Remote Sensing as a Tool in the Aquatic Macrophyte Mapping of a Eutrophic Lake: a Comparison Between Visual and Digital Classification

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Abstract. In this study two aerial photograph interpretation methods, visual and digital classification, were used for the aquatic macrophyte mapping of a eutrophic study lake in the Finnish Lake District. The study indicated that aerial photograph interpretation is a useful monitoring method of aquatic macrophytes in lakes dominated by helophytes and nymphaeids. Visual classification produced the taxonomically best, mainly species-specific information, while in digital classification aquatic macrophytes were categorized according to life forms or phenotypes and the coverage of vegetation stands. The overall classification accuracies were defined to be 81% for visual and 83% for digital classification. In the sense of time used, digital classification was 3.5 times more effective than visual classification. With the aid of both the methods the abundance of different macrophyte categories in hectares were produced and the areas for the corresponding categories were rather similar. It is also possible to combine these interpretation methods in order to reach the best solution between the effectiveness and taxonomical accuracy of the methods.

1. Introduction

Aquatic vegetation (macrophytes) is an essential part of the productive zone in northern lakes [1]. The vegetation provides food, shelter and breeding habitats for aquatic animals like invertebrates, fish and birds [2], [3], [4], [5]. Macrophytes have an effect on the bottom quality and composition and protect the shore from erosion [6], [7], [8]. The overgrowth of water bodies together with physical and chemical changes affect species composition of macrophytes as well as other biotic communities [9], [10], [11]. From the human point of view, overgrowth affects the recreational value of lakes and restoration efforts are economically expensive.

Aquatic macrophytes include vascular plants, water mosses and some macro algae [12]. Macrophyte species can be divided into different life form groups based on their structure and adaptation to the environment [13]. The classification is based on three morphological basic criteria consisting of the occurrence of emerged, floating and submerged leaves. The main life forms are helophytes, nymphaeids, isoetids, lemnids, elodeids, ceratophyllids, charids and bryids [14].

The Water Framework Directive (WFD) of the European Community aims at protecting aquatic environments and supporting the sustainable use of water resources [15]. The WFD advocates changes in the monitoring of water bodies emphasizing the biological quality elements (e.g. phytoplankton, macrophytes and fish) alongside traditional concerns for their hydromorphological and physico-chemical properties. Monitoring programmes required by the directive to establish a coherent and comprehensive overview of water body status have to be operational by 2006. Before that the quality elements to be monitored, monitoring methods, sites and frequencies, reference conditions and other factors important in the implementation of the WFD, must be determined for each surface water category. For lakes, macrophytes have been defined to be a relevant biological quality element. Macrophyte taxonomic composition and average abundance are parameters defined by the directive. In a monitoring guide for the directive [16] aerial photography is mentioned as a sampling method of macrophytes in addition to transect sampling. Implementation of the WFD requires information not only on the present ecological status of water bodies, but also on the trend of change in the biological quality elements. The information is needed in order to obtain an estimate of the probability of the water bodies to meet the requirement of good ecological status by the year 2015 [15].

Aerial photographs are the most commonly used form of remote sensing data for mapping aquatic vegetation [17]. The traditional image interpretation method for aerial data is visual classification. In visual classification recognition of an object is based on its shape, size, pattern, tone, texture, shadow, site and association observed by a human eye. In digital classification interpretation is based on differences in digital number (DN) values of the wavelength areas, i.e. bands available in the image, and is performed with the aid of automated, statistical methods [18]. In Finland aerial photograph interpretation has been mostly used in the monitoring of regulated lakes or lakes where the water table has been lowered [19], [20]. The visual classification of aerial photographs has provided a powerful tool for studying long-term effects of water level regulation on aquatic macrophytes [21].

In this study two image interpretation methods, visual and digital classification, are used for the aquatic macrophyte mapping of a eutrophic study lake in the Finnish Lake District. The aim of this study is to compare the interpretation methods in regard to taxonomic composition, average abundance of species and classification accuracy (compared to field observations) of macrophyte categories produced. The overall time used for the field survey and interpretation is also taken into account.

