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An Assessment of Epiphytic Lichens, Lichen Diversity and Environmental Quality in the Semi-natural Woodlands of Knocksink Wood Nature Reserve, Enniskerry, County Wicklow

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MPhil

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School of Spatial Planning

An Assessment of Epiphytic Lichens, Lichen Diversity and Environmental Quality in the Semi-natural Woodlands of Knocksink Wood Nature Reserve, Enniskerry, County Wicklow.

MPhil

January 2009

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An Abstract of the Thesis

This research work adapted and applied a recently developed method for assessing epiphytic lichen species diversity to the Irish semi-natural woodlands of Knocksink Wood Nature Reserve, Enniskerry, County Wicklow. The study focused on the differences that arise in relation to acidophilous oak woodland (*Blechno-Quercetum petraeae*) versus ash-hazel woodland (*Corylo-Fraxinetum*). The research also addressed differences in relation to the mixed oak-ash-hazel woodland located in Knocksink Wood and the neighbouring woodland at the Powerscourt Waterfall. The frequency of occurrence of lichen species on a defined portion of tree bark was used as an estimate of diversity and to evaluate the degree of environmental stress on the sensitive lichen community. In total 52 lichen taxa were recorded on the trees in the woodlands in Knocksink Wood. The sequence of lichen numbers recorded per tree genera in Knocksink Wood was oak > ash > willow > beech > sycamore. The oak trees in the oak woodland were richer in lichen flora on the trunk area (35 lichen taxa) than the ash trees in the ash- hazel woodland (24 lichen taxa). Very low lichen diversity (LD) values were recorded in the oak woodland and the oak-ash-hazel woodland and a higher LD was recorded in the ash - hazel woodland. The overall pattern for Knocksink demonstrated low diversity of epiphytic lichens. 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 had been further corroborated by comparison with the epiphytic lichen flora of other broadleaf woodlands in Ireland. The unique setting of Knocksink Wood in a sheltered river valley and human input were identified as the main factors influencing development of epiphytic lichens in Knocksink Wood. The most significant parameters influencing epiphytic lichen development at trunk level in the woodlands at Knocksink were tree species, age profile and diversity of woodlands, bark properties and light availability, past woodland management and contemporary human input. The results of this research suggest that the European guideline for mapping lichen diversity developed in mainland Europe has applicability in the Irish setting and can detect differences between woodland habitats in terms of epiphytic lichen distribution. 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.

Declaration

I certify that this thesis which I now submit for examination for the award of Master of Philosophy, is entirely my own work and has not been taken from the work of others save and to the extent that such work has been cited and acknowledged within the text of my work.

This thesis was prepared according to the regulations for postgraduate study by research of the Dublin Institute of Technology and has not been submitted in whole or in part for an award in any other Institute or University.

The work reported on in this thesis conforms to the principles and requirements of the Institute's guidelines for ethics in research.

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Signature ___________________________________ Date _______

Candidate

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Abbreviations

AD	Anno Domini (in the Christian era)
ANPA	Agenzia Nazionale per la Protezione dell’Ambiente
ASI	Area of Scientific Interest
BC	Before Christ
BP	Years before present
CBD	Convention on Biological Diversity
CO	Carbon monoxide
Coillte	State forestry company in Ireland
E	East
EA	Environmental Alteration
EEC	European Economic Community
EU	European Union
F	Frequency
FIPS	Forest Inventory and Planning System
FMU	Forest Management Unit
FWS	Forest and Wildlife Service
HA	Hectares
IAP	Index of Atmospheric Purity
IAP_{18}	Index of Atmospheric Purity ‘18’
IHI	Index of human impact
ILD	Index of Lichen Diversity
IWA	Absent phase
IWB	Beginning phase
IWC	Climax phase
IWD	Degradation phase
IWF	Finish phase
LBI	Lichen Biodiversity Index

LB	Lichen biodiversity
LD	Lichen diversity
LDV	Lichen diversity value
LDVs	Lichen diversity values
LGW	Luftgütewert (air quality values)
N	North
NBSAP	National Biodiversity Strategy and Action Plan
NH_3	Ammonia
NHA	Natural Heritage Area
NIEC	New Index of Ecological Continuity
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NP	National park
NPMR	Non parametric multiple regression
NPWS	National Parks and Wildlife Servise
pH	Measure of acidity or alkalinity of a material when dissolved in water.
pNHA	Proposed Natural Heritage Area
REPS	Rural Environment Protection Scheme
RIEC	Revised Index of Ecological Continuity
S	South
SAC	Special Area of Conservation
SACs	Special Areas of Conservation
SNHM	Scottish Natural Heritage Management
Sp.	Singular for species
Spp.	Plural for species (more than one species)
SPA	Special Protection Area
VDI	Verein Deutcher Ingenieure
W	West

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1. INTRODUCTION

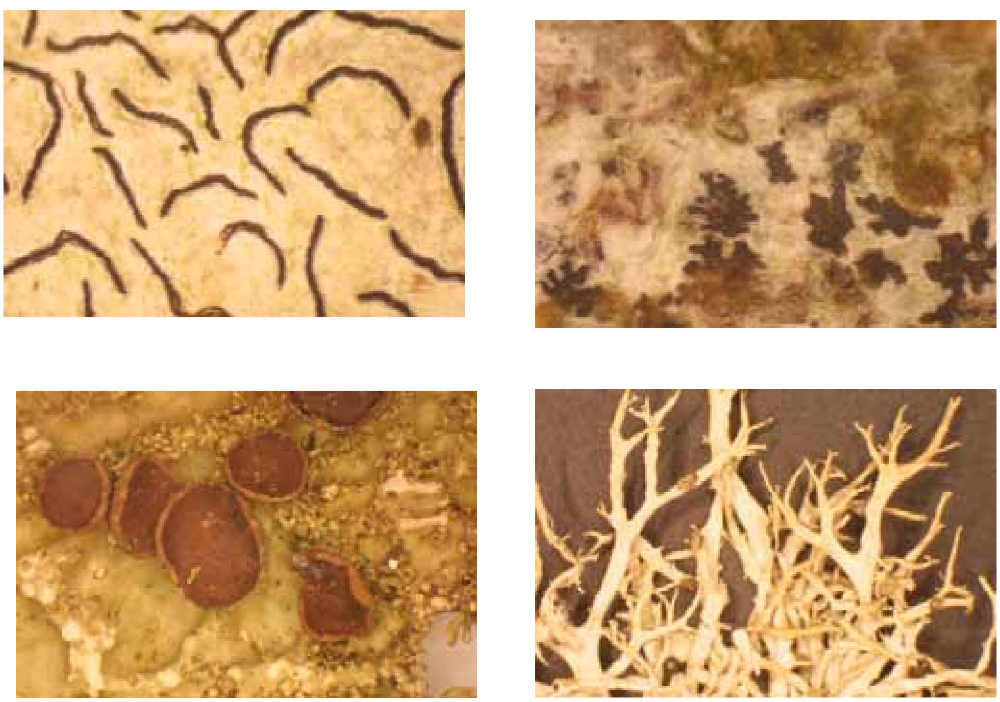
1.1 Definition and classification of lichens

From Latin 'līchēn' means 'a kind of plant'. 'Lichen' (lie 'ken) was introduced into Greek literature about 300BC by Theophrastus primarily to describe outgrowths from the bark of olive trees, and this is the first written record on lichens (Howksworth and Hill 1984). Up to the end of the 16^{th} century, descriptions of lichens were entirely based on their physical appearance and were often incorrectly described as types of mosses or seaweeds. However, the advent of microscopes in the beginning of 18^{th} century enabled detailed anatomical studies of lichens, which revealed their special dual character consisting of algal and fungal partners. This led to a series of more refined definitions. Schöller (1997) described how in the 18^{th} century lichens on the bark of trees and rocks were recognised as physically joined algae and filaments of fungi. Indeed, this dual character of lichens was recorded as comprising algae and fungi living in a symbiotic relationship. This symbiotic description provided a more specific explanation of the living arrangement between both partners.

The difficulty in finding a universal definition for 'lichen' results from the variability of fungal-algal associations and the range of symbiosis. A number of definitions of lichens are provided in contemporary literature (Hawksworth and Hill 1984, Orange 1994, Purvis 2000, Ulloa and Hanlin 2002, Wolseley *et al*. 2002, Allaby 2004, Gilbert 2004, Lawrence 2005). However, the interpretation of lichen as an association of two organisms living in symbiotic relationship seems to be the most common dimension of these definitions. Indeed, in the Ainsworth and Bisby's Dictionary of the Fungi (Kirk *et al*. (eds.) 2001) lichen is defined as a stable self-supporting association of a fungus (mycobiont) and an alga or cyanobacterium (photobiont). More precisely, lichen is described as an ecologically obligate, stable mutualism between an exhabitant fungal partner and an inhabitant population of extracellularly located unicellular or filamentous algal or cyanobacterial cells (Kirk *et al.* (eds.) 2001).

Commonly lichen consists of a fungus and a photosynthetic alga or blue-green alga (cyanobacterium). The photosynthetic partner produces food for the whole lichen and the fungus provides a stable, protective environment for its alga. The fungus forms the main lichen body of the lichen, and in most cases, the alga lies in layers between upper and lower fungal cortex. Many lichens have a remarkable tolerance to drying out, during which state they can survive extremes of heat and cold and tolerate being scorched by the sun in summer months, yet also survive ice and snow, and are therefore able to grow higher up in the mountains than other plants. Irish lichens are many colours: white, grey, black, yellow, orange, sulphur, apple-green, pinc or scarlet. Most grow as crusts (crustose), some are leafy (foliose), while others are shrubby (fruticose) (Figure 1.1).

Figure 1.1 Crustose *Graphis scripta* (x 14) and *Arthonia radiata* (x 23), foliose *Lobaria pulmonaria* (x 7) and fruticose *Ramalina farinacea* (x 7).



Lichens are completely different from the mosses and liverworts with which they often grow. The upper surface of many lichens bears special structures which appear as miniature pots, or volcanoes with a minute pore at the tip. Some are brightly coloured, others more muted, and many are black. All these structures are known as 'fruit bodies' as they forcibly discharge tiny spores, which become airborne (Figure 1.2 and 1.3).

Figure 1.2 Fruit bodies of *Parmelia saxatilis*, apothecia, (x 20) and *Pertusaria pertusa*, perithecia (x 27).

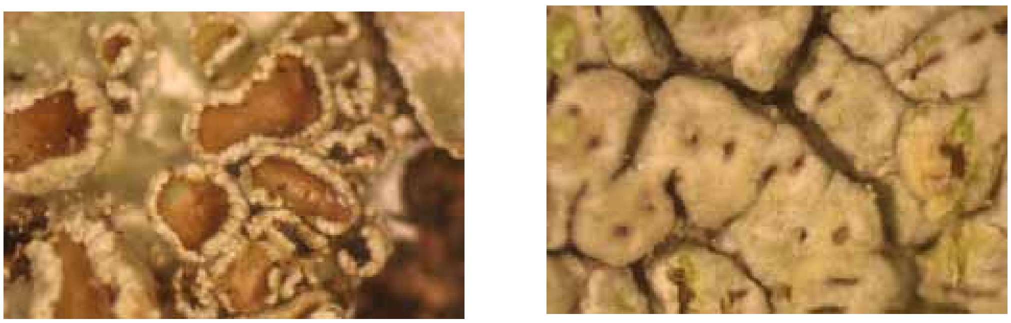
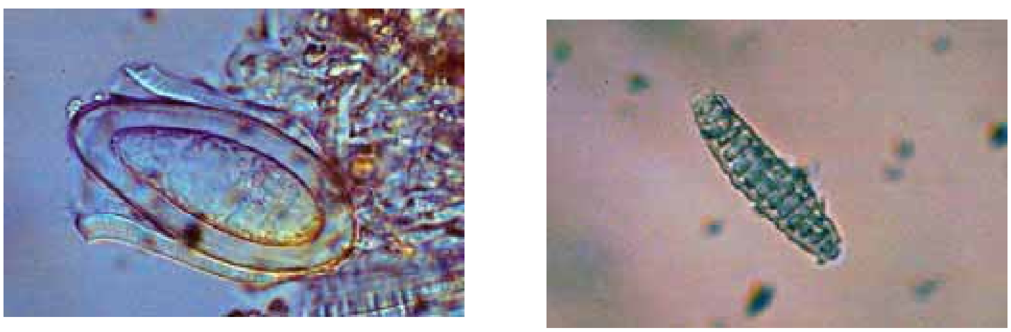


Figure 1.3 Spora of *Pertusaria hymenea* (x 400) and *Thelotrema lepadinum* (x 400).



Spores need to meet the right algal partner before they can form a new lichen therefore this type of reproduction is unreliable. Many lichens increase their chance of successful reproduction by producing special parts that become detached and grow into a new plant (propagules) containing both alga and fungus. The most common are powdery structures (soralia) that develop as pustules on the upper surface. These release small clumps of algal cells (soredia) held together by a web of fungal threads (hyphae). The other structures for vegetative reproduction, also unique to lichens, are isidia and they contain both alga and fungus (Gilbert 2004).

Lichens do not have independent scientific names; the fungal and photosynthetic partners each have separate names, and names given to lichens are considered as referring to the fungal partner alone. The classification of lichens is therefore integrated into the system of Fungi. Current nomenclature is consistent with the recognition of lichens as a nutritional rather than a taxonomic group. The nomenclature of fungi including lichen–forming fungi is governed by the international code of botanical nomenclature (Kirk *et al.* (eds.) 2001).

1.2 Research background

Ireland's climate is mild and its geology is exceptionally diverse. The extended coastline and large expanse of territorial waters have contributed to its extraordinary maritime and marine diversity, while the montane areas concentrated near the coast, rather than along a central spine created circumstances for the development of extensive and diverse freshwater wetlands. Among the features of international importance are the unique juxtapositions of Mediterranean flora (and fauna) with species of colder climates, the extensive coverage of peat lands, and the exceptional range of coastal and wetland bird species in summer and winter. Some of the habitats for which Ireland is most famous, such as the machair of the west and northwest coast and the limestone pavement, are the result of the interaction of nature with an agricultural regime that stabilized in post-famine times. Presently, habitat degradation and loss constitute the main factors eroding biodiversity (Anon. 2002a). Woodland is the rarest of the major habitat types in Ireland (Anon. 2002b). The total area of land under forests in Ireland is relatively small (around 15%). The predominant reliance on non-native conifer species in the afforestation programmes has had major implications for biological diversity of forests in Ireland. There is a recognized need for biodiversity conservation in all stages of the forestry cycle, planning, planting or management. In particular, preventing any damage to the most important sites for biodiversity is needed and avoiding damage to other sites, habitats and features which are important. Planting and managing forests should maximize their value for biodiversity. A special attention is needed to the conservation of the remaining semi-natural woodlands. Most of Ireland's semi-natural woods are relatively small, fragmented and widely scattered (Anon. 2002b). In recent years, concern about the loss of lichen diversity in connection with forest management and forest fragmentation has led to many studies assessing and monitoring the patterns and trends of lichen biodiversity in forests (Rose 1974, Seaward 1975, James *et al.* 1977, Howksworth and Hill 1984, Coppins 1984, Alexander *et al*. 1989, Broad 1989, Cullen and Fox 1999, Wolseley and Pryor 1999, Gilbert 2000, Fox *et al.* 2001, Coppins and Coppins 2002, Rose and Coppins 2002, Humphrey *et al.* 2002, Will-Wolf *et al*. 2002, Higgins *et al.* 2004, Hauck 2005, etc.). Forest environments are an important refuge for lichens. Knowing which factors influence lichen diversity improves understanding of lichens' development requirements and helps to identify forest management techniques with lesser negative impact on lichen diversity. It is generally known that the undisturbed character of woods and persistent ecological continuity are important for lichen diversity (Rose 1974, Rose and Coppins 2002, Coppins and Coppins 2002, Rose and Coppins 2002).

This research focuses entirely on lichens growing on trees, so called epiphytic lichens. Epiphytic lichens are extremely sensitive to environmental perturbations. Epiphytic lichens have been identified as valuable 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 (2001). 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 with stress creating factors, such as atmospheric pollution, eutrophication, and climate change. The European Guideline presents the first attempt to develop a unified guideline with application at European level with aim to provide a repeatable and objective strategy for mapping lichen diversity as an indicator of environmental changes.

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 and Coppins 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 semi-natural woodlands at Knocksink Wood Nature Reserve. This research focuses on the differences that arise in relation to epiphytic lichens in woodland habitat categories within Knocksink and aims to advance understanding of the factors that drive the sensitive and dynamic patterns for epiphytic lichen abundance and distribution in Irish broadleaf woodlands.

2. LITERATURE REVIEW

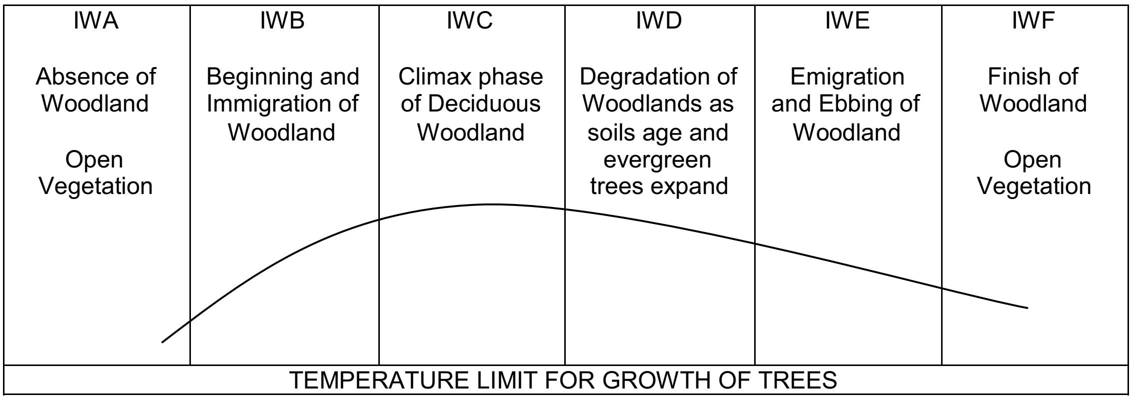
2.1. History of woodland development in Ireland

Over 12,000 years ago, Ireland was joined to Britain and both landmasses were a peninsula of continental Europe, connected by the great ice sheet several miles deep, an epoch referred in history as the Pleistocene ice age. The climate gradually warmed and the glaciers retreated giving rise to the next epoch called the Holocene. This represents an interglacial in the current ice age and began approximately 11,550 BP. After the ice cap melted, Ireland became, first, a country of tundra and, then of grasslands (Mitchell and Ryan 1997, Hickie 2002). Woodland development giving rise to the tree species we know today began as a process of trees migration from Europe into Britain and Ireland during Holocene. The process of woodland development can be divided into five phases: (1) Absent phase (IWA), (2) Beginning phase (IWB), (3) Climax phase (IWC), (4) Degradation phase (IWD) and (5) Finish phase (IWF).

The Absence phase (IWA) was the first phase of vegetation development during this warm stage and during this phase closed woodland was absent from Ireland. The period during which woodland development began was characterised by tree immigration processes and was called the Beginning phase (IWB). This phase opened when the first pioneer trees in Ireland, the juniper (*Juniperus*), which led to an expansion of woodland that continued without interruption until high forests were established. At the beginning of the warm stage, sea level would still have been low and immigration from Europe into Britain and Ireland would have been easy. However, rising sea level gradually reflooded the old channels, drowning the land-bridges and eventually overland migration into Ireland was no longer possible. As a response to the warmer conditions deciduous woodlands composed of oak (*Quercus*), lime (*Tilia*) and elm (*Ulmus*) developed on deep forest soils in Ireland. The dominant tree types of the first woodlands in Ireland were oak, elm, ash, willow, birch, hazel, pine and alder, this was about 9500 BP (Mitchell and Ryan 1997). The climax of this phase was a time of tall deciduous woodlands on deep forest soils labelled as IWC, the Climax phase. Woodland composed of oak (*Quercus*), lime

(*Tilia*) and elm (*Ulmus*) was regarded as climax woodland. The climax phase of woodland stability – a hazel-oak-elm-alder phase was established about 5900 to 7000 years ago and persisted for about 2000 years until the elm trees were dramatically reduced by a wave of elm disease. As time progressed, leaching gradually reduced the fertility of the soils and there was a tendency to acidity and to a replacement of the deciduous trees by conifers and heath. A time of soil degradation leading to consequent degradation of the woodlands was labelled IWD, the Degradation phase. The cyclical fluctuations of the Ice Age began to draw the warm stage to a close and temperatures fell. Birch (*Betula*) and pine (*Pinus*) were eliminated from the woodlands. It was a time of ebbing of woodland and subsequent disappearance, named as IWE, the Ebbing phase. An increase in asperity of climate caused stagnation of further woodland development. The Finish phase was a time when the trees had fled to distant refuges and all vegetation was on the retreat (Mitchell and Ryan 1997, Hickie 2002). The dynamics of the climate changes and woodland development were interpreted in diagrams (Mitchell 1976, Tansley 1965). Mitchell (1976) shows successive phases of woodland development in relation to temperature fluctuations (Fig. 2.1).

Figure 2.1 Successive phases of woodland development in a warm stage. (adapted from Mitchell 1976).



Tansley (1965) related climatic periods with woodland development and human influence in a time frame from 9000 BC to the present in an instrumental diagram (Table 2.1).

Table 2.1 British post-glacial history (adapted from Tansley 1965).

	CLIMATIC PERIODS according to BLYTT and SERNANDER		FOREST VEGETATION etc.	HUMAN INFLUENCE ON VEGETATION	ARCHAEOLO-GICAL PERIODS
B.C.9000	SUBARCTIC	Cold & dry	Dryas vegetation		End of PALAEOLITHIC
8000	PREBOREAL	Fluctuations of Climate	Birch & Pine: some Hazel & Oak and a little Elm & Alder in eastern England.		
7000	BOREAL	Warm & dry	Birch and then Pine dominant Hazel maximum; Expansion of mixed Oak forest		
6000			Recession of Pine and great increase of Alder		MESOLITHIC
5000		"Climatic optimum"			
4000	ATLANTIC	Warm & wet	Mixed Oak forest dominant (Sphagnum vigorous in wetter climates)		
3000					
2000	SUB-BOREAL	Drier	Local increase of Pine & Yew Disappearance of Lime, Entry of scattered Beech	Extension of upland grassland under human influence: increase of agriculture	NEOLITHIC
1000			Bog growth checked		BRONZE AGE
0	SUBATLANTIC	Cool & wet	Formation of younger Sphagnum peat; Spread of Beech	. . . .	IRON AGE
A.D. 1000	RECENT	Warmer and drier		Increasing destruction of forest: great increase of agriculture & pasture spread of weeds of cultivation.	HISTORICAL PERIOD
2000					

2.2 Anthropic influences on Irish woodlands

A wealth of archaeological evidence (Mitchell and Ryan 1997) indicates that humans have been present in Ireland for a considerable time. Since the arrival of farming in Ireland approximately 6,000 BP during Neolithic times, humans have had a substantial impact on woodland clearance. The Neolithic farmers opened up clearings in the woodlands. Although these forests usually regenerated, the second growth forest differed from the primeval woodlands (e.g. ash and yew were favoured by the opening of the woodland canopy) (Mitchell and Ryan 1997). With the rise in agriculture, the changes in woodlands begun in the later Iron Age (300-450 AD). During the early Christian period in Ireland (c.400-800 AD), the landscape had been largely cleared of trees. Those native Irish woodlands that survived were mainly located in upland regions or on rocky soils, steep slopes or confined river valleys and gorges, making them inaccessible and inappropriate for any other land use. The greatest reduction in the expanse of native Irish woodlands occurred during the Tudor Plantations (1550-1700 AD) (Mitchell and Ryan 1997). Towards the end of this period (1698 AD), some recognition was given to the importance of woodlands through a series of acts of parliament promoting the planting of trees. Despite the efforts of the government (such as Acts of Parliament and grants to encourage tree planting from 1698 onwards and the planting of many 'Estate Woodlands') overall woodland cover continued to decline. This is mostly explained by the displacement of the native population onto marginal land (resulting from the 'plantations'), political unrest and the pre-famine population explosion. The Land Acts (1881, 1903 and 1909), which resulted in the compulsory transfer of lands from landlords to the State, lead to the clearance of more woodland as the dispossessed liquidized their assets (Higgins *et al.* 2004). More over, most of the woods vanished in World War I (over 80,000 ha) and less then 0.5% of Ireland was covered by forest. During World War II, once again there was wholesale felling of trees (Mitchell and Ryan 1997).

During the late 20th century the state embarked on an active policy for afforestation. A minimum cover of 1 million acres (405,000 ha) of forest was the target. By 1951, forest cover in the Republic of Ireland was 1.8%. However, most of the planting undertaken comprised non-native species and even native planting was often derived from foreign provenance. Sitka spruce (*Picea sitchensis*), Lodgepole pine (*Pinus contorta*), Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) were the most abundantly planted species. During the 1970s many state forests were opened to the public (Forest and Wildlife Service 1985) and their amenity and wildlife value became an issue. By 1985, one single species, Sitka spruce, accounted for almost half (49%) of state planting and broadleaved species only 5%. In 1985, a review of Irish woodlands concluded that 6% of the state (382,000 ha) was wooded (Review Group on Forestry 1985). 21% of this was privately owned, and 79% was held in public hands. The composition of the state forest was 49% Sitka spruce, 47% other conifer species and 4% broadleaved. Since the 1980s, Ireland's ratification of the Convention on Biological Diversity in 1996, increasing public concern over the environmental effects of coniferous block planting, and lobbying by various groups (*e.g.* The Tree Council of Ireland, Crann) has prompted Coillte (the state forestry body) to increase the proportion of broadleaved species planted. In 1999, it was estimated that 13,182 ha of the Coillte forest were under broadleaved species. Of this, beech accounted for almost 30%, oak for 22.6%, and ash for 17% (Coillte 1999). Given that most of the state plantations originated from the 1950s and 1960s, most plantations are today a maximum of 50 years old (Higgins *et al.* 2004).

2.3 Current status of native woodlands in Ireland

The most recent census of woodland cover in the Republic of Ireland was carried out as part of the Forest Inventory and Planning System (FIPS). FIPS has identified 571,344.5 ha of land in the State as being forested. Forest areas are classified into six woodland categories and the most abundant of these is 'conifer forest' (Table 2.2).

Table 2.2 Summary of the FIPS 1998 data set (adapted from Higgins *et al.* 2004)

Woodland Category	Area (ha)	% of Forest Area
Broadleaf forest	57,548.1	10.1%
Mixed forest	28,350.7	5.0%
Conifer forest	299,184.8	52.4%
Planting Grant Application	102,653.4	18.0%
Cleared	81,799.2	14.3%
Other forest	1,808.2	0.3%
Total	**571,344.5**	

Of the six FIPS categories, those that are most likely to contain native woodland are 'broadleaf forest' and 'mixed forest'. These two woodland categories cover 85,898.8 ha and constitute 15.1% of the total area of forestry in Ireland. None of the woodland present in Ireland today may be considered as wholly 'natural' as even the oldest woodland shows evidence of human activity and modification. The term 'native' woodland is therefore generally accepted to refer to broadleaved woodlands, comprised of native species that are not intensively managed (Higgins *et al.* 2004). A summary of putative native woodland in Ireland on a county basis was developed by Higgins *et al.* (2004) (Figure 2.2 and Table 2.3). County Wicklow is the fifth county with the largest cover of native woodlands.

Figure 2.2 The areas of putative native woodland in Ireland based on the FIPS 1998 data set (Higgins *et al.* 2004).

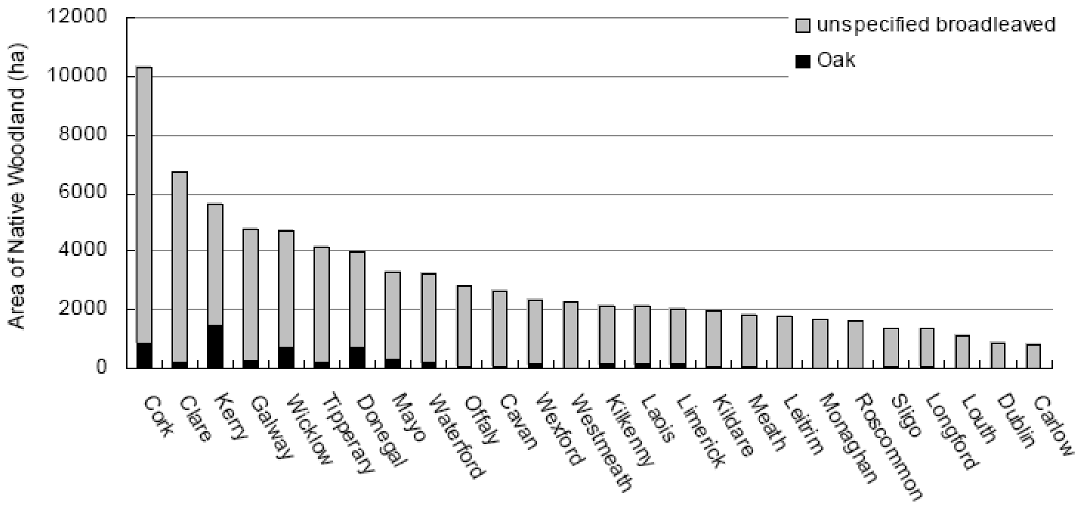


Table 2.3 Summary of the areas (ha) of putative native woodland and beech woodland in Ireland based on the FIPS 1998 data set (adapted from Higgins *et al.* 2004).

County	Oak (*Quercus* sp.)	Other broadleaves	Mixed woodland	Total area (excl. Beech)	Beech (*Fagus sylvatica*)
Cork	831.8	6150.9	3288.0	10270.7	629.4
Clare	202.0	4821.6	1677.0	6700.6	126.2
Kerry	1453.9	2677.7	1468.6	5600.2	12.3
Galway	240.0	2460.7	2047.9	4748.6	274.3
Wicklow	**692.6**	**1432.0**	**2559.4**	**4684.0**	**158.4**
Total Rep.of Ireland	5652.3	44491.8	26902.9	77047.0	3091.6

The area of county Wicklow is 202,400 ha and yet only 4684 ha are covered by native woodlands (Table 2.3). This indicates that numbers of natural and semi-natural woodlands in Ireland are limited (Mitchell and Ryan 1997, Cross 1998, Higgins *et al.* 2004). It is therefore important to understand and classify the ecological status and range of environmental pressures that these remaining natural and semi-natural woodlands face. It is only in the context of such understanding that it is possible to develop meaningful policy for their management and preservation.

2.4 Woodland conservation in Ireland

Ireland aims to conserve habitats and species through a designation of conservation areas. This is required under European and national laws. The Department for the Environment, Heritage, and Local Government is responsible for the designation of conservation sites in Ireland. The National Parks and Wildlife Service (NPWS, formerly Dúchas), has been responsible for the implementation of nature conservation (NPWS 2007). Woodland conservation is a relatively recent development in Ireland. The principal instruments of woodland conservation in the country today are the Wildlife Act (1976), the Wildlife (Amendment) Act (2000) and the European Union (Natural Habitats) Regulations 1997. There are four main designations relevant to woodland conservation: (1) National Park, (2) Nature Reserve, (3) Natural Heritage Areas and (4) Special Areas of Conservation. National Park represents the most strictly protected conservation area in Ireland. Nature Reserve is an area of importance to wildlife protected under Ministerial order. There are currently 78 Statutory Nature Reserves in Ireland, of which 33 contain woods of conservation value. The total area of woodland contained within these designated areas is 5,736 ha (O' Sullivan 1999 in Higgins *et al.* 2004). Natural Heritage Area (NHA) is the basic designation for wildlife and currently there are 630 proposed NHAs (pNHAs), which have not been yet statutorily designated. Proposed NHAs are subject to limited protection, e.g. in the form of Rural Environment Protection Scheme (REPS) plans and by Planning and Licencing Authorities. Special Areas of Conservation (SACs) are prime wildlife conservation areas in the country, considered important on a European as well as national level. Conservation management plans are available for many SACs. The SACs in Ireland cover an area of approximately 10,900 square kilometres, 67% on land and the remainder being marine or large lakes (Higgins *et al.* 2004).

2.4.1 Irish native woodlands

Nature conservation in general has gained increasing attention from all sectors in recent decades and this has resulted in the development of several initiatives of relevance to native woodland. The Biodiversity Action Plan was published in 2002, and proposes various actions to enhance the status of native woodland in Ireland. Coillte, the state forestry body has been pursuing a nature conservation strategy since 1999 with commitment to manage 15% of each Forest Management Unit with nature conservation as the primary objective. In addition, Coillte has adopted a policy of sustainable forest management and is working towards achieving certification from the Forest Stewardship Council (Higgins *et al.* 2004). Several initiatives have been developed recently for restoration of existing broadleaved woodlands and for the establishment of new native woodlands. These include the Peoples Millennium Forest organized by Woodlands of Ireland and the Native Woodland Grant Scheme administrated by the Forest Service (Higgins *et al.* 2004). The most recent national inventory of native woodland was carried out by Higgins *et al.* 2004. This survey identified all potentially native woodland sites in the country and provided important baseline data for monitoring.

2.4.2 Conservation of natural heritage in County Wicklow

It is recorded that up to the early 16th century, a vast expanse of oak woodland covered much of east Wicklow County (Griffiths 2003, Dúchas 2005). However, over time these woodlands have been considerably modified. There is evidence of the woods being coppiced between 1600 and 1800 AD. Many of the oaks were used as charcoal for iron smelting. During the Napoleonic Wars the oaks of Wicklow were felled for shipbuilding and in the early 1900's itinerant Lancashire clog makers worked in the area making clogs from alder and birch. The most recent changes have occurred since the 1950's when many of the native hardwoods were removed or replanted with conifers and County Wicklow was left with a mosaic of pure Sessile Oak and commercial plantations of conifers (Dúchas 2005). Despite extensive exploitation, there were still substantial areas of woodland left in County Wicklow (Doyle 2002).

The Wicklow County Council recognises that County Wicklow has a unique and valuable natural heritage. It is the aim of the County Development Plan to conserve and protect this heritage, and enhance it. Legislation governing conservation of natural heritage in County Wicklow includes: Planning and Development Act 2000, The Wildlife Act 1976, Wildlife (Amendment) Act 2000, European Commission Natural Habitat Regulations 1997, Birds Directive (Council Directive 79/409/EEC) 1979, Habitats Directive (Council Directive 92/43/EEC), Water Framework Directive (Council Directive 2000/60/EEC), Heritage Act 1995, The National

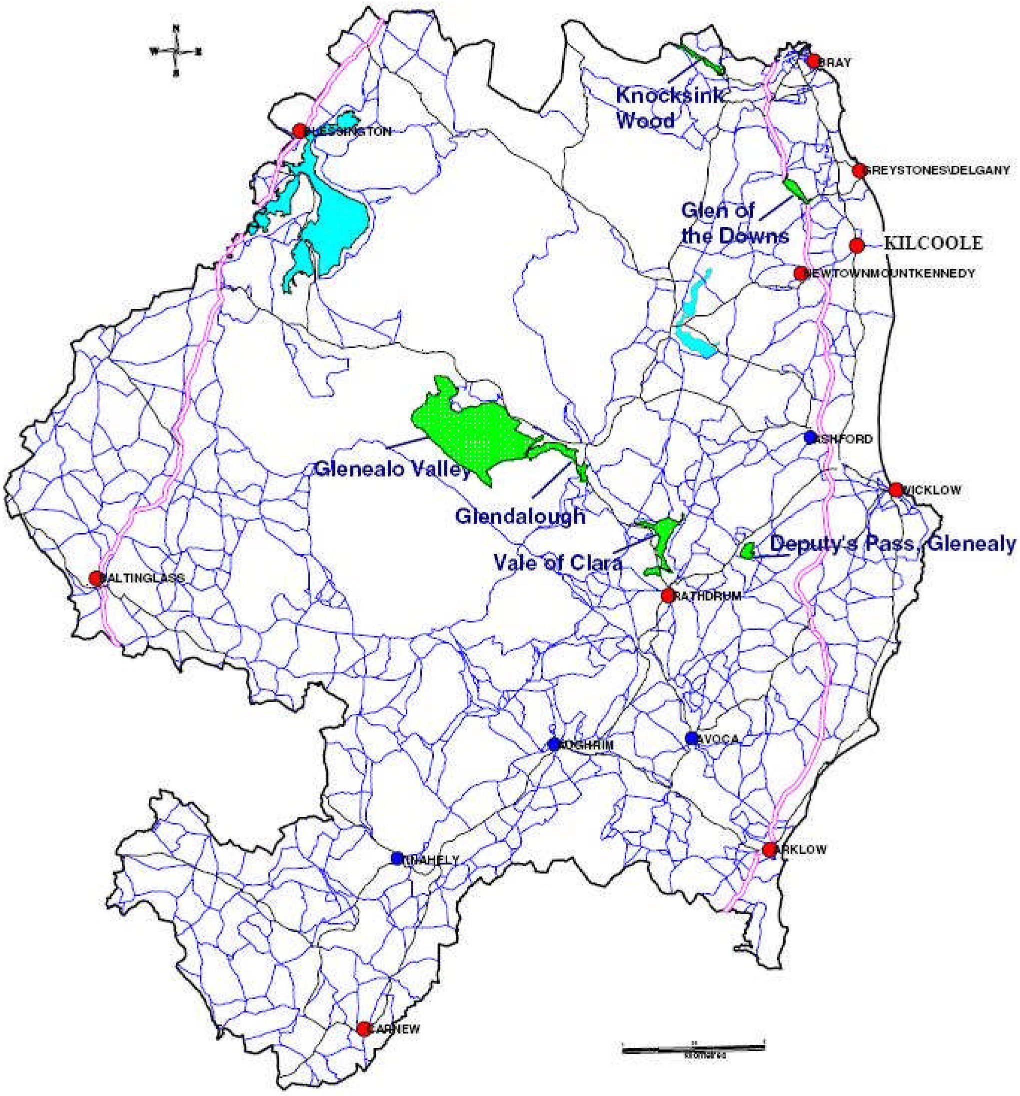
Heritage Plan 2002 and The National Bio-Diversity Plan 2002 (County Wicklow Development Plan 2004 – 2011).

County Wicklow has a rich and diverse natural landscape containing a diverse range of habitats including woodland, many of which are recognised as being of local, National and EU importance, and are designated under National and/or EU legislation. In total County Wicklow contains one National Park (Wicklow Mountains National Park), 13 Special Areas of Conservation (SAC), five (proposed and candidate) Special Protection Areas (SPA), 34 proposed Natural Heritage Areas and six Nature Reserves. The Wicklow Mountains National Park was established in 1991. The park occupies approximately 20,000 hectares of the county. The National Park is covered by Special Protection Area (SPA) and Special Area of Conservation (SAC) designations. There are six Nature Reserves in County Wicklow, of which five contain woods of conservation value (Table 2.4) (Figure 2.3).

Table 2.4 Description of Nature Reserves in County Wicklow (County Wicklow Development Plan 2004 – 2011).

Name of Nature Reserve	Characteristic of Nature Reserve	Owner -ship	Location	Size [ha]
Glen of the Downs	Sessile oak dry woods on acidic soil. Established 1980.	State	8km south of Bray	59
Deputy's Pass	Coppiced woodland. Established 1982.	State	Glenealy	47
Vale of Clara	Fragmented oak-woods. The largest semi-natural hardwood wood in County and nationally. Established 1983.	State	Eastern side of the Avonmore River	220.57
Glendalough	Oak woods extending from the Upper Lake to the lower slopes of Derrybawn Mountain. Established 1988.	State	Glendalough	157
Glenealo Valley	A broad open valley surrounded by mountains, which consists of a large plateau of mixed heathland and peatland. Established 1988.	State	To the west of Glendalough	1,958
Knocksink Wood	Sessile oak wood and mixed woodland, petrifying springs. Established 1994.	State	Glencullen river valley, Enniskerry	52.3

Figure 2.3 Nature Reserves in County Wicklow (County Wicklow Development Plan 2004-2011).



There are 13 SAC sites in County Wicklow, of which only four are woodlands, Knocksink Wood is one of them (Table 2.5).

Table 2.5 Special Areas of Conservation in County Wicklow (County Wicklow Development Plan 2004-2011).

Name	Number / Identification
Ballyman Glen	SAC 000713
Bray Head	SAC 000714
Carriggower Bog	SAC 000716
Deputy's Pass Nature Reserve	SAC 000717
Glen Of The Downs	SAC 000719
Knocksink Wood	SAC 000725
Buckroney-Brittas Dunes And Fen	SAC 000729
Vale Of Clara (Rathdrum Wood)	SAC 000733
Holdenstown Bog	SAC 001757

Table 2.5 continued	
Name	**Number / Identification**
Magherabeg Dunes	SAC 001766
Wicklow Mountains	SAC 002122
The Murrough Wetlands	SAC 002249
Wicklow Reef	SAC 002274

The summary of the expanse of semi-natural woodlands in Wicklow today is related to woodlands protected as Nature Reserves. Knocksink Wood is the second smallest Nature Reserve in County Wicklow and it is the youngest Nature Reserve in the county (established in 1994).

2.5 Threats to native woodland

Most of our semi-natural woods are relatively small, fragmented and widely scattered and woodland is the rarest of the major habitat types in Ireland (Anon. 2002b). The limited extent of this habitat type means that any clearance for development (e.g. road development) would have a proportionately high impact on the total native woodland resource. In addition to the vulnerability of these habitats caused by such rarity and fragmentation, there are several other issues which pose a threat to their conservation (Higgins *et al*. 2004). Ireland has a relatively poor flora, and it is estimated that approximately one third of the vascular plant species present are naturalised introductions (Webb 1982 in Higgins *et al.* 2004). Most of these species are relatively benign, and have little impact on the function of native ecosystems. Some, however are highly effective competitors, to the extent that they may out-compete native species and, to a lesser or greater extent, result in the degradation of native habitats. There are several such species that affect native woodland. Red osier dogwood (*Cornus sericea*) and Himalayan balsam (*Impatiens glandulifera*) are a particular threat to wet woodlands. In drier sites, cherry laurel (*Prunus* laurocerasus), rhododendron *(Rhododendron ponticum),* sycamore (*Acer pseudoplatanus)* and beech (*Fagus sylvatica)* are among the more widespread introductions, and have achieved local dominance in some places. Rhododendron is a particular threat because of the difficulties entailed in successfully clearing it from an area once serious infestation has occurred. While beech and sycamore are certainly widespread, and in some places abundant, their impact on the native vegetation is less well understood, and attitudes towards these species vary among woodland managers and ecologists (Higgins *et al.* 2004).

Grazing (including browsing) is a natural part of the woodland ecosystem (Putman, 1994 and Vera 2000 in Higgins *et al.* 2004, SNHM 2004). The continued expansion of introduced grazing species, particularly sika deer (*Cervus nippon* L.) and the intense grazing of woodlands by domestic stock, chiefly cattle and sheep, has reduced the field layer and limited the success of natural regeneration in some Irish woods (Higgins 2001, Hester *et al*.1998 in Higgins *et. al* 2004). Native woodland is also threatened by the underplanting of broadleaved stands with exotic species, mainly conifers and in some cases conifers and other exotics are being removed from within former native woodlands in order to reinstate the native habitat. In addition, in recent years there has been growing recognition of the need to preserve the genetic integrity of native species and many schemes (Native Woodland Grant Scheme, Peoples Millennium Forest) place emphasis on using not only Irish seed, but on sourcing it as locally as possible (Forest Service 2001 in Higgins *et al.* 2004). Despite the changes taking place in Irish woodlands, there are still numerous mature deciduous woodlands in County Wicklow on estates under private ownership, and as pockets within mainly coniferous woodlands under state ownership (Seaward 1975).

2.6 The importance of epiphytic lichens in woodland ecosystems

In recent years, concern about the loss of lichen diversity in connection with forest management and forest fragmentation has led to many studies assessing and monitoring the patterns and trends of lichen biodiversity in forests worldwide (Rose 1974, Seaward 1975, James *et al.* 1977, Howksworth and Hill 1984, Coppins 1984, Alexander *et al*. 1989, Broad 1989, Cullen and Fox 1999, Wolseley and Pryor 1999, Gilbert 2000, Fox *et al.* 2001, Coppins and Coppins 2002, Humphrey *et al.* 2002, Rose and Coppins 2002, Will-Wolf *et al.* 2002, Higgins *et al.* 2004, Hauck 2005, etc.). Forest environments are an important refuge for lichens. Knowing which factors influence lichen diversity improves understanding of lichens' development requirements and helps to identify forest management techniques with lesser negative impact on lichen diversity. Since it is generally known that the undisturbed character of woods and persistent ecological continuity are important for lichen diversity (Rose 1974, Rose and Coppins 2002, Coppins and Coppins 2002) this in turn facilitates the preservation of natural native woodlands.

Lichen communities only occasionally comprise a major portion of the biomass of a forest, but they play many ecological roles in forest ecosystems. Important among these roles are nitrogen fixation, nutrient cycling, and the provision of food and nesting material for wildlife (Will-Wolf *et al.* 2002). Cyanolichens, lichens containing cyanobacterial photobionts, contribute fixed nitrogen to forest nutrient cycles; this contribution is most important in moist forests. Nitrogen fixation is a particularly energy-demanding process and nitrogen can only be obtained from the atmosphere by utilising an abundant energy source, such as solar energy. There is a wide variation in the rates of nitrogen fixation in lichens and the most important factors are water content, irradiance, pH and temperature, and time of day and time of year. Lichens have low growth rate, which is associated with a low rate of net accumulation of mineral nutrients. Rainwater and run-off are expected to be sufficient for most lichens, although the substratum may also contribute minerals in some species. In addition, rain leaches nutrients from lichen thalli, particularly potassium and nitrogen. Lichens have the ability to absorb minerals intracellularly from dilute solutions, but the concentrations of nutrient in lichens vary considerably between species. Lichens interact with other organisms in a variety of ways, as sources of food, shelter or camouflage. Associations with invertebrates are particularly varied. Lichen-feeders can occur in large numbers in lichen populations and include springtails, psocids, oribatid mites, orthopterans and molluscs such as slugs. The most frequent lichen mimics include the *Lepidoptera* and about 30 European moths eat or mimic lichens. A wide range of ungulates such as reindeer and caribou can utilise lichens as a part of their diet (Howksworth and Hill 1984).

2.7 Factors influencing development of epiphytic lichens in forests

A large number of factors determine the development of particular assemblages of epiphytic lichens (Barkman 1958, Brodo 1981, Coppins 1984, Howksworth and Hill 1984, Broad 1989, Orange 1994, Wirth 1995 a, b, etc.). James *et al*. 1977 outlines the more important of these in the British Isles as the:

1) Degree of illumination;
2) Humidity of the environment;
3) Age of the bark surface;
4) Degree of corrugation of the bark;
5) Degree and rate of sloughing of bark;
6) Continuity and age of woodland cover in a particular site;
7) Inclination of tree;
8) Aspect;
9) Degree of bark leaching by rain;
10) Degree of impregnation of bark with organic nutrients;
11) Air pollution;
12) Soil pollution by agricultural chemicals;
13) pH of the bark surface;
14) Basic nutrient status of bark;
15) Presence of tannins, betulin or resins in the bark;
16) Moisture-retaining and absorbing properties of the bark.

The influence of these factors on lichen development in a given ecosystem varies. Broad (1989) suggests that the natural distribution of epiphytic lichens in woodlands of the British Isles is mainly influenced by the species of trees and microhabitats available. The most important microhabitat characteristics are humidity and availability of light through the canopy. In addition, general ecological factors such as climate, topography and geology as well as the prevailing land use, the extent of pollution, and the age and type of trees, influence the occurrence of lichens (Broad 1989, Orange 1994).

Coppins (1984) also emphasises the importance of the tree species suggesting that the structure of the epiphytic lichen community on a given tree is strongly influenced by the species of that tree as well as the specific location on the tree where growth occurs. The author also suggests that the other important parameters to be considered in studying lichen growth on trees in woodland are the:

- Topographical situation of the tree (including aspect, slope, etc.); and
- Exposure (e.g. isolated tree or sheltered by other trees, located on an exposed hill-top or at the bottom of a sheltered ravine).

In the diverse conditions that prevail in forest ecosystems, trees and their epiphytes are subjected to varying degrees of exposure in terms of light, temperature, humidity, physical abrasion and the drying effects of wind (Coppins 1984).

Will-Wolf (2002) suggests that forest age and the continuity of forest canopy are the critical factors for the development of epiphytic lichen communities. Indeed, forest structure affects lichen distribution through its influence on light and the moisture regime. Gaps with low shrubby substrates or low branches on surrounding trees are important for lichen growth. Such microhabitats provide both high moisture and direct light and represent diversity hotspots in moist forest climates. Forest edges differ from forest centres in both light and wind, which affect the moisture regime present (Will-Wolf 2002). Tree age, the size and age of gaps, standing dead snags and the size, age and quantity of downed woody debris are all important microhabitat characteristics for lichen growth. However, Will-Wolf (2002) also recognises that lichen communities in forests co-vary most closely with climatic variables such as precipitation, moisture status, temperature, and evapotranspiration.

There are a number of factors, which have been highlighted in the literature as having a special significance in terms of influencing lichen abundance in forest ecosystems. These include:

a) **Dead wood**

   The quantity of dead wood represents a particularly important host for epiphytic lichens in forests (Hauck 2005, Humphrey *et al.* 2002). Indeed, the significance of deadwood for lichen biodiversity in forests has only recently been recognised. Humphrey *et al.* (2002) note its importance for lichen species-richness in semi-natural woods and plantations.

b) **Air quality**

   Epiphytic lichen diversity differs between forests with a high degree of atmospheric pollution and those with a low pollution status (Hauck 2005). In forests with moderate or low atmospheric pollution the microclimatic factors (light, water availability, physical substrate properties, substrate age, stand history, and competition) were found to have a greater importance than in forests with high atmospheric pollution, where pollutants were the dominant factor.

c) Relative humidity

Lichen abundance is particularly sensitive to changes in relative humidity (Frahm 2003). Indeed, lichen habitats are characterized by 20-30% shorter wet phases and accordingly longer phases of desiccation than bryophyte habitats. Generally, lichens are present in higher numbers in the crowns of trees and bryophytes at the trunks. Fox *et al.* (2001) has reported that the location of lichens on trees is important in relation to relative humidity. Stems and trunks that rise perpendicularly from the ground tend to have a continuous cover of bryophytes. In contrast those growing at an angle to the ground have a denser cover of bryophytes on the wetter surface while lichens dominate on the drier surfaces. Lichens are more tolerant of desiccation, and require dry periods for the purposes of metabolism (carbon assimilation) (Fox *et al.* 2001).

d) Bark and pH

The nature of the bark is an important factor for epiphytic lichen development. The physical and chemical properties of bark vary between different tree species. Bark properties also vary on a single mature tree depending on the age of the bark. A range of bark related parameters include the presence of other epiphytes, nutrient status, water holding capacity, and buffer capacity all of which are important determinants of lichen development (Coppins 1984, Farmer *et al.* 1990, Larsen *et al.* 2006). However, the pH of the bark is one of the most significant parameters and has been studied intensively by various workers (Barkman 1958, James *et al.* 1977, Looney and James 1988 in Kricke 2002). Although bark is a solid material and cannot strictly have a pH, bark pH refers to the pH of unbuffered aqueous solution in contact with the bark (Kricke 2002). Barkman (1958) has reported on the kind of epiphytic communities that may be present on the bark of trees with different pH levels. The importance of bark pH has been further emphasised in the classification of British lichen communities by James *et al.* (1977). The pH of tree bark varies naturally between different species of trees (Table 2.6) and is also influenced by pollution (Orange 1994, Wolseley and Pryor 1999).

