CHANGES IN THE FERN FLORA OF THE CITY OF BATH

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INTRODUCTION

Recent discoveries of numerous exotic fern species on walls and in the basements of Bath (Crouch and Rumsey 2007; Crouch 2008) have led us to examine to what extent the presence of this alien fern flora is a recent phenomenon and how unique, from a British perspective, these occurrences might be. We have also considered how we might account for the changes in survival and distribution of both native and alien ferns in this man-made urban environment. In the light of increasing concerns regarding the effects of non-native, potentially invasive species, and also growing interest in mobile taxa which may help to demonstrate responses to climate change, a consideration of these species, their ecology, dynamics and spread is, we feel, timely.

In this paper we aim to provide a comprehensive account of the fern flora of Bath recorded over the last 400 years, show how the species composition and the abundance of those species has changed in the area over that time and consider what this might lead us to infer about the factors responsible. We examine whether exotic species are truly new arrivals or have been previously overlooked, attempting to disentangle the effects of possible changes in recording interest over time and the role that the availability of Floras and guides to species identification may have had historically on the quality of records and recording.

THE CITY OF BATH

The beautiful city of Bath in Somerset (now within the modern administrative county of Bath & North East Somerset) nestles on slopes of the valley of the River Avon, within the Cotswold Area of Outstanding Natural Beauty, surrounded on all sides by limestone hills. Utilising the natural hot spring, the Romans developed Bath as a spa town, Aquae Sulis, building a large complex of luxurious baths and a temple, around which a settlement developed. During the 16th and 17th centuries, the curative properties of the waters at Bath became widely recognised once more and many people flocked to Bath. In the 18th century, the city was largely rebuilt to accommodate the large numbers of visitors who came to take the waters. This Georgian legacy of beautifully proportioned houses gave Bath the status of a World Heritage Site in 1987. The tall, elegant honey-coloured buildings are all built from Bath Stone: an oolitic limestone, quarried locally. Many of the houses have basement floors and are fronted by a paved basement area, far below street level, surrounded by railings (Fig. 1).

In 1727, Bath became an inland port, with the opening of the Avon Navigation from Bristol. Wharves and associated industries developed, expanding further with the construction of the Kennet and Avon Canal which opened in 1810, allowing inland transportation of goods between Bristol and London. The heyday of canals was short-lived, declining dramatically with the coming of the railways. Brunel's Great Western Railway arrived in Bath in 1840 and accelerated the development of industry in the south and west of the city. Both canal and railway provided potential transport routes for plants, in addition to suitable habitats for several fern species.

Fig. 1 A Georgian street: Norfolk Crescent, Bath

There are a number of parks within the city, the largest being Royal Victoria Park, which includes the botanic gardens. Within walking distance of the centre are several small woods, steep hills with rocky outcrops and disused quarries. All of these add to the variety of habitats for ferns around Bath.

THE EARLY FERN FLORA OF BATH

The earliest fern record for Bath was perhaps made by Gerard (1597), who wrote: 'Lunaria or small Moonewort groweth … about Bathe in Somersetshire in manie places'. In 1834, Charles Babington's *Flora Bathoniensis* was published, to provide 'A catalogue of the plants indigenous to the vicinity of Bath'. It is worth noting that this was perhaps one of the first really local Floras and unusual in that its focus was on an area even then predominantly urbanised. Babington largely restricted his geographical scope to within four miles of the city, but included a few more distant sites of particular interest. He listed 13 species of fern to be found in and immediately around Bath, all of them native to this area and, valuably, gave an indication of the distribution and abundance of each species.

Seven species were considered so frequent or common that no location details were given:

Polypodium vulgare (Common Polypody) – at that time only the aggregate species was recognised
Asplenium ruta-muraria (Wall-rue)
Asplenium trichomanes (Maidenhair Spleenwort)
Scolopendrium vulgare = Asplenium scolopendrium (Hart's-tongue)
Grammitis ceterach = Asplenium ceterach (Rustyback)
Pteris aquilina = Pteridium aquilinum (Bracken)
Aspidium filix-mas = Dryopteris filix-mas (Common Male-fern)

The other six species all had limited distributions, which Babington gave in some detail (see Appendix):

Botrychium lunaria (Moonwort)
Ophioglossum vulgatum (Common Adder's-tongue)
Polypodium dryopteris = Gymnocarpium dryopteris (Oak-fern)
Asplenium adiantum-nigrum (Black Spleenwort) (Fig. 2)
Aspidium dilatatum = Dryopteris dilatata (Broad Buckler-fern)
Cistopteris fragilis = Cystopteris fragilis (Brittle Bladder-fern)

In a second edition, Babington (1839) noted that *Polypodium dryopteris* was 'Not now to be found, and perhaps a mistake for the next [*P. calcareum*], which had been introduced with the stone'. He thus added to his list for the neighbourhood of Bath, in place of Oak-fern:

Polypodium calcareum = Gymnocarpium robertianum (Limestone Fern)
and three other native species:
Asplenium filix-foemina = Athyrium filix-femina (Lady-fern)
Aspidium aculeatum = Polystichum aculeatum (Hard Shield-fern)
Aspidium angulare = Polystichum setiferum (Soft Shield-fern)
(He also included *Aspidium lobatum*, but this is now considered to be conspecific with *Polystichum aculeatum*).

Jenyns (1867) added another British native, *Aspidium rigidum = Dryopteris mindshelkensis* (Rigid Buckler-fern), which had been found in a quarry on Hampton Down in 1853, growing very sparingly (Vize 1853). It caused great excitement at the time, but by 1867 it had gone (see Appendix).

