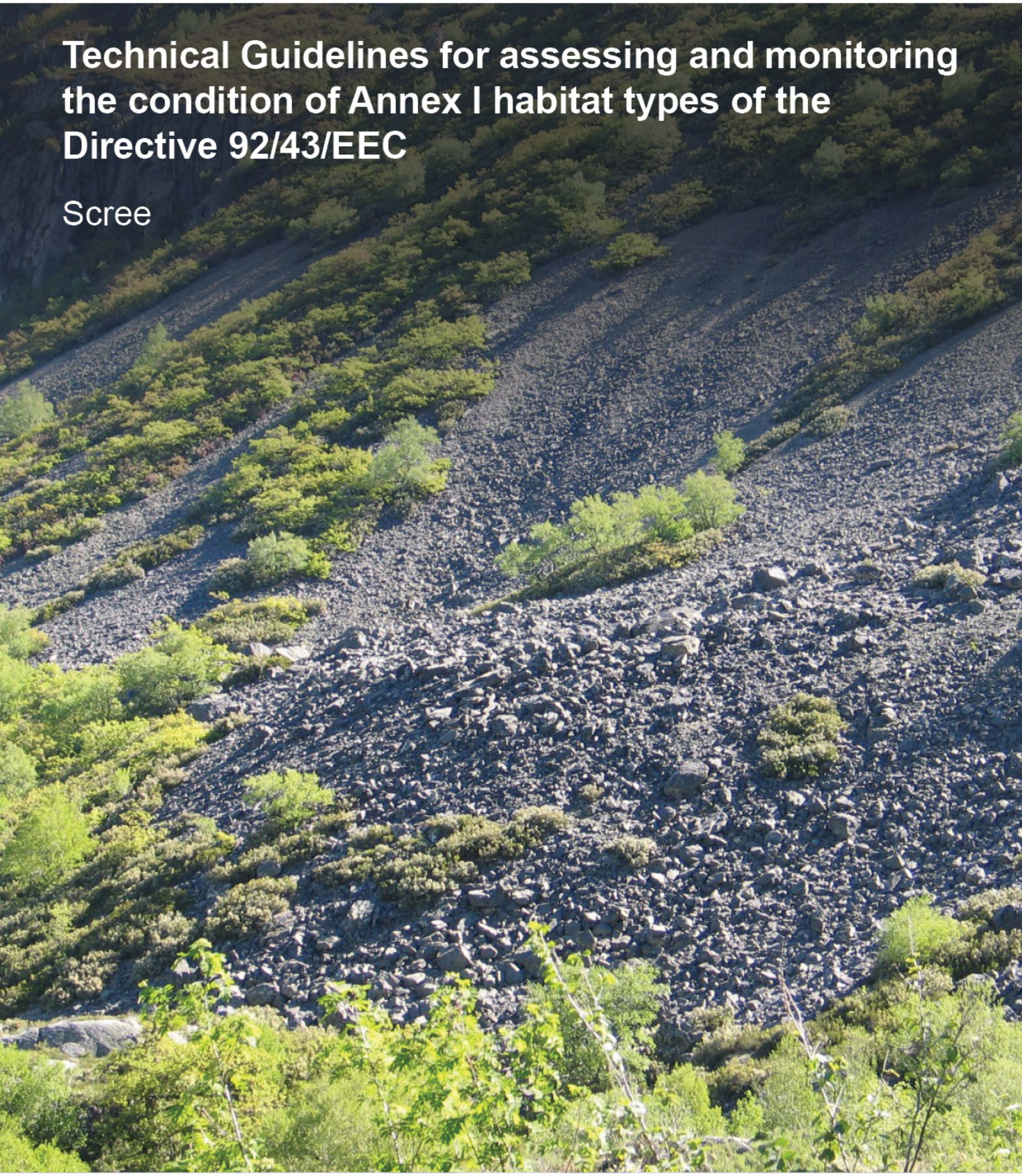
European Commission

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

Scree



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

Scree

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Contents

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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

Scree are unique and dynamic habitats arising from the weathering and fragmentation of rocks through various physical and chemical processes. These habitats are classified in Group 81 in the Habitats Directive, (8110, 8120, 8130, 8140, 8150, 8160), according to their lithology, biogeographical location, and bioclimatic range. Their ecological definition is shaped by geomorphological components (such as slope dynamics and substrate composition), lithology (physical and chemical properties of rocks), climate, soil characteristics, topography, and the biological communities and species they support. Scree habitats are characterised by their unstable and resource-poor substrates.

A review of current methodologies implemented across EU Member States reveals a high degree of similarity in the monitoring of these habitats. Most Member States measure physical characteristics such as grain size composition and slope gradient. Compositional attributes are assessed by recording the presence and number of defining characteristic and typical species, including vascular plants, ferns, lichens, and mosses. Structural variables focus on various measures of species coverage and the proportion of distinct taxa, while functional features are evaluated through indicators of ecological processes, such as grazing pressure. Landscape characteristics are commonly assessed by analysing habitat fragmentation and landscape metrics. The thresholds and procedures used to interpret these variables often rely on expert judgement, which is sometimes inadequately justified or inaccessible. Furthermore, while aggregation procedures differ notably between Member States when looking at the local level, there is greater convergence in approaches used for aggregation at broader spatial scales. Monitoring activities are predominantly based on periodic field surveys.

These guidelines propose a set of essential, recommended, and additional variables for the monitoring of scree habitats. Variables are organised into abiotic (e.g. granulometric composition, soil pH, soil nutrient content), compositional (e.g. number of herbaceous species, presence of invasive species), structural (e.g. coverage of bryophytes and lichens), functional (e.g. habitat dynamics), and landscape (e.g. patch size, degree of fragmentation) categories. Criteria and guidance for the determination of reference values and critical thresholds for assessing favourable condition are provided; however, specific reference values should be adapted to the context of the variable in question, the particular habitat type, prevailing biogeographical gradients, and relevant historical, cultural, and socio-economic factors.

The guidelines identify several priorities for future development. These include improved information exchange among Member States, the establishment of standardised monitoring methodologies—potentially supported by training and evaluation programmes—and the exploration of new data sources and incorporation of remote sensing technologies. Integrating the impacts of climate change into monitoring frameworks is highlighted as an emerging need. Strengthening coordination as well as knowledge and technology transfer will be essential for fostering an inclusive and collaborative approach to conservation. Ultimately, aligning monitoring and assessment methodologies with EU biodiversity policies, particularly the Nature Restoration Regulation, will be crucial for achieving restoration and conservation objectives.

1. Definition and ecological characterisation

1.1 Definition and interpretation of habitats covered

A defining feature of rocky habitats (classified in group 8 of Annex I of the Habitats Directive) is their underlying rock substrate. However, two key characteristics distinguish two main sub-groups of rocky habitats: the extent of fragmentation and the resulting geomorphological dynamics. Group 81 – Scree habitats are dominated by superficial deposits, arising from the breakdown of rock through various processes, and are inherently unstable. In contrast, habitats included in group 82 – Rocky slopes with chasmophytic vegetation, are primarily shaped by the presence of in situ rock forming slopes, with greater geomorphological stability. Accordingly, habitats in group 81 are characterised by ongoing geomorphological change, while those in group 82 remain comparatively stable over time. This distinction highlights the need to address the monitoring of these habitat groups separately, as they require different approaches.

Scree habitats, also known as talus slopes, are unique and dynamic environments formed by the breakdown of rocks through the weathering effect of wind, water, snow movement, processes such as freeze-thaw action, and the gravity. These habitats are characterised by a scarcity of soil and soil nutrients, yet still support specialised communities adapted to such harsh conditions. Scree habitats play an important role in supporting various forms of life, including lichens, graminoids, clubmosses, and ferns, as well as certain animal communities. Many of these species have developed particular adaptations that allow them to thrive in these challenging settings (Nitzu et al., 2014; Hájek et al., 2021).

According to the Interpretation Manual of European Union Habitats (2013), the primary characteristics defining Scree habitat types are lithology (siliceous or calcareous), biogeography (e.g., western-eastern Mediterranean, Middle European), and bioclimatic ranges (montane, alpine, nival, thermophilic, upland). In addition, the composition of plant communities arises from the interaction of these environmental factors with historical biogeographical processes, which is formally classified through syntaxa in phytosociology.

Table 1. Habitat types included in group 81 - Scree, their main characteristics and EU MSs where they occur (according to reference list of Article 17)

Habitat	Name	Characteristics	MSs
8110	Siliceous scree of the montane to snow levels	Lithology, altitude, mobility, granulometry, vegetation	AT, BG, CZ, DE, ES, FI, FR, IE, IT, PL, RO, SK
8120	Calcareous and calcschist screes of the montane to alpine level	Lithology, altitude, climate, vegetation	AT, BG, DE, ES, FR, HR, IE, IT, PL, RO, SE, SI, SK
8130	Western Mediterranean and thermophilus scree	Exposure, climate, biogeography, lithology, altitude, vegetation	ES, FR, IT, PT
8140	Eastern Mediterranean screes	Lithology, biogeography, altitude, vegetation	CY, GR, HR
8150	Middle- European upland siliceous screes	Lithology, biogeography, altitude, vegetation.	AT, BE, CZ, DE, FR, HU, LU, PL, SK
8160	Middle-European calcareous scree of hill and montane levels	Lithology, biogeography altitude, vegetation	AT, BE, BG, CZ, DE, FR, LU, PL, RO, SI, SK

Box 1. Definition of habitats included in habitat group 81 provided by the Interpretation Manual of European Union Habitats (2013)

8110 Siliceous scree of the montane to snow levels (*Androsacetalia alpinae* and *Galeopsietalia ladani*)

This habitat consists of: a) Communities of siliceous scree of the superior montane level to the snow level, growing on more or less moving "cryoclastic systems" with variable granulometry and belonging to the *Androsacetalia alpinae* order. b) Vegetation of the montane level of the west and centre of Europe growing on scree sometimes of artificial origin (extraction of materials). It consists of alpine communities often rich in bryophytes, lichens and sometimes in ferns (*Cryptogramma crispa*) of the order *Galeopsietalia*.

8120 Calcareous and calcshist screes of the montane to alpine levels (*Thlaspietea rotundifolii*)

Calcshist, calcareous, or marl screes of the montane to alpine levels under cold climates, with associations with *Drabion hoppeanae*, *Thlaspion rotundifolii* and *Petasition paradoxi* respectively.

8130 Western Mediterranean and thermophilous screes

Screes under warm exposure in the Alps and the Pyrenees, of calcareous substrates in the Pyrenees, of Mediterranean mountains, hills and lowlands and, locally, of warm, sunny middle European upland or lowland sites. The vegetation present belongs to the *Androsacetalia alpinae*, *Thlaspietalia rotundifolii*, *Stipetalia calamagrostis* and *Polystichetalia lonchitis* orders.

8140 Eastern Mediterranean scree

Limestone and serpentine screes of the Balkan Peninsula and larger islands in the Eastern Mediterranean with vegetation of the order *Drypidetalia spinosae*.

8150 Medio-European upland siliceous scree

Siliceous screes of hills of western and central Europe, which support *Epilobium collinum, Galeopsis segetum, Senecio viscosus, Anarrhinum bellidifolium, Cryptogramma crispa*. Upland siliceous screes may originate from quarry activity, often colonised by impoverished forms of the Alpine communities. These are rich in mosses, lichens and sometimes ferns, notably *Cryptogramma crispa*. Although included, these rare instances should not be taken into account as representative

8160 Medio-European calcareous scree of hill and montane levels

Calcareous or marly screes of the hill and montane levels extending into mountainous regions (subalpine and alpine), often in dry, warm stations and have association with *Stipetalia calamagrostis*.

Calcareous screes of the Paris Basin, and more precisely the calcareous fine screes of the thermo-medio European plains irradiating into the lower valley of the Seine (*Leontodontion hyoseroidis*), may be included here.

In addition, **rock glaciers** are also covered in these guidelines, although they are included in the Habitats Directive under habitat type 8340 – Glaciers. Rock glaciers are made up of large blocks and fine particles that show evidence of movement through time as well as interstitial ice or a solid ice core, when active. Rock glaciers can also hold some vegetation and, therefore, share characteristics with scree habitats, which makes it advisable to include their monitoring recommendations in these guidelines.

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

Scree slopes display a wide range of forms and characteristics, shaped by the movement of individual particles, slope energy dynamics, and past geological processes. Their profiles may be concave or straight, often exhibiting marked sorting of particles, and are notable for their dynamic evolution over time. The ultimate angle of the slope is primarily determined by the internal friction between particles, allowing for clear differentiation between modern and ancient scree deposits (Statham, 1973, 1976; Bithell et al., 2014).

The development of scree slopes involves a complex sequence, beginning with intense disturbance of the parent rock followed by a period of stabilisation. This evolution is influenced by climatic factors, continuous particle movement, wind-driven (aeolian) activity, and the geological setting of the area (Hétu & Gray, 2000; de Vet & Cammeraat, 2012; Bithell et al., 2014). Sediment transport on scree slopes typically follows a nonlinear, diffusive pattern, with transport rates increasing rapidly as the slope gradient approaches a critical threshold. This approach is considered more accurate in explaining observed patterns of slope curvature and sediment flow than linear or uniform models (Roering et al., 1999).

Scree habitats support a broad diversity of specialised and endemic species. Their ecological character is determined by factors such as soil chemistry, altitude, and local microclimatic conditions. These environments provide stable micro-refugia for numerous species and play an important role in sustaining biodiversity (Nitzu et al., 2014; Noroozi et al., 2014; Panitsa et al., 2021).

The main features and ecological characteristics of these habitats are described below.