Table 2.6: Illustrating some typical pH values (Orange 1994).

Substrate	pH
Pine bark	3.4-3.8
Birch bark	3.2-5.0
Oak bark	3.8-5.7
'pure' rain water	5.6
Ash bark	5.2-6.6
Elm bark	4.7-7.1

2.8 Distribution patterns of lichens on trees

Lichens are colonisers of bark on trunks, branches and twigs. The early colonisers are frequently inconspicuous crustose or endophloeodal species (Broad 1989). Twigs carry species that are rapid colonisers. The microclimatic differences on different parts of a tree are very significant. The base of a tree is more shaded, less exposed to the effects of wind and consequently more humid than exposed uppermost parts of the trunk and branches. There are also major differences between the upper and lower sides of a branch, a leaning trunk and ridge-tops of rough bark (Coppins 1984). The underside of a leaning trunk may carry species that are adapted to very dry conditions (Orange 1994). Consequently, a given tree carries several different lichen communities on different parts of the tree according to the range of general ecological conditions and microhabitat variables prevailing. A model of the distribution patterns of lichens on trees could provide useful insights and aid understanding of epiphytic lichen population dynamics. Fox *et al.* (2001) has described the bark surfaces of trees as comprising four zones:

- Zone *a* comprises the bark on the tree trunk;
- Zone *b* represents the bark on boughs emerging from the main trunk;
- Zone *c* includes the branches; and
- Zone *d* is represented by the twigs.

Each zone is defined using the variation in epiphytic flora, their phytosociology and bio-geometric structures. Consequently, each zone has a strong biological and physical basis and supports different assemblages of lichens. This concept of compartmentalising a tree's surface facilitates the assessment of anthropogenic inputs such as forest management practices and pollution on epiphytic species population (Fox *et al.* 2001). Based on this concept diagrams showing the distribution patterns of lichens on trees and the associated natural succession of lichen communities were developed (Broad 1989, Rose 1974). Broad (1989) identified the main lichen communities, which develop on an oak (*Quercus*) over a period of time (5 – 40 years) in an unpolluted environment (Figure 2.4). In comparison Rose (1974) drew up a detailed sequence of lichen communities on oak and the change in lichen associations on oak over time considering also SO_2 pollution and nitrophication of the environment (Figure 2.5).

Figure 2.4 Natural succession of lichen communities on an oak tree in unpolluted lowland old forest (Broad 1989).

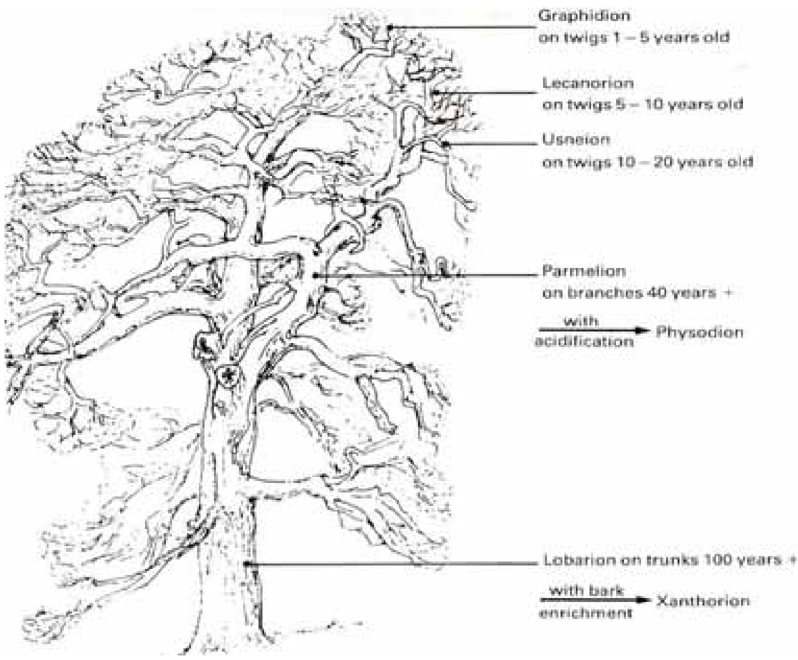
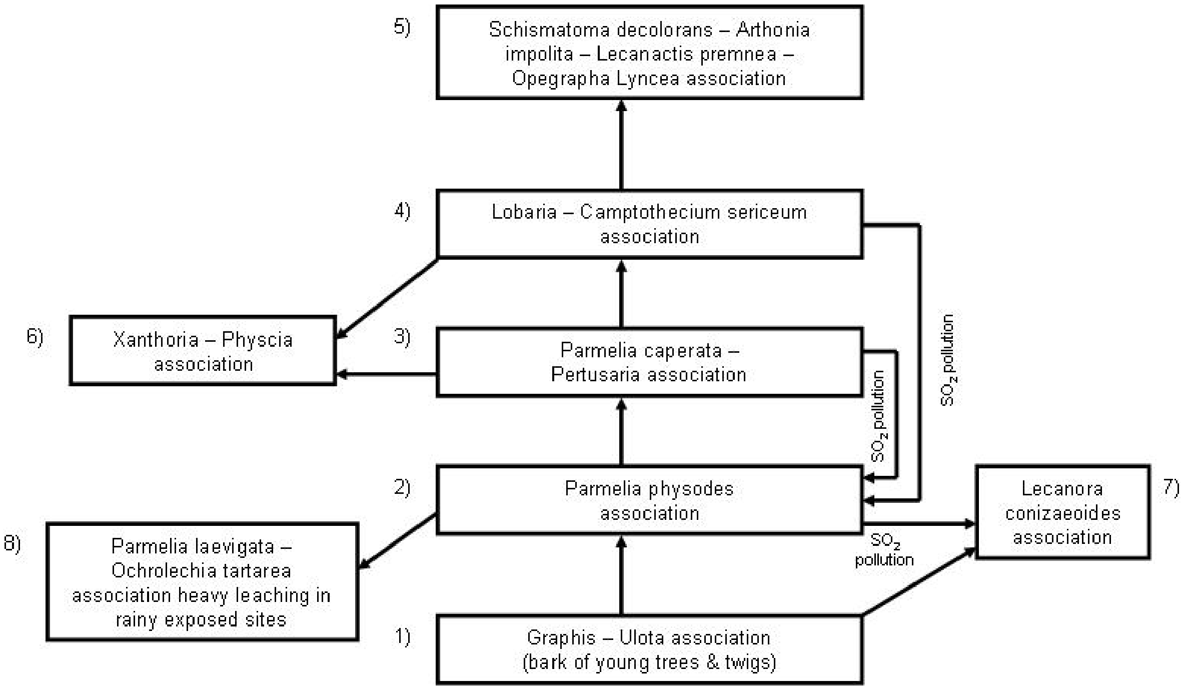


Figure 2.5 Change in association on *Quercus* with time (Rose 1974).

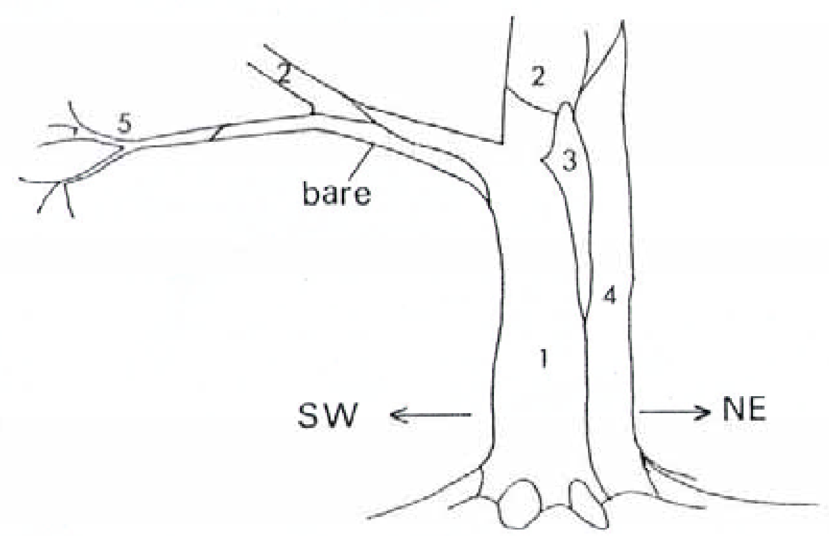


Rose (1974) studied epiphytes on oak in two different environments: open area and closed forest and further distinguished lichen communities on solitary oaks and oaks in forests.

2.8.1 Epiphytic communities in open situations

The epiphytic lichen communities for trees in open stand situations seem to present a definite spatial pattern. Rose (1974) has reported that mature oaks in open situations have the bulk of the associated lichens on the south to south-west of the tree, the side of the tree that receives most sunshine. The bulk of the precipitation striking the trunk tends to fall on the south-west side of the tree which is consistent with the prevailing wind direction for the British Isles. The north side of the tree tends to carry a more limited numbers of species, usually with a lower percentage cover, and these communities largely consist of crustose species (Figure 2.6) (Rose 1974).

Figure 2.6 Spatial patterns of epiphytic lichen communities on mature oaks in open situations (1 = *Graphis - Ulota* association, 2 = *Parmelia physodes* association, 3 = *Parmelia caperata - Pertusaria* association, 4 = *Lobaria - Camptothecium sericeum* association and 5 = *Schismatoma decolorans - Arthonia impolita – Lecanactis premnea – Opegrapha Lyncea* association (Rose 1974).

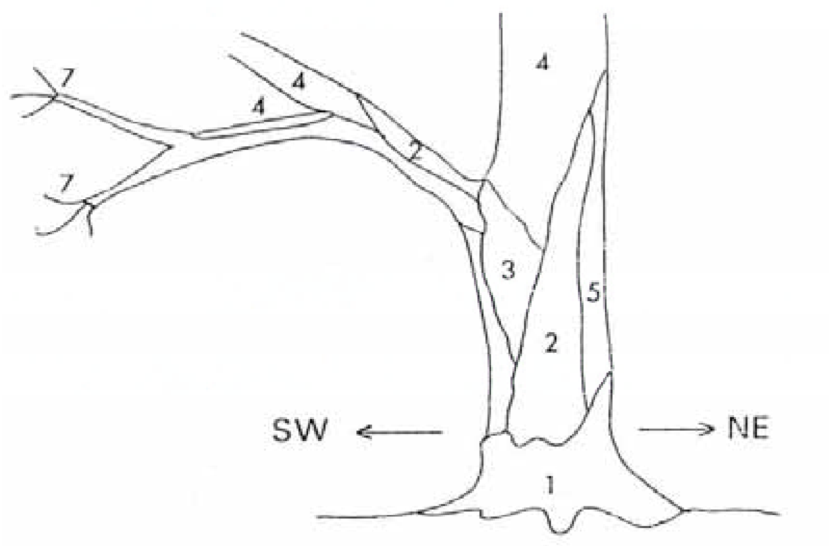


On pastures and farmyards, where farming activity produces higher levels of atmospheric nitrogen, the bark of trees becomes enriched by nitrophilous and species-rich communities of the alliance *Xanthorion parietinae*. Such communities are best seen on *Acer*, *Fraxinus*, *Populus*, *Sambucus* and *Ulmus*, whose neutral pH of bark becomes easily nitrophytic and to lesser extent on *Quercus* and *Tilia,* whose bark pH is naturally more acidic (Coppins 1984).

2.8.2 Epiphytic communities in forest situations

A different distribution pattern of lichen communities was recorded on mature oaks in forest situations (Figure 2.7). In forest situations, lichens dominate the south and south-west sides of the trunks, but bryophytes dominate on the north and north-east sides and on the roots. In sheltered forests, bryophytes may dominate the lower trunk completely, and lichens only occur higher up on the upper trunk and main boughs. This is especially true in humid and sheltered forests, where epiphytes occupy the upper sides of horizontal boughs with water accumulation. Bryophytes dominate the central parts of boughs and lichens occur towards the edges (Rose 1974).

Figure 2.7: Spatial patterns of epiphyte lichen communities on mature oaks in closed forest (1 = *Graphis - Ulota* association, 2 = *Parmelia physodes* association, 3 = *Parmelia caperata - Pertusaria* association, 4 = *Lobaria - Camptothecium sericeum* association, 5 = *Schismatoma decolorans - Arthonia impolita – Lecanactis premnea – Opegrapha Lyncea* association, 6 = *Xanthoria – Physcia* association and 7 = *Lecanora conizaeoides* association (Rose 1974).



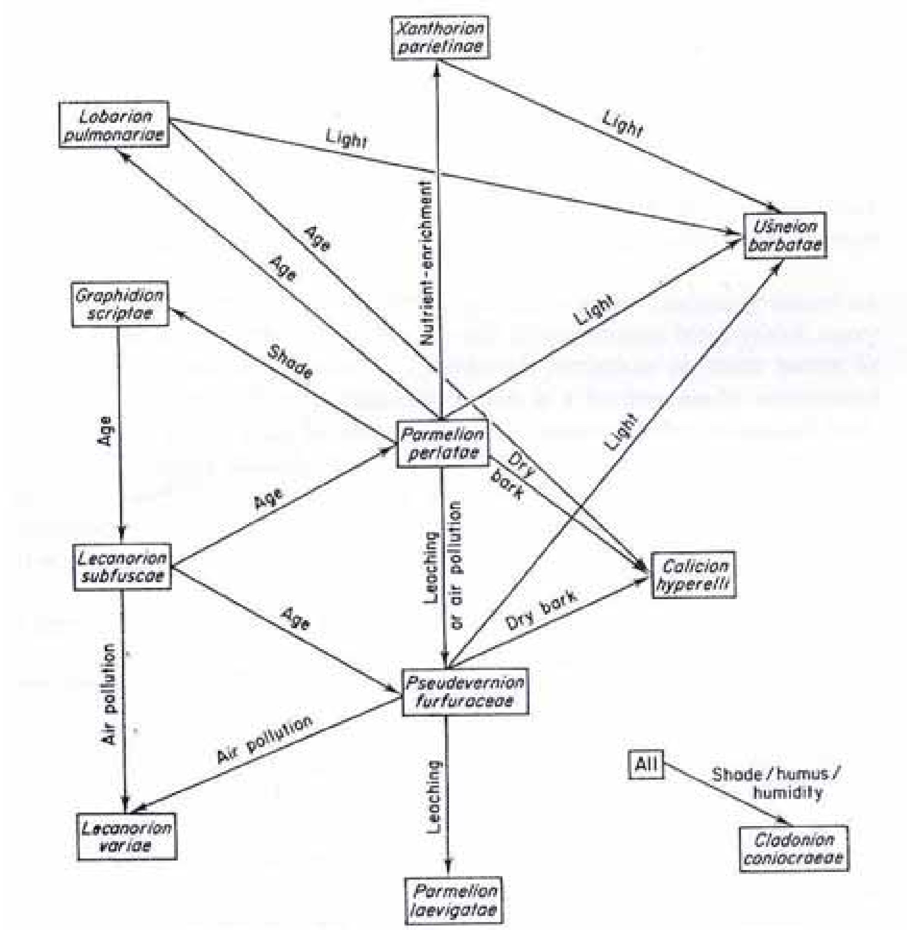
The climax vegetation on mature trees in old woodlands is generally considered to be the phytosociological alliance *Lobarion pulmonariae*, which is species-rich and includes many old woodland indicator species (Table 2.7) (James *et al.* 1977, Coppins 1984). The *Lobarion pulmonariae* is composed mainly of large foliose lichens and robust bryophytes and appears to be the natural forest climax community on mature hardwood trees with barks pH 5-6 in western Europe outside areas with Mediterranean climates. It is now very much fragmented in distribution due to the felling and management of primeval forests, drainage and various forms of pollution. In drier areas it tends to be confined either to sheltered glades in more open forests where there is more light in the upper boughs of trees. It is largely restricted to mature or older tree trunks. Today in drier districts the alliance is unable to spread into woodlands less than 200 years old unless these adjoin ancient woodlands from which dispersal is possible when the trees reach sufficient maturity (James *et al.* 1977).

Table 2.7 Components of the *Lobarion pulmonariae* in the alliance *Nephrometum lusitanicae* Barkm. (James *et al.* 1977).

Lichen species	
Arthonia didyma	*P. rubiginosa*
Acrocordia gemmata	*Parmelia crinita*
Bacidia affinis	*P.glabratula*
B. biatorina	*P. reddenda*
Biatorella ochrophora	*P. revoluta*
Catillaria atropurpurea	*P. saxatilis*
C. sphaeroides	*Parmeliella atlantica*
Dimerella lutea	*P. corallinoides aggr.*
Evernia prunastri	*P. plumbea*
Haematomma elatinum	*Peltigera collina*
Lecanora quercicola	*P. horizontalis*
Lecidea cinnabarina	*P. praetextata*
Leptogium lichenoides	*Pertusaria hemisphaerica*
L. teretiusculum	*P. hymenea*
Lithographa dendrographa	*P. pertusa*
Lobaria amplissima	*P. velata*
L. laetevirens	*Porina coralloidea*
L. pulmonaria	*P. hibernica*
L. scrobiculata	*P. leptalea*
Nephroma laevigatum	*Ramalina farinacea*
Normandina pulchella	*Rinodina roboris*
Opegrapha sorediifera	*Sticta limbata*
Pachyphiale cornea	*S. sylvatica*
Pannaia mediterranea	*Thelopsis rubella*
P. pityrea	*Thelotrema lepadinum*

Each particular substrate tends to comprise characteristic and uniform lichen vegetation within a single climatically uniform region under the influence of similar environmental factors (James *et al.* 1977). Based on this theory, James *et al.* (1977) developed a description of the ecology and types of epiphytic lichen communities in the British Isles. Using the phytosociological approach major nodes were identified in the continuum of lichen communities and the epiphytic lichen communities of the British Isles were arranged into eleven alliances (Figure 2.8) (James *et al.* 1977).

Figure 2.8 Principal relationships between epiphytic lichen alliances in the British Isles (James *et al.* 1977).



James *et al.* (1977) is the only work on the classification of lichen communities in the British Isles. It was published as a preliminary concept, which recognises only the major alliances and the most distinctive associations within lichen communities. There is a need for a more complete and improved classification of lichen communities in the British Isles and this represents a challenge for lichenologists today.

2.8.3 Number of lichens per tree genera

A number of epiphytic lichens occur on the two Irish native oaks, Pedunculate Oak and Sessile Oak. The highest number of lichen species recorded on oaks in British Isles was 324 compared with 255 on ash (Springthorpe and Myhill 1985 in Broad 1989, Rose 1974). The number of epiphytic lichens varies per individual tree. This number is normally greater on older trees and on trees that are well lit as compared to younger trees or those in shaded locations. Old oaks in parkland or in forest glades tend to have the highest numbers of lichens. Figures of 30 species per tree are common (Rose 1974). The greatest number recorded for a single tree is 52 taxa on an oak in Britain (Rose 1974) and 51 taxa on an oak in Ireland (Fox *et al*. 2001). For comparison, Rose (1974) recorded the numbers of lichen taxa per tree genera in the British Isles (Table 2.8).

Table 2.8 Numbers of lichen taxa per tree genera in the British Isles (adapted from Rose 1974).

Tree species	Number of lichen taxa	Bark attributes
Quercus sp.	303	
Fraxinus excelsior	230	Bark fissured and rather similar to *Quercus*, but often of higher pH, lacks certain species of old *Quercus*.
Fagus sylvatica	194	In spite of smooth bark, carries a flora very like *Quercus*, but has few epiphytes in chalk woodlands. Bark of low pH.
Acer pseudoplatanus	170	Carries a flora remarkably like elm (ph high).
Salix (*cinerea, caprea*)	128	Quite rich on lichens especially in humid western areas.
Corylus avellana	124	The same as *Salix*.
Acer campestre	88	Very favourable bark of high pH, but of limited occurrence of lichens.

The native oak species have a considerably greater number of lichen epiphytes than any other tree species, or genera, occurring in Britain and Ireland. However, no species of epiphytic lichens is specific to oak in the British Isles. Lichen species *Arthonia didyma* is almost confined to oak, but the species has been recorded on Sweet Chestnut (*Castanea*) and Sycamore (*Acer pseudoplatanus*) (Rose 1974).

2.9 Impact of woodland management on lichens

Felling and coppicing have been important practices in the management of deciduous woodlands in Ireland and Great Britain (Rose 1974, Seaward 1975, Gilbert 2000, Rose and Coppins 2002, Coppins and Cppins 2002). The main effect of these management practices on woodlands is to disrupt ecological continuity (Rose and

Coppins 2002). The epiphytic component of the Irish lichen flora has been seriously affected by extensive felling of hardwoods and a preference for replanting with softwoods (Seaward 1975). Furthermore, many woodland interiors proved to be unsuitable for epiphytic lichens due to the dense understorey, which limits sunlight. Rhododendrons are particularly effective in this respect. Many peripheral trees in woodlands as well as many roadside trees (mainly oak and ash, with some sycamore and beech) are often heavily clad with a dense growth of ivy – a condition unsuitable to lichen growth (Seaward 1975, Mulcahy 1996). Lichen communities are generally poor in woodlands that have been managed for coppice. Most of the old coppice woodlands have very few old forest lichen species. Clear felling and subsequent coppice management with the drastic alternations of high and low light intensity and low and high humidity in the bark environment eliminates most of the old forest lichen species (Rose 1974, Coppins and Rose 2002). These events generally lead to poorly developed and species-poor lichen communities, despite the fact that some trees may be of a great age (Coppins and Coppins 2002).

2.10. Lichens as ecological bio-indicators

Lichens are among the most widely used biomonitors in the terrestrial environment. Many lichens are long-lived organisms with high habitat specificity and they can be used to estimate species diversity and habitat potential at all times of year. Lichens are sensitive organisms. Their response to environmental change may include biodiversity, morphology, physiology, accumulation of pollutants, etc. Such responses can be used as indicators for many complex factors, from climatic change to pollution (Nimis *et al*. 2002). In particular, lichens are highly effective biological indicators of air pollution, responding to its effects at the cellular, individual, population and community levels. Lacking a protective cuticle and roots, they absorb substances from the atmosphere via dry and wet deposition. Lichens are widely distributed, occurring in all terrestrial ecosystems, and collectively covering (in many cases dominating) about 8% of the Earth's land surface. Globally, they play an important biogeochemical role in the retention and distribution of nutrients and trace elements usually accumulating lead, cadmium and other heavy metals of environmental concern (Purvis 2006).

The use of lichens as bioindicators is based on the concept that there is a close, sensitive and dynamic relationship between lichen communities and their environments. The derivation of meaningful outcomes from the application of such indices requires the monitoring of change in epiphytic lichen communities under a strictly standardized sampling protocol. Several lichen diversity indices have been developed during the last four decades. 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 for air quality led to the development of the Index of Atmospheric Purity (IAP) 1968 (LeBlanc and De Sloover 1970; Kricke and Loppi 2002). Subsequently a number of regional systems were developed, viz. the IAP_{18} guideline (Herzig *et al.* 1987), the VDI (Verein Deutcher Ingenieure) Lichen Mapping Guideline 3799 (VDI 1995) and the ANPA (Agenzia Nazionale per la Protezione dell'Ambiente) guideline (ANPA 2001).

2.11 Index of Atmospheric Purity

The Index of Atmospheric purity (IAP) was developed by LeBlanc and De Sloover (1970) and is presented as:

$$IAP = \sum_{1}^{n} \frac{(Q \times f)}{10}$$

Where: n is number of species; Q is factor for accompanying species; f is a combined value of cover and frequency of each species.

Q can be defined:

$$Q = \frac{\sum_{j=1}^{m} \sum_{i=1}^{n} S_{ij}}{m}$$

Where: n is the number of species; m is the number of stations (e.g. trees) where the species of interest are present and S_{ij} equals 1 if species i is present at station j.

In this index, the degree of cover is estimated using a 5-class scale based on the abundance and degree of cover of species (Table 2.9).

Table 2.9 5-class scale for assessment of lichen abundance and degree of cover (LeBlanc and De Sloover 1970).

Class	Estimates of degree of cover (f)
5	An abundant species with a high degree of cover on most trees
4	A frequent species with a high degree of cover on some trees
3	An infrequent species with moderate degree of cover on some trees
2	A rare species or one with a low degree of cover
1	A very rare species with a very low degree of cover

All lichen species occurring up to a height of 2m on tree trunk, regardless of exposure, are analysed. An IAP value is allocated to a study site by sampling 10-12 trees per site. The IAP value permitted local evaluation of air quality based on a pre-defined scale (LeBlanc and De Sloover 1970). The IAP assessment process is time expensive and vulnerable to variations in the percentage cover estimates as these are depended on the individual surveyor and consequently have a significant subjective component. There were few attempts to improve this measure with aim to develop more objective component. For example Kirschbaum (1973) developed a quantitative method for describing lichen vegetation based on screening grid placed across the trunk of the tree between 0.3 and 1.3m above the ground. At the same time, Kunze (1971 in Kricke and Loppi 2002) introduced the use of frequency values based on a grid divided into 10 squares, also known as the "Flechtenleiter" and suggested use of common tree species. Kunze also noticed a statistical dependence between lichen data and the effects of certain stressors, including air pollution. This finding was recognised in further modifications of the IAP approach (Kricke and Loppi 2002).

2.11.1 Index of Atmospheric Purity $_{18}$

Progress in the IAP method development was made by the Swiss project in 1987 (Herzig *et al.* 1987). The project aimed to develop an objective and reproducible air pollution index and model, sensitive towards the combined influence of several atmospheric pollutants for use in Switzerland. Such a model would facilitate the development of an air pollution assessment protocol using epiphytic lichens. Based on the original formula for IAP (LeBlanc and De Sloover 1970), further models have been developed taking into account parameters such as: cover degree, number of companion species, frequency, vitality and damage. In total 20 different formulae have been developed and the relationship between pollution data (mean annual values of eight air contaminants) and the lichen vegetation has been statistically tested. The results of the project revealed that the highest correlation between pollution data and the lichen vegetation was found while using frequency assessment within a sampling grid, which became the core of the Index of Atmospheric Purity$_{18}$ (IAP_{18}) method. The main improvement of the IAP_{18} method compared to the original IAP (LeBlanc and De Sloover 1970) is in recognising the importance of lichen species frequencies in an air pollution assessment. The use of the frequency measure significantly simplifies the method and enables more rapid and objective assessment. The validity of the IPA_{18} has been tested in different regions of Switzerland and the IAP_{18} was implemented as a national guideline for monitoring atmospheric pollution using lichens (Kricke and Loppi 2002). The structure of IAP_{18} is:

$$IAP_{18} = \sum_{1}^{n} F$$

Where: *n* is number of species; *F* is frequency value (1-10)

2.11.2 IAP studies

The IAP approach became very popular and has been used in many recent studies (Loppi 1996; Jeran *et al*. 2002; Gombert *et al*. 2004 a, b). The IAP approach was used in the evaluation of the suitability of lichens as bioindicators of geothermal air pollution in central Italy (Loppi 1996). Geothermal air pollution is associated with airborne pollutants, which affect species composition and cause community changes as pollution levels change. This study was the first to use the Index of Atmospheric Purity (IAP) for precise mapping of lichen communities around geothermal plants. The individual steps of this approach were as follows:

(1) 30 x 50cm grid, divided into 10 units of 10 x 15cm, was placed on the trunk of each tree at a height of 120-200cm on the part of the bole with highest lichen density;
(2) All lichen species were tabulated with their frequency (*F*). Frequency (*F*) was the number of grid units in which the species was present;
(3) Index of Atmospheric Purity (*IAP*) was calculated for each grid as the sum of frequencies of all the species present ($IAP = \sum F$);
(4) *IAP* for each sampling unit was taken as the maximum score of frequency on a tree in the sampling unit thus reflecting the potential performance of the epiphytic lichen vegetation at each unit.

The results of the correlation analysis between IAP values and substrate factors such as tree height, circumference of trunk and the buffering capacity of the trees showed almost no significant correlations. The only positive correlation was found with bark pH. A two-dimensional map of zones of different air quality in the region and geothermal air pollution was drawn using IAP results. The results confirmed that this IAP guideline produces information for delimiting overall geothermal air pollution based on epiphytic lichens. Epiphytic lichens were found to be reliable bioindicators of geothermal air pollution (Loppi 1996).

The IAP approach was applied to air pollution monitoring in Slovenia (Jeran *et al.* 2002). The main aim of this work was to combine the IAP results with the quantitative levels of certain trace elements in *Hypogymnia physodes*. The calculation of IAP values was based on the assessment of cover and abundance of crustose (*C*), foliose (*F*) and fruticose (*R*) lichens on different tree species. The cover (*c*) of all three thallus types of lichens was assessed using this subjective scale:

0 - no lichens
1 - thalli cover up to 10% of the observed trunk surface
2 - thalli cover between 10 and 50% of the observed surface
3 - thalli cover between 50 and 100% of the observed trunk surface

The abundance (*a*) was assessed using a following scale:

0 - no lichens

1 - very few lichen thalli (1-5 for observed surface)

2 - moderately frequent thalli (6-10)

3 - very frequent thalli (more than 10)

From the data collected an Index of Atmospheric Purity (IAP) was calculated for each sampling unit for each stratum of observation separately (IAP_1 = observations on tree trunks up to 0.5m, IAP_2 = 0.5-2.5m; IAP_3 = above 2.5m), using the following formulas:

$$IAP_{1,2,3} = C(a+c) + F(a+c) + R(a+c)$$

$$IAP_{unit} = IAP_1 + IAP_2 + IAP_3$$

Where: *C* are crustose lichens, *F* foliose and *R* fruticose; *a* is abundance and *c* is cover.

A direct comparison between IAP values and the trace element composition of *Hypogymnia physodes* revealed relatively low loadings for IAP in factor analysis. This indicated that there were different effects which cause poor lichen vegetation and only part could be explained by trace elements. Elementary substances such as arsenic, chrome, cadmium, molybdenum and zinc were identified as factors with particularly negative influence on lichen vegetation. The levels of these pollutants in lichens indicated the types and origin of possible pollution sources. However, a direct influence of these substances on reduced lichen diversity was not confirmed. Based on the results of this study (Jeran *et al*. 2002) an IAP map was drawn which visualized through lichen vegetation regions where air quality was poor. The IAP approach was found useful for the air quality assessment in the area affected by air pollution giving indication of the most polluted areas (Jeran *et al*. 2002).

The IAP approach was also used for the assessment of air quality in the Grenoble area of France (Gombert *et al*. 2004 b). The aims of this study were: *a)* to estimate and to map the air quality of the Grenoble survey area using the IAP method; *b)* to create an index of human impact (IHI) for the survey area, and *c)* to compare the two indices, one based on biological parameters (IAP, lichen diversity) and the other on urban and landscape parameters (IHI). The hypothesis was that lichen diversity may be dependent not only on atmospheric pollution but also on other general environmental parameters, such as landscape interpretation. The lichen cover in the survey area was assessed using the Braun-Blanquet method (Braun-Blanquet 1964):

0.5 (<1% cover, median 0.5)
1 (1-5% cover, median 3)
2 (6-25% cover, median 15)
3 (26-50% cover, median 37.5)
4 (51-75% cover, median 62.5)
5 (76-100% cover, median 87.5)

The Index of atmospheric purity (IAP) developed by LeBlanc and De Sloover (1970) was adapted as follows:

$$IAP = \frac{1}{10}\sum_{1}^{n} Q_i \times r_i$$

Where: n is number of species, Q_i is ecological index of each species (Q for a species is determined by adding together the number of its companion species present at all investigated sites and then dividing this total by the number of sites), r_i is cover of species.

The IAP was calculated for each sampling unit. In the field, each sampling unit was characterised by a subjective index of human impact (*IHI*). The *IHI* was based on averages of environmental variables such as urbanisation (*U*), traffic (*T*), local developments (*D*) and exposure (*E*). Two categories ('1' and '4') were attributed to each parameter to express a gradient of alteration (Table 2.10).

Table 2.10 Environmental variables assessment (Gombert *et al.* 2004 b).

Parameters	Category 1	Category 2
Urbanisation 'U'	Rural = 1	Sub-urban and Urban = 4
Traffic 'T'	Weak road exposure = 1	High road exposure = 4
Local developments 'D'	Crop fields, Green areas = 1	Housing sites, Car parks, and roads = 4
Exposure 'E'	Trees isolated or in rows = 1	Trees grouped = 4

The index of human impact (IHI) was calculated for each sampling unit using the formula (Gombert *et al*. 2004 b):

$$IHI = U(T + D + E)$$

In this calculation, a low IHI value was more closely related to rural and low artificial conditions and a high IHI value was related to high environmental artificiality. Lichen species were assessed according to three ecological settings based on bark type and nutrient needs: *nitrophytic* species which prefer to grow on deciduous tree bark enriched with dust or nutrients (26 recorded), *acidophytic* species which prefer acidic barks (28 recorded), and *neutrophytic* species which are indifferent species (29 recorded). Similar numbers of species in each setting were recorded. The use of the IAP method in this study defined five air quality categories, with medium air quality being the best represented. Surprisingly, the geographical pattern of the IAP map showed no clear connection with local sources of pollution, such as the vicinity of a road or industrial plant, but was partially influenced by urban pollution and elevation. High or very high IAP values were found in different types of habitats: in natural environments at high elevations, in artificial environments of lowland areas, and in very artificial environments located in the plain. It appeared that IAP values were strongly influenced by the predominance of one of the three ecological groups (neutrophytic, nitrophytic and acidophytic species). IAP values showed a decrease when the proportions of these ecological categories varied in sequence: % acidophytic > % nitrophytic > % neutrophytic or when an ecological group was clearly predominant (Gombert *et al.* 2004 b).

IHI and IAP were compared to characterise lichen biodiversity in terms of environmental variables and human impact. The sampling units were grouped into six categories based on IHI and IAP characteristics. The defined categories of environment type under IHI (elevation, artificiality, location of roads, industrial plants, green areas etc.) were clearly associated with the lichen flora (abundance, frequency in the survey area and ecology setting of species). The cover, abundance and prevalence of species characterised by the three ecological groups in IAP (neutrophytic, nitrophytic and acidophytic) were found to influence lichen diversity. The prevalence of any of these ecological groups was shown to be linked with increased human impact on the environment.

A comparison of IAP values and data on atmospheric SO_2, NO_2 and NO justified the use of IAP as a general indicator of atmospheric pollution. However, no significant correlation was found between the average IAP and pollutant data, indicating that IAP is probably related to other factors than atmospheric pollution. Lichen biodiversity appeared to be influenced by human impact on the environment. The results indicated that it would be more appropriate to designate IAP as a general index of environmental quality rather than as a strict indicator of atmospheric pollution (Gombert *et al*. 2004 b).

2.12 German VDI guideline

The German VDI (Verein Deutcher Ingenieure) guideline 3799 (VDI 1995) is another bioindication method to monitor atmospheric pollution using lichens along with the IAP approach (LeBlanc and De Sloover 1970) and IAP_{18} method (Herzig *et all.* 1987, Kricke and Loppi 2002). In fact, the German VDI guideline is based on the IAP_{18} formula which advances the use of a more objective tool - a frequency count in front of the relatively subjective technique of cover assessment used in IAP approach. The standard steps of the German VDI guideline are:

(1) According to its size, the study area is divided into sampling units using a grid of 1 x 1km and sampling trees are selected on a basis of six trees per 1 x 1km.

(2) Only tree species with comparable bark properties (e.g. pH-value, water storing capacity, nutrient content, and girth) are selected for sampling.

(3) A screening grid of 50 x 20cm, (divided into 10 equal squares of 10 x 10cm) is placed 1.5m above ground on the side of the tree trunk most densely vegetated by lichens.

(4) LGW (Luftgütewert) meaning the air quality value for each sampling unit is calculated as an average of the LGWs of the single trees. Air quality values (LGW) are calculated according to the following equation:

$$LGW_j = \sum F_{ij} \div n_j$$

Where:

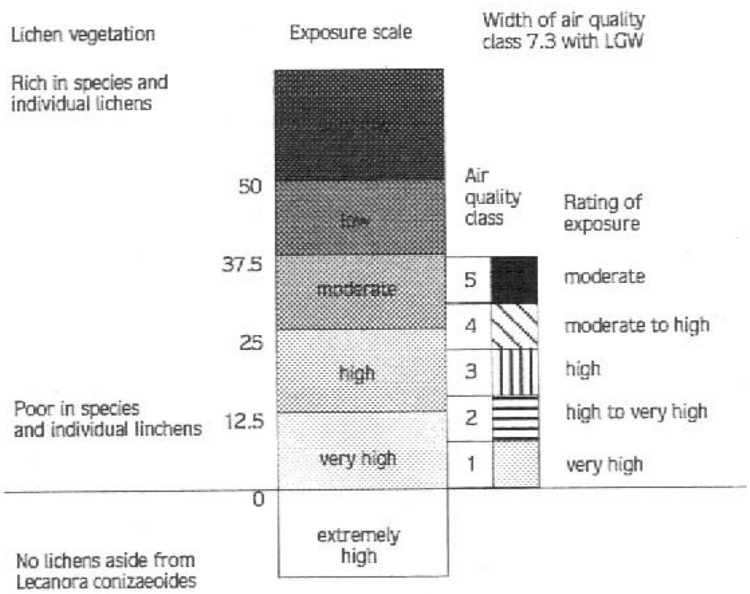
	i	is the number of the trees examined in sampling unit j
	j	is the number of the examined sampling units
	F_{ij}	is the sum of the frequencies of occurrence on tree i in examined unit j
	n_j	is the number of surveyed trees within examined unit j

(5) Air quality values (LGW) are assigned to classes which represent the different ranges of air quality, with the standard deviation of the results determining the class width.

The standard deviation is influenced by the size of the sampling area, the number of trees examined and the ecological homogeneity (degree of similarity in ecological parameters such as altitude, landscape, tree formation, land use etc.) of the area investigated.

(6) The LGW classes are interpreted on the basis of a predefined exposure scale according to the VDI-guideline (Figure 2.9). The threshold values of the expose scale were derived from several extensive surveys in Central Europe. The air quality classes have been assigned to the exposure scale so that they match the most suitable verbal expressions and colour code. If the air quality class falls into two exposure categories, the evaluation of exposure is composed of both categories (Sommerfeldt and Volker 2001, Kricke and Loppi 2002).

Figure 2.9 Exposure scale according to the VDI-guideline (1995).



The VDI guideline with some modification for the sampling of trees was used for the assessment of air quality in the city of Izmir, Turkey (Sommerfeldt and Volker 2001). Lichen examination followed the VDI-guideline entirely. According to the

VDI-guideline air quality values (LGW) were calculated for trees and sampling units and five air quality classes were distinguished in the city of Izmir. In the central part of the city, the air was found heavily polluted. In the outer zone air quality was slightly better, except the heavily polluted northern and north-western areas. The best air quality values were determined in the southern and western outer zone. The results of the mapping corresponded with those determined from emission measurements made in 1986 (Barth *et al.* 1988 in Sommerfeldt and Volker 2001) so that the general picture of the lichen zones was found to be similar in both surveys. However, the disappearance of lichens in some zones indicated a worsening of the air quality between 1986 and 1997 (Sommerfeldt and Volker 2001). In this study, the VDI- guideline was found useful in determining zones with different air quality in city setting.

2.13 Italian Guideline

The IAP approach has also been widely applied in Italy in the form of the Italian Guideline (ANPA 2001), which introduces some modification in the IAP method (Le Blanc and De Sloover 1970, VDI-Guideline 1995, Kricke and Loppi 2002). The most significant modification has been the use of a grid of fixed size (50 x 30 cm) divided into 10 units of 10 x 15 cm. In the Italian Guideline, the air quality index is called ‘Lichen Biodiversity Index’ (LBI) or ‘Index of Lichen Diversity’ (ILD). The Italian Guideline was incorporated by the Italian Environmental Protection Agency (Agenzia Najionale per la Protezione dell’ Amblente ANPA) into the national guidelines for monitoring the effects of atmospheric pollution by phytotoxic gases (especially SO_2 and NO_x,) using epiphytic lichens. In contrast to the German guideline, the Italian Guideline bioindication techniques measure not only air pollution/quality, but also estimate the degree of alteration from natural conditions by pollution i.e. the sensitive components of ecosystems (ANPA 2001, Kricke and Loppi 2002). The standard steps of the Italian Guideline are:

1. The sampling grid density of sampling units is 1 x 1km, and each sampling unit is represented by a square area of 250 x 250m within the unit. It is suggested to sample 3 – 6 trees per sampling unit.

2. Only tree species with comparable bark pH-properties are selected for sampling. The trees have to meet the following requirements: a) inclination of tree not exceeding 10°; b) circumference greater than 60cm; c) absence of evident factors of disturbance (damage, disease, etc.).
3. A sampling grid of 50 x 30cm, (divided into 10 units of 10 x15 cm) is positioned on the part of the bole with the highest lichen coverage, at a height of 100cm, on tree trunks. All lichen species within the grid are noted and their frequency (*f*), namely the number of grid units in which the species occurred, is recorded.
4. The lichen biodiversity (LB) of each tree is calculated as the sum of frequencies of all lichen species $LB = \sum f$.
5. The LB value of the sampling unit is the arithmetic mean of the LB values of the trees sampled in the sampling unit.

LB data can be further analysed using statistical analyses such as multivariate analysis, cluster analysis, Euclidean distance and ordination analysis, etc. Lichen biodiversity values can be plotted on maps of lichen diversity based on grid-based interpolation between irregularly spaced points (units) producing a contour map. Interpretive scales of deviation from naturality of lichen diversity can be produced based on the protocol proposed by Loppi *et al.* (2002 a).

The Italian guideline was used for an air quality assessment in the urban area of Siena, Italy (Loppi *et al.* 2002 b). The aim of the study was to provide a general picture of the air pollution pattern within the study area and to look for changes since a study in 1995 (Monaci *et al.* 1997 in Loppi *et al.* 2002 b). The assessment was based on a monitoring of biodiversity of epiphytic lichens. Lichen sampling followed the Italian guideline (ANPA 2001) and a sampling grid was applied on 6-10 lime trees (*Tilia* sp.) per unit in a mapping grid of 500 x 500m. The sampling grid was placed on the side of the trunk, which had the greatest lichen cover. Then Lichen Biodiversity (*LB*) values were calculated as the sum of frequencies of all lichen species. *LB* values were further interpreted in terms of deviations from normal conditions using a scale of environmental naturality/alteration developed for the Tyrrhenian region of Italy (Table 2.11) (Loppi *et al.* 2001, Loppi *et al*. 2002 a).

Loppi *et al.* (2002 a) has defined normal conditions as those areas that are free from heavy anthropization and from long-distance transport of pollution loads.

Table 2.11 Scale of environmental naturality/alteration developed for Tyrrhenian region, Italy (Loppi *et al.* 2001).

LB values	%Deviation from normal conditions	Interpretation	Predicted SO_2 (98th percentile)
0-25	75-100	Alteration	>50
25-50	50-75	Semi-alteration	15-50
50-75	25-50	Semi-naturality	5-15
>75	0-25	Naturality	<5

Based on the LB results a two-dimensional zone-map was drawn, on which areas with different LB classes and levels of alteration were marked. The results indicated that areas classified as 'altered' were lacking and most of the study area (60%) was 'semi-altered' or 'semi-natural' (Loppi *et al.* 2002 b). Through the use of the Italian guideline this study identified ameliorating air quality conditions in the city of Siena.

The Italian guideline was used for an assessment of the biodiversity of epiphytic lichens in connection with air pollution monitoring in the town of Montecatini Terme, Italy, during 1993-2000 (Loppi *et al*. 2004). The aim of this study was to test if changes in the air pollution status, as expressed by the biodiversity of epiphytic lichens and the accumulation of heavy metals in thalli of *Flavoparmelia caperata*, can be detected at intervals of seven years (1993-2000). The lichen sampling was carried in 26 sampling units. In each unit 3-5 isolated lime trees (*Tilia* sp.) were sampled for lichens using a sampling grid 30 x 50cm, 10 units of 15 x 10cm placed on a tree trunk at a height of 100-120cm above ground. An index of lichen diversity (ILD) was calculated for each sampling unit. The results indicated that the overall air quality situation in Montecatini Terme is improving, with higher lichen biodiversity values and lower metal concentrations in *Flavoparmelia caperata* thalli being recorded. Vehicular traffic was identified as the main source of atmospheric pollution in the study area. The ILD values recorded in each station were interpreted in terms of deviations from 'natural' conditions, using scale calibrated for trees in the Tyrrhenian region (Table 2.11) (Loppi *et al.* 2001, 2002 a). From the maps of environmental naturality/alteration, a clear trend of ameliorating conditions emerged, especially after year 1998. The conversion of heating systems to methane (abatement of SO_2) and the use of unleaded gasoline (reduction of Pb) were identified as the main cause for improvement of lichen communities and a drop in heavy metals contains in *Flavoparmelia caperata* thalli. The results showed that lichens respond rapidly to decreasing concentrations of air pollutants despite their slow growth rate (Loppi *et al.* 2004).

The effects of air pollution on lichen biodiversity (LB) were studied in the northwestern Liguria region (northwest Italy) in order to evaluate the environmental quality of both suburban and rural areas (Giordani *et al.* 2002). The aims of the study were a) to provide a first application of the scale for interpreting the LB counts scored in Mediterranean and sub-Mediterranean regions; b) to provide information on the effects of atmospheric pollution on the biodiversity of epiphytic lichens in the Liguria region; c) to obtain information for developing a complementary monitoring network for the assessment of atmospheric pollution, based jointly on lichen biomonitoring and chemical-physical methods. A grid 9 x 9km was placed over the survey area and 69 sampling units were selected at the intersections of the grid (Nimis 1999 in Giordani *et al.* 2002). At each sampling unit, five LB relevés were carried out on nearest standard trees within an area of $1km^2$ centred on the intersection co-ordinates. The lichen sampling followed the Italian guideline. The sampling grid was positioned on the part of the bole with the highest lichen coverage, at a height of 100cm on trees that had circumference greater than 70cm. Ecological indicator values (*e*) for eutrophication (Nimis 2000 in Giordani *et al.* 2002) were used to detect possible ecological gradients for this parameter in the region, based on a 5-class ordinal scale (Table 2.13).

Table 2.12 Ecological indicator values (*e*) according to Nimis (2000) (Giordani *et al.* 2002).

1. no eutrophication
2. very weak eutrophication
3. weak eutrophication
4. rather high eutrophication
5. very high eutrophication

For each sampling unit, the average eutrophication indicator value (E_s) was calculated.

It was found that the eutrophication indicator value was low in the whole region. This result is probably due to a lack of intensive agriculture, which generally causes high eutrophication. It was noted that a positive correlation existed between LB values and the SO_2 and NO_x concentrations and this provided evidence of the sensitivity of lichens to these air pollutants. The interpretative scale for LB values (Loppi *et al.* 2001) revealed that large parts of the Liguria region have a high degree of naturality and lichen biodiversity, which corresponds to good air quality conditions. The 'altered' areas were limited to urban and industrial districts where three large thermoelectric power plants and other industrial factories were located. The SO_2 and NO_x were shown as the main causes of alteration of lichen biodiversity in this region. The results suggested including the use of lichen monitoring in atmospheric pollution assessment (Giordani *et al.* 2002).

The Liguria region (which is as area of 5,314 km^2) has a very heterogeneous bio climate and according to Nimis (2000 in Giordani *et al.* 2002) there are at least three different bioclimatic regions in the area, characterised by humid Mediterranean, humid sub-Mediterranean and dry sub-Mediterranean conditions. Brunialti and Giordani (2003) has examined how such an area should be divided into more homogeneous bioclimatic areas and how to develop lichen naturality/alteration scales for each area. The study considered the extent to which environmental variables (mainly relative humidity, distance from the sea, and altitude) might modify epiphytic lichen communities and hence affect the interpretation of LB scores. Based on available pollution data and LB data (Giordani *et al.* 2002) the study area was divided into four transects:

1) Genova transect with high anthropogenic impact.
2) Savona transect with high impact from a thermoelectric power plant – the most industrialised district.
3) Imperia transect ranging from the coast to the Ligurian Alps with moderate anthropogenic influence.
4) Tigullio transect characterised by natural and semi-natural conditions.

An analysis of the lichen communities led to hypotheses concerning the boundaries of bioclimatic regions in the survey area. In particular, geomorphology was identified to affect distribution of lichen communities. Especially mountain ridges and valley watersheds were found to limit the distributional range of three lichen communities: *Parmelion* community with high frequency of coastal suboceanic species, *Parmelion* community rich in oakwood and *Parmelietum acetabuli* association situated beyond the valley watershed. LB counts differed with different transects, trees and altitudes, while no significant differences were noticed in relation to bioclimatic region in which relevés were carried out. Environmental variables did not cause significant differences in LB counts in the natural transects (Imperia and Tigullio). Thus, LB values seemed to be related principally to atmospheric pollution. Environmental variables seemed to act as factors which limited lichen diversity in transects with high pollution impact (Genova and Savona). The results of the study presented problems with interpretation of LB counts in different bioclimatic regions. Due to the great influence of microclimatic parameters on epiphytic lichen communities, the phytoclimatic delimitation proposed by Nimis (2000) is only applicable to large areas (i.e. on a country-wide scale). Brunialti and Giordani 2003 suggested that for smaller areas, further research is necessary in order to establish a more reliable method for delimitation of scales of naturality/deviation from natural conditions based on lichens, particularly in areas of transition between different bioclimatic regions.

The Italian guideline has been applied in a number of diverse settings that indicate trends and causes of environmental change. Frati *et al.* (2006) investigated whether NO_2 and NH_3 emitted by road traffic in Siena-Grosseto (central Italy) could influence lichen diversity and lichen vitality (e.g. changes in lichen metabolism). The study utilised the Italian approach for the calculation of ILD values. The results indicated that road traffic from a highway in a rural environment of central Italy was not a significant source of NH_3 and NO_2. Applications of N-based fertilisers were suggested as the main reason for the higher accumulation of nitrogen and other inner changes such as reduction in the content of chlorophyll *a*, chlorophyll *b,* and total carotenoids in lichen thalli of *Evernia prunastri*. The results indicated that pollution emitted by road traffic in a rural environment had less significant influence on lichen diversity than N-based fertilisers used in agriculture (Frati *et al.* 2006). In a similar study Frati *et al.* (2007) examined the effects of ammonia (NH_3) and nitrogen emissions (NOx) on the lichen flora arising from a pig stock farm in central Italy.

