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Change in species distributions at tetrad scale – a supplement to *Change in the British Flora 1987-2004*

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Abstract
The report on BSBI's 'Local Change' repeat tetrad survey (LC) was published in 2006 as *Change in the British Flora 1987-2004*. Excellent species distribution maps at tetrad (2 km) scale are now readily accessible on BSBI's online Distribution Database (DDb). The opportunity has been taken to download a selection of such maps and match them with the species chosen for detailed accounts, including maps and statistics, in the LC Report. Statistics on species distribution change at tetrad scale have also been derived from data extracted from the DDb for England and Scotland comparing the dateclass 1987-99 with 2000-19. Further statistics have been derived for Bedfordshire v.c.30), where two complete surveys at tetrad scale have been completed. The statistics of change for the chosen species are expressed as '% Change per decade'. Taken together, the maps and statistics provide greater insight into the geographic patterns of change than was available at the time of the LC Report.

Keywords: BSBI Distribution Database; Local Change survey; England; Scotland; Bedfordshire

Introduction

Tetrad surveys of a county are popular as the finest scale at which it is practical for a small group of dedicated field-botanists to envisage full coverage of a vice-county over a 20-year period. However, tetrads are large units of 400 hectares and it is just not possible to record a complete species list in one, two or even three visits. The outcome is coverage that is invariably less-complete than it appears and, in particular, it follows that any repeat survey is difficult to compare statistically with the earlier one.

In the 'Local Change' (LC) survey run by the Botanical Society of Britain and Ireland (BSBI), a sample of 755 tetrads across Britain (but not Ireland) were revisited in 2003/04, sixteen years after the original 'Monitoring Scheme' survey in 1987/88 (Braithwaite *et al.*, 2006). It proved challenging to analyse the survey results to demonstrate change in the flora. Success was achieved, but only by accepting broad confidence limits in the statistics. There was greater confidence in the analysis of groups of species from a given habitat.

Since 2004 there has been a huge amount of tetrad recording in Britain. Most English vice-counties have either completed a tetrad survey or have one in progress.

In contrast Scotland took to tetrad recording later and many vice-counties are content to aim to record only a sample of the tetrads. The sample is often selected to cover as much of the ground thought to be as bio-diverse as possible together with a more limited sample of other habitats, such as arable fields. There are other possible strategies, such as those recognising physical frailties of team members.

The recording strategy makes a substantial difference to the relative frequencies of the species recorded as present in a vice-county. A strategy prioritising bio-diverse habitats will record a higher proportion of locally-scarce species than a random selection or a complete survey.

For this paper, the methodology used for analysis has been varied to reflect the contrasting recording histories of England, Scotland and Bedfordshire. An attempt to analyse data from Wales failed, seemingly because of a disparate mix of recording strategies in the individual vice-counties. There is insufficient data for Ireland.

One of the outcomes of the LC survey was confirmation that changes in distribution are observed where a species is scarce, usually at the fringes of its geographic range. If, on the other hand, there have been several populations of a declining species in a recording unit, all are unlikely to have been lost and no change is observed. For species that are spreading the same applies in reverse, as even a single plant of a species colonising a recording unit increases its recorded range. For a moderately widespread species there is thus a much greater opportunity to observe decline at tetrad scale than at hectad scale, as there is a higher proportion of recording units at the fringes of its range where the species has been scarce. In looking at a map of a declining species covering two dateclasses, it is a study of the fringes of the distribution that will provide the evidence sought.

There are two possible ways to map a species distribution using 'dots' for presence. In 'most recent on top' maps any apparent decline will show up as 'dots' from the earlier survey. However, many of these dots may simply reflect the absence of a more recent survey, so an understanding of the recording history is necessary to interpret the maps fairly. In 'oldest on top' maps recent colonisation may be expected to show at the fringes of the former distribution, often with outliers resulting from rare long-distance dispersal events. Interpretation is generally more straightforward than for 'most recent on top' maps.

Tetrad maps for a selection of species are presented alongside statistics of change with a brief discussion of the insight gained by taking the two together.

Methodology for analysis

Analysis of the LC survey results involved taking each species/tetrad combination separately and scoring the result as a refind, an apparent gain or an apparent loss. This procedure was not applicable to the data downloaded from the DDb as no attempt was made to match individual tetrads. A first step was therefore to analyse the LC data using simpler alternative methodology.

A linear regression of the frequencies in the two surveys was found to be adequate when the x, y axes intercept was set at 0, 0 (Fig. 1). This indicated a need to scale down the frequencies for the second survey by about 6%, compared with about 8% indicated by the more elaborate method used in the LC Report (the regression used was linear, but without the x, y axes intercept being set). Scarce species and very widespread species produced invalid results under both methods and were omitted.

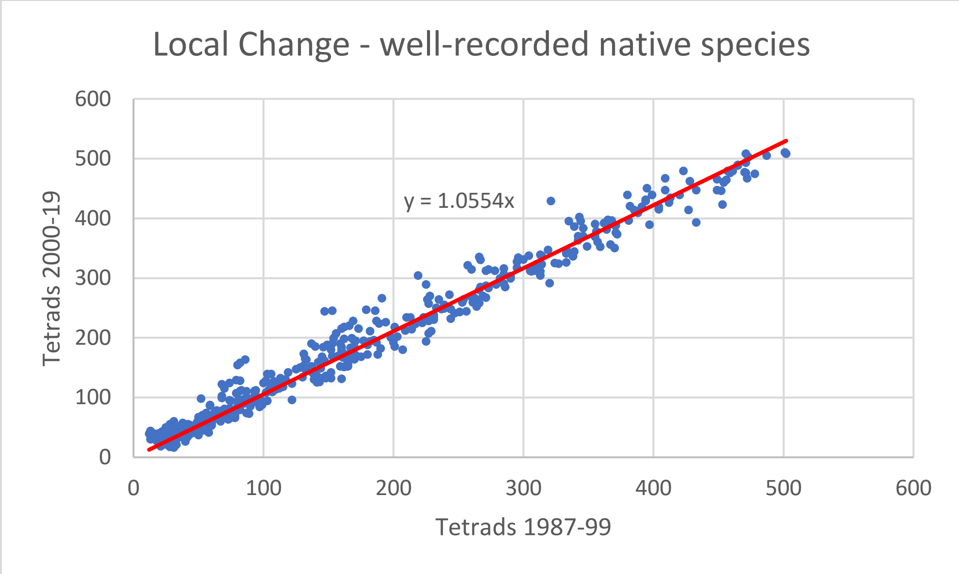


Figure 1. Linear regression of Local Change data

The method used in the LC Report involved taking a selection of 498 well-recorded native species and using these to set the adjustment factor required, and then using this factor for all species: native, archaeophyte or neophyte. The same method, using the same species was then applied to tetrad data for the chosen dateclasses for England, Scotland and Bedfordshire.

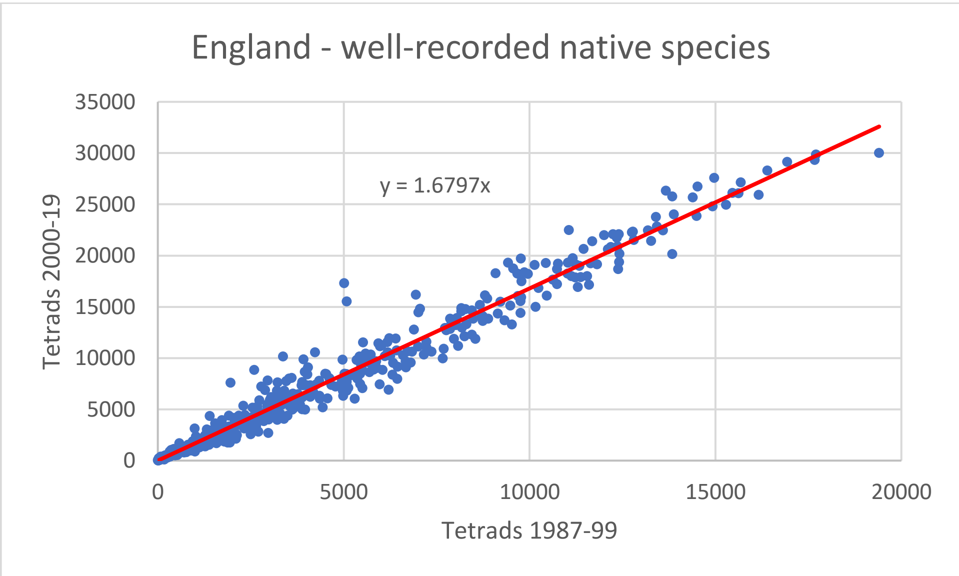


Figure 2. Linear regression of England data

The data fit linear regression surprisingly well, given the many differences in the recording history of English vice-counties (Fig. 2). The adjustment required to compare the two dateclasses is almost 70%, a far cry from the 6% for the LC data, so inconsistencies were inevitable. The most pervasive factors relate to Cumbria and Northumberland. Cumbria was recorded for a complete tetrad Flora over a period with part before the first dateclass and part in the first dateclass, but only as sample tetrads in the second dateclass. In contrast, Northumberland was recorded at 5 km scale in the first dateclass and by a sample tetrad survey in the second. The montane flora, in particular, was unevenly sampled and apparent losses are invalid.

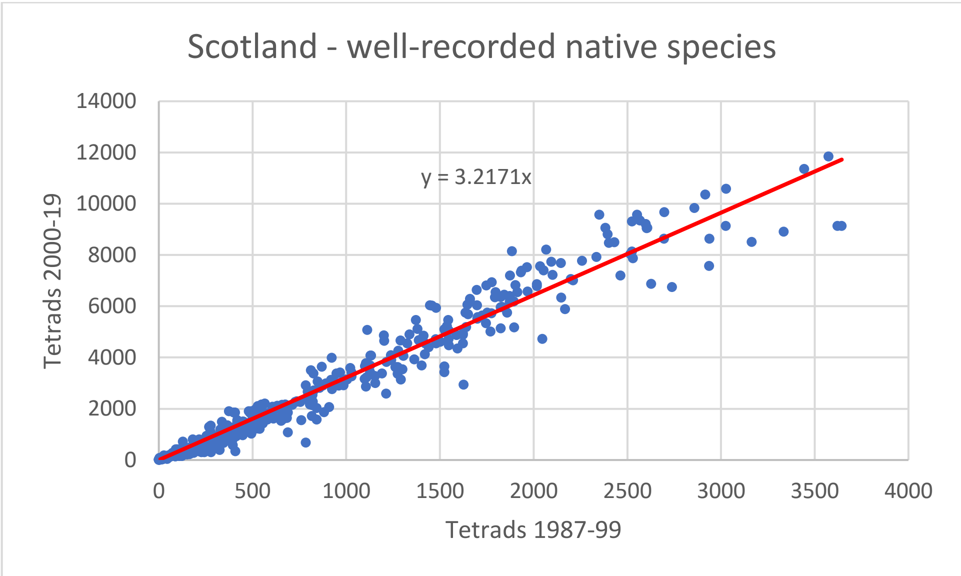


Figure 3. Linear regression of Scotland data

The linear regression for Scotland is only a moderate match to the data and the adjustment required to compare the data is extreme, with a factor of over three (Fig. 3). While it is true that around three times as much tetrad recording was done in the second dateclass over much of the Highlands, only about twice as much was done in the Lowlands. There is much variation even within these broad divisions. There are two further major sources of inconsistency. SNH carried out an intensive 'Scottish Loch Survey' in the first dateclass. Nothing of comparable intensity was attempted in the second dateclass. As a result, comparisons for aquatic and waterside plants show large invalid losses. The other major distortion relates to intensive recording of montane plants in the second survey, leading to invalid gains. Despite these frustrations, comparisons for many moderately widespread species yield believable statistics, which can be used where they seem consistent with other measures of change.

The comparison between the two Bedfordshire tetrad surveys is soberingly loose (Fig. 4). Both surveys (Dony, 1976; Boon & Outen, 2011) were carried out by experienced botanists who achieved notably comprehensive coverage. Despite this concern, comparisons for many moderately widespread species once again yield believable statistics, which can be used where they seem consistent with other measures of change.

To gain perspective on the degree of scatter in the Bedfordshire data, a chart is presented of the number of the 498 well-recorded native species recorded in each survey in each tetrad (Fig. 5). As before, the very widespread species are omitted. While there is consistency, there is a wide scatter. It is suggested that this chart gives an insight into what is, and is not, achievable in repeat tetrad recording.

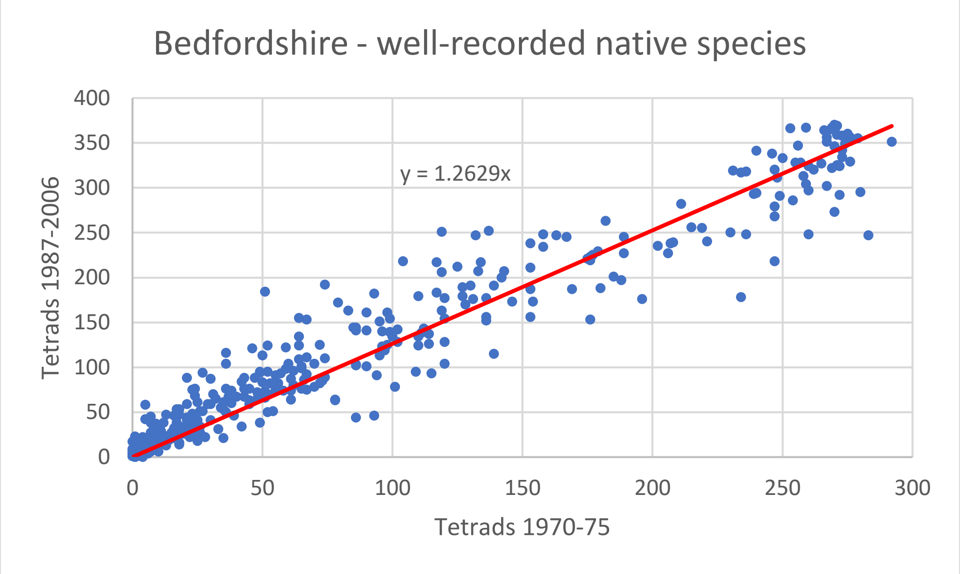


Figure 4. Linear regression of Bedfordshire data

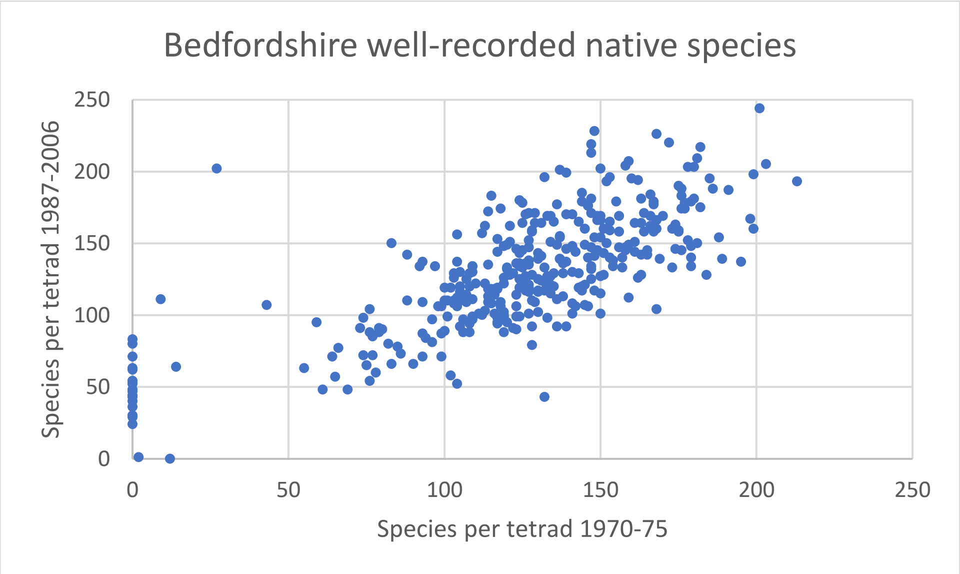


Figure 5. Scatter chart of Bedfordshire species per tetrad

% Change per decade

After scaling the data for each of the three additional datasets by the factors derived from the linear regressions, an index of change was derived that is directly comparable to the 'Relative Change' of the LC Survey, that is to say that the index of change was calculated in relation to a group of well-recorded native species. Any change in the reference group of species remained unknown.

