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Using aerial photography for identification of marine and coastal habitats under the EU's Habitats Directive

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ABSTRACT

1. Implementation of the E.U. Habitats Directive requires information on the distribution, abundance and area covered by the habitats listed in Annex I of the Directive.

2. In Finland, 21 of these habitats occur in marine and coastal areas. The demand for spatial information of these habitats is increasing, so rapid and relatively inexpensive mapping methods are needed.

3. This study examines the identification of 15 habitats using high altitude black and white aerial photographs. Our goal was to find out how well these habitats could be identified using these types of photographs. We used a test group of 34 persons who were given only brief instructions on how to identify the habitats prior to the test. Their results were compared to a set of field data from an archipelago area at the entrance of the Gulf of Finland, in August 1999 and autumn 2000.

4. The test group identified sandy beaches, lagoons, submerged sandbanks and cliffs with an accuracy of 82%, 71%, 66% and 65%, respectively. The main reasons for these high accuracy percentages were apparently the high contrast and/or easy delineation of the habitat from the surrounding areas.

5. Reefs, wooded dunes and submerged reefs were identified with an accuracy of 39%, 44% and 45%, respectively. The remaining habitats were less precisely identified, apparently due to their small size or poor contrast to the surrounding areas.

6. High altitude aerial photographs are shown to be a useful tool for identifying several of these habitats and can be used as a complement to field mapping methods, GIS methods and other remote sensing techniques. The use of high altitude photographs for monitoring change is discussed.

KEY WORDS: aerial photography; Baltic Sea; coastal; EU; Habitats Directive

INTRODUCTION

Marine and coastal habitats are continuing to deteriorate, and an increasing number of wild species are seriously threatened. As part of EU conservation efforts, many of these habitats are included in the list of habitats in Annex I of the Habitats Directive (Anon., 1992). These habitat types represent a broad range of

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biological features, characterized by several biotopes or community types (Airaksinen and Karttunen, 1998; Anon, 1999). One of the main aims of the Habitats Directive is to preserve these habitats, yet in order to do so it is important to know their distribution, abundance, cover, as well as changes taking place. These objectives are difficult to achieve for all 21 Annex I marine and coastal habitat types in Finland (Table 1) due to the geomorphology and environmental conditions of the coastal areas. Finland has one of the longest coastlines in Europe, with more than 45 000 km of fragmented shoreline and large archipelagos comprising more than 94 000 islands and skerries (calculated by the vector shoreline data of the 1:20 000 base map of Finland). Field mapping of the entire shoreline would consequently be very time consuming. The Finnish coastal waters can be turbid, with Secchi depths commonly a few metres or less, rarely 5–10 m, thus making mapping of sub-surface features difficult (Kirkkala, 1998; Erkkilä and Kirkkala, 2000). Furthermore, due to cold winters with ice cover the period available for field surveys is short. An additional problem arises from the great variety in size and shape of the 21 marine and coastal Annex I habitats

Table 1. The Coastal habitat types of Annex I of the Habitats Directive found in Finland (Anon., 1992)

Annex I. Number	Coastal habitat type occurring in Finland	Short name used in this study	Included in this study?	Type aquatic = A terrestrial = T both = AT
11	Open sea and tidal areas			
1110	Sandbanks which are slightly covered by sea water all the time	Sandbanks	YES	A
1130	Estuaries		NO	A
1150*	Coastal lagoons	Lagoons	YES	A
1160	Large shallow inlets and bays	Shallow bays	YES	A
1170	Reefs	Reefs	YES	A
12	Sea cliffs and shingle or stony beaches			
1210	Annual vegetation of drift lines	Driftlines	YES	T
1220	Perennial vegetation of stony banks	Stony banks	YES	T
1230	Vegetated sea cliffs of the Atlantic and Baltic Coasts	Cliffs	YES	T
16	Boreal Baltic archipelago, coastal and landupheaval areas			
1610	Baltic esker islands with sandy, rocky and shingle beach vegetation and sublittoral vegetation		NO	AT
				AT
1620	Boreal Baltic islets and small islands	Islets	YES	AT
1630*	Boreal Baltic coastal meadows	Coastal meadows	YES	T
1640	Boreal Baltic sandy beaches with perennial vegetation	Sandy beaches	YES	T
1650	Boreal Baltic narrow inlets		NO	A
21	Sea dunes of the Atlantic, North Sea and Baltic coasts			
2110	Embryonic shifting dunes	Embryonic dunes	YES	T
2120	Shifting dunes along the shoreline with Ammophilia arenaria (white dunes)	White dunes	YES	T
2130	Fixed coastal dunes with herbaceous vegetation (grey dunes)	Grey dunes	YES	T
2140	Decalcified fixed dunes with Empetrum nigrum		NO	T
2180	Wooded dunes of the Atlantic, Continental and Boreal region	Wooded dunes	YES	T
2190	Humid Dune slacs		NO	T
2320	Dry sand heaths with Calluna and Empetrum nigrum		NO	T
9030	Natural forests of primary succession stages of land upheaval coast	Primary forests	YES	T

occurring in Finland. For example, the smallest of these habitat types, annual vegetation of drift lines, is a variable linear feature commonly less than one metre wide while the boreal Baltic narrow inlets, may cover up to several square kilometres.

Remote sensing methods are generally acknowledged as effective tools for rapid large-scale mapping (Table 2) and, together with geographic information systems (GIS), are known for their suitability in managing, analysing and presenting large amounts of geo-referenced information that simultaneously need to be taken into account (Lillesand and Kiefer, 1994; Miller, 1994; Phinn *et al.*, 2000; Nagendra, 2001). Remote sensing techniques have also proven their suitability in mapping water quality and land cover in marine and coastal areas (Lehmann and Lachavanne, 1997; Cracknell, 1999). When focusing specifically on habitat mapping there is a wide variety of options when choosing a remote sensing technique for the task (Table 2). For example, numeric data from satellites tend to be too coarse-grained to detect details (Kalliola and Syrjänen, 1991). Airborne radar and microwave sensing systems also seem unsuitable for identifying and delineating the habitat types we want to map (Singh *et al.*, 1990; Dammert *et al.*, 1998; Jones and Mitchelson-Jacob, 1998; Trivero *et al.,* 1998; Espedal and Johannesen, 2000).

The ground resolution of aerial photographs make them the best remote sensing data source for mapping coastal habitats in Finland, considering the size and the richness of detail in the Finnish coastline and the size variation of the habitats to be mapped. When also considering image availability, coverage, frequency by which areas are re-photographed as well as availability of old data (dating back to the 1960s) high altitude black and white photographs are likely to be the first choice of environmental officials for extensive large-scale mapping of the Habitats Directive Annex I marine and coastal habitats in Finland. No other type of aerial images readily available in Finland match all these criteria. However, before applying high altitude photographs for extensive national scale mapping the accuracy by which these habitats can be identified should be determined.

