# Potential contribution of soil diversity and abundance metrics to identifying high nature value farmland (HNV)

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**Potential contribution of soil diversity and abundance metrics to identifying high nature value farmland (HNV)**

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**Abstract**

Identifying and halting the decline of High Nature Value farmland (HNV) is seen as essential to the EU meeting its 2020 biodiversity targets. Data on HNV farmland is used to target policy instruments and monitor changes in HNV to assess policy impact and development. Initial estimates of HNV land were based on land cover data with limited spatial resolution. The EU has since taken a distributed approach, allowing countries to develop their own data and metrics to report on the presence of HNV land, and changes to it. Land cover type has been the main data used for reporting but no consistent set of data metrics have been agreed. Therefore, there is interest in both developing standardised reporting metrics and identifying land with high restoration potential to increase the area of HNV land. We explore the relationship between soil associations and broad habitats across a member state (Wales) to determine if any discernible patterns exist between soil and habitat diversity and if soils information might be useful for identifying areas with high restoration potential. We developed a set of criteria to identify soil abundance, combining soil diversity with ecological rare species approaches. The rare (<1,000 ha) and occasional (1,000-10,000 ha) soils identified were associated with significantly higher levels of habitat diversity than the national average. We propose that soil diversity information could supplement habitat information in identifying areas of potential restoration interest. Two iconic areas of Wales, the Llŷn Peninsula and Conwy Valley, were compared for restoration potential. Soil diversity in both areas is higher than the national average; habitat diversity

was average, or lower in the case of the Llŷn Peninsula. These areas with higher soil diversity offer greater potential for restoration to type-2 HNV. Soil diversity and habitat diversity were found to be positively correlated at a national level despite major management modification of habitats. Given this relationship it is proposed that soil diversity information offers useful metrics alongside land cover data for identifying or comparing areas with regard to potential restoration for HNV.

**Keywords:** High nature value farmland, pedodiversity, habitat diversity, soil diversity, rare soils, Wales, ecosystem services.

## 1 Introduction

The intensification of agriculture since the middle of the twentieth century has been recognised as a major driver of biodiversity decline (Kleijn et al., 2009). However, since the 1990's, it has been increasingly recognised that some types of farming are not only less damaging to the environment but are positively linked to both above- and below-ground biodiversity. What might be termed 'traditional', or 'low-intensity', farming systems have co-evolved with an inherent biodiversity and may play a crucial role in maintaining and restoring overall biodiversity (Baldock, 1990; Beaufoy et al., 1994; Bignal et al., 1994; Andersen et al., 2003, and references therein). These low intensity farming systems are of interest because they frequently enhance biodiversity, which is increasingly recognised as adding resilience to ecosystems and to ecosystem functions that are important for maintaining earth system life support (e.g., soil carbon storage, pollutant attenuation, pollination; Loreau et al., 2001). In Europe, these ideas are brought together under what is now termed High Nature Value (HNV) farmland (Andersen et al., 2003).

HNV farmland is increasingly seen by the EU as having an important contribution to meeting its 2020 biodiversity obligations, specifically to protect species and habitats, achieve more sustainable agriculture and forestry and maintain and restore ecosystems (Keenleyside et al., 2014). Recent CAP reforms also encourage more "greening" of agricultural areas by rewarding farmers who can

demonstrate environmental benefits (such as farmland biodiversity) of their agriculture practices (European Commission 2013; Bouma and Wösten, 2016). A definition of HNV farmland can be found in Andersen et al. (2003). It broadly recognizes three HNV types as defined in Paracchini et al. (2008):

- Type 1 – Farmland with a high proportion of semi-natural vegetation.
- Type 2 – Farmland with a mosaic of low intensity agriculture and natural and structural elements, such as field margins, hedgerows, stone walls, patches of woodland or scrub, small rivers etc.
- Type 3 – Farmland supporting rare plant and animal species or a high proportion of European or World populations, e.g. corncrakes in the UK's Western Isles.
- Not HNV: Typically the major arable areas, intensively managed land (including livestock production).

Whilst both a noble concept and of practical value, creating a pan-European assessment of HNV is challenging. In a report for the EU, Andersen et al. (2003) tested three different approaches (land cover, farming system and species approaches) for assessing the total HNV land area. Each approach has strengths and weaknesses, but land cover, despite using the 25 km*25 km CORINE data set, gave the most precise and detailed picture of where the higher probabilities of finding HNV were. More recently, Paracchini et al. (2008) have presented a revised map on a 1 km basis using a combination of CORINE, EU and national scale biodiversity data. Assessing the extent, condition and dynamics of HNV farmlands is now mandatory under the Common Monitoring and Evaluation Framework (CMEF) and the reporting is left to each EU Member State. Whilst this bottom up approach allows those most familiar with the landscape to assess it, quantification remains challenging due to a lack of specific criteria and rules for the identification of HNV farmland. Recently, Lomba et al. (2014) have proposed a hierarchical, bottom-up approach to the collaborative monitoring of HNV which at least provides a coherent contextual framework which could help produce an 'accurate and realistic spatially-explicit' pan-European information set. Going forward this presents two major challenges:

- How do we best identify HNV land?

- If we want to reverse declines and restore land to HNV status, how do we identify land with the best potential for restoration?

Soil science may have an important contribution to make towards answering these questions through the increasingly developing field of soil-, or pedo-diversity (Ibañez et al., 1995, 1998; Amundson et al., 2003). We argue that in many landscapes, soils and above-ground habitats have co-evolved and that above-below ground biodiversity and below-ground soil properties (i.e. physical, chemical and biological) are often linked in native systems from species to habitat levels (John et al., 2010). Whilst modern agricultural intensification may drastically reduce above-ground biodiversity, we suggest that in many cases the soil can maintain a long-term record (ca. 10-1000 y) of the landscape's potential habitat diversity that can be exploited in restoration. Recent work has demonstrated that strong relationships exist between species distributions and pedodiversity or soil resource diversity in some ecosystems (John et al., 2010; Petersen et al., 2010). Ibáñez (2005a,b) has gone as far as to argue that soils and pedodiversity indices are the single best predictor of habitat heterogeneity as they reflect the synthesis of many environmental factors. Petersen et al. (2010) argue that given the importance of soils as an indicator, and because soils are a more stable landscape property than above-ground biodiversity, they can be used to detect local to regional impacts on biodiversity. Conversely, pedodiversity measures may serve as an indirect estimator of biodiversity when species data is limited or unavailable.

Given the potential importance and usefulness of soils information to identifying HNV, and potential HNV, farmland our aim for this research was to determine if soils information is useful in the context of assessing areas of high nature value, which has not been done before. We focus particularly on HNV type-2 farmland because it is concerned with mosaics, which pedodiversity may directly contribute to. Our objectives are:

- To develop criteria for assessing soil abundance and rarity.
- Determine if rare soil types are associated with more diverse habitats, than soil types that are more common.

- To establish if there is any relationship between pedodiversity and habitat diversity across a highly modified landscape like Wales, given more diverse habitats are associated with HNV.
- To use the above information to determine if soil information could be used as an indicator of HNV restoration potential for highly modified farmland areas.

This research is intended to act as an initial assessment of pedodiversity in the context of HNV and determine its potential usefulness and identify challenges, knowledge and data gaps.

## 2 Materials and methods

### *2.1 Data*

**Soils - NATMAP**

The soils of Wales are mapped as part of the soil survey of England and Wales (Avery, 1980; Rudeforth et al., 1984). The National Soil Map (NATMAP) for Wales is available at reconnaissance scale (soil associations), 1:250,000 for all of Wales (NSRI, 2001). The soil survey of England and Wales uses a hierarchical classification scheme that identifies four hierarchical levels; 11 Major Groups, 44 Groups, 125 Sub Groups and 747 Series (e.g. 5.00, Brown soils; 5.1, Brown calcareous earths; 5.11, Typical brown calcareous earths; Coombe series). There is no discrete coverage of Wales at the series level of classification, so the 1:250,000 scale map groups series into soil associations, for which 298 are recognised in England and Wales (Cranfield University, 2015), with 94 being mapped in Wales (excluding uncategorised soils). The soil sub-groups are used in the following analysis to identify rare soils and to assess spatial patterns across Wales.

**Land Cover – LCM2007**

Land Cover Map 2007 (LCM2007) (Morton et al., 2011) is a vector-based land cover map for the UK containing around 10 million objects. The LCM2007 spatial framework is based on the

generalisation of national cartography products (OS MasterMap for Great Britain and Ordnance Survey Northern Ireland for NI). LCM2007 was derived by classifying 30 m-pixel size satellite data, with classes based on the UK Biodiversity Action Plan Broad Habitats. It was validated against 9127 ground reference polygons distributed across the UK and representative of all the LCM2007 classes. The validation gave an overall accuracy for LCM2007 of 83%, although accuracy varied widely between classes and between countries, highlighting the thematic and spatial variability of the classification accuracy (Morton et al., 2011). There are additional knowledge-based enhancements (KBEs) which resolve spectral confusion and/or increase the thematic resolution of land cover using contextual and ancillary information. These are regionally adaptive rules that reassign land parcels to a more appropriate land cover class and therefore enhance the accuracy of LCM2007. They may be based on additional data such as soils, and are particularly relevant to habitats that are difficult to classify remotely such as grasslands. This study uses the Broad Habitat Sub-Class information to assess landscape pattern and diversity and compare these to pedo-diversity metrics. Since we are most interested in type-2 HNV land (farmland with a mosaic of low intensity agriculture and natural and structural elements, such as field margins, hedgerows, stone walls, patches of woodland or scrub, small rivers etc.), habitat diversity based on spatial patterns of land cover should provide enough information to allow comparison of above and below ground diversity.

Species level information of above and below ground diversity is not considered here, although we recognise that this may be of more interest in terms of species conservation. However, species level information is more expensive to collect, and hence rarely available, particularly at large scales (e.g. national scale). The use of soil diversity and abundance information in conjunction with habitat diversity metrics provides a novel approach to identifying and assessing potential areas for restoration to HNV status using readily available, and generally nationally consistent, data.

### *2.2 Soil abundance*

A number of attempts have been made to assess soil pedodiversity or abundance (Ibáñez et al., 1995; Amundson et al., 2003; Nikitin et al., 2007). This is not trivial given that most countries use different soil classifications. Attempts to unify classifications into a single typology is attempted through the World Reference Base (WRB, 2006); for example, soils have been analysed at European (Ibáñez, 2013) and global (Minasny et al., 2010) scales using the WRB database. No agreed classification of soil abundance exists, so a number of researchers tend to follow the criteria proposed by Amundson et al. (2003) who analysed the USA using the STATSGO database, a similar 1:250,000 scale reconnaissance soils map as that available for Wales. The following criteria were proposed by Amundson et al. (2003):

a) rare soils—less than 1,000 ha total area in US,
b) unique soils (for example, "endemic")—exist only in one state,
c) rare-unique soils—occur only in one state and have a total area less than 10,000 ha, and
d) endangered soils: rare or rare-unique soil series that have lost more than 50% of their original area to various land disturbances.

In Scotland, work has been undertaken to identify soils of national conservation importance (Towers et al., 2005; 2008) by assessing soils based on conservation and functional importance. The work in Scotland also used the 1:250,000 map and soil sub-groups, suggesting that 'the Major Soil Sub-Group is the unit in which soil forming processes are best expressed and therefore is an appropriate level within the soil classification at which to seek to define and measure rarity.' Abundance was one of the criteria used (Towers et al., 2005), and they tested three methods of assessing abundance. These were 1) Aggregated Soil Map Units, 2) dominant Scottish Major Soil Sub-Groups, and 3) component Scottish Major Soil Sub-Groups (Supplementary Information, S2). This work presented here focuses on method 2 (with figures for method 3 presented only in the supplementary information, S3) for the Wales data as it requires more readily available national soil information; the first approach (Aggregated Soil Map Units) requires additional information which seemed beyond the

scope of methodologies suitable for generation of HNV metrics, whilst method 3 is applicable with UK data, but may not be in other data sets where the relative proportion of soils within an association is unknown.

- To apply the dominant soil sub-group method in Wales, each soil association map unit is allocated to the predominant soil sub-group within it.
- To apply the component soil sub-group summation method in Wales, the percentage cover of each soil series sub-group, in all associations, is estimated based on the Soils Guide (Cranfield University, 2015).

