AN ASSESSMENT OF EPIPHYTIC LICHEN DIVERSITY AND ENVIRONMENTAL QUALITY IN KNOCKSINK WOOD NATURE RESERVE, IRELAND

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ABSTRACT

Epiphytic lichens are extremely sensitive to environmental perturbations. This research work has adapted and applied recently developed methods of assessing epiphytic lichen species diversity to the Irish semi-natural acidophilous woodlands of Knocksink Wood Nature Reserve, Enniskerry, Co. Wicklow, Ireland. The study has focused on the differences that arise in relation to acidophilous oak versus ash–hazel woodlands at Knocksink. The frequency of occurrence of lichen species on a defined portion of tree bark is used as an estimate of diversity and to evaluate the degree of environmental stress on the sensitive lichen community. Epiphytic lichens were investigated across the oak woodland (*Blechno-Quercetum petraeae*) and ash–hazel woodland (*Corylo-Fraxinetum*) and a total of 30 lichen taxa were recorded on trunks and 11 on twigs and branches. Results showed that 26 epiphytic lichen taxa were found on the oak tree trunks in the oak woodland and 14 epiphytic lichen taxa on the ash tree trunks in the ash–hazel woodland. The genera with the highest number of species were *Opegrapha*, *Pertusaria* and *Arthonia* for tree trunks and *Parmelia*, *Hypogymnia* for tree canopies. Lichen diversity (LD) results were interpreted in terms of environmental assessment and a relatively low environmental quality was detected. Further comparison to other broadleaf woodlands in Ireland revealed a poverty of epiphytic lichen flora at Knocksink. Oak trees in the oak woodland were recognized as richer in lichen flora on the trunk area than ash trees in ash–hazel woodland. However, the epiphytic lichens in the ash–hazel woodland showed a higher LD score than that in the oak woodland at Knocksink Wood. This research advances understanding of environment influences on sensitive epiphytic lichens and their abundance and distribution in Irish broadleaf woodlands.

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INTRODUCTION

The Knocksink Wood Nature Reserve (Enniskerry, Co. Wicklow) is a semi-natural woodland in an upland region of the Glencullen River valley, grid reference O2019–O221707 (Fig. 1). The woodland extends in a linear fashion along either side of the river valley; it is approximately 75 hectares in area and is less than half a kilometre wide at its narrowest point. The importance of this site lies in the diversity of woodland habitats (National Parks and Wildlife Service 2000). This research aimed to assess the epiphytic lichen diversity and distribution across woodland habitats and to evaluate environmental quality using lichens as ecological bioindicators.

Lichens have been identified as indicators of environmental quality, particularly air quality, since as early as 1866 (Kricke and Loppi 2002). Recent developments in the use of lichens as bioindicators of air quality have led to the development of the Index of Atmospheric Purity (IAP) 1968 (Kricke and Loppi 2002). Subsequently a number of regional systems were developed, viz. the IAP_{18} guideline (1987), the VDI (Verein Deutcher Ingenieure) Lichen Mapping Guideline 3799 (1995) and the ANPA (Agenzia Nazionale per la Protezione dell'Ambiente) guideline (1999). Various workers have applied these guidelines for assessments of environmental quality (Loppi 1996; Giordani *et al*. 2001; 2002; Sommerfeldt 2001; Jeran *et al*. 2002; Loppi *et al*. 2002a; 2002b; Brunialti *et al*. 2003; Pirintsos *et al*. 2003; Gombert *et al*. 2004; Loppi *et al*. 2004). The need for a general and widely applicable lichen based system for the determination of environmental stress within ecosystems led to the development of the European Guideline for Mapping Lichen Diversity as an Indicator of Environmental Stress (Asta *et al*. 2002a; 2002b). For the first time the concept of 'environmental stress' was integrated

Fig. 1— A map of Ireland and the location of Knocksink Wood Nature Reserve with marked sampling units (map adapted from the Ordnance Survey Archive, 1910).

with stress creating factors, such as atmospheric pollution, eutrophication and climate change. The European Guideline has been recently applied in a number of major studies (Davies *et al*. 2002; Pinho *et al*. 2002; Wolseley *et al*. 2002a; 2002b, Castello *et al*. 2005).