2. Materials and Methods

2.1. Study Area

The study area is located in the northern part of Lake Onkivesi (63º19´-63º22´N, 27º20´-27º24´E). Lake Onkivesi is a part of the Vuoksi drainage basin, which forms the core of the Finnish Lake District. The catchment area of Lake Onkivesi is dominated by nutrient rich soils, which cause a naturally eutrophic water quality [22]. The lake receives high non-point nutrient input from the surrounding catchment area. The northern part of the lake also receives some effluents from a wastewater treatment plant.

Water quality of the open-water period is characterized by high total phosphorous (avg. 56.4 µg/l ± stdev 9.83) and nitrogen (avg. 761 µg/l, ± stdev 138), which stimulate high primary production with high chlorophyll-a (avg. 24.6 µg/l, ± stdev 16.9) and pH values (avg. 7.08 ± stdev 0.27). Enhanced primary production and humic water quality (avg. 104 mgPt/l, ± stdev 15.6) decrease Secchi depth values to 0.95 m.

The aquatic vegetation of the study area is dominated by the helophytes *Phragmites australis* (Common Reed), *Schoenoplectus lacustris* (Common Club-rush) and *Equisetum fluviatile* (Water Horsetail) along with the nymphaieds *Nuphar lutea* (Yellow Water-lily) and *Sparganium gramineum* (Bur-reed). The stands of helophytic vegetation are dense and due to the gently steeping shores the vegetated littoral zone is wide. The vegetation includes many species indicating high nutrient status like *Hydrocharis morsus-ranae* (Frogbit), *Stratiotes aloides* (Water-soldier), *Potamogeton compressus* (Grass-wrack Pondweed) and *Lemna minor* (Common Duckweed).

2.2. Data

The aerial photographs of Onkivesi were acquired on July 29th, 2002 at 11:33 local time using a Leica RC30 camera equipped with a 153 mm focal length lens and UAG-S 13260 lens, Kodak 1443 colour infrared film, a 500 nm cut-off filter and an 80% infrared filter. The acquired data are CIR photographs and for the needs of digital classification the three bands, green (500-575 nm), red (575-675 nm) and near-infrared (675-900 nm), were separated. The aerial photography coincided with the period of maximum abundance of aquatic macrophyte vegetation, which is on average from the middle of July to the beginning of September in Finland. The minimum useful solar elevation angle was deemed to be 33° in order to avoid long shadows on the shores and strong sun glint. Optimum weather conditions were defined to be clear sky and wind not higher than 4.0 m/s. An endlap of 80% was chosen in order to acquire a glint-free image mosaic. The scale of the photographed images is 1:20000.

The field data of aquatic macrophytes were collected between July 23–24, 2002 and also on July 31 for digital classification. The interpreters themselves made the field surveys for use of both the interpretation methods. The field data for the accuracy assessment were collected at the same time as the data for digital classification. An outsider (non-interpreter) collected the data and performed the accuracy assessment.

The field observations for the visual classification were investigated from a boat. A two-year old aerial photograph of the study area was used during field survey since the aerial photographs of the same year were not available by the time of the field survey. The location and species composition of the macrophyte communities were marked on the printout of the aerial photograph. The field observations were based on the occurrence of helophytes and nymphaieds. Growth depth, density and biomass were not measured.

The field data for digital classification consisted of information on aquatic macrophyte species, estimated coverage (+, 0.5, 1, 2, 3, 5, 7, 10, 15, 20, 25, 30, …, 90, 95, 100%), water depth and bottom quality. The information was collected using reference plots (size at least 3 x 3 m^2) of varying species composition and coverage from the study area. Each reference plot was geo-referenced with a 12-channel differential global positioning system (DGPS). Altogether 178 reference plots were collected, from which 58-61 reference areas were used for the accuracy assessment of the classifications of both the interpretation methods.

