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Short Note

Assessing stone walls habitat quality – Which factors affect bryophytes and macrolichens on farmland stone walls in Ireland?

Sara Ruas [a,c,*], Roser Rotchés-Ribalta [b], Daire Ó hUallacháin [c], Alessio Volpato [a,d], Michael Gormally [e], Blanaid White [f], James Moran [a]

[a] Galway-Mayo Institute of Technology, Marine and Freshwater Research Centre, Old Dublin Rd, Galway, Ireland
[b] CREAF, Bellaterra 08193, Barcelona, Spain
[c] Teagasc, Johnstown Castle, Co. Wexford, Ireland
[d] Teagasc, Mellows Campus, Athenry, Co. Galway, Ireland
[e] National University of Ireland Galway, Applied Ecology Unit, Centre for Environmental Science, Galway, Ireland
[f] Dublin City University, Glasnevin Campus, School of Chemical Sciences, Dublin, Ireland

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ABSTRACT

Stone walls are ubiquitous field boundaries used to restrict livestock movement or to separate property. Bryophytes and lichens are often the dominant vegetation in dry stone walls and are strongly affected by local microhabitat characteristics. Bryophytes and lichens related metrics can be used to define habitat quality of stone walls.

The current study assessed how richness and cover of bryophytes and macrolichens in dry stone walls related to each other and how different environmental variables and farm management descriptors determined richness and cover of both groups in dry stone walls. Bryophytes and macrolichens were sampled in stone walls on sixteen farms across a management intensity gradient in Ireland.

Bryophyte cover correlated positively and significantly with bryophyte richness and macrolichen cover and richness, and can thus be used to assess stone walls quality. Farm management intensity emerged as the variable most strongly related with species richness of bryophytes and cover of both groups. Altitude also emerged as a strong predictor of both groups' richness and cover. This study provides a novel perspective on stone wall habitat quality and results indicate that by promoting extensive farming it is possible to increase stone walls quality.

1. Introduction

Farmland stone walls are man-made linear elements used as field boundaries to restrict livestock movement or to separate property and are typically built using stones removed from fields (Powell et al., 2018). These man-made structures are ubiquitous farmland linear features in some European agricultural landscape (Collier, 2013). In Ireland, traditional dry stone walls i.e. walls built of stones only, without the use of mortar (Manenti, 2014; Powell et al., 2018), are particularly abundant in the west of the country (Collier, 2013).

The "*art of dry stone walling, knowledge and techniques*" was inscribed on the Representative List of the Intangible Cultural Heritage of Humanity (Council of Europe, 2019) and in Ireland, the recognition of stone walls as an important feature of the landscape, with cultural and historical value (Historic Monuments Advisory Committee, 2018), has been translated into protection through Irish agri-environment schemes (AES). However, whilst the quantity of stone walls may be recognised there is little emphasis on the quality of this type of habitat. Relative to other linear boundaries, such as hedgerows or drainage ditches (Shaw et al., 2015; Graham et al., 2018), the ecology of stone walls is understudied (Jennings and Stewart 2000; Manenti, 2014).

Stone walls have been shown to be important habitats for a diversity of vascular plants, ferns, mosses and lichens (Jennings and Stewart, 2000; Presland, 2007; Collier, 2013), along with pollinators, spiders, butterflies, reptiles amphibians and birds (Clifford and King, 2006; Manenti, 2014). Yet, only a small amount of scientific research in Europe is dedicated to the study of stone walls quality (Presland, 2007; Collier, 2013) and some uncertainty still overshadows the definition of "high habitat quality" of stone walls. The higher ecological value of older/neglected stone walls (Fossitt, 2000) conflicts with the delivery of other

* Corresponding author at: Teagasc, Johnstown Castle, Co. Wexford, Ireland.
E-mail address: Sara.Ruas@teagasc.ie (S. Ruas).

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stone wall functions, including the limitation of livestock movements, the division of fields, the preservation of cultural landscapes (Historic Monuments Advisory Committee, 2018). The loss of landscape value can also occur when stone walls are overgrown by trees, shrubs or brambles, thus resembling hedgerows or treelines (Fossitt, 2000).