Most changes in species distributions follow an exponential regression, whether positive or negative, doubling or halving in a given period of time. Change between the two dateclasses were adjusted accordingly to give '% Change per decade' in proportion to a period defined by the medians of the two very wide dateclasses. The change for declining species was calculated in relation to the frequency in the first dateclass, so that -50% means that half the units present in the first dateclass have been lost, while the change for increasing species was calculated in relation to the frequency in the second dateclass, so that +50% means that half the units present in the second dateclass are new, so the frequency has doubled. Clearly, the width of the dateclasses is a major limiting factor in the interpretation of the statistics.

Distribution maps

The opportunity has been taken to download a selection of tetrad maps from the DDb and to match them with the species chosen for detailed accounts, including maps and statistics, in the LC Report, updating the nomenclature to follow Stace (2019). The selection has been structured by Broad Habitat, as in the LC Report (Table 1). While the maps divide the tetrad records into two dateclasses, 1970-99 (not 1987-99) and 2000-19, the uneven coverage makes it hard to identify change in some of the maps, though it is evident in others.

It is often more instructive to study the overall pattern of distribution, ignoring the dateclasses, to gain insight into how closely a given species adheres to the Broad Habitat in which it is a component of the vegetation. Where the habitat is tightly prescriptive, there is an inevitability of decline. Where the species is more adaptable, it may be possible to visualise the colonisation of secondary habitats near at hand, allowing the species to spread if conditions favour it. Only a few species, notably the ferns and orchids, have the natural ability to colonise newly available habitat at a long distance from existing populations. However, many other species, including wind-dispersed species like *Taraxacum,* now exploit the traffic along the transport network to achieve rare long-distance dispersal, followed by local bulking-up to form a new population.

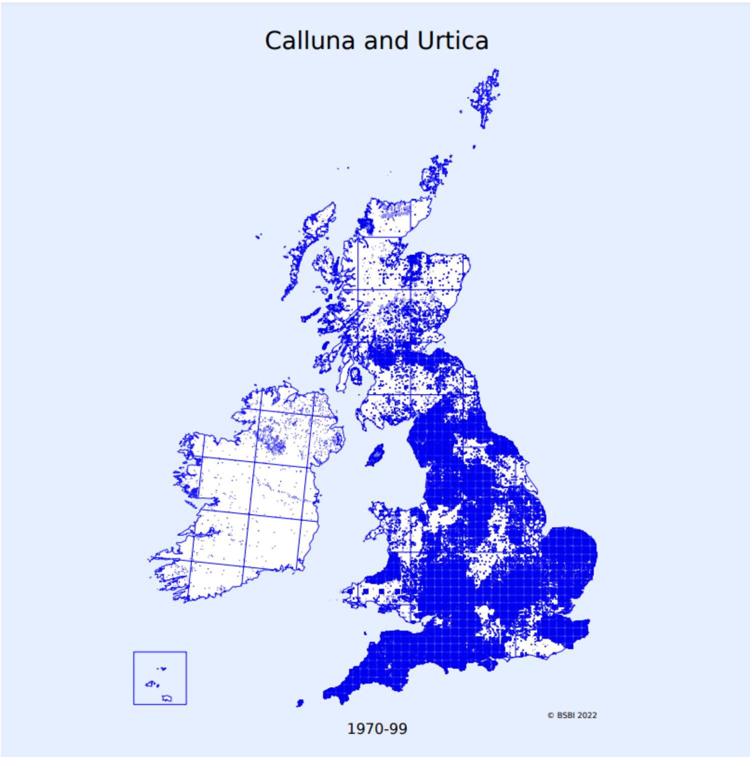
The processes of decline and dispersal are much more evident at tetrad scale than at hectad scale.

As the tetrad coverage is incomplete, maps are presented of *Calluna vulgaris* and *Urtica dioica* together to simulate recording coverage in the two periods 1970-99 and 2000-19 (Fig. 6). Coverage in England is patchy, while Scotland is mostly on a sample tetrad basis.

Table 1. Species mapped by Broad Habitat

Broad Habitat	**Species**	**Fig.**	**LC Report page**
Broadleaved, mixed and yew woodland (BH1)	*Ranunculus auricomus* *Campanula latifolia*	7 8	30 33
Arable and horticultural (BH4)	*Galeopsis speciosa* *Fumaria muralis*	9 10	65 66
Neutral grassland (BH6)	*Allium vineale* *Silene vulgaris* *Saxifraga granulata*	11 12 13	94 98 100
Calcareous grassland (BH7)	*Scabiosa columbaria* *Anacamptis pyramidalis* *Campanula rotundifolia*	14 15 16	114 115 121
Acid grassland (BH8)	*Spergularia rubra*	17	138
Wetland habitats (BH11, 13, & 14 in part)	*Dactylorhiza incarnata* *Jacobaea aquatica*	18 19	157 170
Montane habitats (BH15)	*Alchemilla glabra*	20	205
Inland rock (BH16)	*Lactuca virosa* *Asplenium scolopendrium*	21 22	216 219
Built-up areas and gardens (BH17)	*Sagina apetala s.l.*	23	233
Coastal habitats (BH18, 19 & 21)	*Atriplex littoralis*	24	251
Neophytes (Group 1) – widely naturalised	*Myrrhis odorata* *Anisantha diandra* *Allium paradoxum*	25 26 27	258 273 277
Neophytes (Group 2) – widely naturalised with further introductions	*Lunaria annua* *Hyacinthoides non-scripta x hispanica = H. x massartiana*	28 29	282 283

Tetrad survey coverage



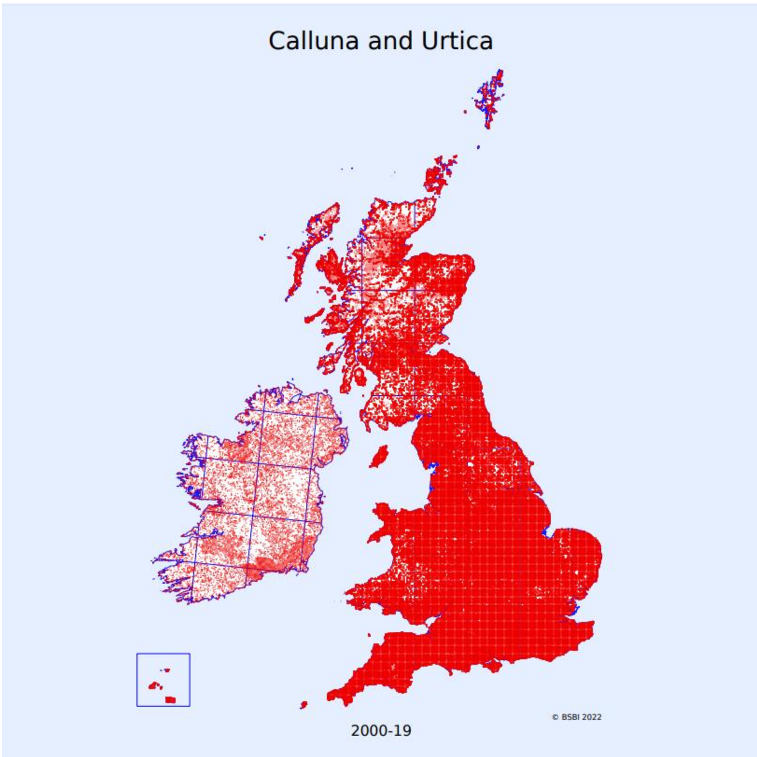
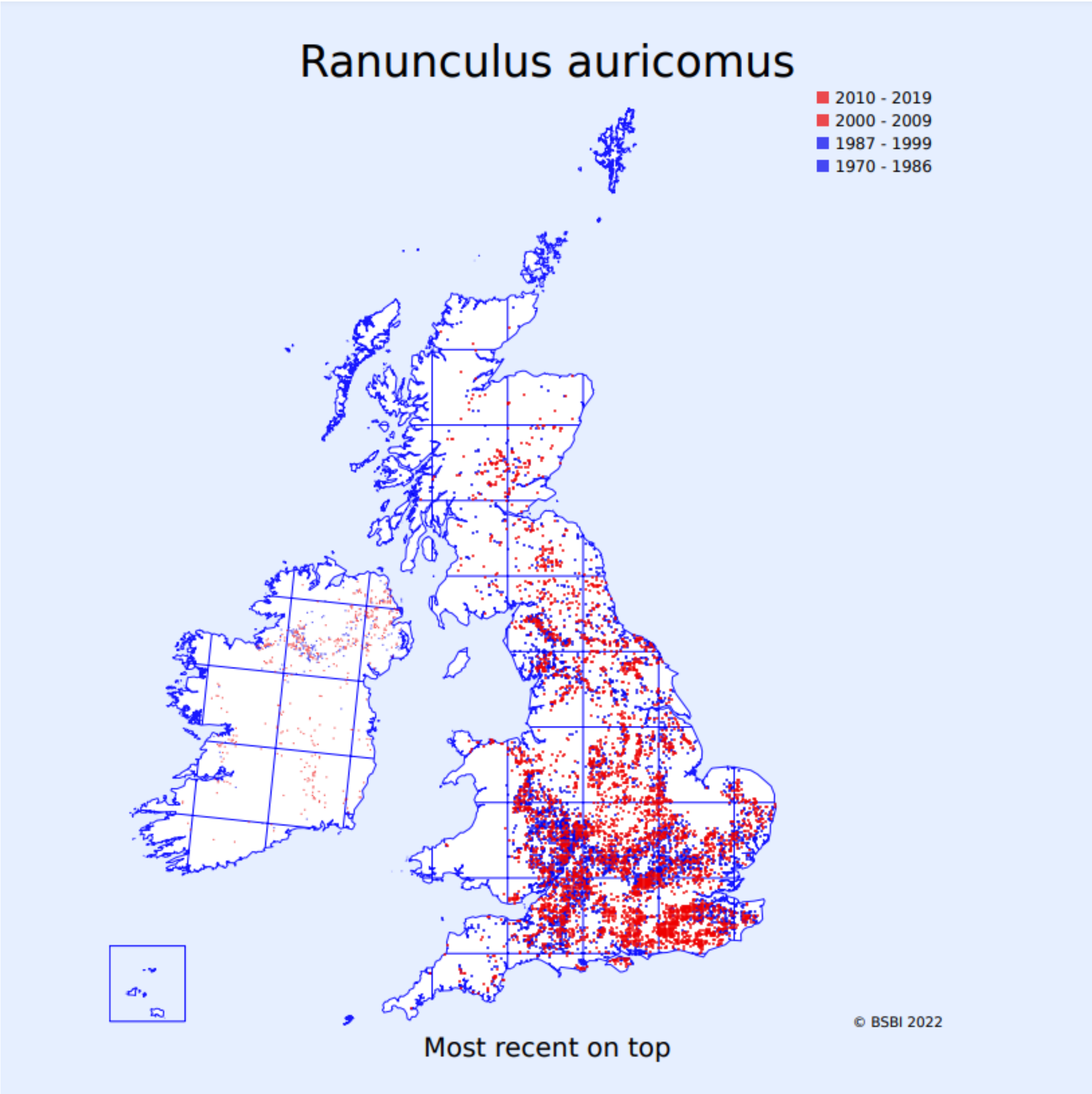


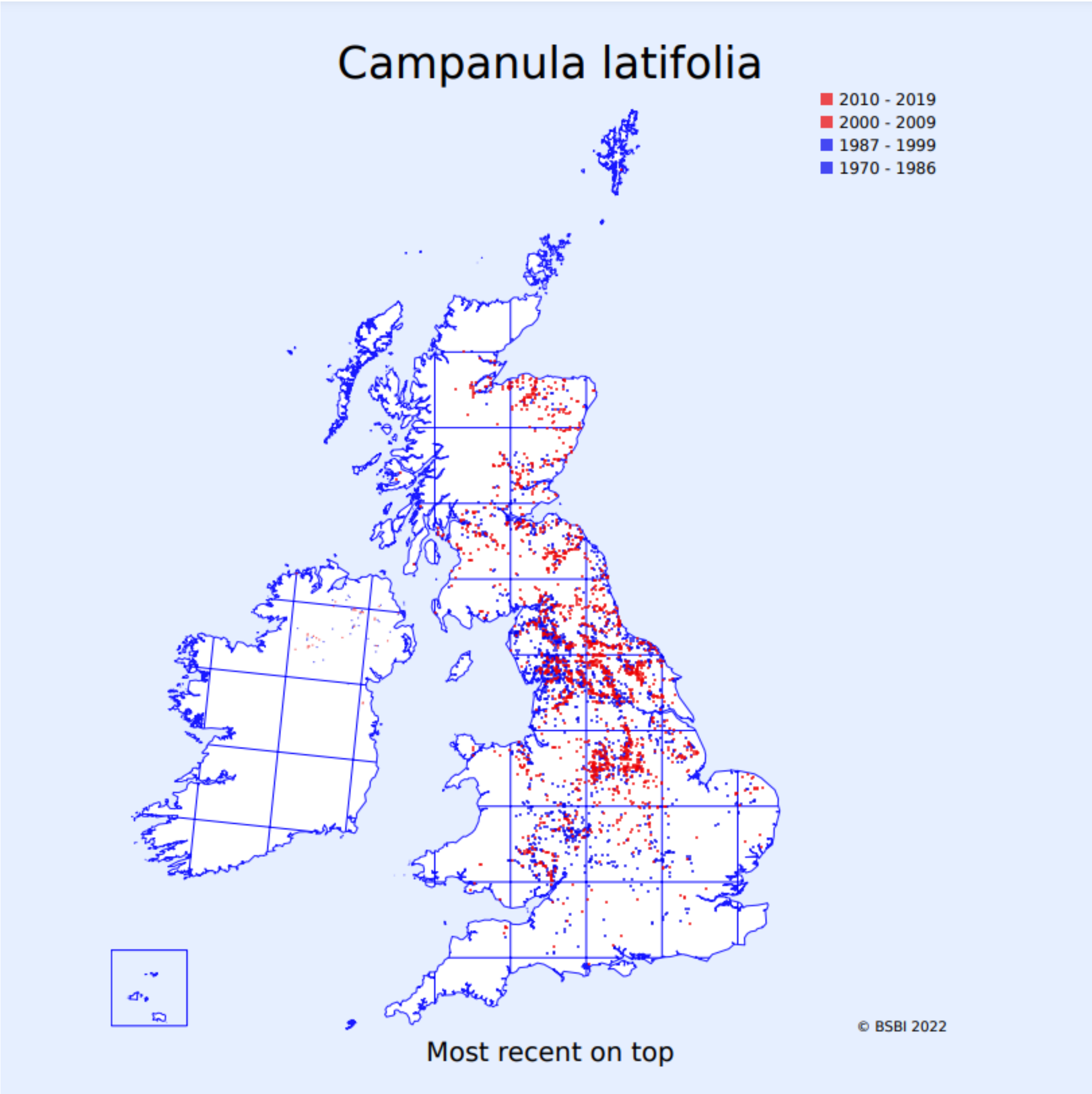
Figure 6. Tetrad survey coverage simulated by mapping *Calluna vulgaris* and *Urtica dioica* together for the periods 1970-99 (top) and 2000-2019 (bottom)



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
-13	-8	-13	-8

Ranunculus auricomus is a herb of woodland and scrub that requires calcareous soils, as indicated by its distinctive distribution at tetrad scale. Its LC decline is confirmed across its range. There is a hint of blue round the fringes of some of its strongholds in southern England indicating probable losses.

