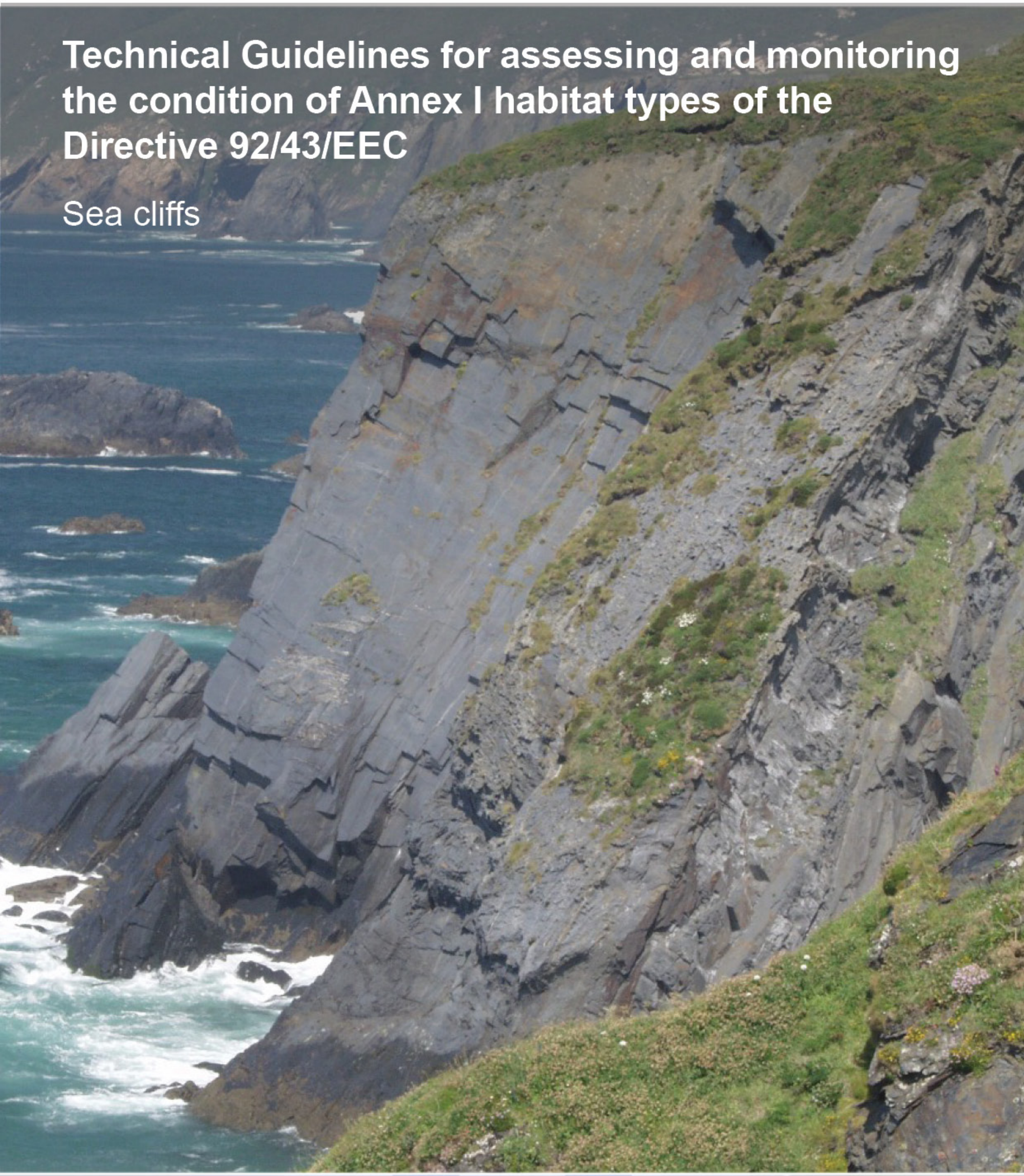
European Commission

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

Sea cliffs



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

Vegetated sea cliffs

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This document must be cited as follows:

Pérez-Alberti, A. & Zuazu Bermejo, A. (2025). Vegetated sea cliffs. In: C. Olmeda & V. Šefferová Stanová (eds.), Technical guidelines for assessing and monitoring the condition of Annex I habitat types of the Directive 92/43/EEC. Luxembourg: Publications Office of the European Union, ISBN 978-92-68-32015-0. https://doi.org/10.2779/4962460

Manuscript completed in September 2025

Luxembourg: Publications Office of the European Union, 2025

PDF ISBN 978-92-68-32015-0 DOI: 10.2779/4962460 KH-01-25-200-EN-N

Contents

Acknowledgements

This document was prepared in the framework of a European Commission contract with Atecma, Daphne and the IEEP for the elaboration of Guidelines for assessing and monitoring the condition of Annex I habitat types of the Directive 92/43/EEC (Contract nr. 09.0201/2022/883379/SER/ENV.D.3).

An ad-hoc group of experts nominated by Member States administrations, the European Topic Centre for Biodiversity and Ecosystems (ETC-BE), the Joint Research Centre, EuropaBON, the European Environment Agency and the European Commission, provided advice and support throughout the development of these technical guidelines.

Concha Olmeda (Atecma) and Viera Šefferová Stanová (Daphne) coordinated a team of scientific experts that elaborated the guidelines for all habitat types, and provided input during their preparation. In particular, they prepared the Overall Methodology, from which some common texts are included, with adaptations, in all these Technical Guidelines (i.e. sections 1.3, 3.2, 3.3 and 3.6).

Several members of the project team, of an ad-hoc group supporting the project, experts and representatives from EU Member States authorities and other relevant organizations revised the drafts and helped refine this document.

All those contributions are gratefully acknowledged.

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 MSs 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

HD – Habitats Directive

IAS – Invasive Alien Species

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

Sea cliffs have been traditionally defined as coastal slopes of variable height created by marine erosion, by the elevation of land as a result of tectonic movements, or as a result of differential erosion processes. Vegetated sea cliffs represent diverse habitats depending on their location in relation to the sea, geology and geomorphology. Three sea cliff habitat types are protected under the habitats Directive: 1230 - Vegetated sea cliffs of the Atlantic and Baltic coasts, 1240 - Vegetated sea cliffs of the Mediterranean coasts with endemic Limonium spp and 1250 - Vegetated sea cliffs with endemic flora of the Macaronesian coasts.

Their ecological characterization is given by climate-related variables influencing on the alteration of coastal rock outcrops, which are the result of physical, chemical and biological processes due to the action of the wind and the sea.

An analysis of existing methodologies across EU Member States was conducted finding some commonalities but also disparities regarding the variables used for the assessment of biotic and abiotic characteristics of these habitats. The abiotic characteristics present in the consulted methodologies focus on cliff morphological features (e.g. height and slope), cliff stability (e.g. dynamics and erosion), wave exposure and soil physical and chemical properties (e.g. thickness, humidity, organic matter content, pH). Composition and structural characteristics are assessed through the presence and coverage of characteristic vascular plant species as well as fauna species. Presence of functional processes like regeneration of shrubs and successional stage patterns is assessed. The analysis of the habitat landscape characteristics is measured through landscape metrics and habitat fragmentation assessment.

Thresholds for interpreting these metrics are absent or when provided, is not specify how are they estimated. Those consulted methodologies that describe an aggregation system use in general arithmetic operators or categorical majority rules to the values obtained from the measurement of the variables used in the assessment. Monitoring procedures are largely based on periodic field observations.

A set of essential, recommended and descriptive variables for monitoring vegetated sea cliffs habitat are proposed. They are categorized into abiotic (e.g., linear erosion, soil pH), biotic (e.g. characteristic vascular plants, bryophytes, algae species, nesting seabirds), structural (e.g. cover of characteristic plant species and communities, cover of invasive alien species), functional (e.g. pollinators, phenology), and landscape (e.g. coastline changes).

The guidelines outline several priority areas for future effort, beginning with the thorough testing of the proposed variables and measurement procedures using common protocols. A central objective is the development of standardised methods for establishing ecological thresholds and reference values to assess habitat condition, which is vital for monitoring change and anthropogenic impacts. Concurrently, criteria must be refined for selecting monitoring localities and for aggregating local-scale results to the biogeographical level to ensure data is representative and comparable. Finally, harmonised approaches for using typical species as key indicators of habitat status should be formally established and integrated into the overall condition assessment.

1. Definition and ecological characterisation

1.1 Definition and interpretation of habitats covered

Sea cliffs are traditionally defined as coastal slopes of variable height created by marine erosion, by the elevation of land as a result of tectonic movements, or as a result of differential erosion processes. They exist on various types of rock formations with a wide range of inclinations and are generally in recession due to marine erosion at their base and the resulting impact of climatic agents on their façade.

Sea cliffs are strongly influenced by their geological context, particularly by the structure and typology of the rock formations that emerge on the coast and their response to wear and erosion processes. Cliff profiles vary with the nature of the rocks on which they formed and with the geomorphology of the adjoining land. While most maritime cliffs have been formed by coastal erosion, steep slopes falling to the sea in mountainous districts may have been formed long before the sea level reached its present position; in such cases, only the lower part of the slope will have been steepened by the sea (JNCC, 2008).

Rock type, geological structure, and the general evolution of the relief are important factors of variation on the European coast. Coastal cliffs can have different shapes and heights and can be found above exposed rocky platforms, block clusters sandy and pebble beaches, or directly sinking into the sea. There is also a great diversity of cliffs in terms of surface and volume.

Two major types of cliffs can be distinguished: composite cliffs and flat-topped cliffs. Composite cliffs have at least two major slope elements: a basal scarp or sea cliff itself and an upper slope with a concave or convex shape. Each of these elements may have different heights and slopes depending on various factors. Flat-topped cliffs end in a plain or a low-sloping area that extends inland.

Coastal cliffs are important geomorphological features that provide habitat to plants and animals. Vegetated sea cliffs can represent diverse habitats depending on their location in relation to the sea, geology and geomorphology. Three sea cliff habitat types are protected under the habitats Directive:

- 1230 - Vegetated sea cliffs of the Atlantic and Baltic coasts
- 1240 - Vegetated sea cliffs of the Mediterranean coasts with endemic Limonium spp.
- 1250 - Vegetated sea cliffs with endemic flora of the Macaronesian coasts

In the Atlantic and Boreal coasts, the vegetated sea cliffs have a varying vegetation cover depending on the influence of the sea and degree of maritime exposure, geology, geomorphology, and habitat management decisions. Vegetated cliffs exhibit a complex pattern of vegetation zoning and variation, with cliff ledges and crevices on the steepest parts closest to the sea free of vegetation or overgrown with blue-green algae, while rocky shelves and slopes in places where soil has been able to accumulate may be grassy. In more sheltered locations, herbs, shrubs and windswept woodland vegetation (Naturvårdsverke, 2011).

Mediterranean cliffs are usually located on coasts with steep or vertical topography and significant action from winds, marine spray, and aerosols. The vegetated sea cliffs of the Mediterranean and of the Black Sea coats are covered, albeit discontinuously, by halo-rupicolous species. These are mostly chasmophytic species that have the ability to live in rock crevices and to tolerate direct contact with sea water and marine aerosol, notably these include various endemic *Limonium* species. This habitat type is often associated and coexists with some other characteristic habitats found near the sea cliffs. These include:

- 5320 - Low formations of *Euphorbia* close to cliffs, which occur in the immediate vicinity of sea cliffs, forming the transition between cliff vegetation or clifftop phryganas and thermo-Mediterranean;
- 5410 West Mediterranean clifftop phryganas (*Astragalo-Plantaginetum subulatae*), which are rare, extremely local and isolated, cushion-forming thermo-Mediterranean sclerophyllous vegetation of clifftops and adjacent areas dispersed along the coasts.

Sea cliffs of the Macaronesian region have specific features, due to their formation on more or less complex volcanic structures, which determine their profile, morphology, verticality and height. They host aerohaline communities dominated by endemic plant species of the Canaries, Madeira and the Azores.

Regarding the characteristic plant species present in these three habitats, *Chrithmn maririmun* occurs in all of them, accompanied by other coastal species from the genera *Armeria, Silene, Sedum, Daucus* and *Limonium.* The latter, having a rich representation of endemic species, is particularly relevant in the Mediterranen sea cliffs but is also represented on the Macaronesian cliffs.

Sea cliffs also act as important nesting sites for birds like *Phalacrocorax aristotelis, Rissa tridactyla, Uria aalge, Falco eleonorae, Pandion haliaetus* and many other seabirds.

Table 1. Sea cliff habitat types protected under the Habitats Directive in the EU MSs

Habitat type	BG	CY	DE	DK	EE	ES	FI	FR	GR	HR	IE	IT	LV	MT	PL	PT	SE	SI
1230																		
1240																		
1250																		

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

1.2.1 Ecological characterization of sea cliff habitats

Climate-related variables have an important influence on the alteration of coastal rock outcrops as marine and atmospheric action drives various physical, chemical and biological processes. Rocks disintegrate through continuous wetting and drying from sea and rainwater, by thermal expansion and contraction, or by processes derived from freezing/thawing, which cause the fall of debris to the base of the cliff.

The profile of a cliff is a function of the interaction between geology, climate, tidal and wave regime, vegetation, type and quantity of material at the base, topography of the cliff top and changes in relative sea level (Trenhaile, 1987). It is also a function of the relative rates of erosion by marine or subaerial agents, and the duration of time during which they operate (Emery & Kuhn, 1982). Marine erosion involves processes of abrasion, alteration, mechanical attack and biological activity; moreover, the effects of marine erosion con trigger other types of profile alteration processes, such as fast and slow mass movements. These can also occur as a consequence of continental processes. Coastal morphogenetic processes do not have a linear character, nor are they cumulative, but rather vary according to a previous system (Cowell et al, 1995). Although they can act simultaneously at the same time ion the same location place, changes occur under there is also a temporal succession. Thus, many of the cliff profiles show inherited forms, currently affected by other phenomena.

Abiotic characteristics

Physical characteristics

Cliffs can be described and classified in relation to their lithology, height, slope, orientation and degree of stability, the latter being the most influential aspect in its evolution. As long as a cliff is stabilised, that is, as long as there are few landslides, or reduced surface flows on its façade, it will, in principle, be predominantly covered by the vegetative communities typical of each belt marked by the marine influence.

Lithology: As regards to dominant rocks, sea cliffs on granitic rocks do not have a uniform composition nor do they respond in a consistent way to alteration processes. An additional important feature to take into account to understand their lithology is also the degree of fracturing. Cliffs on metamorphic rocks are very different from those of granitic rocks. Looking at their mineralogical composition, depending on the abundance of quartz, their degree of stratification and alteration, they generate a multitude of cliff types. The cliffs formed on slates and schists are highly conditioned, both by the dip of the strata and by their orientation in relation to the action of the waves. Cliffs on volcanic rocks, existing in the Macaronesian and Mediterranean regions, present a diversity of forms derived from the denudation by waves of volcanic structures or from the remodelling of slope and ravine deposits. Cliffs modelled on limestone have different features depending on the degree of fracturing, the existence of landslides at the base, and the intensity of dissolution processes that motivate the abundance of remains of karstic conduits or caves. Cliffs modelled on recent sediments display a completely different behaviour from those that have developed from granite or metamorphic rocks. They are generally much more active, offering a greater degree of mobility, dominated by washing and, in particular, by landslides or detachments. The alteration and fracturing of the rock are notable, as they have an influence not only in the occurrence of landslides and detachments but also determine important differences in the vegetation cover.