Various studies have addressed the abundance and distribution of lichens in Irish woodlands (James *et al*. 1977; Alexander *et al*. 1989; Cullen and Fox 1999; Fox *et al*. 2001; Coppins *et al*. 2002). However, the environmental status of Irish woodlands has not been well addressed through the use of formal lichen-based indices. Consequently, there is potential for the development of new insights from the application of the European Guideline for Mapping Lichen Diversity as an Indicator of Environmental Stress (Asta *et al*. 2002a; 2002b) to the woodlands at Knocksink. This research focuses on the differences that arise in relation to two major woodland habitat categories within Knocksink, viz. acidophilous oak woodland, corresponding to the *Blechno-Quercetum petraeae* phytosociological association, and ash–hazel woodland, referable to the *Corylo-Fraxinetum* association (White 1982).

MATERIALS AND METHODS

SELECTION OF SAMPLING UNITS AND TREES

The sampling strategy follows the European Guideline for Mapping Lichen Diversity as an Indicator for Environmental Stress (Asta *et al*. 2002a; 2002b). A mapping grid of 50m × 50m was placed over the map of Knocksink Wood to facilitate selection of sampling units (Fig. 1). This size of sampling unit was designed to record variation of epiphytic lichen distribution within the designated habitat type. A total of 15 sampling units were selected using stratified sampling (Kent and Coker 1996). Woodland types were used for stratification and oak and

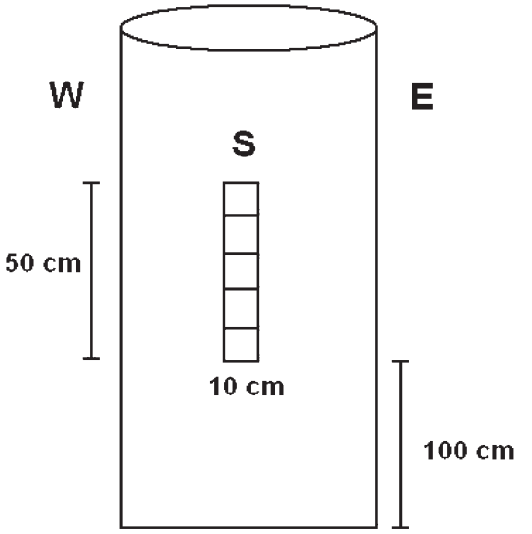

Fig. 2— Surveying quadrat segment with five quadrat squares (adapted from Asta *et al*. 2002a; 2002b).

ash–hazel woodlands were selected. Sampling units were selected based on accessibility, representative woodland type, presence of suitable trees and no road disturbance. Eight sampling units were located within the oak woodland and seven sampling units were selected in the ash–hazel woodland. The selected sampling units were divided into equal quadrants. One tree was then selected within each of these quadrants according to a defined set of criteria derived from Asta *et al.* (2002a; 2002b). These criteria specified that the sample tree should be:

- a dominant character species of the woodland habitat type (i.e. an oak tree in oak woodlands and an ash tree in ash woodlands);
- a free-standing tree showing no evidence of damage or interference by humans or animals;
- a tree with a trunk circumference greater than 70cm and an inclination of less than 10° from vertical;
- located as close as possible to the centre of the sampling unit.

SURVEYING LICHEN DIVERSITY ON TREE TRUNKS

Lichen diversity (LD) was surveyed on the selected trees, using a surveying quadrat. This quadrat consisted of four quadrat segments, each 50cm in height and 10cm in width. Quadrat segments were placed on the north, east, south and west side of the trunk 100cm above the ground. Each quadrat segment was subdivided into five quadrat squares 10×10cm (Fig. 2), and the presence of lichen species was recorded in each quadrat square. A list of lichen species with their frequency values in one quadrat segment constitutes a relevé of lichen vegetation. The adopted nomenclature for lichen species follows the checklist in Coppins (2002) and Fox (in press). Following the procedures of Asta *et al*. (2002a; 2002b) LD values for each sampling unit were calculated. Within each sampling unit a sum of frequencies of all lichen species for each aspect on each tree (i) was calculated. For each tree there were four sums of frequencies (SF_i) on the north (SF_{iN}), east (SF_{iE}), south (SF_{iS}) and west (SF_{iW}) side of the trunk. Then the arithmetic mean of the sums of frequencies (*MSF*) for each aspect (north, east, south, west) in sampling unit (*j*) was calculated using the following formula:

$$MSF_{Nj} = (SF_{1Nj} + SF_{2Nj} + SF_{3Nj} + SF_{4Nj})/n$$

where: MSF_{Nj} is mean of the sums of frequencies of all trees of unit j for each aspect (e.g. North)

SF_{iNj} is sum of frequencies of all species recorded for each aspect (e.g. North) of tree *i* in unit j

n is the number of surveyed trees with a given aspect in unit *j*

The LD value of sampling unit *j* (LDV_j) was then calculated as the sum of the *MSFs* of all aspects:

$$LDV_j = (MSF_{Nj} + MSF_{Ej} + MSF_{Sj} + MSF_{Wj})$$

Sampling lichens on twigs and branches

This research aimed to produce a complete list of all epiphytic lichens on oak and ash trees in Knocksink wood. Therefore, twigs and branches from ash and oak trees, which had fallen on the ground, were collected randomly in the sample units and the occurring lichen species recorded on a list.