2.3. Methods

In visual classification the aerial photograph was scanned with an accuracy of 63.5 μm, which produced a spatial resolution of 1.27 m. This digital image was geo-referenced on the Finnish digital base map of scale 1:20000. The vegetation was digitized using the coastline of the Finnish digital base map as a reference layer. Stereo glasses were used to obtain a three-dimensional view when necessary. The visual classification was carried out using ArcView.

For digital classification the images were scanned using an accuracy of 28 μm, which produced a spatial resolution of 0.56 m. The scanned aerial photographs were geo-referenced on the Finnish digital base map of scale 1:20000. In order to eliminate the areas affected by sun glint an aerial photograph mosaic was created. The pixel size of the images was tripled (pixel size of c. 1.5 m has proved to produce the best classification result) and terrestrial areas were masked out with a mask derived from the Finnish digital base map. The aerial photograph mosaic was categorized using a maximum likelihood classifier [18]. The reference plots collected from the field were used as training areas for the classification. The digital classification was performed using the Erdas Imagine image processing software.

The classification accuracy assessment was performed by comparing known reference data (ground truth) with the corresponding results of the classifications using an error matrix [18]. The accuracy of each category was defined according to the vegetation type that covered over 50% of a reference plot, which was used as a test area in the accuracy assessment.

The study areas were defined to be the zones where the lake bottom has a suitable depth for macrophytic vegetation. In this case, the littoral zone was defined to be the area with a depth less than two meters from the mean water level of Lake Onkivesi. The area was outlined using a Digital Elevation Model (DEM) of the lake.

3. Results

The visual classification resulted in an aquatic macrophyte classification into seven categories (Fig. 1, Table 1). The 1) *Phragmites australis*, 2) *Equisetum fluviatile*, 3) *Schoenoplectus lacustris* and 4) *Stratiotes aloides* –stands formed their own categories. The *Phragmites* category contained also tall *Calamagrostis* sp. (Reed Bent Grasses) stands along with small *Carex* sp. (Sedges) and *Calla palustris* (Bog Arum) stands. The 5) *Carex* sp. category included all the major *Carex* sp. stands and some short *Calamagrostis* species. The 6) Nymphaeids (Water-Lilies) category contained species of *Nuphar*, *Nymphaea*, *Potamogeton*, *Sparganium* and *Sagittaria natans* (Arrowhead). The 7) *Sagittaria sagittifolia* and *Menyanthes trifoliata* (Buckbean) stands were combined into one category.

As a result of the digital classification macrophytes were categorized into five categories according to life forms or phenotypes and the coverage of vegetation stands (Fig. 2, Table 2). The 1) Dense stands (coverage over 50%) of *Phragmites australis* and shore meadow species, like *Carex* sp., formed one helophytic category and 2) dense *Schoenoplectus lacustris*, *Equisetum fluviatile* and *Stratiodes aloides* vegetation another. Nymphaeid species (*Nuphar lutea*, *Sparganium gramineum*, *Potamogeton* spp. etc.) were divided into two coverage categories (3 & 4) with the limit value being a coverage of 50%. Sparse helophytic vegetation (coverage less than

