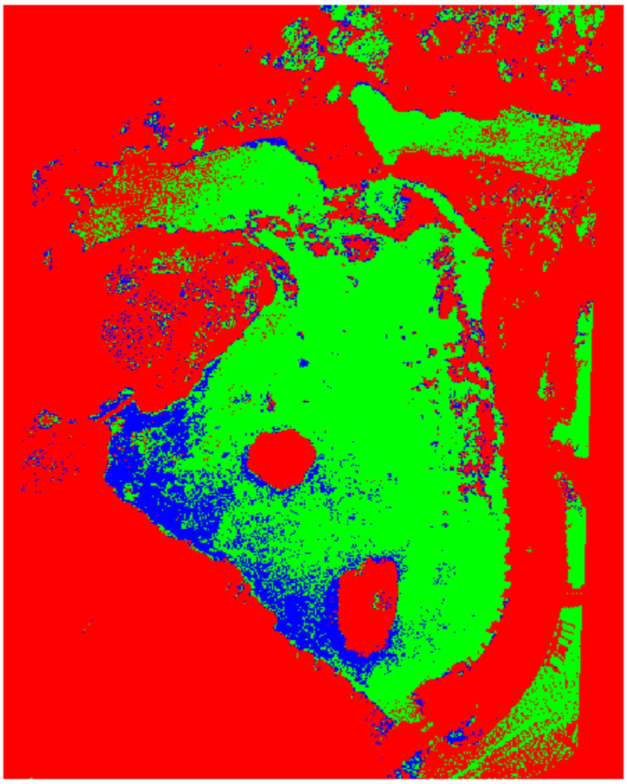
Visual interpretation and digital classification of aerial photographs, a tool to monitor submerged vegetation in shallow coastal areas in the Baltic Sea proper?



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Abstract

This project is aimed to test, 1) how well visual interpretation and digital classification from aerial photographs fits inventoried field data, 2) if these interpretation of aerial photographs could be used to map and monitor vegetation in shallow coastal areas and be used as a tool assessing the state of shallow coastal areas. Based on our results a modified method for mapping and monitoring shallow coastal areas by interpretation and classification of aerial photographs is presented and the time demand of the method is discussed. Further we suggest that this method will be a useful tool in mapping and assessing the state of shallow coastal areas.

The visual interpretation aimed to investigate at what time in the growth season aerial photographs preferably should be taken and to what depth visual interpretation, and digital classification, of aerial photographs could be used in Baltic waters with comparably high turbidity. It also aimed to describe the inventoried species from the aerial photographs focusing on their colour, height, texture, zone-structure and discrepancy in cover between estimated cover in field and estimated cover from photographs. The results from the visual interpretation are descriptive and focus on synthesising the description of interpretable species. A comparison between early (July) and late (August) photographs showed that the cover of the vegetation was less legible on the early pictures then on the late. Large species and perennials appeared clearer in the early pictures, due to lower abundance of covering filamentous and sheet-like algae in July than in August. Plant cover, for all species, was obviously lower in the early photographs than in the late and the transparency was slightly better in the early photographs. The aerial photographs should preferably be taken in late July or August when the submersed vegetation reaches maximum cover.

The accuracy of the digital classification was initially tested on different taxonomic levels to find a level that visually would predict vegetation with an acceptable accuracy. As a result of the digital classification the submerged macrophytes were first classified into 7 categories (Level 1). The seven categories for the classification are composed of two types of bare bottom, i.e. Bare bottom, sand and Bare bottom, mud, ≤ 25 % plant cover, and five types of vegetated bottom, i.e. Dense filamentous algae, ≥ 50 % cover, Thin sheet-like algae, ≥ 50 % cover, *Najas marina*, ≥ 50 % cover, Mixed stands of phanerogams, ≥ 50 % cover and *Fucus vesiculosus*, ≥ 50 % cover. The overall classification accuracy at Level 1 was 72 %. The best accuracy of the classification, in Level 1, had category 5, 3 and 6, i.e. *Najas marina*, ≥ 50 % cover, Dense filamentous algae, ≥ 50 % cover and Mixed stands of phanerogams, ≥ 50 % cover.

To further improve the accuracy of the classification the classes in Level 1 was reduced, by adding categories together, to three and two categories at Level 2 and Level 3. The seven categories were reduced to three categories in Level 2, Bare bottom, sand and mud, ≤ 25 % cover, Dense filamentous algae, thin sheet-like algae included, ≥ 50 % cover and Mixed stands of phanerogams, *Fucus vesiculosus* and *Najas marina* included, ≥ 50 % cover. The two categories in Level 3 are, Bare bottom, sand and mud, ≤ 25 % (category 1) and Vegetated areas, ≥ 50 %, category 2 and 3 in Level 2 included. The overall accuracy improved from 72 %, Level 1, to 85 % and 87 % in Level 2 and 3 respectively. At Level 2, both vegetated categories have a producer's and a user's accuracy above 85 % while the combined mud and sand category amount to 77 %, producer's accuracy, and have a user's accuracy of 81 %. At Level 3, the category 2, Vegetated areas, 50 % cover, have a producer's accuracy of 96 % and a user's accuracy of 95 %.

A combined analysis with both visual interpretation and digital classification would be favourable but would also be more time consuming then a digital classification only. The result shows that digital classification seems to be appropriate to use as monitoring-method for low detailed information, i.e. when monitoring functional groups of vegetation, such as mats of green alga or mixed stands of canopy forming species, but does not seem to be an good method to monitor single species or specific species combinations. On the other hand, calibration data have to be collected for the digital classification and the reference plots could be more thoroughly inventoried than needed for the digital analysis. Thus, species abundance data from the reference plots could, after the digital classification, be interpolated within the classified categories, which make it possible to use aerial photographs as monitoring method at species level.

