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Comparison of three modelling approaches of potential natural forest habitats in Bavaria, Germany

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Abstract

In the context of the EU Habitats Directive, which contains the obligation of environmental monitoring, nature conservation authorities face a growing demand for effective and competitive methods to survey protected habitats. Therefore the presented research study compared three modelling approaches (rule-based method with applied Bavarian woodland types, multivariate technique of cluster analysis, and a fuzzy logic approach) for the purpose of detecting potential habitat types. The results can be combined with earth observation data of different geometric resolution (ASTER, SPOT5, aerial photographs or very high resolution satellite data) in order to determine actual forest habitat types. This was carried out at two test sites, situated in the pre-alpine area in Bavaria (southern Germany). The results were subsequently compared to the terrestrial mapped habitat areas of the NATURA 2000 management plans. First results show that these techniques are a valuable support in mapping and monitoring NATURA 2000 forest habitats.

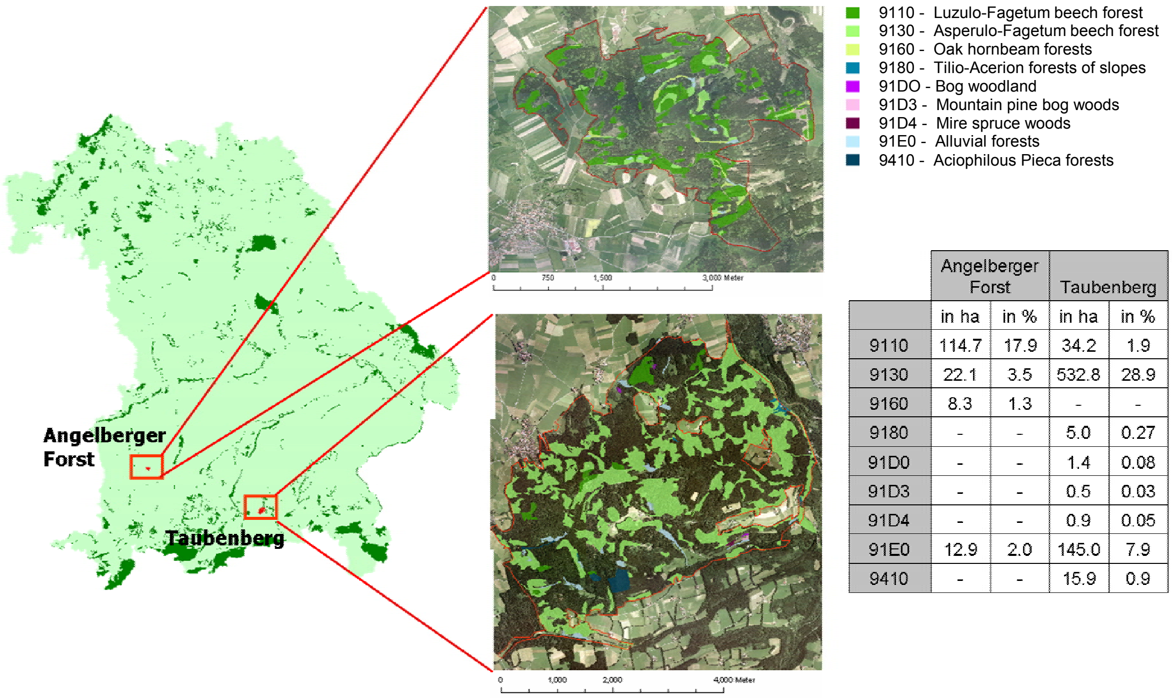
Introduction

NATURA 2000 sites cover approximately seven per cent of the territory of Germany. The EU Habitats Directive (council directive 92/43/ECC, EUROPEAN COMMISSION 2003) requires a standardised monitoring of the habitat types and a reporting every six years. For this reason, an operational, objective, economically priced and as far as possible automated application is required. The rapidly developing remote sensing sensor technique and also new image processing methods offer new possibilities to apply remote sensing data for NATURA 2000 monitoring. The possibilities of remote sensing techniques for detecting and monitoring of biodiversity within the scope of the Habitats Directive has already been proven by EU projects SPIN (LANGANKE et al. 2004) and EON 2000+ (SELL et al. 2004). Consequently this study is a contribution to an effective implementation of these methods for operational use at the regional level (of German federal states). Therefore these methods have to be cost-effective and highly standardised to be a support in terrestrial mapping processes.

