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Technical Guidelines for assessing and monitoring the condition of Annex I habitat types of the Directive 92/43/EEC

Rocky slopes with chasmophytic vegetation

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Rocky slopes with chasmophytic vegetation

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Glossary and definitions

Habitats

Natural habitats: are terrestrial or aquatic areas distinguished by geographic, abiotic and biotic features, whether entirely natural or semi-natural (Habitats Directive).

Habitat condition: is the quality of a natural or semi natural habitat in terms of its abiotic and biotic characteristics. Condition is assessed with respect to the habitat composition, structure and function. In the framework of conservation status assessment, condition corresponds to the parameter "structure and function". The condition of a habitat asset is interpreted as the ensemble of multiple relevant characteristics, which are measured by sets of variables and indicators that in turn are used to compile the assessments.

Habitat characteristics: are the attributes of the habitat and its major abiotic and biotic components, including structure, processes, and functionality. They can be classified as abiotic (physical, chemical), biotic (compositional structural, functional) and landscape characteristics (based on the Ecosystems Condition Typology defined in the SEEA-EA; United Nations et al., 2021).

Species

Characteristic species: are species that characterise the habitat type, are used to define the habitat, and can include dominant and accompanying species.

Typical species: are species that indicate good condition of the habitat type concerned. Their conservation status is evaluated under the structure and function parameter. Usually, typical species are selected as indicators of good condition and provide complementary information to that provided by other variables that are used to measure compositional, structural and functional characteristics.

Variables

Condition variables: are quantitative metrics describing individual characteristics of a habitat asset. They are related to key characteristics of the habitat that can be measured, must have clear and unambiguous definition, measurement instructions and well-defined measurement units that indicate the quantity or quality they measure. In these guidelines, the following types of condition variables are included:

- **Essential variables:** describe essential characteristics of the habitat that reflect the habitat quality or condition. These variables are selected on the basis of their relevance, validity and reliability and should be assessed in all Member States following equivalent measurement procedures.
- **Recommended variables:** are optional, additional condition variables that may be measured when relevant and possible to gain further insight into the habitat condition, e.g. according to contextual factors; these are complementary to the essential variables, can improve the assessment and help understand or interpret the overall results.
- **Specific variables:** are condition variables that should be measured in some specific habitat types or habitat sub-groups; can thus be considered essential for those habitats, which need to be specified (e.g. salinity for saline grasslands, groundwater level for bog woodlands, etc.).

Descriptive or contextual variables: define environmental characteristics (e.g. climate, topography, lithology) that relate to the ecological requirements of the habitat, are useful to characterise the habitat in a specific location, for defining the relevant thresholds for the condition variables and for interpreting the results of the assessment. These variables, however, are not included in the aggregation of the measured variables to determine the condition of the habitat.

Reference levels and thresholds: are defined for the values of the variables (or ranges) that determine whether the habitat is in good condition or not. They are set considering the distance from the reference condition (good). The value of the reference level is used to re-scale a variable to derive an individual condition indicator.

Condition indicators: are rescaled versions of condition variables. Usually, they are rescaled between a lower level that corresponds to high habitat degradation and an upper level that corresponds to the state of a reference habitat in good condition.

Aggregation: is defined in this document as a rule to integrate and summarise the information obtained from the measured variables at different spatial scales, primarily at the local scale (sampling plot, monitoring station or site).

Abbreviations

EU**:** European Union

MS: Member State

EU Member States acronyms:

Austria	(AT)	Estonia	(EE)	Italy	(IT)	Portugal	(PT)
Belgium	(BE)	Finland	(FI)	Latvia	(LV)	Romania	(RO)
Bulgaria	(BG)	France	(FR)	Lithuania	(LT)	Slovakia	(SK)
Croatia	(HR)	Germany	(DE)	Luxembourg	(LU)	Slovenia	(SI)
Cyprus	(CY)	Greece	(EL)	Malta	(MT)	Spain	(ES)
Czechia	(CZ)	Hungary	(HU)	Netherlands	(NL)	Sweden	(SE)
Denmark	(DK)	Ireland	(IE)	Poland	(PL)		

Executive summary

The following guidelines present an overview of the methodologies used by Member States to monitor and assess habitat condition of habitats under Group 82 of the Habitats Directive (8210, 8220, 8230, 8240) and a proposal to harmonize these methodologies.

Rocky slope habitats are primarily defined by in situ rock, leading to a stable structure and function. These environments typically feature sparse vegetation, with variations in lithology, altitude, exposure, and local climatic conditions significantly influencing the types of plants and animals that can thrive there. They are characterized by limited soil availability and exposure to wind and rain.

The analysis of existing methodologies across EU Member States reveals significant similarity in monitoring these habitats. Measurement of the physical characteristics of the rock and soil can be found as variables across the majority of methodologies analysed. Compositional characteristics are assessed by focusing on presence and number of characteristic and typical species of vascular plants, ferns, lichens and mosses. Structural variables measure coverage and proportion of different taxa. Functional characteristics are not measured in most of the methodologies consulted. Landscape characteristics are commonly analysed by assessing habitats fragmentation and landscape metrics. Thresholds for interpreting these metrics and procedures are often based on exert judgement, which often is poorly justified or absent. Similarly, aggregation procedures exhibit notable differences among Member States, particularly at stand or local level, though procedures for aggregating variables at the supra-local level tend to converge. Monitoring procedures are largely based on periodic field observations

A set of essential, recommended and specific variables for monitoring rocky slopes habitat are proposed. They are categorized into abiotic (e.g., lithology, presence of cracks and cavities), compositional (e.g., number of characteristic species, presence of invertebrate species), structural (e.g. cover of bryophytes, cover of invasive species), functional (e.g., presence of pollinator species) and landscape (e.g., patch size, fragmentation). The main criteria and guidance for setting reference values and critical thresholds to determine good condition are provided, but specific values should consider the specific contexts for the particular habitats and biogeographical gradients across their distribution range.

The guidelines also set out several priorities for future development, including improving information exchange among Member States, establishing common monitoring protocols, working further on setting thresholds and aggregation methods, and integrating remote sensing and advanced technologies into monitoring programmes.

1. Definition and ecological characterisation

1.1 Definition and interpretation of habitats covered

Rocky habitats are primarily found in mountainous areas, uplands, and hills where the underlying rock is exposed. These environments typically feature sparse vegetation, with variations in geology, altitude, exposure, and local climatic conditions significantly influencing the types of plants and animals that can thrive there. Common characteristics include limited soil availability and exposure to wind and rain.

Rocky habitats can be categorized based on the chemical nature of their parent rocks, particularly their acidity or alkalinity. These habitats may originate from acidic, basic, ultrabasic, or neutral rocks across various geological eras. Siliceous (acidic) rocks, such as granite, gneiss, sandstone, and quartzite, are prevalent in many mountainous regions, depending on the area's geological history. Conversely, basic rocks rich in calcium include limestone (including chalk), dolomite, some calcareous schists and basalt (higher in silica than ultrabasic rocks, can sometimes be described as “neutral” in certain ecological or soil contexts). Ultrabasic rocks as serpentine (high magnesium, low calcium, and very low silica) can be a parent rock for rocky habitats (8220).

Under the Habitats Directive, rocky habitats are categorized into three main groups: 81. Screes, 82. Rocky slopes with chasmophytic vegetation, and 83. Other rocky habitats, which include caves, lava fields, and glaciers. The latter group encompasses three distinct habitat types, each with unique characteristics and ecological requirements that warrant separate assessment in these guidelines.

Screes and rocky slopes can be differentiated based on two main characteristics: the degree of rock fragmentation and their geomorphological dynamics. Habitats included in group 81 (scree) are dominated by superficial formations resulting from rock destruction, exhibiting geomorphological instability. In contrast, habitats in group 82 (rocky slopes) are primarily defined by in situ rock, leading to a stable structure and function. These distinctions underline the necessity of treating both groups separately for monitoring purposes.

These habitats are shaped by a complex interplay of environmental gradients, physical and chemical characteristics, species composition, and both anthropogenic and natural disturbances, all of which determine their ecological dynamics. Rock outcrops, cliffs, and pavements frequently form isolated habitat islands, creating stable microclimates and specialised conditions that support a diverse and distinctive range of species, resulting in high levels of biodiversity and endemism (Clarke, 2002, Porembski et al., 2016). Owing to their remote and often inaccessible nature, many rocky habitats have evolved largely in the absence of significant human disturbance and act as refugia for numerous regional and local endemic plant species adapted to these unique environments (Panitsa et al., 2021). Nevertheless, grazing by domestic and wild animals is common in many regions, and only the most inaccessible ledges and screes remain truly unaffected. Given the biological diversity they support, these habitats are of particular conservation importance, serving as refuges for endemic species and contributing significantly to regional biodiversity (García et al., 2020).

Rocky slopes with chasmophitic vegetation are found on all continents across most climate zones and vegetation types, forming when the least resistant parts of the substrate erode over millions of years (Fitzsimons & Michael, 2017). According to the Interpretation Manual of European Union Habitats (2013), the main characteristics defining the habitats of group 82 include lithology (siliceous, calcareous), biogeography (west-east Mediterranean, Middle

European), bioclimatic region (montane, nival, thermophiles, upland), and plant communities classified by syntaxa (phytosociology).

Habitat types included in the Habitats Directive group 82 - Rocky slopes with chasmophytic vegetation, are shown below, with their main characteristics and the EU MSs where they (in Table 1), and their definition (Box 1).

Table 1. Habitat types included in group 82, their main characteristics and EU MSs where they occur

Habitat type	**Name**	**Characteristics from the definition**	**EU MS** (according to reference list art. 17)
8210	Calcareous rocky slopes with chasmophytic vegetation	Lithology, altitude, climate, plant communities	AT, BE, BG, CY, CZ, DE, EE, ES, FI, FR, GR, HR, IE, IT, LT, LV, MT, PL, RO, SE, SK, SI
8220	Siliceous rocky slopes with chasmophytic vegetation	Lithology, altitude, climate, plant communities	AT, BE, BG, CZ, DE, DK, EE, ES, FI, FR, GR, HR, IE, IT, LT, LV, PL, PT, RO, SE, SI, SK
8230	Siliceous rock with pioneer vegetation of the *Sedo-Scleranthion* or of the *Sedo albi-Veronicion dillenii*	lithology, altitude, climate, plant communities	AT, BG, CZ, DE, DK, ES, FI, FR, HU, IT, LU, PL, RO, SE, SK
8240	Limestone pavements	Lithology, altitude, climate, plant communities.	AT, EE, FR, IE, IT, PT, SE, SI

1.2 Environmental and ecological characterization and selection of variables to measure habitat condition

1.2.1 Ecological characterization

Rocky slopes habitats comprised in Group 82 occur in a range of forms, including cliffs, crags, rocky outcrops, and limestone pavements. Each of these habitats is closely linked to specific geological and structural substrates, with the nature and properties of the underlying rock exerting a major influence on plant colonisation. Accordingly, an initial level of habitat characterisation is based on the chemical composition of the rocks. Beyond chemical composition, factors such as the porosity and, in particular, the degree of fracturing of the rock significantly affect plant establishment. Compact, fine-grained rocks make rooting difficult, thus restricting the presence of most species, whereas coarse-grained or heavily fractured substrates facilitate colonisation by creating favourable micro-sites for rooting. In addition, the position on the landform introduces further variation: conditions on the summit of a granite dome, a gentle slope, or a steeply inclined wall can differ markedly in terms of microclimate and substrate stability.

Box 1. Definition of habitats included in habitat group 82 provided by the Interpretation Manual of European Union Habitats (2013)

8210 Calcareous rocky slopes with chasmophytic vegetation

Vegetation of fissures of limestone cliffs, in the mediterranean region and in the euro-siberian plain to alpine levels, belonging essentially to the *Potentilletalia caulescentis* and *Asplenietalia glandulosi* orders. Two levels may be identified: a) thermo- and meso-Mediterranean (*Onosmetalia frutescentis*) with *Campanula versicolor, Campanula rupestris, Inula attica, Inula mixta, Odontites luskii;* b) montane- oro-Mediterranean (*Potentilletalia speciosae*, including *Silenion aurticulatae, Galion degenii* and *Ramondion nathaliae*). This habitat type presents a great regional diversity, with many endemic plant species.

8220 Siliceous rocky slopes with chasmophytic vegetation

Vegetation of fissures of siliceous inland cliffs, which presents many regional subtypes.

8230 Siliceous rocks with pioneer vegetation of the *Sedo-Scleranthion* or of the *Sedo albi-Veronicion dilleniialliances*

Pioneer communities of the *Sedo-Scleranthion* or the *Sedo albi-Veronicion dilleniialliances*, colonising superficial soils of siliceous rock surfaces. Because of drought, this open vegetation is characterised by mosses, lichens and Crassulaceae.

8240 Limestone pavements

Regular blocks of limestone known as “clints” with loose flags separated by a network of vertical fissures known as “grykes” or “shattered pavements”, containing more loose limestone rubble. The rock surface is almost devoid of overlying soils (considerably less than 50% cover) except for some patches of shallow skeletal or loessic soils, although more extensive areas of deeper soil occasionally occur; sometimes there is encroachment of peat. This morphology offers a variety of microclimates allowing the establishment of complex vegetation consisting of a mosaic of different communities. The fissures provide a cold humid microclimate where shade-tolerant vascular plants such as *Geranium robertianum* and *Ceterach officinale* occur, as well as formations of herbaceous species typical of calcareous woodland; the small pockets of soil are occupied by communities of Mesobromion (e.g. *Seslerio-Mesobromenion*); heath and scrub also occur (e.g. *Corylo-Fraxinetum*). Apart from the species rich areas of scrub (generally *Prunetalia spinosae*), the ecosystem is maintained by grazing in some regions; this, combined with severe winds, means that isolated shrubs can only survive in prostrate growth form (e.g. *Dryas octopetala*); at ungrazed sites, marginal areas of *Geranium sanguineum* occur. In Sweden, limestone blocks are larger, and cracks are smaller. The species composition reflects a more continental, dryer and cooler climate. The pavements are mostly exposed with scattered cushions of bryophytes, more seldom covered by a thin layer of soil. The surface is covered by Se*dum album, Cerastium pumilum, Cerastium semidecandrum,* lichens (*Aspicilia calacrea*, *Thamnolia vermicularis, Verrucaria nigrescens*) and bryophytes (*Tortella tortuosa, Grimmia pulvinata*). The vegetation in the cracks contains *Gymnocarpium robertianum, Asplenium ruta-muraria, Asplenium trichomanes* ssp. *quadrivalens* and, occasionally, bushes of *Prunus spinosa, Fraxinus excelsior, Cotoneaster* spp*., Rosa* spp. Some sites in Ireland host an open *Taxus-Juniperus* scrub of major interest; certain arctic alpine species such as *Gentiana verna* and *Dryas octopetala* are characteristic and in The Burren, these species occur with Atlantic-Mediterranean species such as *Neotinea maculata*.

Climatic variables are also critical, as they dictate patterns of precipitation (whether as rainfall or snow), temperature, and insolation—all of which may vary depending on the slope’s orientation. It is important to remember that relief is itself defined by the interplay of altitude, slope, and aspect, and these factors must be considered when explaining patterns of species presence and community composition.

Rocky outcrops and cliffs function as vital microhabitats within often harsh ecosystems. Their inaccessibility, exposure to severe environmental fluctuations, and relative isolation from biotic interactions enable them to serve as refugia for native, relict, and endemic species. However, such habitats are also subject to a range of limitations, including shallow soils, water and nutrient scarcity, low night-time temperatures, intense sunlight, and strong winds. This results in a high degree of spatial and ecological fragmentation, which limits dispersal and migration and contributes to the distinctive biogeographical features of these systems (Rafiee et al., 2022).

