Acta ZooBot Austria **160**, 2024, 255–268

Evaluation of habitats under the EU's Habitats Directive, according to their feasibility for a remote sensing-based identification and delineation

Nina Weber, Thomas Strasser, Hannah Augustin

A European Union wide recognised instrument for monitoring habitat diversity is the assessment of habitats protected under Annex I of the European Union's Habitats Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and wild fauna and flora). Nevertheless, there is still no system for a comprehensive mapping of the distribution of the Habitats Directive Annex I habitat types throughout Austria. In this study, the feasibility of using remote sensing (RS) data and methods as a source for identification and delineation of Annex I habitat types, was evaluated. The evaluation was conducted through an expert-based multiple criteria decision analysis approach (MCDA). Within MCDA, various methodologies are available. It was decided to conduct a weighted scoring method (i.e., decision matrix). For the decision matrix all the Annex I habitat types relevant for Austria were chosen as selection options. For the evaluation of the selection options (FFH-habitat types), assessment criteria, which refer to habitat related environmental site conditions, vegetation characteristics, RS sensor-, platform-, and data related characteristics (e.g., spectral and multitemporal properties of vegetation and height information), were defined. With the support of an expert team (experts in vegetation ecology and remote sensing) descriptive attributes were assigned for each habitat type and corresponding assessment criteria. Thus, a comprehensive qualitative knowledge database, including relevant habitat properties for a remote sensing-based identification and delineation, was created. Based on this underlying knowledge database all the habitat types relevant for Austria were evaluated by the experts: The descriptive attributes, for each criterion, were rated according to their feasibility for explicit identification and delineation of habitats and transferred to quantitative scores (whereas a higher feasibility achieved a higher score). The achieved scores for all the assessment criteria were then summed up for each habitat. The ranking and interpretation of the summed scores for each habitat type provides information on the feasibility of country-wide identification and delineation of the EU's Habitats Directive Annex I habitat types using remote sensing modelling approaches (the higher the final score – the more feasible is an explicit identification and delineation through remote-sensing modelling approaches for the respective habitat). It was found that forest habitat types have a higher likelihood for country-wide identification, whereas most of the grassland habitat types have a very low likelihood.

Weber N, Strasser T, Augustin H (2024) Bewertung von FFH-Lebensraumtypen bezüglich der Machbarkeit einer fernerkundungsgestützten Identifikation und Abgrenzung.
Die Bewertung der nach Anhang I der FFH-Richtlinie (Fauna-Flora-Habitat Richtlinie) geschützten Lebensräume ist ein EU-weit anerkanntes Instrument zur Überwachung der Biodiversität und Lebensraumvielfalt. Obwohl in Österreich ein Stichproben-basiertes Monitoring- und Reporting-Verfahren implementiert ist, gibt es noch kein System für eine flächendeckende Kartierung der Verbreitung von FFH-Lebensräumen. In dieser Studie wurde die Machbarkeit der Verwendung von Fernerkundungs-basierten Methoden und Daten als Quelle für die Identifizierung und Abgrenzung von Lebensraumtypen, nach Anhang I der FFH-Richtlinie, bewertet. Die Bewertung wurde mit Hilfe eines Experten-basierten Ansatzes zur multikriteriellen Entscheidungsanalyse (multiple criteria decision analysis – MCDA) durchgeführt. Im Rahmen der MCDA gibt es verschiedene Methoden. Es wurde beschlossen, ein gewichtetes Scoring-Verfahren (d. h. eine Entscheidungsmatrix) durchzuführen. Für die Entscheidungsmatrix wurden alle für Österreich relevanten Anhang I-Lebensraumtypen als Auswahloptionen festgelegt. Für die Evaluierung dieser Auswahloptionen (FFH-Lebensraumtypen) wurden Bewertungskriterien definiert, die sich auf Umwelt- und Standortbedingungen

sowie Vegetationseigenschaften der jeweiligen Habitate beziehen, und bezüglich der Identifikation durch RS-Sensoren, RS-Plattformen und datenbezogener Eigenschaften (z. B. spektrale und multitemporale Eigenschaften der Vegetation und Höheninformationen) Relevanz haben. Mit Unterstützung eines Expertenteams (Experten für Vegetationsökologie und Fernerkundung) wurden für jeden Lebensraumtyp, entsprechend den definierten Bewertungskriterien, beschreibende Attribute festgelegt. Auf diese Weise wurde eine umfassende qualitative Wissensdatenbank geschaffen, die relevante Habitat-Eigenschaften für eine fernerkundungsbasierte Identifizierung und Abgrenzung enthält. Auf Basis dieser zugrunde liegenden Wissensdatenbank wurden alle für Österreich relevanten Lebensraumtypen von den Experten bewertet: Die beschreibenden Attribute wurden für jedes Bewertungskriterium entsprechend dessen Bedeutung bzw. Relevanz für die eindeutige Identifizierung und Abgrenzung der jeweils zugeordneten Lebensraumtypen bewertet und in quantitative Punktzahlen übertragen (wobei eine bessere Abgrenzbarkeit durch das Attribut eine höhere Punktzahl ergab). In einem letzten Schritt wurden die erreichten Punktzahlen aller Bewertungskriterien für jeden Lebensraum summiert. Die Einstufung und Interpretation der summierten Punktzahlen für jeden Lebensraumtyp gibt Aufschluss über die Machbarkeit der eindeutigen und großflächigen Identifizierung und Abgrenzung von Anhang I Lebensraumtypen durch Fernerkundungsmodellierung (je höher die endgültige Punktzahl, desto durchführbarer ist eine explizite Identifizierung und Abgrenzung durch Fernerkundungsmodelle für den jeweiligen Lebensraum). Es wurde festgestellt, dass Waldlebensraumtypen eine höhere Wahrscheinlichkeit für die eindeutige und großflächige Abgrenzbarkeit und Identifizierung haben, während die meisten Grünlandlebensraumtypen diesbezüglich eine geringe Wahrscheinlichkeit aufweisen.