With the introduction of a more detailed monitoring guideline as an extension of the EU Habitats directive (DocHab 04-03/03 rev.3, EUROPEAN COMMISSION 2005) the EU states that assessing and evaluating the conservation status of habitats and species within the NATURA 2000 network is not sufficient. Therefore an aggregation of the evaluated monitoring sites to the biogeographical level is necessary (NEUKIRCHEN 2005). The estimation of the spatial distribution and the kind of NATURA 2000 habitat types in a biogeographical region can be based on the modelling of potential natural vegetation associations. This can be done by the use of expert knowledge about the requirements of the habitat types in respect to site specific factors, such as soil type or relief. For this task, besides the study of historical sources, a modelling of potential natural vegetation as well as a monitoring with remote sensing techniques is required. Furthermore the modelled results of potential natural vegetation can give a support for mapping aerial photographs or classification of satellite images. Up to now, area-wide information about the potential natural vegetation is available only on a large scale 1 : 500.000 (SEIBERT 1968; a new edition of the outline map is expected soon, SUCK & BUSHART 2005) or in form of statistical data (WALENTOWSKI 2001). In order to derive spatially more detailed facts, a rule-based, a multivariate, and a fuzzy logic approach were applied.

Test Areas

As test areas two sites („Angelberger Forst“ and „Taubenberg“) in the pre-alpine region of southern Bavaria were chosen. These test sites sized 640 and 1850 hectares respectively, are nearly completely wooded. Within these NATURA 2000 sites, different semi-natural mixed forest types exist, including Beech forests (9110, 9130), Alluvial forests with *Alnus* and *Fraxinus* (91E0), and bog woodland (91D0). To evaluate the results of this study forest management plans (SEITZ & KESSLER 2004) or publications including mapped woodland habitats (WALENTOWSKI et al. 2005) were available for the two selected areas. Figure 1 shows the locations of the test sites and the existing forest habitat types.



	Angelberger Forst		Taubenberg	
	in ha	in %	in ha	in %
9110	114.7	17.9	34.2	1.9
9130	22.1	3.5	532.8	28.9
9160	8.3	1.3	-	-
9180	-	-	5.0	0.27
91D0	-	-	1.4	0.08
91D3	-	-	0.5	0.03
91D4	-	-	0.9	0.05
91E0	12.9	2.0	145.0	7.9
9410	-	-	15.9	0.9

Fig. 1: Test sites in the pre-alpine area of the federal state Bavaria. The “Angelberger Forst” area is dominated by habitat type 9110 (L u z u l o – F a g e t u m) while the “Taubenberg” area is dominated by habitat type 9130 (A s p e r u l o – F a g e t u m). For the area of the “Taubenberg” it is important to notice that habitat type 9130 consists of a considerable percentage of fir-mixture. Within European NATURA 2000 areas *Abies* forests should be recorded carefully as special habitats. Because of their transitional character between temperate beech forests (habitat type 9130) and boreal spruce forests (habitat type 9410) the forest type is assigned to habitat type 9130 (WALENTOWSKI et al. 2005).

Spatial modelling of potential natural forest associations

Although the forest composition in Central Europe is heavily influenced by human utilization, the existence of certain forest types depends on environmental conditions. Those site factors, e.g. determined by soil type, altitude above sea level and steepness of the surface, by specific meso- and micro-climatic conditions, or availability of water are even included in planting decisions with the use of forestry site maps. Consequently, spatial modelling based on the most significant environmental factors and empirical knowledge about the growth conditions of the important tree species can help to determine potential natural vegetation on comprehensible algorihtms (DÖRING & JANSEN 2005; JANSEN et al. 2002). Moreover, at a biogeographic scale the approach can help to identify the range and the area covered for each habitat. In combination with remote sensing data a spatial modelling provides an important tool for complex monitoring tasks (FÖRSTER et al. 2005; FRICK 2004).

For the modelling of the potential natural forest associations a digital terrain model (DTM 5 and DTM 25), a conceptual soil map (1 : 25.000) as well as a forestry site map were used (see Table 1). To exclude regional knowledge and receive results transferable to other NATURA 2000 sites, the data was processed without a field survey.

Tab. 1: List of existing spatial data. Because of the higher percentage of private forest in the „Taubenberg“ area, the availibility of information is more difficult.

Data Type	Angelberger Forst	Taubenberg
Map of habitat types	available	available
Digital Terrain Model	available (DTM 25)	available (DTM 5 and DTM 25)
Climate data	Climate atlas Bavaria	Climate atlas Bavaria
Conceptual Soil Map	available	available
Forestry Site Map	available	not available
Silvicultural Map	available	not available
Management Plan	available	not availbale

Rule-based method
The purpose of this easily comprehensible and rule-based method was to model potential natural forest associations in areas with identical natural woodland composition (WALENTOWSKI et al. 2004). The test sites are situated in the region of mountainous mixed forest (Taubenberg) and beech forest (Angelberger Forst). For habitat types, which could exist in this natural woodland composition, a register of location-factors was developed, including soil type, relief type, water balance, and site-related additional attributes, such as the location of very dry areas. Furthermore sites with a high (H) suitability and sites where the existence of the habitat type is generally possible (P) or excludable (E) were distinguished. Based on the existing suitability the geo-data were combined to a set of rules (see Figure 2):

