ON THE CAPABILITIES OF DIGITAL HIGH RESOLUTION MULTISPECTRAL REMOTE SENSING TECHNIQUES TO SERVE NATURE CONSERVATION REQUIREMENTS

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ABSTRACT

Humid areas and natural wetlands are among the most important ecological resources. Management of these areas is becoming a mandatory element in nature conservation. Until today, the collection of relevant information on humid areas is mainly based on field work. Use of digital imagery has not yet evolved beyond an experimental stage. In order to set up a processing chain for remote sensing products that help in wetland management, the MANHUMA project has been funded and launched by the European Union.
Based on a report on customer needs and according to three given management functions, three remote sensing products have been defined. In order to evaluate the potential of future satellite missions, it was our task to process data of the DAEDALUS airborne sensor. In this paper a land cover map, based on a class list defined by the customers, will be presented as the base product for all three management functions.
Results show that the main limit is not only to be found on the technical side of the sensor, but also in nature's great variety. Soil parameters like moisture or fertility often vary within distances of 10–20 m, affecting the phenological status of vegetation significantly. Overall classification results show that an accurate delineation of the different land cover types was possible at the sensor's resolution. A good characterisation of all test sites through land cover classes that are relevant to nature conservation measures has been achieved.

1 INTRODUCTION

Humid areas and natural wetlands are among the most important ecological resources on Earth, acting as habitats for many species, as flood control regions and sources of drinking water supplies. Increasingly, wetland areas are being bought by non government organizations (NGOs) as they represent key strategic areas for nature conservation. Management of these areas is becoming a mandatory element in nature conservation decision making at all levels, local through international. Until today, the collection of relevant information on humid areas is mainly based on field work which is both time consuming and expensive. The application of remote sensing techniques is currently limited to visual and computer assisted interpretation of colour or colour infrared aerial photography. Use of digital multispectral remote sensing imagery has not yet evolved beyond an experimental stage. Reasons may be the low spatial resolution satellite images offer (10 m to 30 m), but also the methods for extraction of information out of these images are different to traditional tools in environmental work and therefore may not have found wide acceptance.

In order to fill this gap, to assess the capability of remote sensing techniques for wetland applications, to define geo-information products that may help in wetland management, and to try to set up a processing chain for remote sensing data, the MANHUMA project has been funded and launched by the European Union. The project, which started in August 1998 and will continue until the end of September 2000, is characterised by interaction and co-operation between three groups of partners: business development partners, research partners and customers. These groups will work interactively to understand and serve the customer's information needs.

1.1 Nature conservation requirements

In order to serve the requirements of organizations responsible for nature convservation, one has to assess their needs. A major task in the early phase of the MANHUMA project was the compilation of a general report on customer needs, regardless whether or not these needs could be satisfied by remote sensing applications (Whitelaw, 1999). The objective was to gather information on customer requirements from interested parties and organizations within Europe and to produce a list of high priority requirements that can be used as a project standard.

As a guideline for the MANHUMA project, management of protected areas had been split up into three generic functions: (1) management planning, (2) monitoring and control, and (3) protection policy evaluation. Each of these management functions corresponds to a certain phase within the overall timeframe and has its own special requirements. Some, certainly not all of these requirements may be fulfilled with the help of remote sensing. The next paragraphs summarise the results of a questionnaire sent to the customers.

1.1.1 Management planning We will not join the debate over wetland definition; there are competent organizations like RAMSAR who deal with this problem. The MANHUMA project concentrated on central european wetland types like coastal areas, salt marsh, riverine areas, moorland, shallow ponds, marshes, and swamps. Wetland information requirements include (1) geophysical information such as basic physical and chemical variables, (2) compound variables and indicators used to delineate and characterise wetlands. The evaluation of the customer questionnaire revealed a set of requirements for specific variables ranked in the following order: landscape category, surface topography, vegetation type, bird species, soil moisture, dry / wet areas, animal species, ecological status and hydrological factors. This indicates that there is a strong requirement for basic variables characterising land cover and topography, but also for hydrological aspects and wild life habitats.