Different types of sea cliffs based on their lithology.
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Height: Based on the categories defined by Guilcher (1966), sea cliffs can be classified in three categories. Megacliffs are above 450 m high, very high cliffs are higher than 250 m, high cliffs is are between 100 and 250 m and the height of low cliffs is usually less than 50-70 m.

Slope: According to their slope, cliffs can be classified into three categories, as those having a high slope, above 32%, those with a medium slope, between 16 and 32% and those with a low slope, below 16%.

The base of the cliff:

The composition of the base of the cliff is fundamental to understand its dynamics and evolutionary behaviour, given that its existence can slow down certain processes. Cliffs can have a sand beach at their base as a result of the action of sedimentary drift. The beach acts as a defence for the base of the cliff, so that only at times of high energy is the cliff faced by the waves. In such cases, the coastal front evolves mainly due to the action of continental runoff. Other cliffs have accumulations of blocks of various sizes at their base, which provide an effective protection of the cliff wall against the waves, as they dissipate their energy and cause them to reach the cliff with weakened strength. Sea cliffs can also have a rock platform of variable size at their base, especially in areas of metamorphic rocks where either the stratification of the materials, or their degree of alteration, favoured the retreat of the cliff and the genesis of such platforms. Finally, hanging cliffs (submerged) are cliffs that sink below the low tide level without any coastal platform or rock accumulations or outcrops on the surface.

Low slope: 0 -16°

Medium slope: 16°- 32°

High slope: > 32°

Possible categories of sea cliffs based on their slope.
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Degree of stability: A key element to take into account when analysing sea cliffs is their degree of stability, which is determined by 1) the type of rock; 2) the slope; 3) the degree of stratification and/or degree of fracturing; 4) the degree of weathering of the materials; 5) their location in a high or low energy area; 6) their orientation towards the passage of storms and, consequently, the possibility of receiving a greater quantity of rainwater and/or storms, and 7) the degree of surface and/or subsurface runoff. The degree of stability determines the possibility of mass movements in the cliff which can be of different type, including landslides, rock falls and collapses.

Cliffs are subject to a variety of processes conditioned by the above-mentioned aspects and by the presence of water. The hydrostatic load is the engine that triggers the occurrence of mass movements when the pores of the soil fill with water and the weight of the whole reaches a certain threshold. The type of movement depends on the degree of inclination of the cliff, the type of rock, the resistance of the materials and the availability of water. While some movement is cause by marine processes, those of non-marine origin take on great importance in the retreat of the cliffs especially in areas with very altered or fractured rocks. Thus, a close relationship between the retreat of the cliffs and extraordinary precipitation events or associated with long rainy periods have been demonstrated (Castillo Rodríguez & Pérez Alberti, 2001). The saturation of the interstitial spaces of weathered, intensely fissured materials or sedimentary deposits causes an increase in hydraulic pressure that ends up destabilising the cliff face, either during the rainy episode or afterwards.

Landslides can affect the entire cliff face or a segment occurring high on the cliff or close to the base. In both cases, they affect deeply fractured and altered rocks or unconsolidated deposits. Falls and topples are movements in which a section of the cliff, separated from the ground by a fracture, tilts and falls towards the base. Collapses occur when there is a basal undermining. It can be a cave carved in sediments or opened in any type of rock, in which its roof collapses. The movement can occur at any time, when the weight of the cover exceeds the grip resistance.

Considering the degree of stability, cliffs can be classified as stable (no evidence of erosion), unstable (25% of the surface of the cliff affected by erosion) and very unstable (more than 50% of the surface affected).

Coastal cliffs can be also differentiated as loose or soft cliffs – made of sand, silt, clay, marl and chalk – or hard cliffs, made of limestone, sandstone, granite and other rock types. Loose cliffs are more prone to erosion and landslide than rocky cliffs, which are more characterized by rock or block fall.

Cliff erosion: Cliff erosion in coastal areas usually involves the erosion of the cliff foot, caused by wave and storm surges action, resulting in a gradual retreat of the coastline. Climate change aggravates coastal erosion even more through: sea level rise, increased frequency and intensity of storminess, changes in prevalent wind directions and higher waves putting Europe's coast under additional pressure.

Due to the processes described above or to the continuous removal of materials from the coastal front, the erosion rates of cliffs depend on the resistance of the rock and the energy of the waves. Structural aspects such as the dip and direction of the strata or the fracture planes, as well as the characteristics of the base of the cliff must be taken into account (Trenhaile, 1987).

Cliffs are eroded by the action of the waves, but as long as they resist, they form a protective barrier, dissipating the energy of the wave action. Where the rocks are very resistant, the slopes and coastlines have changed little, but where the formations are less resistant, the retreat has been faster. In this regard, it should be noted that although waves are a fundamental agent in the retreat of cliffs, their action is highly controlled by the structural elements and by the degree of weathering of the forms and materials on which they act.

The action of waves on the escarpment of cliffs varies greatly depending on their profile. In cliffs with a platform or a beach at their base, the energy of the waves is dissipated, their impact also depends on the inclination, width and roughness of the surface on which they break. In cliffs that do not have a platform or where it is very narrow, so that they have an almost vertical escarpment, the action of the waves is stronger (Sunamura, 1992) and can cause the abrasion of the rock surface and the removal of materials. Most cliffs, except for those with a flat top, have a basal scarp and an upper slope. The extension of the marine action to the upper slope, by triggering instability, depends greatly on the type of rock, density and geometry of the fracturing and stratification planes, degree of alteration, shape of the upper slope and the marine scarp, and wave energy.

The cliffs are cut mainly during storms or high rainfall episodes, when the base is lowered by the waves impact and the abrasive action of the water loaded with rock fragments (sand and gravel) repeatedly being thrown at the base of the cliff during a storm event. As a result, the face of the cliff becomes unstable and an overhanging rock mass eventually collapses. After the storm, the base of the cliff is covered with fallen debris. Under the wave action, they break up and wear away as they crash together (a process known as attrition), and are either retained on a beach protecting the base of the cliff from further abrasion, or carried along the shore or out to sea by wave action and currents.

Coastal vegetation and fauna also cause alteration in cliffs, as some species, with their growth and metabolic processes, break down rock outcrops, particularly in limestone cliffs. Bioerosion causes the widening of fissures through plant root growth on the cliff face. Equally, marine organisms contribute to the dissolution of limestone on the shore. Under favourable conditions, biochemical processes can consume rock at least as fast as pure physical and chemical erosion.

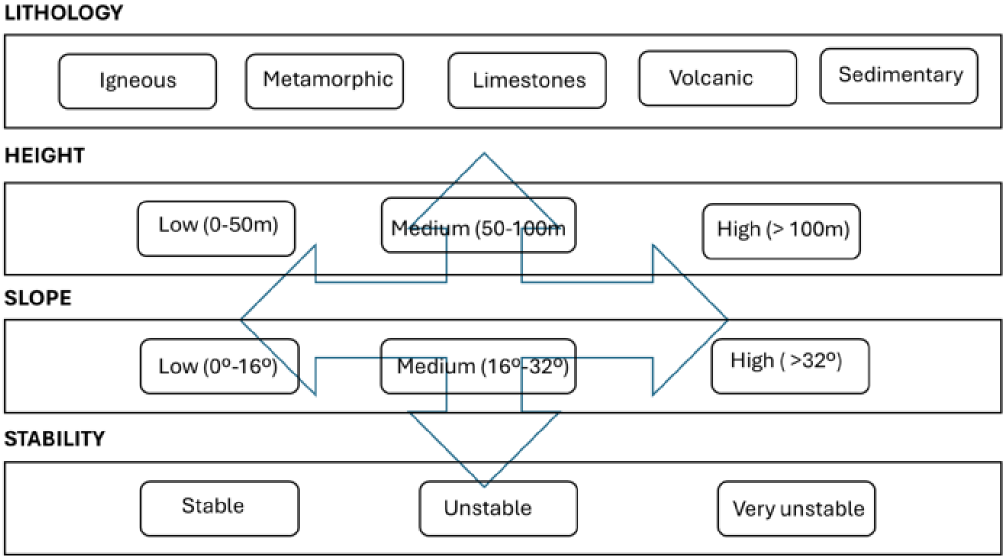
The variety of organisms that inhabit the intertidal zone contribute to erosion by boring, scraping, plucking and grazing, and dissolution from their exudate flows. Algae can dig grooves and bore into limestone; mollusc movement polishes the surface, dislodging rock fragments and excavating cavities; marine worms, sponges and sea urchins drill or chip away at the rock.

Bioerosion occurs when accumulations of algae that have formed on rock dry out and become detached while still adhering to some rock particles, especially during dry and windy periods where the zone above high neap tides is not submerged. Bioerosion processes may thus contribute to rock weathering, as well as to shelf formation and dissection.

Bioerosion rates on limestone, calcarenite cliffs and emerged coral have been summarised by Trenhaile (1987). Weathering of rock surfaces by organism movement can be several mm/yr. Some marine organisms provide bioprotection where rock surfaces are encrusted by algae and barnacles that prevent weathering and erosion, preventing wetting and drying.

The cliff base ledges and projections are elements protected and built by marine organisms. Alternatively, resistance to wear and tear processes and the abrasion of waves can also be increased by the crusting of the coastal rocks also, contributing to the persistence of rock outcrops on cliffs and on coastal platforms. This cementation is usually due to surface enrichment of coastal outcrops by the precipitation of carbonates, ferruginous or siliceous cementation compounds.

Figure 1. Cliff typology based on the main environmental characteristics



Source: Own elaboration

Chemical characteristics

Soil properties: Soils undergo limited development on cliffs. In general, they have an A/R or A/C profile, depending on the geological nature of the area. Furthermore, due to the steep slopes often present in this habitat, their stability is very limited, favouring erosion processes.

There exists a certain zonation in terms of cliff soil development. The lower part of the cliff is characterised by its rocky nature and where little soil is found, being strongly affected by the wave action. This is followed higher up by an intermediate zone with shallow soil formation and abundant rocky outcrops, and an upper zone where the soil is practically a continuous layer with pre-forest vegetation cover.

Due to the minimal edaphic development, the properties and composition of the soil are greatly influenced by the lithological material and, occasionally, by the layer of sediment that fossilises the former. In coastal sections of siliceous rocks (granites, slates, schists), the soils usually have an acidic or strongly acidic reaction, with a variable texture that can range from loamy to sandy loam and a high content of organic matter. In this case, the dominant soils are Lithic Leptosol, Eutric Leptosol or Skeletal Leptosol in the lower part, turning to Mollic Leptosol, Umbric Leptosol or Arenic Leptosol (when a layer of sand fossilises the geological substrate) towards the upper part. In contrast, in coastal sections of limestone or dolomitic rocks, the soil reaction is alkaline, and the texture is fine. The soils in the upper part usually fall into the Rendzic Leptosol or Dolomitic Leptosol group.

Soil is especially scarce or absent in vertical or steeply sloping cliffs, it occurs mostly on ledges and in crevices and breaks in slope which allow soil to accumulate and support some plant growth. However, in some areas with lesser slopes, soils with a certain thickness may appear.

Relevant parameters and indicators of soil conditions include pH, organic carbon and C/N ratio, Phosphorous and Potassium. The amount of Nitrogen has a significant influence on the vegetation on cliffs. Nitrophilous species presence, for example, is a sign of an increase in the amount of nitrogen in the soil, originated from rainwater, human activities or, seabird colonies (Tashev et al., 2018; Gracia et al., 2019). The habitat condition is considered good when the number of nitrophilous species is low relative to the total vegetation coverage (Bicchierai & Mistarz, 2023; Boulet & Mistarz, 2024).

Despite the limited development of soil, its presence is the key factor that allows for continuous vegetation cover. In the absence of soil, vegetation is sparse and discontinuous, appearing associated with cracks or areas where erosional input accumulates. However, the extent of the importance of soil in the distribution of flora and vegetation is unclear. Botanists believe that marine influence (salinity) is a determining factor affecting vegetation cover, especially saline events associated with storms.

Biotic characteristics

Variation in geology, climate, location, and exposure to wind and salt spray shapes the floral and faunal communities in sea cliffs. Other key factors include the lithology or chemistry of the underlying rock, the water content, the stability of the substrate and soil thickness.

Sea cliff microhabitats or zones can be defined on the basis of their relative position on the cliff, the marine influence and their vegetation. The most commonly recorded zone types along the cliff are crevice and ledge zones and splash zones (Barron et al., 2011).

Cliffs also have a relationship with other neighbouring habitats, for example thickets or forest formations that exist nearby, and it is not always evident how to define the limit of the cliff with respect to these other habitats.

Vegetation of sea cliffs

On the Atlantic cliffs (1230), the vegetation is usually subject to extreme ecological constraints: spraying by sea spray, strong winds, skeletal soil, summer drought. These environmental constraints give rise to distinct coastal ecotypes, including anemomorphic woody species and herbaceous plants characterised by thick, hairy, or even succulent leaves or of small stature (Bioret & Boullet, 2014; Martínez-Flores et al., 2020). Moreover, vegetation dynamics may become arrested at a sole maturity stage, a condition referred to as a permaseries (Bioret & Boullet, 2014).

This habitat exhibits considerable variability due to the geomorphological, climatic, substrate, and exposure diversity of the cliffs throughout the region. Vegetation expression can vary greatly from one site to another, but also within a cliff depending on site conditions (Boulet & Mistarz, 2024). However, a gradient of wind exposure, salinity, and soil depth along a vertical cliff transect, contributes to a certain layering of the vegetation. From the summit of these cliffs to their base, regularly subjected to the action of waves and swell, a gradient of vegetation can be observed, which is closely dependent on the substrate and sea spray (Duhamel et al., 2017).