Introduction

The submersed vegetation is essential in structuring the aquatic habitats in shallow coastal areas and vegetated shallow areas function as nursery and recruitment habitat for fish (Karås, 1999), These areas provides both shelter and food for the macrofaunal community and stabilise the sediment and prevent erosion (Barko et al., 1991). The shallow soft bottoms in the Baltic Sea have a high biodiversity (Tobiasson, 2001). The phytobenthic communities on the shallow soft bottoms in the Baltic Sea region are dominated by phanerogams and Characeans, of which three are listed in the national red-list (Gärdenfors, 2000).

Changes in the macrophytobenthic communities in coastal areas have been reported from the Baltic Sea area, (e.g. Schramm & Nienhuis, 1996, Dahlgren & Kautsky, 2002, and reference therein), and from many other areas in the world, (e.g. Lavery et al., 1991; Duarte, 1995; Sfriso & Marcomini, 1996; Schramm & Nienhuis, 1996; Valiela et al., 1997). Eutrophication is probably the major environmental treat to the shallow areas (Schramm & Nienhuis, 1996; Pihl et al., 1997; Münsterhjelm, 2000; Dahlgren & Kautsky, 2002; Tobiasson, 2001; Dahlgren & Kautsky, 2004). Other threats, as for example, intense boat-traffic, dredging and the construction of harbours also affect those areas. Increasing loads of nutrients or nutrient enrichment in the water column may result in a progressive replacement of species with low surface:volume ratio, e.g. *Fucus vesiculosus* and *Zostera marina*, to species with high surface:volume ratio, i.e. fast growing macroalgae, e.g. *Cladophora glomerata*, *Ulva lactuca, Ulvopsis grevilleï* and *Entheromorpha* spp. and phytoplankton (Littler, 1980; Wallentinus; 1984; Duarte, 1995).

The Water Framework Directive (WFD) aims at protecting aquatic environments and a sustainable use of water resources. According to the WFD monitoring and evaluation of biological quality elements, e.g. macrophytes and phytoplankton, is required together with monitoring of physico-chemical parameters. The Habitat Directive of the European Community aims to protect rare species and habitat. To attain the aims of those directives monitoring, maintenance and restoration of specific marine habitats are required. Different methods to monitor vegetation in the shallow soft bottom areas have been discussed and interpretation of aerial photographs is mentioned as an alternative to transect sampling in the Guidance on Monitoring for the WFD (Littlejohn et al., 2002). The national and regional phytobenthic monitoring programs in the Baltic Sea have focused on rocky shores whereas monitoring of phytobenthos in shallow soft bottom areas have been neglected. Interpretations of aerial photographs have been viewed as a possible method to monitor and assess the status of marine shallow soft bottoms. The method has advances in mapping large areas to a limited cost compared to scuba diving and other field methods (Boberg & Ganning, 1986; Tobiasson, 2001, Helminen et al., 2001).

This project is aimed to test how well visual interpretation and digital classification from aerial photographs fits inventoried field data and if interpretation of aerial photographs could be used to map and monitor vegetation in shallow coastal areas and be used as a tool assessing the state of shallow coastal areas. We also discuss when aerial photographs should be taken, from what height pictures need to be taken and to what depth interpretation seems valuable. Finally we propose a modified method for mapping and monitoring shallow coastal areas by interpretation and classification of aerial photographs and discuss the time demands of the method.

The following questions were raised:

1) To what taxonomic level and to what depths can visual interpretation and digital classification of aerial photographs be used in the Baltic Proper?

2) Can species or groups of species be described and separated according to their colour, height, texture, zone-structure and how well can their cover be estimated from aerial pictures compared with estimates in field?

3) How well can different types of species or groups of species be interpreted by digital classification and how well can the total abundance of vegetation and the total area of bare bottom be estimated from aerial photographs?

Further we discussed if the method is suitable to map habitat, plants or plant groups distribution, the quality of a defined area can be evaluated from visual interpretation and digital classification and lastly what spatial resolution is needed for visual interpretation and digital classification of vegetation in shallow coastal areas.

Method

Study area

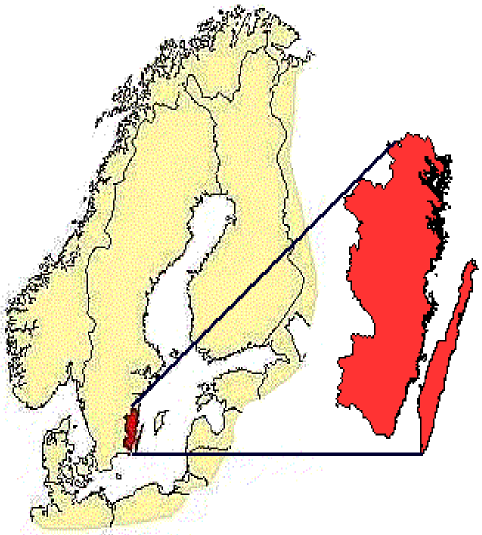

Fig. 1. The Baltic Sea and Kalmar Sound (blown up). The inventory area lies in the southernmost part of the sound.

The data from the study comes from a set of inventories in shallow bays along the coast of the municipality of Torsås, which is localised in the southern part of Kalmar Sound in the Baltic Sea, figure 1. The field-inventories of the coastal area have been performed in six sub-areas, table 1. The sub-areas are complex with several shallow bays within each of them. Totally 17 bays were investigated in the field and visually interpreted. The water quality of the coastal area is characterised by high nutrient concentration, both nitrogen (N) and phosphorus (P). Land-use in the catchments areas is dominated by agriculture (Dahlgren, 2003), which in combination with the strong regional eutrophication enhances primary production along the coast. The submerged vegetation in the studied bays are dominated by species favoured by eutrophication such as *Myriophyllum spicatum*, *Ceratophyllum demersum*, filamentous alga, mainly *Cladophora glomerata*, and mainly thin tube and sheet-like algae as *Enteromorpha* spp. and *Monostroma* spp. Other common species were *Najas marina*, *Potamogeton pectinaus*, *Potamogeton perfoliatus*, *Fucus vesiculosus*, *Ruppia* spp. Other species, i.e. *Zannichellia* spp., *Ranunculus baudoti*, *Zostera marina*, *Ceramium* spp., *Pilayella littoralis, Ectocarpus siliculosus* and *Chorda filum*, occurred but were not as common as the former once. During several years inhabitants in the area have noticed enhanced production of submerged vegetation, particularly filamentous and sheet-like algae and finely branched phanerogams, i.e. *Myriophyllum spicatum* and *Ceratophyllum demersum*. However, blooms of phytoplankton have not been observed along the coastline and Secchi-depth have since 1995 increased in the southern Kalmar Sound. The Secchi-depth reached the maximum depth, i.e. the bottom, in all investigated bays, and light was thus not limiting plant growth.

