Land Use Policy 75 (2018) 557–569

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Methods for landscape characterisation and mapping: A systematic review

Trond Simensen[a,c,*], Rune Halvorsen[a], Lars Erikstad[a,b]

[a] Natural History Museum, University of Oslo, P.O. Box 1172, Blindern, NO-0318 Oslo, Norway
[b] Norwegian Institute for Nature Research (NINA), Gaustadalléen 21, NO-0349 Oslo, Norway
[c] Norwegian Environment Agency, P.O. Box 5672 Torgarden, N-7485 Trondheim, Norway

ARTICLE INFO

Keywords:
Landscape characterisation
Landscape classification
Landscape typology
European Landscape Convention
Land use policy

ABSTRACT

Due to the multidisciplinary nature of landscape research, many different systems and methods for landscape identification and classification exist. This paper provides a systematic review of 54 contemporary landscape characterisation approaches from all over the world, with the aim of identifying major methodological strategies. Multivariate statistical analyses revealed segregation of the approaches according to the landscape concept applied, the degree of observer independence and various other factors involved in the landscape characterisation process. Our review confirmed a major distinction between approaches rooted in the natural sciences and approaches rooted in the arts and the humanities. Three substantially different methodological approaches or strategies were identified: 1) 'holistic' landscape character assessment approaches, by which visual perception and socio-cultural aspects of the landscape are emphasised; 2) landscape characterisation methods based on *a priori* selection of geo-ecological and land-use-related properties of the landscape; and 3) biophysical landscape characterisation approaches which rely strongly on statistical analyses in order to identify gradients of variation in the presence and/or abundance of landscape elements and properties. Assessment of landform and the composition of natural and human landscape elements was a central part of all of the reviewed methods. A trend towards increasing observer-independence over time was identified.

1. Introduction

There is an increasing need for planning and management strategies that combine preservation of landscape diversity with sustainable use of land resources (Council of Europe, 2000; Wascher, 2005; Kim and Pauleit, 2007; Mücher et al., 2010; Hazeu et al., 2011). 'Landscape' is often regarded as a unifying concept within integrated environmental research (Fry, 2001; Sayer et al., 2013), and 'landscape approaches' to integrated land management have recently gained considerable attention, both in the scientific literature and in other international fora (Reed et al., 2017). In addition, the landscape level is central in specialised scientific studies, e.g. as a main level of organisation within the hierarchy of biodiversity levels (Noss, 1983, 1990).

The European Landscape Convention (ELC; Council of Europe, 2000) leaves it to the parties (the countries that have ratified the convention) themselves to identify the landscapes of their territories, to analyse their characteristics, to identify the forces and pressures that may impact them, and to implement strategies for landscape management, planning and protection. All of these tasks are challenging and call for a foundation that consists of systematised knowledge about the variation at the range of spatial scales that define the landscape level, i.e. a typology of landscapes. With nation-wide coverage, such a typology may provide a framework for landscape research, monitoring, management and planning (Blankson and Green, 1991; Bastian, 2008; Brabyn, 2009; Chuman and Romportl, 2010; Mücher et al., 2010; Erikstad et al., 2015).

The complex, varied and continuous landscape can be understood better when classified in types and spatial units (Christian, 1958; Antrop and Van Eetvelde, 2017). Regardless of approach, any system for spatial landscape characterisation inevitably implies a strong simplification of the almost infinite variability in landscapes, into spatial units suitable for communication in management and research (Bunce et al., 1996b; Hazeu et al., 2011). Critical for typologies to gain general acceptance, for landscape units as well as for all other properties that can be generalised into types, is that they are developed by use of explicitly stated rules by repeatable procedures (Brabyn, 2005; Mücher et al., 2010). Establishing such rules and procedures is a challenging process because landscapes share with ecosystems (Whittaker, 1967; Økland, 1990) the property that, by and large, their composition, structure and processes vary in a gradual, continuous manner along multiple 'directions of gradual variation'. The multidimensional structure of the physical landscape makes all approaches involving

* Corresponding author at: Norwegian Environment Agency, P.O. Box 5672 Torgarden, N-7485 Trondheim, Norway.
E-mail address: trond.simensen@miljodir.no (T. Simensen).

https://doi.org/10.1016/j.landusepol.2018.04.022
Received 30 October 2017; Received in revised form 9 April 2018; Accepted 9 April 2018

classification artificial, because they involve drawing boundaries in a basically continuous environment, with its correspondingly continuous change in composition of landscape elements. The numerous characterisation approaches that have been, and are still in use, for description of the structure of the landscape are per se a proof that no single correct characterisation method exists. Alfred Hettner mentioned already in 1928 that there are no right and wrong landscape classifications, but appropriate and unsuitable ones (Hettner, 1928). Thus, choice of characterisation method and spatial resolution should rely on user needs, and which information is available with full area coverage for the study area.

Due to the multidisciplinary nature of landscape research, different systems and methods for landscape identification and classification exist. These are rooted in different traditions and mostly also in different, related disciplines such as geography, geology, geomorphology, ecology, history, archaeology and landscape architecture. Depending on their scientific rooting, these systems and characterisation methods emphasise different aspects of the landscape to variable degrees, and address variation in landscape properties on different spatial and temporal scales (Wascher, 2005; Mücher et al., 2010; Sayer et al., 2013).

In any discussion of landscape characterisation, 'the elephant in the room is the question of just what a landscape is' (Olwig et al., 2016): there has been, and still is, considerable debate about how the term should be understood and the term's legitimacy (Jones, 1991; Bastian, 2008; Sandström and Hedfors, 2018). Several authors (Antrop, 2000; Bastian, 2008; Brabyn, 2009; Sarlöv Herlin, 2016) divide landscape research into two different traditions: a) a biophysical approach to landscape characterisation rooted in the natural sciences, and b) a landscape character assessment tradition rooted in arts and the humanities. The former, adopted by physical geographers and landscape ecologists, define landscape units as tangible and physically delineated areas on the Earth's surface (Bastian, 2008). The biophysical tradition is consistent with the German meaning of the word 'Landschaft', originally used to describe the physical content of an area or a region (Antrop and Van Eetvelde, 2017). The scientific history of biophysical landscape research dates back to the systematic landscape descriptions during the naturalistic explorations (e.g. von Humboldt and Bonpland, 1807). Important contributions from the period up to 1990 include references such as Berg (1915); Schlüter (1920); Troll (1939); Solnetsev (1948); Christian (1958); Vinogradov et al. (1962); Neef (1967); Noss (1983); Forman and Godron (1986) and Zonneveld (1989).

The latter tradition contrasts definitions of landscape commonly used in landscape ecology and natural geography (Jones et al., 2007; Erikstad et al., 2015) by making the landscape units dependent on human perception and sociocultural relations to areas. This concept is implicit in the definition of landscape adopted by the ELC (Council of Europe, 2000), as '(…) an area, as perceived by people (…)', with resemblance to the British meaning of the word 'landscape', namely a scenery (Antrop and Van Eetvelde, 2017). This concept has roots in fields such as landscape painting, aesthetic theory and cultural geography (Plieninger et al., 2015). Classical references include e.g. Sauer (1925); Granö (1929); Lynch (1960); Litton (1972); Cosgrove (1984); Zube (1984) and Bourassa (1991), while good overviews are provided by Zube et al. (1982) and Tveit et al. (2006).

Landscape characterisation and assessment (LCA) methods developed in the UK and France in the early 1990s (e.g. Swanwick, 2002) and have become central in landscape characterisation throughout Europe (Van Eetvelde and Antrop, 2009; Butler and Berglund, 2014). LCA-methods aim to integrate natural and cultural aspects of landscapes, and people's perceptions, whilst forming a spatial framework for planning and development. While many perception-based approaches explicitly deal with identification of landscape values, LCA-approaches draw an important distinction between two stages: the relatively value-free process of characterisation and the subsequent making of judgements and value assessment based on knowledge of landscape character (Swanwick, 2002).

Testing the validity of the result is one of the most problematic aspects of any landscape characterisation (Bunce et al., 1996b; Alcántara Manzanares and Muñoz Álvarez, 2015). Traditional landscape characterisation methods are inductive; 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 (Bunce et al., 1996b). No hypothesis is formulated initially, and no statistical testing of the results occurs. Furthermore, the validity of a method needs to be measured against the purpose of the characterisation process. Within a biophysical landscape concept, validity means whether the landscape is correctly classified according to the applied method, and to what extent the method is based upon empirical evidence. Within methods that put emphasis on human perception and cultural relations, validity may be evaluated by different means, 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 (Kaltenborn and Bjerke, 2002; Erikstad et al., 2015), and human perception may also vary with landscape type (Tveit et al., 2006; Sevenant and Antrop, 2009).

Briefly summarised, the landscape may be studied as an object in the natural sciences, as a social construct, or as an aesthetic object (Cosgrove, 2008). Each of these ways has its proper definitions, vocabulary and methods, and each way demands proper skills and specialisation (Antrop and Van Eetvelde, 2017). No single method for landscape characterisation can possibly suit all purposes. A comprehensive analysis of landscape typologies in Europe (Groom, 2005) showed considerable differences between typologies adopted for different European countries. Several sets of landscape properties, which are referred to as six 'dimensions' by Groom (2005), are addressed in landscape-type mapping and landscape character assessment: (1) the biophysical dimensions; (2) landscape ecological issues; (3) socio-economic-technical dimensions; (4) historical dimensions; (5) human-aesthetic dimensions; and (6) user participation and policy dimensions.

A proliferation of approaches to landscape characterisation has taken place in the recent decades, with a rapid increase in the number of publications since 1990 (Groom, 2005). This proliferation has continued also after 2005, as indicated by comprehensive overviews (Antrop and Van Eetvelde, 2017) and reviews in landscape research and comparable fields (Tveit et al., 2006; Brunetta and Voghera, 2008; Hazeu et al., 2011; Vallés et al., 2013; Plieninger et al., 2016; Vogiatzakis et al., 2017). One reason, among others, is the improved availability of advanced statistical analysis methods in combination with geographical information systems (GIS) and area-coverage of information relevant for the landscape scale in open databases, which have provided new opportunities for systematising landscape variation in a more observer-independent manner (Alcántara Manzanares and Muñoz Álvarez, 2015). By 'observer-independent' we mean that 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). A high degree of observer-independence is a prerequisite for specific research questions within landscape ecology and physical geography, such as the spatial distribution and abundance of landscape types and landscape elements, quantification, assessment and predictions of landscape changes and studies of patterns, structure and processes in the landscape. Degree of observer independence is thus of particular interest for scientists within these fields, because this attribute will directly affect the relevance of a landscape characterisation study for their purposes.

Older and more recent approaches to landscape characterisation have evolved within different traditions. The various methods and approaches therefore differ in landscape concept applied, spatial resolution, complexity, degree of observer independence, and the extent to which the different elements in the landscape are taken into account in the characterisation process. With a background within the fields of physical geography, ecology and landscape architecture, we have observed that methodological properties directly determine the applicability and usefulness of an approach for subsequent use within each sub-discipline.

This diversity of methods and approaches for landscape characterisation calls for a systematic review that addresses how and to which degree the various methods differ and, if possible, a sorting of them into distinct traditions or 'schools'.

The aim of this study is thus to identify relationships (and, implicitly, differences) between a selection of recent landscape characterisation methods. The following research questions are specifically addressed:

(i) What are the main methodological characteristics of the various landscape characterisation methods and how are the methods related?
(ii) Which landscape characteristics are used to identify landscape types and/or landscape character areas by the various characterisation methods?
(iii) How do the choice of landscape concept relate to the methodology used for landscape characterisation?

