A prototype methodology to mapping selected bio-physical aspects of CICES-defined Aesthetics in Scotland

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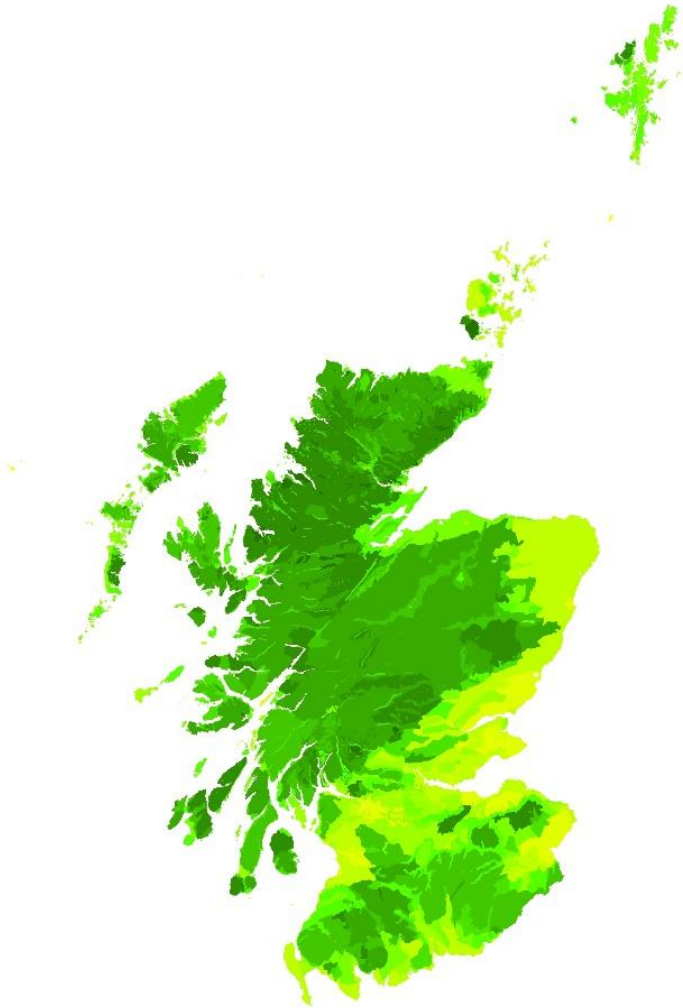

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Executive Summary

This report forms part of the project *Assessing ecosystem service delivery and interactions* (RD1.4.1 Objective B), that is part of the RESAS Strategic Research Programme (2016-2022) Work Package 1.4 on Sustainable and Integrated Management of Natural Assets. The project focused on the development of prototypes of Cultural Ecosystem Services (CES) maps for the Natural Asset Register: Data Portal (NAR; Donnelly et al., 2021). Central to the work is the identification, development and application of appropriate, robust yet flexible approaches for mapping CES.

The focus of this report is on building a prototype methodology for mapping CES-"Aesthetics" at the national scale of Scotland, within the context of CICES v4.3. Version 4.3 limits itself to the description of final services from the environment through the bio-physical output from the ecosystems. The 2018 update (CICES v5.1) includes a second part to the assessment by adding a description of the contribution to an eventual user or benefit as well as inclusion of abiotic elements of the environment. The latest version of CICES also provides further details on "Aesthetics" by describing it as "The beauty of nature" with the following ecological clause: "The bio-physical characteristics or qualities of species or ecosystems (settings/cultural spaces)".

This project started prior to the CICES update to 5.1. To allow for consistency with other CES work already produced as part of the 2016-2022 RESAS programme, the decision was taken to adhere to the framework of CICES v4.3. Thus, **the chosen methodology will limit itself to the bio-physical approach of landscape characterisation** (Siemensen et al., 2018). Within the context of bio-physical approaches, perceived landscape aesthetics has been reported to be consistent with the degree of naturalness and diversity in landscapes (Frank et al., 2016), and also correlated with ecological landscape qualities (Sahraoui et al., 2021). **The prototype mapping methodology of Aesthetics presented in this report thus has an underlying assumption of a correlation of Aesthetics qualities with natural/ecological qualities and diversity.**

However, **the aesthetics of landscape is a broad research subject, and it is investigated by scientists from a wide range of disciplinary backgrounds**. The scientific research in Landscape Aesthetics includes studying the origin of Aesthetics perceptions (evolutionary, biological, cultural); Landscapes Aesthetics' link to biodiversity and the proposition that knowledge can shift our perception of beauty; and the aesthetics of necessity to support biological diversity in the context of global climate change (Jorgensen, 2011). **The relationship between ecological quality and human preferences, on which this reported prototype mapping is based, has been contested** (Gobster et al., 2007; Zhao et al., 2017). The sense of aesthetics can also be shaped and elicited by bio-physical environments that have been formed by human activity through social and economic systems. For example, agricultural and cultural landscapes can elicit aesthetic experiences such as perceived care and identity (e.g. Nassauer, 1995; Brady et al., 2018), despite these types of landscapes often lacking in ecological quality. Those dimensions of Aesthetics are not captured in the chosen bio-physical approach reported here.

The prototype mapping methodology presented in this report does not aim nor claim to be fully encompassing of all aspects of Aesthetics research topics nor of the common use of the word. The focus is on selected bio-physical aspects of the environment. As with the prototype mapping for Cultural Heritage and Entertainment CES (Aalders et al., 2018) **also conducted as part of the RESAS 2016-2022 programme, this work highlights a methodological approach, rather than providing an authoritative and definitive result.** A more holistic approach, closer to the European Landscape Convention and CICES v5.1, with strong local stakeholder and public engagement could be part of a follow up project.

The chosen bio-physical methodology is based on Frank and Walz's (2017) German case study which forms part of a collection of approaches to mapping ecosystem services developed through the EU-funded project ESMEREALDA – Enhancing ecosystem services mapping for policy and decision making (Burkard and Maes, 2017). Part of the analysis was adapted for Scotland's landscape and available spatial datasets. The Aesthetics values of the landscapes were calculated for Landscape Character Assessment (LCA) disaggregated spatial units (smallest continuous areas) as they provide relatively homogeneous landscape characteristics. Ten individual metrics were calculated:

1. relief diversity
2. density of freshwater edges (without coasts)
3. density of coastlines
4. proportion of unfragmented open space greater than $100km^2$
5. hemeroby index
6. core area index of 11 semi-natural areas
7. Shannon diversity index
8. patch density of native woodland
9. patch density of heather areas
10. density of forest-dominated ecotones

These metrics were averaged into one final Aesthetics prototype map with equal weights (Figure 1).

The ten metrics and their Aesthetics values and ranks at the LCA "Level 3" are also summarised in a non-spatial format (bar chart in Figure 11 & table in Appendix E).

The resultant prototype map of Aesthetics for selected bio-physical aspects exhibits a pattern of higher aesthetics values in the mountainous areas towards the West Coast and around the Cairngorms, whereas the lowest values are concentrated in agricultural and dense population centres (predominantly in the east). The highest aesthetics values are linked to the large contribution of the Unfragmented Open Space metric and undisturbed core areas of habitats. The lowest values arise from a combination of limited unfragmented open space due to transport network interruptions, high level of anthropogenic disturbance (low hemeroby index) and limited continuous large areas of habitats (core area index and patch density indices).

Ranking in some locations might raise questions. For example, on Hoy, the moorland on its east side is more highly ranked than Hoy's west side, which is part of a National Scenic Area (NSA). Both sides have very similar values, with the exception of the metric on "Patch density – Heather", which favours the non-NSA side. The striking difference in the final set of prototype maps stems from the unfortunate threshold in the map colour classification, which artificially exacerbates this difference beyond its meaning. The overall low ranking of coastal areas can be linked to multiple cumulative issues: i) ratio length of coastline over spatial unit is dependent on how the LCA spatial units were delimited (smallest islands rate the highest); ii) the openness of the sea is not considered in any metrics except the Coastline metric; and iii) small islands were often missing from spatial datasets (particularly LCM2007), thus misrepresenting them in the overall ranking.

When summarised at LCA Level 3 (broad landscape types), "Lowland Loch and Shore" (Loch Lomond southern shores), "Highland Straths", "Highland and Island Glens" and "Highland Cnocan" were the four highest ranked. The two lowest ranked included "Smooth Upland Moorland Hills" (area situated between Forfar and Brechin), "Lowland Cities, Towns and Settlements". The interpretation of the LCA Level 3 ranking requires familiarity of their spatial locations and extent, this is particularly important when the Level 3 label might lead to overestimate their representation (e.g. "Smooth Upland Moorland Hills" could have been expected to include most Scottish moorland hills, which it does not).

These prototype rankings of Aesthetics for the selected bio-physical aspects are a reflection of the methodology used particularly the mix of metrics, limitations in input data and the weights applied.

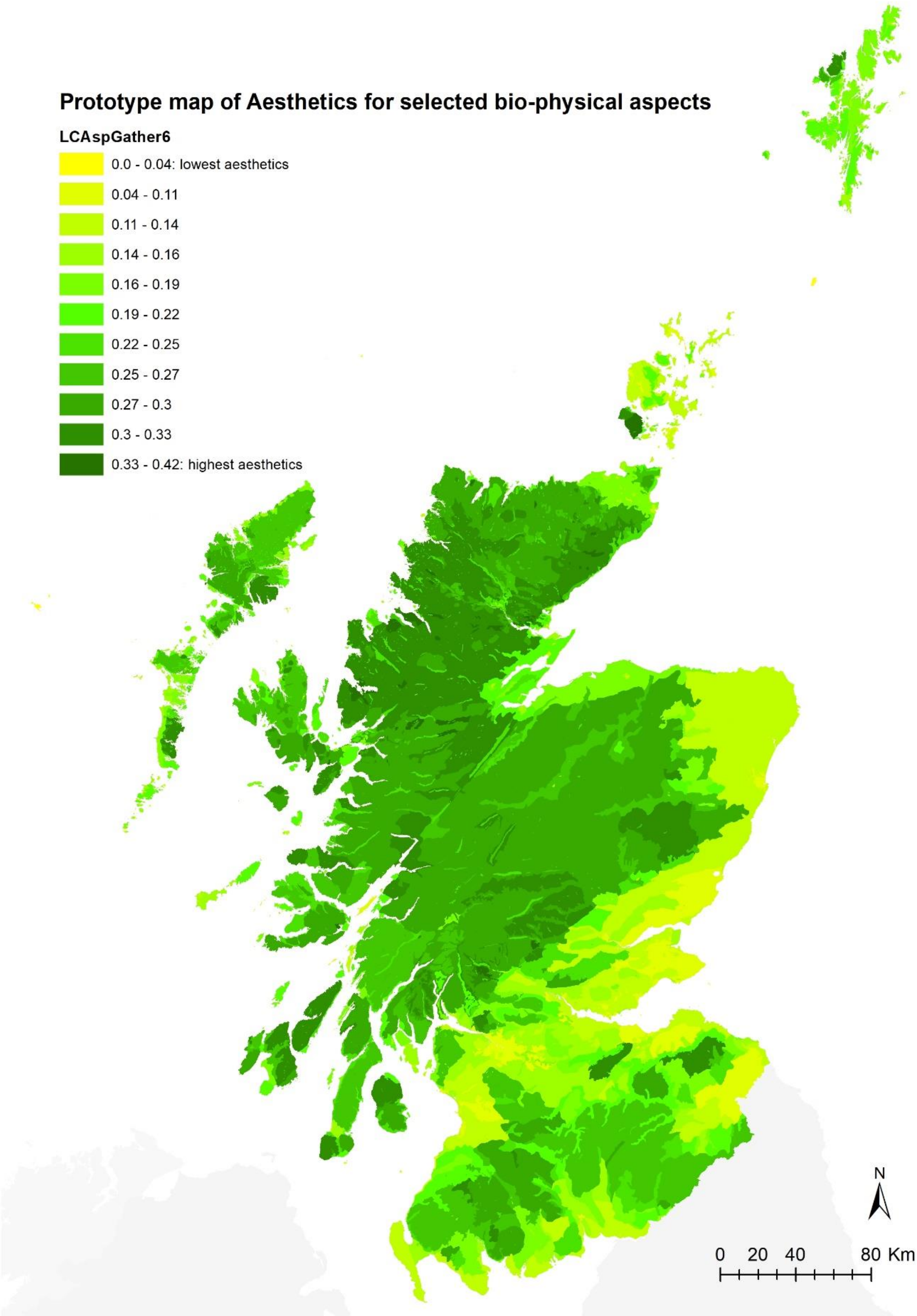

Figure 1. Estimated Aesthetics values for selected bio-physical aspects from a prototype methodology at the Landscape Character Assessment smallest spatial units (LCAsp). Natural breaks classification with in yellow: lower Aesthetics values for selected bio-physical aspects, in dark green: higher Aesthetics values for selected bio-physical aspects.

When compared with existing maps thematically related to Aesthetics, similarities with the Relative Wildness map (SNH, 2014) were apparent, and were reflected in the high ranking of every Wild Land Areas (SNH, 2014). Similar but less strong patterns were also found with National Scenic Areas and National Parks; the prototype Aesthetics scores for Local Landscape Areas included a non-negligeable proportion of lower ranking scores. These comparisons highlight a better general agreement with national scale designations and national map of Wild Land Areas, and far less agreement with local scale designations. The included comparisons are only indicative, and more in-depth assessments would be required to thoroughly investigate and validate those preliminary assessments.

Overall, the choice and respective weights of the metrics included could be refined with more in-depth study and stakeholder engagement. In particular, the next step in the development of this work could be to expand the methodology to have a more holistic approach, fully including participatory social science methods to incorporate the perspectives and perceptions of Scottish landscapes from stakeholders, the general public and visitors, and the relevance of proxies for mapping at national scale.

Content

1 General context

1.1 Mapping Cultural Ecosystem Services for the Natural Asset Register: Data Portal (NAR)

The Scottish Economic Strategy (Scottish Government, 2015) recognises the importance of natural assets in achieving the Scottish Government's overall ambition to make Scotland a more successful country with opportunities for all. The development of a "Natural Asset Register: Data Portal" (NAR) has been funded by the RESAS Strategic Research Programme (SRP) [1] to create a publicly accessible register of Scotland's natural assets (Donnelly et al., 2021). The Natural Asset Register: Data Portal (NAR) aims for information at a national level and is structured in line with the CICES classification (https://cices/eu).

Research under RD1.4.1 Objective B (Assessing ecosystem service delivery and interactions) provides data for analysis of ecosystem services (ESS) relationships and trade-offs. Cultural ecosystem services (CES) have been the least well developed among the ESS in terms of methods, indicators and data sources although the scientific discourse on CES is rapidly addressing this issue (see Aalders and Stanik, 2016).

Within RD1.4.1, a focus of CES work has been specifically on the development of prototype CES maps that explore the basis for developing a flexible, but systematic process of mapping CES for inclusion in the Natural Asset Register: Data Portal (NAR; Donnelly et al., 2021). The processes need to be able to incorporate new data and indicators as well as new methodologies for CES. **The emphasis has been on developing methods that take advantage of existing available data** (see Aalders and Stanik, 2016). Prototype maps have been developed for cultural heritage and entertainment to illustrate the use of polygon and point data respectively (Aalders et al., 2018).

The third class for which prototype mapping was to be done is "Aesthetics" as named under CICES v4.3. The CICES classification was updated to version 5.1 during the lifetime of this project, the implications are discussed in the next section.

1.2 CICES classification versions update

The project started under **CICES v4.3**, which is the first fully operational version published in 2013 (Table 1). The classification focuses on describing ecosystem outputs from living processes as they directly contribute to human well-being (Haines-Young and Potschin, 2013). The **classification is limited to the final services from the Environment with the "Social and Economic system" considered outside the scope of the classification**, i.e. beyond the "boundary production" line (Figure 2).