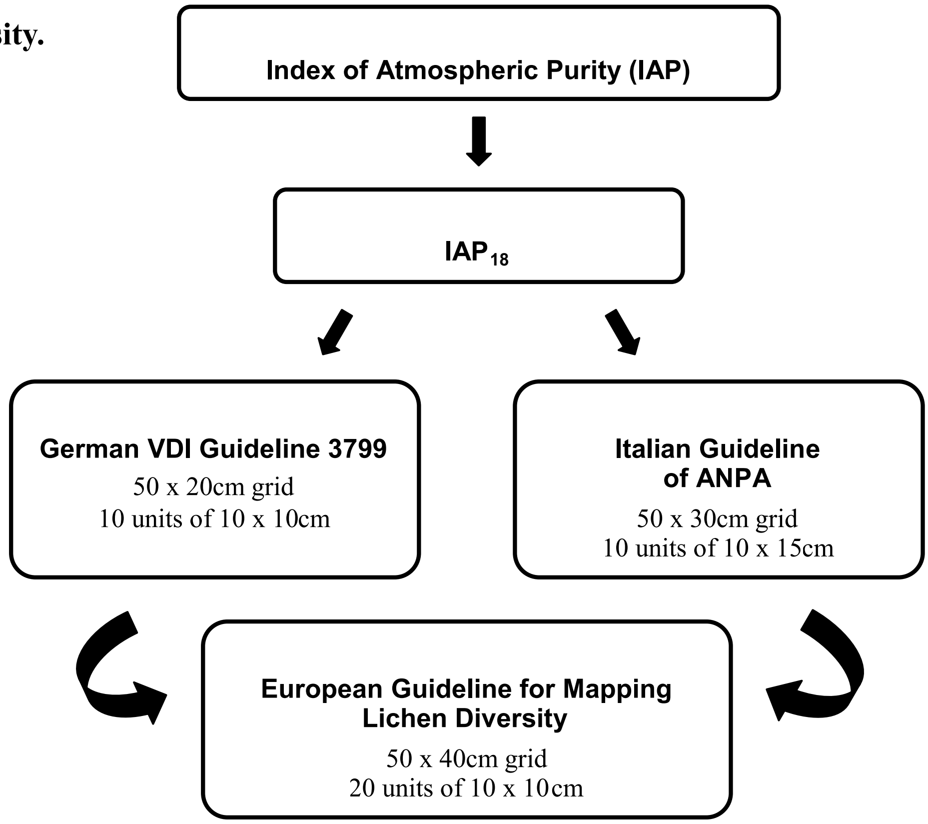
The Italian approach was applied and ILD values were calculated. Lichen diversity in general was found not to be associated with NH_3 concentrations, but the diversity of strictly nitrophytic species such as *Physconia grisea* was highly correlated with this parameter. Results of the study confirmed that NH_3 directly influence the lichen vegetation. The results confirmed that the diversity of strictly nitrophytic lichen species such as *Physconia grisea* could be used to monitor and map NH_3 pollution. *Physconia grisea* was positively correlated with airborne NH_3, showing decreasing association with increasing distance from the pig stock farm (Frati *et al.* 2007).

2.14 European guideline

The need for a general and widely applicable lichen based system for the determination of environmental stress within ecosystems lead to the development of the European Guideline for Mapping Lichen Diversity as an Indicator of Environmental Stress (Asta *et al.* 2002 a, b). For the first time the concept of 'environmental stress' was integrated into a lichen diversity assessment tool through the use of a range of stress factors, such as atmospheric pollution, eutrophication and climate change. The European guideline presents the first attempt to develop a unified guideline with application at European level with the aim to provide a repeatable and objective strategy for mapping lichen diversity as an indicator of environmental changes. The procedures of this method are rapid and low cost.

The European guideline is based on the German VDI Lichen Mapping Guideline (VDI 1995) and the Italian Guideline of ANPA (2001) with several important modifications (Figure 2.10).

Figure 2.10 Development of the European Guideline for Mapping Lichen Diversity.



The most significant of these involved several elements of subjectivity in the sampling process, which were present both in the VDI and in the Italian guidelines. For example, placing the sampling grid on the most densely covered side of tree trunk by lichens was a subjective measure in the VDI and Italian guidelines. The European guideline implemented a more objective measure, sampling lichens in a sampling grid, which consists of four segments (10 x 50cm) placed on the north, south, east and west side of tree trunk. Additionally, the Italian, German, and the European guideline differ in the size of the sampling grid for recording of lichen species frequencies on a tree trunk. The German guideline uses a sampling grid of 50 x 20cm divided into 10 units 10 x 10cm and the Italian guideline uses a sampling grid of 50 x 30cm divided into 10 units of 10 x 15cm. The European guideline uses a sampling grid of 50 x 40cm divided into 20 units of 10 x 10cm. However, all three guidelines map environmental changes and develop a map with different environmental quality zones. The main steps of the European guideline include:

1. The size of sampling units depends on the grid size and on the geographical scale of the study, which can range from $1km^2$ to $0.25km^2$.

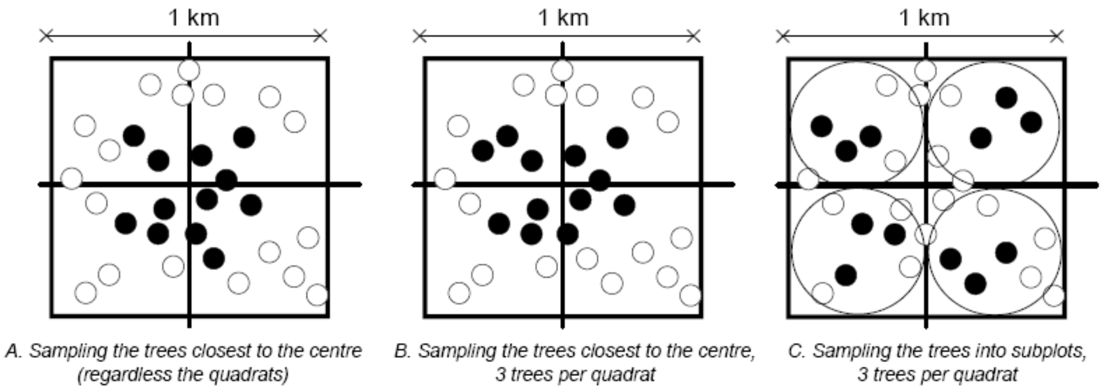
2. The number of trees per sampling unit depends on its size (Table 2.13).

Table 2.13 Number of trees per sampling unit (Asta *et al*. 2002 a, b).

Size of sampling unit	0.25 x 0.25 km	0.5 x 0.5 km	1 x 1 km
Number of trees	3 – 4	4 - 6	6 - 12

3. Where more trees occur in a sampling unit than the number chosen for sampling, the following objectives are used for selecting trees:
    - Select suitable trees closest to the centre of the sampling units, regardless of their position in the unit (Figure 2.11A);
    - Divide the mapping units into four quadrants and select 3 trees per quadrant, either considering the distance from the centre of the unit (Figure 2.11B) or;
    - Using sub-plots (Figure 2.11C).

Figure 2.11 Sampling tactics for the selection of sample trees (Asta *et al.* 2002a).



4. Only trees of the same species or with similar bark properties (e.g. pH, water storing capacity, nutrient content) can be selected. Selected trees must be free standing (well-lit), with girths >70cm and near straight trunks (inclination <10° from vertical). Damaged trees from liming/fertilisers, grazing animals etc. should be avoided.
5. A monitoring quadrat, consisting of four independent quadrat segments of five 10 x 10cm squares each, is attached vertically to the trunk so that the lower edge of each segment is 1m above the highest point of the ground. The

four segments of the sampling quadrat must be placed to correspond with the four aspects (north, south, east, and west) of the tree trunk.

6. All lichen species present within each quadrat segment are recorded and the frequency of the occurrence of each species in the five squares of each quadrat segment noted. All lichen species are suitable for the calculation of Lichen Diversity Values (LDV).
7. The Lichen Diversity Value (LDV) of a sampling unit is a statistical estimator of the environmental conditions in that unit. The first step in calculating the LDV of a sampling unit is to sum the frequencies of all lichen species found on sample trees within the unit. The frequencies have to be summed separately for each aspect. Next, for each aspect the arithmetic mean of the sums of frequencies is calculated. The LDV of sampling unit is then the sum of the arithmetic means.
8. LDV values should be grouped into classes, sufficiently wide to reflect statistically and environmentally significant differences among sampling units to interpret and present results. The standard deviation of the sampling unit is determined, then the standard error of each unit is calculated according to the formula:

   $error(unit) = sdev(unit) - \sqrt{n-1}$; n is number of trees sampled in each unit

   The width of the LDV classes is then determined as 3 x standard error.
9. LDV data can be interpreted using maps with different lichen diversity zones.

Asta *et al*. (2002 a, b) described the European guideline as a modern standardized method to assess lichen diversity on tree bark with aim of identifying environmental change within an area. Results of such lichen diversity surveys can be interpreted as a map with different lichen diversity zones and environmental quality. This can provide a greater understanding of the long-term effects of air pollutants, eutrophication, anthropization and climatic change on sensitive organisms. It has been well recognised that lichen diversity studies in general, and the use of the European guidelines in particular, can help identify areas of greater environmental stress. Repeated monitoring at these sites can facilitate modelling the dynamics of the environmental change. The European guideline provides new opportunities for comparative studies and cross tabulation of data gathered in different parts of Europe by different workers.

An important milestone was the acceptance of the European guideline as a new tool for environmental assessment using lichens in Italian national monitoring. Castello and Skert (2005) contributed to this process by comparing the Italian guideline to the European guideline in the Friuli Venezia Giulia region of Italy and in municipalities of Gorizia, Collio, Isonzo Plain, and Karst in Slovenia. The aim of the study was to test the applicability of the sampling method proposed by Asta *et al.* (2002 b) and officially adopted in Italy from 2001 onwards and to provide a regional scale of environmental alteration based on lichen diversity in the North Adriatic submediterranean bioclimatic area. Lichen diversity was investigated following two sampling strategies: the Italian guideline (ANPA 2001) and the European guideline (Asta *et al.* 2002 b). Locations of sampling stations and trees followed the Italian guideline. The sampling grid density of sampling units was 1 x 1km, while each unit was represented by a square area of 250 x 250m. 161 *Tilia* spp. trees and 53 *Quercus* spp. trees were sampled for lichens using both the European and the Italian guideline. LB and LDV data taken by the two methods in the two survey areas were analysed following the protocol proposed by Loppi *et al.* (2001) to establish interpretive scales of deviation from naturality of lichen diversity. The European guideline proved to be applicable for assessing lichen diversity in this study. However, the method was criticised for being time-expensive and requiring very good knowledge of lichen identification. Results from this study confirmed that lichen biodiversity values obtained from the two sampling methods were highly statistically correlated, and this supported the adoption of the new European approach on the national level in Italy. Further research was suggested to determine whether the interpretive scale of deviation from naturality proposed in this work could be applied to the rest of the bioclimatic region.

2.14.1 European guideline mapping lichen diversity in urban and rural settings

The European Guideline has been applied in a number of other recent studies (Davies *et al*. 2002; Castello and Skert 2005; Giordani 2006 and Isocrono *et al*. 2007). Giordani (2006) evaluated the reliability of epiphytic lichen diversity as an indicator of air pollution in the Genova province (NW Italy) using the European guideline. This case study aimed to evaluate: 1) the influence of the main gaseous air pollutants (SO_2, NO_x, CO) on the diversity of epiphytic lichens in a complex Mediterranean area and; 2) the effectiveness of lichen diversity to assess the effects of air pollution in the survey area. A total of 53 sampling sites were selected by means of stratified random sampling approach, based on habitat type and altitude. Each site consisted of a 30m radius plot, in which all suitable trees (circumference > 60cm; inclination of the bark < 10°; absence of damage and decorticated areas on the trunk) were sampled for lichens. Lichen sampling followed the European guideline. The lichen diversity values were compared to the trends of the following variables in the study area: SO_2 concentrations; NO_x concentrations; CO concentrations; forest management (coppicewood, old coppicewood, old-growth forest); occurrence of forest fires; and agricultural practices (vegetation & soil management, no management). The application of non parametric multiple regression analysis (NPMR) indicated that the influence of climatic variables on lichen diversity is in agreement with the correlation between lichen diversity and atmospheric precipitation. In the study area, under the same level of air pollution, lichen diversity was higher in regions with higher rainfall, confirming the need for regional scales for interpreting patterns of LDV in different bio-climatic regions. The use of indicator species with a known response to pollutant concentrations has also proven to be a valid tool under conditions of decreasing pollution. This study partially confirmed the hypothesis that methods based on the total lichen diversity (the European guideline) might not be appropriate for monitoring future scenarios of urban air pollutants such as SO_2. This is due to sharp decrease of SO_2 concentrations in urban settings worldwide. Then the future lichen diversity will be less effective in monitoring the effects of this pollutant. However, the results confirmed that high NO_x concentrations from road traffic negatively affect lichen presence. Indeed, NO_x pollution was described as the future main limiting factor for lichen colonisation in urban areas. The diversity of epiphytic lichens in general was found closely correlated with mean annual rainfall and mean annual temperature. In addition several other factors which affect lichen diversity were described with respect to both antropogenic sources and natural site characteristics. Based on this, a range of variables which affect lichen diversity in urban vs. forested areas were identified. At present in urban areas, air pollutants, mainly SO_2 still remains the main factor influencing lichen diversity. In forested areas, harvesting and forest fires showed a predominant effect on lichen diversity (Giordani 2006).

The European guideline was used for lichen diversity assessment in major European cities: Rome (Munzi *et al.* 2006), London (Davies *et al*. 2002; Larsen *et al.* 2006) and Turin (Isocrono *et al.* 2007). Davies *et al.* (2002) used the European guideline to assess the distribution of corticolous lichens at six sites in London on selected ash and oak trees with the objective of identifying the impact of NO_x pollution on lichens. The study applied for the first time the European guideline in a UK setting. The aim of the study was to investigate the diversity and distribution of corticolous lichens on a single phorophyte, ash (*Fraxinus excelsior*) at six sites in London and on oak (*Quercus*) at one site. Westminster, Southwark and Tower Hamlets were selected as the inner London sites, all within 6km of Charing Cross, and outer London locations were selected in Enfield, Harrow and Bromley. Ash was selected as the major phorophyte as it is widely distributed across London, with oak as the second species. Bark pH measurements were taken to detect acidification / eutrophication. Eight bark pH measurements were taken per tree. Five trees were selected per site. Suitable trees had to meet the following criteria: unbranched below 200cm, upright, open aspect, without injury or disease with a minimum girth of 50cm and a maximum girth of 150cm and at least 150m distant from the entrance of parks (to avoid roadside influence). Lichen sampling followed the European guideline. In addition, all lichen species below 50cm and all lichen species above 50cm up to 200cm on a tree trunk were recorded and any special features noted. The LDV were calculated for each site. A comparison of lichen species on ash indicated major differences in species numbers and composition between the inner and outer London sites. A trend towards increasing diversity with distance from Charing Cross was identified. The findings were set against previous lichen studies in this area (e.g.

Laundon 1970, Hawksworth and McManus 1989 in Davies *et al*. 2002). The large number of recorded species, a total of 56 species, demonstrated a significant increase in lichen diversity in London in recent decades. The highest lichen species diversity was recorded on ash trees at the outer London sites and Harrow and Enfield. Generally, a total of 35 lichens were recorded on ash trees and 32 on oak trees. The highest lichen diversity value was recorded in Harrow. High occurrence of nitrophytic lichen species suggested that NOx was readily assimilated by many lichen species and was encouraging species considered indicative of eutrophicated areas. The disappearance of some species preferring a more acidic substrate (such as *Evernia prunastri* and *Ramalina farinacea*) was noted during this study due to increasing concentrations of nitrogen and other transport emitted pollutants. The European guideline was recognised as a valuable protocol for quantifying lichen diversity in this study; however, further evaluation concerning assessment of nitrogen emissions was recommended. This pilot study has highlighted the need for standardised recording techniques for epiphytic lichens in combination with physical-chemical data, which is necessary in order to develop a practical indicator scale that can be used to monitor the new pollution climate (Davies *et al*. 2002).

Distribution of lichens and bryophytes on oak trees was assessed in London (Larsen *et al.* 2006). The aim of this study was to investigate lichen and moss diversity and frequency in relation to air pollution and bark pH on oak trees. The study tested the hypothesis that there was an association between epiphytic species distribution and transport emissions. An area extending 33km in radius from Charing Cross in central London was investigated. Epiphytes were recorded on 145 oak trees (*Quercus robur, Q. petraea* and their hybrids) from 20 sites. 5-9 trees were selected per site. Trees were selected according to the European guideline and further criteria were applied: only trees with a girth 40-60cm, situated in open, unshaded locations, at least 100m from the nearest road (in order to minimise direct road effects) were selected. Bark pH was measured in situ on four aspects (N, S, E and W) 1m above ground level. The occurrence and frequency of lichens and bryophytes was recorded according to the European guideline and LDV values were calculated. Results provided further evidence for a NOx and/or transport-related pollution influence on the composition and frequency of lichens and bryophytes. Data suggested that peak concentrations of NOx limit the diversity and abundance of certain lichens and bryophytes in London, including most nitrophytes. NOx may stimulate plant growth, including lichen photobionts but may be toxic at high levels. Indeed, NOx was suggested as a factor preventing colonisation of *Parmelia saxatilis* and damaging *P. sulcata* and *Hypogymnia physodes*. The relationship between lichen frequency and bark pH confirmed pH is an important driver for lichen distribution. Other factors, including humidity and temperature, may also play a role. Lichens and bryophytes were found to respond to factors that influence human and environmental health in London. Biomonitoring therefore has a practical role in monitoring the effects of measures to improve air quality. This study found the European guideline useful for identifying possible drivers of the observed patterns of lichen species distribution and frequency (Larsen *et al.* 2006).

Isocrono *et al.* (2007) assessed the lichen diversity in the city of Turin. The aim of this study was to assess the current environmental quality in the urban area of Turin with the use of lichens as bioindicators, and to compare the results with the historical data available. Eighteen sampling stations (1km^2 each) were selected at the intersection of a 3 x 3km grid and 3-9 trees with moderately acid bark (*Tilia* spp. and deciduous *Quercus* spp.) were sampled in each station. An interpretative scale of LD values in terms of environmental alteration in the western dry sub-Mediterranean belt was devised following the suggestions of Loppi *et al.* (2002 a). The maximum naturality value was calculated as the average of LD values in 20 releves carried out in open woods or near small villages, far from anthropogenic influences. Ecological indices were calculated for each station to detect local trends related to eutrophication. The history of lichen recording in Turin, spanning over a period of 200 years, provided a valuable historical record and helped in data interpretation. Lichen assemblages over different time periods were related to changes in environmental conditions. Comparison of the present data with older records indicated a general improvement, as shown by increased numbers of both species and thalli in the city. Nitrophytic lichen species were a considerable percentage of the total number of species and contributed greatly to LD values. NOx and total suspended particles were identified as the main air pollutants affecting lichen diversity in Turin (Isocrono *et al.* 2007).

2.15 Indices of ecological continuity

Numerical counts of epiphytic lichen species occurring in woodlands do not always reflect the environmental quality of woodlands; rather it is the species composition and associations that are important. A wide range of lichens may occur in a wood and different species may be present for different reasons. Studies of a large number of oak woodlands in Britain and France in areas with low air pollution revealed that certain epiphytic lichens and bryophytes occur in nearly all woodlands containing standard oak or ash trees, whether it is an old forest, coppiced stand, or a mature oak plantation. In contrast to this, a specific group of epiphytic lichens and bryophytes was found to only occur in association with mature old stands of oak or mixed oak forests (Rose 1974). This study subsequently led to the development of a theory for the assessment of a woodland's maturity or 'ancient woodland' character, using indices of ecological continuity.

2.15.1 Revised Index of Ecological Continuity

It was observed that deciduous woodlands in lowland Britain, which had retained some degree of long-term ecological continuity, supported significant lichen assemblages. A total of 55 lichen species were associated with woods of known ancient origin which showed ecological continuity over time. The list was revised to a manageable 30 species. These species represented a 'relict flora' and were incorporated into the concept of 'indicator species' for grading woodlands on a scale of increasing or decreasing levels of past disturbance – the Revised Index of Ecological Continuity (RIEC) (Rose and Coppins 2002). The RIEC is based on a set of 30 indicator lichens, which appear to be faithful to woods that have retained varying degrees of ecological integrity over time.

2.15.2 New Index of Ecological Continuity

A New Index of Ecological Continuity (NIEC) was developed to address advances in taxonomic, ecological and biogeographical knowledge on epiphytic lichens (Rose and Coppins 2002, Coppins and Coppins 2002). The NIEC is based on a list of 70 indicator lichen species primarily devised with the purpose of grading woodlands for their conservation status. The NIEC incorporates most of the core 30 RIEC species, but encompasses wider ecological amplitude (in relation to light, humidity, acidity, nutrient availability, etc.) to include significant species associated with other lichen communities found in additional niches (e.g. *Calicion hyperelli* – alliance of aged dry bark of deciduous trees and decorticate wood and *Usneion barbatae* – alliance of acidic barks, both in very well lit situations). The core list of 70 NIEC species can be enhanced by additional 'bonus' species, nationally rare lichen species. The NIEC can be used for the assessment of the conservation importance of a woodland ecosystem in terms of its lichen flora. The NIEC should be used in conjunction with the RIEC (Rose and Coppins 2002, Coppins and Coppins 2002).

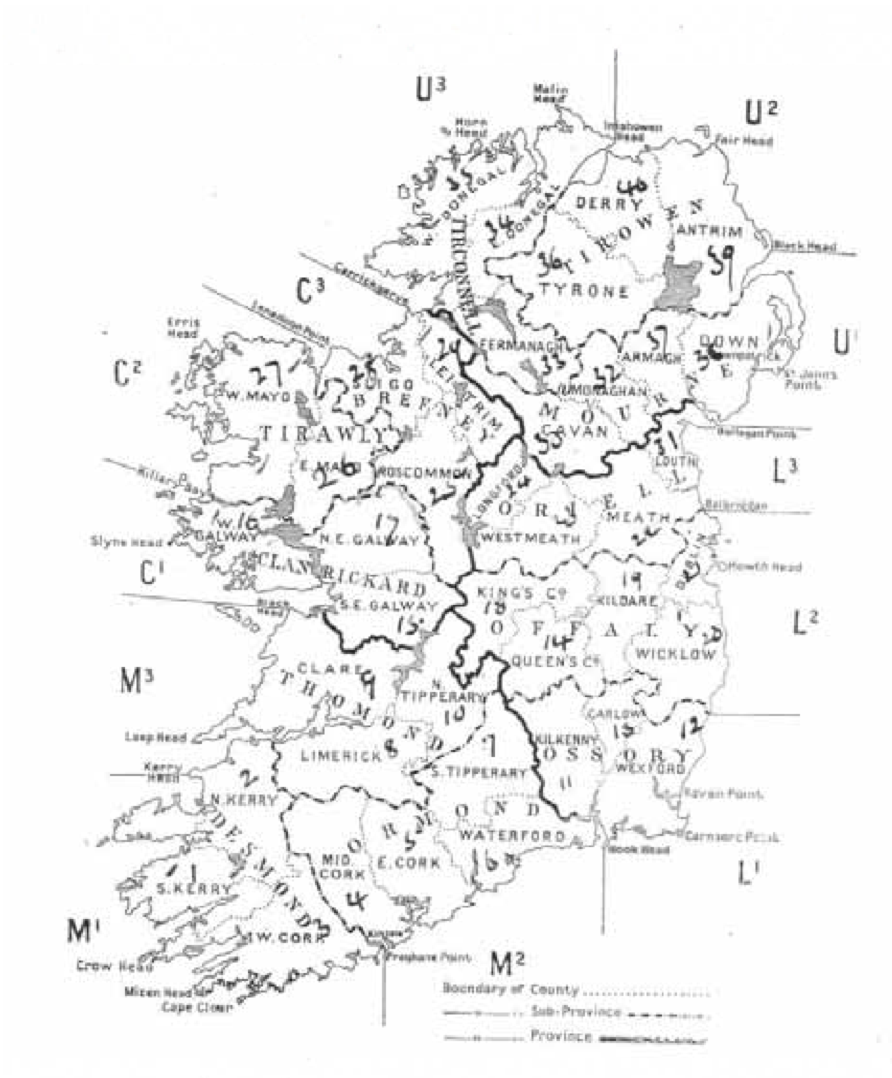
2.16 Lichen studies in Ireland

Irish lichen records, going back to Caleb Threlkeld (1676-1728), occur sporadically throughout 18th century botanical literature, but the true foundations of Irish lichenology were laid in the 19th century by Thomas Taylor (c. 1787-1848), Theobald Jones (1790-1868), David Moore (1808-1879) and Isaac Carroll (1828-1880). In the first half of the twentieth century Matilda C. Knowles (1864-1933), Annie Lorrain Smith (1854-1937), Robert Lloyd Praeger (1865-1953), Robert A. Phillips (1866-1945), John Adams (1872-1948) and Lilian E. Porter (1885-1973) added considerably to our knowledge of the flora, their records being summarised by Walter Watson (1872-1960) in his Census Catalogue published in 1953. About this period, the Scandinavian lichenologists G. Degelius, E. Dahl and A.H. Magnusson collected in Ireland. During the next two decades M. E. Mitchell and A. F.-G. Fenton were particularly active in the west and north of Ireland respectively. More recently, a wider area has been investigated, mainly due to the work by B.J. Coppins, P.W. James, P.M. McCarthy, C. Moore, D.H.S. Richardson, F. Rose and M.R.D. Seaward with additional support from B.W. Ferry, D.L. Hawksworth, J.R. Laundon and others (Seaward 1984).

Various approaches have been taken in recording and classifying the occurrence of lichens in Ireland. Leighton (1871) described the lichen flora of Ireland as being arranged to families, tribes and genera based on Nylander's system. The work listed a full diagnosis of each lichen species giving the chemical reaction of the thallus and medulla and the description of general habitat, relative frequency or scarcity, and a date of lichen's first discovery (Leighton 1871). The distribution of lichens in

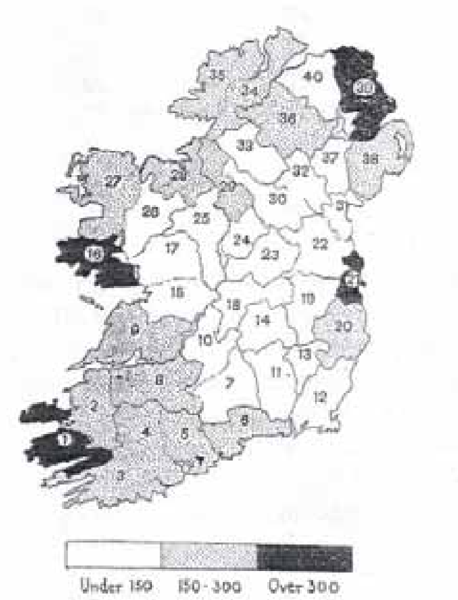
Ireland was recorded by Adams (1909). In this work Ireland was sub-divided into four provinces and three sub-provinces. County Wicklow was classified as sub-province L2 (Dublin, Wicklow, Kildare, Queen's County, King's County) within the province of Leinster (Figure 2.12). The number of species recognised as occurring in sub-province L2 was 182. The number of species occurring in Leinster was 198. In all a total of 779 lichen species were recorded throughout Ireland.

Figure 2.12 Biological subdivisions of Ireland (Adams 1909).



Further, Knowles (1929) studied lichen flora in 40 topographical divisions of Ireland (Figure 2.13). In this work, divisions: 21 (Dublin), 1 (South Kerry), 16 (West Galway) and 39 (Antrim) were found to be the most interesting parts of the country with over 300 lichen species recorded. Between 150 – 300 lichen species were recorded in division 20, which is identical to the current County Wicklow area. The number of lichen species and subspecies recorded as occurring in Ireland was 802.

Figure 2.13 Botanical divisions of Ireland marked according to lichen numbers recorded (Knowles 1929).



The first Irish census catalogue for lichens was published by Watson in 1953. This work drew substantially on the publications of Knowles (1929) and Porter (1948) and listed 1,090 lichen taxa occurring in Ireland (Watson 1953). Following the establishment of the British Lichen Society in 1958 there have been several significant initiatives promoting lichen research in Ireland. These include extensive taxonomic revisions, herbarium analyses, literature searches and fieldwork sessions, much of which has been associated with the accumulation of records for the British Lichen Society's distribution maps scheme. Subsequently, this came to comprise the second 'Census Catalogue of Irish Lichens' which incorporated all earlier records and was based on vice-county distribution (Seaward 1975, Seaward 1984). The work listed 957 lichen taxa (including 6 subspecies, 14 varieties and 2 forms). It was significant to note that the number of lichen taxa recorded from vice-county Wicklow was 455.

Despite the creditable lichenological foundations laid down by numerous workers in the 19th century, in the first half of the 20th century lichenological activities over the past two decades have been mainly confined to the west and north of Ireland (Seaward 1975). Various local studies have addressed the abundance and distribution of lichens in different areas (Mitchell 1961, Sheard 1968, Seaward 1975, Moore 1976, James *et al.* 1977, McCarthy and Mitchell 1992, Alexander *et al.* 1989; Cullen and Fox 1999; Fox *et al*. 2001; Coppins and Coppins 2002). Popular aspects of Irish lichens, which have been studied, include eu-oceanic species (Mitchell 1961) and saxicolous lichens (Sheard 1968, Moore 1976). The sea shores of the west were studied for saxicolous lichens on Inishowen (Sheard 1968) and the Burren and Aran Islands (McCarthy and Mitchell 1992). The distribution of saxicolous lichens was used for air pollution zoning in the city of Dublin (Moore 1976).

Little attention has been paid to an understanding of the ecology and distribution of lichens in the central, eastern, south-eastern, and southern regions of Ireland. This was partially addressed by Seward (1975), who compiled a list of 203 lichen taxa for the south-east Ireland. The lichen flora of the area was however described as inherently poor. Deforestation and agricultural practices and to a lesser extent urbanisation and industrialisation were identified as the main reasons for this. Field meetings of the British Lichen Society researched areas all over Ireland, rich in natural heritage but under-recorded with respect to lichens. Areas such as Clifden (County Galway) and Bantry (County Cork) were studied in 1966, County Kilkenny and County Laois in 1982 and County Sligo and the Connemara National Park in 1987 (Alexander *et al.* 1989). Lichenologists from Britain, Germany, the Netherlands and Scandinavia have been and continue to visit Ireland and provide data for the British Lichen Society mapping scheme.

2.17 Lichen studies in Irish woods

Irish woodlands have been known for their rich lichen flora especially in the west of Ireland (Alexander *et al.* 1989, Fox *et al*. 2001). A total of eighteen areas in County Sligo and County Galway were visited by the British Lichen Society between 29 August and 12 September 1987 in order to expand the lichen data-bases for Ireland. Lichens were studied on various habitats including trees; monastic buildings;

churches; peat soils; rocky shores; beaches; and sand dunes. Epiphytic lichens were recorded in six sites:

a) Union Wood, Co. Sligo

The Union Wood site was described as one of the few undisturbed areas of local woodland, composed mainly of large old oaks. The wood was found rich in epiphytic lichens with 57 species recorded, among which rare lichen species of the genus *Lobaria* were abundant (Alexander *et al.* 1989).

b) Slish Wood, Co. Sligo

Slish Wood in Co. Sligo, a remnant of an old wood with evidence of clear felling, was found rich in epiphytic lichens, 72 species were recorded. Trees such as *Quercus*, *Fraxinus* and *Acer* were identified as supporting interesting assemblages of lichens including the rare *Lobaria* and *Sticta* species (Alexander *et al.* 1989).

c) Church Island Wood in Lough Gill, Co. Sligo

Both the ancient ruins and the woods on the island carried more than 100 lichen species, but *Lobaria pulmonaria* and other notable lichens proved to be rare. This was probably because many of the trees were evenly aged and relatively young (Alexander *et al.* 1989).

d) Estates, Co. Sligo

Parkland trees often are found to support rich and varied lichen floras. Two estates, Templehouse and Tanrego, were visited, where *Lobaria* and *Sticta* species were recorded among a total of 80 species in parkland and orchard settings (Alexander *et al.* 1989).

e) Sruffaunboy Wood, Connemara, Co. Galway

Sruffaunboy was described as a mixed deciduous woodland with mainly young trees. Younger, smoother-barked trunks were found clothed in abundant *Pyrenula macrospora*, and *P. chlorospila* whilst *Enterographa crassa*, *Dimerella lutea* and *Nomandina pulchella* were common on older trunks, and *Pannaria rubiginosa* made an occasional appearance. *Parmelia* species, including *P. crinita* were frequent on many of the trees, as were several species of *Pertusaria* and *Lecanora* (Alexander *et al.* 1989).

f) Ellis Wood, Connemara, Co. Galway

This wood was found to be exceptionally rich in lichens, especially in the swamp woodland area. Here *Nephroma laevigatum*, *Pannaria rubiginosa*, *P. conoplea*, *Parmeliella atlantica* and *P. plumbea* were abundant together with various *Sticta* species. Other parts of the wood supported a more typical lichen flora, with a rich assemblage of *Parmelia* species including *P. borreri* and *P. crinita*. *Parmeliella pumbea* was recorded on large *Fraxinus* trees. Other species recorded here included *Sticta limbata*, *S. sylvatica*, *Collema fururaceum*, *Pannaria rubiginosa*, *Nephroma laevigatum*, *Peltigera horizontalis*, *P. lactucifolia*, *P. membranacea* and *P. praetextata* (Alexander *et al.* 1989).

Both Sligo and Connemara proved to be lichenologically interesting. Over 340 species were recorded from the Sligo area, of which 140 were new vice-county records and one was new to Ireland. Of the 236 species recorded from the Connemara Park, 18 were new vice-county records, including two new to Ireland. All records from the meeting have been incorporated into the computer database of the British Lichen Society's mapping scheme.

Other studies of lichen abundance include that undertaken in Brackloon Wood, a semi-natural oak-dominated woodland in County Mayo (Fox *et al*. 2001). This study sampled an area in a large oak stand of 7.2 ha. Three vegetation monitoring areas were selected. Seven oak trees were randomly selected in each of the three vegetation monitoring areas. Thus, epiphytes were recorded on the trunks of 21 oak trees in total. Trunk epiphytes were monitored using a measuring tape, which was fastened around the trees at a height of 120cm above ground. Recording of the epiphytic lichen flora started on the north side of the trees. The presence of epiphytic species was recorded at 10cm intervals around the circumference of the trees. A total of 192 lichen species were recorded on trees and rocks within the woodland. Generally, the boles of the trees at 1.2m from the ground were dominated by mosses, with relatively few lichen species present. Stems and trunks that rose perpendicularly from the ground tended to have a continuous cover of bryophytes, while those growing at an angle to the ground had a denser cover of bryophytes on the wetter surfaces – usually facing west – with more lichens on the drier surfaces (Fox *et al.* 2001).

Studies with a more regional scale include Higgins *et al.* (2004) where a range of native woodlands throughout Ireland were surveyed with aim to develop a set of indicator species in native woodlands including epiphytic lichens. A total of 32 lichen species were identified as indicative of native woodland in the south-east of Ireland (Higgins *et al.* 2004). Lichen species *Graphis scripta, Lepraria incana* and *Parmelia perlata* were the three most frequently recorded species and six lichens from the list, not recorded during the 2003 field season, were identified through this study, these were: *Leptogium sp.*; *Peltigera horizontalis*; *Phaeophysica orbicularis*; *Physconia distorta*; *Ramalina fraxinea*; and *Sticta sp.* The greatest number of lichen species recorded from any one locality on the indicative list was seven species for wet pedunculate oak-ash woodland. Generally, it was observed that the wet woodland types had the highest levels of lichen cover.

Although much of the recent research effort have focused on the western regions of Ireland there have been some significant studies that address the status of lichen occurrence in native woodlands in eastern counties. The lichens of County Wicklow have been studied sporadically for over two hundred years namely by Admiral Theobald Jones, Whitley Stokes, David Moore, Matilda Knowles and Annie Lorraine Smith (Cullen and Fox 1999). Cullen and Fox (1999) studied the status and distribution of lichens in the Wicklow Mountains. This work has produced a checklist of 300 lichen species for the Wicklow Mountains National Park (NP) area. The British Lichen Society studied lichens in Powerscourt Waterfall woodland in County Wicklow during a field meeting in July 1994. Similar studies on the eastern coast of Ireland have identified some mature or semi-natural woodlands supporting rare lichens, such as at the Vale of Clara, Glendalough oak woods, and at Powerscourt Waterfall Deer Park in County Wicklow (Seaward 1975, Cullen and Fox 1999, Higgins *et al.* 2004). However, knowledge about the level of ecological continuity and the undisturbed status of many of these woodlands is incomplete. Equally significant is the relationship between these ecosystems and anthropogenic influences, particularly given the greater level of urbanisation and higher population density of the eastern coast of Ireland. Consequently, where such woodlands exist it is important that these areas are carefully investigated as without an understanding of their current status and function it is not possible to plan for their preservation and management. The role of lichens in this process is particularly significant given the sensitivity of lichens to anthropogenic influences. Indeed, the higher population densities and proximity to major urban centres in the east of Ireland are likely to play a greater role in limiting the abundance of undisturbed woodlands. Lichen phytosociology and its integration with environmental stress provide a crucial key not only to understanding the level of naturalness in the woodland but also in terms of understanding the current stresses that the ecosystem is undergoing. Recent developments in understanding the relationship between lichens and their environment and the establishment of regional scales and standards (Asta *et al.* 2002 a, b) for the interpretation of lichen phytosociology have greatly improved the potential for insight into the complex interaction between a woodland, its ecological history, and the current environmental pressures that it is experiencing.

2.17.1 The status of Knocksink Wood

Native and semi-native woodlands close to major urban centres are relatively rare in the east of Ireland. However, Knocksink woodlands represent a particularly special case. This woodland is a semi-native woodland and a nature reserve located close to Dublin city which is regularly frequented by many visitors and subject to a wide range of anthropogenic influences. Yet, it is this interplay between anthropogenic influences and the ecological status of the woodland that is so important to understand, and which is crucial for the proper management and preservation of this woodland as a natural resource into the future. The implications of lichen phytosociology and environmental stress in native and semi-native woodlands in eastern Ireland are poorly understood. Thus while the woodlands in Knocksink Wood have been studied in recent years (Anonymous 1976, Ball 1997, Kelemen and Dromey 2000) this has not addressed in any detail the abundance of lichen flora nor the interplay between the lichens and the woodland with regard to ecological status. Consequently this study proposes to investigate epiphytic lichen occurrence and phytosociology in the semi-native woodlands at Knocksink Wood in County Wicklow, eastern Ireland.

2.18 Research aim and objectives

2.18.1 Aim

This research aims to assess the epiphytic lichen diversity and its distribution across woodland habitats in Knocksink Wood Nature Reserve. The main focus in this research is on the differences that arise in relation to three major woodland habitat categories within Knocksink, viz. acidophilous oak woodland, corresponding to the *Blechno-Quercetum petraeae* phytosociological association, ash-hazel woodland, referable to the *Corylo-Fraxinetum* association and mixed oak-ash-hazel woodland floristically close to *Corylo-Fraxinetum* (White 1982, Cross 1998, Fossitt 2000).

2.18.2 Objectives

1) Identify and describe the epiphytic lichen flora of Knocksink Wood Nature Reserve.
2) Establish an epiphytic lichen list characteristic for main woodland types, acidophilous oak woodland, ash-hazel woodland and mixed oak-ash-hazel woodland.
3) Compare the epiphytic lichen flora particularly on acidophilous oak (*Quercus* spp.) versus ash (*Fraxinus excelsior*) and to a lesser degree between beech (*Fagus sylvatica*), sycamore (*Acer pseudoplatanus*) and willow (*Salix caprea*).
4) Assess the abundance, frequency, and diversity of epiphytic lichen species in woodlands at Knocksink Wood.
5) Relate how environmental parameters and human management may cause variation of epiphytic lichens.
6) Evaluate environmental quality using lichens as ecological bioindicators.

Various studies have addressed the abundance and distribution of lichens in Irish woodlands (James *et al.* 1977, Alexander *et al.* 1989, Purvis *et al*. 1992, Cullen and Fox 1999, Fox *et al.* 2001, Coppins and Coppins 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.* 2002 a, b) to the woodlands at Knocksink. This research generates new data on epiphytic lichen distribution within the woodlands of Knocksink Wood and contributes to a better understanding of lichen flora at the site and the importance and relevance of this site in terms of: (1) the existing lichen flora; (2) development of lichen based bio-indicators of environmental quality as a tool for future resource management and; (3) identifying environmentally sensitive areas within Knocksink Wood in relation to lichen flora. The need for the development of bio-indicators for natural resource management, particularly for sensitive ecosystems such as semi-natural woodlands, is well recognised (United Nations Convention on Biological Diversity, Biodiversity Strategy COM (98) 42, Biodiversity Action Plans (2001), EU 6th Environment Action Programme 2002 – 2012, NATURA 2000 network, EU Habitats Directive 92/43/EEC, Bioforest - Environmental Protection Agency, National Biodiversity Plan, etc.).

3. METHODS

3.1 General setting of the study area

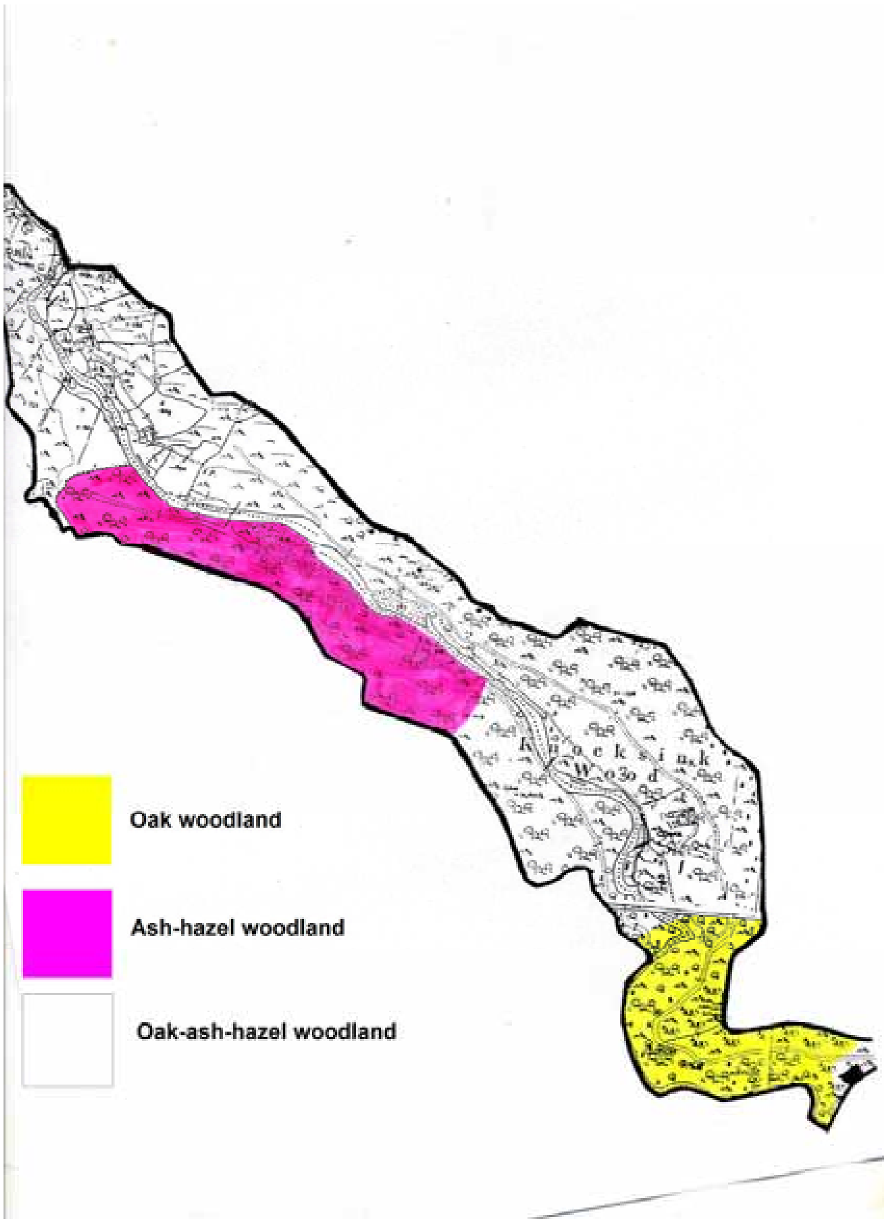
Knocksink Wood is situated in the valley of the Glencullen River north-west of Enniskerry in County Wicklow. The fast-flowing Glencullen River flows over granite boulders along the valley floor. The steep sides of the valley are mostly covered with calcareous drift. Knocksink Wood is semi-natural woodland, which extends in a linear fashion along either side of the river valley. The woodland is approximately 75 hectares in area and is less than half a kilometre wide at its narrowest point (Kelemen and Dromey 2000). Most of this site has been designated a Statutory Nature Reserve in 1994 and there is presently an educational centre within the site. The south-eastern part of the wood was listed as an Area of Scientific Interest (ASI) in 1976 (Anonymous 1976). The woodlands of Knocksink Wood were owned by Viscount of Powerscourt since the early 17th century. The origin and management history of Knocksink Wood is unclear as no direct reference is available to the history of these woods. Another study area included the woodland at Powerscourt Waterfall, which is situated 5.5km south southwest from the eastern end of Knocksink Wood. The Powerscourt Waterfall woodland is located in the Dargle River valley with a 121m waterfall at the western end. The woodland is part of the Powerscourt estate. The 7th Viscount of Powerscourt established a deer park on the site in the 1850s and a herd of Japanese Sikka deer was introduced to the valley. The woodland at the valley floor resembles old pasture woodland with solitary specimens of trees. The Powerscourt Waterfall area has been a popular amenity area for centuries (An Chomhairle Leabharlanna).

3.1.1 Habitat description

Notable features of the slopes in Knocksink Wood are the frequent and extensive springs and seepage areas within the woodlands. These petrifying springs are listed as a priority habitat in Annex I of the EU Habitats Directive. Associated with the springs and the river are stands of wet alluvial forest, which is also listed as a habitat with priority status in Annex I of the EU Habitats Directive. The wet woodland is dominated by Ash and Alder (*Alnus* spp.) and is assigned to the group *Carici remotae-Fraxinetum*. Other species include Willow (*Salix* spp.), Birch (*Betula pubescens*) and Hazel. Described habitats are listed as 'Special Area of

Conservation' (SAC) under two categories: (1) Petrifying springs with tufa formation (*Cratoneurion*) (habitat code 7220) and (2) Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*) (habitat code 91E0). A number of scarce or rare plants occur within the Knocksink Wood woodlands including Blue Fleabane (*Erigeron acer*), Ivy-leaved Bellflower (*Wahlenbergia hederacea*) and Yellow Archangel (*Lamiastrum galeobdolon*) (Kelemen and Dromey 2000). Three main woodland habitat categories exist at Knocksink Wood: Acidophilous Oak wood; Ash-Hazel dominated woodland over calcareous soil and mixed Oak-Ash-Hazel woodland (Ball 1997) (Figure 2.14).

Figure 3.1 Distribution of three main woodland habitats in Knocksink Wood.



The Acidophilous Oakwood

The Acidophilous Oakwood is characterised by dry, broad-leaved semi-natural woodland including old oak woods and occurs at the eastern side of the wood on relatively small areas compared to other parts of the woodland (Figure 3.1). The canopy consists mainly of *Quercus petraea* and *Quercus* x *rosacea* (Ball 1997). Sessile Oak (*Quercus petraea*) dominates on some slopes with a sparse shrub layer of Holly (*Ilex aquilinum*) and Hazel (*Corylus avellana*), while the ground is covered by a carpet of Great Wood-rush (*Luzula sylvatica*). Other areas are characterised by mixed woodland, with Oak, Ash (*Fraxinus excelsior*), Beech (*Fagus sylvatica*), Sycamore (*Acer pseudoplatanus*) and the occasional conifer occurring. *Betula pubescens* is a common part of the canopy along with occasional *Fagus sylvatica*. *Ilex aquifolium* is the most common component of the shrub layer. The ground flora is dominated by *Luzula sylvatica* and *Vaccinium myrtillus*. The ground flora also includes Ivy (*Hedera helix*) and Brambles (*Rubus fruticosus* agg.), and often luxuriant ferns, such as Hart's Tongue (*Phyllitis scolopendrium*), Soft Shield-fern (*Polystichium setiferum*), Bracken (*Pteridium aquilinum*) and mosses (Ball 1997, Kelemen and Dromey 2000). This habitat is similar to the *Blechno-Quercetum petraeae* association established by Braun – Blanquet and Tüxen (White 1982) and described as species-poor *Quercus petraea* forests *Blechno-Quercetum typicum* on the Map of the Potential Natural Vegetation of Ireland (Cross 1998). According to the latest classification of woodlands in Ireland (Fossitt 2000) the habitat can be classified as Oak-birch-holly wood.

The Ash-Hazel woodland

The Ash – Hazel dominated woodland is characteristic by a canopy of Ash and Oak with an understorey of Hazel. Other understorey trees are Holly (*Ilex aquifolium*) and Spindle (*Euonymus europaeus*). The ground flora consists of Ivy (*Hedera helix*) and Bramble (*Rubus fruticosus*), Soft Shield Fern (*Polystichum setiferum*), Scaly Male Fern (*Dryopteris affinis*) and violets (*Viola spp*.). Other common species are *Sanicula europea*, *Geum urbanum*, *Arum maculatum*, *Primula vulgaris* and *Brachypodium sylvaticum* (Ball 1997, Kavanagh 2002). The ash-hazel wood in Knocksink Wood is floristically close to the *Corylo-Fraxinetum* association and the sub-association *veronicetosum* (White 1982, Kavanagh 2002). On the Map of the Potential Natural Vegetation of Ireland this habitat belongs to *Quercus robur* –

Fraxinus excelsior forests with *Corylus avellana*, *Circaea lutetiana*, *Brachypodium sylvaticum* and *Veronica Montana* specified as *Corylo-Fraxinetum veronicetosum* (Cross 1998). According to Fossitt (2000) this habitat can be classified as Wet Pedunculate oak – ash woodland and Wet Willow-alder-ash.

The Oak – Ash – Hazel woodland

The area between the oak woodland and the ash-hazel woodland in Knocksink Wood (Figure 3.1) consists of mixture of trees mainly Oak, Ash, Sycamore and Beech and is referred to Oak-ash-hazel woodland floristically close to *Corylo-Fraxinetum* (Fossitt 2000).

Powerscourt Waterfall woodland

The rocky area within the waterfall zone is rich in mosses, liverworts and ferns such as the Hart's Tongue (*Phyllitis scolopendrium*). Grassland is predominant on the slopes with Woodrush (*Luzula sylvatica*) and Bracken (*Pteridium aquilinum*) invading some areas. Broadleaved woodland occurs around the upper slopes on both sides of the waterfall. This is mainly oak woodland with some Rowan and Holly, although there are substantial plantations of Beech and conifer on the northern slopes. On the valley floor there are scattered Oak, Scots pine and Sycamore trees and extensive areas have been planted with hardwoods (An Chomhairle Leabharlanna).