2. Material and methods

2.1. Terminology

For the purpose of the study, we define the term 'landscape' as 'a geographical area, characterised by its content of observable, natural and human-induced, landscape elements'. This definition encompasses the physical content of areas without necessarily excluding human perception, and allow for a broad inter-disciplinary comparison among approaches. We recognise that landscapes may vary in size, down to less than a few kilometres in diameter, while 'landscape elements' are usually identifiable in aerial photography and often range from 10 m to 1 km in width (Forman and Godron, 1986). 'Landscape element' is defined as 'a natural or human-induced object, category or characteristic, including ecosystem type, which is observable at landscape scale' (Erikstad et al., 2015). 'Biophysical landscape concept' is used in the review to describe methods concerned with the material content of the landscape (natural and man-made landscape elements), while the term 'holistic' is applied to landscape concepts that include human perception and cultural relations to areas. Both landscape concepts are clearly different from related concepts; terms such as 'land' and 'territory' are less integrative and more related to property rights and territorial ownership, while the term 'region' is normally used for areas with a larger areal extent than landscapes. The terms 'community' and 'environment' are used for the livings organisms that occur together within an area and their surroundings (biotic or abiotic), respectively, while the term 'ecosystem' is used for the community and the environment and the mechanisms and processes that regulate relationships between these components (Tansley, 1935). The term 'landscape characterisation' is here defined as a collective term for systematic, area-covering identification, classification and/or character assessment of landscapes. In line with Swanwick (2002) we differentiate between landscape characterisation and value judgements or quality assessments, although the former may be a knowledge base for the latter.

2.2. Selection of approaches for the review

The review process started with a broad scoping of articles that provide a method for general-purpose landscape characterisation. Scoping was performed in accordance with the guidelines for systematic reviews in environmental management (Collaboration for Environmental Evidence, 2013). From a selection of 183 potentially relevant references, a subset of 54 references that satisfied all of the following nine criteria were selected for the review (Table 1):

a) publicly available, i.e. published in peer reviewed scientific journals, other academic literature, influential guidelines, handbooks and guidance material;
b) available in digital form,
c) written in, or translated to, English or Germanic languages
d) published 1990–2016;
e) clearly aiming at identification, classification or, more broadly, characterisation, of landscapes based on their content of landscape elements (studies with a scope that is restricted to judgement of landscape value, or that characterise landscapes by use of very few selected aspects of the landscape, are not included);
f) addressing general patterns of observable landscape variation, including physical, ecological and land-use/land-cover characteristics;
g) applying a method for terrestrial area-covering landscape characterisation that is explicitly described or deducible from the end result;
h) containing an application of this method to a specific study area which is divided into discrete landscape units; and
i) containing a map representation of the distribution of landscape units, to scale less detailed than 1:20 000

For eleven studies (marked with an asterisk in Table 1), the detailed descriptions in Wascher (2005) was used as our main source of information.

Criterion (e) excludes approaches that restrict themselves to one 'dimension', e.g. that only take human-aesthetic or visual perception criteria (e.g. Tetlow and Sheppard, 1979) or a small and thematically restricted set of biophysical criteria such as landforms (e.g. Menz and Richters, 2009) or landscape ecological diversity, patterns, structure, connectivity, heterogeneity (Hou and Walz, 2013; Walz, 2015), into account. Furthermore, this criterion excludes ethnoclassifications of landscapes (e.g. Roba and Oba, 2009; Riu-Bosoms et al., 2015), historical landscape classifications (e.g. Antrop, 1997; Fairclough, 1999; Turner, 2006) and agricultural landscape classifications (e.g. van der Zanden et al., 2016). Criterion (f) excludes methods for site-specific landscape analysis (e.g. European Council for the Village and Small Town, 2006) and excludes bioclimatic stratification systems (e.g. Bakkestuen et al., 2008; Metzger et al., 2013; Bailey, 2014), none of which do not explicitly addresses observable landscape elements. Landscape characterisation studies do not always have to be expressed in spatial form and discrete units due to criterion h), but for many purposes, a spatial representation including a division of the landscape in the study area into discrete units is a prerequisite. In this review, we are explicitly interested in such approaches.

Even though the set of 54 references selected by criteria (a–i) is far from exhaustive, we consider this set to be representative for the main contemporary approaches to general-purpose characterisation of landscapes, sufficient for a quantitative analysis of relationships between methods.

2.3. Variables used to characterise the approaches

In order to reveal patterns and structure in the material (Table 1), statistical analyses were applied complementary to a careful and close reading of the approaches included in the review. Twenty-seven variables, listed in Table 2, were recorded for each of the 54 landscape characterisation approaches to describe their basic properties. The variables applied in the analysis were developed by iterations. Variables that were strongly correlated and expressed almost the same properties, were merged together prior to the multivariate statistical analyses (e.g. the three original categories 'hydrology', 'wetlands' and 'glaciers' were merged to one category: 'hydrography' before the statistical analyses). Publication year (Pub) 1990–2016 was recorded as a discrete variable. The extent (Ext) of the study area was recorded as the base-10

Table 1
The 54 references that make up the data set, which is analysed for properties of landscape characterisation approaches in this study.

ID	Landscape characterisation approach	Reference	Country/region
1	Global land system classification map	van Asselen and Verburg (2012)	Worldwide
2	A new map of global ecological land units	Sayre et al. (2014)	Worldwide
3	A typology of natural landscapes of central Europe	Fňukalová and Romportl (2014)	Central European
4	Pan-European landscapes	Meeus (1995)	Pan-European
5	European landscape character map*	Mücher et al. (2003)	Pan-European
6	A new European landscape classification	Mücher et al. (2010)	Pan-European
7	Classification of Austrian cultural landscapes	Wrbka et al. (2000); Peterseil et al. (2004)	Austria
8	Characterisation of the contemporary Belgian landscapes	Van Eetvelde and Antrop (2009)	Belgium
9	Biological valuation map of Belgium*	De Blust et al. (1994)	Belgium
10	The landscape territories of Wallonia*	Feltz et al. (2004)	Belgium
11	The ecodistricts of Flanders*	Sevenant et al. (2002)	Belgium
12	A study on biogeographical divisions of China	Xie et al. (2004)	China
13	Tropical forest landscape types in Hainan Island, China	Bosun et al. (2007)	China
14	Landscape classification of the Czech Republic based on the distribution of natural habitats	Divíšek et al. (2014)	Czech Republic
15	Landscape types of the Czech Republic	Chuman and Romportl (2010)	Czech Republic
16	Landscape character assessment in landscape protected areas of the Czech Republic*	Bukáček and Matějka (1997)	Czech Republic
17	Landscape atlas	Miljøministeriet Naturstyrelsen (2011)	Denmark
18	Valuable landscapes in the Roskilde region*	Anon. (2005)	Denmark
19	Landscape regions and provinces of Finland	Käyhkö et al. (2004)	Finland
20	Landscape atlases of France	Raymond et al. (2015)	France
21	Landscape atlas of Lower Normandy*	Brunet and Girarden (2001)	France
22	Types of natural regions in the former GDR*	Richter (2005)	Germany
23	Distribution and threats of German Landscapes*	Gharadjedaghi et al. (2004)	Germany
24	Geographical characterisation, Mecklenburg-Vorpommern	Umweltministerium Mecklenburg-Vorpommern (2003)	Germany
25	Natural areas and natural area potentials of Saxony	Bastian (2000)	Germany
26	A typology for the Greek landscape	Tsilimigkas and Kizos (2014)	Greece
27	An inventory of microregions of Hungary*	Marosi and Somogyi (1990)	Hungary
28	Landscape character assessment in County Clare	Environmental Resources Management Ireland Ltd. (2004)	Ireland
29	Classification and mapping of the ecoregions of Italy	Blasi et al. (2014)	Italy
30	A landscape typology in the Mediterranean context	Vogiatzakis et al. (2006)	Italy
31	Landscape character, biodiversity and land use planning, Kwangju City Region, South Korea	Kim and Pauleit (2007)	Korea, Republic of
32	Environmental units of La Malinche volcano, central Mexico	Castillo-Rodríguez et al. (2010)	Mexico
33	Neder-landschap Internationaal*	Farjon et al. (2002)	Netherlands
34	New Zealand Landscape Classification	Brabyn (2009)	New Zealand
35	National reference system for landscape	Puschmann (2005)	Norway
36	Nature in Norway (NiN) - landscape types	Erikstad et al. (2015)	Norway
37	Landscape analysis for Nordfjella mountain area	Clemetsen and Knagenhjelm (2011)	Norway
38	Landscape units in Portugal	Pinto-Correia et al. (2003)	Portugal
39	Delineation of national landscape units for Puerto Rico	Soto and Pintó (2010)	Puerto Rico
40	Landscape classification and mapping of European Russia	Lioubimtseva and Defourny (1999)	Russian Federation
41	Landscape types of Slovakia	Otahel (2004)	Slovakia
42	Natural landscape typification of Slovenia	Perko et al. (2015)	Slovenia
43	The landscape catalogues of Catalonia	Nogué et al. (2016)	Spain
44	Landscape classification of the Cantabrian mountains, northwestern Spain	García-Llamas et al. (2016)	Spain
45	Landscape classification of Huelva	Alcántara Manzanares and Muñoz Álvarez (2015)	Spain
46	Landscape analysis for Västra Götaland	Trafikverket (2012)	Sweden
47	Landscape quality of Mobilité Spatiale Regions	Eidgenössisch Forschungsanstalt für Wald (2007)	Switzerland
48	The landscape character analysis in Turkey, regional level, Konya Closed Basin	Uzun et al. (2011)	Turkey
49	Character assessment of Southern Black Sea landscape	Guneroglu et al. (2015)	Turkey
50	Land Classification for strategic ecological Survey	Bunce et al. (1996a); Bunce et al. (1996b)	United Kingdom
51	Landscape characterisation - the living landscapes approach	Warnock and Griffiths (2014)	United Kingdom
52	The character of England map	Swanwick (2002)	United Kingdom
53	Scottish national programme of landscape character assessment	Swanwick (2002); Julie Martin Associates and Swanwick (2003)	United Kingdom
54	Northern Ireland landscape character assessment	Environmental Resources Management (2000)	United Kingdom

* The detailed descriptions in Wascher (2005) was used as our main source of information.

logarithm of its total area (in km^2). Relative relief (Rel) was recorded as the difference between the highest- and lowest-situated points in the area, in m. The variable ‘spatial resolution’ (Res) expressed, on a relative scale, the level of detail addressed in the study. For multi-level hierarchical examples we addressed the most detailed scale containing an area-covering map. As a benchmark for the Res variable we used the length of grid-cell or pixel edges in studies that made use of rasterised data. The resolution or spatial grain of polygon-based studies (including studies in which maps with landscape-unit polygons were presented without documented analysis) was taken as the length (in the terrain) of the minimum polygon dimension of 2 mm. For a landscape mapped to scale 1:200 000, 2 mm × 200 000 = 400 000 mm = 0.4 km (Table S1, Appendix A in Supplementary data). The variable ‘observer independence’ (Obsi), which expresses the degree to which the study in question relies on human interpretation vs. quantitative data and rigorous statistical analyses, was recorded as a semi-quantitative variable with five classes by use of the criteria listed in Table S2 (Appendix A in Supplementary data).

The five (semi-)quantitative variables (Pub, Ext, Rel, Res and Obsi) were transformed to zero skewness (formulae given in Table S3, Appendix A in Supplementary data) in order to improve homoscedasticity (Økland et al., 2001). After transformation, each variable

Table 2
The 27 variables used to characterise landscape characterisation approaches, including summary statistics. Abbr = abbreviation. Statistical variable categories: C = continuous variable, B = binary variable. *n* = number of presences (1) for binary variables. SD = standard deviation. Transformation: statistical transformation applied prior to multivariate statistical analysis: $\log_{10}$ = transformed to base-10 logarithm; ZS = zero-skewness transformation, R = ranging to 0–1 scale. A '+' sign between transformations implies that the transformations are applied successively.

