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The use of the axiophyte species concept to describe the ecological network of the Birmingham and Black Country of the UK West Midlands

Ian C. Trueman[1], Sara Carvalho[2], Andrew Slater[2]

[1]Biology and Environmental Sciences, Faculty of Science and Engineering, University of Wolverhampton, Wulfruna Str., WV1 1LY., Great Britain; E–mail address (corresponding author): I.C.Trueman@wlv.ac.uk
[2] EcoRecord, 16 Greenfield Crescent, Birmingham B15 3AU, Great Britain

ABSTRACT

The UK conurbation of Birmingham and the Black Country has recently been surveyed for a new Flora, on the basis of a 1 km square grid. The present paper uses the data to describe the ecological network of the conurbation. The total number of taxa per 1 km squares is shown to be moderately but significantly correlated, and the number of native taxa more strongly correlated, with the area of the previously-established network of protected sites. Nevertheless coincidence maps of total numbers or numbers of native species per 1 km square give only poor representations of the ecological network compared with maps of protected sites. Axiophytes are defined as plant species 90% restricted to conservation habitats and recorded in fewer than 25% of 2km x 2km squares in a county. Applying the concept to 1 km squares in Birmingham and the Black Country creates a list of 256 axiophytes. Numbers of axiophytes are shown to be more strongly correlated with areas of protected sites than total taxa or native taxa and a coincidence map of the axiophytes is found to provide a useful quantitative assessment of the ecological network. Maps of axiophytes are used to divide the network into core and linking areas and their use in consolidating and improving the botanical ecological network is explored.

KEY WORDS: urban ecology; indicator species, flora, landscape, conservation

1. Introduction

Nature conservation in the UK has traditionally been site-oriented. It has its roots in the Society for the Promotion of Nature Reserves, founded in 1912. In 1949 the British government legislated to found the Nature Conservancy, mainly to create a system of national Nature Reserves and Sites of Special Scientific Interest. The Wildlife and Countryside Act of 1981 included measures to protect certain threatened species but the emphasis was still on site protection.

Responding to habitat fragmentation and the need for species distribution to respond to climate change, a focus on landscape scale nature conservation has started to develop. This concept had already developed a wide currency in various parts of the world (BENNETT & MULONGOY, 2006), ranging from proposals for a supra-national Pan-European Ecological Network in Central and Eastern Europe to schemes for the city of Moscow. British developments are exemplified by the main non-governmental UK nature conservation organisation the Wildlife Trusts' 'Living Landscape' vision, launched in 2006 (WILDLIFE TRUSTS, 2006, 2009) and by the report commissioned and accepted by the UK government entitled "Making Space for Nature" (LAWTON ET AL., 2010). The latter defined a landscape-scale ecological network as "a suite of high quality sites which collectively contain the diversity and area of habitat that are needed to support species and which have ecological connections between them that enable species, or at least their genes, to move." *Core areas* with high nature conservation value form the heart of the network. They contain habitats that are rare or important because of the wildlife they support or the ecosystem services they provide. They generally have the highest concentrations of species or support rare species. They provide places within which species can thrive and from which they can disperse to other parts of the network. They include protected wildlife sites and other semi-natural areas of high ecological quality. *Linking areas* such as corridors, stepping stones, restoration areas and buffer zones are designed to connect, reinforce and repair core areas.

'A Nature Conservation Review' (RATCLIFFE, 1977) was written by the then Chief Scientist of the Nature Conservancy as a basis for the first selection of National Nature Reserves in the UK. Ratcliffe based his evaluation for nature conservation largely on considerations of the vegetation, partly because of the relatively complete nature of the botanical evidence but also because vegetation is both "an integrated expression of a complex of interacting environmental influences, and at the same time is the major determinant of the animal component" (RATCLIFFE, 1977). Although much has been written on evaluation for nature conservation since (e.g. USHER, 1986; SPELLERBERG, 1992), an emphasis on the plant component has tended to persist at least in terrestrial ecosystems.

Modern local Floras are usually based on data collected on a grid, and the present paper is an attempt to use such data as a basis of evaluation for nature conservation and the identification of an ecological network in an entire urban landscape. For a local Flora in the UK, the grid typically used has a 2 km × 2km square (the 'tetrad') as the unit. ROY ET AL. (1999) demonstrated that although the tetrad unit was capable of distinguishing urban tetrads from other types it was of less use in their analysis, although in the analysis of the tetrad data for the Staffordshire Flora (LAWLEY, 2011) some differentiation within the urban tetrads based on the presence or absence of species of old habitats is apparent. MILLARD (2008) investigated relationships at the landscape scale between species numbers and urban greenspace in selected areas of Leeds in Yorkshire, UK after a tetrad survey. The greenspace was differentiated according to the degree of nature conservation value. He found that total numbers of species correlated positively and significantly both with total areas of greenspace and with areas of greenspace designated for relatively high nature conservation value, also that numbers of native species correlated positively and significantly with areas of greenspace designated for relatively high nature conservation value. He also examined the relationship between such sites and the numbers of species with national conservation designations, but the number of designated species was small and no significant correlation was detected. There seems to be a need for a more inclusive method than national designation to identify species associated with high nature conservation value.

Recently the Botanical Society of the British Isles (BSBI) has attempted to characterise a wider range of species associated with nature conservation value as 'axiophytes'. The BSBI axiophyte project (http://www.bsbi.org.uk/axiophytes.html) defines axiophytes as "the 40% or so of species that arouse interest and praise from botanists when they are seen…They are indicators of habitat that is considered important for conservation, such as ancient woodlands, clear water and species-rich meadows." LOCKTON (2011) writes that they are "the species that we want, because they are the ones that grow in the habitats that we want to protect".

Defining particular species as axiophytes can be largely achieved by first drawing up a list of habitats of conservation importance for the vice-county to be investigated. The vice-county is the basic recording unit in the UK. The axiophytes are those species which are: 1/ 90% restricted to these conservation habitats; 2/ recorded in fewer than 25% of tetrads in the vice-county.

Often there is insufficient information to fulfil the 90% criterion. It may also be difficult to define 'site' or even 'habitat' rigorously. Also species that have only ever been recorded in one or two sites in a vice-county are often just chance occurrences, having little ecological significance, so that the omission of very rare species should be considered. Nevertheless, many of the 112 vice-counties of the UK now have lists of axiophytes selected by the nominated BSBI vice-county Recorders and published on the BSBI website. In practice they differ considerably between vice-counties since many of the more ecologically constrained species are also geographically constrained to particular parts of the country.

Lists of axiophytes potentially provide a powerful technique for determining conservation priorities. Sites with many axiophytes are arguably of greater conservation importance than those with fewer. The present paper explores the characterisation of the 1 km × 1 km squares (monads) within a conurbation by the number of axiophytes they contain. The relationship between conservation value derived by this means, and conservation value derived from the presence of designated areas, is examined. It also explores whether these data can be used to map and evaluate its ecological network.

2. Study area

Birmingham and the Black Country together comprise a conurbation covering 624.8 km^{-1} in central England (Fig. 1). In the first decade of the 21st century, fieldwork took place for a first Flora of Birmingham and the Black Country (TRUEMAN ET AL., 2013). For this, data was collected on a 1 km square grid. Birmingham and the Black Country is a largely continuous urban area made up of five contiguous but independently-administered municipalities: Birmingham, Dudley, Sandwell, Walsall and Wolverhampton (Fig. 2). The total human population is (2011 census data) 2,212,800.