In *The Flora of Bristol*, White (1912) added no more native species of fern, but notably recorded the first exotic species: *Adiantum capillus-veneris* (Maidenhair Fern), discovered in the air-shaft of a Bath stone quarry by E.J. Lowe in 1853 (see Appendix). Although Maidenhair Fern (Fig. 3) grows as a British native on wet calcareous cliffs in some western coastal sites, when found inland in urban areas it has almost certainly arisen from the spores of cultivated plants, which have been shown not to be of native origin (Pryor *et al.* 2001).

Fig. 2 Black Spleenwort (Asplenium adiantum-nigrum)*, a native species recorded by Babington and found today in urban Bath*

Fig. 3 Maidenhair Fern (Adiantum capillus-veneris) *at Batheaston church*

By the end of the 19th century then, 18 British native species of fern had been found in Bath. One species (Rigid Buckler-fern) was considered by some (eg White 1912) to have been planted, but there was no evidence that this was the case; another (Maidenhair Fern) was growing in Bath as an alien. During the last 150 years, the only further native fern species to have been recorded in Bath are *Polypodium interjectum* (Western Polypody), added to the flora as a result of the segregation at specific rank of the cytotypes previously aggregated under *P. vulgare*, and *Dryopteris affinis* (Scaly Male-fern), once considered to be merely a variety of *Dryopteris filix-mas*, but now accorded specific rank.

THE ARRIVAL OF EXOTIC SPECIES

After Maidenhair Fern was first found in Bath, there were no further records of alien fern species until 1930, when this species was found again, at Batheaston churchyard, by C.D. Heginbotham and E.H. Stevenson. It still persists at that site, growing on a retaining wall at the west end of the church, and has since been recorded at about ten other sites, including the Roman Baths, walls in Lyncombe Vale Road and in Widcombe, on the west-facing wall of a railway cutting near Sydney Wharf, and in basements in Nelson Place West, Beaufort Square, St James' Parade and, most abundantly, Monmouth Street.

In 1939, *Azolla filiculoides* (Water-fern) was observed by J.P.M. Brenan in the Kennet and Avon Canal, between Bathampton and the Dundas Aqueduct. This interesting floating fern, native to western North America, was first recorded in the wild in Britain in 1883 and is now widely distributed (Preston *et al.* 2002). Its ability to double its biomass in a few days allows it to spread rapidly to cover a water-body, becoming an environmental pest. Until the 1970s it was noted to be increasing in the Kennet and Avon Canal, but it has not been seen since the restoration of the canal, partly because the section in which it thrived was no longer still, but also because nutrient-enriched river water was then regularly pumped into the canal at Claverton (R.D. Randall, pers. comm.). This pattern of expansion then rapid loss is mirrored over much of the British Isles, few sites showing any extended continuity.

A third alien species of fern was recorded in Bath in 1978, when R.M. Payne found a single plant of *Pteris cretica* (Ribbon Fern) growing on the stonework of a deserted basement in New King Street. By 1979, it was gone, however in that year several plants were found on an old basement wall in Beaufort Square: it did not persist here either (Green *et al.* 2000). Ribbon Fern has recently been found in basements at three further locations: Laura Place in 2007, St James' Parade in 2008 and Catharine Place in 2009 (Fig. 4). A cultivar of this species, *Pteris cretica* 'Wimsettii', identified by the pronounced irregular lobing of the pinnae and the repeatedly bifurcating apices, was found by R.D. Randall in 2006 on a basement wall in Sydney Buildings; however the plant has now gone. This cultivar has only ever been reported as naturalised in one other site in Britain, on a house wall in Clifton, Bristol (VC 34), from which it is also apparently now lost.

Fig. 4 Ribbon Fern (Pteris cretica) *at Catharine Place, Bath*

Fig. 5 Spider Brake (Pteris multifida) *in Pierrepont Street, Bath*

In 1982, D.E. Green discovered two clumps of *Osmunda regalis* (Royal Fern) growing against the church wall at St Catherine, to the north-east of Bath, but they were short-lived (Green *et al.* 2000). Like Maidenhair Fern, this species is a British native, but was probably growing here as an escape from cultivation.

In the last five years, six further exotic fern species have been identified growing naturalised in basements in Bath. *Pteris* plants had been known under a grille on Lansdown Road since 2002, and on the stonework of a basement in Pierrepont Street for ten years longer (Randall 2003). It was only in 2006 that these were both identified by F.J.R. as *P. multifida* (Spider Brake), a native of Japan and China (Fig. 5), grown in this country as a houseplant and first recorded in a naturalised situation in Devon in 1935 (Crouch and Rumsey 2007). The related species, *Pteris nipponica* (Variegated Ribbon-fern), was found by the authors in 2008, in a deep basement area on St James' Parade. A *Pteris* plant found in a disused basement in Rivers Street by C. and M.A.R. Kitchen in 2009 has been tentatively identified as *Pteris umbrosa* (Jungle Brake), a native of Australia (Fig. 6). This is the first record of this species becoming naturalised in Britain. In the same derelict basement, the authors found a single plant of *Polystichum tsus-simense* (Korean Rock-fern), new for Somerset (Fig. 7). In 2008, *Adiantum raddianum* (Delta Maidenhair) was discovered in a basement near the Royal Crescent by M.A. Spencer, the identity confirmed by F.J.R. This South American fern, widely grown as a houseplant, was first reported as an escapee on a wall in London in 1997 (Rumsey 1998), but has not been recorded elsewhere outside London, although it may be overlooked. A native of

Fig. 6 Jungle Brake (Pteris umbrosa) *in Rivers Street, Bath*

Fig. 7 Korean Rock-fern (Polystichium tsus-simense) *in Rivers Street, Bath*

Japan and South-east Asia, *Cyrtomium fortunei* (Fortune's Holly-fern) is widely grown in gardens and increasingly found naturalised. A small plant of this species was seen growing from the stonework of a Bath basement in 2009.