Environmental conditions: Scree habitats are defined by their unstable substrate, which consists of loose rock fragments that can shift and move. This instability creates a challenging environment for plant establishment and growth (Statham, 1973). These habitats are typically resource-poor, with low levels of organic matter and nutrients. The absence of light and photoperiod, along with low temperatures, further complicates the living conditions for organisms (Hrivnák et al., 2019). Altitude, exposure, and edaphic qualities (soil properties) are major ecological factors influencing the species composition and vegetation mosaic in scree habitats (Noroozi et al., 2014).

Slope dynamics and particle movement: The shape and character of scree slopes are influenced by the movement of individual rock particles. Higher energy particles tend to accumulate at the slope foot, creating a basal concavity in the profile. Sorting of particles occurs as smaller particles are trapped in depressions, while larger particles move downslope (Statham, 1973). The slope angle and stability are affected by the rate of particle movement and deposition. Scree slopes can vary widely in their angle of repose, depending on the rate of basal removal and deposition (Statham, 1973).

Vegetation and biodiversity: Scree habitats are often sparsely vegetated but serve as refugia for many endemic and specialised plant taxa. These plants have evolved to thrive in the extreme conditions of scree environments, contributing to high levels of taxonomic, phylogenetic, and functional plant diversity. The calcareous screes in the Meridional Carpathians, for instance, host a variety of plant associations, each characterised by unique species adapted to the calcareous substrate (Valachovič et al., 1997). In the Pyrenees, a large proportion of the endemic plant species are adapted to calcareous screes (e.g. *Borderea pyrenaica, Veronica aragonensis, Cirsium carniolicum subsp. rufescens, Cochlearia* *aragonensis)*, and rocky outcrops and scree represent the primary habitats for approximately half of all Pyrenean endemics (Gómez et al., 2020).

Trophic structure and soil communities: Soil arthropod communities, such as oribatid mites, in scree habitats exhibit a narrow range of trophic levels due to the resource-poor conditions. These communities are important components of the scree ecosystem, contributing to nutrient cycling and soil formation (Hrivnák et al., 2019). Arthropod communities, partly, are dependent on-site history, and scree can host a considerable number of glacial or periglacial relict species of different insect orders such as carabid beetles and spiders. The trophic structure of these communities is consistent and predictable across different scree sites, indicating a stable ecological niche despite the harsh conditions (Hrivnák et al., 2019).

Habitat heterogeneity and species abundance: Habitat heterogeneity, including variations in slope, vegetation cover, and soil depth, significantly influences the abundance and distribution of plant species in scree habitats (Nowak, 2016). For example, the submediterranean *Saponaria bellidifolia* shows a preference for scree habitats due to lower interspecific competition and occasional natural disturbances (Csergő et al., 2009).

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Hlinská dolina Valley in High Tatras, Slovakia

1.2.1 Main ecological characteristics and identification of variables to measure the condition of scree habitats

The classification of key characteristics and the corresponding variables to measure habitat condition in these guidelines follow the ecosystem condition typology (ECT) defined in the System of Environmental Economic Accounting - Ecosystem Accounting (SEEA-EA; United Nations et al., 2021), which is also 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

ECT defines six classes of characteristics: abiotic physical, abiotic chemical, biotic compositional, biotic structural, biotic functional and landscape.

Abiotic characteristics

Abiotic characteristics include geomorphological, lithologic, climatic and edaphic components.

Geomorphological component

Scree are accumulations of rock fragments generated by the weathering of rocky outcrops, primarily through processes associated with water in the form of snow or ice. Materials are transported either by simple fragmentation and fall, associated with freeze/thaw cycles, by variations in temperature and humidity, or by mass-movement processes such as by snow avalanches, solifluction or runoff; which result in slopes with an unstable balance.

Slope dynamics are essential to understand the functioning of scree habitats and it is therefore important to consider the role of hillside deposits in their monitoring. This also allows for a better understanding of the interactions between vegetation and geomorphology, which have long been of interest, as Marston (2010) pointed out.

The **granulometric composition** conditions the rooting of vascular plants, determining their presence or absence. A scree dominated by large clasts without a fine matrix, makes it difficult for plants to root, while if the dominant formations are small clasts with a fine matrix, the colonisation by plants is favoured. However, in an active slope that continuously receives sediment through runoff, avalanches or simple gravity, the possibility of plant colonisation is much more difficult than in an inactive slope.

The classification of rock fragment sizes in screes is essential for understanding sedimentary processes and geological formations. It encompasses a continuum from small pebbles to large tectonic blocks. This variation is influenced by factors such as the distance from the rock source, strain rates during fragmentation, and the inherent strength of the parent rock. The intensity of fragmentation is closely linked to the amount of energy input, which increases increasing markedly as the slope angle rises. On gentle slopes, fragments tend to travel further and are generally larger, whereas steep slopes generate higher momentum and impact forces, resulting in more efficient fragmentation and, therefore, predominantly finer sized deposits (Zhao et al., 2017). Various studies (e.g., Sundell & Fisher, 1985) have explored the size distribution and classification of rock fragments, providing insights into the common classes and their characteristics. However, there is no standardisation of the classification of scree elements.

For grain size classification, the Udden-Wentworth scale (Wentworth, 1922) is commonly employed in geological studies and forms the basis for subdividing clastic sediments by clast size. According to Bensettiti et al. (2004), scree fragments may be grouped into three categories: fine elements (diameter less than 0.2 cm), medium elements (diameter between 0.2 cm and 20 cm), and large elements (diameter greater than 20 cm).

In addition to their granulometric composition, which may predominantly comprise gravel, stones, or blocks, it is important to distinguish between materials that contain interstitial ice and those that lack it (Pérez-Alberti, 2019a). The former category includes rock glaciers and snow moraines (such as protalus ramparts), which may be either active or fossilised. The latter category encompasses block slopes and screes, which may remain active or have become stabilised. Consideration should also be given to seasonal snow cover.

Although the Habitats Directive classifies various habitat types as scree, from a geomorphological perspective, different types of surface formations can be identified.

Describing these various surface formations can aid in the appropriate interpretation of habitat structure and function. The principal formations associated with screes are outlined in Box 2. However, differentiating between types of surface formations does not imply that each should be categorised as a distinct habitat type. Currently, no clear correspondence exists between the habitat types listed under group 81 (and their characteristic plant communities) and the geomorphological forms recognised as screes. Nevertheless, some authors have proposed phyto-geomorphological definitions of screes, such as those applied in the Pyrenees (Huc, 2008).

In addition, **rock glaciers**, which are also included in these guidelines (though listed in the Directive under habitat type 8340, Glaciers), are formed by masses of blocks mixed with fine material, typically situated on slopes or valley floors (Haeberli et al., 2006). When active, rock glaciers contain interstitial ice or a solid ice core and exhibit evidence of movement. From a granulometric perspective, they comprise sediments ranging from fine particles to large blocks, with overall size influenced by the lithological context.

Rock glaciers are commonly classified into three stages: active, dormant, and fossil (or relict). Active rock glaciers contain ice and are in motion; dormant rock glaciers still contain ice but have ceased moving; and fossil rock glaciers no longer contain ice and are immobile. As Kääb (2013) notes, this classification is largely theoretical, with transitions between stages occurring gradually in nature. Active rock glaciers generally move at rates ranging from a few centimetres to several decimetres per year (Janke et al., 2013), although surface velocities of several metres per year have been observed in some cases (Gorbunov et al., 1992; Kääb et al., 2003). Their active movement produces distinctive, flow-like morphometric features that reflect their visco-plastic properties. These include spatially organised sets of longitudinal or transverse ridges and grooves; steep (typically >30–35°) sharp-crested frontal and lateral slopes rising 15–70 metres above surrounding terrain; and a contrasting surface appearance, with a light-coloured, poorly weathered frontal slope and a darker, rock-varnished, heavily weathered upper surface. Morphologically, they often display a swollen, longitudinally concave surface with a highly concave, longitudinally convex profile.

Vegetation cover on active rock glaciers is typically sparse (often <10%), dominated by pioneer species and herbaceous plants adapted to mechanical disturbance. These plants exhibit various growth strategies, such as creeping shoots and roots, extension growth, caespitose forms, and cushion plants (Cannone & Piccinelli, 2021).

Disturbances to the physical structure of these geomorphological features can arise from activities such as the construction of retaining walls, undercutting the base of scree slopes as a result of engineering works, or the dumping of debris or slag from above. Such interventions can cause significant degradation of the ecosystem’s natural condition. Consequently, disturbances to the physical structure should be systematically monitored to ensure effective conservation and management.

Box 2- Geomorphological forms included in the habitat group 81 - Screes

Some of the main forms that can be associated with the general term "screes" are described below. The existing information at the level of the different Member States does not make it possible to know clearly what the representation of each of them is in the different territories .

a) Blockfields

Accumulations of blocks and stones found in the upper part of mountain systems. The blocks can reach two meters in their longest axis. They do not have a fine matrix (Pérez Alberti & Rodríguez Guitián, 1993; Ballantyne & Harris; 1994, Ballantyne, 1998).

b) Block slopes

Accumulations of blocks, (Pérez Alberti & Rodríguez Guitián, 1993) that totally or partially cover slopes that can reach 30º inclination. In general, they cover the slopes as a discontinuous blanket with a sinuous front in which narrow flows develop and descend channelled towards the foot of the slope.

c) Block streams

Accumulations that form streams of blocks (Wilson, 2007). They are located in places where there are flattened sectors at the foot of the slopes, which favour the accumulation of blocks, or at the openings of small valleys.

d) Snow moraines (Protalus rampart)

These are deposits associated with rocky cliffs drawing an arc with a deep depression inside, generally semicircular, which facilitates the accumulation of snow at present (Francou, 1977). In general, they have half-moon plains, with an asymmetrical elevation, a concave and steeper inner sector and a convex outer sector with a softer profile.

e) Scree slopes

Deposits, generally located at the foot of a slope with slopes greater than 30-40º, fall within this category. These are accumulations of stones and blocks with size varying from centimetres to metres (Ozouf et al., 1995; Pérez-Alberti, 2012).

Climatic component

The habitats of group 81 are closely linked to mountainous regions, where, at different latitudes, the conditions for their formation currently exist or have been observed in the past. These conditions include the presence of slopes with steep gradients, the necessary temperature oscillations, for ice/thaw processes, which promote rock fragmentation through thermoclastic or cryoclastic processes.

Climate plays a crucial role in characterising screes, primarily influenced by air temperature and precipitation. The impact of climate is further shaped by topography, which involves three key aspects: altitude, slope, and orientation (exposure). It is important to consider that altitude leads to significant variations in radiation, temperature, humidity, and wind, among other factors.

Precipitation, whether as rain or snow, directly affects the development of plant cover, while surface humidity and temperature also play a role in their growth. A thorough understanding of both surface and subsurface water movement, as well as temporal changes in temperature and humidity at ground and atmospheric levels, is essential for assessing scree habitats health, especially under changing global conditions. For instance, on slopes with highly permeable clastic deposits, the majority of rainfall or snowmelt infiltrates into the ground rather than running off the surface, leading to a deficit of surface moisture and increased subsurface moisture. This dynamic has a significant influence on the potential for plant colonisation.

Lithology

Screes develop on different lithologies, such as i) silicate rocks, further divided into a) siliceous rocks (quartzite, granite), b) Mafic rocks (basalt, gabbro), c) Ultramafic rocks (serpentinite); and ii) non-silicate rocks, including carbonate rocks (dolomites, limestones).

While the **mineralogical composition** of silicate, such as siliceous (high silica) and mafic (low silica) rocks and non-silicate rocks (e.g. dolomite), is an important factor to consider, the **degree of fragmentation** is even more critical. This fragmentation can also be influenced by the lithology, affecting the size and shape of the particles, as well as the presence of fine fractions. Therefore, although distinguishing between acidic (siliceous) and basic (both mafic igneous and non-silicate sedimentary rocks) is significant, it is essential to also account for the size of the clasts. This aspect plays a vital role in the ecological dynamics and stability of scree habitats, highlighting their relevance in the ecological context. However, in metamorphic massifs, screes are fed by cliffs composed of highly heterogeneous lithological strata, resulting in formations composed of a mixture of diverse rock types. While geological substratum does not serve as a reliable criterion for monitoring purposes—since lithology is expected to remain relatively stable over time—it plays a significant role in shaping the ecological dynamics and species distributions within these high-alpine environments. Therefore, while we should be cautious in using lithology as a monitoring criterion, it remains an important aspect of our understanding of habitat formation and the underlying geological processes that influence biodiversity.

Edaphic component

The presence of **soil patches** (leptosols - shallow soils with lithic contact close to the soil surface less than 20 cm thick) between the clasts or beneath the layer formed by them, along with a specific **humidity**, are necessary for the establishment of vegetation. Soils are characterised by a high proportion of coarse materials, limited organic matter, and a low nutrient-holding capacity. Nutrient availability, particularly nitrogen (N) and phosphorus (P), is a critical factor limiting plant growth in leptosols. Soil parent materials significantly influence P limitation, while N limitation is more climate-dependent (Augusto et al., 2017).

The rock alteration processes present in the scree typically lead to an increasingly fine fragmentation of the materials, providing their mineral fraction. The organic fraction originates from the accumulation of plant and animal remains, as well as dust transported by wind and snowmelt. Screes function as "micro-environments" dominated by physical weathering processes and gravitational processes that transport rocks and debris downslope (Pignatti & Pignatti, 2014).