The aim of this study is to find out how useful and reliable high altitude aerial photographs are for identifying and mapping the marine and coastal Habitats Directive Annex I habitat types in Finland. We evaluated the reliability of the identification using a test group of researchers, environmental administrators and students in physical geography.

METHODS

Study area

Suitable areas for this study were found at the entrance of the Gulf of Finland, in the Ekenäs archipelago and the Hanko peninsula (Figure 1).

A set of five photographs from five archipelago areas that included 15 habitat types were analysed (Table 1, Figure 2). The area in photograph 1 (Figure 2) is predominantly a sandy moraine spit with gently sloping shores and a small dune area (Hanko Tulliniemi Lat. 59°49′; Long. 22°55′). The areas in photographs 2, 3 and 5 (Figure 2) include a dense group of small low islands in the outer archipelago, dominated by stony and rocky shores (Ekenäs archipelago, Lat. 59°51′; Long. 23°30′). Of these three photographs, area 3 is the most exposed to wave and wind action, and the area 5 the most sheltered. The area shown in photograph 4 (Figure 2) consists mainly of gently sloping sandy moraine shores sheltered only by a few skerries (Täktom Vedagrundet Lat. 59°50′; Long. 23°08′).

The six habitats not covered by these photographs included the three largest habitat types, 1130 (estuaries), 1610 (Baltic esker islands with sandy, rocky and shingle beach vegetation and sublittoral vegetation), 1650 (boreal Baltic narrow inlets) and three of the dune types, 2140* (decalcified fixed dunes with *Empetrum nigrum*), 2190 (humid dune slacks) and 2320 (dry sand heaths).

Table 2. Remote sensing techniques used for mapping marine, coastal, estuarine or river habitats.

Sensors and techniques	Advantages (+) and disadvantages (−) for mapping marine and coastal habitats	Reference
Satellite panchromatic and multispectral sensors with very high or high resolution, e.g. IKONOS	+ Area covered/time unit larger than for most airborne or acoustic techniques + Good spatial resolution, + Multispectral data make ground and vegetation discrimination possible + Data always numeric (digital) − Image price/area covered usually higher than for other satellite sensors − Clouds may mask a part of the image − Large numeric data-sets per area covered − The image analysis require special skills e.g. for atmospheric correction and classification	we did not find any reference on the use of these sensors for mapping marine and coastal areas. A similar result was reported by Cracknell (1999).
Satellite panchromatic and multispectral sensors with high or medium high resolution	+ Area covered/time unit larger than for airborne or acoustic techniques + Data always numeric (digital) + Multispectral data make ground and vegetation discrimination possible − Too crude of delineation of small habitat patches − Poor image resolution for identification of marine and coastal habitats, − Clouds may mask a part of the image − The image analysis require special skills e.g. for atmospheric correction and classification	Kalliola and Syrjänen (1991), Kuittinen *et al*. (1991), Guillaumont *et al.* (1993), Lavery *et al.* (1993), Long and Skewes (1996), Ferguson and Korfmacher (1997), Henderson *et al.* (1999), Erkkilä and Kirkkala, 2000
Airborne multispectral sensors	+ Area covered/time unit larger than for most airborne or acoustic techniques + Spatial resolution better than for satellite sensors, + Data always numeric (digital) + Multispectral data make ground and vegetation discrimination possible − Image price/area covered high compared to other airborne techniques − Large numeric data-sets per area covered − The image analysis require special skills e.g. for managing spectral data and classification	Zacharias *et al.* (1992), Malthus and George (1997), Althuis (1998), Wernand *et al.* (1998), Alberotanza *et al.* (1999)
Aerial multispectral videography	Pro's and con's same as for the previous one but with additional difficulties in rectifying image	Niedrauer (1991)

Table 2 (*continued*)

Sensors and techniques	Advantages (+) and disadvantages (−) for mapping marine and coastal habitats	Reference
Aerial panchromatic colour or black and white videography	Pro's and con's same as for the previous but with additional difficulties in rectifying images	Jennings *et al.* (1992), Estep *et al.* (1994), Eleveld *et al.* (2000)
Aerial black and white photography	+ Images available from the coastal areas of Finland (high altitude images taken every 2–4 years, low altitude images less frequently) + Good image resolving power (for numerical data good spatial resolution) + Used successfully for decades, mainly for mapping of terrestrial habitats + Image analysis easy (visual interpretation), expensive equipment not required + Photographic series dating back several decades are available − Computer aided image analysis difficult compared to spectral data − Loss of resolution may take place when converting data to numerical form	Estep *et al.* (1994), Ward *et al.* (1997)
Aerial colour infrared photography	Same as for the previous one but with the following exceptions: + The colour IR give enhanced possibilities to identify and outline the vegetation cover − Photographs from coastal areas are relatively scarce in Finland	
Aerial colour photography	Same as for aerial black and white photographs but with the following exceptions: + The colour give enhanced possibilities to identify and outline the vegetation cover − Photographs from coastal areas are very uncommon in Finland	Nyquist (1979), Raal and Burns (1996), Robbins (1997)
Accoustic mapping of sublittoral areas	+ Spatial resolution sufficient for habitat mapping	Fortin *et al.* (1993), Donnan and Davies (1996), Greenstreet *et al.* (1997), Sotheran *et al.* (1997), Downie *et al.* (1999)
	+ Deep areas can be mapped relatively rapidly − Difficult to apply in areas where the borders between patches are unclear − Require ground truthing by sampling or visual interpretation (divers, camera) − The image analysis require special skills and expensive equipment	
Field mapping (Aquatic, benthic or terrestrial) including underwater photography techniques	A compulsory part of remote sensing!	Norris *et al.* (1997), Riegl and Piller (2000)
	+ 'Spatial resolution' superior i.e. the identifiable objects very small (< cm)	

Table 2 (*continued*)

Sensors and techniques	Advantages (+) and disadvantages (−) for mapping marine and coastal habitats	Reference
	+ Additional data collection possible (sampling, quality assessment) + Area covered/time unit small compared to airborne, acoustic techniques or satellite techniques (thus often time consuming) − Assessment of the spatial coverage of habitats can in some cases be more difficult to comprehend than by remote sensing techniques	

The list is not intended to be comprehensive.