Species diversity

The Sørensen coefficient (Kent and Coker 1996) was calculated for expressing similarity in species composition between oak and ash–hazel woodland and between Knocksink Wood and Powerscourt Waterfall woodland (Brodekova 2005, unpublished data).

The Shannon diversity index (H') (Kent and Coker 1996) was used to establish alternative estimates of species diversity at Knocksink Wood.

The biological diversity was quantified using Simpson's Index of Diversity (1-D) (Odum 1993).

RESULTS

EPIPHYTIC LICHEN STRUCTURE IN KNOCKSINK WOOD

A total of 30 lichen taxa were recorded on the trunks of 32 oak and 28 ash trees in Knocksink Wood (Table 1) and 11 were found only on the fallen twigs and branches of the oak and ash trees within the sample units. The latter were: *Evernia prunastri, Flavoparmelia caperata, Hypogymnia physodes, H. tubulosa, Melanelia subaurifera, Parmelia saxatilis, P. sulcata, Parmotrema chinense, Physcia tenella, Ramalina farinacea* and *Usnea subfloridana*. The majority of lichen species recorded on tree trunks were crustose lichens (29 taxa) and the majority on twigs and branches were foliose lichens (8 species). The genera with the highest number of species were *Opegrapha* (5 taxa), *Pertusaria* (5 species), *Arthonia* (4 species) on tree trunks and *Parmelia* (2 species) and *Hypogymnia* (2 species) on branches and twigs.

Epiphytic lichens in oak woodland

Results showed that 26 epiphytic lichen taxa occurred on oak tree trunks (Table 1). The most frequent lichen taxa on oak tree trunks were *Lepraria* sp. ($F = 116$), *Anisomeridium biforme* ($F = 55$), *Enterographa crassa* ($F = 55$) and *Pertusaria leioplaca* ($F = 49$) (Table 1).

Epiphytic lichens in ash–hazel woodland

A total of 14 epiphytic lichen taxa were recorded on ash tree trunks (Table 1). The most frequent lichen species on ash tree trunks were *Opegrapha atra* ($F = 181$), *Pyrenula macrospora* ($F = 166$), *Enterographa crassa* ($F = 154$) and *Lecanora chlarotera* ($F = 106$).

Lichen diversity analysis

The LD values of sampling units for Knocksink Wood were compared with the LD interpretation scale (Table 2). The scale distinguishes five LD classes further divided into subclasses to provide a higher degree of resolution in lichen analysis (Table 2).

Species richness

Using the Sørensen coefficient (Kent and Coker 1996) the similarity in species composition between oak and ash–hazel woodland was calculated as 36.7%. The similarity between Knocksink Wood and Powerscourt Waterfall woodland was calculated as 30%.

The Shannon diversity index (H′) in oak woodland was estimated at 2.81 and in ash–hazel woodland at 2.26.

The Simpson's Index of Diversity (1-D) was calculated as 0.92 for the oak woodland and 0.87 for the ash–hazel woodland.

DISCUSSION

LICHEN DIVERSITY

Lichen diversity counts can be taken as estimates of environmental quality, where high values correspond to good quality and low values indicate poor quality (Asta *et al*. 2002a, 2002b). Most LD values in the oak woodland studied fell into the 'Very Low' LD class and the subclass 'Very-low' (Table 2). The situation in the ash–hazel woodland was slightly different. LD values for the ash–hazel woodland were more scattered around the middle of the scale in the class with 'Low' LD (Table 2). Higher LD was recorded in two units in the ash–hazel woodland, which was interpreted as belonging to the 'Moderate' LD class. Although the LD score for the ash–hazel woodland showed a slightly higher value than that in the oak woodland, the overall pattern demonstrated a clustering of values around the bottom of the scale. Results indicate that the diversity of epiphytic lichens is low in the woodlands of Knocksink.