Fig. 1. UK showing location of Birmingham and the Black Country (after: Trueman et al., 2013)

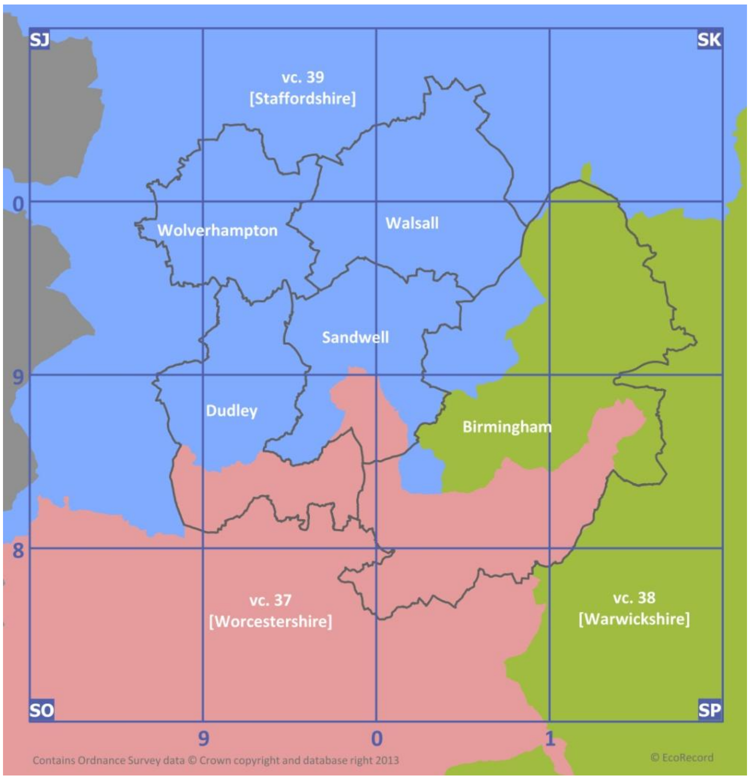

Fig. 2. Birmingham and the Black Country showing metropolitan district and vice-county boundaries (grid squares shown are 10 kilometre squares) (after: Trueman et al., 2013)

Fig. 2 shows that the area of the Birmingham and Black Country conurbation is also divided between three of the UK vice-counties. Since the conurbation only covers small proportions of all three vice-counties this situation has been unsatisfactory for evaluating the biodiversity of the conurbation as a whole. In 1980 a voluntary conservation body (now called the Birmingham and Black Country Wildlife Trust) was inaugurated for the whole conurbation and in 1991 it initiated a local biological record centre, EcoRecord, to collect and store its records in collaboration with the three constituent vice-counties. As a result of the activities of these organisations and of the relevant national and international bodies, nature and geology in Birmingham and the Black Country are conserved by law in eighteen (mostly geological) nationally-protected Sites of Special Scientific Interest (SSSIs), including two with European status as Special Areas of Conservation (SACs), and two National Nature Reserves (NNRs). In addition, two tiers of wildlife sites exist without national statutory protection although the local authorities give them some recognition in the planning system. These comprise 392 Sites of Importance for Nature Conservation (SINCs) and 403 Sites of Local Importance for Nature Conservation (SLINCs). Figs. 3 and 4 show the distribution of these protected areas across the conurbation.

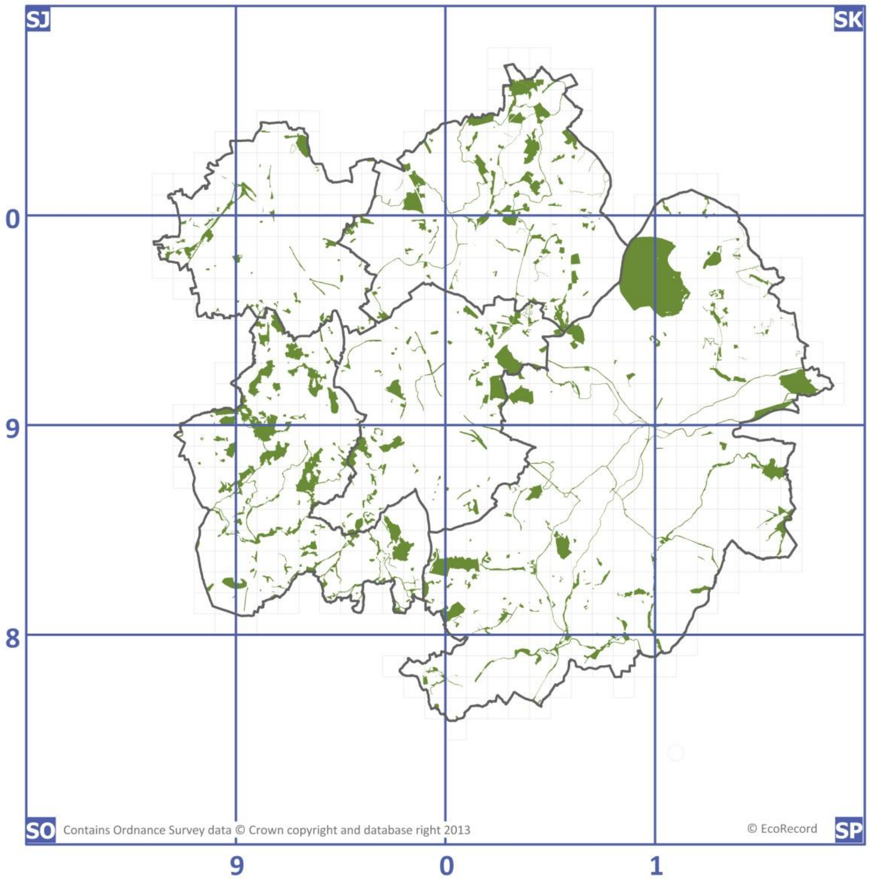

Fig. 3. Protected sites (SACs, NNRs, SSSIs, SINCs and SLINCs) in Birmingam and the Black Country (after: EcoRecord data)

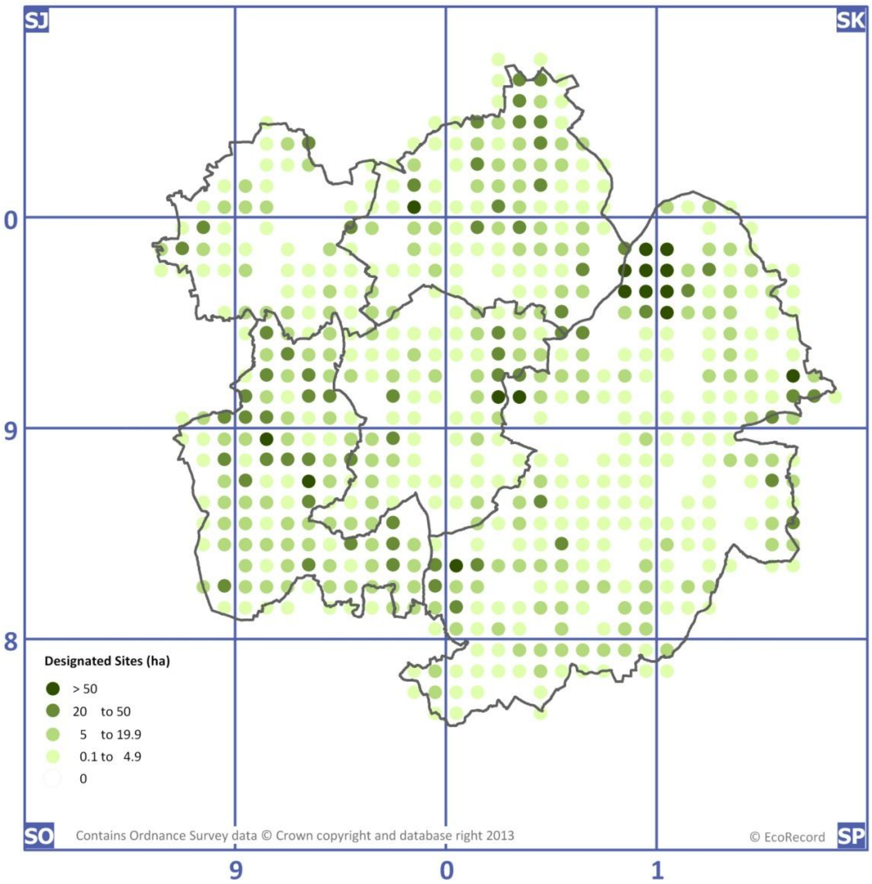

Fig. 4. Areas of each 1 km square designated as protected sites (SACs, NNRs, SSSIs, SINCs and SLINCs) in Birmingham and the Black Country (after: EcoRecord data)

Figs. 3 and 4 show that Birmingham and the Black Country has moderately well-marked concentrations of designated sites, together constituting a broadly definable ecological network. This comprises a series of remnant ancient woodlands, botanically-rich grasslands and mires, heathlands, open-water habitats and post-industrial sites. The ecological network includes two large coherent open spaces, one in eastern Sandwell (the 'Sandwell Valley') and one in northern Birmingham (Sutton Park).