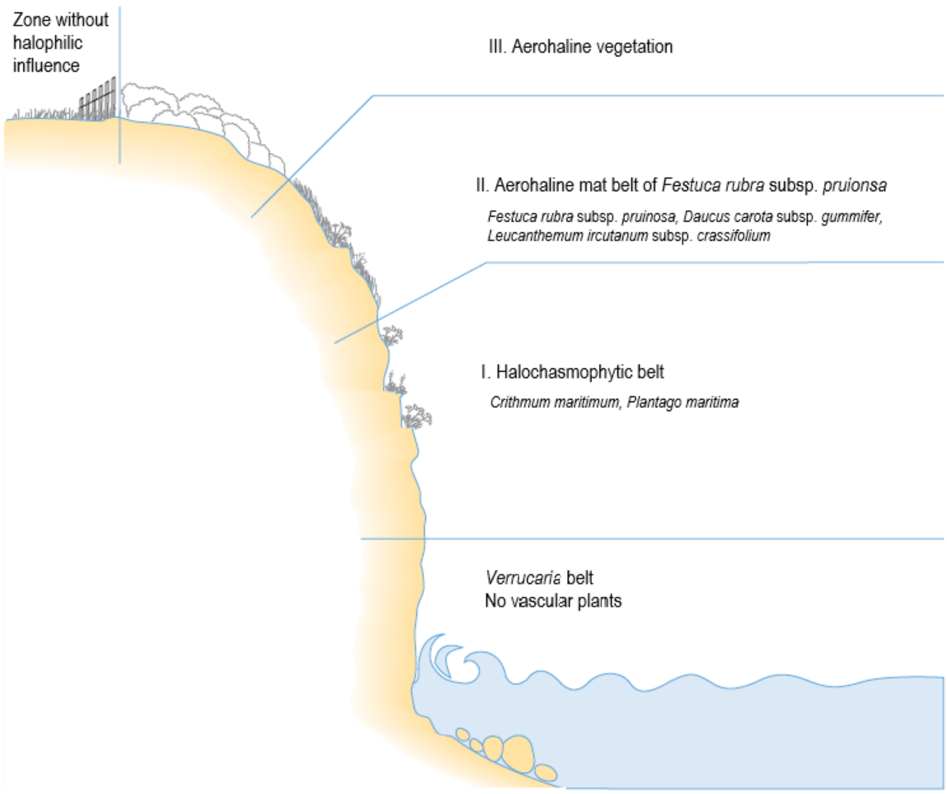
Intertidal zones (within wave reach) and supralittoral zones are inhabited by rich and diverse communities of invertebrates, algae, and lichens. Above this zone, rocky cliffs may be covered by scattered carpets of aerohaline chasmophytic vegetation or by more or less closed aerohaline grasslands. On the upper part of the cliff and at the top, where the slope is gentler and less severely exposed, cliffs can support grasslands, heaths, scrubs or forests (Figure 2).

Plant communities in Atlantic heaths (1230) vary according to the lithology or chemistry of the underlying rock, exposure to wind and salt spray, the stability of the substrate and soil thickness. Typically, the most exposed cliffs, contain more salt-tolerant species like *Crithmum maritimum* and *Spergularia rupicola* (Boulet & Mistarz, 2024). There is a zonation from crevice and ledge communities of the steepest slopes beside the sea (*Crithmo-Armerietalia*, Géhu

1964) to closed maritime grasslands on upper cliff slopes, cliff tops and cliff ledges where there is deeper accumulation of soils (*Silenion maritimae*, Malloch 1973). The upper sections and cliff-tops of hard cliffs on acidic rocks in some areas may also support maritime heaths characterised by heather Calluna vulgaris (JNCC, 2008).

On cliffs and slopes that are more sheltered from the prevailing winds and salt spray, the vegetation communities resemble those found inland, and are influenced by the chemistry of the substrate. These communities include complex assemblage of maritime and para-maritime types of heath, calcareous grassland, acid grassland, therophyte, tall herb, scrub and wind-pruned woodland vegetation, each enriched by floristic elements characteristic of coastal habitats. On sheltered chalk or limestone cliff, calcareous grassland communities with a few maritime specialist species occur. On soft coasts with active movement, complex assemblages of maritime and non-maritime vegetation can be found (European Commission, 2013). Soft cliffs can support a wide range of vegetation from pioneer communities on freshly exposed faces through ruderal and grassland communities to scrub and woodland (JNCC, 2008).

Figure 2. Characteristic profile of a coastal cliff and zoning of vascular vegetation



Source: Adapted from Loidi et al., (2011).

Mediterranean coastal cliff habitats (1240) are developed on all types of rock, both acidic and basic, with a steep or vertical topography and maximum influence from winds, marine spray and aerosol. Perennial vegetation is dominated by chamephytic and strictly halophilic species, found in cracks or small flat areas, under the direct influence of sea spray. Annual aerohaline vegetations covers the flat areas associated with the habitat. The vegetation is typically composed of an open rupicolous formation, often dominated by *Crithmum maritimum* accompanied by different species of *Limonium*, these are generally endemic and with a restricted distribution which provides a great biogeographic variability across communities.

The rupiculous vegetation found in these environments is replaced inland by cushion-forming thermo-Mediterranean sclerophyllous thickets representative of clifftops and adjacent areas along the coasts corresponding to habitat types 5410 West Mediterranean clifftop phryganas (*Astragalo-Plantaginetum* subulatae), 5430 Endemic phryganas of the *Euphorbio-Verbascion* and 5320 - Low formations of Euphorbia close to cliffs, or even by 5330 Thermo-Mediterranean pre-desert scrub formations, which form the second vegetation band in the rocky coastal gradient.

On the cliffs of the Macaronesian region (Azores and Canary Islands), volcanic substrate frequently determines soil scarcity. Environmental conditions are very restrictive, as semi-aridity in some areas is combined with strong winds and salinity, making it difficult for vegetation to develop. The most representative vegetation is composed of chamophytes and hemicryptophytes with prostrate forms, as pillow and rosette morphologies, which loss much of their above-ground biomass during the driest months. Due to high salinity caused by wave splashing and sea spray, vegetation on the front of coastal escarpments is limited to strictly halophilic communities (Yanes & Beltrán, 2009).

Fauna: Regarding fauna, aside from the specialized terrestrial fauna of the supralittoral zone (primarily insects) and the numerous marine invertebrates of the meso- and infralittoral zones (molluscs and crustaceans), the most representative species of cliff habitats are birds. A range of avian species has been observed on maritime cliffs, as these provide nesting habitat for significant populations of seabirds, many of which are of EU and international importance. For instance, *Morus bassanus, Phalacrocorax aristotelis, Alca torda, Uria aalge, Puffinus puffinus* and *Fratercula arctica* form nesting colonies on cliff ledges or nest in burrows in turf on cliff-tops or slopes, especially in Atlantic cliffs. Coastal cliffs are also important for crag nesting species, such as *Corvus corax* and *Falco peregrinus*, and cliff-top vegetation may provide important feeding grounds for *Pyrrhocorax pyrrhocorax*.

The nesting communities on Mediterranean vegetated sea cliffs are as diverse as that of the Atlantic cliffs. They include Eleonora's falcon (*Falco eleonorae*), the osprey (*Pandion haliaetus*) and the Balearic shearwater (*Puffinus mauretanicus*) (Balaguer et al., 2009).

Cory's shearwater (*Calonectris diomedea*), the Little Shearwater (*Puffinus assimilis*), and Bulwer's petrel (*Bulweria bulwerii*) can be found nesting on Macaronesian cliffs, where also some endemic species of lizards (*Gallotia* spp. in the Canary Islands) find refuge (Yanes & Beltrán, 2009).

Where there are large colonies of cliff-nesting seabirds, nesting ledges are enriched by guano, which can generate substantial changes in the composition of vegetation and support particular communities.

The table below (Table 2) summarises the main ecological characteristics of sea cliff habitats and possible variables that can be used to measure their condition, classified in accordance with the SEEA-EA framework (United Nations, 2021) as abiotic and biotic characteristics.

Table 2. Ecological characteristic and a selection of variables to measure their condition.

Ecological characteristics	Types	Group of characteristics	Examples of variables useful to measures key characteristics
Abiotic characteristics	**Physical state characteristics**	Lithology Cliff profile and stability Erosion Soil physical characteristics	- Rock type - Height, slope, base - Linear erosion due to runoff - Mass movements - Soil thickness
	Chemical state characteristics	Soil chemical characteristics	- pH - Organic carbon, C/N ratio - Phosphorous, Potassium - Amount of Nitrogen in soil
Biotic characteristics	**Compositional state characteristics**	Vegetation composition Fauna indicating good habitat quality Invasive alien species	- Presence and abundance of characteristic species – vascular plants - Presence of nesting seabirds and other relevant animal species - Presence of IAS
	Structural state characteristics	Proportion of communities indicating habitat naturalness	- Halophilous species cover - Cover of nitrophilous species - Cover of IAS
	Functional state characteristics	Regeneration Pollination	- Coastline modification detected by laser scanning or photometry
Landscape characteristics (connectivity / fragmentation)		Coastal trend	- Urban, agrarian occupation and human activities in the surrounding area that affect the habitat and colonisation processes
Other		Habitat alteration	- Presence of coastal defences - Percentage of are occupied by infrastructure: roads, paths, fences on the cliff - Contamination by agricultural, urban and other activities on the top of the cliff.

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, 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 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.

Table 3. Examples of typical species for monitoring sea cliffs

Species group	Ecological role: bio-indicator of
***Ulva intestinalis* - Algae**	Pioneer green algae that bioindicates inland water infiltrations (Bergillos et al., 2020).
***Mytilus galloprovincialis* - Mollusc**	They indicate stable substrates since they are organisms that take at least a year to reach adulthood (Bergillos et al., 2020).
***Eokochia Saxicola* – Shrub species**	Endemic to S Italian peninsula (Strumia et al., 2020)
***Caloplaca marina* – Crustose lichen**	Indicators of overall quality. Sensible to trampling and pollution.
***Puffinus puffinus* - Bird**	Nests in cliffs
***Gallotia* spp - Lizard**	Genus endemic to the Canary Island

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

The following analysis is based on the methodologies collected from 10 EU countries: Bulgaria, Germany, Denmark, France, Greece, Ireland, Italy, Poland, Spain and Sweden.

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

The main types of variables used in EU Member States for the assessment and monitoring of sea cliff habitats are summarised in Table 4. A more detailed description of these main variables is presented in the text below, and a more precise explanation of the metrics and measurement methods applied in the various methodologies is included in Annex 1.

Abiotic variables

Regarding abiotic variables, physical variables are frequently described in the methodologies. These variables are focused on cliff dynamics and structure, erosion, coastline dynamics and soil characteristics.

Cliff stability and dynamics are evaluated based on visual identification or mapping of erosive processes, and categorised as high, medium, or low. This assessment involves detecting changes in the coastal façade between measurement periods, often utilising photointerpretation techniques. These variables are indicated in four of the methodologies consulted (see Annex 1).

The **height and slope** of the highest cliff within a transect are measured in meters, providing essential dimensional data (Hedenås et al., 2020). Cliff slope inclination and dynamics are quantified in degrees and percentages, involving initial field work for morphological characterization, analysis of micro-drainage density, and surface weathering. These measurements may be conducted using various methods, including tape and graduated pole measurements, computer programs for surface parameter determination, serial topographic profiling and both direct and indirect measurements of gravitational and slope phenomena, as described in some of the methodologies analysed (Łabuz, 2012; Barron et al., 2011).

Lastly, cliff structural quality is proposed by Krause et al. (2008) to be assessed through expert judgment, relying on the evaluator's experience and knowledge to provide a comprehensive understanding of the cliff's overall condition and stability.

The assessment of **coastal cliff erosion** incorporates two key aspects: areas with erosion and landslides, and linear erosion. Areas with erosion and landslides are evaluated using a scoring system, though the specific scoring criteria are not provided in the available information (Fredshavn & Nygaard, 2014). This assessment likely involves identifying and quantifying zones where erosion and mass movements have occurred or are actively occurring. Linear erosion, on the other hand, is categorised by intensity levels including high, medium, or low. This parameter focuses on the effects of surface and sub-surface runoff on cliff faces, particularly in terms of erosion induction. The evaluation of linear erosion involves detailed field studies, including the use of control plots on cliff walls to monitor runoff patterns. These plots are designed to collect and measure both surface and subsurface runoff flows, providing valuable data on the erosive processes affecting the cliff structure over time (Pérez-Alberti, 2019).

Table 4. Ecological characteristic and a selection of variables to measure their condition

Characteristics	Variable types used in MS methodologies	BG	DE	DK	FR	GR	IE	IT	PL	ES	SE
Abiotic Physical	Cliff morphological features: height, slope						■		■		■
	Cliff stability, dynamics and erosion		■	■		■				■	
	Wave exposure and wave dynamics								■		■
	Soil physical properties: thickness, humidity							■		■	■
Abiotic Chemical	Organic matter content					■					
	Soil characteristics: pH, salinity									■	
Biotic Compositional	Typical and characteristic vascular plant species, species richness	■	■	■	■	■	■	■	■	■	
	Typical fauna species		■		■			■	■		
	IAS and negative species	■		■	■		■			■	
Biotic Structural	Characteristic species cover		■	■	■			■			■
	Cover of halophytic, nitrophilous species				■					■	
	IAS and negative species cover			■	■			■			
Biotic Functional	Regeneration of shrubs								■		
	Successional stage patterns					■					
Other	Anthropic disturbance		■	■			■			■	■
Landscape	Habitat fragmentation	■									
	Landscape metrics							■			

BG (Bulgaria): MOEW, 2013. DE (Germany): Krause et al., 2008. DK (Denmark): Fredshavn & Nygaard, 2014. FR (France): Bicchierai & Mistarz, 2023. Boulet & Mistarz, 2024. GR (Greece): Dimopoulos et al., 2018. IE (Ireland): Barron et al., 2011. IT (Italy): Angelini et al., 2016. PL (Poland): Łabuz, 2012. SE (Sweden): Hedenås et al., 2020.

Coastline dynamics and wave characteristics are crucial factors in assessing coastal erosion and change. The coastline retreat parameter measures the advance or retreat of the coastline, providing a quantitative measure of change over time. This assessment involves sophisticated mapping techniques, integrating ortho-photographs from different years into a Geographic Information System (GIS). High-resolution digital models are used to detect changes in the cliff profile, focusing on both the lower and upper parts. The process can be enhanced by continuous photogrammetric surveys using drones or unmanned aerial vehicles (UAVs). A specific tool, the Digital Shoreline Analysis System (DSAS) extension in ArcGIS, developed by the US Geological Survey, is particularly useful for detecting coastline changes.

This tool analyses the upper limit of cliffs to calculate statistical parameters of coastline evolution between different survey periods.

Sea waves range is another important factor, it is assessed through expert visual assessment. While specific measurement units are not provided, this parameter likely involves evaluating the typical height and frequency of waves affecting the coastline.

Wave exposure is categorised into classes, though the specific class definitions are not detailed in the available information. This classification involves mapping and assessing wave exposure according to predefined exposure classes, which likely consider factors such as fetch, wind patterns, and coastal orientation. This classification helps in understanding the potential impact of wave action on different sections of the coastline.

Soil characteristics play a significant role in cliff stability and erosion processes. Soil depth is measured in centimetres and is assessed by studying soil profiles along the cliff's slope. This method involves examining vertical sections of the soil to detect changes in depth over time, allowing researchers to identify potential losses or gains in soil material. This information is crucial for understanding the cliff's erosion patterns and stability.

Soil temperature and humidity are measured in degrees Celsius (ºC) and percentage (%) respectively. These parameters are monitored using data loggers and sensors, which can be programmed to record measurements at various intervals, ranging from daily to second-by-second recording. This high-resolution data collection allows for a detailed analysis of how temperature and moisture fluctuations affect soil and rock conditions, which in turn influence cliff stability and erosion rates.