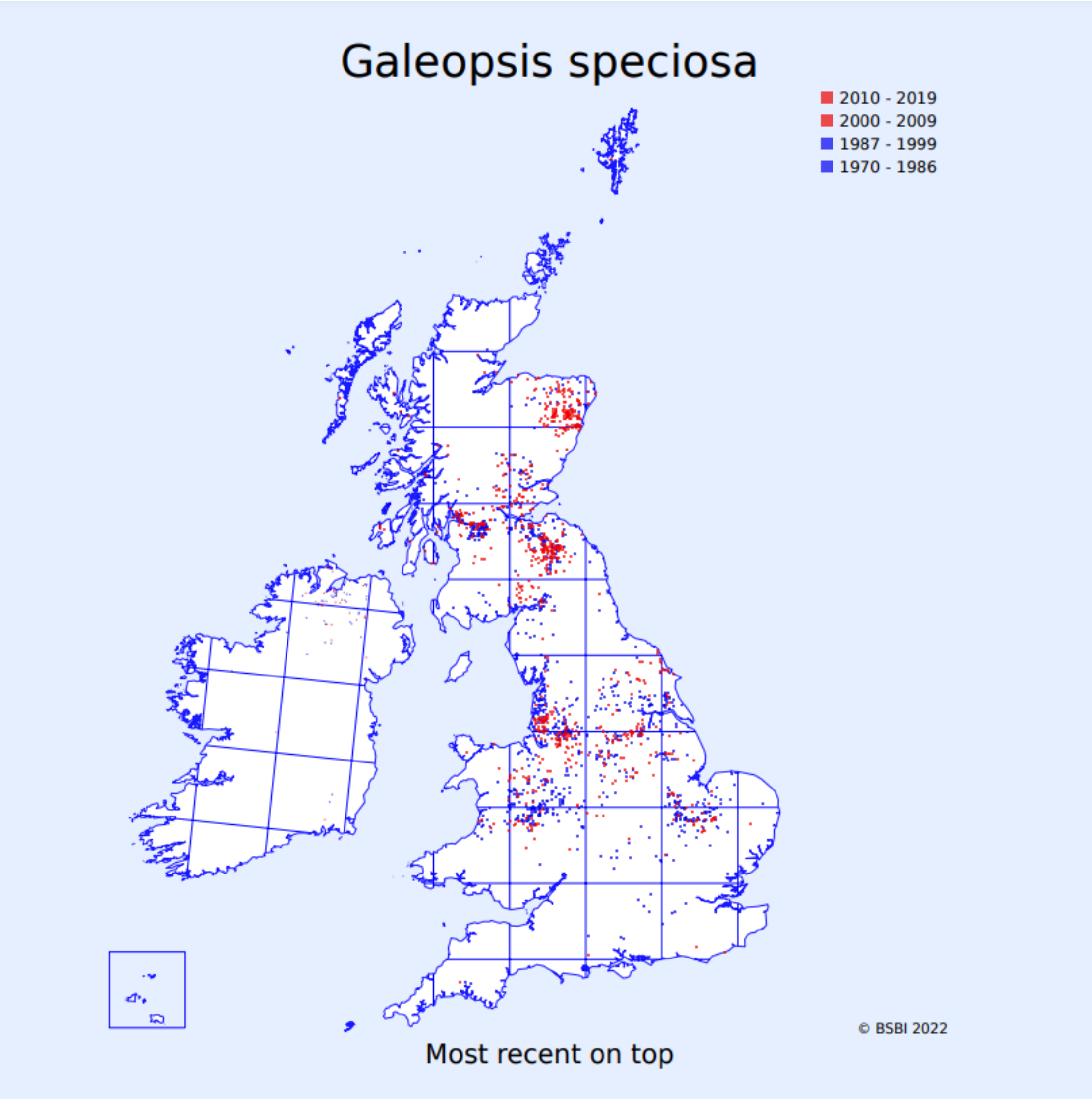
Figure 7. *Ranunculus auricomus*



% Change per decade			
LC	England	Scotland	Bedfordshire
-31	-21	-28	-37

Campanula latifolia is a specialist of riverside woodland that requires slightly calcareous soils, as indicated by its distinctive distribution at tetrad scale. Its decline is confirmed across its range and is indicative of the whitling-away of ancient woodland fragments. Many of the isolated occurrences away from its core distribution may relate to introductions.

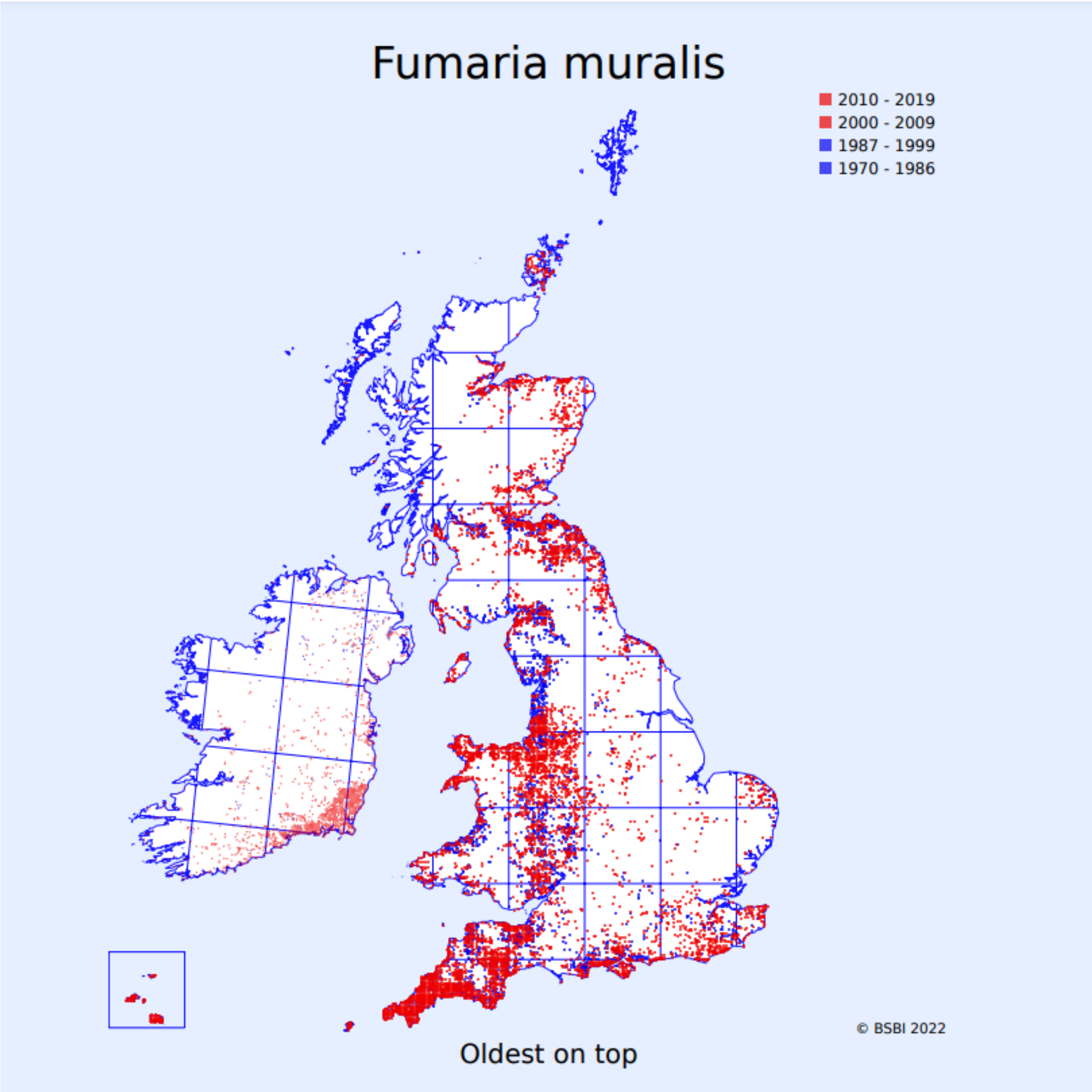
Figure 8. *Campanula latifolia*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
-28	-24	-29	-43

The clustered distribution of *Galeopsis speciosa*, evident at tetrad scale, is related to the peat-rich soils with which it is often associated. These soils are under intensive cultivation and their arable weeds are in decline. The scatter of records away from the main strongholds reflects the mobility of arable weeds, even those with large seeds.

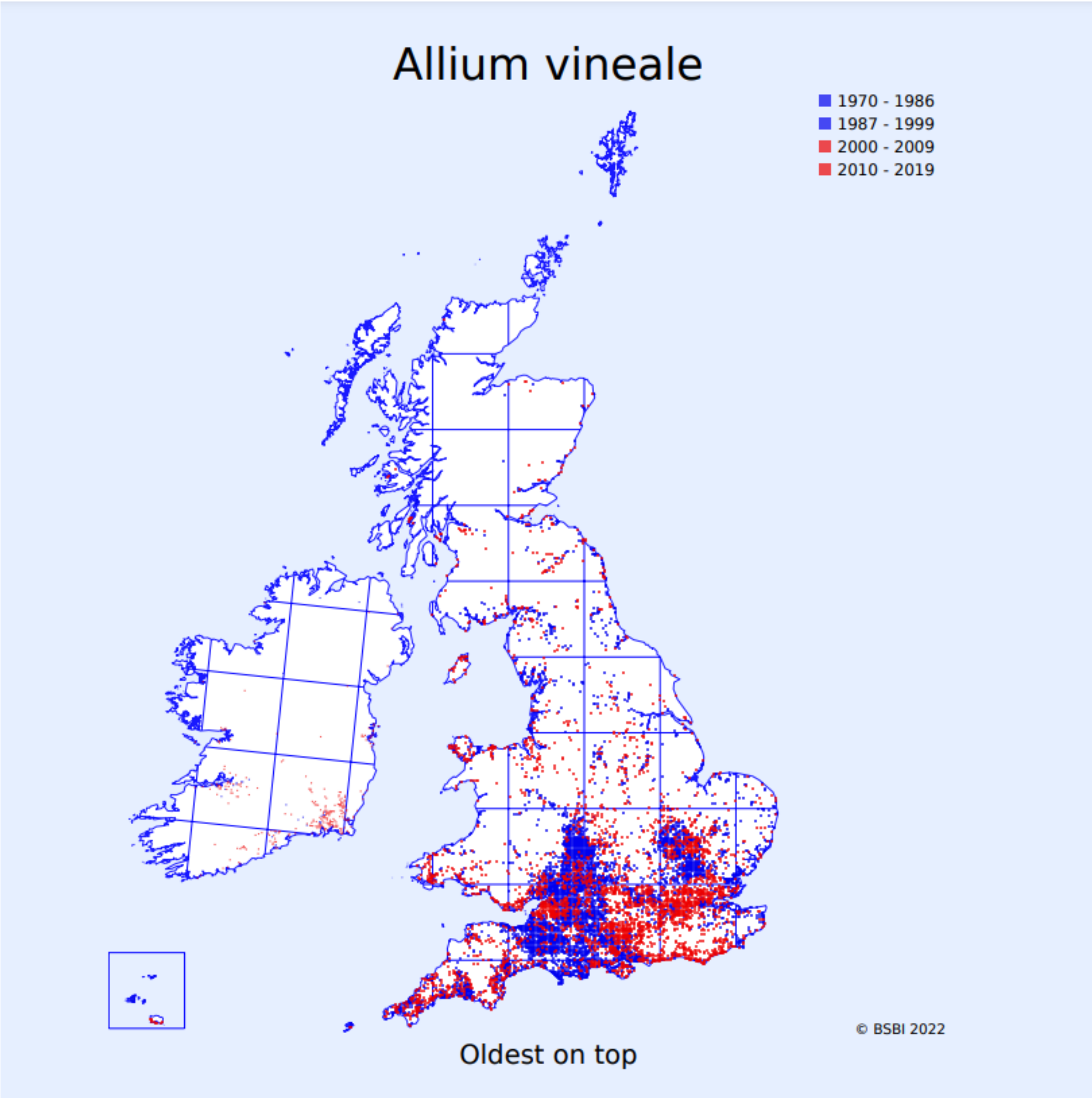
Figure 9. ***Galeopsis speciosa***



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+24	+17	[-2]	+30

Fumaria muralis prospers in areas with mixed farms, where it can be plentiful in root crops grown for sheep. It is more tolerant of nutrient-rich soils than *Fumaria officinalis*, and this may be the reason for its recorded gains. The losses calculated for Scotland are probably invalid.

