Journal of Environmental Management 289 (2021) 112498

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

Research article

A landscape classification map of Ireland and its potential use in national land use monitoring

J. Carlier [a,*], M. Doyle [b], J.A. Finn [c], D. Ó hUallacháin [c], J. Moran [a]

[a] Agroecology and Rural Development Group, Marine and Freshwater Research Centre, Galway-Mayo Institute of Technology, Galway Campus, Dublin Road, Galway, Ireland
[b] Agriculture & Food Science Centre, University College Dublin, Belfield, Dublin, 4, Ireland
[c] Teagasc Environment Research Centre, Johnstown Castle, Co. Wexford, Ireland

ARTICLE INFO

Keywords:
Landscape characterisation
Multivariate classification
Environmental stratification
Land use monitoring
Ecological survey

ABSTRACT

This study presents a novel landscape classification map of the Republic of Ireland and is the first to identify broad landscape classes by incorporating physiographic and land cover data. The landscape classification responds to commitments to identify and classify the Irish landscape as a signatory to the European Landscape Convention. The methodology applied a series of clustering iterations to determine an objective multivariate classification of physiographic landscape units and land cover datasets. The classification results determined nine statistically significant landscape classes and the development of a landscape classification map at a national scale. A statistical breakdown of land cover area and diversity of each class was interpreted, and a comparison was extended using independent descriptive variables including farmland use intensity, elevation, and dominant soil type. Each class depicts unique spatial and composition characteristics, from coastal, lowland and elevated, to distinct and dominating land cover types, further explained by the descriptive variables. The significance of individual classes and success of the classification is discussed with particular reference to the wider applicability of the map. The transferability of the methodology to other existing physiographic maps and environmental datasets to generate new landscape classifications is also considered. This novel work facilitates the development of a strategic framework to efficiently monitor, compare and analyse ecological and other land use data that is spatially representative of the distribution and extent of land cover in the Irish countryside.

1. Introduction

The European Landscape Convention encourages signatories to develop and implement measures towards promoting and protecting landscapes (Council of Europe, 2000). The identification of landscape characteristics, pressures and their driving forces is required under Article 6 of the Convention, informing sustainable land use strategies and policy. These measures can be informed to some extent by systematic knowledge of the variation and spatial extent of the landscape composition (Simensen et al., 2018; Wurtzebach and Schultz, 2016), for example through the classification of landscape types or strata (e.g. Antrop and Van Eetvelde, 2017). There exist several pan-European landscape stratifications based on standardised datasets (e.g. the 'Environmental Stratification of Europe' (EnS) (Metzger et al., 2005) and 'European Landscape Typology and Map' (LANMAP2) (Wascher, 2005)), providing generic strata for strategic, cross-continent sampling and modelling exercises (Hazeu et al., 2011). Other landscape level classifications have been developed and are used for a range of monitoring purposes by individual Member States; for example national breeding bird and High Nature Value farmland monitoring in Germany (Mitschke et al., 2005; Benzler et al., 2015), and the ITE Merlewood Land Classification of Great Britain (Bunce et al., 1996 (b) used in the UK Countryside Survey (Bunce et al., 1996 (c)).

The classification of a landscape can be used for stratification purposes to increase the efficiency and representation of sampling or monitoring (Bunce et al., 1996a; Hazeu et al., 2011). In the absence of landscape stratification, national monitoring systems often apply systematic sampling systems such as grid overlays (e.g. National Forest Inventory (Forest Service, 2018); Countryside Bird Survey (Lewis et al., 2019); Butterfly Atlas 2021 (National Biodiversity Data Centre, 2020)). Although systematic sampling methods are straightforward to establish (Moore and Chapman, 1986), they have a fundamental tendency to

* Corresponding author.
E-mail address: Julien.carlier@gmit.ie (J. Carlier).

https://doi.org/10.1016/j.jenvman.2021.112498
Received 12 January 2021; Received in revised form 4 March 2021; Accepted 26 March 2021
Available online 17 April 2021

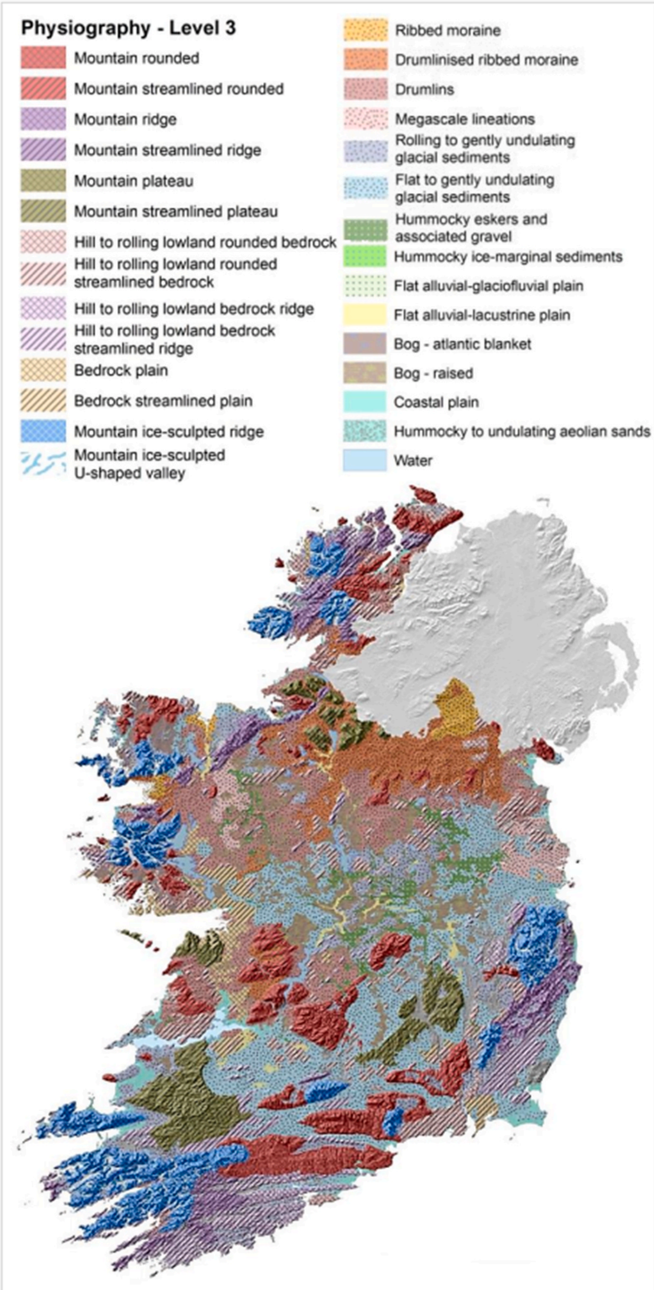


Fig. 1. The Physiographic Units Map of Ireland illustrated under level three classification (29 classes).

inefficiently under- and over-sample areas of extreme spatial extent (Goedickemeier et al., 1997), and may result in sub-optimal representation, unless some stratified sampling design is implemented. This highlights the need for a national landscape classification to develop a representative and an efficient stratified sampling system, under a common national monitoring framework (Bunce et al., 1996 (c)).

The complexities in the composition of a given landscape ensure a degree of subjectivity in a classification (Simensen et al., 2018); 'in any discussion of landscape characterisation the elephant in the room is the question of just what is landscape?' (Olwig et al., 2016). Devising class boundaries can thus be intrinsically challenging. Landscape classification has been achieved under a wide variety of approaches, including intuition, formalised subjectivity and objective mathematical methods (Bunce et al., 1996 (a)). The latter provides for a more objective classification which, although it may be limited by available spatial data, can be statistically tested and interpreted. Increasing availability of geo-spatial data has enabled the growing use of statistical techniques to generate such classifications (Burnett and Blaschke, 2003; Warnock and Griffiths, 2014), often through the multivariate analysis of various geographic and environmental variables including land cover to address various specific user requirements such as land use and ecological monitoring (Bunce et al., 1996 (a); Mücher et al., 2003; Metzger et al., 2005; Chuman and Romportl, 2010; Fňukalová and Romportl, 2014; Carlier and Moran, 2019).