3. Materials and Methods

The Birmingham and Black Country Flora project was initiated in 1997 although most of the recording was accomplished in the first ten years of the 21st century. All spontaneously-present species were recorded within those parts of each of the 715 monads included within the boundaries. Each monad was surveyed, wherever possible both in spring and in summer, by a survey team with the aim of sampling the entire area and particularly features such as woodland, mires, canals and post-industrial sites which would be likely to contain raised botanical diversity. At least 100 records from a list of 400 species thought previously to be relatively common in the conurbation were required as a minimum record for each monad, although in a few cases, where only a tiny proportion of a monad was within the boundaries of the conurbation, even this modest target was not achieved. Other records made within the period 1995 – 2012 by statutory and voluntary bodies were incorporated into the database. These were mostly for the designated sites. Coincidence mapping (SINKER, 1985), showing the number of taxa from monad to monad in gridded maps of the conurbation was used to display variation in botanical diversity incorporating both the whole data set and also a variety of subsets. These maps have been used to describe the existing ecological network of the conurbation, to compare it with the previously existing description based on the protected areas and to suggest what measures might be used to reinforce the network following the logic of LAWTON ET AL. (2010). The botanical nomenclature used is that of STACE (2010).

4. Results

Based on over 240000 records, the final database forms a matrix of 715 monads × 1449 taxa. For the purposes of the analysis, species of *Hieracium* spp., *Rubus* subgenus *Rubus*, *Euphrasia* spp., *Taraxacum* spp. and a few smaller groups were treated as aggregates. Well-defined and widely-recorded inter-specific hybrids and a few important subspecies have however been included, e.g. to differentiate the invasive neophyte *Lamiastrum galeobdolon* subsp. *argentatum* (Smejkal) Stace from the ancient woodland indicator *Lamiastrum galeobdolon* subsp. *montanum* (Pers.)Ehrend. & Polatschek. The numbers of taxa in each 1 km square is shown in Fig. 5.

Fig. 5 shows that there is considerable variation in numbers of taxa per monad in these data. 81 monads have records of at least 250 taxa and eight monads more than 350 taxa. The mean number of taxa in monads with at least 25% of the area within Birmingham and the Black Country was 188 and the maximum was 403. Fig. 5 shows however that monads with low scores are quite common and widespread throughout the Birmingham and Black Country conurbation, especially in some predominantly residential areas of Birmingham.

Few extended areas of the UK have been mapped on a monad basis, however CRAWLEY (2005) recorded that among the 508 monads making up East Berkshire the majority had between 100 and 250 species per monad, with an average of 155 and a maximum of 518. He also accumulated some further UK examples which suggested that mean species richness varied from 130 to 258 and maximum species richness from 270 to 518. The highest scores in East Berkshire were associated with long- and intensively-recorded University land rather than botanically remarkable areas, suggesting that exceptional numbers may sometimes be attributable to an exceptionally high level of botanical recording. Monad records have been accumulated for the Surrey Flora (http://www.surreyflora.org.uk/1km_records.php) and the well-surveyed, largely urban 10 km square TQ26 in South London has an average number of 247 and a range from 108-462 for records accumulated between 1666 and the present. Similarly the maximum for the recent Flora of well-urbanised South Yorkshire (WILMORE ET AL., 2011) was 445 for a monad including a wetland SSSI. 21 monads had 300 or more taxa recorded and six of those were predominantly urban (WILMORE, G.T.D., pers. comm.). In Scotland, a sample monad survey of Berwickshire gave a highest category of 256-64 taxa per monad (BRAITHWAITE, M.E. pers. comm.).

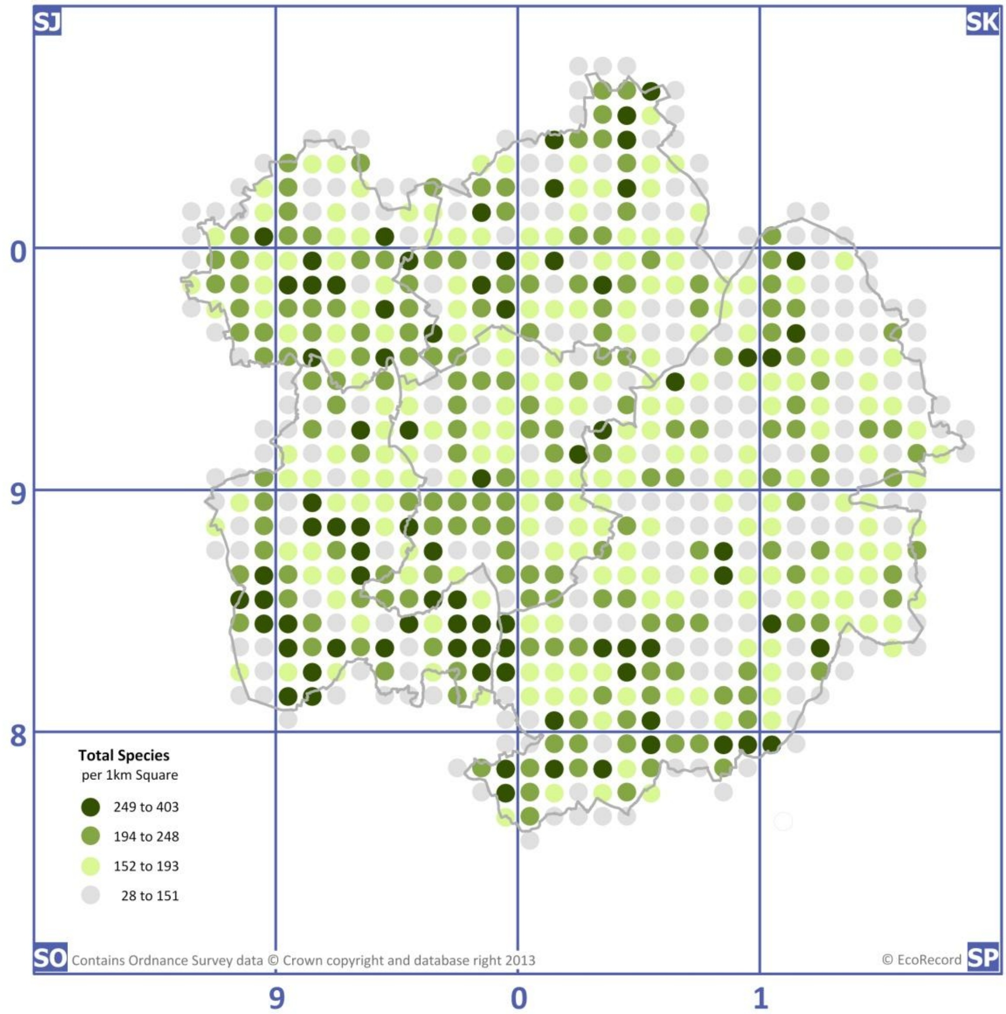

Fig. 5. Coincidence map showing the number of taxa recorded in each monad in the Birmingham and Black Country study area (after: EcoRecord data from the Birmingham and Black Country Flora project)

These data are reasonably comparable with those for Birmingham and the Black Country, although they do confirm that much variation may be associated with variation in intensity of botanical recording. There will also be variations in degree to which critical species and microspecies are distinguished. Fig. 5, however, clearly does not provide a sufficiently coherent description of the botanical ecological network of the conurbation, even though the correlation coefficient between number of taxa and area ($\log_{10} + 1$ transformed) of designated sites at the monad level is 0.465, a figure which is significant at the 0.1% level of probability.