A typical cliff system can be structurally divided into three distinct zones, each characterised by unique microenvironmental conditions and vegetation assemblages. Firstly, the cliff edge refers to the plateau or plain situated above the cliff face. This area is generally marked by thin, dry soils and supports stunted woodland or xerophilous grassland vegetation. Plant communities here are typically dominated by drought-adapted species, including winter annuals, mosses, lichens, and other specialists tolerant of xeric conditions. Secondly, the pediment denotes the rock base at the foot of the cliff. This zone provides a more favourable environment for plant growth due to enhanced access to water and oscillating microclimates—from warmer, sun-exposed sites to cooler, shaded niches. The pediment frequently hosts talus communities, which develop on the debris accumulated at the base, offering substrates for a variety of species. Thirdly, the cliff face itself forms the steep, near-vertical expanse of exposed rock between the upper edge and the lower pediment. Soil accumulation is minimal in this challenging environment, and vegetation consists predominantly of long-lived perennials such as certain trees, shrubs, vines, and ferns that are specially adapted to persist in extreme conditions (Larson et al., 2000; Bogges et al., 2017).

Piatra Secuiului Mountains near Torok Town, Romania. © Jozef Šibík, 2017.

Following the zonation and ecological gradients observed in cliff systems, limestone pavements represent another distinctive rocky habitat, sharing features of abrupt topography and environmental heterogeneity. Limestone pavements are typically horizontal or gently inclined outcrops, although some examples may be steeply sloped. Over millions of years, the surface limestone has been sculpted by water into characteristic 'paving blocks' separated by a network of deep crevices known as grikes, forming a complex reticulate structure.

This geomorphology creates a **mosaic of microhabitats**, supporting a diversity of calcareous rock, heath, grassland, scrub, and woodland communities. The vegetation of limestone pavements is particularly noteworthy for its unique assemblages; woodland-edge species are often found on the exposed block surfaces or upper walls of the crevices, while the deeper, shaded and humid grikes provide refugia for woodland plants. In a manner similar to the role of the pediment and cliff face in shaping plant assemblages on cliffs, the physical heterogeneity and microclimatic variation within limestone pavements promote high biodiversity. Grazing pressure, as on many rocky habitats, remains a key driver of ecological variation, influencing the composition and structure of these specialised communities (JNCC).

The following main characteristics can be linked to rocky outcrops and cliff habitats:

Physical and chemical properties: The type of bedrock, such as limestone or granite, determines soil acidity or alkalinity, nutrient availability, and consequently which plant and animal species can successfully colonise and persist in these environments (Porembski et al., 1996; JNCC, 2019). Physical characteristics, including porosity, degree of fracturing, and grain size, strongly influence water retention, root establishment, and microhabitat formation; highly fractured or porous substrates foster greater microhabitat diversity and support specialised communities—such as those found in limestone pavements and cliffs (JNCC, 2019). These structural features also mediate rates of physical erosion and habitat turnover.

Environmental gradients: The microclimatic variation created by topography and substrate heterogeneity—such as differences in aspect, altitude, and slope—results in stark ecological gradients and high levels of local endemism within rocky habitats (Porembski et al., 1996; Rafiee et al., 2022).

Species diversity and endemism: Rocky outcrops are notable for supporting high levels of species diversity and endemism, a pattern attributed to their stable microclimates and heterogeneous physical environments (Fitzsimons & Michael, 2017). The sparsely vegetated habitats of cliffs and screes serve as important refugia for numerous regional and local endemic plant taxa, many of which are highly specialised. This functional role underscores the value of rocky habitats in conservation planning, particularly for the maintenance of biodiversity and ecosystem services (Panitsa et al., 2021). Furthermore, these rocky environments buffer temperature fluctuations and reduce exposure to extreme climatic events, thereby benefitting relict, endemic, and peripheral plant populations (García et al., 2020). The complex array of microhabitats provided by cracks and crevices on cliff faces contributes further to elevated levels of floral diversity within these systems (Boggess et al., 2017).

Human and natural disturbances: Rocky outcrops are exposed to a variety of threats, including soil compaction, erosion, nutrient enrichment, weed invasion, introduced predators, and physical disturbance arising from both recreational use and quarrying activities (Fitzsimons & Michael, 2017). Even in relatively undisturbed environments, these habitats can be adversely affected by altered fire regimes, air pollution, and ongoing climate change (Fitzsimons & Michael, 2017). Of particular concern is ammonium (NH_4^+) pollution, which poses direct toxicity risks to cryptogams—such as mosses and lichens—that often dominate the vegetation in some rocky habitat subtypes. It is important to note, however, that while quarrying is typically considered a source of disturbance, it can also, under certain circumstances, create the specific abiotic conditions required for the development of characteristic rocky habitats (Guarino & Pignatti, 2017).

Succession and colonization: On exposed terrestrial cliff lines, the most frequent plants are typically generalist nanophanerophytes and chamaephytes, with community structure strongly influenced by the geomorphological and lithological characteristics of the cliff itself.

1.2.2 Main ecological characteristics and identification of variables to measure habitat condition

The description of key characteristics of and the corresponding variables that are useful to measure habitat condition in these guidelines follows the approach to assess ecosystem condition defined in the framework of the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA EA), adopted by the United Nations Statistical Commission as international standard for ecosystem accounts (United Nations, 2021), which is also integrated and proposed in the EU wide methodology to map and assess ecosystem condition (Vallecillo et al., 2022).

According to this framework, ecosystem condition is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics. The SEEA ecosystem condition typology (ECT) establishes a common language to support increased comparability among different ecosystem condition studies. The ECT has six classes of characteristics: abiotic physical, abiotic chemical, biotic compositional, biotic structural, biotic functional and landscape.

Abiotic characteristics

Within abiotic characteristics, the geomorphological, climatic and edaphic components are very relevant.

Geological and geomorphological features

Lithology, particularly the distinction between siliceous and carbonate rocks, along with the degree of stratification and fracturing, are key factors in shaping the characteristics of rocky slope habitats. The orientation of strata and patterns of fractures generate diverse micro-environments, which are essential considerations when analysing the biotic components present.

As Marston (2010) notes, there is significant value in examining the interactions between vegetation and geomorphology. Although systematic study of the processes linking vegetation and geomorphic dynamics is relatively recent, research has increasingly focused on the ways plants exert biomechanical and biochemical influences on rocks, sediments, and soil. Plant roots, for example, can alter the texture, structure, cohesion, and chemical properties of the substrate, thereby affecting subsequent plant colonisation (Viles, 1995; De Baets et al., 2006; Wilkinson & Humphreys, 2006). Consequently, it is essential not only to assess plant cover, but also to understand the interactions between vegetation and substrate in order to evaluate habitat condition and its long-term evolution.

Unlike scree habitats (Group 81), where sediment fragmentation and transport strongly influence slope dynamics and plant colonisation, rocky slope habitats (Group 82) are predominantly shaped by surface weathering processes. Rainfall, while increasing humidity, exerts limited erosive force on these rocky surfaces. Additionally, mineralogical composition plays a crucial role: in granular rocks, the varied response of individual grains leads to differentiation of surface properties.

The physical integrity of the rock structure can be compromised by a range of disturbances, including the installation of infrastructure (such as power lines and rockfall protection), quarrying activities, road construction, trail development, equipped climbing routes, and the building of pedestrian facilities. Maintaining the integrity and natural state of the rock substrate is fundamental to the conservation of these habitats. Consequently, metrics used to assess such disturbances and their temporal variation should be prioritised and given substantial weighting in habitat evaluations.

Climatic characteristics

Climate is a fundamental factor in shaping rocky ecosystems, influencing both their physical substrate and biological dynamics. Temperature and humidity at the rock surface directly affect weathering, erosion, and the overall ecosystem processes. Variations in altitude introduce important changes in radiation, temperature, humidity, and wind, further modulating local conditions. Likewise, precipitation—whether as rain or snow—regulates not only surface moisture and temperature but also the microclimatic conditions within cracks, fissures, and hollows, which in turn impact vegetation development.

Microclimatic conditions on rocky slopes can deviate significantly from those of the surrounding region, with steep gradients occurring over very short distances (Porembski et al., 1996). However, there is still limited knowledge about the diurnal and seasonal variability of these microclimates and their effects on species colonization. As Meineri and Hylander (2017) highlight, large-scale distribution models often overlook the microrefugia provided by rocky environments, as these models are primarily based on broad climatic gradients. To address this gap, the authors advocate for methodologies that integrate fine-scale topographic data and local climatic measurements.

Such pronounced microclimatic contrasts are evident in all climatic variables. For instance, substantial temperature differences can exist between exposed rock surfaces and the interiors of cracks or cavities. Experiments on granodiorites in Galicia, Spain (Pérez-Alberti, 2017), demonstrated that while ambient air temperature was around 25°C, the surface of unaltered rock reached 40°C, whereas temperatures inside cavities closely matched the ambient air. These findings illustrate the complexity and heterogeneity of microclimates within rocky habitats, which play a crucial role in shaping ecological patterns and processes.

Edaphic component

Soil constitutes a dynamic physical support for plants, as well as a nutrient medium whose characteristics (for example, presence/absence of calcium carbonate, pH, water retention capacity, etc.) can explain the presence or absence of a given plant species or group of species. This dependence on the soil explains why some places with suitable microclimatic conditions remain almost completely devoid of vegetation, since plants are unable to establish. In dry situations, rock weathering and soil formation are particularly slow (Bensettiti et al., 2004).

The presence of soil cover in rocky outcrops is practically non-existent or is reduced to cracks or cavities. This shallow or non-existent soils and the particular environmental conditions characteristics of rocky outcrops have led to the development of specific adaptations in plants which allow some species to survive in extreme environments (Poot et al., 2012; Rafiee et al., 2022). Rocky outcrops also provide shelter for fire-sensitive flora (Michael & Lindenmayer, 2018; Speziale & Ezcurra, 2014).

Biotic characteristics

Plants in rocky habitats have evolved a suite of specialised adaptations that enable them to persist in these challenging environments. Vascular plants are typically restricted to ledges and crevices, where their survival is facilitated by traits such as low, cushion-like or compact growth forms, small in-rolled leaves, and robust root systems. On exposed rock surfaces, highly specialised lichens and mosses frequently dominate. Chasmophytic vegetation comprises plant communities that colonise the cracks and fissures of rock faces, while broader cliff ledges—especially those inaccessible to grazing animals—can support tall-herb flora. At lower altitudes, these ledges occasionally sustain trees, which struggle to regenerate elsewhere due to grazing pressure.

The establishment and diversity of plant communities on rocky outcrops are strongly influenced by topography, lithology, and substrate characteristics, with basic (alkaline) rocks generally supporting greater species richness than acidic substrates, as predicted by the evolutionary species pool hypothesis (Ewald, 2003; Sekulová et al., 2013). The shallow soils, microclimatic variability, and structural heterogeneity of rocky habitats foster the evolution of endemic and specialised species, often resulting in marked habitat fragmentation and “terrestrial islands” that differ markedly from surrounding vegetation (Prance, 1996, as cited in Sarthou, 2001). These microhabitats—including moist channels formed by fractures and crevices—not only support unique flora but also specialised animal species. Moreover, rocky outcrops serve as important microclimatic refugia, buffering temperature extremes and providing critical safe havens for relictual, endemic, and range-edge species, which is especially relevant for the conservation of biodiversity under climate change scenarios (García et al., 2020); notably, recent research demonstrates that rocky plant communities, particularly at lower and mid-elevations, persist with high stability and resilience despite increasing climatic pressures (Reczyńska & Świerkosz, 2024).

Rocky habitats are also threatened by direct destruction of vegetation, particularly during the development of equipped climbing routes. Such impacts should be monitored through the assessment of plant communities and populations of habitat-quality indicator species. Notably, total plant cover is not a reliable indicator of conservation status in these habitats, since optimal conditions may be maintained even with minimal vegetation. However, the proliferation of non-rupicolous species colonising rocky surfaces should be monitored as a negative trend.

Below (Table 2) is a summary table of the main ecological characteristics of these habitats, as indicated above, with some examples of useful variables to evaluate these characteristics.

Table 2. Ecological characterization and selection of variables to measure the condition of rocky slopes with chasmophytic vegetation (group 82 habitats)

Ecological characteristics	Types	Group of characteristics	Examples of variables useful to measures key characteristics
Abiotic characteristics	**Physical state characteristics**	Climate	- Air temperature - Surface temperature of the rock - Precipitation - Humidity in rock surface, channels and cavities - Shade
		Geomorphology	- Diversity of natural structures - Slope - Substrate dynamics
		Lithology	- Mineral composition - Porosity and degree of alteration
		Soil (physical characteristics)	- Presence/absence, thickness - Humidity - Leaf litter - Dead organic matter carpet
		Orientation	- Dominant orientation
	Chemical state characteristics	Soil (chemical characteristics)	- pH - Nutrient content - Calcium, carbonate content
Biotic characteristics	**Compositional state characteristics**	Presence, abundance of biological communities and species	- Presence and number of characteristic species from relevant groups: lichens, mosses, ferns and vascular plants - Number of habitat-specialist plant and animal species - High quality indicator species - Negative indicator species as cover of competitive native herbs and dwarf shrubs or invasive species
		Habitat ruderalisation	- Presence and number of ruderal species
	Structural state characteristics	Pattern of occupancy of communities and species	- Cover of relevant communities or species groups (lichens, mosses, ferns and vascular plant)
		Habitat ruderalisation	- Cover of ruderal species
	Functional state characteristics	Dynamics and natural processes	- Impact of native animals
Landscape characteristics (connectivity / fragmentation)		Landscape metrics	- Size of patch - Spatial structure of habitat patches - Relation with other habitats - Habitat fragmentation
Other (disturbance, habitat alteration)		Anthropic disturbance	- % of affected surface, type and intensity of effects (trampling, climbing, quarrying, constructions, etc)

1.3 Selection of typical species for condition assessment

Typical species of the habitat are used to assess the habitat conservation status. The Habitats Directive uses the term ‘typical species’, but it does not give a definition for use in reporting. For a habitat type to be considered as being at favourable conservation status, the Habitats Directive requires that both its structure functions and its ‘typical species’ are in a favourable status (Article 1(e)).

The formulation of Art. 1(e) could suggest that the assessment of typical species could be carried out separately and complement the assessment of structure and function. In this regard, the selection of typical species should be as robust and appropriate as possible. However little guidance has been provided on how to use the typical species in this assessment.

According to the Guidelines for Article 17 reporting (European Commission, 2023), the assessment of typical species is part of the assessment of the structure and function parameter; however, a full assessment of the conservation status (as for species listed in Annexes II, IV and V) of each typical species is not required. Typical species should include species which are good indicators of favourable habitat quality, and which are sensitive to changes in the condition of the habitat (‘early warning indicator species’) and may be drawn from any species group. The sum of sites and occurrences of each habitat type should support viable populations within the region being assessed of the typical species on a long-term basis for Structure and functions to be favourable.

Typical species can vary across the habitat range. Given the ecological and geographical variability of the Annex I habitats across their range, even within a single biogeographical or marine region, it is very unlikely that all typical species will be present in all examples of a given habitat type, particularly in large Member States. Indeed, even within one Member State different species may be present in different parts of the range of a habitat type or in different subtypes.