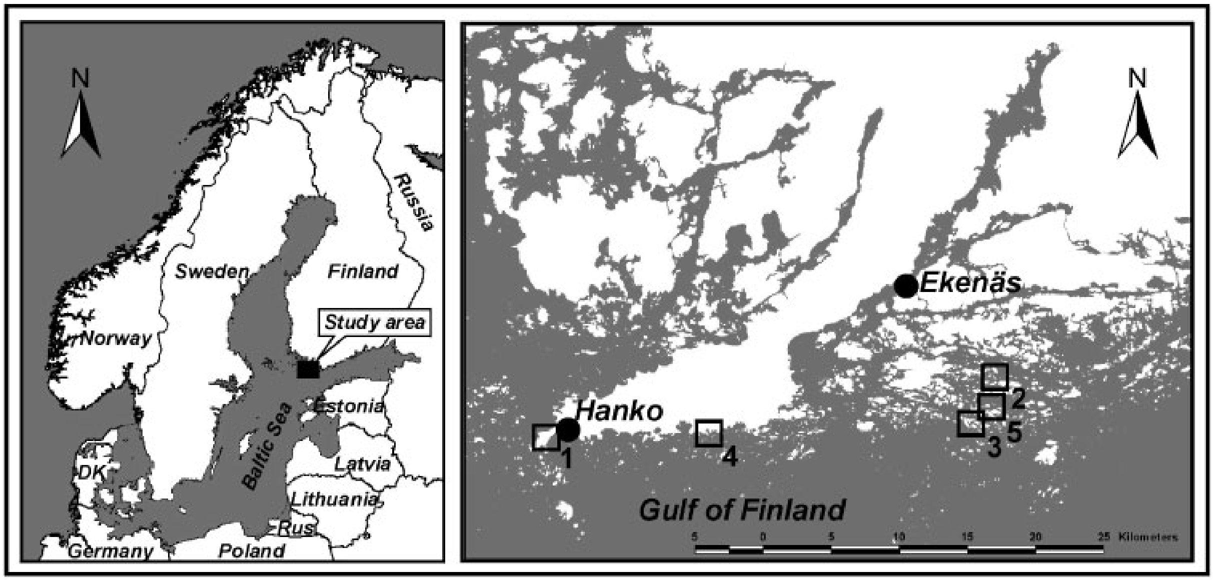

Figure 1. The location of the study area (left map) and the five archipelago areas in the test photographs.

Aerial photographs

In this study high altitude ($h = 9299$ m) panchromatic black and white aerial images (scale 1:60 000) were used. The photographs were purchased from the Finnish Defence Forces, Topographic Services, Aerial Photography Unit (TopK publication permit 20). Non-rectified 40 cm × 40 cm 1:5000 prints were used for the visual interpretation test. The resolution in these photographs corresponds, at best, to a ground resolution of approximately 60 cm in scanned photographs. Individual trees, footpaths, small piers and rock pools can easily be identified in the photograph if the contrast to surrounding areas is good.

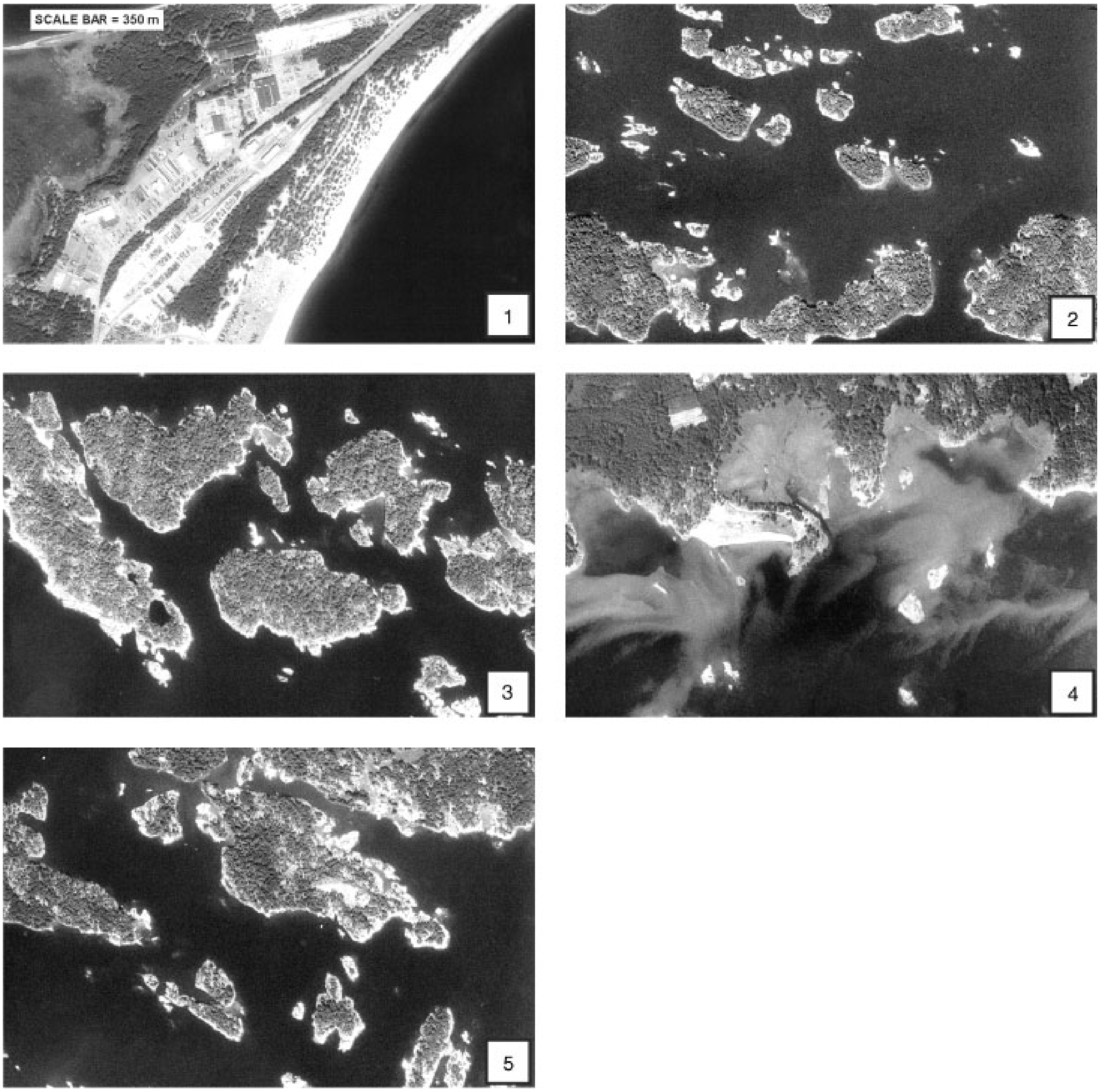

Figure 2. The photographs of areas 1, 2, 3, 4, and 5 (scale bar in photograph 1 applies to all photographs). Photograph copyright, The Finnish Defence Forces, Topographic Services, TopK publication permit 20.