THE CULTIVATED FERNS OF BATH

For an understanding of the processes of colonisation and naturalisation of exotic taxa, it is important to consider the past and present garden flora of Bath, because of the role that cultivated plants may play as the source of propagules. We have little if any data relating to ferns grown in gardens in the past, although a study of Victorian fern catalogues suggests that a far wider array of species and cultivars were available for cultivation during the 19th century than is the case now. Ferns are particularly suited to cultivation in the small, humid, shaded gardens and basement areas so typical of the city. Of the species commercially available recently, only a few are rupestral (inhabiting rock crevices), eg *Asplenium scolopendrium* (usually sold as morphologically distinct monstrous cultivars) and *A. trichomanes* subsp. *quadrivalens*, although other taxa such as *Cyrtomium* species do exploit this habitat. Establishing adult plants in walls, however, is not easy, and we can assume that plants in such situations are invariably self-sown. A wider range of the larger terrestrial fern species, including such dramatic plants as the tree-fern *Dicksonia antarctica*, are currently cultivated in pots and shallow flowerbeds in basement areas visible from the street, the most frequently observed being *Dryopteris filix-mas*. Other *Dryopteris* species noted over the last five years include the native *D. affinis* and the exotic *D. erythrosora*. The related genus *Polystichum* is widely represented by the native *P. setiferum*, particularly forms in the horticultural Divisilobum Group, with finely divided fronds, which mostly breed true from spores, and the glossy exotic *P. polyblepharum*. Plants from the exotic Asian genus *Cyrtomium* are also widely cultivated: both *C. falcatum* and the hardier, now more commonly available *C. fortunei* have been noted as planted. All of these taxa have been found naturalised on walls in urban situations elsewhere in the British Isles but interestingly, apart from the ubiquitous *D. filix-mas*, only *C. fortunei* has been found (very recently and ephemerally) in Bath. We have seen no examples of *Pteris* species cultivated out of doors; however these plants are generally grown as indoor or greenhouse subjects and may be lurking in bathrooms and kitchens only an open window away.

IS THE APPARENT PAST ABSENCE OF ALIEN FERNS A REAL ONE?

Before we can explore the reasons for the sudden appearance of a number of exotic ferns on the walls of Bath, we must consider whether their apparent past absence was a real one, or simply the result of poor recording of aliens. Although some field botanists have certainly tended to disregard aliens of transient occurrence, in the Bristol region there has clearly been considerable interest in adventive species for more than a century. White (1912), unusually amongst authors of early Floras, regarded it judicious to include all 'outlanders' since 'when accompanied by explanatory suggestions respecting their origin, the record is rendered a fact of real value to the botanical geographer.' His *Flora of Bristol* (which in fact covered much of North Somerset, including Bath) detailed 981 natives, 60 denizens, 79 colonists and 282 aliens and casuals, but only one non-native fern: *Adiantum capillus-veneris*. It seems inconceivable that he would have failed to record exotic ferns if they were truly present at that time. White's enthusiasm for aliens in Bristol was shared by other local botanists and in 1933 Mrs C.I. Sandwith, the first Botanical Society of the British Isles (BSBI) Recorder for North Somerset (VC6), published *The Adventive Flora of the Port of Bristol*, which included records for 717 non-native species, but not a single alien fern. The local interest in alien species continued throughout the 20th century, Bristol being the home of the great 'Tip Botanist' A.L. Grenfell, who edited the Alien News section of *BSBI News* for several years. Ian Green, the BSBI Recorder for VC6 in the 1990s, was also a keen recorder of aliens. It thus seems highly unlikely that exotic ferns would have gone unnoticed in this area, where aliens have perhaps received rather more attention than in other parts of the country.

Careful consideration of national recording of alien ferns shows that a disproportionate percentage of the records have been made by very few observers. Whether this reflects a lack of general awareness because of inadequate coverage in the standard guides and Floras (see below), or a more general lack of interest in the urban built environment, is debateable. Both are probably true. It does, however, indicate the probability of a distinct bias, which could

lead to plants being overlooked in those areas where these recorders have not been active. It is pertinent to note that several active recorders of alien ferns have contributed records for the Bath area since 1978.

Until the last five years, only two exotic species of fern were recorded from within the urban area of Bath (*Adiantum capillus-veneris* and *Pteris cretica*), although, in addition, plants now known to be *Adiantum raddianum* were first recorded in 1997 (as *A. capillus-veneris*), while plants of *Pteris multifida* were first recorded nearly 20 years ago (as *Pteris cretica*). These misidentifications were not made because the species are inseparable, but because of their poor coverage in standard identification guides. Not one of the six recently recorded species is included in Stace (1997) – the most up-to-date Flora of the British Isles until this year – or in the popular *Fern Guide* by Merryweather (2007), which does include *Pteris cretica* but illustrates it with a drawing of *Pteris multifida*! Also, the most comprehensive published listing of alien plants in the British Isles (Clement and Foster 1994) does not include most of the fern taxa now being found in urban areas and furthermore is of limited use to field botanists as it provides no descriptions, keys, or illustrations. It does list four species of *Pteris*, but the records of one, *P. incompleta*, from a basement in Bristol, should have been given as *P. multifida*, the mistake a result of a nomenclatural confusion caused by homonymic synonyms (Crouch and Rumsey 2007; Rumsey and Crouch 2008). Disappointingly, Clement *et al*. (2005) include illustrations of only five alien ferns and only one *Pteris* species (*P. cretica*).

HOW UNIQUE IS THE CURRENT ASSEMBLAGE OF FERNS?