Fig. 6 is a coincidence map showing the number of taxa considered to be native in Britain recorded in each monad in the Birmingham and Black Country study area. Fig. 6 shows a much clearer relationship between numbers of native species and the areas of designated sites shown in Figs. 3 and 4 than the number of records per monad shown in Fig. 5 and must be considered a better estimate of the nature conservation value exhibited by the individual monad. The correlation coefficient between number of native species and areas ($\log_{10} + 1$ transformed) of designated sites for all 715 monads is 0.621, higher than that for total taxa. However many native species, such as *Atriplex prostrata*, *Apium nodiflorum* and *Conium maculatum* are associated with a variety of disturbed and eutrophic soils and are not associated with nature conservation sites. Similarly some non-native species, particularly archaeophytes threatened by modern changes in agriculture, should also be included in assessing nature conservation value and defining the ecological network.

The axiophyte concept allows the focus to be specifically on species directly associated with conservation habitats. Since the area covered is small compared with a typical vice-county, identification of a list of axiophytes for Birmingham and the Black Country has taken place on the basis of taxon presence in monads rather than in tetrads. Of the 1449 taxa in the Birmingham and Black Country database, 229 (mostly native) are present in 25% or more of monads. Of the remaining 1220, 63 are nationally considered to be of only casual occurrence and 550 are neophytes. Only one of the neophytes is at present, tentatively, considered to be characteristic of conservation habitats. This is *Pilosella praelta* which has started to appear in a few old post-industrial sites of nature conservation interest. Of the 71 less-common archaeophytes, most in Birmingham and the Black Country are rare, possibly random occurrences or are too widespread in habitat to qualify. A small number, characteristic of arable land, either agricultural or horticultural (including allotment gardens) are nationally threatened or near-threatened, largely because of the modern use of selective herbicides. However even some threatened arable weeds such as *Centaurea cyanus*, *Glebionis segetum* and *Agrostemma githago* are thought to owe their present distribution in Birmingham and the Black Country entirely or almost entirely to their deliberate sowing as decorative annuals. Therefore, only *Apera spica-venti* (4 monads), *Stachys arvensis* (23), *Thlaspi arvense* (36) and *Chenopodium polyspermum* (39) were selected as axiophytes. *Chaenorhinum minus* (22), *Reseda lutea* (110) and *Sambucus ebulis* (4) were selected as archaeophyte species characteristic of post-industrial sites with nature conservation interest.

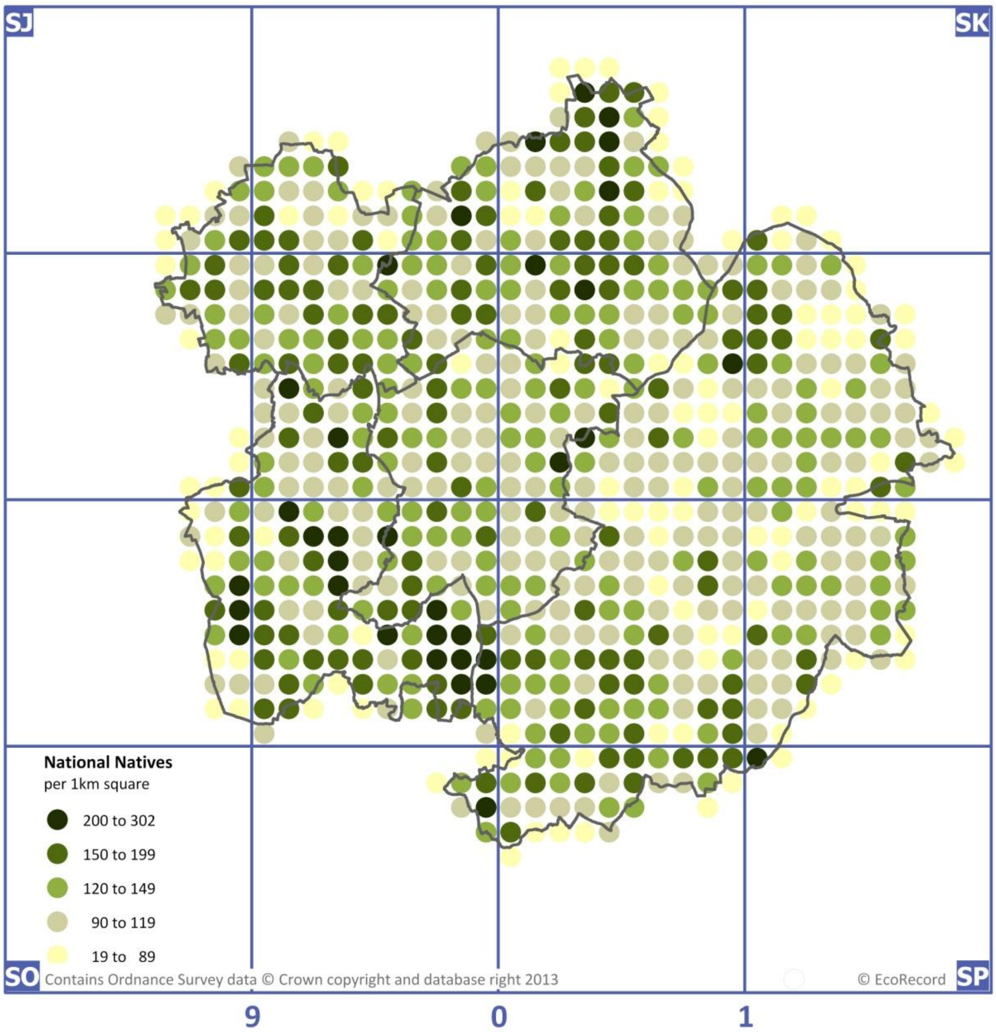

Fig. 6. Coincidence map showing the number of taxa considered to be native in Britain recorded in each monad in the Birmingham and Black Country study area (after: EcoRecord data from the Birmingham and Black Country Flora project)

Of the 538 taxa native in the UK and present in less than 25% of monads, 71 are considered to be doubtfully native or entirely escapes from cultivation or definite recent adventives in Birmingham and the Black Country. In addition, some locally native taxa were rejected because they are not strongly associated with habitats with nature conservation value, for example *Arum maculatum* (165), *Potentilla anserina* (117) or *Apium nodiflorum* (174). Other locally native taxa with records from one or two monads were also rejected because, like *Potentilla argentea* (1) or *Juncus subnodulosus* (2), they were also considered to be recent adventives or deliberate introductions. A few species such as *Carex dioica*, *Oreopteris limbosperma* and *Carex strigosa* with only one or two records in

Birmingham and the Black Country, but where the distribution is considered to be a remnant of higher frequency in conservation habitats in the recent past were however not rejected. These processes removed a further 219 taxa and identified 248 native taxa which are rarely or never seen in commoner habitats such as private gardens, recently-disturbed land and road margins. They are entirely or almost entirely associated with habitats considered to be of nature conservation importance in Birmingham and the Black Country, namely old, mature woodlands, grasslands and heathlands, a variety of long-established mires plus some more recently-originating open water, post-industrial and arable habitats which are also considered to be of nature conservation importance. All the species from open water and almost all from post-industrial sites are native species. The flora of relatively long-persisting post-industrial sites tends to be dominated by native species, many with recognised nature conservation value (Rostański, 1998, Cohn et al., 2001). These 248 native taxa, together with the seven archaeophytes and one neophyte identified above, form the axiophyte list.