The **coverage of bare soil** is quantified as a percentage and is estimated through field surveys. This parameter involves assessing the proportion of the cliff face or surrounding area that lacks vegetation cover. The percentage of bare soil is an important indicator of erosion susceptibility, as areas without vegetation are generally more prone to erosion processes. Field surveys provide direct observations and measurements, allowing for accurate estimations of this critical factor in cliff stability assessment.

Only two methodologies have included **chemical variables**: Pérez-Alberti (2019) and Dimopoulos et al., (2018). Soil chemical parameters, including pH, salinity, and eutrophic state, are typically measured as a percentage deviation from values specific to the area. The pH is determined using a pH meter in a soil/water suspension with a ratio of 1:2.5. Salinity is assessed by measuring the electrical conductivity of an extract obtained from a soil/water suspension, often using a 1:5 ratio (10 g of dry soil to 50 ml of water). To evaluate the eutrophic state of the soil, laboratory analyses are conducted to determine exchange cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), NH_4^{+}, nitrate (NO_3^{-}), and plant-assimilable or 'bioavailable' phosphorus. Organic content is mentioned by Dimopoulos et al., (2018) but no information on measurement methods or thresholds are provided.

Biotic variables

Regarding biotic variables, compositional and structural variables are the most frequently proposed by the methodologies reviewed.

Compositional variables are mainly centred around vascular plants but some methodologies have also included recording of animal species (Krause et al., 2008; Łabuz, 2012; Angelini et al., 2016; Bicchierai & Mistarz, 2023).

The **presence and completeness of typical vascular plants, birds, and wild bees** are assessed according to a predetermined list of typical species in Germany (Krause et al., 2008).

The composition of plants in the habitat is usually evaluated by visual field inspection. As proposed in MOEW (2013), the species combination and dominant species are evaluated for each polygon to determine if they are characteristic of the natural habitat, using the Braun-Blanquet scale or percentage coverage. Bicchierai and Mistarz (2023) propose a rate of the number of characteristic species in relation to the total number of species, which is visually assessed and counted at the plot scale, referring to a proposed list that can be adapted to local contexts. **Species richness** is determined through field inventories (Pérez-Aberti, 2019), while positive and negative indicator species (including non-native species) are assessed based on lists specific to each vegetation zone, such as splash zones and crevice and ledge zones (Barron et al., 2011).

Typical plant communities are evaluated based on their presence and proportion within the cliff habitat. Vegetation composition is surveyed in Angelini et al., (2016) by using the Braun-Blanquet scale or percentage coverage, including dominant, typical, disturbance indicator, and alien species. This methodology also evaluates the presence of animal species through the identification and census of target species relevant to the habitat's conservation status. The presence of animal species indicating good conservation status is recorded as a bonus, evaluating the habitat's functional role in supporting biodiversity and reproduction, in the methodology proposed by Bicchierai and Mistarz (2023) in France.

The **proportion of nitrophilous species** (Bicchierai & Mistarz, 2023) to the total number of species is visually assessed and counted at the plot scale.

The presence of **invasive and exotic species** is considered, paying special attention to the number of communities affected and the degree of abundance or dominance over native cliff species. Habitat ruderalisation is evaluated by determining the percentage cover of ruderal and replacement plant species in the field.

Pérez-Alberti (2019) suggests measuring the presence of **species indicating environmental quality or pollution** through vegetation inventories and the identification of bioindicator species, such as lichens, and species indicative of contamination.

Regarding **structural variables**, for habitat type 1240 (vegetated sea cliffs of the Mediterranean coasts), ratios are used to evaluate habitat quality in one of the methodologies analysed (Bicchierai & Mistarz, 2023). The ratio of **characteristic species cover** to total species cover is visually assessed at the plot level, based on a list of species that can be adapted to local contexts. Similarly, the ratio of halophytic species cover to total vegetation cover is estimated visually. The relative **cover of halophytic species**, i.e. species adapted to salty environments, is considered an indicator of increased marine influence. The habitat is deemed to be in good status when the coverage of halophytic species exceeds that of non-halophytic species.

The **coverage of nitrophilous species** relative to total coverage is another important indicator. This visual assessment, based on a proposed list of species, provides information about the amount of nitrogen present in the soil. The habitat is considered to be in good condition when the coverage of nitrophilous species is low compared to the total coverage. **Invasive alien species** coverage is also evaluated (e.g. for habitat type 1240), through visual estimation at the plot level. Similarly, the cover of ryegrass and other **negative species** is visually estimated to assess habitat degradation. Coverage of **species indicating pollution** is estimated visually at the plot level. This helps identify potential contamination issues affecting the habitat.

Other methodologies (Krause et al., 2008) also employ expert judgment to evaluate the completeness of habitat structures characteristic of these environments. Vegetation cover is a key component of this assessment, analysed through various methods.

The **vegetation cover** is measured by Angelini et al., (2016) and Hedenås et al., (2020) as a percentage of the surface area, considering both covered and uncovered areas. This analysis includes the coverage of **dominant, typical, disturbance indicators, and alien species**.

Functional variables are not as frequently described as the other biotic variables. These are only indicated in two methodologies, Łabuz (2012) and Dimopoulos et al., (2018), with the latter not providing any information on measurement methods or thresholds.

Regeneration of shrubs is assessed by expert visual assessment in one of the methodologies considered in this analysis (Łabuz, 2012) and its relevance relies on its relation to the successional stages. The pattern of succession is proposed in one of the national methodologies analysed to inform about the overall health and dynamics of the plant communities on the cliff slopes (Dimopouls et al., 2018). Cliffs often exhibit diverse developmental stages depending on their geological structure and dynamics. The presence and growth of shrubs, and even trees can reflect periods of stabilisation and lack of erosion, which influences the plant habitat mosaic. In coastal cliff ecosystems, succession often involves the gradual colonisation of bare rock or unstable substrates by pioneer species, followed by the establishment of more complex plant communities.

The presence of certain functional traits or biotic forms, such as succulent, rosette growth forms, or wind-resistant adaptations, indicates the ability of vegetation to adapt and withstand harsh coastal conditions including salt spray, strong winds, and limited soil resources. These adaptations are key indicators of the habitat's ecological integrity and its capacity to support specialised coastal vegetation communities. The diversity of functional traits also reflects the habitat's ability to provide various ecological niches, supporting biodiversity and ecosystem resilience.

Only two variables have been proposed to assess **landscape characteristics**: habitat fragmentation and landscape metrics. The first variable, present in MOEW (2013), focuses on detecting the presence of fragmenting infrastructures rather than assessing connectivity or the actual degree of fragmentation affecting the habitat. Angelini et al., (2016) propose the measurement of spatial conditions using GIS tools but does not specify the metrics and methods.

Other variables are mostly focused on assessing the habitat alteration or degradation by the presence of artificial structures and anthropic activities, and understanding how these are affecting the habitat. Most of the methodologies reviewed include this type of variables.

Artificial structures can significantly alter the natural processes and ecological integrity of these environments. These structures, which are normally part of the management of coastal areas and can include sea defences (e.g., rock armour), paths, fences and tracks, can directly impact the cliff structure, vegetation composition, and habitat connectivity. They may lead to habitat fragmentation, increased erosion, altered drainage patterns, and the introduction or spread of invasive species. The presence of these structures can also disrupt natural succession patterns and negatively affect the distribution and abundance of characteristic plant and animal species. Modifications to coastal processes through artificial structures or management practices can also alter erosion and sedimentation patterns, water flow, and overall habitat stability. The measurement method for this type of variable involves visual inspection and recording of paths, tracks, and sea defences affecting the cliff, including an estimate or assessment of the extent and nature of human-induced modifications to the habitat.

According to Pérez Alberti (2019) it is important to consider changes in vegetation cover and disturbance caused by agricultural, forestry, and livestock activities that occur in proximity of coastal cliffs. Monitoring these activities would involve mapping changes observed from field sampling or orthophotography. Activities affecting the cliffs could be visible by the presence of waste, trampling, opening of paths or roads, etc. As a result of these activities, excessive nutrient input can alter plant community composition, favouring nutrient-demanding species and potentially leading to a loss of characteristic cliff vegetation.

The consequences of **leisure activities**, such as trampling by hikers or disturbance from recreational vehicles, can directly damage vegetation, compact soil and disrupt wildlife. The presence of garbage, including plastic waste, can pollute the habitat, harm wildlife through ingestion or entanglement, and alter soil chemistry. Another variable negatively affecting the habitat is the process of urbanisation and increase of anthropic density. These are accompanied by an increase in infrastructures and pollution that can cause damages as the ones previously described: habitat fragmentation, altered coastal dynamics, increased erosion, pollution, and the introduction of invasive species. The measurement methods used for these variables include assessing the density of anthropic elements within the coastal strip to quantify the overall level of human development and its potential impact and the identification of new constructions, using the Land Use Information System and orthophotography.

2.2 Definition of ranges and thresholds to obtain condition indicators

Some of the consulted methodologies, such as Angelini et al. (2016) or Dimopoulos et al. (2018) do not indicate any threshold values. On the other hand, those that include information about threshold values usually do not specify how these were estimated.

For example, Barron et al. (2011) consider a good condition when the variable used to assess the presence of positive species is above some minimum number (e.g. for the crevice and ledge zone ≥ 4). In the methodology proposed by Łabuz (2012), the number of species present is used to indicate good condition (e.g., for the variable related to the number of typical species present in the monitoring station, the following reference values are used: FV > 15 > U1 > 5 > U2).

Krause et al. (2008) use three qualitative categories associated with favourable or unfavourable condition. For instance, the proposed variable to assess cliff structural quality can have the following values of A (excellent) = natural or, unchanged, B (good) = slightly altered and C (medium-poor) = strongly altered. Barron et al. (2011), on the other hand, have set quantitative or qualitative values to determine good condition for the all the variables used, which means that any other value would indicate not-good condition. For instance, for the variable relating to the presence of negative species, it is considered a good condition when none is present.

Thresholds for composition and structural variables are defined in some of the methodologies analysed as a percentage of the number or cover of some species or groups of species. For example, the coverage of invasive or ruderal species is considered unfavourable if it represents more than 10% of the area of the sampled polygons (MOEW, 2013). Boulet and Mistarz (2024) define condition categories for plant communities of Atlantic cliffs (1230) in Natura 2000 sites where the condition of the vegetation is indicated by the coverage of characteristic species, trophic enrichment indicator species, invasive and negative species. In these, optimal status is defined by presence of certain values of characteristic species cover, a coverage of trophic enrichment indicator species below 5% and of invasive/negative below 5% with almost no signs of disturbance. Similarly, Biccherai and Mistarz (2023) define the condition categories for 1240 in Natura 2000 sites by the ratio of characteristic species, halophytic species, nitrophilous species and Invasive Alien Species (IAS), where good condition is indicated by a ratio of characteristic and halophytic species above 0.7, while the ratio for nitrophilous species should be below 0.1 and IAS must be absent.

The methodologies developed by Bicchierai and Mistarz (2023), Boulet and Mistarz (2024) and Fredshavn and Nygaard (2014) assign scoring values to the different possible outcomes of the variables. These points are then added or used in a formula to obtain an overall result for assessment of the structure and function parameter. For instance, for the variable used to assess the characteristic species cover, no score (0) is given if its value is > 0.7 but a negative score of -10 is given when it is below that percentage cover.

However, in some methodologies, the scores assigned to some variables have been described but no threshold values are indicated (e.g. coverage of ryegrass and other negative species, in Fredshavn and Nygaard, 2014).

2.3 Aggregation at local scale

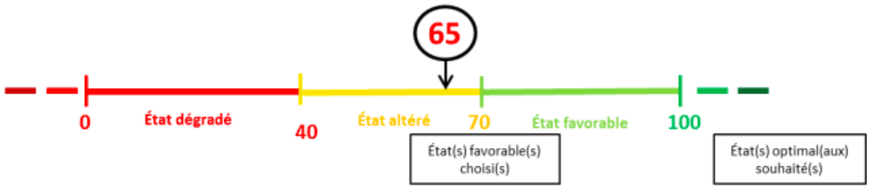
Aggregation of the values obtained in the variables measured to obtain an overall assessment at the local level (monitoring plot or site) is described in only some of the methodologies analysed. Those that describe an aggregation system use in general arithmetic operators or categorical majority rules. A few methodologies apply the one-out-all-out-rule or a variant of that method, which considers that a sample area cannot be in good condition if any of the variables measured is not in good condition.

In the methodology developed by Fredshavn and Nygaard (2014) a weighting is assigned to the different variables measured and a formula is used to obtain an index. Variables are grouped in four categories: vegetation structure, hydrology and coastal protection, grazing and, impact of agricultural operations, and habitat-characteristic structures. The variables described for each category (e.g. areas with erosion and landslides is a variable belonging to the category of habitat-characteristic structures) are assigned points from 0 to 100 to each of their possible values, with 100 representing favourable condition. The variables are weighted according to their importance for the overall index (from 0 to 1) and are normalised so that the sum of the weights is 1. Since they are built in a tiered system, the weighting is done at each hierarchical level. As with the points, the weights should be assigned on a solid basis of data, but in the absence of this, the weighting has been done based on best expert judgment. Each of the four variable categories is also weighted according to its importance in a similar way.

The aggregation system described in Bacchieri and Mistarz (2023) and Boulet and Mistarz (2024) for Natura 2000 sites is based on a 0-100 score (from bad to good condition) and the F-U1-U2 scale. The assessment of the conservation status on a local scale is based on three major parameters: (i) composition, structure and functions of the habitat, (ii) undergoing deteriorations, (iii) evolution of the area within the site. These parameters are themselves composed of criteria to which one or more indicators (variables) are associated.

A score is attributed to each variable based on its threshold values. A final score is obtained by subtracting the addition of these variables' scores from 100. Lastly, the overall score obtained is assigned a favourable or unfavourable status based on a conservation status gradient, which can be divided into different levels of conservation status (Figure 3).

Figure 3. Conservation status gradient used in the conservation status assessment methods at the scale of Natura 2000 sites proposed by PatriNat



Source: Maciejewski et al., (2016).

Categorical majority rules establish the habitat condition according to pre-established combinations of ordinal condition categories indicating good/favourable or not-good/ unfavourable condition. The result of these combinations roughly corresponds to the majority of these categories in the set of variables.

The methodology proposed by Krause et al. (2008) groups the variables in three categories: 1) completeness of the typical habitat structures, 2) completeness of the habitat typical species inventory, 3) impairments. Then, a status is given to each of these variable groups: Excellent, Good and Medium-poor. Subsequently, the following rules are applied considering the status of the three criteria: if all three criteria share the same status, they have a common status condition; two criteria share the same status, in general, they result in the most common status condition. For example, two Excellent and one Good, results in Excellent. But, if there is a C rating, an overall rating of A is not possible, so two Excellent and one Medium-Poor status result in an overall Good status.