Table 1. Positions (RT90) for the sub-areas. The visual interpretation was performed on photographs from all sub-areas. Digital classification was performed on photographs from area 1-4.

No.	Sub-area	Coordinates		Visual interpretation	Digital classification
1	Örarevet	1519843	6257445	X	X
2	Ragnabo	1518323	6253727	X	X
3	Kitteln/Eneskärsviken	1517843	6252133	X	X
4	Ängaskär	1517412	6251421	X	X
5	Skäppevik	1517515	6249196	X	-
6	Södra Kärr	1515428	6244679	X	-

Data collection

The inventory was performed during the end of July, August and the beginning of September 2002 by snorkelling along transects perpendicular to the depth gradient down to 3 meters depth. The same area was photographed during two periods, i.e. July and August, and from three different heights, i.e. ca. 200, 350 and 600 m. The photographs were examined both by means of visual interpretation and digital classification. The interpretation has been concentrated on photographs from the lowest heights, i.e. 200 and 350 m, and the digital classification has been concentrated to four sub-areas, see Table 1. The visual interpretation is a subjective way of analysing the material and has only been used to investigate to what extent different taxonomical units can be defined and interpreted and to describe colour, height, texture, zone-structure for separable species. The definition of classes in the digital classification was done with the visual interpretation as a basis for the classification.

The submersed vegetation was inventoried by snorkelling along 2 m wide transect which were subjectively placed perpendicular to the shoreline and extending from the shoreline to the deepest area of the inventoried bays, i.e. about 3 m. In each transect the vegetation was divided into more or less homogenous vegetation-zones along a sinking line with 1 m markers. Within each zone the cover of species of the benthic macroflora, the sediment type, i.e. mud or sand, was recorded. The cover of each species was determined using a seven-graded scale, i.e. 0.1, 5, 10, 25, 50, 75 and 100 %. Within each zone the distribution along the markers was recorded. Between each zone depth was measured. In addition to the transect-inventory, the whole inventoried area was scanned from a small boat to find parts dominated by other plant species and other types of vegetative zones then found in the transects. In areas where parts with deviant vegetation were found reference plots, 2 X 2 m, were inventoried from boat. The end and beginning of the transects and the central point of the reference plots were geo-referenced with a 12 channel GPS, GARMIN 12 CX to (RT90). The bottom area colonised by emergent vegetation was not included in the inventory neither in the visual interpretation nor in the digital classification.

The aerial photographs were taken with a hand-held digital camera (Canon D60) with a 35 mm focal length lens from the side window of a small high-winged aircraft. The photographs were taken as vertically as possible and saved as jpeg-format. The camera had a fixed objective with a circular polarizing filter. Photographs were taken in July (020710) and August (020806) from ca. 200, 350 and 600 m height. This gives an approximate scale of 1:5700, 1:10 000 and 1:17 100 and a spatial resolution of approximately 0.04, 0.07, and 0.13 m/pixel, respectively The photographs were taken around noon, between 10.00-14.00, with the target area at approximately the same direction in relation to the sun. Optimum weather conditions with clear sky and weak winds prevailed when the photographs were taken.

Visual interpretation

The visual interpretation aimed to investigate at what time in the growth season aerial photographs preferably should be taken and to what depth visual interpretation, and digital classification, of aerial photographs could be used in shallow coastal areas of the Baltic Proper. It also aimed to describe the species from the aerial photographs focusing on their colour, height, texture, zone-structure and to compare discrepancy in cover, between estimated cover in field and estimated cover from photographs, with the purpose to discern which species could be uniquely described and which may be confused with each other. Both the early and the late photographs were used to describe the vegetation during the visual interpretation though the main effort was focused on late pictures. The estimation and comparison of plant cover between photographs and inventory data was performed on late photographs only.

Before the visual interpretation was done, pictures with too large photographic angel and sun glint were sorted out. The visual interpretation was performed on un-rectified photos directly on the screen, using ArcView, and revealed that interpretation and classification below 2 meters depth was of no or little value. Hence, further visual and digital analysis was concentrated to reference areas down to 2 m only. Differences between early (July) and late (August) photographs were only controlled visually. Inventory data was split and interpreted in two depth intervals, < 1 m and 1-2 m and two cover categories, ≤ 25 % cover and ≥ 50 % cover. From the inventory data, 517 spots differing in size between ca.1-4 m², with relatively clean stands of a single species were selected.

Digital classification

The photographs were rectified to RT90 in Idrisi32 to under-laying maps at the scale 1:10 000. The Swedish Land-use maps 4G0d1 and 4G1d1 were used. They were scanned and imported to Idris32. During the rectification the pixel size was changed to 1 m² per pixel.
The aerial photographs were split in three bands, red, green and blue and the classification was performed on pictures with all bands active. The rectified pictures were classified in ENVI 4.0 by a supervised maximum likelihood classification on all three bands: Totally 10 transects, on different pictures, were classified and evaluated. During the classification, parts (zones within transects and reference plots) were used as calibration data in the supervised classification while other parts, all pixels (1 m²) in homogenous zones or selected pixels with known reference data in miscellaneous zones, were used as validation data to assess the result.