The area for each soil subgroup is summed and the hectares of soil estimated and compared to 1 million ha (Mha), an arbitrary size of a suitable scale for comparison, to set an upper bound for comparison as shown in Eq 1.

$$ha\ of\ soil\ in\ 1\ million\ ha = \frac{Soil\ area\ (ha) \times 1{,}000{,}000\ ha}{Total\ area\ of\ soil\ in\ Wales\ (2{,}065{,}848\ ha)} \quad \text{(Eq.1)}$$

A substantial body of work is available from ecology that is used to define rare and endangered species, which are compiled in the IUCN Red List (IUCN, 2001; Rodrigues et al., 2006). We use a synthesis of the red list approach (IUCN, 2001) and soil pedodiversity approaches (Amundson et al., 2003) to classify soil abundance and apply it to Wales. The soils were analysed based on the area occupied by a soil sub-group in 1 million ha of Wales according to the following criteria:

a) **Abundance: Area of Occupancy (ha)** = area covered by soil subgroup / total area of political boundary >1 million

| | |
|---|---|
| <1000 ha per 1000000 ha = 0.001 = <0.1% | Rare |
| <10,000 ha per 1000000 ha = 0.01 = <1% | Occasional |
| <50,000 ha per 1000000 ha = 0.05 = <5% | Frequent |
| <100,000 ha per 1000000 ha = 0.1 = <10% | Common |
| >100,000 ha per 1000000 ha = >0.1 = >10% | Abundant |

b) **Extent: of occurrence (ha) =** Perimeter length of a polygon around all the exposures / outcrops.

c) **Uniqueness: Number of locations** = 1 million ha from the political boundary of interest.

1 location in 1,000,000 ha = Unique

<10 locations in 1 million ha = Occasional

<50 locations in 1 million ha = Frequent

<100 locations in 1 million ha = Common

>100 locations in 1,000,000 = Abundant

### *2.3 Measures of pedodiversity and habitat diversity*

To be consistent with the HNV map for Europe (Paracchini et al., 2008) our analysis was conducted on 1 km squares. To analyse pedodiversity across Wales, and to compare metrics on soils to above-ground habitat diversity, we applied some commonly used metrics borrowed from biological diversity studies (e.g. Ibáñez et al., 1995). Mean patch size (MPS) is the average size of all patches of all land cover classes or soil classes over a particular landscape, area, or in this case 1 km squares in Wales, and is written

$$MPS = \frac{\sum_{i=1}^{n} a_i}{n} \qquad \text{(Eq. 2)}$$

where $n$ is the number of patches of any type within the square and $a_i$ is the patch size of the $i$-th individual. It represents the amount of subdivision over this area and can be a measure of fragmentation (Leitao et al., 2006). Two squares with the same number of soil or land cover types may have quite different mean patch size values if one of those squares is made up of many smaller fragments of a soil or land cover type, compared to a square which may only have one occurrence of each object within it.

Richness is one of the fundamental and most frequently used measures of diversity, mainly due to the simplicity and intuitive nature of the concept (Gotelli and Colwell, 2011; Kiester, 2013). Richness $s$ is the number of different objects (e.g. landscape classes or soil types) within a community, landscape, area or taxonomic group (Ibáñez et al., 1995).

One of the drawbacks of the richness index is that it looks solely at the variety of objects (in this case soils or habitats) within a specified area, and ignores the relative distribution (abundance) of each type within the square (Leitao et al., 2006). It gives as much weight to those objects that take up a small proportion of the area of interest as those that take up a larger proportion. Diversity measures aim to incorporate both richness and abundance. The Shannon Index (SH) estimates the average uncertainty in predicting which land cover or soil type a randomly selected pixel will belong to (Jost, 2006). It gives greater weighting to richness rather than evenness, and therefore is particularly influenced by rare objects. The Shannon index is written

$$SH = -\sum_{i=1}^{s} p_i \ln p_i \qquad \text{(Eq. 3)}$$

where $s$ is the number of land cover or soil classes within the landscape unit and $p_i$ is the proportion of the landscape occupied by the $i$-th patch type. A larger SH value is an indication of greater overall diversity, with high values given to those areas which tend to be richer. A value of zero indicates only one soil or land cover type in the area of interest, and hence no diversity (McBratney and Minasny, 2007).

Similarly, Simpsons Index (SI) incorporates richness and relative abundance in its calculation, but is less affected by rare/uncommon soils or habitats and is weighted more towards evenness (Magurran, 1988). Simpsons Index is written

$$SI = \sum_{i=1}^{s} {p_i}^2 \qquad \text{(Eq 4)}$$

As Simpson's diversity increases the value of SI will approach zero, indicating higher diversity where objects are more evenly distributed. Although less commonly used in pedodiversity studies (McBratney and Minasny, 2007), Simpsons index is considered more intuitive and superior to the Shannon index by many authors (Lo Papa et al. 2011; Magurran, 1988).

An additional habitat metric that applies to identification of type-1 HNV farmland is the proportion of semi-natural vegetation within each 1 km square. This was calculated based on the percentage cover of all vegetation types excluding those most modified by human intervention (i.e. improved grassland, conifer woodland, urban/suburban areas and arable).

A grid of 1 km squares was overlain over Wales, and for each square the four soil and four habitat diversity metrics are calculated. To achieve this, we use the Land Utilisation and Capability Indicator (LUCI) – a second generation extension and software implementation of the Polyscape framework described in Jackson et al. (2013). LUCI is an ecosystem services framework, which is more commonly used to assess the impact of land management interventions on a range of ecosystem services (including habitat connectivity, flood mitigation, nutrients, erosion and sedimentation, carbon and agricultural productivity). As it has already been set up to operate over all of Wales (Emmett et al., 2014; Emmett et al., 2015) and includes calculation of all the metrics described above for soil and land cover/habitat products within Wales, it was a suitable tool for this purpose.

The soil units used are at the sub-group level of NATMAP (NSRI, 2001). The digitised NATMAP produced (derived from the National Soil Map of England and Wales) has a spatial resolution of 1:250,000 and information for nearly 300 map units across England and Wales. Land cover data is taken from the Land Cover Map 2007 (Morton et al., 2011) which is derived from satellite images and digital cartography. It has a minimum mappable unit area of 0.5 ha, and covers all of the UK. Habitat diversity metrics are calculated using the 23 sub-classes of the LCM2007, which belong to 17 Broad Habitats, all of which can be found in Wales.

# 3 Results

## *3.1 Soil resources of Wales*

Eleven major soil groups are recognized in the soil survey of England and Wales, of which nine are found in Wales (Table 1). Three major groups are dominant – brown soils, podzolic soils and surface-water gley soils. The brown soils tend to be well drained and have iron oxides bound to silicate clays giving them their characteristic brown colour. Podzols are leached acidic soils, whilst the surface water gleys are subject to periodic saturation (Avery, 1980). There is not a one-to-one translation of England and Wales soil types into the WRB (World Reference Base, 2006) reference soil groups. Those

that correspond, and are found in Wales, are shown in the fourth column of Table 1. Conversion to WRB is useful because it allows comparison at global scales. The final column in Table 1 shows the approximate percentage abundance for WRB reference soil groups globally. The three major groups, brown soils, podzolic and surface water gley, are common in Wales but less common globally. Wales has a particularly high abundance of surface-water gley (stagnosol) soils (25%), whereas globally these represent ~1% of soils, and podzolic (podzolic/umbrisol) soils (Wales ~33% versus ~3% globally). This is important because these "common" soils within Wales have lower abundance globally and represent an important occurrence of these soil systems from a global perspective. The processes that make the soils unique may well result in rare or unique soil ecosystems containing unusual organisms that may be of benefit to humanity.

### *3.2 Soil abundance in Wales*

Following the approach of Towers et al. (2005), soil abundance was analysed using two contrasting methods. The dominant method assumes that each mapped association contains its dominant soil series, whereas the component method assumes that each association may contain all series found in that association, in standard proportions as distributed with the dataset. In this section, we only refer to the 'dominant' method because this is the most readily available data in other areas of the world (analysis using the 'component' method is presented in the on-line supplementary information). However, the combined output from these two methods essentially provides an upper (component) and lower (dominant) bound to the occurrence of soil types across Wales. Given the 94 associations, and based on the percentage of dominant soil series in the association, one can estimate that as many as 434 soil series may occur in Wales.

Results using the dominant soil Sub-Group method are presented in Table 2. Thirty-four soil sub-groups are found in dominant amounts, occurring in 94 soil associations. Of these soil sub groups, four would be classified as rare, each occupying less than 1000 ha $Mha^{-1}$, and 18 would be occasional, each occupying less than 10,000 ha $Mha^{-1}$. Of the rare soils, two are unique with only one

occurrence at this scale. These rare soils occur due to a confluence of unusual parent materials (e.g. calcareous in Wales, or certain organic materials) or soil forming processes. For example, organic soils normally form in, and are associated with, high rainfall acidic environments. However, the Cors Erddreiniog fens on Anglesey (a map of Wales and places of interest mentioned in this study is provided in Figure 1) are organic soils with alkaline water draining into them, giving alkali organic fen soils. It is not known whether the soil organisms associated with these ecosystems are unusual compared to other soils, however, these fens do support a wide range of rare above-ground biodiversity.

Figure 2 shows the exposures of (a) rare and (b) occasional soils across Wales using the dominant method (the associated output using the component method can be found in Figure S1:1). The rare soils tend to occur in North and South Wales rather than in mid-Wales, and are often close to coastal areas or water courses. The distribution of the occasional soils is more informative showing the existence of complexes on the Llŷn Peninsula, Anglesey, the South Wales Valleys, the Gower Peninsula and the Dee Valley in North Wales. These areas are consistent with more complex geology, providing a diversity of parent materials that is perhaps reflected by the soils.

### *3.3 Soil diversity*

In Wales, 27% of 1 km squares analysed contained only one soil subgroup type, and a further 51% just two. Consequently, mean patch size across Wales is generally high with an average of 46 ha (Table 3). Although there are large parts of Wales with generally low soil diversity (in the south-east, south-west and around the River Dyfi estuary), most regions contain some squares with high soil diversity.

Squares that displayed high soil diversity across all four metrics (richness, mean patch size, Shannon Index and Simpson's Index) could be found in all parts of the country, although some obvious gaps in the central, south west and south eastern areas exist. Clusters of high pedodiversity were found around the Brecon Beacons in the south and areas draining from it, Snowdonia in the north-west and a smaller area west of the upper catchment of Afon Teifi (Figure 3). While many of these

areas are associated with higher elevation, it was difficult to categorically state a relationship as much of the central highlands could not be associated with high diversity. Less complex geology in this region compared to areas in the south and north could explain some of this pattern.

### *3.4 Above- and below-ground diversity*

Our results indicate that soils tend to be less spatially variable and less fragmented than above-ground habitat. Figures 4-7 show the results for habitat diversity and pedodiversity across Wales. Average habitat richness was 5.7; in one 1 km square there was a maximum of 14 land cover types. This compares to a maximum soil richness of six and an average of two. There was also a considerable difference in mean patch size between soils (46.7 ha) and habitat (9.8 ha), as shown in Table 3. Soil diversity using the Shannon Index (0.39) and Simpson's Index (0.75) were lower than corresponding metrics for habitat, which were 1.03 for the Shannon Index and 0.48 for the Simpson's Index.

High habitat diversity within 1 km squares broadly coincided with areas of higher soil diversity across all four metrics (Figures 4-7). However, although significant, correlations between habitat diversity and pedodiversity were generally low, with national average r values of ~0.13 and 0.07 respectively for the most highly correlated indices, richness and Shannon's indice (Table 4, Figure 8). This is possibly due to the large number of squares ($n$ = 19,490) upon which this analysis was based, but most likely due to the highly managed nature of the landscape and the coarse scale. In less managed landscapes correlations became significantly higher, as is demonstrated in the case study areas discussed later. Some of the highest diversity in land cover is found in areas of rare and occasional soils, particularly in north-western areas and areas in the north-east and south (dominant method, Figure 9; component method, Figures S1:2a-d). Statistical analysis comparing average habitat metric values for all of Wales and those over rare and occasional soils indicate that above-ground diversity is significantly higher in these areas (Table 5). They tend to be richer and have greater diversity in terms of both Shannon and Simpson's indices. However, they also tend to be more fragmented. Rare and occasional soils were also analysed separately. Habitat metric values in areas of

occasional soils are greater than average Welsh values, and significant at the 5% level. Areas of rare soils also tend to have greater above-ground diversity (compared to the Welsh average and areas of occasional soils). Habitat diversity was significantly higher above rare soils, in three metrics (Table 5). Despite a larger difference in mean patch size compared to occasional soils, the smaller sample size (70 squares) of rare soils resulted in a non-significant difference for this metric.

### *3.5 Benchmarking diversity*

Using the iconic Llŷn Peninsula and Conwy Valley as case studies, we compared the soil and habitat diversity metrics to ascertain whether we can use soil diversity as a way to identify potential type-2 HNV land or land which has the best potential for restoration to type-2 with habitat mosaics.