Keywords: biodiversity, Habitats Directive, habitat classification, earth observation, feasibility evaluation.

Introduction

Biodiversity in Austria has been in sharp decline for decades (e.g. Umweltbundesamt, 2022; Teufelbauer & Seaman, 2023; Bartel, 2019; Suske et al. 2019; Zuna-Kratky et al., 2022; Ellmauer et al. 2020). This development has also been recognised at a global and European level, and attempts are being made to intervene socially and politically, for example, by the "Kunming-Montreal Global Biodiversity Framework" (CBD/COP/DEC/15/4, 2022), the "EU Biodiversity Strategy for 2030" (European Union, 2020), and the "National Biodiversity Strategy Austria 2030+" (Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie, 2022). Every 6 years, mapping and evaluation of habitats protected under Annex I of the Habitats Directive (HabDir) (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora) is conducted for the European Union's reporting obligation according to Articles 11 and 17 of the FFH-Directive. This is an essential Europe-wide instrument for monitoring habitat and plant diversity and could possibly also be applied as baseline / for evaluation purposes for the upcoming EU`s "Nature Restoration Law". The system in Austria for assessing HabDir Annex I habitat types and evaluation of their conservation status is a sampling design for expert-based in-field observations of species (presence / absence), including rating of the species composition and structure, and additional site conditions (Ellmauer & Essl 2005). This system fulfils the requirements for EU reporting duties on conservation status. However, this system does not provide comprehensive and up to date information with respect to the country-wide distribution of the HabDir Annex I habitat types.

Satellite and airborne remote sensing data are considered as an appropriate data source for country-wide habitat monitoring approaches, since acquired data (i.e., images) cover large areas and are regularly updated or available on demand (Lang et al. 2015a, 2015b; Corbane et al. 2015). The availability of different sensors has developed over the past years in terms of increased spatial resolution, higher temporal frequency, more cost-free data, growing data availability and a wider variety of data providers and archives (for more information on the current state of the art, also see "Textbox – State of the art: Earth observation sensors and data providers").

Textbox – State of the art: Earth observation sensors and data providers

Copernicus Sentinel-2 optical data are provided cost-free and offer a high spatial resolution (up to 10 m) with an average temporal frequency of at least 5 days, and up to 2 to 3 days, depending on the aerial coverage of the relative orbits. Sentinel-1 radar data are also available on average every 6 days. Planet Labs PlanetScope and SkySat satellite constellations, as well as Satellogic's NewSat constellation offer optical satellite data with higher spatial resolution and very high temporal frequency (up to intra daily) based on small cube satellites in high numbers. New satellite constellations are in development, like Maxar's WorldView Legion and Planet Labs Pelican. Other very high optical spatial resolution satellite missions offer a lower temporal frequency (daily on request with increased sensor viewing) but a high data fidelity, like Maxar's WorldView-2/3/4, Airbus Pléiades and Pleaides-Neo, or SuperView1 (GaoJing1) operated by Beijing Space View Tech.

In Austria, airborne remote sensing campaigns are conducted on a regular basis, with orthoimage acquisitions occurring every three years and LiDAR-data in a cross of every five to ten years. The spatial resolution and high frequency of observations over time are key requirements for characterizing habitats through the phenology of species and structural composition. The HabDir Annex I habitats consists of biotic or abiotic entities (e.g., individual plants, plant communities and various plant community compositions), that can be measured over all levels of the vegetation and biodiversity hierarchy (Lausch et al. 2016; Strahler et al. 1986). Based on the urgent need for up-to-date information on country-wide distribution of the HabDir Annex I habitat types, and the current state of the art of satellite and airborne remote sensing data availability, this study conducts an evaluation on the feasibility of identification and delineation of FFH-habitat types through remote sensing based data and methods.