In this study, bryophytes and macrolichens are proposed as the main biodiversity-related metrics to define habitat quality of stone walls in agricultural landscapes. Habitat quality can be defined as the ability of the ecosystem to support and maintain communities of organisms (Hall et al., 1997). Therefore, it is assumed that stone walls with higher richness and cover of either group can be considered as having higher habitat quality. This proposal is based on several criteria that make these organisms potentially suitable for stone wall quality assessment. They are: 1. often the first pioneers of a stone wall structure and are known to colonize all types of walls (Hollingsworth and Collier, 2020); 2. important elements within the ecosystem, as they provide food for a variety of invertebrates, shelter for insects and serve as an environment where other organisms interact (Bokhorst et al., 2015; Asplund and Wardle, 2016; Glime, 2017); 3. unlikely to cause stone wall collapse and threaten the cultural value of stone walls due to the absence of a real root system; 4. strongly affected by local microhabitat characteristics (Hespanhol et al., 2011) and 5. known to be affected by management intensity with a reduction of cover and/or species richness being reported (e.g. Müller et al., 2012; Boch et al., 2016, 2018), making them useful indicators of habitat quality (Nimis et al., 2002; Wolseley et al., 2009).

The specific objectives of the study were: 1) to identify how richness and cover of bryophytes and macrolichens are related to each other and to vascular plants cover. If a positive correlation exists between the cover of any of these groups and species richness, then they can potentially be used as a rapid indicator of habitat quality; 2) to assess if bryophyte and macrolichen richness and cover in dry stone walls are related to farm management and farm setting; and 3) to assess if specific bryophyte or macrolichen species are indicators of farm management.

2. Material and methods

2.1. Definition of stone wall

In this study only dry stone walls were considered. Hereafter referred to as “stone walls”. The stone walls sampled were linear field boundaries (<3 m wide) and were constructed of limestone, with a range of maintenance. When a stone wall was overgrown by trees, shrubs or brambles for greater than 30% of its length, it was excluded from the study. Only stone walls that were greater than 40 m in length were surveyed. A visual investigation of orthoimages (satellite imagery) available on the Irish Heritage Council (n.d.) webpage (https://www.heritagemaps.ie/WebApps/HeritageMaps/index.html) indicated that all of the stone walls sampled were present in the year 2000. Precise verification before this year was not possible.

2.2. Study region and farm selection

The present study was located in Co. Sligo, in the North-West of Ireland. Farming enterprises in this region are primarily sheep and cattle rearing (beef and dairy). Sixteen farms were included in the study (see sampled farms distribution in Figure S1, Supplementary Materials (SM)). Each farm was classified into intensive (n = 4), intermediate (n = 5), or extensive (n = 7) (see Rotchés-Ribalta et al., 2021). The farming intensity was determined using a Nature Value (NV) score developed by Boyle et al. (2015) which is a composite index based on the proportion of improved agricultural grassland, stocking density and density of linear features.

2.3. Assessment of bryophytes and macrolichens on farmland stone walls

The study included stone walls with various aspects (N/S; W/E; NW/SE; or SW/NE), with between one and three stone walls sampled per farm. A total of 34 stone walls were sampled. A transect of 30 m was sampled in each stone wall. Along this transect, three quadrats (0.5 m × 0.5 m) were placed 14.25 m apart on both sides of each stone wall (measured from the centre). The top of the stone walls was also sampled using smaller quadrats (0.25 m × 0.25 m). This gave a total of 9 quadrats per stone wall. Within each quadrat, the cover of each species of bryophyte and macrolichen (foliose and fruticose lichens, excluding crustose lichens, as defined by Bergamini et al. (2007)) was recorded. A sample of each specimen was collected for taxonomic identification in the laboratory. Bryophytes and macrolichens were identified following Frey et al. (2006) and Atherton et al. (2010), and Smith et al. (2009), respectively.

Additional ecological and floristic variables were recorded for each quadrat: orientation; tree cover (projection) (%) (woody plants greater than 4 m height (Fossitt, 2000)); shrub cover (%) (woody plants in between 0.5 and 4 m height (Fossitt, 2000)); herb and grass cover (%); and fern cover (%). The cover of these different groups was averaged across the nine quadrats per stone wall. However, as opposed to averaging the species richness of bryophytes and macrolichens, we considered the total species richness of both groups in each stone wall. All stone walls sampled are listed in Table S1 (Supplementary Materials (SM)), with associated farm code, farm intensity category (farm type), farm NV score, proximity to a field of semi-natural pasture, altitude, orientation and floristic variables.

2.4. Statistical analyses

Spearman correlation analyses were used to investigate how all the floristic variables were correlated with each other, together with the farm setting and the management variables (e.g. altitude, distance from the stone wall to the closest semi-natural pasture; NV score etc.).