*Conwy Valley*

Located in north Wales, the dominant land cover of the Conwy Valley (580 $km^2$) is a mixture of agriculture and forestry. The geology of the catchment is predominantly sedimentary, with large areas of volcanic lithologies in the west. The Conwy Valley has 34 Sites of Special Scientific Interest, covering 25% of the catchment. Of the 643 1 km squares that make up the Conwy Valley, only 2.3% contain occasional soils. Like the Llŷn Peninsula, there are no rare soils present (dominant method).

Soil diversity in the Conwy Valley is significantly higher than the Welsh average, with higher soil richness and diversity (Shannon Index and Simpson's Index), and lower mean patch size (Table 3, Figures 10,12,14,16). Twenty-eight 1km squares were considered to have high pedodiversity over all four metrics. Above-ground habitat richness, Shannon index and Simpson's index in this catchment showed no significant difference to all of Wales. Mean patch size was, however, significantly higher indicating less fragmentation. Above-ground habitat diversity tended to increase with soil diversity in all four metrics, and although correlations were not particularly strong, they were much stronger than the still statistically significant national averages (Table 4).

*Llŷn Peninsula*

The Llŷn Peninsula (474 $km^2$) is located in north-west Wales, and extends out into the Irish Sea south of the Isle of Anglesey. It is an Area of Outstanding Natural beauty primarily because of its coastline and coastal features. It is an area of relatively complex geology. Llŷn's farming pattern is of small-scale, traditional, family farms raising sheep and cattle with dairying on pockets of better pasture. The area is covered mostly in improved and other grassland and contains many hedgerows and other linear features. There are 42 Sites of Special Scientific Interest, covering just 3020 ha (6%) of the Peninsula's area. Twenty percent of the 1 km squares in this area contain occasional soils. Although there are no rare soils identified in this area using the dominant method, rare and occasional soils identified using the component method, covered most of the Llŷn Peninsula (71%).

Across all four metrics, soils in the Llŷn Peninsula show significantly higher diversity and less fragmentation than the Welsh average. However, there were only a few squares that showed high absolute pedodiversity in all four metrics. Habitat diversity in this area was also significantly lower than the Welsh average in three of the four metrics (Table 3, Figures 11,13,15,17). Mean patch size showed no significant difference. Similarly to the Conwy Valley results, correlations between land cover and soil metrics were significant at the 5% level and stronger than those derived over all of Wales.

## 4 Discussion

### *4.1 Pedodiversity and habitat diversity*

Across all of Wales, there were weak but significant correlations between current habitat diversity and soil diversity in all four metrics. This was somewhat unexpected at the habitat soil association level, due to extensive modification of climax vegetation with agriculture. However, even in this highly modified environment some correlation of significance still existed increasing to 30% for example for species richness in specific regions e.g. Llŷn Peninsula (Table 4). These results are

encouraging for future analysis at species and soil series level, where data permits. Other researchers have found correlations between species and soil series between 0.4-0.8 in savannah systems (Petersen et al., 2010) and strong and consistent relationships between tree distributions and soil nutrient distributions for more than one-third of the tree species in three diverse neotropical forests (John et al., 2010). Finding weak, but significant correlation at the habitat and soil association level is encouraging and this work lays the foundation for future observational and experimental work at the soil series and species level for niche differentiation, which in time may prove useful for management habitat restoration planning.

Soils tend to be more stable (Petersen et al., 2010) and less complex over wider areas than land cover, hence soil maps are typically based on point soil surveys, and interpolated between these points based on expert knowledge. In contrast, land cover has been more extensively modified, resulting in a more variable and fragmented distribution over Wales. Further, the ease at which land cover can be identified and mapped is greater than that for soils. Land cover can be mapped by surveying, imagery and remote sensing options (to name a few). There are more obvious distinctions between some land cover types from these methods, allowing for wide variability in land cover units to be mapped. While soil variability is only captured at association level in general, depending on the resolution of the map being produced, some finer resolution land cover features (such as hedgerows, stone walls, priority habitats e.g. flush etc) can still be overlooked in land cover mapping methods. In addition, distinguishing between closely related vegetation types from imagery may be challenging.

The low habitat diversity in relation to soil diversity estimated in the Llŷn Peninsula may in part be due to some of its landscape features not being adequately represented in the LCM2007. In particular, the LCM2007 product doesn't contain patches with area <0.4 ha, or linear features such as hedgerows, which can be important for determination of type-2 HNV. Despite this, the relationship between above-ground and below-ground diversity was stronger in this area than for all of Wales. Similarly, analysis of the Conwy Valley also indicated a stronger relationship between habitat and soil diversity across all four metrics than was evident in the all of Wales correlation. The smaller population

sizes of the two catchments analysed may be more statistically manageable in size and the relationships less obscured by a wide range of diversity scores.

The relationship between above-ground and below-ground diversity was clearer when analysing habitat diversity above rare and occasional soils. Above-ground diversity was significantly greater in areas underlain by rare and occasional soils, using both dominant and component methods. This suggests that these soils have the capacity to support a wider range of habitats than more common soils in Wales.

### *4.2 Value for High Nature Value farmland (HNV)*

HNV farmland, especially type-2, has generally been associated with higher habitat diversity compared to other more intensive farmland areas. Due to the omission of linear features and small patches, the land cover dataset used here is not ideal for identifying HNV farmland in a highly modified landscape like Wales. However, it was deemed the most appropriate dataset for this assessment, since the omitted features are also absent from other land cover products generated from satellite imagery, such as would be available to perform this type of assessment in other European countries where our methodology might be reproduced. To date, many approaches to the identification of HNV farmland have used land cover products which did not incorporate linear and mosaic features and have nonetheless performed well (e.g. Andersen et al., 2003).

Our results suggest that nationally available soil data, abundance and pedodiversity indices can be used not only to enhance land cover mapping categorisation but also as an additional metric to help identify areas of existing HNV and those with the potential for restoration to type-2 HNV status; it is likely that soil series level information would improve results compared to soil association data. Soils tend to be a more stable feature of the landscape (Petersen et al., 2010) than the more easily modified above-ground habitat, and the relationships between above and below-ground diversity indicate that areas of high pedodiversity are likely to support greater habitat diversity, and potentially type-2 HNV land as we found for the Conwy Valley for example.

*Conwy Valley*

There are two main areas of interest in the Conwy catchment with respect to HNV. In the north of the catchment, an area of rare and occasional soils is present. Primarily covered in improved grassland, with a low proportion of semi-natural vegetation, we suggest that this area could be a focus for potential restoration to HNV as it is likely to support a diverse range of habitats. A small area of rare and occasional soils in the south is found in an area of above average proportion of semi-natural vegetation. Beyond this, wider areas of the south and east of the catchment tend to generally contain high levels of semi-natural vegetation which also coincides with areas of high pedodiversity values. It could be argued that these areas already have existing HNV status, and should be a focus for preservation.

*Llŷn Peninsula*

The large areas of rare and occasional soils in the Llŷn Peninsula suggest that it is these areas that have the most potential to be restored to type-2 high nature value, more so than areas of more common soils. Along the eastern boundary, the presence of relatively high levels of semi-natural vegetation above rare and occasional soils suggests that this area could be classified as an area of existing high nature value.

### *4.3 Potential for wider application*

The UK has reasonably good soils data, although it is inhibited by lacking detailed (<1:50,000) series level data for large areas, meaning exploratory (>1:250,000) association level is the best available for national coverage. Looking out across Europe the availability of soil data is inconsistent, some countries having detailed survey and some countries with poor national mapping. Within the EU about half of the countries have detailed (<1:50,000) national soil map coverage, whilst about two thirds have exploratory (>1:250,000) national coverage (Hartemink et. al., 2008). The best EU coverage data products are currently the European soil database (European Commission and the European Soil Bureau Network, 2004; Panagos, 2006; Panagos et. al., 2012), at a nominal 1:1,000,000 scale,

substantially less detailed than the exploratory scale used in this work 1:250,000. The more detailed soil map products tend to be associated with the smaller EU countries, those with an extent less than 200 $km^2$. On its own, detailed soil information is not likely to be economic to collect solely for the purpose of HNV identification. However, there is an opportunity to piggy-back on increasing efforts to collect, refine and map soils information world-wide for a range of other purposes (e.g. agriculture, hydrology, resource management etc.), the outputs of which provide a suitable resource for the identification of HNV land. It could also be a useful check for consistency against other more commonly used biodiversity and land cover datasets.

The UK has very good coverage of land cover and at resolution of 25m and a minimum mappable unit of 0.5 ha (Morton et al., 2011). Similar products are available for other EU member states, for e.g. Spain, Netherlands, Germany and Austria (Hazeu, 2014; Martínez et al.,2015). The Corine land cover product has full spatial coverage across the European Economic Area, but its resolution is significantly coarser (1:100 000, with a minimum mappable unit of 25 ha) (Martínez et al.,2015). In all cases, information is aggregated over the spatial scale used and finer landscape features (for e.g. hedgerows and field margins), which may be important to classifying land as HNV, cannot be represented. The use of more detailed high resolution datasets (1m) could result in these features being more adequately mapped, and their contribution to HNV more robustly assessed.

Despite these limitations, the testing of this approach is important, and the success at habitat and association level in this work encourages future analysis at the species, series level which may give stronger associations. Such data could play an important role in land restoration, and hence is an important rationale for improving soil data resources along with comparable land cover products. Future steps will also be to test this approach out with more detailed soil and land cover data products to determine if the relationships hold and the value added of having greater detail, given the effort required to collect this level of data.

## 5 Conclusions

The role of HNV farmland (which combines conservation practices through provision of habitat on agricultural land) in halting the decline of biodiversity across Europe has received considerable attention since the 1990s, and is seen as an important aid in reaching the European Union's 2020 biodiversity targets.

However, identification of HNV, and areas with potential restoration to HNV, is challenging. The EU has allowed member states to develop and use their own metrics for identifying HNV. To date, most methodologies have been based on land cover products which are often at too coarse resolution to adequately identify finer landscape features that may contribute to overall biodiversity. Other methods have included information on farming systems and biodiversity.

This paper offers an additional approach incorporating soil information to identify areas of both HNV and high potential restoration value to type-2 HNV land. We presented a modified set of criteria for identifying rare and unique soils which we argue are of high nature value. We identified three rare soils in Wales using these criteria at the soil sub-group level. The main conclusions to this study are:

- Over the entirety of the highly modified Welsh landscape soil diversity and land cover diversity are significantly, but weakly, correlated. However, in exemplar areas studied on the Llŷn Peninsula and Conwy Valley the relationship was stronger on less abundant soils (rare and occasional). This suggests that in these cases these soils may have the capacity to support a wider range of habitats than more abundant soils and so offer greater potential for restoration to type-2 HNV.
- Habitat diversity tends to increase as soil diversity increases. Although obscured using all data for Wales, over smaller catchments/areas the correlation between soils and land cover was clearer.
- In general the use of soils information and soil diversity metrics can offer an additional way to identify areas with existing HNV status. In conjunction with land cover information (habitat metrics and proportion of semi-natural habitat) it can aid with separating out which

areas should be the focus for preservation of above and below-ground diversity and which areas offer good restoration potential.