An important question deals with scale, timing and review period for data. The scales requested range from 1 : 1 000 to 1 : 25 000 or – in case of raster based information representation – a grid size from 1 m to 30 m. Data should be acquired mainly in spring and summer. For some cases, the customers underlined the importance to coordinate the timing with specific phases of the agricultural cycle. Annual or even seasonal repeats were requested, even though financial restrictions often may allow revisits every two or three years, only. In addition, information generated under this activity will serve as the basis for assessment of changes and landscape evolution.

1.1.2 Monitoring and control A variety of actions have been listed for this field of activities such as general environmental monitoring, monitoring water biology, monitoring relevant geophysical characteristics. In general, the tasks in this area tend to relate to either of the two most rapidly changing characteristics of wetlands, i. e. (1) water quality and quantity, and (2) biodiversity. The emphasis here is on the detection of change in relation to various threats which may affect protected area. Responses to the questionnaire included mineral / peat extraction, housing / land development, excessive use of fertilisers, industrial development, land drainage and atmospheric pollution. Wetland monitoring should also contribute to process modelling and understanding tasks such as linking wetland observations to models, understanding the transfer processes that influence changes, interpolating the time gaps between observation dates, and forecasting future landscape status evolution.

1.1.3 Policy evaluation requirements The policy evaluation activity should contribute to efforts of assessing the effectiveness of measures and nature conservation decisions in relation to wetland threats. Effectiveness needs to be conveyed to regulating government bodies, NGO members and trusties. In essence, the traditional policy evaluation process should be complemented by illustrative result presentations; clear indicators should be defined and developed which highlight regions of critical landscape evolution; modern digital tools including GIS and expert systems should be integrated into the evaluation process.

1.2 Contribution of remote sensing

The previous section gave rather general needs of customers. In the next sections, a particular solution for some requirements stated above will be presented which applies a specific sensor.

1.2.1 Sensor hardware used Most of the MANHUMA research work is done using the well-known SPOT spaceborne sensor. The use of such a system has the advantage that large areas in the range of hundreds of kilometers can be mapped and monitored and that it is possible to find historical image data in the archives. On the other hand, the SPOT sensor has limited capabilities due to a spatial resolution of 20 m and four spectral bands – historical SPOT 3 data comprise only three of them.

As sensor technology evolves rapidly, it does not suffice to stick to traditional equipment. In order to evaluate the potential of future satellite missions, it was the task of our institute to process image data from a sensor that offers both a high spatial and spectral resolution. We have chosen the DAEDALUS ATM airborne sensor as it offers a wide spectral range of eleven channels from visible blue to thermal infrared (see tab. 1). The flight parameters were chosen as to receive an average raster grid of 2 m by 2 m on ground.

Band	Spectral Region	Band Edges in μm
1	violet	0,420–0,450
2	blue	0,450–0,520
3	green	0,520–0,600
4	orange	0,605–0,625
5	red	0,630–0,690
6	NIR	0,695–0,750
7	NIR	0,760–0,900
8	NIR	0,910–1,050
9	SWIR	1,55–1,75
10	MWIR	3,3–5,0
11	TIR	8,5–13,0

Table 1: The spectral bands of DAEDALUS ATM as used in MANHUMA project.