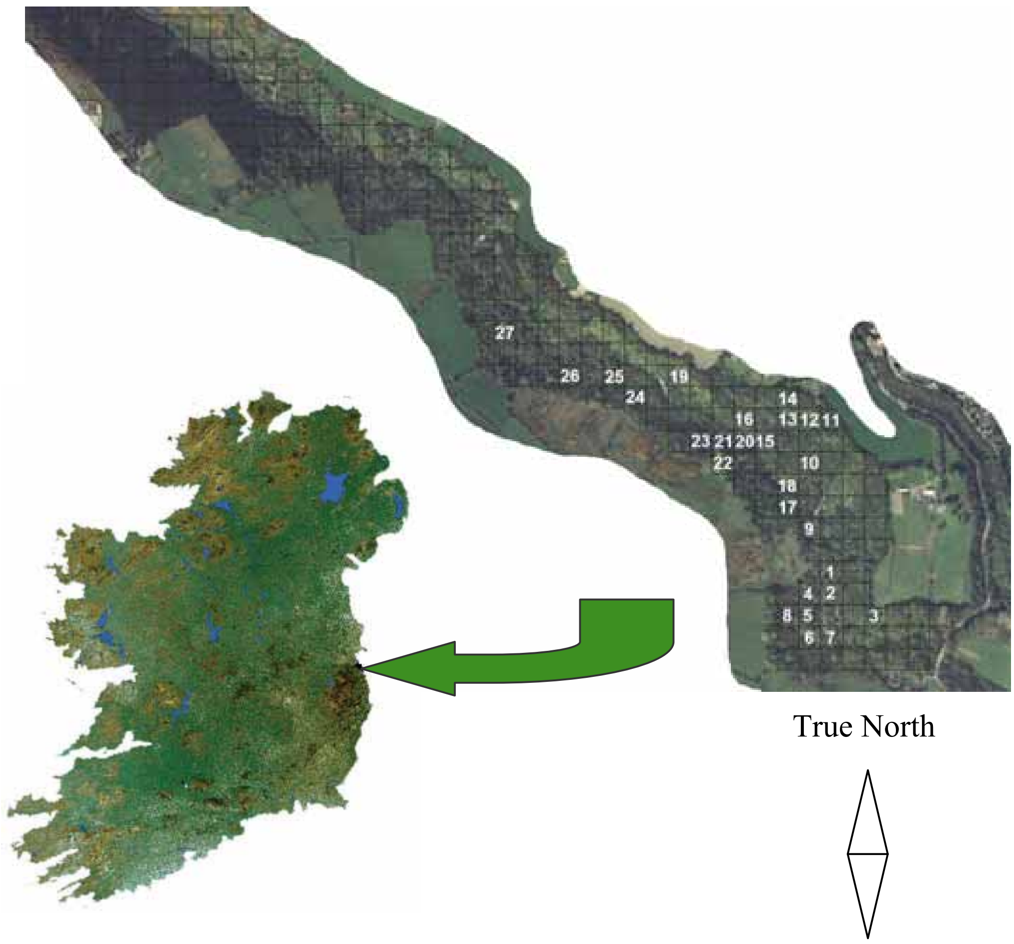
3.1.2 Importance of the sites

The woodlands in Knocksink Wood have been studied in detail in recent years (Ball 1997, Kelemen and Dromey 2000). However, lichens were not studied in any detail. It is the objective of this study to gather new information on epiphytic lichens in Knocksink and to advance understanding of the occurrence and dynamics of lichens in connection to different woodland habitats in Knocksink Wood Nature Reserve. The woodland at Powerscourt Waterfall has been studied for lichen species previously by the British Lichen Society during their field meeting to County Wicklow in 1994 and by Cullen and Fox (1999) (Anonymous 2005). From both studies, it emerged that rare lichen species occur in this woodland. However, the distribution of lichens on tree trunks was not assessed in detail and it is the objective of this study to generate new data through the use of formal lichen-based indices.

3.2 Grid map

The sampling strategy followed the European Guideline for Mapping Lichen Diversity as an Indicator for Environmental Stress (Asta *et al.* 2002 a, b). A mapping grid of 50 x 50m was placed over the map of Knocksink Wood to facilitate selection of sample plots (Figure 3.2). This size of sample plot was designed to record variation of epiphytic lichen distribution within the designated habitat type.

Figure 3.2 Map of Ireland with marked location of Knocksink Wood Nature Reserve and grid map of Knocksink with marked sample plots (enlarged copy of grid map is in Appendix 8.1).



☐ 50 x 50m

1 – 27 Location of sampling units South

3.3 Selection of sample plots

A total of 27 sample plots were selected using stratified sampling (Kent and Coker 1994) in the woodlands of Knocksink Wood (Figure 3.2). Woodland types were used for stratification and three types were selected: oak woodland; oak-ash-hazel woodland; and ash-hazel woodland. Sample plots were chosen based on accessibility, representative woodland type, presence of suitable trees and no road disturbance. Eight sample plots were located within the entire oak woodland (N. 1 to 8); eleven sample plots in the oak-ash-hazel woodland (N. 9 to 19) and eight sample plots were selected in the ash-hazel woodland (N. 20 to 27) (Figure 3.2). Two sample plots (also 50 x 50m) were sampled in the woodland at Powerscourt Waterfall (Figure 3.3).

Figure 3.3 Location of two sample plots (yellow squares) in the woodland at Powerscourt Waterfall.

☐ 50 x 50m

3.4 Sampling period

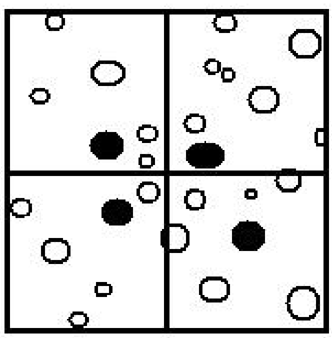
Sampling took place over a period of two years, from June 2003 until August 2005. Sampling dates were chosen preferably during the spring and summer season when most of the lichen species were fertile.

3.5 Sampling within a sample plot

The selected sample plots were divided into equal quadrats (Figure 3.4). One tree was then selected within each of these quadrats according to a defined set of criteria derived from Asta *et al.* (2002 a, b). 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, an ash tree in the ash-hazel woodlands, oak and ash trees in the oak-ash-hazel woodland and oak and sycamore trees in the woodland at Powerscourt Waterfall);
- A free standing tree showing no evidence of damage or interference by humans or animals;
- A tree with a trunk circumference greater than 60cm at a height of 100cm and an inclination of less than 10° from vertical. Trees of different trunk circumference and different age were considered for sampling as they naturally occurred within semi-natural woodlands in order to generate a complete list of epiphytic lichens on tree trunks and
- They were located as close as possible to the centre of the sample plot (Figure 3.4).

Figure 3.4 Selection of trees for sampling within a sample plot (adapted from Asta *et al.* 2002 a, b).

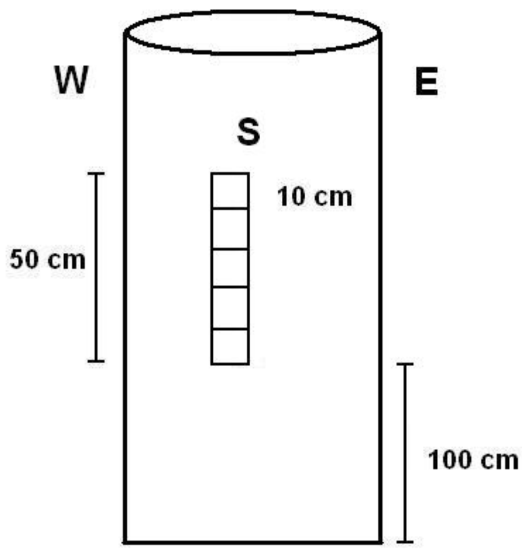


The position of selected trees within a sample plot was marked using numbers 1, 2, 3 and 4 on a survey map. A Georeferencing Positioning System – GPS 12 GARMIN was used for the geo referencing of trees. Four readings were taken at each tree location on its trunk at a height 100cm above the ground. The assigned GPS location value for each tree was the mean value of the four readings (Appendix 8.2).

3.6 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 x 10cm (Figure 3.5) 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 constituted a relevé of lichen vegetation.

Figure 3.5 Surveying quadrat segment with five quadrat squares (adapted from Asta *et al.* 2002 a, b).



3.7 Laboratory work

All samples of lichens collected in the woodlands were processed for identification in the laboratory. An Olympus microscope BH-2 with x 40, x 100, x 200, x 400 and x 1000 magnifications was used for identification of micro lichen species. An Olympus Binocular stereomicroscope (SZH 10) with magnifications from x 7 to x 70 was used for the identification of foliose and fruticose lichens and for making the cut sections for microscopic identification. The insights of thallus, fruiting organs, spores and other characteristics have been measured using a built in micrometer. Nomarski differential – interference – contrast was used to produce a high contrast image of unstained living cells and tissues. Images from microscopic identification have been recorded using a digital camera (Canon EOS D30) attached to the microscopes. Spot colour reaction tests were applied for distinguishing some of the problematic lichen species using 10% solution of Potassium hydroxide (K), 5% solution of Sodium hypochlorite (C) and the Steiner's Stable Pd solution of para-phenylenediamine (Pd). Species identification was further assisted by reference to the work of Wirth (1995 a, b), Purvis *et al.* (1994), Duncan (1970), Brodo (1981), Dobson (2000) and Orange (1994). Alan Orange was used to identify the soredioso – leprose sterile lichen species of the *Lepraria* genus. The adopted nomenclature for lichen species followed the checklist in Coppins (2002) and Fox (2004). Statistical software MINITAB 14 was used to perform multivariate cluster variable analyses on the lichen data.

3.8 Calculation of lichen diversity values

Following the procedures of Asta *et al.* (2002 a, b) LD values for each sample plot were calculated. Within each sample plot 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 sample plot j was calculated following the formula:

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

where:

MSF_{Nj} is the mean of the sums of frequencies of all trees of plot *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 plot *j*

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

The LD value of sample plot *j* (LD_j) was then calculated as the sum of the *MSFs* of all aspects:

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

The LD value of tree *i* (LD_i) was calculated as the sum of frequencies (MSF_i) on tree *i*:

$$LD_i = \sum MSF_i$$

where $MSF_i = SF_{iN} + SF_{iE} + SF_{iS} + SF_{iW}$

3.9 Mapping lichen diversity

The lichen diversity values (LDVs) of sample plots were grouped into classes, sufficiently wide to reflect statistically and environmentally significant differences among sampling areas to interpret results. Interpretative scales of Asta *et al.* (2002a) and Loppi (1996) were used as examples for developing a scale for Knocksink. The classification was based on mean LD value and mean standard deviation of all LD, which determined the interval of Class 1:

$$Class1 = MeanLDV - \frac{1}{2} stdev$$

where: *stdev* means standard deviation
meanLDV is mean LD value

According to the equation a value defining the first class was obtained by subtracting half of the standard deviation value from the mean LDV of all LDVs. The second class was obtained by adding the standard deviation value. The standard deviation value was used as the interval between zones. The lower limit of class 1 was zero and the upper limit of class 5 was open.

$$Class2 = Class1 + stdev$$
$$Class3 = Class2 + stdev$$
$$Class4 = Class3 + stdev$$
$$Class\ 5 = > upper\ limit\ of\ Class\ 4$$

Accordingly a LD interpretation scale with different LD classes was developed. The scale distinguished five LD classes marked in five colours, red for 'Very Low' LD, orange for 'Low' LD, yellow for 'Moderate' LD, green for 'High' LD and blue for 'Very High' LD. These classes were further divided into subclasses (Castello *et al.* 2006) to provide a higher degree of resolution in lichen analysis (Table 3.1). Subclasses were defined for class 'Very Low' LD, 'Low' LD, 'Moderate' LD and 'High' LD by subdividing these classes into equal intervals. LD values of sample plots were marked using the defined colour scheme on the grid map of Knocksink Wood.

Table 3.1 LD interpretation scale with classes further subdivided into subclasses.

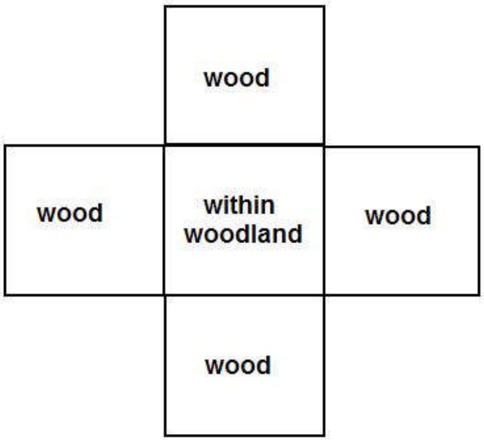
Class	Subclass	LDV	Oak wood plots	Oak-ash-hazel wood plots	Ash-hazel wood plots
			Location numbers (plots)		
Very High LD					
High LD	High to Very High				
	High				
Moderate LD	Moderate to High				
	Moderate				
Low LD	Low to Moderate				
	Low				
Very Low LD	Very Low				
	Extremely Low				

3.10 Lichen diversity and environmental variables

3.10.1 Light

Each sample plot was assigned to one of two categories: (1) Woodland perimeter or (2) Within woodland. The 'Within woodland' category was defined as a sample plot, which was surrounded by other woodland plots 50 x 50m on all four sides, to the north, east, south and west (Figure 3.6). The 'Woodland perimeter' category was defined as a sample plot, which was not surrounded by woodland plots 50 x 50m on all four sides and was less than 50m from the woodland periphery.

Figure 3.6 Specification of 'Within woodland' sample plots.



Sample plots were divided based on these criteria accordingly:

Woodland perimeter: Plot 1; 3; 4; 8; 9; 11; 14; 19; 22; 23; 24; 26; and 27 (Figure 3.2).

Within woodland: Plot 2; 5; 6; 7; 10; 12; 13; 15; 16; 17; 18; 20; 21; and 25 (Figure 3.2).

3.10.2 Trunk circumference

Trunk circumference of sampled oak trees in the oak woodland and ash trees in the ash-hazel woodland was recorded at 100cm above the ground. Trunk circumference categories were established as 20cm intervals starting at 60cm. In total 13 trunk circumference categories were established (Table 3.2).

Table 3.2 Trunk circumference categories.

Category	Trunk circumference
Category 1	≤ 60cm
Category 2	61 – 80cm
Category 3	81 – 100cm
Category 4	101 – 120cm
Category 5	121 – 140cm
Category 6	141 – 160cm
Category 7	161 – 180cm
Category 8	181 – 200cm
Category 9	201 – 220cm
Category 10	221 – 240cm
Category 11	241 – 260cm
Category 12	261 – 280cm
Category 13	> 280cm

The trunk circumference categories were used to group data (1) for lichen frequency and tree circumference and (2) for lichen numbers and tree circumference.

3.11 Sørensen coefficient

The Sørensen coefficient (S_s) (Kent and Coker 1994) was calculated for expressing similarity in species composition between oak and ash-hazel woodland, oak and oak-ash-hazel woodland and oak-ash-hazel and ash-hazel woodland and between Knocksink Wood and Powerscourt Waterfall woodland using formula:

$$S_s = 2a / 2a + b + c$$

where a is number of species common to both quadrats/samples

b is number of species in quadrat/sample 1

c is number of species in quadrat/sample 2

3.12 Alternative diversity indices

Lichen data recorded in the oak woodland and the ash-hazel woodland at Knocksink was analysed using alternative diversity indices with the aim to assess diversity of lichen species on oak and ash trees.

The Shannon diversity index (H') (Kent and Coker 1994) was used to establish alternative estimates of species diversity in the woodlands following a formula:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where s is the number of species

p_i is the proportion of individuals or the abundance of the i^{th} *species* expressed as a proportion of total cover

ln is log base_e

The biological diversity was also quantified using Simpson's Index of Diversity (*D*) (Odum 1993) applying formula:

$$D = \sum (n/N)^2$$

where n is the total number of organisms of a particular species

N is the total number of organisms of all species

3.13 Identifying patterns of local environmental alteration

The local pattern of environmental alteration was designated using the LD values of sampled trees within Knocksink Wood based on the approach of Loppi *et al.* (2002a). An interpretive scale was designed for oak and ash trees based on an average LDV greater than the 98° percentile for the LDVs of the trees. This value was used as the upper limit in class 5 (five class scale). The lower limit of the scale was set at zero LDV in class 1. The width of class 2, class 3 and class 4 was based on subdividing the upper limit value into three equal intervals. Loppi *et al.* (2002a) proposed five interpretive classes to include:

Class 1 'Lichen desert' with very high environmental alteration;
Class 2 'Alteration' with high environmental alteration;
Class 3 'Semi-alteration' with moderate alteration;
Class 4 'Semi-naturality' with low environmental alteration; and
Class 5 'Naturality' with no environmental alteration (Table 3.3).
Sample plots were assigned to the appropriate classes using the LDVs. Sample plots were marked according to their interpretation class on the grid map for Knocksink

using a colour coding scheme: Class 5 in dark green; Class 4 in bright green; Class 3 in yellow; Class 2 in orange; and Class 1 in red.

Table 3.3 Environmental alteration classes for Knocksink Wood Nature Reserve.

Class	Interpretation	LD values	% alteration
Naturality	NO environmental alteration		0
Semi-naturality	LOW environmental alteration		1 - 25
Semi-alteration	MODERATE environmental alteration		26 - 50
Alteration	HIGH environmental alteration		51 - 75
Lichen Desert	VERY HIGH environmental alteration		76 - 100

3.14 Assessing ecological continuity

Indices of ecological continuity were applied to assess ‘ancient woodland’ character and the ecological continuity of the woodlands at Knocksink Wood and Powerscourt Waterfall (Rose and Coppins 2002; Coppins and Coppins 2002). Indicator epiphytic lichen species were identified following the indicator species list from Rose and Coppins (2002) (Table 3.4).

Table 3.4 The RIEC indicator lichen species (Rose and Coppins 2002)

Lichen species	
Arthonia vinosa	*Pachyphiale carneola*
Arthopyrenia ranunculospora	*Pannaria conoplea*
Biatora sphaeroides	*Parmelia crinita*
Catillaria atropurpurea	*Parmelia reddenda*
Degelia atlantica / D. plumbea, Parmeliella triptophylla	*Petigera collina*
Dimerella lutea	*Peltigera horizontalis*
Enterographa crassa	*Porina leptalea*
Lecanactis lyncea	*Pyrenula chlorospila / P. macrospora*
Lecanactis premnea	*Rinodina isidioides*
Lobaria amplissima	*Schizmatomma quercicola / Pertusaria pupillaris*
Lobaria pulmonaria	*Stenocybe septata*
Lobaria scrobiculata	*Sticta fuliginosa / S. sylvatica*
Lobaria virens	*Sticta limbata*
Loxopora elatina	*Thelopsis rubella*
Nephroma laevigatum	*Thelotrema lepadinum*

The Revised Index of Ecological Continuity (RIEC) was calculated using the approach outlined by Coppins and Coppins (2002):

$$RIEC[\%] = (n / 20) \times 100$$

where:

n is the number of indicator species present in the study area

20 is the maximum number of species expected in any "good" site

According to Rose and Coppins (2002) a total number of 20 indicator species is required to achieve a score of 100, which can be interpreted as indicating high ecological continuity within a study site.

The New Index of Ecological Continuity (NIEC) was estimated following Coppins and Coppins (2002) and Rose and Coppins (2002). A NIEC value represents the total number of indicator lichen species present at the site based on a list of 70 main indicator species and 36 bonus indicator species (Table 3.5). Based on the NIEC value the conservation importance of the woodlands was graded. According to Rose and Coppins (2002) a NIEC value greater than 20 indicates high conservation importance for a site and a NIEC value lower than 20 indicates limited conservation importance.

Table 3.5 The NIEC indicator lichen species (Rose and Coppins 2002)

Main lichen species	
Agonimia allobata	*Loxospora elatina*
Agonimia octospora	*Megalospora tuberculosa*
Arthonia astroidestera	*Micarea pycnidiophora*
Arthonia ilicina	*Nephroma laevigatum*
Arthonia vinosa	*Nephroma parile*
Arthopyrenia antecellens	*Ochrolechia inversa*
Arthopyrenia ranunculospora	*Opegrapha corticola*
Bacidia biatorina	*Opegrapha prosodea*
Biatora epixanthoides	*Pachyphiale carneola*
Biatora sphareoides	*Pannaria conoplea / P. rubiginosa*
Buellia erubescens	*Parmelia crinita*
Catillaria atropurpurea	*Parmelia reddenda*
Cetrelia olivetorum	*Parmeliella jamesii*
Chaenotheca spp. (excl. *C. ferruginea*)	*Parmeliella triptophylla*
Cladonia caespiticia	*Peltigera collina*
Cladonia parasitica	*Peltigera horzontalis*
Collema furfuraceum / C. subflaccidum	*Pertusaria multipuncta*
Degelia atlantica, / D. plumbea	*Pertusaria velata*
Dimerella lutea	*Phaeographis* sp. (excl. *P. smithii*)
Enterographa sorediata	*Phyllospora rosei*
Heterodermia obscurata	*Rinodina isidioides*
Lecanactis amylacea	*Schizmatomma niveum*

Table 3.5 continued	
Main lichen species	
Lecanactis lyncea	*Schizmatomma quercicola / Pertusaria pupillaris*
Lecanactis premnea	*Stenocybe septata*
Lecanactis subabietina	*Sticta limbata*
Lecanora jamesii	*Sticta fuliginosa / S. sylvatica*
Lecanora quercicola	*Strangospora ochrophora*
Lecanora sublivescens	*Thelopsis rubella*
Leptogium cyanescens	*Thelotrema lepadinum*
Leptogium lichenoides	*Usnea ceratina*
Leptogium teretiusculum	*Usnea florida*
Lobaria amplissima	*Wadeana dendrographa*
Lobaria pulmonaria	*Zamenhofia coralloidea*
Lobaria scrobiculata	*Zamenhofia hibernica*
Lobaria virens	
Bonus species: the inclusion of following species is dependent on geographical considerations.	
Anaptychia ciliaris (Devon only)	*Pannaria mediterranea*
Arthonia anombrophila	*Pannaria sampaiana*
Arthonia anglica	*Parmelia arnoldii*
Arthonia arthonioides	*Parmelia horrescens*
Arthonia zwachii	*Parmelia minarum*
Bacidia circumspecta	*Parmelia sinuosa*
Bacidia subincompta	*Parmelia taylorensis*
Catillaria laureri	*Parmeliella testacea*
Caloplaca lucifuga	*Pseudocyphellaria crocata*
Collema fragrans	*Pseudocyphellaria intricate / P. norvegica*
Collema nigrescens	*Ramonia* sp.
Collema subnigrescens	*Schizmatomma graphidioides*
Cryptolechia carneolutea	*Sphaerophorus globosus* (S England only)
Gyalecta derivata	*Sphaerophorus melanocarpus* (S England only)
Leptogium burgessii	*Sticta canariensis / S. dufourii*
Leptogium cochleatum	*Teloschistes flavicans*
Megalaria grossa (S England only)	*Usnea articulate*
Opegrapha fumosa	*Zamenhofia rosei*

3.15 Lichen species indicative of native woodlands

Lichen species recorded on the trees in the woodlands in Knocksink Wood and Powerscourt Waterfall were compared to the list of thirty-one indicative lichens for native woodlands in the south-east of Ireland (Table 3.6) (Higgins *et al.* 2004).

Table 3.6 Lichen species indicative of native woodland in the south-east of Ireland (Higgins *et al.* 2004).

Species	No. of releves	Most frequent host species	Main substrate
Graphis scripta	172	*Fraxinus excelsior*	Trunk/bark
Lepraria incana agg.	64	*Quercus* sp.	Trunk/bark
Parmelia perlata	52	*Salix* sp.	Twig/bark
Thelotrema lepadinum	28	*Fraxinus excelsior*	Trunk/bark
Enterographa crassa	17	*Fraxinus excelsior*	Trunk/bark
Lecidella elaeochroma	16	*Fraxinus excelsior*	Trunk/bark
Cladonia coniocraea	15	*Betula pubescens*	Trunk/bark
Arthonia cinnabarina	14	*Fraxinus excelsior*	Trunk/bark
Parmelia caperata	13	None	Trunk/bark
Ramalina farinacea	11	*Crataegus monogyna*	Twig/bark
Dimerella lutea	6	None	Trunk/bark
Pyrenula macrospora	6	*Fraxinus excelsior*	Trunk/bark
Usnea subfloridana	6	*Alnus glutinosa*	Trunk/bark
Cladonia chlorophaea	5	*Alnus glutinosa*	Trunk/bark
Evernia prunastri	5	None	Trunk/bark
Lecanora chlarotera	5	None	Trunk/bark
Normandina pulchella	5	None	Trunk/bark
Xanthoria parietina	5	*Salix* sp.	Twig/bark
Chrysotrix candelaris	4	*Quercus*	Trunk/bark
Lecanactis abietina	2	None	Trunk/bark
Parmelia sulcata	2	None	None
Physcia tenella	2	None	None
Ramalina fastigiata	2	None	Twig/bark
Peltigera praetextdata	1	*Salix* sp.	Twig/bark
Physcia apolia	1	*Crataegus monogyna*	Twig/bark
Leptogium spp.	-	None	None
Peltigera horizontalis	-	None	None
Phaeophyscia orbicularis	-	None	None
Physconia distorta	-	None	None
Ramalina fraxinea	-	None	None
Sticta sp.	-	None	None

4. RESULTS

4.1 Lichen taxa recorded on the trunks of trees in Knocksink Wood woodlands

In total 53 lichen taxa were recorded on trunks of 108 trees in the Knocksink Wood woodlands. Of these 44 lichen species were crustose lichens, 6 foliose lichens and 3 fruticose lichens. The full list of the lichen taxa is presented in Appendix 8.3. Up to 35 lichen taxa were recorded on the tree trunks of oak trees in the oak woodland, 36 lichen taxa on oak, ash, beech, willow and sycamore trees in the oak-ash-hazel woodland and 24 lichen taxa on ash trees in the ash-hazel woodland (Table 4.1).

Table 4.1 Lichen taxa recorded in Knocksink Wood woodlands.

Lichen taxa	Oak wood	Oak-ash-hazel wood	Ash-Hazel wood
Acrocordia gemmata	1	-	-
Amandinea punctata	1	-	-
Anisomeridium biforme	1	1	1
Arthonia cinnabarina	1	1	-
Arthonia didyma	1	1	1
Arthonia punctiformis	-		1
Arthonia radiata	1	1	1
Arthonia sp.	1	-	-
Arthonia spadicea	-	-	1
Arthonia vinosa	1	-	-
Cladonia coniocraea	1	-	-
Dimerella pineti	1	1	-
Enterographa crassa	1	1	1
Eopyrenula leucoplaca	-	-	1
Evernia prunastri	-	1	-
Flavoparmelia caperata	-	1	-
Graphis britannica	1	-	1
Graphis scripta	1	1	1
Haematoma caesium	1	-	-
Lecanactis premnea	1	-	-
Lecanora argentata	1	1	1
Lecanora chlarotera	1	1	1
Lecanora sp.	1	1	-
Lecidea exigua	-	-	1
Lecidella elaeochroma	1	1	1

Table 4.1 continued			
Lichen taxa	**Oak wood**	**Oak-ash-hazel wood**	**Ash-hazel wood**
Lepraria lobificans	1	1	-
Melanelia glabratula	-	1	-
Melanelia subaurifera	-	1	-
Opegrapha atra	1	1	1
Opegrapha herbarum	1	1	1
Opegrapha niveoatra	1	1	1
Opegrapha sp.	1	1	-
Opegrapha varia	-	-	1
Opegrapha viridis	1	1	-
Opegrapha vulgata	-	1	1
Parmelia saxatilis	-	1	-
Parmelia sulcata	-	1	-
Parmotrema chinense	-	1	-
Pertusaria albescens	1	1	-
Pertusaria amara	1	1	-
Pertusaria hymenea	1	1	-
Pertusaria leioplaca	1	1	1
Pertusaria pertusa	1	1	-
Pertusaria sp.	1	1	1
Phlyctis argena	1	1	-
Physcia tenella	-	1	-
Porina aenea	-	1	1
Porina borreri	-	-	1
Porina sp.	1	-	-
Pyrenula macrospora	1	1	1
Ramalina farinacea	-	1	-
Schizmatomma cretaceum	1	-	-
Vouauxiella lichenicola	-	-	1
Total	**35**	**36**	**24**

The Sørensen coefficient was calculated for expressing similarity in species composition between the three woodland types in Knocksink Wood (Section 3.11) (Table 4.2).

Table 4.2 The Sørensen coefficient calculated between the three woodland types in Knocksink Wood.

Woodlands	Number of common lichens in woodland 1 and 2 (a)	Number of lichens in woodland 1 (b)	Number of lichens in woodland 2 (c)	Sørensen coeficient
Oak wood (1) and Oak-ash-hazel wood (2)	25	35	36	**41.3%**
Oak-ash-hazel wood (1) and Ash-hazel wood (2)	16	36	24	**34.8%**
Oak wood (1) and Ash-hazel wood (2)	15	35	24	**34%**

4.2 Lichen species on the trunks of oak, ash, sycamore, willow and beech trees in Knocksink Wood woodlands.

The distribution of lichen taxa within the three woodland types was assessed for each tree species separately (Table 4.3).

Table 4.3 Distribution of lichen taxa on sampled tree genera within Knocksink Wood woodlands.

Lichen taxa	Oak wood	Oak-ash-hazel wood					Ash-hazel wood
	oak	oak	ash	sycamore	willow	beech	ash
Acrocordia gemmata	1	-	-	-	-	-	-
Amandinea punctata	1	-	-	-	-	-	-
Anisomeridium biforme	1	1	1	-	1	1	1
Arthonia cinnabarina	1	1	-	-	-	-	-
Arthonia didyma	1	1	1	-	1	1	1
Arthonia punctiformis	-	-	-	-	-	-	1
Arthonia radiata	1	1	1	-	-	1	1
Arthonia sp.	1	-	-	-	-	-	-
Arthonia spadicea	-	-	-	-	-	-	1
Arthonia vinosa	1	-	-	-	-	-	-
Cladonia coniocraea	1	-	-	-	-	-	-
Dimerella pineti	1	1	-	-	-	-	-
Enterographa crassa	1	1	1	1	-	1	1
Eopyrenula leucoplaca	-	-	-	-	-	-	1
Evernia prunastri	-	-	-	-	1	-	-
Flavoparmelia caperata	-	-	-	-	1	-	-

Table 4.3 continued							
Lichen taxa	**Oak wood**	**Oak-ash-hazel wood**					**Ash-hazel wood**
	oak	**oak**	**ash**	**sycamore**	**willow**	**beech**	**ash**
Graphis britannica	1	-	-	-	-	-	1
Graphis scripta	1	1	1	1	-	1	1
Haematomma caesium	1	-	-	-	-	-	-
Lecanactis premnea	1	-	-	-	-	-	-
Lecanora argentata	1	1	-	-	-	1	1
Lecanora chlarotera	1	1	1	1	1	1	1
Lecanora sp.	1	-	1	-	-	-	-
Lecidea exigua	-	-	-	-	-	-	1
Lecidella elaeochroma	1	-	1	-	1	1	1
Lepraria lobificans	1	1	-	-	1	1	-
Melanelia spp. glabratula	-	-	-	-	1	-	-
Melanelia subaurifera	-	-	-	-	1	-	-
Opegrapha atra	1	1	1	-	1	1	1
Opegrapha herbarum	1	-	1	-	-	-	1
Opegrapha niveoatra	1	-	1	1	-	-	1
Opegrapha sp.	1	1	1	1	-	-	-
Opegrapha varia	-	-	-	-	-	-	1
Opegrapha viridis	1	-	1	-	-	-	-
Opegrapha vulgata	-	-	1	-	-	-	1
Parmelia saxatilis	-	-	-	-	1	-	-
Parmelia sulcata	-	-	-	-	1	-	-
Parmotrema chinense	-	-	-	-	1	-	-
Pertusaria albescens	1	1	-	-	-	-	-
Pertusaria amara	1	-	-	-	1	-	-
Pertusaria hymenea	1	1	-	-	-	1	-
Pertusaria leioplaca	1	1	1	1	1	1	1
Pertusaria pertusa	1	1	-	-	-	-	-
Pertusaria sp.	1	-	1	-	1	1	1
Phlyctis argena	1	-	-	-	1	-	-
Physcia tenella	-	-	-	-	1	-	-
Porina aenea	-	-	1	-	-	-	1
Porina borreri	-	-	-	-	-	-	1
Porina sp.	1	-	-	-	-	-	-
Pyrenula macrospora	1	1	1	-	-	1	1
Ramalina farinacea	-	-	-	-	1	-	-
Schizmatomma cretaceum	1	-	-	-	-	-	-
Vouauxiella lichenicola	-	-	-	-	-	-	1
Totals	**35**	**17**	**18**	**6**	**19**	**14**	**24**

A total of nine lichen taxa, *Acrocordia gemmata*, *Amandinea punctata*, *Arthonia* sp., *A. vinosa*, *Cladonia coniocraea*, *Haematoma caesium*, *Lecanactis premnea*, *Porina* sp. and *Schizmatomma cretaceum*, were recorded on oak tree trunks in the oak woodland and not on any trees in the other woodland types. Similarly, nine lichen taxa, *Evernia prunastri*, *Flavoparmelia caperata*, *Melanelia glabratula*, *M. subaurifera*, *Parmelia saxatilis*, *P. sulcata*, *Parmotrema chinense*, *Physcia tenella*, *Ramalina farinacea* were only recorded on willow tree trunks in the oak-ash-hazel woodland. There were six lichen taxa, *Arthonia spadicea*, *Eopyrenula leucoplaca*, *Lecidea exigua*, *Opegrapha varia*, *Porina borreri* and *Vouauxiella lichenicola*, recorded only on ash tree trunks in the ash-hazel woodland (Table 4.3).

The number of lichen species occurring on oak, ash, beech, willow and sycamore trees in the Knocksink Wood woodlands was recorded (Table 4.4). This is distinct from the list of species occurring on tree genera within the three woodland types (Table 4.1).

Table 4.4 Number of lichen species recorded on oak, ash, beech, willow and sycamore trees in Knocksink Wood woodlands.

Tree genera	Number of lichen species
Oak	35
Ash	27
Beech	14
Willow	19
Sycamore	6

4.3 The most frequent lichen species on trees in Knocksink Wood woodlands.

The frequency of lichen species within the three woodland types was assessed for each tree species separately (Table 4.5).

Table 4.5 Frequency of lichen species recorded on oak, ash, sycamore, willow and beech trees in the three Knocksink Wood woodlands.

Lichen taxa	Oak wood	Oak-ash-hazel wood					Ash-hazel wood
	oak n=32	oak n=3	ash n=26	sycamore n=2	willow n=4	beech n=9	ash n=32
Acrocordia gemmata	20	-	-	-	-	-	-
Amandinea punctata	3	-	-	-	-	-	-
Anisomeridium biforme	**51**	3	10	-	1	6	3
Arthonia cinabarinna	8	1	-	-	-	-	-
Arthonia didyma	3	11	11	-	1	2	6
Arthonia punctiformis	-	-	-	-	-	-	19
Arthonia radiata	15	4	**41**	-	-	8	64
Arthonia sp.	8	-	-	-	-	-	-
Arthonia spadicea	-	-	-	-	-	-	5
Arthonia vinosa	1	-	-	-	-	-	-
Cladonia coniocraea	28	-	-	-	-	-	-
Dimerella pineti	4	1	-	-	-	-	-
Enterographa crassa	**47**	4	9	1	-	5	**131**
Eopyrenula leucoplaca	-	-	-	-	-	-	12
Evernia prunastri	-	-	-	-	**16**	-	-
Flavoparmelia caperata	-	-	-	-	2	-	-
Graphis britannica	7	-	-	-	-	-	2
Graphis scripta	20	1	25	**4**	-	**18**	96
Haematoma caesium	9	-	-	-	-	-	-
Lecanactis premnea	1	-	-	-	-	-	-
Lecanora argentata	31	**15**	-	-	-	7	16
Lecanora chlarotera	30	**30**	22	1	**28**	**57**	**156**
Lecanora sp.	8	-	1	-	-	-	-
Lecidea exigua	-	-	-	-	-	-	22
Lecidella elaeochroma	19	-	1	-	12	12	37
Lepraria lobificans	**111**	2	-	-	2	1	-
Melanelia glabratula	-	-	-	-	1	-	-
Melanelia subaurifera	-	-	-	-	9	-	-
Opegrapha atra	39	**21**	**209**	-	1	**33**	**178**
Opegrapha herbarum	5	-	**41**	-	-	-	1
Opegrapha niveoatra	2	-	3	**3**	-	-	82
Opegrapha sp.	4	3	7	1	-	-	-
Opegrapha varia	-	-	-	-	-	-	9
Opegrapha viridis	2	-	3	-	-	-	-
Opegrapha vulgata	-	-	1	-	-	-	7
Parmelia saxatilis	-	-	-	-	2	-	-
Parmelia sulcata	-	-	-	-	**14**	-	-
Parmotrema chinense	-	-	-	-	3	-	-
Pertusaria albescens	6	1	-	-	-	-	-
Pertusaria amara	4	-	-	-	2	-	-

Table 4.5 continued							
Lichen taxa	**Oak wood**	**Oak-ash-hazel wood**					**Ash-hazel wood**
	oak n=32	**oak n=3**	**ash n=26**	**sycamore n=2**	**willow n=4**	**beech n=9**	**ash n=32**
Pertusaria hymenea	36	10	-	-	-	2	-
Pertusaria leioplaca	**56**	11	31	**10**	**13**	**79**	110
Pertusaria pertusa	25	**12**	-	-	-	-	-
Pertusaria sp.	5	-	19	-	2	2	1
Phlyctis argena	1	-	-	-	1	-	-
Physcia tenella	-	-	-	-	1	-	-
Porina aenea	-	-	5	-	-	-	29
Porina borreri	-	-	-	-	-	-	5
Porina sp.	1	-	-	-	-	-	-
Pyrenula macrospora	1	1	**41**	-	-	7	**148**
Ramalina farinacea	-	-	-	-	5	-	-
Schizmatomma cretaceum	3	-	-	-	-	-	-
Vouauxiella lichenicola	-	-	-	-	-	-	5
Total frequencies	**614**	**131**	**480**	**20**	**116**	**239**	**1144**

The most frequent lichen species for each tree genera were marked (Table 4.5). The four most frequent (F) lichen species on oak trees in oak woodland were: *Lepraria lobificans* (F=111), *Pertusaria leioplaca* (F=56), *Anisomeridium biforme* (F=51), *Enterographa crassa* (F=47). The most frequent lichen species on oak, ash, sycamore, willow and beech trees in the oak-ash-hazel woodland were:

Oaks: *Lecanora chlarotera* (F=30), *Opegrapha atra* (F=21), *Lecanora argentata* (F=15) and *Pertusaria pertusa* (F=12).

Ash: *Opegrapha atra* (F=209), *Arthonia radiata* (F=41), *Opegrapha herbarum* (F=41), *Pyrenula macrospora* (F=41) and *Pertusaria leioplaca* (F=30).

Sycamore: *Pertusaria leioplaca* (F=10), *Graphis scripta* (F=4), *Opegrapha niveoatra* (F=3).

Willow: *Lecanora chlarotera* (F=28), *Evernia prunastri* (F=16), *Parmelia sulcata* (F=14), *Pertusaria leioplaca* (F=13).

Beech: *Pertusaria leioplaca* (F=79), *Lecanora chlarotera* (F=57), *Opegrapha atra* (F=33), *Graphis scripta* (F=18).

The four most frequent lichen species on ash trees in the ash-hazel woodland were: *Opegrapha atra* (F=178); *Lecanora chlarotera* (F=156); *Pyrenula macrospora* (F=148); and *Enterographa crassa* (F=131).

4.4 Distribution of lichen species on oak tree trunks within sample plots in the oak woodland

The three most frequent lichen species occurring on oak trees in the oak woodland were recorded for plots 1 to 8 (Figure 3.2) (Appendix 8.4) (Table 4.6).

Table 4.6 The most frequent lichen species on oak tree trunks in sample plots of the oak woodland.

Plot	Lichen species	Frequency (F)
Plot 1	*Pertusaria leioplaca*	20
	Lecanora argentata	19
	Lepraria lobificans	12
Plot 2	*Pertusaria hymenea*	27
	Lecidella elaeochroma	11
	Lecanora sp.	8
Plot 3	*Anisomeridium biforme*	15
	Acrocordia gemmata	11
	Pertusaria leioplaca	9
Plot 4	*Enterographa crassa*	13
	Pertusaria pertusa	12
	Cladonia coniocraea	10
	Lepraria lobificans	10
Plot 5	*Lepraria lobificans*	17
	Cladonia coniocraea	10
	Enterographa crassa	7
Plot 6	*Lepraria lobificans*	17
	Enterographa crassa	15
	Pertusaria leioplaca	12
Plot 7	*Lepraria lobificans*	36
	Cladonia coniocraea	3
	Opegrapha atra	2
Plot 8	*Anisomeridium biforme*	26
	Opegrapha atra	19
	Enterographa crassa	11

4.5 Distribution of lichen species on oak, ash, sycamore, willow and beech tree trunks within sample plots in the oak-ash-hazel woodland

The three most frequent lichen species occurring on oak, ash, sycamore, willow and beech trees in the oak-ash-hazel woodland were recorded for plots 9 to 19 (Figure 3.2) (Appendix 8.4) (Table 4.7).

Table 4.7 The most frequent lichen species on tree trunks in sample plots in the oak-ash-hazel woodland.

Plot	Lichen species	Frequency (F)
Plot 9	*Lecanora chlarotera*	32
	Opegrapha atra	32
	Lecanora argentata	20
	Pertusaria leioplaca	20
Plot 10	*Lecanora chlarotera*	28
	Evernia prunastri	16
	Parmelia sulcata	14
Plot 11	*Opegrapha atra*	29
	Arthonia radiata	25
	Anisomerdium biforme	4
Plot 12	*Opegrapha atra*	46
	Pyrenula macrospora	11
	Pertusaria leioplaca	2
Plot 13	*Opegrapha herbarum*	37
	Opegrapha atra	20
	Graphis scripta	9
Plot 14	*Opegrapha atra*	42
	Pyrenula macrospora	20
	Pertusaria leioplaca	13
Plot 15	*Lecanora chlarotera*	25
	Arthonia didyma	13
	Pertusaria pertusa	12
Plot 16	*Opegrapha atra*	57
	Pertusaria leioplaca	13
	Graphis scripta	8
Plot 17	*Arthonia radiata*	13
	Opegrapha atra	11
	Enterographa crassa	2
Plot 18	*Lecanora chlarotera*	17
	Arthonia didyma	9
	Enterographa crassa	7
Plot 19	*Pertusaria leioplaca*	62
	Lecanora chlarotera	25
	Opegrapha atra	19

4.6 Distribution of lichen species on ash tree trunks within sample plots in the ash-hazel woodland

The three most frequent lichen species occurring on ash trees in the ash-hazel woodland were recorded for plots 20 to 27 (Figure 3.2) (Appendix 8.4) (Table 4.8).

Table 4.8 The most frequent lichen species in sample plots in the ash-hazel woodland.

Plot	Lichen species	Frequency (F)
Plot 20	*Enterographa crassa*	44
	Lecanora chlarotera	25
	Graphis scripta	20
	Opegrapha atra	20
Plot 21	*Enterographa crassa*	46
	Pyrenula macrospora	31
	Graphis scripta	18
	Pertusaria leioplaca	17
Plot 22	*Opegrapha atra*	50
	Opegrapha niveoatra	46
	Enterographa crassa	31
Plot 23	*Opegrapha atra*	35
	Pyrenula macrospora	22
	Graphis scripta	21
Plot 24	*Pyrenula macrospora*	35
	Graphis scripta	29
	Lecanora chlarotera	4
Plot 25	*Pertusaria leioplaca*	29
	Opegrapha atra	27
	Pyrenula macrospora	24
Plot 26	*Lecanora chlarotera*	69
	Lecidea exigua	22
	Lecidella elaeochroma	18
	Pertusaria leioplaca	18
Plot 27	*Arthonia radiata*	45
	Lecanora chlarotera	41
	Opegrapha niveoatra	32

4.7 Lichen diversity assessment

Lichen diversity values were calculated for each sample plot (Section 3.8) according to Asta *et al*. (2002) (Appendix 8.5). LDVs of plots are listed in Table 4.9.

Table 4.9 Lichen diversity values in sample plots in Knocksink Wood.

Oak woodland	LDV	Oak-ash-hazel woodland	LDV	Ash-hazel woodland	LDV
Plot 1	**28.25**	Plot 9	**39.5**	Plot 20	**38.75**
Plot 2	**18.75**	Plot 10	**29**	Plot 21	**34**
Plot 3	**19.25**	Plot 11	**15.75**	Plot 22	**40.25**
Plot 4	**24**	Plot 12	**15.25**	Plot 23	**25**
Plot 5	**11**	Plot 13	**21.5**	Plot 24	**19.25**
Plot 6	**17.75**	Plot 14	**24.5**	Plot 25	**27.25**
Plot 7	**10.5**	Plot 15	**18.5**	Plot 26	**50**
Plot 8	**24**	Plot 16	**23.2**	Plot 27	**51.5**
		Plot 17	**11.75**		
		Plot 18	**16**		
		Plot 19	**31.25**		
Average LDV	**19.188**	**Average LDV**	**23.382**	**Average LDV**	**35.75**
Standard deviation of all LDVs			11.04		
Mean LDV			25.4		
Half value of Stdev			5.52		
Class 1			19.88		

The lowest LDV was recorded in Plot 7 (10.5) in oak woodland and the highest LDV was recorded in ash-hazel woodland in Plot 27 (51.5) (Table 4.9).

4.7.1 Lichen diversity interpretation scale for Knocksink Wood

The lichen diversity values of sample plots in the study site were compared with the LD interpretation scale (Asta *et al*. 2002). The scale distinguishes five LD classes: very high LD, high LD, moderate LD, low LD and very low LD. A lichen diversity interpretation scale was developed specifically for Knocksink based on the approach of Loppi (1996). The standard deviation and mean of all LDVs (Table 4.9) was calculated as 11.04 and 25.4 respectively. Based on this the width of the first class was estimated as having a value of 20 (Section 3.9). Then the local scale of LD for Knocksink was developed accordingly (Table 4.10).

Table 4.10: Local LD scale for Knocksink Wood.

Class 1	< 20
Class 2	21 to 32
Class 3	33 to 44
Class 4	45 to 56
Class 5	> 57

The interpretation of LDVs in Knocksink Wood woodlands (Section 3.9) is shown in Table 4.11.

Table 4.11: LD interpretation scale for Knocksink Wood woodlands.

Class	LDV	Oak woodland plots	Oak-ash-hazel woodland plots	Ash-hazel woodland plots
Very high LD	> 57	-	-	-
High LD	45 –56	-	-	26, 27
Moderate LD	33–44	-	9,	20, 21, 22,
Low LD	21 – 32	1, 4, 8	10, 13, 14, 16, 19	23, 25
Very low LD	< 20	2, 3, 5, 6, 7,	11, 12, 15, 17, 18	24

The classes were further divided into subclasses (Section 3.9) to provide a higher degree of resolution in lichen diversity analysis (Table 4.12).

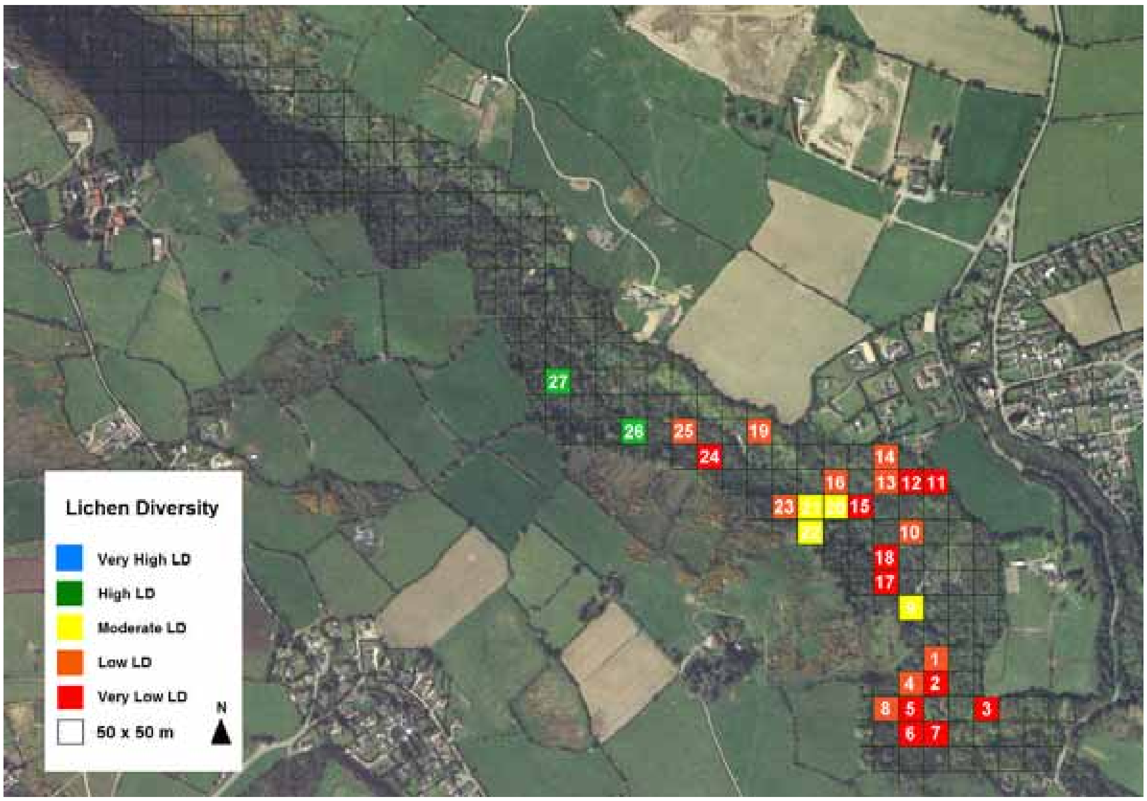
Table 4.12 Local LD interpretation scale further divided into subclasses.

Class	Subclass	LDV	Oak wood	Oak-ash-hazel wood	Ash-hazel wood
			Location numbers (plots)		
Very High LD		> 57	-	-	-
High LD	High to Very High	51 – 56	-	-	27
	High	45 – 50	-	-	26
Moderate LD	Moderate to High	39 – 44	-	9	20, 22,
	Moderate	33 - 38	-	-	21,
Low LD	Low to Moderate	27 - 32	1,	10, 19	25,
	Low	21 - 26	4, 8	13, 14, 16,	23,
Very Low LD	Very Low	11 – 20	2, 3, 5, 6	11, 12, 15, 17, 18,	24,
	Extremely Low	< 10	7	-	-

4.7.2 Mapping of lichen diversity

LD values of sample plots were assigned to the LD classes (Table 4.12) and sample plots were coloured according to the respective class (Section 3.9) (Figure 4.1).

Figure 4.1 LD map based on LDVs recorded on trees in Knocksink Wood.



4.8 Lichen diversity and environmental variables

4.8.1 Light

This analysis aims to identify differences between sample plots with regard to light availability. Each sample plot and its LDV was assigned to one of these categories: (1) Woodland perimeter or (2) Within woodland (Section 3.10.1). Then an average LD value (Table 4.9) and total lichen species number (Appendix 8.4) were calculated for each category (Table 4.13).

Table 4.13: Average LDV and species number in 'woodland perimeter' and 'within woodland' category.

Woodland Perimeter			Within woodland		
Plot	**LDV**	**Species Number**	**Plot**	**LDV**	**Species Number**
Plot 1	28.25	17	Plot 2	18.75	15
Plot 3	19.25	16	Plot 5	11	8
Plot 4	24	17	Plot 6	17.75	12
Plot 8	24	13	Plot 7	10.5	4
Plot 9	39.5	13	Plot 10	29	19
Plot 11	15.75	7	Plot 12	15.25	4
Plot 14	24.5	10	Plot 13	21.5	10
Plot 19	31.25	7	Plot 15	18.5	16
Plot 22	40.25	7	Plot 16	23.2	9
Plot 23	25	5	Plot 17	11.5	9
Plot 24	19.25	7	Plot 18	16	9
Plot 26	50	15	Plot 20	38.75	10
Plot 27	51.5	12	Plot 21	34	8
			Plot 25	27.25	7
Mean	**30.19231**	**11.23077**	**Mean**	**20.43846**	**10.23077**

4.8.2 Trunk circumference

Sampled oak trees in the oak woodland and ash trees in the ash-hazel woodland were grouped into 13 trunk circumference categories (Section 3.10.2) and average frequency and species number was calculated for each category (Appendix 8.6 and 8.7) (Table 4.14).

Table 4.14 Average frequency and lichen species numbers in different trunk circumference categories.

Category Number	Trunk girth category [cm]	Average frequency		Average lichen species number	
		oak	ash	oak	ash
1	<60	-	28.5	-	4
2	61-80	13	33.73	4.5	5.09
3	81-100	21.3	35.56	5.17	5.19
4	101-120	13.75	75	5	8
5	121-140	38	56	6	8
6	141-160	-	16	-	4
7	161-180	16.3	-	4.33	-
8	181-200	17.67	-	3.67	-
9	201-220	14.25	-	2.75	-
10	221-240	10.5	-	2	-
11	241-260	35.5	-	8	-
12	261-280	22	-	4.5	-
13	281-340	24	-	6.67	-

4.8.3 North, east, south, west aspect on trees - studying trends of epiphytes on tree trunks based on frequency.

The frequency of lichen species on tree trunks was recorded for each of the three woodland types in relation to each aspect of the trunk (Figure 3.5) for Knocksink Wood and for the trees in the woodland in Powerscourt (Appendix 8.5, 8.8 and 8.9) (Table 4.15).