Methodology

To assess the feasibility for the identification of HabDir Annex I habitat types through a remote sensing approach, an expert-based multiple criteria decision analysis approach (MCDA) was chosen. Within MCDA, various methodologies are available (Cinelli et al. 2020). It was decided to conduct a weighted scoring method (i.e., decision matrix – also see Tab. 1), because this methodology requires an ongoing expert discussion and achieves transparent outcomes which enable a ranking of the results.

As preconditions, the current state of remote sensing technology was considered, and only data and technology that allow for a country-wide implementation in Austria were included. The focus was put on remote sensing data that provide adequate spatial and temporal coverage in a regular and timely way, and methods with a high degree of automatization. Furthermore, multiple remote sensing data sources and thematic datasets that seemed suitable to identify HabDir Annex I habitats were considered. The considered remote sensing data included multispectral and multitemporal optical satellite data with high (10 to 20 m) to very high spatial resolution (< 3 m), orthophotos and their derivatives (e.g., spectral values on pixel and object level, texture), and LiDAR-based digital elevation models (DEM) and derivatives (e.g., slope, curvature, terrain wetness). Additionally, thematic datasets on: ecoregions, geology, soils, wetness and humidity, glaciers, caves, rivers, land use, as well as datasets from the European Union's Copernicus Program, for example, CLMS (Copernicus Land Monitoring Service dataset) high resolution layer, CORINE land cover and CLC+ (Copernicus Land Cover – complemented and extended CLMS dataset), biophysical parameters, riparian zones, and N2K (Copernicus Land Monitoring Service – Natura 2000 product) were used.

For the MCDA approach, first, the list of the EU's Habitats Directive Annex I habitat types and habitat descriptions for Austria (e.g., Ellmauer & Essl 2005; Ellmauer et al. 2020) was reviewed. All Annex I habitat types relevant for Austria were chosen as selection options (sometimes also referred to as "alternatives") for the MCDA decision matrix.

In a second step, specific assessment criteria and corresponding weightings were selected and defined. The assessment criteria needed to regard relevant distinguishing features and therefore include habitat related environmental site conditions, vegetation characteristics, as well as RS sensor-, platform-, and data related characteristics (e.g., spectral and multitemporal properties of vegetation and height information). The weightings were assigned to each respective criterion, ranging from 1–5 (also see Tab. 1) and correspond to the influence a criterion has on the overall results (whereas a higher weighting refers to a higher influence of the criterion with respect to the results).

Tab. 1: Weighted scoring method (decision matrix). – Tab. 1: Gewichtetes Scoring-Verfahren (Entscheidungsmatrix).

Selection Options		**Assessment criteria**					**Scoring result**
		Criterion a	Criterion b	Criterion c	Criterion d	Criterion e	
	Weightings	1	2	3	4	5	
Habitat type 1	Score	0	1	0	2	1	
	Total	0	2	0	8	5	15
Habitat type 2	Score	1	1	2	2	0	
	Total	1	2	6	8	0	17
Habitat type 3	Score	2	1	2	0	1	
	Total	2	2	6	0	5	15

The selection and definition of the assessment criteria was based on the habitat definitions and corresponding habitat characteristics in the respective literature (e.g. Ellmauer & Essl 2005; Ellmauer et al. 2020). For the specific definitions of assessment criteria also see Table 2. Both the definition of assessment criteria and assignment of corresponding weights were subject to expert-discussions and feedback loops within an expert-team.

Tab. 2: Selected assessment criteria, description and corresponding assigned weights, for MCDA weighted scoring method. – Tab. 2: Definierte Bewertungskriterien, Beschreibungen und entsprechend zugeteilte Gewichtungen, für das MCDA gewichtete Scoring-Verfahren.

Assessment criteria	**Explanatory remarks / considerations for experts to rate each criterion according to their contribution for discerning habitat types:**	**Assessment criteria weights (1 to 5)**
Climatic conditions	determining climate factors (e.g., climate zone, average temperature, annual precipitation; integration of available spatial data)	2
Altitude level	altitudinal range of habitat distribution (e.g., based on LiDAR DEM)	2
Slope	average expectable range of inclination (e.g.: 1st order derivative of LiDAR DEM)	5
Terrain curvature	specific terrain (e.g., flat, concave, convex; 2nd order derivative of LiDAR DEM and terrain indices, geomorphological mapping)	2
Geology	geological substratum (e.g., silicious, or calcareous; spatial intersection of available geological maps and data)	2
Ground Humidity	degree of humidity (e.g., dry, moist, wet, permanent, or periodically flooded; soil moisture index or ground water modelling, land surface data)	2
Human impact	habitat-specific land use patterns (e.g., mowing, grazing, forestry)	1
Frequency of occurrence (in Austria)	expected frequency of occurrence in Austria and success for identification (e.g., rare, uncommon, common)	1
Dominance	vegetation composition (e.g., characteristic, and dominant plant life forms and plant species)	3
Structural homogeneity / heterogeneity of surface	composition and variation of biotic and abiotic entities and instructions for delineation according to Ellmauer & Essel (2005) and Ellmauer et al (2020)	2
Neighbourhood relations	any mandatory, expected, or probable neighbourhood relationships with biotic or abiotic entities or habitat types, and degree to support explicit identification (e.g., rule-based integration in object-based image analysis)	2
Spatial distribution	any other location-based information and neighbourhood relations (e.g., geographical location; by rule-based integration in object-based image analysis)	1
Minimum size of eligible area	according to Ellmauer.& Essel (2005); and Ellmauer et al (2020)	4
Pattern	pattern of biotic and abiotic surface composition and variation (e.g., using image texture)	3
Spectral properties of vegetation	spectral values of biotic and abiotic entities in contrast to sensor specific spatial, spectral, and radiometric resolution and discernability	5
Temporal properties of vegetation	variation of spectral values concerning temporal aspects (e.g., seasonal changes of vegetation, e.g., change detection, deep learning of temporal curves)	5
Plant height	specific height of characteristic plant life forms or plant species (e.g., from LiDAR nDSM – Normalised Digital Surface Model, or point clouds)	3
Plant growth form	composition and structure of dominant vegetation (e.g., through visual image analysis and / or potential application of structural indices, OBIA – Object-Based Image Analysis)	1
Other comments	any other aspects for habitat type identification	1