No national landscape classification exists for the Republic of Ireland that represents land cover and is suitable for stratified sampling of ecological and land use data. A number of Irish landscape classifications exist at county and regional scale (e.g. Geological Survey of Ireland, 2004; Cooper and Loftus, 1998; Carlier and Moran, 2019). Other national-scale landscape divisions include Soil Physiographic Divisions (Gardiner and Radford, 1980), Land Use Capability (Aalen et al., 2011) and more recently the Physiographic Units (PU) Map of Ireland (Geological Survey of Ireland, 2018). However, the PU Map of Ireland uses a three-tier classification scheme representing a number of hierarchical landscape divisions with increasing levels of complexity (Fig. 1). The expert-driven classification differentiates various landscape morphologies and landforms based on elevation, bedrock geology, sediment and geomorphology, and orthophotography datasets and has potential to contribute to the development of a national landscape classification that includes land cover.

The aim of this study is to generate and subsequently interpret a national landscape classification map of Ireland using objective, multivariate reclassification of the highest PU complexity (level 3, see Fig. 1), guided by additional spatial datasets. Specifically, the aims are to i) analyse and group PU classes based on land cover composition to generate broad landscape classes, and ii) interpret the resulting landscape classes in the context of a range of additional, landscape variables.

The resulting map and interpretation presents a first broad-scale classification of the Irish landscape into classes that represent homogenous areas of land cover and physiographic morphologies. The results are intended to inform surveyors, planners and policymakers in developing stratified, multi-scale sampling approaches within land use monitoring programmes, or for more nuanced uses such as landscape-level design and targeting of agri-environment schemes. The methodology presented in this study is highly transferable to other commonly available geo or physiographic datasets, with the integration of environmental variables to generate new landscape classifications for a wide range of end uses.

2. Materials and methods

Four main steps were taken to develop a landscape classification map for the Republic of Ireland (Fig. 2). An overlay analysis was undertaken to combine and extract national physiographic and landcover data. This geospatial data was subsequently analysed using a cluster analysis to seek a reduction of the data into emerging broad landscape classes. These emerging landscape classes were further interpreted using a summary breakdown of additional environmental exploratory data. Finally, the clusters were used to define a new landscape classification map. All geographic information system work used ArcGIS Pro v.2.6 (ESRI, 2020) and all statistical analyses were performed using PCORD v.7 (McCune and Mefford, 2016) and SPSS v.26 (IBM Corp, 2019) software.

2.1. Study area

The Republic of Ireland (70,273 km^2) lies between latitudes 51°–55° N and longitudes 11°–5° W within the Atlantic biogeographical region (EEA, 2002) in the north-west of Europe. Its predominantly pastural landscape consists of a rim of distinctive upland areas surrounding a low central plain interrupted by detached hills and mountains (Aalen et al.,

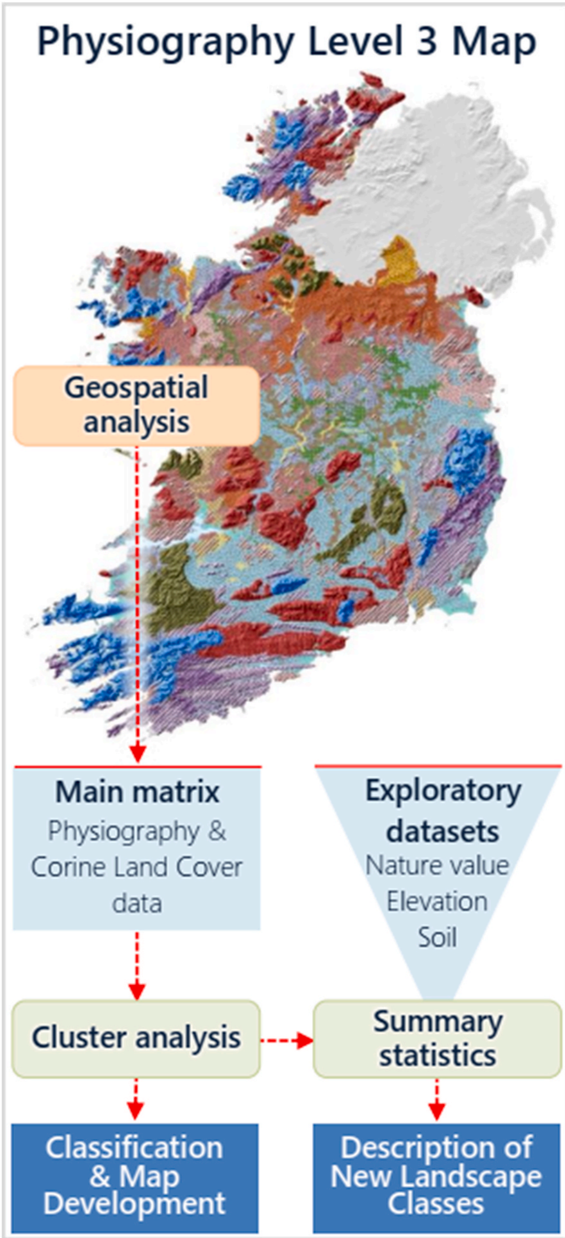


Fig. 2. Schematic overview of the main steps taken to develop a landscape classification map of Ireland.

2011). The climate is typically temperate maritime, influenced by the North Atlantic Drift (Met Éireann, 2020) with annual mean temperatures ranging between 9 °C and 10 °C and rainfall of 1230 mm (Walsh, 2012). An environmental contrast of altitudinally higher and mainly wet mineral soils to lower, drier and mainly well drained soils follows a north-west to south-east gradient, generally influencing land use throughout the country (Aalen et al., 2011).

2.2. Data preparation

The Physiographic Units (PU) dataset comprises 944 polygon features with a minimum mapping unit of 5 km^2, classified under 29 Physiographic Units at its highest complexity- Level 3. In its application as a landscape classification map, various PU classes from the three complexity levels could be subjectively merged in a reclassification exercise, retaining intuitive classes (e.g. 'Mountain to hill' [Level 1], 'Bog plain' [Level 2], 'Coastal plain' [Level 3] etc.). However, such amalgamation may be subject to perceptive bias and become complex due to lacking ground cover composition to inform the decision-making process. Physiographic Unit features from the Physiography Level 3 shapefile (obtained from GSI, 2018) were overlaid onto the CORINE Land Cover (CLC) 2018 level 3 classification scale shapefile features (CLC 2018) using the 'Clip' geoprocessing tool in ArcGIS. This enabled the extraction of the respective CLC % cover composition for each PU, resulting in a main matrix, with PU's as rows and respective CLC % cover composition as columns (Fig. 3) for subsequent Cluster Analysis. The PU 'Water' was not included for analysis, since its composition was solely of water bodies and could be re-introduced as a unique class when finalising the landscape classification map. In order to achieve a non-technogenic, rural landscape classification, non-agricultural man--made CLC classes were omitted; thus, 21 out of 33 CLC classes occurring in Ireland were retained for analysis.

2.3. Cluster iterations

A polythetic hierarchal agglomerative Cluster Analysis (with Euclidean distance measure and Wards linkage method) was used to objectively seek clusters of physiographic units (PUs) using the main matrix (of PU and CLC cover). Data from the main matrix was modified to reduce skewness and influential outliers were removed under a series of Cluster Analysis iterations (Fig. 4) until a meaningful and statistically significant clustering was achieved (a full breakdown of all iterations is provided in supplementary material Appendix 1). A multi-response permutation procedure (MRPP) was used to test the effect size of within-group homogeneity of each iteration and evaluate optimal clustering. An MRPP A-value of >0.4 indicates a 'large' effect size of within-group agreement other than expected by chance (Peck, 2016). Mean CLC % cover composition was examined to determine unique, dominant, or absent land covers, and mean Richness S and Simpson's D' (Simpson, 1949) provided an indication of land cover diversity for each cluster.

To aid further interpretation, additional exploratory data (elevation, High Nature Value farmland (HNVf) score, and soil type) within each cluster were collated and extracted, following the same procedure as that for generating the main matrix. Elevation was included to aid interpretation of potential separate Mountain PU clusters. Mean elevation for each PU was obtained using European Digital Elevation Model (EU-DEM), version 1.1 dataset (Copernicus, 2016). High Nature Value farmland score is a mapped likelihood measure of farmland that has high biodiversity and potential presence of species of conservation concern, and was included as a composite indicator to measure variation of farmland use intensity. Mean HNVf score was calculated for each PU using the HNVf farmland distribution map of the Republic of Ireland dataset obtained from Matin et al. (2020). Finally, since physiographic divisions are interrelated with soil formation (Gardiner and Radford, 1980), % soil type composition for each PU was obtained using the National Soils and Subsoils Map (Fealy et al., 2009) and used to determine dominant soil types within the clusters. A summary of all exploratory data and a brief description is available in supplementary material Appendix 2.