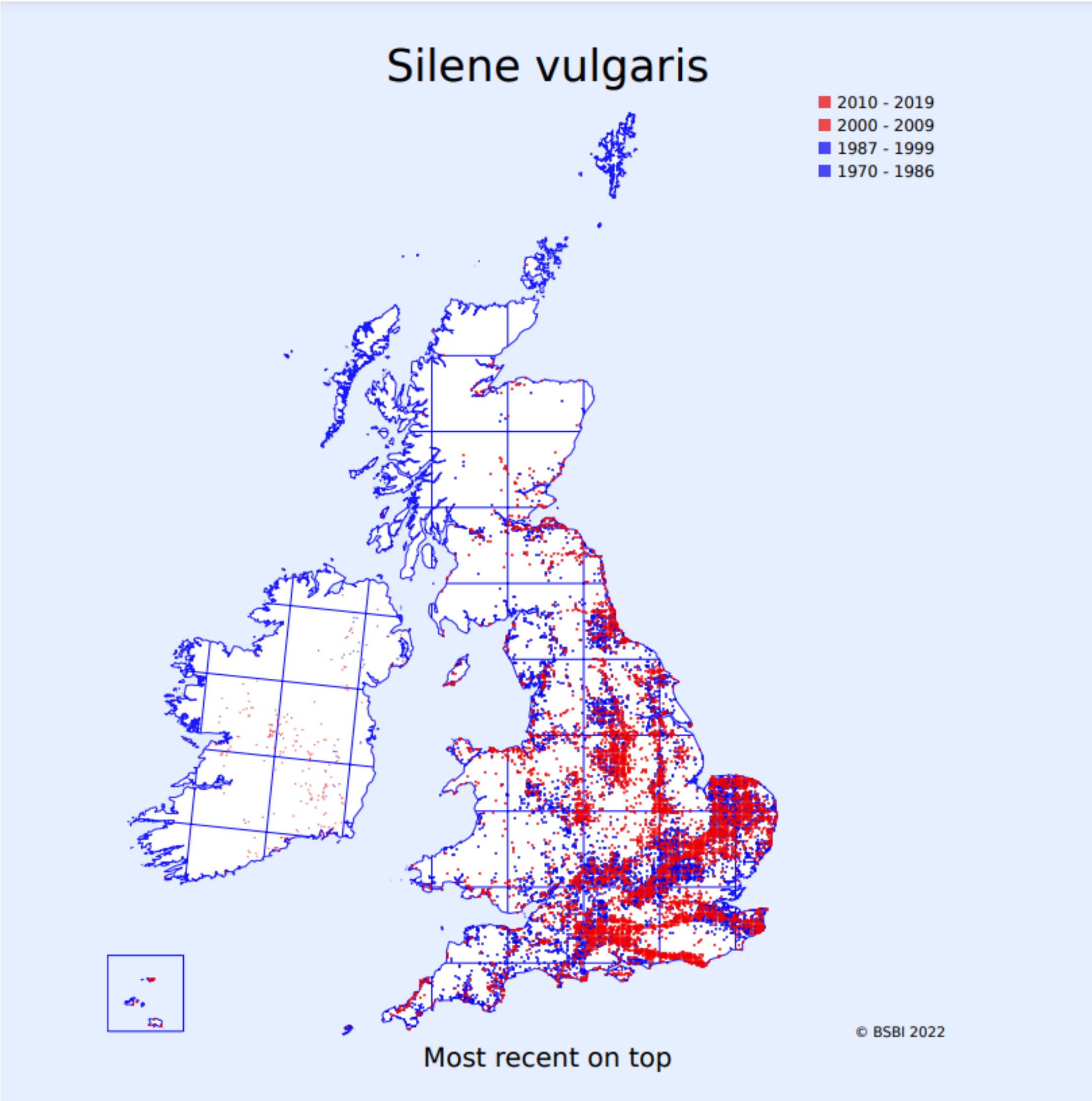
Figure 10. *Fumaria muralis*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+16	+6	[-26]	+8

Allium vineale is an arable weed in the south, but is also found on rock ledges and in alluvium on river banks. There may be some northward spread. The map emphasises how scarce it is in the northern half of its range. The recorded losses in Scotland are invalid, as the methodology fails for purely lowland species.

Figure 11. *Allium vineale*

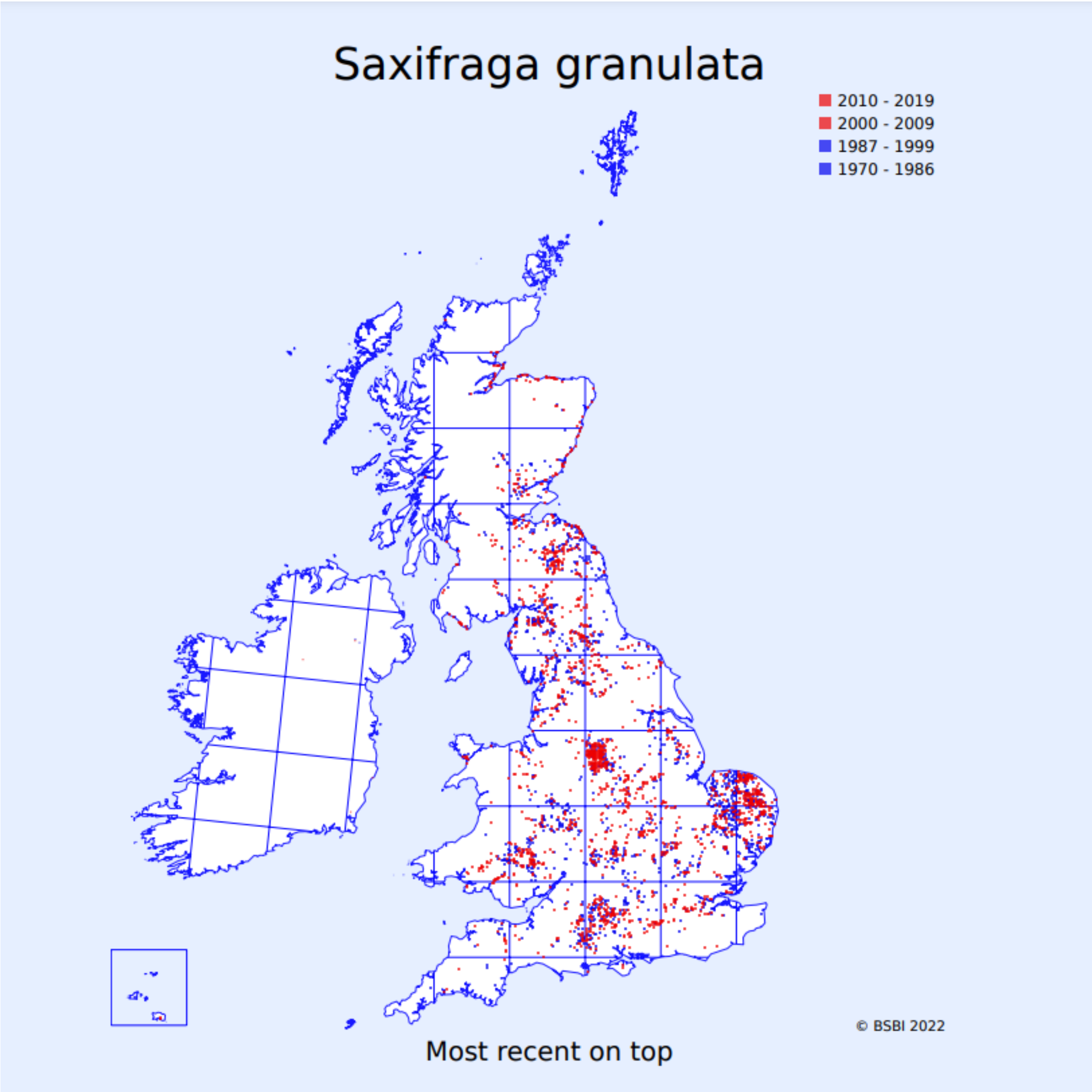


% Change per decade			
LC	England	Scotland	Bedfordshire
-19	-20	-64	-21

Silene vulgaris requires slightly calcareous soils, as indicated by its distinctive distribution. Its decline is confirmed across its range. It colonises away from its core strongholds, for example on road verges, but it is not very successful as a road verge plant where it often succumbs to competition driven by eutrophication.

Figure 12. *Silene vulgaris*

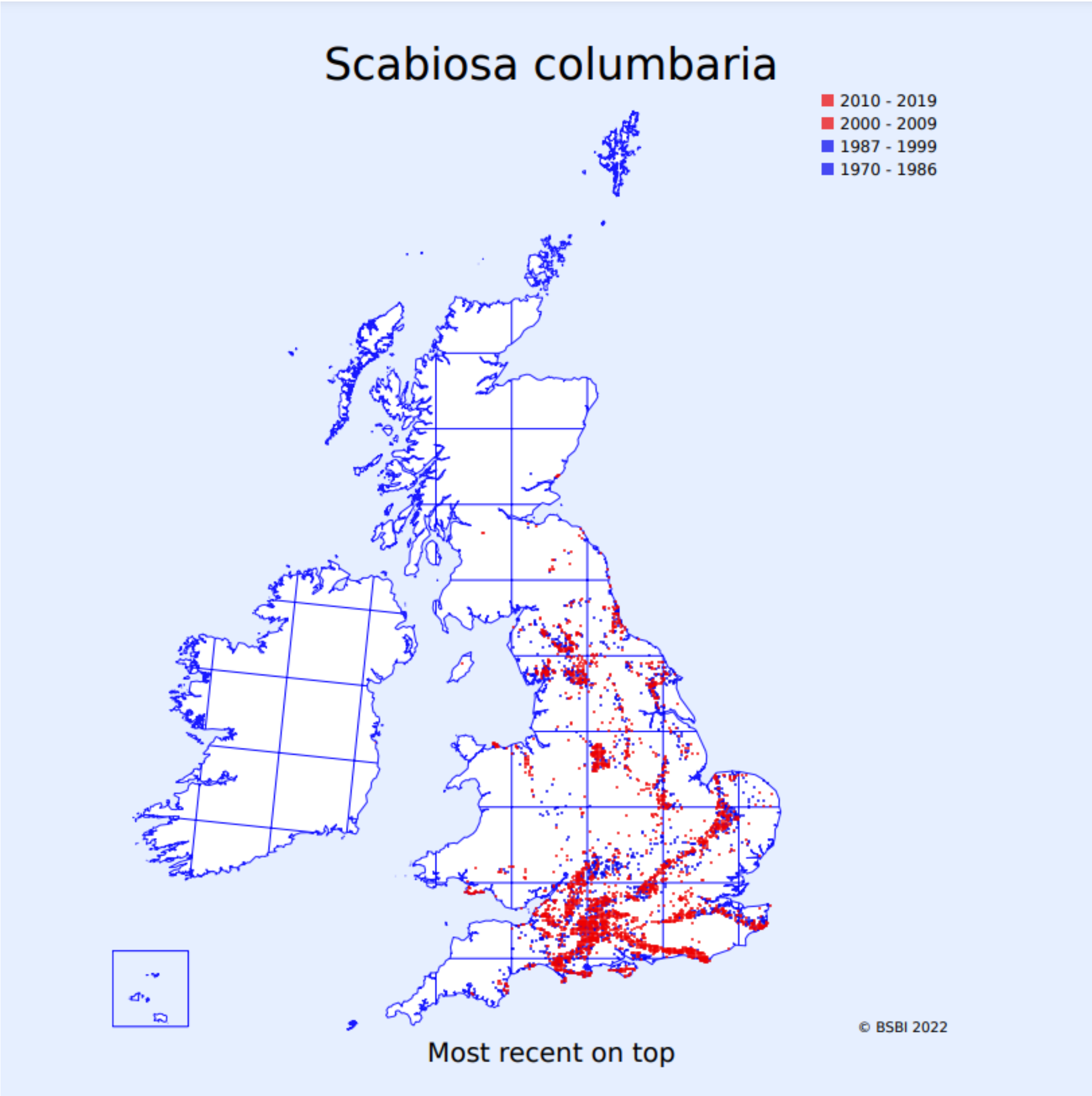
Neutral grassland (BH6)



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
-26	-21	-32	-4

Saxifraga granulata is found both on sandy soils and slightly calcareous rocky outcrops as shown by its clustered distribution. However, there are scattered colonies in less-obviously favourable habitats. All its habitats are subject to being whittled away by changes in land use.

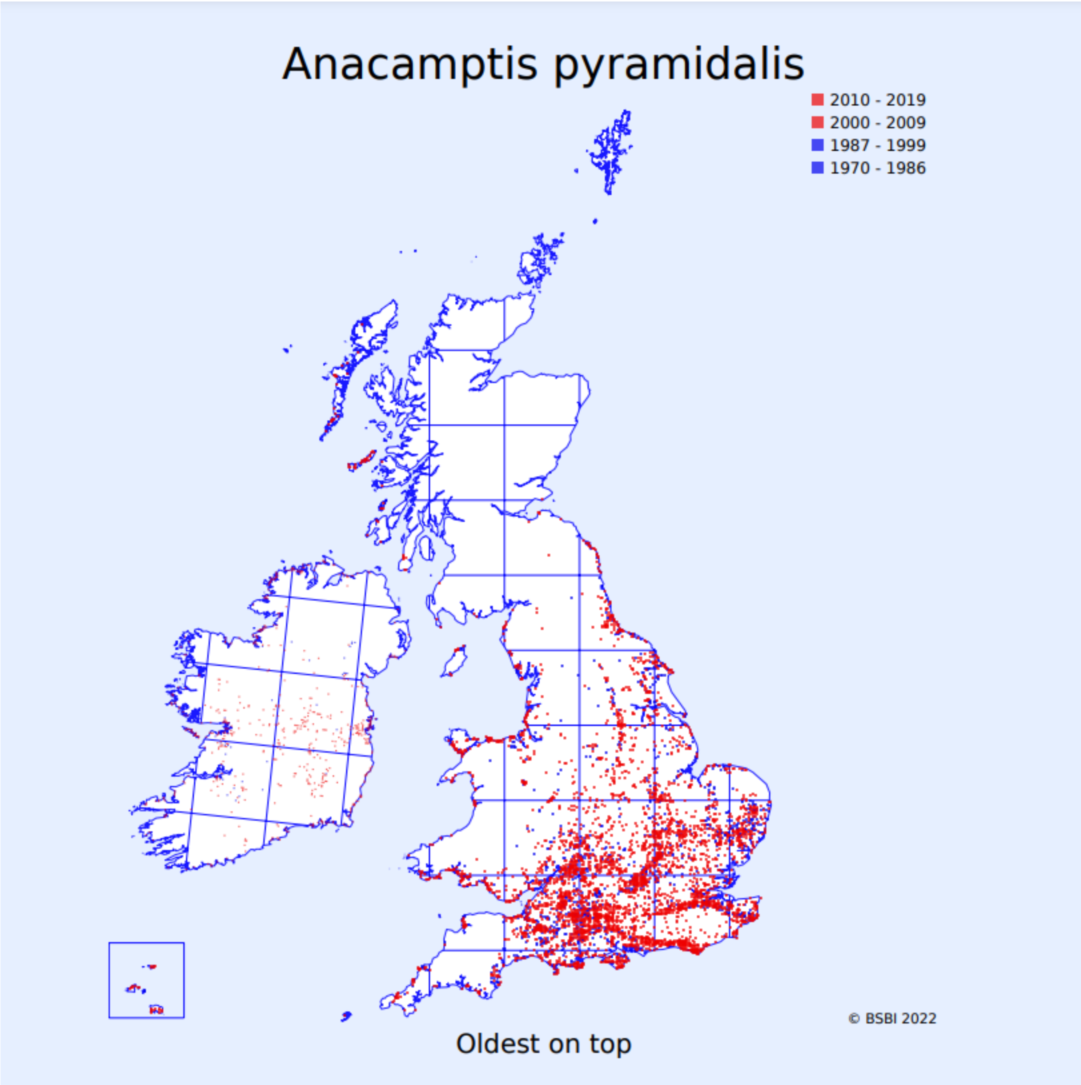
Figure 13. *Saxifraga granulata*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
-16	-18	-21	-4

Scabiosa columbaria has the classic distribution of a herb of calcareous grassland, though with a limited number of outliers. Such habitat is subject to losses at its fringes, as is evident in the map.