All MSS have communicated a list of typical species for each habitat type[1], although usually they have not provided any justification or rationale for their selection. The variability of the selection of typical species by MSs seems to indicate that different interpretations are done on the concept of typical species. Mostly plants are proposed as typical species (> 90% of the selected species) and in many cases most dominant characteristic species are included. However, species from other taxonomic groups are also considered (e.g., lichens, insects, birds, mammals)

According to the analysis of national methodologies available for the assessment of habitat structure and function, some MSs assess the typical species separately, while other seem to include the typical species in the assessment of the habitat compositional characteristics. However, the use or consideration of typical species in the habitats assessments is not well documented, in general, in the methodologies analysed for the elaboration of these guidelines.

For instance, in Greece and Cyprus, the assessment of typical species is carried out separately (considering species cover and vitality) from the variables used to assess the

[1] See the compilation of typical species used by Member States to assess the parameter 'Specific structure and functions for the reporting periods 2008-2012 and 2013-2018, available at the Reference portal for reporting under Article 17 of the Habitats Directive: https://cdr.eionet.europa.eu/help/habitats_art17.

structure and functions of the habitats, and the results of both assessments are afterwards integrated into one single value for the habitat condition (Dimopoulos et al., 2018).

In the Netherlands, the assessment of conservation status of habitat types is carried out by aggregating the assessments of two sub-parameters: 'structure and functions (without typical species)' and 'typical species' at biogeographical level according to EU evaluation matrix. The determination of the status of the sub-parameter 'typical species' at a biogeographical level is based on the proportion of species belonging to different categories of the Red List and subsequent aggregation with the sub-parameter 'structure and functions' (Ellwanger et al., 2018).

In Germany, the assessment of the habitat type in each plot is based on the evaluation of the following components: 'habitat structures', 'typical species', and 'pressures and threats'. Usually, the number of typical plant species is considered in the assessment of the habitat compositional characteristics. Animal species are included in the assessment of a few habitat types only (Ellwanger et al., 2018).

As above mentioned, typical species may be drawn from any species group and, although often most species reported were vascular plants, consideration should be given to also selecting lichens, mosses, fungi, and animals, including birds.

It can be useful to consider key functional groups for the selection of typical species, taking into account the habitat's ecology, the role of typical species as bioindicators (e.g., pollinators, dispersers, decomposers, trophic and symbiotic relationships, etc.) and their sensitivity to changes.

Table 3 provides an illustrative list of species' groups that can be used as indicators to assess rocky slopes habitats condition.

Campanula carpatica.
Nízke Tatry Mountains, Slovakia.
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Table 3. Selecting typical species for monitoring habitats from group 82 – Rocky slopes with chasmophytic vegetation

Species group	Ecological role: bio-indicator of	Sensitive to changes in quality
Lichens	Environmental pollution, climate change and stabilization of the soil on the surface of the rock outcrop, diversity	Lichens contribute to ecosystem nutrient inputs and fluxes, and their decomposition affects nutrient cycling (Asplund & Wardle 2017; Lõhmus et al. 2023)
Bryophytes	Diversity, Habitat quality, Soil and Water Conservation	Bryophytes, including mosses and liverworts, play significant ecological roles in rocky habitats and cliffs (Sabovljević, 2004; Silva & Germano, 2013). These roles encompass biodiversity support, soil and water conservation, and environmental stabilization (Kubešová & Chytrý, 2005; Shaohua et al., 2014; Tu et al., 2022)
Ferns	Diversity, Habitat quality	Number of positive indicator ferns.
Vascular plants	Diversity, Habitat quality	Occurrence of diagnostic species. Occurrence of indicator species of positive or negative changes (habitat dependent). *Saxifraga* spp. Endemic and specialized plant species (Panitsa et al., 2017).
Arthropods	Tolerance to human activity	Some arthropod species appear to be tolerant of human activities such as rock climbing, suggesting that they can persist in disturbed cliff habitats (Covy et al., 2019).
Reptiles	Habitat quality and biodiversity, Microhabitat use and adaptation	Impact of habitat degradation (Michael et al., 2021). Habitat use drives morphological and performance evolution in lizards (Goodman et al. 2008).
Birds	Habitat diversity and heterogeneity	Cliffs and rocky outcrops create habitat heterogeneity, which is crucial for supporting diverse bird communities (Ward & Anderson, 1988).
Birds	Impact of human activities:	Human activities such as rock climbing can negatively affect bird diversity and community conservation value, although some species show tolerance to these disturbances (Fitzsimons & Michael, 2017).
Mammals	Biodiversity and species richness	Cliffs and rocky outcrops support high levels of species diversity and endemism, contributing to the overall biodiversity of the area (Andino et al., 2014).
Mammals	Ecological refuges	Rocky habitats serve as ecological refuges for ancient lineages and provide critical breeding sites for top-order predators, indicating their importance in maintaining ecological balance (Fitzsimons & Michael, 2017).

2. Analysis of existing methodologies for the assessment and monitoring of habitat condition

2.1 Variables used, metrics and measurement methods, existing data sources

This analysis is based on a review of methodologies compiled from 16 EU countries for the assessment and monitoring of rocky slopes with chasmophytic vegetation (20 references in total): Austria (AT), Belgium-Wallonia (BE), Bulgaria (BG), Czech Republic (CZ), Germany (DE), Greece (EL), Hungary (HU), Ireland (IE), Italy (IT), Lithuania (LT), Poland (PL), Romania (RO), Spain (ES) and Sweden (SE).

Abiotic variables

Abiotic variables are incorporated into the methodologies of eight Member States. Physical variables are employed to assess the geomorphological and dynamic characteristics of scree habitats, including the structural diversity of rock formations, such as cracks, chasms, ledges, micro-habitats, sheltered areas, and micro-relief features (BfN, 2017), as well as changes in crack patterns, alterations or erosion of the rock substrate, the presence of soil, microclimatic conditions, and shade.

Chemical characteristics are evaluated by recording the coverage of organic matter and by monitoring changes in leaf litter. In addition, one methodology utilises an indirect assessment of chemical characteristics through the application of Ellenberg indices for macro-nutrient availability and soil pH, in which plant communities are used as bioindicators of soil properties (Toräng et al., 2022).

Biotic variables

Biotic variables are considered in all the methodologies analysed, focusing mainly on the presence and coverage of species and functional groups that indicate favourable or unfavourable condition.

Compositional variables include the presence and number of typical, dominant, characteristic, or key species, which are assessed during fieldwork by visual inspection and based on national species inventories for the various habitat types. In addition to vascular plants, mosses and lichens are also considered, while animal species are included in only two methodologies (Hendrickx, 2021; Angelini et al., 2016). The presence of negative indicator species—such as weeds, ruderal, nitrophilous, invasive, non-native, or disturbance-indicating species—is often included in the assessments by many Member States (see Annex 1).

Structural variables have been described in the methodologies of eleven Member States. The coverage and percentage of species considered negative or disturbance indicators (including ruderal species, scrubs and trees, invasive, non-native species, and nitrophilous species) are included in several methodologies. The coverage of typical and characteristic species, including mosses and lichens, is also measured in some of the national methodologies analysed. Total vegetation cover and vegetation structure diversity are measured in a few methodologies.

Functional variables are only described in two methodologies, which include a variable indicating the reproduction of plants (such as flowering), as well as another on interactions with native animals (e.g., ants, rodents), which can have either positive or negative impacts—for example, through trampling or the creation of pools and puddles.

Landscape variables are included in several methodologies, including the size of the patch and the distance to other habitat patches, the relationship with neighbouring habitats, and the presence of fragmenting infrastructures, which may also be considered as degradation factors or pressures.

Finally, additional variables indicating degradation or disturbance are frequently included in the methodologies reviewed. These include the impact of human activities (such as quarrying), infrastructure, and recreational use (e.g., climbing). Rock climbing and other human activities can have significant impacts on rocky habitats and cliffs, particularly affecting vegetation and contributing to erosion (Fitzsimons & Michael, 2017; Covy et al., 2019). Potential climbing-use intensity has a small negative effect on vascular plant species richness and abundance (range 3–6%) and a substantial effect on lichens (range 10–12%), with cliff angle being a fundamental control on cliff vegetation (Clark & Hessl, 2015). In most cases, the percentage of the total habitat affected, and threshold values are provided. The impact of grazing is also measured in two methodologies, either as the percentage of the area that shows visible signs of grazing or as a qualitative classification into light, moderate, or heavy grazing.

A summary overview of the types of variables used in the national methodologies considered in this analysis is presented in Table 4. More detailed information on these variables is presented in Annex 1, including metrics, measurement methods and threshold values.

Table 4. Classification of variable groups, according to the environmental and ecological characterisation of scree habitats (SEEA ecosystem condition typology (ECT)), indicating Member States that have included them in their methodologies for assessing rocky slope habitats condition

Ecological characteristics and variables	AT	BE	BG	CZ	DE	ES	GR	HU	IE	IT	LT	PL	RO	SE
1. Abiotic characteristics														
1.1 Physical state characteristics														
Diversity of natural structures on rocky slopes (8210, 8220, 8230)					■									
Substrate dynamics (8210, 8220, 8230, 8240). Presence of fine-grained soil							■			■				
Erosion						■		■						
Canopy shade											■	■		
1.2 Chemical state characteristics														
Dead organic matter carpet (8210, 8220)												■		
Ellenberg index for macro-nutrient availability; pH														■
2. Biotic characteristics														
2.1 Compositional state characteristics														
Typical, dominant, characteristic, key species, positive indicator species (vascular plants, lichens and mosses)	■	■	■	■	■			■	■	■	■	■	■	
Typical animal species		■							■					
Presence of weeds, ruderal, nitrophilous, invasive, non-native, alien, negative indicator species or disturbance indicating species.			■		■			■	■	■		■		

Ecological characteristics and variables	AT	BE	BG	CZ	DE	ES	GR	HU	IE	IT	LT	PL	RO	SE
2.2 Structural state characteristics														
Coverage of vascular plants, characteristic and typical species														
Coverage of mosses, lichens and exposed rock														
Coverage of woody plants, scrub and tree cover														
Structural integrity														
Height of trees and shrubs														
2.3 Functional state characteristics														
Typical species reproducing (e.g., flowering and reproducing)														
Leaf litter														
Impacts of native animals														
3. **Landscape characteristics**														
Presence of fragmenting structures														
Landscape metrics: patch size, distance between patches, presence of ecotonic zones														
Distribution of habitats in mountain massifs														
4. **Other**														
Anthropic disturbances														

2.2 Definition of ranges and thresholds to obtain condition indicators

Examples of thresholds used to assess whether variables in the monitoring and assessment of rocky slope habitats are in good or not good condition are presented in the Annex 1). Here, a summary of how these thresholds are established in the national methodologies analysed is provided.

When defining threshold values, all Member States associate a range of possible values for each variable with qualitative categories that express the condition of the habitat for that variable. Most MSs apply the Favourable (FV), Unfavourable-Inadequate (U1), and Unfavourable-Bad (U2) categories, or alternatively, an A-B-C scale where A represents excellent, B medium-good, and C low condition, as implemented by the methodologies of Austria and Germany (Ellmauer, 2005; BfN, 2017).

Overall, the criteria for establishing thresholds to determine habitat condition are insufficiently documented (BfN, 2017; Šeffer & Lasák, 2022). Some methodologies do not specify any threshold values for variables; others that do include thresholds usually do not explain the approach used to determine those values. It may be assumed that such reference values are based on expert judgement, as no alternative methodology is provided (BfN, 2017). For example, threshold values for coverage of invasive species within a plot may be set (e.g., less than 5% for good condition and over 10% for poor condition), but the basis for these percentages is often not indicated.

Nevertheless, there are common patterns among reference values and thresholds employed across the methodologies reviewed. Compositional variables are typically assessed on the basis of lists or catalogues of species that are characteristic for each habitat or sub-type. The number of species from the list found in the sample plot or survey area is used to indicate habitat condition (e.g., FV: more than three species, U1: two to three species, U2: one species) (BfN, 2017).

Most MSs that have defined thresholds for structural variables assessing species or vegetation coverage establish ranges for values according to the FV-U1-U2 or A-B-C scales (BfN, 2017). In some cases, a single value indicates good condition (for example, coverage of Pteridium aquilinum, native trees, and scrub should be below 25% to indicate good condition in habitat 8210 in Ireland) (BfN, 2017).

Comparison of reference values defined by different MSs is not always possible and, in some instances, reveals significant discrepancies, even for variables measuring the same characteristic, as in the case of scrub and tree cover (see Annex 1) (BfN, 2017).

In Slovakia, data were evaluated based on a selection of indicator species that characterise habitats in terms of: (1) representativeness—diagnostic species combination (DSC), including species with high fidelity, with thresholds of 0.2–0.4 for the Phi index and 25–60% for constant species; (2) species indicative of improved habitat quality—the so-called "optima" species (OS), mainly endangered and protected taxa; (3) species indicative of habitat deterioration—"negative" species, typically invasive taxa; (4) coverage of trees (E3) and shrubs (E2); and (5) the cover of monitored habitat in permanent monitoring localities (PML). The classification of three species groups was carried out by experts for all 46 non-forest habitat types and tested using data from the monitoring database. Filtering resulted in the assignment of indicator species counts for each habitat and monitoring record (Šeffer & Lasák, 2022).

2.3 Aggregation at local scale

The overall assessment at the local scale—typically at the monitoring plot or station—requires integrating measured abiotic and biotic variables using aggregation methods. Aggregation may be performed through arithmetic operations where quantitative values are available, or through defined aggregation rules, often with the possibility of applying weightings to individual variables according to their relevance for habitat condition. This enables a more nuanced final assessment. This section provides a summary account of the methodologies employed by different countries to aggregate indicators for assessing the condition of rocky habitats, focusing on the specific methods, formulas, and indicators used in various national frameworks (Table 5).

Germany applies the LANA method, which incorporates multiple criteria to evaluate habitat structure and function on a scale from A (excellent) to C (moderate condition). The method aggregates indicators of characteristic habitat structures, inventories of typical habitat species, and disturbance indicators to derive an overall condition score following specific aggregation rules (BfN, 2017; BayLU, 2022).

Denmark's NOVANA programme monitors the condition of terrestrial habitats using hierarchical statistical modelling. Data from a network of monitoring stations are analysed using models that estimate spatial variance due to regional differences and assess the relationship between indicator values and habitat conditions. The framework also employs multi-criteria calculations that reflect both species composition and vegetation structure (Aarhus Universitet DCE, 2020; Nygaard et al., 2019).

Spain uses the INER index (Naturalness Index of Rocky Ecosystems) for site-level evaluations. The index is calculated as INER = (E + B + TS + An)/4, where E represents geomorphological stability, B refers to biotic components, TS denotes changes in soil and ice temperature, and An indicates the degree of anthropisation (Pérez-Alberti, 2019).

Hungary's assessment framework evaluates each sampled habitat plot against 16 primary variables via 30 scoring tables. The resulting scores classify habitats into three condition classes: good (>40), non-satisfactory (30–40), and bad (<30), with thresholds informed by expert judgement based on long-term monitoring data (Horváth et al., 2021).

In Ireland, the assessment utilises a binary approach: if two or more attributes at a monitoring stop fail, the overall condition for that stop is considered failed (Wilson & Fernandez, 2013). Lithuania applies multidimensional data matrices in habitat assessments, employing the Bray-Curtis index to compare ecological indicators, as well as descriptive statistics and non-hierarchical cluster analysis to allocate data into conservation status classes (Rašomavičius, 2015).

Poland's expert judgement approach evaluates structure and function based on core variables such as species presence and visible disturbance. The local condition index combines area-based measurements and applies the One Out-All Out rule for aggregation (Świerkosz & Reczyńska, 2012; Reczyńska & Świerkosz, 2012). Romania defines attribute limits for assessments but does not provide a clear aggregation approach for combining conservation statuses (Deák et al., 2014).