1. Modelling of locations with high (H) and excludable (E) suitability for a habitat type. As an example, the possibility of the existence of bog woodland (91D0) on brown soils will be excluded, while the existence on peaty soils is highly possible.
2. Modelling of the possible occurrences (P) of a habitat type. A case in point would be the suitability of Luzulo – Fagetum (9110), which has a wide range of possibilities to occur. This habitat type can grow on different relief types (southern exposition, steep slopes, hilltops) as well as on different soil types (sand, gravel). These geo-factors are not spatially exclusive. Therefore a site can be chosen as a possible habitat type due to one or several parameters. In this case, the number of possible occurrences was summed up.
3. The calculated site qualities for the habitat types were combined. Firstly a potential forest association is chosen for areas with high suitability (H). At sites without H the habitat type with the largest number of possible occurrences was selected.
4. At each grid cell the dominating habitat type will be chosen as the potential natural forest association. The result is a complete spatial database of the potential natural vegetation.

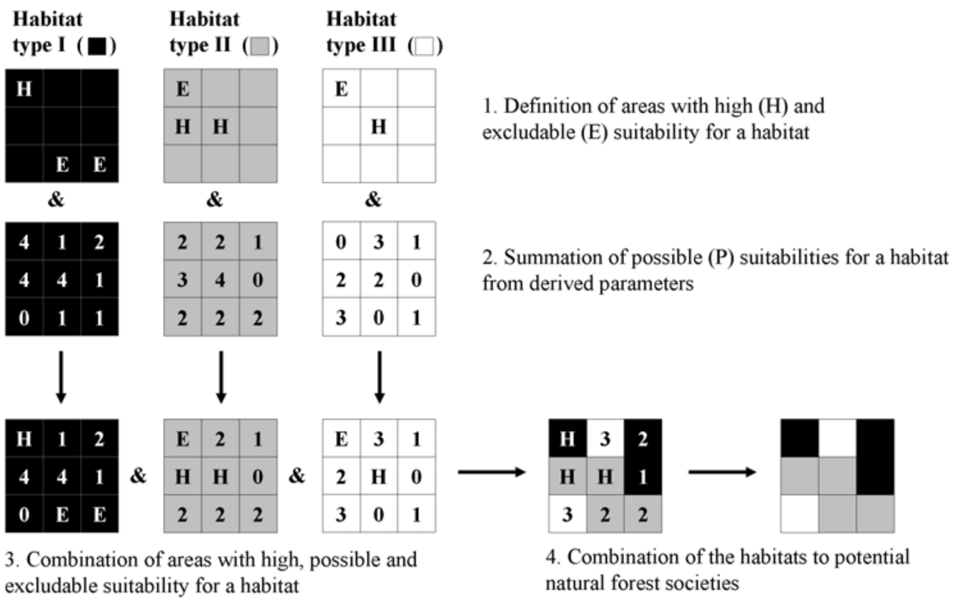


Fig. 2: Scheme of the rule-based model.

Multivariate clustering of relief types
The multivariate clustering method of relief types (developed from SCILANDS inc.) assumes that distribution patterns of various site specific factors are significantly affected by changes of the terrain. Classifying the terrain into landscape ecologic relevant morphographic units can give important evidences concerning the distribution of woodland associations. Therefore three autonomous relief type categories of the terrain were calculated:

- Subdivision of the relief in summit areas, bottom areas, slopes, and closed depressions.
- Differentiation of areas with convergence of discharge (e. g. valleys), areas with divergence of discharge, and intermediate areas, which mediate between convergence and divergence.

- The terrain is organised into areas with a slope perpendicular to contour lines and into areas which are steepened or flattened relative to the extremes.

The calculated subdivisions were summarised to clusters. The applied approach is a combination of the iterative minimum distance method (FORGY 1965) and of the hill climbing routine (RUBIN 1967). The differentiated clusters were assigned to the possible habitat type in the pre-alpine area. The method relies exclusively on the digital terrain model (DTM). Hence only habitat types which strongly depend on relief parameters, such as Tilio – Acerion forests of slopes, screes and ravines (9180), can be processed. Because of the higher intensity of the relief only the NATURA 2000 area „Taubenberg“ was used for the multivariate clustering of single habitat types, such as 9180 or 9150.