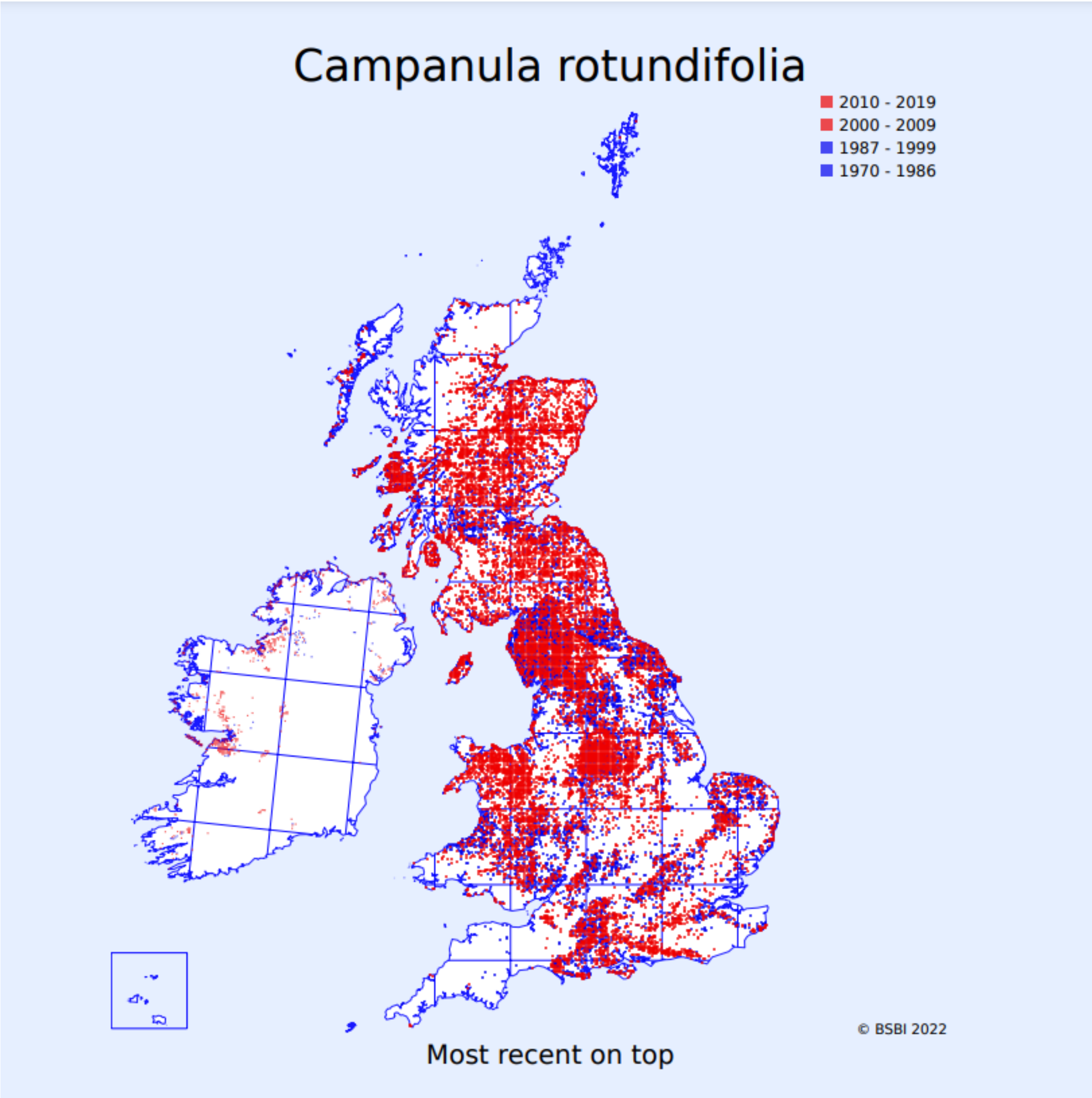
Figure 14. *Scabiosa columbaria*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+29	+19	+6	+17

Anacamptis pyramidalis has its core distribution on the limestone grassland of southern England, but, with its wind-blown seeds, has been able to colonise much more widely on motorway embankments, within industrial areas and the like. There it is increasing.

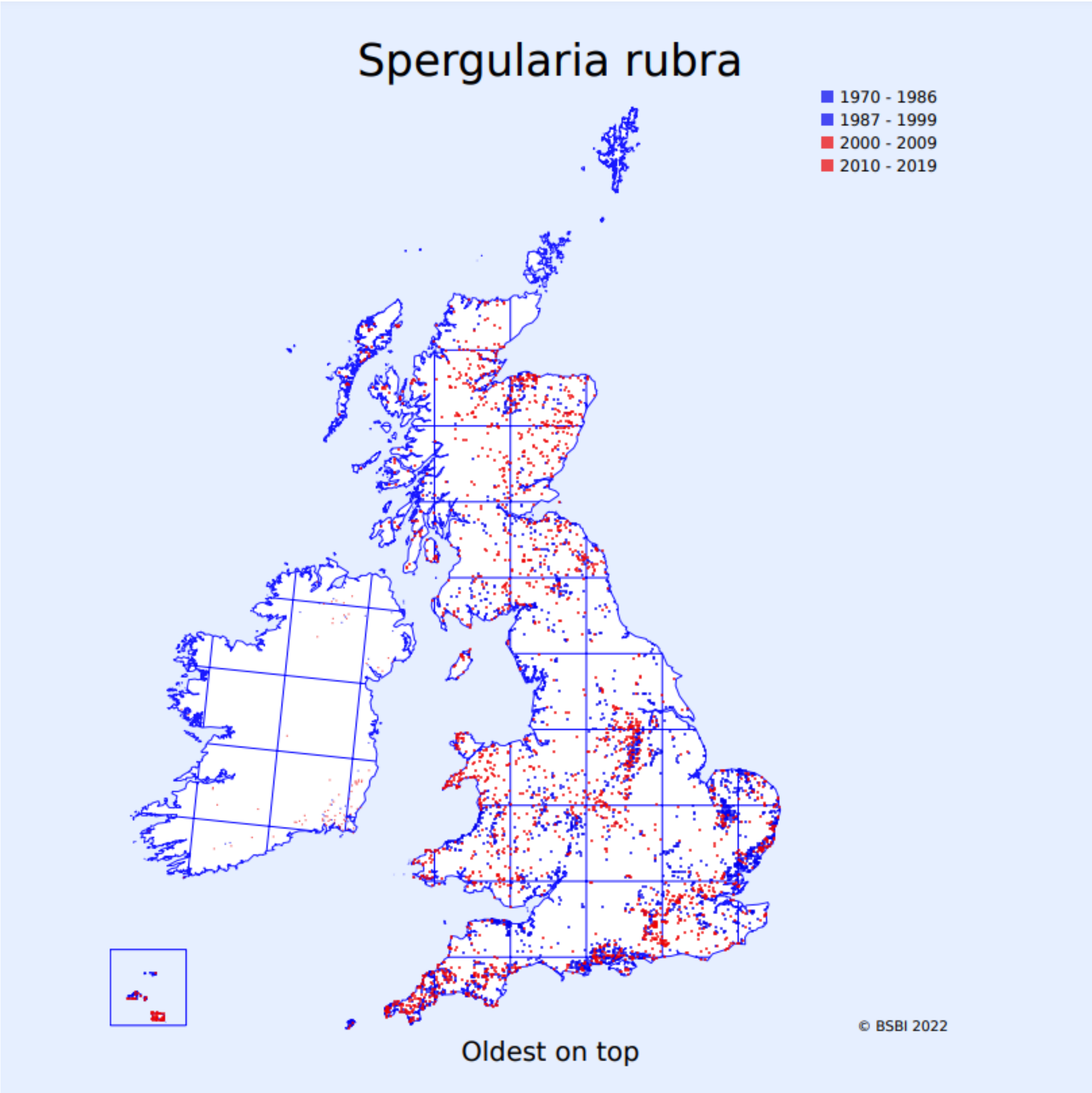
Figure 15. *Anacamptis pyramidalis*



% Change per decade			
LC	England	Scotland	Bedfordshire
-7	-12	-8	-19

Campanula rotundifolia has a curious distribution. In southern England it is largely a herb of calcareous grassland, as becomes evident at tetrad scale. Further north it is almost ubiquitous at tetrad scale, exploiting skeletal soils on rock outcrops varying from neutral to mildly acid. It is also found in sandy habitats. It is the southern colonies that are suffering losses.

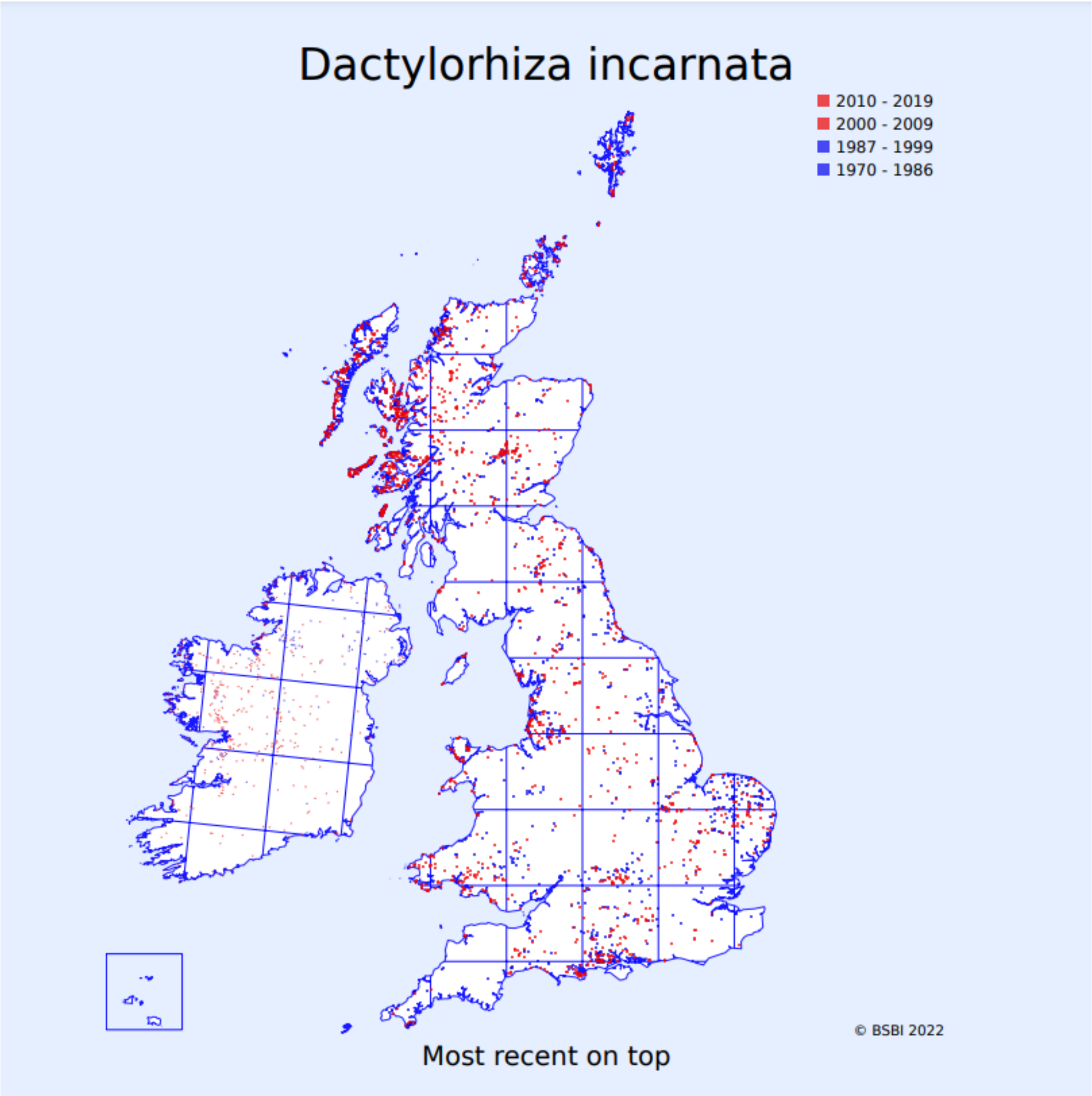
Figure 16. *Campanula rotundifolia*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+27	-7	+1	-25

Spergularia rubra is an annual that is often dispersed by vehicles and has a widely scattered distribution. It is only locally common. It has been increasing on forestry tracks and the like, but decreasing in its traditional habitat of sandy grassland in the southeast.

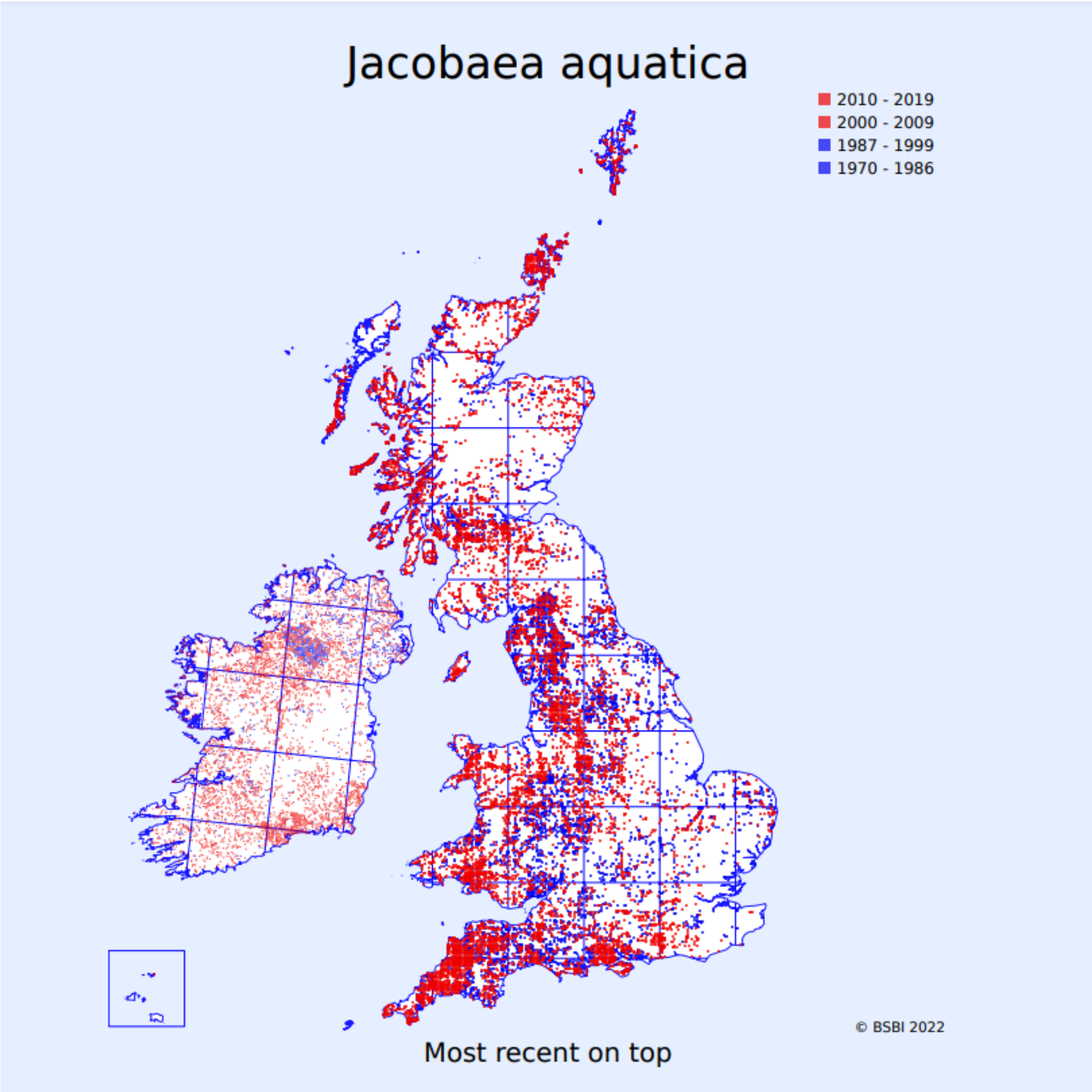
Figure 17. *Spergularia rubra*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
-19	-26	-16	+100

Dactylorhiza incarnata is an orchid of calcareous flushes. It has a stable distribution on the west coast of Scotland, but elsewhere is very vulnerable to habitat disturbance. The tetrad distribution highlights the very local occurrence of its habitat.