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*Table 1. Area of soil Main Groups within Wales as determined based on the dominant soil type in each association. Data derived from Natmap (NSRI, 2001).*

**Soils of Wales NATMAP (NSRI) 1:250,000**

| Main Group | Area (ha) | Name of Major Group | WRB 2006 name | Abundance in Wales (%) | Abundance Globally (%) |
|---|---|---|---|---|---|
| 1 | 0 | Terrestrial raw soils | | 0.00 | |
| 2 | 3846 | Raw gley soils | Fluvisol | 0.19 | 2 |
| 3 | 48797 | Lithomorphic soils | Leptosol / Arenosol / Histosol | 2.36 | 11 / 6 / 2 |
| 4 | 2652 | Pelosols | Luvisol | 0.13 | 4 |
| 5 | 651862 | Brown soils | Cambisol / Luvisol / Arenosol | 31.55 | 10 / 4 / 6 |
| 6 | 681136 | Podzolic soils | Podzolic / Umbrisol | 32.97 | 3 / 1 |
| 7 | 526706 | Surface-water gley soils | Stagnosol | 25.50 | 1 |
| 8 | 68275 | Ground-water gley soils | Gelysol | 3.3 | 5 |
| 9 | 12707 | Man made soils | Regosol | 0.62 | 2 |
| 10 | 69867 | Peat soils | Histosol | 3.38 | 2 |
| 11 | 0 | Compost deepened man-modified soils | | 0.00 | |
| | 2065848 | Soil total | | 100 | |
| | 10990.29 | Other, lakes etc | | | |
| | 2076838 | Wales terrestrial area | | | |

*Table 2. Soil metrics (dominant method) determined from Natmap (NSRI, 2001) data according to the rarity, extent and uniqueness outlines above. Where "extent" is calculated as the minimum bounding convex hull polygon.*

**Soils of Wales NATMAP (NSRI) 1:250,000**

| Subgroup | Area (ha) | Subgroup Name | Abundance (%) | Abundance classif. | Cumul. Abundance | Extent† | Number of occurrences | % occupied by subgroup‡ |
|---|---|---|---|---|---|---|---|---|
| 5.41 | 545751 | Typical brown earths | 26.418 | Abundant | 100.000 | | | |
| 6.11 | 453114 | Typical brown podzolic soils | 21.934 | | 73.582 | | | |
| 7.13 | 308997 | Cambic stagnogley soils | 14.957 | | 51.649 | | | |
| 6.54 | 179201 | Ferric stagnopodzols | 8.674 | Common | 36.691 | | | |
| 7.21 | 164033 | Cambic stagnohumic gley soils | 7.940 | | 28.017 | | | |
| 10.13 | 67543 | Raw oligo-amorphous peat soils | 3.270 | Frequent | 20.077 | | | |
| 5.71 | 42767 | Typical argillic brown earths | 2.070 | | 16.807 | | | |
| 8.11 | 40673 | Typical alluvial gley soils | 1.969 | | 14.737 | | | |
| 5.61 | 37925 | Typical brown alluvial soils | 1.836 | | 12.768 | | | |
| 7.11 | 36216 | Typical stagnogley soils | 1.753 | | 10.932 | | | |
| 3.11 | 31807 | Humic rankers | 1.540 | | 9.179 | | | |
| 5.12 | 26830 | Humic brown podzolic soil | 1.299 | | 7.640 | | | |
| 7.12 | 17459 | Pelo-stagnogley soils | 0.845 | Occasional | 6.341 | 0.525 | 50 | 1.44 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 6.31 | 14899 | Humo-ferric podzols | 0.721 | | 5.596 | 1.000 | 45 | 0.64 |
| 5.72 | 13444 | Stagnogleyic argillic brown earths | 0.651 | | 4.774 | 0.387 | 26 | 1.50 |
| 3.61 | 13142 | Typical sand pararendzinas | 0.636 | | 4.124 | 0.873 | 49 | 0.65 |
| 9.62 | 10474 | Permeable, seasonally wet raw made ground soils | 0.507 | | 3.488 | 0.316 | 44 | 1.44 |
| 8.14 | 9828 | Pelo-calcareous alluvial gley soils | 0.476 | | 2.981 | 0.012 | 16 | 36.05 |
| 6.51 | 6950 | Ironpan stagnopodzols | 0.336 | | 2.505 | 0.035 | 14 | 8.64 |
| 5.51 | 6898 | Typical brown sands | 0.334 | | 2.168 | 0.490 | 14 | 0.61 |
| 8.13 | 6837 | Pelo-alluial gley soils | 0.331 | | 1.835 | 0.439 | 30 | 0.67 |
| 8.12 | 4925 | Calcareous alluvial gley soils | 0.238 | | 1.504 | 0.005 | 6 | 42.36 |
| 3.13 | 3848 | Brown rankers | 0.186 | | 1.265 | 0.722 | 25 | 0.23 |
| 2.20 | 3846 | Unripened gley soils | 0.186 | | 1.079 | 0.327 | 60 | 0.51 |
| 8.21 | 3512 | Typical sandy gley soils | 0.170 | | 0.893 | 0.180 | 13 | 0.84 |
| 5.43 | 2795 | Gleyic brown earths | 0.135 | | 0.723 | 0.002 | 2 | 52.72 |
| 4.31 | 2652 | Typical argillic pelosols | 0.128 | | 0.587 | 0.010 | 5 | 11.51 |
| 8.71 | 2294 | Typical humic gley soils | 0.111 | | 0.459 | 0.022 | 10 | 4.49 |
| 5.42 | 2282 | Stagnogley brown earths | 0.110 | | 0.348 | 0.056 | 8 | 1.77 |
| 9.24 | 2233 | Well aerated raw made ground soils' | 0.108 | | 0.238 | 0.065 | 10 | 1.50 |
| 10.24 | 1659 | Earth eutro-amorphous peat soils | 0.080 | Rare | 0.129 | 0.163 | 13 | 0.44 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 10.22 | 665 | Earthy eu-fibrous peat soils | 0.032 | 0.049 | 0.000 | 1 | 72.55 |
| 8.31 | 207 | Typical cambic gley soils | 0.010 | 0.017 | 0.000 | 1 | 66.97 |
| 6.52 | 144 | Humus-ironpan stagnopodzols | 0.007 | 0.007 | 0.000 | 2 | 23.34 |
| TOTAL | 2065848 | | 100 | | | | |

† Extent (proportional to greatest extent)

‡Percentage of extent occupied by subgroup (area/extent)*100

*Table 3. Benchmarking areas or catchments to determine if the area has above or below average soil diversity or land cover (LC) diversity metrics for the Llŷn Peninsula.*

| **Diversity Metrics** | | **Soils** | | | **Land cover** | |
|---|---|---|---|---|---|---|
| **Average Values** | **All Wales** | **Llŷn** | **Conwy** | **All Wales** | **Llŷn** | **Conwy** |
| Richness (no) | 1.98 | 2.17 | 2.28 | 5.71 | 5.13 | 5.60 |
| *P-value* | | *P=0.00* | *P=0.00* | | *P=0.00* | *P=0.12* |
| *direction* | | *Higher* | *Higher* | | *Lower* | *No diff* |
| Mean Patch Size (ha) | 46.73 | 43.78 | 43.99 | 9.81 | 9.05 | 11.53 |
| *P-value* | | *P=0.01* | *P=0.00* | | *P=0.14* | *P=0.00* |
| *direction* | | *Lower* | *Lower* | | *No diff* | *Higher* |
| Shannon Index | 0.39 | 0.48 | 0.48 | 1.03 | 0.95 | 1.04 |
| *P-value* | | *P=0.00* | *P=0.00* | | *P=0.00* | *P=0.94* |
| *direction* | | *Higher* | *Higher* | | *Lower* | *No diff* |
| Simpson's Index | 0.75 | 0.69 | 0.70 | 0.48 | 0.50 | 0.47 |
| *P-value* | | *P=0.00* | *P=0.00* | | *P=0.00* | *P=0.00* |
| *direction* | | *Lower* | *Lower* | | *Higher* | *No diff* |

*Table 4. Correlations between above and below-ground diversity. Although significant, correlations are generally weak across all of Wales. Stronger correlations are found between habitat and soils in both the Conwy Valley and Llŷn Peninsula.*

| **Soil vs Habitat Metrics** | | | |
|---|---|---|---|
| | **All Wales** | **Conwy Valley** | **Llŷn Peninsula** |
| Richness | r=0.1295 | r=0.1490 | r=0.3192 |
| *P-value* | *P=0.00* | *P=0.00* | *P=0.00* |
| Mean Patch Size | r=0.0483 | r=0.1066 | r=0.1956 |
| *P-value* | *P=0.00* | *P=0.01* | *P=0.00* |
| Shannon Index | r=0.0687 | r=0.1943 | r=0.1882 |
| *P-value* | *P=0.00* | *P=0.00* | *P=0.00* |
| Simpson's Index | r=0.0493 | r=0.1769 | r=0.1489 |
| *P-value* | *P=0.00* | *P=0.00* | *P=0.00* |

*Table 5. Average above-ground diversity metrics and corresponding significance value using two-sample t-test at 5% significance level.*

| **Average Values** | **Richness (no)** | **Mean Patch Size (ha)** | **Shannon Index** | **Simpson's Index** |
|---|---|---|---|---|
| All of Wales | 5.71 | 9.80 | 1.03 | 0.48 |
| Rare + Occasional Soils | 6.11 | 8.75 | 1.15 | 0.42 |
| *P-value* | *P=0.00* | *P=0.00* | *p=0.00* | *P=0.00* |
| Rare Soils | 6.54 | 7.79 | 1.16 | 0.43 |
| *P-value* | *P=0.00* | *P=0.00* | *p=0.00* | *P=0.00* |
| Occasional Soils | 6.10 | 8.78 | 1.15 | 0.42 |
| *P-value* | *P=0.00* | *P=0.00* | *p=0.00* | *P=0.00* |

*Note that smaller values for the Simpson Index indicate greater diversity.*

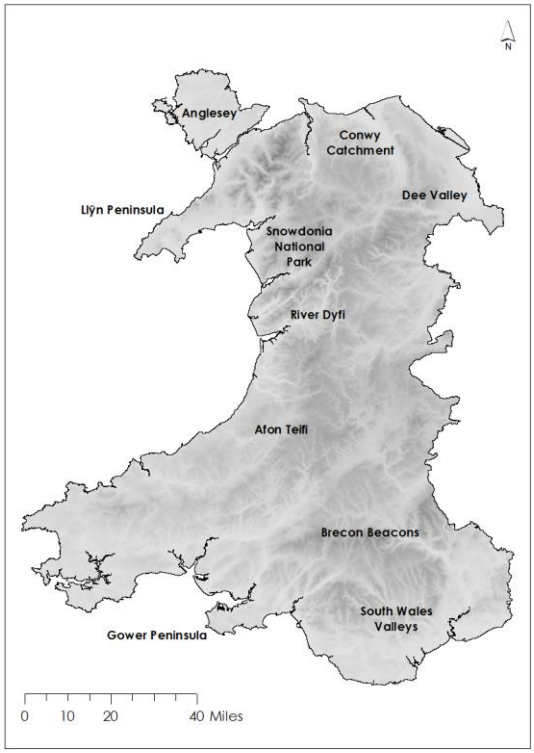


*Figure 1. Map of Wales showing locations of areas discussed in this paper.*

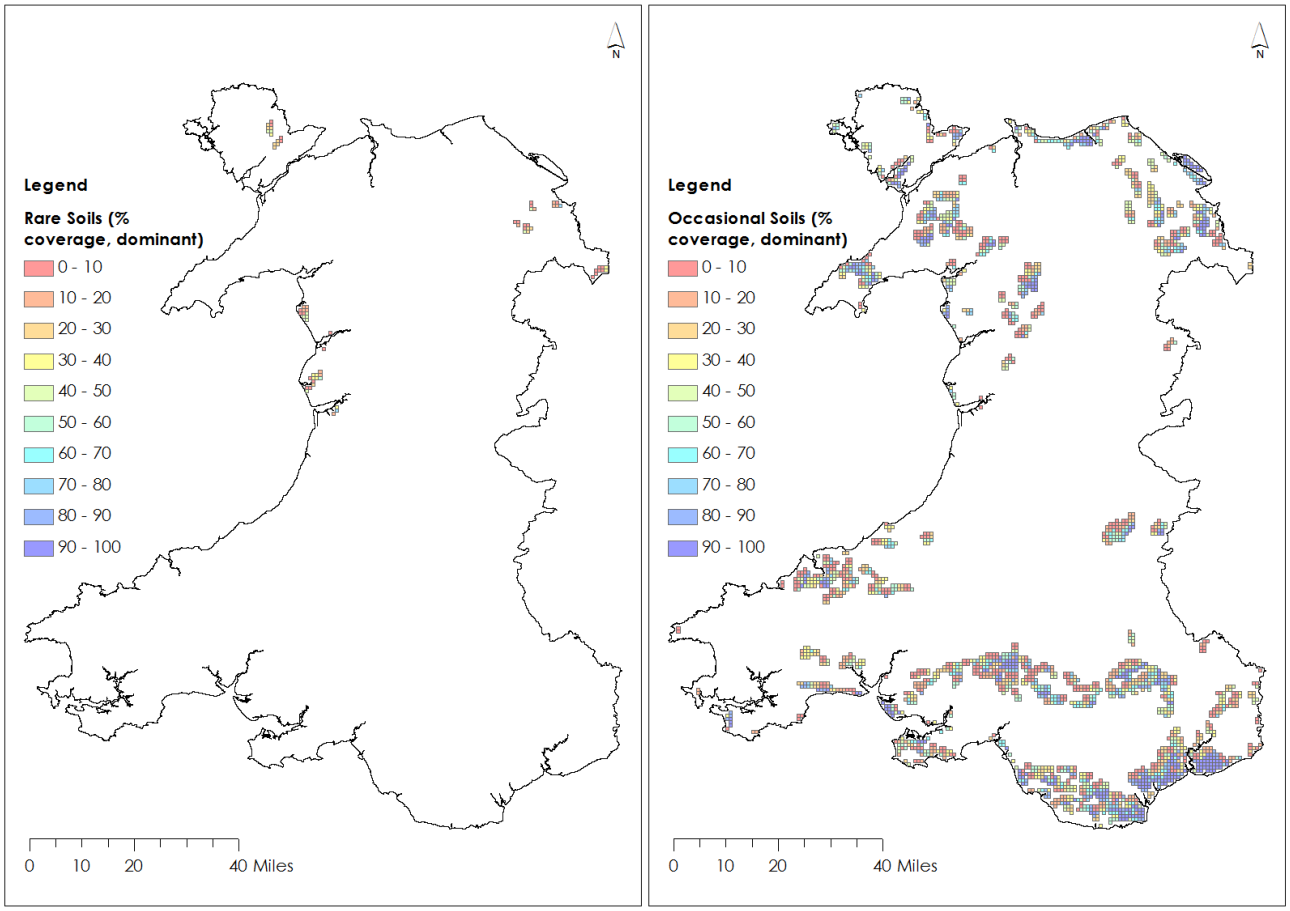


*Figure 2. (Left) Rare soils (<1% total land cover) and (right) occasional soils (11% total land cover) using the dominant soil sub-group method. The dominant sub group assumes that each soil association (as mapped by NSRI) is made up of the dominant series for that association; this soil may make up 100% of the relevant association, but where the percentage is lower, there is a possibility that the association mapped does not contain the soil of interest.*