2.4. Landscape classification map development

The final clustering from Cluster Analysis was used to re-classify the PU level 3 map dataset and generate a landscape classification map in GIS. The PU 'Water' was included directly from the original Physiography Level 3 shapefile.

3. Results

3.1. Clustering

A series of five cluster analysis iterations were performed until a meaningful and statistically significant clustering was achieved.

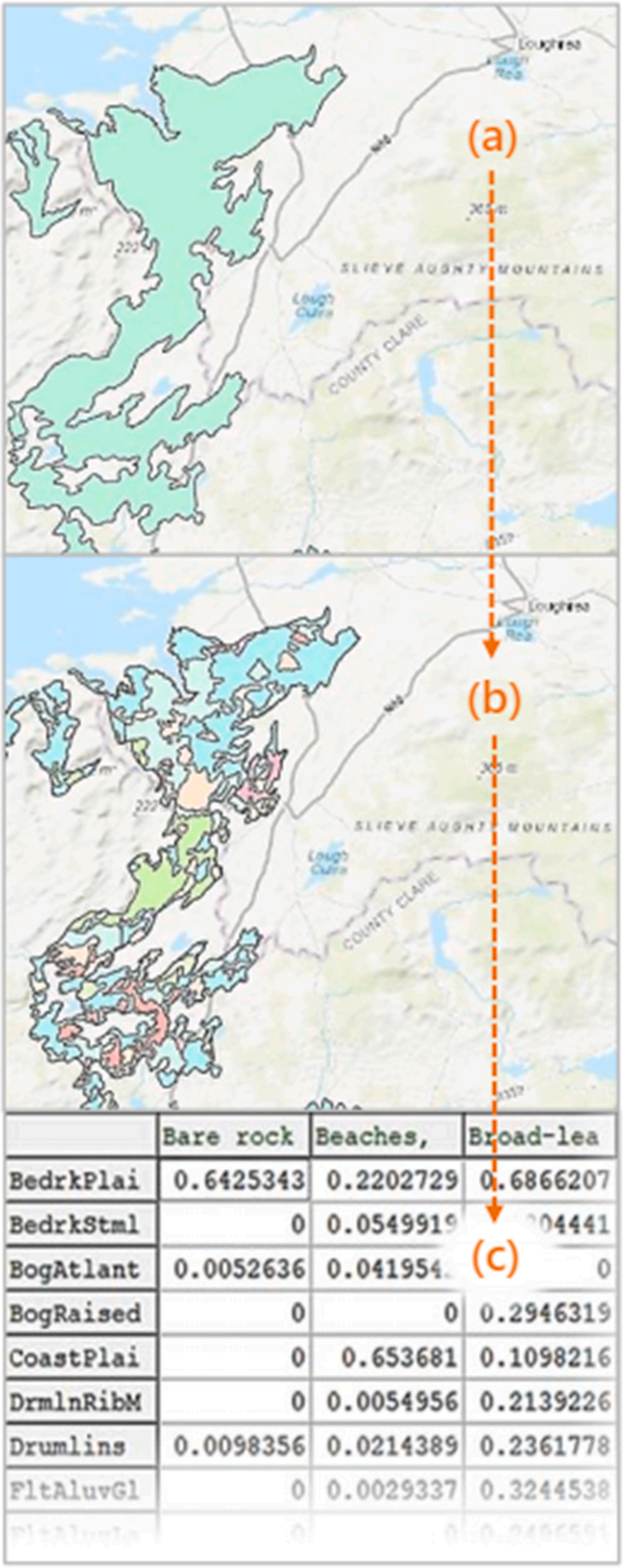


Fig. 3. Example illustration of the 'Bedrock plain' PU class (a) analysed using an overlay of CORINE Land Cover composition (b) to generate a main matrix of both physiography and land cover data (c).

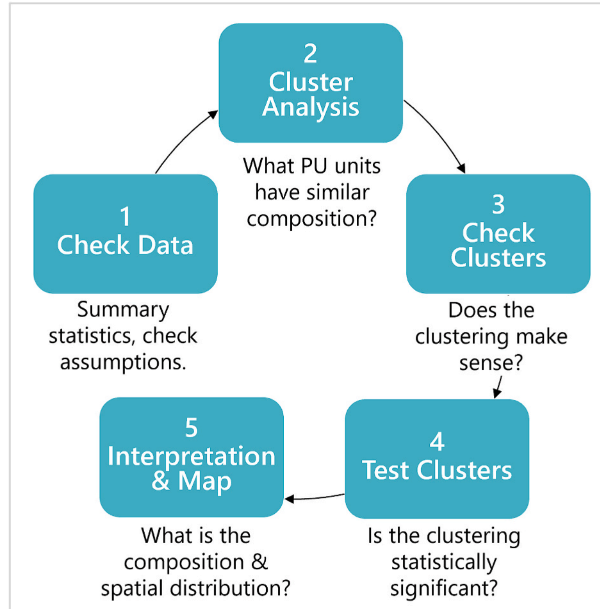


Fig. 4. Illustration of the process flow used for the iterative process of Cluster Analysis.

Following the first iteration, CLC class 'Pastures' was determined to have a significant effect as an outlier (3.69 standard deviations above the mean) and was log transformed. This did not significantly improve the results in the second iteration and the entire matrix was log transformed. This resulted in some meaningful and statistically significant clusters in the third iteration, and a clustering with CLC class 'Pastures' removed from the matrix was subsequently examined. This resulted in several meaningful and statistically significant clusters in an improved fourth iteration. A final fifth iteration was achieved by cutting the cluster dendrogram at a higher level in order to examine a separation of two mountain clusters. This final clustering of 9 clusters was achieved by cutting the cluster dendrogram (Fig. 5) with 8.18% chaining. A Multi Response Permutation Procedure (MRPP) test result of $A = 0.50$ indicated a 'large' effect size, i.e. indicating strong within-group agreement other than expected by chance (Peck, 2016).

Fig. 5 highlights that the data rapidly separated into two clusters broadly representing uplands and lowlands. Further separation of the two clusters separated mountain and bog cluster from the Moraine cluster and the Bedrock plain PU, and the Hummocky to undulating aeolian sands PU from the remaining lowland landscape clusters. Finally, the Bedrock plain PU was separated from the Moraine cluster, the Bog cluster was separated from two Mountain clusters, and Coastal plains and Flat alluvial lacustrine plains were separated from the two remaining lowland clusters.

A full breakdown of all nine clusters is provided in Table 1, including mean CLC composition, richness and diversity. Results from the subsequent extraction of additional exploratory data (mean HNVf score, elevation and dominant soil type) are also included.

3.2. Landscape classification map

A national landscape classification map of Ireland was generated by reclassifying the PU Level 3 map using the nine new clusters (with the PU 'Water' included as an additional class) and a legend was generated using the descriptive titles from Table 2. The integration of CORINE Land Cover (with a working scale of 1:100,000) with the PU dataset as a new composite map results in the final scale of 1:250,000 and minimum mapping unit of 5 km^2 of the PU dataset being retained. The map illustrates the spatial distribution and extent of nine landscape classes

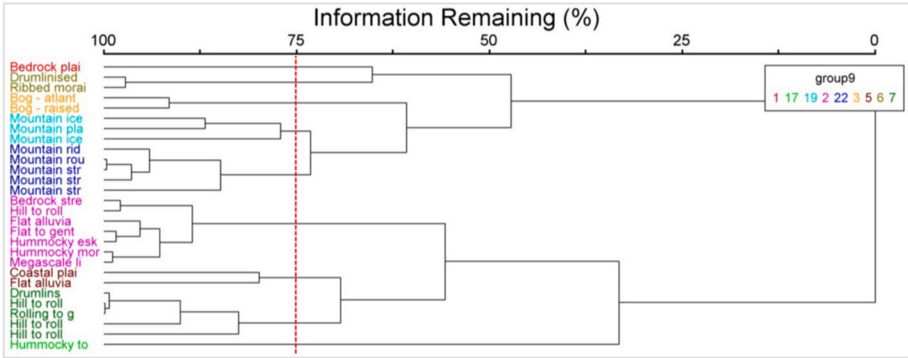


Fig. 5. Cluster analysis dendrogram is cut vertically (red dashed line) to illustrate the grouping membership and distance among nine groups of PU's. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

(Fig. 6).

3.3. *Landscape classification description*

Landscape classes were interpreted by examining the breakdown of land cover composition, richness and diversity of the PU groupings. The additional exploratory variables of HNVf likelihood (a conversion of HNVf scores to HNVf categories was also included to ease interpretation-see Matin et al., 2020), elevation, and predominant soil types are also summarised and compared. Each class presents distinct environmental variations that can be considered when designing a stratified sampling approach within a national land use monitoring programme. Descriptive titles, summary interpretations and representative Google Street View imagery located within each new class are provided in Table 2.