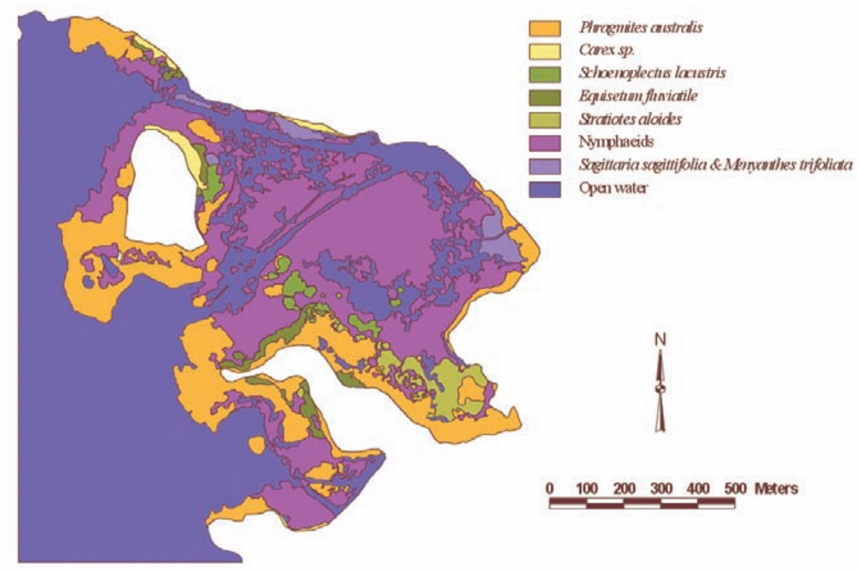

Fig. 1. Aquatic macrophyte classification image from bay Hujalanlahti (63°20´-63°21´N, 27°22´-27°24´E) based on visual classification

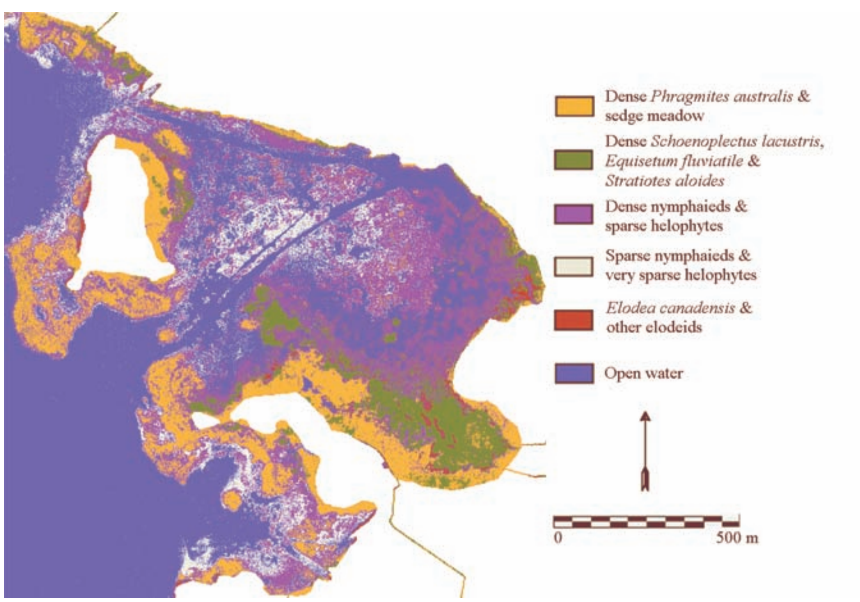

Fig. 2. Aquatic macrophyte classification image from bay Hujalanlahti (63°20´-63°21´N, 27°22´-27°24´E) based on digital classification. The macrophyte categories are described more precisely in Table 2

Table 1. Macrophyte categories and areas of macrophytes in hectares for visual classification from the bay Hujalanlahti (Fig. 1)

Macrophyte category	Area in hectares
Phragmites australis	21
Equisetum fluviatile	2
Schoenoplectus lacustris	1.5
Stratiotes aloides	2.5
Carex sp.	1.2
Nymphaieds	34.5
Sagittaria sagittifolia ja *Menyanthes trifoliata*	1.8
Total vegetation	64.5
Open water	32.5

Table 2. Macrophyte categories and areas of macrophytes in hectares for digital classification from the bay Hujalanlahti (Fig. 2). Unit c is coverage assessed in the field with the aid of %-scale

Macrophyte category	Area in hectares
Dense *Phragmites australis* (c>50%) & sedge meadow	16
Dense *Schoenoplectus lacustris*, *Equisetum fluviatile* and *Stratiotes aloides* (c>50%)	8
Dense nymphaieds (c>50%), sparse helophytes (30<c<50)	26
Sparse nymphaieds (c<50), very sparse helophytes (c<30)	9
Elodea canadensis & other dense elodeids	1
Total vegetation	60
Open water	37

50%) was combined with the categories of nymphaeids. In addition, dense elodeid vegetation dominated by *Elodea canadensis* (Water-weed) formed category 5. The aquatic vegetation was merged with open water areas if the vegetation was very sparse (coverage less than 10%).