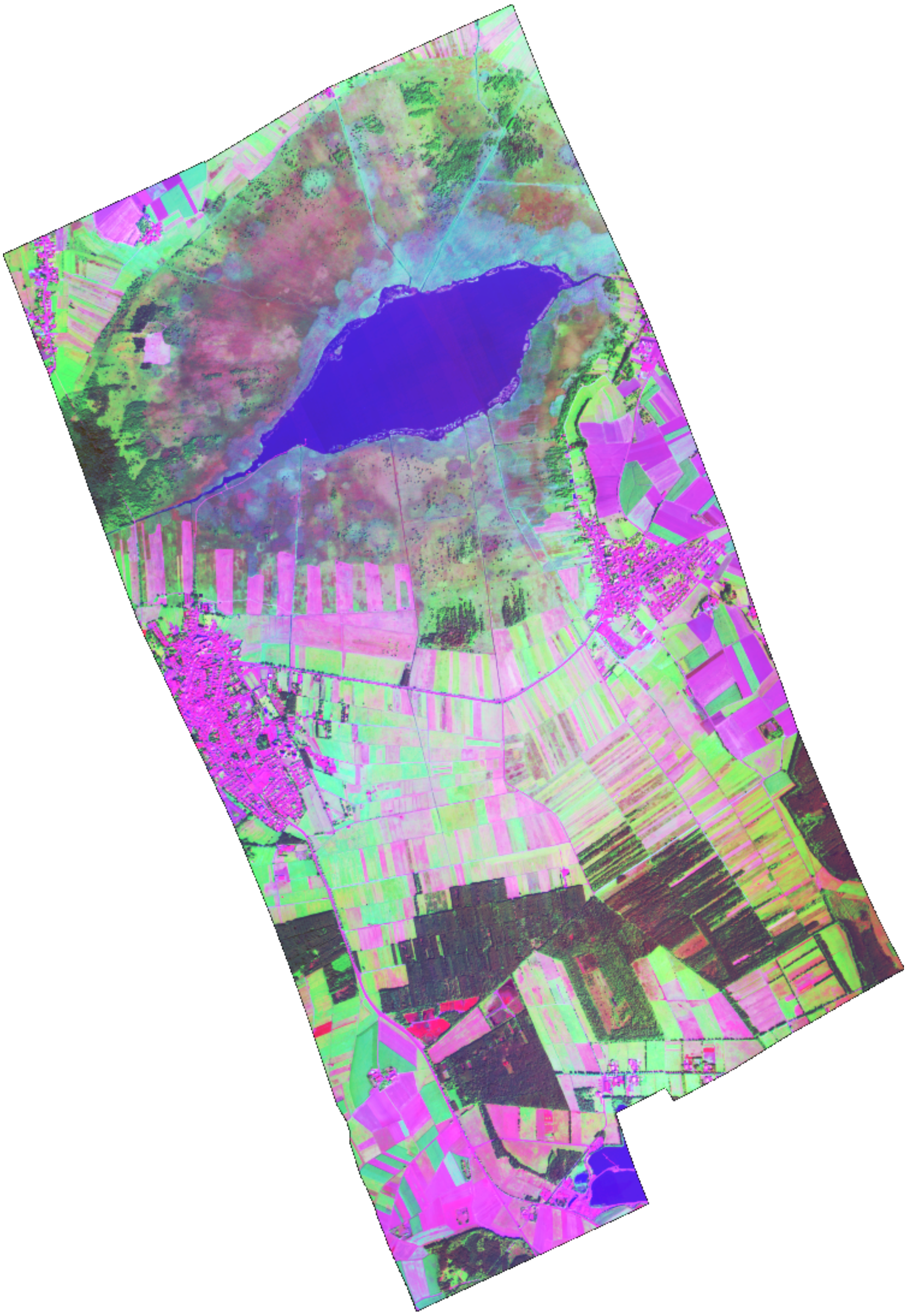

Figure 1: Colour composite of channels 10 / 7 / 2 (MWIR / NIR / blue) of *Federsee* test site at scale 1 : 50 000. The site is located to the west of Biberach (35 km southwest of Ulm and 90 km southeast of Stuttgart). In the northern part of the site, there is the lake surrounded by reed beds and sedge fens, whereas to the south the site is made up by humid meadows and forests.

1.2.2 Remote sensing products defined According to the three wetland management functions, three products have been defined that are extracted from remote sensing data. For the planning task, the remote sensing data will be converted into a land cover map by means of a maximum likelihood classification. Maps of this kind will be the starting point for the other two products. The changes between two dates can be turned into a map for the monitoring task, making it possible to document whether and how effective the measures had been.