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[1] Scottish Government's Strategic Research Programme – Theme 1 – Natural Assets

Table 1. Cultural Ecosystem Services Classification CICES v4.3 – Cultural section (Haines-Young and Potschin, 2013)

Division	Group	Class	Class type	Examples
Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/ seascapes in different environmental settings	By visits/use data, plants, animals, ecosystem type	In-situ whale and bird watching, snorkelling, diving etc.
		Physical use of land-/seascapes in different environmental settings		Walking, hiking, climbing, boating, leisure fishing (angling) and leisure hunting
	Intellectual and represent-tative interactions	Scientific	By use/ citation, plants, animals, ecosystem type	Subject matter for research both on location and via other media
		Educational		Subject matter of education both on location and via other media
		Heritage, cultural		Historic records, cultural heritage e.g. preserved in water bodies and soils
		Entertainment		Ex-situ viewing/experience of natural world through different media
		Aesthetic		Sense of place, artistic representations of nature
Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Spiritual and/or emblematic	Symbolic	By use, plants, animals, ecosystem type	Emblematic plants and animals e.g. national symbols such as American eagle, British rose, Welsh daffodil
		Sacred and/or religious		Spiritual, ritual identity e.g. 'dream paths' of native Australians, holy places; sacred plants and animals and their parts
	Other cultural outputs	Existence	By plants, animals, feature/ ecosystem type or component	Enjoyment provided by wild species, wilderness, ecosystems, land-/seascapes
		Bequest		Willingness to preserve plants, animals, ecosystems, land-/seascapes for the experience and use of future generations; moral/ethical perspective or belief

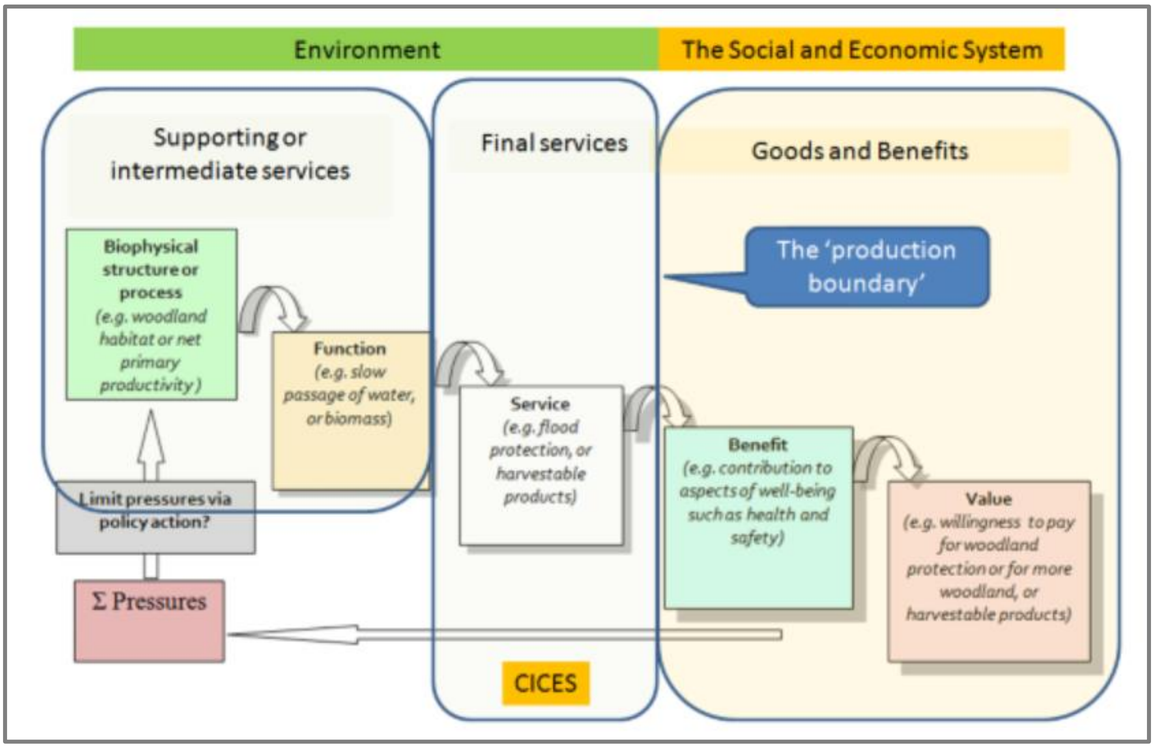

Figure 2. CICES 4 framework from Haines-Young and Potschin (2013; figure 4).

In 2018, during the life of this research project (RD1.4.1), the CICES classification was updated to **v5.1** (Haines-Young and Potschin, 2018), Table 2. **Each service is now defined by two parts: 1) description of the bio-physical output from the ecosystem** (i.e. what the ecosystem does), and **2) description of its contribution it makes to an eventual user or benefit** (i.e. how that output is used or enjoyed by people) (Haines-Young and Potschin-Young, 2018). The main classification still focuses on ways biotic/living systems ("biodiversity") contributes to ES, but for completeness, it now also includes relevant abiotic systems (Haines-Young and Potschin-Young, 2018).

Table 2. Cultural Ecosystem Services Classification CICES v5.1 – biotic (Haines-Young and Potschin, 2018)

Section	**Division**	**Group**	**Class** (by living system /environmental setting)	**V4.3 Equivalent**
Cultural (Biotic)	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	**Physical and experiential interactions** with natural environment	Characteristics of living systems that that enable activities **promoting health, recuperation or enjoyment through active or immersive interactions**	*Experiential use of plants, animals and land-/seascapes in different environmental settings*
			Characteristics of living systems that enable activities **promoting health, recuperation or enjoyment through passive or observational interactions**	*Physical use of land-/seascapes in different environmental settings*
		Intellectual and representative	Characteristics of living systems that **enable scientific investigation** or **the**	*Scientific*

		interactions with natural environment	**creation of traditional ecological knowledge**	
			Characteristics of living systems that **enable education and training**	*Educational*
			Characteristics of living systems that are resonant in terms of **culture or heritage**	*Heritage, cultural*
			Characteristics of living systems that **enable aesthetic experiences (code: 3.1.2.4)**	***Aesthetic (code: 3.1.2.5)***
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have **symbolic meaning**	*Symbolic*
			Elements of living systems that have **sacred or religious meaning**	*Sacred and/or religious*
			Elements of living systems used for **entertainment or representation**	*Entertainment*
		Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have **an existence value**	*Existence*
			Characteristics or features of living systems that have **an option or bequest value**	*Bequest*
	Other characteristics of living systems that have cultural significance	Other	Other	*Not recognised in V4.3*

As the CICES v4.3 was used for two previously studied CES, Cultural Heritage and Entertainment (Aalders et al, 2018; Alders and Stanik, 2019), it was decided to continue with the same version for the CES Aesthetics. Thus **the focus for the prototype mapping methodology reported here is on the final output from the environment and not specifically on the social and economic system** (Figure 2). Version 5.1 includes this as its first part of ES definition, namely the "description of the bio-physical output from the ecosystem". The second part, which is **"description of its contribution to an eventual user or benefit" will not be addressed here**. Version 5.1 is also providing further descriptors of the Aesthetics class (Table 3), those are considered to inform the scope of this project. The limitations of this will be explored in the next two sections (1.3 and 1.4) and in the Discussion (section 6.2 "Wider discussion on alternative methodologies").

Table 3. Aesthetics descriptors from Cultural Ecosystem Services Classification CICES v5.1 (Haines-Young and Potschin, 2018)

Simple descriptor	Ecological clause	Use clause	Example Service	Example Goods and Benefits
The beauty of nature	*The bio-physical characteristics or qualities of species or ecosystems (settings/cultural spaces) ....*	*... that are appreciated for their inherent beauty*	*Area of Outstanding Natural Beauty; panorama site*	*Artistic inspiration*

1.3 Landscape characterisation approaches: Bio-physical and Holistic

The CICES approach, which **focuses on the way living systems ('biodiversity') generate ecosystem services for human well-being** (Haines-Young and Potschin-Young, 2018), has primarily emerged from environmental accounting and natural science disciplines. Natural science or bio-physical approaches to landscape characterisation tend to consider that a descriptive investigation of the landscape by experts using transparent methods and spatial datasets are likely to reach repeatable results (McHarg, 1969 in Simensen et al., 2018). The landscape tends to be perceived as an object, independent from the observer (Simensen et al., 2018; Table 4).

In contrast, a holistic approach, also referred to as "Landscape Character Assessment" by Simensen et al. (2018), considers the landscape as a social construct or an Aesthetics object which is **dependent on human perceptions**, cf. Table 4. The "Landscape Character Assessment" approach is being followed by the European Landscape Convention, and usually is structured in 2 stages: a process of characterisation using social science (people-centred), followed by a judgement/value assessment based on this initial social-focused characterisation (Simensen et al., 2018).

Table 4. Two main approaches to landscape characterisation (from Simensen et al., 2018)

	Bio-physical	**Holistic or Landscape character assessment**
Origin	Natural science	Arts & humanities (landscape painting, aesthetics theory, cultural geography)
Landscape perceived as	Object	Social construct or **aesthetic** object
Landscape units	Tangible, physically delineated areas on the Earth's surface	Dependent on human perception and sociocultural relations to areas
Adopted by	Landscape ecology, natural geography	European Landscape Convention
Approach	Inductive method; knowledge of the landscape emerges from a general-purpose, intuitive and descriptive investigation by the expert, guided by approaches of available maps and other sources	2 stages: 1) relatively value-free process of characterisation, 2) judgement/value assessment based on knowledge of landscape character.
Degree of observer independence	'**Observer-independent**': a method is transparent and repeatable, in the sense that any person, accepting the method and the evidence, is likely to reach the same conclusion in the study (McHarg, 1969).	Dependent on human perception
Main tools	GIS & statistical analyses using Earth observation datasets & open databases	Photography, interviews, spatial datasets of land uses
Validation	Whether the landscape is correctly classified according to the applied method, and to the extent the method is based upon empirical evidence	e.g. whether the results of the characterisation is in concordance with how a representative sample of the population actually perceive the landscape, or relate to it. A major challenge with the ELC landscape definition has been to operationalise and validate

	the phrase 'as people perceive it': persons with different backgrounds, attitudes and interests will tend to perceive landscapes differently, and human perception may also vary with landscape type.

Methodologies to assess CES are still being developed from a range of disciplines (Aalders and Stanik, 2019). The methodologies to map CES tend to merge and recombine the two above approaches, by bringing social sciences and human perceptions within the boundaries of CICES classification.

1.4 Landscape Aesthetics

As a landscape characterisation, Aesthetics is a highly charged word generating contrasting and sometimes polemic discussions (Parsons and Daniel, 2002; Jorgensen, 2011; Gobster et al., 2007). Landscape aesthetic has been the focus of a wide range of scientific research (Haines-Young et al., 2018) from arts and humanities, environmental psychology and landscape ecology to landscape urbanisms; each with their own perspective on what aesthetics is and how to evaluate it, Table 5 (Parsons and Daniel, 2002; Jorgensen, 2011).

Table 5. Examples of research focus on Aesthetics (Jorgensen, 2011)

Aesthetics research focus	**by**
Origin of Aesthetics perceptions: evolutionary, biological, social or cultural	Environmental psychology
Ecological aesthetics: linked to biodiversity, knowledge can shift our perception of beauty	Nature science
Questioning if landscape aesthetics should be abandoned to landscape pragmatism and instrumentality.	Landscape urbanism
Aesthetics of necessity: to sustain biological diversity in the context of global climate change	Nature science

For this project, the focus is on Aesthetics within the context of the other CICES classes (Table 1 for CICES v4.3 and to some degree of Table 2 for CICES v5.1) and the research background of Natural living system (biotic). CICES v.5.1 indicates the ecological clause for the Aesthetics ES as "The bio-physical characteristics or qualities of species or ecosystems (settings/cultural spaces)" (Table 3). Hence, **our definition of Aesthetics within the context of this project will be <u>limited to the bio-physical characteristics of the ecosystems</u> and does not aim or claim to be fully encompassing of all aspects of landscape Aesthetic**.

In particular, part of the holistic experience of landscapes is not being taken into account here. For example, brochs, castles, bridges or any other man-made elements would not be included as they are considered part of another CICES class (Heritage & Cultural - "Characteristics of living systems that are resonant in terms of culture or heritage"). This delineation is arbitrary, as human perception would not differentiate them *a priori*, however it is important that elements are not double counted in this case.

As an example, holistic approaches were used by Peña et al. (2015) and Plieninger et al. (2013) to evaluate Aesthetics within the context of CICES, with their analyses being a combination of local engagement through interviews or photo-based questions along with spatial analyses. However, these holistic studies were limited to relatively small areas from five villages to a region. Scaling them up to national level would require significant resources. In contrast, Frank and Walz (2017) were able to carry out a national scale study (Germany) using a solely bio-physical approach through the calculation of spatial metrics. This use of spatial metrics was considered the most relevant for providing a partial template for our current analysis.

1.5 Template methodology: bio-physical metrics for national scale

The chosen approach is based on a published methodology by Frank and Walz's (2017), part of Burkard and Maes (2017), Mapping of Ecosystem Services. To date this has only been applied to the German landscape. However, given the simple universality of their landscape metrics, the fundamentals of the approach are applicable to other landscapes. The application of their approach to the Scottish landscape provides an opportunity to replicate, extend and evaluate the methodology.

Frank and Walz (2017, p. 83) highlight that "Strong interrelations between indices of biodiversity and landscape aesthetics can be identified as potential of landscape metrics application in mapping ES". For the middle-Saxony administrative planning region (Germany), they evaluated "ecological integrity as the precondition for biodiversity and the cultural service landscape aesthetic" using six metrics:

- percentage of connected (semi-)natural areas
- core areas
- effective mesh size of unfragmented areas
- shape index
- Shannon's diversity index
- patch density

For assessing at **national scale** the Cultural ES scenic attraction in Germany, they based their spatial analyses on the assumption that "certain features of the landscape have a positive or negative impact on the attraction of the landscape and recreation" (Frank and Walz, 2017, p. 85). Their seven metrics included:

- relief diversity
- proportion of open space
- hemeroby index
- density of forest-dominated ecotones
- density of water edges (without coasts)
- the coastlines
- the proportion of unfragmented open space greater than 50km^2

The seven metrics were aggregated, and five levels of scenic attraction were created using the standard deviation of the nationwide coverage. This allowed the detecting of whether an area has above or below average scenic attractiveness without using a fixed scale.

Out of the metrics listed above, those derived from landscape ecology have a prominent place. The relationship between ecological quality and human preferences for landscape (aesthetics) has been the subject of many studies (Sahraoui et al., 2021 for a review), and has been contested in some instances (Gobster et al., 2007; Zhao et al., 2017). However, common ground has been highlighted by Fry et al., (2009) (Figure 3), and ecological landscape metrics can be useful as a proxy, particularly

as they are easily mapped. For example, one study demonstrating this positive correlation between landscape metrics and landscape aesthetics, particularly for the purpose of monitoring ES, is Frank et al. (2013). They concluded that indicators of naturalness and landscape diversity (through Shannon's Diversity Index, Shape Index and Patch Density) were consistent with the landscape aesthetics ratings provided by 153 participants on German landscape types based on photographs; those metrics could thus be used for monitoring landscape aesthetics. Sahraoui et al. (2021) analysed the covariation between visual and ecological landscape qualities, and they identified more convergences than divergence on land cover change in rural-urban fringes in France.
These reported positive correlations demonstrate the usefulness of exploring the chosen methodology to design a prototype map of bio-physical aspects of Aesthetics in Scottish landscapes.

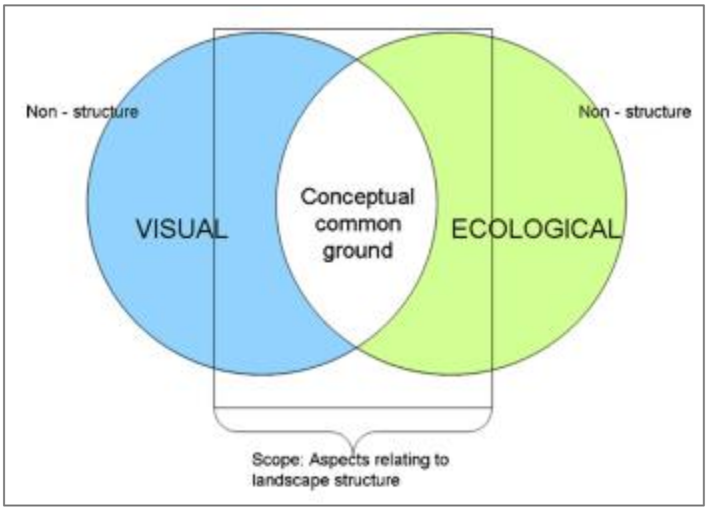

Figure 3. Common grounds between Visual (Aesthetics) and Ecological landscape characteristics (from Fry et al., 2009; Figure 1)

1.6 Scope & framework for this project

Scotland has a number of designated areas that represent aesthetic values, in particular national scenic areas, remoteness/wildness, special local landscape, and gardens/designed landscapes. **The identified data gap for Scotland is an assessment of aesthetic values outside designated areas** (Aalders and Stanik, 2016), but rather than simply address the identified gap this project will assess the whole country.

As an initial study of Scotland at national scale, a bio-physical spatial approach to Aesthetics was deemed useful as a first scoping analysis. **This mapping prototype does not aim at replacing or competing with existing designated areas, but at providing an alternative perspective on some bio-physical parts of landscape Aesthetics, which could be mapped in a consistent manner across the whole of Scotland.** The approach has the advantage of being able to provide rapid results, which could then be further explored and refined through subsequent stakeholder or public engagement. As a spatial unit for the analysis, instead of using a regular grid as could be expected from a bio-physical approach, we decided to use the pre-existing landscape character assessment (LCA) polygons. The LCA classes could be expected to be homogeneous in Aesthetics levels.

2 Mapping methodology for Scotland

The overall methodology from Frank and Walz (2018) was reused directly as it is based on common GIS and mathematical algorithmic (multi-criteria analysis) approaches. In this method, individual landscape metrics are estimated at national scale, and they are brought together in one map, in order to reach overall Aesthetics values. The numbers used are qualitative (not quantitative) and are only aiming at providing a basis to rank areas comparatively with each other.

Landscape preferences are dependent upon the individual and context (Gobster et al., 2007) thus preferences are deemed to be varying geographically and are influenced by local preferences (Zanten et al., 2016). For this desk-based project, local people and stakeholders were not directly engaged, however scientific literature and reports were used as reference material.

Two main elements have been adapted to reflect some particularities of Scottish landscapes: i) the spatial unit for the analyses; and ii) the underlying metrics. These adaptations are needed both because of the specificities of Scotland's bio-physical landscapes, which differ from the original German case study, but also due to the availability of different datasets from the original study. More details are provided below.

2.1 Spatial unit for the analyses: Landscape Character Assessment

The landscape metrics of Aesthetics have to be calculated at a spatial unit large enough to encapsulate the landscape configuration. Hence, although land cover is commonly used in ES mapping, CES, and in particular Aesthetics, are generally not attributed to a single landcover, as diversity of land cover in a landscape is commonly given a high aesthetic value (Frank et al., 2013; Howley, 2011; Alcon et al., 2020).

Wider spatial units like 5km regular grids are used by Frank and Walz (2017). However, for mapping Landscape Aesthetics in Scotland, the Landscape Character Assessment (LCA) map (SNH, 2019) is available, and it provides spatial units relatively homogeneous in their physical environment and the way that people interact with that environment (Aalders et al., 2018). A comparison study of the different spatial units by Aalders and Stanik (2019) illustrated that 1 km^2 raster was less appropriate as a spatial unit than using the LCA (Level 3 as polygons) and land cover (LCM as polygons).