The transects and reference plots shape files were adjusted to the rectified aerial photographs in ArcView where the classification results were compared with validation data. To meet the questions asked the vegetation were post priori divided into categories. The accuracy of the classification was first tested on different taxonomic levels to find a level that visually would predict vegetation with an acceptable accuracy. As a result the submerged macrophytes were classified into 7 categories (Level 1, below). To further improve the accuracy of the classification the categories in Level 1 was reduced, added together, to three and two categories at Level 2 and Level 3. The subdivision into different levels was designed to test how much taxonomic information it was possible to extract by analysing the photographs and to see if it was possible to extract sufficient information to evaluate the quality and the vegetative state of the inventory areas, according to Dahlgren & Kautsky (2004). The corresponding result from the classification is presented and evaluated in an error matrix.

Level 1:
Category 1) Bare bottom, sand.
Category 2) Bare bottom, mud, ≤ 25 % plant cover.
Category 3) Dense filamentous algae, ≥ 50 %.
Category 4) Thin sheet-like algae.
Category 5) *Najas marina*, ≥ 50 % cover.
Category 6) Mixed stands of phanerogams, ≥ 50 % cover.
Category 7) *Fucus vesiculosus,* ≥ 50 % cover.

Level 2:
Category 1) Bare Bottom, sand and mud, ≤ 25 % plant cover.
Category 2) Dense filamentous algae, ≥ 50 % cover, thin sheet-like algae, i.e. *Enteromorpha* spp. and *Monostroma* spp, included.
Category 3) Mixed stand of phanerogams, *Najas marina* and *Fucus vesiculosus* included, ≥ 50 % cover.

Level 3:
Category 1) Bare Bottom, sand and mud, ≤ 25 % plant cover.
Category 2) Vegetated bottom, ≥ 50 % cover.

Results and discussion

Visual interpretation

A comparison between early (July) and late (August) photographs showed that the cover of the vegetation was less legible on the early pictures then on the late. Large species and perennials, e.g. *Potamogeton* spp. and *Fucus vesiculosus*, appeared clearer in the early pictures due to lower abundance of covering filamentous and sheet-like algae in July than in August. Plant cover, for all species, was obviously lower in the early photographs than in the late and in the field data and the transparency in the water were slightly better in July compared to August. The main effort in this project has been focused on the submersed vegetation. Though, the distribution of the emers vegetation seems to be easily interpreted visually and probably also digitally. Only three emers species occurred in the inventoried area, i.e. *Phragmites australis*, *Scirpus maritimus* and *Scirpus tabernaemontani*. *P. australis* can visually be separated from the two other species. The two *Scirpus* species seems not to be easily separated from each other though.

Common species in the inventory area, which could be marked off as clean stands from its surroundings, were (1) *Ceratophyllum demersum*, (2) *Chaetomorpha* spp., (3) *Chara* spp., (4) *Cladophora* spp., (5) *Enteromorpha* spp., (6) *Fucus vesiculosus*, (7) *Monostroma* spp., (8) *Myriophyllum spicatum*, (9) *Najas marina*, (10), *Potamogeton pectinatus*, (11) *Potamogeton perfoliatus*, (12) *Ruppia* spp., (13) *Vaucheria* spp. Numbers within parenthesis refer to the species number in Table 5. The descriptive result from the visual interpretation is presented in Table 5.

In Table 5, the interpreted species are described according to their texture, height, zone-structure and to their discrepancy in cover, between estimated cover in field and estimated cover from photographs. Texture describes the granularity of the different species in the photographs and is estimated in the categories, smooth, grainy and ball-like, where ball-like means larger granularity then is described by grains. Height describes if the species gives a flat or elevated impression in the photographs.

The zone-structure describes if the species grow in small spatially dispersed patches (Patchy), form a patchy zone or homogenous coherent zone. The discrepancy in cover is the result from the comparison between estimated cover from the photographs and estimated cover in field. The discrepancy is shown as the divergence in scale step in the seven graded cover scale, see data collection in methods.

Other species then those presented in Table 5, i.e. *Zannichellia* spp., *Ranunculus baudoti*, *Zostera marina*, *Ceramium* spp., *Pilayella littoralis, Ectocarpus siliculosus* and *Chorda filum* and other filamentous algae, were abundant in the inventory area but occurred with very low cover, ≤ 5 %, or were growing intermingled in stands dominated by other plants and have therefore not been included in the visual interpretation or the digital classification.

The large phanerogams and *Najas marina* and *Fucus vesiculosus* produce a more or less elevated and grainy to ball-like texture and are dark brown to green or red in colour. Among those species *Najas marina*, and sometimes *Fucus vesiculosus*, have a strong red hue in contrast to the others, while *Potamogeton pectinatus*, *P. perfoliatus* and *Ceratophyllum demersum* often have an olive-green hue while *Myriophyllum spicatum* mostly are darker then the other species. The small *Ruppia* spp. often grow at sandy, slightly exposed sites and form a zone between 0.2-0.5 m depth with a dark brown to grey hue.

Among these species *Najas marina* and *F. vesiculosus* may be confused with each other, (Table 5). Further, *F. vesiculosus* could also be mistaken for *C. demersum* due to both their ball-like texture and an overlap in colour. *Chara* spp., only one zone, looked also rather dark with a red hue in the aerial pictures but was both smooth and flat in texture. The filamentous algae *Cladophora* spp. and *Chaetomorpha* spp. were both bright green to yellow in color and smooth and flat in texture. The filamentous algae could be separated from the other phanerogams and algae but not from each other. The two sheet-like species *Enteromorpha* spp. and *Monostroma* spp. were bright green like the filamentous algae but with a darker green colour. Attached *Enteromorpha* spp. that reached above the water surface had a yellow colour and could not be visually separated from floating filamentous alga. The only filamentous algae that could be separated from the other filamentous algae were *Vaucheria* spp., which had a dark green colour and a flat and smooth to grainy surface in the photographs.