Leaving aside the brief 19th-century occurrence of *Dryopteris mindshelkensis* (until recently known as *D. submontana*) in a quarry on the city outskirts, the native fern flora has been diverse but unremarkable. As elsewhere in urban areas, it has been affected by the vagaries of past collection, near catastrophic loss through pollution and subsequent ongoing re-population from natural and horticultural sources. What is most remarkable is the diverse assemblage of non-native fern taxa now to be found in the city. Towns such as Cambridge and Oxford, which show similar architectural features and substrates, lack the breadth or abundance of non-native fern taxa seen in Bath. This is particularly true of the genus *Pteris*. Only in the much larger, more populous and culturally/ethnically diverse capital do we see greater alien fern diversity, with 15 species listed by Edgington (2008) for Inner London. The proportion of the recorded alien flora which is pteridophytic is, however, much greater in Bath. It is tempting to speculate as to why Bath has such a wealth of exotic ferns.

THE FERN FLORA OF URBAN WALLS

The ferns of walls and built structures can be conveniently considered in two broad categories: those taxa which naturally occur on impervious substrates, rocks (cliffs, screes, tufa) or as epiphytes on tree-trunks, and those which are primarily terrestrial in occurrence. The rupestral (rock-dwelling) element of the fern flora of Bath is typical of much of lowland England; those species absent are the more montane taxa (very rare generally) and/or those taxa exclusively associated with acidic substrates, for example *Asplenium trichomanes* subsp. *trichomanes*, *A. obovatum* subsp. *lanceolatum* and *A. septentrionale*, for which the use of local limestone and calcareous mortars greatly restricts habitat availability. What is perhaps most surprising is the current relative rarity (or absence) in Bath of three calcicolous taxa widely encountered on built structures elsewhere in lowland England and naturally occurring quite close to Bath: *Gymnocarpium robertianum*, *Cystopteris fragilis* and *Polypodium cambricum*. Away from its natural occurrences on limestone cliffs, *Polypodium cambricum* (currently not known in Bath) is largely found on old ecclesiastical buildings (eg in Hampshire and Sussex). Age, or more correctly the long duration of availability of a suitable substrate, is perhaps a critical factor, possibly indicating a poor colonising potential for this species. The smaller rupestral species are better suited to more nutrient-limited and xerophytic situations, but they produce far fewer propagules than the common woodland taxa. Terrestrial species are usually ultimately larger plants; their presence on walls tends to be more ephemeral and less predictable, the result of chance colonisations, the plants stunted and often failing to achieve fertile maturity. Male-fern (*Dryopteris filix-mas*), one of the two commonest terrestrial species on walls in Bath (as elsewhere, see eg Payne 2005; Edgington 2008), is the most generally abundant woodland species in lowland England. Individual

Male-fern plants produce many millions of spores annually; these would therefore be expected to be the greatest component in the 'spore rain' falling on built structures.

Another near ubiquitous terrestrial fern species, which offers an insight into the factors controlling reproduction and recruitment, is Bracken (*Pteridium aquilinum*). Rare on Bath's walls, White (1912) noted seeing it on a wall near the Tower of London and indeed it is now commonly found on walls in London. In this habitat though, Bracken is usually present as juvenile plants, with an unfamiliar morphology, which has often caused identification difficulties; indeed juvenile plants are almost uniquely to be found in such situations. In 'natural' habitats growth of Bracken is clonal, with extensive vegetative propagation and extremely low levels of recruitment from spores. The relatives of Bracken are all tropical and like them our species is surprisingly frost sensitive. Rhizomes survive underground, but spores in the upper soil fractions do not (Dyer and Lindsay 1992). The gametophyte generation also differs from the sporophyte in showing optimal growth at higher pHs (Conway 1949). Damp mortared walls in urban areas, where heat islands maintain temperatures consistently above freezing, provide, perhaps almost uniquely, the conducive environment for *Pteridium* spore germination, fertilisation and subsequent growth. Larger terrestrial species such as this possess more extensive root systems to gather the required water and exploit necessary soil nutrients; most walls and built structures allow only restricted root-runs, have poor nutrient availability and a limited and unreliable water supply. It is therefore not surprising that terrestrial species are stunted when present and show high rates of sudden mortality.

For the area as a whole, the native species list has remained essentially stable (see Table 1), although abundance and distributions, particularly within the strictly urban area, have changed markedly. Although pollution can be clearly identified as a major cause of the decline of the native urban ferns (and, as importantly, as a cause of suppression of their recolonisation), collecting was also responsible for the demise of some species. White (1912) gave a clear account of the disappearance in Bristol of Hart's-tongue, now one of the most regularly encountered species in Bath and other urban areas (Edgington 2008; Payne 2005; Middleton 2005). He pointed out that ferns are among plants most easily affected by smoke and building, but blamed collecting as the main cause for the disappearance of Hart's-tongue in Bristol; this is likely to have been the case in Bath as well. White's condemnation of gardeners for their activities in this despoliation may show his stronger interest in semi-natural or natural habitats over the built environment, but perhaps also reflected the comparative absence of plants on these structures at the time. It is ironic that we now find that much of the pteridophytic interest in and around urban areas is the consequence of natural repatriation of sites from garden sources.

FACTORS LIMITING ESTABLISHMENT OF FERNS

The nature of ferns means that it may be difficult to identify which factors limit the establishment of a species: structures are small and difficult to observe and the critical phases of the life cycle are poorly known. The dispersive units – microscopic airborne propagules (spores) which can demonstrate dormancy – may enable colonisation to be distant from the parent source, both spatially and temporally. Some of the non-native taxa found recently are not widely cultivated or generally available; indeed, those species available now (eg *Pteris cretica*) are mostly sold as genetically distinct monstrous forms, quite unlike the plants usually encountered as naturalised, and therefore unlikely to be their progenitors. Little is known about the dormancy capability of most rupestral fern species, but the recurrence of particular taxa at localities where they were thought lost following building work and repairs, for example *Pteris multifida* in Pierrepoint Street, suggests that a viable spore-bank is retained in the interstices of walls. This may help to explain how effective meta-populations of taxa may develop and persist, even when not now apparently in cultivation locally.