The Shannon diversity index (H') recorded a value of 2.81 for the oak woodland and 2.26 for the ash–hazel woodland indicating higher species diversity for the oak woodland. In considering Simpson's diversity index (1-D) a value of 0.92 was recorded for the oak woodland and 0.87 for the ash–hazel woodland, indicating again slightly higher sample diversity in the oak woodland by comparison to the ash–hazel woodland. In contrast with these diversity indices the LD results generated higher diversity for the ash–hazel woodland. This results from the unequal balance between species richness and evenness in deriving the LD index. The frequency as a measure of evenness contributes more to the value of LD. The sum of all species frequencies in the oak woodland was 622 while that in the ash–hazel woodland was 970, therefore the LD was identified as being higher in the ash–hazel woodland.

SPECIES COMPOSITION AND RICHNESS

Most of the epiphytic lichen species recorded in the Knocksink woodlands were crustose lichens (29 taxa) (Table 1). Foliose and fruticose lichens were almost entirely allocated to the canopy environment on branches and twigs. The higher occurrence of fruticose and foliose lichens, predominantly aerohygrophytic species, in canopies is probably related to higher precipitation in

the canopy as well as the relatively greater availability of light on twigs and branches.

Differences have been identified in epiphytic lichen species composition and numbers between the oak and ash–hazel woodland at Knocksink. Oak trees in the oak woodland were richer in lichen taxa on the trunks (26 recorded) than ash trees in ash–hazel woodland (14 recorded)

Table 1—Epiphytic lichen taxa recorded on the trunks of trees in the oak and ash–hazel woodlands of Knocksink Wood.

Species★	*Oak woodland*			*Ash–hazel woodland*		
	NSu $n=8$	*Trees* $n=32$	*F* *n*	*NSu* $n=7$	*Trees* $n=28$	*F* *n*
Acrocordia gemmata	3	4	17			
Anisomeridium biforme	7	12	55			
Arthonia cinnabarina	3	6	5			
Arthonia didyma	3	6	18	3	3	8
Arthonia radiata	5	5	9	3	7	38
Arthonia sp.	2	2	2	2	3	5
Arthonia vinosa	1	1	1			
Cladonia coniocraea	7	8	24			
Dimerella pineti	2	2	4			
Enterographa crassa	5	9	55	5	17	154
Graphis britannica	2	1	4			
Graphis scripta	5	10	20	7	23	102
Lecanora argentata	3	5	40	2	3	11
Lecanora chlarotera	5	9	40	7	13	106
Lecanora sp.				2	3	11
Lecidella elaeochroma	2	4	21	2	4	45
Lepraria sp.	7	22	116			
Opegrapha atra	6	15	41	6	26	181
Opegrapha herbarum	1	1	1			
Opegrapha niveoatra	3	5	14			
Opegrapha sp.				3	3	6
Opegrapha vulgata	1	1	5			
Pertusaria albescens	2	2	6			
Pertusaria amara	2	2	11			
Pertusaria hymenea	2	8	32			
Pertusaria leioplaca	6	12	49	6	18	97
Pertusaria pertusa	3	6	25			
Pertusaria sp.	1	1	5			
Phlyctis argena	1	1	1			
Porina sp.				2	3	13
Porina borreri				1	1	10
Porina aenea				4	7	17
Pyrenula macrospora	1	1	1	7	24	166

Nsu = is the number of sampling units in which the taxon was recorded;
Trees = is the number of trees on which the species was recorded;
F = is the number of quadrat squares, in which the species occurred (maximum frequency possible: oak woodland = 320, ash-hazel woodland = 280).
★Taxa *Arthonia* sp., *Pertusaria* sp. and *Porina* sp. were not identified to species level and may already be included in the table, therefore they were omitted from the counts.
Taxa *Lecanora* sp. and *Opegrapha* sp. differ from those species already identified in the table and therefore were included in the counts.
All sorediosо–leprose crustose lichens were grouped under taxon *Lepraria* sp. This taxon was included in the counts.

(Table 1). According to the Sørensen coefficient the similarity in species composition between oak and ash–hazel woodland was relatively low at 36.7%. This may in part relate to substrate differences as noted by Rose (1974). Indeed, Rose (1974) has reported a considerably greater number of lichen taxa (303) on native oak trees than on ash trees (230 lichen taxa).