Table 5. Descriptive results from the visual classification, describing colour, texture, height, zone-structure and discrepancy in cover for interpreted plants at different depth and cover. See text above for further description. * = green algal mats dominated by *Cladophora* spp. but including other filamentous green algae.

No.	Depth (m)	Cover	Colour	Texture	Height	Zone-structure	Discrepancy in cover
1	0-1	50-100	Dark green to brown, with a red hue	Ball-like	Elevated	Homogenous zone	0
1	0-1	25	Dark green to brown	Smooth to ball-like	Feeble elevated	Patchy	+ - 1 scale step
1	1-2	25	Dark green	Smooth to ball-like	Flat	Patchy	+ - 1 scale step
2	0-2	25-100	Yellow to bright green	Smooth	Flat	Homogenous zone	0
3	0-1	75-100	Dark brown, with a red hue	Smooth	Flat	Homogenous zone	0
4*	0-1	50-100	Bright green to yellowish green	Smooth	Flat	Partly patchy to homogenous zone	0
4*	0-1	25	Bright green to yellowish green	Smooth	Flat	Patchy zone	0
4*	1-2	50-100	Bright green to yellowish green	Smooth	Flat	Homogenous zone	0
4*	1-2	25	Bright green	Smooth	Flat	Homogenous zone	0
5	0-1	50-100	Dark bright green to yellowish green	Grainy	Flat to elevated	Patchy to homogenous zone	0
6	0-1	50-100	Dark green- brown to dark red-brown	Smooth to ball-like	Flat to elevated	Patchy to homogenous zone	0 to + - 1 scale step
6	0-1	25	Dark grey-brown	Smooth to grainy	Flat	Patchy zone	0
6	1-2	50	Dark red-brown	Smooth to grainy	Flat	Patchy to homogenous zone	0 to + - 1 scale step
7	0-2	50-100	Dark bright green	Smooth	Flat	Homogenous zone	0
8	0-1	50-100	Dark to dark dark brown	Grainy to ball-like	Elevated	Patchy to homogenous zone	0 to + - 1 scale step
8	0-1	25	Dark to dark dark brown	Grainy to ball-like	Elevated	Patchy to homogenous zone	0 to + - 1 scale step
8	0-2	50-100	Dark brown	Grainy to ball-like	Elevated	Homogenous zone	0 to + - 1 scale step
8	0-1	50-100	Dark brown	Grainy to ball-like	Smooth	Patchy to homogenous zone	+ 1 scale step
9	0-1	50-100	Dark red to red brown	Grainy or small balls	Elevated	Patchy to homogenous zone	0
9	0-1	25	Dark red to red brown	Smooth	Flat	Patchy zone	- 1 scale step
10	0-1	50-100	Dark olive-green	Grainy	Elevated	Patchy to homogenous zone	0 to - 1 scale step
10	0-1	25	Olive-green with a grey hue	Grainy	Elevated	Patchy zone	0
10	1-2	50-100	Dark olive-green	Grainy	Elevated	Patchy to homogenous zone	+ - 1 scale step
10	1-2	25	Olive-green with a grey hue	Grainy	Elevated	Patchy zone	0 to - 1 scale step
11	1-2	50-100	Dark olive-green	Grainy	Elevated	Patchy to homogenous zone	0 to - 1 scale step
12	0-1	50-100	Dark brown to grey	Grainy	Flat	Homogenous zone	0 to - 1 scale step
12	0-1	25	Dark brown to grey	Grainy	Flat	Homogenous zone	0
13.	0-1	50-100	Black-green	Smooth to grainy	Flat	Homogenous zone	0

Digital classification

The accuracy of the classification was first tested on different taxonomic levels to find a level that visually would predict vegetation with an acceptable accuracy. As a result of the digital classification the submerged macrophytes were classified into 7 categories (Level 1, Table 2). The prediction accuracy of Level 1 was tested against data from the diving transects (Ground truth data), Table 2. To further improve the accuracy of the classification the categories in Level 1 was reduced, added together, to three and two categories at Level 2 and Level 3, respectively.

The seven categories are composed of two categories of bare bottom, three categories with more than one species within the categories and two categories composed of only one species in each category. Sandy bottoms (Bare bottom, sand) occurred very shallow, mainly only down to 0.5 m, in slightly exposed sites where the finer sediments was washed out by wave-action. Areas with sand bottom generally lacked filamentous algae or other vegetation. In some zones attached *Cladophora* spp. or *Ceramium* spp. occurred sparsely, ≤ 5 %, on the sand. Muddy bottoms, category 2 (Bare bottom, mud, ≤ 25 % plant cover), were in the eutrophicated investigation area the most common bottom substrate. The muddy bottoms consisted mainly of organic matter and had generally a layer of un-decomposed organic matter, which made it difficult to separate them from areas with low cover, 10-25 %, of filamentous algae. In the classification bare mud bottoms had to be separated in two depth categories, 1 and 2 m, which were added together in the evaluation. The majority of areas classified as bare mud-bottom consisted of ≤ 10 % filamentous algae. Some zones, classified as bare mud-bottom, had up to 25 % cover of vegetation although.