*[To view this figure in colour, please see the online issue of the Journal.]*

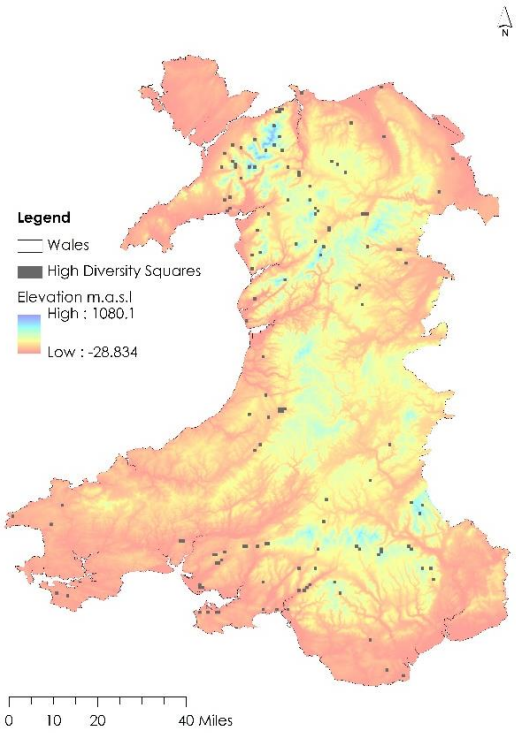


*Figure 3. Location of squares with high soil diversity versus elevation. [To view this figure in colour, please see the online issue of the Journal.]*

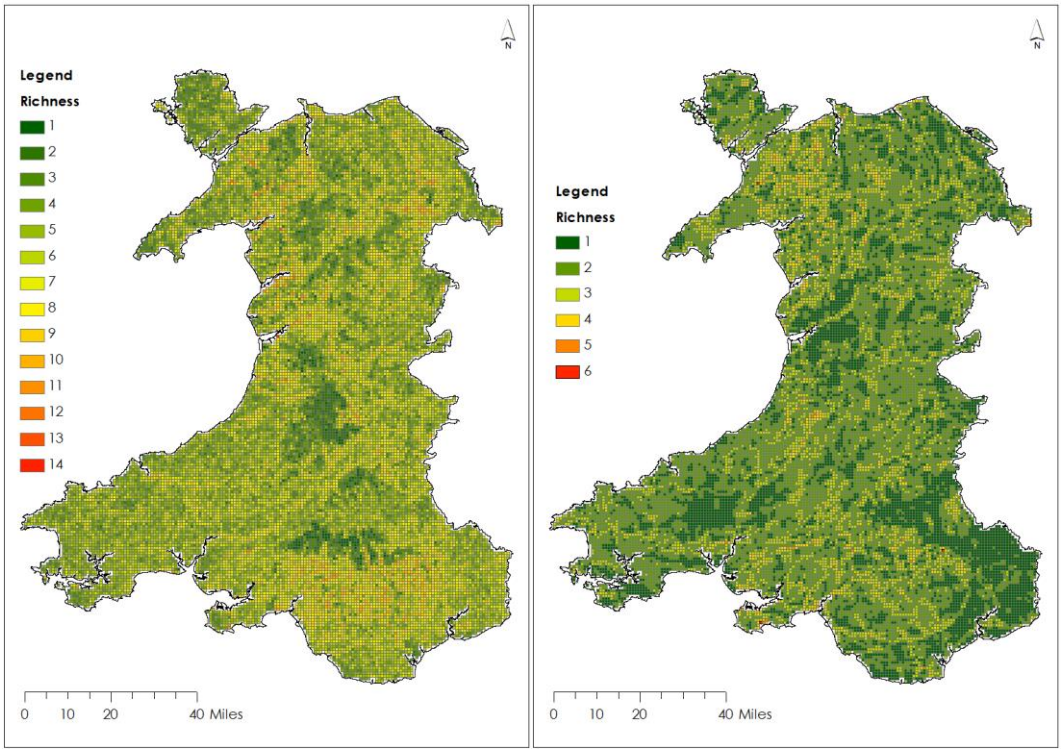


*Figure 4. Land cover diversity (left) and pedodiversity (right) in terms of richness. Red squares identify 1km squares with greater richness/diversity. [To view this figure in colour, please see the online issue of the Journal.]*

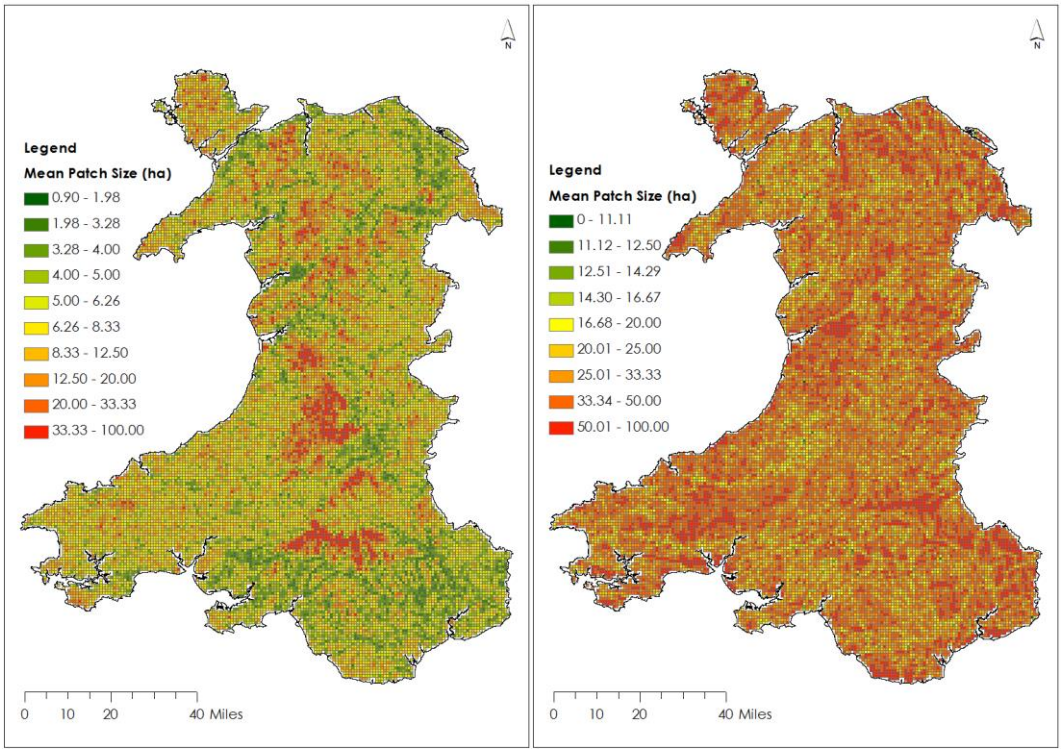


*Figure 5. Land cover diversity (left) and pedodiversity (right) in terms of mean patch size (ha). Red squares identify 1km squares with larger average patch sizes. [To view this figure in colour, please see the online issue of the Journal.]*

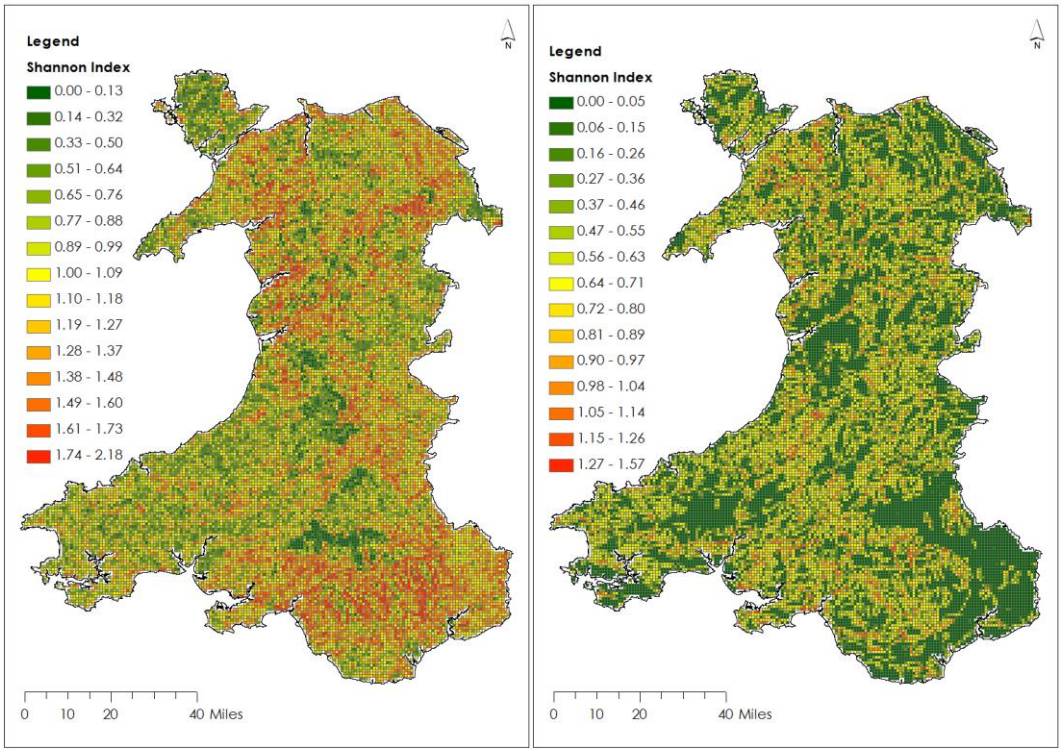


*Figure 6. Land cover diversity (left) and pedodiversity (right) in terms of the Shannon Index. Red squares identify 1km squares with greater diversity. [To view this figure in colour, please see the online issue of the Journal.]*

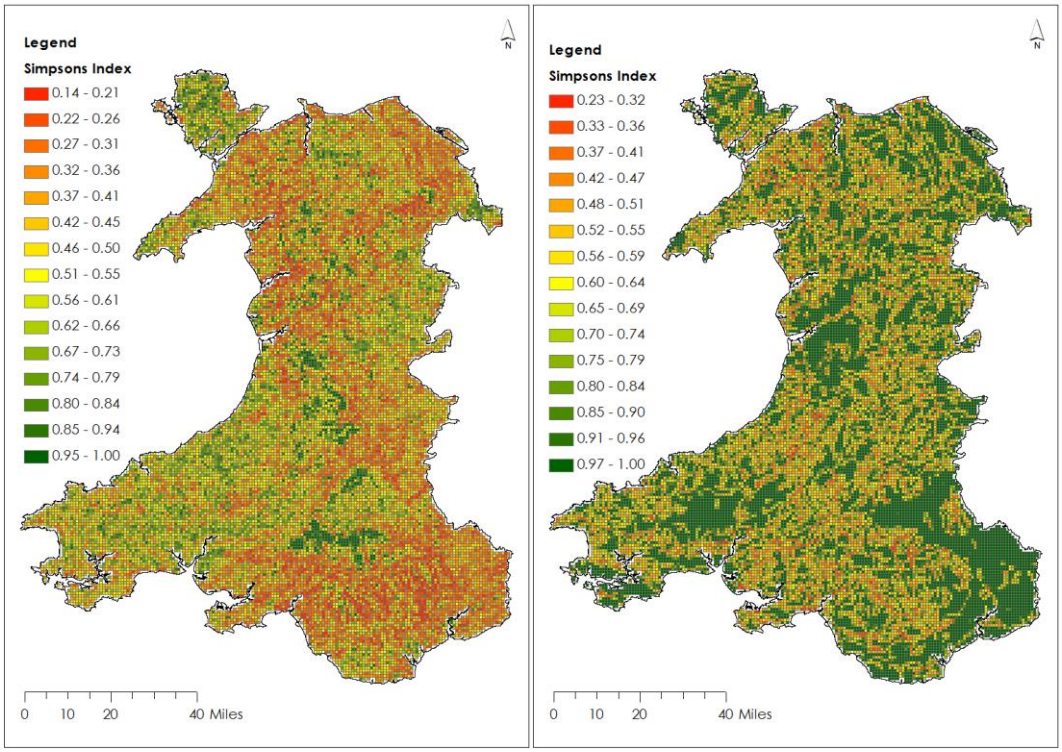


*Figure 7. Land cover diversity (left) and pedodiversity (right) in terms of Simpson's Index. Red squares identify 1km squares with greater diversity. [To view this figure in colour, please see the online issue of the Journal.]*