Sweden integrates qualitative expert assessments with quantitative, automated classification of habitat condition, assessing key parameters such as species and biotope value on a four-level ordinal scale. Automated models use predictor variables to estimate ecological state (Toräng et al., 2022).

Slovakia performs aggregation through ordination in multi-dimensional space, interpreting monitoring records based on variable scores. The evaluation cube method calculates the distance of records from optimal status, producing quality coefficients that inform overall assessment (Šeffer & Lasák, 2022). In the Czech Republic, the Nature Conservation Agency is developing algorithms for aggregating condition indicators at Natura 2000 sites. However, as of now, final details of these algorithms are pending.

Table 5. Methodologies for aggregation of indicators at the local scale

Country	Methodology Description	Aggregation Approach	References
Austria	Uses categories from good to bad condition (A, B, C) both in the assessment of the particular variables as in the overall assessment at the local scale.	Status is determined based on combination of results in each variable and in groups of variables (e.g., A/B, B/C).	Ellmauer (ed.), 2005)
Czech Republic	Developing algorithms for condition aggregation at Natura 2000 sites.	Not specified yet; algorithms are in development.	Vydrová & Lustyk, 2014
Germany	Uses categories from good to bad condition (A, B, C) both in the assessment of the particular variables as in the overall assessment.	Overall condition at the local scale is assessed by aggregating individual scores following specific rules.	BayLU, 2022
Denmark	NOVANA program uses hierarchical statistical models to document habitat state, with a focus on predictor variables for condition.	Incorporates multicriteria calculations for structure and function assessments based on indicator values.	Aarhus Univ., 2020; Nygaard et al., 2019
Spain	INER index evaluates local rocky systems across 11 variables grouped into four categories.	Aggregation based on individual variable scores within each category.	Pérez-Alberti, 2019
Hungary	Assessment based on 16 variables using 30 tables to classify habitats into three condition classes (good, non-satisfactory, bad).	Aggregated scores from tables determine local habitat value.	Horváth et al. 2021,
Ireland	Fail of two or more attributes in monitoring leads to overall failure for that stop.	Simple binary pass/fail system based on attribute performance.	Wilson & Fernandez, 2013,
Lithuania	Utilizes multidimensional data matrices and statistical methods (Bray-Curtis index, cluster analysis) for condition assessment.	Comparative results are evaluated statistically to determine conservation status.	Rašomavičius, 2015
Poland	Expert judgement based on cardinal variables (species presence, invasive species) to assess structure and function.	Local condition index assessed using One Out-All Out rule for aggregation.	Świerkosz & Reczyńska 2012; Reczyńska & Świerkosz 2012
Romania	Methodology outlines attribute limits but lacks a clear aggregation method.	No defined aggregation method due to varying conservation statuses.	Deák et al., 2014,
Sweden	Combines expert assessments with automated classification, focusing on species and biotope values.	Models' relationships between predictor variables and ecological condition for aggregation.	Toräng et al., 2022
Slovakia	Uses ordination in multi-dimensional space to evaluate monitoring records.	Distance calculations in evaluation cube provide quality scores for monitoring records.	Šeffer & Lasák, 2022

There are notable similarities and differences among the national approaches to assessing the condition of rocky habitats. A common feature is the assessment of various ecological indicators at the scale of the monitoring plot or station, with results subsequently aggregated at that level. Several countries employ ordinal scales, such as A, B, and C categories, to classify habitat condition, combining these categories to determine the overall assessment for each locality.

Many methodologies, including those from Denmark, Spain, and Poland, incorporate multiple indicators, such as species presence and habitat structure, to provide a comprehensive evaluation. The use of quantitative assessments and statistical analyses is also evident in countries like Denmark, Lithuania, and Sweden, reflecting a broader trend toward data-driven methods for both indicator calculation and aggregation.

Despite these shared elements, differences are apparent in aggregation strategies and methodological complexity. Countries such as Austria and Germany utilise predefined rules to combine categorical assessments into overall scores, while others favour various forms of quantitative aggregation for the variables measured.

Differences also arise in the extent of expert judgement versus automation: Sweden, for example, integrates both expert assessments and automated classification models, whereas Ireland adopts a straightforward binary pass/fail system. Additionally, the stage of methodological development varies, with some countries, like the Czech Republic, still in the process of refining their systems, while others have well-established protocols. The overall complexity of approaches differs too, ranging from the hierarchical statistical models and multicriteria analyses seen in Denmark and Sweden to the more basic, easily applied frameworks in Hungary and Ireland.

2.4 Aggregation at biogeographical scale

Most Member States have followed the recommendations outlined in the Article 17 reporting guidelines for the 2013–2018 period, which state that if 90% of a habitat area is considered to be in ‘good’ condition, then the status of the ‘structure and functions’ parameter is deemed ‘favourable’. Conversely, if more than 25% of the habitat area is reported as ‘not in good condition’, the ‘structure and functions’ parameter is classified as ‘unfavourable-bad’. However, some Member States have adopted alternative aggregation methods to derive overall assessments at the biogeographical scale. For example, in cases where a habitat type has a limited distribution and only a few monitoring locations are available, the minimum aggregation rule may be applied. This rule requires that favourable conservation status can only be achieved if all conditions important for the specific habitat type are present at every assessed location.

The methodology implemented in Lithuania (Rašomavičius, 2015) exemplifies a statistical approach to large-scale aggregation. Here, the national-level assessment of habitat condition is based on a multivariate analysis of all parameter indicators across surveyed sites. This involves applying non-hierarchical cluster analysis methods, such as K-means, to allocate sites into groups representing different conservation condition classes, using a comprehensive data matrix of indicator values. Ordinal analytical techniques, such as Principal Component Analysis (PCA), are then used to visualise and evaluate the relationships between these groups, supporting robust and objective classification of conservation status at the national scale.

2.5 Selection of monitoring localities

Selection of localities based on expert judgement is reported for two Member States (Poland and Ireland) and relies on the knowledge and experience of experts, supplemented by literature reviews and available database information. However, most of them do not specify instructions for rocky habitats and provide methodologies for open habitats or any habitat type.

Three Member States (Germany, Romania, Austria) employ random stratified sampling for the selection of survey localities, utilising GIS tools, existing surveys, maps, and grid systems to determine random sampling plots. In Germany, a minimum of 63 random samples per habitat type (typically averaging 70–80) are selected to ensure both representativeness and diversity across the habitat's range. Some methodologies make use of habitat mapping as the primary tool for selecting localities. For example, Angelini et al. (2016) describe the selection of sites based on the 1:50,000-scale Natura 2000 habitat map. In Austria, the approach described by Ellmauer (2005) requires on-site recording and delineation of habitat type boundaries at a scale of 1:10,000.

Other countries, such as Czechia (Vydrová & Lustyk., 2014) and Slovakia (Saxa et al., 2015), base locality selection on sites established in previous monitoring cycles. Here, habitat status is assessed at permanent monitoring plots (PMPs) or points (PMLs), which are predefined polygons where a specific habitat occurs, and management is typically homogeneous.

In Greece (Dimopoulos, 2018), monitoring localities were selected based on sampling sites identified during the IDH-TACI project (1999–2001) and according to the need to evaluate habitat conservation status in areas with insufficient existing data. The majority of habitat types are assessed within the 10 km EEA reference grid, as recommended by Evans and Arvela (2011). For habitat types with a restricted distribution, a 5 km grid is applied instead. In Ireland, the selection of localities was based on the National Survey of Upland Habitats (NSUH). This included Special Areas of Conservation (SACs) with upland habitats, upland Special Protection Areas (SPAs), coastal SPAs that contain upland habitats, Natural Heritage Areas (NHAs), proposed NHAs, as well as extensive upland habitats outside designated sites (Perrin et al., 2014). In Romania, sampling locations were distributed according to the biogeographical regions in which the target habitats are present (Deák et al., 2014). Sweden utilises data from broad biogeographical monitoring programmes; however, specific details regarding the sampling are not provided (Nygaard et al., 2019). In Slovakia, monitoring boundaries are defined to encompass the habitats under observation as accurately as possible, resulting in 4,290 monitoring locations for various non-forest habitats, monitored on a minimum six-year cycle. In Lithuania, monitoring locations are selected for different habitat types using structured 10×10 m plots at specified outcrops, with tailored protocols in place for monitoring both coastal and aquatic habitats. In Poland, monitoring sites are generally located within Natura 2000 areas, largely because most suitable habitats are already contained within these protected sites.

2.6 General monitoring and sampling methods

Although not specified by most Member States, it can generally be assumed that the square plot is the most commonly used shape for monitoring plots. An exception is Italy, where the use of transects has been documented (Angelini et al., 2016).

Regarding sampling plot size, the area selected for monitoring varies between countries. Some Member States report a specific plot size—for example, Hungary uses plots of 0.5 m^2, while Ireland selects 2 x 2 m plots—whereas others specify only the overall sampling area, such as 100 m² (Ellmauer, 2005). In Poland, monitoring is conducted exclusively within Natura 2000 sites, typically using a three-point transect (usually 10 m x 200 m) selected by GPS coordinates (Mróz, 2017). In Ireland, thirty-six plots of 100 m x 100 m were surveyed, with selection based on criteria such as plot size, habitat diversity, species rarity, and proximity to designated sites. This process involved an extensive desk-based survey (Perrin et al., 2014).

Concerning the number of plots, some countries—such as Czechia, Hungary, Germany, and Ireland—provide precise numbers of plots to be surveyed per habitat type. Hungary, for instance, requires that six plots of 0.5 m² each be set along the diagonal of permanent monitoring sites (Horváth et al., 2021). In Czechia, 124 permanent monitoring plots were established in 2005 to represent a range of habitat types, with non-forest habitats monitored at six-year intervals (Vydrová & Lustyk, 2014).

Some countries (including Italy, Ireland, and Germany) emphasise a relationship between the total area occupied by a habitat, its geographical variation, and the required number of monitoring plots. Larger and/or more variable habitats require more plots (Angelini et al., 2016). However, the relationship between habitat area and the number of required plots is not linear, and increasing the number of plots does not always improve data quality, especially in highly variable areas (Table 6, Perrin et al., 2014). In fact, proportionally fewer monitoring stops are generally needed for larger sites. Perrin et al. (2014) recommend that the number of monitoring plots be a multiple of four and provide suggestions for plot numbers according to different habitat area sizes.

Most Member States carry out fieldwork for habitat monitoring during the spring or summer months, typically from May to July or April to June. There are some differences between countries regarding the specific months selected, although these variations are not of major significance.

Table 6. Proposed number of monitoring stops for different areas of rocky habitats

Adapted from Perrin et al., (2014)

Area of habitat (ha)	Number of monitoring stops
<0.04	1
0.04 -10	4
10 - 50	8
50-100	12
100 - 500	16
500 - 1,000	20
1,000 - 2,000	24
2,000 - 4,000	28
4,000 - 10,000	32
> 10,000	36

2.7 Other relevant methodologies

Most literature on the monitoring of rocky ecosystems globally tends to overlook the wide range of spatial scales and complexity present in these habitats. Furthermore, there are distinct challenges associated with using existing datasets and remotely sensed information for effective habitat monitoring.

Rowland and Vojta (2013) emphasised the fundamental principles required for the planning and design of habitat monitoring programmes. Notably, they advocate for the early inclusion of a statistician in the planning process, rather than consulting one only after data collection has taken place. The authors identify several sources of error and uncertainty inherent in habitat monitoring, highlighting a key design choice: whether to sample independent units at each time point, or to conduct repeated measurements on the same units. Repeated measurements on permanent plots facilitate the rapid detection of changes and trends, whereas independent sampling of new units each time provides broader spatial coverage, which may be essential in certain circumstances. In general, monitoring designs tend to prioritise the rapid detection of changes, often for management reasons, over strict spatial independence of sampling units (Rowland & Vojta, 2013).

Monitoring objectives may vary between tracking long-term trends and assessing whether current habitat conditions meet predefined thresholds for certain attributes, which in turn informs management decisions. Trend monitoring requires long-term data collection, while threshold assessments may be achieved with a single inventory, or assessed at any stage within an ongoing monitoring programme.

The complex structure and challenging accessibility of rocky habitats, such as cliffs, mean that land managers require up-to-date, site-specific information to ensure effective conservation. Cliff biodiversity has often been overlooked, partly due to the logistical challenges of access and the misconception that these habitats are species-poor (Harrison et al., 2024). Drawing from approaches such as population mapping of rare endemic plants in the Southern Appalachian Mountains (USA), photo-based surveys of cliff-specialist plants in Spain, and monitoring of peregrine falcons in Western North Carolina (USA), Harrison et al. (2024) identified the best practices, advantages, and limitations of three proposed methods for cliff monitoring (Table 7).

Table 7. Summary of three in-situ monitoring techniques suitable for cliff ecosystem
Adapted from Harrison et al., (2014)

Photo Point Survey		
Best Practices	**Advantages**	**Limitations**
- Select memorable and recognisable locations (e.g., distinctive features) - Use permanent markers or GPS for precise location - Standardised naming and storage of photos	- Simple, inexpensive, and broadly accessible - Understandable by non-experts - No botanical expertise required - Only requires visual access to cliff	- Does not quantify plant cover or traits - Difficult to ensure consistency in location and angle - Only provides visual data, cannot measure abundance or phenology - Camera/storage issues possible
Photo Cover Survey		
Best Practices	**Advantages**	**Limitations**
- Use appropriate plot frames for taxa (e.g., 1x1m for vascular plants) - Select plot size/frequency based on vegetation and site - Include controls for climbing impact assessments	- Allows quantification of abundance, plant size, diversity - Increased precision for detecting changes - No advanced botanical skills required	- May require climbing skills or drones - Needs high-resolution cameras - Can be difficult for cryptic or clonal species - Still subject to equipment and data management/storage issues

Species Inventory		
Best Practices	**Advantages**	**Limitations**
- Divide into subzones, consult expert guidance/apps - Take high-quality photos, especially for cryptic species - Collect specimens where appropriate and permitted	- Facilitates thorough baseline data - Allows inclusion of cryptic/faunal species - Many participants can join (e.g., BioBlitz) - Enables rarity/trend assessment	- Time-consuming with possible need for repeated visits - Needs botanical expertise for ID - May require technical climbing and permits - Focus on presence/absence, not always abundance; some localities may require special permission

Monitoring of montane and rocky habitats focuses on a set of key attributes, including physical features such as bare cliffs, rocky outcrops, scree, soil types, and the persistence of snow patches (Hill et al., 2005). For evaluating physical properties and the extent of habitat types, they recommend employing aerial photography, along with field-based inventories that utilise quadrat sampling. This combination provides reliable information about the size, distribution, and changes in habitats over time. To assess habitat composition, encompassing features such as exposed rock, scree, bare soil, and persistent snow patches, Hill et al. (2005) advocate the use of both aerial or fixed-point photography and traditional field methods, such as quadrats or transects. These approaches enable researchers to monitor structural characteristics and overall composition in a repeatable, objective manner. The evaluation of soil nutrients and characteristic plant communities should be conducted through systematic sampling using quadrats or transects. This structured methodology is essential for tracking environmental changes and detecting shifts in the assemblage of characteristic species. For a more detailed analysis of species composition and richness, the use of mini-quadrats is advised, allowing for the capture of fine-scale patterns in plant diversity. Finally, Hill et al. recommend determining the presence or absence of typical or indicator species by conducting total counts and targeted surveys with quadrats or along transects. This ensures a thorough assessment of the key species that define habitat quality and supports informed conservation management decisions.