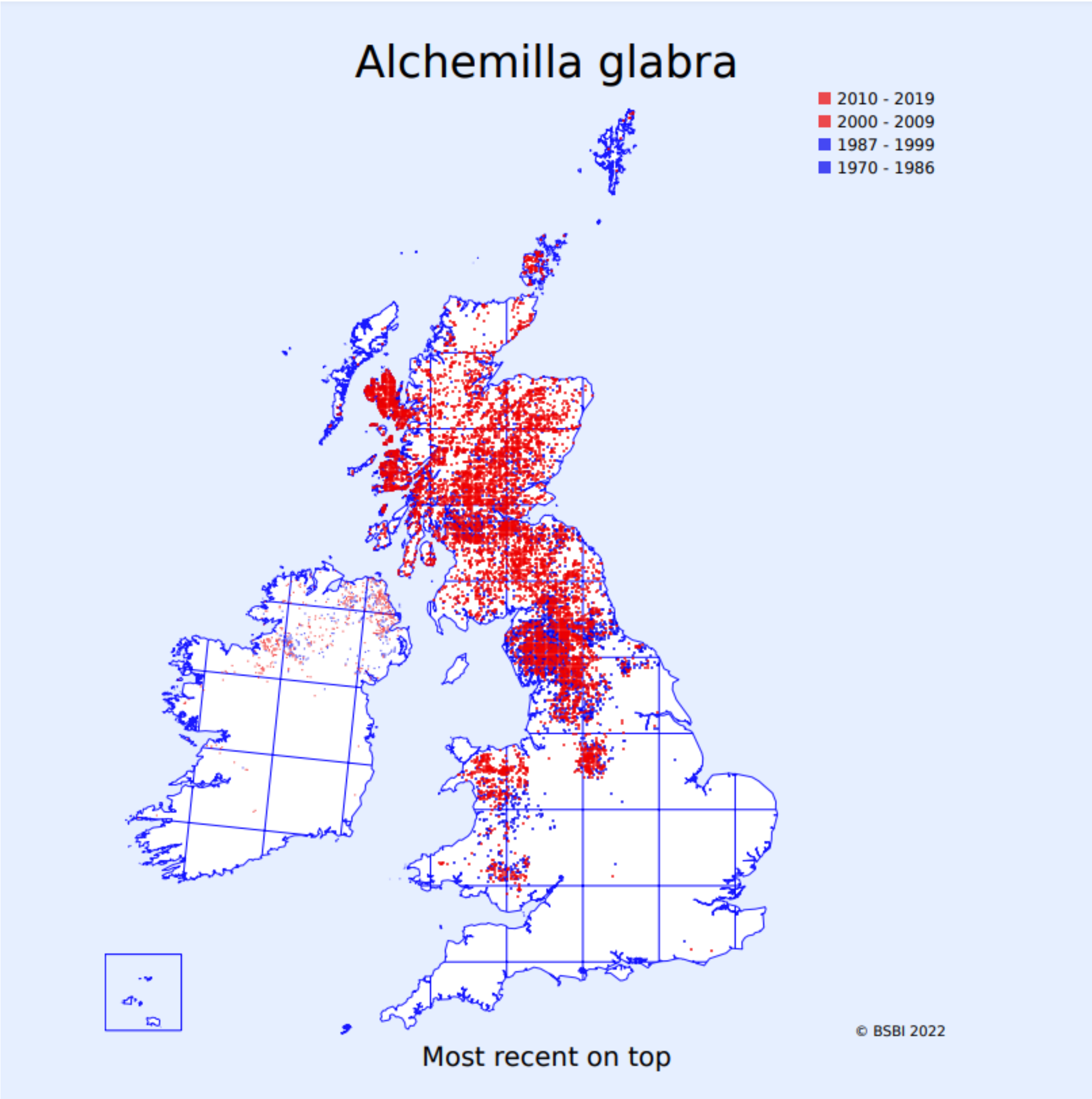
Figure 18. ***Dactylorhiza incarnata***



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+22	+35	-21	-11

Jacobaea aquatica is a familiar plant of ditches and other wetland habitats in the west of Britain, where it is increasing. In the east it is local and decreasing. The tetrad distribution emphasises the difference in frequency between west and east.

Figure 19. ***Jacobaea aquatica***

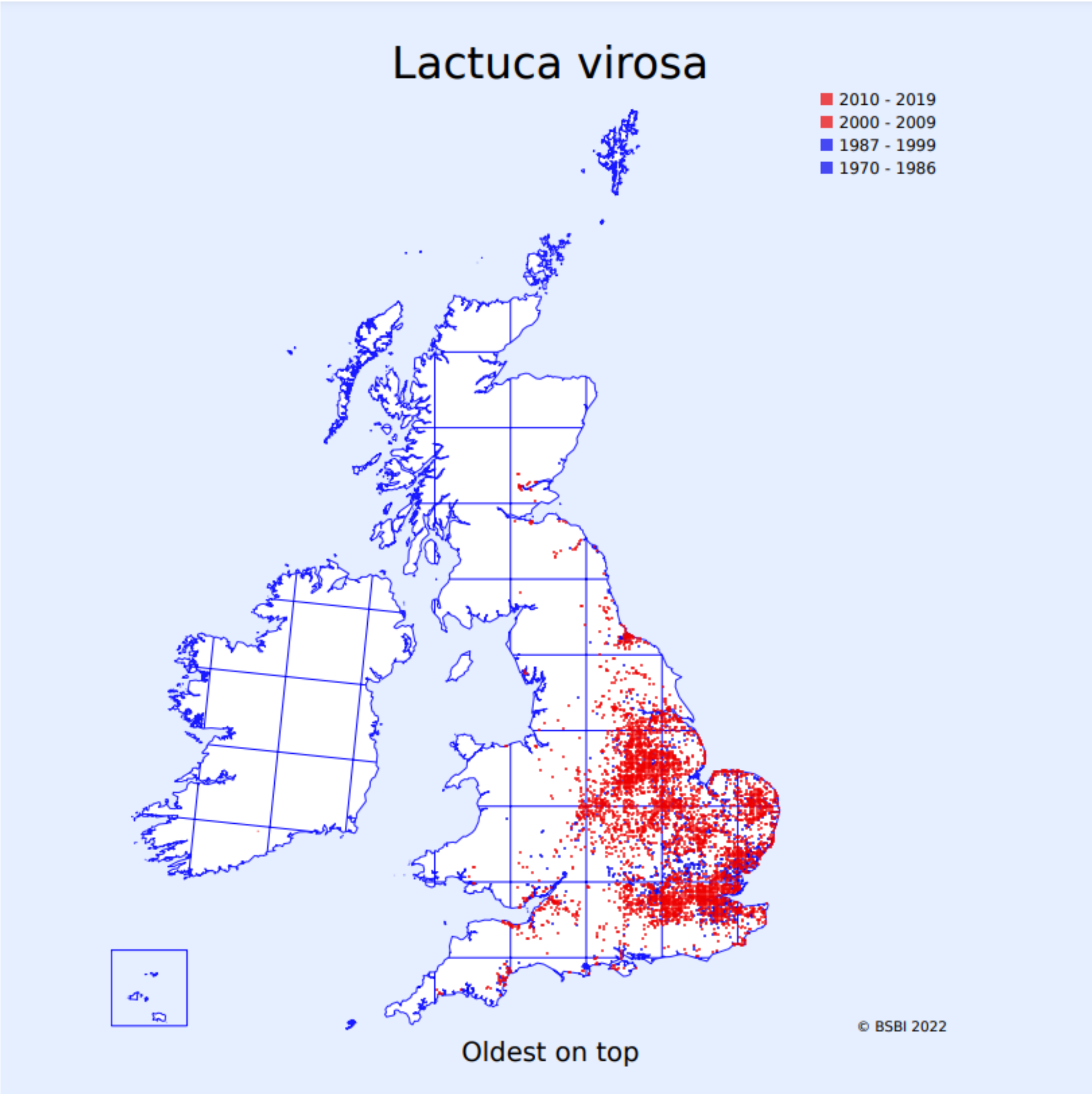


% Change per decade			
LC	England	Scotland	Bedfordshire
-14	+18	+4	absent

Alchemilla glabra is a very widespread plant of acid and neutral grassland in the uplands which would be expected to suffer losses at the southern fringe of its range, where such grassland is scarce, as indicated by the LC survey. The apparent gains calculated for England seem to relate especially to Northumberland from where there is no tetrad data for the earlier dateclasses.

Figure 20. *Alchemilla glabra*

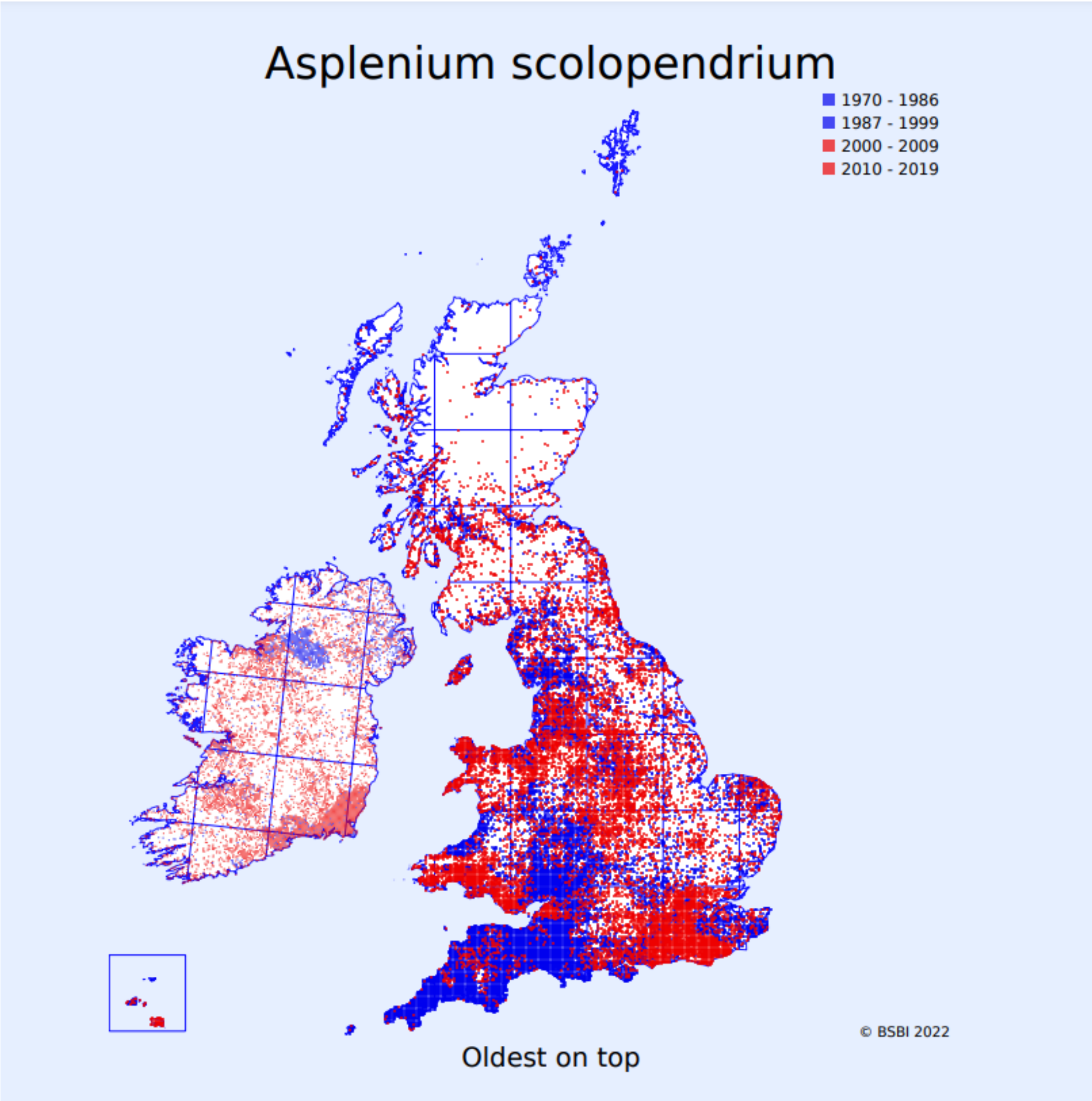
Inland rock (BH16)



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+45	+31	+1	+19

Lactuca virosa grows on rocks and in other infertile habitats, often associated with the transport network. It has the classic distribution of an increasing species with high frequency in its core areas surrounded by a scatter of records. These isolated records represent relatively-rare long-distance dispersal events, often by seeds adhering to vehicles. These then bulk up locally, in this instance by wind-dispersed seeds.