Edgington (2008) suggested four requirements for successful colonisation by ferns: a supply of fertile parents, an efficient dispersal mechanism, a suitable breeding system and a receptive habitat. In addition, he indicated that climate limits establishment of ferns (see also Middleton 2005). In an attempt to understand the current assemblage of fern species on walls in Bath, we consider each of these as a potential limiting factor.

(i) Supply of fertile parents

If the exotic species recently recorded in Bath had not been introduced into cultivation there would have

TABLE 1: FERN SPECIES RECORDED IN BATH BY DIFFERENT AUTHORS

	Babington (1834)	Babington (1839)	Jenyns (1867)	White (1912)	Green *et al.* (2000)	Recorded since 2005
Botrychium lunaria	+	+	(+)	+	–	–
Ophioglossum vulgatum	+	+		(+)	+	+
Polypodium vulgare agg.	+	+		C	+	+
Gymnocarpium dryopteris	+(error)	–	–	–	–	–
Gymnocarpium robertianum		+	(+)	+	–	–
Asplenium adiantum-nigrum	+	+		NC	+	+
Asplenium ruta-muraria	+	+		C	+	+
Asplenium trichomanes	+	+		C	+	+
Asplenium scolopendrium	+	+		C	+	+
Asplenium ceterach	+	+	(+)	+	+	+
Pteridium aquilinum	+	+		C	+	+
Dryopteris dilatata	+	+		+	+	+
Dryopteris filix-mas	+	+		C	+	+
Cystopteris fragilis	+	+	(+)	+	+	+
Athyrium filix-femina		+	(+)	+	+	+
Polystichum aculeatum		+		(+)	+	+
Polystichum setiferum		+		(+)	+	+
Dryopteris mindshelkensis			+	(+)	–	–
Adiantum capillus-veneris				+	+	+
Polypodium interjectum					+	+
Dryopteris affiinis					+	+
Azolla filiculoides					+	–
Osmunda regalis					+	–
Pteris cretica					+	+
Pteris cretica 'Wimsettii'						+
Pteris multifida						+
Adiantum raddianum						+
Pteris nipponica						+
Pteris umbrosa						+
Polystichum tsus-simense						+
Cyrtomium fortunei						+

+ = recorded for Bath
(+) = merely repeated an earlier record
C = just listed as common by White (1912)
NC = 'not common around Bath' (White 1912)
– = recorded as being no longer present

been no available source of spores (failing inter-continental transfer from natural populations), and their past absence could be clearly explained by an absence of parents. However this is demonstrably not the case. When the Victorian Fern Craze swept Britain the cultivation of fern species reached its apogee. Many specialist nurseries existed to fuel the demand, some listing thousands of fern cultivars for sale. Cultivation of ferns during the Victorian period may have been primarily in glasshouses, or indoors in Wardian cases (decorative glass cases, originally invented by Nathaniel Ward for the transportation of living plants from abroad), to protect them from the damaging atmosphere created by the blossoming industrial age; one might argue that this hampered the release of spores into the atmosphere for wider

dispersal, yet similar constraints must still exist today for the recently increasing species of *Pteris*, which are not cultivated out of doors. It is unlikely therefore that spore availability was a factor limiting the colonisation of walls by exotic fern species in this period.

(ii) Dispersal

Mature ferns produce copious quantities of reproductive propagules: 10^4–10^7 spores per plant annually. Trapping experiments using sticky-slides show that of the spores recovered, more than 90% fall within a few metres of the parent plant (eg Glaves 1991). The recent recolonisation of London walls by two native species of *Asplenium* has presented an opportunity to study the dynamics of dispersal (Edgington 2007). Careful study of distribution patterns suggests that most new plants are found in close proximity to parent plants, but that long-distance dispersal also occurs, resulting in 'plumes' of colonisation, following prevailing wind directions. We know from the occurrence of arctic-alpine taxa on lowland walls, for example *Cystopteris alpina* in Essex (Rumsey 2003), *Asplenium septentrionale* in Kent (Leonard 2008), *A. viride* in central London (Rumsey 1997) and *Polystichum lonchitis* in Northamptonshire (Gent 1995), that long-distance spore dispersal and establishment is a reality, albeit extremely infrequent.

(iii) Appropriate breeding system

Many native ferns are outbreeding, requiring the development of two separate gametophytes (ie two spores must have landed) within the range of sperm motility, generally only a few centimetres apart. Conditions then need to be suitable across this space for fertilisation to occur. Thus the probability of an outbreeding species colonising beyond the limited range in which the majority of its spores fall is low. Accordingly most common British native wall ferns demonstrate an inbreeding reproductive strategy: their success as colonists is inextricably linked to their breeding system (see Vogel *et al*. 1999). These ferns can produce a sporophyte plant from a single spore through intragametophytic mating: the male and female organs mature synchronously on one gametophyte and, being only a millimetre or so apart, reproduction is more likely to occur. A different breeding system again, apomixy, is employed by some fern species, increasing the probability of recruitment still further; it is this which confers an advantage to several of the increasing non-native taxa. Species such as the *Pteris* species now found in Bath are not grown nationally in great numbers and are therefore unlikely to contribute greatly to general spore rain, and yet they are obviously good colonists. This can be explained by their breeding system: all are apomicts, capable of producing sporophyte plants from gametophytes without the sexual process. Reproduction is thus more definitely assured and moreover the dependence on available moisture is also reduced. Spores of apomicts are generally larger than their sexual counterparts, but this has not been demonstrated to hamper their dispersal. Whilst clearly a limiting factor for some species, the greater availability of apomictic taxa in the past, yet the absence of records of naturalised offspring, suggests that breeding system was not a factor limiting the early colonisation of Bath walls by exotic fern species. We therefore conclude that establishment of juvenile plants has hitherto been the most critical phase controlling the distribution and abundance of Bath's fern taxa. The features of the habitat, climate and other ecological factors which may have prevented establishment are considered below.