Collection of field data

The entire study area was in general well known to one of the authors (JE). However, in order to obtain additional ground truth data for photographs 2, 3 and 5, approximately 100 km of shoreline was mapped in August 1999. The mapping was done from a boat at a distance of 200 m offshore, or closer, using binoculars when necessary. The mapping covered approximately 10 km^2. In December 2000, additional ground truth data for photographs 1 and 4 were obtained through further visual mapping, covering approximately 2 km^2.

Interpreting the test

The accuracy with which each habitat type can be identified from the photographs was examined by two test groups consisting in total of 34 persons. The persons invited for the tests were students in geography, researchers in geography, marine biology or nature conservation, or persons who use maps, GIS or aerial photograph interpretation in their profession. Two test occasions were arranged and the same test programme was used in both. Prior to the test, participants were given an approximately 60 min briefing on how to identify the Annex I habitat types in aerial photographs. This briefing included the presentation of an illustrated interpretation manual designed especially for the test. The manual included descriptions of each habitat, illustrations, a description of the habitat features that can be identified from photographs and remarks on the geographic context of the habitats. The two test groups interpreted the five aerial photographs using a grid (18×26 cells) (Figure 3), a magnifying glass ($\times$ 8) and the interpretation manual. Printed topographic maps and nautical charts were provided as aids for the identification of photographs 3 and 4 in order to examine the advantage of these for habitat identification. Each photograph was analysed for exactly 20 min. All the identified habitat types within a single grid cell were marked with single character codes.

After the test each person filled out a questionnaire, allowing us to evaluate their opinions of the interpretation process and the test itself. The testee also reported personal background information relevant to the test, such as field experience and experience in interpretation of aerial photographs. The results of each interpreted grid were combined in a confirmation matrix presenting all habitat types surveyed.

Data analysis of the test results

We counted all the cells that each testee had interpreted (some testees ran out of time and left blank cells). For the cells they had marked, we then calculated the number of correct habitat identifications based on the ground truth data collected in the field. The result is reported as the percentage of correctly identified cells as well as the corresponding percentage of incorrectly identified habitats (Table 3). Uninterpreted gridcells were omitted.

Many of the 15 habitats in Table 1 overlap and consequently more than one habitat may occur within a single grid cell. It is hence possible to find one or several correctly or incorrectly identified habitats within a cell, as well as one or several overestimated habitats (Figure 4). We have divided the errors into two main categories. Category I errors include all incorrectly identified habitats divided into three main types. Type (a): a habitat type was overlooked completely (missed). In this case an actual habitat in the cell was not recorded, but neither was an erroneously identified (overestimated) habitat. Nevertheless, this cell may also contain a correctly identified habitat. Type (b): the habitat was identified as another habitat. This type is complicated to analyse in cases where the testee included more than one incorrect, or overestimated, habitat. Type (c): was identified as an empty cell.

Every overestimated habitat might be a potential cause for misinterpretation. However, it is in this case possible to identify a relatively small group of habitats that might have caused the misconception and this is reported as a percentage of the actual total number of cells for this habitat (Table 3).

Category II errors include the overestimated habitats, i.e. a habitat has been recorded by the testee for a grid cell although this habitat does not, according to the ground truth data, occur in that particular cell at all.