Thus, the use of the LCA was deemed the most adequate dataset for this attempt at mapping Landscape Aesthetics in Scotland. This will both facilitate processing and interpretation of the resulting maps. However, one drawback in the methodology is an inability to include the positive effect of the mosaic of different LCA classes.

2.1.1 Level 3 from the original (1990s) LCA

This report is based on the aggregation of the original (1990s) landscape character assessment into 57 classes in the "Level 3" across Scotland (reported in Julie Martin Associates and Carys Swanwick, 2003), Figure 4. The current LCA dataset (2019) consists of 390 individual Landscape Character Types (LCTs) over the whole of Scotland (cf. SNH, 2019). The original LCA (1990s) was selected over the current LCA (2019) as its higher level of aggregation of landscape characteristics (57 versus 390) was deemed more appropriate, as it would support the interpretation and exploration of the data non-spatially, e.g. as a chart or table format. Assessing and reporting using the latest LCA with 390 LCTs would have made an unwieldy report with very large tables, and near impossible to represent it accurately in cartographic outputs with 390 different classes (cf. the complexity of showing 57 classes in Figure 4). It would also have led to accurately and convincingly assessing the overall performance of the analyses very difficult. Using the older version with an aggregation of the "Level 3" 57 classes will facilitate stakeholders' and users' discussions and validation of the outputs in the future, although this is beyond the scope of this project.

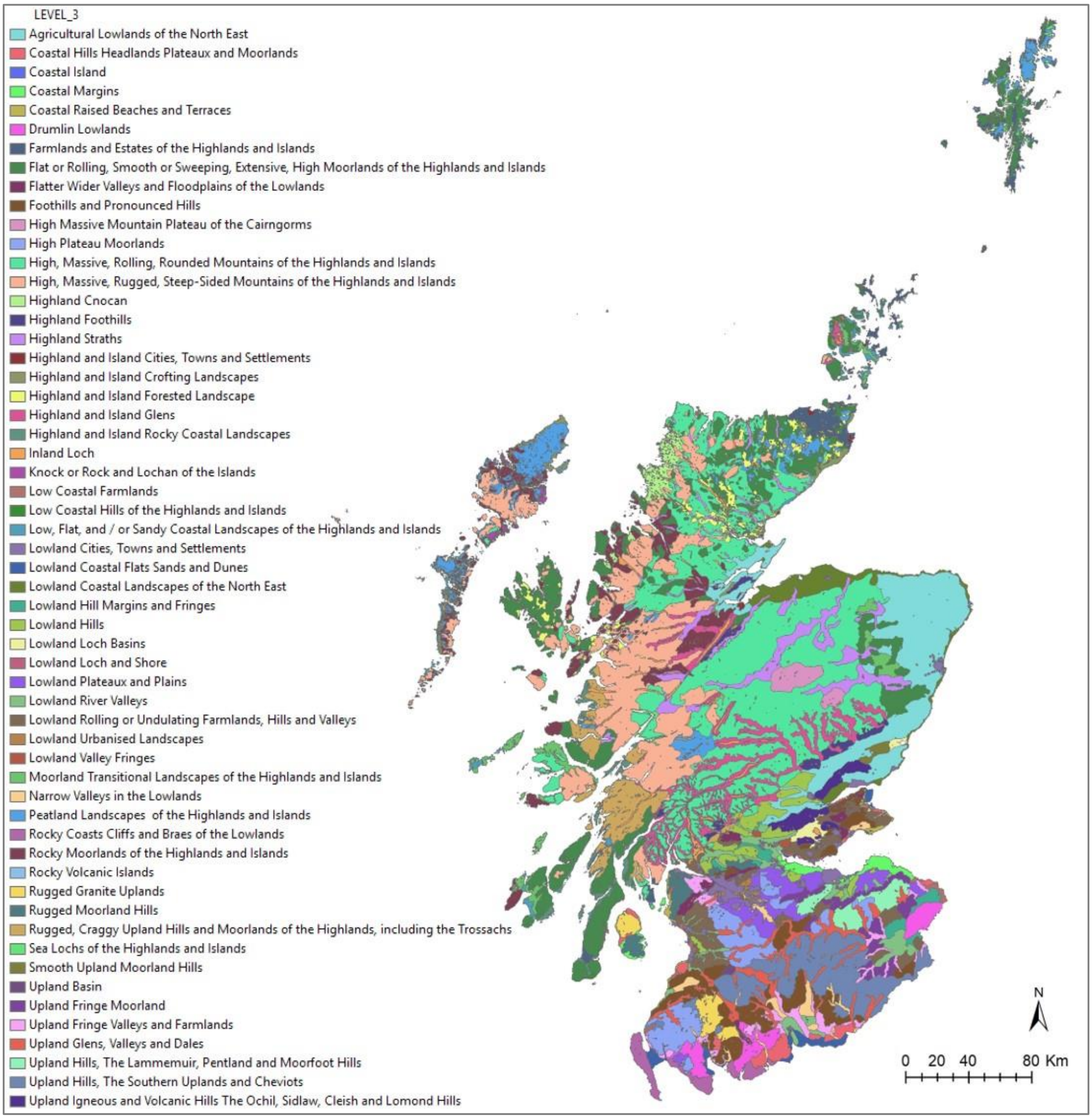

Figure 4. Landscape Character Assessment at "Level_3" (57 classes)

It should be noted that most Level 3 spatial units are composed of multiple spatially separated polygons spread across Scotland. For example, the "Coastal Islands" (L3id 3) have 1,558 smaller spatial units, and the "Lowland Coastal flats" (L3id 29) have 20. The Level 3 "Coastal Islands" are so small that they are far less visible at Scotland scale than other Level 3 units.

The Level 3 spatial units aimed at being homogenous in landscape characteristics. However, we cannot yet be sure that this is the case for all the landscape metrics that will be run for the creation of the Aesthetics map. To avoid, or at least to limit. spatial discrepancies (i.e. values averaged across a Level 3 placed in a spatial location where it is not the case) in the final Aesthetics prototype map for Scotland, it was decided to run the spatial analyses on the single polygons composing Level 3, hereafter called LCAsp (LCA single-parts/single polygons).

2.1.2 LCAsp (single polygons)

The spatial analyses themselves are carried out at the smallest spatial units available: LCA Level 3 spatially disaggregated into single polygons, aka LCAsp (Figure 5). For the purposes of the spatial analyses associated with this methodology, we treated each of the Level 3 individual polygons (i.e. each continuous area) independently. This will ensure that every calculated result will be placed at the correct spatial location, hence increasing the robustness of the final Aesthetics prototype map and facilitating its visual interpretation.

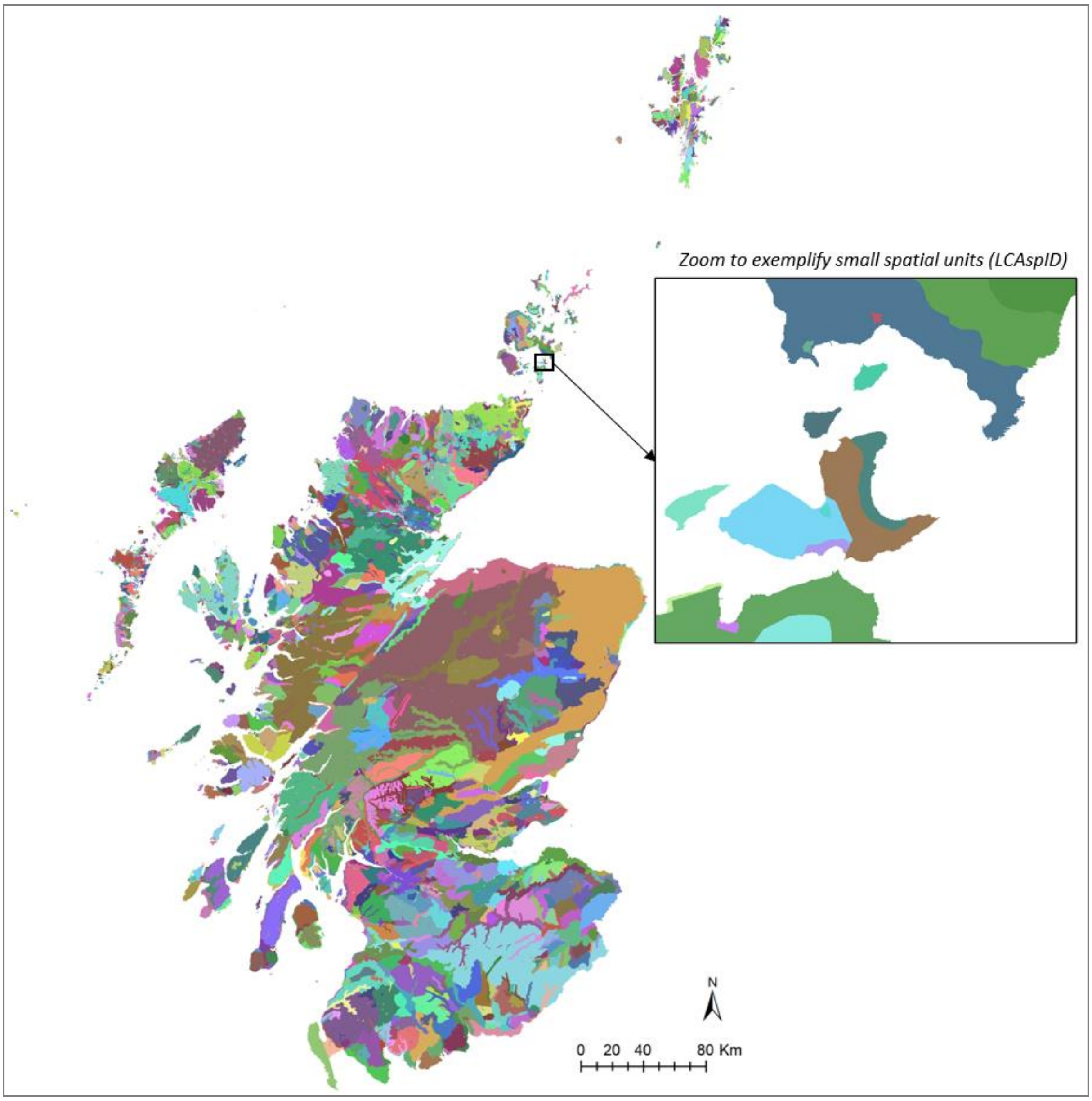

Figure 5. The smallest spatial units (LCAspID) of the Landscape Character Assessment. They are used for all the spatial analyses (7,246 LCAspID, represented by different colours). Their individual area ranges from a 700m² to 600,000ha.

2.2 The 10-underlying metrics

The chosen approach is based on a published methodology by Frank and Walz's (2017), part of Burkard and Maes (2017), Mapping of Ecosystem Services. Following the recommendation of their German case study (section 1.5. "Template methodology: bio-physical metrics for national scale"), ten individual metrics were selected, cf. Table 6. Each metric is calculated individually at LCAsp (7,246 units, Figure 5) following the descriptions in Table 6.

Table 6. Short descriptions of the 10 metrics

Type	Metrics	Aesthetics metrics description	High Aesthetics when	references	Spatial inputs
Physical	Relief diversity	3D area / 2D area (i.e. true surface / planimetric surface)	High relief diversity values	(Peña et al., 2015; Frank et al., 2013; Norton et al., 2012)	DTM
Physical	Density of freshwater edges (without coasts)	National and regional river length & lochs edges / LCA area	Large length	(Peña et al., 2015; Frank et al., 2013; Norton et al., 2012)	River network lines and loch edges
Physical	Density of coastlines	Coastal length / LCA area	Large length	(Peña et al., 2015; Frank et al., 2013; Norton et al., 2012)	Coastlines
Physical	Proportion of unfragmented open space >100km²	Area of open space > 100km² / LCA area opens space: un-interrupted by motorway, A roads, B roads, rail network	Large areas		Road & rail networks lines
Landscape ecology	Hemeroby index	Mean of hemeroby index *(area weighted mean)*	Low hemeroby values		Land use map
Landscape ecology	Core area index of (semi-) natural areas (TCA)	Mean of the sum of Total Core Area (TCA; class metrics for 11 semi-natural habitats: r*ough grassland, neutral grassland, calcareous grassland, acid grassland, fen marsh and swamp, heather, heather grassland, bog, montane habitats, broadleaves, coniferous)* *(area weighted mean)*	High TCA		Land use map

Landscape ecology	Shannon diversity index (SHDI)	Mean of SHDI as a landscape metric *(area weighted mean)*	High diversity	(Fuller et al., 2007)	Land use map
Landscape ecology	Patch density – native woodlands	Native woodlands area (broadleaves, coniferous, woodlands) / LCA area	Large areas		Land use map
Landscape ecology	Patch density - heathers	Heather & heather grasslands area / LCA area	Large areas		Land use map
Landscape ecology	Density of forest-dominated ecotones	Length of woodlands ecotone (adjacent to other land uses) / LCA area	Large length		Land use map

Most metrics above are self-explanatory or common in landscape ecology, except probably for the hemeroby index, its concept is thus more detailed in section “2.2.2 Concept: hemeroby index”.

While processing the metrics, two important issues emerged that need to be highlighted. Firstly, all metrics could not be calculated for all LCAspID (Figure 5), due to the difference in extents in the original spatial inputs. Particularly, the spatial extent of the land use map (LCM2007) and DTM (digital terrain model) did not overlap with some of the LCA spatial units, hence generating missing data. The LCA “Level 3” class called “Coastal Islands” was disproportionately impacted by those missing data. Secondly, the “Coastal Islands” also had the highest number of spatially disconnected small units (LCAspID), which would impact on some of the metrics. For example, coastal length divided by island area would tend to lead to higher values as island areas tend to be smaller than most other “Level 3” LCAspID.

2.2.1 Adapting the 10 metrics for Scotland Aesthetics

The metrics presented above were adapted from the original methodology of Frank and Walz (2017). Firstly, the original threshold of 50km^2 for unfragmented open space was increased to 100km^2, to be more appropriate for Scotland’s less fragmented landscape. Most of the landscape ecology metrics had been calculated during a previous project (Gimona et al., 2018) and could be directly reused, hence their increased detail in comparison with the original methodology. However, the hemeroby index was kept at a simpler level by only using the land cover dataset as input, and not including further topographic elements, nor the impact of agriculture and grazing intensity (mineral and organic nitrogen input and livestock unit density), as reported in Paracchini and Capitani (2011). The concept of hemeroby and its adaptation for the Scottish landscapes are detailed in section 2.2.2 below and Appendix B.

2.2.2 Concept: hemeroby index

The hemeroby concept originated in ecology and was then extended to landscape scale (for an overview from the rural-agrarian landscape perspective, refer to Paracchini and Capitani, 2011, p. 4). The index ranks the level of anthropogenic influence/disturbance on the landscape, in comparison from its original natural state, given the site restrictions. The hemeroby scale starts at the value of 1 for no disturbance at all to value 7 with sealed surfaces and biocenosis destroyed (Table 7).

Table 7. Definition of the degree of hemeroby (Blume and Sukopp, 1976) and corresponding human impact of ecosystems (Steinhardt et al., 1999; Zebish et al., 2004); information aggregated by Paracchini and Capitani, 2011.

Hemero by value	Hemeroby level	Degree of natural-ness	Example	Processes/Human impact
1	Ahe-merobe	Natural	Bogs, tundra	No disturbance
2	Oligohe-merobe	Close to natural	Forest with species, typical for the site, semi-natural grasslands	Limited removal of wood, pastoralism, minor changes in matter circles, imissions through air and water
3	Mesohe-merobe	Semi-natural	Forest with species atypical for the site, extensive grasslands	Clearing and occasional ploughing, extensive grazing, rare and small doses of fertiliser
4	β-euhe-merobe	Relatively far from natural	Intensive grassland, extensive arable land	Use of fertilisers and biocides amelioration, ditch drainage
5	α-euhe-merobe	Far from natural	Intensive arable land	Deep ploughing, planting, major changes in matter circle, drainage, heavy use of fertilizers and biocides
6	Polyhe-merobe	Strange to natural	City green, golf courses, pits	Strong changes in biocenosis, covering of the biotope with external material
7	Metahe-merobe	Artificial	Streets, buildings	Sealed surface, biocenosis destroyed

To estimate the degree of hemeroby, a simple land use correspondence was applied based on Walz and Stein (2014) and adapted to the land use categories available for Scotland (further details are in Appendix B). The concept of hemeroby is closely associated to the concept of "closeness to nature" state. However, hemeroby refers to the "contemporary potential natural vegetations", taking into account irreversible change that happened on the site that might limit potential natural vegetation, whereas "closeness to nature" refers to "primary natural vegetation" (Walz and Stein, 2014). Both hemeroby and closeness to nature are concepts aiming at describing naturalness and are thus closely linked. Links and comparison between the hemeroby values and the values of Perceived naturalness (SNH, 2014) are reported in Appendix B and section 5.1.1.

2.3 From 10 individual metrics to a final value

Each metric (Table 6) individually only reports on one small potential part of the bio-physical aspect of landscape Aesthetics. Having a low value in one metric does not mean that this location has no aesthetics value. The cumulative effect of all metrics is what allows us to identify a prototype final aesthetics ranking. The combination of all 10 metrics follows a spatial Multiple-Criteria Decision Analysis (sMCDA) methodology, which is commonly used to support complex decision making in a spatial context (Malczewski and Rinner, 2015; Wikipedia, 2021).

The 10 metrics were calculated separately for each 7,246 spatial units (LCAspID, Figure 5); those calculated values (raw values) are in a range of units, e.g. m/ha, hemeroby index (Figure 7). To facilitate combining their values, each of the 10 metrics values were rescaled from 0 to 1 (0 being lowest Aesthetics contribution, 1 highest Aesthetics contribution). For each spatial unit (LCAspID), the 10 rescaled metrics are then averaged into a final Aesthetics value.

