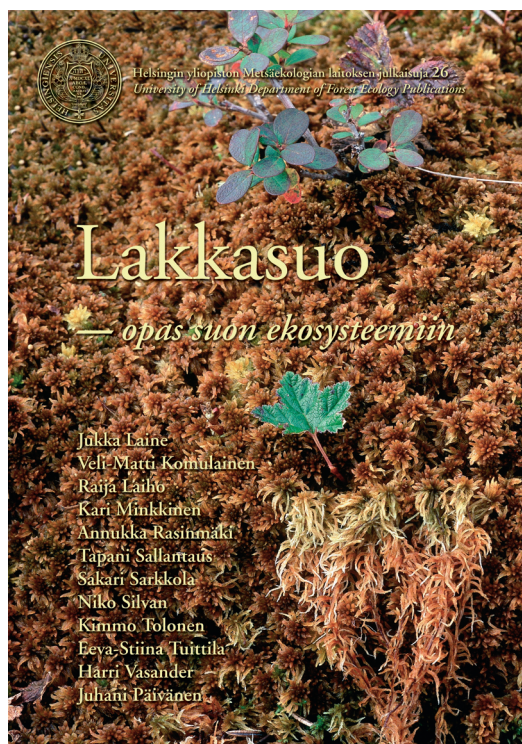
Tutkimuksessa kartoitettiin värillisen leijailmakuvauksen mahdollisuuksia soiden tutkimuksessa kolmella suolla itäisessä ja lounaisessa Virossa. Normaali-väri- sekä väri-infrakuvia otettiin eri kulmista maahan ja aurinkoon nähden filmi- ja digitaalikameroilla. Kuvien resoluutio oli 10–30 cm, mikä mahdollistaa mikrotopografisen tarkastelun. Normaaleissa värikuvissa eri kasvillisuusvyöhykkeet erottuvat selvästi värin ja pintarakenteen mukaan, ja vapaat vesipinnat muodostavat selvän kontrastin kasvivyhdyskuntiin. Kasvivyhdyskuntien mätäs-painannepintavaihtelu erottuu kuvissa selvästi ja varsinkin kelluvat sammalmatot muodostavat selkeän rajan muuhun kasvillisuus-

teen. Väri-infrakuvissa erottuu erityisen voimakkaasti yhteyttäviä kasvivyhdyskuntia kapeina juotteinä kuljupintojen reunoilla. Tällä saattaa olla merkitystä soiden morfologian, biomassan kertymisen, metaaniemissioiden ym. ympäristötekijöiden kannalta. Vapaat vesipinnat näyttävät olevan yllättävän yleisiä, ja niiden osuus suon pinnanmuodoista saattaa olla aiemmin luultua suurempi. Eri kuvauskulmat paljastavat monenlaisia eroja suon eri pinnanmuotojen ja -rakenteiden välillä. Kokemusten perusteella leijailmakuvamenetelmä näyttäisi käyttökelpoiselta menetelmältä monenlaisen suontutkimukseen, mm. mikrotopografisten pintojen kartoitukseen.

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UUTTA SUOKIRJALLISUUTTA:

Laine ym. 2002. Lakkasuo — opas suon ekosysteemiin. Helsingin yliopiston Metsäekologian laitoksen julkaisuja 26. 120 värisivua.



Oriveden Lakkasuo muodostaa välittömine ympäristöineen poikkeuksellisen monipuolisen suoalueen, jossa esiintyvät lähes kaikki eteläisessä Suomessa tavattavat suotyypit. Helsingin yliopistossa Lakkasuo on käytetty metsätieteiden tutkimus- ja opetuskohteena jo vuosikymmenien ajan. Tähän värikkääseen oppaaseen on kirjattu nykyinen tietämys Lakkasuoista toiminnallisena ekosysteeminä. Katso kirja-arvostelu tämän lehden sivuilta 27–29.

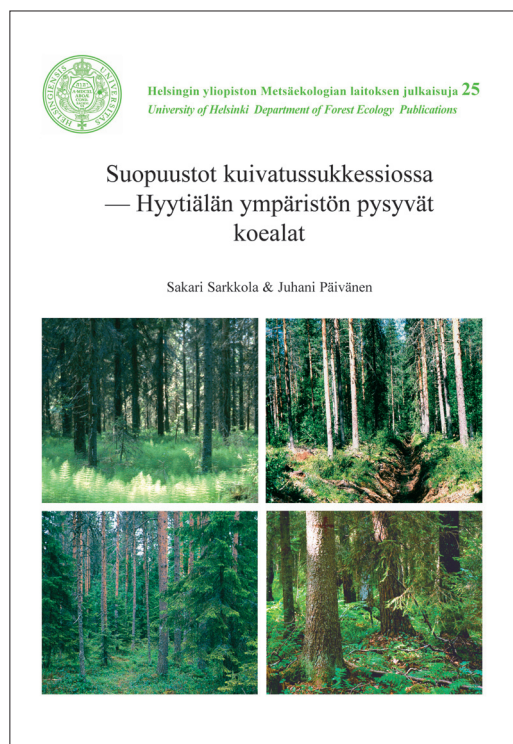
Hinnat:

Opiskelijat: 5 e

Muut: 15 e (yli 10 kpl tilaukset 10 e/kpl)

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Sarkkola & Päivänen 2001. Suopuustot kuivatussuksessiossa — Hyytiälän ympäristön pysyvät koealat. Helsingin yliopiston Metsäekologian laitoksen julkaisuja 25. 109 sivua.



Helsingin yliopiston suometsätieteen laitoksen toimesta perustettiin Hyytiälän ympäristön metsäojituille soille 1950- ja 1960-luvuilla lukuisa joukko pysyviä metsikkökoaloja. Tavoitteena on ollut ylläpitää edustavaa näyteala-aineistoa, jolla pystytään havainnollistamaan toisaalta metsäojituksen ja toisaalta metsänhoidollisten käsittelytapojen vaikutusta puuston ja koko metsäekosysteemin kehitykseen ojitusalueilla. Opas tarjoaa hyvän havaintopakettin niille, jotka joko opinnoissaan, ammatissaan tai vapaa-aikanaan haluavat perehtyä suoekosysteemeihin metsänkasvupaikkoina — niin ulkona luonnossa kuin kirjoituspöydänkin ääressä.