2.8 Conclusions

In the assessment of rocky habitats across EU Member States, relatively few physical variables are utilised, despite the recognized importance of physical characteristics such as climatic and temperature conditions, which are often overlooked. Lithology, fundamental for understanding these habitats, is similarly under-recorded or inadequately incorporated.

The most frequently used variables tend to focus on the coverage of particular species groups, including diagnostic, endemic, key, and umbrella species, as well as cryptogams and vascular plants, collectively referred to as “emphasis species” (see Rowland & Vojta, 2013). However, there is a lack of transparency in many methodologies regarding the establishment of threshold values for these variables, with a marked reliance on expert input. Compositional variables are typically evaluated through species lists, in which the number of species present is used to determine the habitat’s condition. For example, the presence of more than three species may correspond to a favourable (FV) status, two or three species to unfavourable-inadequate (U1), and a single species to unfavourable-bad (U2). Structural variables are assessed using similarly categorised thresholds. In Slovakia, habitat quality is evaluated with the aid of indicator species, focussing on indicators such as representativeness, the ecological impact of species, and coverage metrics.

Threshold values are crucial for assessing habitat condition and are generally used by most Member States to categorise habitat quality according to scales such as Favourable (FV), Unfavourable-Inadequate (U1), and Unfavourable-Bad (U2), or using an A-B-C grading system. Nevertheless, the documentation underpinning these thresholds is often incomplete, and in some countries is absent, leading to continued reliance on expert judgement. For instance, coverage-based thresholds used to assess the impact of invasive species may range from less than 5% (good condition) to over 10% (bad condition), yet these cut-off points are rarely justified in the reporting.

At the local scale, the assessment of habitat condition involves integrating abiotic and biotic variables using various aggregation methods. Approaches include the “one-out, all-out” rule—where the overall assessment defaults to unfavourable unless all variables are favourable—or weighted quantitative approaches. Certain Member States, such as Bulgaria, will only assign a favourable status to habitats if all variables meet the required thresholds or, at most, if up to 25% of variables lack sufficient information. In contrast, countries such as Greece and Ireland use majority rules, deeming habitat condition favourable based on the proportion of variables that are in good condition.

Regarding aggregation at the biogeographical scale, general practice follows Article 17 reporting guidelines: a habitat is considered favourable if 90% or more of the area is in good condition. Some countries implement alternative minimum aggregation rules or use descriptive statistics, while others, like Lithuania, adopt multivariate methods for national assessments.

The selection of localities for assessment is often based on expert judgement or on random stratified sampling. In Poland, for example, localities are primarily chosen within Natura 2000 areas, largely because most suitable habitat sites are already included in this network. In Germany, GIS and random sampling are used to ensure comprehensive representation of habitat diversity. The use of permanent plots is widespread, for instance in the Czech Republic and Hungary, both of which employ established monitoring locations to evaluate changes in habitat conditions systematically.

Overall, while certain methodologies in EU Member States offer robust frameworks for the definition of thresholds and assessment of habitat conditions, there is still considerable variability and inconsistency in both the approaches used and the level of documentation provided. This highlights ongoing gaps and the continued need for harmonised and transparent methodologies across Member States.

3. Guidance for the harmonisation of methodologies for assessment and monitoring of habitat condition

The analysis of existing methodologies for assessing and monitoring the condition of rocky slopes with chasmophytic vegetation reveals some commonalities and differences among the EU MSs. These guidelines aim to provide recommendations that will contribute to the harmonisation of these methodologies, while also addressing some gaps detected, with the objective of achieving more robust and comparable results across the EU.

3.1 Selection of condition variables, metrics and measurement methods

A proposed list of essential, recommended and specific condition variables for group 82 habitats is presented in Table 10 including metrics and general measurement procedures. The selection is based in the main characteristics of rocky habitats, as described in chapter 1, and the methodologies available from MSs for the assessment of rocky slope habitats condition. The proposed metrics are intended to be easily, but reliably obtained, most of them at plot level.

Essential variables (E) correspond to characteristics that are vital for the habitat (e.g., rock surface temperature and humidity), describe the distinctness of the habitat (e.g., characteristic species) or its condition (e.g., typical and alien species, coverage). **Recommended variables** (R) correspond to additional variables which are relevant but that can be neglected to be measured in some contexts. **Specific variables** (S) should be measured in some specific habitats due to their particular characteristics.

In addition, several **descriptive variables** (D) are also proposed, which inform on the context of the habitat and can be relevant to understand the processes that can influence their ecological status, but do not directly inform of such condition (e.g., lithology).

Among the **abiotic variables**, the nature of the bedrock and the climatic conditions are firstly considered. These variables are considered as descriptive variables because they do not inform on their own about the habitat condition but provide information on the context in which the habitat occurs and influence its key characteristics and functions.

The mineralogical composition and texture of the rock, i.e., lithology, including features such as mineral makeup and grain size, are fundamental in shaping both alteration processes and plant colonisation patterns. The degree of rock alteration is also a critical determinant, as it directly influences which species can establish and persist, making it an essential factor in habitat assessments. The extent of rock fracturing further contributes to habitat diversity by creating varied microenvironments in adjacent areas, thereby supporting a broader range of ecological communities.

These variables influence the alteration or the rock and plant colonization patterns, as well as the presence of cavities which, ultimately, will also have an influence on the presence of micro and mesofauna. The mineralogical makeup and texture of the rock, including grain size, is measured through the variables of lithology of type of geo-forms present. Altitude, exposure to light and temperature provide information of the climatic conditions. The slope gradient and the presence of cracks and cavities inform on the instability of the habitat and the alteration processes active, as well as on the presence of potential microhabitats for flora and fauna.

As essential variables, **surface temperature**, more than air temperature, plays a pivotal role because it has a direct and immediate effect on local ecological conditions. Similarly, **surface humidity**, especially that retained within cracks and cavities, is a more decisive indicator of habitat health than overall precipitation levels, as it directly influences microhabitat suitability for many species. Measurement of erosion is also proposed.

Soil pH has a direct influence on the solubility and availability of nutrients for plant uptake, as well as on the activity of soil microbes that drive nutrient cycling and organic matter decomposition, processes that are especially important in scree habitats where organic content is sparse and mineral substrates dominate. It can be measured using a pH meter during fieldwork (Table 8).

Essential **biotic compositional variables** include the presence and abundance of characteristic plant species from various groups, as well as notable animal species and invasive alien species that may colonise these environments.

Characteristic species serve as key descriptors for habitats and should be evaluated against a pre-established list specific to each habitat type. The presence of typical chasmophytic vegetation, including ferns, lichens, and bryophytes, acts as a reliable indicator of the condition of rocky slope habitats. Additionally, the presence of arthropods, reptiles, and breeding birds is recommended as essential variables reflecting good habitat condition. Conversely, the presence of alien species and nitrophilous species is considered an essential variable signifying altered or degraded conditions, given their substantial negative impact on native populations and their potential to disrupt ecosystem functioning (Keller et al., 2011).

For essential **biotic structural variables**, it is proposed that the coverage of the same taxa groups be designated as a required indicator.

As regards **functional biotic** variables, some physical and compositional variables already inform on habitat functions. For example, the degree of rock alteration has direct consequences for system stability and influences the establishment processes for both plants and animals—processes that are already captured through compositional and structural assessments. However, monitoring of pollinator species diversity is proposed as a functional variable. The most significant pollinator groups observed in these environments are wild bees and butterflies, with moths and certain beetles (such as ground beetles and flower beetles) also often present. These groups are particularly well-adapted to the harsh, heterogeneous microclimates found on rocky slopes, where exposed rocks, shallow and patchy soils, and variable floral resources limit the presence of less specialised pollinators (European Environment Agency, 2025).

As recommended variables**, landscape metrics** and the assessment of the impact of anthropic disturbances are proposed.

Rocky slope habitats with chasmophytic vegetation are naturally isolated due to their patchy distribution on cliffs, outcrops, and steep slopes. Consequently, landscape fragmentation in these systems cannot be evaluated in the same manner as more continuous habitats, such as heathlands or forests. Standard metrics like edge density or total habitat area may not provide meaningful insights given the inherent isolation and ecological uniqueness of rocky slopes. A pragmatic and intuitive way to assess the impact of fragmentation on these habitats is to quantify habitat patch size, measure distances between habitat patches, and record the presence of fragmenting infrastructures such as roads, quarries, or urban development. Remote sensing and GIS mapping are now widely recommended for this purpose in ecological monitoring, as they enable repeatable assessments and facilitate the tracking of landscape changes over time.

Finally, the presence and intensity of anthropogenic activities, such as tourism, building projects, and resource extraction—must also be closely monitored. These human influences are recognised as essential variables because they significantly affect habitat quality and connectivity, especially in fragile and isolated rocky slope systems.

Disruptions to the physical structure could be recorded and assessed using a physical disturbance index (e.g., Goñi & Guzmán, 2019). For each type of disturbance identified, the extent (localized or extensive), intensity (low or high), and frequency (sporadic or frequent) are assessed. The categories “localized,” “low,” and “sporadic” receive a score of 0, while “extensive,” “high,” and “frequent” are scored as 1. The scores for each aspect are then summed. A total score of 3 can be reached either when a single disturbance type receives the highest rating in all three aspects, or when three separate disturbance types each receive a maximum score in one aspect. Roads, tracks, and paths, together with infrastructure such as stone and gravel extraction, artificial slopes, irrigation channels, and artificial elements like anchors, metal staples, fences, carved steps, and wire mesh, all contribute to significant alterations in the landscape (Goñi & Guzmán, 2019).

Table 8. Proposal of variables for habitats included in group 82 - rocky slopes with chasmophytic vegetation

Characteristics	Variables	Metrics	App.	Standardised measurement procedures	Considerations relating to methodologies
1. Abiotic characteristics					
1.1 Physical state characteristics					
Climate	Air temperature	ºC	D	Measured with thermometer or retrieved from meteorological stations.	
	Rock surface temperature	ºC	E	Installation of temperature sensors/ dataloggers.	Monitored at surface and various depths, in cracks and cavities.
	Rock surface humidity (in cracks and cavities)	%	E	Installation of humidity sensors/ dataloggers.	Monitored at surface and various depths.
Topography	Altitude	m	D	Measured using GPS altimeters.	
Lithology	Lithology	Rocky type	D	Field or laboratory analysis of physical characteristics when bibliography not available.	Rock type: limestone, granite….
Geomorphology	Slope characteristics, exposure	Degree of slope	D	Measured using clinometers or digital inclinometers. Photo surveys using of drones (Lidar) / multispectral camera	Monitored using rods installed across the slope for movement assessment.
	Presence of fissures, cracks, cavities, ledges	Presence, number and % surface cover	D	Visual inspection in the field or using aerial photography.	
	Alteration degree of the rock	kg/m²/yr	E	Installation of surface erosion control stations with a micro erosion meter or, if not possible, with a durometer.	
1.2 Chemical state characteristics					
Soil characteristic	soil pH	pH	E	Portable pH meter	

Characteristics	Variables	Metrics	App.	Standardised measurement procedures	Considerations relating to methodologies
2. Biotic characteristics					
2.1 Compositional state characteristics					
Presence and number of characteristic species	Characteristic species (mosses, ferns, grasses, and other vascular plants)	Presence and number of species.	E	Visual inspection in the field or via photo survey.	Based on local or regional reference lists.
	Presence and number of plant species in the family Crassulaceae	Presence and number of species	S	Visual inspection in the field or via photo survey.	For habitat 8320. Based on local or regional reference lists.
	Fauna: invertebrate species, reptile, bird species.	Presence and number of species	E	Visual inspection in the field or via photo survey. Sampling using pitfall traps or sweep nets, Malaise traps for invertebrate collection. Nest counting can be used to indicate bird presence.	Based on local or regional reference lists.
Presence of negative indicator species	Nitrophilous species	Presence and number of species	E	Visual inspection in the field or via photo survey.	Based on local or regional reference lists.
	Presence of alien species	Presence and number of species	E	Visual inspection in the field or via photo survey.	Based on local or regional reference lists.
2.2 Structural state characteristics					
Pattern of occupancy of species	Cover of bryophytes, lichens and vascular plant species	%	E	Estimated cover using quadrat sampling methods or photo survey.	For 8230: a higher plant cover is indicative of a better conservation status.
	Cover of alien invasive species	%	E	Estimated cover using quadrat sampling methods or photo survey.	Based on local or regional reference lists.
	Cover of tree and scrubs	%	E	Estimated cover using quadrat sampling methods or photo survey.	Based on local or regional reference lists.

Characteristics	Variables	Metrics	App.	Standardised measurement procedures	Considerations relating to methodologies
2 Biotic characteristics					
2.2 Structural state characteristics					
Habitat ruderalisation	Cover of nitrophilous species	%	E	Estimated cover using quadrat sampling methods or photo survey.	Based on local or regional reference lists.
2.3 Functional state characteristics					
Natural processes	Presence of pollinator species	Presence and number of species	E	Sweep nets and direct observation, Malaise traps for invertebrate collection.	Based on local or regional reference lists.
3. Landscape					
Landscape metrics	Total area of habitat patch and distance from other patches	m^2 or ha (area) and km or m (distance)	E	Assessed using aerial imagery and GIS tools.	Based on remote sensing methods.
	Presence of fragmenting structures	Presence	R	Visual assessment in the field and from aerial photographs	Roads, mines, etc.
4. Other					
Anthropic disturbance	Effects of anthropic activities	Presence and signs of impact	R	Visual assessment of importance and surface affected by anthropic disturbance/alteration of the habitat, using 3 point scoring: frequent/sporadic, intense/mild and extensive/isolated	Anthropic signs such as garbage, trampling, climbing, hiking, climbing.

App: Application of variables. D: descriptive/contextual; E: essential; R: recommended; S: Specific.

3.2 Guidelines for the establishment of reference and threshold values, and obtaining condition indicators for the variables measured

The measured variables need to be compared with reference values and critical thresholds to assess the condition. A reference level is the value of a variable under reference conditions, against which it is meaningful to compare past, present or future measurements. The difference between a variable's measured value and its reference level represents its distance from the reference condition.

Reference levels should be defined consistently across different variables within a given ecosystem type, and for the same variable across different ecosystem types. This ensures that derived indicators are compatible and comparable, and that their aggregation is ecologically meaningful (United Nations, 2021).

Reference levels are typically defined with upper and lower values reflecting the endpoints of a condition variable's range, which can then be used in re-scaling. For instance, the highest value may represent a natural state, while the lowest value may represent a degraded state where ecosystem processes fall below the threshold required to maintain function (Keith et al., 2013, in United Nations, 2021). For example, pH values in freshwater ecosystems clearly indicate whether biological life can be sustained, while soil nutrient enrichment beyond a certain threshold can lead to the loss of sensitive species.

Establishing reference values and thresholds is essential for determining whether habitats are in good condition or have become degraded. Reference values represent the desired state of an ecosystem, typically reflecting intact or minimally disturbed conditions. These values serve as benchmarks for assessing habitat condition.

These guidelines do not aim to prescribe specific threshold values. Rather, they outline the main criteria and provide guidance for establishing reference values that support the determination of good or not-good condition, while accounting for the ecological variability of habitats across their range.

With regard to the variables, the harmonisation of reference values and thresholds should consider a set of **common requirements**:

- For a given habitat, the final assessment of its condition and trend over time – based on the reference values and thresholds of the variables characterising the habitat – should be equivalent across Member States (MSs), after accounting for the contextual factors specific to each MS (e.g., climate).
- Thresholds, limits, and reference values should be tested using sufficiently robust datasets that represent the full range of habitat conditions, from degraded to high-quality sites.
- Thresholds must account for the natural variability of habitats across their range. Consequently, different threshold or reference values for the same habitat type may be appropriate in different MSs or in different regions within a single MS.
- Establishing reference values requires information external to the evaluated site, which can provide insight into the condition of the habitat and be translated into variable values that characterise that condition.
- Reference values should meet the criteria of validity (ecological relevance), robustness (reliability), transparency, and applicability (Czúcz et al., 2021; Jakobsson et al., 2020).
- Each MS should provide a clear, justified, and comprehensible description of the methodology used to establish threshold and reference values for each variable.