Table 4.15 The frequency of lichen species on north, east, south and west aspect of tree trunks in the woodlands in Knocksink Wood and Powerscourt Waterfall.

Knocksink Wood woodlands					
	Frequency on aspects				
Woodland	North	East	South	West	Total
Oak	170	158	134	152	614
Oak-ash hazel	227	249	265	244	985
Ash-hazel	312	307	288	237	1144
Total	**709**	**714**	**687**	**633**	**2743**
Percentage	**25.85%**	**26.03%**	**25.04%**	**23.08%**	100.00%
Woodland at Powerscourt Waterfall					
	Frequency on aspects				
	North	East	South	West	Total
Total	**117**	**180**	**97**	**135**	**529**
Percentage	**22.12%**	**34.03%**	**18.33%**	**25.52%**	100.00%

4.9 Frequency of lichen species and tree genera

This analysis compares the average frequency of lichen species on oak, ash, beech, sycamore, and willow trees in the three woodland types in Knocksink Wood (Appendix 8.10) (Table 4.16).

Table 4.16 The average frequency of lichen species on oak, ash, beech, willow and sycamore trees in Knocksink.

Tree species	Average Frequency
Oak	20.7
Ash	28.5
Beech	26.6
Willow	29
Sycamore	10

4.10 Alternative species diversity indices

4.10.1 Shannon diversity

The Shannon diversity index (*H'*) was used to establish alternative estimates of species diversity at Knocksink Wood (Section 3.12). The Shannon diversity index (H') in oak woodland was estimated at 2.94 and in ash-hazel woodland at 2.52 (Appendix 8.11).

4.10.2 Simpson's Index of Diversity

The biological diversity was quantified using Simpson's Index of Diversity (D) (Section 3.12). The Simpson's Index of Diversity using the format 1-D was calculated as 0.93 for the oak woodland and 0.90 for the ash-hazel woodland (Appendix 8.12).

4.11 Identifying environmental alteration

Following Loppi *et al.* (2002) a theoretical maximum naturality value was estimated for both substratum oak and ash in Knocksink Wood based on LD values for each tree (Section 3.13) (Appendix 8.13) (Table 4.17).

Table 4.17 Estimating theoretical maximum naturality value for oak and ash trees

Substrate	N. of relevés	Max LD value	98° LD value	Mean LD value ≥ 98° LD value
Oak & Ash	93	75	65.64	72

Accordingly a scale for interpretation of environmental alteration was designed (Table 3.2) (Table 4.18).

Table 4.18 Environmental alteration interpretation scale for Knocksink Wood.

Class	Class 1	Class 2	Class 3	Class 4	Class 5
Interpretation	Lichen desert / Very high environmental alteration	Alteration / High environmental alteration	Semi-alteration / Moderate environmental alteration	Semi-naturality Low environmental alteration	Very low environmental alteration
LDVs	0	1 - 24	24 - 48	48 - 72	> 72

Based on LDVs, sample plots were assigned to the interpretation scale (Table 4.19).

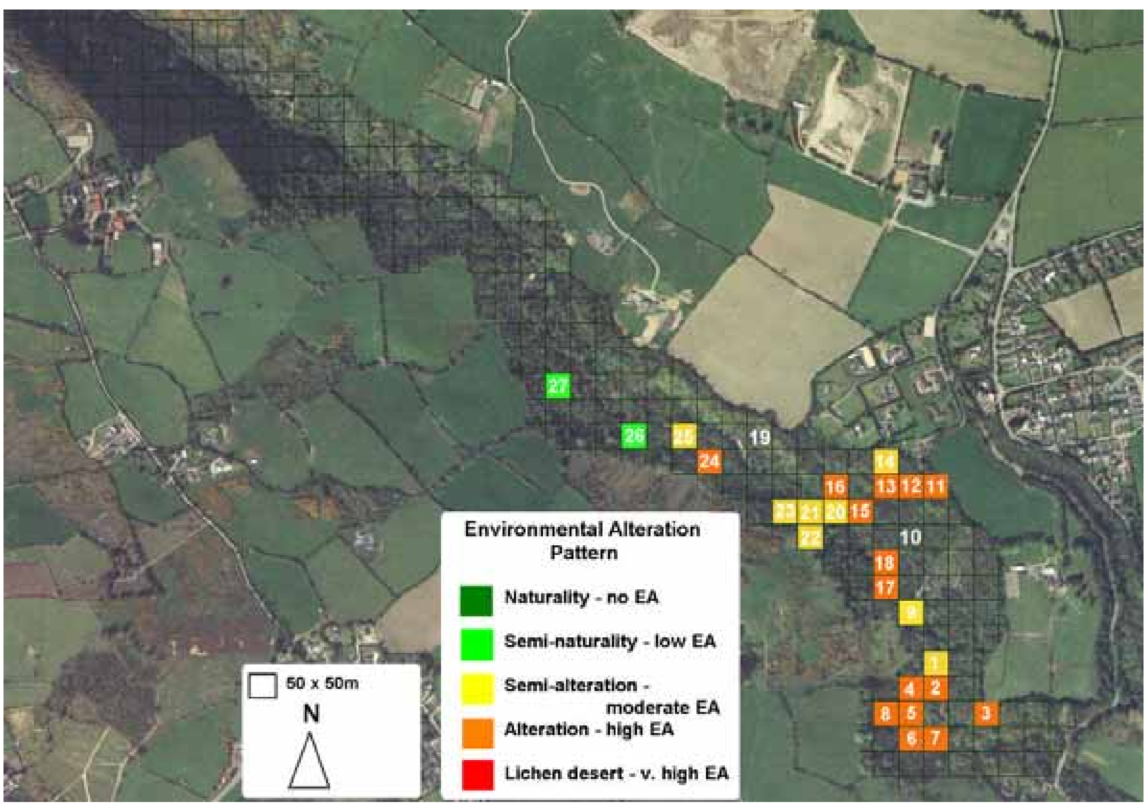
Table 4.19 Environmental alteration pattern for Knocksink Wood Nature Reserve.

Class	Interpretation	LD values	Location	Alteration [%]
Naturality	NO environmental alteration	> 72	-	0
Semi-naturality	LOW environmental alteration	48 - 72	26, 27	1 - 25
Semi-alteration	MODERATE environmental alteration	24 - 48	1, 9, 14, 20, 21, 22, 23, 25	26 - 50
Alteration	HIGH environmental alteration	1 - 24	2, 3, 4, 5, 6, 7, 8, 11, 12, 13, 15 16, 17, 18, 24	51 - 75
Lichen desert	VERY HIGH environmental alteration	0	-	76 - 100

4.11.1 Mapping environmental alteration

Based on LDVs of oak and ash trees in Knocksink, sample plots were presented on the grid map of Knocksink Wood (Figure 3.2) using the environmental alteration zones (Table 4.17) (Figure 4.2).

Figure 4.2 Map of environmental alteration in Knocksink Wood.



4.12 Indices of Ecological Continuity

Recorded lichen species in Knocksink Wood woodlands were compared to the Revised Index of Ecological Continuity (RIEC) indicator lichen species (Table 3.3) and the RIEC values were calculated for the three woodland types in Knocksink Wood (Section 3.14) (appendix 8.14) (Table 4.20). A total of four RIEC species were recorded in the Knocksink Wood woodlands. The latter included *Arthonia vinosa*, *Enterographa crassa*, *Lecanactis premnea* and *Pyrenula macrospora* (Table 4.1). *Arthonia vinosa* and *Lecanactis premnea* were only recorded in the oak woodland in Knocksink Wood. The combined RIEC for the Knocksink Wood woodlands was calculated as 20. The RIEC value for Powerscourt Waterfall woodland was calculated as 20 (Section 3.14) (Appendix 8.14) (Table 4.20).

Table 4.20 RIEC and NIEC values in the three woodland types in Knocksink Wood and for the woodland at Powerscourt Waterfall.

Woodland	RIEC	NIEC
Oak woodland	20	2
Oak-ash-hazel woodland	10	0
Ash-hazel woodland	10	0
All three woodlands at Knocksink Wood	20	2
Mixed Woodland at Powerscourt Waterfall	20	5

Recorded lichen species in Knocksink Wood woodlands were also compared to the New Index of Ecological Continuity (NIEC) indicator lichen species (Table 3.4) and the NIEC values were estimated for the three woodland types in Knocksink Wood (Section 3.14) (Appendix 8.14) (Table 4.20). A total of two NIEC indicator species were recorded in the oak woodland in Knocksink Wood. The latter included *Arthonia vinosa* and *Lecanactis premnea* (Table 4.1). None of the NIEC indicator lichen species were recorded in the oak-ash-hazel woodland or the ash-hazel woodland. The combined NIEC value for the Knocksink Wood woodlands was two. A total of five NIEC indicator lichen species viz. *Collema furfuraceum*, *Lobaria pulmonaria*, *Ochrolechia inverse*, *Parmelia crinita* and *Thelotrema lepadinum* were recorded in the woodland at Powerscourt Waterfall. The NIEC value for the woodland at Powerscourt Waterfall was 5 (Appendix 8.14).

4.13 Lichen species indicative of native woodlands

The lichen species indicative of native woodland in the south-east of Ireland (Section 3.15) were identified on oak, ash, sycamore, willow and beech in the three woodland types in Knocksink Wood (Table 4.21).

Table 4.21 Lichen species indicative of native woodland on trees in Knocksink Wood.

	Knocksink Wood woodlands							Pow. Waterf. Wood
	Oak w.	Oak-ash-hazel wood					Ash-hazel w.	
Lichen taxa	oak	oak	ash	sycamore	willow	beech	ash	
Arthonia cinnabarina	1	1	-	-	-	-	-	-
Cladonia coniocraea	1	-	-	-	-	-	-	1
Enterographa crassa	1	1	1	1	-	1	1	-
Evernia prunastri	-	-	-	-	1	-	-	1
Graphis scripta	1	1	1	1	-	1	1	1
Lecanora chlarotera	1	1	1	1	1	1	1	1
Lecidella elaeochroma	1	-	1	-	1	1	1	1
Normandina pulchella	-	-	-	-	-	-	-	1
Parmelia sulcata	-	-	-	-	1	-	-	-
Physcia tenella	-	-	-	-	1	-	-	-
Pyrenula macrospora	1	1	1	-	-	1	1	1
Ramalina farinacea	-	-	-	-	1	-	-	1
Thelotrema lepadinum	-	-	-	-	-	-	-	1
Totals	**7**	**5**	**5**	**3**	**6**	**5**	**5**	**9**

4.14 Lichen taxa recorded on tree trunks in Powerscourt Waterfall woodland

A selected number of trees were sampled for lichens in Powerscourt Waterfall woodland (Figure 3.3) to enable comparison of lichen diversity results from Knocksink Wood. In total 34 lichen taxa (Appendix 8.15) were recorded on trunks of four sycamore and two oak trees in the Powerscourt Waterfall woodland. A total of 17 lichen species were crustose lichens, 13 foliose lichens, three fruticose lichens and one lichenicolous lichen. The Sørensen coefficient was calculated for expressing similarity in species composition between the three woodland types in Knocksink Wood and Powerscourt Waterfall woodland (Appendix 8.16) (Table 4.22).

Table 4.22 The Sørensen coefficient calculated for the three woodland types in Knocksink Wood and Powerscourt Waterfall woodland.

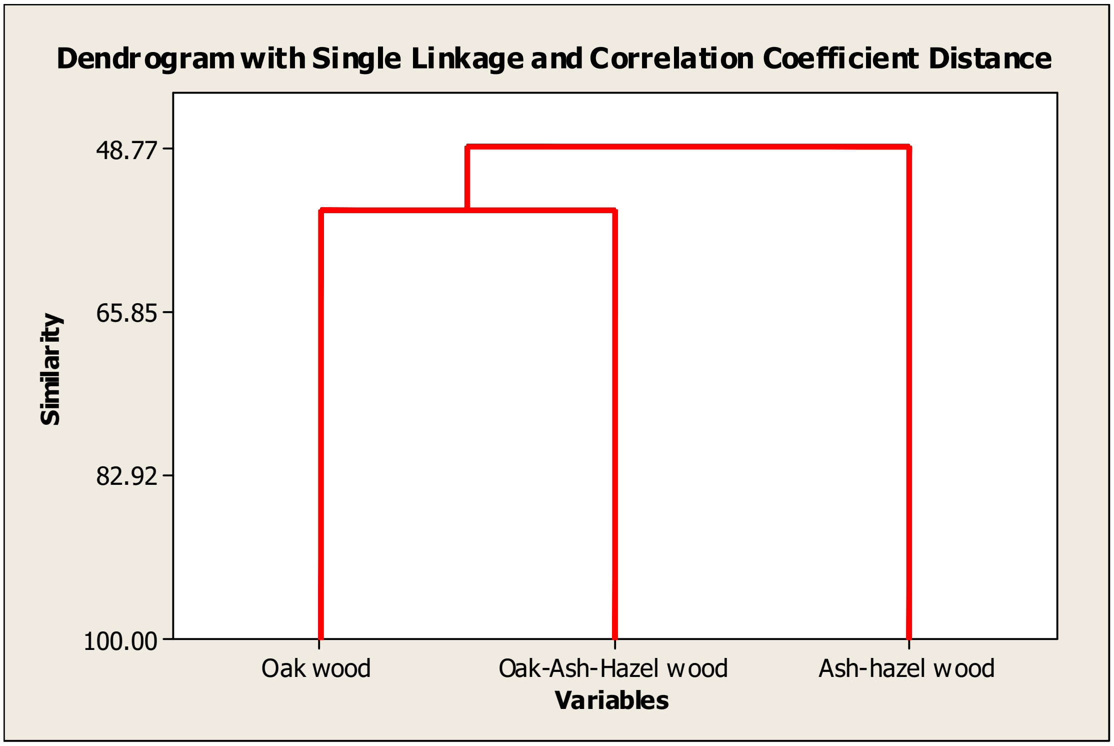
Woodlands	Number of common lichens in woodland 1 and 2 (a)	Number of lichens in woodland 1 (b)	Number of lichens in woodland 2 (c)	Sørensen coefficient
Oak wood (1) and Powerscourt W. (2)	14	35	34	**29%**
Oak-ash-hazel wood (1) and Powerscourt W. (2)	22	36	34	**39%**
Ash-hazel wood (1) and Powerscourt W. (2)	12	24	34	**29%**
Knocksink wood (1) and Powerscourt W. (2)	26	52	34	**38%**

5. DISCUSSION

5.1 Lichen taxa recorded on the trunks of trees in Knocksink Wood woodlands

A total of 53 lichen taxa were recorded on tree trunks in Knocksink Wood woodlands (Table 4.1). Most of the epiphytic lichen species recorded were crustose lichens (44 taxa). The remaining six lichens were foliose lichens and included *Flavoparmelia caperata*, *Melanelia fuliginosa* subsp. *glabratula*, *Melanelia subaurifera*, *Parmelia saxatilis*, *Parmelia sulcata*, *Parmotrema chinense*. Three lichens were fruticose lichens viz. *Evernia prunastri*, *Physcia tenella* and *Ramalina farinacea*. These lichens were recorded only on the willow trunks in the oak-ash-hazel woodland. There were no foliose and fruticose lichens recorded on the trunks of oak and ash trees in any of the woodland types at Knocksink. However, it has been generally reported where light conditions are appropriate that foliose and fruticose lichens occur on tree trunks of oak and ash trees in similar woodland types (James *et al*. 1977, Rose 1974, Coppins 1984, Broad 1989 etc.). Because of their light sensitivity foliose and fruticose lichens are typically associated with the canopy environment, specifically twigs and branches. Indeed, they are known as light demanding lichens (Wolseley and Pryor 1999). Therefore the absence of foliose and fruticose lichens on the tree trunks within Knocksink suggests that the light conditions are relatively poor below the canopy. Based on the data presented in Table 4.1 the lichen species composition was analysed to establish similarity between the three woodland types in Knocksink Wood (Appendix 8.17) (Figure 5.1).

Figure 5.1 Comparison of lichen species composition between woodland types in Knocksink Wood.



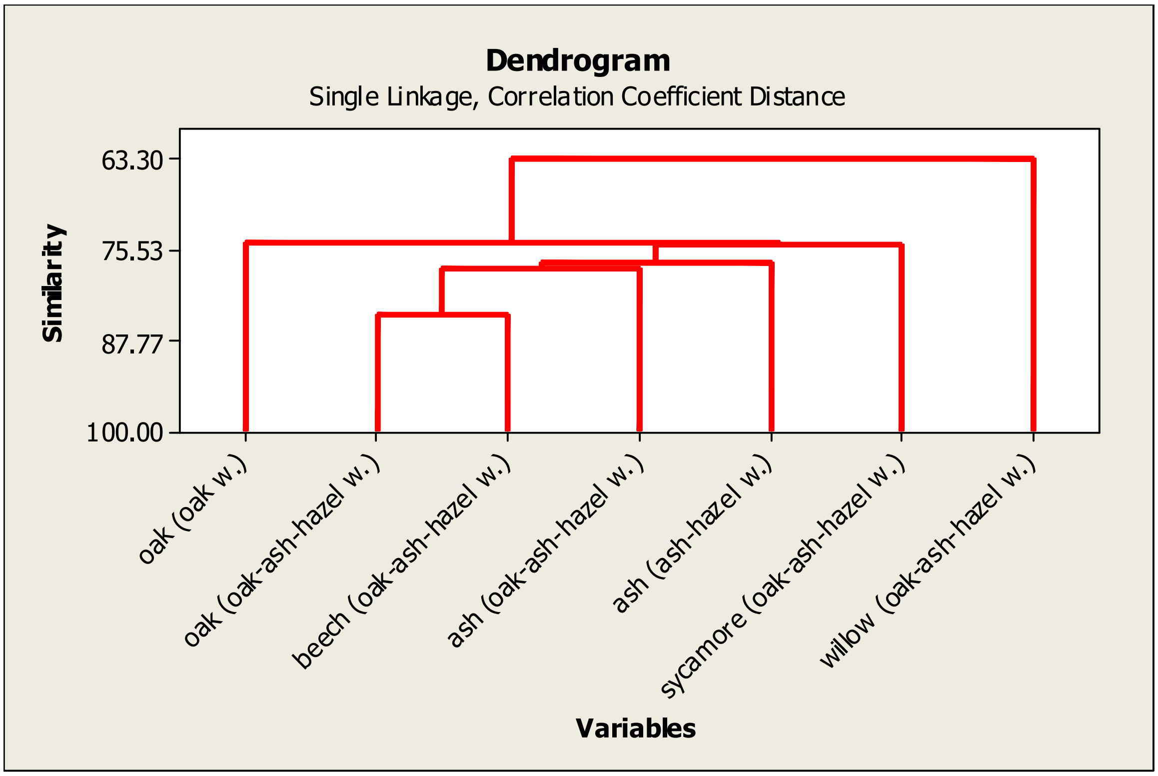
The oak woodland was found to be similar to the oak-ash-hazel woodland (similarity = 55.23%). The ash-hazel woodland showed a relatively greater difference in lichen species composition with a similarity measure of 48.77% in comparison to the oak woodland and the oak-ash-hazel woodland. Alternative assessment of similarity between the three woodland types was carried out using the Sørensen coefficient (Table 4.2). The similarity value between the oak woodland and the oak-ash-hazel woodland was recorded as 41.3%. The similarity value between the oak-ash-hazel woodland and the ash–hazel woodland was 34.8% and the similarity between the oak woodland and the ash-hazel woodland was 34%. Both assessments indicate that while there are floristic differences between the woodland types in lichens there are also strong similarities in lichen species composition.

5.2 Lichen species on the trunks of oak, ash, sycamore, willow and beech trees in Knocksink Wood woodlands.

The occurrence of lichen species within the three woodland types was assessed for oak, ash, sycamore, willow and beech trees (Table 4.3). In total 35 lichen taxa were recorded on the oak trees in the oak woodland. There was a group of lichens only recorded on the oak trees in the oak woodland; the latter included *Acrocordia gemmata*, *Amandinea punctata*, *Arthonia* sp., *Arthonia vinosa*, *Cladonia coniocraea*, *Haematomma caesium*, *Lecanactis premnea*, *Porina* sp. and *Schizmatomma cretaceum*. The oak trees in the oak-ash-hazel woodland were supporting similar lichen species to that on the oak trees in the oak woodland. However, a significantly lower number of species was recorded on the oak trees in the oak-ash-hazel woodland (17 species). In total 19 lichens were recorded on the willow trees in the oak-ash-hazel woodland. The willow trees in the oak-ash-hazel woodland supported a unique lichen assemblage at Knocksink consisting of fruticose and foliose lichens viz. *Evernia prunastri*, *Flavoparmelia caperata*, *Melanelia fuliginosa* spp. *glabratula*, *Melanelia subaurifera*, *Physcia tenella* and *Ramalina farinacea*. The beech trees supported a lower number of lichens (14 species), all of which were common lichen species recorded on the tree trunks in the three woodlands in Knocksink. The sycamore trees recorded the lowest number of lichen species (6 species). Similar lichen species occurred on both ash substrata in the oak-ash-hazel and the ash-hazel woodland. However, the ash trees in the ash-hazel woodland were recorded with higher number of species (24 lichen taxa) than the ash trees in the oak-ash-hazel woodland (18 lichen taxa). There was a group of six lichens only recorded on the ash trees in the ash-hazel woodland (*Arthonia spadicea*, *Eopyrenula leucoplaca*, *Lecidea exigua*, *Opegrapha varia*, *Porina borreri* and *Vouauxiella lichenicola*). Two lichen species were recorded on each of the oak, ash, sycamore, willow and beech viz. *Lecanora chlarotera* and *Pertusaria leioplaca*. The occurrence of the various lichen species on oak and ash trees is consistent with the findings of Alexander *et al*. (1989), Rose (1974) and Broad (1989).

Based on the data presented in Table 4.3 the lichen species composition was analysed to establish similarity between oak, ash, beech, sycamore and willow trees in the three woodland types in Knocksink (Figure 5.2).

Figure 5.2 Comparison of lichen species composition between oak, ash, beech, sycamore and willow trees in the three woodland types in Knocksink Wood.



The oak, beech, ash and sycamore in the oak-ash-hazel woodland were found to be similar to the ash in the ash hazel woodland in lichen species composition, the similarity measures were ranging from 84.43% to 74.91%. The oak in the oak woodland was also very similar (similarity = 74.64%). The willow in the oak-ash-hazel woodland was found to have similarities to some extent in lichen species composition to all the other tree species sampled in the woodlands at Knocksink (similarity = 63.30%), however the lower similarity number indicated that to some extent different lichen species also occurred on the willow trees. The number of lichens in the three woodland types in Knocksink Wood were recorded separately for each tree genera (Table 4.4) and compared (Figure 5.3).

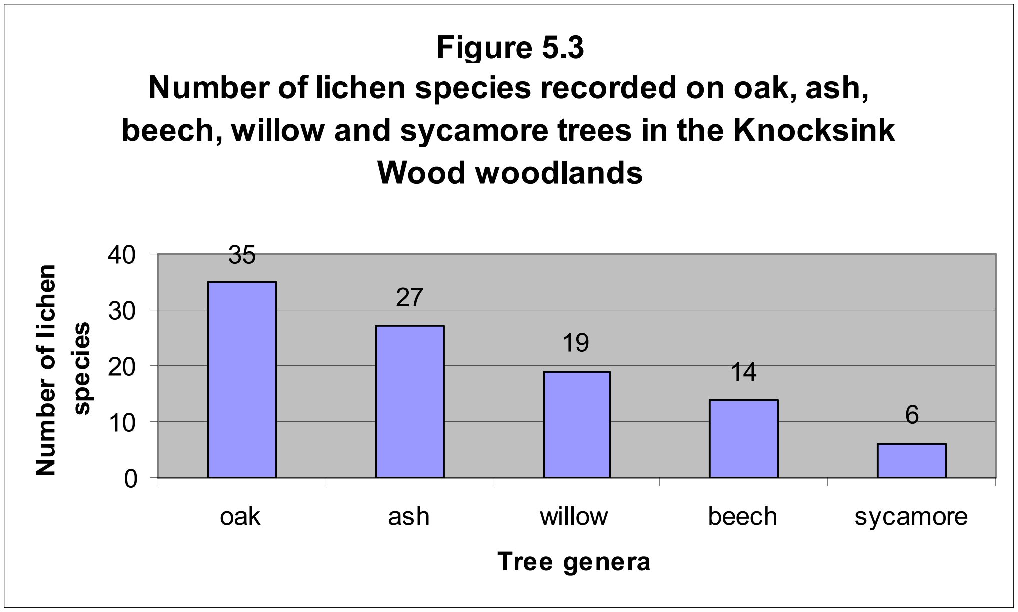


Figure 5.3 shows that the highest number of lichens was recorded on oak trees (35 lichens). A lower number, 27 species was recorded on ash trees, followed by willow trees (19 species) and beech trees (14 species). The lowest number of lichens was recorded on sycamore trees (6 species). The sequence of lichen numbers recorded per tree genera in Knocksink Wood was then: oak > ash > willow > beech > sycamore. A similar sequence was recorded by Rose (1974), although it is also recognised that no lichen species is exclusively substrate specific in relation to a given tree. Generally, oak trees support a greater number of lichen species than ash trees (Rose 1974, Broad 1989, Fox *et al*. 2001, Brodekova *et al.* 2006). The differences in lichen species numbers reflect the variable ecological conditions available to lichen development on each tree type. Mostly tree maturity, bark properties such as the roughness and availability of light and humidity at the tree trunk location are important for development of a rich lichen community.

5.3 The most frequent lichen species on trees in Knocksink Wood.

5.3.1 Oak woodland and Ash-hazel woodland

The four most frequent lichen species on the oak trees in the oak woodland were: *Lepraria lobificans*, *Pertusaria leioplaca*, *Anisomeridium biforme* and *Enterographa crassa* (Table 4.5). *Lepraria lobificans* is associated with shaded bark and grows directly on the surface and especially over mosses (Purvis *et al.* 1994). Indeed, a high occurrence of mosses was recorded on the oak tree trunks in the oak woodland. *Lepraria* lichens were also reported to be indicative of native woodlands in the south-east of Ireland especially on oaks (Higgins *et al.* 2004). The most frequent lichens on the ash trees in the ash-hazel woodland were with the exception of *Enterographa crassa* different to those on the oak trees in the oak woodland (*Opegrapha atra*, *Lecanora chlarotera*, *Pyrenula macrospora* and *Enterographa crassa*). *Pyrenula macrospora* was dominant on the ash trees. Whereas *Enterographa crassa* was abundant on both oak in the oak woodland and ash in the ash-hazel woodland. This is consistent with the findings of Higgins *et al.* 2004 where *Enterographa crassa* was reported on ash trees in native woodlands in the south-east of Ireland. Generally, *Enterographa crassa* occurs on the shaded bases and trunks of mature or senescent broad-leaved trees, especially in ancient woodlands and is tolerant of low illumination (Purvis *et al*. 1994). The high occurrence of this species on the oak trees in the oak woodland and the ash trees in the ash-hazel woodland indicated good environmental conditions for its growth and dispersal. In addition, it suggests that a degree of ancient woodland character is persistent within the woodlands of Knocksink Wood.

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 had 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. 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. 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. Clearly, certain substrate conditions favour the development of some species more than others and this may be reflected in the greater abundance of lichen species such as *Opegrapha atra*, *Lecanora chlarotera*, *Pertusaria leioplaca*, *Enterographa crassa*, *Graphis scripta* and *Arthonia radiata* on the relatively smooth barks of the ash trees. These species were recorded with significantly higher frequencies on the ash trees than on the oaks (Table 4.5). Most of these species are characteristic species found on trees with smooth bark (Broad 1989, James *et al*. 1977, Rose 1974). In this respect the occurrence of these species on the ash trees is consistent with the expectations. 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*) (Wirth 1995 a, b) in the general epiphytic lichen flora at Knocksink clearly reflects the acidic character of the bark of the trees in the woodlands.

5.3.2 Oak-ash-hazel

A variety of tree genera viz. oak, ash, willow, beech and sycamore were sampled for lichens in the oak-ash-hazel woodland. The most frequent lichens on the oak trees in the oak-ash-hazel woodland were *Lecanora chlarotera*, *Opegrapha atra*, *Lecanora argentata* and *Pertusaria pertusa.* These species also occurred on oak trees in the oak woodland, however their frequencies were lower. The most frequent lichens on the ash trees in the oak-ash-hazel woodland included *Opegrapha atra*, *Arthonia radiata*, *Opegrapha herbarum*, *Pyrenula macrospora* and *Pertusaria leioplaca*. These species also occurred on ash trees in the ash-hazel woodland and *Opegrapha atra* was recorded with relatively high frequency.

The most frequent lichen species on the willow trees (*Salix caprea*) in the oak-ash-hazel woodland included *Lecanora chlarotera*, *Evernia prunastri*, *Parmelia sulcata* and *Pertusaria leioplaca*. The high abundance of the fruticose lichen *Evernia prunastri* on the willow trees indicates that there is a high degree of illumination on the bark of these

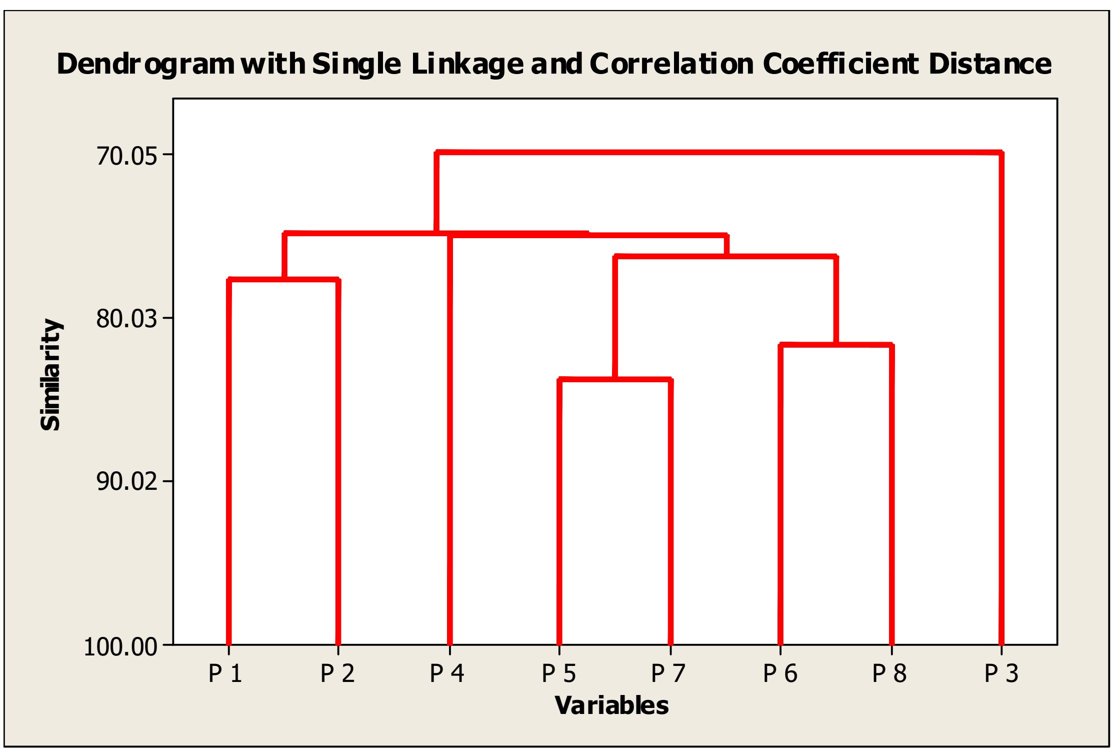
willows. The willows grow on the periphery of a small fresh water pond near the main walking path in the oak-ash-hazel woodland. Generally, Goat willow trees (*Salix caprea*) favour wet environments along streams and ponds and are usually part of the understorey in woodlands. Willows are small trees and a mature tree trunk has in average circumference 80cm (Meikle 2006). One of the sampled willow trees had a trunk circumference of 86cm at 100cm above the ground. This indicates that it is an old tree. Also the gap in the canopy created by the fresh water pond probably allows a greater penetration of light to the tree trunks than in other parts of the woodland. The occurrence of these fruticose and foliose assemblages on the willow trees is consistent with the observed maturity and roughness of their bark as well as the higher availability of light and elevated humidity at this location.
The most frequent lichen species on the sycamore trees in the oak-ash-hazel woodland included *Pertusaria leioplaca*, *Graphis scripta* and *Opegrapha niveoatra*. Similarly, the most frequent lichen species on the beech trees in the oak-ash-hazel woodland included *Pertusaria leioplaca*, *Lecanora chlarotera*, *Opegrapha atra* and *Graphis scripta*. *Graphis scripta* and *Pertusaria leioplaca* were recorded among the most frequent lichens on both sycamore and beech. Generally, both species are frequent on shaded smooth bark on a wide range of broad-leaved trees (Purvis *et al.* 1994). The occurrence of *Pertusaria leioplaca*, *Graphis scripta*, *Opegrapha atra* and *O. niveoatra* on sycamore and beech was matched by high occurrence on the ash trees in the Knocksink Wood woodlands. This may be related to the similarities in bark properties and the relatively smooth bark on beech, ash and sycamore.

This analysis confirms that there are some floristic differences between lichens on oak, ash, beech, sycamore and willow trees. These differences are related to bark properties such as the roughness and age of the substrate, water holding ability, light and humidity, etc. Indeed, all these factors were identified as important for lichen species development on trees in forests (James *et al.* 1977, Barkman 1958, Brodo 1974, Coppins 1984, Howksworth and Hill 1984, Broad 1989, Orange 1994, Wirth 1995 a, b, etc.). These results confirmed the general theory that each particular substrate tends to comprise characteristic lichen vegetation within a single climatically uniform region and under the influence of similar environmental factors, which underpins the classification of lichen communities by James *et al.* (1977).

5.4 Comparison of lichen species composition on oak tree trunks between sample plots in the oak woodland.

The three most frequent lichen species recorded in the eight sample plots in the oak woodland (Table 4.6) were compared. *Lepraria lobificans* was common to five sample plots (plot1 and plot 4 – 7). *Enterographa crassa* was recorded in four sample plots (plot 4 – 6 and plot 8). *Pertusaria leioplaca* was recorded in three sample plots (plot 1, 3, 6) and *Cladonia coniocraea* was also recorded in three plots (plot 4, 5, 7). The data (Table 4.6) suggests that no single species dominates this woodland habitat type. The lichen species composition was analysed to establish similarity between the sample plots in the oak woodland at Knocksink (Appendix 8.16) (Figure 5.4).

Figure 5.4 Similarity of lichen species composition between sampling plots in the oak woodland

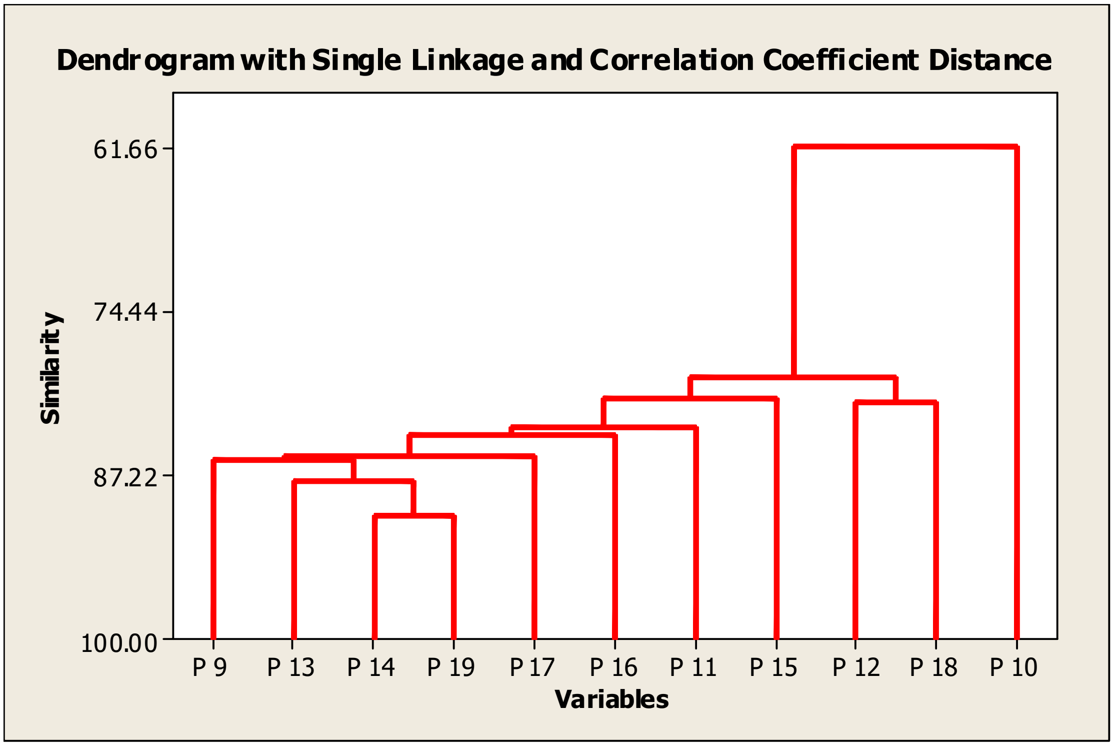


The sample plots in the oak woodland were found to be significantly similar in lichen species composition with similarity measures ranging from 70.05% to 84%. The plots with the highest degree of similarity were plot 5 and plot 7 (similarity = 83.88%) (Figure 5.4). The lowest value for similarity was recorded between plot 3 and all the other plots (similarity = 70.05%). This indicates that while there are minor floristic differences between the sample plots there are strong similarities in lichen species composition on oak trees between sample plots in the oak woodland.

5.5 Comparison of lichen species composition on oak, ash, sycamore, willow and beech tree trunks between sample plots in the oak-ash-hazel woodland.

The three most frequent lichen species recorded in the eleven sample plots in the oak-ash-hazel woodland (Table 4.7) were compared between sample plots. *Opegrapha atra* was recorded as the most common species in eight sample plots (plot 9, 11-14, 16, 17, 19) and was also the one with the highest frequency in five of the eight plots (plot 9, 11, 12, 14, 16). *Lecanora chlarotera* was recorded in five sample plots (plot 9, 10, 15, 18 and 19) and had the highest frequency in four of these (plot 9, 10, 15, 18). *Pertusaria leioplaca* was also common in five plots (plot 9, 12, 14, 16, 19) with the highest frequency being recorded in plot 19. The remaining lichens listed as frequent in Table 4.5 were frequent only in one or two plots. This in part reflects the variation of the tree bark substrate in the oak-ash-hazel woodland, which includes oak, ash, sycamore, beech and willow trees. The lichen species composition was analysed between the sample plots in the oak-ash-hazel woodland at Knocksink (Appendix 8.16) (Figure 5.5).

Figure 5.5 Similarity in lichen species composition on tree trunks in the oak-ash-hazel woodland.

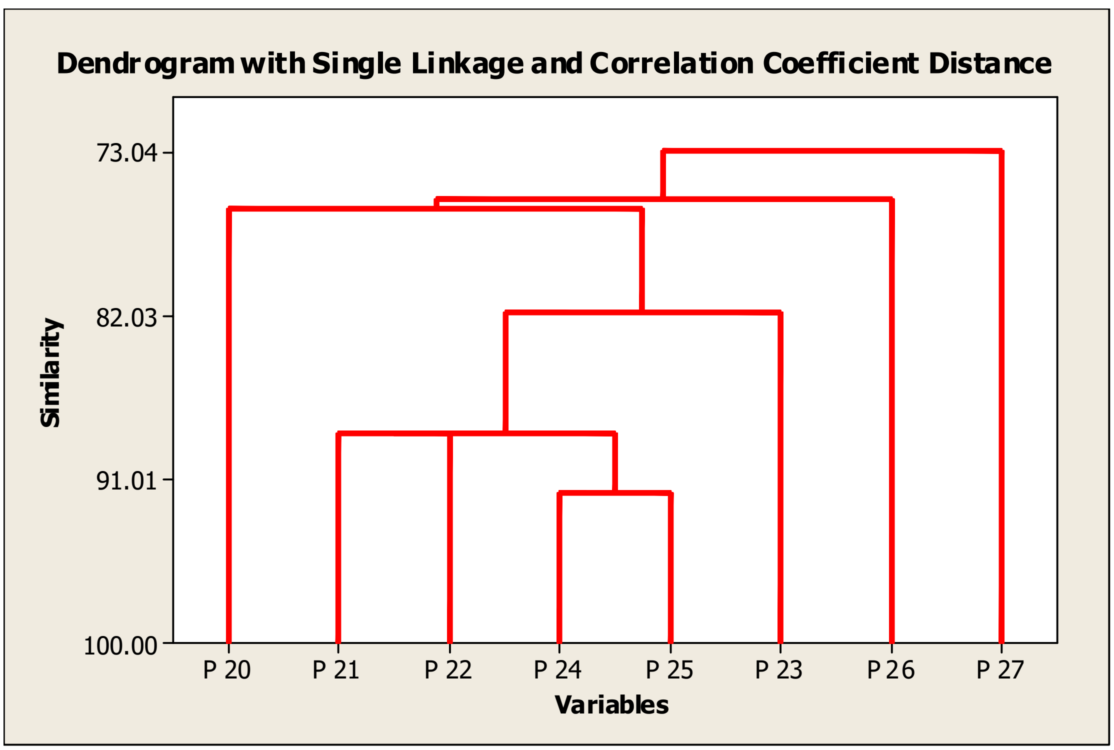


The majority of sample plots in the oak-ash-hazel woodland were found significantly similar in lichen species composition with similarity measures ranging from 90.45% to 79.63%. Plot 14 (three ash trees and one oak) and plot 19 (four beech trees) showed the greatest similarity (90.45%). This indicates that while there are minor floristic differences between the sample plots there are also strong similarities in lichen species composition on oak, ash, beech and sycamore trees between sample plots (plot 9, 11-19) in the oak-ash-hazel woodland. Plot 10 showed the highest difference in lichen species composition to all the other plots in the oak-ash-hazel woodland (similarity = 61.66%). This reflects the dominance of foliose and fruticose lichens on willow trees in this location (Table 4.5 and 4.7). The generally high similarity between the various substrate categories (different tree types) suggests that in the case of Knocksink, substrate is less significant than other factors in determining the diversity of lichen species composition.

5.6 Comparison of lichen species composition on ash tree trunks between sample plots in the ash-hazel woodland.

The most frequent lichen species recorded in the eight sample plots in the ash-hazel woodland (Table 4.8) were compared. The most frequent lichen species were *Lecanora chlarotera, Graphis scripta, Opegrapha atra* and *Pyrenula macrospora*, which all occurred in four sample plots. *Enterographa crassa* was recorded in three sample plots (plot 20-22) and *Pertusaria leioplaca* was also recorded in three sample plots (plot 21, 25, 26). The data (Table 4.8) suggest that no single species dominates this woodland habitat type. The lichen species composition was analysed to establish similarity between the sample plots in the ash-hazel woodland at Knocksink (Appendix 8.16) (Figure 5.6).

Figure 5.6 Similarity in lichen species composition on ash trees in the ash-hazel woodland.



The sample plots in the ash-hazel woodland were found to be significantly similar in lichen species composition with similarity measures ranging from 73.04% to 91.77%.

The plots with the highest degree of similarity were plot 24 and plot 25 (similarity = 91.77%) (Figure 5.6). The lowest value for similarity was recorded between plot 27 and all the other plots (similarity = 73.04%). This indicated that while there are minor floristic differences between the sampling plots there are strong similarities in lichen species composition on ash trees between sample plots in the ash-hazel woodland. This is consistent with the relatively homogenous nature of the bark substrate as all the trees sampled in this habitat type were ash. It may also reflect the dominance of other environmental factors in driving lichen species composition.

5.7 Lichen diversity assessment

Lichen diversity values (LDVs) were recorded for each sampling plot (Table 4.9). The LDVs ranged between 10.5 (Plot 7) and 28.25 (Plot 1) in the oak woodland. This value of 10.5 in the oak woodland represented the lowest LDV recorded across all three woodland habitat types. The LDV range was from 11.75 (Plot 17) to 39.5 (Plot 9) in the oak-ash-hazel woodland and the LDV interval in the ash-hazel woodland was between 19.25 (Plot 24) and 51.5 (Plot 27). The value of 51.5 in the ash-hazel woodland was the highest LDV recorded. The highest average LDV was recorded in the ash-hazel woodland (35.75), and then significantly lower in the oak-ash-hazel-woodland (23.382) with the lowest average LDV recorded in the oak woodland (19.188) (Table 4.9). Most LD values in the oak woodland fell into the 'Very Low' LD class and the subclass 'Very-low' (Table 4.12). The situation in the oak-ash-hazel woodland was slightly different. LD values for the oak-ash-hazel woodland were distributed equally between the classes 'Very Low' LD and 'Low' LD (Table 4.11 and 4.12). However, in both woodland types subclass 'Very Low' LD was the most well represented. The situation in the ash - hazel woodland was different. LD values were more scattered around the scale in classes with 'High' LD, 'Moderate' LD and 'Low' LD (Table 4.11 and 4.12). High LD was recorded in two plots in the ash - hazel woodland (plot 26 and 27). Although the LD score for the ash - hazel woodland showed a higher value than that in the oak woodland and the oak-ash-hazel woodland, the overall pattern for Knocksink Wood demonstrated a clustering of values around the bottom of the scale. This indicated that the diversity of epiphytic lichens was generally low in the woodlands of Knocksink.

LD was interpreted on the grid map for Knocksink Wood and sample plots were coloured according to the colour of respective LD class (Figure 4.1). The visual interpretation of the LD results using the colour code facilitated the assessment of differences in lichen diversity between sample plots and their location within the three woodland types in Knocksink. Most of the plots with a moderate LD score (yellow plots 20, 21, 22, 9) and a high LD score (green plots 27 and 28) were located at the south-west periphery of Knocksink mainly in the ash-hazel woodland and one plot (plot 9) in the oak-ash-hazel woodland. This south-west periphery of Knocksink is located on the southern side of the Glencullen River bank where the slope is orientated to the east. This suggests that the location of trees at the woodland edge and the orientation of the valley to the east provide conditions for greater lichen diversity in Knocksink Wood. The topographical setting (including aspect and slope) of the tree and the level of exposure have been well recognised as important parameters for lichen growth on trees in woodlands (Coppins 1984). Gilbert (2004) has also reported on the significance of location within the woodland along woodland margins, which are well lit for lichen development.

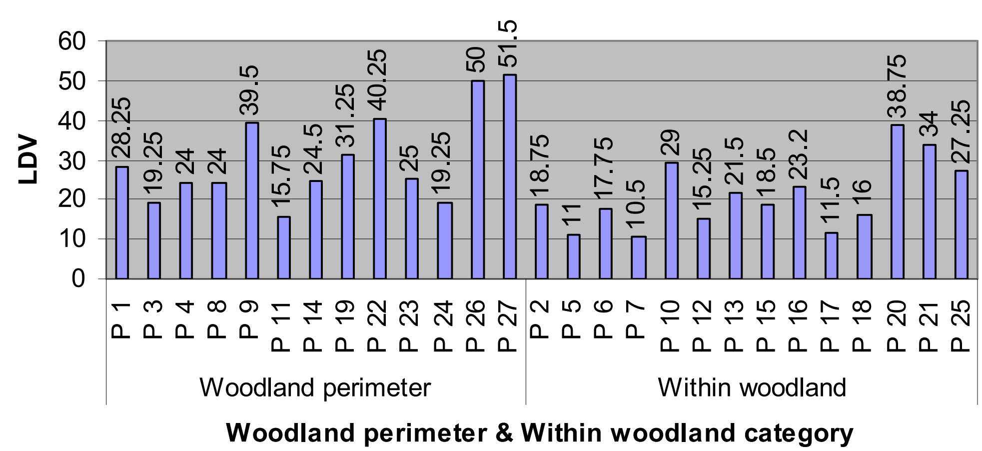
Lichen diversity counts can be taken as estimates of environmental quality, where high values correspond to good quality and low values indicate poor quality (Asta *et al*. 2002 a, b). ‘High’ LD scores were recorded mostly in the ash-hazel woodland while the majority of the ‘Low’ and ‘Very Low’ LD scores were recorded in the oak-ash-hazel woodland and the oak woodland. According to Asta *et al.* (2002 a, b) this suggests that the ash-hazel woodland has more favourable environmental conditions for the development of epiphytic lichen species than the oak-ash-hazel woodland or the oak woodland. The monoculture of oak woodland seems to have less favourable conditions for epiphytic lichen development in terms of frequency than the mixed oak-ash-hazel woodland. The mixed oak-ash-hazel woodland showed some level of woodland management (coppicing of hazel and ash trees) and this may have facilitated greater light reception at trunk level and greater development of lichens. In addition, a greater diversity of tree genera in the oak-ash-hazel woodland (oak, ash, willow, sycamore and beech trees) also contributed to diverse conditions which may have suited development of lichen species. The ash-hazel woodland seems to provide the most favourable conditions for lichen species development in terms of frequency in Knocksink Wood. The topography of the ash-hazel woodland with its proximity to woodland margin may have contributed to the greater lichen development at trunk level. Also the past woodland management of the ash-hazel woodland (coppicing of ash and hazel trees) may have facilitated greater light availability at trunk level and subsequent greater frequency of certain lichen species.

5.8 Lichen diversity and environmental variables

5.8.1 Light

This analysis aimed to identify differences between sampling plots with regard to light availability. Each sample plot was assigned to one of the two categories: (1) Woodland perimeter or (2) Within woodland (Section 3.10.1). The average LD values in sample plots were compared between both woodland categories (Table 4.13, Figure 5.7).

Figure 5.7 LDVs in sampling plots in 'woodland perimeter' and 'within woodland'



The LD value per plot in the 'Woodland Perimeter' category ranged between 15.75 and 51.5. The LD value per plot in the 'Within Woodland' category ranged between 10.5 and 38.75 (Figure 5.7). In general higher LD values were recorded in plots in the 'Woodland Perimeter' category when compared to the 'Within Woodland' category. A higher mean LD value was recorded for the 'Woodland Perimeter' category (value of 30.19) and a lower mean LD value was recorded in the 'Within Woodland' category (value of 20.44) (Table 4.13). This indicates that there are some differences in LD between sample plots located around the woodland perimeter compared to those located within the woodland. The higher LD values in sample plots at the woodland perimeter may be explained by the higher availability of light, which is one of the most important parameters for lichen species development (James *et al*. 1977). Indeed, light was also described by Coppins (1984) as one of the factors having a strong influence on the development of epiphytes on trees in forest ecosystems. The total numbers of lichen species in sample plots were also compared between both woodland categories (Table 4.13, Figure 5.8).