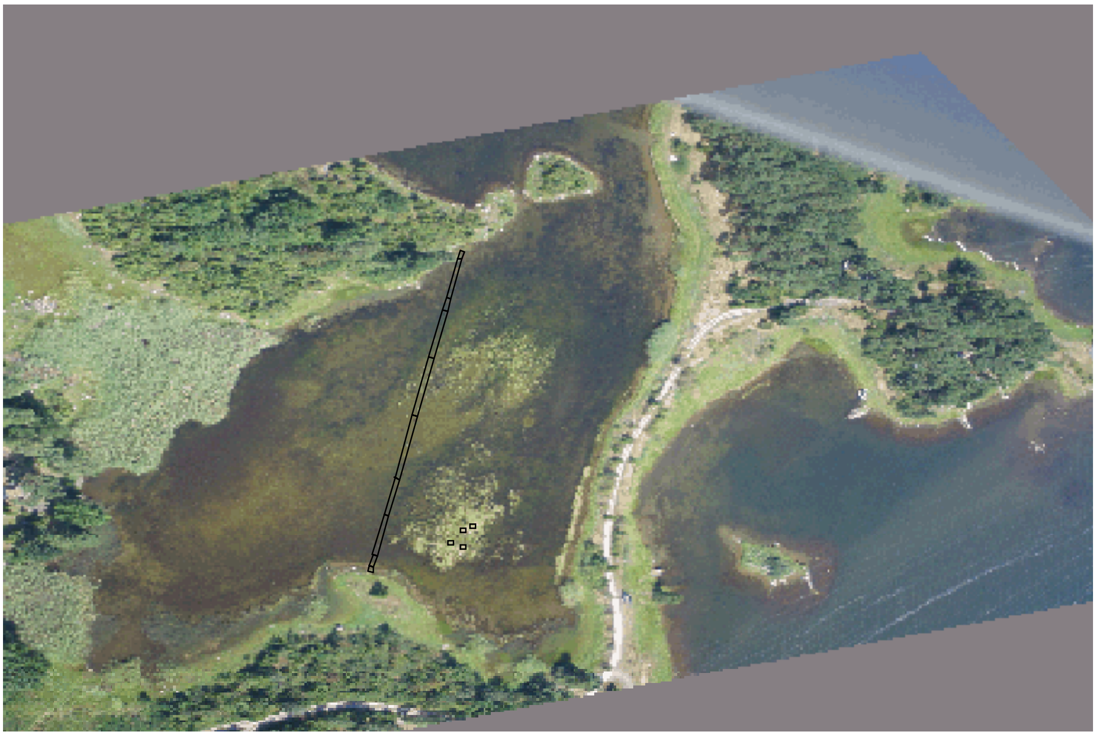

Fig. 2. Kitteln, one of the inventoried and interpreted bays with transect and reference plots. Dense stand of emers, mainly reed, vegetation dominates the inner (left) part of the bay with dense stand of *Najas marina* connecting to the reed-belt. In the central part of the bay mats of epiphytic green algae dominates and on the right side of the inventory transect the algal mat reach above the water surface. In the bay opening and to the right of the algal mat mixed stands of phanerogams prevail, mainly *Myriophyllum* spicatum and *Potamogeton pectinatus*. On sandy bottom in the opening also *Ruppia* spp. occur.

Dense mats of filamentous algae, category 3 (Dense filamentous algae, ≥ 50 % cover), dominated large parts of the inventoried areas *Cladophora* spp. and *Chaetomorpha* spp. were the most common species but other uniserat green algae occurred in the green algal mats. The brown filamentous algae, *Pilayella littoralis* and/or *Ectocarpus siliculosos* occurred also but were not very common. The red algae *Ceramium* spp. was uncommon but occurred sparsely, ≤ 5 % cover, as epiphyte on *Fucus vesiculosus* and in the areas with sandy substrate. Dense mats of filamentous algae were growing epiphytic on stands of phanerogams. In some areas, parts of these mats reached above, and covered, the water surface. Areas with mats covering the water surface and very shallow and dense stands of *Enteromorpha* spp. that reached the surface was classified separately and added to the dens filamentous algae category or to category 4, Fig. 1 and 2.

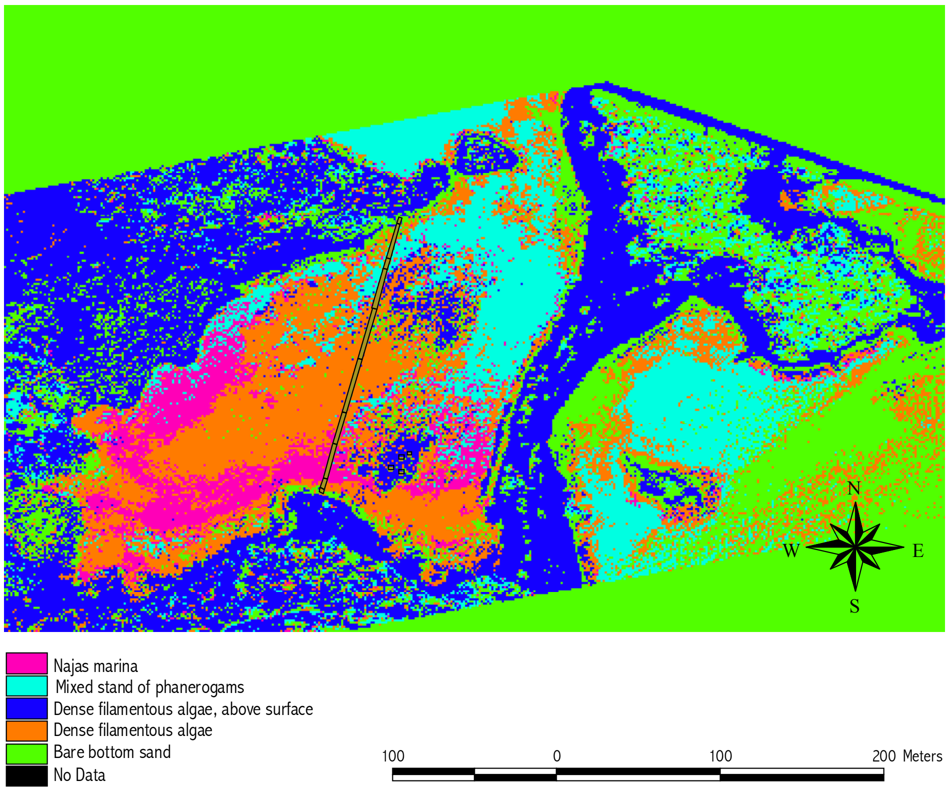

Fig. 3. A classified aerial photograph of the bay, Kitteln. The dense stand of *Najas marina* is, as well as the dense filamentous alga zone and the mixed stands of phanerogams, well defined and delimited, compare with Fig. 2. Land areas and dense filamentous algae above surface have been classed together in the picture.