In a third step, each listed habitat type (selection option) was evaluated by an expert team, consisting of vegetation ecologists and remote sensing specialists (also see chapter "Acknowledgements"). The evaluation was based on the assessment criteria, as defined in Table 2. This expert-based evaluation also included feedback loops and discussion rounds within the team. The evaluation process was conducted by identifying habitat-specific qualitative attributes for each criterion, transferring these attributes into a numeric score (whereas values are zero – no distinct identification, one – probable identification or two – for a distinct identification through remote sensing-based technology) and finally, summing the weighted scores to produce a final scoring result for each habitat type (whereas the maximum possible summed score is 65). An example for the evaluation procedure is displayed in Table 3. In a last step, for better readability and easier interpretation of the results, the summed scores for each habitat type were transferred into four feasibility categories of "very low", "low", "likely" and "very likely". The thresholds for the categories were identified by calculating the range of the highest and lowest score. The range was then divided into intervals to define thresholds for the categories, which were again discussed and adjusted by experts in terms of their feasibility.

Results

The expert-based MCDA process resulted in two products: a criteria table and a scoring table. For easier understandability of the the conducted expert-based MCDA rating process and its corresponding results, an example is presented in Table 3. For this demonstration purpose the HabDir Annex I habitat type 4070, called "scrub vegetation with *Pinus mugo* and *Rhododendrum hirsutum*" was chosen due to its rather suitable habitat characteristics for a remote sensing-based identification and delineation, and due to the resulting high

Tab. 3: Example of the MCDA rating process for the habitat type 4070, Scrub vegetation with *Pinus mugo* and *Rhododendrum hirsutum*. Descriptive attributes for each assessment criteria specific to the habitat type, weighted score (score x weight) and final score for the habitat type (sum of all weighted scores). – Tab. 3: Beispiel des MCDA Scoring-Verfahrens für den Habitattyp 4070, Buschvegetation mit *Pinus mugo* und *Rhododendrum hirsutum*. Habitattyp-spezifische beschreibende Attribute für jedes Bewertungskriterium, gewichtete Punktezahl (Punktezahl x Gewichtung) und endgültige Punktezahl (Summe aller gewichteten Punktezahlen).

Selection option				
HabDir Annex I habitat type	4070			
Name of habitat	Scrub vegetation with *Pinus mugo* and *Rhododendron hirsutum* (Mugo-Rhododendretum hirsuti).			
MCDA Assessment				
Assessment criteria	**Descriptive attributes**	**Score [0 to 2]**	**Weight per criterion [1 to 5]**	**Weighted score**
Climatic conditions	Oceanic to sub-oceanic	1	2	2
Altitude level	High-montane to subalpine	1	2	2
Slope	Steep	1	5	5

Terrain curvature	Not distinctive	0	2	0
Geology	Mainly over carbonate rock but also silicate rock	1	2	2
Ground Humidity	Mostly dry, sometimes fresh to alternating humidity	0	2	0
Human impact	None	0	1	0
Frequency of occurrence (in Austria)	Frequent	2	1	2
Dominance	*Pinus mugo*	2	3	6
Structural homogeneity / heterogeneity of surface	*Pinus mugo* covers > 50 % of the area. Structure = mostly uniformly covering mountain pine scrub	2	2	4
Neighbourhood relations	No explicit rules	0	2	0
Spatial distribution	No explicit rules	0	1	0
Minimum size of eligible area	0.25 hectares	2	4	8
Pattern	Mostly uniform, area-wide coverage with mountain pine scrub	2	3	6
Spectral properties of vegetation	In combination with criteria "plant height" (2 m) and "pattern" likely spectrally differentiable from other vegetation	2	5	10
Temporal properties of vegetation	As evergreen plants temporally distinguishable at the edge / end of the vegetation period	2	5	10
Plant height	Up to 2 m	2	3	6
Plant growth form	Extensively shrubby	2	1	2
Other comments	Priority habitat type	–	1	0
Final score				**65**

final score. The criteria table contains all the attributes that describe the main characteristics of each habitat type with respect to the defined assessment criteria. The scoring table contains the scores assigned to each rated assessment criterion's descriptive attribute (see the right 3 columns of Tab. 3). The sum of all weighted scores presents the final score for the given habitat type (see the bottom of Tab. 3).