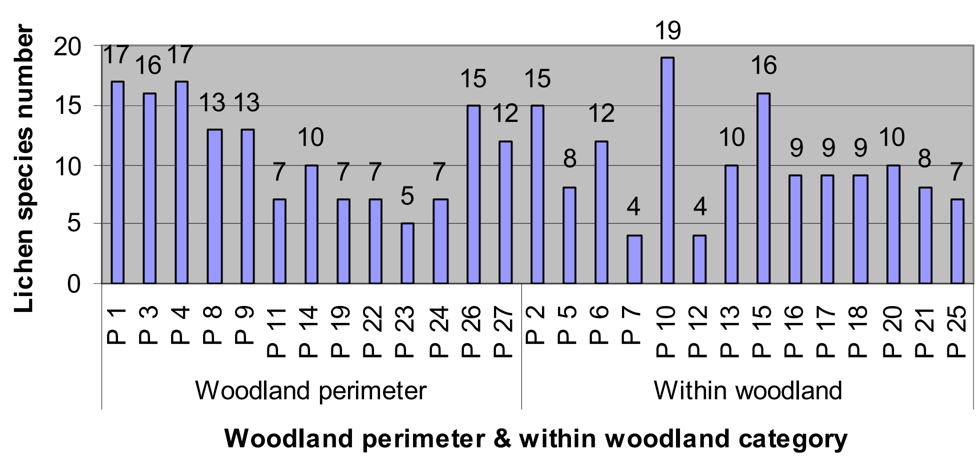


Figure 5.8 Lichen species numbers in sampling plots in 'woodland perimeter' and 'within woodland'

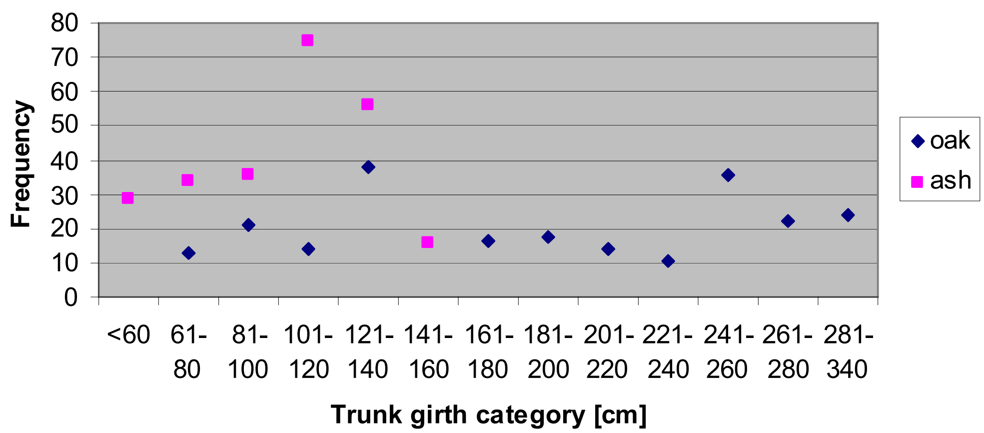
The lichen species numbers per plot ranged from 5 to 17 in the 'Woodland Perimeter' category and from 4 to 19 in the 'Within Woodland' category (Figure 5.8). Although the 'Woodland Perimeter' category had a lower upper value of occurrence compared to the 'Within Woodland' category, the mean lichen species number in the 'Woodland

Perimeter' category was 11.23 and that in the 'Within Woodland' category was 10.23 (Table 4.13). That the mean number was slightly higher in the 'Woodland Perimeter' category is consistent with the higher penetration of light at the perimeter of the woodland. This is consistent with the findings of Rose (1974), who observed that the number of lichens was generally greater on trees that were well lit than on very shaded trees. Other influential factors include temperature, humidity, physical abrasion and the drying effect of wind (Coppins 1984).

5.8.2 Trunk circumference

This analysis aimed to compare lichen frequencies on the oak trees in the oak woodland and the ash trees in the ash-hazel woodland in Knocksink with regard to the tree trunk circumference. Average lichen frequencies were calculated for each trunk circumference category separately for oak trees in the oak woodland and ash trees in the ash-hazel woodland (Table 4.14). The results were compared (Figure 5.9).

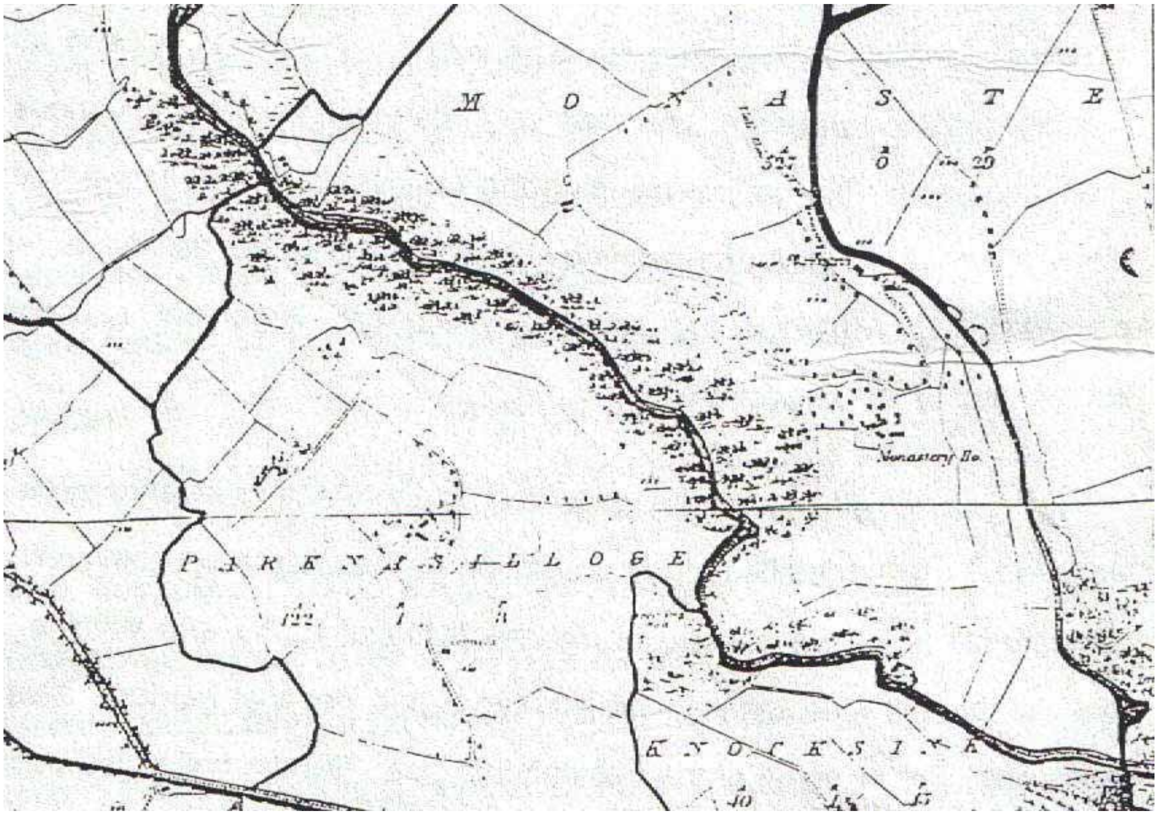
Figure 5.9 Lichen frequencies on oak and ash trees in trunk circumference categories



It was observed that there were no ash trees among the sampled trees with a trunk circumference greater than 160cm in the ash-hazel woodland. Though no oak trees were represented in two trunk circumference categories, category 1 (< 60cm) and category 6 (141 – 160cm), the oak trees had a more diverse range of trunk circumference, with some values grater than 160cm. The highest lichen frequency for ash trees was reported at the circumference of 101-120cm (F=75). There were two notable high frequencies for oak trees, one occurring where the circumference was 121-140cm (F=38) and the second where the circumference was 241-260cm (F=35.5). It is evident, that higher lichen frequencies were recorded at the same circumference category on ash trees than on oak trees up to 160cm and the lichen diversity for the ash trees was in all cases greater than that of the oaks. The higher lichen frequencies on the ash trees in the ash-hazel woodland reflect the setting of the habitat type and the similar age profile of the ash trees.

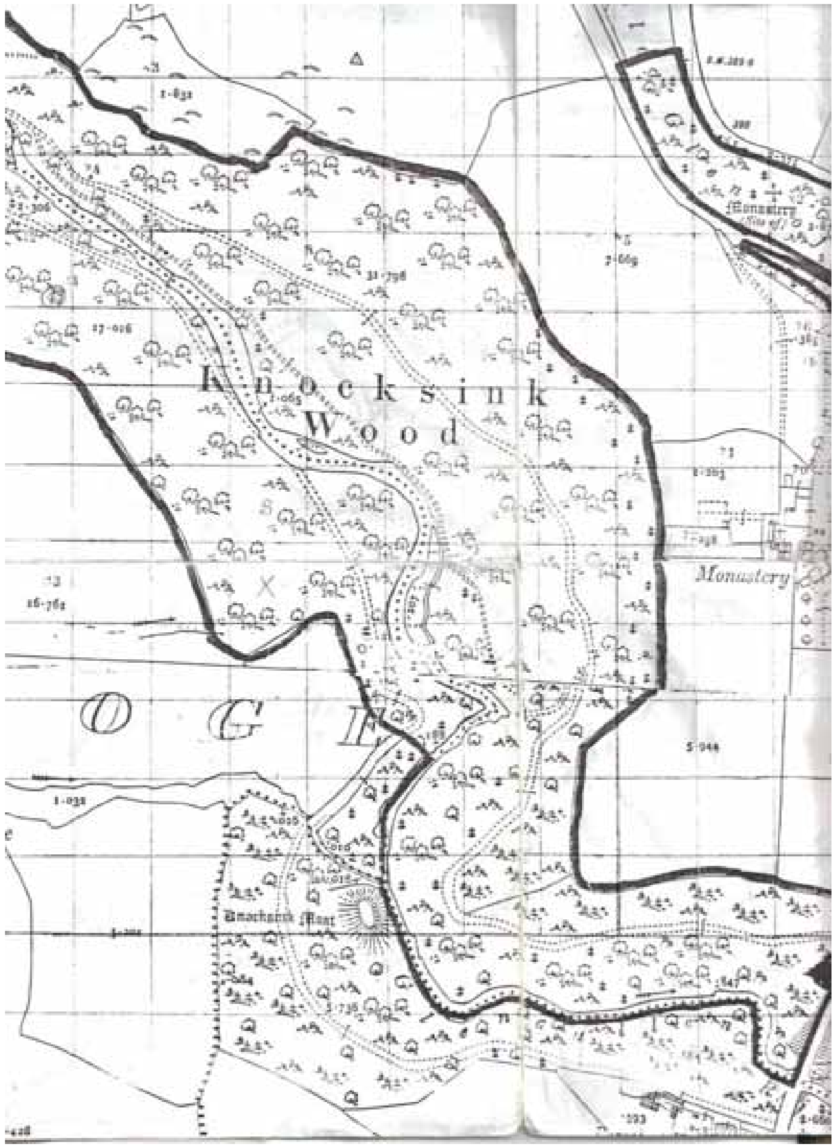
The diverse range of trunk circumference of the oaks in the oak woodland indicates that the age profile of the oak woodland is more diverse than that of the ash-hazel woodland. The trunk circumference of the mature oaks in the oak woodland was considerably greater than that of the mature ash trees in the ash-hazel woodland. The maximum circumference value for ash trees was 153cm while that for oak trees was 337cm (Appendix 8.18). This indicates that the oak woodland is probably older than the ash-hazel woodland. 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) (Figure 5.10).

Figure 5.10 Knocksink Wood on Ordnance Survey Map from 1840 (Ordnance survey archive).



The 1910 Ordnance Survey map for the same site shows woodlands covering a wider area broadly consistent with that observed today (Figure 5.11).

Figure 5.11 Knocksink Wood on Ordnance Survey Map from 1910 (Ordnance survey archive).

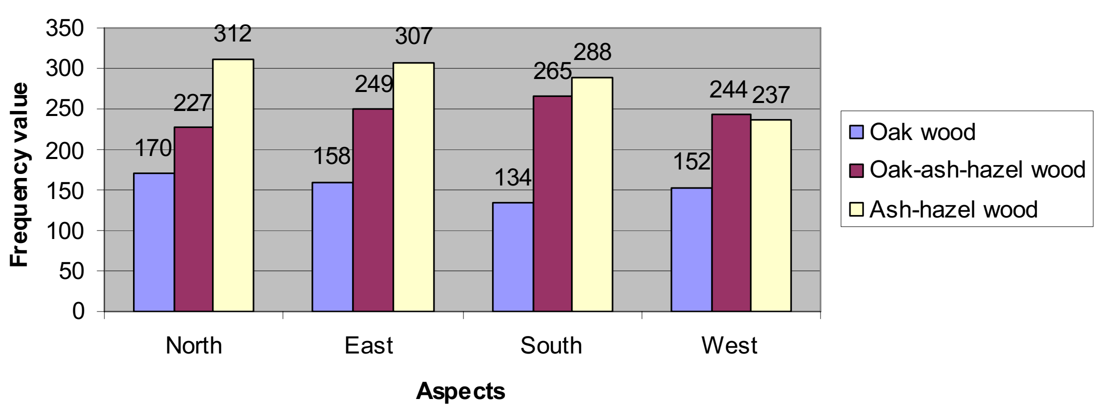


This would suggest that the selected study sites probably represent some of the oldest parts of Knocksink Wood. However, this is not consistent with the relatively low numbers of lichens observed (Section 5.1). This in turn may be related to the current sizes and growth forms of trees within the woodland, 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 85.06cm (Appendix 8.18). 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 177.63cm), 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 (Section 5.2).

5.8.3 Lichens on north, east, south and west aspect of trees.

The frequency of lichen species on the north, east, south and west sides of the tree trunks were compared between the three woodland types in Knocksink (Table 4.15) (Figure 5.12).

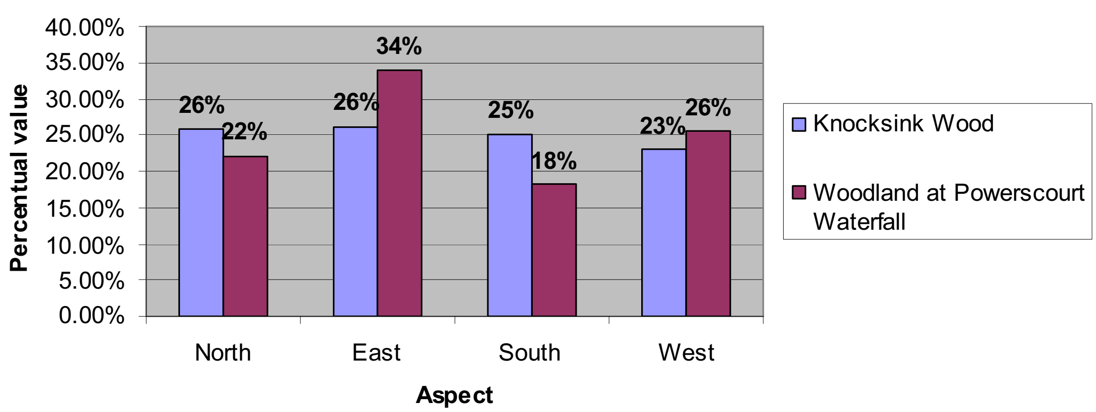
Figure 5.12 Frequency totals on aspcts of tree trunks in the three woodland types in Knocksink Wood



It was observed that greater frequency numbers were recorded on the ash trees in the ash-hazel woodland than on the oak trees in the oak woodland. In the oak woodland, the highest frequency was recorded on the northern side of the oak trees (F=170). Similarly, in the ash-hazel woodland, the highest frequency was also recorded on the northern side of the ash trees (F=312). In contrast to this the highest frequency for the oak-ash-hazel woodland was recorded on the southern side (F=265). Rose (1974) has reported that in many forest situations, lichens have been found to dominate the southern and south-western sides of the trunks. However, this was not the case in the oak woodland and the ash-hazel woodland at Knocksink. The development of lichens depends on the range of nutrients and environmental conditions in the ecosystem (James *et al.* 1977). The distribution of lichens on trees in Knocksink Wood is probably strongly influenced by the deep 'V' shaped river valley, which leads to a unique lichen distribution pattern. The sheltered river glen with the deep narrow valley in Knocksink Wood 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.

The total frequencies of lichen species in the three woodland types of Knocksink Wood were compared to the sums of frequencies on trees in Powerscourt Waterfall woodland (Table 4.15) (Figure 5.13).

Figure 5.13 The sum of frequencies on aspects of trees in woodlands at Knocksink and Powerscourt Waterfall



The maximum lichen frequency in the woodlands at Knocksink were on the north (F=709) and east (F=714) sides of the tree trunks; (north and east were recorded with 26% of all frequencies each Figure 5.13). A lower frequency score was recorded on trees with a western aspect (F=633) (Table 4.15). The west side was recorded with 25% of all frequencies (Figure 5.13). In general, the lichens in the woodlands at Knocksink Wood were distributed evenly on the different aspects of tree trunks viz. north, east, south and west. In Powerscourt the maximum frequency score was recorded on the east side of the tree trunks, F=180 or 34%, (Table 4.15 and Figure 5.13). The west side had a F=135 or 26% and the north side recorded a F=117 or 22% (Table 4.15, Figure 5.13). The minimum frequency score was recorded on the south side (F=97) with 18% recorded in the woodland at Powerscourt. The lichens in the woodland at Powerscourt Waterfall recorded a maximum on the eastern aspect of the tree trunks and a minimum on the southern side. Although different trends in lichen frequencies were observed in Knocksink and Powerscourt, some similarities were noted such as the high frequency score recorded on the east side in both woodlands. This variation may be related to the unique and contrasting setting of the woodlands and the orientation of the valleys, northwest to southeast in Knocksink and southwest to northeast in Powerscourt Waterfall woodland.

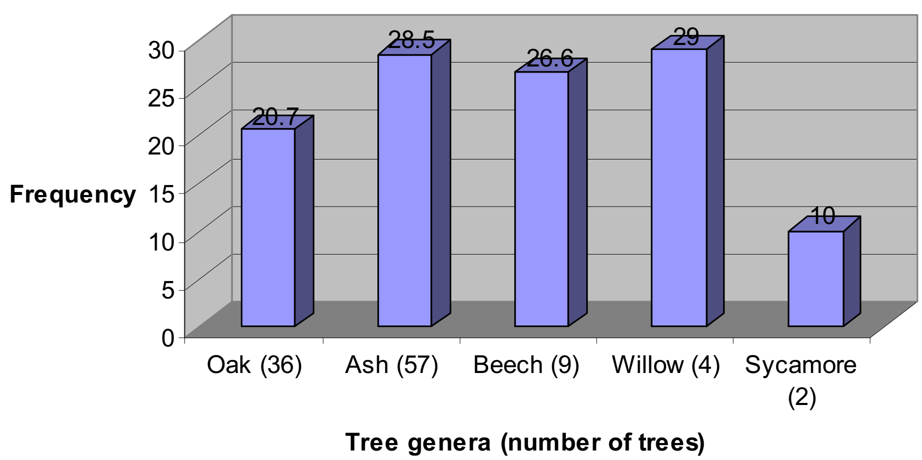
5.8.4 Air quality

Traditionally air quality has been recognised as one of the main factors influencing development of lichen species. The occurrence of fruticose and foliose lichen species associated with good air quality (Richardson 1992), viz. *Evernia prunastri*, *Flavoparmelia caperata*, *Melanelia fuliginosa* spp. *glabratula*, *Melanelia subaurifera* and *Ramalina farinacea* on the willow trees in the oak-ash-hazel woodland at Knocksink, indicates relatively good air quality at trunk level within Knocksink Wood. These foliose and fruticose lichen species were only recorded on the willow tree trunks at Knocksink and not on any trunks of sampled oak, ash, beech and sycamore trees. However, it is evident that these foliose and fruticose lichens are more abundant in the canopy environment of Knocksink Wood. Indeed, lichen species *Evernia prunastri*, *Melanelia subaurifera*, *Ramalina farinacea* and *Usnea subfloridana* were recorded on oak and ash twigs and branches fallen from the tree canopy at Knocksink Wood (Brodekova *et al.* 2006). 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. Consequently, level of air quality does not have a significant influence on the low numbers of foliose and fruticose epiphytic lichens at trunk level in Knocksink Wood.

5.9 Frequency of lichen species and tree genera

The average lichen frequencies were compared between oak, ash, beech, sycamore and willow trees in the three woodland types in Knocksink Wood (Table 4.16) (Figure 5.14).

Figure 5.14 Average lichen frequency per tree genera



There were two notable highest average frequencies, the first was recorded on the willow trees (F=29) and the second on the ash trees (F=28.5). A lower average frequency was recorded on the beech trees (F=26.6) and the oak trees (F=20.7). The lowest average lichen frequency was recorded on the sycamore trees. The sequence of average lichen frequency per tree genera in Knocksink Wood was then: willow > ash > beech > oak > sycamore. This is in contrast to the recorded sequence of lichen numbers per tree genera oak > ash > willow > beech > sycamore (Figure 5.3), where the oak trees were recorded with higher numbers of lichen species than the ash trees. The results for willow, beech and sycamore trees may be influenced by the small sample size. Based on the larger sample of the oak and ash trees it is evident that the ash trees had higher average lichen frequencies than the oak trees in the Knocksink Wood woodland. This demonstrates the influence of frequency in the computation of LDVs. While the ash trees had a higher frequency of lichen species occurrence than the oak trees, the oak trees were recorded with richer lichen community in terms of diversity. The higher frequency of a smaller group of lichens on the ash trees can be explained by similar bark properties on the ash trees (e.g. smooth, moist and soft bark and similar age profile) and suitable environmental factors (e.g. distance between trees, wind direction, humidity, light, etc.).

5.10 Alternative species diversity indices

The Shannon diversity index (H') and Simpson's diversity index (D) were calculated to assess the lichen diversity between the oak woodland and the ash-hazel woodland in Knocksink. This provides an opportunity to compare the other major diversity indices, Shannon diversity index (H') and Simpson's diversity index (D), with the European guideline LDV. The Shannon diversity index (H') recorded a value of 2.94 for the oak woodland and 2.53 for the ash-hazel woodland indicating higher species diversity for the oak woodland (Section 4.10). In considering Simpson's diversity index (D) a value of 0.93 was recorded for the oak woodland and 0.90 for the ash-hazel woodland, indicating again slightly higher sample diversity in the oak woodland by comparison to the ash - hazel woodland (Section 4.10). In contrast with these diversity indices the European guideline LDV generated higher diversity for the ash-hazel woodland (Table 4.11). This is in part because of the influence of frequency in the calculation of the LDV results. The sum of all species frequencies in the oak woodland was 614 while that in the ash-hazel woodland was 1144 (Table 4.5) therefore the LD was identified as being higher in the ash–hazel woodland. The European guideline is a relatively new and more sophisticated method for environmental assessment using lichens, therefore it is to be expected that new results will arise. Generally, the concept of species diversity has two components, *richness*, also called species density, based on the total number of species present, and *evenness*, based on relative abundance of species and the degree of its dominance. A community dominated by one or two species is considered to be less diverse than one in which several different species have a similar abundance. As species richness and evenness increase, so diversity increases (Odum 1971, Begon *et al.* 1990, Kent and Coker 1996). Both diversity indices, Shannon (H') and Simpson's (D) combine both components of diversity, species richness and evenness and are general indices of diversity. Of the two indices, the Simpson's gives greater weight to common species (Odum 1971). This explains the similar values recorded for the oak and ash-hazel woodland. In contrast to this, the Shannon index gives greater weight to rare species (Odum 1971). This explains the higher Shannon value recorded in the oak woodland and lower value in the ash-hazel woodland.

5.11 Identifying environmental alteration

LD results were further interpreted in terms of environmental alteration. This assessment was based on theoretical maximum naturality value, which was estimated as the mean value of maximum LDVs recorded on oak and ash trees in Knocksink Wood greater than 98° of all LD values (Table 4.17). This theoretical maximum naturality value represents environmental conditions, which are free from heavy human impact (e.g. industrialisation, urbanisation, vehicular traffic, intensive agriculture, etc.) and free from air pollution (Loppi *et al.* 2002a).

Using the scale of environmental alteration established for Knocksink Wood woodland (Table 4.18) and based on the LDVs, sample plots were assigned to five classes of environmental alteration (Table 4.19). Very high environmental alteration (lichen desert class) was not recorded in any of the sample plots in Knocksink Wood. This indicates that the environmental conditions were favourable for epiphytic lichen growth and development in all sample plots in Knocksink Wood. In addition, no sample plot was recorded as being free from environmental alteration (naturality class), which indicates that all sample plots were found to have some level of environmental alteration. High environmental alteration was recorded in the majority of the plots in the oak woodland (plot 2 - 8) and the oak-ash-hazel woodland (plot 11 to 13 and plot 15 to 18) (Table 4.19). Moderate environmental alteration was recorded in plot 1 in the oak woodland and in plots 9 and 14 in the oak-ash-hazel woodland. The situation in the ash-hazel woodland was different. Here the majority of the plots (plot 20 – 23 and 25) were recorded with moderate environmental alteration. Two plots in the ash-hazel woodland (plot 26 and 27) showed low environmental alteration and plot 24 was identified with high environmental alteration. Environmental alteration results were placed on the grid map of Knocksink Wood and sampling plots were coloured according to the colour of respective classes (Table 4.19, Figure 4.2). The visual interpretation using the colour code facilitated the assessment of differences in environmental alteration between the sampling plots and their location within the three woodland types in Knocksink. On the grid map, plots with low environmental alteration (light green plots) were located at the south-west periphery of the Knocksink Wood in the ash-hazel woodland (plot 26 and 27). The moderate environmental alteration was also confined to the south-wet end of the Knocksink Wood mainly in the ash-hazel woodland (plot 20-23 and 25) and in plot 9 and 14 in the oak-ash-hazel woodland and plot 1 in the oak woodland. Most of the plots with low and moderate environmental alterations were plots classified as the woodland perimeter (plot 1, 9, 14, 20-23, 26 and 27) with location at the south-west and north-east periphery of Knocksink. This indicates that the periphery of Knocksink, specifically the southwestern periphery, has good environmental conditions for epiphytic lichen development at Knocksink. This is in agreement with previous findings (Section 5.7 and 5.8) which also identified the south-west periphery of Knocksink as having suitable environmental conditions for development of epiphytic lichens at Knocksink. The high environmental alteration was located mainly in the oak woodland (plot 2, 3, 4, 5, 6, 7 and 8) and the central part of the oak-ash-hazel woodland and also on the south-west of the riverbank within the woodland (plot 11-13, 15-18). The environmental alteration results were in agreement with the LD results. In both assessments, the recorded frequency of lichen species played an important role in generating LDVs and subsequently was found influencing the degree of environmental alteration of a sample plot. Plots with high LDVs were recorded with low environmental alteration and with high frequency of lichens. Plots with low LDVs were identified with high environmental alteration and low frequency of lichen species. This indicates that environmental alteration assessment identifies areas, which have favourable environmental conditions for lichen species development (semi-natural and semi-altered areas) and those, which are poor on frequency of lichen species (alteration areas).

5.12 Indices of Ecological Continuity

The ecological continuity represented by RIEC was assessed between the three woodland types in Knocksink and between Knocksink and the Powerscourt Waterfall woodland (Section 3.14). The highest RIEC value was recorded in the oak woodland (RIEC = 20) in Knocksink (Table 4.20). A total of four RIEC species were recorded in the oak woodland in Knocksink: *Arthonia vinosa*, *Enterographa crassa*, *Lecanactis premnea* and *Pyrenula macrospora*. These findings are consistent with reported epiphytic associations (Purvis *et al.* 1994). Indeed, Purvis *et al.* (1994) describes *Arthonia vinosa* as being associated with the bark of old trees, especially *Quercus* and also being confined to the old woodlands and ancient parklands. *Enterographa crassa* is also associated with trunks of mature trees in ancient woodlands. *Lecanactis premnea* is associated with well-lit bark of ancient *Quercus* and is the dominant species of the post-climax *Lecanactidetum premneae* association on old trees. *Pyrenula macrospora* is related to the smooth and shaded bark of deciduous trees (Purvis *et al.* 1994). A lower RIEC was recorded in the oak-ash-hazel woodland and the ash-hazel woodland (RIEC = 10) (Table 4.20). A total of two RIEC species were recorded in the oak-ash-hazel woodland and the ash-hazel woodland viz. *Enterographa crassa* and *Pyrenula macrospora*. The combined RIEC for Knocksink Wood was calculated as 20 (Table 4.20). This score indicates that ecological continuity in the three woodlands in Knocksink is low. A total number of 20 indicator species is required to achieve a score of 100, which is considered indicating high ecological continuity within a study site (Rose and Coppins 2002).

The RIEC value in the Powerscourt Waterfall woodland was 20 (Table 4.20). Different RIEC indicator lichen species were recorded in the woodland at Powerscourt waterfall. The latter included *Lobaria pulmonaria*, *Parmelia crinita*, *Pyrenula macrospora* and *Thelotrema lepadinum*. The genus *Lobaria* contains some of the largest Irish lichens (e.g. *Lobaria pulmonaria*), now seriously threatened in many areas owing to their extreme sensitivity to SO_2 pollution (<25 µg m^{-3}), acid rain and to changes in woodland management. *Lobaria pulmonaria* is associated with broad-leaved trees, locally abundant but rare and decreasing. The presence of *Lobaria* suggests that the environmental conditions for sensitive lichen communities are optimal in this region. This is further evidenced by the identification of *Parmelia crinita,* which is related to the mossy bark of broad-leaved trees, characteristic of well-lit *Lobarion* in undisturbed sites. Although, Purvis *et al*. (1994) has described *Thelotrema lepadinum* as in general decline due to woodland disturbance and air pollution, its occurrence in Powerscourt lends further evidence to support the favourable environmental conditions for the development of lichen communities in this area. The presence of *Lobaria pulmonaria*, *Parmelia crinita* and *Thelotrema lepadinum* indicates that the woodland at Powerscourt Waterfall is an important site with rare lichen species. However, the RIEC value identified for the Powerscourt Waterfall woodland indicates that in general a relatively low level of ecological continuity exists (Rose and Coppins 2002).

The conservation importance of the woodlands at Knocksink and Powerscourt Waterfall was assessed using the NIEC approach (Section 3.14). Two NIEC indicator lichen species, *Arthonia vinosa* and *Lecanactis premnea* were recorded in the oak woodland in Knocksink and the NIEC value was calculated as 2 (Table 4.20). No NIEC indicator lichens were recorded in the oak-ash-hazel woodland or in the ash-hazel woodland in Knocksink, and therefore the NIEC value for both woodland types was zero. This assessment indicates that the oak woodland has some level of conservation importance; however, the conservation value of the woodland is relatively low (Rose and Coppins 2002). On this basis, the oak-ash-hazel woodland and the ash-hazel woodland were identified as having no conservation importance with reference to rare lichen communities. This finding is in contrast to the environmental alteration findings (Section 5.11), in which the ash-hazel woodland was found to have 'Low' environmental alteration and the oak woodland 'High' environmental alteration. This is due to a different approach used by these assessments. The NIEC assessment is based on indicator lichen species, whose occurrence in a woodland environment refers to signs of ecological continuity and presents such environment with a conservation value. The environmental alteration assessment approach is based on assessing frequency of lichen species. This method identifies areas of high lichen frequency as having low environmental alteration, and areas with low lichen frequency are interpreted to have high environmental alteration.

The highest NIEC was recorded in the Powerscourt Waterfall woodland (NIEC = 5) and a total of five NIEC indicator lichen species, *Collema furfuraceum*, *Lobaria pulmonaria*, *Ochrolechia inversa*, *Parmelia crinita* and *Thelotrema lepadinum* were recorded in the Powerscourt Waterfall woodland. Purvis *et al.* (1994) reports *Collema furfuraceum* as being a rare and declining lichen species. Similarly, *Ochrolechia inversa* is described as a typical lichen species on *Quercus* trees in old moist woodlands. The occurrence of these species suggests that the conservation importance of the Powerscourt Waterfall woodland is greater than that in the Knocksink Wood woodlands.

5.13 Lichen species indicative of native woodlands

Lichen species indicative of native woodland in the south-east of Ireland were compared between oak, ash, sycamore, willow and beech in the three woodland types in Knocksink Wood (Table 4.21). The highest number of lichens indicative of native woodlands was recorded on the oak trees in the oak woodland (7 species) (Table 4.21). This is consistent with the RIEC and NIEC results, which also identified the oak woodland with a higher occurrence of ancient lichen species and with a higher conservation value. In total six lichens were recorded on the willow trees in the oak-ash-hazel woodland. Five lichen species were recorded on the ash, oak and beech trees in the oak-ash-hazel woodland. Three lichen species indicative of native woodlands were also recorded on the sycamore trees in the oak-ash-hazel woodland. This result suggests some modest level of native woodland character within the oak-ash-hazel woodland consistent with findings of Higgins *et al.* (2004). Similarly five lichen species were recorded on ash trees in the ash woodland also suggesting that this woodland has some native character. Clearly, the oak-ash-hazel woodland and the ash-hazel woodland have a measure of ecological continuity and may be also experiencing a level of natural regeneration. Thus although these outcomes are not supported by the RIEC and NIEC measures the oak-ash-hazel and the ash-hazel woodland at Knocksink demonstrate an important degree of naturality. In Powerscourt Waterfall woodland a total of nine lichen species indicative of native woodland character were identified (Table 4.21). This finding is in agreement with the RIEC and the NIEC result, which identified the Powerscourt Waterfall Woodland as having a relatively high conservation value.

5.14 Comparison with other broad-leaved Irish woodlands

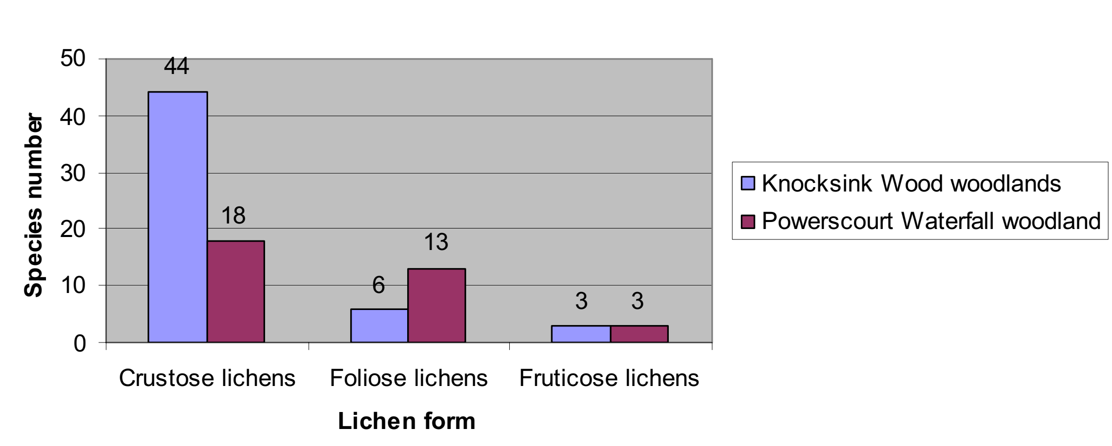
The measure of the LD scale and the composition of epiphytic lichens in the Knocksink Wood woodlands can be appreciated when it is compared with other similar Irish broadleaf woodlands. At Knocksink a total of 53 lichen taxa were recorded on the trunks of trees studied. In comparison a total of 57 epiphytic lichens were reported on the deciduous trees at Union Wood, County Sligo (Alexander *et al.* 1989) and 47 lichen taxa on the trunks of deciduous trees in the Brackloon Wood, County Mayo (Fox *et al.* 2001). Greater numbers of species have been recorded for other woodlands e.g. 72 species were recorded at Slish Wood, County Sligo, 100 species were recorded in Church Island Wood in Lough Gill, County Sligo and 80 lichen species were recorded in parklands and orchards in estates in County Sligo (Alexander *et al.* 1989). Similarly, a total of 88 lichen species were recorded on trees in Wicklow Mountains National Park and a total of 100 lichens were recorded in Coronation Plantation in Kippure, County Wicklow and in woods in Glendalough (Glendalough Nature Reserve), County Wicklow (Cullen and Fox 1999). Clearly compared to these other broadleaf woodland sites Knocksink Wood has a lower number of epiphytic lichens. Although the species numbers may in some cases be similar, the actual species composition can show considerable differences. Indeed, applying the Sørensen coefficient to the data of Fox *et al.* (2001) for Brackloon Wood and Knocksink Wood gives a similarity value of 25.56% which is relatively low (Appendix 8.19). This lends support to the proposition that Knocksink Wood has a unique lichen flora when compared to other Irish broadleaf woodlands. Although, the lichen flora at Knocksink comprises many common lichen species, it is interesting to notice that lichen composition at Knocksink does not copy patterns recorded in other Irish broadleaf woodlands (Fox *et al*. 2001, Alexander *et al.*

1989, Cullen and Fox 1999). This may in part be related to the unique setting of the Knocksink Wood.

5.14.1 Knocksink Wood and Powerscourt Waterfall woodland

Lichens recorded in the Knocksink Wood woodlands were compared to the Powerscourt Waterfall woodland in County Wicklow. A lower number of lichen species was recorded in Powerscourt than in Knocksink Wood woodlands (34 lichen taxa). The numbers of crustose, foliose and fruticose lichens were compared between both woodland sites (Figure 5.15).

Figure 5.15 Lichen forms in Knocksink Wood and Powerscourt Waterfall woodlands



Both woodlands had a greater number of crustose lichens and a lower number of fruticose lichens. A higher number of foliose lichens was recorded in the Powerscourt Waterfall woodland (13 species) than in the Knocksink Wood woodlands (6 species). This may suggest that the Powerscourt Waterfall woodland has more favorable light conditions at the trunk level, which favored the development of foliose lichens when compared with the trees in Knocksink Wood. The Sørensen coefficient was also used to assess similarity between the three woodland types in Knocksink Wood and the Powerscourt Waterfall woodland (Table 4.22). The oak-ash-hazel woodland and the Powerscourt Waterfall woodland were found to have the highest similarity in lichen species composition (similarity was 39%). An identical similarity value (29%) was recorded between both the oak woodland and the ash-hazel woodland and the Powerscourt Waterfall woodland. The overall similarity between lichens in the woodlands of Knocksink and those of Powerscourt Waterfall was estimated as 38%. This indicates that while there were similarities in lichen species between Knocksink and Powerscourt, significantly different lichen species were also recorded in both woodlands. This confirms that while there are some floristic similarities between woodlands in the Knocksink Wood and the Powerscourt, there are significant differences in lichen species composition.

6. CONCLUSION

The research presented in this thesis adapted and applied a recently developed method for assessing epiphytic lichen species diversity (Asta *et al.* 2002 a, b) to the semi-natural woodlands of Knocksink Wood Nature Reserve, Enniskerry, County Wicklow. The research aimed to assess the epiphytic lichen diversity and its distribution across woodland habitats and to evaluate environmental quality using lichens as ecological bioindicators. The study focused on the differences that arise in relation to acidophilous oak woodland (*Blechno-Quercetum petraeae*) versus ash-hazel woodland (*Corylo-Fraxinetum*). The research also addressed differences in relation to the mixed oak-ash-hazel woodland located in Knocksink Wood and the neighbouring woodland at Powerscourt Waterfall. The frequency of occurrence of lichen species on a defined portion of tree bark was used as an estimate of diversity and to evaluate the degree of environmental stress on the sensitive lichen community and the wider woodland ecosystem. Epiphytic lichens were investigated on 108 trees in 27 sample plots across the woodlands in Knocksink Wood and on 6 trees in two sample plots in the woodland at Powerscourt Waterfall. These objectives formed the research basis:

1) Identify and describe the epiphytic lichen flora of Knocksink Wood Nature Reserve.
2) Establish an epiphytic lichen list characteristic for the main woodland types, acidophilous oak woodland, ash-hazel woodland and mixed oak-ash-hazel woodland.
3) Compare the epiphytic lichen flora particularly on acidophilous oak (*Quercus* spp.) versus ash (*Fraxinus excelsior*) and to a lesser degree between beech (*Fagus sylvatica*), sycamore (*Acer pseudoplatanus*) and willow (*Salix caprea*).
4) Assess the abundance, frequency, and diversity of epiphytic lichen species in woodlands at Knocksink Wood.
5) Relate how environmental parameters and human management may cause variation of epiphytic lichens.

6) Evaluate environmental quality using lichens as ecological bioindicators.

6.1 Identifying and describing the epiphytic lichen flora of Knocksink Wood Nature Reserve.

Using the European guideline method a total of 53 lichen taxa were recorded on tree trunks in the woodlands in Knocksink Wood. Most of the epiphytic lichen species recorded were crustose lichens (44 taxa). The absence of foliose and fruticose lichens on most of the tree trunks within Knocksink suggested that the light conditions were relatively poor below the canopy.

6.2 Establishing an epiphytic lichen list characteristic for the main woodland types, acidophilous oak woodland, ash-hazel woodland and mixed oak-ash-hazel woodland.

An epiphytic lichen list characteristic for each woodland type, specifically oak woodland, oak-ash-hazel woodland and ash-hazel woodland in Knocksink Wood was prepared and lichen lists were compared between each woodland type. Comparison of lichen composition using multivariate analysis and Sørensen coefficient indicated that while there were floristic differences between the woodland types there were also strong similarities in lichen species composition, the oak woodland was found to be relatively similar to the oak-ash-hazel woodland and the ash-hazel woodland showed a relatively greater difference in lichen species composition in comparison to both the oak woodland and the oak-ash-hazel woodland.

6.3 Comparing the epiphytic lichen flora particularly on acidophilous oak (*Quercus* spp.) and ash (*Fraxinus excelsior*) and between beech (*Fagus sylvatica*), sycamore (*Acer pseudoplatanus*) and willow (*Salix caprea*).

The epiphytic lichen flora was compared specifically between acidophilous oak (*Quercus* spp.) and ash (*Fraxinus excelsior*) and also between beech (*Fagus sylvatica*), willow (*Salix caprea*) and sycamore (*Acer pseudoplatanus*). It was confirmed that there were some floristic differences between lichens on oak, ash, beech, sycamore and willow trees in the woodlands in Knocksink Wood. These differences were found to be related to bark properties (such as roughness and age of substrate, water holding ability, etc.), light and humidity, etc. The oak trees in the woodlands at Knocksink were found to be supporting a similar group of lichen species. Similarly, all ash trees in the woodlands at Knocksink were recorded with a group of common lichen species. In both cases this can be related to similar bark properties on each type of tree. The willow trees in the oak-ash-hazel woodland supported a unique lichen assemblage comprising of foliose and fruticose lichens. This was found to be consistent with the observed maturity and roughness of their bark as well as the higher availability of light and elevated humidity influenced by a fresh water pond. The beech and sycamore trees supported common lichen species. *Lecanora chlarotera* and *Pertusaria leioplaca* were recorded on each of the oak, ash, sycamore, willow and beech. The sequence of lichen numbers recorded per tree genera in Knocksink Wood was: oak > ash > willow > beech > sycamore.

It was confirmed that the nature of the substrate on which lichens grow had considerable influence on the diversity and abundance of lichen species that arose in the woodlands in Knocksink Wood. The majority of oak trees in the oak woodland at Knocksink had 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. Higher moisture holding ability promoted development of other epiphytes, especially mosses and climbing ivy. 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. It was identified that certain substrate conditions favoured development of some species more than others and this was reflected in the greater abundance of lichen species such as *Opegrapha atra*, *Lecanora chlarotera*, *Pertusaria leioplaca*, *Enterographa crassa*, *Graphis scripta* and *Arthonia radiata* on the relatively smooth barks of the ash trees. Most of these species were characteristic species found on trees with smooth bark and their occurrence on the ash trees was consistent with the expectations. It was also recognised that rougher bark, as found on the oak trees, provided a better habitat for the development of a wider spectrum of lichen species at Knocksink. The dominance of acidophytic lichen taxa (e.g. *Arthonia*, *Lepraria* and *Opegrapha*) in the general epiphytic lichen flora at Knocksink clearly reflected the acidic character of the bark of the oak trees and to a some degree the ash trees in the woodlands.

6.4 Assessing the abundance, frequency and diversity of epiphytic lichen species in woodlands at Knocksink Wood.

Lichen diversity values were established for each sample plot and were compared specifically between oak and ash trees and between the three woodland types within Knocksink. Most LD values in the studied oak woodland and oak-ash-hazel woodland fell into the 'Very Low' LD class and the subclass 'Very-low'. The situation in the ash - hazel woodland was different and LD values were more scattered around the scale in classes with 'High LD', 'Moderate LD' and 'Low' LD. Although the LD score for the ash - hazel woodland showed a slightly higher value than that in the oak woodland, the overall pattern for Knocksink demonstrated a clustering of values around the bottom of the scale. Results indicated that the diversity of epiphytic lichens was low in the woodlands of Knocksink. Most of the plots with higher LD score were located at the south-west periphery of the Knocksink located on the Glencullen River bank where the slope is orientated to the east. This suggests that location of trees at woodland edge and orientation of valley to the east provide conditions for greater lichen diversity in Knocksink Wood. This also indicated light availability as one of the most important factors influencing lichen diversity in Knocksink Wood. The LDV results indicated that the ash-hazel woodland has better environmental quality for development of epiphytic lichen species than the oak-ash-hazel woodland and the oak woodland. This however was in contrast with a higher number of lichen species recorded on the oak trees in the oak woodland and greater species diversity.

The LDV results generated higher species diversity for the ash-hazel woodland than the oak woodland. In contrast the Shannon diversity index (H') indicated higher species diversity for the oak woodland when compared to the ash-hazel woodland. The

Simpson's diversity index (D) also indicated higher sample diversity in the oak woodland than the ash-hazel woodland. The higher LDV values in the ash-hazel woodland were found to be influenced by frequency measure in the calculation of the LDV results. Indeed, the sum of all species frequencies in the ash-hazel woodland was recorded to be almost twice higher than in the oak woodland and then the LD was identified as being higher in the ash–hazel woodland. This indicated that LDV was greatly influenced by frequency. In contrast to this the Simpson's diversity index (D) gave greater weight to common species and the Shannon diversity index gave greater weight to rare species. The LD index is largely based on frequency of species and this has strong influence on results and identifies areas with high lichen species frequencies. This research recommends using other species diversity indices along with LDV, especially those, which value rare species (e.g. Shannon diversity index).

6.5 Relating how environmental parameters and human management may cause variation of epiphytic lichens.

6.5.1 Light

The higher LD values and species numbers in sample plots located at the woodland perimeter were explained by higher availability of light, which was confirmed to be one of the most important parameters for lichen species development in the woodlands in Knocksink.

6.5.2 Trunk circumference

It was observed that the age profile of the oak woodland was more diverse than that of the ash-hazel woodland and the trunk circumference of the mature oaks was considerably greater than that of the mature ash trees. This indicated that the oak woodland was older than the ash-hazel woodland. The 1840 Ordnance Survey map for Knocksink Wood confirmed that broadleaf woodland extended in areas contiguous with part of the existing oak woodland and with part of the ash - hazel woodland. The evidence suggested that the selected study sites represented some of the oldest parts of Knocksink Wood. This in turn was 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, evidence of coppicing was recorded on the ash trees within the ash - hazel woodland. This had 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 and the more undisturbed character of the oak woodland was in part explained by the relatively higher richness of epiphytic lichens compared to the ash - hazel woodland. Higher LDVs were recorded at the same girth category on ash trees than on oak trees. This was found to be related to greater frequency numbers recorded on ash trees than on oaks.

6.5.3. Lichens on north, east, south and west aspect of trees.

Lichens were found to be distributed evenly on north, east, south, west side of tree trunks in the woodlands in Knocksink Wood. It was suggested that the distribution of lichens on trees in Knocksink Wood was influenced by the deep ‘V’ shaped river valley which leads to a unique lichen distribution pattern. The sheltered river glen with the deep narrow valley in Knocksink Wood 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.

6.5.4 Tree genera

The sequence of average LDVs per tree genera in Knocksink Wood was: willow > ash > beech > oak > sycamore. The ash trees were recorded with higher average LDVs than the oak trees in the Knocksink Wood woodland. This was in contrast to the recorded sequence of lichen numbers per tree genera oak > ash > willow > beech > sycamore, where the oak trees were recorded with higher numbers of lichen species than the ash trees. This demonstrated the influence of frequency in the computation of LDVs and explained higher LDV on ash than on oak.

6.6 Evaluating environmental quality using lichens as ecological bioindicators.

6.6.1 Identifying environmental alteration

High environmental alteration was recorded in the majority of the plots in the oak woodland and the oak-ash-hazel woodland. The situation in the ash-hazel woodland was different and the majority of the plots were recorded with moderate environmental alteration and low environmental alteration. The plots with moderate and low environmental alteration were located at the south-west periphery of the Knocksink Wood and were classified as the woodland perimeter. This indicated that the south-west periphery of Knocksink had good environmental conditions for epiphytic lichen development at Knocksink. This was in agreement with previous findings which also identified the south-west periphery of Knocksink with high LDVs and a greater abundance of lichen species. The high environmental alteration was located mainly in the oak woodland and the central part of the oak-ash-hazel woodland and also on the south-west of the riverbank within the woodland. The environmental alteration results were in agreement with the LD results. Plots with high LD were recorded with low environmental alteration and plots with low LD were identified with high environmental alteration.

6.6.2 Indices of Ecological Continuity

A higher RIEC value was recorded in the oak woodland in Knocksink when compared to the oak-ash-hazel woodland and the ash-hazel woodland. The combined RIEC for Knocksink Wood was 20 and this score indicated that ecological continuity in the three woodlands in Knocksink was low. The NIEC assessment indicated that the oak woodland had some level of conservation importance; however the conservation value of the woodland was relatively low. The oak-ash-hazel woodland and the ash-hazel woodland were identified as having no conservation importance with reference to rare lichen communities. This finding was in contrast to the environmental alteration findings, in which the ash-hazel woodland was found to have ‘Low’ environmental alteration and the oak woodland ‘High’ environmental alteration.

6.6.3 Lichen species indicative of native woodlands

The highest number of lichens indicative of native woodlands was recorded on the oak trees in the oak woodland (7 species). This was consistent with the RIEC and NIEC results, which also identified the oak woodland with a higher occurrence of ancient lichen species and with a higher conservation value. Some modest level of native woodland character was also identified within the oak-ash-hazel woodland and the ash-hazel woodland. However, this outcome was not supported by RIEC and NIEC values.

6.7 Comparison with other broad-leaved Irish woodlands

Clearly compared to other Irish broadleaf woodland sites Knocksink Wood had a lower number of epiphytic lichens. Although the species numbers were in some cases similar, the actual species composition showed considerable differences. This indicates that Knocksink Wood has a unique lichen flora when compared to other Irish broadleaf woodlands. Although, the lichen flora at Knocksink comprised many common lichen species, it was observed that the lichen composition at Knocksink did not copy patterns recorded in other Irish broadleaf woodlands (Fox *et al*. 2001, Alexander *et al.* 1989, Cullen and Fox 1999). This was in part related to the unique setting of the Knocksink Wood.

6.7.1 Woodland at Powerscourt Waterfall

In total 34 lichen taxa were recorded on four sycamore and two oak trees in the Powerscourt Waterfall woodland. This woodland comprised a higher number of foliose lichens than the woodlands at Knocksink Wood. This indicated that the Powerscourt Waterfall woodland had better light conditions at the trunk level which enabled development of foliose lichens. The oak-ash-hazel woodland and the Powerscourt Waterfall woodland were found to have the highest similarity in lichen species composition. While there were similarities in lichen species between Knocksink and Powerscurt, significantly different lichen species were also recorded in both woodlands. The lichens in the woodland at Powerscourt Waterfall showed a maximum frequency on the east aspect of the tree trunks and minimum on the south side. Although different trends in lichen frequencies were observed in Knocksink and Powerscourt, some similarities were noted such as the high frequency score recorded on the east side in both woodlands. This variation was related to the unique setting of woodlands and orientation of the valleys, northwest to southeast in Knocksink and southwest to northeast in Powerscourt Waterfall woodland. The Powerscourt Waterfall woodland was also identified with low ecological continuity. However, the presence of *Lobaria pulmonaria*, *Parmelia crinita* and *Thelotrema lepadinum* indicated that the woodland at Powerscourt Waterfall is an important site with some rare lichen species. The highest NIEC was recorded in the Powerscourt Waterfall woodland where a total of five NIEC indicator lichen species, *Collema furfuraceum*, *Lobaria pulmonaria*, *Ochrolechia inversa*, *Parmelia crinita* and *Thelotrema lepadinum* were recorded. The occurrence of these species further suggested that the Powerscourt Waterfall woodland has a high conservation importance. In addition, a greater presence of lichens indicative of native woodland character was recorded in the woodland at Powerscourt. This finding was in agreement with the RIEC and the NIEC result, which identified the Powerscourt Waterfall Woodland as having a higher conservation value.