Thin sheet-like algae, category 4 (Thin sheet-like algae, ≥ 50 % cover), consist of submersed *Enteromorpha* spp. and *Monostroma* spp. Large sheets of epiphytic *Monostroma* spp. covered *Fucus vesiculosus* and the dense filamentous algal mats. *Najas marina*, category 5, (*Najas marina*, ≥ 50 % cover), is together with *Fucus vesiculosus* the only classification group that consists of only one species. *Najas marina* grows very shallow, between 0-0.75 m, in dense stands, ≥ 50 % cover, in the most sheltered sites in the inventory area, as in the area Kitteln (Fig. 2 and 3). Category 6, (Mixed stands of phanerogams, ≥ 50 % cover), consist of several species, i.e. *Myriophyllum spicatum*, *Ceratophyllum demersum*, *Potamogeton pectinatus*, *Potamogeton perfoliatus*, *Zannichellia palustris* and *Ruppia* spp.

Classifications of single species or groups of species within the category mixed stands of phanerogams were tested initially. However, the predicting accuracy was low and finally all those species had to be grouped together. The distribution of the species in the category varied spatially with *M. spicatum*, *C. demersum* and *Potamogeton perfoliatus* mainly occurring in open areas, between 0.50-2 m, while *Ruppia* spp. commonly occurred shallower, between 0-0.75 m. The other single species category, category 7, (*Fucus vesiculosus*, ≥ 50 % cover), consist mainly of small, 20 X 20 cm, free-floating *Fucus*-balls which form mats or zones on the muddy substrate in the inventoried area. *Fucus vesiculosus* occurred from the shallowest shoreline down to 2 m in the diving transects. Near the shoreline some of the *F. vesiculosus* plants were growing attached to stones.

Table 2. The table shows result from the classification of the seven categories in Level 1, see text above. Rows shows the predicted results (in 1 m² pixels) and totals for the categories in the classification. The columns show ground truth data and correctly predicted number of pixels for each category and the total number of pixels for each category in ground truth data. The right column shows percentage correct predicted pixels of totally predicted pixels for each category, user's accuracy. The bottom row shows percentage correct pixels of the total number of pixels in ground truth data, producer's accuracy.

Categories	Ground truth data								
	1) Bare bottom, sand.	2) Bare bottom, mud, ≤ 25 % plant cover.	3) Dense filamentous algae, ≥ 50 % cover.	4) *Enteromorpha* spp. and *Monostroma* spp., ≥ 50 % cover.	5) *Najas marina* ≥ 50 % cover.	6) Mixed stands of phanerogams, ≥ 50 %	7) *Fucus vesiculosus*, ≥ 50 % cover.	Total	User's accuracy in %
1) Bare bottom, sand.	56	22	17	0	3	1	1	100	56
2) Bare bottom, mud, ≥ 25 % cover plant cover.	0	252	6	3	13	18	13	305	83
3) Dense filamentous algae, ≥ 50 % cover.	13	9	657	0	11	52	8	750	88
4) *Enteromorpha* spp. and *Monostroma* spp, ≥ 50 % cover	0	4	6	8	0	0	2	20	40
5) *Najas marina* ≥ 50 % cover.	2	5	12	0	299	0	0	318	94
6) Mixed stands of phanerogams, ≥ 50 % cover.	14	51	44	8	5	535	85	742	72
7) *Fucus vesiculosus*, ≥ 50 % cover.	0	2	17	0	0	6	110	135	81
Total	85	345	759	19	331	612	219	2370	-
Producers' accuracy in %	66	73	87	42	90	87	50	-	72

The overall classification accuracy for Level 1 was 72 % (Table 2). The right column shows percentage correct predicted pixels of totally predicted pixels for each category, user's accuracy. The bottom row shows percentage correct pixels of the total number of pixels in ground truth data, producer's accuracy. The best producer's accuracy, of the classification in Level 1, had category 5, 3 and 6, (i.e. *Najas marina*, ≥ 50 % cover, Dense filamentous algae, ≥ 50 % cover and Mixed stands of phanerogams, ≥ 50 % cover). *Najas marina* occurred in dense "single species" stands, which made it easy to define the *Najas marina* category in the interpretation of the digital photographs. The grouped category 6 (Mixed stands of phanerogams, ≥ 50 %) could also easily be defined but had a spectral resonance similar to category 7 (*Fucus vesiculosus*, ≥ 50 % cover) which lowered the producer's accuracy to 50 % for category 7 and the user's accuracy to 72 % for category 6. The lowest producer's accuracy, at Level 1, had the category 1 (bare sand bottom), category 4 (Thin sheet-like algae) and category 7 (*Fucus vesiculosus)*. The sandy sites occurred only at the most shallow and exposed sites near the shoreline. The zones were very narrow, with a maximum of a few meters. *Monostroma* spp. in category 4, was randomly distributed in the diving transects and often occurred growing in small spots, 1 m². Both small narrow zones and randomly distributed species are very sensitive to small displacement and error in positioning, which probably explains the low classification accuracy of these two classes, i.e. category 1 and 4. The other categories occurred in more or less well defined and homogenous zones and were therefore not as sensitive to small positioning error. The low producer's accuracy for category 7, (*Fucus vesiculosus*, ≥ 50 % cover), i.e. only 50 % of ground truth data was classified as category 7, see Table 2, is explained by a high similarity with category 6 (Mixed stands of phanerogams, ≥ 50 % cover). Almost 40 % of inventoried *F. vesiculosus* were classified to category 6, probably due to similarities in colour.