4. Discussion

Currently there is no existing national landscape classification for Ireland that represents broad land cover which can be used for stratified sampling to efficiently collect ecological or land use data. This study addresses this knowledge gap, presenting a first broad-scale classification of the heterogenous Irish landscape into classes that represent more homogenous areas of land cover and can be applied in a national stratified sampling system. Numerous landscape classifications have been widely developed using statistical analysis of environmental data for stratified ecological surveying (Simensen et al., 2018), often using various gridline, point or cell overlays to sample and delineate landscape units (e.g. Bunce et al., 1996 (a); Metzger et al., 2005; Van Eetvelde and Antrop, 2009). Despite various contexts and scales, these example classifications are derived through clustering of landscape cell units in a mainstream approach. The methodology in the present study uses a similar clustering approach but differs in its novel application of a classification of broad similarities in CORINE Land Cover, within existing physiographical landscape features. Opportunities exist to develop similar landscape classifications from other existing geomorphological maps (e.g. Jasiewicz et al., 2014; Rinaldi et al., 2013; Gawde et al., 2009; Siart et al., 2009; Johnson and Fecko, 2008; etc.). It should be noted that the methodology presented in this study is not limited to a land cover and land use application, but depending on user requirements, data availability and study regions, it could be repeated using different variables to incorporate, for example, species distributions, climatic, cultural or historical factors.

The results reveal nine statistically significant and distinct classes reflecting the variation from broad lowlands and uplands, to smaller classes of more defined land cover composition. This resulting classification provides a similar scheme to the seven physiographic units categorized under Level One of the Physiographic Units Map of Ireland (Geological Survey of Ireland, 2018), but differs in its objective reclassification of two separate mountain groups, three separate lowland groups and the retention of individual PUs from the Physiography Level 3 that comprise apparently distinct landcover compositions. These new divisions distinguish broader landscape classes that are intuitive and suitable for the basis of developing stratified sampling and monitoring systems at national scale. Some similarities can also be drawn to the highly generalised 'Land use capability' and 'Physical regions' maps observed in Aalen et al. (2011), though neither map account for land cover.

'Mountain to hill' PUs were clustered under two very distinct groups, though sharing similar traits such as the highest land cover proportions of 'Coniferous forests', 'Transitional woodland scrub' and an association with acidic soils and increased elevation. The divergence between these two landscapes is evident in terms of differences in land cover proportions of 'Peat bog', 'Coniferous forests' and 'Pastures'. The distinction of the Extensive Mountainous landscape is essential to defining more elevated and therefore less accessible landforms, represented by regions that are dominated by peat soils and have extremely limited land use capacity. This is particularly evident through the inclusion of some of Ireland's most elevated mountains (e.g. MacGillycuddy's Reeks, Wicklow and Derryveagh Mountains etc.) in this landscape. In comparison, less elevated landforms (e.g. Mullaghareirk, Slieve Bloom, Burren region etc.), classified here as a Semi-intensified Elevated landscape, are generally more accessible and have sustained a limited degree of pastural land use and afforestation.

The lowland landscapes are all represented by large proportions (64–73%) of 'Pastures'. The distinction between regions of lowlands based on an extensive – intensive gradient (in terms of decreasing semi-natural and natural land cover) reflects observations in farmland use intensity and capability in Ireland (Sullivan et al., 2017; Matin et al., 2016, 2020; Aalen et al., 2011). This farmland intensity gradient broadly follows a West to East to South-East pattern, predominantly as a result of lessening Atlantic climatic influence and a prevalence of basic mineral well-drained soil conditions that support increased land use capacity (Crowley et al., 2008; Aalen et al., 2011). A decreasing trend in mean elevation also reflects the more elevated hillocky drumlin characteristics of more extensive, hilly landscapes with poorly draining acidic soils, compared to lower and undulating landscapes. The distinction of Extensive Lowlands along with the Extensive Bedrock Plains may be useful to define low intensity, lowland landscapes likely to support areas of High Nature Value farmland (HNV) (Keenlyside et al., 2014; EEA, 2004), though Type 3 HNV farmland areas (supporting rare species or a high proportion of European or World populations) extend across all gradients (Matin et al., 2020).

The clustering of both Bog PU's into a Peatlands landscape is similar to the PU Level 2 map scheme 'Bog plain' and is reflected by this landscape's dominant 'Peat bog' land cover. A low presence of other land covers including 'Pasture', 'Coniferous' and 'Mixed forests' is reflected by its lowest landscape richness value of all classes and highlights the limited land use capacity of these peat soil regions. High Nature

Table 1
Summary breakdown of mean CORINE Land Cover % (±Standard Error) and mean richness and diversity within each cluster (first five most dominant CORINE Land Cover classes in each cluster are highlighted in bold). Additional exploratory data is also listed, including mean HNVf score, elevation, dominant soil type and area.

CORINE Land Cover 2018	Clusters								
	1 (1 PU)	2 (2 PUs)	3 (2 PUs)	4 (3 PUs)	5 (5 PUs)	6 (7 PUs)	7 (2 PUs)	8 (5 PUs)	9 (1 PU)
(332) Bare rocks	3.39	0.00 (±0.00)	0.01 (±0.01)	0.38 (±0.34)	0.64 (±1.11)	0.03 (±0.06)	0.00 (±0.00)	0.01 (±0.01)	0.00
(331) Beaches, dunes, sands	0.66	0.09 (±0.11)	0.05 (±0.07)	0.02 (±0.02)	0.08 (±0.13)	0.04 (±0.05)	1.75 (±2.48)	0.28 (±0.39)	**30.21**
(311) Broad-leaved forest	**3.86**	0.53 (±0.15)	0.49 (±0.69)	1.51 (±1.65)	0.81 (±0.31)	0.69 (±0.32)	0.35 (±1.06)	0.85 (±0.33)	0.00
(521) Coastal lagoons	0.00	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.00 (±0.00)	0.57 (±0.80)	0.00 (±0.00)	0.00
(242) Complex cultivation patterns	2.12	0.03 (±0.01)	0.17 (±0.21)	0.05 (±0.04)	0.38 (±0.17)	1.50 (±0.56)	2.41 (±0.65)	**2.15** (±1.91)	0.03
(312) Coniferous forest	0.28	**2.71** (±2.21)	**5.57** (±1.16)	**7.23** (±1.39)	**10.76** (±2.45)	**1.17** (±0.69)	1.59 (±0.17)	**2.15** (±0.89)	0.12
(522) Estuaries	0.03	0.01 (±0.01)	0.01 (±0.02)	0.08 (±0.14)	0.00 (±0.00)	0.05 (±0.08)	0.80 (±0.69)	0.04 (±0.04)	0.00
(411) Inland marshes	1.74	0.32 (±0.46)	0.64 (±0.79)	0.20 (±0.32)	0.02 (±0.01)	0.24 (±0.16)	**4.87** (±2.38)	0.21 (±0.25)	2.23
(423) Intertidal flats	0.08	0.04 (±0.02)	0.02 (±0.03)	0.00 (±0.00)	0.01 (±0.01)	0.07 (±0.07)	0.59 (±0.83)	0.08 (±0.04)	2.66
(243) Land … agri … with … natural veg.	**19.09**	**17.25** (±8.42)	**5.97** (±1.91)	**14.22** (±6.17)	**7.34** (±3.09)	**3.88** (±2.07)	**6.95** (±3.04)	**6.93** (±2.80)	**7.13**
(313) Mixed forest	1.34	1.07 (±0.39)	1.52 (±2.15)	1.00 (±0.13)	1.21 (±0.50)	0.81 (±0.47)	0.84 (±0.73)	1.11 (±0.76)	0.04
(322) Moors and heathland	1.06	0.05 (±0.03)	0.00 (±0.00)	5.52 (±4.31)	3.26 (±2.37)	0.68 (±1.20)	0.06 (±0.09)	1.10 (±2.08)	0.05
(321) Natural grasslands	0.81	0.06 (±0.09)	0.00 (±0.00)	4.48 (±3.72)	0.65 (±0.65)	0.30 (±0.48)	0.13 (±0.18)	0.27 (±0.42)	**8.60**
(211) Non-irrigated arable land	0.72	0.07 (±0.10)	0.23 (±0.33)	0.03 (±0.05)	1.77 (±2.50)	**13.66** (±7.31)	**6.19** (±1.52)	**6.28** (±2.74)	0.39
(231) Pastures	**46.98**	**70.26** (±13.05)	**21.16** (±19.52)	**9.50** (±6.04)	**47.55** (±9.95)	**72.89** (±7.81)	**59.51** (±4.89)	**63.94** (±13.54)	**36.74**
(412) Peat bogs	**10.46**	**3.81** (±0.05)	**55.59** (±16.80)	**44.24** (±5.50)	**17.99** (±8.61)	**2.92** (±1.96)	**6.01** (±1.56)	**12.31** (±7.55)	1.82
(421) Salt marshes	0.15	0.00 (±0.00)	0.00 (±0.00)	0.03 (±0.06)	0.00 (±0.00)	0.04 (±0.07)	1.48 (±1.99)	0.04 (±0.03)	**3.71**
(333) Sparsely vegetated areas	**4.66**	0.00 (±0.00)	0.13 (±0.13)	2.21 (±3.30)	0.73 (±0.57)	0.08 (±0.16)	0.00 (±0.00)	0.11 (±0.15)	2.45
(324) Transitional woodland-shrub	0.89	**2.50** (±0.27	**6.31** (±1.61)	**7.59** (±2.77)	**6.60** (±1.27)	0.63 (±0.34)	1.01 (±0.59)	1.35 (±0.49)	0.00
(512) Water bodies	1.67	1.18 (±1.09)	2.12 (±2.22)	0.08 (±0.14)	0.21 (±0.21)	0.12 (±0.11)	2.65 (±3.29)	0.56 (±0.25)	**3.81**
(511) Water courses	0.00	0.00 (±0.00)	0.02 (±0.02)	1.65 (±2.85)	0.01 (±0.01)	0.20 (±0.41)	2.06 (±2.02)	0.23 (±0.34)	0.00
Richness (S)	20.0	16.0	13.5	16.3	18.8	17.1	17.5	19.6	16.0
Diversity (D′)	0.73	0.46	0.60	0.75	0.70	0.44	0.62	0.54	0.76
Extracted exploratory data									
Mean HNVf score	3.82 (±0.30)	3.85 (±0.32)	3.65 (±0.36)	4.22 (±0.34)	3.53 (±0.44)	3.12 (±0.37)	3.16 (±0.35)	3.45 (±0.51)	3.94 (±0.37)
Mean elevation (m ASL)	25.70 (±16.60)	84.49 (±40.48)	61.60 (±26.87)	245.04 (±153.64)	170.98 (±83.09)	68.30 (±34.54)	4.80 (±4.17)	72.78 (±41.12)	7.12 (±6.92)
Dominant soil type	Deep well drained mineral (Mainly basic)	Mineral poorly drained (Mainly acidic)	Blanket peat/ Cutaway peat	Blanket peat	Deep well drained mineral (Mainly acidic)	Deep well drained mineral (Mainly basic)	Mineral alluvium	Deep well drained mineral (Mainly acidic)	Aeolian (un-differentiated)
Area									
km^2	983.50	4940.80	4005.09	7461.42	14624.95	16744.75	924.09	19352.05	92.57
% of total coverage	1.42	7.15	5.79	10.79	21.16	24.22	1.34	27.99	0.13