For plants, the soil provides a dynamic physical support and a nutrient medium. The characteristics of the soil, such as **presence or absence of calcium carbonate, pH and water retention capacity**, can explain the presence or absence of a particular species or group of species. This dependence on the soil explains why some landslides established in warm and dry microclimatic conditions remain almost completely devoid of vegetation, as plants are unable to establish themselves. This phenomenon is especially pronounced in siliceous scree, where hydrolysis processes represent a major mechanism for rock alteration. In dry situations, rock weathering and soil formation are particularly slow (Bensettiti et al., 2004).

Biotic characteristics

Scree communities, characterised by loose rock debris on slopes, host a variety of biotic components that contribute to their unique ecological dynamics. These components **include higher plants, lichen, mosses, fungi, fauna,** and **microorganisms**, each playing a significant role in the ecosystem. Within these biotic components, many species are endemic to these specialised habitats. The flora includes various plants that have evolved unique adaptations to thrive in the harsh conditions of screes, such as limited soil depth, high winds, and extreme temperatures. These plants often can survive in nutrient-poor environments. In addition to the plant life, the fauna in scree habitats may include specialised animals that are adapted to the rocky terrain. These species often rely on the unique microhabitats created by the vegetation and the topography of the scree for shelter and food. All this further highlights the ecological significance of scree communities and their potential vulnerability to environmental changes. Together, the endemic flora and fauna contribute to the rich biodiversity and ecological singularity of scree ecosystems.

Screes are inhabited by a wide range of plant species (Leuschner & Ellenberg, 2017; Giupponi & Giorgi 2019), which are able to colonise a mineral medium for a given period and resist various types of movements that may occur. Depending on the climatic and soil conditions, screes can support a diverse flora. Living conditions in these environments are harsh, with generally severe daily and annual temperature variations, especially at high altitudes and latitudes. Scree habitats are typically not affected by prolonged droughts, particularly at higher altitudes, where they are fed by water from melting snow and soil moisture is usually high (Braun-Blanquet, 1954; Favarger, 1995). The layer of air trapped between the stone elements provides protection against desiccation for scree plants (Baudière & Bonnet, 1963). Plants in scree communities are adapted to rocky environments through physiological and morphological changes, life-cycle stage adjustments, and symbiotic relationships with rhizosphere fungi, additionally serving as refugia for specialised endemic taxa. Annual plants in scree communities have life-cycles that align with local climatic patterns, ensuring germination in early autumn, vegetative growth through winter, and flowering in spring, enabling their survival through seasonal variations (Ratcliffe, 1961). Plants in karst regions, which share similarities with scree environments, adapt by altering their physiological and morphological structures to cope with drought, high temperatures, and high light conditions. These adaptations include changes in water utilisation strategies and nutrient management (Liu et al., 2021).

Bryophytes, encompassing mosses, liverworts, and hornworts, are recognized for their ability to flourish in diverse environments. However, their presence and abundance often do not accurately reflect site conditions. While vascular plants can quickly respond to changes in site conditions through a reduced number of chasmophytes or by completely abandoning old habitats and colonizing new suitable ones, the response of bryophytes and other cryptogams may be much slower. Despite being frequently underestimated and seldom included in studies, the research of Surina & Martinčič (2012) has demonstrated their significant diagnostic value for delineating groups of stands based solely on floristic criteria.

Screes and rocky outcrops, are among the richest habitats in endemic and rare plants. The European Alps are home to 35-40% of Europe's endemic species (Nagy & Grabherr, 2009). Scree habitats support a high level of taxonomic, phylogenetic, and functional plant diversity, with many endemic species having evolved specifically for these extreme conditions (Panitsa et al., 2021). In the Alps, there are siliceous screes (mainly in the inner Alpine areas) and dolomitic calcareous screes (mainly in the Prealps, the Dolomites and the Carnic Alps) (Pfiffner, 2014), each characterised by a specific flora. Fungal communities in the soil, rhizosphere, and roots play a significant role in plant adaptation to rocky environments. These fungi help plants manage nutrient availability and enhance their ecological performance, particularly in karst rocky desertification areas (Tang et al., 2021).

The main limitation for plant life on scree slopes is instability caused by clast mobility. This is linked to the quantity and frequency of materials contributed by the destruction of the surrounding rock outcrops and landslides caused by phenomena such as snow avalanches and runoff. It also depends on the degree of the slope and the size of the clasts, i.e. the granulometry. Therefore, the greater the slope and the finer the granulometry, the greater the instability. The movements of the scree elements and the resulting limitations exert a selective pressure on plant organisms, which have developed anatomical and morphological characteristics that allow them to respond favourably to environmental pressures. These plants are known as lithophytic, epilithic, saxicolous or rupicolous. Some of them migrate by elongation and/or regeneration, having very long and highly branched roots that take root once they find fine soil. When a part of the stolon or the rest of the plant is damaged by mobile clasts, each intermediate part can become independent. Other migratory lithophytes have a fasciculate root system that allows them to adhere strongly to the substrate and follow its movements (Bensettiti et al., 2004).

Scree therefore generates ecologically heterogeneous environments, both in their dynamic and static components. Species are generally highly specialised and distributed according to biological, morphological or physiological characteristics that allow them to colonise different biotopes.

The dynamics of vegetation in screes is highly variable, from non-existent to rapid, and directly depends on the degree of instability of the scree (Bensettiti et al., 2004). These dynamics are influenced by the granulometry, quantity and depth of the available soil, the exposure, the altitude, the nature of the rock, etc.

In highly unstable environments, vegetation cover is typically sparse, consisting primarily of migratory lithophytes (rock-dwelling plants). This vegetation stage remains while the scree maintains a high rate of disturbance. Although grassland species are not adapted to these changing substrate conditions, they often encroach upon the less active parts of the slopes of active scree. However, their marginal and diffuse presence prevents them from effectively competing with lithophytes.

A reduction in environmental instability generally favours alternative plant strategies. If this lower level of instability persists—such as after a rockfall or other disturbance that alter the dynamics and reduce the input of new rock material, or when lithophytes (rock-adapted plants) contribute to scree stabilisation—grassy species gradually become more abundant and may eventually form dense grasslands that exclude the original lithophytes. As grassland vegetation develops and matures, it can be followed or paralleled by the establishment of shrubs, leading to the development of moorlands or scrublands, and potentially progressing to a tree-dominated phase. Notably, on large scree slopes, except for those that are permanently alpine or under snow cover, vegetation often develops directly into shrub and tree formations without the intermediate step of a grassland stage (Bensettiti et al., 2004).

Overall, maintaining some degree of instability is beneficial for the ecological integrity of scree habitats, as the presence of actively moving scree and a complex structural mosaic are considered indicators of good habitat condition.

Bryophytes, which include mosses, liverworts, and hornworts, are non-vascular land plants known for their ability to thrive in a wide range of environments. These communities are especially adapted to the harsh and unstable conditions typical of screes, thriving where vascular plant cover is sparse due to frequent disturbance, low water retention, and poor nutrient availability. Cryptogams initiate primary succession on bare rock by trapping dust and organic matter, contributing to early soil formation and facilitating the eventual colonisation by vascular plants. They also play crucial roles in ecosystem functioning by stabilising loose substrates, supporting nutrient and water cycling, and sustaining notable biodiversity, including many rare or endemic species. The EuroVeg classification (EuroVegChecklist; Mucina et al., 2016) systematically organises these cryptogam-rich communities in screes into hierarchical syntaxa, highlighting their diversity and ecological importance. In Europe, and especially in regions like Scotland, cryptogam associations on scree represent a significant proportion of national and continental biodiversity and are prioritised for conservation (Ellis et al., 2007; Mucina et al., 2016). However, other findings suggest that their presence and abundance only poorly reflect site conditions (Surina & Martinčič, 2012).

Scree habitats are unique ecological environments that support a rich diversity of arthropod fauna, including soil-dwelling species (like ants and beetles), characteristic taxa adapted to rocky conditions, and troglobiotic species—organisms specially evolved to live in subterranean darkness.

Rumex scutatus and *Arabis alpina* in the Západné Tatry Mountains, Western Carpathians. Slovakia. © Jozef Šibík, 2008.

These habitats act as critical microrefugia, providing stable microclimates and shelter for a range of arthropods, including both important predators (such as spiders and centipedes) and detritivores, which are fundamental for nutrient cycling and decomposition processes in these nutrient-poor and unstable substrates (Rendoš et al., 2012; Nitzu et al., 2014; Eusébio et al., 2021).

The abundance and diversity of arthropods within scree habitats highlight marked seasonal dynamics, with studies showing that some groups reach their peak abundance during the winter months, possibly due to the insulating properties of scree. which These include moderating extreme temperatures, and the continuous supply of organic detritus protected from freezing conditions. This seasonal pulse helps maintain ecosystem stability and supports higher trophic levels (Rendoš et al., 2012; Eusébio et al., 2021).

Cliff environments within scree complexes further enhance biodiversity by offering nesting sites for native avian fauna. Bird diversity and their conservation value are notably higher in areas that experience lower levels of human disturbance, such as limited climbing activity. While commonly observed cliff-dwelling birds may tolerate some human activity, overall avian richness is strongly influenced by cliff orientation and the extent of human presence (Covy, 2019).

Table 2 presents a summary of the main ecological characteristics of these habitats, as indicated above, with some examples of useful variables to evaluate these characteristics.

Table 2. Ecological characterisation and selection of variables to measure the condition of scree habitats

Ecological characteristics	Types	Group of characteristics	Examples of variables useful to measure key characteristics
Abiotic characteristics	**Physical state characteristics**	Climate	- Air temperature - Surface temperature - Precipitation
		Geomorphology	- Slope degree - Granulometry, size of clasts and ratio of different size of clasts
		Lithology	- Type of rock - degree of fracturing/fragmentation of clasts
		Soil	- Soil thickness - Humidity
		Topography	- Altitude - Dominant orientation
	Chemical state characteristics	Soil	- pH - Nutrient content (N, P) - Calcium, carbonate content
Biotic characteristics	**Compositional state characteristics**	Presence and abundance of biological communities and species	- Presence and number of characteristic species from relevant groups: lichens, mosses, ferns and vascular plants, invertebrates (diverse insect groups and arachnids - Number of habitat-specialist plant and animal species - High quality indicator species - Negative indicator species as cover of competitive native herbs and dwarf shrubs
	Structural state characteristics	Pattern of occupancy of communities and species	- Cover of relevant communities or species groups (lichens, mosses, ferns and vascular plant)
	Functional state characteristics	Dynamics and natural processes	- Slope dynamics - Substrate dynamism - Degree of stability - Erosion
Landscape characteristics (connectivity / fragmentation)			- Area - Relation with other habitats, in particular rocky slopes and ravine forests
Other (disturbance, alteration…)		Impact of human alterations	- % of affected surface - Disturbances to the physical structure, type of alteration (trampling, quarrying, constructions….)

1.3 Selecting 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 dominant of 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 structure and

[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.

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.

Table 3. Selecting typical species for monitoring habitats from group 81

Species Group	Ecological role (bioindicator of)	Sensitive to changes in quality
Lichens	Diversity, later successional stages	Site condition effect, Lower/higher diversity, higher in more stable scree
Bryophytes	Diversity, later successional stages	Site condition effect, Lower/higher diversity, higher in more stable scree
Ferns	Diversity, Habitat quality	Total number of ferns and species
Vascular plants	Diversity, Habitat quality	Occurrence of diagnostic species, Occurrence of indicator species of positive or negative changes (habitat dependent) Endemic and specialised plant species
Vascular plants	Climate Change Impact	Glacial relict Papaver occidentale in the Western Prealps is at risk of extinction due to habitat loss from global warming (Fragnière et al., 2020)
Arthropods (a variety of arthropods, including soil-dwelling, characteristic, and troglobiotic species)	Seasonal assemblages, with the Mesovoid Shallow Substratum (MSS) acting as an ecological microrefuge (Nitzu et al., 2014)	Quality: ecological microrefugia for many soil-dwelling species, indicator of organic material

Species Group	Ecological role (bioindicator of)	Sensitive to changes in quality
Arthropods: Oribatida (Acari)	Content of organic carbon in the soil substratum (Jakšová et al. 2019)	Quality change
Arthropods: Collembola (Springtails)	Soil depth (Jureková et al. 2021a)	Quality change: a decrease in abundance with soil depth (Jureková et al., 2021a)
Predatory invertebrates	Diversity, Habitat quality, functional groups	Quality change, occurrence of diagnostic specialised species
Specialised pollinator groups (Lepidoptera, Syrphidae, Wild bees)	Diversity, Habitat quality, functional groups	Quality change, occurrence of diagnostic specialised species, changes in climate warming, altitudinal community shifts
Reptiles: for example Batuecan Lizard (*Iberolacerta martinezricai*), cf. Lizana-Ciudad et al.,2021)	Habitat connectivity and quality	Critically endangered and highly specialized to scree slopes. Presence is influenced by habitat connectivity
Mammals: Snow Vole (*Chionomys nivalis*)	Diversity, Habitat quality (Ferrari et al., 2023)	Quality indicator. The snow vole is a specialist species that is typically resident in high-alpine scree habitats.
Birds: e.g., *Anthus trivialis*, *Oenanthe Oenanthe, Lagopus mutus* etc.	Habitat connectivity and quality	Bird species inhabiting screes

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

This section presents the results of the review and analysis of existing methodologies for assessment and monitoring of scree habitat condition from EU MSs. This review is based on methodologies compiled for monitoring this group of habitats from the following countries: Austria (AT), Belgium Wallonia (BE), Bulgaria (BG), Cyprus (CY), Germany (DE), Spain (ES), Greece (GR), Hungary (HU), Ireland (IE), Italy (IT), Poland (PL), Romania (RO) and Czech Republic (CZ). A detailed table with examples of variables, metrics and measurement methods used by the different methodologies is presented in Annex 1.