As an outcome of the MCDA rating process, all the HabDir Annex I habitats relevant for Austria (in total 71), and the resulting categories of their feasibility for identification and delineation based on RS-based modelling approaches, are listed in Table 4. The categories of feasibility were identified according to the description in the "methodology" chapter and result is the following defined thresholds: "very low" [13 to 36], "low" [37 to 44], "likely" [45 to 56], and "very likely" [57 to 65]

Tab. 4: Results of MCDA weighted scoring for HabDir Annex I habitat types and categorized scoring results for assessing the feasibility of habitat type identification and delineation using remote sensing modelling approaches. – Tab. 4: Ergebnisse des MCDA gewichten Scoring-Verfahrens für Habitattypen nach Anhang I der FFH-Richtlinie, sowie kategorisierte Scoring-Ergebnisse für die Machbarkeit der Identifikation und Abgrenzung von Habitattypen mittels Fernerkundungsverfahren.

FFH-Habitat type	Name	Scoring Result	Expert-based feasibility categories
	COASTAL HABITATS AND HALOPHYTIC VEGETATION		
1530*	Pannonic salt steppes and salt marshes	37	low
	DUNES ON SEA COASTS AND IN THE INLAND		
2340	Pannonic inland dunes	33	very low
	FRESHWATER HABITATS		
3130	Oligo- to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and / or the Isoeto-Nanojuncetea	40	low
3140	Hard oligo-mesotrophic waters with benthic vegetation of *Chara spp.*	52	likely
3150	Natural eutrophic lakes with Magnopotamion or Hydrocharition – type vegetation	45	likely
3160	Natural dystrophic lakes and ponds	44	low
3220	Alpine rivers and the herbaceous vegetation along their banks	30	very low
3230	Alpine rivers and their ligneous vegetation with *Myricaria germanica*	37	low
3240	Alpine rivers and their ligneous vegetation with *Salix elaeagnos*	36	very low
3260	Water courses of plain to montane levels with the Ranunculion fluitantis and Callitricho-Batrachion vegetation	34	very low
3270	Rivers with muddy banks with Chenopodion rubri p.p. and Bidention p.p. vegetation	39	low
	TEMPERATE HEATH AND SCRUB VEGETATION		
4030	European dry heaths	54	likely
4060	Alpine and boreal heaths	47	likely
4070	Bushes with *Pinus mugo* and *Rhododendron hirsutum* (Mugo-Rhododendretum hirsuti)	65	very likely
4080	Sub-Arctic *Salix spp.* Scrub	57	very likely
40A0	Subcontinental peri-Pannonic shrublands	59	very likely

FFH-Habitat type	Name	Scoring Result	Expert-based feasibility categories
	SCLEROPHYLLOUS SCRUB		
5130	*Juniperus communis* formations on heaths or calcareous grasslands	40	low
	NATURAL AND SEMI-NATURAL GRASSLAND		
6110	Rupicolous calcareous or basophilic grasslands of the Alysso-Sedion albi	27	very low
6130	Calaminarian grasslands of the Violetalia calaminariae	23	very low
6150	Siliceous alpine and boreal grasslands	29	very low
6170	Alpine and subalpine calcareous grasslands	27	very low
6190	Rupicolous pannonic grasslands (Stipo-Festucetalia pallentis)	22	very low
6210	Semi-natural dry grasslands and scrubland facies on calcareous substrates (Festuco-Brometalia) (* important orchid sites)	16	very low
6230	Species-rich Nardus grasslands, on silicious substrates in mountain areas (and submountain areas in Continental Europe)	29	very low
6240	Sub-Pannonic steppic grasslands	27	very low
6250	Pannonic loess steppic grasslands	37	low
6260	Pannonic sand steppes	39	low
6410	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (Molinion caeruleae)	28	very low
6430	Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	31	very low
6440	Alluvial meadows of river valleys of the Cnidion dubii	33	very low
6510	Lowland hay meadows (Alopecurus pratensis, Sanguisorba officinalis)	31	very low
6520	Mountain hay meadows	30	very low
	RAISED BOGS AND MIRES AND FENS		
7110	Active raised bogs	46	likely
7120	Degraded raised bogs still capable of natural regeneration	31	very low
7130	Blanket bogs (* if active bog)	28	very low
7140	Transition mires and quaking bogs	30	very low
7150	Depressions on peat substrates of the Rhynchosporion	36	very low