The complete list of the axiophytes for Birmingham and the Black Country is presented in table 1, together with number of monads from which they have been recorded. Axiophyte lists are available for two of the three vice-counties which include portions in Birmingham and the Black Country and a column in the table shows where a species is included in those lists. This comparison shows that certain species which are too common in rural areas to qualify as axiophytes may be sufficiently uncommon and restricted in habitat in urban areas to qualify. The major habitat types of nature conservation interest with which each of the taxa can be associated are also listed in a column of the Table 1.

Table 1. Proposed axiophyte list for Birmingham and the Black Country (after: Trueman et al., 2013)

Latin name of species	Number of monads in B&BC	Range of habitats* in B&BC	Axiophyte in consistuent vice-counties
Achillea ptarmica	40	GM	2
Adoxa moschatellina	12	W	1
Agrimonia eupatoria	25	G	1
Agrostis canina	30	GM	2
Agrostis vinealis	7	H	2
Aira caryophyllea	33	I	2
Aira praecox	66	HI	2
Ajuga reptans	42	WG	
Alchemilla filicaulis subsp. *vestita*	29	GM	2
Allium ursinum	133	W	
Anacamptis pyramidalis	8	GI	1
Anagallis tenella	3	M	2
Anemone nemorosa	93	W	1
Angelica sylvestris	164	M	
Anthyllis vulneraria	44	I	2
Apera spica-venti	4	C	
Apium inundatum	3	MA	2
Arenaria serpyllifolia sensu lato	48	I	
Asplenium adiantum-nigrum	29	I	
Asplenium ceterach	11	I	
Athyrium filix-femina	99	WM	
Betonica officinalis	53	G	1
Bidens cernua	9	A	2
Bidens tripartita	28	A	2
Blackstonia perfoliata	4	GI	2
Blechnum spicant	12	WGH	2
Brachypodium sylvaticum	156	WG	1
Briza media	27	GM	1
Bromopsis erecta	13	G	1
Bromopsis ramosa	104	W	1
Butomus umbellatus	92	A	2
Calamagrostis epigejos	16	MI	2
Calluna vulgaris	64	H	1

Caltha palustris	79	WGM	
Campanula rotundifolia	32	GH	
Cardamine amara	28	WM	2
Carex acuta	2	MA	2
Carex acutiformis	80	MA	
Carex binervis	6	H	2
Carex canescens	2	M	2
Carex caryophyllea	4	G	2
Carex demissa	17	M	2
Carex diandra	2	M	
Carex dioica	1	M	
Carex disticha	8	M	2
Carex echinata	7	GM	2
Carex hostiana	2	M	2
Carex hostiana x *viridula* (*C.* x *fulva*)**	1	M	
Carex nigra	66	HM	1
Carex pallescens	5	GM	2
Carex panicea	23	M	2
Carex paniculata	19	WMA	2
Carex pilulifera	12	H	2
Carex pseudocyperus	37	M	2
Carex pulicaris	2	M	2
Carex remota	90	W	
Carex riparia	18	MA	1
Carex rostrata	15	MA	2
Carex strigosa	2	W	2
Carex sylvatica	46	W	1
Carlina vulgaris	2	GI	2
Catabrosa aquatica	2	M	2
Catapodium rigidum	40	I	
Centaurea scabiosa	47	I	2
Centaurium erythraea	113	GI	1
Cerastium semidecandrum	15	GI	2
Ceratocapnos claviculata	6	W	2
Chaenorhinum minus	22	I	
Chaerophyllum temulum	32	W	
Chenopodium polyspermum	39	C	
Chrysosplenium oppositifolium	47	W	
Cirsium dissectum	6	GM	2
Cirsium palustre	112	GM	
Clematis vitalba	78	I	
Comarum palustre	16	M	2
Dactylorhiza fuchsii	39	GM	1
Dactylorhiza fuchsii x *praetermissa* (*D.* x *grandis*)**	10	GM	
Dactylorhiza maculata	2	HM	2
Dactylorhiza praetermissa	48	GM	1
Danthonia decumbens	25	GH	2
Daucus carota subsp. *carota*	141	GI	
Deschampsia flexuosa	154	WGHI	1
Drosera rotundifolia	2	M	2
Dryopteris affinis agg.	28	W	2
Dryopteris carthusiana	34	WM	2
Eleocharis palustris	68	MA	1
Eleocharis quinqueflora	2	M	1
Eleogiton fluitans	1	MA	1
Empetrum nigrum agg.	2	H	1
Epilobium palustre	41	M	2
Epipactis helleborine	21	W	2
Equisetum fluviatile	56	MA	1
Equisetum palustre	39	M	1

Equisetum sylvaticum	21	WG	2
Equisetum telmateia	23	W	2
Erica cinerea	9	H	2
Erica tetralix	13	HM	2
Erigeron acris	45	I	1
Eriophorum angustifolium	11	M	2
Eriophorum vaginatum	6	M	1
Erophila verna s.l.	79	I	2
Euphrasia spp.	13	G	2
Festuca filiformis	16	GH	1
Filago minima	3	I	2
Filago vulgaris	9	I	2
Filipendula ulmaria	169	WGM	
Fragaria vesca	78	WG	1
Frangula alnus	34	W	2
Fumaria muralis	17	C	
Galium album	36	G	
Galium odoratum	34	W	1
Galium palustre s.l.	88	M	
Galium saxatile	65	GH	1
Galium uliginosum	3	M	2
Genista tinctoria	7	G	2
Geum rivale	4	WGM	2
Geum rivale x *urbanum* (*G.* x *intermedium*)**	1	WGM	1
Glyceria declinata	49	M	1
Glyceria notata	34	MA	1
Hydrocotyle vulgaris	17	M	2
Hypericum pulchrum	4	WG	1
Hypericum tetrapterum	68	M	1
Inula conyzae	9	I	2
Isolepis setacea	22	GM	2
Juncus acutiflorus	76	M	
Juncus bulbosus	10	M	2
Juncus squarrosus	27	H	2
Lamiastrum galeobdolon subsp. *montanum*	91	W	1
Lathraea squamaria	6	W	2
Lathyrus linifolius	10	G	1
Lathyrus nissolia	12	G	1
Leontodon hispidus	65	G	1
Linum catharticum	35	GI	1
Lotus pedunculatus	116	M	
Luronium natans	6	A	1
Luzula multiflora	28	HM	2
Luzula pilosa	5	W	2
Lysimachia nemorum	23	W	1
Lysimachia vulgaris	20	M	2
Lythrum portula	6	MA	2
Malus sylvestris	65	W	
Melampyrum pratense	1	WH	2
Melica uniflora	64	W	1
Mentha arvensis	20	M	1
Menyanthes trifoliata	13	MA	1
Mercurialis perennis	173	W	
Milium effusum	55	W	1
Moehringia trinervia	32	W	
Molinia caerulea	34	HM	2
Montia fontana	4	M	2
Nardus stricta	43	GH	2
Odontites vernus	117	G	1
Oenanthe fistulosa	2	MA	2