Currently, the rescaling of the individual metrics is linear. However, some metrics like Density of Coastlines could be more appropriately rescaled using a logarithmic transformation; this could be part of future work. The impact of the chosen rescaling methodology is explored further in section 5.2.2 “Rescaling methodology”.

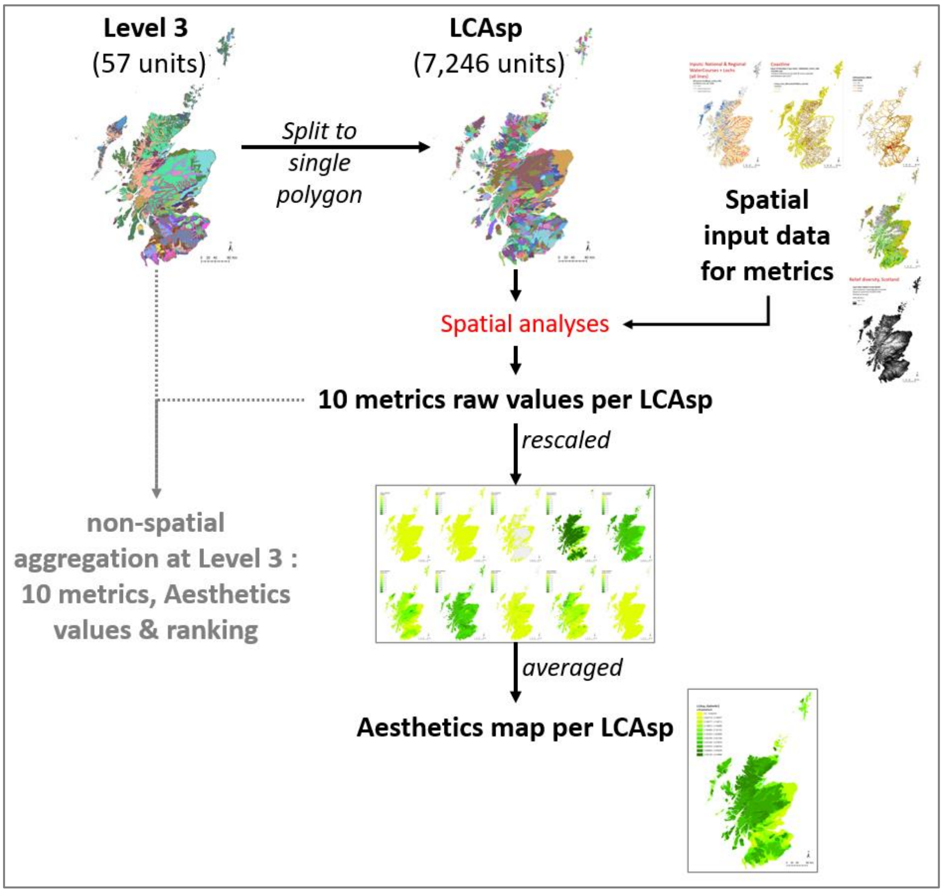

Figure 6. Overview of methodology towards the Aesthetics map

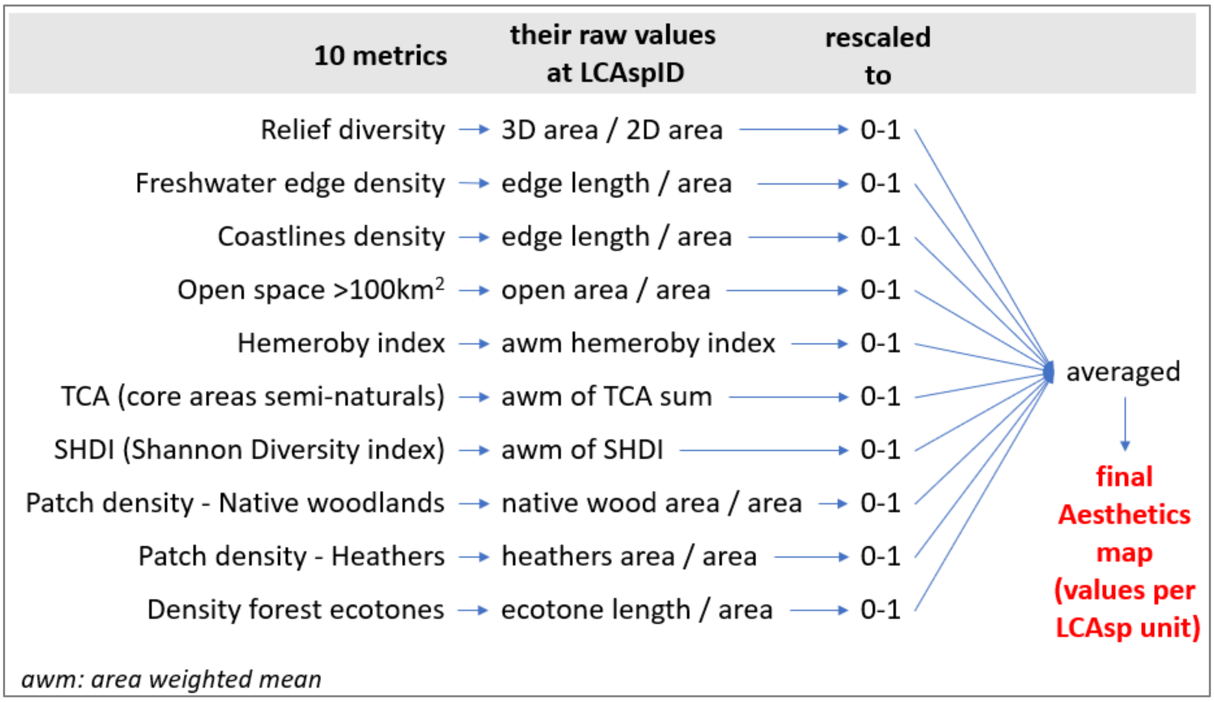

Figure 7. Methodology from the 10 metrics raw values to the final Aesthetics value (all done at LCAspID spatial unit; awn: area weighted mean)

3 Results: 10 metrics maps & final aesthetics prototype map

3.1 Maps of the 10 metrics

The individual maps of the 10 metrics are presented in two colour schemes: 1) Figure 8: colour breaks are optimised to show patterns within each map, thus best to explore maps independently from each other; 2) Figure 9: colour breaks are identical across all maps, thus best to compare the metrics. Figure 8 classification helps to showcase the spatial spread within each metric, whereas the Figure 9 maps help the visual comparisons of the metrics and to understand their respective impact on the final Aesthetics prototype map. The individual maps are included at higher resolution in Appendix C and Appendix D respectively.

The general spatial pattern of the ten metrics in Figure 8 are as could be expected, except for the coastline metric. As the metrics are weighted per LCAspID area, it means that in certain cases like for “coastline length/area”, small islands have all the highest values, but due to their small size they are not visible at Scotland scale (e.g. Coastlines in Figure 8). Thus, the Coastline map at national scale appears uniform in Figure 8. The metrics, which are showing limited spread in values (i.e. mostly one colour in the maps in Figure 9) could benefit from a different type of rescaling methodology, such as logarithmic rescaling instead of the linear rescaling currently used. This could be part of future work.

For Figure 9, the ten metrics have identical colour scale (10 regular steps of 0.1 values) and the general spatial pattern evident in Figure 8 gets lost, when the values of the majority of large polygons are closely grouped together (very skewed spread of the values). This is particularly the case for Relief diversity, Freshwater edges and Forest ecotones. For example, for Relief diversity, in Figure 8, the highest visible values (bright green) are below 0.15, which is represented in Figure 9 as the 2nd and 3rd lowest coloured values (yellow/light green). As for the Coastline metric, the relief diversity metrics highest values (1.0) are situated in small islands, which are thus skewing the value distribution during the rescaling. The same applies to the Freshwater edges and Forest ecotones.

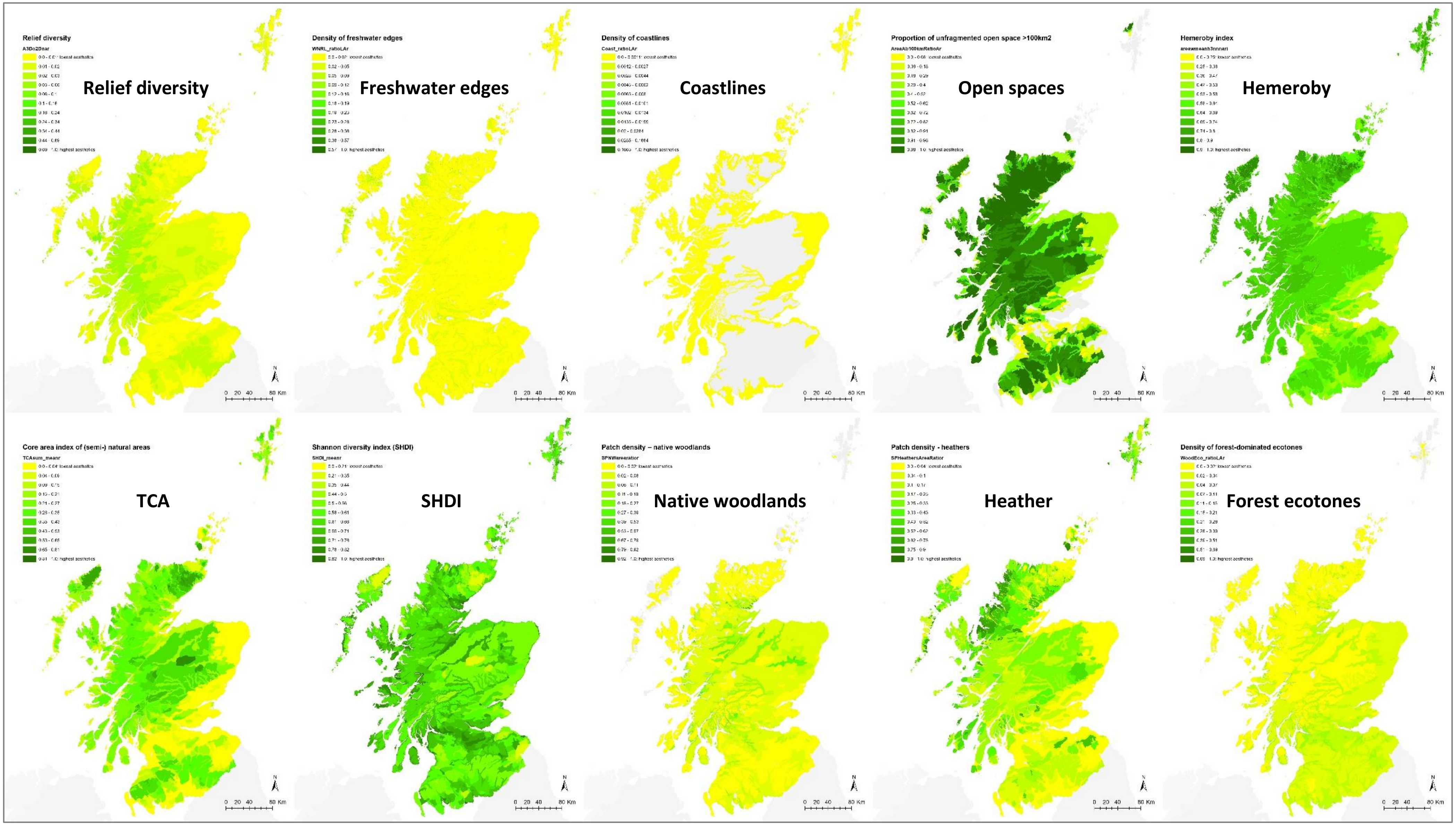

Figure 8. Ten metrics rescaled 0-1, each break in the colours is optimised to show patterns within a map (natural breaks classes with 0: yellow to 1: dark green; 0 in raw data: grey). <u>Purpose: exploring the spatial pattern within each metric.</u> cf. Appendix C for higher resolution maps.

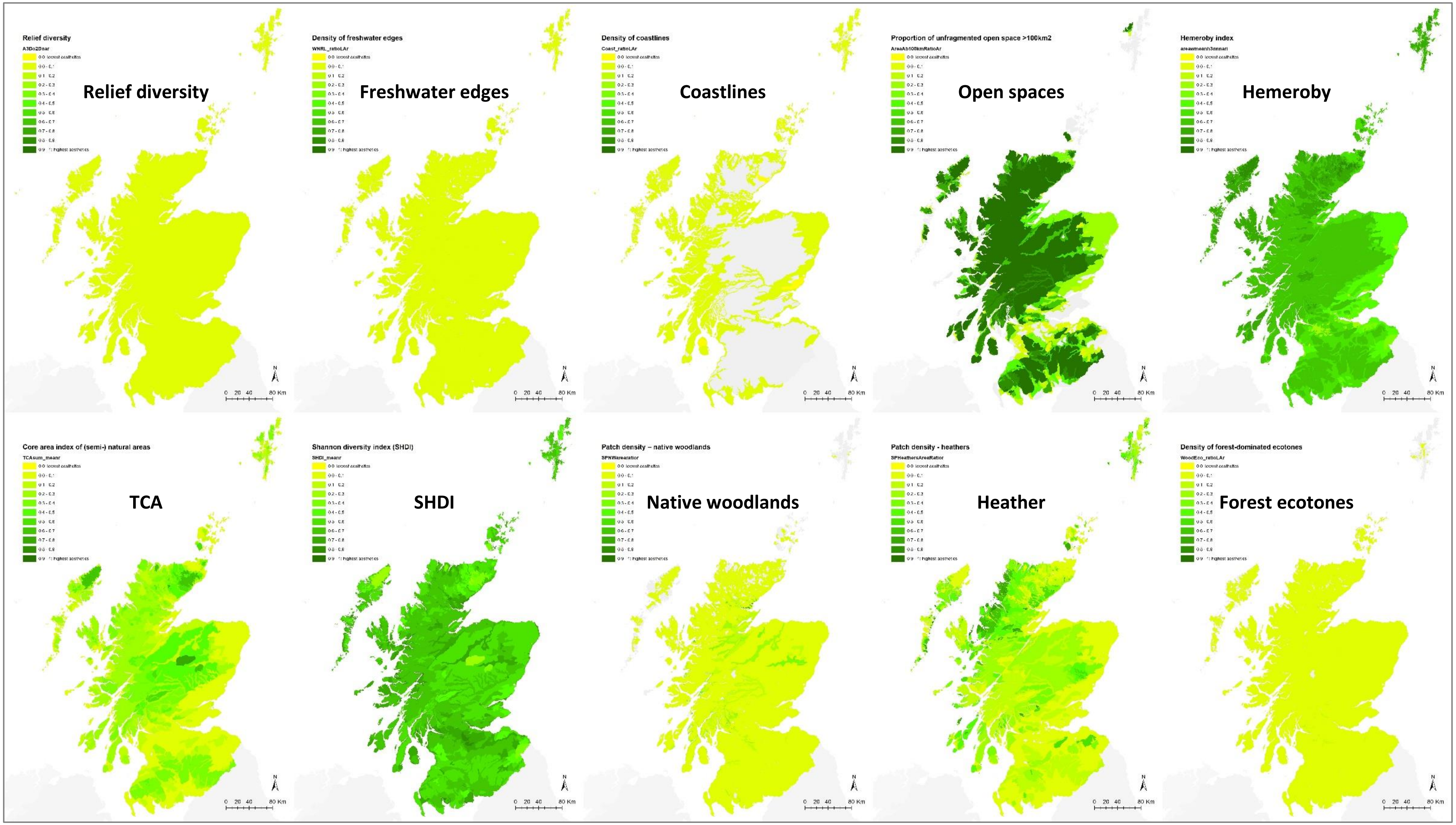

Figure 9. Ten metrics rescaled 0-1, displayed with identical scales across all maps (equal intervals classes, with 0: yellow to 1: dark green; 0 in raw data: grey). Purpose: comparing the metrics values contributing to the final Aesthetics prototype map. cf. Appendix D for higher resolution maps.

3.2 Prototype map of Aesthetics

The final Aesthetics prototype map is created by averaging the 10 rescaled metrics (as detailed in Figure 9, Appendix D) for each spatial unit (LCAspID) Figure 10.

This prototype map aims at showcasing a methodology. The inclusion of individual metrics and their respective weights could easily be refined. **This analysis should be regarded as a discussion starter rather than a final authoritative result.**

In the current prototype map, the first striking pattern is the lower rating of the East side of Scotland, Central belt and most of Orkney, which all tend to be at lower altitude, more agricultural and with dense population centres. The highest rankings are located in more mountainous areas towards the West Coast and around the Cairngorms. Those areas have more open spaces and undisturbed core areas of habitats, even if the relief diversity metrics doesn’t contribute much to it due to its overall low uniform values.

Some ranking might raise questions. For example, the Tiree Island shows a lighter shade of green than surrounding islands. Tiree is subdivided into 18 spatial units (LCAspID) under four Level 3 categories: “3-Costal Island”, “23-Inland Loch”, "27-Low, Flat, and / or Sandy Coastal Landscapes of the Highlands and Islands" (19.9% of the island area), “40-Moorland Transitional Landscapes of the Highlands and Islands” (79.9% of the island area). Both “3-Costal Island” and “23-Inland Loch” will not be visible at national scale map. Tiree’s low, flat and / sandy coastal landscapes are rating at the lower end of the scale for all metrics (cf. Appendix D for high resolution maps), except for the hemeroby index, Patch of Heathers, and Shannon’s Diversity index, all metrices from Landscape Ecology. The island moorland transitional landscape rates relatively similarly for the 10 metrics, except for high rating in “relief diversity” and “coastline”. None of the spatial units within the island get any values from the “unfragmented open space > 100km^2” metric, as only land areas were considered. The closeness to large sea areas is not being considered in any metric, except in the Coastline one. However, as the coastline of the Tiree is mostly subdivided into different spatial units in the LCAspIDs, the coastline length versus the area of individual LCAspIDs leads to a lower rank nationally for the coastline metric than if the island was considered as a single spatial unit.