FFH-Habitat type	Name	Scoring Result	Expert-based feasibility categories
7210	Calcareous fens with *Cladium mariscus* and species of the Caricion davallianae	39	low
7220	Petrifying springs with tufa formation (Cratoneurion)	20	very low
7230	Alkaline fens	30	very low
7240	Alpine pioneer formations of the Caricion bicoloris-atrofuscae	33	very low
	ROCKY HABITATS AND CAVES		
8110	Siliceous scree of the montane to snow levels (Androsacetalia alpinae and Galeopsietalia ladani)	36	very low
8120	Calcareous and calcshist screes of the montane to alpine levels (Thlaspietea rotundifolii)	38	low
8150	Medio-European upland siliceous screes	32	very low
8160	Medio-European calcareous scree of hill and montane levels	29	very low
8210	Calcareous rocky slopes with chasmophytic vegetation	32	very low
8220	Siliceous rocky slopes with chasmophytic vegetation	32	very low
8230	Siliceous rock with pioneer vegetation of the Sedo-Scleranthion or of the Sedo albi-Veronicion dillenii	33	very low
8240	Limestone pavements	41	low
8310	Caves not open to the public	13	very low
8340	Permanent glaciers	64	very likely
	Forests		
9110	Luzulo-Fagetum beech forests	49	likely
9130	Asperulo-Fagetum beech forests	49	likely
9140	Medio-European subalpine beech woods with *Acer* and *Rumex arifolius*	59	very likely
9150	Medio-European limestone beech forests of the Cephalanthero-Fagion	47	likely
9160	Sub-Atlantic and medio-European oak or oak-hornbeam forests of the Carpinion betuli	57	very likely
9170	Galio-Carpinetum oak-hornbeam forests	50	likely
9180	Tilio-Acerion forests of slopes, screes and ravines	45	likely
91D0	Bog woodland	64	very likely
91E0	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (Alno-Padion, Alnion incanae, Salicion albae)	63	very likely

FFH-Habitat type	Name	Scoring Result	Expert-based feasibility categories
91F0	Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and *Ulmus minor*, *Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (Ulmenion minoris)	57	very likely
91G0	Pannonic woods with *Quercus petraea* and *Carpinus betulus*	49	likely
91H0	Pannonian woods with *Quercus pubescens*	49	likely
91I0	Euro-Siberian steppic woods with *Quercus spp.*	48	likely
91K0	Illyrian *Fagus sylvatica* forests (Aremonio-Fagion)	49	likely
91L0	Illyrian oak-hornbeam forests (Erythronio-Carpinion)	47	likely
91M0	Pannonian-Balkanic turkey oak- sessile oak forests	56	likely
9410	Acidophilous *Picea* forests of the montane to alpine levels (Vaccinio-Piceetea)	47	likely
9420	Alpine *Larix decidua* and/or *Pinus cembra* forests	60	very likely
9430	Subalpine and montane *Pinus uncinata* forests (* if on gypsum or limestone)	49	likely
9530	(Sub-) Mediterranean pine forests with endemic black pines	53	likely

Discussion and Conclusion

The developed and defined criteria, with all the corresponding descriptive attributes and expert-based scoring, provide a scientific basis for developing a RS-based methodology for large-scale identification and monitoring of HabDir Annex I habitat distribution in Austria. This scientific basis includes two products, the "criteria table" and the "scoring table". The "criteria table" includes criteria (as defined in Tab. 2) and assigned qualitative attributes for each habitat type and serves as a knowledge database for habitat type characteristics and their suitability to be identified by remote sensing-based modelling approaches. The "scoring table" rates habitat type characteristics according to their suitability for integration into remote sensing-based modelling approaches (for detailed viewing of the "criteria table" and the "scoring table" also see Electronic Supplement S1. As an example, the scores for habitat type characteristics of the habitat type 4070 are also displayed in Tab. 3). The MCDA for Annex I habitat types is an expert-based methodology; thus, the assessment is inherently subjective to a certain degree. Though another team of experts in the domains of vegetation ecology and remote sensing may rate and weight the descriptive attributes differently, it was assumed that they would achieve comparable final scores for the habitat types and a similar ranking order. The relative magnitude (ranking position) for each habitat type needs to be considered rather than their absolute numeric value and interpreted accordingly. For better readability and easier interpretation, the absolute numeric scoring results were transferred into four feasibility categories ranging from very low to very likely (cf. Tab. 4). It can be concluded that the habitat types associated with the habitat-group forests prospectively have the highest chance for successful identification and delineation in large-scale, country-wide applications using a remote sensing-based modelling approach (cf. Tab. 4). This is supported by the comparatively high rating of the assessment criteria with respect to forest's vegetation and habitat characteristics and their detectability based on available sensors. Forest habitats' characteristic entities (e.g., individual tree species) are larger and thus easier to capture by satellites of high to very high spatial resolution compared to the characteristic entities (species) of grasslands, scrubs, or bushes. At a community level, forest habitats usually consist of larger homogenous patches composed of similar biotic entities but contain a higher variability of spectral and structural characteristics, which can be used to discern them from other land surface types.