Ononis repens	20	G	2
Ophioglossum vulgatum	5	G	2
Ophrys apifera	29	I	1
Oreopteris limbosperma	1	H	2
Ornithopus perpusillus	11	GHI	2
Orobanche minor	4	I	1
Oxalis acetosella	51	W	
Parnassia palustris	2	M	1
Pedicularis palustris	2	M	1
Pedicularis sylvatica	4	HM	2
Persicaria bistorta	56	G	2
Persicaria hydropiper	47	M	
Phleum bertolonii	32	G	1
Picris hieracioides	12	GI	1
Pilosella praealta	3	I	
Pimpinella saxifraga	21	G	1
Pinguicula vulgaris	2	M	
Plantago media	21	G	1
Poa angustifolia	5	I	
Poa compressa	26	I	
Poa nemoralis	56	W	1
Polygala vulgaris	6	G	2
Polystichum aculeatum	7	W	1
Polystichum setiferum	29	W	1
Populus nigra subsp. *betulifolia*	26	W	
Potamogeton berchtoldii	4	A	2
Potamogeton crispus x *friesii* (*P.* x *lintonii*)	5	A	
Potamogeton friesii	4	A	2
Potamogeton lucens	14	A	2
Potamogeton obtusifolius	3	A	2
Potamogeton perfoliatus	46	A	2
Potamogeton polygonifolius	4	MA	2
Potamogeton pusillus	7	A	2
Potentilla anglica	6	G	2
Potentilla erecta	87	GH	
Potentilla sterilis	51	G	
Potentilla x *mixta* s.l. (*P. anglica* or *P. erecta* x *reptans*)	24	GI	
Poterium sanguisorba subsp. *sanguisorba*	36	GI	2
Pulicaria dysenterica	37	M	1
Quercus petraea	84	W	
Ranunculus aquatilis + *R. peltatus*	40	MA	2
Ranunculus auricomus	9	W	1
Ranunculus circinatus	9	MA	2
Ranunculus flammula	45	M	
Ranunculus hederaceus	9	M	2
Ranunculus omiophyllus	2	M	2
Reseda lutea	110	I	
Rhamnus cathartica	5	W	1
Rhinanthus minor agg.	62	G	1
Sagina nodosa	3	M	2
Sagittaria sagittifolia	72	A	2
Salix aurita	10	H	2
Salix aurita x *caprea* (*S.* x *capreola*)**	1	H	
Salix aurita x *cinerea* (*S.* x *multinervis*)**	7	H	
Sambucus ebulus	4	I	
Sanguisorba officinalis	91	G	2
Sanicula europaea	12	W	1
Scabiosa columbaria	4	G	2
Schedonorus giganteus	124	W	1
Scirpus sylvaticus	5	WM	2

Scutellaria minor	1	M	1
Senecio aquaticus	45	M	1
Senecio erucifolius	34	I	1
Senecio sylvaticus	7	H	2
Senecio viscosus	65	I	
Sherardia arvensis	23	GI	1
Silaum silaus	6	G	1
Silene flos-cuculi	48	GM	
Silene vulgaris	136	I	
Sorbus torminalis	7	W	
Spergularia rubra	10	GHI	2
Stachys arvensis	23	C	2
Stachys palustris	17	M	1
Stellaria alsine	44	M	
Stellaria holostea	140	W	
Stellaria pallida	5	I	
Succisa pratensis	45	GM	
Tamus communis	95	W	
Teucrium scorodonia	64	WH	
Thalictrum flavum	3	M	2
Thlaspi arvense	36	C	1
Tilia cordata	33	W	1
Torilis japonica	59	W	
Trifolium arvense	132	I	1
Trifolium medium	165	GI	
Trifolium micranthum	25	I	1
Trifolium striatum	9	I	2
Triglochin palustris	7	M	2
Ulex gallii	57	H	1
Vaccinium myrtillus	25	H	2
Vaccinium oxycoccos	3	M	2
Vaccinium vitis-idaea	8	H	1
Valeriana dioica	3	M	2
Valeriana officinalis	14	WM	
Veronica beccabunga	158	M	
Veronica catenata	7	A	1
Veronica montana	47	W	1
Veronica officinalis	14	GH	1
Veronica polita	15	C	1
Veronica scutellata	5	MA	2
Vicia tetrasperma	82	IC	
Viola palustris	4	HM	2
Viola reichenbachiana	30	W	1
*Key to habitats: W – woodland (including hedgerows); G – grassland; H – heath; M – mire; A – open water; I – post-industrial sites; C – cultivation (arable + allotments)	**Occurrences of these hybrids have been included with those of one of the parent species in figs. 7-10 to limit their over-emphasis in the analysis		

Axiophyte taxa identified for Birmingham and the Black Country in Trueman et al. (2013), listing number of monad and range of habitats in which each is present and identifying those listed as axiophytes for two of the three UK vice-counties of which Birmingham and the Black Country forms a part (Names from Stace, 2010).

Fig. 7, showing the distribution of axiophytes in Birmingham and the Black Country, bears a clear relationship with the network of Wildlife Sites shown in Figs. 3 and 4. The correlation coefficient comparing areas ($\log_{10}$ + 1 transformed) of protected sites with number of axiophytes is 0.684, higher than that for either total records or native species.

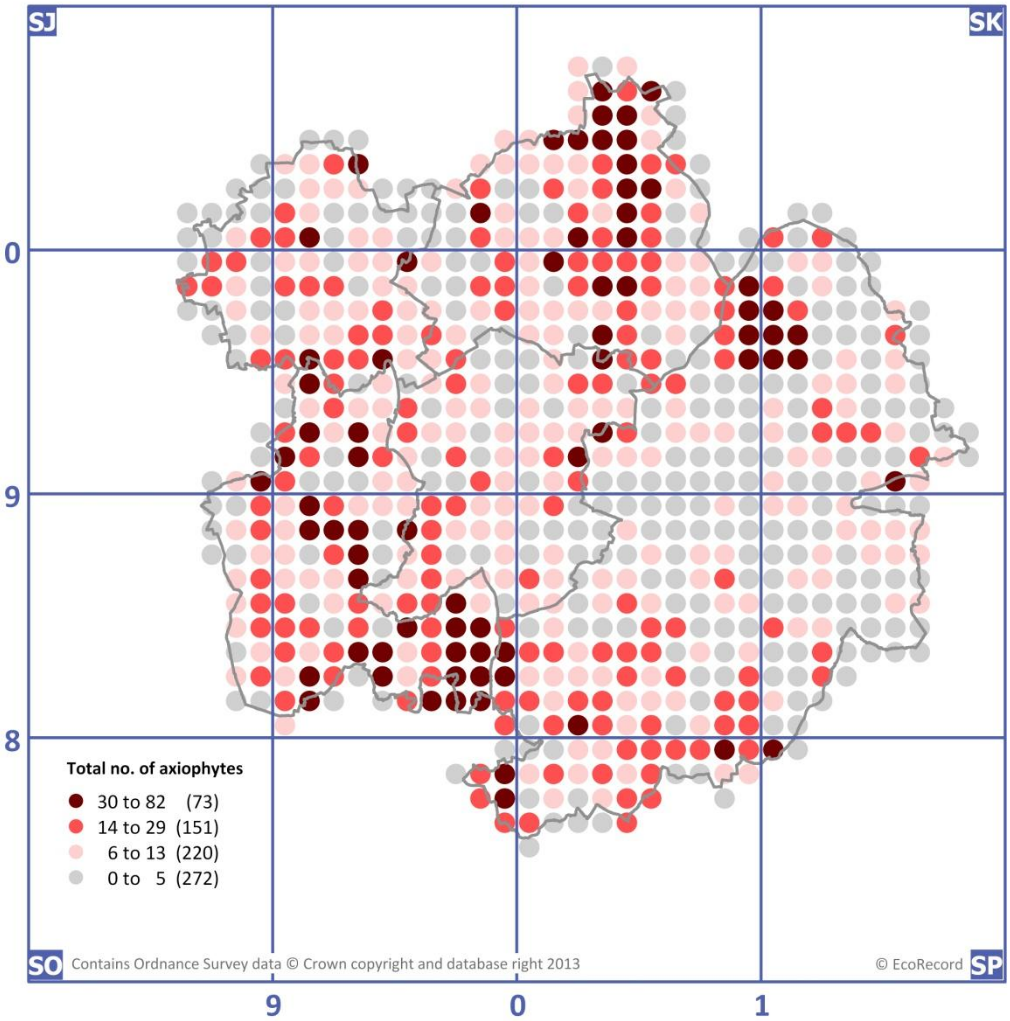

Fig. 7. Coincidence map showing the distribution of axiophytes in each monad of Birmingham and the Black Country (after: original EcoRecord data, from the Birmingham and Black Country Flora project; figure after: Trueman et al., 2013, modified)

Woodland axiophytes are particularly associated with the field layers of old woodlands because of their well-documented inability to invade new plantations and their association with woodlands marked on very old maps (PETERKEN, 1974). Due to the lack of sufficiently detailed ancient maps delimiting grasslands, mires and even heathlands it is less easy to prove that associated axiophytes characterise ancient habitats. Such taxa nevertheless seem largely to characterise old, long-established sites. This is much less true of open water, post-industrial and arable taxa which can all be found in habitats with a fairly recent history. The rivers of the conurbation are relatively minor since the conurbation lies on a watershed; also they have a long history of pollution by industry and residential effluent and as a result they tend to support relatively few species of nature conservation interest at present. In Birmingham and the Black Country the typical open water habitat is the canal and canals are not ancient habitats. Canals began to be built in the late 18th century and the system was complete by the mid-19th century when they began to be replaced by railways. Post-industrial sites are also characteristic of the 19th century and more recent times. The allotment gardens of the conurbation are similarly relatively recent.