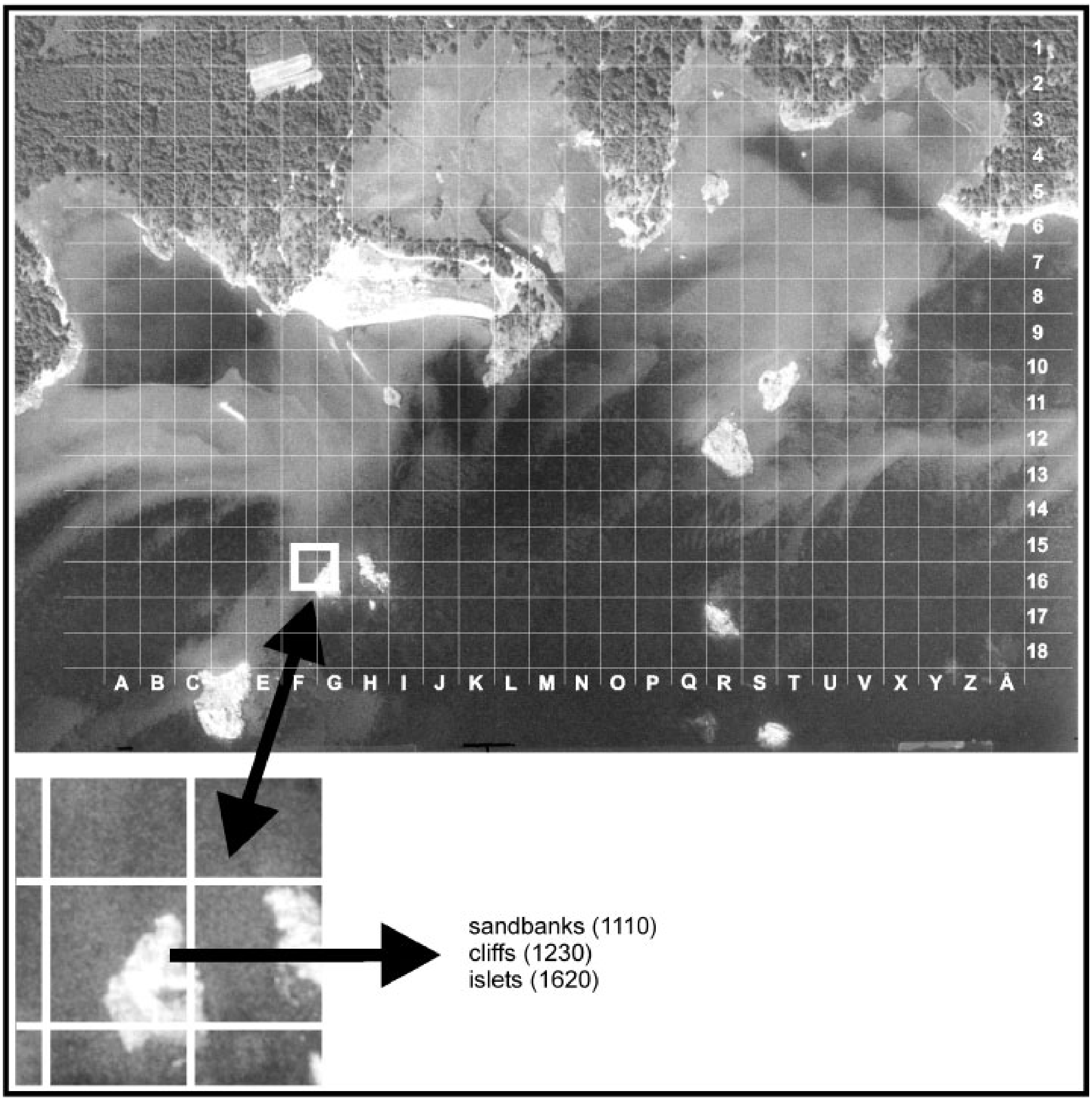

Figure 3. The area covered by photograph 4 with its grid-overlay. A single grid and the habitat types identified in this grid is also shown. (Photograph copyright, The Finnish Defence Forces, Topographic Services, TopK publication permit 20).

RESULTS

The confirmation matrix

Table 3 shows the accuracy with which the test persons were able to identify the habitat types, as the total number of identified habitats and as a percentage of the total number of habitats. Table 3 also presents the two main error categories, including error category I types a, b, and c.

Table 3. An error matrix presenting the precision by which the test groups were able to identify each habitat in the five photographs as well as the errors that were made

	Col.1	Col.2	Col.3	Col.4	Col.5	Col.6	Col.7	Col.8	% identified as another habitat (error I. type b, as a % of the total number of the misinterpreted habitat)																		
	The number of photographs in which the habitat occurs	Tot. number of evaluated cells with this habitat	Total number of cells with the habitat correctly identified	% of all cells correctly identified	% incorrectly identified (% error I. a,b,c)	% overlooked t (% error I., type a.)	% overestimated t (% error II.)	% identified as empty (% error I., type c.)	As sandbanks	As estuaries	As lagoons	As shallow bays	As reefs	As driftlines	As stony banks	As cliffs	As esker islands	As islets	As coastal meadows	As sandy beaches	As narrow inlets	As dunes (in general)	As embryonic dunes	As white dunes	As grey dunes	As empetrum dunes	As wooded dunes	As dune slacks	As calluna heaths	As primary forests
Sandbanks	3	7157	4745	66	34	11	7	11	0	0	0	3	2	0	1	2	1	1	0	1	0	0	0	0	0	0	0	0	0	1
Lagoons	3	1167	831	71	29	14	69	2	0	0	0	1	1	0	1	7	0	0	2	1	0	0	0	0	0	0	0	0	0	1
Shallow bays	2	2727	545	20	80	52	29	5	6	0	3	0	4	0	3	1	1	1	1	1	1	0	0	0	0	0	0	0	0	2
Reefs	4	2546	999	39	61	14	70	32	1	0	1	0	0	0	2	3	1	7	0	0	0	0	0	0	0	0	0	0	0	0
Driftlines	2	188	3	2	98	36	23	2	1	0	0	1	5	0	7	46	0	0	3	2	0	1	1	1	1	1	0	0	0	2
Stony banks	5	5020	1086	22	78	39	22	5	2	0	3	1	6	0	0	16	1	0	4	3	0	0	0	0	0	0	0	0	0	2
Cliffs	5	14 230	9189	65	35	14	12	6	0	0	1	1	6	0	5	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0
Islets	4	17 533	1927	11	89	47	2	14	0	0	2	0	8	0	5	7	2	0	2	1	0	0	0	0	0	0	0	0	0	3
Coastal meadows	5	2324	1041	45	55	11	18	7	8	3	9	13	1	0	3	1	1	0	0	1	0	1	0	0	0	0	0	0	0	2
Sandy beaches	4	1371	1117	82	19	8	56	2	1	0	1	0	0	0	1	1	0	0	0	0	0	0	2	1	2	1	0	0	0	0
Dunes (in general)	2	2260	1243	55	45	22	9	9	1	0	0	0	0	1	0	0	0	0	1	6	0	0	2	0	2	2	1	0	0	0
Embryonic dunes	1	210	23	11	89	71	90	0	0	0	0	2	0	0	1	0	0	0	2	7	0	0	0	2	2	1	0	0	0	0
White dunes	2	980	74	8	92	59	4	2	2	0	0	0	0	3	0	0	3	0	3	7	0	0	5	0	5	3	3	0	0	0
Grey dunes	1	196	18	9	91	55	43	4	0	0	0	0	0	6	1	0	3	0	0	13	0	0	5	0	0	3	7	0	0	0
Wooded dunes	1	1366	598	44	56	28	12	13	0	0	0	0	0	0	0	0	4	0	1	7	0	0	1	0	2	2	0	0	0	0
Primary forests	5	428	30	7	93	36	110	27	6	0	0	2	1	0	7	2	1	0	6	0	0	4	0	0	0	0	5	0	0	0
Empty cells	5	11 883	10 565	89	11	0	38	0	1	0	0	1	1	0	0	2	1	1	0	2	0	1	0	0	0	0	1	0	0	0
Total		61 295	24 373																											
Average per cent				38	62																									

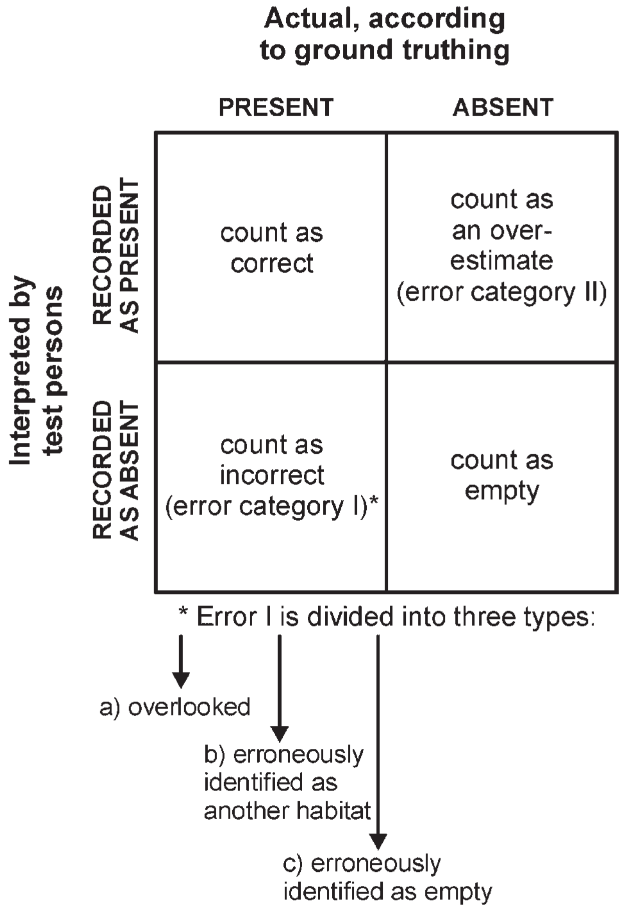

Figure 4. A schematic presentation of the interpretation procedure.