The overall classification accuracies for the classification images were defined to be 81% for visual (Table 3) and 83% for digital classification (Table 4). If elodeids are not taken into account the overall classification accuracy is 90% for visual classification (Table 3). In visual classification the greatest misclassification was in the categories of *Stratiotes aloides*, *Carex* sp. and in the category of *Sagittaria sagittifolia* & *Menyanthes trifoliata*. In digital classification the greatest misclassification was in the category of sparse nymphaeids and the sparsest helophytic vegetation and in the category of elodeids. The time used for the field survey of visual classification was 3 minutes per hectare of littoral zone and the same time for digital classification was 2 minutes. Visual classification itself took 7 min and digital classification 2 min per hectare of littoral zone. The preprocessing for both of the interpretation methods is included in these values.

Table 3. An error matrix for the visual classification of aquatic macrophytes. The error matrix does not take into account elodeids that were not classified in visual interpretation. *The total classification accuracy with the eloideids included is 81%

Classification data	Ground truth data									
	Phragmites australis	*Equisetum fluviatile*	*Schoenoplectus lacustris*	*Stratiotes aloides*	*Carex* sp.	Nymphaieds	*Sagittaria sagittifolia* & *Menyanthes trifoliata*	Open water	Total	%
Phragmites australis	9				1		1		11	82
Equisetum fluviatile		9		2					11	82
Schoenoplectus lacustris			7						7	100
Stratiotes aloides				2					2	100
Carex sp.					2				2	100
Nymphaieds				1		16			17	94
Sagittaria sag. & *Menyanthes tri.*									0	0
Open water						1		10	11	91
Total	9	9	7	5	3	17	1	10	61	
%	100	100	100	40	67	94	0	100		90*

4. Discussion

With the aid of visual classification a great part of the most abundant helophytic species of the study area were discriminated to their own categories [19], [23]. Nymphaeids were placed to one category. Elodeids, on the other hand, were not classified to a category of their own. The densest stands of elodeids could have, although, been seen visually, but since they tend to form mixed vegetation stands with more than one category in one area, they were ignored.

In digital classification the taxonomic composition could not be mapped exactly as in visual classification but aquatic macrophytes were categorized according to life

Table 4. An error matrix for the digital classification of aquatic macrophytes. The macrophyte categories are described more precisely in Table 2

Classification data	Ground truth data							
	Dense *Phragmites australis* & sedge meadow	*Schoenoplectus lacustris, Equisetum fluviatile* & *Stratiotes aloides*	Dense nymphaieds, sparse helophytes	Sparse nymphaieds, very sparse helophytes	*Elodea canadensis* & other elodeids	Open water	Total	%
Dense *Phragmites australis* & sedge meadow	8						8	100
Schoenoplectus lacustris, Equisetum fluviatile & *Stratiotes aloides*		9	2				11	82
Dense nymphaieds, sparse helophytes			16	4	1		21	76
Sparse nymphaieds, very sparse helophytes			3	4			7	57
Elodea canadensis & other elodeids					1		1	100
Open water						10	10	100
Total	8	9	21	8	2	10	58	
%	100	100	76	50	50	100		83

forms or phenotypes and the coverage of vegetation stands. As a difference to visual classification, in digital classification the densest elodeid stands dominated by *Elodea canadensis* were classified to their own category. Overall, aquatic macrophyte interpretation merely based on spectral characteristics of vegetation stands is not able to discriminate vegetation on the species-level. Other characteristics of vegetation stands such as shape, size, pattern, texture, site and association, are also important in a species-specific classification and these are taken into account in visual classification.