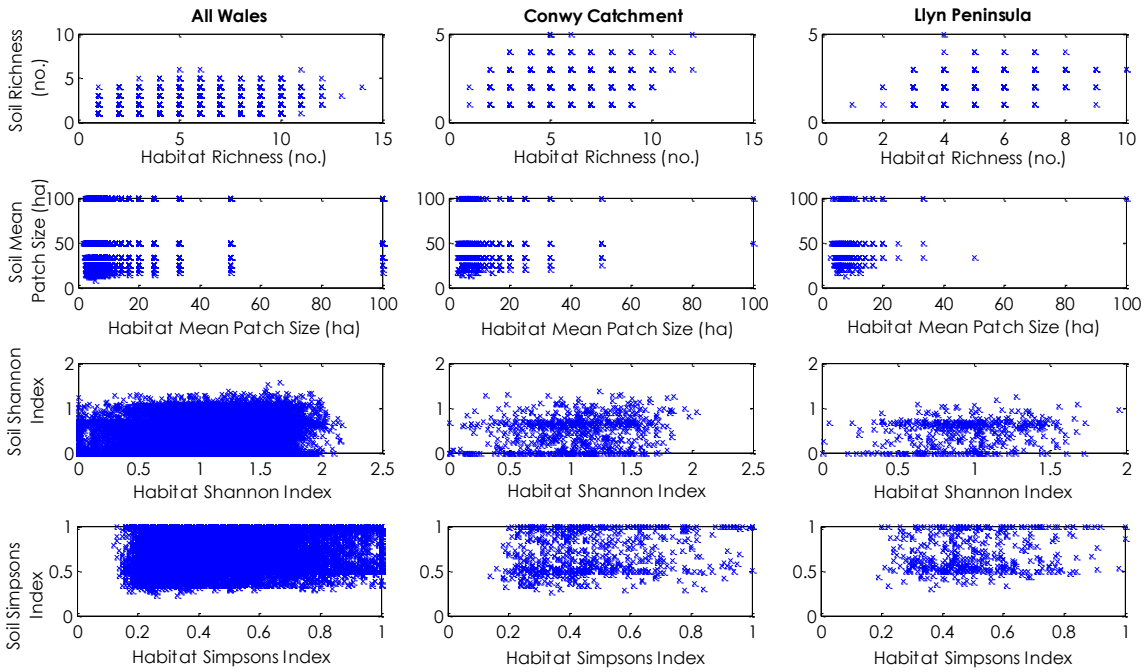


*Figure 8. Scatterplots of four different diversity metrics for soil and land cover over Wales. Although significant, correlations are generally weak across all of Wales, stronger correlations are found between habitat and soils in both the Conwy Valley and Llŷn Peninsula.*

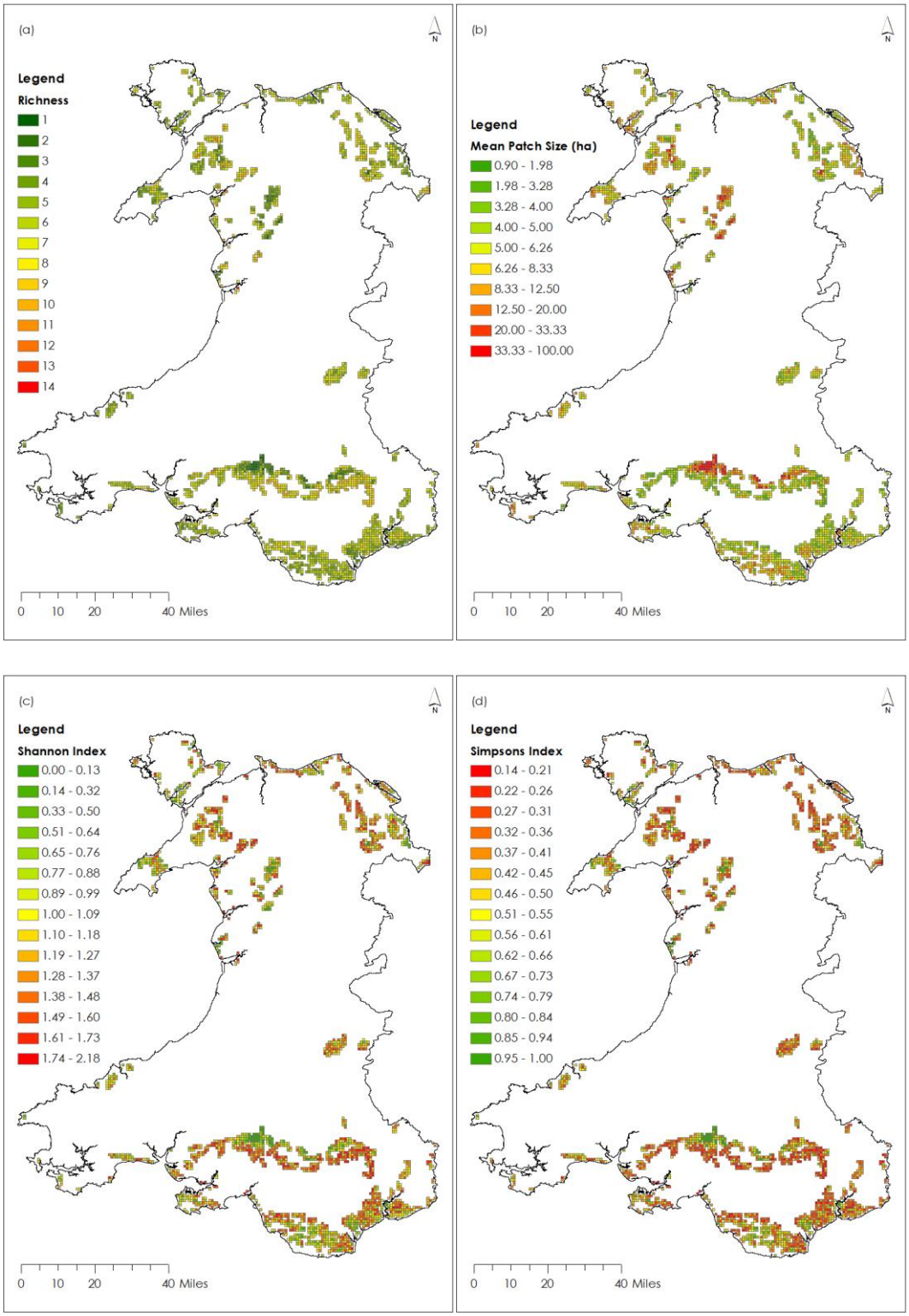


*Figure 9. Land cover metrics in areas of rare and occasional soils (dominant method). Black areas identify rare or occasional soils with greater above-ground diversity in terms of (a) richness (no.), (b) mean patch size (ha), (c) Shannon Index and (d) Simpson's Index.*

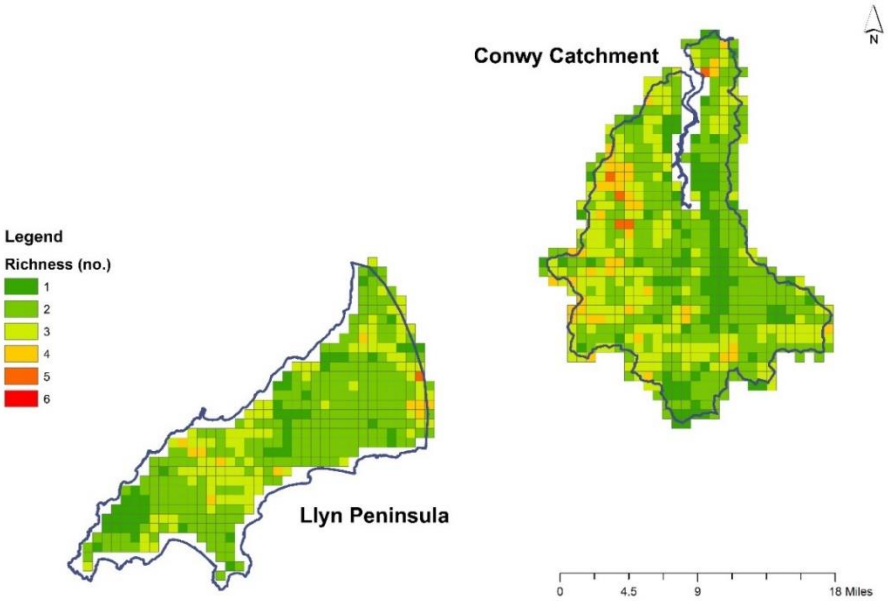


*Figure 10. Richness index values for soils across the Llŷn Peninsula and Conwy Valley. [To view this figure in colour, please see the online issue of the Journal.]*

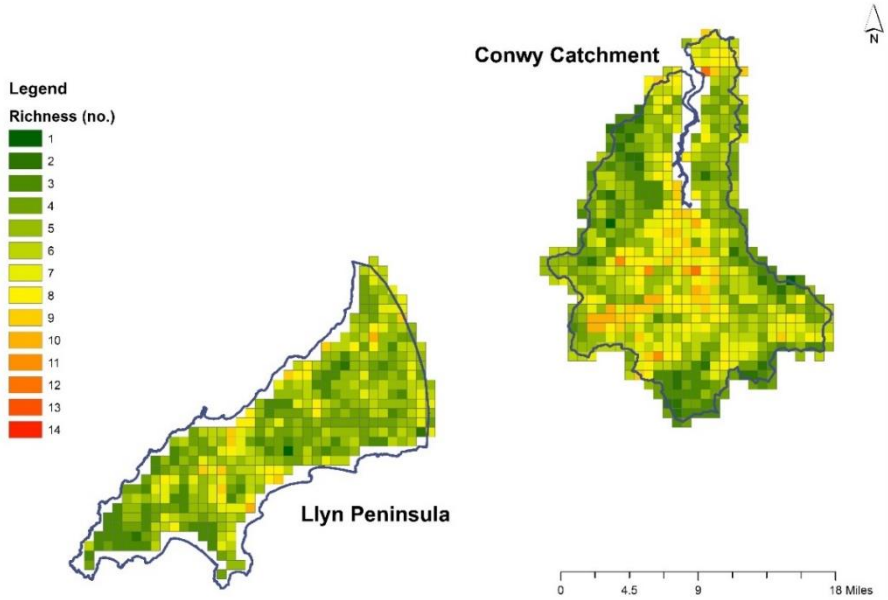


*Figure 11. Richness index values for habitat across the Llŷn Peninsula and Conwy Valley. [To view this figure in colour, please see the online issue of the Journal.]*