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

According to the environmental and ecological characterization of scree habitats (Table 1) described in section 1.2., the used variables can be grouped as described in Table 4.

The most frequently used variables focus on physical, compositional and structural characteristics of the habitats included in the group of Scree. An overview of the types of variables used by MSs for assessing habitat condition is presented in table 4 and further details are provided below.

Table 4. Types of variables used in Member States for assessing scree habitat condition

Variable group	AT	BE	BG	CY	CZ	DE	ES	GR	HU	IE	IT	PL	RO	SK	SI
1. Abiotic characteristics															
1.1 Physical state characteristics															
Geomorphology	■						■	■				■			
Lithology				■											
Topography features				■		■						■			
Erosion									■						
Slope gradient, exposure, inclination.	■			■								■			
2. Biotic characteristics															
2.1 Compositional state characteristics															
Presence and number of characteristic species of phanerogams and pteridophytes.		■			■	■						■			
Characteristic species inventory of lichens and mosses				■		■									
Number of characteristic species															

Variable group	AT	BE	BG	CY	CZ	DE	ES	GR	HU	IE	IT	PL	RO	SK	SI
Presence of nitrophilous species				■											
Presence and number of characteristic fauna species		■													
2.2 Structural state characteristics															
Typical species and characteristic species cover	■				■							■	■	■	■
Coverage of invasive species and habitat ruderalisation			■						■			■		■	
Coverage of tree and shrubs			■						■			■		■	
Coverage of different layers/species groups				■					■	■	■	■			
Height of tree and herbaceous layer				■					■		■	■			
Proportion of negative indicator species										■					
2.3 Functional state characteristics															
Dynamics: moving and fixed scree	■					■									
Grazing effects										■					
Dynamics: shrub and trees densities									■						
3. Landscape															
Cover of fragmenting structures	■		■												
Patch size, isolation rate									■		■				
4. Other															
Anthropic disturbance: afforestation, mining, trampling, climbing	■	■				■			■						

Member State code and references: AT – Austria (Ellmauer, 2020); BE - Belgium-Wallonia; (Hendrickx et al., 2021); BG – Bulgaria (MOEW, 2013), CY - Cyprus: (Dimopoulos & Tsiripidis, 2013); CZ – Czechia (Vydrová & Lustyk, 2014), DE - Germany (BfN, 2017); ES – Spain (Pérez-Alberti et al., 2019b): GR – Greece (Dimopoulos et al., 2018); HU - Hungary (Horváth et al., 2021), IE – Ireland (Perrin et al., 2014); IT- Italy (Angelini et al., 2016): PL – Poland (Stawowczyk et al., 2015); RO – Romania (Deák et al., 2014); SI - Slovenia (Kačičnik Jančar, 2011); SK – Slovakia (Šeffer & Lasák, 2022)

Abiotic variables

Abiotic variables are measured in several Member States, although measurement methods and thresholds are not specified for all of them. Some of these variables are regarded as “descriptive” of the contextual situation and are therefore not formally assessed, but simply recorded to allow the detection of changes that may be linked to habitat condition. These descriptive variables can also play a role in establishing appropriate thresholds for other variables.

Physical variables are included in the methodologies of eight Member States considered in this review. These are frequently related to habitat geomorphology, such as the granulometric composition of scree, substrate characteristics, and the diversity of structural elements.

Grain size composition and the distribution of grain classes are measured by three Member States (AT, ES, GR). One Member State (AT) distinguishes grain classes as fine debris, coarse debris, and blocks, although no thresholds are defined. In another methodology (ES), grain size composition (for habitat 8130) is assessed within a grid of 100-metre-wide plots by measuring the size of at least 25 blocks in the upper, middle, and lower parts of one or more plots selected for their granulometric diversity. Each block must be geo-referenced using GPS (Global Positioning System), and the geo-referenced data is integrated into a Geographic Information System.

The percentage of area occupied by stone rubble not covered by vegetation is measured by one Member State (PL); this assessment relies on visual estimates, and thresholds are provided only for the percentage of exposed stone rubble (see Annex 1). Topography and the presence of typical structural elements are included by one Member State (DE) to assess habitat alteration. Expert assessment of unvegetated soil, large rocks, and rock faces is described, with thresholds ranging from high structural diversity to degraded habitat structure resulting from human influence.

Slope characteristics are considered by two Member States (AT and CY), which measure inclination, exposure, and average slope gradient. However, only exposure (AT) is accompanied by a described measurement method, and no threshold values are established for these variables. Shade is recorded by one Member State (PL) and can be regarded as an alternative means of assessing exposure. The percentage of shaded area is estimated through visual assessment, and its influence on the colonisation of thermophilus or shade-tolerant vegetation is reflected in the threshold values used (see Annex 1).

Measurement of substrate dynamics is included as a variable in one of the methodologies reviewed (AT). The degree of acclivity or steepness of the slope, has a direct impact on clast mobility: steeper slopes generally result in greater mobility of clasts due to gravity-driven processes, while gentler slopes tend to have more stable substrates. Ellmauer et al., (2020) outlines the use of both indirect methods—such as relating succession stages to slope steepness—and direct observations, for example detecting ongoing natural processes like cryoturbation or active rock supply from surrounding rocky walls. Threshold values are based on the presence or absence of these natural processes.

It is also worth noting that only one methodology (CY) has indicated variables for lithology and rock characteristics. Lithology is assessed as the percentage composition of each rock type present, while rocks are categorised by shape into six classes (Angular, Rounded, Blocky, Platy, Columnar, Prismatic), and the median diameter is recorded in centimetres. However, no specific methods or threshold values are indicated for these measurements.

On the other hand, none of the methodologies analysed include **chemical variables**.

Biotic variables

Biotic variables are the most commonly used, with all 13 Member States including them in their assessments. Among these, structural variables are described most frequently, followed by compositional variables.

All national methodologies considered in this analysis include **compositional variables**. Typical, characteristic, key, and dominant species are often recorded, with the number or percentage cover of these species used to indicate good condition of the target habitat. The presence of vascular plants, pteridophytes (ferns), and cryptogams, including bryophytes (mosses, liverworts, and *Sphagnum* species) and lichens, is assessed depending on the habitat type. The identification of specific plant communities, following a syntaxonomical or phytosociological system, is also recorded. Animal species are only occasionally considered (for example, birds and reptiles in Belgium). In contrast, the presence of invasive or neophyte species, weeds, ruderal or nitrophilous species, and species indicative of disturbance are also documented to identify unfavourable habitat conditions.

Structural variables mainly relate to the measurement of coverage of relevant species groups or growth forms. Vegetation cover is frequently assessed, with certain thresholds indicating good condition (for example, less than 50% cover in Austria, for habitat 8150). Coverage of characteristic species and plant community types is also recorded, and the diversity of vegetation structure, such as the presence of lichen communities, moss communities, ferns, or scattered trees or shrubs of typical species, is positively evaluated. Conversely, low cover of negative indicator species, such as ruderals, invasive species, or non-typical trees and shrubs, is considered favourable. The height of herbaceous species, trees, and shrubs is recorded in one Member State (CY). However, thresholds and specific measuring techniques are generally not provided.

Functional variables, understood as biotic variables that can measure relevant ecosystem functions and processes performed by specific functional groups of species (United Nations et al., 2021) are rarely used in the methodologies analysed. However, information relevant to ecosystem functioning can often be inferred from other compositional variables (e.g., species abundances), and structural variables (e.g., vegetation cover), both of which are widely measured. Scree dynamics and stability are assessed by three Member States (DE, IT, and HU). The first two measure the dynamics of active or mobile screes indirectly, in relation to the established vegetation. For example, BfN (2017) documents the presence of the characteristic mosaic of typical vegetation, single trees, mosses, and the proportion of bare soil. Angelini et al. (2016) considers the ratio between areas in an initial-pioneer stage, with little or no vegetation, and those in a mature, stabilised stage. While no threshold values are provided in the latter, BfN (2017) considers screes to be in unfavourable condition if no movement of fragments is observed.

Grazing is recorded by two Member States (GR and IE); however, only Perrin et al. (2014) provides detailed information on this variable. Here, the impact of grazing is estimated as the percentage of visible grazing signs, with higher values indicating unfavourable conditions in certain habitats and on selected sample plots (see Annex 1). Horváth et al., (2021) measures changes in shrub and tree densities compared to earlier monitoring actions. An average growth rate lower than 1%/year is considered favourable.

Landscape variables

Regarding landscape characteristics at least 4 countries are measuring some variables related to habitat fragmentation and isolation. Some (HU and IT) measure the degree of isolation of habitat patches using size and distance between the different patches. The other two (BG and AT) use the presence of fragmenting structures as a proxy for the level of fragmentation of the habitat.

Other

Other variables related to habitat deterioration are included in some of the national methodologies reviewed. One MS (HU) includes erosion as a variable, measuring intensity and extension in the sample area. High levels of erosion are considered unfavourable. Anthropogenic disturbance or damage to the habitat observed during field surveys are also included.

2.2 Definition of ranges and thresholds to obtain condition indicators

When defining thresholds for the variables measured to assess habitat condition, many of the national methodologies analysed use three categories, such as good, medium, and low, or alternatively, favourable, unfavourable, and bad. However, in general, the methods used by Member States to set threshold values are poorly documented, and it is often not specified how these values have been determined. Furthermore, some Member States have yet to define thresholds or reference values for all variables and habitats. In these cases, monitoring is limited to tracking changes and trends by comparing current data with historical records.

Some examples of threshold values are provided in Annex 1. With regard to physical variables, thresholds are generally not defined; these variables are mainly used to describe habitat suitability for particular species or communities, to characterise microclimatic conditions, and to assess the natural dynamics and stabilisation of screes.

For compositional characteristics, quantitative thresholds are often established, such as the number of characteristic or typical species indicating a favourable condition for certain habitats, or the presence of invasive, alien, or other negative indicator species signalling some degree of degradation. Similarly, thresholds for structural variables are usually defined as the percentage cover of certain species or functional groups (e.g. lichens, mosses, vascular plants, trees, and shrubs). It can be assumed that these reference values are predominantly based on expert judgement, as the methodology used to set such thresholds is seldom explained.

Thresholds for habitat fragmentation are set in some methodologies by specifying the percentage of the sampled habitat area occupied by fragmenting anthropogenic structures (such as ski slopes, lift systems, pipelines, power lines, roads, and paths) or by recording areas affected by human activities.

The differing approaches adopted by different countries for defining threshold values and ranges highlight the need for standardisation to improve the comparability of habitat condition assessment and monitoring across Europe.

2.3 Aggregation methods at the local scale

The assessment of habitat structure and function at the biogeographical scale is done as the proportion of area which falls under two categories, ‘good’ or ‘not-good’ condition.

In the national methodologies analysed, however, many MSs use three categories (good, medium, low, or favourable, unfavourable, bad) both in the establishment of thresholds for the variables measured and in the overall result obtained from aggregation.

The overall assessment at the local scale, usually at the level of the monitoring plot or station, requires the integration of the measured abiotic and biotic variables by using aggregation methods, such as one-out, all-out rule (minimum aggregation), or additive or hierarchical quantitative operations (Langhans et al., 2014). Following the assessment of each variable using a quantitative value, or a qualitative category, (indicating, for instance good/favourable, medium/unfavourable, low/bad condition), the aggregation is carried on by an arithmetic operation (when quantitative values are used) or by aggregation rules; A weight can also be applied to the individual variables, according to its relevance for the habitat condition, so that a more nuanced final assessment is obtained.

Conditional rules are used by some MSs, usually overweighting non-favourable condition, i.e., non-favourable habitat condition is established unless all variables are in favourable condition ("one-out, all-out" approach, or minimum aggregation, sensu Langhans et al., 2014). This type of procedure is applied by Bulgaria, Greece and Ireland. Bulgaria considers that local condition is "favourable" when all variables are assessed as "favourable" or when most variables are indicated as "favourable" and a maximum of 25% of the variables have been assessed to have insufficient information available. In case the assessment is "unfavourable – bad" for just one parameter, the overall assessment becomes unfavourable – bad. Unfavourable – insufficient status is determined by any other combination of parameters (Zingstra et al., 2009).

Greece defines a list of structure and function variable values that indicate good condition. If the number of variables in good condition is >50%, the sampling station is considered to be in favourable (FV) condition; if between 50-25% of variables are in good condition, the overall status is inadequate (U1) and if a favourable condition is assessed for < 25% of the variables, the overall condition would be Bad (U2) (Dimopoulos et al., 2018).

Categorical majority rules. Some MSs measure groups of variables related to compositional, structural and functional characteristics to obtain partial results for each set of variables. For instance, Germany and Austria consider the following groups: 1) Completeness of the typical habitat species composition; 2) Completeness of the typical habitat structure; and 3) Impairments of the habitat. A threshold/range is given to each variable to determine three categories, e.g. in Germany: A = excellent conservation status, B = good conservation status, C = medium to poor conservation status (Krause et al., 2008). The results of the evaluation of individual variables are summarised by means of an accounting matrix to an overall evaluation for each individual sample plot, according to a majority rule, e.g., 3A = A; 2A+1B = A; 2A+ 1C = B; 1A + 1B +1C = B; if there is a C rating, an overall rating of A is no longer possible.

Romania and Poland also follow a majority rule approach. The overall assessment in the methodology of Romania is calculated on the basis of the value assigned to each variable as follows: A= all variables assessed as A or 2A + 1 X (Unknown); B= one or more variables assessed as B and none as C; C= one or more variables assessed as C. Poland (Mróz, 2017) follows the same approach but applied to the FV-U1-U2 scale (three FV assessments (or possibly two FV assessments and one XX assessment) -> overall assessment FV; one or more U1 assessments and no U2 assessments -> overall assessment U1; one or more U2 assessments -> overall assessment U2).