It is more difficult to contribute to the evaluation of policy effects because that requires to have the nature conservation measures and policies in a computer compatible form. A simpler approach is to convert the land cover map – which still needs interpretation to be of any use – into a map that has some *ecological value* assigned to each grid cell. Such an abstraction reflects nature quality directly and without any interpretative work required. Similar to the change detection between two land cover maps, it is also possible to show land evolution in terms of *ecological value differences*.

All three levels of remote sensing products are being processed in the project. In this paper, however, we will concentrate on the land cover map as it is the base product and any loss of quality herein will propagate through to the others.

1.2.3 Data processing The main task is to find a link between the contents of a digital image and reality. Working in the domain of nature conservation means working in the domain of biologists. They define different land cover types by applying a classification scheme, that is based on plant species, to the different plant communities. Note that this is contrary to digital classifications where all decisions are based on the spectral information. Many of the problems with classification quality arise from these different methodologies. For the MANHUMA project, a similar list had been produced as a subset of existing catalogues, having in mind that it will certainly not be possible to differentiate at the same level as an expert in biology could do. This list has not been made publicly available yet, but general structure and contents are given in (von Hansen and Sties, 2000).

The idea was to apply supervised classification, especially because there was enough time to accomplish the necessary field work before the georeferenced and radiometrically corrected data was available. The training areas have been mapped with the help of biologists, as the assignment of nature to rather specific classes is not possible without expert knowlegde. During classification it turned out that to few areas had been mapped to cover the great variety in nature's appearance. Because of that, all training areas had to be used in the classification process and none were left for control. An independent control of the classification results therefore is not possible at the time of writing.

2 RESULTS

In the course of the MANHUMA project, seven different test sites in Baden-Württemberg, Germany and Alsace, France have been covered by the DAEDALUS sensor. Although the sites are all different with respect to the habitat they represent, the results are similar from the technical point of view. In this paper, the results for one of the seven sites will be presented as an example. The test site chosen is *Federsee* (see fig. 1), a lake surrounded by reed beds, sedge fens, humid meadows and raised bogs, in the perialpin landscape of Oberschwaben, Germany. With size of 4 km by 7 km approx., this site is the largest one of the seven and also has the biggest variety of plant species ranging from *euhydrophyte communities* to *hay meadows*.

2.1 Classification result

The land cover map obtained from Federsee test site is shown in fig. 2. As no control areas are available – these will be mapped during this springtime – two methods to assess the quality with available means have been applied to date.

2.1.1 Separability of classes A first approach to test the sensor's capabilities is to check the separability of the classes. The method chosen is to compare the spectral signatures of all training areas that define a pair of classes. Each comparison yields the confidence, as a percentage, in the assumption that both training areas describe the same class. Hence, any combination of classes will result in a list of percentages of their similarity in feature space.

For visualization two different matrices are built up by selecting a specific percentage limit for each combination. One matrix displays the maximum value in each element of the list. This gives an idea for the highest degree of similarity, i. e. the worst case in separability of both classes involved. If this value is in the high percentage range, i. e. greater than 90% approx., at least one pair of training areas is rather similar in the statistical sense. If the maximum is a small value, the classes are very likely to be separable. The second matrix is filled up with the median value of the percentage list, which is a robust approximation for the average overlap between classes, especially if more than only a few training areas are available for each class. Since both matrices are symmetric – "class A compared to class B" is identical to "class B compared to class A" – they had been roled into one. For a quicker overview, the maximum values (upper right section of the matrix) were put on a coloured background according to the quality level they represent. Similarity values up to 50%, which guarantee very good class separability, are in the colour *green*. *White* is used for values between 50% and 90%,