(iv) Availability of suitable habitat and climate

Although the Industrial Revolution began in the 18th century, the arrival of the Great Western Railway in Bath in 1840 accelerated the development of industry in the south and west of the city. Coal fires, as well as industry, meant that buildings were very heavily polluted, the honey-coloured Bath Stone becoming blackened with accumulated pollutants. This is likely to have led to the demise of native ferns within the city, many species disappearing altogether. The Clean Air Act of 1956 resulted in a decline in atmospheric sulphur dioxide in urban areas. Subsequent cleaning of buildings has revealed a substrate suitable for colonisation by ferns. The more toxic chemicals have now been leached away; stones have become more weathered and possibly, through changing atmospheric conditions, more nutrient-enriched.

Middleton (2005) suggested that in Hull recent climatic changes (warmer wetter winters) may have promoted fern growth, implying that climate was previously a limiting factor. Edgington (2008) also believes that the bitter winters of the mid-20th century may have been responsible for previous poor performance of both native and alien ferns in London. In city centres, however, the effect of climate as a factor limiting fern colonisation and survival is lessened by a 'heat island' effect. In Bath,

as in London, the limitations of climate are further reduced by the distinctive architecture: the deep sheltered basement areas provide a warmer and, critically, damper microenvironment. We think that climate may have been a lesser limiting factor to fern success in Bath than in many other towns and cities, eg Hull.

A major factor influencing the abundance and spread of urban ferns (and indeed the chance of them being recorded!) is the duration of their presence. Plants may be lost if the habitat becomes unsuitable through natural means, for example due to succession or drought, or by disturbance or damage from activities such as repointing, painting or general tidying; the distribution and abundance of a species will clearly be affected by the frequency and severity of such impacts and activities. The larger Georgian buildings with basement areas (which account for the majority of recently discovered fern sites) would formerly have been mostly owner-occupied, and with domestic staff employed, amongst other things, to help keep the external fabric of the building in good order. Today many of these buildings are in multiple occupancy, with less regular maintenance of external areas and basement flats occasionally left unoccupied. An extended phase of gentle dereliction, with poorly maintained mortar and leaking downspouts, creates ideal fern habitat (Fig. 8). These properties are often interspersed or juxtaposed with those in which pride and horticultural prowess are demonstrated, creating both spore sources and ideal receptor sites in close proximity.

We suggest that the reason there were formerly so few records of exotic species was primarily the unsuitability of the habitat due to pollution. The time lag between the Clean Air Act of 1956 and the subsequent amelioration of the atmosphere and cleaning of the city's buildings has meant that surfaces have only recently become sufficiently free from pollutants to allow successful colonisation by ferns. Changes in the occupation and maintenance of housing stock may have also played a contributory role. We cannot completely discount past poor recording but feel that this factor has, for the reasons outlined earlier, played only a minor role here in Bath; elsewhere in the British Isles the same claim may be more difficult to make.

CONCLUSIONS

The native fern flora of the environs of Bath appears

Fig. 8 Derelict basement in Bath

now to be similar to that recorded by Babington in the 1830s (see Table 1); however the species lists conceal changes over the last 175 years. Only a few native taxa, eg *Botrychium lunaria* (Moonwort), have been lost, through habitat degradation and eutrophication, a decline which mirrors national trends. It is likely that many more species suffered a dramatic decline during the 19th and early 20th centuries, partly due to collecting, but to a large extent as a result of pollution; some, eg *Asplenium ceterach* (Rustyback), disappeared completely from the urban area and are only now recolonising the walls of Bath. The losses, however, have been offset by a growing number of exotic arrivals in the built environment of central Bath. This is a comparatively recent phenomenon and one which is likely to continue. Bath is not unique in this respect: a number of alien fern species have been reported in Cambridge, Reading and to a lesser extent Oxford, but only in Greater London is there a more varied assemblage of taxa; however, the numbers of sites and the effective naturalisation (creation of self-sustaining populations) of the thermophilous exotic taxa in Bath is distinctive. The apomictic breeding system adopted by *Pteris* species confers a clear advantage for colonisation of new areas, but the main reasons for the recent success of these exotics in Bath are related to the availability of suitable habitat:

- Deep basements in front of Georgian houses provide a sheltered damp environment;
- Reduction in pollution, followed by cleaning of buildings, means that walls are now a suitable substrate for rupestral fern species;
- Building stone and mortar have reached a suitable age (and state of deterioration) for easier

colonisation by spores and establishment of young plants;

• Economic and sociological conditions result in some basements being less assiduously maintained, allowing time for establishment of ferns.

The horticultural interests of some provide a source of spores in close proximity to ideal receptor sites, although we suggest that the supply of spores is unlikely to be on the scale of, or as varied as, that which existed at the peak of the Victorian Fern Craze. Whilst climate (humidity and winter temperatures) is a factor limiting establishment of exotic ferns, we suggest that this has had a lesser impact in Bath, with its sheltered basements, than in some other cities where changes in the fern flora have been studied.

Further study may reveal the presence of similar floras in other towns and cities nearby, where similar housing stock and conditions apply, for example in Bristol and Cheltenham, where a few past records of exotics suggest potential suitability for colonisation. It is difficult to predict how this exotic flora will change over time but none of the non-native fern species found in Bath has yet proved to be invasive in Britain and we anticipate that they will have little impact on our native species.