Quantitative rules are used by some MSs (HU, ES) which apply arithmetic operators to the values estimated for each variable. Hungary uses a scoring system assigning positive and negative scores to the variables based on thresholds, and providing weights to the variables according to their importance. These are determined by expert judgment. The positive and negative scores for the indicator variables are aggregated separately. Afterwards, based on the rating algorithm, the habitat receives a "favourable" category if the sums of the positive and negative scores are greater than a given limit, while a "bad" category is determined if the sums of the positive and negative scores are smaller than a given limit value. In all other cases, the final result of the qualification will be “unsatisfactory”.

Spain has developed a specific Index of Naturalness of Rocky Ecosystems (INER), which, as the authors pointed out, should be subject to future revisions (Pérez-Alberti et al., 2019b). Eleven variables included into four groups are considered (geomorphological stability, biotic components and grade of anthropisation).

2.4 Aggregation at biogeographical scale

Aggregation at the biogeographical scale for habitat assessment involves combining data from multiple locations and sampling sites within a particular biogeographical region to provide a comprehensive overview of the habitat’s condition and trends.

Most Member States follow the latest recommendations from the Art. 17 reporting guidelines for aggregation of the assessment of local condition to obtain an overall assessment at the biogeographical scale. The guidelines establish that “if 90% of habitat area is considered as in ‘good’ condition, then the status of ‘structure and functions’ parameter is ‘favourable’. If more than 25% of the habitat area is reported as ‘not in good condition’, then the ‘structure and functions’ parameter is ‘unfavourable-bad’”.

The application of this rule requires that a sufficient representation of the habitat is subjected to the assessment of condition, so that the results can be extrapolated to the total habitat surface. The selection of localities and the number of sampling plots/stations should carefully consider this requirement.

2.5 Selection of localities

Several countries employ similar approaches for identifying and selecting monitoring localities, primarily relying on expert judgement and ecological criteria to ensure effective habitat assessment. In Poland, the selection process is guided by expert assessment, with an emphasis on ensuring that monitoring locations and plots adequately represent the diversity of scree habitats across various mountain ranges. The methodology recommends monitoring at least two localities per mountain range to account for habitat variability (Stawowczyk et al., 2015; Świerkosz, 2012; Perzanowska, 2010). This approach is part of the National Habitat Monitoring Programme, which aims to provide a comprehensive strategy for assessing conservation status; however, certain aspects remain insufficiently defined, particularly regarding threshold values for assessment variables.

Similarly, in Hungary, expert judgement is used to determine the required number of monitoring localities and plots, considering factors such as habitat distribution, rarity, and overall conservation significance. Nevertheless, the methodology has been criticised for relying on a limited number of relevés and for lacking clear recommendations for aggregating data (Horváth et al., 2021).

In Greece, the selection of monitoring localities draws on previous projects, such as the IDHTACI project, which sought to address gaps in conservation status assessment. Data collection relies on field recording sheets; however, there are no specified sampling protocols or indicator thresholds, with expert judgement serving as the primary source for habitat type assessment (Dimopoulos, 2018).

Slovakia utilises a flexible methodology during initial visits to monitoring sites, allowing for the adjustment of monitoring plots to ensure comprehensive coverage of biotopes, a particularly important consideration in complex habitats. The methodology is underpinned by extensive datasets from national inventories of non-forest habitats and prioritises the use of larger plots to achieve better representation of habitat conditions (Saxa et al., 2015). However, challenges arise in implementation, primarily due to rigid database structures that complicate the integration of data.

In Czechia, the methodology benefits from biotope mapping, which documents changes in habitat quality and area, although it partially depends on the subjective assessment of individual mappers (Lustyk, 2023). The use of permanent monitoring plots offers the advantage of generating data amenable to statistical analysis, facilitating the identification of trends in vegetation change (Vydrová & Lustyk, 2014).

All these methodologies demonstrate a strong reliance on expert knowledge and ecological considerations to guide sampling design for habitat monitoring.

2.6 General monitoring and sampling methods

This analysis focuses specifically on sampling protocols, monitoring frequency, criteria for selecting monitoring localities, and the integration of existing data sources. By critically examining these key components, the review seeks to identify the strengths and limitations present within different national methodologies, and to assess their implications for robust habitat assessment.

Monitoring approaches across the various countries display a wide spectrum, ranging from structured frameworks to more flexible systems, frequently relying on expert judgement and incorporating pre-existing datasets. Despite marked differences in protocols and sampling strategies, several common challenges remain—most notably, ambiguity in methodological documentation, dependence on subjective evaluation, and insufficient integration of available data sources.

In Austria, the monitoring methodology consists of baseline surveys designed specifically for alpine and continental habitats. The sampling framework incorporates a census that includes 55 quadrants for alpine regions and 15 for continental ones. For these surveys, the minimum area sizes are set at 1,000 m² for alpine habitats and 200 m² for continental habitats. The monitoring plots are typically circular, with a radius of 10 m for alpine areas (yielding an approximate area of 315 m²) and a 3 m radius for continental areas (resulting in about 28 m²). Vegetation is consistently recorded over a designated area of 16 m², and monitoring activities take place from the beginning of May through the end of September (Ellmauer et al., 2020).

In Czechia, the monitoring framework is primarily based on permanent monitoring plots (PMP), similarly as in Slovakia and Hungary, which represent predefined polygons characterized by homogeneous habitat features. The methodology delineates specific equipment requirements, monitoring timelines, and data processing protocols. This approach is aimed at achieving long-term monitoring of habitat changes, enabling assessments of species composition, dominant species, the presence of rare species, and the impacts of surrounding land use (Vydrová & Lustyk, 2014). However, a notable drawback is the subjective nature of biotope mapping, which can introduce inconsistencies in assessments (Lustyk, 2023).

Greece employs a standardised sampling approach grounded in conservation status assessment protocols tailored to each habitat type. Researchers utilise field sheets to gather data on typical species and compliance with particular features for structure and function adjusted to each habitat type; however, the methodology lacks explicit sampling protocols and measurement criteria, relying instead on expert-defined benchmarks (Dimopoulos, 2018). This absence of clarity may present challenges in ensuring consistency and reliability across assessments.

The methodology available from Hungary includes fixed permanent monitoring localities (so called TML) and monitoring plots (TMP) situated within these areas. The typical size for a TML is around 400 m², although smaller sizes can be justified for rare habitats. The methodology suggests that sampling of TMPs should occur every six years, yet the actual implementation of repetitive sampling has not yet begun. Concerns have been raised regarding the outdated nature of data forms and the absence of clear guidelines for aggregating local data (Horváth et al., 2021). Ireland employs permanent plots from National Inventories in its monitoring strategy, thereby enhancing the reliability and consistency of collected data. A number of monitoring stops for different areas of rocky habitats are recommended, as shown in Table 5 below. Using GIS, a large number of random monitoring points are generated at the site or section level—typically about 500–1,000 points for every 10 km². For each Annex I habitat to be assessed, a threshold area is determined subjectively based on the total area of that habitat within the site or section. The use of thresholds ensures that monitoring focuses on the largest areas of each habitat. Polygons containing more than this threshold area constitute sampling areas. For abundant habitats, a threshold of 10–20 hectares are appropriate, while for rarer habitats a threshold of 0.5 hectares or less may be used. From the random monitoring points within each sampling area, the required number of monitoring stops is then selected at random.

For scree and rocky slope habitats (codes 8120, 8110, 8210, and 8220), plot placement also takes into account the degree of safe access. At each monitoring stop, a comprehensive relevé is recorded. The standard plot size is 2 m × 2 m, although this may be adjusted as needed—for example, when sampling springs, flushes, rocky clefts, or hepatic mats—to ensure that each relevé captures a relatively homogeneous sample of a single vegetation type. All vascular plants, bryophytes, and terricolous microlichen species are recorded together with their cover in the relevé. Several digital photographs are taken at each monitoring stop to document the vegetation, with the best images retained for reference (Perrin et al., 2014).

Table 5. 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+

In the methodology available from Poland, transects or clusters of phytosociological relevés are used to evaluate habitat condition (Stawowczyk et al., 2015). The National Habitat Monitoring Programme has been applied across various localities, though specific monitoring protocols can display considerable variability among different studies.

Some other methodologies establish a proportional relationship between the area taken up by the habitat and the requisite number of monitoring plots (Angelini et al., 2016; Perrin et al., 2014).

In Romania, a stratified and/or clustered adaptive sampling approach is recommended, with plot sizes ranging from 1 to 25 square meters. Nonetheless, several methodological aspects remain poorly articulated, particularly in terms of how threshold values for the variables used in assessments are determined (Deák et al., 2014).

Slovakia adopts a strategy of using permanent monitoring localities to evaluate habitat conditions. Data collection follows a zig-zag transect method across larger areas, which facilitates a comprehensive evaluation of habitat quality. This methodology is enhanced by utilising extensive datasets from national inventories, although challenges in implementation arise from the rigid structure of existing databases (Saxa et al., 2015).

In Slovenia, there is currently a lack of a comprehensive monitoring framework for assessing the conservation status of habitat types. The approach relies instead on existing data derived from habitat type mapping, databases, and expert knowledge. The fragmented nature of the available data complicates accurate assessments, and the adaptation of the Physis typology may lead to inconsistencies in comparing habitat types at the European level (Kačičnik Jančar, 2011). Germany selects a minimum of 63 (on average 70-80) random samples per habitat type to ensure that both representativeness and diversity are captured (Sachteleben & Behrens, 2010).

The majority of field work takes place during the spring and summer months. In countries such as Austria and Poland, sampling is typically conducted from May to September. While some countries may designate slightly different periods for field activities, these variations are not considered significant for the overall comparability of results.

In terms of monitoring frequency, this is not specified in most countries' methodologies. Hungary is one of the few to recommend a defined interval, suggesting that monitoring plots be sampled every six years. By contrast, countries like Germany and Italy do not provide guidance on a regular monitoring schedule, highlighting the need for more standardised practices in this area.

An overview of the monitoring methodologies presented in the consulted methodologies is presented in Table 6.

Table 6. Summary of monitoring methodologies, sampling periods, and monitoring frequencies across Member States

Country	Monitoring Methodology	Sampling Period	Monitoring Frequency
Austria	Baseline surveys for alpine and continental habitats, utilising quadrants for sampling and vegetation recording.	May to September	Not specified
Belgium	Field work for monitoring, specifics not provided.	Not specified	Not specified

Country	Monitoring Methodology	Sampling Period	Monitoring Frequency
Bulgaria	Field work methodology, details not available.	Not specified	Not specified
Czechia	Permanent monitoring plots (PMP) to assess habitat changes over time.	Not specified	Not specified
Germany	Permanent monitoring localities	Not specified	Every six years
Greece	Standardised sampling based on expert-defined protocols for habitat types, with field sheets for data collection.	Not specified	Not specified
Hungary	Fixed permanent monitoring localities (TML) and monitoring plots (TMP) within these areas.	Not specified	Suggested every six years
Ireland	Utilises permanent plots from National Inventories for monitoring.	May to September	Not specified
Italy	Field work based on previous reporting periods for monitoring sites.	Not specified	Not specified
Poland	Transects or clusters of phytosociological relevés to assess habitat conditions, as part of a structured National Habitat Monitoring Programme.	May to September	Not specified, but varies by locality
Romania	Stratified and/or clustered adaptive sampling approach recommended.	Not specified	Not specified
Slovakia	Permanent monitoring localities (PML) assessed via zig-zag transect methods.	Not specified	Not specified
Slovenia	Relies on existing data and expert knowledge, with no comprehensive monitoring framework in place.	Not specified	Not specified
AT (Ellmauer et al., 2020), BE (Hendrickx et al., 2021), BG (MOEW, 2013), CZ (Vydrová & Lustyk, 2014), DE (BfN, 2017), ES: Spain, GR: Greece, HU (Horváth et al., 2021), IE (Perrin et al., 2014), IT (Angelini et al., 2016), PL (Stawowczyk et al., 2015), RO (Deák et al., 2014), SK (Šeffer& Lasák, 2022), SI (Kačičnik Jančar, 2011).			

2.7 Other relevant methodologies

New technologies such as remote sensing and robotic systems, as well as advanced modelling approaches, offer promising solutions for overcoming the challenges associated with monitoring scree habitats.

Robotic monitoring of scree habitats: One of the innovative methodologies for monitoring scree habitats involves the use of robotic systems to navigate and monitor various natural environments, including scree habitats (Angelini et al., 2023). This approach leverages the concept of Natural Intelligence, which integrates the robot's environmental interactions, the intelligent design of its body, and sophisticated algorithms to manage its operations. This methodology addresses several challenges inherent in scree habitats, such as navigating irregular and rough terrains, ensuring long-lasting operations, and handling unexpected collisions.

Geotechnical and geophysical monitoring: Seasonal field monitoring of soil temperature, and volumetric water content, combined with geophysical measurements, help in assessing slope stability. This method includes the use of Ground Penetrating Radar (GPR) to create bedrock maps and numerical analysis to predict slope stability under various conditions (Lucas et al., 2020).

Remote sensing: Remote sensing has emerged as a powerful tool for assessing biodiversity across various ecosystems, to map habitat distribution and monitor their over large spatial extents. One of the primary applications of remote sensing in ecological monitoring is change detection. Techniques such as those using Landsat and MODIS data are particularly effective for monitoring changes in scree habitats due to their high temporal resolution and accessibility (Willis, 2015; Nagendra et al., 2013). These methods help in detecting both natural and anthropogenic changes, which are critical for conservation efforts (Pettorelli et al., 2014).