COMPARISONS WITH OTHER BROADLEAF WOODLANDS

The measure of the LD scale and the composition of epiphytic lichens in Knocksink woodlands can be appreciated when it is compared with other similar Irish broadleaf woodlands. At Knocksink a total of 41 lichen taxa (30 on trunks and 11 on twigs and branches) were recorded on studied trees. This contrasts with a total of 47 lichen taxa (3 on trunk; 7 on trunk, boughs, branches, twigs; 37 on twigs and branches) recorded on a single oak tree in Brackloon Wood, County Mayo (Fox *et al*. 2001). Similarly, a total of 57 epiphytic lichens were reported on deciduous trees at Union Wood, County Sligo, and more than 72 species were recorded at Slish Wood, County Sligo (Alexander *et al*. 1989). Clearly compared to these other broadleaf woodland sites Knocksink Wood has a lower number of epiphytic lichens. Similarity in species composition between the epiphytic lichen flora of Knocksink and these other woodlands is also low. Indeed, applying the Sørensen coefficient to the data of Fox *et al.* (2001) for Brackloon Wood gives a similarity value of 32.31% which is relatively low.

Closer to Knocksink Wood in County Wicklow is the Powerscourt Waterfall woodland, which is located along the Dargle river valley at Enniskerry (GR02012). This woodland was selected for comparison with the woodlands at Knocksink because it is a broadleaf woodland with a similar environment (sheltered river glen) and because it was known to have several rare ancient forest lichen species (Cullen and Fox, pers. comm.). At Powerscourt Waterfall woodland a total of 36 lichen taxa were recorded on the trunks of six trees (four sycamores, two oaks) (Brodekova 2005, unpublished data). This score is similar to the number of epiphytic lichen taxa recorded in the woodlands at Knocksink (30). However, the Sørensen coefficient indicated a clear floristic difference between these two sites (similarity was expressed as 30%).

ENVIRONMENTAL CONDITIONS IN KNOCKSINK WOOD

The oak and ash–hazel woodlands at Knocksink have been classified with a relatively low level of epiphytic lichen diversity and some evidence of environmental disturbance. Differences in species richness, evenness and composition between oak and ash related lichen species were observed. The pattern of diversity of epiphytic lichens at Knocksink Wood is driven by many environmental factors. Indeed, the range of parameters within broadleaf woodlands influencing epiphytic lichen development has been well recognised (James *et al*. 1977; Coppins 1984; Hawksworth *et al*. 1984; Broad 1989; Orange 1994; Wirth 1995a; 1995b; Humphrey *et al.* 2002; Will-Wolf *et al.* 2002; Hauck 2005). Some of the more significant parameters which influence epiphytic lichens in the oak and ash–hazel woodlands at Knocksink include: tree species and bark roughness; competition; bark pH; nutrient availability; light; water; air quality; past woodland management practices; and contemporary human impacts.

Table 2—LD interpretation scale showing LD value ranges of sampling units and the corresponding LD interpretation subclasses (adapted from Asta *et al*. 2002a; 2002b). The location of sampling units on the map of Knocksink Wood is marked in Fig. 1.

LD interpretation class	*LD interpretation subclass*	*LD scale (LD values)*	*Oak wood units (location numbers)*	*Ash–hazel wood units (location numbers)*
1. Very high	very high	>81		
2. High	high to very high	71–80		
	high	61–70		
3. Moderate	moderate to high	51–60		15
	moderate	41–50		9
4. Low	low to moderate	31–40		10, 11
	low	21–30	1, 3, 4,	12, 14
5. Very low	very low	11–20	2, 5, 6, 8	13
	extremely low	0–10	7	

These can be considered under the three broad headings of substrate and competition, resource inputs and management.

Substrate and competition

The nature of the substrate on which lichens grow has considerable influence on the diversity and abundance of lichen species that arise in a woodland. The majority of oak trees in the oak woodland at Knocksink have a relatively rough bark surface with consequently a greater potential to hold moisture when compared with the smoother bark of ash trees in the ash–hazel woodland. A higher moisture holding ability promotes development of other epiphytes, especially mosses and climbing ivy. Indeed, the occurrence of moss and ivy was observed as greater on oak trees in the oak woodland than on ash trees in the ash–hazel woodland. Such a reduced level of competition between lichens and other epiphytes on the ash trees encourages the development of lichen species and leads to greater abundance. Clearly, certain substrate conditions favour development of some species more than others and this may be reflected in the greater abundance of lichen taxa such as Arthonia, Opegrapha and Pertusaria on the relatively smooth barks of the ash trees (Table 1). It is also recognised that rougher bark, as found on the oak trees, provides a better habitat for the development of a wider spectrum of lichen species at Knocksink, which is in agreement with the findings (Table 1).