If the axiophytes associated with these relatively recent habitats are omitted, the correlation coefficient between numbers of the axiophytes of woodland, grassland, mire and heath habitats and areas ($\log_{10}$ + 1 transformed) of designated sites is slightly lower than for total axiophytes at 0.661. Fig. 8 is a coincidence map showing these axiophytes only, and consolidates core nature conservation areas even more sharply.

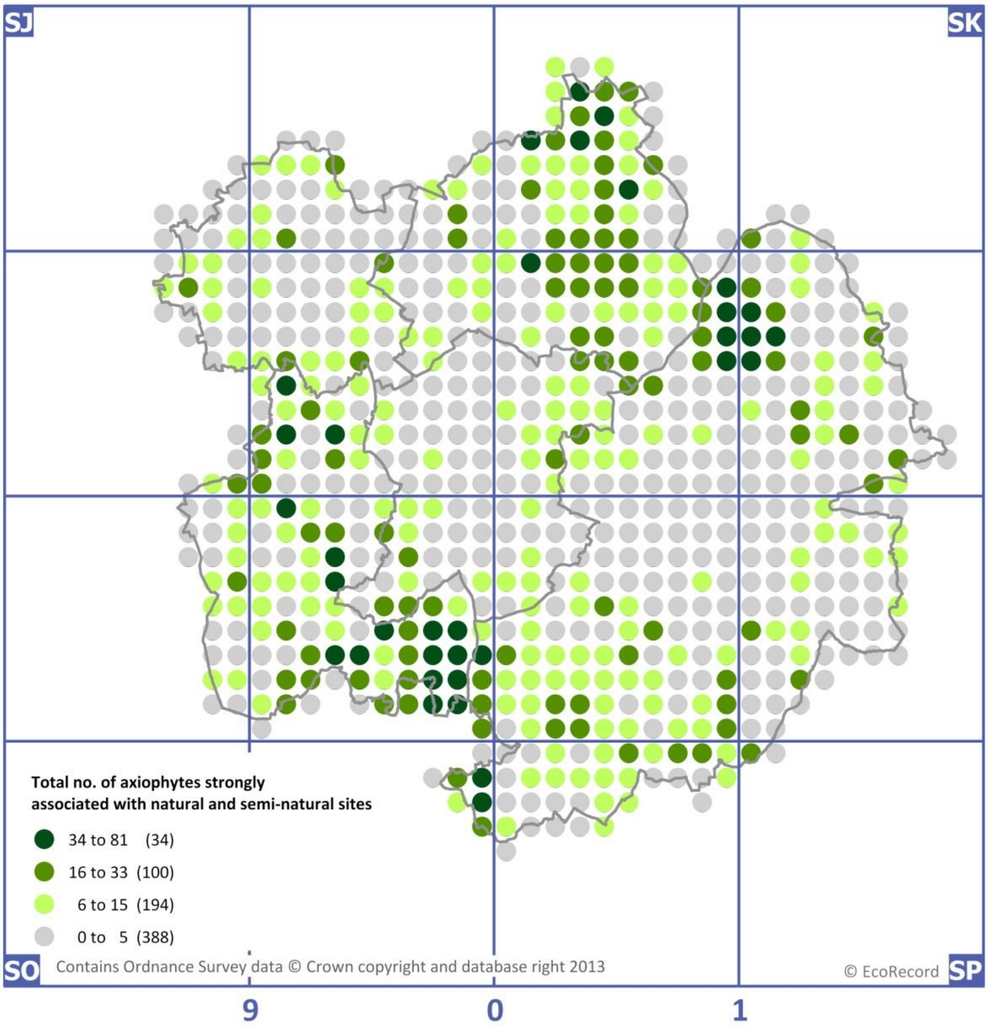

Fig. 8. Coincidence map showing the distribution of axiophytes associated with woodland, grassland, mire and heathland habitats in each monad of Birmingham and the Black Country (after: original EcoRecord data from the Birmingham and Black Country Flora project; figure after: Trueman et al., 2013, modified)

Fig. 8 suggests that botanically-rich examples of these habitats are largely absent in a band passing south-east from Wolverhampton across Sandwell and Birmingham except in a few monads associated with the Sandwell Valley (SP0291 and SP0392). The comparison between Fig. 7 and Fig. 8 shows the importance of the canals, post-industrial sites and allotments in enhancing the connectivity of the ecological network, particularly in the Black Country. Birmingham is also well provided with canals but, possibly because of more intensive use and more enthusiastic canal-side building development, the Birmingham canals do not currently appear to form important botanical links.

5. Discussion

Disparity between different habitats in numbers of suitable axiophyte species clearly undervalues dry heathland which is characteristically dominated by a small number of vascular plants and may over-emphasise many species-rich wetland habitats. Some habitats such as post-industrial sites are not well understood and lists of axiophytes, especially for those, are by necessity still tentative. The maps are probably quite dependent on a high standard of thoroughness and evenness in recording which cannot be guaranteed. The results obtained by mapping axiophytes show nevertheless considerable agreement with maps showing the sites designated for their nature conservation value. This fact is not surprising, since the axiophytes have been chosen as characterising sites of nature conservation interest. The results do however suggest that even in the absence of a detailed, established system of designated sites, the axiophyte concept might allow the delimitation and possibly the protection of an ecological network in a conurbation or other defined area.

Fig. 7 and 8 also show that, botanically at least, monads with particularly high scores tend to form an inner core within areas rich in designated sites. It clearly suggests that much of Sutton Park in north Birmingham forms an especially high scoring 'core area'. A second core area extends rather narrowly through the central and northern area of Walsall. A third core area exists in south east Dudley (Halesowen) and into Birmingham. There is also a well-marked but narrow network of high-scoring monads extending northwards through Dudley into south Wolverhampton. The Sandwell Valley in east Sandwell, a site with a very varied land-management history, is however only locally rich in axiophytes. The core areas are shown in Fig. 9.