Tiree’s neighbour, Coll, rates similarly as Tiree for the 10metrics (cf. Appendix D for high resolution maps), except for the Core area index of semi-natural areas and the patch density – native woodlands and heathers, where Coll ranks higher nationally than Tiree.

Another unexpected difference is on Hoy, where the moorland on its east side is more highly ranked than Hoy’s west side, which is part of a National Scenic Area (NSA, cf. section 5.1.3). The east side moorland is part of Level 3 “8-Flat or Rolling, Smooth or Sweeping, Extensive, High Moorlands of the Highlands and Islands”, and this LCAspID ranks at 0.3344, whereas the three largest LCAspID under the NSA designation are ranked from 0.3182 to 0.3314 (level 3 “14-High, Massive, Rugged, Steep-Sided Mountains of the Highlands and Islands” and “18-Highland and Island Glens”). The higher ranking of the moorland east side mostly stems from the “Patch density – Heather” metric contributing at 0.77 instead of only 0.69 to 0.46 for the NSA side. This could indicate that the Heather metric might not be as relevant in the context of Hoy. But as well, it should be noted that the east and west side of Hoy overall score very similarly, and, unfortunately, the threshold for the colour display on the map artificially exacerbated this difference beyond its meaning.

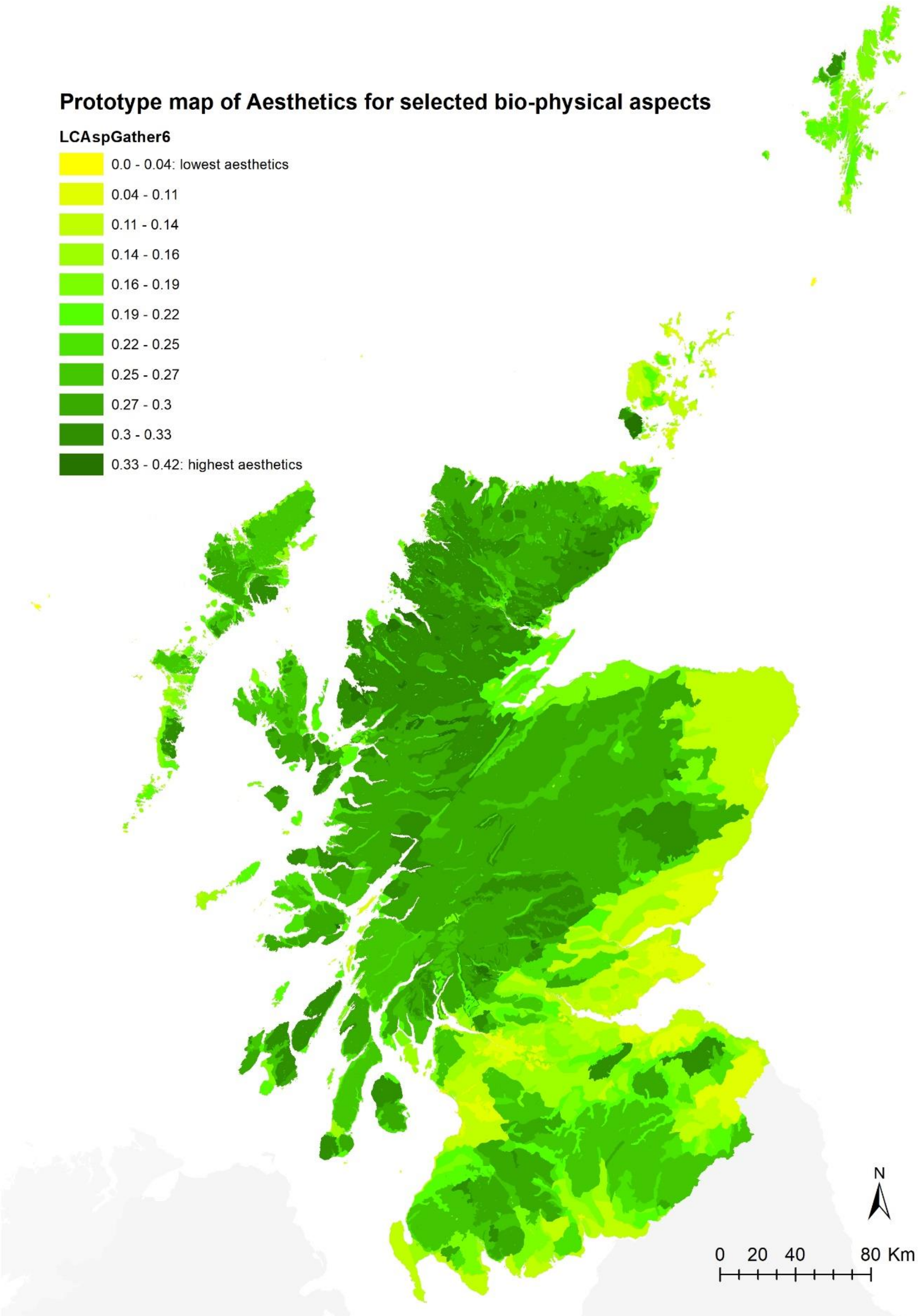

Figure 10. Aesthetics map for selected bio-physical aspects (LCAsp). Natural break classification (yellow: low aesthetics for selected bio-physical aspects; dark green: high aesthetics values for selected bio-physical aspects). If all metrics were at the highest possible values in one spatial area, it would have the theoretical maximum aesthetical value of 1.0. Refer to *Appendix C for a higher resolution map.*

4 Summary of Aesthetics at LCA "Level 3"

The spatial analyses were carried out at the **smallest spatial units (LCAspID),** which is the most appropriate for creating the final map of Aesthetics (Figure 10), cf. section 2.1.2 "LCAsp (single polygons)". LCAspID are continuous areas within the same LCA "level 3" definition, the landscape within each LCAspID polygon is expected to have homogenous characteristics regarding the ten metrics and the potential aesthetics ranking. The ten metric values for each LCAspID can thus be estimated and displayed at their "real" location independently from the characteristics of other LCAspIDs, whether of the same "Level 3" definition or not. Those characteristics make the **Aesthetics mapping at LCAsp more spatially rigorous & correct.**

However, those spatial estimations can be aggregated non-spatially to provide a different view on the results of the 10 metrics and final aesthetics ranking. As stated earlier, in the chosen version of the Landscape Character Assessment map, the **smallest spatial units can be grouped to a Level 3, which are 57 national types combining all broadly similar smaller units** (Julie Martin Associates and Carys Swanwick, 2003), Figure 4. This very broad level of aggregation is an opportunity to summarise the results of the 7,246 small spatial units (LCAsp) into 57 broad categories (Level 3), which can be reported non-spatially into a chart (Figure 11) or table (Appendix E). This aggregation facilitates the exploration of the metrics & Aesthetics ranking for broader landscape character types.

4.1 Methodology: Aesthetics at Level 3

The raw values of each metric at LCAsp were aggregated at Level 3 (area weighted), before being rescaled to 0-1. Those 10 rescaled metrics are then averaged to get the "L3 Aesthetics" values (corresponding to the 57 broad categories, one for each Level 3). The resulting values and their ranking are reported in the chart in Figure 11 (the full table of rescaled values is in Appendix E).

4.2 Caveat: Aesthetics ranking in LCAspID vs Aesthetics ranking in Level 3

It should be noted that the method of calculation for Level 3 (section 4.1) by rescaling at Level 3 instead of LCAsp, means that the exact Aesthetics values at LCAspID level cannot be directly compared to the values at Level 3. For example, the highest Level 3 Aesthetics is 0.53 (Lowland Loch and Shore, Appendix E), whereas the maximum LCAspID in the map in Figure 10 is 0.41.

- ⇨ **The Aesthetics values are only to indicate ranking within a map for LCAspID (Figure 10) and non-spatially for Level 3 (Figure 11, Appendix E). Both these sets are coherent within themselves, but their exact values cannot be directly compared.**

4.3 Prototype ranking of Aesthetics at Level 3

The 57 Level 3 were ranked for overall Aesthetics values and the contribution of the 10 metrics are visually represented in Figure 11.

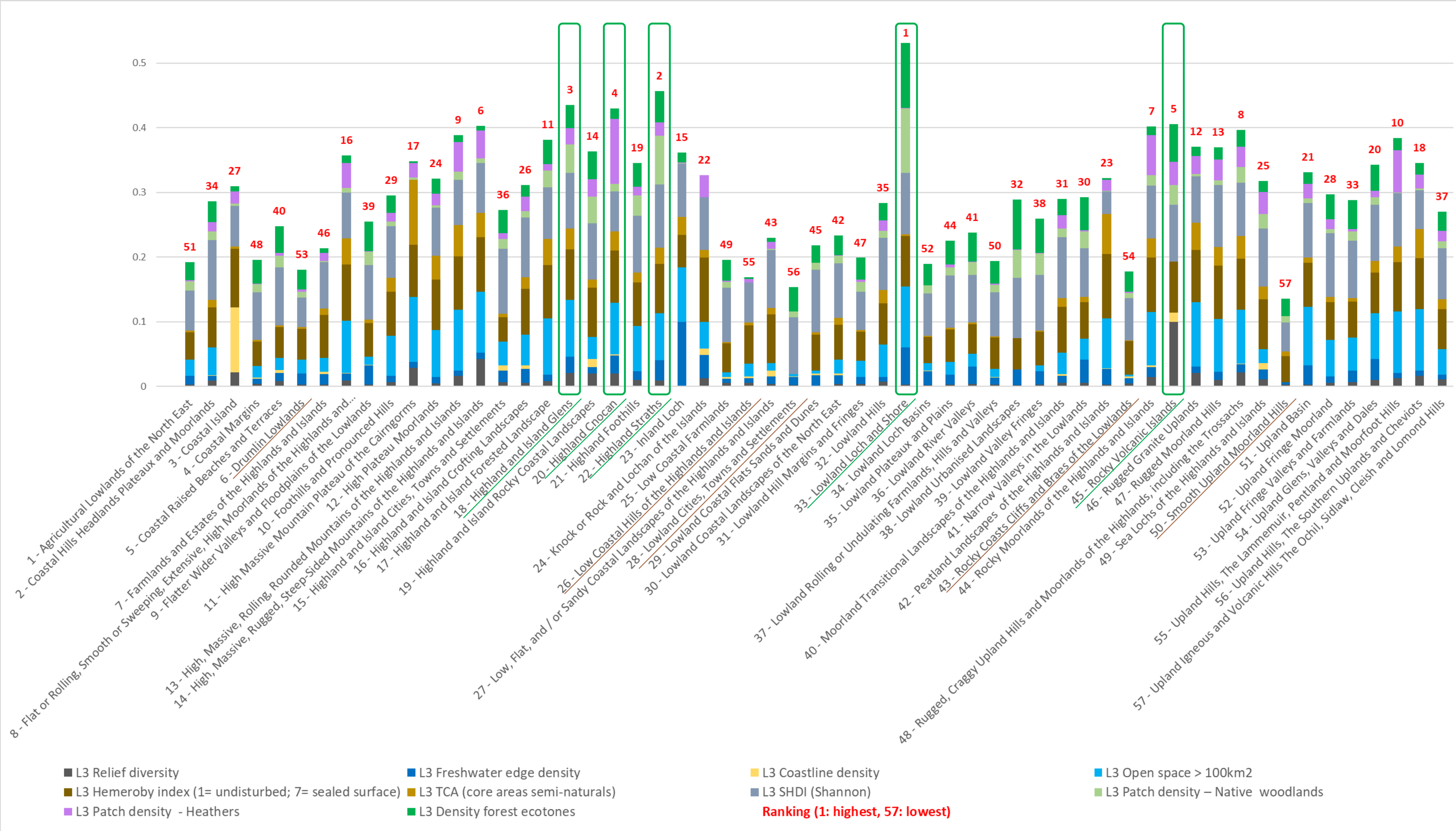

Figure 11. Summary of the 10 metrics contribution towards Aesthetics ranking for selected bio-physical aspects for each Level 3 (ranking in red)

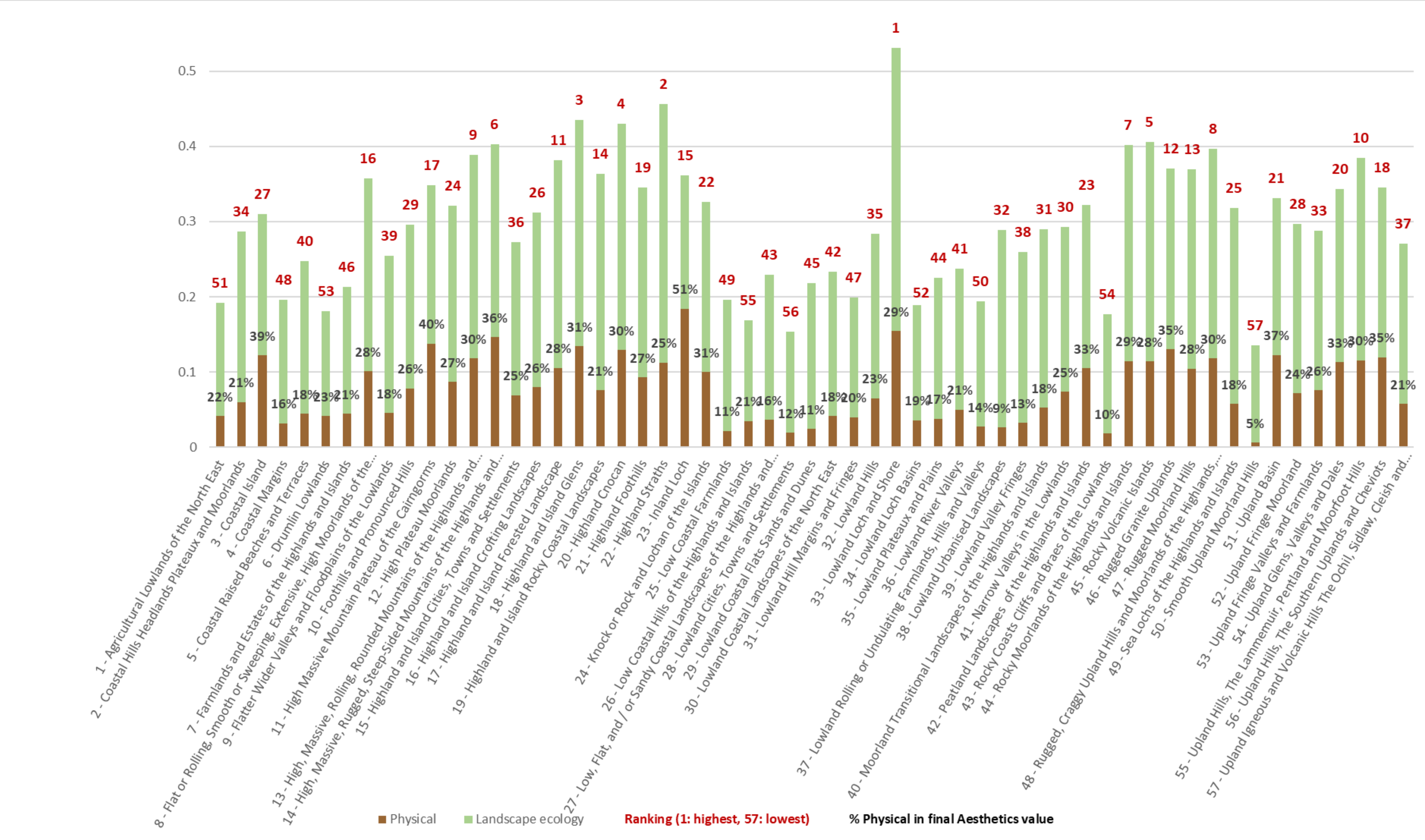

Figure 12. Contribution of Physical and Landscape Ecology metrics for each Level 3 towards the prototype Aesthetics values for selected bio-physical aspects (% of physical contribution in black, ranking in red)

4.3.1 Difference stemming from summarising the metrics at "Level 3" instead of LCAspID

The rescaling of the metrics at "Level 3" instead of LCAspID (Figure 9) leads to different spreads of the rescaled values as the maximum and minimum values for any metrics will be affected. To exemplify the difference, the "Level 3" 10 metrics maps rescaled are included in Appendix F. The differences between the 10 metrics maps calculated at LCAspID (Figure 9) and at "Level 3" (Appendix F) are an example of the well documented "Modifiable Areal Unit Problem" in GIS (MAUP; Jelinski and Wu, 1996; Wong, 2009). For this report, the mapping at LCAspID was chosen as most appropriate to have accurate final maps (cf. section 2.1.2). The maps as Level 3 are only provided to exemplify the issue of spatial units of aggregation and to support the understanding of the final ranking at "Level 3".

4.3.2 Highest and lowest Aesthetics ranking at "Level 3"

The highest ranking is the "33-Lowland Loch and Shore" with an overall score of 0.53, with the next four being "22-Highland Straths" (0.46), "18-Highland and Island Glens" (0.44), "20-Highland Cnocan" (0.43), and "45-Rocky Volcanic Islands" (0.41). At the other end of the spectrum, "50-Smooth Upland Moorland Hills" scores the lowest with 0.14, followed by "28-Lowland Cities, Towns and Settlements" (0.15), "26-Low Coastal Hills of the Highlands and Islands" (0.17), "43-Rocky Coasts Cliffs and Braes of the Lowlands" (0.18), and "6-Drumlin Lowlands" (0.18).