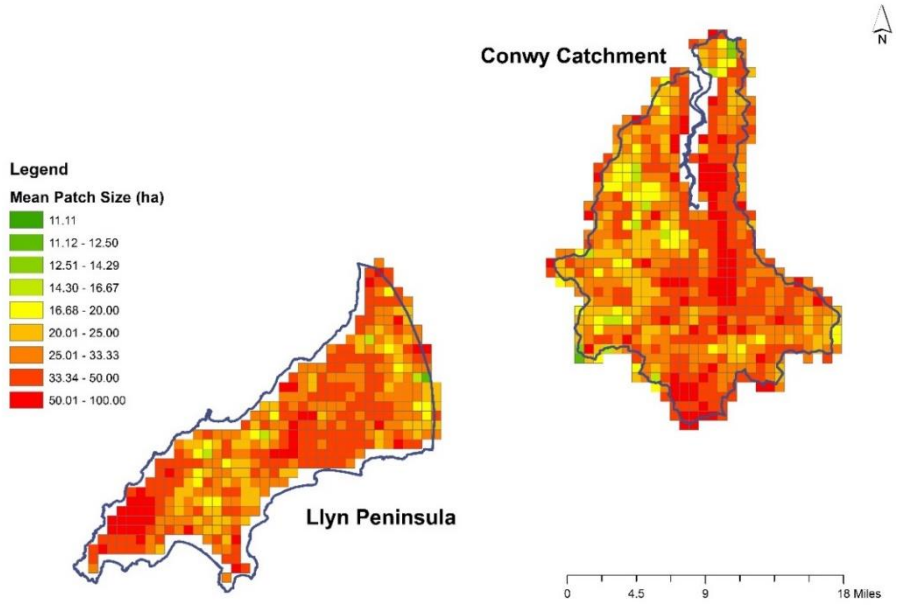


*Figure 12. Mean patch size values for soils across the Llŷn Peninsula and Conwy Valley. [To view this figure in colour, please see the online issue of the Journal.]*

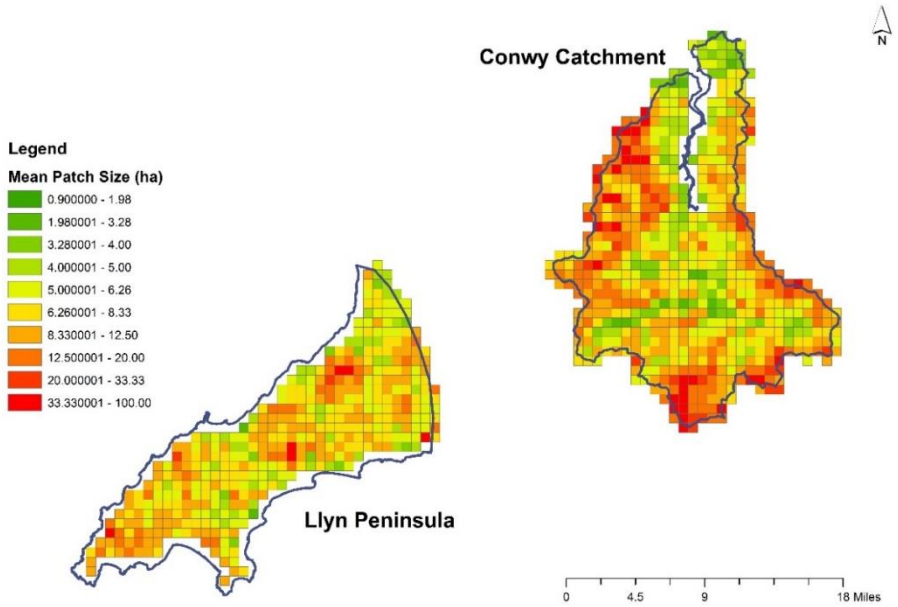


*Figure 13. Mean patch size values for habitat across the Llŷn Peninsula and Conwy Valley. [To view this figure in colour, please see the online issue of the Journal.]*

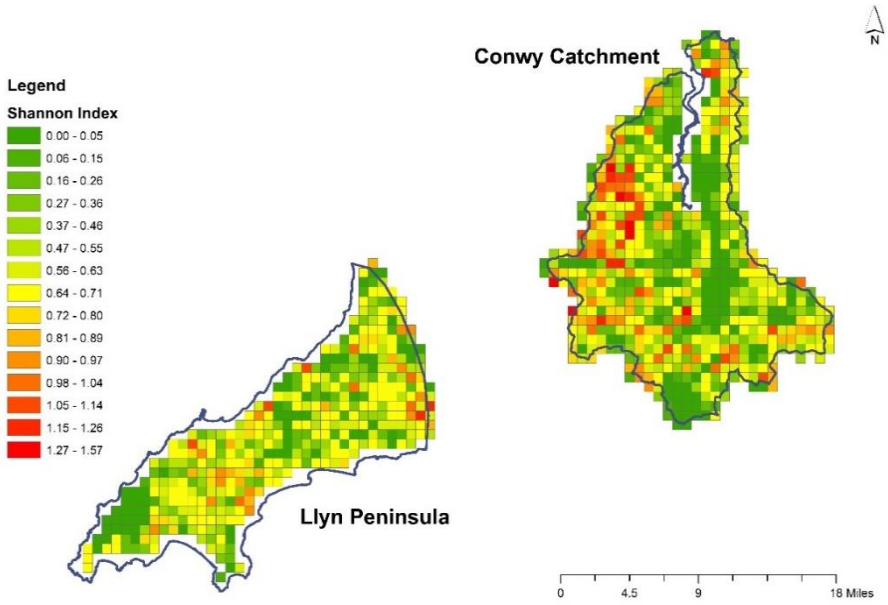


*Figure 14. Shannon index values for soils across the Llŷn Peninsula and Conwy Valley. [To view this figure in colour, please see the online issue of the Journal.]*

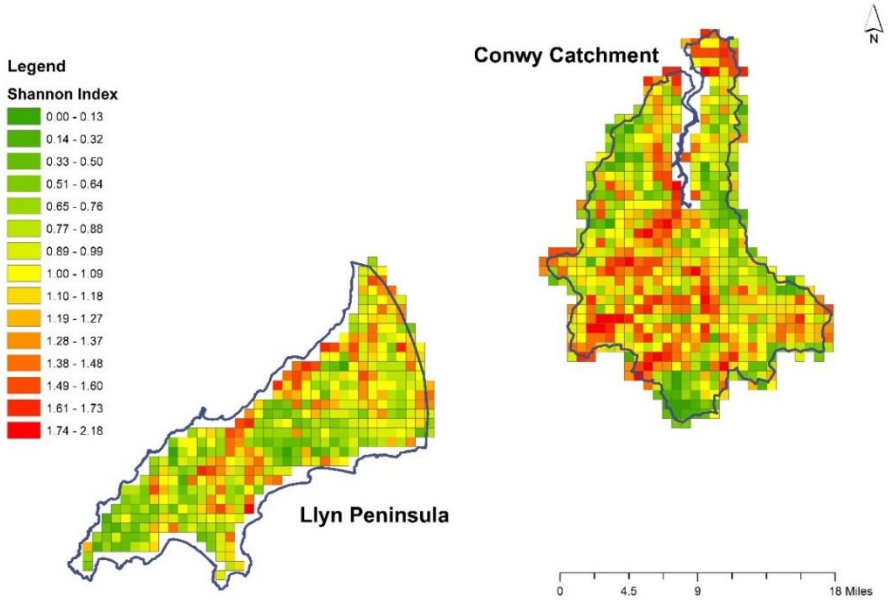


*Figure 15. Shannon index values for habitat across the Llŷn Peninsula and Conwy Valley. [To view this figure in colour, please see the online issue of the Journal.]*

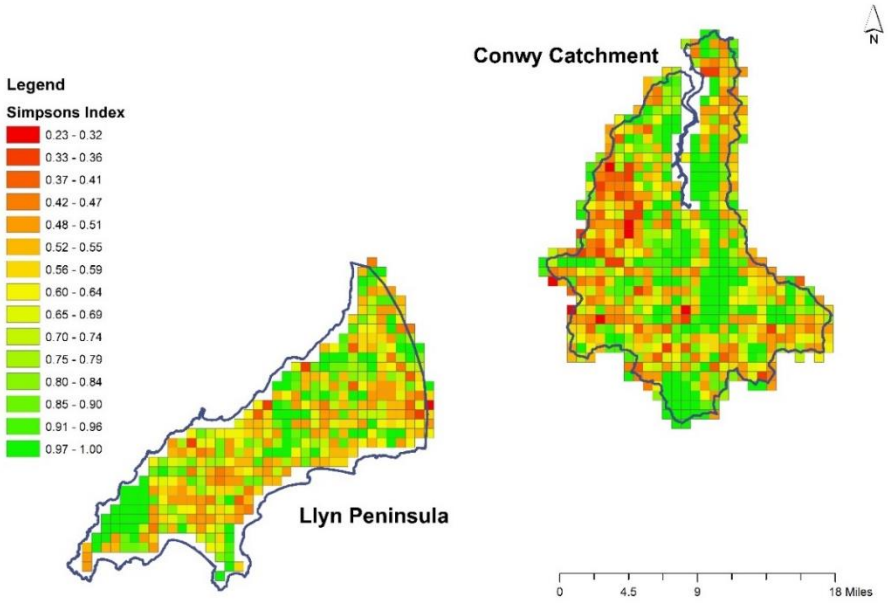


*Figure 16. Simpsons index values for soils across the Llŷn Peninsula and Conwy Valley. [To view this figure in colour, please see the online issue of the Journal.]*

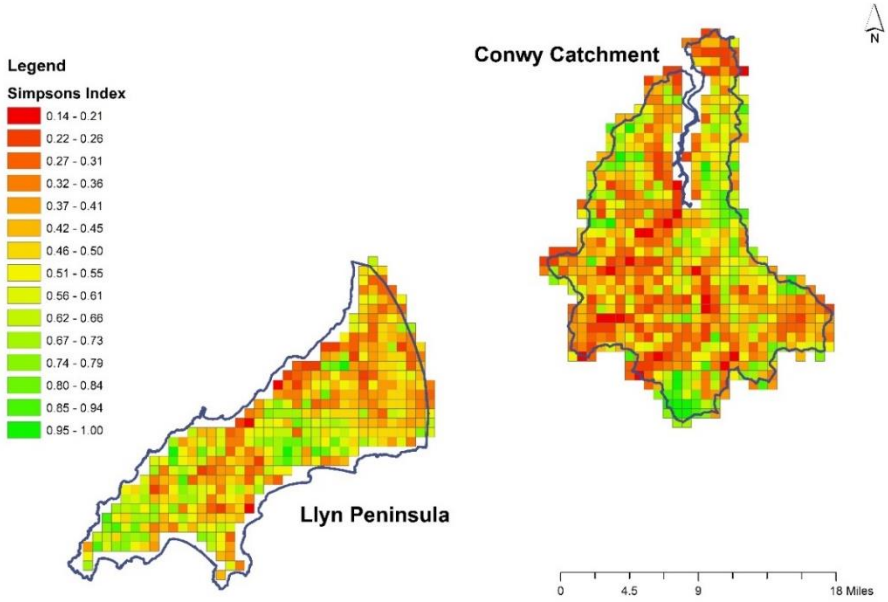


*Figure 17. Simpsons index values for habitat across the Llŷn Peninsula and Conwy Valley. [To view this figure in colour, please see the online issue of the Journal.]*

## S1. Supplementary information – Component method of soil assessment

The dominant method used to identify the soils in Table 2 can be compared with the component method, shown in Table S1:1 of the supplementary information, which suggests that a much greater number of rare (22) and occasional (18) soil sub-groups may be present; values of extent have not been calculated, because it is not possible to identify where within an exposure the soil of interest may occur.

Figures are provided in the supplementary information only for the component method (Figure S1:1). Using the component method there is no guarantee that the mapped association will actually contain a soil series of interest. The number of associations that might include rare soils is greater and when plotted appears to cover a greater area simply because the association is plotted, not the exposure of the soil series that might be contained within it.