Value farmland (HNVf) indicators such as stocking density, soil diversity and density of landscape linear features (i.e. hedgerows, stone walls, watercourses) as used in Matin et al. (2020) would be typically low in this specific landscape, although the resulting moderate HNVf likelihood score does not necessarily reflect an increase in land use intensity in this instance. Indeed, as is the case in the following two classes, the low-moderate HNVf likelihood score may be based on the relatively low proportion of farmland in these landscapes. The Marshland-Estuarine landscape exhibits the highest proportion of ‘Inland marshes’ and ‘Salt marshes’ and ‘Estuaries’, though its inland extent is limited to upper reaches of major estuaries and is likely to be predominantly under estuarine influence. Its large land cover proportion of ‘Pastures’ and

Table 2
Descriptive title; summary of land cover composition, richness and diversity; HNVf likelihood; elevation; predominant soil types, and example class imagery extracted from Google Street View.

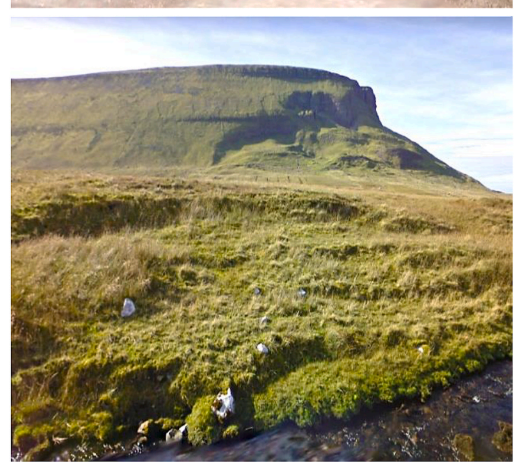
New landscape class summary interpretation

1. Extensive Bedrock Plains
This landscape is composed solely of the PU 'Bedrock plain'. It comprises the highest cover of CLC classes 'Bare rocks' (3.4%), 'Broad-leaved forest' (3.9%), 'Land principally occupied by agriculture with significant areas of natural vegetation' (19.1%) and 'Sparsely vegetated areas' (4.7%). It has a HNVf likelihood score of 3.82 (high), is of very low elevation and supports the highest landcover richness (S = 20) The predominant soil type is deep well drained mineral (mainly basic). This landscape is predominantly located in the mid-western regions.

2. Extensive Lowlands
This landscape is composed of PU's 'Drumlinised ribbed moraine' and 'Ribbed Moraine'. It comprises the second-highest cover of CLC classes 'Pastures' (70.3%) and 'Land principally occupied by agriculture, with significant areas of natural vegetation' (17.3%). It has a HNVf likelihood score of 3.85 (high), is of moderate elevation and the predominant soil type is mineral poorly drained (mainly acidic). This landscape extends from the north-west to north-east coastal regions.

3. Peatlands
This landscape is composed of PU's 'Bog atlantic' and 'Bog raised'. It comprises the highest cover of CLC classes 'Peat bogs' (55.6%) and 'Mixed forest' (1.5%)'. It has a HNVf likelihood score of 3.65 (moderate), is of low elevation and supports the lowest landcover richness (S = 13.5). The equally predominant soil types are blanket and cutover/cutaway peat. This landscape occurs predominantly in the central and extends to the mid-western regions.

4. Extensive Mountainous
This landscape is composed of PU's 'Mountain ice-sculpted ridge', 'Mountain ice-sculpted U-shaped valley' and 'Mountain plateau'. It comprises the highest cover of CLC classes 'Moors and heathland' (5.5%) and 'Transitional woodland-shrub' (7.6%), the second highest cover of 'Natural grasslands' (4.5%) and 'Peat bogs' (44.2%), and the lowest cover of 'Non-irrigated arable land' (0.0%), 'Pastures' (9.5%) and Water bodies' (0.1%). It has a HNVf likelihood score of 4.22 (high) and has the highest elevation of all landscapes. The predominant soil type is blanket peat. This landscape occurs predominantly along the western coastal regions, occasionally extending inland.



5. Semi-intensified Elevated
This landscape is composed of PU's 'Mountain ridge', 'Mountain rounded', 'Mountain streamlined plateau', 'Mountain streamlined ridge', 'Mountain streamlined rounded'. It comprises the highest cover of CLC class 'Coniferous forest' (10.8%), and the second highest cover of 'Moors and heathland' (3.3%). This landscape is distinguishable from the Extensive Highlands Landscape in terms of a lower proportion of 'Peat bogs' (18%) and higher proportion of 'Pastures' (47.6%). It has a HNVf likelihood score of 3.53 (moderate) and has the second-highest elevation of all landscapes. The predominant soil type is deep, well drained mineral (mainly acidic). This landscape has a wide distribution, though it is more concentrated in the mid-southern regions.

(*continued on next page*)

Table 2 (*continued*)

New landscape class summary interpretation

6. Intensified Lowlands

This landscape is composed of PU's 'Bedrock streamlined', 'Flat alluvial-glaciofluvial plain', 'Flat to gently undulating glacial sediments', 'Hill to rolling rounded bedrock', 'Hummocky eskers' 'Hummocky moraines' and 'Megascale lineations'. It comprises the highest cover of CLC classes 'Non-irrigated arable land' (13.7%) and 'Pastures' (72.9%), the second-lowest cover of 'Peat bogs' (2.9%) and lowest cover of 'Land principally occupied by agriculture, with significant areas of natural vegetation' (3.9%). This Landscape supports the lowest landcover diversity (D' = 0.44). It has a HNVf likelihood score of 3.12 (low), is the lowest in elevation of the Lowlands Landscapes and the predominant soil type is deep, well drained mineral (mainly basic). This landscape is concentrated in central regions, though it also extends to coastal regions.