The spatial location of those five tops and bottoms "Level 3" are shown in Appendix H as the "Level 3" names can be misleading if their spatial location and extent are unknown to the reader. For example, the highest ranking "33-Lowland Loch and Shore" is only at one location on the southern shores of Loch Lomond. It scores the highest values for "Level 3" "Density of forest ecotone" and "Patch density – Native woodlands" across all other "Level 3" (cf. Appendix E and Appendix F). The lowest Aesthetics ranking of "50-Smooth Upland Moorland Hills" can be explained by its more limited spatial extent and its less remote location than its name suggests: 11,700ha between Forfar and Brechin (Appendix H). It is crossed by multiple roads, hence its unexpected lack of contribution from the "Open Space >100km^2" metric.

The four highest ranking Level 3 have large contributions from 4-6 metrics, mostly "Open Space", "Freshwater edge density", "Shannon Diversity Index", "Total Core Area", and "Density of forest ecotone" (cf. Figure 11, Appendix E and Appendix F). Whereas the fifth highest ranking, "45. Rocky Volcanic Islands" rates in the highest for "Relief diversity", "Shannon Diversity Index", and "Hemeroby Index".

4.3.3 Further comments on "Level 3" results

The contribution of "Coastline density" to "3-Coastal Island" is high, whereas it barely contributes to "30-Lowland Coastal Landscapes of the North-East". This is due to the metrics being the length of coast over the Level 3 area. Islands tend to have a much larger ratio coastline/area than the long polygon along the North-East Coast. This discrepancy is a direct consequence of using the LCA as a spatial unit for the analysis. Using a regular grid instead of the LCA would be more appropriate for this case.

Out of the ten metrics, four are based on physical aspects of the landscape, whereas six are derived from landscape ecology metrics. Their relative contributions in the final Aesthetics values are represented in Figure 12, physical contribution ranges from 5% for "50-Smooth Upland Moorland Hills" to 51% for "23-Inland loch".

5 Assessment of the current methodology and results

The chosen methodology of implementing Frank and Walz (2017) bio-physical metrics as a proxy for landscape Aesthetics was presented in section 2 ("Mapping methodology for Scotland"), and results reported in section 3 ("Results: 10 metrics maps & final aesthetics prototype map"). The creation of the final Aesthetics prototype map (Figure 10) and the summary Aesthetics values at Level 3 (Figure 11, Figure 12) provides two ways to investigate how landscape character types within Scotland rank between themselves for the prototype Aesthetics values.

This work aimed at exploring and presenting a methodology to map the Aesthetics in Scotland at national scale, and not to provide an "authoritative" ranking nor a local level assessment. Any such claim would require thorough validation work that is beyond the scope of this project.

This section reviews the results above by comparing them to pre-existing maps that could be linked to Aesthetics in Scotland (cf. 5.1), and then provides alternative improvements to the current methodology (cf. 5.2).

5.1 Comparison with other Scottish maps linked to Aesthetics values

Several previous initiatives led to the creation of maps which could usefully be compared with Aesthetics values. These include the Relative Wildness map which was used for the Wild Land Areas 2014 map, National Scenic Areas and Local Landscape Areas and National parks. Two pre-existing CES maps are also considered for comparison.

5.1.1 Wildness map and its four component layers

A relevant dataset that was not included as a metric for the prototype map is the SNH Relative Wildness map (SNH, 2014) and its four component maps: "Perceived naturalness", "Rugged or challenging terrain", "Remoteness from public mechanised access", "Lack of build modern artefacts". Despite differing methodology, it could be argued that "Rugged or challenging terrain" could be used instead of "Relief diversity"; "Perceived naturalness" instead of the hemeroby index (for a comparison of indexes cf. Figure 15 in Appendix B); and "Remoteness" instead of "Proportion of unfragmented open space > 100km^2". Thus, the Wildness map has many similarities to the bio-physical aspects of Aesthetics as reported here. The general patterns between the two maps are closely related, e.g. agricultural areas and high population centres being ranked in the lowest. This similarity exists despite the use of different spatial units of resolution i) 25m for "Wildness map", ii) LCA smallest spatial units for the prototype Aesthetics map. However, there are stark differences in some locations, for example the Black Isle and the coast east of Inverness rate relatively higher in the Aesthetics map (middle of scale) than in the Relative Wildness one (bottom of scale). Those areas are also better rated for Aesthetics than other intensively managed farmland like the area between Arbroath and Dundee. This points to the different scope of the prototype Aesthetics map in comparison to the components included for the Relative Wildness map.

For the purposes of this application of the approach to the Scottish landscape it was decided to adhere to Frank and Walz's (2017) methodology, aiming at replicating the simplicity of the metrics, data inputs and methodology they used. The methodological advantage of this approach is simpler individual metrics that could easily be updated in the future, and each metric having limited overlap with the others. Due to the inherent complexity behind the Relative wildness, its methodological integration might have led to more overlaps in the metrics. An appropriate way of including it could form part of a follow up project.

5.1.2 Wild Land Areas 2014

The Wildness map formed the basis for the Wild Land Areas 2014 (SNH, 2014). For each area the mean value was calculated from the prototype Aesthetics (Figure 13, c). The estimated Aesthetics values of the Wild Land Areas are at the higher end of the scale: from 0.26 for "Duirinish", to 0.33 for "Hoy" or 0.33 for "Applecross". The correlation between Wild Land Areas and the current prototype Aesthetics map can thus be observed.

5.1.3 National Scenic Areas

The National Scenic Areas (NSAs) are defined by legislation as an area "of outstanding scenic value in a national context". They include spectacular mountain ranges, dramatic island landscapes, and picturesque, richly diverse scenery. The purpose of the designation is two-fold: identify the finest scenery; and to ensure its protection from inappropriate development (NatureScot, 2020). The mean prototype Aesthetics values per NSA is reported in Figure 13 (d), the mean value across all NSAs is 0.25 and ranges from 0.02 for "St Kilda" (refer to section 5.1.7 for the origin of the low value) to 0.32 for "Glen Strathfarrar".

5.1.4 Local Landscape Areas

The Local Landscape Areas (LLAs) complement the NSAs designations, the designation also helps to protect the landscape from inappropriate development (NatureScot, 2021). The mean prototype Aesthetics values per LLA is reported in Figure 13 (e), the mean value across all LLAs is 0.15 and ranges from 0.0038 for the "Isle of May" (refer to section 5.1.7 for the origin of the low value), to 0.31 for "Loch Fleet, Loch Brora and Glen Loth". The prototype Aesthetics values are in far less agreement with the LLAs than with the NSAs, highlighting the difference in outcomes between National and Local level assessments.

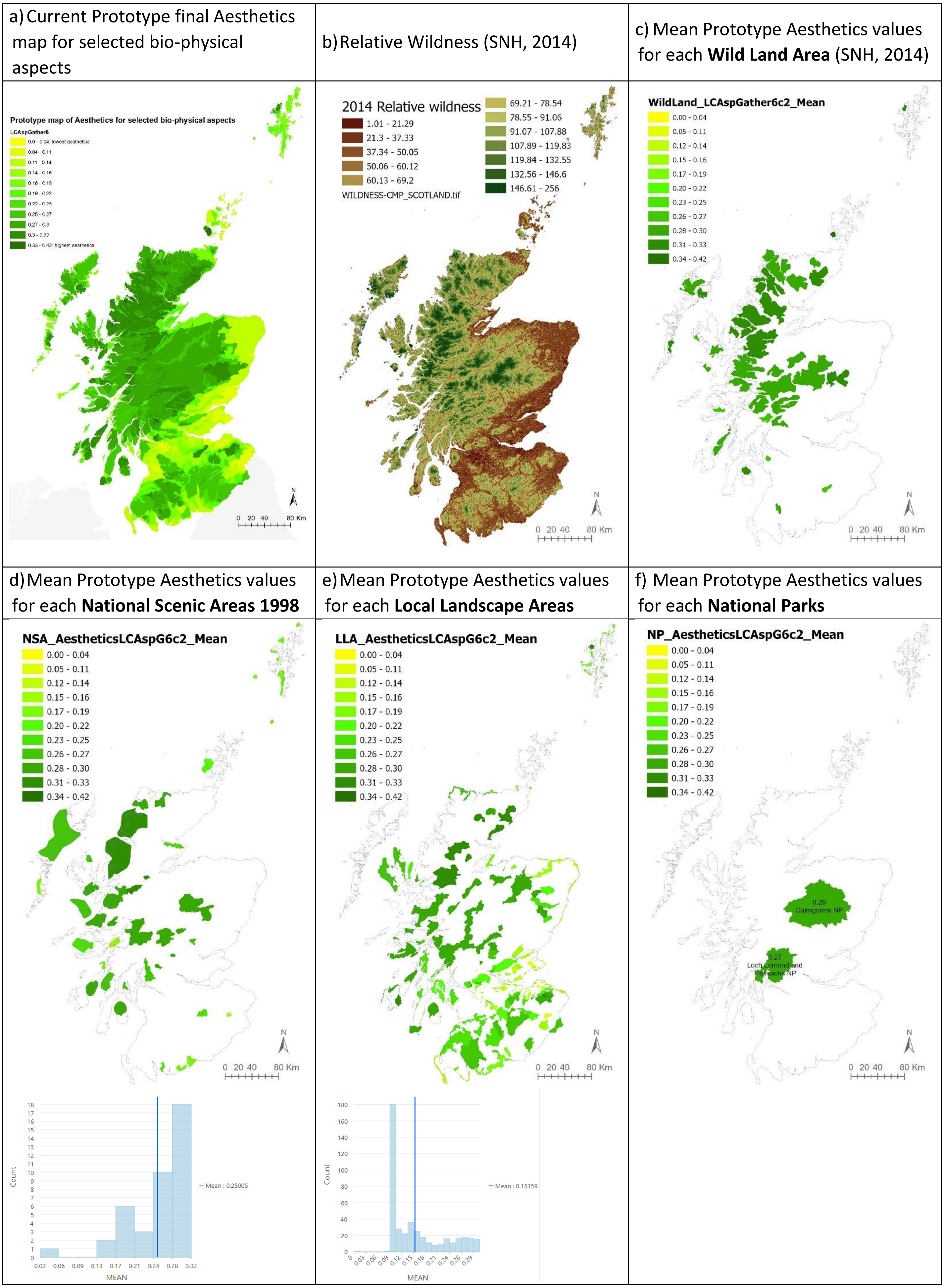

Figure 13. Pre-existing maps related to Aesthetics values in Scotland

5.1.5 National Parks (Cairngorms, Loch Lomond and Trossachs)

The mean Prototype Aesthetics values per National Park (NP) is reported in Figure 13 (f), with the mean value for the Cairngorms NP being 0.29 and for Loch Lomond and Trossachs 0.27. It can be seen that both have a ranking at the higher end of the prototype Aesthetics map.

5.1.6 CES Cultural Heritage and Entertainment

Two previously studied CES are Cultural Heritage and Entertainment (Figure 14; see Aalders and Stanik, 2019 for methodology). An indicator for Cultural Heritage is Historic Land Use Values (HLUV), which has the "assumption that earlier land-use introductions represent a longer cultural history of an area than more recent" (Aalders and Stanik, 2019, p. 1638). The indicator was calculated by LCA single parts polygons, as in the prototype Aesthetics map. The highest HLUV are mostly located in the East Coast, Central Belt; in contrast, those areas are among the lowest ranked in the prototype Aesthetics map.

CES Entertainment, through the Artistic References (ArtRef) indicator (Figure 14) might indicate "potentially inspiring places" (Aalders and Stanik, 2019, p. 1637). However, the spatial pattern of high ArtRef does not show any strong correlations with the prototype aesthetics maps. Aalders and Stanik (2019, p. 1647) suggest "that inspirational entertainment values are linked to accessible locations and areas of extraordinary scenic fulfilment or uniqueness and visually preferred natural landscapes rather than land cover (Ode et al., 2009)". Accessibility is not directly part of the current prototype Aesthetics map, even if the inverse of "open space" could be considered as a distant proxy of it.

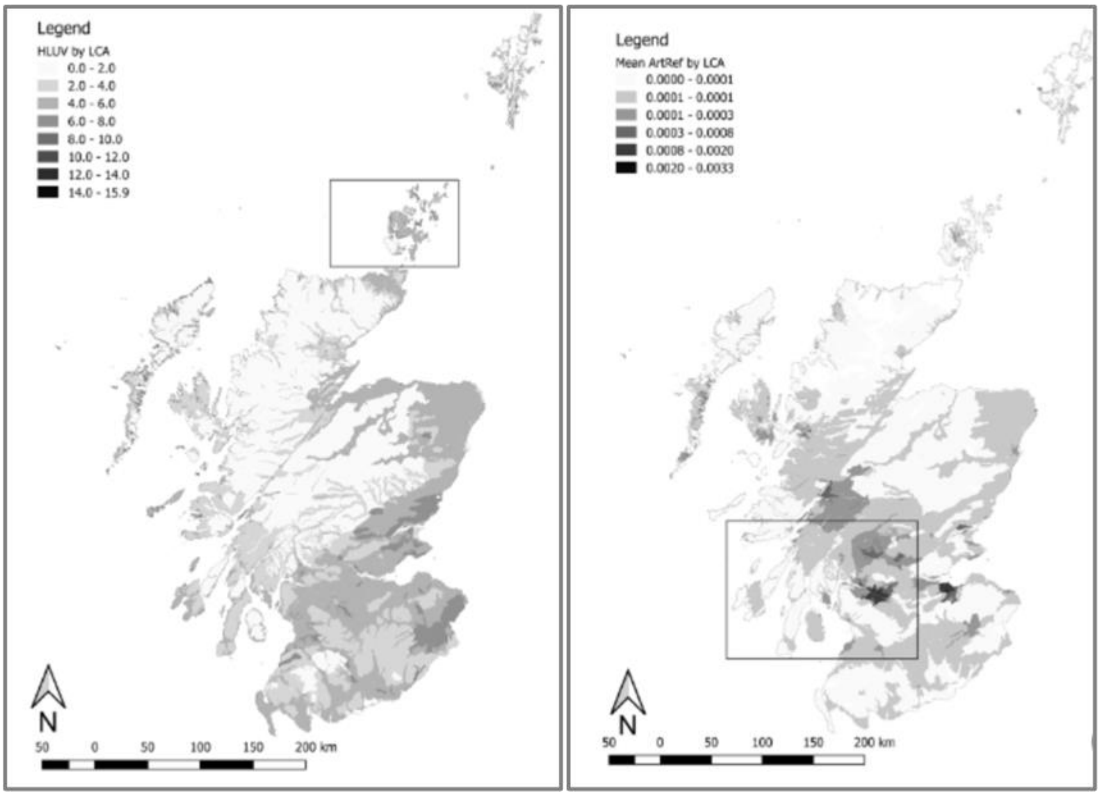

Figure 14. on left: CES Historic Land Use Value (HLUV), per LCA (Aalders and Stanik, 2019), on right: CES Entertainment per LCA, using ArtRef indicator as proxy (Aalders and Stanik, 2019)

5.1.7 Conclusions on the comparison with other Scottish maps

Overall, the prototype Aesthetics map tends to generally be in agreement with national scale designations, such as Wild Land areas, NSA and NP. The higher discrepancies were with local scale designation, i.e. the LLA. Even with good agreements at national scale, some particular areas were ranked very low in the prototype Aesthetics maps due to the different methodology used; this is exemplified by "St Kilda" and the "Isle of May". Unfortunately, both are not present within the LCM2007 (land use map), which is used as the basis for many metrics, thus their ranking end ups being very low. Using the latest LCMs (e.g. 2019) would potentially alleviate this issue.

The comparison with pre-existing CES maps indicates that the prototype Aesthetics map is sharing similar spatial pattern with the inverse of the Cultural Heritage, whereas no particular spatial pattern was visible with the Entertainment one.

5.2 Potential improvements within the scope of the current methodology of the 10 metrics

The ranking reached in this report is highly dependent upon the **10 chosen metrics** and **their underlying input spatial datasets**, as well as **their handling, such as rescaling**.

5.2.1 Improving the current metrics

None of the metrics individually is claiming to evaluate the landscape Aesthetics in its totality and complexity. However, individually they address different potential components of it and their combination into a single prototype map of Aesthetics provides the opportunity to map this complexity.

Each of the chosen 10 metrics could be improved on. The most impactful improvement would be to update the land cover map with one with better and more recent spatial coverage, for example the LCM2019. LCM2007 was used as it was the only data available to the project at the time. The land cover is the basis of the six landscape ecology metrics, and improved coverage on islands would give more appropriate values in the prototype Aesthetics map. Other improvements could include: i) better consideration of the sea space within the metrics, for example in relief diversity with the inclusion of the sea level and for the unfragmented open spaces; ii) a higher resolution input data for the Shannon Diversity Index and Core Area index of semi-natural areas; iii) smaller roads taken in account for the definition of unfragmented open spaces; and iv) inclusion of the land use intensity or degradation for the hemeroby index estimation (e.g. grazing pressure, peat degradation).

5.2.2 Rescaling methodology

For the data handling, as noted in section 3.1 (“Maps of the 10 metrics”), the methodology used for rescaling of the metrics could be improved on (i.e. to go from raw values to 0-1). Currently, a few metrics like relief diversity, freshwater edges, coastlines and forest ecotones show very limited spread of values for the maps at national scale (Figure 9). This is caused by the highest values for those metrics being located in the smallest LCA spatial units: Coastal Islands. The size of the LCA spatial units means that those very high values are not visible on the included national scale maps. For example, this is the case for Relief diversity on several of St Kilda LCA smallest spatial units. Those highest values also tend to be outliers (much larger than all other values), which leads to national scale map to appear of one value/colour. This issue means that currently the affected metrics only have limited impact on the final prototype map, they are mostly strengthening the values for Coastal Islands and do not impact on the ranking of the other LCA units.

Alternative methods to take in account those outliers’ values would include non-linear transformations such as logarithmic to even the spread of the values across the national map.