Recorded variables	Abbr	Statistical variable category	Unit	*n*	Min	Max	Mean	SD	Transformation
General characteristics									
Year of publication	Pub	C	year	–	1990	2016	2005	6.96	ZS + R
Extent of study area	Ext	C	km^2	–	212	$1.49·10^8$	$6.47·10^6$	$2.83·10^7$	$\log_{10}$, + ZS + R
Relative relief of study area	Rel	C	m	–	46	8848	2392	2206	$\log_{10}$, + ZS + R
Methodological characteristics									
Spatial resolution	Res	C		–	0	1	0.41	0.22	$\log_{10}$, + ZS + R
Observer independence	Obsi	C	1	–	0	4	1.78	1.44	ZS + R
Biophysical landscape concept	Bphy	B	0/1	31	0	1	0.57	0.49	–
Typology	Typo	B	0/1	36	0	1	0.67	0.47	–
Spatial unit: polygon	Poly	B	0/1	43	0	1	0.80	0.40	–
Bioclimatic landscape variables									
Climate	Clim	B	0/1	24	0	1	0.44	0.50	–
Altitude	Alt	B	0/1	14	0	1	0.26	0.44	–
Geo-ecological landscape variables									
Bedrock geology	Geo	B	0/1	36	0	1	0.67	0.47	–
Landform	Lfor	B	0/1	52	0	1	0.96	0.19	–
Hydrography	Hydr	B	0/1	31	0	1	0.57	0.49	–
Soil	Soil	B	0/1	34	0	1	0.63	0.48	–
Ecological landscape variables									
Vegetation	Veg	B	0/1	44	0	1	0.82	0.39	–
Biodiversity	Bio	B	0/1	13	0	1	0.24	0.43	–
Landscape ecological metrics	Metr	B	0/1	5	0	1	0.09	0.29	–
Landscape structure	Stru	B	0/1	20	0	1	0.37	0.48	–
Land-use variables									
Land cover	Lcov	B	0/1	45	0	1	0.83	0.37	–
Land management	Lman	B	0/1	15	0	1	0.28	0.45	–
Buildings and infrastructure	Buil	B	0/1	28	0	1	0.52	0.50	–
Agriculture	Agri	B	0/1	29	0	1	0.54	0.50	–
Socio-cultural landscape variables									
History	Hist	B	0/1	17	0	1	0.32	0.46	–
Architecture/cultural heritage	Arch	B	0/1	14	0	1	0.26	0.44	–
Identity/sense of place	Iden	B	0/1	9	0	1	0.17	0.37	–
Scenic aesthetic	Scen	B	0/1	10	0	1	0.19	0.39	–
User participation	Part	B	0/1	6	0	1	0.11	0.31	–

was ranged onto a standard scale with 0 and 1 as minimum and maximum values, respectively.

All the remaining 22 variables were binary factor variables. 'Landscape concept' (Bphy) separates the approaches into two groups according to the landscape concept used; a biophysical landscape concept (1) or a holistic landscape character assessment (LCA) concept (0). Most studies were easily affiliated with one of the landscape concepts. 'Typology' (Typo) separates the approaches according to Holt-Jensen (2009) by their end product into a nomothetic typology (1; describing objective geographical phenomena in general) or an idiographic chorology (0; addressing the individual character of singular areas, landscape units or regions). Some studies, predominantly LCA-studies, include both a typology and a chorology. The typology included in such studies is most often a coarse and pragmatic grouping of character areas that share some key characteristics, while the end product is the chorology (landscape character areas). These studies have therefore been scored as idiographic chorologies. The variable 'Spatial unit: polygon' (Poly) separates approaches according to the spatial units they use: nominal raster cells (0) or vectorised polygons (1).

The remaining 19 variables in Table 2 represent categories of landscape characteristics that were used (1) or not used (0) to identify landscape types and/or character areas. Characteristics used *post hoc* to describe the landscape units in detail are scored as not used (0). The category 'Land cover' is applied in multiple ways throughout the various approaches. Selected land cover types are scored separately when they are explicitly used to identify landscape types or character areas (e.g. vegetation), in addition to land cover as a general category. Whereas 'land cover' refer to the physical land cover type (such as forest or open water), 'land management' is a more complex variable that describes how people use and manage the land in multiple, often overlapping ways. Due to incomplete information throughout the references, we were not able to address variables such as the conceptual scale (i.e. the level of generalisation), number of hierarchical levels, or the explicit purpose of the various approaches. The data matrix with values for the 27 variables for the 54 approaches is given in Appendix B in Supplementary data.

2.4. Statistical analysis

Relationships between variables were assessed by calculation of pairwise Kendall rank correlations (τ) (Kendall, 1938), chi-square tests of independence (e.g. Sokal and Rohlf, 1995) and paired Wilcoxon–Mann–Whitney-tests (e.g. Sokal and Rohlf, 1995). Pairwise relationships between all variables are given in Appendix B in Supplementary data, Table S5.

Ordination methods were used to summarise the main gradients of coordinated variation among the 54 approaches, as characterised by the 27 variables. Ordination methods sort the observation units (the landscape characterisation approaches) so that observation units with similar methodological characteristics are placed near each other in the conceptual geometric space spanned by the ordination axes and

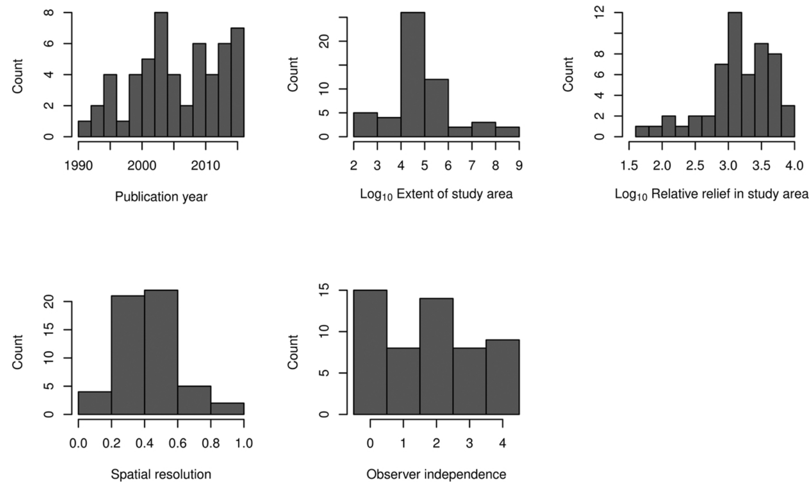

Fig. 1. Histograms of the 5 (semi-)quantitative variables: a) year of publication, b) base-10 logarithm of extent of study area in km^2, c) base-10 logarithm of relative relief in study area, d) spatial resolution according to Table S1 and e) observer independence according to Table S2.

observation units which differ in many respects are placed further apart (Økland, 1990; Legendre and Legendre, 2012). Moreover, ordination methods sort observation units along axes of decreasing importance, i.e. in order of decreasing variation in methodological characteristics explained. To transform these patterns into a clear understanding of gradients in methodological characteristics, the ordination results have to be interpreted (Økland, 1990). Interpretation was performed by statistical methods such as correlation analysis and Wilcoxon-Mann-Whitney tests as well as by use of statistical visualisation tools (see Oksanen et al., 2016). The gradient structure of the data set, with 54 approaches characterised by 27 variables, was extracted by parallel use of detrended correspondence analysis (DCA; Hill, 1979; Hill and Gauch, 1980) and global non-metric multidimensional scaling (GNMDS; Kruskal, 1964a, b; Minchin, 1987). Only axes identified by both methods were considered reliable gradients, as recommended by Økland (1996). Three GNMDS axes were confirmed by DCA (Appendix A in Supplementary data), and provided the basis for further statistical interpretation. R version 3.3.2 (R Core Team, 2016) with the package vegan, version 2.4-1 (Oksanen et al., 2016) was used for all statistical analyses. Detailed information about the statistical analyses is provided in Appendix A in Supplementary data.

3. Results

3.1. Basic properties of the reviewed approaches

The whole time span from 1990 to 2016 was represented in the data set (Fig. 1a). Fig. 1b shows that the extent of study areas ranges from 212 km^2 to the whole terrestrial land mass of the world. Mean ‘relative relief’ in the study areas (Fig. 1c), was 2392 m. Most of the approaches (72%) addressed map scales from 1:50 000 to 1:500 000 or used a grid with a resolution of 1 × 1 km cells (Fig. 1d). Distribution of values for observer-independence (mean = 1.78, Fig. 1d), showed that the material covered the whole range from interpretative, expert-based methods to more observer independent approaches based on rigorous statistical analysis of a sample of observation units.

Thirty-one (57%) and 23 (43%) approaches were conducted within biophysical and holistic/LCA landscape concepts, respectively. A division into spatial units was most often accomplished by the use of vectorised polygons (80%). The geo-ecological landscape variables landform (96%), vegetation (82%), geology (67%) soil (63%) and hydrography (57%) were most frequently used to identify landscape units (Table 2; Fig. 2). Landform was included as a central variable in

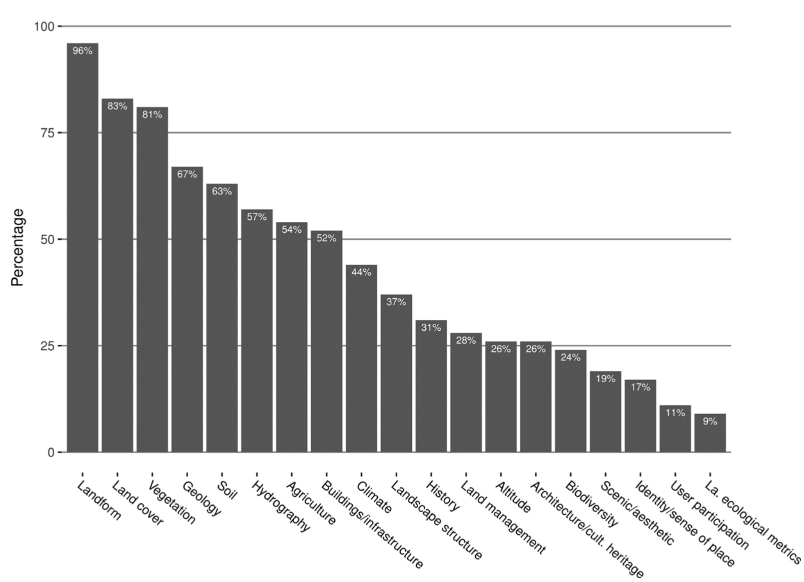

Fig. 2. Bar plot showing the percentage of studies (n = 54) in which each landscape variable is used to identify landscape types/character areas.