Fuzzy logic method

The relation between a suitable site and a vegetation association is often described as a “blurred relation” (GLAVAC 1996). The mathematical branch of fuzzy logic (ZADEH 1978) offers an instrument for handling blurred and only qualitatively described information, so-called fuzzy relations. Due to the fact that there is a great variety of knowledge about the relation between site conditions and plant associations (ELLENBERG 1996), the model BERN (**B**ioindication for **E**cosystem **R**egeneration towards **N**atural conditions) was developed to integrate these facts.

In order to better integrate ecosystematic connections, the BERN model was developed on the basis of empirical compilations, performed within a well-monitored region of Germany (SCHLUTOW & HÜBENER 2004). The BERN model database includes in the first stage only the fundamental niches of the plant species with their blurred thresholds of the suitable site parameters (base saturation, C/N-ratio, soil moisture, length of vegetation period and continentality index (SCHLUTOW & HÜBENER 2005). The combination of these site-factors which influence the vegetation vitality results in a possibility for plant existence. In the second stage the niche of the whole plant community had been modelled by combining the fundamental niches of the constant plant species with a fuzzy “AND” operator.
The model consists of the following stages:

1. Investigation of the primary natural characteristic of the site conditions (soil moisture, climate, relief type, exposition, soil type).
2. The BERN database contains fuzzy constraints for >700 plant species according to the parameters mentioned above, taken from expert literature of the region (OBERDORFER 1992; WALENTOWSKI et al. 2004). The fuzzy constraints are combined by the minimum operator, because the ecological limiting factor (e.g. poor soils) represses the plant growth, even if all other site-factors are in favour for the development of certain vegetation. This leads to a 5 dimensional possibility distribution function of the species for the site conditions.
3. The possibility measures were combined with a fuzzy gamma operator regarding the species of a certain vegetation type.

As Figure 3 shows for the example of the beech (left), different distribution functions of the possibility of occurrence of tree species in relation to the site-factors were developed and used competitively. In a second step the tree species were aggregated to habitat types (here Luzulo – Fagetum – 9110). The habitat type with the highest possibility of occurrence was assigned to each raster cell.

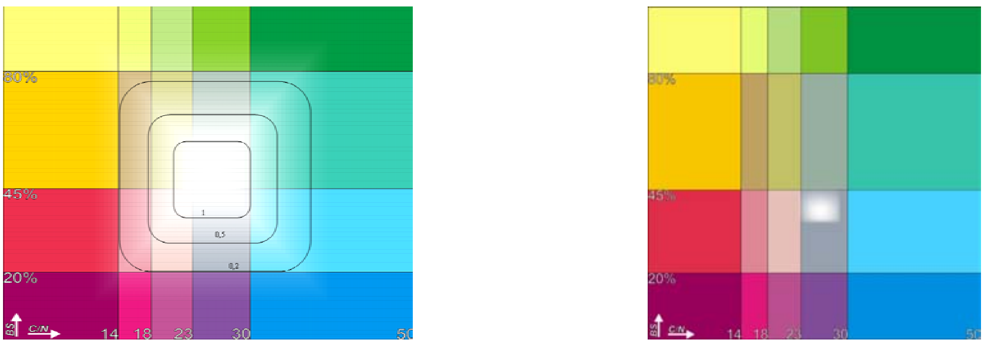
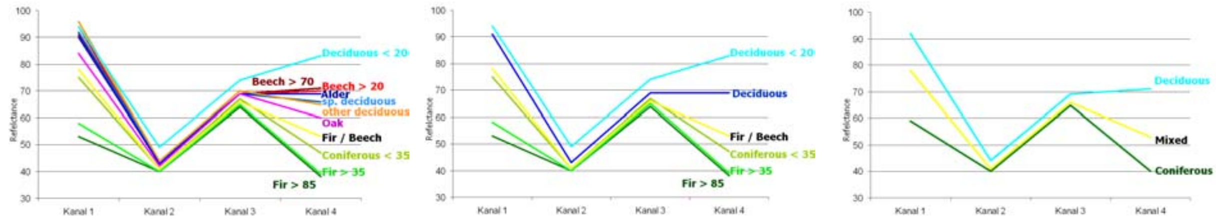


Fig. 3: Distribution function of the possibility of occurrence of beech (*Fagus sylvatica*) and the habitat type Luzulo – Fagetum in relation to the site-factors base saturation and C/N-Relation. The white colour shows the distribution of the possibility of occurrence for beech from 0 to 1.

Classification of forest types and combination with the modelling results

The implementation of remote sensing in detection and monitoring of NATURA 2000 habitats and site quality key parameters is stated by various authors (GRANKE et al. 2004; LANG & LANGANKE 2005). In order to identify real forest habitat types, the modelled potential natural forest associations had to be combined with a classification of the in situ vegetation. To guarantee a possible implementation into the workflow of the local authorities, the acquired data had to be cost-effective and processable using standard methods. The satellites SPOT5 and ASTER were considered suitable for the differentiation of coniferous, deciduous, and mixed forest as they offer a spatial resolution of 5 m to 15 m and spectral bands in the infrared and near infrared region.