5.2.3 Different weights

Each metric was given an equal weight in the creation of the final map. However, the weights could be amended to change the contribution of each metric, for example, to even out the contribution of physical and biological components (e.g. four physical metrics weights each with a value of 0.125 plus six landscape ecology metrics with weights of 0.0833). An alternative set of weights could be evaluated and decided with more in-depth stakeholders’ engagement.

5.2.4 Assessing LCA boundaries

As a potential follow-on to this project the 10 metrics and the final prototype maps could be used to evaluate the relevance of the LCA boundaries, and particularly to evaluate the homogeneity of the LCA smallest units. The variability of the LCA values within each Level 3 would also be of particular interest.

All the issues listed in the above sections, and the potential workarounds could be implemented as enhancements to the current methodology.

6 Limitations of the chosen bio-physical methodology and potential future directions

This discussion section will be two-fold in its consideration of limitations. Firstly we consider limitations within the scope of the current methodology, and secondly, we look beyond it to other potential methodology for mapping Scottish Aesthetics.

6.1 Limitations of the current methodology

6.1.1 Choice of the current 10 metrics

The current 10 metrics were shaped by the choice of replicating the methodology laid out by Frank and Walz (2017). The metrics are **currently biased towards landscape ecology perspective to Aesthetics** (6 out of 10).

Choosing different metrics would bring a different emphasis to the evaluation of the "Aesthetics". For example, landscape mystery could be included; Frank and Walz (2017) suggested to use the "number of landscape elements" as a potential proxy. Wherrett (1996, 1998) highlighted further potential qualities to evaluate such as "complexity", "focality, ground texture and depth", or "prospect and refuge" which is concerned with the openness or enclosure of the views and observation points (Appleton, 1996).

Another relevant metric could encapsulate the designations such as the National Scenic Areas (NSA) or Local Landscape Areas (LLA), as in those the scenic values or Aesthetics of the areas were considered in their creation. However, those would be considered as a different type of metric from the current ones based solely on bio-physical data, as they would encapsulate the conclusion of a human based decision process. Likewise, a type of Aesthetics not fully considered in the current methodology is the aesthetics of designed landscapes, which wouldn't be captured through the current set of metrics due to its difference from "natural" landscapes (i.e. low ranking in hemeroby index). However, the aesthetics impact of designed landscapes might be more easily captured through current designated protections or through local areas surveys.

The metrics could also be **weighted** differently to nuance their respective influence on the final Aesthetics prototype maps. The weighing could be influenced by the perceived relevance of the metric or its accuracy and reliability.

The choice of the metrics and their weights could be refined and explored through in-depth stakeholder engagements.

6.1.2 Choice of LCA as spatial units

The use of the Landscape Character Assessment (LCA) as the spatial unit for the analysis (cf. section 2.1), and particularly its smallest polygons, brought specific issues. This was mainly due to the wide range in size of the polygons which range from 728m^2 for a "coastal island" named the "The Cleats" on the north of the Isle of Sky to 606,025ha for "High, Massive, Rolling, Rounded Mountains of the Highlands and Islands" in the Cairngorms and Monadliath mountains. This leads to the "Modifiable Areal Unit Problem" (MAUP; Jelinski and Wu, 1996; Wong, 2009), which makes developing consistent metrics more challenging. To sidestep the issue of spatial units of highly differing size, an alternative would be to use a regular grid, like kilometre squares. This alternative might fit better with some other GIS layers (Aalders et al., 2018), however, the landscape homogeneity within each spatial unit would be lost. The choice of the spatial units could be explored with stakeholder engagement, particularly regarding the most useful units to support any local or national reporting and actions.

6.1.3 Potential validation process

Approaches to a validation of the Aesthetics output ranking (map and table both at LCAsp and Level 3) could be explored. It would be useful to investigate the MAUP (Modifiable Areal Unit Problem, Jelinski and Wu, 1996; Wong, 2009) impact between LCAsp and Level 3 results. For validation, potential options could be to consider using social media data (e.g. Flickr images), crowd sciences and more in-depth stakeholder engagement.

6.2 Wider discussion on alternative methodologies

As noted in section 1.2, **the focus of this prototype map is on the final output from the environment** (following CICES v4.3) and **not specifically on the social and economic system** (added in CICES v.5.1). However, the more formal involvement of social systems in particular would be highly relevant and add depth, usefulness and further validity to future Aesthetics mapping for Scotland.

6.2.1 Aesthetics is a matter of context

Gobster et al. (2007) argue that the aesthetics experiences of a landscape are context dependent, particularly on the type of landscapes. Aesthetics experiences in large expanses of "wild" land tend to be more closely aligned to ecological functions or processes whereas agricultural land might be more judged on the Aesthetics of care (e.g. well-tended fields), which might or might not be aligned to ecological functions (Gobster et al., 2007). There is also the important issue of the Aesthetics of the built environment and designed landscapes, which is an aspect of the Scottish landscape that is not part of the focus of the current analysis (cf. section 1.4). Therefore, an area of further investigation could be on whether Scottish landscapes need to be subdivided into broad types, and each one to be assessed with a different set of metrics or a different set of weights for those metrics.

6.2.2 Aesthetics is a matter of scale

Human perception is achieved over a relatively small spatial extent, i.e. what can be seen from a viewpoint, also known as a viewshed. Thus, it could be argued that national scale mapping without viewshed analysis is not the best tool to capture this level of perception. With mapping Aesthetics at national scale, there is the issue of the location of an aesthetically pleasing view (viewpoint) being at a different location from what is viewed, and how best to represent this association or spatial dislocation and the resulting differences on maps at national scale.

6.2.3 Stakeholder involvement: defining Aesthetics for Scotland and validation

For this prototype mapping of Aesthetics the work was solely GIS based, with limited stakeholder involvement after a first draft of this report. Focusing on a holistic approach to Aesthetics with the integration of a broad range of perspectives from the start using an array of social science methods (Simensen et al., 2018) would provide an assessment more in line with CICES v.5.1 and the European Landscape Convention (cf. section 1.3). Participants who could be involved include stakeholders (e.g. NatureScot), local residents, national and international visitors with an interest in Scottish landscapes. Previous studies have used surveys, interviews and photograph-based questions (e.g. Peña et al., 2015; Plieninger et al., 2013). This potential expansion of the work would provide more robust and quantifiable information on the relevance of GIS metrics as proxy for national scale studies on Scottish Aesthetics. However, particular attention will be required to identify how to produce a comprehensively national account in a map, while integrating a holistic approach with social science. [see Conniff and Irvine (2022) for a report on the development and application of different social science methods for mapping of Scotland's less tangible CES.]

6.2.4 Final reminder and disclaimer

This report on prototype mapping of Aesthetics in Scotland aimed at exploring a selected set of aspects of Aesthetics through mapping physical and bio-physical aspects of landscapes. The social and economic systems were not considered, and stakeholder engagement was limited. This mapping exercise does not claim to provide a validated Aesthetics map of Scotland.

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Appendix A. Glossary

Awm: area weighted mean

Biocenosis: All the interacting organisms that live together in a specific habitat or biotope, forming an ecological community (https://www.biologyonline.com/dictionary/biocoenosis)

Ecotone: a region of transition between two biological communities.

DTM: Digital Terrain Model

GIS: Geographical Information System

Hemeroby index: the magnitude of the deviation from the potential natural vegetation caused by human activities. (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Hemeroby_index)

L3: within this report, Level 3 of the LCA

L3id: Level 3 unique id (57 of them) of the LCA

Land use map: within this report, LCM2007 (Morton et al, 2011) updated in-house with Native Woodland Survey of Scotland 2014 (NWSS; Forestry Commission Scotland, 2014) and National Forest Inventory 2015 (NFIS; Forestry Commission Scotland, 2015).

LCA: Landscape Character Assessment (Julie Martin Associates and Carys Swanwick, 2003)

LCAmp: within this report, multi-parts/multi-polygons of the LCA for the Level 3 attribute; LCAmp = Level 3.

LCAsp: within this report, single-parts/single polygons of the LCA.

LCM: Land Cover Map, cf. Land use map.

MAUP: Modifiable Areal Unit Problem is a mapping issue inherent to summarising data at any given spatial unit. The location of the spatial unit boundaries and its size impact on the output mapping pattern and interpretations (Jelinski and Wu, 1996; Wong, 2009).
For an introduction refer to https://www.gislounge.com/modifiable-areal-unit-problem-gis.

NAR: Natural Asset Register: Data Portal (NAR; Donnelly et al., 2021)

NFIS15: National Forest Inventory 2015 (NFIS; Forestry Commission Scotland, 2015).

NWSS14: Native Woodland Survey of Scotland 2014 (NWSS; Forestry Commission Scotland, 2014).

Patch: an area of habitat differing from its surroundings

Patch density: area of a patch divided by the whole area

Relief diversity: 3D surface area / 2D surface area

Shannon's diversity index (SDI): (Shannon-Wiener Index) is a way to measure the diversity of species in a community.

Appendix B. Hemeroby values per land use class

The original hemeroby analysis from Walz and Stein (2014) in Germany was based on their “Digital Land Cover Model” (DLM-DE) which follows the Land Cover Classes of the European CORINE nomenclature, while being more spatially detailed. The DLM-DE dataset was used for the main hemeroby assignation (Table 2 from Walz and Stein 2014). Further datasets were brought in to further refine the analyses, such as topographic datasets to introduce the impact of roads, rail and rivers. Their table linking hemeroby values to CORINE land use classes (Table 2 from Walz and Stein 2014) was used to guide the assignation of hemeroby values per land use classes in Scotland (Table 8).

The land use map used for the hemeroby analysis on Scotland was derived from the LCM2007 (Morton et al, 2011) updated in-house with the Native Woodland Survey of Scotland 2014 (NWSS; Forestry Commission Scotland, 2014) and National Forest Inventory 2015 (NFIS; Forestry Commission Scotland, 2015). The vector dataset was used for maximum details. No other spatial dataset was used, particularly as roads, rails, rivers, and coastlines are the main datasets of 3 other metrics, namely the “Proportion of unfragmented open space >100km²”, “Density of freshwater edges (without coasts)”, “Density of coastlines”. Some values in the Table 8 were amended from the German case study, to reflect some specificities of the chosen land use map classification and Scottish landscapes. For example, the Native woodlands were provided with a less disturbed (lower) hemeroby value, than non-natives ones.

A few points could be argued against the chosen values in Table 8.

The LCM 2007 (Morton et al, 2011) defines “Urban” and “Suburban” as:

- ‘Urban’ includes dense urban, such as town and city centres, where there is typically little vegetation. ‘Urban’ also includes areas such as dock sides, car parks and industrial estates.
- ‘Suburban’ includes suburban areas where the spectral signature is a mix of urban and vegetation signatures.

Large greenspaces would thus not be classified as ‘Urban’ nor ‘Suburban’. ‘Suburban’ hemeroby index has thus a reason to have a less disturbed hemeroby index than ‘Urban’.

The difference of rating of Saltwater (2) in comparison with Freshwater (4) could be a-priory justified by the higher degree of potential anthropogenic influence along rivers and lochs rather than alongside the coastlines. Build up areas (sealed surfaces) should have been identified as Urban land use. This point could be further explored within the context of a more in-depth project; particularly as they are rated identical in the Naturalness index (Figure 15 below).

In the German look up table, “Moors and heathland” and” Coniferous Forest rated as potential natural vegetation” were both rated as hemeroby index 3 (Table 7, index 3 = Semi-natural; clearing and occasional ploughing, extensive grazing). This led to Heathers and Montane habitats to be rated as well as 3 for the LCM2007. It could be argued that Heather and Heather grassland are more managed habitats than Bog which has a hemeroby index of 2 (Table 7, index 2 = close to natural) ; thus those values are justifiable. The case with Montane is less clear and could be argued that an index value of 2 would have been more appropriate. The Naturalness index does rate Montane at the same level as Bog, Freshwater, Saltwater and rocks (Figure 15).

“Bogs” are listed as hemeroby index 1 in Table 6. “Definition of the degree of hemeroby”, however, Bogs are downgraded to hemeroby index 2 by Walz and Steiner (2014), as they argue that only natural areas without vegetations (e.g. rocks) could be considered at the lowest level of anthropogenic disturbance. This was applied to Table 7.

It was chosen to keep the hemeroby index on a scale of 7 values, without any decimals for the look up values. Further refinement in the assignation of the values to land use classes could be considered and welcome for more in-depth analysis. The values of Table 8 were chosen to test the relevance of the analyses for inclusion in the 10 metrics to assess Landscape Aesthetics. None of the metrics can or should be considered as the final prototype Aesthetics map, cf. section 1.4, 2.3 and 5.2.

Table 8. Hemeroby values per land use class of the LCM2007 + NWSS14 + NFIS15

Land use ID (WoodR2id)	**Land use name**	**Hemeroby**
3	Arable and horticulture	**5**
4	Improved grassland	**4**
5	Rough grassland	**3**
6	Neutral grassland	**3**
7	Calcareous grassland	**3**
8	Acid grassland	**3**
9	Fen, Marsh and Swamp	**2**
10	Heather	**3**
11	Heather grassland	**3**
12	Bog	**2**
13	Montane Habitats	**3**
14	Inland Rock	**1**
15	Saltwater	**2**
16	Freshwater	**4**
17	Supra-littoral Rock	**2**
18	Supra-littoral Sediment	**2**
19	Littoral Rock	**2**
20	Littoral Sediment	**2**
21	Saltmarsh	**2**
22	Urban	**7**
23	Suburban	**6**
30	Broadleaved – Native	**2**
31	Broadleaved - Non-Native	**3**
32	Coniferous – Native	**2**
33	Coniferous - Non-Native	**3**
34	Felled woodland – Native	**2**
35	Felled woodland - Non-Native	**3**
36	Woodland – Native	**2**
37	Woodland - Non-Native	**3**

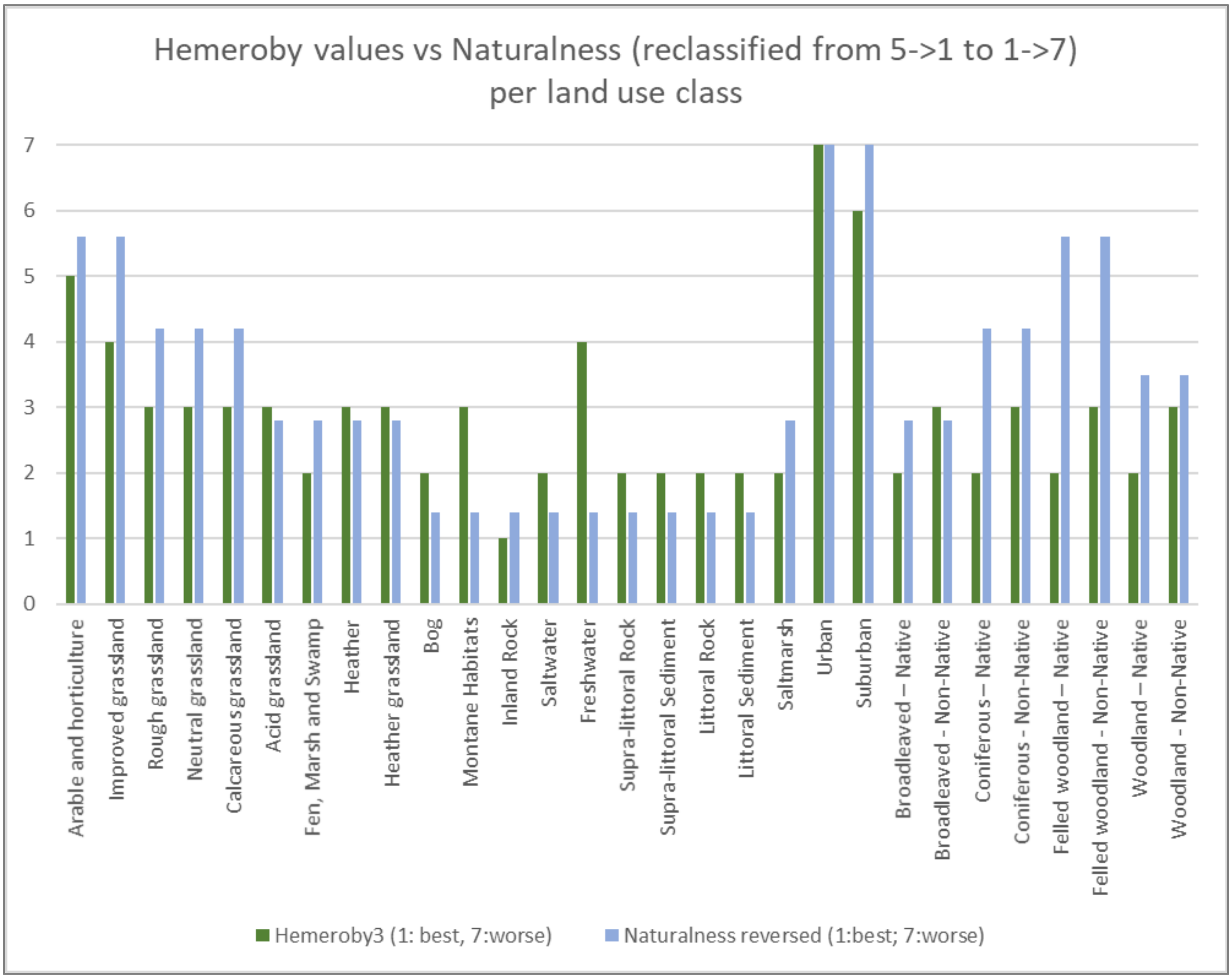


Figure 15. Comparison per land use classes of the hemeroby values versus the Naturalness values (SNH, 2014)

Appendix C. Large scale maps of the 10 metrics and final map, displayed to showcase individual maps patterns (Natural breaks classification)

Filename: AppendixC_finalMap_10metrics_LCAsp_NaturalBreaks.pdf

Equivalent of maps in:

- Figure 8. Ten metrics rescaled 0-1, each break in the colours is optimised to show patterns within a map (natural breaks classes with 0: yellow to 1: dark green; 0 in raw data: grey). <u>Purpose: exploring the spatial pattern within each metric.</u>
- Figure 10. Aesthetics map for selected bio-physical aspects (LCAsp). Natural break classification (yellow: low aesthetics for selected bio-physical aspects; dark green: high aesthetics values for selected bio-physical aspects). If all metrics were at the highest possible values in one spatial area, it would have the theoretical maximum aesthetical value of 1.0.