Modelling approaches: GIS-based method uses remote sensing and field data to predict habitat suitability for indicator species. It combines various environmental variables to create probability maps of species occurrence. This approach can be used to assess the biodiversity value of scree habitats by identifying areas with high habitat suitability for key species.

2.8 Conclusions

The assessment and monitoring of scree habitats reveal some commonalities but also important differences in the methodologies employed across the various Member States.

Among the variables most frequently used, abiotic characteristics are measured with physical variables (granulometry, lithology, slope gradient and dynamics) only. No chemical variables are included in the methodologies reviewed although the lithology at least indicates whether acid or basic rocks are involved in the scree formation. Among the biotic variables, the presence and cover of vascular plants, lichens and mosses are frequently assessed; invasive and negative indicator species are also recorded in some MSs. Functional variables are rarely assessed, just a few MSs consider the dynamics and stability of the scree, vegetation succession, erosion and the effects of human activities on the screes. Measurement methods and thresholds are not properly specified for all the proposed variables in the methodologies analysed. Some of these variables can be considered descriptive or contextual, and are therefore not formally assessed, but simply recorded to allow the detection of changes that may influence the habitat condition. These descriptive variables can also play a role in establishing appropriate thresholds for other variables.

There is some inconsistency in the way of establishing threshold values and determining the condition between MSs. Some countries incorporate clear thresholds and quantitative assessments, allowing for more objective evaluations. In contrast, the methodologies available from other MSs present considerable gaps in terms of reference or threshold values and clear definition of other methodological aspects, hindering effective monitoring efforts. This disparity underscores the need for harmonisation of assessment criteria and methodologies across the EU.

Furthermore, the integration of advanced technologies and innovative methodologies presents a substantial opportunity to enhance monitoring practices. For instance, the use of remote sensing and GIS-based modelling can provide comprehensive insights into habitat conditions and dynamics, enabling more effective tracking of changes over time. Additionally, robotic monitoring systems can navigate the challenging terrains typical of scree habitats, offering real-time data collection that complements traditional field assessments.

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 scree habitats reveals some commonalities and differences among the EU MS. 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

This section aims to provide a **selection of a minimum common set of variables** for the assessment of habitat condition, including abiotic (physical and chemical), biotic (composition, structure, and function) and landscape variables, with a rationale for their selection.

Regarding key abiotic characteristics, the assessment and monitoring of scree habitats require the consideration of several important factors. The **mineralogical composition** is useful for identifying rock types such as limestone and granite and provides insights into the habitat's characteristics. **Granulometric composition**, the analysis of grain size distribution, helps assess the texture and stability of scree materials. **Soil temperature and humidity** are critical for evaluating ecological condition, requiring monitoring at the surface and at various depths. The **degree of rock fragmentation** creates diverse microenvironments that influence species distribution. **Slope measurements** also play a key role; the angle of the slope affects drainage patterns and the accumulation of scree materials, which in turn impacts habitat quality.

A comprehensive assessment of scree habitats should include a range of **biotic variables. Vegetation cover** provides insights into habitat health and productivity, as well as the effectiveness of plant colonisation. The scree habitats are typically devoid of plants or covered by low vegetation cover. In consequence, a high vegetation cover would indicate a poor condition for these habitats. **Invasive species presence** in these habitats can indicate ecological changes and potential threats to native biodiversity. The presence and diversity of animal species, including invertebrates, (soil predatory groups, pollinators, etc.), lizards, birds and small mammals, can indicate habitat quality and is therefore recommended to be included in the study, depending on the ecological context.

A proposed list of **descriptive, essential, recommended and specific variables** for scree habitats is presented in Table 7, including metrics and general measurement methods. The list is based on the main characteristics of scree habitats (as described in section 1.2) and the analysis of methodologies available from EU MSs for the assessment of scree habitat condition. The proposed variables are consistent with those already used by the various MSs, as described in section 2.1.

Essential variables (E) correspond to key characteristics that need to be measured in all the scree habitat types to properly assess the habitat condition. **Recommended variables** (R) correspond to common variables which are relevant but are optional and can be neglected in some contexts. **Specific variables** (S) should be measured in some specific habitats due to their particular characteristics. **Descriptive variables** (D) are measured in order to obtain contextual information needed to understand the environmental gradients that must be considered in the assessment. Such variables do not directly determine the habitat condition but are useful for the definition of thresholds and for the interpretation of results.

Table 7. Proposals for condition variables for assessing and monitoring Scree

Characteristics	Variables	Metrics	App.	Measurement procedures	Considerations relating to methodologies
1. Abiotic characteristics					
1.1 Physical state characteristics					
Climate	Air temperature	ºC	D	Measured with meteorological sensors at various heights.	
	Precipitation	mm	D	Retrieved from local meteorological stations.	
Topography	Altitude	m	D	Measured using GPS altimeters.	
Lithology	Lithology	Rock types	D	Field or laboratory analysis of physical characteristics when bibliography not available.	Rock types: limestone, granite, etc.
Geomorphology	Granulometric composition	Ratios of grain size classes (% composition)	D	Measured via grid sampling.	
	Median diameter of rocks	mm	D	Measured using callipers or visual assessment across selected plots.	
	Slope characteristics and dynamics	Degree of slope; mm	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.
Soil characteristics	Soil temperature	ºC	E	Measured using temperature sensors.	Monitored at surface and various depths.
	Soil humidity (E)	%	E	Measured on the surface and at depths with moisture sensors.	
1.2 Chemical state characteristics					
	Soil pH	pH	E	Measured using soil pH meters or test kits.	
	Soil nutrients	mg/L	E	Measured collecting field samples and using soil test kits.	Assessed for nitrogen, phosphorus and calcium

Characteristics	Variables	Metrics	App.	Measurement procedures	Considerations relating to methodologies
2. Biotic characteristics					
2.1 Compositional state characteristics					
Presence and abundance of biological communities and species	Number of herbaceous species and ferns	Number of species	E	Field surveys to record all herbaceous species present.	Based on local or regional reference lists.
	Number of species of lichens	Number of species	E	Visual inspection in the field.	Based on local or regional reference lists.
	Number of species of bryophytes	Number of species	E	Count of bryophyte species, including endemic species, by field surveys.	Based on local or regional reference lists.
	Number and abundance of invertebrate species	Number of species and % of each species	E	Sampling using pitfall traps or sweep nets, Malaise traps for invertebrate collection.	Based on local or regional reference lists.
	Diversity of top soil predators	Number of species	R	Sampling using pitfall traps, direct time-based collection	Based on local or regional reference lists. e.g. Arachnids, Carabid beetles
	Diversity of specialised pollinator groups	Number of species	R	Sweep nets & direct observation. Malaise traps for invertebrate collection	Based on local or regional reference lists. Lepidoptera, Diptera: Syrphidae, Wild bees
	Presence of non-native species	Number of species	E	Visual assessment and recording in field surveys.	Based on local or regional reference lists.
2.2 Structural state characteristics					
Pattern of occupancy of communities and species	Cover of bryophytes	%	S	Estimated cover using quadrat sampling methods. Multispectral camera with drones	Specific for 8110 and 8150.
	Cover of lichens	%	S	Measured via visual assessment using quadrats. Multispectral camera with drones	Specific for 8110 and 8150.
	Cover of shrubs and trees	%	E	Estimated cover with line-intercept or point-intercept methods. Multispectral camera with drones	

Characteristics	Variables	Metrics	App.	Measurement procedures	Considerations relating to methodologies
2.3 Functional state characteristics					
Dynamics and natural processes	Slope dynamics	Mobility of scree	E	Image comparison through photogrammetry combined with drones (LiDAR) / multispectral camera.	Monitored using rods installed across the slope for movement assessment.
	Habitat dynamics	Successional stages	E	Photo survey using drones or aerial photos to detect substrate and vegetation changes over time.	Successive vegetation mapping is to be conducted using high-resolution orthophotographs, with permanent plots established for ongoing vegetation monitoring.
3. Landscape					
Impact of human activities	Total area of habitat patch and distance from other patches	m^2 or ha (area) and m or km (distance)	R	Assessed using aerial imagery and GIS tools.	Surface area of patch and distance to nearest habitat
	Presence of fragmenting structures	Presence	E	Visual assessment in the field and from aerial photographs	Roads, mines, etc.
4. Other					
Disturbances	Impacts of anthropogenic pressures	Presence and signs of impact	E	Visual assessment	Assessment of the extent and intensity of impacts (e.g. it is directly disturbing the habitat)

D: descriptive, E: essential, S: specific (for certain habitat types), R: recommended.

The proposed **descriptive/contextual variables** are focused on climate parameters and on the physical and geomorphological characteristics of scree habitats. **Granulometric composition**, measured as the grain size of sediments and how they are distributed, together with the **median diameter of surface clasts**, provide valuable information about habitat structure which may influence the pattern of vegetation distribution. These characteristics also influence the development of microhabitats that support a range of animal species. The angle and aspect of a **slope** affect the orientation and arrangement of clasts which in turn determine microclimatic conditions, such as moisture retention and stability (Table 7). The angle and aspect of a slope further influence the orientation and arrangement of clasts (Bithell et al., 2014) which in turn affect microclimatic conditions, such as moisture retention and stability. They can be assessed using methods such as grid or transect sampling for clast analysis, and digital inclinometers for slope measurement (Goudie, 1990). Increasingly, remote sensing techniques—such as LiDAR and high-resolution aerial imagery—are also used to evaluate these features at broader spatial scales (Tarolli, 2014).

Climate also has an indirect effect in shaping landforms, but it has a direct influence on biodiversity by promoting the adaptation of organisms to varying temperature and moisture regimes. Air temperature and precipitation data for selected monitoring time periods can be retrieved from meteorological stations. **Altitude** is recorded as a descriptive/contextual variable due to its relation to the climatic conditions and its influence on the presence and distribution of scree species. GPS altimeters can be used to identify altitude ranges.

Lithology plays an important role in shaping plant communities: landslides composed of carbonate rocks typically foster different vegetation than those formed from siliceous rocks, as the substrates produce basic or acidic reactions, respectively.

The proposed **abiotic essential variables** focus on the measurement of direct climatic and soil conditions. **Soil temperature** has a strong control over biological communities and ecosystem processes. Increased soil temperature tends to shift vegetation composition, favouring graminoids and herbaceous plants, while reducing the abundance of bryophytes and lichens. Warmer soils also alter litter dynamics and can increase the susceptibility of early-stage plants to invertebrate herbivory, although this vulnerability often decreases as plants mature (Warner et al., 2021). Air temperature within the scree is also important for the survival of cold adapted species and glacial relics. Additionally, high temperature, by accelerating evaporation, can further exacerbate the typically dry conditions of scree slopes, influencing habitat suitability for both flora and fauna. **Soil humidity** is often limited in scree due to rapid drainage and exposure. The distribution of soil moisture across a scree slope frequently determines the availability of microhabitats, influencing where particular species can establish and persist (Jureková et al., 2021b). Both can be measured on the surface and at depths with temperature and moisture sensors.

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. These processes 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. **Nutrient availability** in scree habitats is typically low because these environments have little organic matter and are dominated by mineral substrates. Soil samples can be collected on the field and analysed later in the laboratory to assess nutrient content.

Regarding **biotic essential variables**, the proposed variables include the number of herbaceous species and ferns, as well as of invertebrate species, which should be assessed during fieldwork at each sampling location. In addition, the presence of invasive species should also be recorded.

For habitats 8110 and 8150, the cover of lichens and bryophytes are proposed as **specific variables.** These habitats are mainly dominated by cryptograms which play an important role in early succession, soil formation, and as microhabitats for specialised species (JNCC, 2013). Notable examples include rare ferns such as forked spleenwort (*Asplenium septentrionale*), which benefit from the low competition and unique microclimatic conditions offered by bryophyte and lichen mats on scree and crags (European Commission, 2013).

Horizontal structure can be assessed by measuring the cover of major surface types such as: bare soil, bedrock, vascular plants (woody and herbaceous), bryophytes, lichens, etc. A coverage of woody plant, tree, or shrub above 10% is considered an indication of poor condition for scree habitats (Goñi & Guzmán, 2019).

Slope dynamics and **habitat dynamics** are proposed as functional variables, consistent with approaches taken by different Member States, as outlined in section 2.1. Monitoring clast mobility in relation to slope steepness, together with tracking changes in the cover of different vegetation groups, provides valuable insight into successional stages and the functional integrity of the habitat. This approach allows for the assessment of whether the habitat is progressing naturally or experiencing disturbances, supporting informed management and conservation decisions.

Documenting the presence of **fragmenting structures**, like roads, provides further insight into barriers that may limit movement and connectivity within the landscape. This variable can be easily recorded during the development of the site inventory.

The impacts of **anthropogenic pressures** are considered an essential variable. Their effect on the habitat condition can be assessed by estimating the extent and intensity of the impacts observed in the field.

The following variables are **recommended** for monitoring, although they may require additional resources. It is advised to include them in the monitoring programme whenever possible, taking also into account the specific context and characteristics of the habitat area.