In contrast, habitat types that are heavily dependent on the identification of very small-scale entities for their distinct assessment (e.g., differentiation of grass species) were found rather unsuitable for country-wide RS-based assessment. For the identification of habitat types within the habitat-group of natural and semi-natural grassland and raised bogs, mires and fens, image analysis methodologies must be able to deal with non-homogenous reference or image data, where one image pixel might include a variety of key species for habitat type identification. In steep terrain the delineation of habitat types becomes even more difficult, like identifying grasses on steep slopes or cliffs. In images with an aerial view, large steep areas are minimized to a smaller extent. Depending on the aspect of surfaces, topographic shadow may also cover and influence such areas for analysis. Topographical errors of spectral data may also increase with the steepness of the terrain, which introduces a higher level of error to successful delineation (e.g., habitat types associated with the habitat-group rocky habitats and caves, except for the habitat type permanent glaciers). Unsurprisingly, the habitat "caves not open to the public" show the lowest score, because what cannot be seen in remote sensing data is therefore not detectable. This is also valid for all other habitat types with key characteristics that are not included in remote sensing data (e.g., species and species communities covered by a forest canopy).

The results highlighted in this paper can be understood as a decision support system for the development of remote sensing-based approaches for the identification of habitats but can also provide decision support for a remote sensing-based assessment of habitat distribution and extent. The results also offer a starting point to stratify different habitat types based on how well remote sensing can contribute to their identification and delineation and any regular processes for monitoring them in Austria. Further, the results of the expert-based MCDA scoring process show that the HabDir Annex I habitats, which are relevant for Austria have a varied chance of success of being identified through a remote sensing-based modelling approach. In general, the outcomes serve as a fundamental, and comprehensive knowledge database for future RS-based modelling to enable a more cost efficient, standardized, comprehensive and regular monitoring of FFH-habitats. The outcomes therefore provide a step towards an overall objective of a nation-wide, comprehensive, regular, and up-to-date monitoring of the extent, distribution, and areal development of FFH-habitats. Such information is urgently needed to contribute towards knowledge-based policy decision making or the development of environmental plans for different purposes (e. g. expansion of different kinds of infrastructure or nature conservation planning for protected areas). Finally, the results are also transferable into a European or international context (regarding adaptions for possible regional differences in habitat definition). Obviously, the results cannot replace a RS-based modelling approach itself: The methodology / expert-based rating process does not include the various available possibilities for RS-based modelling approaches (whereas methods of artificial intelligence and machine learning are promising tools already, but it is hard to predict their development). Thus, further research about validation of the MCDA rating results and practical realisation of the remote-sensing based modelling is needed.

Acknowledgements

The multiple criteria decision analysis approach (MCDA – weighted scoring method) could not have been conducted without the support of a profound expert team ready for discussion. The expert team for discussion rounds and feedback loops included the vegetation ecologists and remote sensing experts Tobias Köstl, Hanns Kirchmeir, Vanessa Berger, Klaus Steinbauer & Larissa Posch (all of them are vegetation ecologists and / or remote sensing experts from: E.C.O. – Institut für Ökologie, Lakeside B07b, 2.OG 9020 Klagenfurt, Austria. E-Mail: office@e-c-o.at).

Electronic Supplements

Electronic Supplement S1: criteria and scoring table: URL: https://www.zobodat.at/publikation_volumes.php?id=73195

Literature

Bartel A (2019) HNVF Auswertungen 2017, 2018. Wien: Umweltbundesamt.

Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie (2022) Biodiversitäts-Strategie Österreich 2030+. Wien. At: https://www.bmk.gv.at/themen/klima_umwelt/naturschutz/biol_vielfalt/biodiversitaetsstrategie_2030.html (accessed: 06-01-2024)

CBD/COP/DEC/15/4 (2022) Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity – 15/4 Kunming-Montreal Global Biodiversity framework. At: https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf (accessed: 06-01-2024)

Cinelli M, Kadzinski M, Gonzalez M, Slowinski R (2020) How to support the application of multiple criteria decision analysis? Let us start with a comprehensive taxonomy. Omega, Volume 96. (DOI: https://doi.org/10.1016/j.omega.2020.102261)

Corbane C, Lang S, Pipkins K, Alleaume S, Deshayes M, García Millán V E, Strasser T, Vanden Borre J, Toon S, Michael F (2015) Remote sensing for mapping natural habitats and their conservation status – New opportunities and challenges. International Journal of Applied Earth Observation and Geoinformation, Volume 37, 7-16 (DOI: https://doi.org/10.1016/j.jag.2014.11.005)

Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. At: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31992L0043 (accessed: 25-01-2024)

Ellmauer T, Essl F (2005) Entwicklung von Kriterien, Indikatoren und Schwellenwerten zur Beurteilung des Erhaltungszustandes der Natura 2000-Schutzgüter. Band 3: Lebensraumtypen des Anhangs I der Fauna-Flora Habitat-Richtlinie. Im Auftrag der neuen österreichischen Bundesländer, des Bundesministerium f. Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft und der Umweltbundesamt GmbH. Wien. At: https://www.umweltbundesamt.at/fileadmin/site/themen/naturschutz/band_3_ffh-lebensraumtypen.pdf (accessed: 25-01-24)