Mixed effect models: In most cases more than one stone wall per farm was sampled, thus mixed effect models were used to address possible pseudoreplication/non-independence and identify which of the gathered variables (see Table S1, SM) most explained the bryophyte and macrolichen richness and cover. The farm code was set up as the random factor. Univariate mixed effect models were developed for each of the following explanatory variables due to high collinearity (Table S2 in SM) – type of adjacent pastures, altitude, farm type, distance to semi-natural pastures, NV scores, tree cover, shrub cover, herb and grass cover, fern cover, combined cover of herbs, grasses and ferns, and total vascular plants cover. Generalised mixed effect models (GLMMs) with Poisson distribution and fitted by maximum likelihood (Laplace approximation) were conducted for species richness variables. For cover variables (cover of bryophytes and cover of macrolichens) linear mixed effect models (LMMs) were performed and fitted by Restricted Maximum Likelihood (RML) estimation method (Luke, 2016).

LMMs’ residuals were tested for normality via Shapiro-Wilk normality tests and visual investigation of the residuals’ qq-plots, while GLMM were tested for overdispersion (Bolker et al., 2009) using the dispersion_glmer function of the blmeco package (results shown in SM – Table S4). The models’ goodness of fit was compared for each explanatory variable (AIC values and marginal/conditional R^2). The marginal R^2 can be used to indicate the variance explained only by fixed effects and the conditional R^2 provides the variance explained by the entire model (both fixed effects and random effects) (Nakagawa and Schielzeth, 2013). A low or inexistent difference between the marginal R^2 and conditional R^2 (here considered < 0.1) indicate that the random effect does not contribute to the observed variance. Only the three best models obtained for each response variable are reported. We further tested the floristic variables modelled for spatial autocorrelation (the Moran’s I) and also for the three best models’ residuals. When the farm type (3 levels categorical variable) emerged as significant variable, post-hoc Tukey HSD Tests (over Estimated Marginal Means) were performed.

Indicator species analysis: We also investigated which species of bryophytes and macrolichens were significantly related to each of farm type defined. We used the R function 'multipatt', which calculates the IndVal index (measurement of the association between a species and a group of sites (De Cáceres & Jansen, 2013)) and inputted a community matrix of both bryophytes and macrolichens (cover values). Species with <2 occurrences were excluded. Due to the results obtained, we also conducted Kruskal-Wallis tests and post-hoc tests to compare differences in the average cover of two indicator species amongst farm types.

All statistical analyses were conducted in R version 3.5.2 (R Development Core Team, 2013).

3. Results and discussion

A total of 77 bryophyte species and 38 macrolichen species were identified in this study. On average 2 stone walls were sampled per farm (min = 1; max = 3). The number of bryophyte species per stone wall was, on average (±SE), 12.82 ± 1.10 and the average number of macrolichen species was 3.17 ± 0.41. The average cover of bryophytes was 19.18% ± 2.36, and of macrolichens 5.60% ± 1.23. The most common bryophyte and macrolichen species identified were *Hypnum cupressiforme* Hedw. and *Parmelia saxatilis* (L.) Ach., respectively (see full list of species identified in Table S3 in SM). *H. cupressiforme* was also the most common surveyed species in the study conducted by Duchoslav (2002), confirming the ubiquitous presence of this moss.

Richness and cover of bryophytes were strongly correlated, as was the richness and cover of macrolichens (Table S2, SM). The cover of bryophytes seems to be a good indicator of bryophytes species richness and macrolichen richness and cover in farmland stone walls. As a result, this variable has the potential to be used as an indicator of stone wall habitat quality. Yet, a positive correlation between these groups richness is not always found (Pharo and Beattie, 1997) and a unimodal relationship between bryophyte and lichen cover was reported by Löbel et al. (2006). Therefore, these results should be confirmed by extending the study to other regions and farm systems, especially considering the significant spatial autocorrelation found for macrolichen cover and richness values (Table S5). Moran's I results indicate that macrolichen cover is significantly more similar for farms that are closer from each other; in turn, for species richness the opposite was observed (negative Moran's I). However, this later result might be somehow affected by the low variability in species richness values. The results of the Spearman correlation and the mixed effect models (Table 1) verified that farm management variables seem to have a significant effect on bryophyte richness and cover, and macrolichen cover. On the other hand, macrolichen species richness seems to be more strongly related to the farm setting (altitude). In fact, the results of the spatial autocorrelation tests for the models' residuals also confirmed that location seems to be important for explaining the observed patterns for macrolichens. Altitudinal effects seem to differ between bryophytes and lichens and between species richness and cover, depending on the climatic and regional context of the study (Bruun et al., 2006; Grau et al., 2007). Most variables related to farm management were also strongly correlated with farm altitude, which is not surprising given the farm type distribution (see Figure S1 and Table S2, SM). Factors related to farm topography and soil type can explain this clustering of extensively managed farms in higher altitudes of the sub-catchment. This is in line with the observation of Gardiner and Radford (1980) that farms in mountain and hill slopes consist mainly of extensive grazing. Therefore, it was not possible to design a study that disentangles the effects of farm topography and management in the study region and a similar pattern is probably seen throughout Ireland.