Diversity of top soil predators and of specialised pollinator groups is proposed, as a high diversity and abundance in these groups reflects the presence of intact microhabitats. These include suitable nesting and foraging opportunities, providing a valuable insight into habitat structure. Scree slopes offer a gradient for spider colonisation, adaptation, and the potential for evolutionary processes linking the surface to deeper underground habitats. Dominant spider groups in scree environments include species such as *Bathyphantes eumenis buchari*, *Lepthyphantes notabilis,* and *Rugathodes bellicosus*. Scree habitats host several exclusive or highly characteristic spider species, many of which display troglomorphic traits with species richness declining with depth (Růžička et al., 2013). Carabid beetles (ground beetles) also occur in scree and stony European habitats. Studies from the Alps and Central Europe have found distinctive assemblages of *Carabus* and other carabids associated with calcareous scree slopes and rocky grasslands. These beetles function as important predators, helping to regulate populations of other invertebrates, and are widely recognised as bioindicators of habitat quality and ecological change within open, rocky, and high-altitude landscapes (Gobbi et al., 2021). Regarding pollinators, scree is considered important habitats for pollinators (Kudrnovsky et al., 2020). Wild bees, especially solitary ground-nesting species, benefit from the loose, well-drained soils and microhabitat heterogeneity of screes (Westrich, 2018). Syrphid flies and butterflies are also prominent, with many species adapted specifically to stony, xeric, and high-altitude zones (Speight, 2020). Sampling can be carried out using various methods, including pitfall traps and direct timed collections. Sweep nets and direct observation are also effective for gathering surface-dwelling species, while Malaise traps are particularly useful for capturing flying insects.

Scree habitats are inherently fragmented due to their scattered and patchy distribution across slopes, talus fields, and mountainous terrain. Nevertheless, the ability of specialised invertebrates, reptiles, small mammals, and certain plants to move between scree patches is vital for maintaining gene flow, enabling colonisation of new sites, supporting population persistence, and enhancing resilience to disturbances. To assess the level of habitat connectivity/fragmentation it is important to use **landscape metrics** that measure the degree of isolation—such as the size of habitat patches and the distances between them.

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

The observed measurements of the condition variables need to be compared to reference values and critical thresholds, in order to assess the condition for each variable. A reference level is the value of a variable at the reference condition, against which it is meaningful to compare past, present or future measured values of the variable. The difference between the value of a variable and its reference level represents the distance from the reference condition.

The measured values of the condition variables need to be compared with reference values and critical thresholds to assess the condition of each variable. 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 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 et al., 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 approaches 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.

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.

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, after accounting for the contextual factors specific to each MS (e.g., climate).

Reference values and thresholds should be tested using sufficiently robust datasets that represent the full range of habitat conditions, from degraded to high-quality sites.

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.

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 (validity), 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.

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 and not good; or good, medium and 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.

In habitat condition assessments, each characteristic and its associated variable is likely to be measured in a different unit. 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 in order to build indicators that combine multiple variables.

Measurement values can be re-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).

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 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 (v_i) 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.

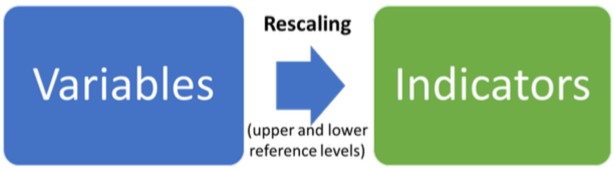
However, a robust basis for assigning weights is not always available. In such cases, weighting often relies on expert judgment, which can be subjective, as expert opinions may differ considerably.

Normalisation 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. 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:

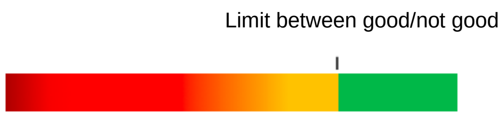
$$Local\ condition = \sum_{1}^{n} v_i * w_i/\mathrm{n}$$

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 $\sum wi = 1$. 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 of condition indices obtained at the local scale is essential for assessing habitat conditions at a broad habitat biogeographical region level. According to the Art. 17 reporting guidelines (European Commission, 2023), specific rules have been established to determine the overall habitat condition based on local assessments:

- If **90%** of the habitat area is considered in **'good' condition**, then the status of the **'structure and functions'** parameter is classified as **'favourable'**.
- Conversely, if more than **25%** of the habitat area is reported as **'not in good condition'**, then the **'structure and functions'** parameter is deemed **'unfavourable-bad'**.

The application of this rule requires that the assessment covers a sufficient representation of the habitat, so that the results properly reflect the conditions in the total habitat area. The selection of localities and the number of sampling pots/stations should be carried out to ensure that they are statistically representative of the whole habitat distribution.

3.5 Guidelines on general sampling methods and protocols

These guidelines are designed to offer a comprehensive and standardized approach to sampling design and monitoring protocols that can be effectively applied across EU member states. The recommendations presented in this section cover the design of sampling protocols including the size and number of sampling areas, monitoring frequency, various spatial scales, including biogeographical regions, the Natura 2000 network, and site-level assessments.

Once the main habitat, locations have been identified in the biogeographical region. A stratified sampling design that encompasses diverse ecological zones within the region should be implemented to ensure representative coverage of the habitat type under assessment, both inside and outside the Natura 2000 network. All sampling locations should be exactly georeferenced for future monitoring and pictures of the sampling location and its surrounding area should be taken.

The monitoring methodology suggested is based on the method proposed by Goñi and Guzmán (2019), which uses a combination of transects and quadrats and is consistent with the sampling methods applied by several MSs (see Box 3). Inside these quadrats, the presence and abundance of species, the vegetation cover and other proposed variables will be measured.

The **monitoring frequency** proposed in these guidelines is set from 6 to 12 years, depending on the habitat's stability and ecological dynamics. Specific habitats may require more frequent assessments based on their susceptibility to disturbance and changes. **Monitoring periods** should focus monitoring efforts during optimal growth seasons; for most habitats, this would typically be from April to September. These can be adjusted based on species-specific life cycles and seasonal variations.

Recent advances in technology offer valuable opportunities to enhance monitoring programmes. The use of high-resolution orthophotographs, digital elevation models, multispectral imaging, and LiDAR —particularly when deployed from Unmanned Aerial Vehicles (UAVs)— allows for more precise and comprehensive data collection. These modern tools can greatly improve our understanding of scree habitat structure, change, and overall health.

Box 3 - Temporal Transects with Quadrats and Intersection Points Method

Adapted from Goñi & Guzmán (2019)

1. Transect installation

The first step of the method consists of the **transect installation** within the area defined as the sampling location. Several parallel transects are established, each transect being fixed with two iron rods, one at each end, between which a measuring tape is stretched. These transects should be laid out parallel to the contour lines, i.e., horizontally. Each transect will be 20 meters long, and every two meters a rigid 1 x 1 m quadrat will be placed upward from the tape, with the observer positioned beneath the tape. This is particularly important in scree slopes, as the substrate is unstable, and if the surveyor moves above the quadrat or the measuring tape, rocks may dislodge and disturb the entire setup. Once the tape is in place, the geographic coordinates of the starting and ending points of each transect must be recorded.

The starting point is always defined as the right-hand end when facing the transect from below. Additionally, the azimuth (orientation) from start to end should be measured, and photographs taken from both ends of the transect.

2. Measurement in quadrats with intersection points

The second step is the **measurement in the quadrats.** Each quadrat is placed at the pre-defined intervals (from meter 0 to meter 18), with the **lower-right corner of the quadrat** marking each measurement point. In each quadrat, all plant species present are recorded to the finest taxonomic resolution possible, along with a set of predefined surface types (e.g., fine soil, loose stones, boulders, bryophytes, lichens, etc.). Additionally, using a thin rod, intersection-points contacts are made at each of the four corners of the quadrat, recording what type of surface or biological element the rod touches. For lichens and bryophytes, when precise identification is not feasible in the field (often very difficult), provisional names may be assigned to visually distinguishable entities. This allows at least the recording number of lichen species and number of bryophyte species.

Approximately six 20-meter transects are established, each with 10 quadrats. After each transect is completed, the iron rods are removed. The resulting data provide species frequency (presence/absence in 60 quadrats) and cover values (percentage of contacts out of a total of 240). For relatively small areas (e.g., 0.5 hectares), this method is considered both representative and robust, even when transects are not placed in exactly the same locations during subsequent years of monitoring. Is advisable, however, for subsequent sampling events following the initial data collection, to position the transects as close as possible to their original start and end points, which were previously marked with coordinates during earlier surveys. Field experience in various contexts has shown that this complete sampling can be conducted in under two hours by a two-person team at the sampling station.

3.6 Selecting monitoring localities and sampling design

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 (see Box 4).

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 **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.

Box 4 - Key elements for statistical representation

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

Assessing and monitoring scree habitats can benefit significantly from the use of available data sources, open databases, new technologies, and modelling techniques. The integration of satellite imagery, robotic systems, and advanced modelling techniques offers a comprehensive approach to assessing and monitoring scree habitats. Satellite-derived habitat metrics provide detailed and dynamic data, while robotic systems enhance on-the-ground monitoring capabilities. Together, these technologies enable more accurate and efficient habitat conservation efforts.

Use of available data sources and open databases, **e.g. satellite imagery**: Continuous variables derived from satellite imagery, such as Landsat, provide detailed habitat metrics that capture land-cover characteristics more effectively than traditional categorical maps. These metrics can be derived automatically and are sensitive to fine-scale habitat heterogeneity, making them highly useful for monitoring habitat dynamics over time (Oeser et al., 2019).

New technologies, such as robotic systems: Legged robotic systems equipped with Natural Intelligence can navigate and monitor scree habitats effectively. These robots are designed to handle irregular and rough terrains, perform long-lasting operations, and manage unexpected collisions. They assist humans in assessing habitat conservation status by providing real-time data from challenging environments (Angelini et al., 2023).

Modelling techniques, e.g. Spectral-temporal metrics: Models using spectral-temporal metrics derived from Landsat imagery outperform those based on categorical land-cover maps. These metrics capture intra-annual variability in habitat conditions and are particularly effective for seasonal habitat models. They offer a significant improvement in model accuracy and sensitivity to habitat heterogeneity (Oeser et al., 2019).

4. Guidelines to assess fragmentation at appropriate scales

As mentioned above, scree habitats are inherently fragmented due to their scattered and patchy distribution across slopes, talus fields, and mountainous terrain. Nevertheless, the ability of specialised invertebrates, reptiles, small mammals, and certain plants to move between scree patches is vital for maintaining gene flow, enabling colonisation of new sites, supporting population persistence, and enhancing resilience to disturbances. In this regard, the degree of isolations has been proposed as an essential variable to be measured at the landscape level (see section 3.1).

An approximation for evaluating fragmentation is proposed in these guidelines based on quantifying patch size, which provides valuable insight into the area of suitable habitat available, while measuring the distances between patches and the presence of fragmenting infrastructures, such as roads, quarries, or urban development, helps assess the degree of isolation and potential barriers to species dispersal, gene flow and habitat quality (Turner, 2005; With et al., 1997).

The ecological condition of scree habitats is influenced by landscape features that extend beyond individual plots. For effective management of biodiversity in rocky and scree environments, it is helpful to consider both the local state of scree patches and their distribution and connectivity in the wider landscape. Local-scale analysis can reveal immediate effects on habitat structure, while landscape-scale evaluation provides information on patch arrangement and connectivity. At the biogeographical scale, integrating data from several landscapes can offer a broader perspective, highlighting any specific challenges present in different rocky regions.

Data collection could use remote sensing, GIS, and field surveys to gather spatial information about these habitats. Mapping patch distribution, calculating key metrics, and analysing trends will aid in integrating fragmentation data with other habitat condition variables.

Regarding monitoring protocols, tools such as high-resolution satellite imagery and drones can facilitate mapping and quantification of patch size, connectivity, and other relevant features at both local and broader spatial scales (Foody, 2023). Regular assessments can help identify trends in habitat structure, supporting responsive management measures as needed.

5. Next steps to address future needs

These guidelines recommend standard methods for assessing and monitoring scree habitat 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 a common set of variables/indicators with well-defined metrics and standard measurement procedures. These should include physical, chemical, compositional, and functional variables to comprehensively evaluate the health of mire habitats.

To implement 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 use of typical species:** Typical species provide a practical way to evaluate habitat status, reflecting specific ecological conditions. 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.

The current proposal should be viewed as a starting point and may be adapted where more suitable alternatives are identified based on national experience or ecological requirements.

Further research is also needed to advance scree habitat mapping and monitoring using new technologies. The most promising research avenues include:

- **Improving knowledge** about scree habitats distribution and characterisation: A comprehensive characterisation, inventory, and mapping of rocky habitats across each country is crucial. This effort should focus on identification and characterisation of minimum occurrence localities considering relevant factors related to climate, topography, lithology and vegetation (considering in particularly endemic and (peri)glacial relict species). Establishing this foundational knowledge is vital for understanding the biodiversity and ecological significance of these unique environments shaped by ice/thaw processes, snow, wind, water, and gravity. It is also essential to properly design an effective monitoring programme to assess the status of scree habitats.

- Identifying **reference localities and sampling locations:** Utilising mapping and characterisation data, we can identify key reference sites that will serve as benchmarks for monitoring biodiversity and ecological quality or condition. These reference localities will facilitate comparative studies and long-term assessments, providing a standard against which changes can be measured.
- Incorporating **advanced technologies:** Integrating advanced technologies into monitoring efforts can significantly improve data collection efficiency. Technologies such as drones, remote sensing, and environmental DNA (eDNA) sampling can provide valuable insights. Drones can capture high-resolution images of hard-to-reach areas, while remote sensing allows for large-scale habitat assessments.
- **Implementing tailored monitoring methods:** To address the unique challenges of scree habitats, a variety of monitoring methods should be tested and employed, including:
    - **Remote sensing**: Utilising satellite imagery and aerial photography to assess land cover and habitat distribution.
    - **Drones (UAVs)**: Deploying unmanned aerial vehicles for high-resolution data collection in inaccessible areas.
    - **Camera traps**: Setting up motion-activated cameras to monitor wildlife presence and behaviours.
    - **Environmental DNA (eDNA) sampling**: Collecting water or soil samples to identify species without direct observation.
    - **Acoustic monitoring**: Using sound recorders to capture animal calls, particularly from birds, bats, and amphibians.
    - **Robotic systems:** Legged robotic systems equipped with Natural Intelligence can navigate and monitor scree habitats effectively.
    - **Field surveys with local experts**: Collaborating with local guides to conduct surveys more effectively.
    - **Citizen science**: Engaging local communities in biodiversity monitoring, allowing them to report sightings and assist in data collection.