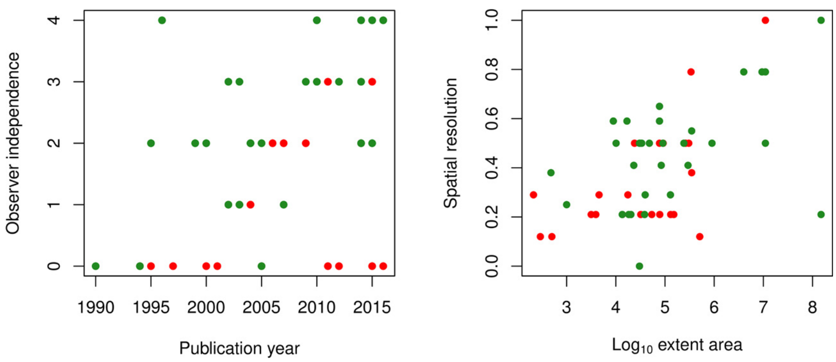

Fig. 3. Scatterplots of a) the relationship between observer independence and publication year (Kendall rank correlation, $\tau = 0.3953$, $p = 0.0002$) b) the relationship between the level of detail/spatial resolution and area covered by the landscape characterisation study (Kendall rank correlation, $\tau = 0.3399$, $p = 0.0006$). Biophysical landscape concept indicated with green dots, holistic/LCA-approaches with red dots. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

the characterisation processes also when the relative relief in the study areas was low. General land cover (83%) was the variable most often used to represent human influence on the landscape in the approaches, while specific land-use related variables such as agriculture (54%) and buildings and infrastructure (52%) were used in approximately half of the approaches. History was the most common socio-cultural variable (32%), followed by architecture/cultural heritage (26%) and scenic-aesthetic features (19%). User participation was included in the characterisation process in six approaches (11%).The degree of observer independence increased with time (Fig. 3a). Increasing observer independence over time was clearly associated with increasing use of a biophysical landscape concept; mean observer independence was 0.65 for biophysical approaches and 0.22 for LCA/holistic approaches. The level of detail decreased with increasing extent of the study area (Fig. 3b), with a notable exception of the detailed study with worldwide coverage by (Sayre et al., 2014).

A typology as an end product was slightly more common with a biophysical (25 out of 31; 80%) than with a LCA/holistic approach (11 out of 23; 48%). Use of grid cells was typical of approaches using a biophysical landscape concept (Chi-square test of independence $\chi^2 = 8.178$, $p = 0.0042$, see Appendix B in Supplementary data).

3.2. Ordination

The main gradient in the set of 54 landscape-characterisation approaches, as revealed by GNMDS axis 1 (Fig. 4a, Table 3), separated approaches based upon holistic landscape concepts (low scores) from approaches based upon biophysical landscape concepts. The main gradient was also clearly related to observer independence, which increased towards the biophysical landscape-concept end of GNMDS axis 1 (Fig. 4a, Table 3). The centroids of socio-cultural landscape variables used for characterising landscapes were placed near the 'holistic end' of the gradient (Fig. 4b, Table 3), showing that use of this group of positively related variables was typical for holistic approaches. Similarly, the bioclimatic variables climate and altitude were also positively related and typically associated with approaches based upon a biophysical landscape concept (Fig. 4b, Table 3, Table S5).

The second axis revealed a gradient from older, intuitive and expert-based approaches to increasing use of observable and measurable variables related to human land use. The variables associated with GNMDS axis 2 were publication year, observer independence, agriculture, buildings and infrastructure, land cover and geology (Table 3).

The variables associated with GNMDS axis 3 were hydrography, biodiversity and the use of typology (Table 3). This axis summarised residual variation in the use of geo-ecological landscape variables that was not clearly related to axis 1 or 2.

4. Discussion

4.1. Main methodological differences; Landscape concept, observer independence and variables included in the characterisation process

The ordination results reveal a pattern of variation in methodological properties that is gradual and 'multidimensional'. Nevertheless, a very clear trend was identified, reflected in the variation from the lower left in the ordination diagram to the middle and upper right (Fig. 4a). This trend is related to the complex interaction of a) landscape concept, b) degree of observer independence, and c) the various factors involved in the landscape characterisation process. Interestingly, these factors tend to be more strongly decisive for the choice of methodology than, e.g. the physical properties of the area that is the subject of the landscape characterisation (as recorded in the review by the variables areal extent and relative relief of the study area).

When Groom (2005) made a review of several landscape classifications in Europe, he concluded that the majority of the classifications were based on expert knowledge and elaborated in a top-down manner. Highly automated derivation of landscape types and character areas were limited (Groom, 2005; Van Eetvelde and Antrop, 2009). The results show that this has changed since 2005, and that this development is associated with both the applied landscape concept and the selection of variables included in the characterisation process.

4.2. Principally different methodological approaches to landscape characterisation

Although the variation in methodological properties is gradual, three substantially different methodological approaches are identified and discussed below. The first group of approaches [placed on the (lower) left side of the ordination diagram in Fig. 4a and b] is associated with a holistic landscape concept, and consists of intuitive, interpretative approaches. These approaches seek to include many aspects of the landscape in the characterisation process, including visual perception, history, architecture and scenic-aesthetic values in addition to geo-ecological aspects and structural variation. Typical examples are LCA-approaches from the UK (Swanwick, 2002; Julie Martin Associates and Swanwick, 2003), various Scandinavian adaptations of the LCA-method (Clemetsen and Knagenhjelm, 2011; Miljøministeriet Naturstyrelsen, 2011; Trafikverket, 2012) and the Landscape Atlases of France (Raymond et al., 2015) and Catalonia (Nogué et al., 2016). Some of these approaches are even open to the inclusion of feelings, memories or associations in the characterisation process (e.g. Swanwick, 2002). It is not always clear how these different aspects of the landscape affect the characterisation process, since both the delineation of units and the process of character assessment in these

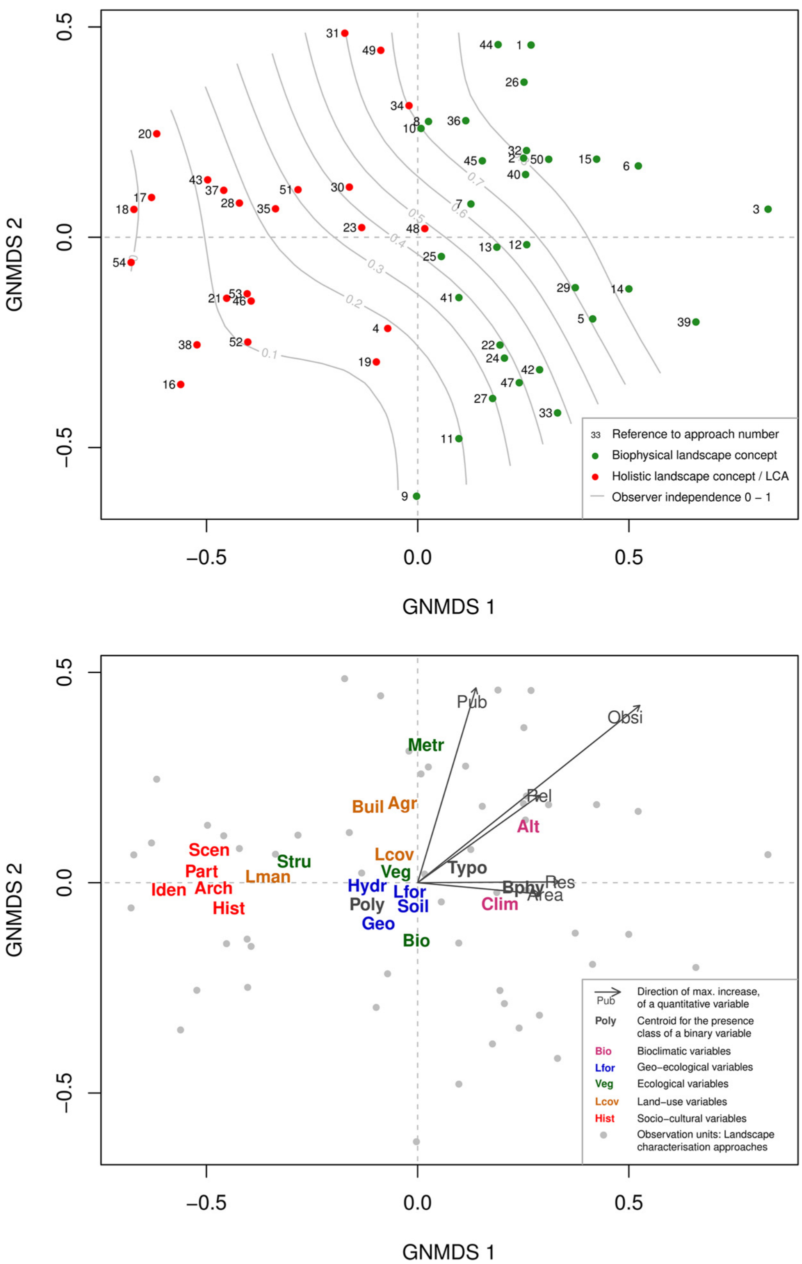

Fig. 4. GNMDS ordination of the 54 approaches to landscape characterisation (numbered according to Table 1), axes 1 and 2 [scaled in half-change (H.C.) units]. (a) Ordination diagram with observation units represented by dots, the colours of which indicating type of landscape concept, and isolines for the variable 'observer-independence'. (b) Ordination diagram showing relationships between recorded variables (abbreviated in accordance with Table 2) and ordination axes, with observation units shown by grey dots. Quantitative variables are represented by arrows pointing in the direction of maximum increase of the variable (relative lengths of arrows are proportional to the correlation between the recorded variable and the ordination axis). Binary variables are represented by the abbreviated name, placed at the centroid for the presence class (value = 1; the centroid for the absence class is placed at opposite side of the origin (not shown). Axes are scaled in half-change (H.C.) units.

methods to a large extent is intuitive, holistic and interpretative, and thus difficult to replicate. The six approaches in which user participation is part of the characterisation process all affiliate with this group of approaches (e.g. Raymond et al., 2015; Nogué et al., 2016). In line with the findings of Brunetta and Voghera (2008), our study indicate that user participation has a weak role in landscape characterisation applied at regional scales. Interestingly, examples of user participation in the characterisation process tend to be limited to discussions with 'focus groups' and NGOs, and in no case based upon the way a representative sample of the population perceives the landscape.

The second group of approaches, typically placed in the middle of the ordination diagram, includes examples of both biophysical and holistic methods. Approaches in this group build the characterisation process on *a priori* selection of variables, based on theory and tradition within the applied scientific discipline. A typical example is the approach of Mücher et al. (2010) in which the landscape is considered a complex function of eight 'factors',

$$\text{Landscape} = f\,(C_{(t)}, G_{(t)}, H_{(t)}, S_{(t)}, V_{(t)}, F_{(t)}, LU_{(t)}, STR_{(t)});$$

climate (C), geology and geomorphology (G), hydrology (H), soils (S), vegetation (V), fauna (F), land use (LU) and landscape structure (STR) and time (t). The ordering of factors by Mücher et al. (2010) from more to less 'basic' and 'independent' and from abiotic via biotic to cultural, reflects an understanding of landscape variation that can be traced back to original works of, e.g. von Humboldt and Bonpland (1807), Geddes (1915) and McHarg (1969). Typical examples of studies based upon *a priori* defined key variables are Brabyn (2005), Sayre et al. (2014) and Perko et al. (2015). When this approach is combined with GIS-overlay techniques, the selection of characterisation variables are adjusted to available area-covering spatial data at the given resolution. Spatial overlaying of landscape component layers, which dates back to McHarg (1969), is an important function of GIS that can be easily automated and implemented in landscape analysis (Brabyn, 2009). GIS-based overlay analyses are most commonly used in biophysical approaches, but our results show an interesting trend towards higher observer independence also in approaches that include landscape perception and cultural variables. Notable examples are found in the upper middle part of the ordination diagram (bordering on the next group), and includes

Table 3
Relationships between GNMDS ordination axes and the 27 variables used to characterise the 54 landscape characterisation approaches. Stat. test = statistical test, Test stat. = test statistic: K = Kendall rank correlation coefficient (τ), W = Wilcoxon–Mann–Whitney-test.