We discarded the test results for three test persons regarding photograph 1 and the result of one test person regarding photograph 4 because the site was well known to these persons, and their results might otherwise have led to biased results. Results from the confirmation matrix are also presented in Figure 5 (% correctly identified habitats) and Figure 6 (% overlooked and overestimates).

In Table 3, the first column shows the number of photographs that include the habitat and the second column the total number of cells with the habitat evaluated by the test group. The third column shows the number of cells with the habitat identified correctly and the following two columns the percentage of cells with the habitat correctly and incorrectly identified by the test group, respectively. The following columns show the percentage of erroneously identified habitats, i.e. errors I a, b, and c and error II.

Neither previous experience in interpreting aerial photographs (Figure 7) nor previous field experience (Figure 8) had any major influence on the outcome of the test.

Figure 9 shows the results grouped in aquatic habitats, terrestrial habitats and the only habitat with aquatic as well as terrestrial components. These results shows that the few aquatic habitats in this study were identified with an accuracy similar to that of most of the terrestrial habitats. Sandy habitats (sandbanks and sandy beaches and dune areas in general) were the most easily identified.

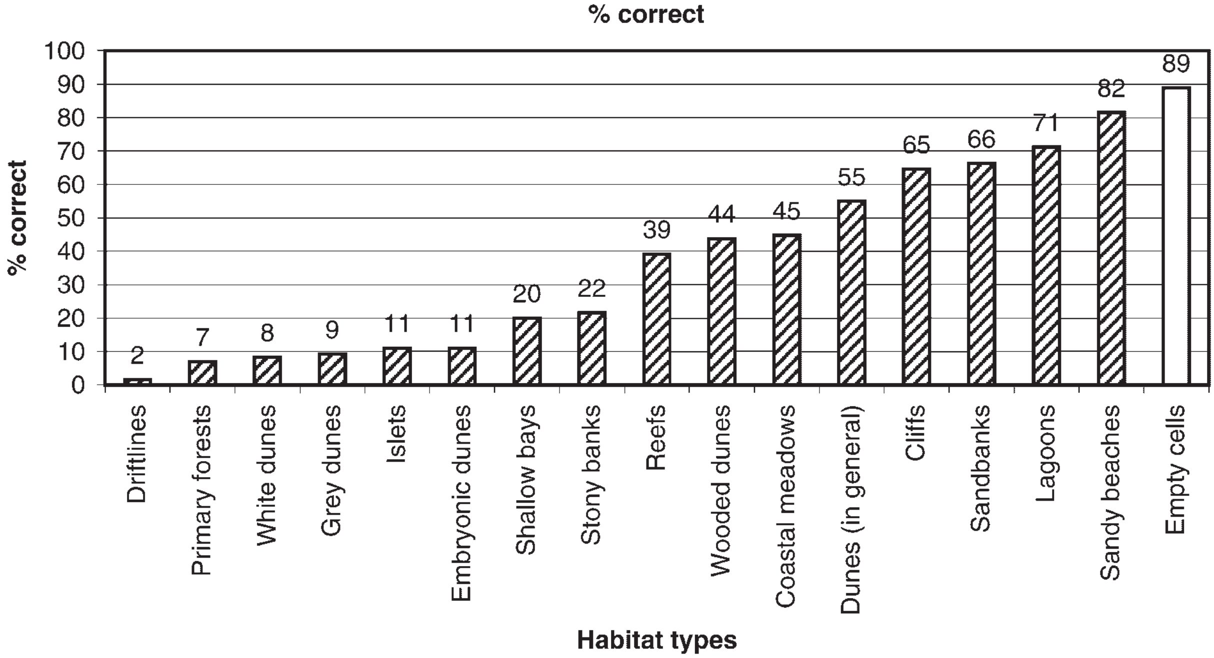

Figure 5. A histogram showing the correctly identified habitat types in percent (hatched bars) and correctly identified empty cells (empty bars).

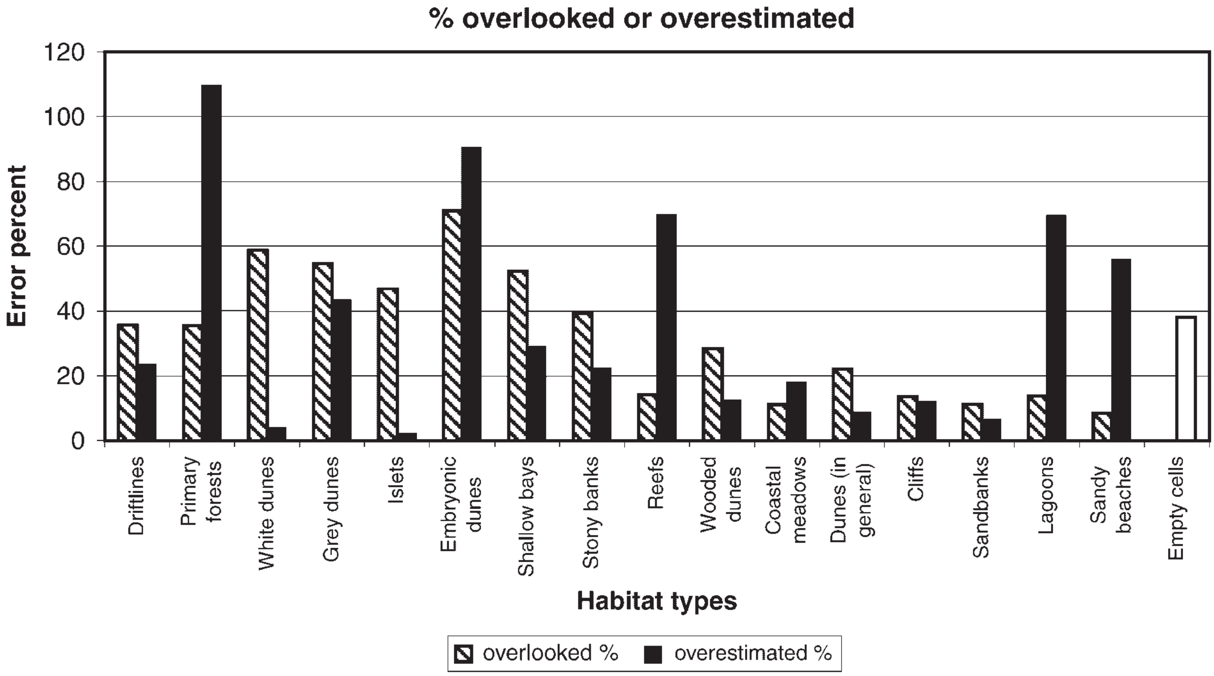

Figure 6. A histogram showing the overlooked habitats in percent (hatched bars) and overestimated habitats (black bars).