The satellite scenes of SPOT5 (acquisition date: 07.09.04) and ASTER (acquisition date: 14.09.04) were georeferenced using the DTM. Furthermore a Minnaert correction was carried out with the objective of topographic normalisation (KLEINSCHMIT & COENRADIE 2005). On the basis of scanned and georeferenced true colour air photographs and silvicultural maps, training areas for all existing principal tree species and types of mixture were defined. The result was summarised to higher-ranking classes (see Figure 4). On the basis of these combined training areas a Maximum Likelihood classification was carried out. The result was validated by the use of forest management maps and local knowledge of forest officials.



(a) (b) (c)

Fig. 4: Example of the summarising of tree classes for the test area "Angelberger Forst". The reflectance values were taken from SPOT5 data and assigned to classes with the help of air photographs and silvicultural maps. In the first step (a) different classes of age, tree species and mixed stands were taken, but a reliable information was not possible due to similar spectral behaviour and individual variance of sample. Therefore deciduous trees were summarised to the class deciduous (b). Because the age information was not necessary for this application, the classes were combined to Deciduous, Mixed and Coniferous (c).

For the test site „Angelberger Forst" the classes deciduous, coniferous, and mixed forest were detected, while for the test site „Taubenberg" the classes deciduous, coniferous – non fir, coniferous – fir and mixed forest were recognised. The results correspond to the experiences of BLASCHKE & FELBERMEIER (2003), who detected similar classes with ASTER and SPOT4. Finally the scenes were segmented in two levels of detail. The majority class in one object was assigned as attribute to each polygon in order to receive more homogeneous classes.

The results of the satellite classification were combined with the methods described in section 2 in order to calculate the potential natural forest associations. The potential forest habitat type is only selected if the classified real vegetation corresponds to the topmost forest association (see Figure 5). An example would be the detection of a potential beech forest association, which is not considered a potential habitat type if the satellite classification result is coniferous forest.

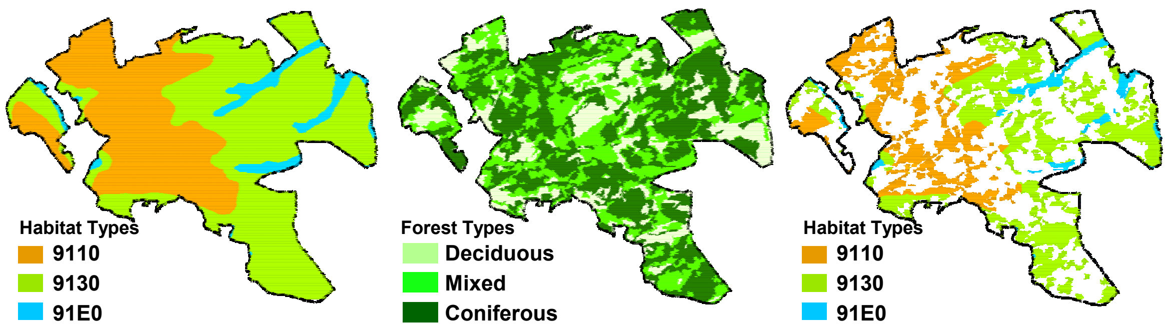


Fig. 5a: Potential natural forest (left), classification of SPOT 5 data (middle) and combination to potential habitat types (right) for the „Angelberger Forst" (example from fuzzy logic method).