7. Marshland – Estuarine

This landscape is composed of PU's 'Coastal plain' and 'Flat alluvial-lacustrine plain'. It comprises the highest cover of CLC classes 'Inland marshes' (4.9%), 'Complex cultivation patterns' (2.4%), 'Estuaries' (0.8%) and 'Water courses' (2.1%) and is the only landscape to have the presence of 'Coastal lagoons' (0.57%). It has a HNVf likelihood score of 3.16 (low) and has the lowest elevation of all landscapes. The predominant soil type is mineral alluvium. This landscape is limited to estuarine inland reaches and coastal regions.

8. Semi-intensified Lowlands

This landscape is composed of PU's 'Drumlins', 'Hill to rolling lowland rounded streamlined bedrock', 'Hill to rolling lowland bedrock ridge', 'Hill to rolling lowland bedrock streamlined ridge' and 'Rolling to gently undulating glacial sediments'. It comprises the second-highest cover of CLC classes 'Complex cultivation patterns' (2.2%) and 'Non-irrigated arable land' (6.3%), and has a high proportion of 'Pastures' (63.9%). This Landscape supports the second highest landcover richness (R = 19.6). It has a HNVf likelihood score of 3.45 (moderate), is of lower elevation to the Extensive Lowlands Landscape and the predominant soil type is deep, well drained mineral (mainly acidic). This class is the most dominant area (27.99%) within the classification. This landscape is ubiquitous in occurrence.

(*continued on next page*)

Table 2 (*continued*)

New landscape class summary interpretation	
	
9. Sandy Coastlands This landscape is composed solely of the PU 'Hummocky to undulating aeolian sands'. It comprises the highest cover of CLC classes 'Beaches, dunes, sands' (30.2%), 'Natural grasslands' (8.6%), 'Salt marshes' (3.7%), and the lowest cover of 'Broad-leaved forest' (0.0%), 'Coniferous forest' (0.1%), 'Mixed forest' (0.0%), 'Peat bogs' (1.8%) and 'Transitional woodland-shrub' (0.0%). This Landscape supports the highest landcover diversity (D' = 0.76). It has a HNVf likelihood score of 3.94 (high) and has the second-lowest elevation of all landscapes. The predominant soil type is aeolian (undifferentiated). This class is the least dominant (0.13%) area within the classification. This landscape occurs solely along coastal regions, with a higher frequency on western coasts.	

highest land cover proportion of 'Complex cultivation patterns' suggests partially intensified land uses, possibly due to the dominance of fertile alluvial mineral soils. The smallest of the landscape classes is the Sandy Coastlands, restricted to coastal areas of beaches, dunes and sands. A lower land cover proportion of 'Pastures' in comparison to other lowland landscapes suggests it supports limited grassland agriculture, and the highest land cover proportion of 'Natural grasslands' is consistent with coastal grassy areas that include Machair and Marram type habitats.

The use of CORINE Land Cover provided a detailed national dataset with a minimum mapping unit of 25 ha and 100 m width for areal and linear features respectively (EEA, 2021). Overall user accuracy for Ireland is 92%, with the worst performing class used in this study (Complex cultivation patterns) resulting in a user accuracy of 20%. Other remaining classes observe accuracies greater than 68% (EEA, 2021). The dominance of the CORINE Land Cover class Pastures highlights Ireland's predominance of permanent grassland and agricultural influence; however, this CLC class includes complex variations of farm types and intensity (Lafferty et al., 1999). The exclusion of Pastures as an outlier from the cluster analysis not only improved the statistical results, but also enabled a distinction of lowland landscapes based on other land covers that are conclusively more indicative of land use intensity.

During the reclassification and final map generation process, it was observed that certain areas considered by the PU map under the 'Mountain' categories appeared to extend beyond obvious mountain regions. Similarly, areas of elevation below what is conventionally considered mountains (i.e. local elevation range >300 m (Blyth et al., 2002)) were also classified under this category-notably the Aran Islands on the west coast of Ireland. Factors such as resolution of datasets and local-scale variability of geomorphic factors could contribute to some potential discrepancies in the original PU classification of certain digitised mountain regions. The definition of uplands in Ireland is commonly indicated around 300 m by Ordinance Survey of Ireland maps and 150 m by the National Parks and Wildlife Service (Perrin et al., 2010), however exceptions exist where regions of lower elevation are named as mountains and regions of higher elevation are not defined as such (Geological Survey of Ireland, 2018). It is assumed in such instances that the definition of mountain PU's was based on such regions being 'significantly higher than the surrounding landscape' and 'rising more or less abruptly from the surrounding ground', as defined in the PU Map report (Geological Survey of Ireland, 2018). These irregularities are predominantly attributed to Mountain PU's grouped in cluster five and as such this study defined this class as an 'elevated' landscape. Nonetheless, this represents a possible overestimation of the extent of mountainous or upland regions within the classes, which should be taken into account in their potential application as landscape strata.

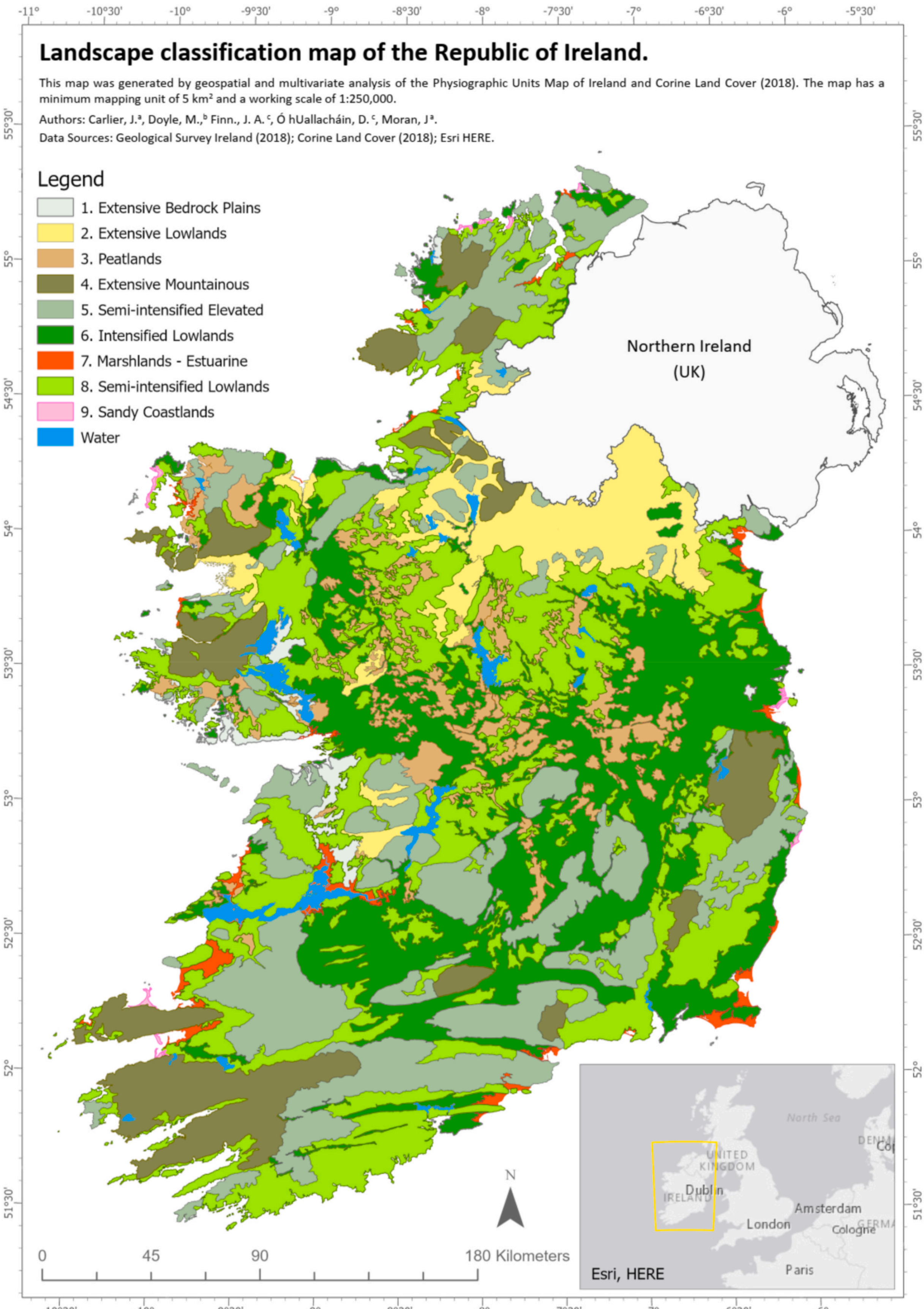


Fig. 6. Landscape classification map based on nine clusters of PU land cover composition.