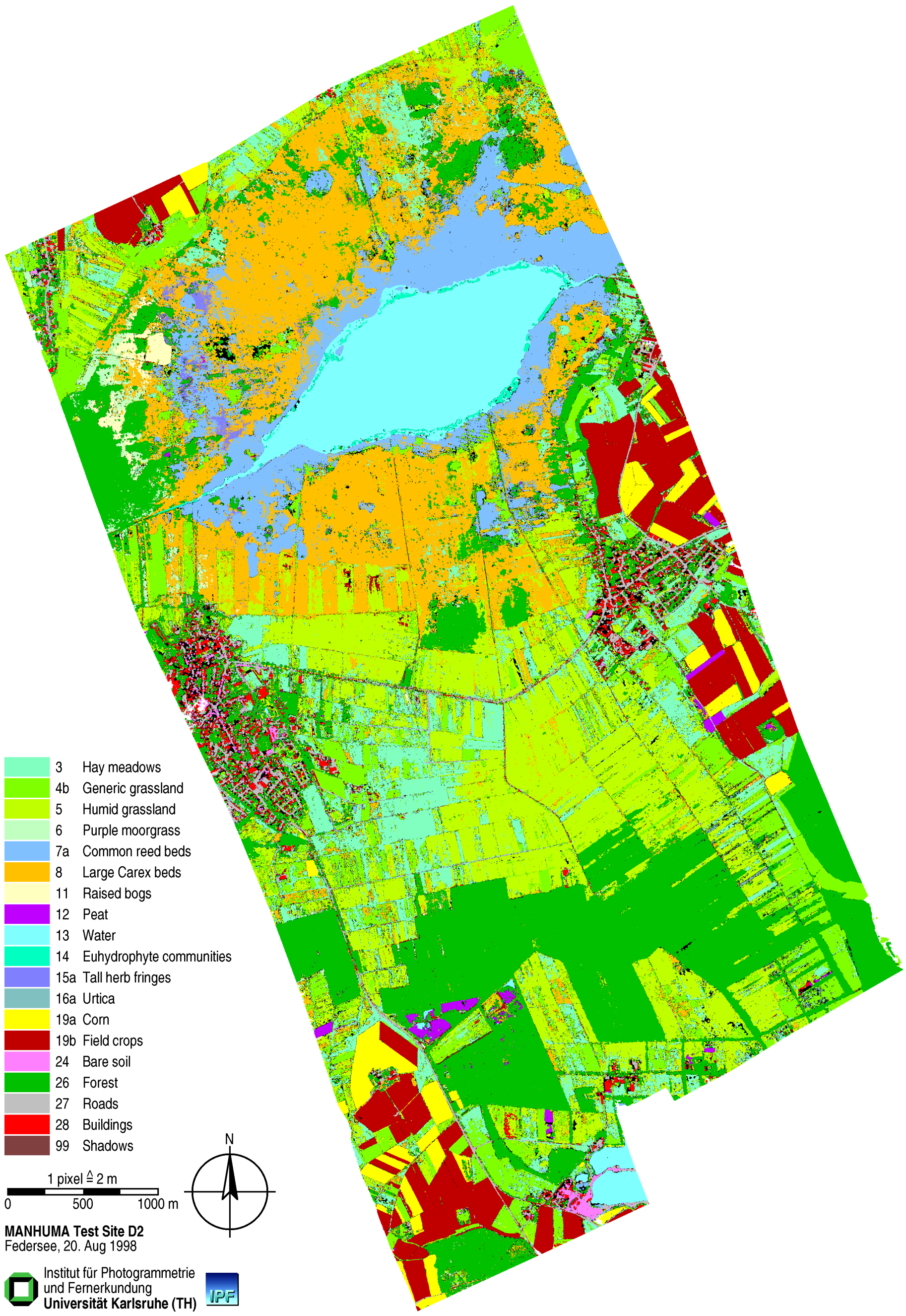

Figure 2: Classification result of *Federsee* test site at scale 1 : 50 000. The class codes in the legend refer to the class list that has been defined during the MANHUMA project.