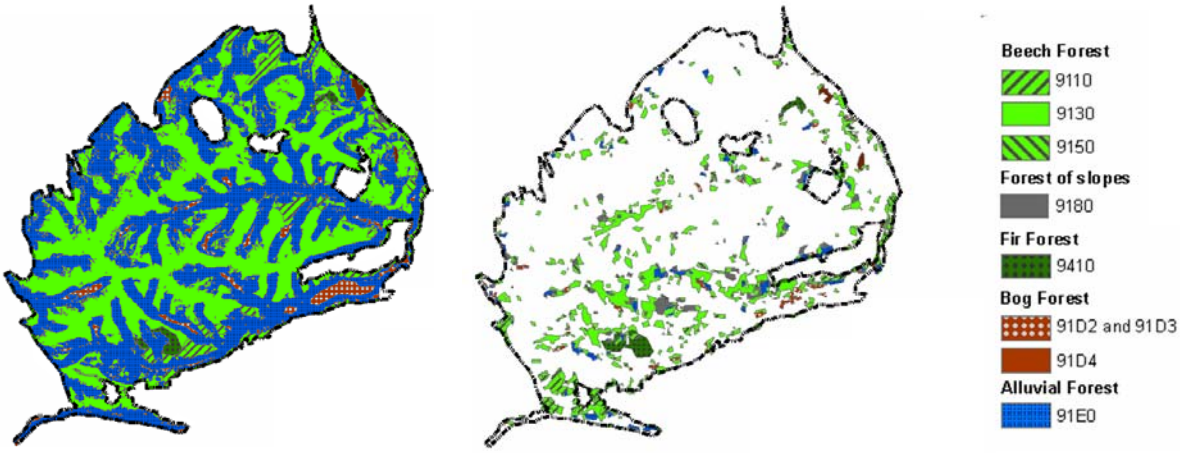


Fig. 5b: Potential natural forest associations (left) and derived potential habitat types (right) for the test site „Taubenberg“ (example from rule-based method).

Comparison of modelled and terrestrial mapped habitat types

The results were compared to the terrestrial mapped habitat types from the forest management plans of the test sites (see Table 2). A great part of the considered habitat types could be detected by the use of the model approaches. The best results were achieved by using the satellite data with higher spatial resolution (SPOT5) on the test site "Angelberger Forst". The rule-based method and the fuzzy-logic approach obtained similar results in comparison to the management plan. Generally, apart from Luzulo-Fagetum (9110) the fuzzy logic approach achieved slightly higher results. An additional factor for a good correlation is the utilisation of a forestry site map (FSM) within the model. It was evident that the models tend to underestimate habitat types with distinct site specific growing conditions, such as Alluvial Forest (91E0) and Tilio-Acerion Forest of slopes (9180).

Tab. 2: Exemplary comparison of the results of the three modelling approaches with the forest management plan. Additionally the test site „Angelberger Forst“ was processed with and without a forestry site map (FSM). The term "n.a." stands for "not available" because the habitat type is inexistent in this area or was not processed due to modelling restrictions (green marked areas with accuracies over 80 per cent, orange marked areas with accuracies below 60 per cent).

	Rule-based Method			Fuzzy Logic method			Clustering of relief types
Habitat types	Angelberger Forst with FSM (in %)	Angelberger Forst without FSM (in %)	Taubenberg without FSM (in %)	Angelberger Forst with FSM (in %)	Angelberger Forst without FSM (in %)	Taubenberg without FSM (in %)	Taubenberg without FSM (in %)
9110	95.4	92.3	62.5	68.0	60.3	72.4	n.a.
9130	70.6	66.0	76.9	74.8	72.0	92.3	n.a.
9180	n.a.	n.a.	40.0	n.a.	n.a.	40.0	80.0
9410	n.a.	n.a.	66.7	n.a.	n.a.	66.7	n.a.
91D2 – 91D4	n.a.	n.a.	80.0	n.a.	n.a.	85.7	n.a.
91E0	91.7	58.8	46.2	75.0	53.3	73.1	n.a.
9160	88.2	73.9	n.a.	86.7	n.a.	n.a.	n.a.

In the case of habitat type 9180 the clustering technique of relief types yields better results. Thus it was possible to detect 80 % of the areas with Tilio – Acerion forests of slopes, screes and ravines (9180), while the rule-based method achieved only 40 % of this habitat type. Within this research study, the clustering of relief types was only used for this habitat type. However it can be suggested, that this modelling approach is especially successful in surface-dominated areas such as alpine forests.

A more detailed comparison, which involved the detected area size of model results and forest management plans, resulted in increased differences. As an example, the areas of Alluvial Forest of the data sets intersect only to 33.2 %. This is due to the model assumption that a habitat type necessarily has the potential natural vegetation. However, a modelled and detected deciduous beech forest can be an artificial planted forest of neophytes. Therefore, it would be impossible to detect these kinds of errors by the use of the methods described above.

The results could be improved if a buffer area surrounding the modelled habitat type would be applied as "suspected potential habitat type". For the rule-based and the fuzzy-logic method the accuracy could significantly be increased by using the second dominant modelled habitat type (see Figure 6). When combining potential habitat type and potential natural forest association the subordinated forest association could be regarded as possible result.