This landscape classification significantly supports the delivery of some of Ireland's commitments as a signatory to the European Landscape Convention (Council of Europe, 2000) in the identification of landscape characteristics as required under Article 6 of the Convention. It demonstrates the broad spatial variation of land cover and use, underpinning the development of a future vision and strategy for sustainable land use in Ireland. The range of unique landscapes classified in this study reflects the need for dedicated landscape or catchment-specific approaches to identifying, addressing and monitoring environmental pressures (EPA, 2020). Indeed, given current absence of a characterisation of Irish landscapes, this work provides the basis for the development of a framework to efficiently monitor, compare and analyse ecological and other land use data that is spatially representative of the distribution (strata) of land cover in the Irish countryside. Using the nine classes as strata, a proportionate number of sampling sites or cells can be randomly selected to provide an efficient and representative sampling effort across broad land cover variations. The use of this national landscape classification to establish a High Nature Value farmland and forest monitoring and assessment framework (as required under EU policy (Keenleyside et al., 2014)) is currently being investigated elsewhere. Furthermore, the adequacy of other national monitoring systems that apply non-stratified sampling could be assessed with respect to their representation of landscape classes observed in this study, potentially strengthening the justification for a common national monitoring framework. Landscape-scale conservation of ecosystem services in rural and agricultural regions (Galler et al., 2015; Tscharntke et al., 2005) can also be achieved through, for example, landscape-specific collaborative agri-environmental schemes targeting bio-physical diversities observed within certain classes (McKenzie et al., 2013). However, the suitability of scales and environmental variables used in a landscape classification should be considered in its use to design a stratified monitoring system (Metzger et al., 2013). The present landscape classification minimum mapping unit of 5 km^2 could successfully accommodate a range of spatial sampling scales, including monad cell field sampling commonly used in various stratified land use monitoring systems (UK Countryside Survey (Bunce et al., 1996 (c); German HNV farmland monitoring (Benzler et al., 2015); Swiss Biodiversity Monitoring BDM (2014)). Other applications include ecosystem services accounting using landscape-scale stratification (e.g. Dittrich et al., Castro et al., 2014; Raudsepp-Hearne et al., 2010; Bennett et al., 2009; Nelson et al., 2009) to identify and monitor high, declining or low landscape-specific ecosystem services for their strategic management, conservation or enhancement.

This landscape classification is applicable to a wide range of users such as surveyors, planners, and policymakers. Practitioners can use it to develop stratified, multi-scale sampling approaches within land use or ecological monitoring programmes, or indeed for more nuanced uses such as landscape-level design and spatial targeting of agri-environment schemes or other conservation measures. Furthermore, the methodology presented is highly transferable to other commonly available geo or physiographic datasets, with the integration of additional variables to generate new landscape classifications, and not limited to land cover. Further evolution and refinements of this new landscape classification is likely to occur from its wider practical application and further research. Evaluation of individual class stratification strengths can result from robust subject population sampling within the strata and correlations with overlay analyses of existing distribution data, at various sampling scale requirements. There is therefore the possibility of some strata to be determined unnecessary (e.g. reduction to mountainous and lowland divisions only), while also requiring further subdivision (e.g. due to climatic variation, habitat fragmentation, known species distributions), depending on the intended sampling or national reporting scales. Indeed, specific landscape stratifications can be developed through inclusion of more specific datasets using the same methodology, resulting in targeted landscape divisions that account for influential and differentiating physical characteristics.

Author contribution

JC and JM conceived and designed the study, JC conducted all the quantitative analyses. All authors contributed to the drafting and critical analysis of the manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was conducted as part of the High Nature Value Farmland and Forestry Systems for Biodiversity (FarmForBio) project funded by the Research Stimulus Fund (2019R425) of the Department of Agriculture, Food and the Marine Research Stimulus Fund. JC and JM conceived and designed the study, JC conducted all the quantitative analyses. All authors contributed to the drafting and critical analysis of the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.112498.

References

Aalen, F.H.A., Whelan, K., Stout, M., 2011. Atlas of the Irish Rural Landscape, second ed. University of Toronto Press, Toronto.

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

Bennett, E.M., Peterson, G.D., Gordon, L., 2009. Understanding relationships among multiple ecosystem services. Ecol. Lett. 12, 1–11. https://doi.org/10.1111/j.1461-0248.2009.01387.x.

Benzler, A., Fuchs, D., Hunig, C., 2015. Methods and first results of high nature value farmland monitoring in Germany. Nat. Landsch. 90, 309–316. https://doi.org/10.17433/7.2015.50153341.309-316.

Blyth, S., Groombridge, B., Lysenko, I., Miles, L., Newton, A., 2002. Mountain Watch. UNEP World Conservation Monitoring Centre, Cambridge, UK.

Bunce, R.G.H., Barr, C.J., Clarke, R.T., Howard, D.C., Lane, A.M.J., 1996a. Land classification for strategic ecological survey. J. Environ. Manag. 47 (1), 37–60. https://doi.org/10.1006/jema.1996.0034.

Bunce, R.G.H., Barr, C.J., Clarke, R.T., Howard, D.C., Lane, A.M.J., 1996b. Special paper: ITE Merlewood land classification of Great Britain. J. Biogeogr. 23, 625–634. https://www.jstor.org/stable/2846051.

Bunce, R.G.H., Barr, C.J., Gillespie, M.K., Howard, D.C., 1996c. The ITE land classification: providing an environmental stratification of Great Britain. Environmental Assessment and Monitoring 39, 39–46. https://doi.org/10.1007/BF00396134.

Burnett, C, Blaschke, T, 2003. A multi-scale segmentation/object relationship modelling methodology for landscape analysis. Ecol. Model. 168 (3), 233–249.

Carlier, J., Moran, J., 2019. Landscape typology and ecological connectivity assessment toinform Greenway design. Sci. Total Environ. 651, 3241–3250.

Castro, A.J., Verburg, P.H., Martín-López, B., Garcia-Llorente, M., Cabello, J., Vaughn, C. C., López, E., 2014. Ecosystem service trade-offs from supply to social demand: a landscape-scale spatial analysis. Landsc. Urban Plann. 132, 102–110. https://doi.org/10.1016/j.landurbplan.2014.08.009.

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

CLC, 2018. Corine Land Cover. Available in Copernicus Land Monitoring Service Datasets. http://land.copernicus.eu/pan-european/corine-land-cover. (Accessed 1 July 2020).

Cooper, A., Loftus, M., 1998. The application of multivariate land classification to vegetation survey in the Wicklow Mountains, Ireland. Plant Ecol. 135, 229–241. https://doi.org/10.1023/A:1009707211061.

Copernicus, 2016. EU-DEM v1.1. Available online: https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1?tab=metadata. (Accessed 8 October 2020).

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

Crowley, C., Walsh, J., Meredith, D., 2008. Irish Farming at the Millennium: A Census Atlas. NIRSA, NUI Maynooth.