- The methodologies should be designed for regular evaluation and improvement, based on the best available scientific knowledge. Any modifications made – and their implications for past monitoring data – must be communicated transparently.
- A reference library and indicator thresholds should be developed for different habitat types across regions, taking into account their ecological characteristics and natural variability.
- Joint training or guidance on setting threshold and reference values should be offered to experts from the different MSs in order to achieve ensure harmonised approaches.

Several approaches have been recognised for estimating reference values to assess habitat condition (Stoddard et al., 2006; Jakobsson et al., 2020; Keith et al., 2020). These can be broadly synthesised into six categories: (1) absolute biophysical boundaries, (2) comparison to reference empirical cases – i.e., areas or communities considered to be in good condition, (3) comparison to undisturbed cases, (4) modelling and extrapolation of variable-condition relationships, (5) statistical assessments, and (6) expert judgement.

All approaches should be grounded in scientific literature. Methods that use values from a single baseline year as a reference for good condition are not recommended, as the selected year may not reflect favourable conditions, and historical data may be unreliable or incomplete (Jakobsson et al., 2020). The use of historical period (e.g., pre-industrial) as a reference state, as proposed by Stoddard et al. (2006) and Keith (2020) aligns with the baseline approach but also overlaps with comparisons to undisturbed cases (see below). If conditions during a specific baseline year are well documented as favourable, they may be useful for trend analyses. Likewise, where historical pristine conditions are clearly documented, they may serve as valid reference states under the undisturbed comparison approach.

Absolute biophysical boundaries

These refer to situations in which observed values of variables exceed the physical and chemical limits (e.g., pH, bare soil cover, critical loads for eutrophication or acidification) or biotic limits (e.g., presence of alien species) that define the habitat. When such limits are exceeded, the habitat cannot be in good condition (Jakobsson et al., 2020). These thresholds therefore indicate negative impacts on the favourable condition of the habitat.

- Advantages: This approach provides robust and transparent criteria that are clearly linked to the ecological integrity of the habitat.
- Disadvantages: It is applicable to a limited number of variables, typically those with direct negative impacts on habitat condition.

Comparison to empirical cases considered to be in good condition

This approach is based on identifying areas or communities considered to be in good condition (Stoddard et al., 2006; Jakobsson et al., 2020; Keith et al., 2020). These serve as reference cases from which the reference values can be derived. Therefore, their careful selection – and the availability of a sufficient number of such cases – is essential for ensuring the reliability of the reference value estimates (Soranno et al., 2011). While this method may appear straightforward, it is often limited by the scarcity of suitable sites, especially in landscapes that have been historically modified.

- Advantages: Providing that sufficient data from high-quality cases are available, this approach offers empirical validity and reliability by directly linking variable values to habitat condition.

- Disadvantages: Methodological challenges arise due to the difficulty of identifying a sufficient number of suitable reference sites in historically altered environments.

Comparison to cases with a natural disturbance regime

This approach is closely related to the previous one, based on the assumption that most human-induced disturbances reduce habitat quality. This assumption is generally valid in human-modified landscapes and can be linked to historical reference conditions when human pressures were less pronounced (Stoddard, 2006). However, disturbances that are part of a natural disturbance regime may actually indicate naturalness and thus good habitat condition. In fact, a certain level of disturbance can be beneficial, supporting microhabitat formation, enhancing biodiversity, and promoting regeneration of habitat-characteristic species (Keith et al., 2020).

Historical reference criteria may include the absence of human intervention or management, as found in “primary” forests (sensu Sabatini et al., 2017), and are often directly connected to climax communities such as old-growth or primeval forests (Wirth et al., 2009; Burrascano et al. 2013; Buchwald, 2005), which are typically assumed to be in good condition. However, in regions with long-standing anthropogenic pressure, it may be difficult to identify unaltered or naturally disturbed habitats for certain types (Keith et al., 2020). Additionally, defining the undisturbed state based on a relatively short time period may overlook disturbance legacies that persist over longer timescales (Alfaro-Sánchez et al., 2019).

- Advantages: This approach provides transparent and empirically grounded criteria for defining reference conditions and can benefit from large-scale information on disturbance and land-use history.
- Disadvantages: The assumption that any disturbance reduces habitat quality may not always be valid. Moreover, identifying sufficient undisturbed or naturally disturbed reference areas can be challenging for some habitat types.

Modelling the relationships between variables and condition

This approach assumes a relationship between variable values and habitat condition. When determining threshold and reference values, models that describe these relationships share a conceptual basis with methodologies based on dose-response curves. Such models assume that certain cases of good condition correlate with specific levels of a condition variable.

The advantage of modelling is that it allows reference values to be inferred where empirical examples of good condition or undisturbed condition are lacking. In these situations, information from known empirical examples can be extrapolated to other contexts, such as locations along a climatic gradient.

Various modelling procedures are available. Functional relationships – linear, saturated, or humped – can be applied (Stoddard et al., 2006; Jakobsson et al., 2020). For instance, deadwood volume in pristine forests can be modelled along productivity gradients to establish reference values in climatic conditions where unaltered forests no longer exist (Jakobsson et al., 2020). Correlative climate niche models can also be used to estimate the suitability of species sets (i.e., variables that characterise the habitat) at different points along the climatic gradient (Jakobsson et al., 2020).

Although these approaches offer a functional basis for establishing reference values, they involve several assumptions that often require expert judgement. It is also possible to create models in which condition is inferred from variables other than the condition variable itself – for example, biodiversity-related condition variables may be inferred from pollution levels.

However, this approach should be used with caution to avoid tautological inferences involving variables that reflect pressures.

- Advantages: Modelling approaches are flexible, transparent, and encompass a variety of procedures based on functional relationships between variables and condition, drawing on scientific knowledge from multiple disciplines. They can also be applied to obtain reference values when empirical examples of good or undisturbed condition are lacking.
- Disadvantages: The information available to build models is often insufficient or unreliable for many variables. Outputs are highly sensitive to the chosen modelling procedure and underlying assumptions, and expert judgement is ultimately required at multiple stages of the modelling process.

Statistical assessments

This approach is based on quantitative data from databases, such as habitat inventories, which report the distribution of variables within a given habitat. It assumes that higher values of certain variables correspond to good condition when a positive relationship exists, and vice versa. For such variables, high percentile values or confidence intervals (e.g., 95%, Jakobsson et al., 2020), or differences from the maximum observed values (Storch et al., 2018), may be used.

For variables with a negative impact on habitat condition, low (e.g., 5%) or minimum values are applied, while for variables that show a hump-shaped (non-linear) relationship with condition – peaking at intermediate values (e.g., gap occurrence, browsing) – a combination of high and low percentiles may be used.

This approach is particularly suited to variables obtainable from forest inventories (Storch, 2018; Pescador et al., 2022), and is useful when empirical examples of good condition are lacking. However, it may provide limited insight into the state of habitats that are in poor condition throughout the entire assessed territory. In other words, this approach is not directly based on reference situations of good condition, but on statistical inferences subject to the constraints of the sampling used to build the reference database.

- Advantages: This approach can be applied with reasonable ease by users with statistical training. It is transparent, replicable, and minimally subjective.
- Disadvantages: The existence of appropriate, quantitative datasets representing the reference state is essential for this method. Its reliability depends on the distribution of condition classes (from bad to good) in the dataset and on how well this distribution corresponds to empirical situations of good condition. As a result, it may lead to under- or overestimation of good condition and may be less reliable for habitats that are poorly represented in the dataset.

Expert judgement

Setting of reference values and thresholds based on expert judgement is common practice, particularly where other sources of information are lacking – for instance, in certain non-abundant habitats where experts have developed empirical knowledge of habitat condition. However, this approach is often criticised for its limited transparency, and the level of expertise may be insufficient in some cases. For this reason, it is sometimes considered a last-resort option for many variables.

Nonetheless, for certain variables – such as assemblages of characteristic species, successional stages, the presence of microhabitats, or regeneration characteristics – expert judgement may be appropriate for establishing thresholds and reference values. In other cases, it can also serve as a complement to other approaches.

In all situations, it is advisable to apply expert judgement through protocols based on consensus and consultation with multiple experts of comparable experience. This should include clear procedures (e.g., standardised questionnaires) and transparent documentation of how conclusions were reached (Stoddard et al., 2006). A further limitation is the lack of available experts for certain habitats, which can hamper the correct application of this approach.

- Advantages: This approach is easy to apply and is commonly used.
- Disadvantages: It entails a high degree of subjectivity and low transparency, which limits replicability and reliability. Its use may also be constrained by the scarcity of suitable experts for particular habitats and Member States.

These approaches are drawn from methodologies applied by Member States and documented in the literature. Given the uncertainties involved in setting reference levels, a combination of approaches is generally recommended to improve reliability. The approaches described are not mutually exclusive, and are often applied in combination. For example, expert judgement is typically required when defining reference cases for good condition or when making modelling decisions about the relationship between variables and condition. Similarly, modelling-based approaches can complement those based on empirical cases of good or undisturbed condition and may also be integrated with statistical methods.

Habitat condition assessments are based on determining whether the variables used indicate good or not good condition. However, it is common practice to define more than two categories for each variable – e.g., good, medium, and bad – as observed in the analysis of methodologies used by MSs. The criteria for assigning these condition categories vary depending on the characteristics of each variable. For example, categorical variables may involve thresholds such as “no alien species allowed”, while quantitative variables may follow linear or non-linear relationships with condition (Jakobsson et al., 2020).

This classification of variable values – whether quantitative or categorical – into condition categories (e.g., good, not good; or good, medium, bad) corresponds to the scaling process needed for joint evaluation through aggregation procedures, as described in the following section. Condition categories can be translated into numerical values (e.g., good = 2, medium = 1, bad = 0). Alternatively, where quantitative values for the variables are available, these can be directly standardised for use in aggregation.

Owing to the different metrics and magnitudes used for the variables that characterise habitats, the values obtained from their measurement require some form of standardisation – e.g., through re-scaling – in order to build indicators that combine multiple variables. In habitat condition assessments, each characteristic and its associated variable is likely to be measured in a different unit. These values are normalised using reference levels and reference conditions, allowing comparison across variables. Measurement values are scaled in relation to their reference levels, thereby normalised to a common scale and aligned direction of change. They can then be combined to form a composite index or used to obtain an overall condition result through appropriate aggregation approaches (see further details in Section 3.3. on Aggregation). Thresholds, limits and reference values must be tested against sufficiently broad data sets, covering the full range of habitat conditions – from degraded to high-quality examples. A reference library should be established, and indicator thresholds identified across mire types and regions.

3.3 Guidelines for the aggregation of variables at the local level

Ecological assessments require the integration of physical, chemical, and biological quality elements. The choice of aggregation method of partial assessments into an overall evaluation has been widely discussed within the scientific community, as it can significantly influence the final outcome. Applying appropriate aggregation approaches is essential for categorising condition at the local scale as good or not good, since the proportions of habitat type area in good/not good condition is the key information needed for evaluating the conservation status of structure and functions at the biogeographical level.

Ecological assessments require the integration of physical, chemical, and biological quality elements. The choice of aggregation method for combining these partial assessments into an overall evaluation has been widely discussed within the scientific community, as it can significantly influence the final outcome.

Various approaches can be used to integrate the values of measured variables into an overall index reflecting the condition of habitat types at the local scale (e.g., monitoring plot, station, or site).

Applying appropriate aggregation approaches is essential for categorising condition at the local scale as good or not good, since the proportions of habitat type area in good/not good condition is the key information needed for evaluating the conservation status of structure and functions at the biogeographical level.

3.3.1 Overview of aggregation methods

Based on the literature (e.g., Langhans et al., 2014; Borja et al., 2014), two main aggregation approaches can be distinguished: the one-out, all-out rule (minimum aggregation) and additive aggregation (e.g., addition, arithmetic mean, geometric mean). Further information on aggregation approaches and methods is provided below.

Minimum aggregation, or the One-out, all-out rule

For the minimum aggregation, the aggregated value is calculated as the minimum of the values of the measured variables.

The one-out, all-out (OOAO) rule has been recommended for assessing ecological status under the Water Framework Directive (CIS, 2003). The principle behind this minimum aggregation method is that a water body cannot be classified as having good ecological status if any of the measured quality elements fail to meet the required threshold.

This is considered a precautionary and rigorous approach, but it has also been criticised for potentially underestimating the true overall status.

A precautionary OOAO approach is also used in the aggregation of parameters when assessing conservation status under the Habitats Directives, the IUCN Red List of Species and the IUCN Red List of Ecosystems.

Conditional rules

Conditional rules require that a certain proportion of variables meet their respective thresholds in order for the overall assessment to achieve a good condition rating. For example, the overall status may be considered as not good when a specific number of variables fail to meet their thresholds.

Simple additive methods and averaging approaches

Simple additive methods calculate an aggregated value as the sum of the n values (vi) of the variables. Averaging approaches are among the most commonly used methods for aggregating indicators. These include straightforward calculations such as the arithmetic mean, weighted average, median, or combinations thereof, to produce an overall assessment value.

Weighting

Differential weighting of indicators may be applied when calculating sums, means, or medians. The choice of weighting system should reflect the relative importance of each indicator in determining the overall condition of the ecosystem. Ideally, the approach should be supported by a clear scientific rationale and informed by input from ecologists with expertise in the relevant ecosystem types.

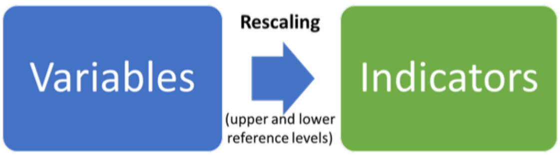
However, a robust basis for assigning weights is not always available. In such cases, weighting often relies on expert judgment, which can be subjective, as expert opinions may differ considerably.

Normalization of variables values (rescaling)

In the assessment of habitat condition, each characteristic and associated variable is likely to involve the use of different measurement units. To ensure comparability, the measured values of variables are often normalised to a common scale (e.g., 0 to 1 or 0 to 100).

This involves rescaling the raw data based on reference values or thresholds that define the boundary between good and not good condition for each variable. By rescaling the condition variables, indicators are standardised to the same scale, making it possible to aggregate them into condition indices that reflect the overall condition at a given plot or location (Figure 1).

Figure 1. Example of deriving condition indicators by rescaling the values obtained for variables, based on upper and lower reference levels



$$Condition\ indicator = \frac{(V-VL)}{(VH-VL)} \quad \text{[Equation 1]}$$

Where:

- V is the measured/observed value of the variable,
- VH is the high condition value for the variable (upper reference level),
- VL is the low condition value (lower reference level).

Source: Vallecillo et al. (2022)

3.3.2 Proposal for the aggregation of measured variables

A quantitative aggregation method should be applied to integrate all essential and specific variables measured to assess the habitat condition. The method should be applied consistently across the habitat range in order to obtain comparable results.

The proposed method to determine the habitat condition at the local scale is the arithmetic mean with a normalisation of the values obtained for each of the measured variables.

Step 1 – Normalisation of the variables

The quantitative values obtained for each variable should be normalised by rescaling based on reference values (as described above). Thus, the value of each variable will be in the range from 0 to 1.