In the methodology developed by Barron et al. (2011) for Ireland and applied in a survey carried out in 2010, a single reference value threshold corresponding to favourable or good condition was assigned to each variable and the assessment had to indicate whether such value was reached or not. 22 criteria were proposed for assessing sea cliffs and different zones in the cliff, when applicable. Three criteria were assessed on all cliff zones, recording the presence of sea defences, such as rock armour, sea walls; fence, artificial structures including piers and slipways; and paths or tracks which affected the zonation, geomorphology or natural hydrology of the cliff. If any of these elements were present, the affected proportion at the site determined whether it was considered as being unfavourable-inadequate (less than 25% of the site affected), or Unfavourable - Bad (more than 25% of the site affected). A fourth criterion considered the presence of non-native invasive species, which would similarly show that the site is not in good condition. The remaining 18 criteria were applied to the relevant habitat zones as appropriate, and the % of assessments that passed the thresholds set in the corresponding zones (e.g. number of positive indicator species present ≥4 in the crevice and ledge zone; no negative indicator species present on coastal grassland on hard cliffs; cover of *Pteridium aquilinum* <10% in coastal heath, etc.) were recorded. The final assessment was done on a site-by-site basis with consideration given to the habitat zone which had been declared unfavourable according to the thresholds set. Of the 32 sites surveyed during 2010, 56% were assessed as Favourable (with no failures in any of the criteria applied to the zones present in each site), 31% were assessed as Unfavourable - Inadequate (due to the presence of quarrying, sea defences, access points and invasive species with a relatively small coverage), and 13% were assessed as Unfavourable - Bad (due to presence of sea defences, modifications for railway, access points and invasive species with a relatively high coverage).

The methodologies proposed by Łabuz (2012) and MOEW (2013) apply a variant of the one-out-all-out rule, considering that the status is favourable for structure and function when all parameters are assessed as “favourable” or when all parameters assessed are “favourable” but a maximum up to 25% of the parameters are assessed to have insufficient information. In the case that the assessment is “unfavourable – bad” for just one parameter, the overall assessment becomes “unfavourable – bad”. “Unfavourable – inadequate” status is determined by any other combination of parameters.

The methodology proposed by Pérez Alberti (2019) describes a Naturalness Index of Rocky Coastal Ecosystems (INECOR) to assess the condition at the local scale. INECOR considers 17 variables grouped into 4 categories depending on whether they are related to geomorphological stability (E), the biotic components of cliffs and rocky platforms (B), the soil (S) or whether they are anthropogenic (An). The assessment of each variable ranges from 0 to 5 (lowest and highest values) for the natural variables, and from 0 to 50 for the anthropogenic variables according to their degree of impact on the ecosystems. Depending on the ecological importance of each variable, it will be given a weight from 1 to 3m. The index is calculated according to this formula: INECOR = (E+B+S+An) /4, where: E is the group of variables related to geomorphological stability; B is the group of variables related to the biotic components of cliffs and rocky platforms; S is the group of variables related to the soil and An is the group of variables of an anthropic nature. The maximum quality (best condition) that can be awarded at a local level is 152.8 points and the minimum is 0 points.

2.4 Aggregation at biogeographical scale

This information is usually not presented in the national methodologies considered in this analysis. We could presume however that most MSs adhere to the guidelines from Article 17 reporting for the period 2013-2018, which state that the 'structure and functions' parameter is considered 'favourable' if 90% of the habitat area is in 'good' condition. It is classified as 'unfavourable-bad' if more than 25% of the habitat area is reported as 'not in good condition,' and 'unfavourable-inadequate' for intermediate percentages.

An estimation of the proportions of good and not good condition areas should be estimated, unfortunately this aspect is not described in the methodologies considered in this analysis.

2.5 Selection of localities

Most of the methodologies considered in this analysis have no indication of how the monitoring localities are selected or the criteria followed to select them.

The methodology proposed in France for habitat 1240 (Bicchierai & Mistarz, 2023) applies to Natura 2000 sites, and a number of sites providing sufficient information on the habitats of interest were chosen to test the method, although some tests could be carried out also outside Natura 2000 sites. The most suitable sites were chosen considering the following aspects: availability of management plan (site information, maps, activities and their impacts on the entire site); habitat polygons of different conservation status or condition in order to calibrate the method, different plant associations for the same habitat in order to be able to produce a method applicable to the entire habitat severity; and lastly, accessibility of habitat polygons in order to maximise the time allocated to the study. Localities for monitoring habitat 1230 were selected based on habitat maps from 55 Natura 2000 sites (Boulet & Mistarz, 2024).

Angelini et al., (2016) do not specify which locations were monitored but indicate that, based on the limited distribution of the habitat (1240) in Italy, locations should be selected via GIS mapping and some priority should be given to threatened sites.

In Barron et al. (2011), a sub-sample of 32 sites was selected from the 196 identified sea cliff sites in Ireland. The location of sea cliffs was mapped and collected in a GIS project with maps of all of the cliff sites, which was made available in a database to the National Parks and Wildlife Service. Various zones were assessed in each site (see further details below, in Section 2.6).

The monitoring conducted in 2011 by Łabuz (2012) in Poland applied to a selection of 15 sites evenly distributed along the entire cliff coastline. The selected sites for monitoring were characterised by diverse cliff configurations in terms of lithology, height and stability. Sections with different types of plant communities in various succession phases were monitored. Due to safety reasons, the most accessible sites were selected, which nevertheless guaranteed a high diversity of habitats and biodiversity.

According to Dimopoulos et al., (2018), monitoring localities for all habitats in Greece were selected based on sampling localities included in a previous project (IDHTACI project, 1999-2001). The exact number of sampling localities selected was specified during the field work and it was not less than five per habitat type per site of the Natura 2000 network. The sampling locations tried to take into consideration the EEA 10 km reference grid, with at least one location in each grid cell where the habitat type occurs.

In the methodology proposed for coastal habitats in Spain (Gracia et al., 2019), 11 criteria are suggested for the selection of monitoring areas, which are listed below. The areas do not need to meet all of the criteria, except for the first three mandatory criteria:

1. Representativeness within the Natura 2000 Network and Protected Area Networks.
2. Statistical significance. A minimum number of monitoring locations is required to allow the assessment to be extrapolated from the local to the regional level.
3. Number of Habitat Types of Community Interest present in the locality.
4. Range/Area occupied.
5. Representative presence within the coastal province.
6. Threat status (risk of extinction) and conservation status. This includes habitat types with a certain degree of degradation or threat, which are currently declining or have historically shown a declining trend.
7. Reference ecosystems.
8. Ecological significance and national/community uniqueness.
9. Environmental-ecological diversity.
10. Distance to other monitoring points.
11. Representativeness within administrative regions.

2.6 General monitoring and sampling methods

According to the methodology described in Barron et al. (2011) for Ireland, a desk study and a field study were conducted on a total of 196 sites. Remote survey techniques were utilised at all sites, using high powered photographic equipment to take photographs of relevés with species lists being developed afterwards by botanists. Rope survey techniques were used in a limited number of sites (five sites out of 32 surveyed sites), which involved a botanist being lowered down the cliff by rope and taking relevés directly from the cliff face.

A first part of the monitoring was a desk study that collected information from 143 sites on cliff characteristics which included: height, length, aspect, slope, location grid references, cliff face features including stratification and hydrological features, cliff base features and cliff top habitats, vegetation cover, exposure to wind and wave action, erosion features, anthropogenic impacts, cliff type and soil type, bedrock and parent material type. These characteristics were assessed using aerial photographs (2005 series) and OSI Discovery Series maps, information on soils from Teagasc soil and parent material maps, and information on bedrock from Geological Survey of Ireland bedrock maps. Sites were divided into sections based on physical characteristics of the cliff and vegetation cover. The minimum length for a cliff section was 100

m. Where there was a break between 80 m and 500 m in a section, it was divided into two sections.

Regarding the field survey, 32 sites were selected based on geology, height, exposure, hydrology, vegetation cover and management. The monitoring unit was a 20-m wide swath of the cliff. In the 32 sampled sites, data were collected from swaths at 62 sea cliff sections with a total of 161 relevés recorded. Swaths were divided into zones based on their location on the cliff, exposure to maritime influences and vegetation. The following zones were defined: a splash zone located at the base of hard cliffs that extends above the water mark; a crevice and ledge zone characterized by exposed rocks and a vegetation cover of 50% or less; ungrazed grasslands on hard cliffs, defined by a bare ground coverage exceeding 50 % of the area; grazed grasslands with evidence of grazing in the area; coastal grasslands, only considered for unstable soft cliffs, generally ungrazed; soft cliff pioneer, unstable communities with vegetation cover less than 50%; and coastal heath, where dwarf shrubs cover at least a 25% of the area. A representative vegetation relevé was recorded from each of these zones.

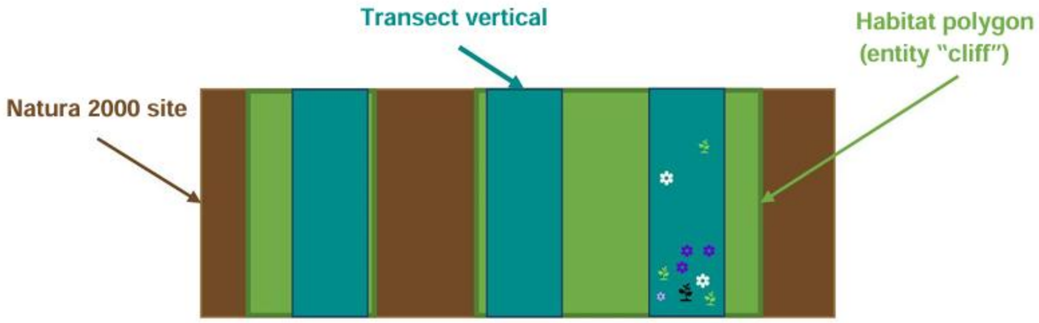
Relevés were generally 2m x 2m, but for areas with very little vegetation (the splash zone and bare rock faces) and for zones which were narrow, 1m x 1m relevés were used. Cover in vertical projection for all vascular plants, bryophytes and, where possible lichens, was recorded using the Domin scale (Kent & Coker, 1992). These as well as other general parameters, including: bare soil, bare rock, leaf litter, surface water, and total cover of bryophytes, lichens, dwarf shrubs, shrubs, canopy species and forbs. The median vegetation height was also recorded and, for grassland habitats, the forb-to-grass ratio was estimated.

In the methodology proposed by Łabuz (2012) in Poland, a monitoring site was defined as the surface of the slope or cliff wall from its edge down to the base and contact with the beach (if present). The general characterisation included the width of the typical community covering the cliff top to its edge. The dimensions of the sites were 100 or 300 m in length along the coast and a width dependent on the slope length, i.e. the distance from the edge to the base, from 5 to 50 m. Regarding measurement techniques, the Polish methodology recommends the use of lightweight geodetic equipment, such as a level or theodolite with a staff for height readings, to measure shape and height of the cliff. The rate of cliff retreat can be calculated by marking benchmarks at a certain distance from the edge. These can be wooden stakes driven into the ground or, for example, a characteristic tree. By calculating the distance of the benchmark from the edge, they obtain the rate of retreat.

Angelini et al. (2016) suggest a random stratified sampling method with a minimum homogeneous area of 5m^2. Vegetation cover is assessed using Braun-Blanquet scale or percentage cover values and all the species present in the sampling area are recorded. The minimum number of samples proposed is one sampling every 2-5 linear km, considering the degree of threat, the geomorphology and the extension of the habitat, with at least one sampling per homogeneous surface unit if possible. In case that a habitat was located in isolated stations, or it had a limited extension, at least 2 representative samplings should be done. The optimal sampling period is indicated from May to June. The methodology advises that the monitoring be repeated over time within permanent plots, in order to describe the transformations in progress, with a recommended frequency of 3 years.

For habitat 1230, Boulet and Mistarz (2024) propose monitoring Atlantic cliffs using randomly placed transects inside the habitat polygon (Figure 4). For cliffs located in unaccessible areas, expert assessment of pressures at the top of the cliff is conducted or a transect is positioned in a more accessible area. Transects of 5 meters width will go from the bottom to the upper limit of the cliff, stopping at the point where the slope was lower than 15 degrees and the characteristic vegetation was no longer present. Thus, the transect might not be vertical and could be fragmented depending on the habitat configuration. The monitoring period is indicated from May to June, at the time of peak vegetation.

Figure 4. Diagram of sampling method proposed by Boulet and Mistarz (2024)



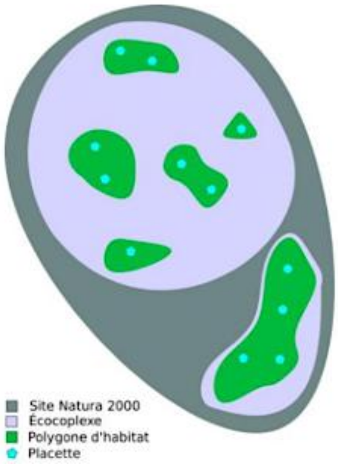
Inside a Natura 2000 site, habitat polygons are identified and transects are placed within them.
Source: Boulet & Mistarz (2024)

Compositional and structural variables regarding the vegetation are assessed by dividing transects into homogeneous sections based on plant composition. Coverage of different species is calculated at the section level and then averaged at the transect level.

In the methodology described by Bicchierai and Mistarz (2023) for habitat 1240, surveys are generally carried out within plots of 3 to 40 m² depending on the size of the habitat polygon and its floristic diversity. The shape of the plot is adapted to the shape of the polygon (circular, rectangular, linear). The field visits allowing the evaluation of the habitat must be carried out at the peak of vegetation, from April to June. The recording of variables during field work can be conducted at different scales depending on the characteristics assessed. The highest scale is the eco-complex, a set of interdependent ecosystems (Blandin & Lamotte 1985, cited in Bicchierai et al., 2023).

Variables related to fauna composition based on mobile species, are measured at this scale. The next level is the habitat polygon that constitutes a relatively homogeneous floristic entity, associated to the habitat. It is constrained by a change in topography or by the existence of different adjacent plant communities or a different habitat, located on the same topographic level. Variables measuring disturbance are recorded at this level. The entire polygon must be subjected to the same management (or lack of management). The lowest level is the plot, an entity representative of the habitat polygon, which brings together all major characteristics observable at the polygon scale (composition, stationary conditions, etc.).

Figure 5. Sampling for habitat 1240



Indicator are recorded at different scales: Natura 2000 site, eco-complex, habitat polygon, and plot.
Source: Bicchierai & Mistarz, 2023

The vegetation structural indicators for habitat 1240 are assessed by estimating the cover of specific vegetation groups divided by the total vegetation cover, e.g.: ratio halophytic species cover/total vegetation cover.

In the methodology proposed by Fredshavn and Nygaard (2014), a circular sample plot with a radius of 5 meters (i.e., an area of 78.5 m^2) is used for recording species composition, but no more information on sampling protocols is provided.