Table 3. The table shows the results after reducing the seven categories in Level 1 to three categories, Bare bottom, mud, ≤ 25 % plant cover, Dense filamentous algae, Thin sheet-like algae included, ≥ 50 % cover and Mixed stands of phanerogams, *Fucus vesiculosus* and *Najas marina* included. ≥ 50 % cover. (Level 2). Rows shows the predicted results (in 1 m² pixels) and totals for the categories in the classification. Columns show ground truth data and correctly predicted number of pixels for each category and the total number of pixels for each category in ground truth data. The right column shows percentage correct predicted pixels of totally predicted pixels for each category, user's accuracy. The bottom row shows percentage correct pixels of the total number of pixels in ground truth data, producer's accuracy.

Categories	Ground truth data				
	1) Bare bottom, sand and mud, ≤ 25 % plant cover.	2) Dense filamentous algae, Thin sheet-like algae included, ≥ 50 %.	3) Mixed stands of phanerogams, *Fucus* spp. and *Najas marina* included. ≥ 50 % cover.	Total	User's accuracy in %
1) Bare bottom, sand and mud, ≤ 25 % plant cover.	330	26	49	405	81
2) Dense filamentous algae, Thin sheet-like algae included, ≥ 50 % cover.	26	671	73	770	87
3) Mixed stands of phanerogams, *Fucus* spp. and *Najas marina* included. ≥ 50 % cover.	74	81	1040	1195	87
Total	430	778	1162	2370	-
Producers' accuracy in %	77	86	90	-	85

Thus, to test if the classification accuracy could be further improved, the seven categories were reduced to three categories in Level 2, Bare bottom, sand and mud, ≤ 25 % plant cover (category 1), Dense filamentous algae, thin sheet-like algae included, ≥ 50 % cover (category 2) and Mixed stands of phanerogams, *Fucus vesiculosus* and *Najas marina* included, ≥ 50 % cover, and to two categories in Level 3, Bare bottom, sand and mud, ≤ 25 % (category 1) and Vegetated areas, ≥ 50 % (category 2).

The total accuracy improved from 72 %, Level 1, to 85 % and 87 %, at Level 2 and 3 respectively. At Level 2, both vegetated categories have a producer's and user's accuracy above 85 % while the combined mud and sand category only amount to 77 %, producer's accuracy, and have an user's accuracy of 81 %, Table 3. At Level 3, the category Vegetated areas, ≥ 50 % cover, have a producer's accuracy of 96 % and a user’s accuracy of 95 %, Table 4.

Table 4. The table shows the results after adding the seven categories in Level 1 to two categories, Bare bottom, mud, ≤ 25 % plant cover and Vegetated areas, ≥ 50 % cover (Level 3). Rows shows the predicted results (1 m² pixels) and totals for the categories in the classification. Columns show ground truth data and correctly predicted number of pixels for each category and the total number of pixels for each category in ground truth data. The right column shows percentage correct predicted pixels of totally predicted pixels for each category, user’s accuracy. The bottom row shows percentage correct pixels of the total number of pixels in ground truth data, producer’s accuracy.

Categories	Ground truth data			
	1) Bare bottom, sand and mud, ≤ 25 % plant cover.	2) Vegetated areas, ≥ 50 % cover.	Total	User’s accuracy in %
1) Bare bottom, sand and mud, ≤ 25 % plant cover.	330	75	405	81
2) Vegetated areas, ≥ 50 % cover.	100	1865	1965	95
Total	430	1940	2370	-
Producers’ accuracy in %	77	96	-	87

Method proposal

Several issues when photographing and interpreting submersed vegetation from air are of great importance for the result. The date of time for photographing is essential for the result and the photographs should be taken in late July or August when the submersed vegetation reaches maximum cover. Later in the autumn many filamentous species have an extensive growth period and rooted phanerogams and macroalgae could thus be covered and not detectable on aerial photographs. Sunny and calm weather is a prerequisite and all photographs should be taken in approximately the same angle in relation to sun. The angel towards the ground is also essential for the digital classification. Many of the photographs in this project could only be used in the visual interpretation and not in the classification due to oblique view, which create difficulties in the rectification process. Photographs with waves and sun glints were also rejected before analysis. The photographs should preferably be taken from ca. 350 m, or slightly higher, and either taken in a straight line or with focuses on well-defined objects. Photographs taken lower then 350 m could also be used but the photographed area would be smaller and the digital part of the working process would thus be more time consuming then necessary. Photographs taken much higher then 350 m may lose important information.

Ground truth data, field inventories, should be performed after a survey of the variations in the photographs and reference plots, 2 x 2 or 3 x 3 m, could be sampled from boat in an advanced planned rout. Validation data must be collected for each object involved but can this way be collected to a lower cost. More information then used in the classification can be collected if needed. A thorough geo-positioning in field is also highly important when assessing the result and small errors in geo-positioning in this investigation probably explain some of the errors in the classification. A weakness using large reference plots is that species or groups of species intermingled spatially with each other, which force the classification to be performed on groups involving several species or demand large areas of homogenous zones.

During just a few hours, 17 objects, varying in size from 5 – 30 ha, within a total area of ca. 6 km² was scanned and photographed from air. This was done twice and the cost for each flight was 25 000 SEK, photographing included. Field inventory could, according to the method proposed, cover about 10 ha per hour, transport between objects not included. If photographs are taken with a digital camera the work with scanning maps, rectifying and adjusting photos and perform a supervised classification would approximately take approximately 1 hour per ha or about 3 hours per photograph (ca. 3.5 ha), taken with 35 mm lens from 350 m, scanning of land-use maps included. An initial start-up week is probably needed before the classification work is running smoothly. Time for analysis and evaluation, which could differ due to the nature of the assignment, must also be taken under consideration.

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