6.8 Overall Conclusion

The results of this research suggest that the European guideline for mapping lichen diversity developed 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 the 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 had been further corroborated by comparison with the epiphytic lichen flora of other broadleaf woodlands in Ireland. This outcome was largely the result of the unique setting of Knocksink Wood and the human input. The most significant parameters influencing epiphytic lichens development at trunk level in the woodlands at Knocksink were identified as tree species available, age profile and diversity of woodlands, bark properties and light availability, past woodland management and contemporary 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.

6.9 Contribution to knowledge and recommendations

This research applied for the first time the European Guideline for Mapping Lichen Diversity to a woodland setting in Ireland. The results from the LDV mapping programme provided new insights into the environmental quality of the study area and identified the south-western periphery of the ash-hazel woodland in Knocksink Wood as the important site with high lichen diversity on tree trunks and with high environmental sensitivity and importance. The oak trees in the oak woodland were recorded as comprising a rich lichen community with the occurrence of some rare lichen species and it is recommended to conserve the undisturbed character of the woodland in line with Nature Reserve management requirements. The woodland at Powerscourt Waterfall was confirmed to be an important woodland site with high LD and occurrence of very rare lichen species. It is recommended that this site should be recognized as an important habitat for epiphytic lichens and should receive the highest conservation status under the Nature Reserve conservation law. The research demonstrated the potential for the implementation of LD mapping in environmental assessment and as a useful tool for the assessment of environmental stress on epiphytic lichens.

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Oak woodland			
Tree	Plot	East-coordinate	North-coordinate
1 Oak	1	21846	17761
2 Oak		21838	17758
4 Oak		21842	17755
5 Oak		21834	17723
1 Oak	2	21829	17718
2 Oak		21834	17709
3 Oak		21840	17700
4 Oak		21876	17664
1 Oak	3	21891	17670
2 Oak		21880	17643
3 Oak		21889	17640
4 Oak		21877	17634
1 Oak	4	21802	17739
2 Oak		21798	17695
3 Oak		21788	17664
4 Oak		21802	17677
1 Oak	5	21809	17614
2 Oak		21801	17619
3 Oak		21821	17627
4 Oak		21793	17603
1 Oak	6	21826	17603
2 Oak		21881	17606
3 Oak		21838	17610
4 Oak		21870	17611
1 Oak	7	21884	17603
2 Oak		21886	17582
3 Oak		21804	17597
4 Oak		21823	17595
1 Oak	8	21746	17693
2 Oak		21766	17631
3 Oak		21768	17623
4 Oak		21762	17616
5 Oak		21769	17625

Oak-ash-hazel woodland			
Tree	**Plot**	**E-coordinate**	**N-coordinate**
1 Beech	9	21803	17787
2 Beech		21788	17785
3 Oak		21783	17773
4 Beech		21760	17769
1 Willow	10	21733	17973
2 Willow		21742	17974
3 Willow		21744	17983
4 Willow		21725	17971
1 Ash	11	21828	18178
2 Ash		21805	18075
3 Ash		-	-
4 Ash		-	-
1 Ash	12	21790	18081
2 Ash		21787	18064
3 Ash		21778ap	18042ap
4 Ash		21778ap	18042ap
1 Ash	13	21733	18072
2 Ash		21730	18068
3 Ash		21707	18073
4 Ash		21705	18087
1 Ash	14	21677	18137
2 Ash		21695	18142
3 Ash		21707	18141
4 Oak		21709	18125
1 Beech	15	21652	18012
2 Oak		21661	18021
3 Beech		21662	18061
4 Oak		21659	18048
1 Ash	16	21577	18101
2 Ash		21563	18072
3 Ash		21549	18092
4 Ash		21581	18094
1 Ash	17	21714	17884
2 Sycamore		21741	17829
3 Sycamore		21724	17862
4 Ash		21729	17850
1 Ash	18	21732	17884
2 Ash		21733	17893
3 Ash		21739	17895
4 Ash		21719	17899
1 Beech	19	21321	18218
2 Beech		-	-
3 Beech		21352	18277
4 Beech		21337	18294

Ash-hazel woodland			
Tree	**Plot**	**East-coordinate**	**North-coordinate**
1 Ash	20	21550	18043
2 Ash		21532	18056
3 Ash		21535	18074
4 Ash		21517	18077
1 Ash	21	21525	18069
2 Ash		21511	18037
3 Ash		21490	18069
4 Ash		21496	18085
1 Ash	22	21498	18074
2 Ash		21493	18055
3 Ash		21501	18054
4 Ash		21505	18042
1 Ash	23	21460	18110
2 Ash		21451	18084
3 Ash		21443	18086
4 Ash		21444	18095
1 Ash	24	21253	18222
2 Ash		21261	18177
3 Ash		21257	18157
4 Ash		21235	18173
1 Ash	25	21189	18178
2 Ash		21192	18154
3 Ash		21177	18185
4 Ash		21162	18183
1 Ash	26	21113	18254
2 Ash		21108	18247
3 Ash		21106	18285
4 Ash		21089	18285
1 Ash	27	20960	18474
2 Ash		20953	18475
3 Ash		20956	18488
4 Ash		20969	18480

Acrocordia gemmata (Ach.) A. Massal.
Amandinea punctata (Hoffm.) Coppins & Scheid.
Anisomeridium biforme (Borrer) R. C. Harris
Arthonia cinnabarina (DC.) Wallr.
Arthonia didyma Körber
Arthonia punctiformis Ach.
Arthonia radiata (Pers.) Ach.
Arthonia sp.
Arthonia spadicea Leight.
Arthonia vinosa Leight.
Cladonia coniocraea (Flörke) Spreng.
Dimerella pineti (Ach.) Vĕzda
Enterographa crassa (DC.) Fée
Eopyrenula leucoplaca (Wallr.) R. C. Harris (1973)
Evernia prunastri (L.) Ach.
Flavoparmelia caperata (L.) Hale
Graphis britannica Staiger
Graphis scripta (L.) Ach.
Haematomma caesium Coppins & P. James (1978)
Lecanactis premnea (Ach.) Arnold (1861)
Lecanora argentata (Ach.) Malme
Lecanora chlarotera Nyl.
Lecidea exigua Chaub. (1821)
Lecidella elaeochroma (Ach.) Choisy
Lepraria lobificans Nyl.
Melanelia fuliginosa subsp. *glabratula* (Lamy) Coppins
Melanelia subaurifera Nyl. Essl.
Opegrapha atra Pers.
Opegrapha herbarum Mont.
Opegrapha niveoatra (Borrer) J. R. Laundon
Opegrapha sp.
Opegrapha varia Pers.
Opegrapha viridis (Ach.) Nyl.
Opegrapha vulgata (Ach.) Ach.
Parmelia saxatilis (L.) Ach.
*Parmelia sulcata*Taylor
Parmotrema chinense (Osbeck) Hale
Pertusaria albescens (Huds.) Choisy & Werner
Pertusaria amara (Ach.) Nyl.
Pertusaria hymenea (Ach.) Schaer.
Pertusaria leioplaca DC.
Pertusaria pertusa (Weigel) Tuck.
Pertusaria sp.
Phlyctis argena (Spreng.) Flot.
Physcia tenella (Scop.) DC.
Porina aenea (Wallr.) Zahlbr.

Porina borreri var. *borreri*
Porina sp.
Pyrenula macrospora (Degel.) Coppins & P. James
Ramalina farinacea (L.) Ach.
Schizmatomma cretaceum (Hue) J. R. Laundon
Vouauxiella lichenicola (Linds.) Petr. & Syd.

Oak Woodland: Plots 1 - 8

Plot 1 Lichen species and frequencies on aspects of sampled tree.

Plot 1 Lichen species	1st oak tree				2nd oak tree				3rd oak tree				4th oak tree				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Amandinea punctata		2	1														**3**
Anisomeridium biforme								2									**2**
Arthonia radiata												1					**1**
Cladonia coniocraea				1													**1**
Dimerella pineti	1			1													**2**
Graphis britannica								2									**2**
Graphis scripta									3		2	2					**7**
Lecanora argentata			4	4									3	2	3	3	**19**
Lecanora chlarotera		1	3	3									1		2		**10**
Lecidella elaeochroma													2	3	3		**8**
Lepraria lobificans	1	1	1										5			4	**12**
Opegrapha atra	1							1	1		1						**4**
Pertusaria amara			1	2													**3**
Pertusaria hymenea		1	5					2							1		**9**
Pertusaria leioplaca									5	5	5	5					**20**
Pertusaria pertusa	2			5		2											**9**
Phlyctis argena															1		**1**
Sum of frequencies	**5**	**5**	**15**	**16**	**0**	**2**	**0**	**7**	**9**	**5**	**8**	**8**	**11**	**5**	**10**	**7**	
17	**Total number of lichen species & Total frequency**																**113**

Plot 2 Lichen taxa and frequencies on aspects of sampled trees.

Plot 2 Lichen taxa	1st oak tree				2nd oak tree				3rd oak tree				4th oak tree				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Anisomeridium biforme				1													**1**
Arthonia cinnabarina									1			1					**2**
Arthonia didyma				1													**1**
Arthonia radiata										2							**2**
Arthonia vinosa				1													**1**
Cladonia coniocraea				1													**1**
Graphis scripta													1				**1**
Lecanora argentata													4				**4**
Lecanora chlarotera										1	2		4				**7**
Lecanora sp.	3	2	3														**8**
Lecidella elaeochroma	3			2	2			2							2		**11**
Lepraria lobificans	2			1											1		**4**
Opegrapha atra		1				1		1									**3**
Pertusaria hymenea		2	3	2	2	2		2	3	2	5	4					**27**
Pertusaria leioplaca																2	**2**
Sum of frequencies	**8**	**5**	**6**	**9**	**4**	**3**	**0**	**5**	**4**	**5**	**7**	**5**	**9**	**0**	**3**	**2**	
15	**Total number of lichen species & Total frequency**																**75**

Plot 3 Lichen taxa and frequencies on aspects of sampled trees.

Plot 3 Lichen taxa	1st oak tree				2nd oak tree				3rd oak tree				4th oak tree				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Acrocordia gemmata					2	5		1						1		2	**11**
Anisomeridium biforme	2					5	5	1						2			**15**
Arthonia cinnabarina											1						**1**
Arthonia radiata																2	**2**
Arthonia sp.	3	5															**8**
Cladonia coniocraea				3													**3**
Dimerella pineti	1	1															**2**
Graphis scripta										1							**1**
Lecanora argentata	3	3	2														**8**
Lecanora chlarotera										1	1					1	**3**
Lepraria lobificans	1	5							1	1							**8**
Opegrapha niveoatra					1			1									**2**
Opegrapha sp.	1																**1**
Opegrapha viridis																2	**2**
Pertusaria leioplaca									5			3	1				**9**
Porina sp.						1											**1**
Sum of frequencies	**11**	**14**	**2**	**3**	**3**	**11**	**5**	**3**	**6**	**3**	**2**	**3**	**1**	**3**	**0**	**7**	
16	**Total number of lichen species & Total frequency**																**77**

Plot 4 Lichen taxa and frequencies on aspects of sampled trees

Plot 4 Lichen taxa	1st oak tree				2nd oak tree				3rd oak tree				4th oak tree				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Acrocordia gemmata		1			2	5	1										**9**
Anisomeridium biforme															2		**2**
Arthonia cinnabarina		1					1				1						**3**
Cladonia coniocraea			5	5													**10**
Enterographa crassa									3	5	5						**13**
Graphis britannica													2				**2**
Graphis scripta							3	1									**4**
Lecanactis premnea																1	**1**
Lecanora chlarotera										2							**2**
Lepraria lobificans	5			5													**10**
Opegrapha atra									3			5					**8**
Opegrapha herbarum									2			3					**5**
Pertusaria albescens														1			**1**
Pertusaria leioplaca						2	3		1								**6**
Pertusaria pertusa	4	2		5											1		**12**
Pertusaria sp.			5														**5**
Schizmatomma cretaceum																3	**3**
Sum of frequencies	**9**	**4**	**10**	**15**	**2**	**7**	**8**	**1**	**9**	**7**	**6**	**8**	**2**	**1**	**3**	**4**	
17	**Total number of lichen species & Total frequency**																**96**

Plot 5 Lichen species and frequencies on aspects of sampled trees.

Plot 5 Lichen species	1st oak tree				2nd oak tree				3rd oak tree				4th oak tree				Total F
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Anisomeridium biforme								2									**2**
Arthonia radiata							1										**1**
Cladonia coniocraea					5									5			**10**
Enterographa crassa			2	3									1			1	**7**
Lepraria lobificans			1						5	1	1	2	4			3	**17**
Opegrapha atra							1										**1**
Pertusaria albescens				5													**5**
Pertusaria leioplaca						1											**1**
Sum of frequencies	**0**	**0**	**3**	**8**	**5**	**1**	**2**	**2**	**5**	**1**	**1**	**2**	**5**	**5**	**0**	**4**	
8	**Total number of lichen species & Total frequency**																**44**

Plot 6 Lichen species and frequencies on aspects of sampled trees.

Plot 6 Lichen species	1st oak tree				2nd oak tree				3rd oak tree				4th oak tree				Total F
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Anisomeridium biforme			3														**3**
Arthonia cinnabarina	1									1							**2**
Arthonia radiata	2		1														**3**
Enterographa crassa					5	5		5									**15**
Graphis britannica								2									**2**
Graphis scripta	1				3												**4**
Haematoma caesium										5	4						**9**
Lecanora chlarotera								1									**1**
Lepraria lobificans							2	4	3			1	2		5		**17**
Opegrapha atra	1		1														**2**
Pertusaria amara						1											**1**
Pertusaria leioplaca	1		5	2	1			3									**12**
Sum of frequencies	**6**	**0**	**10**	**2**	**9**	**6**	**2**	**15**	**3**	**6**	**4**	**1**	**2**	**0**	**5**	**0**	
12	**Total number of lichen species**																**71**

Plot 7 Lichen species and frequencies on aspects of sampled trees.

Plot 7 Lichen species	1st oak tree				2nd oak tree				3rd oak tree				4th oak tree				Total F
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Cladonia coniocraea									3								**3**
Enterographa crassa											1						**1**
Lepraria lobificans	3	2			2				2	5	3	5	5	5	1	3	**36**
Opegrapha atra														2			**2**
Sum of frequencies	**3**	**2**	**0**	**0**	**2**	**0**	**0**	**0**	**5**	**5**	**4**	**5**	**5**	**7**	**1**	**3**	
4	**Total number of lichen species**																**42**

Plot 8 Lichen taxa and frequencies on aspects of sampled trees.

Plot 8 Lichen taxa	1st oak tree				2nd oak tree				3rd oak tree				4th oak tree				Total F
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Anisomeridium biforme					4	5	4	2			2		2	5	2		**26**
Arthonia didyma						2											**2**
Arthonia radiata														3	3		**6**
Enterographa crassa	5			5										1			**11**
Graphis britannica							1										**1**
Graphis scripta							1							2			**3**
Lecanora chlarotera					1	2							2	2			**7**
Lepraria lobificans	3	2								2							**7**
Opegrapha atra					1	5			2	4			2	5			**19**
Opegrapha sp.									3								**3**
Pertusaria leioplaca						2			2	2							**6**
Pertusaria pertusa											1				3		**4**
Pyrenula macrospora														1			**1**
Sum of frequencies	**8**	**2**	**0**	**5**	**6**	**16**	**6**	**2**	**7**	**8**	**3**	**0**	**6**	**19**	**8**	**0**	
13	**Total number of lichen species & Total frequency**																**96**

Oak – Ash – Hazel Woodland: Plots 9 - 19

Plot 9 Lichen species and frequencies on aspects of sampled trees.

Plot 9 Lichen species	1st beech				2nd beech				3rd oak				4th beech				Total F
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Anisomeridium biforme									2								**2**
Arthonia radiata			1														**1**
Enterographa crassa			2	3					3								**8**
Graphis scripta			3	1	3	5											**12**
Lecanora argentata				3					5		5	5				2	**20**
Lecanora chlarotera						5		2	5			5	5	5	5	5	**37**
Lecidella elaeochroma													4	5		3	**12**
Lepraria lobificans						1											**1**
Opegrapha atra						2			5	5	5	5	5			5	**32**
Pertusaria hymenea			1							5	5						**11**
Pertusaria leioplaca					5	5	5		5								**20**
Pyrenula macrospora				2													**2**
Sum of frequencies	**0**	**0**	**7**	**9**	**8**	**18**	**5**	**2**	**25**	**10**	**15**	**15**	**14**	**10**	**5**	**15**	
13	**Total number of lichen species & Total frequency**																**158**

Plot 10 Lichen taxa and frequencies on aspects of sampled trees.

Plot 10 Lichen taxa	1st willow				2nd willow				3rd willow				4th willow				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Anisomeridium biforme															1		**1**
Arthonia didyma	1																**1**
Evernia prunastri					3	5	5	3									**16**
Flavoparmelia caperata					1			1									**2**
Lecanora chlarotera	2		2			1			3	5	5	2		5	3		**28**
Lecidella elaeochroma	2		1							5	2	2					**12**
Lepraria lobificans	1									1							**2**
Melanelia glabratula								1									**1**
Melanelia subaurifera			1	1	1	2	2	2									**9**
Opegrapha atra	1																**1**
Parmelia saxatilis								2									**2**
Parmelia sulcata	1				3	5	5										**14**
Parmotrema chinense		1				2											**3**
Pertusaria amara		1		1													**2**
Pertusaria leioplaca						5	5							2		1	**13**
Pertusaria sp.			2														**2**
Phlyctis argena	1																**1**
Physcia tenella			1														**1**
Ramalina farinacea	2	1		2													**5**
Sum of frequencies	**11**	**3**	**7**	**4**	**8**	**20**	**17**	**9**	**3**	**11**	**7**	**4**	**0**	**7**	**4**	**1**	
19	**Total number of lichen species & Total frequency**																**116**

Plot 11 Lichen species and frequencies on aspects of sampled trees.

Plot 11 Lichen species	1st ash				2nd ash				3rd ash				4th ash				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Anisomeridium biforme	2			2													**4**
Arthonia didyma						2											**2**
Arthonia radiata	3	2		1	1	3	1		3	2			4	2	3		**25**
Graphis scripta											1						**1**
Opegrapha atra	4	3	1	2	1	3	3		2	3			2		3	2	**29**
Opegrapha vulgata											1						**1**
Pyrenula macrospora												1					**1**
Sum of frequencies	**9**	**5**	**1**	**5**	**2**	**8**	**4**	**0**	**5**	**5**	**2**	**1**	**6**	**2**	**6**	**2**	
7	**Total number of lichen species & Total frequency**																**63**

Plot 12 Lichen taxa and frequencies on aspects of sampled trees.

Plot 12 Lichen taxa	1st ash				2nd ash				3rd ash				4th ash				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Opegrapha atra	5	5	2	3	3		1	1	2		3	5	3	3	5	5	**46**
Pertusaria leioplaca	2																**2**
Pertusaria sp.			1							1							**2**
Pyrenula macrospora	1	2			2		1	1		1				1	2		**11**
Sum of frequencies	**8**	**7**	**3**	**3**	**5**	**0**	**2**	**2**	**2**	**2**	**3**	**5**	**3**	**4**	**7**	**5**	
4	**Total number of lichen species & Total frequency**																**61**

Plot 13 Lichen taxa and frequencies on aspects of sampled trees.

Plot 13 Lichen taxa	**1st ash**				**2nd ash**				**3rd ash**				**4th ash**				**Total F**
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Arthonia radiata															2		**2**
Graphis scripta	5		2								1		1				**9**
Opegrapha atra										2	5	3		1	5	5	**21**
Opegrapha herbarum	5	5	5	5	5	2	5	5									**37**
Opegrapha niveoatra				3													**3**
Opegrapha sp.		1							1								**2**
Opegrapha viridis		1				2											**3**
Pertusaria leioplaca		1		2									1			2	**6**
Pertusaria sp.														1			**1**
Pyrenula macrospora				1												1	**2**
Sum of frequencies	**10**	**8**	**7**	**11**	**5**	**4**	**5**	**5**	**1**	**2**	**6**	**3**	**2**	**2**	**7**	**8**	
10	**Total number of lichen species & Total frequency**																**86**

Plot 14 Lichen taxa and frequencies on aspects of sampled trees.

Plot 14 Lichen taxa	**1st ash**				**2nd ash**				**3rd ash**				**4th oak**				**Total F**
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Anisomeridium biforme			3					2					1				**6**
Arthonia radiata							1									1	**2**
Graphis scripta									1								**1**
Lecanora chlarotera				1													**1**
Opegrapha atra	1	4	5	5	3	5	1	5		2	5	5	1				**42**
Opegrapha herbarum									3								**3**
Opegrapha sp.														2	1		**3**
Pertusaria leioplaca						5		2					2		2	2	**13**
Pertusaria sp.		5			2												**7**
Pyrenula macrospora		5	2			2	2	3	2		1	2			1		**20**
Sum of frequencies	**1**	**14**	**10**	**6**	**5**	**12**	**4**	**12**	**6**	**2**	**6**	**7**	**4**	**2**	**4**	**3**	
10	**Total number of lichen species & Total Frequency**																**98**

Plot 15 Lichen taxa and frequencies on aspects of sampled trees.

	1st beech				2nd oak				3rd beech				4th oak				Total
Plo 15 Lichen taxa	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**F**
Anisomeridium biforme											3						**3**
Arthonia cinabarinna					1												**1**
Arthonia didyma								2			2		2	2	2	3	**13**
Arthonia radiata													1		2		**3**
Dimerella pineti																1	**1**
Enterographa crassa							1										**1**
Graphis scripta				1					1						1		**3**
Lecanora argentata											2						**2**
Lecanora chlarotera			1		4		2	3	1	3			3	3	3	2	**25**
Lepraria lobificans																2	**2**
Opegrapha atra	1	1															**2**
Pertusaria albescens													1				**1**
Pertusaria hymenea											1						**1**
Pertusaria leioplaca		2															**2**
Pertusaria pertusa					1			1					3	2	3	2	**12**
Pertusaria sp.												2					**2**
Sum of frequencies	**1**	**3**	**1**	**1**	**6**	**0**	**3**	**6**	**2**	**3**	**8**	**2**	**10**	**7**	**11**	**10**	
16	**Total number of lichen species & Toatl Frequency**																**74**

Plot 16 Lichen taxa and frequencies on aspects of sampled trees.

	1st ash				2nd ash				3rd ash				4th ash				Total
Plot 16 Lichen taxa	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**F**
Graphis scripta		2	1			1					3		1				**8**
Lecanora chlarotera		3		1													**4**
Lecanora sp.											1						**1**
Lecidella elaeochroma											1						**1**
Opegrapha atra	5	5	5	1		5	5	5	2	2	5	3	3	5	1	5	**57**
Opegrapha herbarum																1	**1**
Opegrapha sp.				5													**5**
Pertusaria leioplaca			3	1			3		1			5					**13**
Pyrenula macrospora				2							1						**3**
Sum of frequencies	**5**	**10**	**9**	**10**	**0**	**6**	**8**	**5**	**3**	**2**	**11**	**8**	**4**	**5**	**1**	**6**	
9	**Total number of lichen species & Total frequency**																**93**

Plot 17 Lichen taxa and frequencies on aspects of sampled trees.

Plot 17 Lichen taxa	1st ash				2nd sycamore				3rd sycamore				4th ash				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Anisomeridium biforme	1																**1**
Arthonia radiata													5	5	3		**13**
Enterographa crassa	2						1										**3**
Graphis scripta								1	1		1	1					**4**
Lecanora chlarotera									1								**1**
Opegrapha atra			2	3										2	3	1	**11**
Opegrapha niveoatra								3									**3**
Opegrapha sp.									1								**1**
Pertusaria leioplaca							2	4	1		1	2					**10**
Sum of frequencies	**3**	**0**	**2**	**3**	**0**	**0**	**3**	**8**	**4**	**0**	**2**	**3**	**5**	**7**	**6**	**1**	
9	**Total number of lichen species & Total frequency**																**47**

Plot 18 Lichen species and frequencies on aspects of sampled trees.

Plot 18 Lichen taxa	1st ash				2nd ash				3rd ash				4th ash				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Arthonia didyma	2	2	5														**9**
Enterographa crassa									3	2				2			**7**
Graphis scripta	1			1	1					1	1		1				**6**
Lecanora chlarotera	1	1	1						5	2		2	3			2	**17**
Opegrapha atra					2					1			1				**4**
Pertusaria leioplaca						1	1										**2**
Pertusaria sp.	2	1	3	2										1			**9**
Porina aenea															3	2	**5**
Pyrenula macrospora											5						**5**
Sum of frequencies	**6**	**4**	**9**	**3**	**3**	**1**	**1**	**0**	**8**	**6**	**6**	**2**	**5**	**3**	**3**	**4**	
9	**Total number of lichen species & Total frequency**																**64**

Plot 19 Lichen species and frequencies on aspects of sampled trees.

Plot 19 Lichen species	1st beech				2nd beech				3rd beech				4th beech				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Anisomeridium biforme			2											1			**3**
Arthonia radiata							1				2			2	2		**7**
Graphis scripta								3		1							**4**
Lecanora chlarotera				2	2	1		5	5	5				5			**25**
Opegrapha atra		3	5				3	2			1	3		1	1		**19**
Pertusaria leioplaca	5	5	5	5	5	5	5	5	2		5	5			5	5	**62**
Pyrenula macrospora		5															**5**
Sum of frequencies	**5**	**13**	**12**	**7**	**7**	**6**	**9**	**15**	**7**	**6**	**8**	**8**	**0**	**9**	**8**	**5**	
7	**Total number of lichen species & Total frequency**																**125**

Ash-Hazel Woodland: Plots 20 - 27

Plot 20 Lichen species and frequencies on aspects of sampled trees.

	1st ash tree				2nd ash tree				3rd ash tree				4th ash tree				Total
Plot 20 Lichen species	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**F**
Anisomeridium biforme			1														**1**
Arthonia radiata					2		5	2					1				**10**
Enterographa crassa	1		4	3	5	5	5	5				1	5	5	5		**44**
Graphis scripta					3	2	2	1	1			2	2	4	3		**20**
Lecanora chlarotera	5	3	5	5			5						1	1			**25**
Opegrapha atra	3	2	1	2		3		2				2	5				**20**
Opegrapha varia										2	5	2					**9**
Opegrapha vulgata													2	5			**7**
Porina borreri															5		**5**
Pyrenula macrospora					1	1							5	5	2		**14**
Sum of frequencies	**9**	**5**	**11**	**10**	**11**	**11**	**17**	**10**	**1**	**2**	**5**	**7**	**21**	**20**	**15**	**0**	
10	**Total number of lichen species & Total frequency**																**155**

Plot 21 Lichen species and frequencies on aspects of sampled trees.

	1st ash tree				2nd ash tree				3rd ash tree				4th ash tree				Total
Plot 21 Lichen species	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**F**
Enterographa crassa	2	5			1	5	5		3	5	2		5	5	3	5	**46**
Graphis scripta	2	1	3						4	1		1		2	3	1	**18**
Lecanora argentata						1											**1**
Lecanora chlarotera		3	1			2				1	1					1	**9**
Opegrapha niveoatra							4										**4**
Opegrapha atra	2	2	1		2		1		1			1					**10**
Pertusaria leioplaca		3			5	3			5	1							**17**
Pyrenula macrospora	2	3	2		2	1	1	1	3	1		2	3	2	3	5	**31**
Sum of frequencies	**8**	**17**	**7**	**0**	**10**	**12**	**11**	**1**	**16**	**9**	**3**	**4**	**8**	**9**	**9**	**12**	
8	**Total number of lichen species & Total frequency**																**136**

Plot 22 Lichen species and frequencies on aspects of sampled trees.

	1st ash tree				2nd ash tree				3rd ash tree				4th ash tree				Total
Plot 22 Lichen species	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**F**
Enterographa crassa					5	2			1		1	3	4	5	5	5	**31**
Graphis britannica		1	1														**2**
Graphis scripta									1	1	1						**3**
Opegrapha atra	5	5	5	5	5	5	5	2		2	2	3	3			3	**50**
Opegrapha niveoatra	2			3	5	1	3	5	5	1	1		5	5	5	5	**46**
Pertusaria leioplaca		1	4					3									**8**
Pyrenula macrospora							5		3	1	2	1	4	2		3	**21**
Sum of frequencies	**7**	**7**	**10**	**8**	**15**	**8**	**13**	**10**	**10**	**5**	**7**	**7**	**16**	**12**	**10**	**16**	
7	**Total number of lichen species & Total frequency**																**161**

Plot 23 Lichen species and frequencies on aspects of sampled trees.

	1st ash tree				2nd ash tree				3rd ash tree				4th ash tree				Total
Plot 23 Lichen species	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**F**
Graphis scripta					2			4	3	2	5	2			3		**21**
Lecidella elaeochroma			5														**5**
Opegrapha atra	4	3	4	3	3	4	1	4					3	4	2		**35**
Pertusaria leioplaca		3				4	2						1	4	3		**17**
Pyrenula macrospora	2		1				2	1	3	3	3	2	1	3		1	**22**
Sum of frequencies	**6**	**6**	**10**	**3**	**5**	**8**	**5**	**9**	**6**	**5**	**8**	**4**	**5**	**11**	**8**	**1**	
5	**Total number of lichen species & Total frequency**																**100**

Plot 24 Lichen species and frequencies on aspects of sampled trees.

	1st ash tree				2nd ash tree				3rd ash tree				4th ash tree				Total
Plot 24 Lichen species	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**F**
Arthonia didyma	1	1															**2**
Enterographa crassa	2	1															**3**
Graphis scripta	2	1	4	2	2	2	2		1	3	3		2	1	3	1	**29**
Lecanora chlarotera						2								1		1	**4**
Pertusaria leioplaca													1				**1**
Porina aenea									1			2					**3**
Pyrenula macrospora	2	5	1	3		1	1	1	5	3	5	4	1	1	2		**35**
Sum of frequencies	**7**	**8**	**5**	**5**	**2**	**5**	**3**	**1**	**7**	**6**	**8**	**6**	**4**	**3**	**5**	**2**	
7	**Total number of lichen species & Total frequency**																**77**

Plot 25 Lichen species and frequencies on aspects of sampled trees.

	1st ash tree				2nd ash tree				3rd ash tree				4th ash tree				Total
Plot 25 Lichen species	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**F**
Enterographa crassa	2													2	3		**7**
Graphis scripta					2										2		**4**
Lecanora chlarotera	1			3					2	2							**8**
Opegrapha atra	5	2	1	3	1			3	5	5		2					**27**
Pertusaria leioplaca	5	2	2	5	3				5	3	1	2		1			**29**
Porina aenea			5	5													**10**
Pyrenula macrospora					3	1		5	3	4			2	1	5		**24**
Sum of frequencies	**13**	**4**	**8**	**16**	**9**	**1**	**0**	**8**	**15**	**14**	**1**	**4**	**2**	**4**	**10**	**0**	
7	**Total number of lichen species & Total frequency**																**109**

Plot 26 Lichen species and frequencies on aspects of sampled trees.

Plot 26 Lichen species	1st ash tree				2nd ash tree				3rd ash tree				4th ash tree				Total F
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Anisomeridium biforme														1			**1**
Arthonia didyma								3						1			**4**
Arthonia radiata		1		1							3			2	2		**9**
Eopyrenula leucoplaca			1						3	3	2	3					**12**
Graphis scripta										1							**1**
Lecanora argentata											2			2	4	2	**10**
Lecanora chlarotera	5	5	1	1	5	5	5	2	5	5	5	5	5	5	5	5	**69**
Lecidea exigua					5	5	5				5	2					**22**
Lecidella elaeochroma													3	5	5	5	**18**
Opegrapha atra	1	1	2	3	1		2	5	1								**16**
Opegrapha herbarum														1			**1**
Pertusaria leioplaca				2			4					1		5	3	3	**18**
Porina aenea									1	5		2	2	1		2	**13**
Pyrenula macrospora										1							**1**
Vouauxiella lichenicola					5												**5**
Sum of frequencies	**6**	**7**	**4**	**7**	**16**	**10**	**16**	**10**	**10**	**15**	**17**	**13**	**10**	**23**	**19**	**17**	
15	**Total number of lichen species & Total frequency**																**200**

Plot 27 Lichen species and frequencies on aspects of sampled trees.

Plot 27 Lichen species	1st ash tree				2nd ash tree				3rd ash tree				4th ash tree				Total F
	N	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	**N**	**E**	**S**	**W**	
Anisomeridium biforme			1														**1**
Arthonia punctiformis									5	5		4	5				**19**
Arthonia radiata		2				5	5			5	5	5	5	5	3	5	**45**
Arthonia spadicea					5												**5**
Lecanora argentata	2			2				1									**5**
Lecanora chlarotera	5	5	5	5		5	5	5	2	2						2	**41**
Lecidella elaeochroma	2		1	1	3	2	2	2	1								**14**
Opegrapha atra		3	1		2	1	3	2		5		1		1		1	**20**
Opegrapha niveoatra	5	5	2		5	5	5	5									**32**
Pertusaria leioplaca		2			5	1		1					2	1	5	3	**20**
Pertusaria sp.									1								**1**
Porina aenea									2							1	**3**
Sum of frequencies	**14**	**17**	**10**	**8**	**20**	**19**	**20**	**16**	**11**	**17**	**5**	**10**	**12**	**7**	**8**	**12**	
12	**Total number of lichen species & Total frequency**																**206**

Powerscourt Waterfall: Plots 28 and 29

Plot 28 Lichen taxa and frequencies on aspects of sampled trees.

Plot 28 Lichen taxa	1st sycamore				2nd sycamore				3rd sycamore				4th sycamore				Total F
	N	E	S	W	N	E	S	W	N	E	S	W	N	E	S	W	
Acrocordia gemmata														4	3	5	**12**
Anisomeridium biforme	2									1							**3**
Arthonia didyma																1	**1**
Arthonia radiata	2		2	4		2		2		5						5	**22**
Cladonia coniocraea	1																**1**
Collema furfuraceum						2											**2**
Evernia prunastri													3	3	3		**9**
Flavoparmelia caperata					2			2					1	2			**7**
Graphis scripta														1			**1**
Lecanora argentata	2	5	1	1	5	5		1		1			2	1	1	5	**30**
Lecanora chlarotera	2	5	3	3	5	5		3		5	5	4		4	5	5	**54**
Lecanora expallens		1		1	1					1			5		2	1	**12**
Lecidella elaeochroma	2	5	2	1			3	2									**15**
Lobaria pulmonaria	5	1		3	1	1											**11**
Melanelia glabratula				1						3	5	5		4		2	**20**
Melanelia subaurifera													1				**1**
Normandina pulchella						2											**2**
Opegrapha varia		2	1														**3**
Opegrapha vulgata		1						4									**5**
Parmelia crinita				1													**1**
Parmelia saxatilis					5					1		5	1		1		**13**
Parmotrema perlatum				3	1	4				5		1		3			**17**
Pertusaria albescens															5		**5**
Pertusaria amara						1			3	5	5		5	5	5	5	**34**
Pertusaria hymenea	2	5		1	2	5		2	5	5	3	5	5	5	5	1	**51**
Pertusaria pertusa				4	5	3				3	5		1	5	5	5	**36**
Physcia tenella					5	1											**6**
Porina aenea		2		1			2										**5**
Pyrenula macrospora		1															**1**
Pyrenula sp.															1		**1**
Ramalina farinacea													3				**3**
Schismatomma decolorans		2						2									**4**
Thelotrema lepadinum										1							**1**
Vouauxiella lichenicola	2	5	1	1				1		5							**15**
Sum of frequencies	**20**	**35**	**10**	**25**	**32**	**31**	**5**	**19**	**8**	**41**	**23**	**20**	**27**	**37**	**36**	**35**	
34	**Total number of lichen species & Total frequency**																**404**

Plot 29 Lichen species and frequencies on aspects of sampled trees.

Plot 29 Lichen species	1st oak tree				2nd oak tree				Total F
	N	E	S	W	N	E	S	W	
Acrocordia gemmata								1	**1**
Cladonia coniocraea					5	5			**10**
Flavoparmelia caperata	5	5		5		5	5		**25**
Lecanora expallens			5				5	5	**15**
Melanelia glabratula			2				5		**7**
Ochrolechia inversa			1						**1**
Parmelia saxatilis				5					**5**
Parmelia sulcata	5	5		5					**15**
Parmotrema perlatum					5				**5**
Pertusaria albescens	5	5		5					**15**
Pertusaria pertusa		3						5	**3**
Physcia tenella		5		5					**10**
Thelotrema lepadinum					5	3			**8**
Sum of frequencies	**15**	**23**	**8**	**25**	**15**	**13**	**15**	**11**	
13	**Total number of lichen species & Total frequency**								**120**

Oak woodland

Oak woodland								
Sampling Plot 1	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Oak	5	5	15	16	-1.25	0.75	6.75	6.5
Sums of Frequencies 2 Oak	0	2	0	7	-6.25	-2.3	-8.25	-2.5
Sums of Frequencies 3 Oak	9	5	8	8	2.75	0.75	-0.25	-1.5
Sums of Frequencies 4 Oak	11	5	10	7	4.75	0.75	1.75	-2.5
Means of Sums of Frequencies (MSF)	6.25	4.25	8.25	9.5	**4.092676386**			
LDV of Plot 1	**28.25**							
Sampling Plot 2	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Oak	8	5	6	9	1.75	1.75	2	3.75
Sums of Frequencies 2 Oak	4	3	0	5	-2.25	-0.3	-4	-0.25
Sums of Frequencies 3 Oak	4	5	7	5	-2.25	1.75	3	-0.25
Sums of Frequencies 4 Oak	9	0	3	2	2.75	-3.3	-1	-3.25
Means of Sums of Frequencies (MSF)	6.25	3.25	4	5.25	**2.479919354**			
LDV of Plot 2	**18.75**							
Sampling Plot 3	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Oak	11	14	2	3	5.75	6.25	-0.25	-1
Sums of Frequencies 2 Oak	3	11	5	3	-2.25	3.25	2.75	-1
Sums of Frequencies 3 Oak	6	3	2	3	0.75	-4.8	-0.25	-1
Sums of Frequencies 4 Oak	1	3	0	7	-4.25	-4.8	-2.25	3
Means of Sums of Frequencies (MSF)	5.25	7.75	2.25	4	**3.4278273**			
LDV of Plot 3	**19.25**							
Sampling Plot 4	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Oak	9	4	10	15	3.5	-0.8	3.25	8
Sums of Frequencies 2 Oak	2	7	8	1	-3.5	2.25	1.25	-6
Sums of Frequencies 3 Oak	9	7	6	8	3.5	2.25	-0.75	1
Sums of Frequencies 4 Oak	2	1	3	4	-3.5	-3.8	-3.75	-3
Means of Sums of Frequencies (MSF)	5.5	4.75	6.75	7	**3.746109093**			
LDV of Plot 4	**24**							
Sampling Plot 5	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Oak	0	0	3	8	-3.75	-1.8	1.5	4
Sums of Frequencies 2 Oak	5	1	2	2	1.25	-0.8	0.5	-2
Sums of Frequencies 3 Oak	5	1	1	2	1.25	-0.8	-0.5	-2
Sums of Frequencies 4 Oak	5	5	0	4	1.25	3.25	-1.5	0
Means of Sums of Frequencies (MSF)	3.75	1.75	1.5	4	**2.041241452**			
LDV of Plot 5	**11**							

Sampling Plot 6	Frequencies				Standard Deviation			
	North	East	South	West	North	East	South	West
Sums of Frequencies 1 Oak	6	0	10	2	1	-3	4.75	-2.5
Sums of Frequencies 2 Oak	9	6	2	15	4	3	-3.25	10.5
Sums of Frequencies 3 Oak	3	6	4	1	-2	3	-1.25	-3.5
Sums of Frequencies 4 Oak	2	0	5	0	-3	-3	-0.25	-4.5
Means of Sums of Frequencies (MSF)	5	3	5.25	4.5	**4.080441153**			
LDV of Plot 6	**17.75**							
Sampling Plot 7	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Oak	3	2	0	0	-0.75	-1.5	-1.25	-2
Sums of Frequencies 2 Oak	2	0	0	0	-1.75	-3.5	-1.25	-2
Sums of Frequencies 3 Oak	5	5	4	5	1.25	1.5	2.75	3
Sums of Frequencies 4 Oak	5	7	1	3	1.25	3.5	-0.25	1
Means of Sums of Frequencies (MSF)	3.75	3.5	1.25	2	**2.073644135**			
LDV of Plot 7	**10.5**							
Sampling Plot 8	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Oak	8	2	0	5	1.25	-9.3	-4.25	3.25
Sums of Frequencies 2 Oak	6	16	6	2	-0.75	4.75	1.75	0.25
Sums of Frequencies 3 Oak	7	8	3	0	0.25	-3.3	-1.25	-1.75
Sums of Frequencies 4 Oak	6	19	8	0	-0.75	7.75	3.75	-1.75
Means of Sums of Frequencies (MSF)	6.75	11.25	4.25	1.75	**3.958114029**			
LDV of Plot 8	**24**							

Oak-ash-hazel woodland								
Sampling Plot 9	**Frequencies**				**Standard deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Beech	0	0	7	9	-11.75	-9.5	-1	-1.25
Sums of Frequencies 2 Beech	8	18	5	2	-3.75	8.5	-3	-8.25
Sums of Frequencies 3 Oak	25	10	15	15	13.25	0.5	7	4.75
Sums of Frequencies 4 Beech	14	10	5	15	2.25	0.5	-3	4.75
Means of Sums of Frequencies (MSF)	11.75	9.5	8	10.25	**6.725573086**			
LDV of Plot 9	**39.5**							
Sampling Plot 10	**Frequencies**				**Standard deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Willow	11	3	7	4	5.5	-7.3	-1.75	-0.5
Sums of Frequencies 2 Willow	8	20	17	9	2.5	9.75	8.25	4.5
Sums of Frequencies 3 Willow	3	11	7	4	-2.5	0.75	-1.75	-0.5
Sums of Frequencies 4 Willow	0	7	4	1	-5.5	-3.3	-4.75	-3.5
Means of Sums of Frequencies (MSF)	5.5	10.25	8.75	4.5	**4.909175083**			
LDV of Plot 10	**29**							
Sampling Plot 11	**Frequencies**				**Standard deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	9	5	1	5	3.5	0	-2.25	3
Sums of Frequencies 2 Ash	2	8	4	0	-3.5	3	0.75	-2
Sums of Frequencies 3 Ash	5	5	2	1	-0.5	0	-1.25	-1
Sums of Frequencies 4 Ash	6	2	6	2	0.5	-3	2.75	0
Means of Sums of Frequencies (MSF)	5.5	5	3.25	2	**2.187083294**			
LDV of Plot 11	**15.75**							
Sampling Plot 12	**Frequencies**				**Standard deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	8	7	3	3	3.5	3.75	-0.75	-0.75
Sums of Frequencies 2 Ash	5	0	2	2	0.5	-3.3	-1.75	-1.75
Sums of Frequencies 3 Ash	2	2	3	5	-2.5	-1.3	-0.75	1.25
Sums of Frequencies 4 Ash	3	4	7	5	-1.5	0.75	3.25	1.25
Means of Sums of Frequencies (MSF)	4.5	3.25	3.75	3.75	**2.148642983**			
LDV of Plot 12	**15.25**							
Sampling Plot 13	**Frequencies**				**Standard deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	10	8	7	11	5.5	4	0.75	4.25
Sums of Frequencies 2 Ash	5	4	5	5	0.5	0	-1.25	-1.75
Sums of Frequencies 3 Ash	1	2	6	3	-3.5	-2	-0.25	-3.75
Sums of Frequencies 4 Ash	2	2	7	8	-2.5	-2	0.75	1.25
Means of Sums of Frequencies (MSF)	4.5	4	6.25	6.75	**2.738612788**			
LDV of Plot 13	**21.5**							

Sampling Plot 14	Frequencies				Standard deviation			
	North	East	South	West	North	East	South	West
Sums of Frequencies 1 Ash	1	14	10	6	-3	6.5	4	-1
Sums of Frequencies 2 Ash	5	12	4	12	1	4.5	-2	5
Sums of Frequencies 3 Ash	6	2	6	7	2	-5.5	0	0
Sums of Frequencies 4 Oak	4	2	4	3	0	-5.5	-2	-4
Means of Sums of Frequencies (MSF)	4	7.5	6	7	**3.67876791**			
LDV of Plot 14	**24.5**							
Sampling Plot 15	**Frequencies**				**Standard deviation**			
	North	East	South	West	North	East	South	West
Sums of Frequencies 1 Beech	1	3	1	1	-3.75	-0.3	-4.75	-3.75
Sums of Frequencies 2 Oak	6	0	3	6	1.25	-3.3	-2.75	1.25
Sums of Frequencies 3 Beech	2	3	8	2	-2.75	-0.3	2.25	-2.75
Sums of Frequencies 4 Oak	10	7	11	10	5.25	3.75	5.25	5.25
Means of Sums of Frequencies (MSF)	4.75	3.25	5.75	4.75	**3.54964787**			
LDV of Plot 15	**18.5**							
Sampling Plot 16	**Frequencies**				**Standard deviation**			
	North	East	South	West	North	East	South	West
Sums of Frequencies 1 Ash	5	10	9	10	2	4.25	1.75	2.75
Sums of Frequencies 2 Ash	0	6	8	5	-3	0.25	0.75	-2.25
Sums of Frequencies 3 Ash	3	2	11	8	0	-3.8	3.75	0.75
Sums of Frequencies 4 Ash	4	5	1	6	1	-0.8	-6.25	-1.25
Means of Sums of Frequencies (MSF)	3	5.75	7.25	7.25	**2.807727432**			
LDV of Plot 16	**23.25**							
Sampling Plot 17	**Frequencies**				**Standard deviation**			
	North	East	South	West	North	East	South	West
Sums of Frequencies 1 Ash	3	0	2	3	0	-1.8	-1.25	-0.75
Sums of Frequencies 2 Sycamore	0	0	3	8	-3	-1.8	-0.25	4.25
Sums of Frequencies 3 Sycamore	4	0	2	3	1	-1.8	-1.25	-0.75
Sums of Frequencies 4 Ash	5	7	6	1	2	5.25	2.75	-2.75
Means of Sums of Frequencies (MSF)	3	1.75	3.25	3.75	**2.425558355**			
LDV of Plot 17	**11.75**							
Sampling Plot 18	**Frequencies**				**Standard deviation**			
	North	East	South	West	North	East	South	West
Sums of Frequencies 1 Ash	6	4	9	3	0.5	0.5	4.25	0.75
Sums of Frequencies 2 Ash	3	1	1	0	-2.5	-2.5	-3.75	-2.25
Sums of Frequencies 3 Ash	8	6	6	2	2.5	2.5	1.25	-0.25
Sums of Frequencies 4 Ash	5	3	3	4	-0.5	-0.5	-1.75	1.75
Means of Sums of Frequencies (MSF)	5.5	3.5	4.75	2.25	**2.183269719**			
LDV of Plot 18	**16**							

Sampling Plot 19	Frequencies				Standard deviation			
	North	East	South	West	North	East	South	West
Sums of Frequencies 1 Beech	5	13	12	7	0.25	4.5	2.75	-1.75
Sums of Frequencies 2 Beech	7	6	9	15	2.25	-2.5	-0.25	6.25
Sums of Frequencies 3 Beech	7	6	8	8	2.25	-2.5	-1.25	-0.75
Sums of Frequencies 4 Beech	0	9	8	5	-4.75	0.5	-1.25	-3.75
Means of Sums of Frequencies (MSF)	4.75	8.5	9.25	8.75	**2.980492129**			
LDV of Plot 19	**31.25**							

Ash-hazel woodlands

Sampling Plot 20	Frequencies				Standard Deviation			
	North	East	South	West	North	East	South	West
Sums of Frequencies 1 Ash	9	5	11	10	-1.5	-4.5	-1	3.25
Sums of Frequencies 2 Ash	11	11	17	10	0.5	1.5	5	3.25
Sums of Frequencies 3 Ash	1	2	5	7	-9.5	-7.5	-7	0.25
Sums of Frequencies 4 Ash	21	20	15	0	10.5	10.5	3	-6.75
Means of Sums of Frequencies (MSF)	10.5	9.5	12	6.75	**6.015258376**			
LDV of Plot 20	**38.75**							
Sampling Plot 21	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	8	17	7	0	-2.5	5.25	-0.5	-4.25
Sums of Frequencies 2 Ash	10	12	11	1	-0.5	0.25	3.5	-3.25
Sums of Frequencies 3 Ash	16	9	3	4	5.5	- 2.75	-4.5	-0.25
Sums of Frequencies 4 Ash	8	9	9	12	-2.5	- 2.75	1.5	7.75
Means of Sums of Frequencies (MSF)	10.5	11.75	7.5	4.25	**3.737200378**			
LDV of Plot 21	**34**							
Sampling Plot 22	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	7	7	10	8	-5	-1	0	-2.25
Sums of Frequencies 2 Ash	15	8	13	10	3	0	3	-0.25
Sums of Frequencies 3 Ash	10	5	7	7	-2	-3	-3	-3.25
Sums of Frequencies 4 Ash	16	12	10	16	4	4	0	5.75
Means of Sums of Frequencies (MSF)	12	8	10	10.25	**3.12783205**			
LDV of Plot 22	**40.25**							
Sampling Plot 23	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	6	6	10	3	0.5	-1.5	2.25	-1.25
Sums of Frequencies 2 Ash	5	8	5	9	-0.5	0.5	-2.75	4.75
Sums of Frequencies 3 Ash	6	5	8	4	0.5	-2.5	0.25	-0.25
Sums of Frequencies 4 Ash	5	11	8	1	-0.5	3.5	0.25	-3.25
Means of Sums of Frequencies (MSF)	5.5	7.5	7.75	4.25	**2.152517905**			
LDV of Plot 23	**25**							

Sampling Plot 24	Frequencies				Standard Deviation			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	7	8	5	5	2	2.5	-0.25	1.5
Sums of Frequencies 2 Ash	2	5	3	1	-3	-0.5	-2.25	-2.5
Sums of Frequencies 3 Ash	7	6	8	6	2	0.5	2.75	2.5
Sums of Frequencies 4 Ash	4	3	5	2	-1	-2.5	-0.25	-1.5
Means of Sums of Frequencies (MSF)	5	5.5	5.25	3.5	**2.01246118**			
LDV of Plot 24	**19.25**							
Sampling Plot 25	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	13	4	8	16	3.25	-1.75	3.25	9
Sums of Frequencies 2 Ash	9	1	0	8	-0.75	-4.75	-4.75	1
Sums of Frequencies 3 Ash	15	14	1	4	5.25	8.25	-3.75	-3
Sums of Frequencies 4 Ash	2	4	10	0	-7.75	-1.75	5.25	-7
Means of Sums of Frequencies (MSF)	9.75	5.75	4.75	7	**5.229722746**			
LDV of Plot 25	**27.25**							
Sampling Plot 26	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	6	7	4	7	-4.5	-6.75	-10	-4.75
Sums of Frequencies 2 Ash	16	10	16	10	5.5	-3.75	2	-1.75
Sums of Frequencies 3 Ash	10	15	17	13	-0.5	1.25	3	1.25
Sums of Frequencies 4 Ash	10	23	19	17	-0.5	9.25	5	5.25
Means of Sums of Frequencies (MSF)	10.5	13.75	14	11.75	**5.102287069**			
LDV of Plot 26	**50**							
Sampling Plot 27	**Frequencies**				**Standard Deviation**			
	North	**East**	**South**	**West**	**North**	**East**	**South**	**West**
Sums of Frequencies 1 Ash	14	17	10	8	-0.25	2	-0.75	-3.5
Sums of Frequencies 2 Ash	20	19	20	16	5.75	4	9.25	4.5
Sums of Frequencies 3 Ash	11	17	5	10	-3.25	2	-5.75	-1.5
Sums of Frequencies 4 Ash	12	7	8	12	-2.25	-8	-2.75	0.5
Means of Sums of Frequencies (MSF)	14.25	15	10.75	11.5	**4.460941605**			
LDV of Plot 27	**51.5**							

Appendix 8.6

Average lichen frequency in Tree Circumference Categories

Plot, tree	Trunk circumference category [cm] with average frequency for oak trees											
	<60	61-80	81-100	101-120	121-140	141-160	161-180	181-200	201-220	221-240	241-260	261-280	281-340
P1, oak1											41		
P1, oak 2				9									
P1, oak 3			30										
P1, oak 4												33	
P2, oak 1			28										
P2, oak 2		12											
P2, oak 3				21									
P2, oak 4		14											
P3, oak 1													30
P3, oak 2									22				
P3, oak 3				14									
P3, oak 4				11									
P4, oak 1					38								
P4, oak 2			18										
P4, oak 3											30		
P4, oak 4													10
P5, oak 1												11	
P5, oak 2							10						
P5, oak 3							9						
P5, oak 4									14				
P6, oak 1			18										
P6, oak 2													32
P6, oak 3										14			
P6, oak 4										7			
P7, oak 1								5					
P7, oak 2									2				

Plot, tree	Trunk circumference category [cm] with average frequency for oak trees												
	<60	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-180**	**181-200**	**201-220**	**221-240**	**241-260**	**261-280**	**281-340**
P7, oak 3									19				
P7, oak 4			16										
P8, oak 1								15					
P8, oak 2							30						
P8, oak 3			18										
P8, oak 4								33					
Average LDV	**0**	**13**	**21.333**	**13.75**	**38**	**0**	**16.333**	**17.667**	**14.25**	**10.5**	**35.5**	**22**	**24**

Plot, tree	Trunk circumference [cm] category with average LDV for ash trees												
	<60	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-180**	**181-200**	**201-220**	**221-240**	**241-260**	**261-280**	**281-340**
P20, ash 1		35											
P20, ash 2		49											
P20, ash 3		15											
P20, ash 4					56								
P21, ash 1			32										
P21, ash 2		34											
P21, ash 3		32											
P21, ash 4			38										
P22, ash 1	32												
P22, ash 2		46											
P22, ash 3			29										
P22, ash 4			54										
P23, ash 1			25										

Plot, tree	Trunk circumference [cm] category with average LDV for ash trees												
	<60	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-180**	**181-200**	**201-220**	**221-240**	**241-260**	**261-280**	**281-340**
P23, ash 2			27										
P23, ash 3			23										
P23, ash 4		25											
P24, ash 1	25												
P24, ash 2			11										
P24, ash 3			27										
P24, ash 4			14										
P25, ash 1		41											
P25, ash 2		18											
P25, ash 3			34										
P25, ash 4						16							
P26, ash 1		24											
P26, ash 2		52											
P26, ash 3			55										
P26, ash 4			69										
P27, ash 1			49										
P27, ash 2				75									
P27, ash 3			43										
P27, ash 4			39										
Average LDV	**28.5**	**33.72727**	**35.5625**	**75**	**56**	**16**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Oak trees

Plot, tree	Trunk circumference category [cm] with average lichen species on oak trees												
	<60	61-80	81-100	101-120	121-140	141-160	161-180	181-200	201-220	221-240	241-260	261-280	281-340
P1, oak1											10		
P1, oak 2				5									
P1, oak 3			4										
P1, oak 4												6	
P2, oak 1			9										
P2, oak 2		3											
P2, oak 3				4									
P2, oak 4		6											
P3, oak 1													7
P3, oak 2									4				
P3, oak 3				5									
P3, oak 4				6									
P4, oak 1					6								
P4, oak 2			4										
P4, oak 3											6		
P4, oak 4													6
P5, oak 1												3	
P5, oak 2							5						
P5, oak 3							1						
P5, oak 4									3				
P6, oak 1			6										
P6, oak 2													7
P6, oak 3										3			
P6, oak 4										1			
P7, oak 1								1					

Plot, tree	Trunk circumference [cm] category with average lichen species number on ash trees												
	<60	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-180**	**181-200**	**201-220**	**221-240**	**241-260**	**261-280**	**281-340**
P7, oak 2									1				
P7, oak 3									3				
P7, oak 4			2										
P8, oak 1								2					
P8, oak 2							7						
P8, oak 3			6										
P8, oak 4								8					
Average LDV	**0**	**4.5**	**5.1667**	**5**	**6**	**0**	**4.3333**	**3.6667**	**2.75**	**2**	**8**	**4.5**	**6.6667**

Ash trees

Plot, tree	Trunk circumference [cm] category with average lichen species number on ash trees												
	<60	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-180**	**181-200**	**201-220**	**221-240**	**241-260**	**261-280**	**281-340**
P20, ash 1		4											
P20, ash 2		6											
P20, ash 3		4											
P20, ash 4					8								
P21, ash 1			6										
P21, ash 2		7											
P21, ash 3		6											
P21, ash 4			4										
P22, ash 1	4												
P22, ash 2		5											

Plot, tree	Trunk circumference [cm] category with average lichen species number on ash trees											
	<60	**61-80**	**81-100**	**101-120**	**121-140**	**141-160**	**161-180**	**181-200**	**201-220**	**221-240**	**241-260**	**261-280**	**281-340**
P22, ash 3			5										
P22, ash 4			4										
P23, ash 1			4										
P23, ash 2			4										
P23, ash 3			2										
P23, ash 4		4											
P24, ash 1	4												
P24, ash 2			3										
P24, ash 3			3										
P24, ash 4			4										
P25, ash 1		5											
P25, ash 2		4											
P25, ash 3			4										
P25, ash 4						4							
P26, ash 1		5											
P26, ash 2		6											
P26, ash 3			10										
P26, ash 4			9										
P27, ash 1			8										
P27, ash 2				8									
P27, ash 3			7										
P27, ash 4			6										
Average LDV	**4**	**5.090909**	**5.1875**	**8**	**8**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Frequency totals on aspects of trunks in plots in Knocksink Wood and Powerscourt Waterfall woodlands.