Maximum and average overlap of training areas in feature space in %

Class		3	4b	5c	5d	6	7a	8	11	12	13	14	15	16a	19a	19b	24	26	27	28	99
	n	10	32	9	8	2	16	14	5	8	25	11	1	3	9	35	4	10	16	48	1
3	10		62	81	73	2	49	29	2	0	0	1	0	11	1	3	0	2	13	1	0
4b	32	0		49	39	2	4	48	1	9	0	1	1	52	20	13	0	44	5	29	0
5c	9	1	0		100	2	1	98	5	1	0	0	1	3	1	7	0	4	8	31	0
5d	8	0	0	1		1	2	73	1	0	0	0	0	38	1	1	0	11	2	1	0
6	2	0	0	0	0		1	23	100	0	0	0	1	19	1	1	0	32	0	1	0
7a	16	0	0	0	0	0		89	2	2	1	3	64	1	2	10	0	3	1	1	0
8	14	0	0	0	0	1	0		35	32	1	1	85	39	1	4	0	39	1	1	0
11	5	0	0	0	0	3	0	0		0	0	0	1	3	1	3	0	9	1	1	0
12	8	0	0	0	0	0	0	0	0		12	0	1	1	0	1	0	39	1	35	0
13	25	0	0	0	0	0	0	0	0	0		52	0	0	1	1	0	1	1	1	1
14	11	0	0	0	0	0	0	0	0	0	0		0	0	0	12	1	1	1	4	0
15	1	0	0	0	0	1	0	1	0	0	0	0		1	1	0	0	7	0	0	0
16a	3	0	0	0	1	2	0	1	1	0	0	0	0		0	3	0	26	1	1	0
19a	9	0	0	0	0	0	0	0	0	0	0	0	0	0		4	0	2	0	0	0
19b	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	1	26	23	0
24	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	22	52	0
26	10	0	0	0	0	1	0	0	0	0	0	0	1	1	0	0	0		1	12	2
27	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		99	0
28	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		4
99	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	

Table 2: Similarity analysis for test site *Federsee*. Please refer to fig. 2 for an explanation of the class codes. In this table, class 5 *(eutrophic humid grasslands)* is divided up into two more specific subclasses, 5c *(grobe flowerbrook thistle meadows)* and 5d (same as 5c but with a small number of species). n is the number of training areas that define each class.

which yield good to fair separability. *Orange* represents values between 90% and 95%, which indicate difficulties in class separability and *red* is used for similarity values above 95%, which indicate high class similarity or impossible class separability.

The median values (lower left section of the matrix) have the same colour as their maximum counterpart background colour in order to show their evolution: if the median values are located in the higher percentage range of the similarity feature, the respective pair of classes will not be separable in the image data available. It should be emphasized that this quality check operates only on image data and training areas. Therefore, it provides a-priori information of what can be expected for the classification results.

The result of the similarity analysis is shown in tab. 2. The average overlap of classes in the lower left half of the matrix tends towards zero – hence, a good class separability can generally be expected from the data. The majority of the maximum overlap in the upper right half is below 50% which also predicts a good quality of the classification results. Four class combinations, however, do have a significant overlap in feature space and therefore require further explanation.

Classes 5c and 5d (see caption) are subclasses of class 5 *(eutrophic humid grasslands)* that are rather similar in nature. With the consent of the experts, this distinction will no longer be made for the classifications. Class 5c also conflicts with class 8 *(large Carex beds)*. The reason here is that the set of training areas includes two areas of class 8 that had been cut shortly before data acquisition. These samples are very likely to conflict with areas of class 5 that also had been cut recently. The conflict of class 6 *(purple moorgras)* and 11 *(raised bogs)* is due to nature's variety and hints at the limitations of remote sensing. Classes 27 *(roads)* and 28 *(buildings)* overlap because there is some similarity in the materials that are being used for sealed surfaces. Since the emphasis in this project is on nature, a conflict between these classes is not important.

2.1.2 Comparison of the classification results with vegetation maps A second method is to compare the classification result with existing vegetation maps. For a part of the test site, such a map, which had been generated manually after field work and visual image interpretation, was available. The map has been scanned and coregistrated to the classification results. The idea is to use this map as a reference and to build up a confusion matrix for the area covered by it.