Dittrich, A., Seppelt, R., Václavík, T., Cord, A.F., 2017. Integrating ecosystem service bundles and socio-environmental conditions – a national scale analysis from

Germany. Ecosystem Services 28, 273–282. https://doi-org.ezproxy.gmit.ie/10.1016/j.ecoser.2017.08.007.
EEA, 2002. Europe's Biodiversity — Biogeographical Regions and Seas. EEA report no 1/2002. http://www.eea.europa.eu/publications/report_2002_0524_154909/#.
EEA, 2004. High Nature Value Farmland: Characteristics, Trends and Policy Challenges. European Environment Agency, Copenhagen. https://www.eea.europa.eu/publications/report_2004_1.
EEA, 2021. CLC 2018 and CLC Change 2012-2018 Validation Report Issue 1.3. Validation Report. European Environmental Agency. https://land.copernicus.eu/user-corner/technical-library.
Éireann, Met, 2020. Climate of Ireland. (Accessed 31 December 2020).
EPA, 2020. Ireland's Environment 2020 - an Assessment. Environmental Protection Agency, Johnstown Castle, Co. Wexford, Ireland. http://www.epa.ie/ebooks/soe2020/3/.
ESRI, 2020. ESRI ArcGIS Pro. Release 2.6.3.
Fealy, R.M., Green, S., Loftus, M., Meehan, R., Radford, T., Cronin, C., Bulfin, M., 2009. Teagasc EPA soil and Subsoils mapping project-final report, ume I. Teagasc, Dublin. http://hdl.handle.net/11019/361.
Fňukalová, E.K., Romportl, D.A., 2014. A typology of natural landscapes of Central Europe. Acta Univ. Carolinae. Geogr 49 (2) (6).
Forest Service, 2018. Ireland's National Forest Inventory 2017 – Field Procedures and Methodology. Department of Agriculture, Food and the Marine, Johnstown Castle Estate, Co. Wexford.
Galler, C., von Haaren, C., Albert, C., 2015. Optimizing environmental measures for landscape multifunctionality: effectiveness, efficiency and recommendations for agri-environmental programs. J. Environ. Manag. 151, 243–257. https://doi.org/10.1016/j.jenvman.2014.12.011.
Gardiner, M.J., Radford, T., 1980. Soil associations of Ireland and their land use potential. In: Soil Survey Bulletin, vol. 36. An Foras Taluntais, Dublin.
Gawde, A.J., Zheljazkov, V.D., Maddox, V., Cantrell, C.L., 2009. Bioprospection ofEastern red cedar from nine physiographic regions in Mississippi. Ind. Crop. Prod. 30, 59–64.
Geological Survey of Ireland, 2004. Breifne. https://www.arcgis.com/apps/MapSeries/index.html?appid=a30af518e87a4c0ab2fbde2aaac3c228. (Accessed 27 October 2020).
Geological Survey of Ireland, 2018. Physiographic units map of Ireland. Geological Survey of Ireland. https://www.gsi.ie/documents/Physiographic_Units_Map_of_Ireland_REPORT.pdfGoedickemeier.
Goedickemeier, I., Wildi, O., Kienast, F., 1997. Sampling for vegetation survey: some properties of a GIS-based stratification compared to other statistical sampling methods. Coenoses 12, 43–50.
Hazeu, G.W., Metzger, M.J., Mücher, C.A., Perez-Soba, M., Renetzeder, Ch, Andersen, E., 2011. European environmental stratifications and typologies: an overview. Agric. Ecosyst. Environ. 142, 1–2. https://doi.org/10.1016/j.agee.2010.01.009.
IBM Corp, 2019. IBM SPSS Statistics for Windows, Version 26.0. IBM Corp, Armonk, NY.
Jasiewicz, J., Netzel, P., Stepinski, T.F., 2014. Landscape similarity, retrieval, andmachine mapping of physiographic units. Geomorphology 221, 104–112.
Johnson, P.A., Fecko, B.J., 2008. Regional channel geometry equations: A statisticalcomparison for physiographic provinces in the eastern US. River Res. Appl. 24, 823–834.
Keenleyside, C., Beaufoy, G., Tucker, G., Jones, G., 2014. The High Nature Value Farming Concept throughout EU 27 and its Maturity for Financial Support under the CAP. Institute for European Environmental Policy, London. https://ec.europa.eu/environment/agriculture/pdf/High%20Nature%20Value%20farming.pdf.
Lafferty, S., Commins, P., Walsh, J., 1999. Irish Agriculture in Transition. A Census Atlas of Agriculture in the Republic of Ireland. Teagasc, Dublin. http://hdl.handle.net/11019/1322.
Lewis, L.J., Coombes, D., Burke, B., O'Halloran, J., Walsh, A., Tierney, T.D., Cummins, S., 2019. Countryside Bird Survey: Status and Trends of Common and Widespread Breeding Birds 1998-2016. Irish Wildlife Manuals, No. 115. National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht, Ireland.
Matin, S., Sullivan, C.A., Ó hUallacháin, D., Meredith, D., Moran, J., Finn, J.A., Green, S., 2016. Predicted distribution of high nature value farmland in the republic of Ireland. J. Maps 12, 373–376. https://doi.org/10.1080/17445647.2016.1223761.
Matin, S., Sullivan, C.A., Finn, J.A., Ó hUallacháin, D., Green, S., Meredith, D., Moran, J., 2020. Assessing the distribution and extent of high nature value farmland in the republic of Ireland. Ecol. Indicat. 108 https://doi.org/10.1016/j.ecolind.2019.105700.
McKenzie, A.J., Emery, S.B., Franks, J.R., Whittingham, M.J., 2013. FORUM: Landscape-scale conservation: Collaborative agri-environment schemes could benefit both biodiversity and ecosystem services, but will farmers be willing to participate? J. Appl. Ecol. 50 (5), 1274–1280.
McCune, B., Mefford, M.J., 2016. PC-ORD. Multivariate Analysis of Ecological Data. Version 7. MjM Software, Gleneden Beach, Oregon, U.S.A.
Metzger, M., Bunce, R., Jongman, R., Mücher, C., Watkins, J., 2005. A climatic stratification of the environment of Europe. Global Ecol. Biogeogr. 14 (6), 549–563. http://www.jstor.org/stable/3697672.
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. Indicat. 33, 26–35. https://doi.org/10.1016/j.ecolind.2012.11.009.
Mitschke, A., Sudfeldt, C., Heidrich-Riske, H.u., Dröschmeister, R., 2005. Das neue rutvogelmonitoring in der Normallandschaft Deutschlands- Untersuchungsgebiete, Erfassungsmethode und erste Ergebnisse. Vogelwelt 126, 127–140.
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.
National Biodiversity Data Centre, 2020. What is the butterfly Atlas 2021?. In: 'Monitoring Scheme Initiatives https://www.biodiversityireland.ie/projects/monitoring-scheme-initiatives/butterflyatlas/about/. (Accessed 27 October 2020).
Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K.M., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front. Ecol. Environ. 7, 4–11. https://doi.org/10.1890/080023.
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. https://doi.org/10.1080/01426397.2015.1135321.
Peck, J.E., 2016. Multivariate Analysis for Community Ecologists: Step by Step, second ed. MjM Software Design, Gleneden Beach, OR, p. 192.
Perrin, P.M., Barron, S.J., Roche, J.R., O'Hanrahan, B., 2010. Guidelines for a National Survey and Conservation Assessment of Upland Vegetation and Habitats in Ireland. Version 1.0. IrishWildlifeManuals, No.48. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.
Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M., 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proc. Natl. Acad. Sci. Unit. States Am. 107, 11140–11144. https://doi.org/10.1073/pnas.0907284107.
Rinaldi, M., Surian, N., Comiti, F., Bussettini, M., 2013. A method for the assessment and analysis of the hydromorphological condition of Italian streams: the Morphological Quality Index (MQI). Geomorphology 180, 96–108.
Siart, C., Bubenzer, O., Eitel, B., 2009. Combining digital elevation data (SRTM/ASTER), high resolution satellite imagery (Quickbird) and GIS for geomorphological mapping: a multi-component case study on Mediterranean karst in Central Crete. Geomorphology 112 (1–2), 106–121. https://doi.org/10.1016/j.geomorph.2009.05.010.
Simensen, T., Halvorsen, R., Erikstad, L., 2018. Methods for landscape characterisation and mapping: a systematic review. Land Use Pol. 75, 557–569. https://doi.org/10.1016/j.landusepol.2018.04.022.
Simpson, E.H., 1949. Measurement of diversity. Nature 163 (4148), 688. https://doi.org/10.1038/163688a0.
Sullivan, C.A., Finn, J.A., Ó hÚallacháin, D.O., Green, S., Matin, S., Meredtith, D., Clifford, B., Moran, J., 2017. The development of a national typology for High NatureValue farmland in Ireland based on farm-scale characteristics. Land Use Policy 67, 401–414.
Swiss Biodiversity Monitoring, B.D.M., 2014. Description of methods and indicators. Fedreal office for the environment, bern. Environmental studies no. 1410 103.
Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management. Ecol. Lett. 8 (8), 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x.
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. https://doi.org/10.1016/j.landurbplan.2008.12.008.
Walsh, S., 2012. A Summary of Climate Averages for Ireland. Met Eireann, Dublin.
Warnock, S., Griffiths, G., 2014. Landscape characterisation: the living landscapes approach in the UK. Landsc. Res. 40 (3), 261–278. https://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.
Wurtzebach, Z., Schultz, C., 2016. Measuring ecological integrity: history, practical applications, and research opportunities. Bioscience 66 (6), 446–457. https://doi.org/10.1093/biosci/biw037.