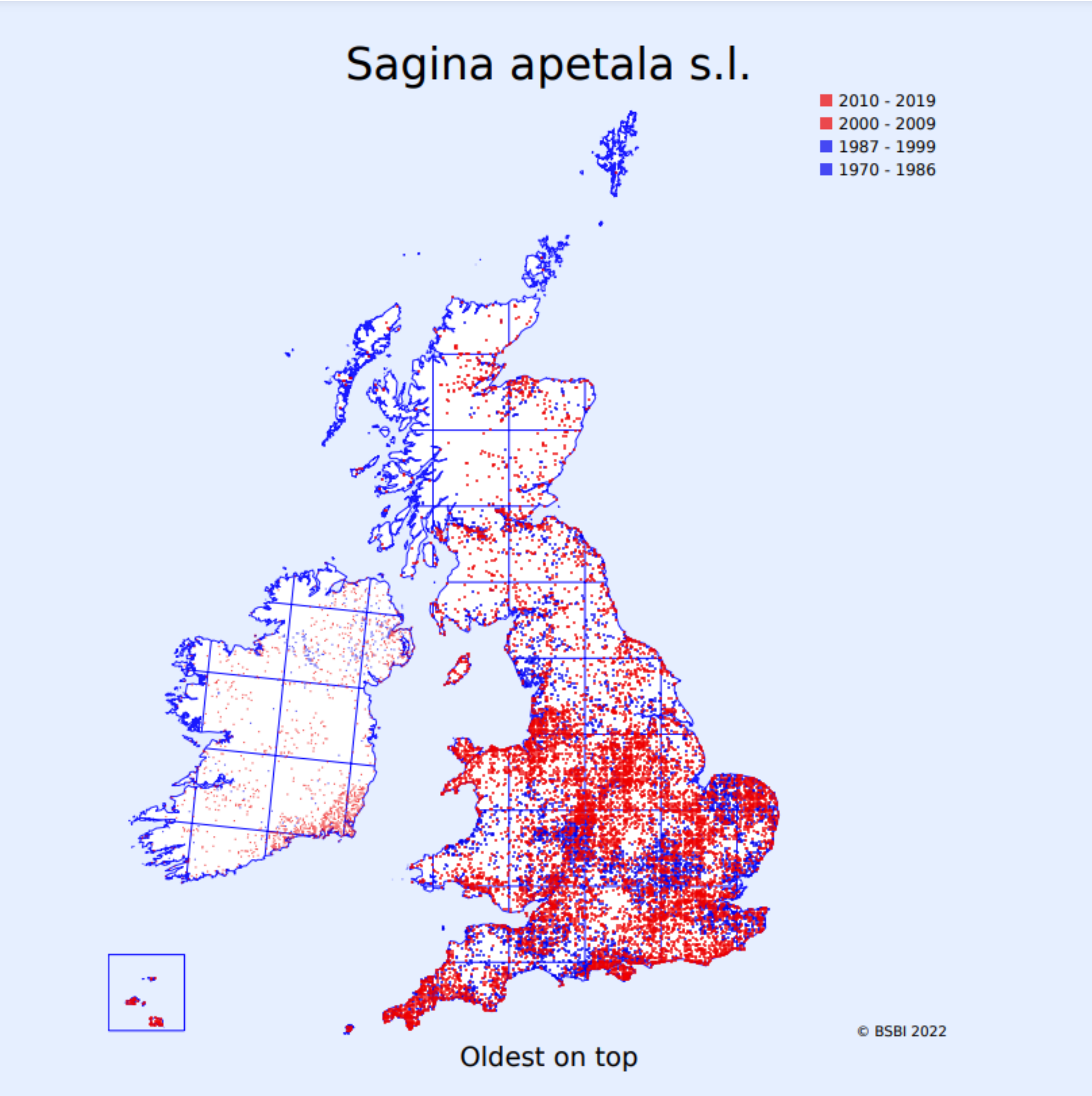
Figure 21. *Lactuca virosa*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+14	+18	+11	+0

Asplenium scolopendrium is a very common fern of rock and walls in western England but scarce in the east where it is sometimes an escape from cultivation. Some of the scatter of records in the east and north represents a response to the milder winters brought about by climate change. Very young plants are subject to frost damage, but not adult plants.

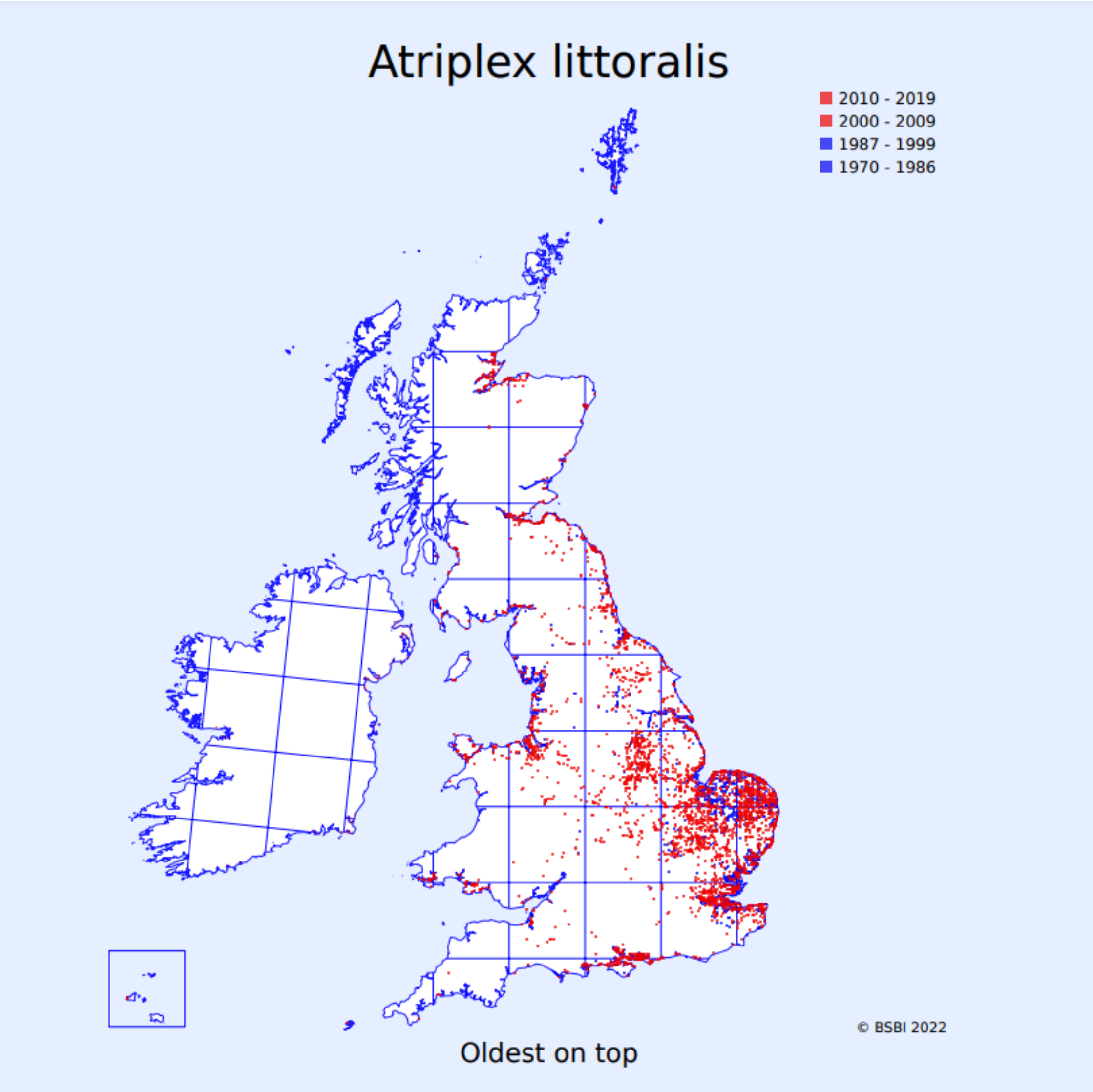
Figure 22. ***Asplenium scolopendrium***



% Change per decade			
LC	England	Scotland	Bedfordshire
+27	+9	[-11]	-3

Sagina filicaulis (but not *S. apetala s.s*) is strongly associated with man, colonising infertile habitats along the transport network and industrial sites. It has been increasing in those areas. The losses calculated for Scotland are invalid, as it is concentrated in urban areas.

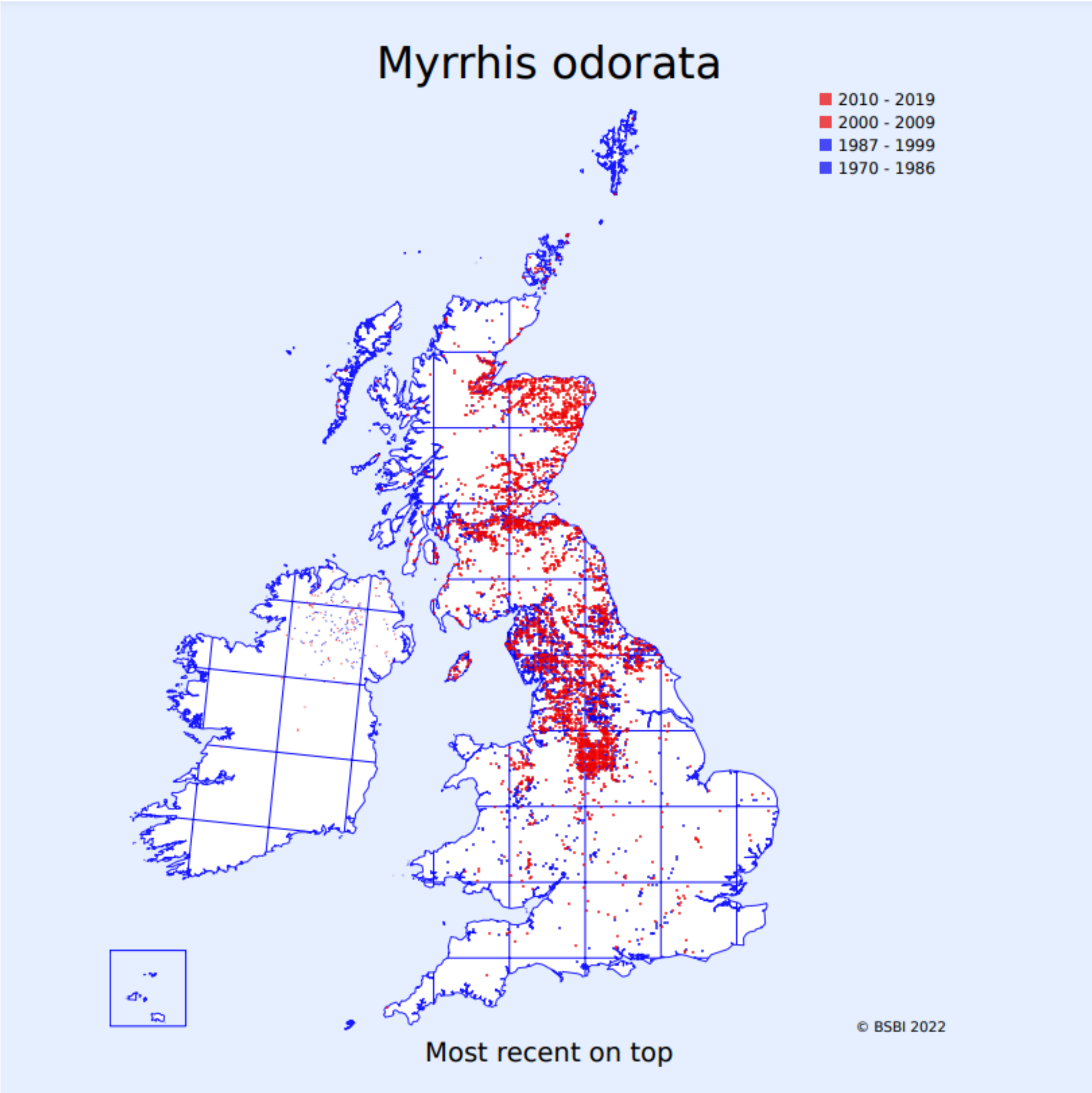
Figure 23. *Sagina apetala s.l.*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+51	+10	+6	+100

Atriplex littoralis has spread from its native beach-strand habitat to join the halophyte community along roads treated with salt in winter. It has the classic distribution of an increasing species with high frequency in its core areas surrounded by a scatter of records, some following major roads. These isolated records represent relatively-rare long-distance dispersal events, often by seeds adhering to vehicles. These then bulk up locally, with vehicles still facilitating much of the dispersal.

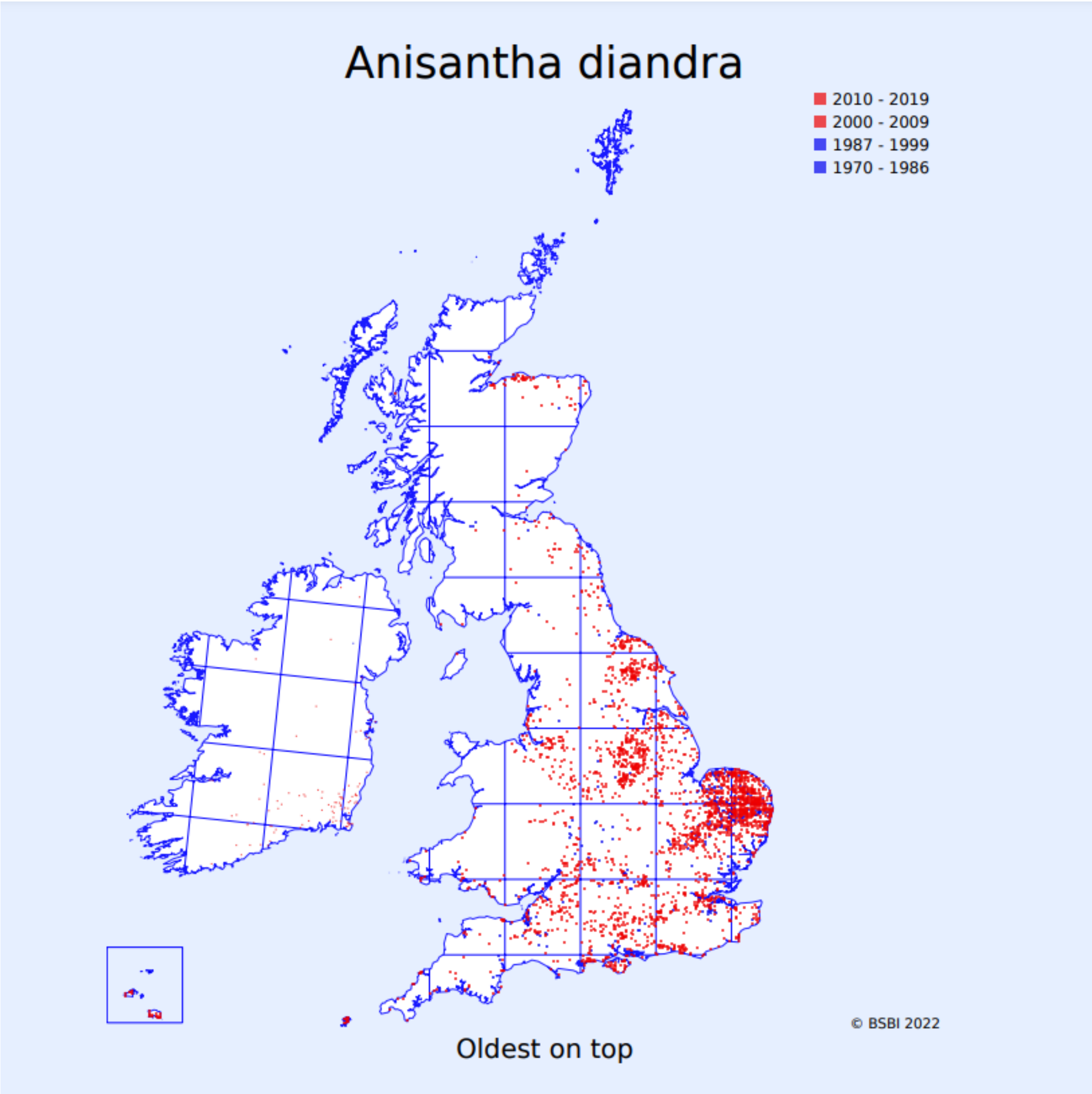
Figure 24. *Atriplex littoralis*



% Change per decade			
LC	England	Scotland	Bedfordshire
-14	-4	-6	absent

Myrrhis odorata was cultivated as a medicinal and culinary plant and naturalised extensively in hill areas, along roadsides and river banks. It is showing gradual decline in some areas but increasing modestly in others. There is a wide scatter of records in southern England, but no evidence of extensive naturalisation there.