	Variable	Stat.test	GNMDS1		GNMDS2		GNMDS3	
			Test stat.	*p*	Test stat.	*p*	Test stat.	*p*
1	Publication year (Pub)	K (τ)	-0.167	0.0800	***0.411***	***< 0.0001***	0.032	0.7307
2	Extent area (Area)	K (τ)	-0.226	0.0162	0.003	0.9762	0.018	0.8462
3	Relative relief (Rel)	K (τ)	-0.282	0.0028	0.146	0.1223	0.045	0.6270
4	Spatial resolution (Res)	K (τ)	***-0.328***	***0.0010***	-0.057	0.5680	-0.052	0.5994
5	Observer independence (Obsi)	K (τ)	***-0.578***	***< 0.0001***	***0.325***	***0.0015***	-0.049	0.6290
6	Biophysical landscape concept (Bphy)	W	***711***	***< 0.0001***	364	0.9034	362	0.9309
7	Typology (Typo)	W	***503***	***0.0007***	247	0.1618	***514***	***0.0003***
8	Polygons (Poly)	W	***43***	***< 0.0001***	357	0.0086	256	0.6873
9	Climate (Clim)	W	***571***	***0.0001***	416	0.3369	375	0.8024
10	Altitude (Alt)	W	***447***	***0.0006***	165	0.0226	288	0.8837
11	Bedrock geology (Geo)	W	195	0.0174	***543***	***< 0.0001***	351	0.6299
12	Landform and topography (Lfor)	W	9	0.0516	78	0.2428	13	0.0778
13	Hydrography (Hydr)	W	261	0.0968	372	0.7947	***65***	***< 0.0001***
14	Soil (Soil)	W	327	0.8244	437	0.0839	454	0.0413
15	Vegetation (Veg)	W	137	0.0656	152	0.1344	195	0.5907
16	Biodiversity (Bio)	W	272	0.9204	369	0.0380	***55***	***< 0.0001***
17	Landscape ecological metrics (Metr)	W	116	0.8622	31	0.0038	155	0.3504
18	Landscape pattern/structure (Stru)	W	***87***	***< 0.0001***	293	0.4082	464	0.0260
19	Land cover/expressed land use (Lcov)	W	123	0.0661	26	***< 0.0001***	205	0.9636
20	Land use management (Lman)	W	***83***	***< 0.0001***	277	0.7745	382	0.0857
21	Buildings and infrastructure (Buil)	W	236	0.0264	***55***	***< 0.0001***	270	0.1059
22	Agriculture (Agr)	W	326	0.5353	***30***	***< 0.0001***	335	0.6421
23	History (Hist)	W	***8***	***< 0.0001***	378	0.2433	312	0.9706
24	Architecture (Arch)	W	***12***	***< 0.0001***	299	0.7181	307	0.6048
25	Identity/sense of place (Iden)	W	***2***	***< 0.0001***	216	0.7667	164	0.3841
26	Scenic-aesthetic values (Scen)	W	***19***	***< 0.0001***	177	0.3494	130	0.0450
27	User-participation (Part)	W	***24***	***0.0002***	133	0.7781	197	0.1519

the landscape characterisation method used in New Zealand (Brabyn, 2009), LCA approaches from South-Korea (Kim and Pauleit, 2007) and Turkey (Uzun et al., 2011) and the Living Landscapes approach in the UK (Warnock and Griffiths, 2014). The latter is developed with the intention of improving the consistency of LCA in the United Kingdom.

The third group of approaches exclusively adopt a biophysical landscape concept. These methods are closer to being 'mapping' than 'character assessment'. The characterisation process includes a strong element of statistical analyses of the landscape element composition in a sample of observation units. These methods are referred to as 'parametric' by Antrop and Van Eetvelde (2017). Subjectivity is restricted to the choice and definition of input variables and the choice of statistical methods. Typical examples are located in the upper middle and the upper right part of the ordination diagram (e.g. Van Eetvelde and Antrop, 2009; Castillo-Rodríguez et al., 2010; Chuman and Romportl, 2010; Soto and Pintó, 2010; Alcántara Manzanares and Muñoz Álvarez, 2015; Erikstad et al., 2015; García-Llamas et al., 2016). The main principles of the multivariate characterisation methods are: 1) a division of the landscape into fixed spatial units (either regular cells or vectorised polygons), 2) recording of a broadest possible selection of physical landscape attributes within the spatial units, and 3) multivariate statistical analyses of the data in order to classify or group landscape units into generic landscape types or distinct areas with similar characteristics. An early example of this approach was the study by Blankson and Green (1991), while a pioneering work at broader scales is the land classification of Great Britain (Bunce et al., 1996a, b).

Within multivariate approaches, hierarchical clustering techniques are commonly used, often in combination with unsupervised classification (Van Eetvelde and Antrop, 2009; Castillo-Rodríguez et al., 2010; Chuman and Romportl, 2010; Soto and Pintó, 2010; Fňukalová and Romportl, 2014; Alcántara Manzanares and Muñoz Álvarez, 2015; Erikstad et al., 2015; García-Llamas et al., 2016). A distinctive approach based upon multivariate analyses is applied by Erikstad et al. (2015) who first collected a broadest possible set of variables for as many characteristics as possible as the base for the characterisation process, with the aim not to identify clusters of areas with similar characteristics but to identify 'landscape gradients', i.e. 'parallel, gradual or stepwise variation in the presence and/or abundance of landscape elements' (Erikstad et al., 2015). The resulting typology is obtained by dividing the few complex landscape gradients that explain most variation in the composition of landscape elements into standard intervals, and then defining landscape types by combining intervals along several gradients.

4.3. Methodological development over time

The ordination analyses reveal a second gradient related to development over time, which is also related to which landscape variables are included in the characterisation process and the degree of observer independence. Within the biophysical approaches, the trend towards increasing observer independence over time is very clear (Fig. 3a). With three exceptions, all biophysical approaches published after 2005 are based either on stepwise, criteria-based GIS overlay techniques (Bastian, 2000; Otahel, 2004; Perko et al., 2015), multispectral segmentation (Mücher et al., 2010), or GIS-analysis in combination with multivariate statistical analysis (e.g. Van Eetvelde and Antrop, 2009; Castillo-Rodríguez et al., 2010; Chuman and Romportl, 2010; Soto and Pintó, 2010; Alcántara Manzanares and Muñoz Álvarez, 2015; García-Llamas et al., 2016). Holistic methods tend to remain intuitive, descriptive and expert-oriented, although some exceptions exist. With one notable exception (Brabyn, 2009), none of the holistic approaches include any of the quantitative indicators of visual landscape perception that have been proposed as a result of research during the recent years (e.g. Tveit et al., 2006; Fry et al., 2009; Ode et al., 2009). A possible explanation is that automatisation of LCA-based mapping approaches including cultural and visual variables is limited by lack of consistent, area-covering spatial data for cultural-historical factors (Van Eetvelde and Antrop, 2009; Mücher et al., 2010).

4.4. Scale and level of detail

As expected, the level of detail (spatial grain) in the landscape characterisation decreases with increasing area (spatial extent). Early examples of characterisation of large regions or continents (Meeus, 1995; Lioubimtseva and Defourny, 1999) were coarse in typology and rather inaccurate, partly due to a lack of systematic digital information with a high-spatial accuracy and computer supported data processing (Mücher et al., 2010). This might change with new technology, as indicated by the notable study developed by Sayre et al. (2014). 'A New Map of Global Ecological Land Units' is a 250 m spatial resolution global map and database of 'ecological land units' derived from a stratification of the earth into unique physical environments and their associated vegetation. The mapping approach first characterises the climate regime, the landforms, the geology, and the land cover of the earth, and then models terrestrial ecosystems as a combination of those four land surface characteristics (Sayre et al., 2014). As such, the work is a classic example of a physical geographic approach to understanding ecological diversity at the landscape level. The detailed resolution combined with the large areal extent demonstrates the opportunities that comes with new technology.

4.5. Spatial units

The spatial units have different names in the different methods, and are referred to as landscape character areas (Swanwick, 2002), landscape areas (Erikstad et al., 2015), landscape units (Nogué et al., 2016), environmental units (Castillo-Rodríguez et al., 2010), land description units (Warnock and Griffiths, 2014), microgeochores (Bastian, 2000) and land classes (Bunce et al., 1996b).

It is not surprising that the use of polygons, as opposed to cells, is associated with a holistic landscape concept, as many of the automated characterisation methods use a grid as a basis for spatial and statistical analysis. Advantages of using a standard sample unit of a constant size (e.g. 1 × 1 km cells) are that grids are easily applied over large areas and that the subjective judgement involved in using naturally defined sample units is removed (Zonneveld, 1989). However, a major drawback is that each sample unit invariably represents a mixture of landforms and land-cover types (Bunce et al., 1996a), and that fundamentally different ecosystems such as mountains and ocean systems might be included in the same unit. The grid as a spatial framework thus forces the landscape into a straitjacket by failing to capture the 'grain' of the landscape, which varies continuously, both physically and culturally (Warnock and Griffiths, 2014). By contrast, LCA approaches tend to be more holistic, starting with the construction of a spatial framework that is gradually filled as more detailed information becomes available. In the biophysical approaches of Castillo-Rodríguez et al. (2010) and Erikstad et al. (2015), landscape units consisting of vectorised polygons are derived form a rule-based delineation from geomorphological units, before they are typified according to the results from of multivariate statistical and analyses and GIS-overlay techniques.

4.6. General findings and implications

Our study confirms the main findings of previous reviews and comprehensive overviews (Groom, 2005; Antrop and Van Eetvelde, 2017) that a variety of different methods are used in assessment and characterisation of landscapes at different scales. The patterns revealed by the statistical analyses clearly confirm existence of a major distinction between approaches rooted in the natural sciences and approaches rooted in the arts and the humanities. Furthermore, three distinct methodological approaches were identified: 1) 'holistic' landscape character assessment approaches, by which visual perception and socio-cultural aspects of the landscape are emphasised; 2) landscape characterisation methods based on *a priori* selection of geo-ecological and land-use-related properties of the landscape; and 3) biophysical landscape characterisation approaches which rely strongly on statistical analyses in order to identify gradients of variation in the presence and/or abundance of landscape elements and properties. The variation in methodological properties (Fig. 4) is, however, gradual and 'multi-dimensional'.

Even though the reviewed approaches emphasise different aspects of the landscape and the way it is perceived, they all share some basic properties. Most notably; they are all integrative, they include both natural and human factors, and thus emphasise on interactions among humans and their surroundings. All approaches address the composition of landscape elements on a conceptual scale less detailed than that of e.g. an ecosystem and more detailed than biomes or regions. Broad-scale landforms and the composition of key geo-ecological and visible land-use-related variables are taken into account by all of the reviewed methods, either as an end product or as a part of the data used for the assessment process.

Many of the patterns established by the statistical analyses were expected; e.g. the correlation between the extent of the study area and the level of spatial resolution/details, that typologies were more common within biophysical than within holistic/LCA approaches, and that the landscape concept applied were more decisive for the methodology that physical properties of the study area. Less obvious were the findings that biophysical landscape characterisation approaches have become more evidence-based and repeatable over time, while holistic methods have remained intuitive and expert-based. Our review indicates that user participation has a weak role in landscape characterisation applied at regional scales, regardless of landscape concept applied.

Several authors (Bunce et al., 1996b; Van Eetvelde and Antrop, 2009; Blasi et al., 2014; Warnock and Griffiths, 2014; Erikstad et al., 2015) argue that the two, both valid, traditions of landscape research may be complementary, and that they may be appropriate for different steps in a two-step procedure for treatment of landscape issues by which landscapes are first typified, characterised and mapped in accordance with the natural science-based material landscape tradition. The resulting landscape maps and datasets may form an appropriate framework for:

a) addressing specific research questions within landscape ecology and physical geography, such as the spatial distribution of landscape elements, assessment of landscape changes, studies of patterns, structure and processes
b) assessment of landscape character, human perception and socio-cultural relations to the landscape, historical landscape evaluation, citizen participation and policy-making, or as a tool for negotiating landscape values

Application of stepwise approaches, or combining complementary methods specifically directed towards user needs, may thus compensate for limitations and trade-offs of single methods.