In the methodology developed by Hedenås et al. (2020) for Sweden, a field inventory based on a 10 m wide transect is used to monitor characteristics of various coastal habitats. The transect is divided in zones (geo-littoral, supra-littoral and extra-littoral) and extends from the water line to the extra-littoral forest for a possible assessment of the following habitats: sea cliffs and shingle or stony beaches (1210, 1220 and 1230), salt marshes and salt meadows (1310, 1330), boreal coastal habitats (1610, 1620, 1630, and 1640), dune habitats (2120, 2130, 2140, 2170, 2180, 2190) and coastal forest (9030). Photointerpretation is used to define the limits of each zone. Detailed inventory in the extra-littoral zone is only carried out in cases where stone banks (1220), sea cliffs (1230), dune (2100) or forest (9030) is found above the supra-littoral zone. In this case, the transect extends along the extra-littoral area until the habitat ceases. The exception is sea cliffs (1230) which are included even if they occur further away without direct contact with the end point of the beach zone. The minimum mapping unit estimated for sea cliffs habitats is 0.1 ha.

The occurrence of species listed on a monitoring protocol is recorded and for some species the number of plants, number of tufts or coverage must also be noted. The coverage is estimated in m^2 with 0.1m^2 being the smallest area to be recorded. Shrub coverage is recorded along with length (m), width (m) and density (in %) of shrubs, determining the distance from the starting point for each shrub species found. Regarding costal forest, a detailed description of the tree layer is made taking into account tree species with a diameter of 130 cm at breast height, alternatively counting tree seedlings higher than 50 cm but lower than 130 cm, as well as their position from the starting point.

2.7 Other relevant methodologies

Relevant methodologies and approaches for the survey and monitoring of sea cliffs are available from the scientific literature and various initiatives carried out in other countries, in particular regarding novel techniques and new technologies applied to the assessment and monitoring of cliff erosion and stability.

Traditional approaches used in monitoring cliff changes over spatial and temporal scales include field surveys, air photo interpretation, airborne light detection and ranging (LIDAR) and terrestrial laser scanning (TLS) surveys. These approaches can be used to provide insight into environmental changes or trends.

A review of traditional techniques used to measure coastal cliff retreat in the United States and some of the new techniques developed to overcome the limitations of earlier techniques has been provided by Hapke (2004).

More recently, the usefulness of various techniques for the mapping and monitoring of cliffs, mostly cliff erosion and stability, have been briefly discussed by Wernette et al. (2022).

In addition to field surveys, aerial photography is often used in the monitoring of all the main characteristics of sea cliffs and coastal erosion. It can be combined with structure-from-motion analysis to measure the volume of eroded material.

Structure from motion (SfM) photogrammetry is an increasingly common technique for measuring landscape change over time by deriving 3D point clouds and surface models from overlapping photographs. Several recent studies are available on the use of this technique to monitor coastal cliffs.

Quantifying coastal change is essential for calculating trends in erosion, evaluating processes that shape coastal landscapes, and predicting how the coast will respond to future storms and sea-level rise, all critical for coastal communities. Sea cliff erosion progression and erosion rates have been estimated by the U.S. Geological Survey scientists, using historical aerial photographs. They applied the “structure-from-motion” technique to five sets of oblique aerial photos spanning the years 2002 to 2010 and measured the volume of material eroded from coastal cliffs close to San Francisco, California (Warrick et al., 2017).

Wernette et al. (2022) discusses best practices for high resolution monitoring of coastal cliffs and present a structure-from-motion approach for monitoring environmental change in high relief coastal environments. This technique does not require all photos to have DGPS location information and does not require field survey data. The study builds on the success of other citizen science coastal monitoring initiatives, as CoastSnap (see details below), and previous SfM research and provides a low-cost approach to landscape monitoring that also represents an opportunity for researchers and managers to engage stakeholders in citizen-science projects.

New methods for topographic-data acquisition, such as LIDAR and those based SfM photogrammetry enable the collection of high-accuracy and high-density 3Dspatial data for researching coastal geomorphology. The advantage of the SfM method in comparison with LIDAR, and other traditional photogrammetric methods, is that the images can be taken with a readily available, single digital camera. For instance, a method for stability analysis of coastal cliffs in the Adriatic Sea using structure-from-motion (SfM) photogrammetry is presented by Ružić et al., (2015). The method provided highly detailed 3D geometrical data of the cliff, which could be used in the calculations of the stability model and demonstrated its usefulness in the stability analysis of lithologically heterogeneous rocks with varied geometry.

A recent study by Krivova et al., (2025) presents a multidimensional analysis approach toward sea cliff erosion forecasting based on remote sensing. It presents an innovative Geographic Information Systems (GIS) algorithm to forecast sea cliff erosion progression utilising imagery datasets ('rasters'), based on Digital Elevation Model (DEM) rasters created from terrestrial LiDAR images integrated into a multidimensional raster to generate trend rasters.

In regards to citizen science for coastal monitoring, CoastSnap (UNSW, n.d.) aims to capture changes in coastlines resulting from processes such as storms, rising sea levels, human activities and other factors, using photos taken by citizens at the same location and photogrammetry. CoastSnap turns photos into valuable coastal data that is used by coastal scientists to understand and forecast how coastlines might change in the coming decades.

2.8 Conclusions

Various methodologies have been developed and implemented across the EU to evaluate the status of sea cliff habitats. We have analysed the methodologies collected from 10 EU Member States, which cover the three habitat types included in the group of Sea cliffs.

An overall analysis of these methodologies shows some commonalities but also disparities regarding the variables used for the assessment of biotic and abiotic characteristics of these habitats.

Regarding physical variables, morphological features (height, slope) and variables that measure the cliff stability and erosion, these are quite frequently included in the methodologies analysed. On the other hand, chemical variables are very rarely used, with only one methodology assessing soil organic matter and another one measuring soil pH and salinity.

Considering the biotic variables, all the national methodologies reviewed in this analysis assess the habitat composition and structure through the presence, number or percentage cover of typical and characteristic vascular plant species, based on reference lists of species. Presence and cover of negative indicator species (e.g., nitrophilous) and invasive alien species are included in many of the methodologies analysed. On the other hand, animal species are only considered in the methodologies available from four MSs.

Biotic functional variables represent an important gap, as these types of variables are only included in two methodologies. In one case the regeneration of shrubs was measured and in the other an assessment of successional stage patterns was carried out. However, many countries consider the impacts and disturbances caused by human activities in their monitoring of cliff habitats, seeing them as a cause of disruption to the natural functioning of these ecosystems. The main activities and disturbances examined include the presence of coastal defences and other artificial structures, tourist activities, nutrient impact from agricultural activities on upper areas, and in some cases not only the presence of such activities but also the surfaces affected are monitored.

Reference values and thresholds to determine whether the variables portray a good or favourable condition are defined in some methodologies, although the methods used to estimate those thresholds are not explained. Qualitative or quantitate values are used depending on the methodologies and often the qualitative categories used to determine favourable and unfavourable condition for some variables are visually assessed by expert judgement.

Various aggregation methods are used to obtain an overall assessment at the local level (monitoring plot or site) depending on the national methodologies considered, including arithmetic operators, majority rules and the one-out-all-out-rule in a few cases. Weighting of the variables is used to calculate an index in two of the methodologies analysed.

Many of the methodologies considered in this analysis do not indicate how the monitoring localities are selected or the criteria followed to select them. In some cases, the selection aims to cover the environmental-ecological diversity of cliffs in terms of lithology, height and stability, types of plant communities, as well as conservation status. Site accessibility is also considered. Other relevant criteria, such as the need to ensure statistical significance, is specifically mentioned in only one of the methodologies considered in this analysis. This aspect is particularly important, since a minimum number of monitoring locations is required to allow the assessment to be extrapolated from the local to the regional level.

Monitoring and sampling protocols are varied but frequently include both fieldwork and use of aerial photography or other remote surveying techniques. Difficulties to access the cliffs required the use of rope survey techniques in some sites. The assessment is usually carried out in different zones of the cliff from the base to the top and monitoring or sampling areas of varied size are used in the methodologies analysed, e.g., plots of 2m x 2m for relevés in Ireland, sample plot with a radius of 5 m in Denmark, a minimum homogeneous area of $5m^2$ in Italy, transects of 5 meters width in Atlantic cliffs in France or, a 10 m wide transect in Sweden.

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

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

As shown in the previous section, there are some commonalities in the methodologies used by the various EU Member States to assess the condition of sea cliff habitats but also significant differences in the specific variables and metrics used. Common procedures would be desirable to obtain comparable habitat assessments across Member States. In order to harmonize the selection of condition variables for the assessment and monitoring of sea cliff habitats, several general principles should be considered:

- Any habitat type can be described with a set of key characteristics, which can be measured with relevant variables.
- There are contextual factors operating in the different MSs, which influence the values of the variables that determine whether the habitat is in good or not good condition.
- For a given habitat, the final assessment of habitat condition, based on the relevant variables associated to key characteristics of the habitat, should be equivalent for the different MS, after accounting the contextual factors of each MS.

Moreover, the harmonisation of the use of relevant variables requires a set of common requirements:

- For any habitat type, the main characteristics must be measured in all MSs using a set of common variables, applying the same measurement procedures.
- The description of the condition variables, metrics and measurement procedures must be clearly defined and clearly understandable so that they can be applied in all the MSs.
- The number of common condition variables should be the minimum needed to determine the habitat condition.
- The common variables should meet the criteria of validity, reliability, availability, simplicity and compatibility (Czúcz et al., 2021).
- Common training on the measurement of the condition variables should be programmed for experts from the different MSs in order to achieve full harmonisation.

This section presents a proposal for a common set of variables, recommended metrics, and measurement procedures for all sea cliff habitat types, classified as follows:

Essential variables (E) correspond to characteristics that are vital for the habitat, describe the distinctness of the habitat or its condition. **Recommended variables** (R) correspond to additional variables which are relevant but that can be neglected to be measured in some contexts. In addition, a number of **descriptive variables** (D) are also proposed, which inform on the context of the habitat and can be relevant to understand the processes that can influence their ecological status, but do not directly inform of such condition.

Table 5 presents a proposed list of variables to assess habitat condition in sea cliff habitats, which are explained below. The list is based on the main characteristics of sea cliff habitats described in Section 1.2, information provided by Member States on habitat condition assessment (see section 2), and available literature on these habitats. The proposed list is intended as a prototype that could be further refined by expert panels. The proposed metrics and measurement methods are designed to be easily and reliably obtained.

The characteristics and proposed condition variables are classified according to the Ecosystem condition typology from SEEA-Ecosystem Accounting (United Nations, 2021).

The main abiotic variables refer to the dimensions of the sea cliff that inform about the dynamics (erosion-sedimentation processes) and some relevant chemical variables that are useful to understand their nutrient status and possible deterioration of the natural conditions.

The proposed biotic variables include the presence and abundance of characteristic species (vascular plants) for each habitat type, as well as the presence of some animal species that can reflect favourable condition, the total cover of vegetation and the presence and cover of negative indicator species (non-native, nitrophilous species).

Some variables are assessed on the basis of sample sites (e.g., characteristic vegetation communities, positive and negative indicator species), while others are more appropriately assessed at a wider scale, e.g., on the whole cliff (e.g. coastal trend, cliff morphology). The natural dynamics of the cliff should be taken into account. The limit of the cliff must also be defined appropriately, it could be, for example, the area up to which the maritime influence does not reach anymore.

Physical variables

Height, orientation, slope

Main cliff morphological features include the slope inclination, the height between the base and the top, and their orientation relative to the sun. Unless major earth movements or erosion occur, these changes happen over long periods of time, so they should only be described when characterising the habitat; since these are descriptive variables short-term monitoring is not necessary.

Height, slope, and aspect maps can be elaborated using digital terrain models (DTM) using LiDAR-derived models. Given the difficulty of analysing the entire cliff face, it is necessary to select locations of particular interest at the beginning of monitoring. Considering the great diversity within cliffs, the cliff segments should be determined based on their height (upper, middle, lower part), slope (steepest slope, flat area, etc.), wave impact, etc.

Oceanographic variables (waves, currents, and tides)

These are considered descriptive variables, which can have a different impact depending on the cliff location. It is important to describe them for the habitat characterisation, based on information derived from national or international organisations. It is essential to prepare an initial report with historical data that allow for the understanding of changes over time.

Linear erosion

Linear erosion on the face of cliffs is mainly due to the action of runoff water. The effects of surface runoff can be detected as linear indentations on studied sections of the cliff with photography. This causes changes in the longitudinal and transverse profile of the cliffs, causing volumetric changes that can be concave (deepening of ravines) and convex (accumulation of materials at the base of the cliff).

Mass movements

Mass movements are caused primarily by the flooding of materials or by the undermining of the base of the cliffs by marine action. They cause changes in the profile of the cliffs and in their stability and, at the same time, can destroy areas that were occupied or could be occupied by plants. Studying variables related to this can be particularly useful for specific coastal sectors with the analysis focusing on locations where greater erosive instability is observed. The assessment requires the definition of thresholds to differentiate stability grades, as high, medium, or low. This, may be complex as there are not enough studies on cliffs of different shapes and nature. It is recommended to calculate volume changes using photogrammetric monitoring, laser scanning, LiDAR, or radar interferometry, methodologies that are well known to specialists.

Chemical variables

Among the main abiotic factors that regulate the presence and distribution of vascular plants in coastal environments, nutrients and soil chemistry play a significant role. Soils in cliffs can be acidic or alkaline, depending on the type of rock the cliff is made of. Soil pH is a measure of acidity or alkalinity and it is an important environmental factor as it has a strong influence on the plant communities that colonise cliffs and also controls the availability of nutrients for plants. Nitrogen (N), Phosphorus (P) and Potassium (K) are essential nutrients for plant growth and development. Soils in sea cliffs can be low in nutrients, especially nitrogen and phosphorus. However, where seabirds are present, the amount of nutrients can increase due to bird guano deposits, which can then affect the plant communities and modify species composition. Soil salinity also greatly influences the pattern of vegetation distribution on cliffs, with salinity level showing a decrease along the seashore-inland gradient. Equally, plant richness and diversity are influenced by the distance from the sea (Maccioni et al., 2021).

All these variables (soil pH, EC, NPK content) can be measured with portable multiparameter soil testers and data loggers.

Compositional and structural variables

Characteristic species are essential components of each habitat type and should be assessed using a reference list of species adapted to the regional and local context. The different zones of the cliff and species from different taxonomic groups need to be considered, including vascular plants, bryophytes and algae depending on the zones. Where accessibility to cliff zones may be difficult, photo surveys and the use of drones can be considered as alternative survey techniques. Both the species occurrence and their cover should be estimated in the different zones and monitoring plots.

In addition to the plant communities, sea cliffs host birds and other animal species of high conservation value that need to be monitored, in particular nesting seabirds, but also other animal species depending on the regional and local context.

Furthermore, species which indicate an alteration of the habitat composition and condition, such as nitrophilous plants and invasive alien species, should be recorded and monitored during field surveys or with the use of photo survey techniques.

Functional variables

As functional variables, we propose monitoring the phenology of some species, e.g., endemic species and threatened species, that are particularly relevant to each habitat type and location.

Photo-survey techniques can be used not only to identify the selected plant species but also to record its phenological stage (e.g., flowering, fruiting) at the time of the survey flight.