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Appendix: A catalogue of the fern species of Bath

Adiantum capillus-veneris (Maidenhair Fern) was first found near Bath in 1853, when three plants were discovered by E.J. Lowe, growing in the airshaft of a stone quarry some 30 feet below the ground, at Combe Down (Lowe 1853). It has since been found at about ten other sites in Bath and persists at some long-known locations: at Batheaston churchyard, found in 1930 by C.D. Heginbotham and E.H. Stevenson, where it still grows on a retaining wall at the west end of the church; at the Roman Baths, first found by Mrs M.J. Oldaker in 1950 and in Lyncombe Vale Road, first recorded by Capt. R.G.B. and Mrs I.G. Roe in 1961, where it persists on old walls. In 1977, R.D. Randall recorded Maidenhair Fern naturalised on a wall in Church Lane, Widcombe, and in a damp cellar at Sydney Wharf (Randall 1978). It persists at the former site, but the cellar in Sydney Wharf is now covered. In 2008, however, the authors found about 30 clumps of this fern growing on a nearby west-facing wall of the railway cutting. It can also be seen in basements in Nelson Place West, Beaufort Square, St James' Parade and, most abundantly, Monmouth Street.

Adiantum raddianum (Delta Maidenhair) is known from a single basement in Marlborough Buildings, near the Royal Crescent. It was first recorded here by M.A. Spencer in 2008, the identity confirmed by F.J. Rumsey. The plants were noticed in 1997, but recorded as *A. capillus-veneris* (Crouch 2008).

Asplenium adiantum-nigrum (Black Spleenwort) was listed by Sole (in Collinson 1791) as growing 'in great abundance on Hampton-cliffs' and by Babington (1834) growing 'on walls near Devonshire Place and near the top of Widcombe Hill'. White (1912) wrote that it was 'not common near Bath' and that has remained the case. In 1977 this species was recorded in a damp basement in New King Street by R.D. Randall and in 1986 H.G. Ward found one plant in a cutting through oolite, by an old railway at Lyncombe Vale. There were no records for Bath in Green *et al.* (2000). In 2006, H.J.C. found several plants on a basement wall in Beaufort Square, the first recent record in the city centre. Further plants have since been found in basements in the Royal Crescent, Duke Street and South Parade (Randall 2007/2008).

Asplenium ceterach, formerly *Ceterach officinarum* (Rustyback) was recorded as being 'frequent on walls' by Babington (1834) and by White (1912). Today it is rare in

the city, occurring on a wall near the canal, just south of Sydney Road, found by the authors in 2007, and at Norfolk Buildings, discovered by R.D. Randall in 2010.

Asplenium ruta-muraria (Wall-rue). The earliest local record for this species was made by Johnson (1634) 'on the Rockes by Bathe'. Babington (1834) gave it as 'frequent on walls and rocks'. It is still common on walls within the city.

Asplenium scolopendrium, formerly *Phyllitis scolopendrium* (Hart's-tongue) was 'common on hedge banks and rocks' when Babington (1834) compiled his *Flora*. White (1912) wrote of the terrible demise of this species in Bristol, attributing the loss to 'a mischievous mechanical extirpation' for the ornamentation of gardens; it is reasonable to assume that the same situation occurred around Bath. This species is now common within the city of Bath, particularly on damp walls and in basements.

Asplenium trichomanes subsp. ***quadrivalens*** (Maidenhair Spleenwort). Babington (1834) listed the species as 'frequent on rocks and walls' and that is the case now.

Athyrium filix-femina (Lady-fern) was recorded by Babington (1839) at Claverton, and locations further afield. R.D. Randall found it plentiful in a small wood at Newton St Loe in 1986 and has found it to be frequent in Smallcombe Wood. The map in Green *et al.* (2000) shows a few other sites around Bath but it has not been found in a strictly urban situation.

Azolla filiculoides (Water-fern) was formerly known in the Kennet and Avon Canal, between Bathampton and the Dundas Aquaduct, first recorded there by J.P.M. Brenan in 1939. It was noted by A.J. Willis to be conspicuous at Claverton in 1967 and reported as increasing in 1972 by I.F. Gravestock. It has not been seen for many years, since restoration of the canal.

Botrychium lunaria (Moonwort) was recorded in the Bath area as early as 1597 by Gerard, who wrote: 'Lunaria or small Moonewort groweth … about Bathe in Somersetshire in manie places'. Babington (1834) gave a record 'In pastures near Claverton', made by Dr Heneage Gibbes; he added 'In the field between the lane leading to Claverton and the farm-house on the down', recorded by Dr. R.C. Alexander in his second edition (Babington 1839). There is a specimen in Jenyns' herbarium from Prior Park, Bath, collected in 1856 (White 1912). There have been no more recent records.

Cyrtomium fortunei (Fortune's Holly-fern) was found by the authors in 2009, in a basement in St James' Parade. It could not be seen in early 2010.

Cystopteris fragilis (Brittle Bladder-fern) was recorded by Babington (1834) in three localities near Bath: in old stone quarries on Hampton Down; on rocks above Bathford and on an old wall near the top of Widcombe Hill. It was still to be found on rocks in Bathampton Wood (Hampton Down) until 1978 and it persists at Brown's Folly Reserve (rocks above Bathford). This species can also be found north of Bath, on rock outcrops on Lansdown (Randall 2007/2008). In 1981, R.D. Randall recorded a single plant at the Roman Baths (Randall 1982); it may appear at other sites within the urban area of Bath where suitable habitat exists.

Dryopteris affinis (Scaly Male-fern) was not included in local Floras until it appeared in Green *et al.* (2000), but this was because of taxonomic confusion and does not mean that the species was not present. The aggregate species (but probably *D. affinis sensu stricto*) is found in Smallcombe Wood (R.D. Randall, pers. comm.) and mapped by Green *et al.* (2000) for a few other locations around Bath. This species has not yet been recorded as naturalised within the urban environment.

Dryopteris dilatata (Broad Buckler-fern) is a fern of woodlands and shady hedgebanks. Babington (1834) recorded this species as occurring 'in Hampton and other woods' and it is still to be found in woods around Bath.

Dryopteris filix-mas (Male-fern) was noted by Babington (1834) to be 'frequent'. This widespread species can be found in damp basements and on walls in the centre of Bath and is common in woods around the city.