5. Conclusion

Although 'landscape' is often regarded as a unifying and interdisciplinary concept, our review indicates that there are substantial differences between landscape characterisation methods, and that no single method can address all dimensions of the landscape without important trade-offs. As the choice of methodological approach will directly determine, and often constrain, the applicability and usefulness of the resulting typologies for applied purposes, multiple landscape characterisation methods are needed in order to address different purposes and user needs. For landscape research, planning and management to be evidence-based, we suggest that more emphasis should be put on testing the relevance of the various landscape characterisation efforts in relation to the purpose of the characterisation, as well as their accuracy and reliability. Understanding the strengths of biophysical and holistic approaches may provide opportunities for improved strategies for landscape management that better comply with e.g. the intentions of the European Landscape Convention to incorporate landscapes in democratic processes, while at the same time enabling much needed progress in making the landscape level relevant for environmental sciences.

Conflicts of interest

None.

Acknowledgements

This work was supported by the Research Council of Norway (Public Sector Ph.D. scheme), the Norwegian Environment Agency and the Norwegian Biodiversity Information Centre. We would like to thank Aslaug Skaar for assistance with literature search and Eirin Bjørkvoll, Morten Clemetsen, Marius Fiskevold and Andrew Butler for helpful advices, discussions and comments on an earlier version of this paper. We would also like to thank two anonymous reviewers for their comments and critical review of the manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.landusepol.2018.04.022.

References

Alcántara Manzanares, J., Muñoz Álvarez, J.M., 2015. Landscape classification of Huelva (Spain): an objective method of identification and characterization. Estudios Geográficos 76 (279), 447–471. http://dx.doi.org/10.3989/estgeogr.201516.

Anon, 2005. Valuable landscapes in the Roskilde region. In: Wascher, D.M. (Ed.), European Landscape Character Areas – Typologies, Cartography and Indicators for the Assessment of Sustainable Landscapes, (2005) Final ELCAI Project Report. Retrieved from. http://library.wur.nl/WebQuery/wurpubs/fulltext/1778.

Antrop, M., 1997. The concept of traditional landscapes as a base for landscape evaluation and planning. The example of Flanders region. Landsc. Urban Plann. 38 (1), 105–117. http://dx.doi.org/10.1016/S0169-2046(97)00027-3.

Antrop, M., 2000. Geography and landscape science. Belgeo, Revue belge de géographie 1–2–3–4http://dx.doi.org/10.4000/belgeo.13975. Special issue: 29th International Geographical Congress.

Antrop, M., Van Eetvelde, V., 2017. Landscape Perspectives.

Bailey, R.G., 2014. Ecoregions: The Ecosystem Geography of the Oceans and Continents, 2nd ed. Springer New York 2014.

Bakkestuen, V., Erikstad, L., Halvorsen, R., 2008. Step-less models for regional environmental variation in Norway. J. Biogeogr. 35 (10), 1906–1922. http://dx.doi.org/10.1111/j.1365-2699.2008.01941.x.

Bastian, O., 2000. Landscape classification in Saxony (Germany) — a tool for holistic regional planning. Landsc. Urban Plann. 50 (1), 145–155. http://dx.doi.org/10.1016/S0169-2046(00)00086-4.

Bastian, O., 2008. Landscape classification between fact and fiction. In: Paper Presented at the Conference Warzaw University and Polish Association of Landscape Ecology. Warzawa: Polska Asocjacja Ekologii Krajobrazu.

Berg, L.S., 1915. The objectives and tasks of geography. Paper Presented at the Proceedings of the Russian Geographical Society.

Blankson, E.J., Green, B.H., 1991. Use of landscape classification as an essential prerequisite to landscape evaluation. Lands. Urban Plann. 21 (3), 149–162. http://dx.doi.org/10.1016/0169-2046(91)90014-D.

Blasi, C., Capotorti, G., Copiz, R., Guida, D., Mollo, B., Smiraglia, D., Zavattero, L., 2014. Classification and mapping of the ecoregions of Italy. Plant Biosyst. Int. J. Deal. Aspects Plant Biol. 1–44. http://dx.doi.org/10.1080/11263504.2014.985756.

Bosun, W., Shaolin, P., Luo, G., Youhua, Y., 2007. Diversity of tropical forest landscape types in Hainan Island, China. Acta Ecol. Sin. 27 (5), 1690–1695. http://dx.doi.org/10.1016/S1872-2032(07)60040-7.

Bourassa, S.C., 1991. The Aesthetics of Landscape. Belhaven Press, London.

Brabyn, L., 2005. Solutions for characterising natural landscapes in New Zealand using geographical information systems. J. Environ. Manage. 76 (1), 23–34.

Brabyn, L., 2009. Classifying landscape character. Landsc. Res. 34 (3), 299–321. http://dx.doi.org/10.1080/01426390802371202.

Brunet, P., Girarden, P., 2001. Inventaire régional des paysages de Basse-Normandi. In: Wascher, D.M. (Ed.), European Landscape Character Areas – Typologies, Cartography and Indicators for the Assessment of Sustainable Landscapes, (2005) Final ELCAI Project Report. Retrieved from. http://library.wur.nl/WebQuery/wurpubs/fulltext/1778.

Brunetta, G., Voghera, A., 2008. Evaluating landscape for shared values: tools, principles, and methods. Landsc. Res. 33 (1), 71–87. http://dx.doi.org/10.1080/01426390701773839.

Bukáček, R., Matějka, P., 1997. Metodický podklad hodnocení krajinného rázu v chráněných krajinných oblastech. Retrieved from Prague:. http://www.ochranaprirody.cz/en/what-we-do/landscape-character/.

Bunce, R.G.H., Barr, C.J., Clarke, R.T., Howard, D.C., Lane, A.M.J., 1996a. Special paper: ITE Merlewood land classification of Great Britain. J. Biogeogr. 23 (5), 625–634.

Bunce, R.G.H., Barr, C.J., Clarke, R.T., Howard, D.C., Lane, A.M.J., 1996b. Land classification for strategic ecological survey. J. Environ. Manage. 47, 23.

Butler, A., Berglund, U., 2014. Landscape character assessment as an approach to understanding public interests within the European Landscape Convention. Landsc. Res. 39 (3), 219–236. http://dx.doi.org/10.1080/01426397.2012.716404.

Castillo-Rodríguez, M., López-Blanco, J., Muñoz-Salinas, E., 2010. A geomorphologic GIS-multivariate analysis approach to delineate environmental units, a case study of La Malinche volcano (central México). Appl. Geogr. 30 (4), 629–638. http://dx.doi.org/10.1016/j.apgeog.2010.01.003.

Christian, C.S., 1958. The concept of land units and land systems. Proceedings of the Ninth Pacific Science Congress.

Chuman, T., Romportl, D., 2010. Multivariate classification analysis of cultural landscapes: an example from the Czech Republic. Landsc. Urban Plann. 98 (3), 200–209. http://dx.doi.org/10.1016/j.landurbplan.2010.08.003.

Clemetsen, M., Knagenhjelm, K., 2011. Landskapsanalyse for Nordfjella. Retrieved from: https://www.academia.edu/30425152/Landskapsanalyse_for_Nordfjella._Utgreiing_av_kunnskapsgrunnlag_Regional_plan_for_Nordfjella._2011?auto=download.

Collaboration for Environmental Evidence, 2013. Guidelines for Systematic Review and Evidence Synthesis in Environmental Management. Version 4.2.

Cosgrove, D.E., 1984. Social Formation and Symbolic Landscape. University of Wisconsin Press.

Cosgrove, D.E., 2008. Geography and Vision : Seeing, Imagining and Representing the World, vol. 12 ARCH 2027 : matchstudio Projects.

Council of Europe, 2000. The European Landscape Convention. CETS No. 176. Retrieved from Strasbourg:. https://www.coe.int/en/web/conventions/full-list/-/conventions/rms/0900001680080621.

De Blust, G., Pælinckx, D., Kuijken, E., 1994. Up-to-date information on nature quality for environmental management in Flanders. In: Klijn, F. (Ed.), Ecosystem Classification for Environmental Management. Kluwer Academic Publishers (pp. 223-249).

Divíšek, J., Chytrý, M., Grulich, V., Poláková, L., 2014. Landscape classification of the Czech Republic based on the distribution of natural habitats. Preslia 86, 209–231.

Eidgenössisch Forschungsanstalt für Wald, Su.L., 2007. Biosphärengebiete in der Schweiz - ein Evaluationsinstrument. Retrieved from: http://www.wsl.ch/land/products/biosphaere/.

Environmental Resources Management, 2000. Northern Ireland Landscape Character Assessment. Retrieved from Leeds (UK):. https://www.daera-ni.gov.uk/articles/landscape-character-northern-ireland#toc-1.

Environmental Resources Management Ireland Ltd, 2004. Landscape Character Assessment of County Clare. Retrieved from. http://oldsitehc.info/tirdhreach/publications/landscape-character-assessment-of-co-clare/?L=3.

Erikstad, L., Uttakleiv, L.A., Halvorsen, R., 2015. Characterisation and mapping of landscape types, a case study from Norway. Belgian J. Geogr. 3.

European Council for the Village and Small Town, 2006. ECOVAST Landscape Identification. A Guide to Good Practice. Retrieved from. http://www.ecovast.org/papers/good_guid_corr_e.pdf.

Fairclough, G.J., 1999. Historic Landscape Characterisation: The State of the Art. London: English Heritage. Forestry Commission. (1996). The Management of Semi-Natural Woodlands. Forestry Practice Guides (Nos 1–8). Forestry Commission, Edinburgh.

Farjon, J.M.J., Dirks, G.H.P., Koomen, A.J.M., Vervloet, J.A.J., Lammers, G.W., 2002. Neder-landschap Internationaal: Bouwstenen voor een selectie van gebieden landschapsbehoud. Retrieved from. http://www.wur.nl/nl/Publicatie-details.htm?publicationId=publication-way-333136333235.

Feltz, C., Droeven, E., Kummert, M., 2004. Les territoires paysagers de Wallonie. Etdues et Documents, CPDT, 4. Ministere de la Region Wallonne, Namur 68 pp.

Fňukalová, Ek., Romportl, Da., 2014. A typology of natural landscapes of Central Europe. Acta Univ. Carolinae. Geogr. 49 (2), 6.

Forman, R.T.T., Godron, M., 1986. Landscape ecology. Wiley, New York.

Fry, G., Tveit, M.S., Ode, Å., Velarde, M.D., 2009. The ecology of visual landscapes: exploring the conceptual common ground of visual and ecological landscape indicators. Ecol. Indic. 9 (5), 933–947. http://dx.doi.org/10.1016/j.ecolind.2008.11.008.

Fry, G.L.A., 2001. Multifunctional landscapes—towards transdisciplinary research. Landsc. Urban Plann. 57 (3), 159–168. http://dx.doi.org/10.1016/S0169-2046(01)00201-8.

García-Llamas, P., Calvo, L., Álvarez-Martínez, J.M., Suárez-Seoane, S., 2016. Using remote sensing products to classify landscape. A multi-spatial resolution approach. Int. J. Appl. Earth Observ. Geoinform. 50, 95–105. http://dx.doi.org/10.1016/j.jag.2016.03.010.

Geddes, P., 1915. Cities in Evolution. Williams & Norgate, London.