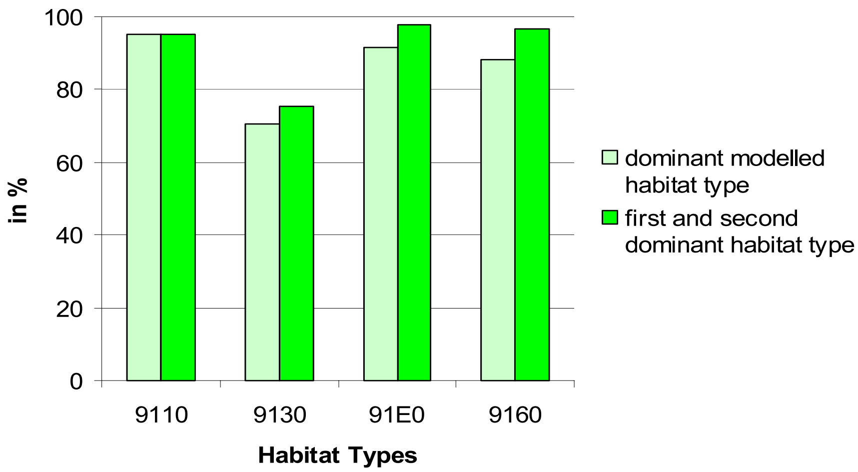


Fig. 6: Increased classification accuracy in modelling the second dominant modelled habitat type (example from rule-based method). The results raise up to 7.6 per cent.

To test the efficiency of the modelled approaches, the time expenses for the realisation were recorded. Because of the restricted model boundaries of the clustering of relief types, this was only possible for the rule-based and the fuzzy-logic methods (see Table 3). The tasks were divided into non-recurring steps (e.g. development of a mathematical and botanical basis, data-base design) and recurring steps (e.g. calibration according to special data availability, exceptional natural conditions). Although from an economic point of view this comparison is only valid to a limited degree, a few tendencies do arise. The rule-based approach is more efficient in the development of non-recurring tasks (165 h) while the fuzzy-logic method can manage the recurring tasks more efficiently (24 to 40 h). Therefore with more modelled NATURA 2000 areas the fuzzy-logic approach is more effective. On the other hand, the rule-based method is implemented in standard GIS software (ArcGIS Model Builder) while the BERN model is a separate software package. This makes the rule-based approach more easily applicable.

Tab. 3: Time expenses for the rule-based and the fuzzy logic modelling approach.

	Required Time (in hours)	
Non-recurring tasks	Rule-based	Fuzzy Logic
Development of mathematical and botanical basis Technical realisation of the model	35	30
Preparation of the vegetation data basis	130	160
Recurring Tasks (for each area)		
Validation and calibration for test sites	30-40	8-24
Presentation of results (cartography)	16	16
Sum	**211 - 221**	**214 – 230**

Analysis of the support the models can give to aerial photograph mapping

Besides the modelling of potential natural forest vegetation for the information on the biogeographic level of NATURA 2000, the results of the modelling could be used to support aerial photograph mapping. The mapping of NATURA 2000 areas with the help of very high resolution aerial or satellite images will become of increasing importance. This is due to the monitoring duties of each EU member state obliged to observe the quality of the NATURA 2000 areas in a 6-years cycle (EUROPEAN COMMISSION 2003).

The modelling results were used to evaluate the usage to support aerial photograph mapping. Aerial photographs of the test sites were acquired, orthorectified and classified by the use of the software ArcGIS Stereo Analyst (SEITZ & FISCHER 2005). The imagery was analysed

- without any additional help,
- with the use of the forestry site map,
- with the rule-based model and
- with both ancillary information.

As was to be expected, the mapping without any additional information yielded the poorest results. However, all other results were not convincing. Even the best approach with only the forest site map tends to heavily underestimate oak-hornbeam forests, while not reaching sufficient results for all other habitat type classes (see Figure 7).

The inadequate results depended on the quality of the aerial photographs. The imagery was supplied without the near infrared information. Additionally, the scan quality was not of a very high standard. It was recognisable that additional information improved the mapping results. However, a definite conclusion as to what kind of information is useful for the mapping process could not be drawn. It can only be stated that mapping NATURA 2000 forest habitat types can only be successful with colour infrared imagery (aerial photographs or satellite based).