Oak woodland

Sampling Plot 1	Frequencies			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	5	5	15	16
Sums of Frequencies 2 Oak	0	2	0	7
Sums of Frequencies 3 Oak	9	5	8	8
Sums of Frequencies 4 Oak	11	5	10	7
Total frequency	**25**	**17**	**33**	**38**
Total frequency in Plot 1	**113**			
Sampling Plot 2	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	8	5	6	9
Sums of Frequencies 2 Oak	4	3	0	5
Sums of Frequencies 3 Oak	4	5	7	5
Sums of Frequencies 4 Oak	9	0	3	2
Total frequency	**25**	**13**	**16**	**21**
Total frequency in Plot 2	**75**			
Sampling Plot 3	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	11	14	2	3
Sums of Frequencies 2 Oak	3	11	5	3
Sums of Frequencies 3 Oak	6	3	2	3
Sums of Frequencies 4 Oak	1	3	0	7
Total frequency	**21**	**31**	**9**	**16**
Total frequency in Plot 3	**77**			
Sampling Plot 4	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	9	4	10	15
Sums of Frequencies 2 Oak	2	7	8	1
Sums of Frequencies 3 Oak	9	7	6	8
Sums of Frequencies 4 Oak	2	1	3	4
Total frequency	**22**	**19**	**27**	**28**
Total frequency in Plot 4	**96**			
Sampling Plot 5	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	0	0	3	8
Sums of Frequencies 2 Oak	5	1	2	2
Sums of Frequencies 3 Oak	5	1	1	2
Sums of Frequencies 4 Oak	5	5	0	4
Total frequency	**15**	**7**	**6**	**16**
Total frequency in Plot 5	**44**			

Frequency totals on aspects of trunks in plots in Knocksink Wood and Powerscourt Waterfall woodlands.

Appendix 8.8

Sampling Plot 6	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	6	0	10	2
Sums of Frequencies 2 Oak	9	6	2	15
Sums of Frequencies 3 Oak	3	6	4	1
Sums of Frequencies 4 Oak	2	0	5	0
Total frequency	**20**	**12**	**21**	**18**
Total frequency in Plot 6	**71**			
Sampling Plot 7	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	3	2	0	0
Sums of Frequencies 2 Oak	2	0	0	0
Sums of Frequencies 3 Oak	5	5	4	5
Sums of Frequencies 4 Oak	5	7	1	3
Total frequency	**15**	**14**	**5**	**8**
Total frequency in Plot 7	**42**			
Sampling Plot 8	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	8	2	0	5
Sums of Frequencies 2 Oak	6	16	6	2
Sums of Frequencies 3 Oak	7	8	3	0
Sums of Frequencies 4 Oak	6	19	8	0
Total frequency	**27**	**45**	**17**	**7**
Total frequency in Plot 8	**96**			

Oak-ash-hazel woodland				
Sampling Plot 9	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Beech	0	0	7	9
Sums of Frequencies 2 Beech	8	18	5	2
Sums of Frequencies 3 Oak	25	10	15	15
Sums of Frequencies 4 Beech	14	10	5	15
Total frequency	**47**	**38**	**32**	**41**
Total frequency in Plot 9	**158**			
Sampling Plot 10	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Willow	11	3	7	4
Sums of Frequencies 2 Willow	8	20	17	9
Sums of Frequencies 3 Willow	3	11	7	4
Sums of Frequencies 4 Willow	0	7	4	1
Total frequency	**22**	**41**	**35**	**18**
Total frequency in Plot 10	**116**			

Frequency totals on aspects of trunks in plots in Knocksink Wood and Powerscourt Waterfall woodlands.

Appendix 8.8

Sampling Plot 11	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	9	5	1	5
Sums of Frequencies 2 Ash	2	8	4	0
Sums of Frequencies 3 Ash	5	5	2	1
Sums of Frequencies 4 Ash	6	2	6	2
Total frequency	**22**	**20**	**13**	**8**
Total frequency in Plot 11	**63**			
Sampling Plot 12	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	8	7	3	3
Sums of Frequencies 2 Ash	5	0	2	2
Sums of Frequencies 3 Ash	2	2	3	5
Sums of Frequencies 4 Ash	3	4	7	5
Total frequency	**18**	**13**	**15**	**15**
Total frequency in Plot 12	**61**			
Sampling Plot 13	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	10	8	7	11
Sums of Frequencies 2 Ash	5	4	5	5
Sums of Frequencies 3 Ash	1	2	6	3
Sums of Frequencies 4 Ash	2	2	7	8
Total frequency	**18**	**16**	**25**	**27**
Total frequency in Plot 13	**86**			
Sampling Plot 14	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	1	14	10	6
Sums of Frequencies 2 Ash	5	12	4	12
Sums of Frequencies 3 Ash	6	2	6	7
Sums of Frequencies 4 Oak	4	2	4	3
Total frequency	**16**	**30**	**24**	**28**
Total frequency in Plot 14	**98**			
Sampling Plot 15	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Beech	1	3	1	1
Sums of Frequencies 2 Oak	6	0	3	6
Sums of Frequencies 3 Beech	2	3	8	2
Sums of Frequencies 4 Oak	10	7	11	10
Total frequency	**19**	**13**	**23**	**19**
Total frequency in Plot 15	**74**			

Frequency totals on aspects of trunks in plots in Knocksink Wood and Powerscourt Waterfall woodlands.

Appendix 8.8

Sampling Plot 16	Frequencies			
	North	East	South	West
Sums of Frequencies 1 Ash	5	10	9	10
Sums of Frequencies 2 Ash	0	6	8	5
Sums of Frequencies 3 Ash	3	2	11	8
Sums of Frequencies 4 Ash	4	5	1	6
Total frequency	**12**	**23**	**29**	**29**
Total frequency in Plot 16	**93**			
Sampling Plot 17	**Frequencies**			
	North	East	South	West
Sums of Frequencies 1 Ash	3	0	2	3
Sums of Frequencies 2 Sycamore	0	0	3	8
Sums of Frequencies 3 Sycamore	4	0	2	3
Sums of Frequencies 4 Ash	5	7	6	1
Total frequency	**12**	**7**	**13**	**15**
Total frequency in Plot 17	**47**			
Sampling Plot 18	**Frequencies**			
	North	East	South	West
Sums of Frequencies 1 Ash	6	4	9	3
Sums of Frequencies 2 Ash	3	1	1	0
Sums of Frequencies 3 Ash	8	6	6	2
Sums of Frequencies 4 Ash	5	3	3	4
Total frequency	**22**	**14**	**19**	**9**
Total frequency in Plot 18	**64**			
Sampling Plot 19	**Frequencies**			
	North	East	South	West
Sums of Frequencies 1 Beech	5	13	12	7
Sums of Frequencies 2 Beech	7	6	9	15
Sums of Frequencies 3 Beech	7	6	8	8
Sums of Frequencies 4 Beech	0	9	8	5
Total frequency	**19**	**34**	**37**	**35**
Total frequency in Plot 19	**125**			

Ash-hazel woodland				
Sampling Plot 20	**Frequencies**			
	North	East	South	West
Sums of Frequencies 1 Ash	9	5	11	10
Sums of Frequencies 2 Ash	11	11	17	10
Sums of Frequencies 3 Ash	1	2	5	7
Sums of Frequencies 4 Ash	21	20	15	0
Total frequency	**42**	**38**	**48**	**27**
Total frequency in Plot 20	**155**			

Frequency totals on aspects of trunks in plots in Knocksink Wood and Powerscourt Waterfall woodlands.

Appendix 8.8

Sampling Plot 21	Frequencies			
	North	East	South	West
Sums of Frequencies 1 Ash	8	17	7	0
Sums of Frequencies 2 Ash	10	12	11	1
Sums of Frequencies 3 Ash	16	9	3	4
Sums of Frequencies 4 Ash	8	9	9	12
Total frequency	**42**	**47**	**30**	**17**
Total frequency in Plot 21	**136**			
Sampling Plot 22	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	7	7	10	8
Sums of Frequencies 2 Ash	15	8	13	10
Sums of Frequencies 3 Ash	10	5	7	7
Sums of Frequencies 4 Ash	16	12	10	16
Total frequency	**48**	**32**	**40**	**41**
Total frequency in Plot 22	**161**			
Sampling Plot 23	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	6	6	10	3
Sums of Frequencies 2 Ash	5	8	5	9
Sums of Frequencies 3 Ash	6	5	8	4
Sums of Frequencies 4 Ash	5	11	8	1
Total frequency	**22**	**30**	**31**	**17**
Total frequency in Plot 23	**100**			
Sampling Plot 24	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	7	8	5	5
Sums of Frequencies 2 Ash	2	5	3	1
Sums of Frequencies 3 Ash	7	6	8	6
Sums of Frequencies 4 Ash	4	3	5	2
Total frequency	**20**	**22**	**21**	**14**
Total frequency in Plot 24	**77**			
Sampling Plot 25	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	13	4	8	16
Sums of Frequencies 2 Ash	9	1	0	8
Sums of Frequencies 3 Ash	15	14	1	4
Sums of Frequencies 4 Ash	2	4	10	0
Total frequency	**39**	**23**	**19**	**28**
Total frequency in Plot 25	**109**			
Sampling Plot 26	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	6	7	4	7
Sums of Frequencies 2 Ash	16	10	16	10
Sums of Frequencies 3 Ash	10	15	17	13

Sums of Frequencies 4 Ash	10	23	19	17
Total frequency	**42**	**55**	**56**	**47**
Total frequency in Plot 26	**200**			
Sampling Plot 27	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Ash	14	17	10	8
Sums of Frequencies 2 Ash	20	19	20	16
Sums of Frequencies 3 Ash	11	17	5	10
Sums of Frequencies 4 Ash	12	7	8	12
Total frequency	**57**	**60**	**43**	**46**
Total frequency in Pot 27	**206**			

Powerscourt Waterfall woodland				
Sampling Plot 28	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	20	35	10	25
Sums of Frequencies 2 Oak	32	31	5	19
Sums of Frequencies 3 Oak	8	41	23	20
Sums of Frequencies 4 Oak	27	37	36	35
Total frequency	**87**	**144**	**74**	**99**
Total frequency in Plot 28	**404**			
Sampling Plot 29	**Frequencies**			
	North	**East**	**South**	**West**
Sums of Frequencies 1 Oak	15	23	8	25
Sums of Frequencies 2 Oak	15	13	15	11
Total frequency	**30**	**36**	**23**	**36**
Total frequency in Plot 29	**125**			

Frequency totals on aspects of tree trunks in woodlands in Knocksink Wood and Powerscourt Waterfall.

Appendix 8.9

Oak woodland				
	Frequency on aspects			
Plot	**North**	**East**	**South**	**West**
Plot 1	25	17	33	38
Plot 2	25	13	16	21
Plot 3	21	31	9	16
Plot 4	22	19	27	28
Plot 5	15	7	6	16
Plot 6	20	12	21	18
Plot 7	15	14	5	8
Plot 8	27	45	17	7
Total	**170**	**158**	**134**	**152**

Oak-ash-hazel woodland				
	Frequency on aspects			
Plot	**North**	**East**	**South**	**West**
Plot 9	47	38	32	41
Plot 10	22	41	35	18
Plot 11	22	20	13	8
Plot 12	18	13	15	15
Plot 13	18	16	25	27
Plot 14	16	30	24	28
Plot 15	19	13	23	19
Plot 16	12	23	29	29
Plot 17	12	7	13	15
Plot 18	22	14	19	9
Plot 19	19	34	37	35
Total	**227**	**249**	**265**	**244**

Ash-hazel woodland				
	Frequency on aspects			
Plot	**North**	**East**	**South**	**West**
Plot 20	42	38	48	27
Plot 21	42	47	30	17
Plot 22	48	32	40	41
Plot 23	22	30	31	17
Plot 24	20	22	21	14
Plot 25	39	23	19	28
Plot 26	42	55	56	47
Plot 27	57	60	43	46
Total	**312**	**307**	**288**	**237**

Frequency totals on aspects of tree trunks in woodlands in Knocksink Wood and Powerscourt Waterfall.

Appendix 8.9

Powerscourt Waterfall woodland				
	Frequency on aspects			
Plot	North	East	South	West
Plot 28	87	144	74	99
Plot 29	30	36	23	36
Total	117	180	97	135

Oak woodland					
Sampling Plot 1	**Frequencies**				**Tree LDV**
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Oak	5	5	15	16	41
Sums of Frequencies 2 Oak	0	2	0	7	9
Sums of Frequencies 3 Oak	9	5	8	8	30
Sums of Frequencies 4 Oak	11	5	10	7	33
Sampling Plot 2	**Frequencies**				**Tree LDV**
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Oak	8	5	6	9	28
Sums of Frequencies 2 Oak	4	3	0	5	12
Sums of Frequencies 3 Oak	4	5	7	5	21
Sums of Frequencies 4 Oak	9	0	3	2	14
Sampling Plot 3	**Frequencies**				**Frequency total**
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Oak	11	14	2	3	30
Sums of Frequencies 2 Oak	3	11	5	3	22
Sums of Frequencies 3 Oak	6	3	2	3	14
Sums of Frequencies 4 Oak	1	3	0	7	11
Sampling Plot 4	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Oak	9	4	10	15	38
Sums of Frequencies 2 Oak	2	7	8	1	18
Sums of Frequencies 3 Oak	9	7	6	8	30
Sums of Frequencies 4 Oak	2	1	3	4	10
Sampling Plot 5	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Oak	0	0	3	8	11
Sums of Frequencies 2 Oak	5	1	2	2	10
Sums of Frequencies 3 Oak	5	1	1	2	9
Sums of Frequencies 4 Oak	5	5	0	4	14
Sampling Plot 6	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Oak	6	0	10	2	18
Sums of Frequencies 2 Oak	9	6	2	15	32
Sums of Frequencies 3 Oak	3	6	4	1	14
Sums of Frequencies 4 Oak	2	0	5	0	7
Sampling Plot 7	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Oak	3	2	0	0	5
Sums of Frequencies 2 Oak	2	0	0	0	2
Sums of Frequencies 3 Oak	5	5	4	5	19
Sums of Frequencies 4 Oak	5	7	1	3	16

Sampling Plot 8	Frequencies				
	North	East	South	West	
Sums of Frequencies 1 Oak	8	2	0	5	15
Sums of Frequencies 2 Oak	6	16	6	2	30
Sums of Frequencies 3 Oak	7	8	3	0	18
Sums of Frequencies 4 Oak	6	19	8	0	33

Oak-ash-hazel woodland

Sampling Plot 9	Frequencies				
	North	East	South	West	
Sums of Frequencies 1 Beech	0	0	7	9	16
Sums of Frequencies 2 Beech	8	18	5	2	33
Sums of Frequencies 3 Oak	25	10	15	15	65
Sums of Frequencies 4 Beech	14	10	5	15	44
Sampling Plot 10	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Willow	11	3	7	4	25
Sums of Frequencies 2 Willow	8	20	17	9	54
Sums of Frequencies 3 Willow	3	11	7	4	25
Sums of Frequencies 4 Willow	0	7	4	1	12
Sampling Plot 11	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	9	5	1	5	20
Sums of Frequencies 2 Ash	2	8	4	0	14
Sums of Frequencies 3 Ash	5	5	2	1	13
Sums of Frequencies 4 Ash	6	2	6	2	16
Sampling Plot 12	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	8	7	3	3	21
Sums of Frequencies 2 Ash	5	0	2	2	9
Sums of Frequencies 3 Ash	2	2	3	5	12
Sums of Frequencies 4 Ash	3	4	7	5	19
Sampling Plot 13	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	10	8	7	11	36
Sums of Frequencies 2 Ash	5	4	5	5	19
Sums of Frequencies 3 Ash	1	2	6	3	12
Sums of Frequencies 4 Ash	2	2	7	8	19

Average frequency on Oak, Ash, Beech, Willow and Sycamore

Appendix 8.10

Sampling Plot 14	Frequencies				
	North	East	South	West	
Sums of Frequencies 1 Ash	1	14	10	6	31
Sums of Frequencies 2 Ash	5	12	4	12	33
Sums of Frequencies 3 Ash	6	2	6	7	21
Sums of Frequencies 4 Oak	4	2	4	3	13
Sampling Plot 15	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Beech	1	3	1	1	6
Sums of Frequencies 2 Oak	6	0	3	6	15
Sums of Frequencies 3 Beech	2	3	8	2	15
Sums of Frequencies 4 Oak	10	7	11	10	38
Sampling Plot 16	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	5	10	9	10	34
Sums of Frequencies 2 Ash	0	6	8	5	19
Sums of Frequencies 3 Ash	3	2	11	8	24
Sums of Frequencies 4 Ash	4	5	1	6	16
Sampling Plot 17	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	3	0	2	3	8
Sums of Frequencies 2 Sycamore	0	0	3	8	11
Sums of Frequencies 3 Sycamore	4	0	2	3	9
Sums of Frequencies 4 Ash	5	7	6	1	19
Sampling Plot 18	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	6	4	9	3	22
Sums of Frequencies 2 Ash	3	1	1	0	5
Sums of Frequencies 3 Ash	8	6	6	2	22
Sums of Frequencies 4 Ash	5	3	3	4	15
Sampling Plot 19	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Beech	5	13	12	7	37
Sums of Frequencies 2 Beech	7	6	9	15	37
Sums of Frequencies 3 Beech	7	6	8	8	29
Sums of Frequencies 4 Beech	0	9	8	5	22

Ash-hazel woodlands

Sampling Plot 20	Frequencies				
	North	East	South	West	
Sums of Frequencies 1 Ash	9	5	11	10	35
Sums of Frequencies 2 Ash	11	11	17	10	49
Sums of Frequencies 3 Ash	1	2	5	7	15
Sums of Frequencies 4 Ash	21	20	15	0	56
Sampling Plot 21	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	8	17	7	0	32
Sums of Frequencies 2 Ash	10	12	11	1	34
Sums of Frequencies 3 Ash	16	9	3	4	32
Sums of Frequencies 4 Ash	8	9	9	12	38
Sampling Plot 22	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	7	7	10	8	32
Sums of Frequencies 2 Ash	15	8	13	10	46
Sums of Frequencies 3 Ash	10	5	7	7	29
Sums of Frequencies 4 Ash	16	12	10	16	54
Sampling Plot 23	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	6	6	10	3	25
Sums of Frequencies 2 Ash	5	8	5	9	27
Sums of Frequencies 3 Ash	6	5	8	4	23
Sums of Frequencies 4 Ash	5	11	8	1	25
Sampling Plot 24	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	7	8	5	5	25
Sums of Frequencies 2 Ash	2	5	3	1	11
Sums of Frequencies 3 Ash	7	6	8	6	27
Sums of Frequencies 4 Ash	4	3	5	2	14
Sampling Plot 25	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	13	4	8	16	41
Sums of Frequencies 2 Ash	9	1	0	8	18
Sums of Frequencies 3 Ash	15	14	1	4	34
Sums of Frequencies 4 Ash	2	4	10	0	16
Sampling Plot 26	**Frequencies**				
	North	**East**	**South**	**West**	
Sums of Frequencies 1 Ash	6	7	4	7	24
Sums of Frequencies 2 Ash	16	10	16	10	52
Sums of Frequencies 3 Ash	10	15	17	13	69
Sums of Frequencies 4 Ash	10	23	19	17	69
Sampling Plot 27	**Frequencies**				

Average frequency on Oak, Ash, Beech, Willow and Sycamore

Appendix 8.10

	North	East	South	West	
Sums of Frequencies 1 Ash	14	17	10	8	49
Sums of Frequencies 2 Ash	20	19	20	16	75
Sums of Frequencies 3 Ash	11	17	5	10	43
Sums of Frequencies 4 Ash	12	7	8	12	39

Average LDV on oak, ash, beech, willow and sycamore.

Tree species	Average LDV
Oak	20.7
Ash	28.5
Beech	26.6
Willow	29
Sycamore	10

Species	oak woodland						ash-hazel woodland					
	NSp	**Trees**	**F**	**Proportion of total frequency (pi)**	**ln pi**	**pi ln pi**	**NSp**	**Trees**	**F**	**Proportion of total frequency (pi)**	**ln pi**	**pi ln pi**
Species	np= 8	nt= 32	N				np= 8	nt= 32	N			
Acrocordia gemmata	2	4	20	0.032573	-3.424	-0.1115						
Amandinea punctata	1	1	3	0.004886	-5.321	-0.026						
Anisomeridium biforme	7	11	51	0.083062	-2.488	-0.2067	3	3	3	0.002622	-5.9437	-0.01559
Arthonia cinnabarina	4	7	8	0.013029	-4.341	-0.0566						
Arthonia didyma	2	2	3	0.004886	-5.321	-0.026	2	3	6	0.005245	-5.2505	-0.02754
Arthonia punctiformis							1	2	19	0.016608	-4.0978	-0.06806
Arthonia radiata	6	6	15	0.02443	-3.712	-0.0907	3	9	64	0.055944	-2.8834	-0.16131
Arthonia sp.	1	1	8	0.013029	-4.341	-0.0566						0
Arthonia spadicea							1	1	5	0.004371	-5.4328	-0.02374
Arthonia vinosa	1	1	1	0.001629	-6.42	-0.0105						
Cladonia coniocraea	6	7	28	0.045603	-3.088	-0.1408						
Dimerella pineti	2	2	4	0.006515	-5.034	-0.0328						
Enterographa crassa	5	7	47	0.076547	-2.57	-0.1967	5	14	131	0.11451	-2.1671	-0.24815
Eopyrenula leucoplaca							1	2	12	0.01049	-4.5574	-0.0478
Graphis britannica	4	4	7	0.011401	-4.474	-0.051	1	1	2	0.001748	-6.3491	-0.0111
Graphis scripta	6	8	20	0.032573	-3.424	-0.1115	7	17	96	0.083916	-2.4779	-0.20794
Haematoma caesium	1	1	9	0.014658	-4.223	-0.0619						
Lecanactis premnaea	1	1	1	0.001629	-6.42	-0.0105						
Lecanora argentata	3	2	31	0.050489	-2.986	-0.1508	3	5	16	0.013986	-4.2697	-0.05972
Lecanora chlarotera	6	10	30	0.04886	-3.019	-0.1475	6	19	156	0.136364	-1.9924	-0.2717
Lecanora sp.	1	1	8	0.013029	-4.341	-0.0566						
Lecidea exigua							1	2	22	0.019231	-3.9512	-0.07599
Lecidella elaeochroma	2	4	19	0.030945	-3.476	-0.1075	3	5	37	0.032343	-3.4314	-0.11098
Lepraria lobificans	8	19	111	0.180782	-1.71	-0.3092						

Species	oak woodland						ash-hazel woodland					
	NSp	**Trees**	**F**	**Proportion of total frequency (pi)**	**ln pi**	**pi ln pi**	**NSp**	**Trees**	**F**	**Proportion of total frequency (pi)**	**ln pi**	**pi ln pi**
Species	np= 8	nt= 32	N				np= 8	nt= 32	N			
Opegrapha atra	7	12	39	0.063518	-2.756	-0.1751	7	24	178	0.155594	-1.8605	-0.28948
Opegrapha herbarum	1	1	5	0.008143	-4.811	-0.0392	1	1	1	0.000874	-7.0423	-0.00616
Opegrapha niveoatra	1	1	2	0.003257	-5.727	-0.0187	3	7	82	0.071678	-2.6356	-0.18891
Opegrapha sp.	2	2	4	0.006515	-5.034	-0.0328						
Opegrapha varia							1	1	9	0.007867	-4.8451	-0.03812
Opegrapha viridis	1	2	2	0.003257	-5.727	-0.0187						
Opegrapha vulgata							1	1	7	0.006119	-5.0964	-0.03118
Pertusaria albescens	2	2	6	0.009772	-4.628	-0.0452						
Pertusaria amara	2	2	4	0.006515	-5.034	-0.0328						
Pertusaria hymenea	2	6	36	0.058632	-2.836	-0.1663						
Pertusaria leioplaca	7	11	56	0.091205	-2.395	-0.2184	7	20	110	0.096154	-2.3418	-0.22517
Pertusaria pertusa	3	6	25	0.040717	-3.201	-0.1303						
Pertusaria sp.	1	1	5	0.008143	-4.811	-0.0392	1	1	1	0.000874	-7.0423	-0.00616
Phlyctis argena	1	1	1	0.001629	-6.42	-0.0105						
Porina aenea							4	6	29	0.02535	-3.675	-0.09316
Porina borreri							1	1	5	0.004371	-5.4328	-0.02374
Porina sp.	1	1	1	0.001629	-6.42	-0.0105						
Pyrenula macrospora	1	1	1	0.001629	-6.42	-0.0105	7	21	148	0.129371	-2.0451	-0.26457
Schizmtomma cretaceum	1	1	3	0.004886	-5.321	-0.026						
Vouauxiella lichenicola							1	1	5	0.004371	-5.4328	-0.02374
sum of Freq.			614			-2.9352			1144			-2.52002
H = Shannon diversity index						**2.9352**						**2.520016**
s=species			34						24			
ln s			3.5264						3.1781			
J= Equitability						**0.8324**						**0.792943**

NSp = number of sampling plots, in which lichen species was recorded
np = total number of sampling plots (8)
nt = total number of trees (32)
F = total frequency of lichen species

Species	oak woodland					ash-hazel woodland				
	NSp	Trees	F	n / N	(n / N)2	NSp	Trees	F	n / N	(n /N)2
	np= 8	nt= 32	N			np= 8	nt= 32	N		
Acrocordia gemmata	2	4	20	0.03257	0.001061019				0	0
Amandinea punctata	1	1	3	0.00489	2.38729E-05				0	0
Anisomeridium biforme	7	11	51	0.08306	0.006899277	3	3	3	0.0026224	6.877E-06
Arthonia cinnabarina	4	7	8	0.01303	0.000169763				0	0
Arthonia didyma	2	2	3	0.00489	2.38729E-05	2	3	6	0.0052448	2.751E-05
Arthonia punctiformis					0	1	2	19	0.0166084	0.0002758
Arthonia radiata	6	6	15	0.02443	0.000596823	3	9	64	0.0559441	0.0031297
Arthonia sp.	1	1	8	0.01303	0.000169763				0	0
Arthonia spadicea					0	1	1	5	0.0043706	1.91E-05
Arthonia vinosa	1	1	1	0.00163	2.65255E-06				0	0
Cladonia coniocraea	6	7	28	0.0456	0.002079598				0	0
Dimerella pineti	2	2	4	0.00651	4.24408E-05				0	0
Enterographa crassa	5	7	47	0.07655	0.005859479	5	14	131	0.1145105	0.0131127
Eopyrenula leucoplaca				0	0	1	2	12	0.0104895	0.00011
Graphis britannica	4	4	7	0.0114	0.000129975	1	1	2	0.0017483	3.056E-06
Graphis scripta	6	8	20	0.03257	0.001061019	7	17	96	0.0839161	0.0070419
Haematoma caesium	1	1	9	0.01466	0.000214856				0	0
Lecanactis premnaea	1	1	1	0.00163	2.65255E-06				0	0
Lecanora argentata	3	2	31	0.05049	0.002549099	3	5	16	0.013986	0.0001956
Lecanora chlarotera	6	10	30	0.04886	0.002387293	6	19	156	0.1363636	0.018595
Lecanora sp.	1	1	8	0.01303	0.000169763					
Lecidea exigua				0	0	1	2	22	0.0192308	0.0003698
Lecidella elaeochroma	2	4	19	0.03094	0.00095757	3	5	37	0.0323427	0.001046
Lepraria lobificans	8	19	111	0.18078	0.032682044				0	0
Opegrapha atra	7	12	39	0.06352	0.004034526	7	24	178	0.1555944	0.0242096
Opegrapha herbarum	1	1	5	0.00814	6.63137E-05	1	1	1	0.0008741	7.641E-07
Opegrapha niveoatra	1	1	2	0.00326	1.06102E-05	3	7	82	0.0716783	0.0051378
Opegrapha sp.	2	2	4	0.00651	4.24408E-05				0	0
Opegrapha varia				0	0	1	1	9	0.0078671	6.189E-05

	oak woodland					ash-hazel woodland				
	NSp	**Trees**	**F**	**n / N**	**(n / N)2**	**NSp**	**NSp**	**Trees**	**F**	**n / N**
Species	np= 8	nt= 32	N			np= 8	np= 8	nt= 32	N	
Opegrapha viridis	1	2	2	0.00326	1.06102E-05				0	0
Opegrapha vulgata				0	0	1	1	7	0.0061189	3.744E-05
Pertusaria albescens	2	2	6	0.00977	9.54917E-05				0	0
Pertusaria amara	2	2	4	0.00651	4.24408E-05				0	0
Pertusaria hymenea	2	6	36	0.05863	0.003437702				0	0
Pertusaria leioplaca	7	11	56	0.09121	0.008318391	7	20	110	0.0961538	0.0092456
Pertusaria pertusa	3	6	25	0.04072	0.001657843				0	0
Pertusaria sp.	1	1	5	0.00814	6.63137E-05	1	1	1	0.0008741	7.641E-07
Phlyctis argena	1	1	1	0.00163	2.65255E-06				0	0
Porina aenea				0	0	4	6	29	0.0253497	0.0006426
Porina borreri				0	0	1	1	5	0.0043706	1.91E-05
Porina sp.	1	1	1	0.00163	2.65255E-06				0	0
Pyrenula macrospora	1	1	1	0.00163	2.65255E-06	7	21	148	0.1293706	0.0167368
Schizmtomma cretaceum	1	1	3	0.00489	2.38729E-05				0	0
Vouauxiella lichenicola				0	0	1	1	5	0.0043706	1.91E-05
sum of Freq.			614					1144		
D= Simpson's index of diversity					0.074897346					0.1000446
1-D					0.925102654					0.8999554
1 / D					13.35160788					9.9955397

Nsp = number of sampling plots, in which lichen species was recorded
np = total number of sampling plots (8)
nt = total number of sampling trees (32)
F = total frequency of lichen species

Plot	Tree	Frequency
Plot 1	Oak 1	41
	Oak 2	9
	Oak 3	30
	Oak 4	33
Plot 2	Oak 1	28
	Oak 2	12
	Oak 3	21
	Oak 4	14
Plot 3	Oak 1	30
	Oak 2	22
	Oak 3	14
	Oak 4	11
Plot 4	Oak 1	38
	Oak 2	18
	Oak 3	30
	Oak 4	10
Plot 5	Oak 1	11
	Oak 2	10
	Oak 3	9
	Oak 4	14
Plot 6	Oak 1	18
	Oak 2	32
	Oak 3	14
	Oak 4	7
Plot 7	Oak 1	5
	Oak 2	2
	Oak 3	19
	Oak 4	16
Plot 8	Oak 1	15
	Oak 2	30
	Oak 3	18
	Oak 4	33
Plot 9	Oak 3	65
Plot 14	Oak 4	13
Plot 15	Oak 2	15
	Oak 4	38
Plot 11	Ash 1	20
	Ash 2	14
	Ash 3	13
	Ash 4	16
Plot 12	Ash 1	21
	Ash 2	9
	Ash 3	12
	Ash 4	19

Plot	Tree	Frequency
Plot 13	Ash 1	36
	Ash 2	19
	Ash 3	12
	Ash 4	19
Plot 14	Ash 1	31
	Ash 2	33
	Ash 3	21
Plot 16	Ash 1	34
	Ash 2	19
	Ash 3	24
	Ash 4	16
Plot 17	Ash 1	8
	Ash 4	19
Plot 18	Ash 1	22
	Ash 2	5
	Ash 3	22
	Ash 4	15
Plot 20	Ash 1	35
	Ash 2	49
	Ash 3	15
	Ash 4	56
Plot 21	Ash 1	32
	Ash 2	34
	Ash 3	32
	Ash 4	38
Plot 22	Ash 1	32
	Ash 2	46
	Ash 3	29
	Ash 4	54
Plot 23	Ash 1	25
	Ash 2	27
	Ash 3	23
	Ash 4	25
Plot 24	Ash 1	25
	Ash 2	11
	Ash 3	27
	Ash 4	14
Plot 25	Ash 1	41
	Ash 2	18
	Ash 3	34
	Ash 4	16
Plot 26	Ash 1	24
	Ash 2	52
	Ash 3	55
	Ash 4	69

Plot	Tree	Frequency
Plot 27	Ash 1	49
	Ash 2	75
	Ash 3	43
	Ash 4	39
98 percentile of LDVs		**65.64**
mean LDV > 98 percentile		**mean (69,75)=72**

Calculation of Revised Index of Ecological Continuity (RIEC)

$$RIEC[\%] = (n/20) \times 100$$

Woodland type	n (number of indicator species present in study area Table 3.3)	RIEC calculation	RIEC [%]
Oak	4	4 / 20 x 100	20
Oak-ash-hazel	2	2 / 20 x 100	10
Ash-hazel	2	2 / 20 x 100	10
Knocksink Wood woodlands	4	4 / 20 x 100	20
Powerscourt Waterfall woodland	4	4 / 20 x 100	20

New Index of Ecological Continuity (NIEC)

Woodland type	NIEC (number of indicator species, Table 3.4)
Oak	2
Oak-ash-hazel	0
Ash-hazel	0
Knocksink Wood woodlands	2
Powerscourt Waterfall woodland	5

Acrocordia gemmata (Ach.) A. Massal.
Anisomeridium biforme (Borrer) R. C. Harris
Arthonia didyma Körber
Arthonia radiata (Pers.) Ach.
Cladonia coniocraea (Flörke) Spreng.
Collema furfuraceum (Arnold) Du Rietz
Evernia prunastri (L.) Ach.
Flavoparmelia caperata (L.) Hale
Graphis scripta (L.) Ach.
Lecanora argentata (Ach.) Malme
Lecanora chlarotera Nyl.
Lecanora expallens Ach.
Lecidella elaeochroma (Ach.) Choisy
Lobaria pulmonaria (L.) Hoffm.
Melanelia fuliginosa subsp. *glabratula* (Lamy) Coppins
Melanelia subaurifera Nyl. Essl.
Normandina pulchella (Borrer) Nyl.
Opegrapha varia Pers.
Opegrapha vulgata (Ach.) Ach.
Parmelia saxatilis (L.) Ach.
Parmotrema chinense (Osbeck) Hale
Parmotrema crinitum (Ach.) M. Choisy
Pertusaria albescens (Huds.) Choisy & Werner
Pertusaria amara (Ach.) Nyl.
Pertusaria hymenea (Ach.) Schaer.
Pertusaria pertusa (Weigel) Tuck.
Physcia tenella (Scop.) DC.
Porina aenea (Wallr.) Zahlbr.
Pyrenula macrospora (Degel.) Coppins & P. James
Pyrenula sp.
Ramalina farinacea (L.) Ach.
Schizmatomma decolorans (Turner & Borrer ex Sm.) Clauzade & Vezda
Thelotrema lepadinum (Ach.) Ach.
Vouauxiella lichenicola (Linds.) Petr. & Syd.

Lichen Taxa	Knocksink Wood	Powerscourt Waterfall woodland
Acrocordia gemmata	1	1
Amandinea punctata	1	0
Anisomeridium biforme	1	1
Arthonia cinnabarina	1	0
Arthonia didyma	1	1
Arthonia punctiformis	1	0
Arthonia radiata	1	1
Arthonia sp.	1	0
Arthonia spadicea	1	0
Arthonia vinosa	1	0
Cladonia coniocraea	1	1
Collema furfuraceum	0	1
Dimerella pineti	1	0
Enterographa crassa	1	0
Eopyrenula leucoplaca	1	0
Evernia prunastri	1	1
Flavoparmelia caperata	1	1
Graphis britannica	1	0
Graphis scripta	1	1
Haematomma caesium	1	0
Lecanactis premnea	1	0
Lecanora argentata	1	1
Lecanora chlarotera	1	1
Lecanora expallens	0	1
Lecidea exigua	1	0
Lecidella elaeochroma	1	1
Lepraria lobificans	1	0
Lobaria pulmonaria	0	1
Melanelia fuliginosa* subsp. *glabratula	1	1
Melanelia subaurifera	1	1
Normandina pulchella	0	1
Opegrapha atra	1	0
Opegrapha herbarum	1	0
Opegrapha niveoatra	1	0
Opegrapha sp.	1	0
Opegrapha varia	1	1
Opegrapha viridis	1	0
Opegrapha vulgata	1	1
Parmelia saxatilis	1	1
Parmelia sulcata	1	0
Parmotrema chinense	1	1
Parmotrema crinitum	0	1
Pertusaria albescens	1	1
Pertusaria amara	1	1
Pertusaria hymenea	1	1

Lichen taxa	Knocksink Wood	Powerscourt Waterfall woodland
Pertusaria leioplaca	1	0
Pertusaria pertusa	1	1
Pertusaria sp.	1	0
Phlyctis argena	1	0
Physcia tenella	1	1
Porina aenea	1	1
Porina borreri var. *borreri*	1	0
Porina sp.	1	0
Pyrenula macrospora	1	1
Pyrenula sp.	0	1
Ramalina farinacea	1	1
Schizmatomma cretaceum	1	0
Schizmatomma decolorans	0	1
Thelotrema lepadinum	0	1
Vouauxiella lichenicola	1	1

Sørensen coefficient formula:

$$S_s = 2a \div 2a + b + c$$

a = 26 (species common in both woodlands are highlighted in bold)
b = 34 (total number of species recorded on 6 trees in Powerscourt Waterfall woodland)
c = 52 (total number of species recorded on 108 trees in Knocksink Wood)

$$S_s = 2 \times 26 \div 2 \times 26 + 34 + 52$$

$$S_s = 52 / 52 + 34 + 52$$

$$S_s = 52 / 138$$

$$S_s = 0.3768$$

$$S_s = 37.68\%$$

Lichen taxa	Oak woodland								Oak - ash - hazel woodland											Ash-hazel woodland							
	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	9	1 0	1 1	1 2	1 3	1 4	1 5	1 6	1 7	1 8	1 9	P 20	P 21	P 22	P 23	P 24	P 25	P 26	P 27
Acrocordia gemmata	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Amandinea punctata	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anisomeridium biforme	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	0	1	0	1	1	0	0	0	0	0	1	1
Arthonia cinabarinna	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Arthonia didyma	0	1	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0	1	0	1	0
Arthonia punctiformis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Arthonia radiata	1	1	1	0	1	1	0	1	1	0	1	0	1	1	1	0	1	0	1	1	0	0	0	0	0	1	1
Arthonia sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arthonia spadicea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Arthonia vinosa	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cladonia coniocraea	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimerella pineti	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Enterographa crassa	0	0	0	1	1	1	1	1	1	0	0	0	0	0	1	0	1	1	0	1	1	1	0	1	1	0	0
Eopyrenula leucoplaca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Evernia prunastri	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Flavoparmelia caperata	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Graphis britannica	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Graphis scripta	1	1	1	1	0	1	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Haematoma caesium	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lecanactis premnea	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lecanora argentata	1	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1
Lecanora chlarotera	1	1	1	1	0	1	0	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1
Lecanora sp.	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Lecidea exigua	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Lecidella elaeochroma	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1
Lepraria lobificans	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Melanelia glabratula	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Melanelia subaurifera	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opegrapha atra	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1

Opegrapha herbarum	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0
Opegrapha niveoatra	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0	1
Opegrapha sp.	0	0	1	0	0	0	0	1	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0
Opegrapha varia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Opegrapha viridis	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Opegrapha vulgata	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Parmelia saxatilis	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parmelia sulcata	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Parmotrema chinense	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pertusaria albescens	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Pertusaria amara	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pertusaria hymenea	1	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Pertusaria leioplaca	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
Pertusaria pertusa	1	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Pertusaria sp.	0	0	0	1	0	0	0	0	0	1	0	1	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1
Phlyctis argena	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physcia tenella	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Porina aenea	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1
Porina borreri	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Porina sp.	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrenula macrospora	0	0	0	0	0	0	0	1	1	0	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	0
Ramalina farinacea	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Schizmatomma cretaceum	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vouauxiella lichenicola	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Oak Woodland

Plot 1 to 4			Plot 5 to 8		
Tree	Plot	Girth [cm]	Tree	Plot	Girth [cm]
1 Oak	1	260	1 Oak	5	264
2 Oak		115	2 Oak		170
3 Oak		90	3 Oak		166
4 Oak		262	4 Oak		208
1 Oak	2	100	1 Oak	6	90
2 Oak		80	2 Oak		340
3 Oak		110	3 Oak		240
4 Oak		70	4 Oak		230
1 Oak	3	337	1 Oak	7	195
2 Oak		213	2 Oak		202
3 Oak		118	3 Oak		209
4 Oak		115	4 Oak		90
1 Oak	4	132	1 Oak	8	187
2 Oak		81	2 Oak		162
3 Oak		259	3 Oak		100
4 Oak		292	4 Oak		197

Oak – Ash – Hazel Woodland

Plot 9 to 14			Plot 10 to 18 & 27		
Tree	Plot	Girth [cm]	Tree	Plot	Girth [cm]
1 Beech	9	400	3 Ash	14	65
2 Beech		200	4 Oak		94
3 Oak		199	1 Beech	15	89
4 Beech		112	2 Oak		64
1 Willow	10	60	3 Beech		268
2 Willow		62	4 Oak		147
3 Willow		60	1 Ash	16	70
4 Willow		86	2 Ash		83
1 Ash	11	97	3 Ash		64
2 Ash		70	4 Ash		84
3 Ash		47	1 Ash	17	200
4 Ash		72	2 Sycamore		117
1 Ash	12	85	3 Sycamore		120
2 Ash		94	4 Ash		100
3 Ash		111	1 Ash	18	125
4 Ash		81	2 Ash		88.5
1 Ash	13	86	3 Ash		106
2 Ash		80	4 Ash		91
3 Ash		124	1 Beech	27	176
4 Ash		75	2 Beech		192
1 Ash	14	100	3 Beech		238
2 Ash		80	4 Beech		190

Ash – Hazel Woodland

Plot 19 to 22			Plot 23 to 26		
Tree	Plot	Girth [cm]	Tree	Plot	Girth [cm]
1 Ash	19	65	1 Ash	23	56
2 Ash		68	2 Ash		93
3 Ash		76	3 Ash		90
4 Ash		153	4 Ash		89
1 Ash	20	86	1 Ash	24	70
2 Ash		70	2 Ash		77
3 Ash		74	3 Ash		97
4 Ash		81	4 Ash		150
1 Ash	21	60	1 Ash	25	74
2 Ash		66	2 Ash		78
3 Ash		81	3 Ash		82
4 Ash		88	4 Ash		90
1 Ash	22	83	1 Ash	26	89
2 Ash		94	2 Ash		104
3 Ash		95	3 Ash		85
4 Ash		67	4 Ash		91

Lichens recorded on tree trunks of 20 trees in the Brackloon Wood (Fox *et al.* 2001)
Arthonia cinnabarina
Arthonia muscigena
Arthonia thelotrematis
Bacidia viridifarinosa
Bactrospora corticola
Biatora sphaeoides
Catillaria atropurpurea
Catillaria pulvurea
Cladonia chlrophaea
Cladonia coniocraea
Dimerela pineti
Dimerella lutea
Enterographa crassa
Lecanactis abietina
Lecanora chlarotera
Lecanora expallens
Lecidea sanguineoatra
Lecidea hypnorum
Lecidella elaeochroma
Lepraria incana
Lepraria sp.
Lobaria pulmonaria
Micarea prasina
Normandina pulchella
Opegrapha atra
Opegrapha herbarum
Opegrapha niveoatra
Opegrapha ochrocheila
Opegrapha sp.
Opegrapha varia
Pannaria conoplea
Pannaria rubiginosa
Parmelia glabratula
Parmelia perlata
Pertusaria albescens
Pertusaria amara
Pertusaria hymenea
Pertusaria leioplaca
Phyllospora rosei
Porina chlorotica

Pyrenula macrospora
Pyrrhospora quernea
Ramalina farinacea
Skyttea nitschkei
Thelotrema lepadinum
Trapeliopis aurea
Trapeliopsis granulosa

Sørensen coefficient formula:

$S_s = 2a \div 2a + b + c$

a = 17 (species common in both woodlands are highlighted in bold)
b = 47 (total number of species recorded on 20 trees in Bracloon Wood)
c = 52 (total number of species recorded on 108 trees in Knocksink Wood)

$S_s = 2 \times 17 \div 2 \times 17 + 47 + 52$

$S_s = 34 / 34 + 47 + 52$

$S_s = 34 / 133$

$S_s = 0.2556$

$S_s = 25.56\%$

9. List of publications

9.1 Peer-reviewed journal article

Brodeková, L., Gilmer, A., Dowding, P., Fox, H., Guttová, A. 2006 An assessment of epiphytic lichen diversity and environmental quality in Knocksink Wood Nature Reserve, Ireland. *Biology & Environment: Proceedings of the Royal Irish Academy*, Vol.106.B, No. 3, 215-223.

9.2 Conference papers

January 2006: Poster presentation at the Annual General Meeting of The British Lichen Society: 'An assessment of lichen diversity in semi-natural woodlands of Knocksink Wood Nature Reserve, Ireland'. Cardiff, Wales, UK.

June 2005: Presentation at the International Conference on 'European Vegetation in the 21st century': 'Mapping the epiphytic lichen diversity & assessment of environmental quality in Irish semi-natural woodland', NUI Galway.

January 2005: Presentation at the 15th Irish Environmental Researchers' Colloquium – I.T. Sligo.