Contents:

Appendix D. Large scale maps of the 10 metrics and final map, displayed to compare the metrics values contributing to the final Aesthetics prototype map (Equal intervals classification)

Filename: AppendixD_finalMap_10metrics_LCAsp_EqualIntervals.pdf

Equivalent of maps in:

- Figure 9. Ten metrics rescaled 0-1, displayed with identical scales across all maps (equal intervals classes, with 0: yellow to 1: dark green; 0 in raw data: grey). Purpose: comparing the metrics values contributing to the final Aesthetics prototype map.

Contents:

Appendix E. Summary table at the LCA "Level 3" for the rescaled values of the 10 metrics

Summary table at the LCA "Level 3" (L3) for the **rescaled values of the 10 metrics at L3** and the L3 Aesthetics values for selected bio-physical aspects (average of the 10 metrics). The table is sorted by L3 Aesthetics values (1: highest, 57: lowest).

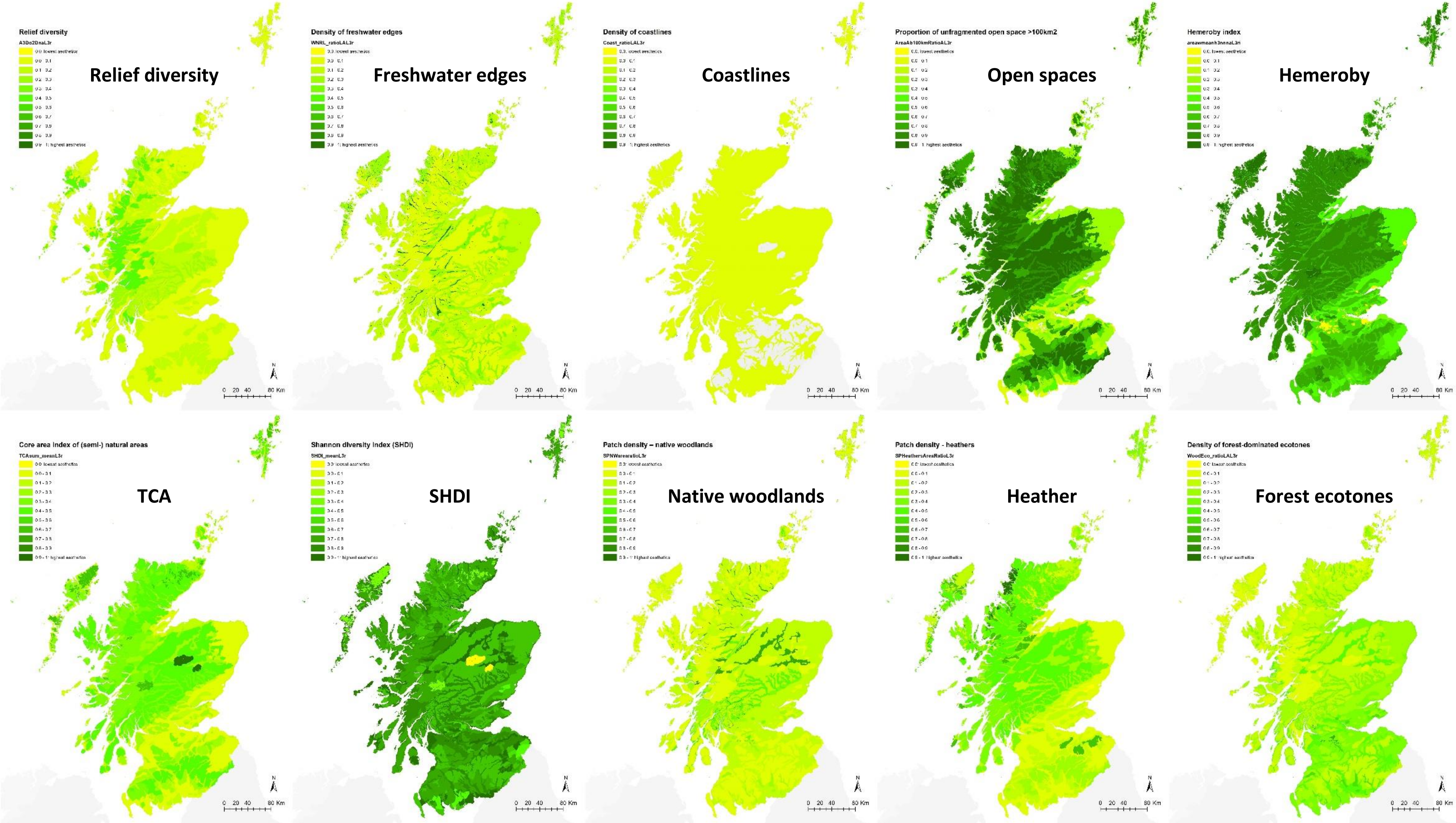
L3id	LEVEL_3	L3area % whole landscape	L3 Relief diversity	L3 Freshwater edge density	L3 Coastline density	L3 Open space > $100km^2$	L3 Hemeroby index (1= undisturbed; 7= sealed surface)	L3 TCA (core areas semi-naturals)	L3 SHDI (Shannon Diversity Index)	L3 Patch density – Native woodlands	L3 Patch density - Heathers	L3 Density forest ecotones	Level 3 Aesthetics	Level 3 Ranking (highest value : 1)
			A3Do2 DnaL3r	WNRL_ ratioLA L3r	Coast_ ratioLA L3r	AreaAb 100km RatioA	areaw meanh 3nnnaL 3ri	TCAsu m_me _ _	SHDI_ meanL 3r	SPNWa rearati oL3r	SPHeat hersAr eaRati	WoodE co_rati oLAL3r	L3Gath er6	
33	Lowland Loch and Shore	0.01	0.03	0.58	0.00	0.94	0.78	0.03	0.95	1.00	0.01	1.00	0.53	1
22	Highland Straths	2.91	0.09	0.31	0.00	0.72	0.77	0.25	0.97	0.75	0.21	0.48	0.46	2
18	Highland and Island Glens	3.69	0.21	0.25	0.00	0.88	0.78	0.32	0.86	0.44	0.24	0.36	0.44	3
20	Highland Cnocan	0.71	0.20	0.27	0.02	0.80	0.80	0.30	0.62	0.12	1.00	0.16	0.43	4
45	Rocky Volcanic Islands	0.00	1.00	0.00	0.14	0.00	0.79	0.00	0.88	0.30	0.36	0.59	0.41	5
14	High, Massive, Rugged, Steep-Sided Mountains of the Highlands and Islands	9.42	0.42	0.09	0.01	0.94	0.84	0.38	0.77	0.08	0.42	0.08	0.40	6
44	Rocky Moorlands of the Highlands and Islands	3.11	0.15	0.15	0.03	0.82	0.85	0.29	0.82	0.16	0.62	0.13	0.40	7
48	Rugged, Craggy Upland Hills and Moorlands of the Highlands, including the Trossachs	2.28	0.22	0.12	0.01	0.83	0.79	0.35	0.82	0.24	0.31	0.26	0.40	8
13	High, Massive, Rolling, Rounded Mountains of the Highlands and Islands	17.43	0.17	0.08	0.00	0.94	0.83	0.49	0.69	0.13	0.45	0.11	0.39	9
55	Upland Hills, The Lammemuir, Pentland and Moorfoot Hills	0.88	0.13	0.08	0.00	0.95	0.77	0.24	0.83	0.01	0.65	0.19	0.38	10
17	Highland and Island Forested Landscape	1.23	0.08	0.10	0.00	0.87	0.82	0.40	0.80	0.27	0.09	0.38	0.38	11
46	Rugged Granite Uplands	0.69	0.21	0.10	0.00	1.00	0.81	0.43	0.72	0.03	0.28	0.14	0.37	12
47	Rugged Moorland Hills	0.65	0.10	0.12	0.00	0.82	0.82	0.29	0.96	0.07	0.32	0.19	0.37	13
19	Highland and Island Rocky Coastal Landscapes	0.97	0.20	0.10	0.13	0.33	0.77	0.13	0.87	0.41	0.27	0.42	0.36	14
23	Inland Loch	1.73	0.00	1.00	0.00	0.84	0.51	0.28	0.82	0.01	0.01	0.15	0.36	15
8	Flat or Rolling, Smooth or Sweeping, Extensive, High Moorlands of the Highlands and Islands	9.04	0.09	0.11	0.01	0.80	0.87	0.40	0.71	0.07	0.39	0.11	0.36	16
11	High Massive Mountain Plateau of the Cairngorms	0.71	0.29	0.09	0.00	1.00	0.81	1.00	0.00	0.04	0.22	0.03	0.35	17
56	Upland Hills, The Southern Uplands and Cheviots	3.89	0.16	0.09	0.00	0.95	0.79	0.45	0.60	0.02	0.22	0.18	0.35	18

L3id	LEVEL_3	L3area % whole landscape	L3 Relief diversity	L3 Freshwater edge density	L3 Coastline density	L3 Open space > 100km^2	L3 Hemeroby index (1= undisturbed; 7= sealed surface)	L3 TCA (core areas semi-naturals)	L3 SHDI (Shannon Diversity Index)	L3 Patch density – Native woodlands	L3 Patch density - Heathers	L3 Density forest ecotones	Level 3 Aesthetics	Level 3 Ranking (highest value : 1)
21	Highland Foothills	0.64	0.10	0.13	0.00	0.70	0.68	0.15	0.88	0.31	0.14	0.36	0.35	19
54	Upland Glens, Valleys and Dales	1.79	0.10	0.32	0.00	0.71	0.63	0.18	0.87	0.12	0.10	0.41	0.34	20
51	Upland Basin	0.05	0.03	0.30	0.00	0.90	0.68	0.09	0.84	0.07	0.22	0.19	0.33	21
24	Knock or Rock and Lochan of the Islands	0.15	0.12	0.36	0.09	0.42	0.99	0.11	0.82	0.00	0.34	0.00	0.33	22
42	Peatland Landscapes of the Highlands and Islands	2.76	0.03	0.24	0.01	0.77	1.00	0.61	0.35	0.01	0.17	0.03	0.32	23
12	High Plateau Moorlands	2.38	0.04	0.10	0.00	0.73	0.78	0.37	0.75	0.04	0.17	0.23	0.32	24
49	Sea Lochs of the Highlands and Islands	0.43	0.11	0.15	0.10	0.22	0.77	0.20	0.90	0.22	0.34	0.17	0.32	25
16	Highland and Island Crofting Landscapes	1.06	0.06	0.22	0.06	0.47	0.71	0.18	0.92	0.10	0.22	0.19	0.31	26
3	Coastal Island	0.06	0.21	0.01	1.00	0.00	0.90	0.04	0.62	0.04	0.19	0.08	0.31	27
52	Upland Fringe Moorland	0.98	0.06	0.10	0.00	0.56	0.59	0.08	0.98	0.07	0.15	0.38	0.30	28
10	Foothills and Pronounced Hills	2.83	0.06	0.09	0.00	0.62	0.68	0.22	0.80	0.07	0.13	0.27	0.30	29
41	Narrow Valleys in the Lowlands	0.75	0.06	0.35	0.00	0.33	0.57	0.08	0.75	0.26	0.02	0.52	0.29	30
40	Moorland Transitional Landscapes of the Highlands and Islands	1.18	0.06	0.10	0.03	0.33	0.71	0.14	0.94	0.13	0.21	0.25	0.29	31
38	Lowland Urbanised Landscapes	0.11	0.02	0.24	0.00	0.00	0.48	0.00	0.93	0.44	0.01	0.78	0.29	32
53	Upland Fringe Valleys and Farmlands	1.16	0.06	0.18	0.00	0.51	0.56	0.06	0.88	0.14	0.03	0.45	0.29	33
2	Coastal Hills Headlands Plateaux and Moorlands	0.72	0.09	0.08	0.01	0.43	0.62	0.11	0.93	0.13	0.15	0.32	0.29	34
32	Lowland Hills	1.38	0.07	0.07	0.00	0.51	0.64	0.20	0.80	0.11	0.17	0.27	0.28	35
15	Highland and Island Cities, Towns and Settlements	0.09	0.06	0.19	0.08	0.36	0.38	0.06	1.00	0.15	0.09	0.36	0.27	36
57	Upland Igneous and Volcanic Hills The Ochil, Sidlaw, Cleish and Lomond Hills	0.80	0.11	0.08	0.00	0.39	0.62	0.15	0.79	0.11	0.16	0.30	0.27	37
39	Lowland Valley Fringes	0.07	0.03	0.20	0.00	0.10	0.52	0.02	0.86	0.34	0.01	0.53	0.26	38
9	Flatter Wider Valleys and Floodplains of the Lowlands	0.53	0.02	0.30	0.00	0.12	0.52	0.06	0.84	0.21	0.01	0.46	0.25	39
5	Coastal Raised Beaches and Terraces	0.21	0.08	0.13	0.05	0.19	0.47	0.03	0.90	0.18	0.04	0.41	0.25	40
36	Lowland River Valleys	1.46	0.04	0.27	0.00	0.20	0.46	0.03	0.74	0.20	0.01	0.44	0.24	41
30	Lowland Coastal Landscapes of the North East	1.51	0.03	0.13	0.03	0.22	0.54	0.10	0.85	0.11	0.02	0.30	0.23	42
27	Low, Flat, and / or Sandy Coastal Landscapes of the Highlands and Islands	0.69	0.03	0.12	0.09	0.12	0.75	0.09	0.90	0.01	0.12	0.06	0.23	43

L3id	LEVEL_3	L3area % whole landscape	L3 Relief diversity	L3 Freshwater edge density	L3 Coastline density	L3 Open space > $100km^2$	L3 Hemeroby index (1= undisturbed; 7= sealed surface)	L3 TCA (core areas semi-naturals)	L3 SHDI (Shannon Diversity Index)	L3 Patch density – Native woodlands	L3 Patch density - Heathers	L3 Density forest ecotones	Level 3 Aesthetics	Level 3 Ranking (highest value : 1)
35	Lowland Plateaux and Plains	1.54	0.02	0.15	0.00	0.20	0.50	0.03	0.80	0.13	0.04	0.37	0.22	44
29	Lowland Coastal Flats Sands and Dunes	0.51	0.01	0.16	0.03	0.04	0.55	0.04	0.97	0.10	0.01	0.27	0.22	45
7	Farmlands and Estates of the Highlands and Islands	1.27	0.03	0.16	0.03	0.22	0.66	0.10	0.71	0.02	0.13	0.07	0.21	46
31	Lowland Hill Margins and Fringes	0.52	0.04	0.11	0.00	0.25	0.44	0.03	0.59	0.15	0.04	0.33	0.20	47
4	Coastal Margins	0.54	0.04	0.08	0.02	0.18	0.38	0.02	0.74	0.12	0.01	0.37	0.20	48
25	Low Coastal Farmlands	0.16	0.05	0.07	0.03	0.07	0.45	0.01	0.84	0.09	0.02	0.32	0.20	49
37	Lowland Rolling or Undulating Farmlands, Hills and Valleys	2.03	0.03	0.11	0.00	0.13	0.48	0.02	0.67	0.12	0.02	0.34	0.19	50
1	Agricultural Lowlands of the North East	6.74	0.03	0.14	0.00	0.25	0.42	0.02	0.62	0.14	0.01	0.28	0.19	51
34	Lowland Loch Basins	0.27	0.02	0.22	0.00	0.12	0.41	0.02	0.65	0.12	0.01	0.33	0.19	52
6	Drumlin Lowlands	1.14	0.03	0.17	0.00	0.22	0.47	0.03	0.46	0.09	0.03	0.31	0.18	53
43	Rocky Coasts Cliffs and Braes of the Lowlands	0.76	0.05	0.08	0.02	0.03	0.52	0.01	0.66	0.08	0.02	0.31	0.18	54
26	Low Coastal Hills of the Highlands and Islands	0.12	0.06	0.07	0.03	0.19	0.59	0.04	0.61	0.01	0.05	0.02	0.17	55
28	Lowland Cities, Towns and Settlements	1.11	0.02	0.12	0.02	0.03	0.00	0.00	0.88	0.09	0.00	0.37	0.15	56
50	Smooth Upland Moorland Hills	0.15	0.03	0.04	0.00	0.00	0.41	0.07	0.45	0.10	0.00	0.26	0.14	57

Appendix F. "Level 3" 10 metrics rescaled 0-1, displayed with identical scales across all maps

(equal intervals classes, with 0: yellow to 1: dark green; 0 in raw data: grey). Purpose: comparing the metrics values contributing to the final Aesthetics prototype map. Those maps are the "Level 3" equivalent of Figure 9 (results of LCAspID analysis).



Appendix G. “Level 3” large scale maps of the 10 metrics and final map, displayed to compare the metrics values contributing to the final Aesthetics prototype map (Equal intervals classification)

Filename: AppendixG_finalMap_10metrics_Level3_EqualIntervals.pdf

Equivalent of maps in:

- Appendix F: “Level 3” 10 metrics rescaled 0-1, displayed with identical scales across all maps

Contents:

Appendix H. LCA "Level 3" with the five highest and five lowest ranks of Aesthetics values for the selected bio-physical aspects