Step 2 – Additive aggregation of normalised variables by arithmetic mean

The aggregated value is then calculated by the aggregation of the normalised values of the variables. For the sake of simplicity, and owing to the difficulty to suggest a more complex method or index, we describe here a preliminary proposal for aggregation based on the arithmetic mean with normalisation of the values obtained for each of the measured variables, which could be used to determine the habitat condition at the local scale, as summarised in the following equation:

$$Local\ condition = \sum_{1}^{n} v_i/\mathrm{n}$$

Where *n* is the number of variables, *vi* the rescaled value of the corresponding variable (between 0 and 1). As a consequence, the aggregated value should range between 0 and 1.

An alternative method would be to use the weighted average, in which the weight of each variable should be decided, justified and agreed upon for each habitat type by all the MSs that would apply the method. This method can be formulated with the following equation:

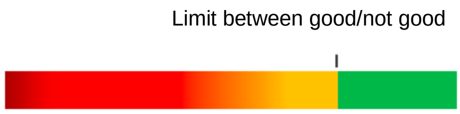
$$Local\ condition = \sum_{1}^{n} v_i * w_i/\mathrm{n}$$

Where *n* is the number of variables, v_i the rescaled value of the corresponding variable (between 0 and 1) and w_i the corresponding weight, with ∑ *wi* =1. As consequence, the aggregated value should range between 0 and 1.

This second method, however, poses serious difficulties in assigning weights to the variables, which must be based on a proper evaluation of their importance and influence on the habitat condition, based on a robust scientific knowledge. It also requires reaching a consensus on the weights assigned to the variables measured for each type of habitat, among all the countries that must assess its condition. This is a crucial aspect to obtain comparable results in the assessments carried out by all the Member States.

Step 3 – Identify the threshold to determine good/not good condition at the local scale

Finally, a threshold must be applied to the aggregated value to distinguish between good and not good overall condition. Wherever possible, this threshold should be established based on empirical data from reference localities in good condition and from localities showing a degraded state. Where such reference localities are not fully available, modelling to obtain such thresholds could be applied.



3.4 Guidelines for aggregation at the biogeographical region scale

The aggregation process for evaluating rocky slopes with chasmophytic vegetation should begin with a comprehensive assessment of local habitat conditions. This assessment must cover a sufficient number of localities to capture the full diversity of the habitat across its range and to ensure representativeness for the entire habitat area.

Following Article 17 guidelines, each local site is classified as either 'in good condition' or 'not in good condition.' At the biogeographic region level, aggregation involves calculating the overall proportion of rocky slope habitats deemed to be in good condition. This is done by summing the total area of monitoring sites assessed as 'good' and dividing it by the total area surveyed. These calculations are then compared against Article 17 thresholds: if 90% or more of the rocky habitat is assessed as being in good condition, the structure and functions parameter is classified as 'favourable.' Conversely, if more than 25% is reported as 'not in good condition,' the status is deemed 'unfavourable-bad.' Outcomes that fall between these thresholds (specifically 0%–75% in good condition) are recorded as 'unfavourable-inadequate.'

3.5 Guidelines on general sampling methods and protocols

These guidelines are intended to provide a standardised framework for sampling design and monitoring that can be implemented consistently across EU member states. The recommendations in this section address key aspects of sampling protocols, including determination of the size and number of sampling areas, monitoring frequency, and the integration of different spatial scales. These approaches have been chosen because they are grounded in methodologies that have demonstrated wide effectiveness and success across diverse EU contexts.

After identifying the principal habitat locations within each biogeographical region, a stratified sampling design should be established to ensure that all major ecological zones within the region are represented. This approach allows for comprehensive coverage of the habitat type under assessment, capturing variation both within and outside Natura 2000 sites. All sampling locations must be precisely georeferenced, with photographs taken of both the plots themselves and their immediate surroundings to facilitate future monitoring and verification.

Regarding the use of permanent plots, the verticality and inaccessibility of many rock outcrops requires that they are defined by easily recognisable reference points, supported by field sketches and photographic documentation. The boundaries of each rock surface under study can be traced directly onto these images.

For conducting counts, ideally, the rock surface being surveyed should be accessible enough for direct observation and enumeration of individual plants at close range. Where direct counts are not possible—such as on distant or sheer rock faces—binoculars or telescopes can be used, and visual estimates can be refined using correction factors (Goñi et al., 2006). Repeated counts conducted over several years make it possible to detect demographic trends and identify emerging threats, including herbivory, competition from invasive species, or habitat disturbance.

Measurements of the abiotic variables are to be conducted inside the plots. Recording of landscape variables is to be done at location level.

Monitoring should be conducted at regular intervals of six to ten years. Alternatively, monitoring every eight to ten years may be appropriate where change is expected to occur more slowly or resources are limited. Following recommendations by Horváth et al. (2021) and Wilson and Fernández (2013), the optimal size for monitoring plots ranges from 0.5 to 2 m^2.

Incorporating new technologies can greatly enhance habitat assessment. The use of orthophotographs, digital elevation models, multispectral cameras, and LiDAR data acquired through unmanned aerial vehicles (UAVs) enables high-resolution mapping and monitoring.

3.6 Selecting monitoring localities and sampling design

The selection of localities for sampling - along with the sample size (number of plots) and power (statistical significance) - is crucial for ensuring the representativeness of the results obtained in the assessment and the monitoring of each habitat at the biogeographical scale. The selection should be grounded in a comprehensive inventory, supported by detailed cartography and ecological characterization of habitat types and their variability.

The selection of sampling localities - along with the sample size (number of plots) and power is essential to ensure that the results of assessment and monitoring are representative for each habitat type at the biogeographical scale.

Identifying and selecting localities for sampling requires a systematic approach to ensure that the chosen sites provide comprehensive and representative data on habitat condition within the biogeographical region. Sampling localities should reflect the full range of habitat diversity, as well as environmental gradients, including variations in elevation, soil types, and climate. Moreover, sites should be selected both inside and outside protected areas. This requires a sound understanding of the distribution and variability of each habitat across its range, including the identification of ecotypes or subtypes, where relevant. The main criteria for selecting monitoring localities are summarised below:

- Ecological variability: Localities must represent the full range of ecological diversity and variability within the habitat type. Selection should include different ecotypes or subtypes, successional stages, and reflect key environmental gradients such as altitude, soil type, moisture levels, geomorphological features, and topography.
- Spatial coverage: Adequate spatial coverage is essential to capture habitat heterogeneity. Localities should be selected across the full geographical range of the habitat type within the region, ensuring they are well distributed and represent a significant proportion of the habitat's total occupied area.
- Degree of conservation and exposure to pressures and threats: The selection of monitoring localities should include areas with varying degrees of conservation and degradation, in order to capture the full range of habitat condition across its distribution. This includes both well-conserved areas with minimal human impact, and areas affected by degradation and subject to different pressures. To reflect the diversity of pressures acting on the habitat, localities should span a range of intensity levels – from low to high – and account for different sources of disturbance, such as urbanisation, agriculture, and climate change.
- Presence inside and outside Natura 2000 sites: The assessment and monitoring of habitat conservation status must be carried out both inside and outside Natura 2000 sites. This requires selecting localities – and an appropriate number of plots – that reflect the proportion to the habitat's distribution within and outside the Natura 2000 network.
- Habitat fragmentation at landscape scale: Localities should be selected based on landscape metrics such as patch size and connectivity. Including both isolated and well-connected sites allow for the assessment of fragmentation effects on habitat condition.

Understanding these patterns is essential for developing strategies to mitigate the negative impacts of habitat fragmentation.

- Lack of Information: Including areas where data are lacking contributes to building a more comprehensive dataset. Selecting localities in historically under-sampled regions ensures a more balanced and complete understanding of habitat condition across its range. This helps to address data gaps and supports more informed conservation planning.
- Accessibility and practicality: Monitoring localities should be accessible for regular field visits, taking into account logistical factors such as distance from roads and ease of access. Practical considerations also include the safety of field personnel and the feasibility of transporting equipment to and from the site.
- Historical Data and existing monitoring sites: Making use of existing monitoring sites with historical data can strengthen the understanding of long-term trends and changes in habitat condition. Such sites provide valuable baselines for comparison and support more robust trend analyses over time

Once sampling localities have been identified for each habitat type, the minimum number of plots per locality – and across the biogeographical region – must be calculated to balance sampling effort with the need for representative data.

The number of sampling areas considered statistically adequate should be determined according to the habitat type distribution in each region. This estimation should consider the specific characteristics and variability of the habitat, ensuring that the sampling design is robust enough to capture the full range of conditions present.

The **size of the sample** influences two statistical properties: 1) the precision of the estimates and 2) the power of the assessment to draw meaningful conclusions. The number of plots must be **statistically sufficient** to detect changes and trends with the desired level of confidence. Appropriate statistical methods should be applied to determine an adequate sample size.

Considering the heterogeneity of habitat types, it is highly recommended to consult a sampling statistician when determining sample size – that is, the minimum number of plots required to ensure representativity and statistical significance.

Some key elements for ensuring proper representation of habitat condition in the sample are summarised below:

Sample size and distribution:

- The number of localities and plots should be sufficient to provide a statistically robust sample size. This ensures that the collected data can be generalised to the entire habitat type within the region.
- Statistical methods such as stratified random sampling are often applied to ensure that all habitat subtypes and environmental gradients are adequately represented.

Sampling design:

- Within each sampling area or locality, multiple plots are established to collect detailed data on vegetation, soil, and other ecological indicators. The number and distribution of plots depend on the size of the habitat patch and its internal variability.
- Sampling areas (e.g., plots, transects) should be laid out with consideration of the main ecological gradients, such as altitude, moisture, and exposure to sea influence.

Replication and randomisation:

- Replicating sampling units within each locality and randomising the location of sampling plots help reduce bias and increase the reliability of the data.
- Randomised plot locations also ensure that sampling captures the natural variability within the habitat.

3.7 Use of available data sources, open data bases, new technologies

To effectively monitor rocky slope habitats, it is important to use a variety of methods tailored to the specific challenges these environments present.

Remote sensing tools, such as satellite imagery and aerial photography, provide valuable large-scale information on land cover and the distribution and fragmentation of rocky outcrops—data that is particularly useful where direct field access is limited. Drones, or unmanned aerial vehicles (UAVs), are especially advantageous on rocky slopes, as they allow for the collection of high-resolution imagery from otherwise inaccessible vertical cliffs and crevices, making it possible to map rare plant communities and monitor habitat changes with minimal disturbance.

Camera traps can be discreetly deployed on cliff ledges and rocky shelters to observe wildlife presence and behaviour, capturing data on elusive or nocturnal species that would be difficult to monitor otherwise. Environmental DNA (eDNA) sampling enables the detection of species by analysing water, soil, or sediment collected from the habitat, an approach that can reveal hidden biodiversity, especially in microhabitats such as fissures or pools. Acoustic monitoring, using sound recorders, is an effective means to document the presence of calling animals—including birds, bats, amphibians, and some insects—on rocky slopes where traditional surveys are challenged by steep terrain.

For the most inaccessible areas, trained researchers employing climbing techniques can directly observe and sample plants and animals inhabiting otherwise unreachable rock faces, which is vital for long-term monitoring of specialist cliff species. In addition, collaboration with local experts, such as experienced mountaineers or botanists, enhances both the safety and quality of field surveys by harnessing their site-specific knowledge. Engaging local communities through citizen science initiatives, enlisting climbers, hikers, and nature enthusiasts, provides additional coverage and reporting, helps with early detection of changes, and strengthens long-term data collection. By combining these complementary methods, monitoring efforts in rocky slope habitats become more comprehensive, repeatable, and minimally invasive, ultimately improving our understanding and conservation of these unique environments.

4. Guidelines for evaluating fragmentation at appropriate scales

As above mentioned, rocky slope habitats with chasmophytic vegetation are naturally fragmented or isolated due to their patchy distribution on cliffs, outcrops, and steep slopes. Consequently, assessing fragmentation in these systems requires a nuanced approach that acknowledges their inherently patchy and isolated nature and cannot be carried out using traditional connectivity indices that are suitable for more continuous habitats.

An approximation for evaluating fragmentation in these habitats can be based on quantifying patch size, obtaining a valuable insight into the area of suitable habitat available, measuring the distances between patches and the presence of fragmenting infrastructures, such as roads, quarries, or urban development, which is useful to assess the degree of isolation and potential barriers to species dispersal and gene flow (Turner, 2005).

Remote sensing and GIS technologies play a crucial role in this process. Satellite imagery, aerial photography, and GIS mapping allow for the systematic identification of habitat patches, evaluation of their size, shape, and proximity, and consistent tracking of landscape changes over time (Foody, 2023). These tools enable the detection of even subtle shifts in fragmentation and permit large-scale assessment across rugged or inaccessible terrain, making them especially valuable for naturally isolated chasmophytic systems in rocky slopes (Donati et al., 2023).

It is important to interpret fragmentation metrics within an appropriate ecological context. Some isolation and small patch size are natural features of chasmophytic habitats and do not inherently indicate ecological degradation. However, anthropogenic fragmentation, in the form of new infrastructure, land-use changes, or resource extraction, can pose significant risks by further reducing patch size, increasing isolation, and impeding the dispersal of specialised flora and fauna. These effects can disrupt ecological processes, and increase the risk of local extinctions, especially in already fragmented systems (Haddad et al., 2015).

By focusing on patch metrics and leveraging remote sensing and spatial analysis, practitioners can monitor condition and trends in chasmophytic habitats more effectively, better target conservation actions, and anticipate threats under ongoing environmental change.

5. Next steps to address future needs

These guidelines recommend standard methods for assessing and monitoring rocky slopes habitats condition with the goal of promoting harmonised procedures across the EU Member States. To ensure that habitat condition assessments are comparable across countries, it is essential to define au common set of variables/indicators with well-defined metrics and standard measurement procedures.

To promote the implementation of these guidelines, the following next steps are suggested:

- **Test the proposed set of variables** with agreed measurement procedures and monitoring methods. Use common protocols for sampling, while considering the particularities of different habitats and the existing contextual factors at local and country level. This testing would be useful to identify gaps of knowledge, flaws of applicability and robustness and reliability of results. The evaluation should provide recommendations to be further integrated in the harmonised procedure, as needed.
- Develop further, test and standardise the methods for the establishment of **reference values and thresholds** to determine good condition. Defining ecological thresholds based on proper habitat characterisation is essential. These thresholds will indicate the health and quality of these rocky habitats, aiding in the monitoring of changes over time. They will also facilitate the assessment of impacts of climate change, human activities, and invasive species, providing critical insight for conservation efforts.
- Develop further, test and standardise the methods for the **aggregation of results** obtained from all the variables measured at the local scale and for each biogeographical region.
- Develop further and test the criteria for the **selection of monitoring localities and sampling design** to ensure a sufficiently representative sample that allows for proper implementation of the aggregation of results at the biogeographical region level.
- Promote harmonised methods for the assessment of **typical species**: Clear criteria should be defined for selecting these species, along with the methodologies to assess their status and integrate the results into overall condition assessment for each habitat.

To monitor rocky slopes with chasmophytic vegetation effectively, a coherent, multi-faceted approach is required, especially in the context of accelerating climate change.

- The priority is **improving foundational knowledge**. Robust monitoring begins with a comprehensive characterisation, inventory, and accurate mapping of rocky habitats within each country. Particular attention should be given to documenting climate patterns, geological substrates, and vegetation—especially the presence of endemic species—since these factors underpin both biodiversity and ecological function. Establishing such baseline information is essential for recognising the sensitivities and resilience of rocky slopes, as well as determining the minimum habitat requirements critical for their persistence under changing climate conditions.
- It is equally important to understand the **ecological relationships between rocky habitats and adjacent communities**, including those found in group 81. These interactions, such as hydrological connectivity or species exchanges, inform integrated management and conservation strategies and highlight how climate-driven changes in one habitat can ripple through neighbouring systems.