Unfortunately, the vegetation map has an age of eight years and therefore, changes may have happened. All areas, where an extended difference between map and actual classification could be detected, were not used for the confusion matrix. All other areas, where no massive differences occurred, were used to deduce a confusion matrix for the classification result, assuming that the contents of the vegetation map is correct. As data from different sources are involved, some

Class	to	3	4b	5	6	7a	8	11	12	13	14	15a	16a	19a	19b	24	26	27	28	99	0
from	A (%)	3	1	11	0	19	33	1	0	17	1	0	0	0	0	0	10	0	0	0	4
3	2	**75**	6	6	0	0	2	0	0	—	—	0	—	0	0	0	1	1	0	0	9
4c	0	6	4	5	0	1	3	0	1	—	—	—	—	—	1	0	14	4	8	1	51
5	12	4	3	**83**	0	0	4	0	0	—	—	0	—	0	0	—	1	0	0	—	5
6	0	1	0	4	**80**	0	2	3	—	—	—	—	—	—	—	—	2	—	—	—	7
7a	21	1	1	0	0	**87**	4	0	0	0	0	0	—	0	0	—	1	0	0	0	5
7b	0	11	2	8	2	10	28	1	—	—	—	1	—	—	0	—	9	—	0	—	27
8	36	1	1	2	0	2	**87**	0	0	0	0	1	0	0	0	—	2	0	0	—	4
9	0	—	3	8	3	15	14	—	—	—	—	—	—	—	—	—	25	—	—	—	31
11	2	1	1	1	4	2	9	**54**	0	0	—	0	0	—	0	—	7	0	0	—	21
13	17	0	0	0	0	0	0	—	—	**99**	1	—	—	—	0	0	0	0	0	—	0
14	1	0	0	—	—	3	0	—	—	16	**74**	—	—	—	0	—	0	—	0	—	6
15	0	9	6	21	2	2	16	1	—	—	—	—	—	0	—	—	11	1	0	—	32
15a	0	—	2	18	1	2	36	—	—	—	—	**5**	—	—	—	—	16	—	—	—	20
26	9	0	0	1	0	0	2	0	0	—	—	0	—	0	0	—	**93**	0	0	—	3

Table 3: Confusion matrix based on a vegetation map for test site *Federsee* that displays the area directly around the lake ('from') and the classification result ('to'). Please refer to fig. 2 for an explanation of the class codes. Class 4c refers to some garden areas in the vegetation map, class 0 represents the reject class. A is the area covered by each class in the map.

difficulties in the definition of the classes arose. Furthermore, not all classes are present in both datasets. Table 3 shows the resulting confusion matrix.

In the matrix, a dash '—' means no confusion at all, whereas the digit zero '0' means "a small amount between 0 and 0.5 has been truncated to 0". The values in the diagonal (which should, ideally, amount to 100%) are typeset in **bold**. Only a part of the test site is covered by the vegetation map, so the confusion matrix may not be valid for the whole site. On the other hand, the interesting part of the site is covered, i. e. the wetland area directly around the lake with its many different land cover types.

In the confusion matrix, the percentages add up to 100% for each row as the map was used as reference; consequently, the percentages do not add up to 100% in the columns. The majority of classes tested score above 70% which is acceptable. The reason for some of the low scores is certainly found in the subjective definition of land cover types in vegetation maps which have been applied by different individuals during their work. Some further comments can still be made.

Not all classes of the vegetation map have been defined for the classification. Classes 11 *(raised bogs)* and 15 / 15a *(tall herb fringes)* show quite some confusion. This reflects nature's variety and thereby the inability to define certain classes. Class 13 *(water)* shows this excellent score because the lake was the only representation for this class and easy to identify. The confusion of class 14 *(euhydrophyte communities)* with class 13 mainly shows the problems in delineating both classes as parts of the plants are submerged but still visible.

3 OVERALL QUALITY ASSESSMENT

3.1 Geometric quality

Besides the quality of the classification itself, it is also important to have a look at the geometric situation. Especially when dealing with small areas of interest, it is vital to have a good georeference. Any displacement will cause additional confusion when two different land cover maps are compared to each other. Unfortunately, for the DAEDALUS sensor, the high geometric resolution is not entirely supported by the aircraft navigation system. Its resolution theoretically is sufficient, but drift effects or errors in reading decrease the geometric quality significantly.