The presence and abundance of pollinators is also considered a relevant functional characteristic of these habitats that could be monitored. Sea cliff habitats hold a significant number of plant species that are important for pollinators (Kudrnovsky et al. 2020) and their monitoring can be useful to indicate good habitat quality.

Landscape characteristics and associated variables

Coastline Changes

Cliff erosion in coastal areas usually involves the erosion of the cliff foot, caused by wave and storm surges action, resulting in a gradual retreat of the coastline. Climate change aggravates coastal erosion even more: sea level rise, increased frequency and intensity of storms, changes in prevalent wind directions and higher waves put Europe's coast under additional pressure.

Erosion processes cause vertical (top-down) changes on the cliff face and horizontal changes at the base of the cliffs. These changes can be positive, when due to sediment accumulation at the base the coast prograde seaward, or negative, for instance when wave erosion cause the cliff to retreat. GIS with applications such as the Digital Shoreline Analysis System (DSAS) can be used to analyse changes on large sections of the coast. The reference point could be the oldest period for which georeferenced orthophotos exist.

Coastal defences and cliff stabilisation

Coastal defences nearby cliffs can modify the sedimentation-erosion patterns and cause cliffs to retreat. It is therefore considered advisable to record their presence in the area where cliffs are monitored. The presence and abundance of infrastructures can be identified using available data and maps, aerial photographs, or by visual assessment during field surveys.

Cliff stabilisation techniques aim at increasing the strength and overall stability of the cliff slope as well as protecting the foot of the cliff against erosion.

Land use and natural habitats/plant communities near the cliff

Land use and land use changes near the cliff can have an impact on the cliff habitats. In particular agricultural uses, urbanisation and tourism development on the cliff top or in the surroundings of the cliff can introduce pollution into the ecosystem and have negative effects on the biological communities. Recording and analysing land uses and plant communities near the cliffs can be carried out by remote sensing and compiling information from available land use, vegetation and habitats maps.

Anthropogenic disturbances

Anthropogenic disturbances can alter the natural condition in cliffs and can include pollution, trampling, tourism, sport and recreational activities, infrastructures, etc. The impacts can be assessed by measuring the surface affected through visual inspection during field surveys, using aerial photography or remote sensing.

Table 5. Proposal of variables for sea cliff habitats (habitat types: 1230, 1250, 1250)

Variable name	Metrics (units)	Measurement methods	Application
1. Abiotic characteristics			
1.1 Physical characteristics			
Lithology	Classes: rock types, soft hard rocks and mineral substrate	Based on existing documents, lithological maps, etc.	D
Cliff morphology features: Surface, height, slope, orientation	Meters, degree of slope, etc.	Digital terrain models (DTM), LiDAR for elaboration of orientation and height maps.	D
Oceanographic variables: waves, currents, and tides	Wave exposure, currents and tides, changes over time	Characterisation of the variables based on information available from national agencies and organizations.	D
Stability: Linear erosion	Volumetric changes between surveys.	Volume of eroded material on the basis of differences detected between surveys. Multi-temporal LiDAR data comparison.	E
Stability: mass movement, rock fall, landslides	Volumetric changes, between two periods. Presence of evidence of instability	Photogrammetry (using drones), Airborne Laser scanning, LiDAR, Radar interferometry (InSAR). Mapping of evidence of instability: : rock fall, landslides, rills, etc.	E
1.2 Chemical characteristics			
Soil pH	pH values in soil	pHmeter- datalogger	D
Soil salinity	Electrical conductivity	Soil analysis with datalogger	D
Amount of P, N and K in soil	mg/kg	Soil analysis in laboratory	E
Cation Exchange Capacity (CEC)	cmolc/kg	Soil analysis in laboratory	R

Variable name	Metrics (units)	Measurement methods	Application
2. Biotic characteristics			
2.1 Compositional characteristics			
Characteristic species: vascular plants, bryophytes, algae	Presence and number of species	Record characteristic species in the field or by photo surveys, in different zones of the cliff, using reference lists of species from regional and local inventories.	E
Nesting seabirds	Presence and number of species, number of nests and breeding pairs	Record species and nests in the field or by photo surveys, using reference lists of species from local inventories.	E
Animal species other than birds (reptiles, arthropods)	Presence and number of species	Record species in the field or by photo surveys, using reference lists of species from local inventories.	R
Nitrophilous plant species	Presence and number of species	Remote detection or record of nitrophilous species during field work based on reference lists	E
Invasive alien species	Number of species	Remote detection or record of IAS during field work	E
2.2 Structural characteristics			
Total cover of vascular plants	Percentage cover of vegetation in the monitoring plot	Photo survey, visual assessment during field work, LiDAR, Multispectral camera	E
Cover of characteristic plant species and communities	Percentage cover in the monitoring plot	Photo survey, visual assessment during field work, LiDAR, Multispectral camera.	E
Cover of invasive alien species	Percentage cover in the monitoring plot	Photo survey, visual assessment during field work	E
2.3 Functional characteristics			
Presence and number of pollinator species	Presence and number	Assessed during field survey and with photo-survey	R
Phenology (flowering, fruiting) of relevant species	Presence and number	Assessed during field survey and with photo-survey	E

Variable name	Metrics (units)	Measurement methods	Application
Landscape characteristics			
Coastal defences	Presence and number	Visual assessment photography. Use of coastal defence maps.	E
Coastline changes	m/year	Estimation of coastline progression or retreat. GIS with Digital Shoreline Analysis System (DSAS), Open Digital Shoreline Analysis System (ODSAS).	R
Land use and other habitats/plant communities in surrounding area	Presence and types of land use	Recording land uses via remote sensing.	E
Anthropogenic disturbances: pollution, trampling, urbanization			
Anthropogenic disturbances: pollution, trampling, urbanisation	Percentage of surface occupied at monitoring plot level.	Visual assessment of visible impacts. Remote sensing	E

D: Descriptive. E: Essential. R: Recommended.

3.2 Definition of ranges and thresholds to obtain condition indicators

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

Reference levels are typically defined with upper and lower values reflecting the endpoints of a condition variable's range, which can then be used in re-scaling. For instance, the highest value may represent a natural state, while the lowest value may represent a degraded state where ecosystem processes fall below the threshold required to maintain function (Keith et al., 2013, in United Nations 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.

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.

Thresholds, limits and reference values must be tested against sufficiently broad data sets, covering the full range of habitat conditions – from degraded to high-quality examples.

Habitat condition assessments are based on determining whether the variables used indicate good or not good condition, according to defined threshold or ranges. 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 – e.g., through re-scaling – in order to build indicators that combine multiple variables.

These values are normalised using reference levels and reference conditions, allowing comparison across variables. Measurement values are thus 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 Aggregation methods at the local scale

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

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

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

3.3.1 Overview of aggregation methods

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

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

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

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

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

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

Conditional rules

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

Simple additive methods and averaging approaches

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

Weighting

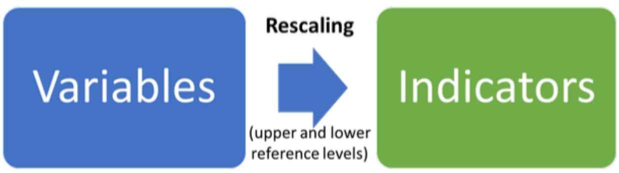
Differential weighting of indicators may be applied when calculating sums, means, or medians. The choice of weighting system should reflect the relative importance of each indicator in determining the overall condition of the ecosystem. Ideally, the approach should be supported by a clear scientific rationale and informed by input from ecologists with expertise in the relevant ecosystem types. However, a robust basis for assigning weights is not always available. In such cases, weighting often relies on expert judgment, which can be subjective, as expert opinions may differ considerably.

Normalization of variables values (rescaling)

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

This involves rescaling the raw data based on reference values or thresholds that define the boundary between good and not good condition for each variable. By rescaling the condition variables, indicators are standardised to the same scale, making it possible to aggregate them into condition indices that reflect the overall condition at a given plot or location (Figure 6).

Figure 6. Deriving condition indicators by rescaling the variables



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

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 main steps for aggregation are described below.

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). The value of each variable will be thus in the range from 0 to 1.

Step 2 – Aggregation of normalised variables

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:

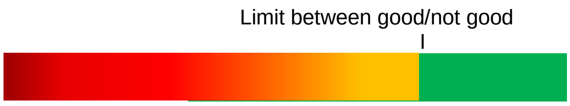
$$Local\ condition = \sum_{1}^{n} v_i * w_i/\mathrm{n}$$

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 $\sum w_i = 1$. 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. This is a crucial step and, 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 Aggregation at biogeographical scale

As a minimum requirement, MSs must adhere to the recommendations from the Article 17 reporting guidelines for the 2013-2018 period. These guidelines state that if 90% of a habitat area is in 'good' condition, the 'structure and functions' parameter is considered 'favourable'. Conversely, if more than 25% of the habitat area is reported as 'not in good condition', the 'structure and functions' parameter is deemed 'unfavourable-bad'.

This rule highlights the importance of using a sample design that is sufficiently representative of the total habitat area and diversity.

Moreover, MSs may choose to adopt stricter thresholds. Therefore, the ‘one-out, all-out’ approach (minimum aggregation) can also be considered appropriate, for instance in the case of very rare habitats.

3.5 General monitoring and sampling methods

Surveying plants and animals on coastal cliffs by traditional methods is challenging mainly because of site inaccessibility, especially in the case of cliffs plunging directly into the sea. Conventional field sampling may be difficult or even impracticable on steep or vertical cliffs.

Where conventional field sampling is possible, climbing and rappelling techniques may be required, as well as remote data collection by means of optical tools (i.e., binoculars, telescopes, telephoto lenses). The use of Fixed Point Photography and/or Photo Point Monitoring has been suggested in inaccessible habitats. The use of oblique aerial photographs derived from video imagery captured using a helicopter, was proposed by Barron et al. (2011).

The use of a small Unmanned Aerial Vehicle (UAV) or drones has proven to be a useful survey tool to gather aerial images of cliffs, which combined with photo-interpretation and GIS analysis tools, allow to (Strumia et al. 2020): (a) recognise and map the plant species, (b) derive and measure the area of distribution on the cliff of habitat and species, and (c) count species individuals and gather quantitative data on their projected area.

Monitoring should be conducted by applying a combination of vertical transects from top to bottom of the cliff, capturing the different recognisable zones and variability of the cliff wall, where monitoring plots can be placed. This approach is proposed in several EU MSs (e.g., Barron et al., 2011; Boulet & Mistarz, 2024), which require using transects and dividing them into homogeneous sections where the relevant variables will then be assessed.

The length of the transects and the size of the monitoring plots could vary depending on the characteristics of the habitat location and the floristic diversity. The shape of the plot can also vary depending on the local conditions.

3.6 Selection of localities

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

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

- Ecological variability: Localities must represent the full range of ecological diversity and variability within the habitat type. Selection should include different ecotypes or subtypes, successional stages, and reflect key environmental gradients such as altitude, soil type, moisture levels, geomorphological features, and topography.
- Spatial coverage: Adequate spatial coverage is essential to capture habitat heterogeneity. Localities should be selected across the full geographical range of the habitat type within the region, ensuring they are well distributed and represent a significant proportion of the habitat's total occupied area.
- Degree of conservation and exposure to pressures and threats: The selection of monitoring localities should include areas with varying degrees of conservation and degradation, in order to capture the full range of habitat condition across its distribution. This includes both well-conserved areas with minimal human impact, and areas affected by degradation and subject to different pressures. To reflect the diversity of pressures acting on the habitat, localities should span a range of intensity levels – from low to high – and account for different sources of disturbance, such as urbanisation, agriculture, and climate change.
- Presence inside and outside Natura 2000 sites: The assessment and monitoring of habitat conservation status must be carried out both inside and outside Natura 2000 sites. This requires selecting localities – and an appropriate number of plots – that reflect the proportion to the habitat's distribution within and outside the Natura 2000 network.
- Habitat fragmentation at landscape scale: Localities should be selected based on landscape metrics such as patch size and connectivity. Including both isolated and well-connected sites allow for the assessment of fragmentation effects on habitat condition. Understanding these patterns is essential for developing strategies to mitigate the negative impacts of habitat fragmentation.
- Lack of information: Including areas where data are lacking contributes to building a more comprehensive dataset. Selecting localities in historically under-sampled regions ensures a more balanced and complete understanding of habitat condition across its range. This helps to address data gaps and supports more informed conservation planning.
- Accessibility and practicality: Monitoring localities should be accessible for regular field visits, taking into account logistical factors such as distance from roads and ease of access. Practical considerations also include the safety of field personnel and the feasibility of transporting equipment to and from the site.
- Historical data and existing monitoring sites: Making use of existing monitoring sites with historical data can strengthen the understanding of long-term trends and changes in habitat condition. Such sites provide valuable baselines for comparison and support more robust trend analyses over time

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

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

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

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

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

Box 1- 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 Other relevant technologies

Effective monitoring of cliff habitats requires a comprehensive approach that combines traditional field surveys with modern technological methods. Field surveys remain the cornerstone of most assessment methodologies, providing detailed, ground-level data essential for understanding the complex dynamics of cliff ecosystems.

To enhance the scope and efficiency of cliff habitat monitoring, remote sensing and GIS analysis are increasingly being integrated into assessment protocols. These technologies complement field data by providing landscape-scale perspectives and facilitating the analysis of changes over time. Satellite imagery and aerial photography can reveal broad patterns of vegetation cover changes and human impacts that might be less apparent at ground level. Where available, existing maps can also provide valuable baseline data, allowing for comparative analyses and the tracking of long-term trends.

New technologies provide useful tools to assess the status of cliff habitats and should be further explored.

Remote sensing, LiDAR, photo survey techniques and the use of drones can be useful to measure some key variables in cliff systems, as described in previous sections, including the following:

- Vegetation characteristics: species composition, vegetation cover and phenological patterns.
- Cliff morphology: height, shape, slope, orientation.
- Erosion patterns.
- Landscape characteristics (e.g., land use, plant communities near de cliff) and human impacts (e.g., urbanisation, recreational use).

Satellite imagery provides a broad-scale view of cliff systems, allowing researchers to track changes in vegetation cover and land use over time. Multispectral sensors on satellites can detect different vegetation types and their health. For instance, the Normalised Difference Vegetation Index (NDVI) derived from satellite data can be used to quantify vegetation cover and its changes.

LiDAR has become an invaluable tool for assessing cliff morphology and vegetation structure in three dimensions. This technology offers several advantages. It can create detailed digital elevation models (DEMs) of cliff systems, revealing subtle changes in cliff morphology. Repeated LiDAR surveys allow for the detection of changes in cliff height, shape, and vegetation cover over time.

4. Guidelines for evaluating fragmentation at appropriate scales

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

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

Remote sensing and GIS technologies play a crucial role in this process. Satellite imagery, aerial photography, and GIS mapping allow for the systematic identification of habitat patches, evaluation of their size, shape, and proximity, and consistent tracking of landscape changes over time (Foody, 2023).