Another important substrate parameter is the pH of the bark. It is well known that the pH of bark has a strong influence on epiphytic lichen development (Rose 1974; James *et al.* 1977; Coppins 1984; Kricke 2002). The dominance of acidophytic lichen taxa (e.g. *Arthonia*, *Lepraria*, *Opegrapha*) in the general epiphytic lichen flora at Knocksink clearly reflects the acidic character of the bark of the oak and ash trees in the woodlands.

Resource inputs

The development of lichens depends on the range of nutrients and environmental conditions in the ecosystem. The relative poverty of the epiphytic lichen flora at Knocksink Wood when compared with that at Brackloon Wood, County Mayo (Fox *et al.* 2001), Union and Slish Woods, County Sligo (Alexander *et al*. 1989) and Powerscourt Waterfall woodland, County Wicklow (Brodekova 2005, unpublished data) may in part be related to the setting of these woodlands. Knocksink Wood represents a sheltered river glen where the deep narrow valley has a strong tendency to limit light availability to the tree trunks and consequently development of light demanding epiphytic lichens.

The river running along the valley floor promotes a relatively higher level of humidity within the immediate environment and modifies fluctuations in the atmospheric moisture content at the sites. Higher levels of humidity also promote the growth of a wider range of other epiphytes, including mosses, liverworts and ivy, which all compete with lichens for available resources.

Traditionally air quality has been recognised as one of the main factors influencing development of lichen species. The presence of lichen species associated with good air quality, e.g. *Evernia prunastri*, *Melanelia subaurifera*, *Ramalina farinacea* and *Usnea subfloridana* (Richardson 1992) in the tree canopy at Knocksink wood indicates relatively good air quality. Consequently, level of air quality does not have a significant influence on the relatively low numbers of epiphytic lichens at Knocksink.

Management

The age and undisturbed character of a woodland is often positively correlated with greater epiphytic lichen flora. From an examination of the 1840 Ordnance Survey map for Knocksink Wood, it is evident that broadleaf woodland extended in a narrow strip along the river (contiguous with part of the existing ash–hazel woodland) and over the south-eastern corner of the current woodland (contiguous with the existing oak woodland). The 1910 Ordnance Survey map for the same site shows woodlands covering a wider area broadly consistent with that observed today. This would suggest that the selected study sites probably represent some of the oldest parts of Knocksink Wood. However, this is not consistent with the relatively low numbers of lichens observed. This in turn may be related to the current sizes and growth forms of trees within the woodland, which suggest a level of human management or interference over time. Indeed, clear evidence exists of coppicing of ash trees within the ash–hazel woodland where ash trees have an average girth of 90.7cm. This has a direct effect on the age profile of the ash tree trunks in the ash–hazel woodland and consequently the epiphytic lichen maturity and richness. In contrast, oak trees in the oak woodland did not show evidence of such management practices (average oak tree girth was 177.5cm), and the more undisturbed character of the oak woodland may in part explain the relatively higher richness of epiphytic lichens compared to the ash–hazel woodland.

The woodlands at Knocksink Wood are one of the most visited woodlands in Ireland accommodating over 7,000 visitors per annum (National Environmental Education Centre 2005, pers. comm.). Knocksink Wood is used for both educational and recreational purposes. The location

of the oak and ash–hazel woodlands close to the visitor centre and parking area in the woodland probably leads to these areas receiving a greater share of visitors than other more remote regions of the woodland. This creates an environmental pressure on the ecosystem, enhances disturbance and contributes to the relatively low diversity of epiphytic lichens.

CONCLUSION

The results of this research suggest that the European guideline for mapping lichen diversity in mainland Europe has applicability in the Irish setting and can detect differences between woodland habitats in terms of epiphytic lichen distribution. Oak trees in the oak woodland were richer in lichen flora on the trunk area than ash trees in ash–hazel woodland. However, the epiphytic lichens in the ash–hazel woodland showed a higher LD score than that in the oak woodland at Knocksink Wood. Based on the recorded epiphytic lichens and LD values generated, the quality of the natural environment in Knocksink Wood was assessed as relatively low. This has been further corroborated by comparison with the epiphytic lichen flora of other broadleaf woodlands in Ireland. This outcome is largely the result of the unique setting of Knocksink Wood and the human input. This research advances understanding of the factors that drive the sensitive and dynamic patterns observed for epiphytic lichen abundance and distribution in Irish broadleaf woodlands and forms a base for future environmental monitoring studies.

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