It is difficult to estimate a numerical value for the geometric accuracy of a land cover classification, mainly because there is no reference for the *real* boundaries between different land cover classes. But due to the phenomenon of mixed pixels, it is obvious that the geometric accuracy of classification results can not be better than 2 to 3 pixels. For our DAEDALUS data this amounts to 4 – 6 m. Because the geometric rectification procedure is error-prone, it is necessary to add the rms-error of the geocoding process which can be calculated from the residuals at the ground control points. The formula used is

$$\Delta = \sqrt{\Delta_{\text{class.}}{}^2 + \Delta_{\text{georef.}}{}^2}$$

where Δ represents the estimated geometric accuracy. For $\Delta_{\text{class.}}$, an average value of 5 m will be used (see tab. 4).

The geometric accuracy seems to be proportional to the strip length which can be explained by drift effects in the airplane navigation instruments. The accuracy estimations for the shortest test site (Mulhouse) reflect the influence of air turbulence during image acquisition.

3.2 Classification quality

The quality of the land cover classification could only be checked by statistical means and a vegetation map that wasn't up to date. A direct comparison of the map with reality, including a test for the usability, will be done in this years springtime.

Test Site	l (km)	$\Delta_{georef.}$ (m)	Δ (m)	Δ (pixels)
Schwäbische Alb	5.6	3.6	**6.2**	3
Federsee	6.7	5.4	**7.4**	4
Elz valley	8.6	7.6	**9.1**	5
Mulhouse	3.7	9.5	**10.7**	5
Ill valley	8.1	9.5	**10.7**	5
Zembs valley	4.3	2.8	**5.7**	3
Zorn valley	6.7	6.3	**8.0**	4

Table 4: Estimated absolute geometric accuracy of the classification results for each of the test sites. l is the length of the image strip.

Visual comparison with the image data and available CIR *(colour infrared)* photographies, as well as the numerical results of the two methods show that the main limit is not only to be found on the technical side of the sensor, but also in nature's great variety. Due to variations in soil parameters, like moisture or fertility, within a few meters, the same class may have completely different phenology. On the other hand, different classes may appear similar in feature space, especially under varying image acquisition conditions (fog and haze).

As a result it should be noted that the geometric quality of the land cover map was higher than its classification accuracy in the sense that the delineation of any pair of areas of a different appearance was determined rather precisely, but the assignment of the respective areas to the correct classes was less accurate.

4 CONCLUSION

During our experiments, some areas had been assigned to false classes with a significant certainty. The reason is the fact, that the definition of classes – as requested by the customers – is based solely on the composition of the plant communities and not on their overall appearance: completely different land cover types may appear similar. To compensate for this effect, it was necessary to define additional, typical training areas. Furthermore, it became evident that the high spatial resolution of the sensor is another possible source for confusion between different pairs of classes. Soil parameters like moisture or fertility often vary greatly within distances of 10 m to 20 m, affecting the phenological status of vegetation significantly. Both the definition of training areas and the quality of classification may suffer from this.

Overall classification results show that, in all 7 test areas, an accurate delineation of the different land cover types was possible at the sensor's resolution, if they are well defined by training areas. This requires several sufficiently large, homogeneous areas distributed across the entire scene. It was possible to achieve a good characterisation of all test sites through their major land cover types which are relevant to nature conservation measures.

Concluding from common experience, even higher confidence in the classification results for wetland delineation can be expected if we could dispose of multitemporal image data sets as described. It will be possible to document the seasonal changes of the landscape which – in turn – serves to distinguish long term changes from such short term variations. Hence, we are certain to dispose of reliable information to meet requirements of the monitoring activities. It is obvious, however, that important parameters in the context of wetland protection initiatives such as physical and chemical parameters, the level of intoxication, etc. cannot be mapped directly, can only be uncovered indirectly through indicators by exploiting remotely sensed imagery. Hence, remote sensing will play a complementary, but important role in wetland conservation.

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