However, given the altitudinal gradient considered in this study (which is of a relative small range – 14–104 m a.s.l), it might be possible that other collinear factors are affecting the results. In fact, as seen in Table 1 there is an underlying effect of each sampled farm (farm code) for mixed models fitted to bryophyte species richness and macrolichen cover – which can be seen by the high differences between the marginal R^2 and conditional R^2. In summary, other farm management variables that influence (to some degree) the habitat quality of the stone walls may not have been captured in this study. For example, information regarding the use of herbicides to control vegetation growth in the stone walls was not available, which is reported to negatively affect bryophytes and lichens (Bartók, 1999; Newmaster et al., 1999). Nonetheless, results from the mixed effect models revealed that farm type and the NV score emerged as more strongly related with species richness of bryophytes and cover of both groups than altitude (Table 1). Information on how the farm type levels are different from each other is further provided via Tukey's tests (over Estimated Marginal Means). Extensive farms always displayed significantly different averages for all the floristic variables in relation to intensive farms (Table S6, SM).

Extensive farms are characterized by a lower percentage of improved agricultural grasslands, lower stocking rates and higher density of linear features. Improved grasslands are frequently reseeded and/or regularly fertilised, normally heavily grazed (Fossitt, 2000), which seems to be impacting stone walls habitat quality. For example, Müller et al. (2012) found that increased fertilizer application and high mowing frequency, reduced bryophyte species richness significantly in grasslands. Thus, we hypothesise that the effects of grassland management intensity cascades onto to the stone walls that separate these intensively managed fields, affecting bryophyte and macrolichen richness and cover.

The results of the indicator species analysis indicate that certain

Table 1
Results of the mixed-effects models using different predictors for each floristic variable. Only the 3 best models are shown for each variable. Significance level codes: ***: p ≤ 0.001; **: p ≤ 0.01; *: p ≤ 0.05. GLMM: Generalized mixed effects models; LMM: Linear mixed effects models; NV: Nature Value; Adj.: adjacent. Results of overdispersion (GLMMs) and normality of residuals (LMMs) are shown in SM (Table S4).

	Best Models (fixed effects coefficients and significance)	AIC Marginal R^2 Conditional R^2
Total species richness of bryophytes GLMM	1) Farm type (Interm.) = 0.659** Farm type (Exten.) = 0.675**	AIC = 230.020; R^2 marg. = 0.388; R^2 cond. = 0.623
	2) NV score = 0.0869*	AIC = 232.700; R^2 marg. = 0.210; R^2 cond. = 0.618
	3) Herb and grass cover = 0.016*	AIC = 233.200; R^2 marg. = 0.100; R^2 cond. = 0.616
Total species richness of lichens GLMM	1) Altitude =0.016***	AIC = 129.350; R^2 marg. = 0.436; R^2 cond. = 0.436
	2) NV score = 0.217***	AIC = 131.100; R^2 marg. = 0.366; R^2 cond. = 0.483
	3) Farm type (Exten.) = 0.966**	AIC = 136.00; R^2 marg. =0.366; R^2 cond. = 0.483
Cover Bryophytes (%) LMM	1) Farm type (Exten.) = 19.739**	AIC = 256.810; R^2 marg. = 0.319; R^2 cond. = 0.378
	2) NV score = 3.250**	AIC = 263.613; R^2 marg. = 0.319; R^2 cond. = 0.363
	3) Adj. to semi-natural pasture (Yes) = 11.641*	AIC = 263.613; R^2 marg. = 0.152; R^2 cond. = 0.358
Cover Lichens (%) LMM	1) NV score = 0.043***	AIC = -53.78; R^2 marg. = 0.507; R^2 cond. = 0.868
	2) Farm type (Exten.) = 0.229**	AIC = -51.772; R^2 marg. = 0.509; R^2 cond. = 0.873
	3) Altitude = 0.003**	AIC = -44.798; R^2 marg. = 0.392;R^2 cond. = 0.872