Gharadjedaghi, B., Heimann, R., Lenz, K., Martin, C., Pieper, V., Schulz, A., Vahabzeadah, A., Finck, P., Riecken, U., 2004. Verbreitung und Gefährdung schutzwürdiger Landschaften in Deutschland. [Distribution and Threats of German Landscapes]. Natur und Landschaft 79, 10.

Granö, J.G., 1929. In: Hicks, Trans. M., Granö, O., Paasi, A. (Eds.), Pure Geography. The Johns Hopkins University Press, Baltimore.

Groom, G., 2005. Methodological review of existing classifications. In: Wascher, D.M. (Ed.), European Landscape Character Areas – Typology, Cartography and Indicators for the Assessment of Sustainable Landscapes, Final ELCAI Project Report, Landscape Europe (pp. 32-45).

Guneroglu, N., Acar, C., Guneroglu, A., Dihkan, M., Karsli, F., 2015. Coastal land degradation and character assessment of Southern Black Sea landscape. Ocean Coast. Manage. 118, 282–289. http://dx.doi.org/10.1016/j.ocecoaman.2015.03.013.
Hazeu, G.W., Metzger, M.J., Mücher, C.A., Perez-Soba, M., Renetzeder, C., Andersen, E., 2011. European environmental stratifications and typologies: an overview. Agric. Ecosyst. Environ. 142 (1–2), 29–39. http://dx.doi.org/10.1016/j.agee.2010.01.009.
Hettner, A., 1928. 2. umgearbeitete aufl. ed. Die Oberflächenformen Des Festlandes : Probleme Und Methoden Der Morphologie, vol. 4 Teubner, Leipzig.
Hill, M.O., 1979. DECORANA—A FORTRAN Program for Detrended Correspondence Analysis and Reciprocal Averaging. Cornell University, Ithaca, New York.
Hill, M.O., Gauch, H.G., 1980. Detrended correspondence analysis: an improved ordination technique. Vegetatio 42, 11.
Holt-Jensen, A., 2009. Geography. History and Concepts: A Student´s Guide, 4 ed. Sage Publications LTD.
Hou, W., Walz, U., 2013. Enhanced analysis of landscape structure: inclusion of transition zones and small-scale landscape elements. Ecol. Indic. 31, 15–24. http://dx.doi.org/10.1016/j.ecolind.2012.11.014.
Jones, M., 1991. The elusive reality of landscape. Concepts and approaches in landscape research. Norsk Geografisk Tidsskrift - Norwegian J. Geogr. 45 (4), 229–244. http://dx.doi.org/10.1080/00291959108552277.
Jones, M., Howard, P., Olwig, K.R., Primdahl, Jr., Sarlöv Herlin, I., 2007. Multiple interfaces of the European Landscape Convention. Norsk Geografisk Tidsskrift - Norwegian J. Geogr. 61 (4), 207–216. http://dx.doi.org/10.1080/00291950701709176.
Julie Martin Associates, Swanwick, C., 2003. Overview of Scotland's National Programme of Landscape Character Assessment. Scottish National Heritage Commissioned Report F03 AA307). 107pp. Retrieved from. Scottish Hational Heritage, Perth (UK). http://www.snh.org.uk/pdfs/publications/commissioned_reports/f03aa.pdf.
Kaltenborn, B.P., Bjerke, T., 2002. Associations between environmental value orientations and landscape preferences. Landsc. Urban Plann. 59 (1), 1–11. http://dx.doi.org/10.1016/S0169-2046(01)00243-2.
Kendall, M.G., 1938. A new measure of rank correlation. Biometrika 30 (1–2), 81–93. http://dx.doi.org/10.1093/biomet/30.1-2.81.
Kim, K.-H., Pauleit, S., 2007. Landscape character, biodiversity and land use planning: the case of Kwangju City Region, South Korea. Land Use Policy 24 (1), 264–274. http://dx.doi.org/10.1016/j.landusepol.2005.12.001.
Kruskal, J.B., 1964a. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. Psychometrika 29, 27.
Kruskal, J.B., 1964b. Nonmetric multidimensional scaling: a numerical method. Psychometrika 29, 115–129 29, 14.
Käyhkö, N., Granö, O., Häyrynen, M., 2004. Finnish landscape studies – a mixture of traditions and recent trends in the analysis of nature-human interactions. Belgeo, Revue belge de géographie 2–3.
Legendre, P., Legendre, L.F.J., 2012. 3 ed. Numerical Ecology, vol. 24 Elsevier Science.
Lioubimtseva, E., Defourny, P., 1999. GIS-based landscape classification and mapping of European Russia. Landsc. Urban Plann. 44 (2), 63–75. http://dx.doi.org/10.1016/S0169-2046(99)00008-0.
Litton, R.B. (Ed.), 1972. Aesthetic Dimensions of the Landscape. John Hopkins University Press, Baltimore, MD.
Lynch, K., 1960. The image of the city. M.I.T. Press, Cambridge, Mass.
Marosi, S., Somogyi, S., 1990. Magyarország kistájainak katasztere I.-II. In: Wascher, D.M. (Ed.), European Landscape Character Areas – Typologies, Cartography and Indicators for the Assessment of Sustainable Landscapes, (2005) Final ELCAI Project Report. Retrieved from Budapest: http://library.wur.nl/WebQuery/wurpubs/fulltext/1778.
McHarg, I.L., 1969. Design with nature. Published for the American Museum of Natural History by Doubleday/Natural History Press, Garden City, N.Y.
Meeus, J.H.A., 1995. Pan-European landscapes. Landsc. Urban Plann. 31 (1–3), 57–79. http://dx.doi.org/10.1016/0169-2046(94)01036-8.
Menz, G., Richters, J., 2009. Quantitative classification of landscapes in Northern Namibia using ASTER digital elevation model. In: Bollig, M., Bubenzer, O. (Eds.), African Landscapes. Interdisciplinary Approach. Springer, New York (pp. 105-117).
Metzger, M.J., Brus, D.J., Bunce, R.G.H., Carey, P.D., Gonçalves, J., Honrado, J.P., Jongman, R.H.G., Trabucco, A., Zomer, R., 2013. Environmental stratifications as the basis for national, European and global ecological monitoring. Ecol. Indic. 33, 26–35. http://dx.doi.org/10.1016/j.ecolind.2012.11.009.
Miljøministeriet Naturstyrelsen, 2011. Landskabsatlas og formidling af landskabskarakterkortlægningen. Retrieved from Copenhagen, Denmark:. https://www2.nst.dk/download/planlaegning/apropos-landskabsatlas.pdf.
Minchin, P.R., 1987. An evaluation of the relative robustness of techniques for ecological ordination. Vegetatio 69, 19.
Mücher, C.A., Bunce, R.G.H., Jongman, R.H.G., Klijn, J.A., Koomen, A.J.M., Metzger, M.J., Wascher, D.M., 2003. Identification and Characterisation of Environments and Landscapes in Europe. Retrieved from Wageningen:. http://content.alterra.wur.nl/internet/webdocs/internet/geoinformatie/projects/LANMAP2/publications/Alterrarep832.pdf.
Mücher, C.A., Klijn, J.A., Wascher, D.M., Schaminée, J.H.J., 2010. A new European Landscape Classification (LANMAP): a transparent, flexible and user-oriented methodology to distinguish landscapes. Ecol. Indic. 10 (1), 87–103. http://dx.doi.org/10.1016/j.ecolind.2009.03.018.
Neef, E., 1967. The theoretical foundations of landscape study. In: Wiens, J.A., Moss, M.R., Turner, M.G., Mladenoff, D.J. (Eds.), Foundation Papers in Landscape Ecology. Columbia University Press, New York (pp. 225-245) 2007.
Nogué, J., Sala, P., Grau, J., 2016. The Landscape Catalogues of Catalonia. Methodology. Landscape Observatory og Catalonia, Olot, Catalonia.
Noss, R.F., 1983. A regional landscape approach to maintain diversity. A regional landscape approach to maintain diversity. BioScience 33 (11), 700–706. http://dx.doi.org/10.2307/1309350.
Noss, R.F., 1990. Indicators for Monitoring Biodiversity: A Hierarchical Approach, vol. 4 pp. 355-364) Oxford, UK.
Ode, Å., Fry, G., Tveit, M.S., Messager, P., Miller, D., 2009. Indicators of perceived naturalness as drivers of landscape preference. J. Environ. Manage. 90 (1), 375–383. http://dx.doi.org/10.1016/j.jenvman.2007.10.013.
Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., Hara, R.B.O., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., Wagner, H., 2016. Vegan: Community Ecology Package. R package version 2.4-1.
Olwig, K.R., Dalglish, C., Fairclough, G., Herring, P., 2016. Introduction to a special issue: the future of landscape characterisation, and the future character of landscape – between space, time, history, place and nature. Landsc. Res. 41 (2), 169–174. http://dx.doi.org/10.1080/01426397.2015.1135321.
Otahel, J., 2004. Landscape and landscape research in Slovakia. Belgeo (2–3), 337–346. http://dx.doi.org/10.4000/belgeo.13769.
Perko, D., Hrvatin, M., Ciglič, R., 2015. A methodology for natural landscape typification of Slovenia. Acta Geogr. Slovenica 55 (2). http://dx.doi.org/10.3986/ags.1938.
Peterseil, J., Wrbka, T., Plutzar, C., Schmitzberger, I., Kiss, A., Szerencsits, E., Reiter, K., Schneider, W., Suppan, F., Beissmann, H., 2004. Evaluating the ecological sustainability of Austrian agricultural landscapes—the SINUS approach. Land Use Policy 21 (3), 307–320. http://dx.doi.org/10.1016/j.landusepol.2003.10.011.
Pinto-Correia, T., Canela d'Abreu, A., Oliveira, R., 2003. landscape units in Portugal and the development and application of landscape indicators. In: Paper Presented at the Agricultural Impacts on Landscapes: Proceedings from NIJOS/OECD Expert Meeting on AgriculturalLandscape Indicators. Oslo, Norway. October 7–9.
Plieninger, T., Draux, H., Fagerholm, N., Bieling, C., Bürgi, M., Kizos, T., Kuemmerle, T., Primdahl, J., Verburg, P.H., 2016. The driving forces of landscape change in Europe: a systematic review of the evidence. Land Use Policy 57, 204–214. http://dx.doi.org/10.1016/j.landusepol.2016.04.040.
Plieninger, T., Kizos, T., Bieling, C., Dû-Blayo, L.L., Budniok, M.-A., Bürgi, M., Crumley, C.L., Girod, G., Howard, P., Kolen, J., Kuemmerle, T., Milcinski, G., Palang, H., Trommler, K., Verburg, P.H., 2015. Exploring ecosystem-change and society through a landscape lens: recent progress in European landscape research. Ecol. Soc. 20 (2), 5. http://dx.doi.org/10.5751/ES-07443-200205.
Puschmann, O., 2005. Nasjonalt Referansesystem for Landskap : Beskrivelse Av Norges 45 Landskapsregioner, vol. 10/2005 NIJOS, Norsk institutt for jord- og skogkartlegging, Ås.
R Core Team, 2016. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Raymond, R., Luginbuhl, Y., Seguin, J.-F., Cedelle, Q., Grare, H., 2015. Les atlas de paysages, méthode pour l'identification, la caractérisation et la qualification des paysages. Retrieved from. https://www.ecologique-solidaire.gouv.fr/sites/default/files/Landscape%20Atlases,%20Landscape%20identification,%20characterisation%20and%20assessment%20method.pdf.
Reed, J., van Vianen, J., Barlow, J., Sunderland, T., 2017. Have integrated landscape approaches reconciled societal and environmental issues in the tropics? Land Use Policy 63, 481–492. http://dx.doi.org/10.1016/j.landusepol.2017.02.021.
Richter, H., 2005. Eine naturräumliche Gliederung der DDR auf der Grundlage von Naturraumtypen (mit einer Karte 1:500000). Beiträge zur Geographie 29, 323–340.
Riu-Bosoms, C., Vidal, T., Duane, A., Fernandez-Llamazares, Onrubia, A., Gueze, M., Luz, A.C., Paneque-Gálvez, J., Macia, M.J., Reyes-Garcia, V., 2015. Exploring indigenous landscape classification across different dimensions: a case study from the Bolivian Amazon. Landsc. Res. 40 (3), 318–337. http://dx.doi.org/10.1080/01426397.2013.829810.
Roba, H.G., Oba, G., 2009. Community participatory landscape classification and biodiversity assessment and monitoring of grazing lands in northern Kenya. J Environ. Manage 90 (2), 673–682. http://dx.doi.org/10.1016/j.jenvman.2007.12.017.
Sandström, U.G., Hedfors, P., 2018. Uses of the word 'landskap' in Swedish municipalities' comprehensive plans: does the European Landscape Convention require a modified understanding? Land Use Policy 70, 52–62. http://dx.doi.org/10.1016/j.landusepol.2017.07.060.
Sarlöv Herlin, I., 2016. Exploring the national contexts and cultural ideas that preceded the landscape character assessment method in England. Landsc. Res. 41 (2), 175–185. http://dx.doi.org/10.1080/01426397.2015.1135317.
Sauer, C.O., 1925. The morphology of landscape. In: Leighly, J. (Ed.), Land and Life (University of California Publications in Geography, 2; Reprinted in, 1974). University of California Press, Berkely, pp. 315–350 (1925).
Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.L., Sheil, D., Meijaard, E., Venter, M., Boedhihartono, A.K., Day, M., Garcia, C., van Oosten, C., Buck, L.E., 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc. Natl. Acad. Sci. U. S. A. 110 (21), 8349–8356. http://dx.doi.org/10.1073/pnas.1210595110.
Sayre, R., Dangermond, J., Frye, C., Vaughan, R., Aniello, P., Breyer, S., Cribbs, D., Hopkins, D., Nauman, R., Derrenbacher, W., Wright, D., Brown, C., Convis, C., Smith, J., Benson, L., Paco VanSistine, D., Warner, H., Cress, J., Danielson, J., Hamann, S., Cecere, T., Reddy, A., Burton, D., Grosse, A., True, D., Metzger, M., Hartmann, J., Moosdorf, N., Dürr, H., Paganini, M., DeFourny, P., Arino, O., Maynard, S., Anderson, M., Comer, P., 2014. A New Map of Global Ecological Land Units - An Ecophysiographic Stratification Approach. Association of American Geographers, Washington DC.
Schlüter, O., 1920. Die Erdkunde in ihrem Verhältnis zu den Naturund Geisteswissenschaften. Geographischer Anzeiger 21, 6.
Sevenant, M., Antrop, M., 2009. Cognitive attributes and aesthetic preferences in assessment and differentiation of landscapes. J. Environ. Manage. 90 (9), 2889–2899. http://dx.doi.org/10.1016/j.jenvman.2007.10.016.
Sevenant, M., Menschaert, J., Couvreur, M., Ronse, A., Heyn, M., Janssen, J., Antrop, M.,