Ellmauer T, Igel V, Kudrnovsky H, Moser D, Paternoster D (2020) Monitoring von Lebensraumtypen und Arten von gemeinschaftlicher Bedeutung in Österreich 2016-2018 und Grundlagenerstellung für den Bericht gemäß Art. 17 der FFH-Richtlinie im Jahr 2019: Teil 3: Kartieranleitungen. Im Auftrag der österreichischen Bundesländer. Umweltbundesamt GmbH, Wien. At: https://www.verwaltung.steiermark.at/cms/dokumente/12812743_123331268/122b324e/S-332_Art11_Teil3_Kartieranleitungen.pdf (accessed: 25-01-2024)

European Union (2020) EU Biodiversity Strategy for 2030. Bringing nature back to our lives. Brussels. At: https://eur-lex.europa.eu/resource.html?uri=cellar:a3c806a6-9ab3-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF (acessed: 06-01-2024)

Lang S, Corbane C, Blonda P, Pipkins K, Foerster M (2015a) Multi-scale habitat mapping and monitoring using satellite data and advanced image analysis techniques. In Remote Sensing Handbook, 499–525. Taylor & Francis Group. New York.

Lang S, Pernkopf L, Mairota P, Schioppa E P (2015b) Earth observation for habitat mapping and biodiversity monitoring (Special Issue). International Journal of Applied Earth Observation and Geoinformation, Volume 37, 1-6 (DOI: https://doi.org/10.1016/j.jag.2014.10.007)

Lausch A, Bannehr L, Beckmann M, Boehm C, Feilhauer H, Hacker J M, Heurich M, Jung A, Klenke R, Neumann C, Pause M, Rocchini D, Schaepman M E, Schmidtlein S, Schulz K, Selsam P, Settele J, Skidmore A K, Cord A F, (2016) Linking Earth Observation and taxonomic, structural and functional biodiversity: Local to ecosystem perspectives. Ecological Indicators, Volume 70, 317-339 (DOI: https://doi.org/10.1016/j.ecolind.2016.06.022)

Strahler A H, Woodcock C E, Smith J A, (1986) On the nature of models in remote sensing. Remote Sensing of Environment, Volume 20, 121-139 (DOI: https://doi.org/10.1016/0034-4257(86)90018-0)

Suske W, Bergmüller K, Depisch B, Ellmauer T, Glaser M, Huber J, Lackner S, Radtke A, Schütz C, Teufelbauer N, Tomaschek J (2019) Ökologische Bewertung der Bewirtschaftung von Grünlandflächen hinsichtlich Nutzungsintensivierung und Nutzungsaufgabe. Wien. At: https://info.bml.gv.at/dam/jcr:656ab490-dabb-471b-9cbd-7f4eb7f52cc1/Studie%204:%20Evaluierung%20Gr%C3%BCnland.pdf (viewed: 06.02.2024)

Teufelbauer N, Seaman B (2023): Farmland Bird Index für Österreich: Indikator 2021 bis 2022. Teilbericht Indikator 2022. Wien. At: https://www.birdlife.at/page/monitoring-der-brutvogel (viewed: 06.01.2024)

Umweltbundesamt (2022) Dreizehnter Umweltkontrollbericht – Unterkapitel Biologische Vielfalt. Wien. At: https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0821.pdf (viewed: 06.01.2024)

Zuna-Kratky T, Frieß T, Heimburg H, Holzinger T, Huber E, Illich I, Neumayer J, Ockermüller E, Pacher K, Pachinger B, Rabl D, (2022) Veränderung von Insektenpopulationen in Österreich in den letzten 30 Jahren – Ursachen und ausgewählte Beispiele. At: https://dafne.at/projekte/insekten-studie (viewed: 02.01.2024)

Received:

Addresses:

Nina Weber, E-Mail: nina.weber@rm-w.at, Ressourcenmanagement Weber,
Flatschacher Straße 134/4/7, A-9020 Klagenfurt, Austria (corresponding author)

Thomas Strasser, E-Mail: thomas.strasser@plus.ac.at
Hannah Augustin, E-Mail: hannah.augustin@plus.ac.at
Department of Geoinformatics – Z_GIS, University of Salzburg, Schillerstraße 30,
A-5020 Salzburg, Austria.

Zeitschrift/Journal: Verhandlungen der Zoologisch-Botanischen Gesellschaft in Wien. Frueher: Verh.des Zoologisch-Botanischen Vereins in Wien. seit 2014 "Acta ZooBot Austria"

Jahr/Year: 2024

Band/Volume: 160

Autor(en)/Author(s): Weber Nina, Strasser Thomas, Augustin Hannah

Artikel/Article: Evaluation of habitats under the EU’s Habitats Directive, according to their feasibility for a remote sensing-based identification and delineation 255-268