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Annex 1

Examples of variables included in the methodologies available from EU MSs

Variables	Member State (Reference)	Explanation of variable and measurement methods	Use in assessment and monitoring	Reference values, thresholds
1. Abiotic characteristics				
1.1 Physical state characteristics				
Geomorphology: substrate ratios/grain size distribution	AT (Ellmauer et al., 2020)	Relative proportion (%) of grain size classes (fine debris, coarse debris, blocks). Measurement methods and thresholds not specified.	Assessing soil composition for habitat suitability.	Not provided.
Grain size composition	ES (Pérez-Alberti et al., 2019b)	Creation of a grid of 100 m wide plots. Measurement of the size of at least 25 blocks in the upper, middle, and lower part of one or more plots selected based on granulometric diversity. Each block must be geo-referenced with GPS. Performed only once at the beginning.	Evaluating sediment transport processes.	Not provided.
Presence of fine-grained soil	GR (Dimopoulos, 2018)	The variable is mentioned in a table but no further information is provided.	Not provided.	Not provided.
Dominating fraction of stone rubble	PL (Stawowczyk et al., 2015)	Expert visual assessment. No metrics or thresholds provided.	Understanding habitat complexity.	Not specified
Structure of topography and features	DE (BfN, 2017)	Expert judgement of the presence of vegetation-free soil, larger rocks, rock faces.	Evaluating erosion risk and habitat stability	A, B, C categories. A = high structural diversity; B = moderate structural diversity or moderately degraded structure due to human influence; C = strongly degraded habitat structure.
Median diameter of rocks	CY (Dimopoulos & Tsiripidis, 2013)	Measured in cm. Measurement methods and thresholds not provided.	Not provided.	Not provided.

Variables	Member State (Reference)	Explanation of variable and measurement methods	Use in assessment and monitoring	Reference values, thresholds
Shape of rocks	CY (Dimopoulos & Tsiripidis, 2013)	Classification in categories: angular, rounded, blocky, platy, columnar, prismatic. No measurement methods or thresholds are provided.	Habitat preference for specific species.	Not provided.
Shade	PL (Stawowczyk et al., 2015)	Expert assessment % of habitat area shadowed (average). Thresholds:.	Understanding microclimates for species distribution.	Termophilous habitat: FV<20% <U1<40% <U2; shadow-tolerant habitat: FV<40% <U1<60% <U2
Exposure	CY (Dimopoulos & Tsiripidis, 2013), AT (Ellmauer et al., 2020)	Indication of the exposure using the eight-part compass rose. The reference area is the entire individual occurrence or that part of the individual occurrence within the sample area.	Assessing habitat conditions for plant growth.	Not provided.
Inclination	CY (Dimopoulos & Tsiripidis, 2013)	Not provided.	Not provided.	Not provided.
Average slope gradient	AT (Ellmauer et al., 2020)	Specification of the average slope gradient (º). The reference area is the investigation area. No threshold provided.	Erosion risk assessments.	Not provided.
Substrate dynamics	AT (Ellmauer et al., 2020); IT (Angelini et al., 2016)	The dynamics of the site can be analysed directly or indirectly. Clast mobility analysis based on the degree of acclivity.	Evaluating ecological processes in dynamic environments.	A, B, C categories. A: existing dynamics; B: dynamics halted by natural processes; C: artificial dynamics.
Geological substrate, lithology	CY (Dimopoulos & Tsiripidis, 2013)	Type and % composition - not provided.	Not provided.	Not provided.
2. Biotic characteristics				
2.1 Compositional state characteristics				
Typical species of phanerogams and pteridophytes	BE-Wal (Hendrickx et al., 2021)	Methods, metrics, and threshold values not provided.	Not provided.	Not provided.
Species number and cover	CZ (Vydrová & Lustyk, 2014)	Species cover on the permanent plots (25 m^2 each)	Assessing ecological	Not provided.

Variables	Member State (Reference)	Explanation of variable and measurement methods	Use in assessment and monitoring	Reference values, thresholds
		is assessed using the phytocenological method. a) species composition change; b) main dominants change; c) change of number of species in the reléves and species coverage change.	changes in populations.	
Typical animal species	Be-Wal (Hendrickx et al., 2021)	Methods, metrics, and threshold values not provided.	Not provided.	Not provided.
Number of characteristic species	RO (Deák et al., 2014)	Number of characteristic species in 10 sample areas	Assessing biodiversity in different habitats.	FV=>3 species, U1=2-3 species, U2=1 species.
Number of typical species	PL (Stawowczyk et al., 2015)	Expert visual assessment during fieldwork.	Monitoring changes in habitat quality over time.	FV=>2, U1=2-3, U2=<1 - same thresholds for all 81 habitats except for 8150: FV=>4; U1=2-3; U2=<1.
Typical species inventory of ferns and vascular plants	DE (BfN, 2017)	Visual expert assessment and development of a species inventory according to lists of typical species.	Condition assessments for specific vegetation types.	A = typical species inventory present; B = typical species inventory mostly present; C = typical species inventory only partly present.
Typical species inventory of lichens and mosses	DE (BfN, 2017); CY (Dimopoulos & Tsiripidis, 2013)	Visual expert assessment and development of a species inventory according to lists of typical species.	Monitoring lichen and moss communities.	A = most typical species present, forming extensive patches; B = many typical species present, or one or more typical species forming extensive patches; C = typical species present only sporadically and at low density, or mostly missing.
Typical species presence	CY (Dimopoulos & Tsiripidis, 2013)	Metric, methods, and thresholds not provided. Includes diagnostic, dominant, and frequent species.	Not provided.	Not provided.

Variables	Member State (Reference)	Explanation of variable and measurement methods	Use in assessment and monitoring	Reference values, thresholds
Occurrence of nitrophilous species	CY (Dimopoulos & Tsiripidis, 2013)	Not provided.	Not provided.	Not provided.
2.2 Structural state characteristics				
Relative area of stone rubble not covered by vegetation	PL (Stawowczyk et al., 2015)	Expert assessment.	Habitat conditions	FV=20-90%, U1=<20% U2 not applicable
Cover of weeds	HU (Horváth et al., 2021)	Cover (%) of ruderal, segetal weeds and spreading grass species. Only the species with higher proportion are considered; the cover is mostly fixed on group level.	Evaluating habitat degradation	For 8150: A=0.1, B=1, C=1, D=5, E=10
Coverage of invasive species and habitat ruderalization	HU (Horváth et al., 2021); BG (MOEW, 2013)	Presence and cover (%) of invasive species estimated for the sampled areas. presence and percentage coverage of formed independent growths of ruderal and/or replacement plant species is also taken into account.	Evaluating habitat degradation.	FV=10%, U1=10-20%, U2=>20%.
Invasive alien species	PL (Stawowczyk et al 2015)	Expert assessment of % in sampled area	Evaluating habitat degradation.	FV = 0; U1= < 1%; U2= > 1%.
Average cover of characteristic species	RO (Deák et al., 2014)	Average cover (%) of characteristic species in 10 sample sites. FV=>15%, U1=5-10%, U2=<5%.	Assessing and monitoring habitat composition.	FV=>15%, U1=5-10%, U2=<5%
Coverage of different groups	IT (Angelini et al., 2016)	Total vegetation cover of different groups: dominant species, typical species, disturbance indicator species, alien species, species indicative of dynamic phenomena in progress. No thresholds provided.	Understanding community composition in habitats	Not provided.
Moss layer coverage	PL (Stawowczyk et al., 2015)	Expert assessment during fieldwork.	Evaluating habitat conditions for moisture-loving species.	For 8150: FV=20-90%, U1=<20%, U2 not used.

Variables	Member State (Reference)	Explanation of variable and measurement methods	Use in assessment and monitoring	Reference values, thresholds
Coverage of *Gymnocarpietum robertiani* plant community	PL (Stawowczyk et al., 2015)	Expert assessment of % of scree covered by this vegetation community	Assessing specific plant community health.	For 8160: FV>5%, U1=<5%, U2=0
Grass cover	PL (Stawowczyk et al., 2015)	Expert assessment of % of scree covered by this vegetation community. FV<20%<U1<50%<U2.	Monitoring grassland health and quality.	For 8160: FV<20%, U1<50%
Herbaceous plants coverage	PL (Stawowczyk et al., 2015)	Expert assessment.	Assessing plant diversity	FV<50%, U1<90%
Trees and shrubs coverage	PL (Stawowczyk et al., 2015)	Expert visual assessment during fieldwork.	Assessing vegetation structure	FV<5%, U1<25%
Cover/height of tree and herbaceous layer	CY (Dimopoulos & Tsiripidis, 2013)	Metrics: % -cm. No methods or thresholds provided.	Assessing vegetation structure	Not provided.
Vegetation structure diversity	DE (Bfn, 2017)	Expert assessment of the number of habitat typical vegetation structures, including lichen communities (crust lichens, leafy lichens, bushy lichens), moss communities, ferns and single trees or bushes of typical species.	Assessing vegetation diversity	A: 5 or more typical vegetation structures (8160 - 4 or more); B: 3-4 (8160 - 3); C: <3 =
Cover of grass species and dwarf shrubs	IE (Perrin et al., 2014)	Expert assessment	Assessing vegetation structure	FV: collectively < 25%)
Proportion of negative indicator species	IE (Perrin et al., 2014)	Proportion of vegetation composed of following negative indicator species: *Cirsium arvense, C. vulgare, Rubus fruticosus agg.,* large *Rumex* species (except R. acetosa), *Senecio jacobaea, Urtica dioica*.	Evaluating habitat degradation.	FV: collectively < 1%
Vegetation cover	AT (Ellmauer et al., 2020)	Determined either during a field survey either or by interpreting high-resolution aerial photographs.	Assessing habitat structure	For 8150: A = <50%; B = 50-75%; C = >75%

Variables	Member State (Reference)	Explanation of variable and measurement methods	Use in assessment and monitoring	Reference values, thresholds
2. 3 Functional state characteristics				
Grazing effects	IE (Perrin et al., 2014)	Live leaves of forbs and shoots of dwarf shrubs showing signs of grazing or browsing.	Assessing impacts on vegetation.	FV<50%
Habitat dynamics: moving and fixed scree	DE (BfN, 2017)	Expert assessment. Recognizable vegetation mosaics of single trees or bushes, moss cushions, bare soil.	Monitoring habitat changes over time.	A, B, C categories. A: moving areas of scree present in habitat typical density; B: moving scree areas at least partly present; C: no dynamic in scree, completely stabilized slopes.
Dynamics: changes in shrubs and trees densities	HU (Horváth et al., 2021)	Changes in the shrub and tree density compared to earlier monitoring activities.	Long-term monitoring of vegetation changes.	A higher score is given to an average rate of growth <1%/ year and cover <10%. A negative score is given if these values are not met.
2. Landscape characteristics				
Habitat fragmentation	BG (MOEW, 2013); AT (Ellmauer et al., 2020)	Percentage of sampled area occupied by fragmenting anthropogenic structures (buildings, ports, roads, etc.). Fragmentation by ski slopes, ascent aids, pipelines, power lines, roads, paths, etc. can be determined either during field inspections or via aerial photo interpretation.	Assessing habitat degradation and fragmentation	BG: FV=<1%, U1=1-10%, U2=>10%. AT: A= Low/no fragmentation of the of the area by infrastructure and no mining activities; B = medium/small fragmentation of the area by infrastructure and no mining activities; C = high: fragmentation of the area by infrastructure or mining activities on the area.

Variables	Member State (Reference)	Explanation of variable and measurement methods	Use in assessment and monitoring	Reference values, thresholds
Landscape environment	HU (Horváth et al., 2021)	Description of the rate of isolation, distance of similar habitats, size of the sampled habitat patch, and the role of neighboring habitats. Measured in m (distance) and m^2 (size of the habitat). No measuring methods described.	Assessing habitat fragmentation	Not specified
Landscape metrics	IT (Angelini et al., 2016)	Spatial analysis of habitat by measuring the degree of fragmentation/isolation of habitat portions. Use of GIS. No thresholds provided.	Assessing spatial patterns, habitat fragmentation and isolation	Not specified
Other: degradation and disturbance				
Erosion	HU (Horváth et al., 2021)	Form and extension (in %) of erosion is estimated. A high score is given if erosion is absent and a negative one if it is present.	Evaluating soil stability and erosion risk.	Not specified
Afforestation or tree planting	DE (BfN, 2017)	Expert judgement of % coverage of total habitat area.	Assessing habitat degradation.	A, B, C categories. A = none; B = < 5%; C = >5%.
Anthropogenic disturbances	Be-W (Hendrickx et al., 2021)	Description of anthropogenic disturbances: exploitation of materials, deposit of exogenous materials, securing infrastructure.	Assessing habitat degradation by human impact	Not specified
Anthropogenic activities	AT (Ellmauer et al., 2020)	Qualitative expert assessment of anthropogenic impairments. Typical impairments include fragmentation by roads, thinning (pruning of trees), mining activities, and structural interventions.	Assessing habitat degradation by human impact	Not specified
Cover of damaged vegetation	DE (BfN, 2017)	Expert estimate of % of vegetation damaged by human activity - removal or addition of substrate, trampling, climbing, etc.	Monitoring human impacts on plant communities.	A=<5%, B=5-10%, C=>10%

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