It is important to interpret fragmentation metrics within an appropriate ecological context. Some isolation and small patch size are natural features of habitats and do not inherently indicate ecological degradation. However, anthropogenic fragmentation, in the form of new infrastructure, land-use changes, or resource extraction, can pose significant risks by further reducing patch size, increasing isolation, and impeding the dispersal of specialised flora and fauna.

5. Next steps to address future needs

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

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

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

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.

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Annex 1. Examples of variables and methods included in the methodologies available from EU Member States for assessing and monitoring sea cliff habitats (1230, 1240, 1250)

Examples of variables	Metrics	Measurement procedure	MS and references
1. Abiotic characteristics			
1.1 Physical state characteristics			
Cliff stability and dynamics	Importance: High, Medium, Low	Visual identification or mapping evidence of different erosive processes that affect the coastal façade indicating instability (landslides, collapses, gullies, etc.), generated between two measurement moments, in various cliff sectors. This can be based on photointerpretation.	DE: Krause et al., 2008; ES: Pérez-Alberti, 2019; PL: Łabuz 2012; GR: Dimopoulos et al., 2018
Height and slope	m	The height and slope of the highest cliff present in the transect are estimated.	SE: Hedenås et al., 2020
Cliff slope inclination and dynamics	degrees, %	– Initial field work for morphological characterization, analysis of micro-drainage density, surface weathering. – Measure with a tape and a graduated pole of the length and height; determination of surface parameters by means of a computer application, if adequate digital cartography is available. – Realization of serial topographic profiles with total station. – Direct measurement of gravitational and slope phenomena using a sediment trap. – Indirect measurement of gravitational and slope phenomena through monitoring and use of cartography.	PL: Łabuz 2012. IE: Barron et al., 2011
Areas with erosion and landslides	Score	Not provided.	DK: Fredshavn & Nygaard, 2014
Linear erosion	Intensity: High, Medium, Low	Study of the effects of surface and sub-surface runoff on cliffs, in terms of erosion induction: control of runoff by means of control plots on the cliff walls and collection of both surface and subsurface runoff flows.	ES: Pérez-Alberti, 2019

Examples of variables	Metrics	Measurement procedure	MS and references
Coastline retreat	Advance (>0) or retreat (<0) of the coastline	Mapping the lower and upper part of the cliffs to detect changes in the profile requires the integration of ortho-photographs from different years into a GIS that allows detecting differences through high-resolution digital models. Continuous photogrammetric surveys can be carried out with the help of drones or unmanned aerial vehicles (UAV. The Digital Shoreline Analysis System (DSAS) extension in ArcGIS developed by the US Geological Survey (Thieler et al. 2003) can be used to detect changes in the coastline. This tool, which uses the upper limit of the cliffs, can be used to calculate the statistical parameters of the coastline evolution between different flights.	ES: Pérez-Alberti, 2019
Sea waves range	NA	Expert visual assessment	PL: Łabuz, 2012
Wave Exposure	Classes	Wave exposure mapping and assessment according to the exposure classes	SE: Hedenås et al., 2020
Soil depth	cm	Studying soil profiles in the cliff, following the slope, in order to detect changes in soil depth, in order to know possible losses and gains over time.	ES: Pérez-Alberti, 2019
Soil temperature and humidity	ºC, %	Changes in soil temperature and humidity can be measured with data loggers and sensors that allow the measurement of both the temperature and humidity of the soil or rock at different intervals (daily, hourly, minute or second).	ES: Pérez-Alberti, 2019
Coverage of bare soil	%	Estimation of the percentage of bare soil cover by field survey.	IT: Angelini et al., 2016
1.2 Chemical state characteristics			
Soil chemical parameters: pH, salinity and eutrophic state	% deviation from values specific to the area	pH: measured with a pH meter in a soil/water suspension of 1:2,5. Salinity: measurement of electrical conductivity of an extract obtained from a soil/water suspension, e.g. 1:5 (10 g of dry and 50 ml of water). Eutrophic state of the soil: exchange cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), NH_4^{+}, nitrate (NO_3^{-}) and plant-assimilable P or 'bioavailable P' are determined in the laboratory.	ES: Pérez-Alberti, 2019
Organic content in the substrate	Not provided	Not provided	GR: Dimopoulos et al., 2018
Organic content in the substrate	Not provided	Not provided	GR: Dimopoulos et al., 2018

Examples of variables	Metrics	Measurement procedure	MS and references
2. Biotic characteristics			
2.1 Compositional state characteristics			
Typical vascular plants, and animals (birds, wild bees).	Presence	Completeness of the typical species inventory according to a list of typical species.	DE: Krause et al., 2008; PL: Łabuz, 2012.
Typical species including dominant species	%, Braun-Blanquet	For each polygon, it is assessed whether the species combination and dominant species are typical for the natural habitat.	BG: MOEW, 2013 IT: Angelini et al., 2016. GR:Dimopoulos et al., 2018
Number of characteristic species/ Total number of species	Rate	Visual assessment and count of the number of characteristic species of the cliff habitat by referring to a proposed list, as well as the total number of vascular plant species, at the scale of the plot. The proposed list can be completed by the operator at the local level if deemed relevant. It is strongly recommended to use flora adapted to the local context when available.	FR: Bicchierai & Mistarz, 2023.
Species richness	Number of species	Species inventory in the field	ES: Pérez-Alberti, 2019
Positive indicator species	Presence	Field assessment based on lists of species for each vegetation zone (splash zone, crevice and ledge zone, etc.)	IE: Barron et al., 2011
Negative indicator species including non-native species	Presence	Field assessment based on lists of species for each vegetation zone (splash zone, crevice and ledge zone, etc.)	IE: Barron et al., 2011
Number of nitrophilous species/Total number of species	Number	Visual assessment and count of nitrophilous species as well as the total number of vascular plant species, at the scale of the plot.	FR: Bicchierai & Mistarz, 2023.

Examples of variables	Metrics	Measurement procedure	MS and references
Typical plant communities	Presence and proportion (%)	Assessment of the presence of typical plant communities in the cliffs	Pérez Alberti, 2019
Vegetation composition	Presence and cover of species	Vegetation survey with assignment of coverage values (Braun-Blanquet scale or percentage coverage) to the total coverage and to all the individual species present within the survey, including dominant, typical, disturbance indicator, alien species (e.g. *Carpobrotus acinaciformis, C. edulis*). alien species). Qualitative-quantitative reduction in endemic species of the genus Limonium indicates degradation and/or disturbance.	Angelini et al., 2016
Animal species	Presence of target species	Identification and census of the presence of target animal species relevant for the assessment of the conservation status of the habitat.	Angelini et al., 2016
Presence of animal species indicating good conservation status	Presence (bonus)	Visual assessment and record of the presence of animal species indicating good status of the cliff habitat by referring to a proposed list of species. The aim is to assess the functional role of the habitat as a support for biodiversity and reproduction for fauna. This indicator provides a bonus in the assessment, at the scale of the habitat ecocomplex.	FR: Bicchierai & Mistarz, 2023.
Presence of invasive and exotic species	Presence of target species	Assessment of the percentage of invasive and/or exotic species in the coastal cliff communities, with special attention to the number of communities affected by these taxa and the degree of abundance/dominance over native species specific to the cliffs in the different sectors (ES). Visual assessment of the occurrence of invasive species (DK).	ES: Pérez Alberti, 2019 DK: Fredshavn & Nygaard, 2014
Habitat ruderalisation and presence of invasive species	%	The presence and percentage cover of ruderal and/or replacement plant species is taken is evaluated in the field.	BG: MOEW, 2013
Presence of species that indicate environmental quality or pollution	Presence of target species	inventories of vegetation and identification of bioindicator species (e.g. lichens) and indicator species of contamination.	ES: Pérez Alberti, 2019

Examples of variables	Metrics	Measurement procedure	MS and references
Number of characteristic species	Number of present characteristic species	Visual assessment of number of species belonging to the characteristic procession of vegetation most common indicators of Atlantic coastal cliffs (*Armerio maritimae – Festucetea pruinosae* only). Simple count at the transect level. Example of species: *Armeria maritima, Beta vulgaris maritima, Plantago maritima.*	FR: Boulet & Mistarz, 2024
Presence of animal species indicating good conservation status	Presence	Visual assessment of presence of animal species included in local inventories. Invertebrates: *Exapion ulicis, Melitea cinxia*. Birds: *Corvus monedula, Alca torda, Hydrobates pelagicus*. Bat: *Rhinolophus ferrumquinum.*	FR: Boulet & Mistarz, 2024
2.2 Structural state characteristics			
Typical habitat structure		Expert judgment of the completeness of habitat structures typical of the habitat:	DE: Krause et al.2008
Vegetation cover	%	Analysis of the surface covered/not covered by vegetation. Coverage of dominant, typical, disturbance indicator, alien species (e.g. *Carpobrotus acinaciformis, C. edulis*). (IT) Estimate of vegetation cover Including all herbs, ferns, graminoids, etc. in various cliff sectors (SE).	IT: Angelini et al., 2016 SE: Hedenås et al., 2020
Characteristic species cover/ total species cover	Rate	For 1240. Visual assessment, at plot level, based on a list of species. The proposed list can be completed by the operator at the local level if deemed relevant. It is strongly recommended to use flora adapted to the local context when available.	FR: Bicchierai & Mistarz, 2023.
Halophytic species cover/ total vegetation cover	Rate	For 1240. Visual estimation at plot level using a reference list for halophytic species. The presence of halophytic species, adapted to a salty environment, is a sign of increased marine influence and is considered a positive indicator (the habitat is considered to be in good status when the coverage of halophytic species is higher than that of non-halophytic species. The proposed list can be completed by the operator at the local level if deemed relevant. It is strongly recommended to use flora adapted to the local context when available.	FR: Bicchierai & Mistarz, 2023.
Nitrophilous species cover /total vegetation cover	Rate	Visual assessment of the coverage of nitrophilous species present in the habitat by referring to a proposed list This variable provides information on	FR: Bicchierai & Mistarz, 2023.

Examples of variables	Metrics	Measurement procedure	MS and references
		the amount of nitrogen present in the soil. The status is good when the coverage of nitrophilous species is low compared to the total coverage.	
Invasive alien species coverage	% cover	For 1240. Visual estimation, at plot level.	FR: Bicchierai & Mistarz, 2023.
Ryegrass and other negative species cover	% cover	Visual estimation.	DK: Fredshavn & Nygaard, 2014
Coverage (%) of species indicating pollution	%, Braun-Blanquet scale	Visual estimation, at plot level.	FR: Bicchierai & Mistarz, 2023.
Coverage of trophic enrichment indicator species	% cover	Visual assessment of the average coverage of species based on a proposed national species inventory. On the 5 meters-width transect, relatively floristically homogenenous sections will be identified. Within these sections, the coverage of the indicator species will be assessed. The sum of the coverage values per species will be performed per section and then the average is calculated per transect. Example of species indicators of trophic enrichment: *Achillea millefollium, Anisantha rigida, Dactylis glomerata*.	FR: Boulet & Mistarz, 2024
Coverage of negative species	% cover	Visual assessment of species listed in the national inventory and refined at local level. Total coverage is assessed by dividing the transect into homogeneous sections and then calculate the average per transect. Negative species include invasive species: *Baccharis halimifolia, Jacobea maritima, Pteridium aquilinium.*	FR: Boulet & Mistarz, 2024
Coverage of lichen structures	% cover	It is presented as a complementary variable but not mandatory, heavily dependent on the operator skills. Visual assessment of covering of lichen layer, number of types of lichens and majority type.	FR: Boulet & Mistarz, 2024
2.3 Functional state characteristics			
Regeneration of shrubs		Expert visual assessment	PL: Łabuz, 2012
Presence of specific functional traits or biotic forms	Presence / absence	Not provided	GR: Dimopoulos et al., 2018
Clear pattern of succession	Not provided	Not provided	GR: Dimopoulos et al., 2018

Examples of variables	Metrics	Measurement procedure	MS and references
3. Landscape characteristics			
Habitat fragmentation	%	The presence of new (after mapping) anthropogenically created structures (buildings, ports, roads, etc.) fragmenting the polygon is taken into account.	BG: MOEW, 2013
Landscape metrics	Not provided	Spatial analysis using GIS.	IT: Angelini et al., 2016
4. Other			
Presence of artificial structures	Presence and extent	Visual inspection and recording of paths, tracks, sea defences affecting the cliff	IE: Barron et al., 2011 DE: Krause et al., 2008
Coastal protection	Presence	Visual inspection and recording	DK: Fredshavn and Nygaard, 2014
Leisure activities, garbage	Presence and intensity: high, medium, low	Visual inspection and recording	DE: Krause et al., 2008 SE: Hedenås et al., 2020
Fencing	Presence	Identification of any kind of fence or stone wall within the transect	SE: Hedenås et al., 2020
Nutrient impact on upper areas	Not provided	Not provided	DK: Fredshavn & Nygaard, 2014
Agricultural, forestry and livestock activity	Presence	Mapping of changes observed from field sampling or orthophotography; if there are activities affecting the cliffs, they are visible by the presence of waste, trampling, opening of paths or roads, etc	ES: Pérez Alberti, 2029
Degree of urbanization	Presence	Identification of new constructions, roads, tracks, new paths or changes to existing ones based on information gathered form the Land Use Information System in Spain and orthophotograph from the National Aerial Orthophotography Plan.	ES: Pérez Alberti, 2029
Density of anthropic elements	Presence	Density of occupation of anthropic elements, as roads, houses, industrial buildings, tourist establishments and other types of infrastructure, over the total surface of the coastal strip of 500 m from the shoreline, using existing	ES: Pérez Alberti, 2029

Examples of variables	Metrics	Measurement procedure	MS and references
		databases: CORINE, Land Use Information System in Spain, urban planning, etc.	
Presence of tourist activities on cliffs and rocky platforms	Presence	Analysis of the implications of different land uses on coastal dynamics and on geomorphological and biotic stability. Mapping of land uses in the vicinity of the cliff, identification and qualification of the associated impacts and risk assessment for the habitat type.	ES: Pérez Alberti, 2029
Quantifiable surface damage		Identification of visible damage on the habitat polygon and estimate of the surface area impacted. Each damage identified is assigned a score from 1 to 2 depending on its origin (anthropogenic or natural), the habitat area impacted or its location in relation to the habitat polygon. The sum of the scores assigned to each damage gives the overall score for the indicator. A list of quantifiable surface damage potentially present on cliffs is used, including trampling, fires, waste, natural erosion, clearing, presence of *Carpobrotus* sp., litter, etc..	FR: Bicchierai & Mistarz, 2023.
Diffuse damage		Based on expert assessment, the overall impact of diffuse damage, whose impact cannot be quantified on the surface, such as atmospheric nitrogen deposition, is recorded.	FR: Boulet & Mistarz, 2024
Alteration, damage to the habitat	Score	Visual estimation of damaged transect surface. Each impact is given a score of 1 or 2 depending on anthropic or natural origin. Examples of scoring: Coastal protection (2), Trampling < 33% (1) and > 33% (2).	FR: Boulet & Mistarz, 2024

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KH-01-25-200-EN-N

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