The total classification accuracy was approximately the same in visual classification (81%) and in digital classification (83%) when elodeids were taken into account (Tables 3 and 4). A weakness with digital classification was the difficulty in distinguishing the various life forms (helophytes and nymphaeids) unambiguously from each other, since coverage of vegetation stands was so greatly involved in spectral separation (Table 2). On the other hand, it can be useful to map the change in the coverage of macrophytes. Unfortunately, the greatest misclassification in digital classification was between different densities of macrophytes (Table 4), which was at least partly due to the subjectivity of the field method to define coverage (as %-scale). The effect of density, which highly correlates with coverage, on the classification results of aquatic macrophytes has also been recognized by Marshall and Lee [24].

The taxonomical accuracy of both the interpretation methods varied in the study area and in Tables 1 and 2 the coarsest categories are listed. For example, in visual classification different nymphaeids species (*Nuphar* spp. and *Nymphaea* spp., *Sparganium* spp. and *Potamogeton natans*) could be distinguished in a part of the study area. In digital classification *Equisetum fluviatile* was distinguished from *Schoenoplectus lacustris* in one bay of the lake. The taxonomical accuracy of visual classification, at least, can be directed and improved according to the main goal of the study.

In the classification based on digital classification it would have been possible to distinguish part of the *Phragmites australis* vegetation to a category of its own as was done in the study of Valta-Hulkkonen et al. [25]. In that study the vegetation on the shore, especially *Carex* sp., but also *Calla palustris* and *Menyanthes trifoliata* was confused with the *Phragmites australis* category with the highest density, when several (3-4) density categories for *Phragmites australis* were distinguished. *Phragmites australis* and sedge meadow vegetation like *Carex* sp. and *Menyanthes trifoliata* were partly confused also in the visual classification of this study (Table 3). The greatest differences in the taxonomical accuracy of the interpretation methods was with helophytes *Equisetum fluviatile*, *Schoenoplectus lacustris* and *Stratiotes aloides*, but also with some other species like *Sagittaria sagittifolia*. In the study of Valta-Hulkkonen et al. [25] it was assessed to be possible to discriminate these macrophyte categories to their own categories with the aid of visual classification. It was also suggested that in order to produce species-specific information, visual classification could be combined with digital classification.

The average abundances of the macrophyte categories expressed as hectares, produced by the different interpretation methods (Tables 1 and 2), were rather similar compared to each other. The total area of macrophytes in the bay Hujalanlahti (Figures 1 and 2) was 64,5 ha in visual classification and 60 ha in digital classification. The difference in the areas (7%) can be due to the digitizing, which simplifies details in visual classification [24]. A comparison between the areas of the vegetation categories produced by the two interpretation methods is, unfortunately, difficult, since digital classification does not distinguish the various life forms (helophytes and nymphaeids) unambiguously from each other. A comparison between the corresponding categories indicates, although, that the areas are rather similar.

Visual classification lasted 3,5 times longer per hectare of littoral zone than digital classification, but the time difference during the field survey was less significant. Presumably, the time needed for interpretation is less in lakes with minor vegetation and the time difference decreases between the two interpretation methods. In this study aerial photograph interpretation was examined in a eutrophic lake, where helophytic and nymphaeid vegetation dominates. The suitability of both the methods to nutrient poor (oligotrophic) lakes with more submerged vegetation like elodeids and isoetids is worse [24].

As the abundance of macrophytes can be analysed using both current and historical [21] aerial photographs, the method of aerial photograph interpretation can provide an effective tool in monitoring the past and present ecological status of lakes as required by the Water Framework Directive. Aerial photograph interpretation produces spatial information about aquatic macrophytes. Geometrically rectified classification data can be compared with other geographical data in order to study interactions between parameters or temporal changes, e.g. see [26]. These are the great advantages of aerial photographs if used as a monitoring method of aquatic macrophytes.

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