*Table S1:1. Soil metrics of rarity determined from Natmap (NSRI, 2001) data according to the component method.*

| **Soils of Wales NATMAP (NSRI) 1:250,000** | | | | | | |
|---|---|---|---|---|---|---|
| **Subgroup** | **Area (ha)** | **Name of subgroup** | **Abundance %** | **Abundance** | **Criteria** | **Cumulative abundance** |
| | 349195 | Uncategorised (Water, coastal) | 16.903 | | | 100.000 |
| 5.41 | 432594 | Typical brown earths | 20.940 | Abundant | >=10% | 83.097 |
| 6.11 | 264319 | Typical brown podzolic soils | 12.795 | Abundant | >=10% | 62.156 |
| 7.13 | 173870 | Cambic stagnogley soils | 8.416 | Common | <10% >=5% | 49.362 |
| 7.21 | 158639 | Cambic stagnohumic gley soils | 7.679 | Common | <10% >=5% | 40.945 |
| 5.42 | 97436 | Stagnogleyic brown earths | 4.717 | Frequent | <5% >=1% | 33.266 |
| 6.54 | 86205 | Ferric stagnopodzols | 4.173 | Frequent | <5% >=1% | 28.550 |
| 3.13 | 64218 | Brown rankers | 3.109 | Frequent | <5% >=1% | 24.377 |
| 10.13 | 51544 | Raw oligo-amorphous peat soils | 2.495 | Frequent | <5% >=1% | 21.268 |
| 6.51 | 44283 | Ironpan stagnopodzols | 2.144 | Frequent | <5% >=1% | 18.773 |
| 7.11 | 31094 | Typical stagnogley soils | 1.505 | Frequent | <5% >=1% | 16.630 |
| 8.11 | 29821 | Typical alluvial gley soils | 1.444 | Frequent | <5% >=1% | 15.125 |
| 5.71 | 29199 | Typical argillic brown earths | 1.413 | Frequent | <5% >=1% | 13.681 |
| 10.11 | 27528 | Raw oligo-fibrous peat soils | 1.333 | Frequent | <5% >=1% | 12.268 |
| 5.72 | 20892 | Stagnogleyic argillic brown earths | 1.011 | Frequent | <5% >=1% | 10.935 |
| 5.61 | 19781 | Typical brown alluvial soils | 0.958 | Occasional | <1% >=0.1% | 9.924 |
| 5.43 | 18771 | Gleyic brown earths | 0.909 | Occasional | <1% >=0.1% | 8.966 |
| 3.11 | 17617 | Humic rankers | 0.853 | Occasional | <1% >=0.1% | 8.058 |
| 7.12 | 17237 | Pelo-stagnogley soils | 0.834 | Occasional | <1% >=0.1% | 7.205 |
| 6.12 | 16117 | Humic brown podzolic soils | 0.780 | Occasional | <1% >=0.1% | 6.370 |
| 5.62 | 15928 | Gleyic brown alluvial soils | 0.771 | Occasional | <1% >=0.1% | 5.590 |
| 8.13 | 13344 | Pelo-alluvial gley soils | 0.646 | Occasional | <1% >=0.1% | 4.819 |
| 8.71 | 11480 | Typical humic gley soils | 0.556 | Occasional | <1% >=0.1% | 4.173 |
| 5.51 | 9674 | Typical brown sands | 0.468 | Occasional | <1% >=0.1% | 3.618 |
| 6.31 | 8642 | Humo-ferric podzols | 0.418 | Occasional | <1% >=0.1% | 3.149 |
| 9.62 | 7855 | Neutral, base-rich dense, seasonally wet made ground soils | 0.380 | Occasional | <1% >=0.1% | 2.731 |
| 8.14 | 7776 | Pelo-calcareous alluvial gley soils | 0.376 | Occasional | <1% >=0.1% | 2.351 |
| 3.61 | 7228 | Typical sand-pararendzinas | 0.350 | Occasional | <1% >=0.1% | 1.974 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 8.21 | 4409 | Typical sandy gley soils | 0.213 | Occasional | <1% >=0.1% | 1.624 |
| 4.31 | 3376 | Typical argillic pelosols | 0.163 | Occasional | <1% >=0.1% | 1.411 |
| 8.12 | 3201 | Calcareous alluvial gley soils | 0.155 | Occasional | <1% >=0.1% | 1.248 |
| 1.10 | 2628 | Raw sands | 0.127 | Occasional | <1% >=0.1% | 1.093 |
| 5.81 | 2183 | Typical paleo-argillic brown earths | 0.106 | Occasional | <1% >=0.1% | 0.965 |
| 2.20 | 1923 | Unripened gley soils | 0.093 | Rare | <0.1% | 0.860 |
| 8.31 | 1609 | Typical cambic gley soils | 0.078 | Rare | <0.1% | 0.767 |
| 6.52 | 1476 | Humus-ironpan stagnopodzols | 0.071 | Rare | <0.1% | 0.689 |
| 3.43 | 1455 | Brown rendzinas | 0.070 | Rare | <0.1% | 0.617 |
| 4.11 | 1380 | Typical calcareous pelosols | 0.067 | Rare | <0.1% | 0.547 |
| 10.24 | 1361 | Earthy eutro-amorphous peat soils | 0.066 | Rare | <0.1% | 0.480 |
| 9.24 | 1340 | well aerated raw made ground soils | 0.065 | Rare | <0.1% | 0.414 |
| 3.21 | 1314 | Typical sand-rankers | 0.064 | Rare | <0.1% | 0.349 |
| 5.32 | 1142 | Gleyic brown calcareous alluvial soils | 0.055 | Rare | <0.1% | 0.286 |
| 9.63 | 838 | Leached, base-rich dense, seasonally wet made ground soils | 0.041 | Rare | <0.1% | 0.230 |
| 10.22 | 830 | Earthy eu-fibrous peat soils | 0.040 | Rare | <0.1% | 0.190 |
| 5.53 | 690 | Stagnogleyic brown sands | 0.033 | Rare | <0.1% | 0.150 |
| 1.30 | 670 | Raw skeletal soils | 0.032 | Rare | <0.1% | 0.116 |
| 5.52 | 487 | Gleyic brown sands | 0.024 | Rare | <0.1% | 0.084 |
| 6.41 | 284 | Typical gley-podzols | 0.014 | Rare | <0.1% | 0.060 |
| 9.58 | 223 | Acid-humose, base-poor well aerated made ground soils | 0.011 | Rare | <0.1% | 0.047 |
| 2.10 | 192 | Raw sandy gley soils | 0.009 | Rare | <0.1% | 0.036 |
| 8.22 | 192 | Calcareous sandy gley soils | 0.009 | Rare | <0.1% | 0.026 |
| 9.23 | 105 | Dense raw made ground soils | 0.005 | Rare | <0.1% | 0.017 |
| 9.44 | 105 | Acid-humose, base-rich dense made ground soils | 0.005 | Rare | <0.1% | 0.012 |
| 5.63 | 79 | Pelogleyic brown alluvial soils | 0.004 | Rare | <0.1% | 0.007 |
| 8.51 | 65 | Typical humic-alluvial gley soils | 0.003 | Rare | <0.1% | 0.003 |

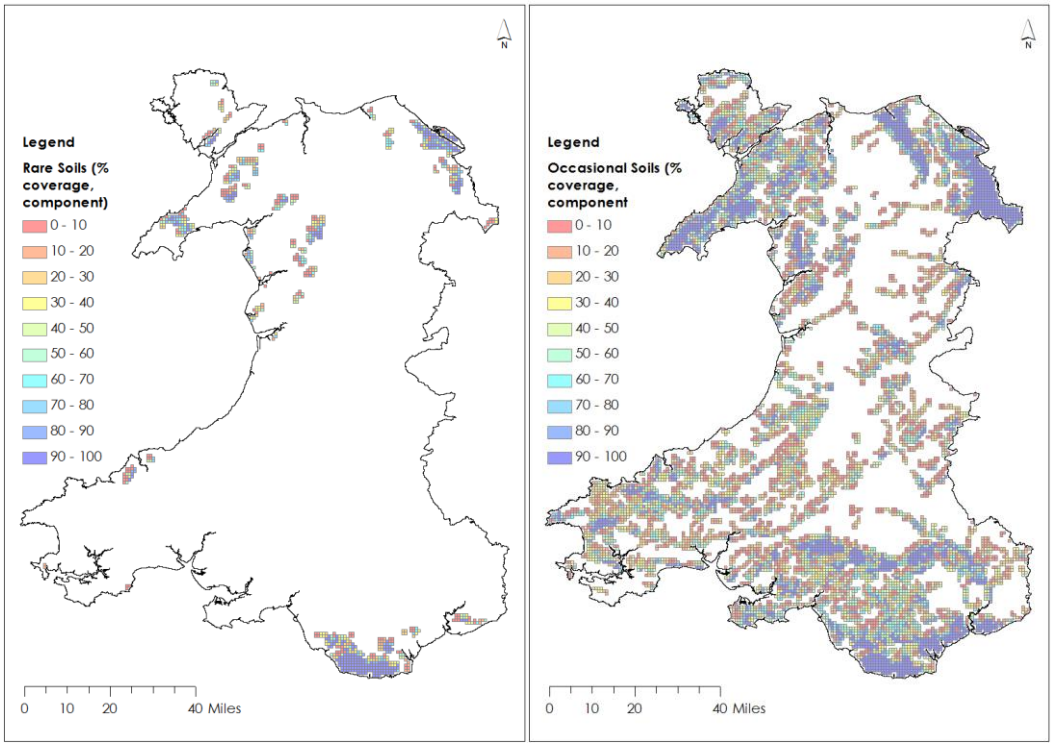


*Figure S1:1. Associations which may contain (left) rare soils (5%) and (right) occasional soils (49%) mapped according to the component soil series sub-group method. The component approach assumes each soil association (as mapped by NSRI) contains all soil series which may be found in that association, in proportions consistent with the average for that association. This approach identifies a greater number of soils which may be present, although there is no guarantee that the mapped association will actually contain the soil series of interest.*

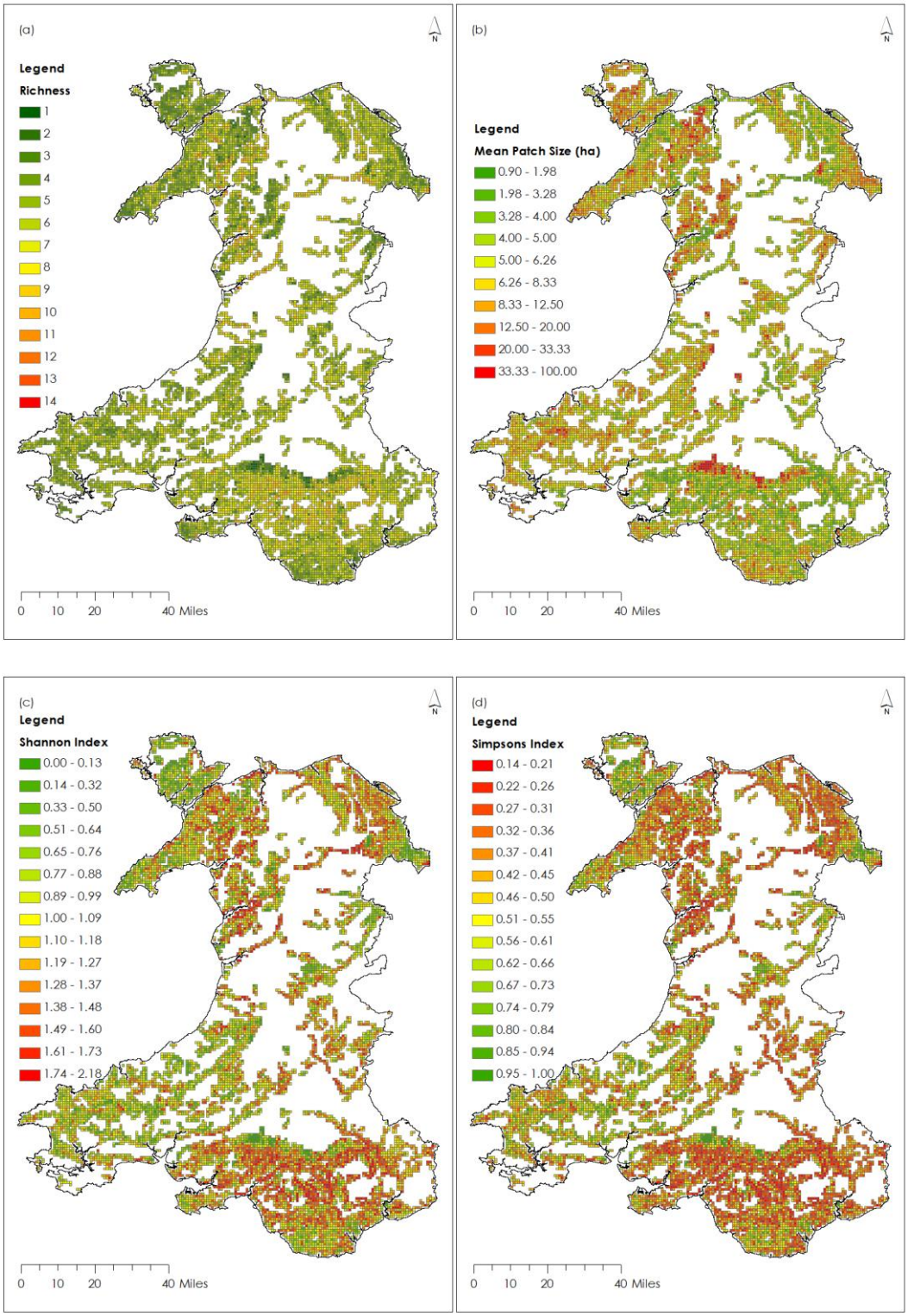


*Figure S1:2. Land cover richness metrics in areas of rare and occasional soils (component method). Areas of red indicate high above-ground diversity in terms of (a) richness, (b) mean Patch size (ha), (c) Shannon Index and (d) Simpson's Index. [To view this figure in colour, please see the online issue of the Journal.]*