- Identifying **reference localities** is another critical step. By leveraging the mapping and characterisation data, well-chosen benchmark sites can be established for repeated monitoring, providing reliable points for comparative studies and long-term trend analysis.
- Integrating **advanced technology** greatly enhances monitoring efficiency and precision. Tools such as drones enable the collection of high-resolution imagery in otherwise inaccessible cliffs and slopes, while remote sensing supports landscape-level assessment of habitat extent and fragmentation. Environmental DNA (eDNA) sampling offers a powerful complementary method for detecting rare or elusive species—including those affected by climate change—without requiring direct sightings.

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Annex 1 - Examples of variables included in the methodologies available from EU MSs

Variable names	Metrics	Measurement methods	Examples of thresholds	MS and references
1. Abiotic characteristics				
1.1 Physical characteristics				
Diversity of natural structures on rocky slopes (8210, 8220, 8230)	Not provided	Visual expert judgement: 8210 & 8220: diversity of rock formations (cracks, chasms, ledges, sheltered areas), micro-habitats (large stones, patches of fine-grained soil, patches with humus, large sized scree, gravel) and micro-climates (light conditions, exposure, moisture). 8230: structure of topography and surface – rock faces and ledges, rock piles, patches of bare earth, natural micro-relief.	A = high diversity of structures and micro-climatic conditions; B = moderate diversity or slightly impoverished structural diversity due to human influence; C = strongly impoverished structural diversity (due to human influence)	DE: BfN ,2017
Substrate dynamics (8210, 8220, 8230, 8240)	Percentage of rocky outcrops	Evolution of the crack pattern in the rock walls by installation of high-precision stations.	Not provided	IT: Angelini et al., 2016
Degree of alteration (erosion)	Rate of alteration	Installation of TMEN (Transverse micro-erosion meter) in control stations on a 50x50 m plot, every 5 years.	Not provided	ES: Pérez Alberti, 2019.
Erosion	% and form	Form (depth, etc.) and extension (in % for the sampled area) of erosion is estimated	Not provided	HU: Horváth et al., 2021
Shade	% of area	Expert assessment of the relative area under crowns of trees and shrubs	8210, heliophilous subtype: FV <20% < U1 < 40% < U2; not used for shadow-tolerant subtype; 8220-1: FV < 50% < U1 < 75% < U2; 8220-2: FV <20% < U1 < 40% < U2; 8230: FV < 10% < U1 < 20% < U2	PL: Świerkosz & Reczyńska, 2012 (8210) and Świerkosz, 2012 (8220), Reczyńska & Świerkosz, 2012 (8230)
Canopy shade	%	Degree of canopy shading is evaluated.	Not available	LT.: Rašomavičius et al., 2015
Presence of fine-grained soil	NA	Not provided	Not provided	GR: Dimipoulos et al, 2018

Variable names	Metrics	Measurement methods	Examples of thresholds	MS and references
1.2 Chemical characteristics				
Dead organic matter carpet (8210, 8220)	% coverage	Expert assessment of relative coverage in the habitat area	8210: heliophiles subtype, 8220-1 and 8220-2 subtypes: FV < 5% < U1 < !0% < U2; 8220: shadow-tolerant subtype, 8220-3 subtype: FV<10% <U1<20% <U2 8230: FV < 1% < U1 < 5%	PL: Świerkosz & Reczyńska, 2012 (8210), Świerkosz, 2012 (8220) and Reczyńska & Świerkosz, 2012 (8230)
Ellenberg index for macro-nutrient availability; Ellenberg index for pH	Ellenberg index	Assessed on pioneer vegetation in 8230	Based on modelling	SE: Toräng et al.,2022
2. Biotic characteristics				
2.2 Compositional characteristics				
Typical, dominant, characteristic, key species, positive indicator species (vascular plants, phanerogams, pteridophytes, lichens and mosses)	number	Species composition recorded on a survey area or plot (usually of few m^2) using a list of habitat types-typical species or specific lists for subtypes.	A: 10 habitat-typical species; B: 6< 10 habitat-typical species; C:<6 habitat-typical species (Ellmauer, 2005) A = typical species inventory present; B = typical species inventory mostly present; C = typical species inventory only partly present (BfN, 2017) Good: Number of positive indicator ferns and Saxifraga spp. Present ≥ 1; total number of positive species >3, for 8210 in IE (Perrin et al. 2014). At least 7 species present in the monitoring stop, for 8240 in IE (Wilson and Fernandez, 2013). FV: 5 typical species or more, quantity and coverage not decreasing; U1: 2-4 species, or more if quantity or coverage decreasing; U2: less than 2 typical species (Świerkosz & Reczyńska 2012).	AT: Ellmauer, 2005 BE: Hendrickx et al., 2021 BG: MOEW, 2013 DE: BfN, 2017. CZ: Vydrová & Lustyk, 2014. HU: Horváth et al., 2021 IE: Perrin et al., 2014; Wilson & Fernandez, 2013 IT: Angelini et al., 2016 LT: Env. Ministry, 2015 PL: Świerkosz & Reczyńska, 2012; Swierkosz, 2012 RO: Deák et al., 2014.

Variable names	Metrics	Measurement methods	Examples of thresholds	MS and references
Typical animal species	NA	Not specified. Currently only bird and reptiles are considered	Not provided	BE-Wal.: Hendrickx et al., 2021
Presence of animal species	NA	Analysis of the presence of animal species, pollinating insects, reptiles and birds. Detection of bird species by visual or acoustic monitoring.	Presence of animal species relevant to the the habitat, it will have unfavourable values in the case of evidence of frequentation by domestic livestock domestic livestock and favourable values in the presence of typical entomofauna	IT: Angelini et al., 2016
Presence of weeds, ruderal, nitrophilous, invasive, non-native, alien, negative indicator species or disturbance indicating species.	Number and %	The presence and percentage cover of ruderal and/or replacement plant species is assessed. Proportion of vegetation composed of non-native species.	Favourable (FV) status: Ruderal and/or invasive species in up to 10% of the polygons. Unfavorable-inadequate status (U1): Ruderal and/or invasive species in >10% to 20% of the area of the monitored polygons. Unfavorable-poor (U2): Ruderal and/or invasive species in >20% of monitored polygons (MOEW, 2013) Good: proportion of non-native species <1% for 8210 in IE (Perrin et al. 2014). FV: invasive species missing; U1: only Impatiens parviflora, scattered (1-2 individuals); U2: More Impatiens parviflora or other species in the habitat or 5m from it (Świerkosz & Reczyńska 2012)	BG: MOEW, 2013 DE: BfN, 2017 HU: Horváth et al., 2021 IE: Perrin et al, 2014 IT: Angelini et al., 2016 PL: Świerkosz & Reczyńska, 2012; Świerkosz, 2012
2.3 Structural characteristics				
Vegetation coverage	% cover	The vegetation cover can be estimated in the course of open land surveys. Sometimes the evaluation of high-resolution aerial photographs can also be helpful.	A. Vegetation cover <25% and/or free-standing rock face (less than 25% canopy cover); B. Vegetation cover 25-50% and/or canopy cover 25-50%; C. Vegetation cover >50% and/or canopy cover >50% (Ellmauer, 2005).	AT: Ellmauer, 2005 ES: Pérez-Alberti, 2019 HU: Horváth et al., 2021
Vegetation structure diversity (8210, 8220, 8230)	expert judgement	Visual expert judgement of diversity of dwarf shrub communities, vegetation communities of rock cracks or ledges, other habitat typical vegetation (mosses & lichens).	A = high diversity and excellent habitat development; B = moderate diversity and good habitat development: C = low diversity and poor habitat development.	DE: BfN, 2017

Variable names	Metrics	Measurement methods	Examples of thresholds	MS and references
Cover of characteristic, typical species	% cover	Field survey and estimate of % cover of the species. Lichens can be used as bio-indicators of environmental pollution, climate changes and soil stabilisation on the surface of outcrops	Characteristic species – FV: >15%; U1: 5-10%; U2: <5% Deák et al., 2014	ES: Pérez-Alberti, 2019 LT: Rašomavičius et al., 2015 RO: Deák et al., 2014.
Coverage of mosses, lichens and exposed rock	%	the coverage of mosses and lichens and the proportion of eposed rock in the monitoring field are evaluated separately	Not provided	LT: Rašomavičius et al., 2015
Coverage of woody plants, scrub and tree cover	% cover	The habitat type can be assessed during a field survey with the aid of an orthophoto.	A: within a radius of 30 m around the habitat type, the cover of woody plants is < 10% ; B: within a radius of 30 m, the cover of woody plants is 10-50% ; C. within a radius of a 30 m, the cover of woody plants is > 50% (Ellmauer, 2005). Good: Cover of Pteridium aquilinum, native trees and scrub < 25% for 8210 and 8220 (Perrin et al. 2014) Cover of scrub species (form a list of species) should be less than 25% for 8240 (Wilson & Fernandez, 2013) Rubus spp. And Sambucus spp. Coverage – FV: up to 5%; U2: 5-10%, scattered; U2: > 20% (Świerkosz 2012) Trees and shrubs – FV: single juveniles, coverage < 1% ; U2: 1-5%; U2: >5%, for 8230 (Reczyńska & Świerkosz 2012)	AT: Ellmauer, 2005 HU: Horváth et al., 2021 IE: Perrin et al., 2014 ; Wilson & Fernandez, 2013 LT: Rašomavičius et al., 2015 PL: Świerkosz & Reczyńska, 2012; Świerkosz, 2012 ; Reczyńska & Świerkosz, 2012.
Shrubs and trees height and distribution	m (height), distribution (non metric)	Average height for each species is estimated. The distribution of shrubs and trees is estimated as scattered, aggregated, or continuous.	A complex table is provided, using scores (+ and -) for the evaluation of the role of the shrubs and trees.	HU: Horváth et al., 2021
Structural integrity	3 categories	Field survey	undamaged, moderately damaged, severely damaged	RO: Deák et al., 2014

Variable names	Metrics	Measurement methods	Examples of thresholds	MS and references
2.4 Functional characteristics				
Typical species reproducing (e.g. flowering and producing)	Not provided	Not provided	Not provided	GR: Dimopoulos, 2018
Leaf litter	Partly non- metric, partly using % scores	Dynamics (spread or retreat of the litter cover) is defined by the changes of the litter compared to earlier monitoring actions.	+2: if the cover of the field since the last survey has decreased, or has not changed, or the increase average rate of growth is less than 1%/year, and the cover is less than 10% -1: if the cover the rate of increase of average rate of increase at least 1%/year	HU: Horváth et al., 2021
Impacts of native animals	Non-metric	Possible impacts by native animals (ants, rodents, etc) are listed and their role (negative or positive, for example by trampling or by establishing pools, puddles) assessed.	Textual description and subjective evaluation	HU: Horváth et al., 2021 (all rocky habitats)
3. Landscape characteristics				
Habitat fragmentation	%	The presence of new (after mapping) anthropogenically created structures (buildings, ports, roads, etc.) fragmenting the polygon is assessed	FV: presence of new fragmenting anthropogenic structures occupying up to 1% of the monitored polygons at the biogeographical level. U1: presence of new fragmenting anthropogenic structures on 1.1% to 10%. U2: presence of new fragmenting anthropogenic structures on >10%	BG: MOEW, 2013
Landscape environment	m (distance), m^2 (size of the habitat patch and non-metric	Description of the rate of isolation (subjective), distance to similar habitats, size of the sampled habitat patch, role of the neighbouring habitats (friendly or non-friendly), presence of potentially invasive species and regeneration potential of the vegetation (subjective) in the sampled area.	Scoring limits (m^2) for assessing the size of the habitat patch: A: 1000; B: 500; C: 200	HU: Horváth et al., 2021
Landscape metrics	Not provided	Patch size/distance between patches. Use of GIS. Indices of landscape heterogeneity can be	Not provided	IT: Angelini et al., 2016

Variable names	Metrics	Measurement methods	Examples of thresholds	MS and references
		useful for assessing macro-scale dynamic processes.		
Ecotonic zones and adjacent territories	Not provided	The transition of the polygon habitat to other natural or semi-natural plant communities is described (width of the transition zone, type of adjacent communities, use of adjacent territories, etc.)	Not provided	LT: Rašomavičius et al., 2015
Distribution of habitats in mountain massifs	Number of mountain massifs where the habitat is present	GIS, published papers and monographs, field survey	8210 - >10 mountain massifs (FV), 5-10 mountain massifs (U1) and <5 mountain massifs (U2); -220 - >20 mountain massifs (FV), 10-20 mountain massifs (U1) and <10 mountain massifs (U2); 8230 - >5 mountain massifs (FV), 3-5 mountain massifs (U1) and <3 mountain massifs (U2).	RO: Deák et al., 2014
4. Other				
Anthropic disturbances		Impairments can be identified by field inspections on site (in the case of larger quarries also via remote sensing) or by researching official authorisations (e.g. mining, quarrying activities).	A: Low: no impairments (e.g. mining activity, recreational use, construction, grazing, etc.) visible; B: Medium: minor impairments (e.g. extensive grazing) visible; C: High: significant impairments or area in an obvious stage of degradation of forests, grassland	AT: Ellmauer, 2005. BE: Hendrickx et al., 2021
Degradation	intensity scale (0, 1, 2, 3, W) + keywords	habitat degradation is assessed	0 – habitat without signs of degradation or degradation degree is insignificant; 1 –low degree of habitat degradation; 2 – medium degree of habitat degradation or the degree of degradation is spatially very different; 3 – high and significant degree of habitat degradation; W – very high degree of habitat degradation and tendency towards unnatural habitat.	CZ: Lustyk, 2023.

Variable names	Metrics	Measurement methods	Examples of thresholds	MS and references
Removal of substrate or quarrying	% coverage	expert estimate of % coverage of total habitat area	A = 5% or less; B = 5-10%; C = more than 10%	DE. BfN, 2017
Cover of damaged vegetation	% coverage	expert estimate of % of vegetation damaged by human activity – removal or addition of substrate, trampling, climbing etc.	A = 5% or less B = 5-10% C = more than 10%	DE. BfN 2017
Disturbance indicator (rocky slopes) – visitation	expert judgement	expert judgement with reasoning – damage or disturbance from trampling, climbing, vehicles, or other visitation	A = none to negligible disturbance without significant impact on habitat functions; B = clear disturbance in parts of habitat affecting habitat functions; C = significant and persistent disturbance in critical time periods (e.g. during breeding season)	DE. BfN 2017
Grazing intensity of domestic or wild animals low	Not provided	Not provided	Not provided	GR. Dimopoulos et al., 2018
Land use and (human) disturbances	non metric, long textural descriptions	The land use (grazing, mowing,, tourism, etc) is described, with subjective terms (missing, too high or too low intensity compared to a “typical, expected” intensity) – everything described on sampled area level (small square plots are not involved).	+5 points if the use (management) necessary for the maintenance of the habitat is currently taking place (e.g. mowing of mowing fields), or if the habitat does not require management and no management is taking place. +5 points if there are no current threats within the whole habitat patch. The following values add up to a maximum of -15 points: -5 points: if the habitat is not currently being managed to ensure its survival within the assessed. The use is inappropriate: -5 points for each major threat or -3 points for each medium threat	HU. Horváth et al., 2021
visible signs of climbing or trampling		Expert assessment	missing = FV; small, indicating occasional pressure only = U1; indicating intensive pressure = U2.	Świerkosz & Reczyńska, 2012 (8210); Świerkosz, 2012 (8220)

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