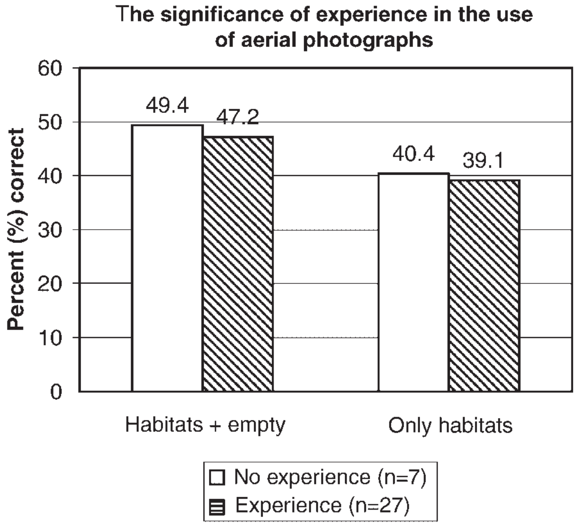

Figure 7. The significance of previous experience in interpreting aerial photographs (hatched bars) vs. no previous experience (empty bars).

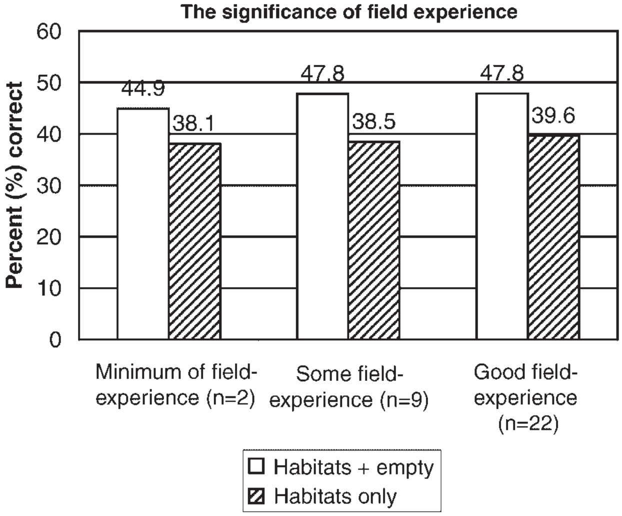

Figure 8. The significance of previous field experience when interpreting aerial photographs (hatched bars) vs. no previous field experience (empty bars).

Of the 34 test persons, 30 reported after the test, that they found maps and nautical charts useful when interpreting the aerial photographs. The effect of using maps and nautical charts as an aid when identifying habitats in photographs 3 and 4 was examined by specifically comparing the results for four habitats occurring in at least four photographs, i.e. reefs, stony banks, cliffs, coastal meadows and empty cells. Results for photographs 3 and 4 were examined together but these results are no more accurate for any of these habitats, or for the empty cells than the results for the other photographs.

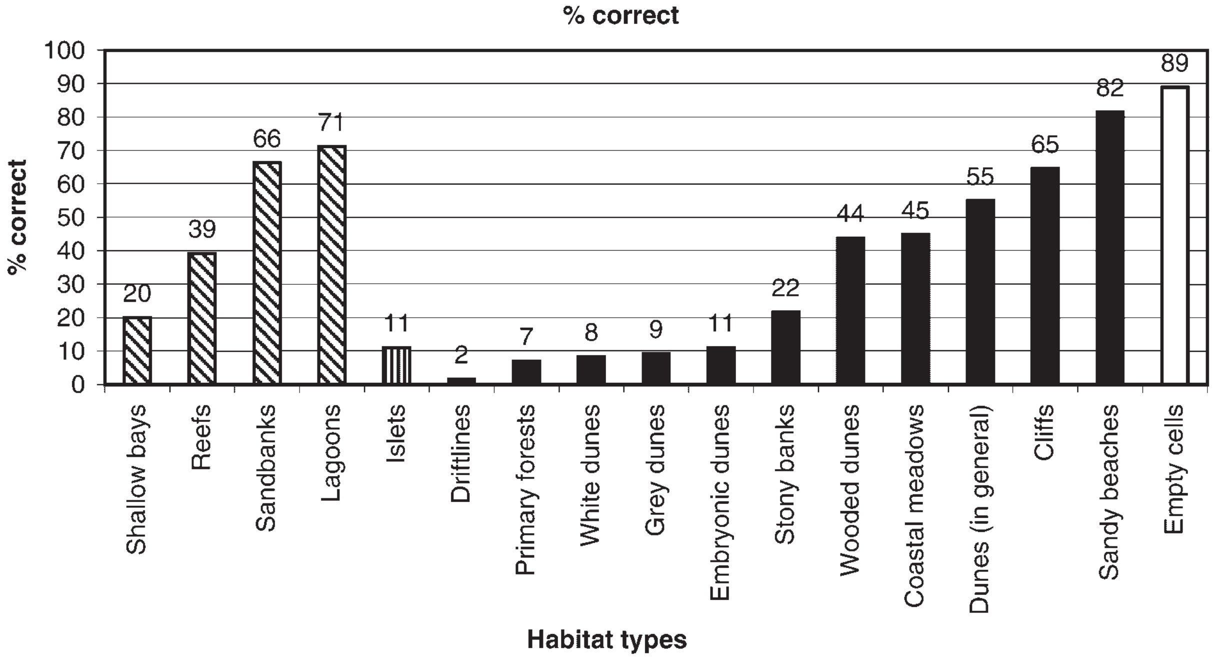

Figure 9. Habitats sorted by type in ascending order: Hatched bars = aquatic habitats; vertical lined bar = aquatic and terrestrial habitats; black (filled) bars = terrestrial habitats; empty bars = empty cells.