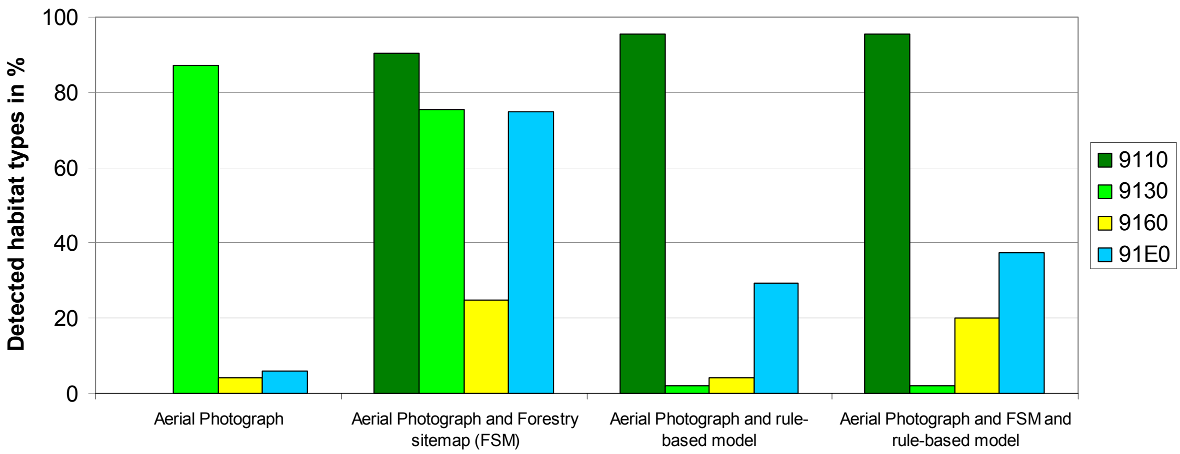


Fig. 7: Mapping of habitat types with different additional information (Angelberger Forst).

Discussion and outlook

The results of this study have shown great potentials of the modelling of forest vegetation. They are especially valuable when combined with remote sensing data of high geometric resolution. These results can support mapping as well as monitoring of biodiversity within and outside of the declared boundaries of NATURA 2000 areas. However, there are some points which should be discussed in the context of NATURA 2000.

Only a small percentage of the European forests is still in the condition of natural circumstances (UNEP WORLD CONSERVATION MONITORING CENTRE 2000). The forest has been changed for economic, touristic or hunting reasons, to name only some. However, the assumption of the model is that the vegetation is still natural. Even the areas within NATURA 2000 boundaries are not without human influences. This supposition can be partly clarified by using remote sensing classifications as worked out in this article. However, only a very detailed classification with very high resolution data and near infrared information is able to reduce these errors due to model restrictions. Another possibility would be to include silvicultural information (LONG et al. 2004) into the modelling process to achieve a more realistic result.

Another point of discussion is the method of terrestrial mapping. Often the transitions in between habitat types or between a habitat type and other forest are not clearly to detect. In addition habitat types will be mapped even if the main species covers only a small proportion of an area. The intention in mapping these poorly developed habitat types is to ascribe a higher importance to them, because there is a potential development of the forest association. As a consequence terrestrial mapped habitat types (especially in cases of low percentages of deciduous forest) cannot be detected with remote sensing techniques.

The difficulties explained above lead to the realisation that the dealing with a probability to a certain habitat type would be more reasonable than searching for defined boundaries of habitat types (see Figure 8). This approach would be more in harmony with the theory of ecotones (HILL et al. 2005). Moreover local knowledge could be included more directly. The rule-based model as well as the fuzzy-logic model could implement such probabilities of occurrence in their computation.

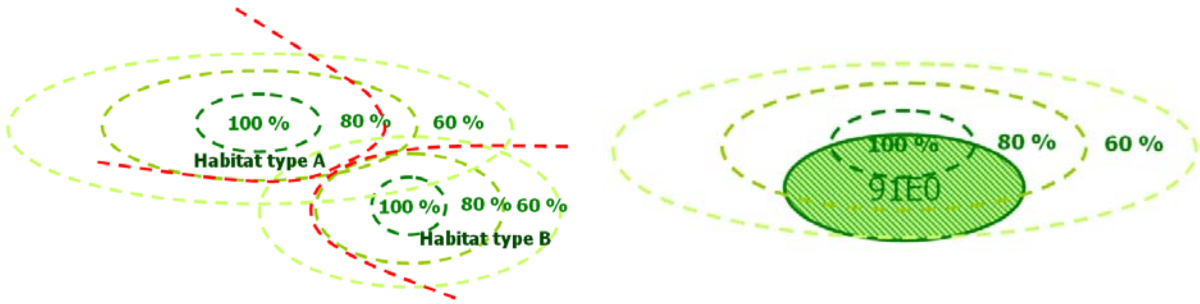


Fig. 8: The use of modelling techniques in monitoring NATURA 2000 areas. Instead of sharp borders of assignment to one habitat type, the modelling approaches could calculate regions of probability (left figure – green dashed lines). Within these regions it is possible for regional authorities with local knowledge to define habitat-type borders (left figure – red dashed lines). Changes of the habitat type could be monitored by percentages of membership to a defined habitat type (right). When the percentage of membership has changed, the habitat type changed its condition.

The most promising way of improving the results is the use of very high resolution remote sensing data. Approaches with the Quickbird satellite data (FRICK et al. 2005) and the HRSC airborne camera (GÄHLER et al. 2004) could achieve very detailed classification outcomes. Moreover, the direct inclusion of additional geo-data in the remote sensing classification could be applied. A combined application of modelled location-factors and precise classification results is certainly a solution for the great demand of monitoring techniques for NATURA 2000 areas.

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