Geypens, M., Hermey, M., De Blust, G., 2002. Ecodistricten: Ruimtelijke eenheden voor gebiedsgericht milieubeleid in Vlaanderen. Deelrapport I: Afbakening van ecodistricten en ecoregions: Theoretische achtergrond en gevolgde methodologie. Studieopdracht in het kader van actie 134 van het Vlaams Milieubeleidsplan 1997–2001. In opdracht van het Ministerie van de Vlaamse GemeenschapAdministratie Milieu, Natuur, Land- en Waterbeheer. Retrieved from. http://docplayer.nl/26458756-Ecodistricten-ruimtelijke-eenheden-voor-gebiedsgericht-milieubeleid-in-vlaanderen-afbakening-van-ecodistricten-en-ecoregio-s-verklarende-teksten.html.
Sokal, R.R., Rohlf, F.J., 1995. Biometry : the principles and practice of statistics in biological research, 3rd ed. Freeman, New York.
Solnetsev, N.A., 1948. The natural geographic landscape and some of its general rules. In: Moscov: State Publishing House for Geographic Literature. Proceedings of the All-Union Geographical Congress, vol. 1.
Soto, S., Pintó, J., 2010. Delineation of natural landscape units for Puerto Rico. Appl. Geogr. 30 (4), 720–730. http://dx.doi.org/10.1016/j.apgeog.2010.01.010.
Swanwick, C., 2002. Landscape character assessment. Guidance for England and Scotland. The Countryside Agency/Scottish National Heritage, Cheltenham/Edinburgh.
Tansley, A.G., 1935. The use and abuse of vegetational concepts and terms. Ecology 16 (3), 284–307. http://dx.doi.org/10.2307/1930070.
Tetlow, R.J., Sheppard, S.R.J., 1979. Visual unit analysis: a descriptive approach to landscape assessment. In: Paper Presented at the Proceedings of Our National Landscape: A Conference on Applied Techniques for Analysis and Management of the Visual Resource. Incline Village, Nevada.
Trafikverket, 2012. Landskap i långsiktig planering. Pilotstudie i Västra Götaland. Retrieved from: http://www.trafikverket.se/for-dig-i-branschen/Planera-och-utreda/Planerings–och-analysmetoder/Miljobedomning/Ett-mangsidigt-verktyg/Landskapskaraktarsanalys-i-Vastra-Gotaland/.
Troll, C., 1939. Luftbildplan und ökologische Bodenforschung. Ihr zweckmäßiger Einsatz für die wissenschaftliche Erforschung und praktische Erschließung wenig bekannter Länder. Zeitschrift der gesellschaft für erdkunde zu Berlin 1939 (7, 8), 241–298.
Tsilimigkas, G., Kizos, T., 2014. Space, pressures and the management of the Greek landscape. Geografiska Annaler Ser. B Hum. Geogr. 96 (2), 159–175. http://dx.doi.org/10.1111/geob.12043.
Turner, S., 2006. Historic Landscape Characterisation: a landscape archaeology for research, management and planning. Landsc. Res. 31 (4), 385–398. http://dx.doi.org/10.1080/01426390601004376.
Tveit, M., Ode, Å., Fry, G., 2006. Key concepts in a framework for analysing visual landscape character. Landsc. Res. 31 (3), 229–255. http://dx.doi.org/10.1080/01426390600783269.
Umweltministerium Mecklenburg-Vorpommern (Cartographer), 2003. Gutachtliches Landschaftprogramm. Naturräumliches Gliederung. Retrieved from: https://www.lung.mv-regierung.de/insite/cms/umwelt/natur/landschaftsplanung_portal/glp.htm. .
Uzun, O., Dilek, F., Cetinkaya, G., Erduran, F., Aciksoz, S., 2011. National and regional landscape classification and mapping of Turkey. Konya closed basin, Sula Lake and its surrounding area. Int. J. Phys. Sci. 6 (3), 550e.
Vallés, M., Galiana, F., Bru, R., 2013. Towards harmonisation in landscape unit delineation: an analysis of Spanish case studies. Landsc. Res., vol. 38 (3), 329–334 01 June 2013.
van Asselen, S., Verburg, P.H., 2012. A land system representation for global assessments and land-use modeling. Glob. Change Biol. 18 (10), 3125–3148. http://dx.doi.org/10.1111/j.1365-2486.2012.02759.x.
van der Zanden, E.H., Levers, C., Verburg, P.H., Kuemmerle, T., 2016. Representing composition, spatial structure and management intensity of European agricultural landscapes: a new typology. Landsc. Urban Plann. 150, 36–49. http://dx.doi.org/10.1016/j.landurbplan.2016.02.005.
Van Eetvelde, V., Antrop, M., 2009. A stepwise multi-scaled landscape typology and characterisation for trans-regional integration, applied on the federal state of Belgium. Landsc. Urban Plann. 91 (3), 160–170. http://dx.doi.org/10.1016/j.landurbplan.2008.12.008.
Vinogradov, B.V., Gerenchuk, K.I., Isachenko, A.G., Raman, K.G., Tsesel'chuk, Y.N., 1962. Basic principles of landscape mapping. Soviet Geogr. 3 (6), 15–20. http://dx.doi.org/10.1080/00385417.1962.10769947.
Vogiatzakis, Griffiths, G.H., Melis, M.T., Marini, A., Careddu, M.B., 2006. Landscape typology in the Mediterranean context: a tool for habitat restoration. J. Mediterranean Ecol. 7 (1–2–3–4), 7.
Vogiatzakis, I.N., Zomeni, M., Mannion, A.M., 2017. Characterizing islandscapes: conceptual and methodological challenges exemplified in the Mediterranean. Land 6 (1), 1–13. http://dx.doi.org/10.3390/land6010014.
von Humboldt, A., Bonpland, A., 1807. In: Jackson, S.T., Romanowski Trans, S. (Eds.), Essay on the Geography of Plants. University of Chicago Press, Chicago 2009.
Walz, U., 2015. Indicators to monitor the structural diversity of landscapes. Ecol. Model. 295, 88–106. http://dx.doi.org/10.1016/j.ecolmodel.2014.07.011.
Warnock, S., Griffiths, G., 2014. Landscape characterisation: the living landscapes approach in the UK. Landsc. Res. 40 (3), 261–278. http://dx.doi.org/10.1080/01426397.2013.870541.
Wascher, D.M., 2005. European Landscape Character Areas – Typologies, Cartography and Indicators for the Assessment of Sustainable Landscapes. Final ELCAI Project Report. Retrieved from: http://library.wur.nl/WebQuery/wurpubs/fulltext/1778. .
Whittaker, R.H., 1967. Gradient analysis of vegetation. Biol. Rev. 42 (2), 207–264. http://dx.doi.org/10.1111/j.1469-185X.1967.tb01419.x.
Wrbka, T., Schmitzberger, I., Pühringer, M., Fussenegger, K., Szerencsits, E., Beissmann, H., Hengsberger, R., Tutsch, G. (Cartographer). 2000. Classification of Austrian Cultural Landscapes. Retrieved from: http://cvl.univie.ac.at/projekte/sinus/karten/reihen_300m_eng.gif.
Xie, Y., MacKinnon, J., Li, D., 2004. Study on biogeographical divisions of China. Biodivers. Conserv. 13 (7), 1391–1417.
Zonneveld, I., 1989. The land unit — a fundamental concept in landscape ecology, and its applications. Landsc. Ecol. 3 (2), 67–86. http://dx.doi.org/10.1007/BF00131171.
Zube, E.H., 1984. Themes in landscape assessment theory. Landsc. J. 3 (2), 104–110.
Zube, E.H., Sell, J.L., Taylor, J.G., 1982. Landscape perception: research, application and theory. Landsc. Plann. 9 (1), 1–33. http://dx.doi.org/10.1016/0304-3924(82)90009-0.
Økland, R.H., 1990. Vegetation Ecology : Theory, Methods and Applications With Reference to Fennoscandia, vol. 1 Botanisk hage og museum, Oslo.
Økland, R.H., 1996. Are ordination and constrained ordination alternative or complementary strategies in general ecological studies? J. Veg. Sci. 7 (2), 289–292. http://dx.doi.org/10.2307/3236330.
Økland, R.H., Økland, T., Rydgren, K., 2001. Vegetation-environment relationships of boreal spruce swamp forests in Østmarka Nature Reserve. SE Norway Sommerfeltia 29, 190.