DISCUSSION

The results show that out of the 15 habitats examined, four (sandbanks, lagoons, cliffs, and sandy beaches) can be identified with reasonably good accuracy, $>65\%$. In addition, three habitats could be identified with more than 39% accuracy: reefs (39%); coastal meadows (44%) and wooded dunes (44%). Furthermore, dune areas, in general, were identified with 55% accuracy. Aquatic habitats were identified with reasonably good accuracy despite the relatively turbid coastal waters which were expected to decrease the contrast between the aquatic habitat and its surrounding areas and thus obscure their form and pattern more than for terrestrial habitats.

We chose a fixed time for providing instructions prior to the test as well as for examining the photographs, in order to get comparable results from the two test groups. A single test group was, due to practical reasons, not an option. More extensive training and longer examination time might improve the results and our results should thus be considered as minimum results.

Large open water areas and large forest-covered areas explain the relatively high number of empty cells that were identified. However, the fact that the testees in more than 56% of the cases identified grid cells that contain at least one habitat indicate that they had a basic understanding of the general structure of the habitats as well as their geographic context and possible locations in the coastal archipelago areas covered by the photographs. We asked each testee to report on the use of maps and nautical charts in the identification of habitats, for photographs 3 and 4. When comparing the results for reefs, cliffs, coastal meadows and islets that occur in photographs 3 and 4 and at least two other photographs, there is no indication that the maps and nautical charts have improved the results for photographs 3 and 4.

Sandy habitats appear to be easier to identify than most other habitats. Sandy habitats have a light colour, contrasting with the surrounding darker areas, which is perhaps why they are easier to identify than other habitats. However, both islets and shallow bays similarly contrast with the surrounding areas, but these habitats were identified with a surprisingly low accuracy. One reason could be that these were overlooked since both have a relatively high percentage for error I, type 'a' (overlooked), but the percentage for error I, type 'b' (identified as another habitat) was low.

It would be strange if islets and shallow bays would be identified by mistake as one of the other habitats in this study since none of the other habitats resemble these two. Other habitats that were also overlooked were embryonic dunes, white dunes and grey dunes, all with a >50% for error I 'a'. These dunes contrast very little with the surrounding dune area and all of them cover relatively small and narrow areas, which is probably why they have an identification accuracy of <12%. The poor contrast also makes it difficult to define the precise extent of the habitat which would explain the high percentage of overestimated cells reported for embryonic dunes and grey dunes. Similarly, poor contrast is the likely reason for the high percentage of overestimated reefs. Reefs are relatively easy to identify, but in the photographs they fade gradually towards their outer margin where deeper water areas surround the reefs. This makes it difficult to define the full extent of the reef, a possible explanation for the high percentage of overestimated cells reported to contain reefs. Drift lines and primary forests were identified in only 2% and 7% of the evaluated grid cells, respectively. Drift lines are difficult to identify due to their small size but we were not able to find any reason for the low percentage of correctly identified cells for primary forests.

Despite the shortcomings described above, high altitude aerial photographs are useful for identifying and mapping the potential location of several of the marine and coastal habitats examined in this study. When also considering the other advantages of high altitude photographs described earlier, i.e. the good coverage of the entire coastal area, and existing historic archives, these photographs are a suitable tool for large-scale mapping of marine and coastal habitats carried out by environmental officials, on a national or regional level. Aerial photography is one of the methods that has been applied in Scotland for broad-scale mapping of the marine habitats listed in Annex I of the Habitats Directive (ENTEC, 1996). High altitude photographs should, in our opinion, preferably be used as a basic tool complemented by other mapping methods, when improved accuracy is required. Such methods are e.g. low altitude aerial photography, different types of samplers and field mapping methods and in the case of aquatic habitats also acoustic methods and remotely operated cameras (Fortin *et al.*, 1993; Donnan and Davies, 1996; Greenstreet *et al.*, 1997; Downie *et al.*, 1999). Terrestrial coastal sites are usually easier to access by foot and map in the field. Improved accuracy might be required when producing habitat maps used for compiling management schemes for marine and coastal Natura 2000 sites. Although our results prove that some marine habitats can be identified in shallow areas, it might not be possible to map the entire area covered by such habitats by any type of aerial photography, at least not the deeper areas or in severely turbid waters.

High altitude photographs have been taken repeatedly with 3–5 year intervals from all parts of the coast of Finland for several decades. This make it possible to use them for monitoring changes in some of the habitats we studied e.g. as done by Williams and Lyon (1997) in river wetlands. In our study, the most accurately identified habitats can probably be outlined with a precision that make it possible to identify changes in habitat cover, especially if the habitat has clearly defined outlines that contrast with the surrounding area, such as lagoons or sandy beaches. Nevertheless, certain habitats, like reefs should preferably be monitored in the field, e.g. by scuba diving. We also identified dredged areas adjacent to our study area which suggest that changes in the use of land and water areas can be identified by high altitude photographs. There is a great variation between testees ability to identify the habitats which indicate that this might be a problem if using aerial photographs as a tool for monitoring habitats. A longer training period for the interpreters in identifying marine and coastal habitats in the field, and by aerial photographs might minimise this variation. Furthermore, if using digital aerial photographs then image analysing software can in some cases be used as an aid when outlining habitats.

Nevertheless, even though monitoring was beyond the scope of our study, our results do encourage further studies concerning monitoring by aerial photography and other remote sensing methods. In fact, such studies covering the northern Baltic Sea are urgently needed in order to enable the realisation of the monitoring responsibility stated in the Habitats Directive. Several recent publications on monitoring the status of, or change in, landscapes, habitat cover or species abundance provide a good starting point for such studies. General approaches for monitoring are described by Brown (2000), Niemelä (2000) and Groom and Reed (2001), all focussing mainly on terrestrial landscapes and species. Practical methods for monitoring marine habitats and species in the Baltic Sea have been described by Krause-Jensen *et al.* (1995), Anon. (1995, 1998). Davies *et al.* (2001) provide a framework of common standards monitoring specifically designed for assessing the favourable conservation status of marine habitats and species as defined in the Habitats Directive. Phinn *et al.* (2000) present also a useful framework for developing and testing remote sensing systems applicable for coastal monitoring.

Thus, if we are to follow the recommendations in these papers, a monitoring programme for the northern Baltic Sea requires wider studies on the distribution, abundance and size range of the marine and coastal habitats. Such survey data are also necessary when setting out specific monitoring objective (e.g. Brown, 2000), or when identifying suitable attributes for monitoring changes in the favourable conservation status (Niemelä, 2000; Davies *et al.*, 2001). This study shows how aerial photographs can be used as one tool, among others, for obtaining such baseline data.

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