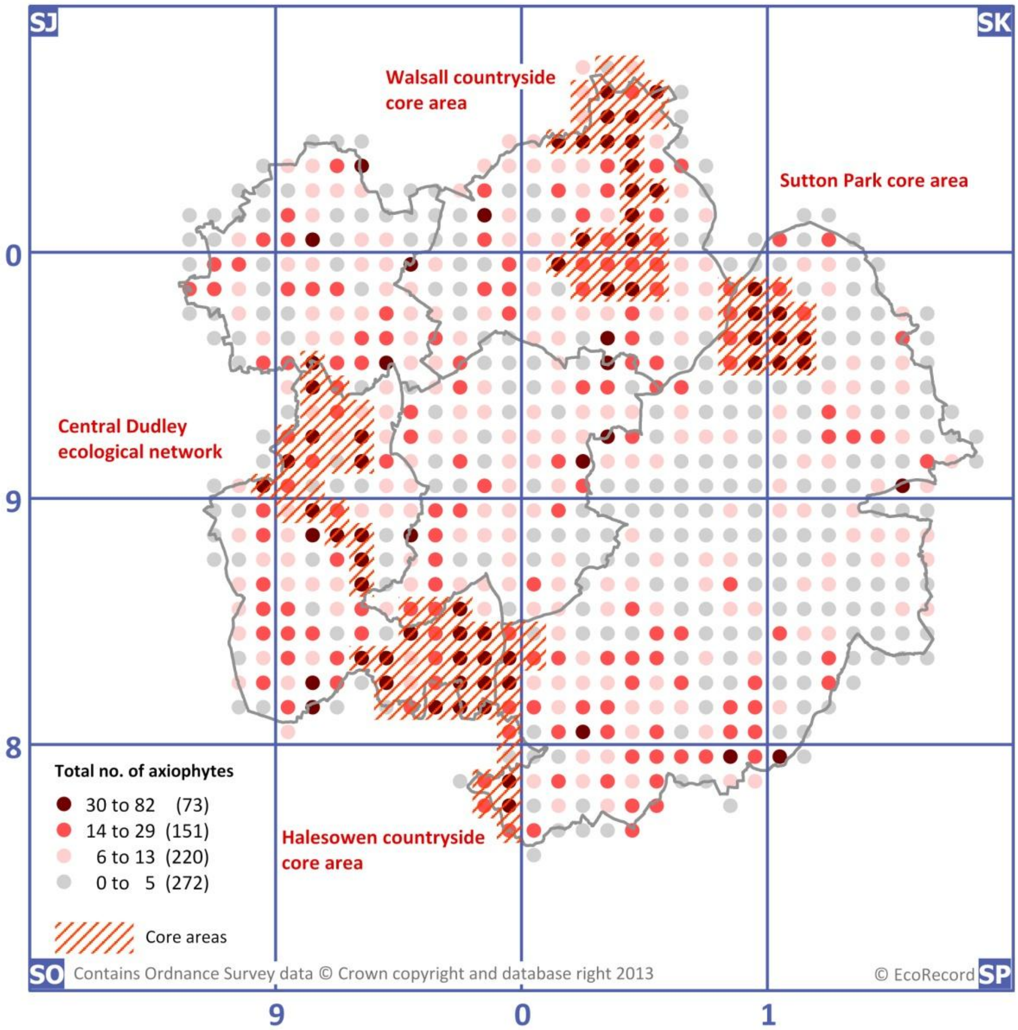

Fig. 9. Coincidence map showing the distribution of axiophytes in each monad of Birmingham and the Black Country with core areas identified (after: original EcoRecord data)

The enhancement of the ecological network in Birmingham and the Black Country is currently being made possible by its being awarded the status of a Nature Improvement Area. This is a government-sponsored designation which was funded in 2011 for twelve, otherwise mostly rural, areas of England. Nature improvement is being implemented by a series of projects aimed at consolidating, enhancing and connecting the existing ecological network using the principles laid down in LAWTON ET AL. (2010), focusing on core and linking areas. Fig. 10 shows how the axiophyte map can be used in helping to plan the enhancement of the ecological network.

Possibly the most significant recommendation is the enhancement of an ecological corridor across the middle of the conurbation, and labelled in Fig. 10 as the 'Sandwell Valley link'. By consolidating the existing interest of the Sandwell Valley and by undertaking habitat enhancement and habitat creation in areas currently without designated sites along the link it should be possible to create a corridor between the two richer zones of the conurbation and to interrupt the relatively poor zone between Birmingham and Wolverhampton. The plan seeks also to consolidate and extend existing interest in South Birmingham and to link the existing Halesowen core area with the central Dudley network and the Walsall core area with Sutton Park. The canal system and existing post-industrial, amenity and arable sites will be used to improve this poorer area both in Birmingham and the Black Country. Consideration will also be given to involving residents in key relevant areas in wildlife gardening. These plans are being developed in a very densely populated urban area and will have to be correlated with plans for industrial and residential development as well as being extended to take account of other groups of organisms but nevertheless provide a useful blueprint for urban nature protection.

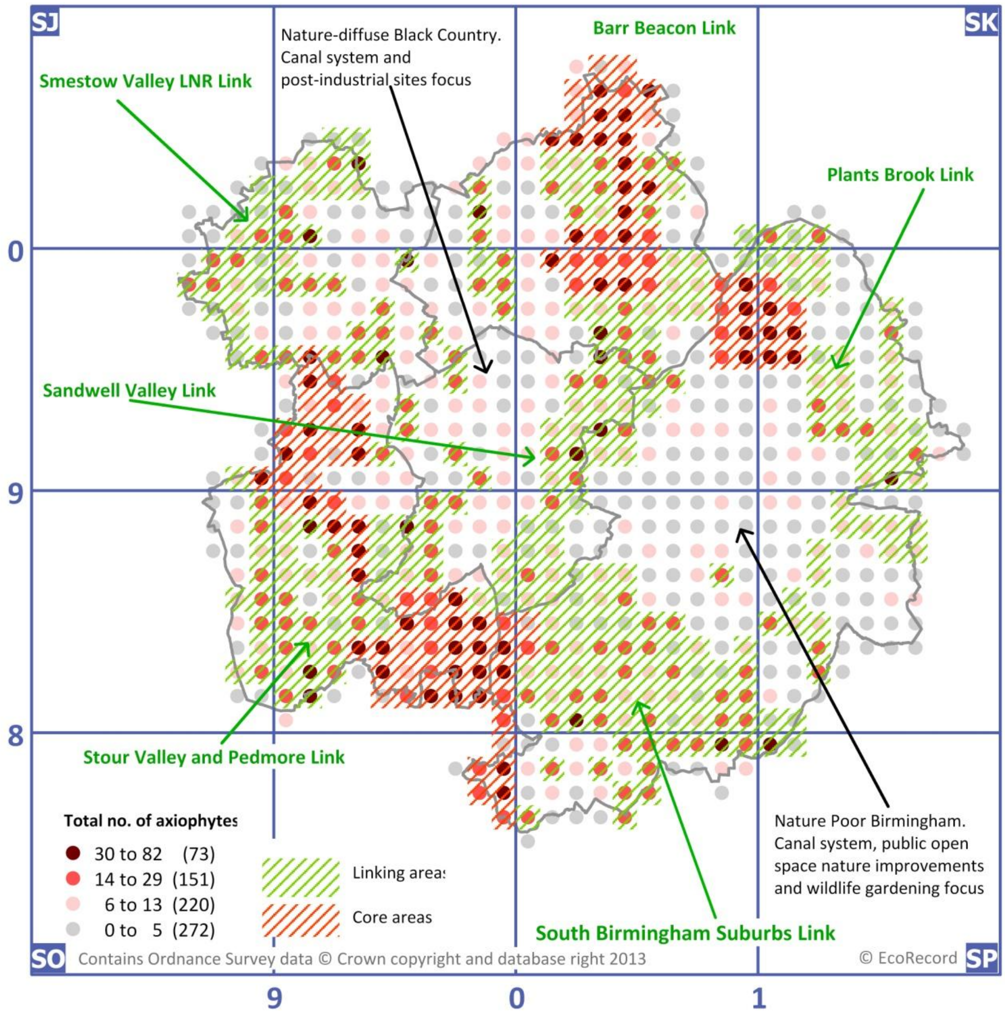

Fig. 10. Possible strategies for the enhancement of the ecological network in Birmingham and the Black Country on a coincidence map showing the distribution of axiophytes in each monad (After: original EcoRecord data)

6. Conclusions

The present investigation in the West Midlands of England confirms the findings of MILLARD (2008) working in north east England that there are close relationships at the landscape scale between nature conservation designation and vascular plant species diversity and suggests that mapping at the monad level increases clarity compared with tetrad maps. It further shows that mapping axiophytes is a particularly useful method for mapping nature conservation value compared with total species numbers or native species numbers. It also suggests that axiophyte coincidence maps offer a productive method for describing, evaluating and enhancing the ecological network.

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