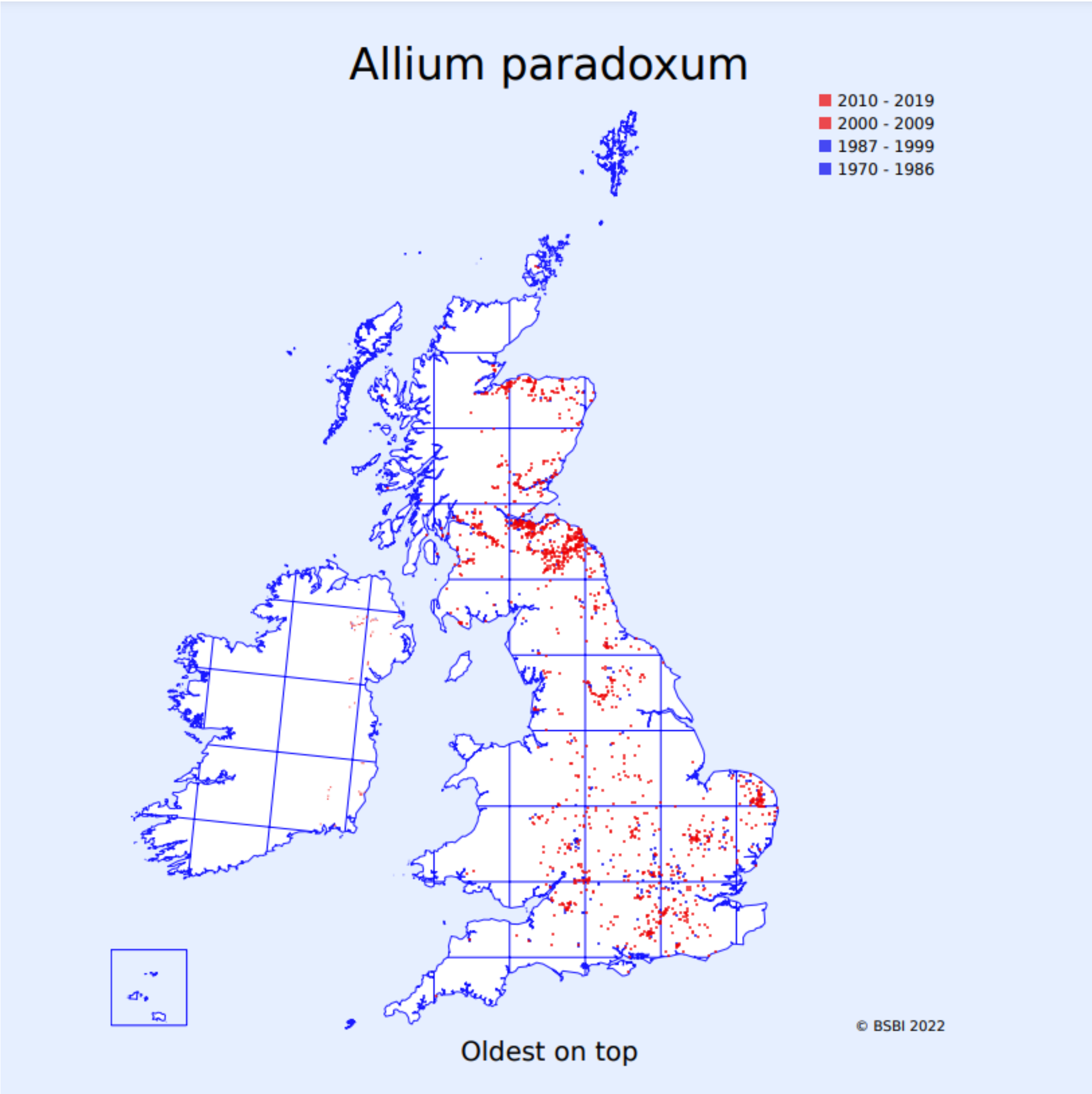
Figure 25. *Myrrhis odorata*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+60	+47	+54	+64

Anisantha diandra is an arable weed of cereal crops that first became established in East Anglia, following its relatively recent introduction. It is increasing rapidly and has spread to Scotland. The pattern of its distribution is instructive. It depends on being transported by farm machinery tyres and as a rare impurity in grain. In these ways it can colonise right across Britain's cereal-growing regions.

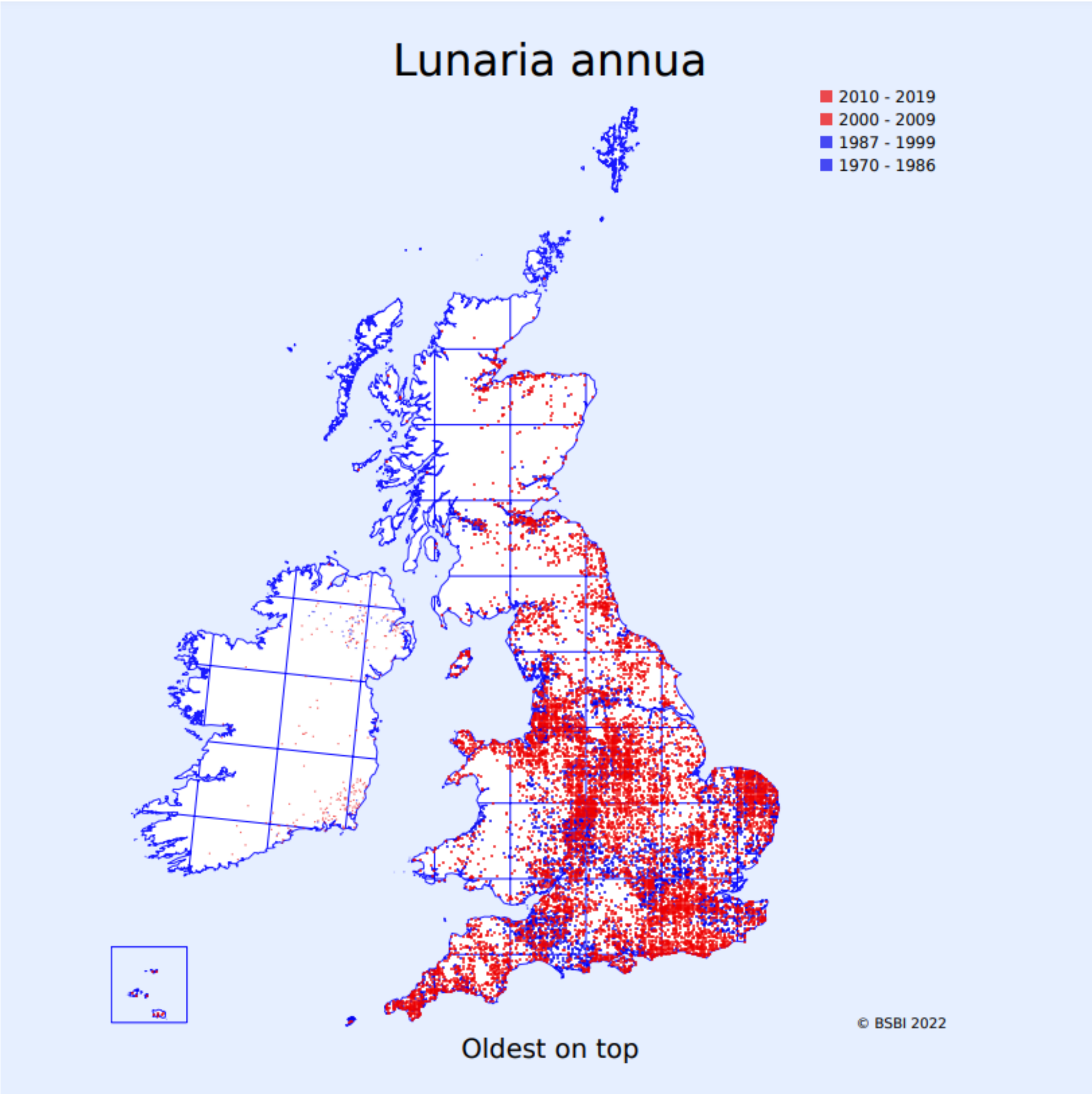
Figure 26. *Anisantha diandra*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+35	+32	+17	-20

Allium paradoxum is a highly invasive colonist of woodland, riverbanks and roadsides. It is a pestilential garden weed and outcasts account for some of its spread. The tetrad map suggests that it is just starting to spread invasively in southern England and might come to match the population densities of the Scottish Borders.

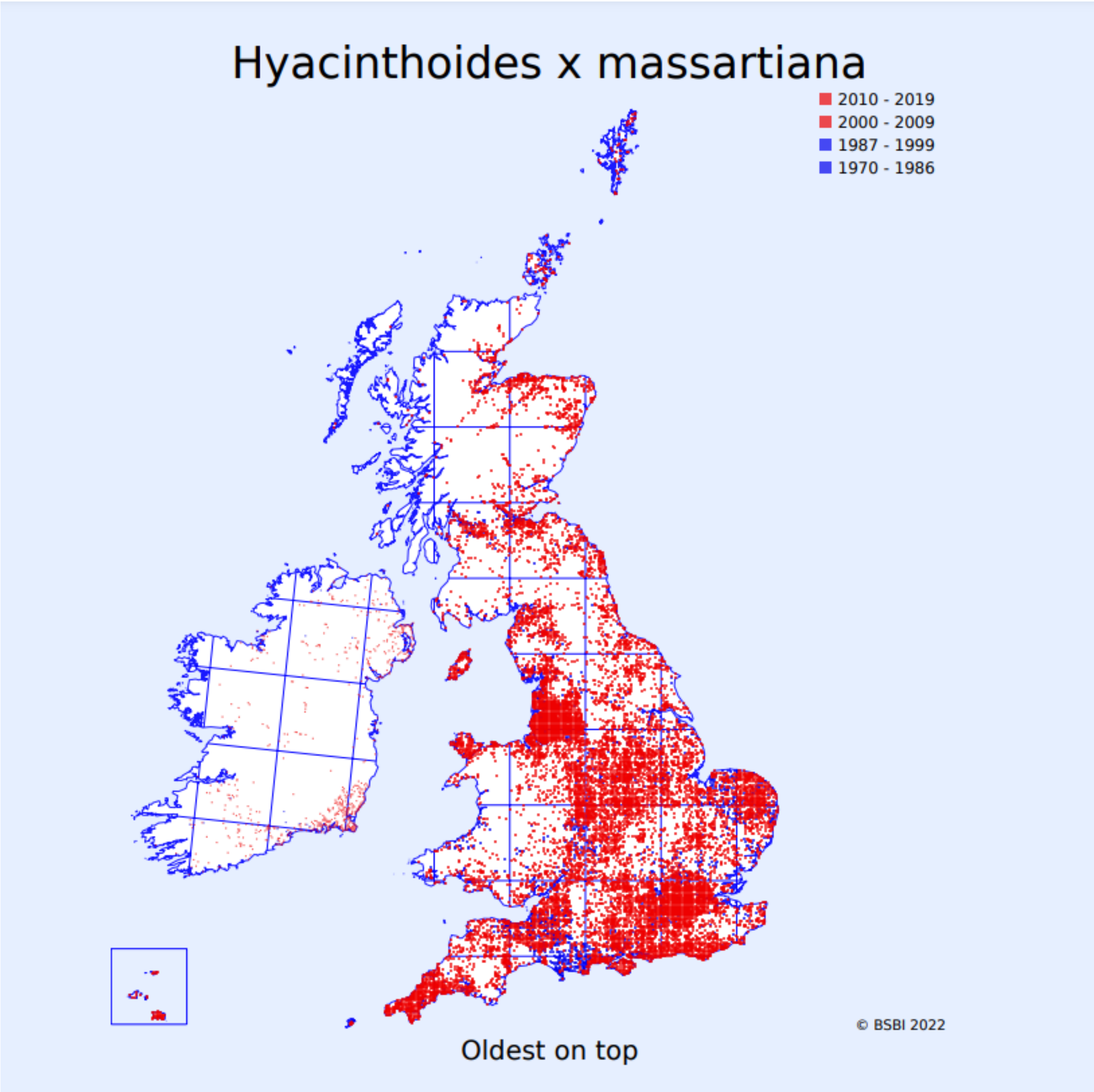
Figure 27. *Allium paradoxum*



% Change per decade			
LC	England	Scotland	Bedfordshire
+35	+10	+2	+61

Lunaria annua is a familiar garden plant that spreads less freely than might be expected. It occupies the same hedge-bottom habitat as *Alliaria petiolata* but is much more often confined to a 100 m strip adjacent to the garden from which it escaped, where field-botanists were reluctant to record it. This rule appears to have been broken in recent years and there is also much evidence of recent colonisation.

Figure 28. *Lunaria annua*



% Change per decade			
LC	**England**	**Scotland**	**Bedfordshire**
+69	+47	+41	+100

Field-botanists have long been aware of *Hyacinthoides* x *massartiana*, but treated it as a cultivar of *Hyacinthoides non-scripta* notable for a modest proportion of mauve-flowered plants. Since its taxonomy was clarified, it has become something of a notoriety and has been recorded assiduously. The density of its distribution at tetrad scale is astonishing.

Figure 29. *Hyacinthoides non-scripta* x *hispanica* = *H.* x *massartiana*

Discussion

The statistics of distribution change for individual species used in the LC Report are fairly closely confirmed by the analysis of the tetrad distributions of these species over the whole of England, albeit for broader dateclasses.

The statistics prepared for Scotland and Bedfordshire are far less satisfactory. The Scottish tetrad coverage was not even roughly comparable between the two dateclasses used, so it is something of a surprise that any usable comparisons could be made. The statistics for Bedfordshire are disappointing, as the two surveys compared both had excellent coverage. It seems that the recording strategies of the individuals concerned differed substantially and that there may have been access issues. This is not unexpected given the difficulties in preparing even a representative list of species for an area of 400 hectares, let alone a full list. It is nevertheless a sobering reflection on the BSBI tetrad recording strategy.

Unlike the statistics, the tetrad distribution maps downloaded from the DDb fully justify tetrad recording. They provide a whole new insight into Britain's species distributions that builds on the hectad maps of the 'New Atlas' (Preston et al, 2002). While maps showing calcareous grassland species following the distribution of chalk and limestone have long been available, Britain-wide maps showing species following river systems are more of a novelty. Equally, the tetrad maps demonstrate the colonisation processes of increasing species. Ferns and orchids are able to cross large areas of unfavourable habitat naturally. Other species depend on the agency of man, whether indirectly via the transport network or more directly as seed contaminants or deliberate introductions. These differing dispersal strategies give rise to differing distribution patterns. DDb, BSBI's Species Distribution Database, has become a formidable resource, one that BSBI has every reason to be proud of.

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