macrolichen and bryophyte species on stone walls are indicators of extensive farm management. Seven taxa emerged as potential indicators of extensive farm management including *Dicranum scoparium* Hedw, *Polytrichastrum formosum* (Hedw.) Smith, *Racomitrium heterostichum* (Hedw.) Brid., *P. saxatilis, Campylopus flexuosus* (Hedw.) Brid., *H. cupressiforme,* and *Cladonia* agg. (see complete statistics in Table S7, SM, including for other farm types, i.e., intensive and intermediate). The most common species of bryophyte sampled (*H. cupressiforme*), and the most common lichen species recorded (*P. saxatilis*) emerged as indicators of extensive farms. Yet, this is related to higher covers of these species found in extensive farms, as can be seen in Table S8 (SM) where results of Kruskal-Wallis tests and post-hoc tests for *H. cupressiforme* and *P. saxatilis* cover per farm type are shown. Most of the species that emerged as indicators of extensive management are common species and ubiquitous (Atherton et al., 2010). This is not surprising given that stone walls are man-made habitats in anthropogenic landscapes. The species *Tortula muralis* Hedw. emerged as indicator of intensive farms, which has been proven to tolerate heavy anthropogenic atmospheric pollution, growing in all types of man-made structures (Kosior et al., 2015).

4. Study limitations and conclusions

The main limitation of this study is related to the fact that it was conducted in a relatively small study area. While this allowed for improved understanding of the impact of other variables at a local scale (by excluding climate as an impacting factor), the small scale means that the results might not be replicated in other climatic zones. It is also acknowledged that the type of stones used to build the stone walls was uniform within the study area and it is well known that bryophyte communities depend strongly on the type of substrate (Pentecost, 1980). Substrate age can also be a strong determinant of lichen and bryophyte richness and affect species assemblages (Peterson et al., 2017) but no accurate figures regarding stone walls age were available. As a result, this variable could not be included as a potential explanatory variable in the statistical analyses performed.

The correlation pattern between altitude and farm type intensity was not possible to disentangle completely, since extensively managed farms are more frequent at higher than at lower altitudes in Ireland. Future studies should address this collinearity and the other identified study limitations.

Despite the limitations highlighted, this study has the potential to stimulate the development of further studies on the ecology of an overlooked farmland habitat, particularly in regions where stone walls are a significant feature in the landscape. It represents a novel approach to stone wall habitat quality assessment by proposing bryophytes and macrolichens as the main indicator of habitat quality.

One of the most promising findings from this study is that there is potential for the percentage cover of bryophytes and macrolichens to be used as variables in rapid assessments of stone wall habitat quality, since they correlate positively with species richness. Furthermore, there seems to be a response of both groups to farm management intensity here defined by a NV scoring system (Boyle et al., 2015). Thus, the improvement of stone walls quality might be dependent on a reduction of grasslands' management intensity and an increase in linear feature density (also an important component of the NV score). Also, the creation of buffer strips adjacent to the stone walls should be further investigated as a way of increasing stone walls quality.

The results of the indicator species analysis indicate that specific species of bryophytes and macrolichens are also indicative of more extensive farm management, and warrant further investigation as indicators of farm management impacts on the stone wall habitats.

Research on the habitat quality of stone walls as measured using bryophytes and macrolichens as indicators has the potential to recognise the ecological value of these important cultural landscape features. Higher cover and richness of bryophytes and lichens may also indicate increased habitat and resource availability for invertebrates and other taxa (Bokhorst et al., 2015; Asplund and Wardle, 2016; Glime, 2017) which warrants future investigation on the ecology of stone walls.

CRediT authorship contribution statement

Sara Ruas: Methodology, Field work, Data analyses, Writing – original draft. **Roser Rotchés-Ribalta:** Methodology, Field Work, Writing – review & editing. **Daire Ó hUallacháin:** Methodology, Writing – review & editing, Supervision. **Alessio Volpato:** Field Work, Writing – review & editing. **Michael Gormally:** Methodology, Writing – review & editing, Supervision. **Blanaid White:** Writing – review & editing. **James Moran:** Methodology, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Appendix A. Supplementary data

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