Dryopteris mindshelkensis (Rigid Buckler-fern) is largely restricted to karstic limestones in north-west England; consequently there was great excitement in the pteridological world when John E. Vize discovered a single plant near Bath in 1853 (Vize 1853). In a letter to E. Newman (attached to a specimen now in the Natural History Museum) John Vize wrote that he found but four fronds: one he enclosed, another was sent to Mr. Harrison of the Botanic Gardens, Liverpool, the others he retained! The identity of the frond sent to E. Newman was confirmed as *Lastrea rigida* (now *Dryopteris mindshelkensis*) (Vize 1853). Within weeks, another correspondent suggested 'the possibility, if not probability, that it had been planted there by Potter, a well-known fern-collector, now dead, en route to Cheddar'. White (1912) also believed it to be 'doubtless planted' and Roe (1981) more cautiously wrote 'probably planted', however there is no evidence that this was the case. Whether planted or not, this species was not seen again and T.B. Flower (in Jenyns 1867) wrote: 'Quarries on Hampton Down, very sparingly. I fear the locality has been destroyed by the numerous fern collectors.'

Gymnocarpium dryopteris (Oak Fern) was listed by Sole in Collinson (1791) 'In the chinks of the garden steps at Widcombe-house'. Babington (1839) suggested that this was perhaps a mistake for *Polypodium calcareum* (now *Gymnocarpium robertianum*), the Limestone Fern.

Gymnocarpium robertianum (Limestone Fern) was probably what Sole recorded as *Polypodium dryopteris* (now *Gymnocarpium dryopteris*) at Widcombe House in Bath. Babington (1839) reported that it was 'Not now to be found', suggesting that it had been introduced with the stone. He gave a site a short distance from Bath: Friary Wood, at Hinton Abbey, found by T.B. Flower. White (1912) included an additional location: 'Walls below the canal between Bath and Batheaston'. There have been no further records.

Ophioglossum vulgatum (Adder's-tongue) was first recorded by Dr. Davis 'In moist meadows near Claverton' (Babington 1834). It has been recorded in several places around Bath (Green *et al.* 2000) including Newton Park, Widcombe Hill, Bannerdown Common, Upper Langridge, Smallcombe Wood, Brown's Folly and Kingswood School playing field; it may persist at some of these sites.

Osmunda regalis (Royal Fern) has only been found once around Bath, in 1982, when D.E. Green recorded two plants growing against the church wall at St Catherine. They were an introduction here and failed to persist (Green *et al*. 2000).

Polypodium vulgare (Polypody) was listed by Babington (1834) as common. Three species of *Polypodium* are now recognised within the *P. vulgare* aggregate. *P. interjectum* is the commonest species in the Bath area and can be found on walls within the city. *P. vulgare sensu stricto* was recorded from Newton St Loe by I.P. Green in 1999. The third species, *P. cambricum* is not recorded from the Bath area.

Polystichum aculeatum (Hard Shield-fern) was listed by Babington (1839) for a wood at Claverton and Friary Wood, found by T.B. Flower, and a lane near Langridge, found by R.C. Alexander. It is still to be found around Bath.

Polystichum setiferum (Soft Shield-fern) was also listed by Babington (1839), found at Beechen Cliff, Friary Wood at Hinton Abbey and a wood on Lansdown, by T.B. Flower. This species can still be found in the woods about Bath.

Polystichum tsus-simense (Korean Rock-fern) was found by the authors in 2009 in a derelict basement in Rivers Street, growing from the stonework above a drain. (This is an aggregate species name, with several former varieties now considered to be separate species; however this is the name in common use. It is possible that, following taxonomic revision, a different species name will be given to the plant in Bath.)

Pteridium aquilinum (Bracken) was regarded as common by Babington (1834) and remains so outside of the city (Green *et al.* 2000). Within the city it was found in the basement of a house on Belmont in 2007, by R.D. Randall, who wrote 'this used to be present in a number of cellars [basements] in central Bath but has now virtually disappeared' (Randall 2007/2008). It still persists in a basement on the north side of Queen Square (R.D. Randall, pers. comm.).

Pteris cretica (Ribbon Fern) was first recorded in Bath in 1978, when R.M. Payne found a single plant growing on the stonework of a deserted basement in New King Street. By 1979 it was gone, however several plants were found on an old basement wall in Beaufort Square: it did not persist here either (Green *et al.* 2000). Plants originally recorded as *P. cretica* in Pierrepont Street and Lansdown Road (Randall 2002) have been found to be *P. multifida*; however *P. cretica* has recently been found in basements at three locations: Laura Place (one plant, found in 2007), St James' Parade (one plant, found in 2008) and Catharine Place (three plants, including one splendid specimen, found in 2009).

***Pteris cretica* 'Wimsettii'**, identified by the pronounced irregular lobing of the pinnae and the repeatedly bifurcating apices, is to date the only cultivar to have been found in the wild in the British Isles. It was found by R.D. Randall in 2006 on a basement wall in Sydney Buildings in Bath; however the plant has now gone.

Pteris multifida (Spider Brake) has been found at two sites in Bath. *Pteris* plants had been known from a basement on Lansdown Road since 2002, and a basement in Pierrepont Street for ten years longer (Randall 2002). It was only in 2006 that these were identified by F.J.R. as *P. multifida* (Crouch and Rumsey 2007). Plants in Pierrepont Street were eradicated when the basement was tidied by builders in 2008; however a small plant has reappeared.

Pteris nipponica (Variegated Ribbon-fern) was discovered by the authors in a basement in St James' Parade, in 2008. Initially five young plants were seen, however only one remains.

Pteris umbrosa (Jungle Brake). A large *Pteris* plant found in a basement in Rivers Street, by C. and M.A.R. Kitchen in 2009, is believed to be a new species for Britain: *Pteris umbrosa*.