

## Environmental Change and Biodiversity

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### Abstract

To avoid reaching conclusions that are subsequently proven to lack realism, details are given of three case studies (a) Mycorrhizas and mycorrhizal fungi, (b) The role of phenology in assessments of plant/animal interactions and (c) Nitrogen and defoliation: their effects on the competitive abilities of *Calluna vulgaris* and *Nardus stricta*. These case studies highlight a range of interactions that may strongly influence the effects of environmental change on biodiversity. The value of longterm monitoring is stressed also the need to take observations in the field where plants, and their responses to environmental change, are likely to be influenced by interactions with other plants, and harmful and beneficial microbes, invertebrates and vertebrates.

**Key Words:** *Climate change, Defoliation, Diversity, Flowering, Interaction, Mycorrhiza, Mycorrhizal fungi, Nitrogen, Phenology*

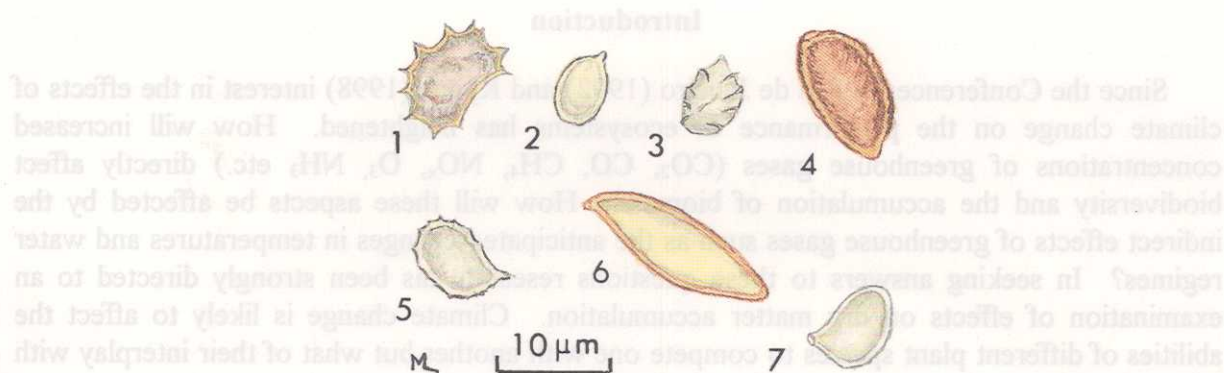
### Introduction

Since the Conferences in Rio de Janeiro (1992) and Kyoto (1998) interest in the effects of climate change on the performance of ecosystems has heightened. How will increased concentrations of greenhouse gases (CO<sub>2</sub>, CO, CH<sub>4</sub>, NO<sub>x</sub>, O<sub>3</sub>, NH<sub>3</sub> etc.) directly affect biodiversity and the accumulation of biomass? How will these aspects be affected by the indirect effects of greenhouse gases such as the anticipated changes in temperatures and water regimes? In seeking answers to these questions research has been strongly directed to an examination of effects on dry matter accumulation. Climate change is likely to affect the abilities of different plant species to compete one with another but what of their interplay with (a) the beneficial microbes upon which they depend, some obligately, in natural environments for instance the many different types (species and isolates) of mycorrhizal fungi and bacteria and (b) the animals, invertebrate and vertebrate, that, directly and indirectly, depend upon them? Knowledge of these interactions is essential if balanced projections are to be made of the responses of multi-faceted ecosystems to climate changes.

#### (a) Mycorrhizas and mycorrhizal fungi

Fifty years ago I was a plant pathologist concerned with the epidemiology of cereal powdery mildew (*Erysiphe graminis*) whose spores (*conidia* and *ascospores*) are distributed through the atmosphere. Before 1952 the methods available for collecting airborne spores (also pollen) – ‘static’ slides and cylinders – were exceedingly inefficient and selective (Gregory, 1952; Gregory and Stedman, 1953): they favoured microbes with large spores but even the collection of these was greatly influenced by air movements – trapping efficiency, while still low, was less so in windy conditions. By modifying the Cascade Impactor, a suction air sampler devised by May (1945), Hirst produced an Automatic Volumetric Spore Trap

(AVST) whose use was to revolutionize aerobiology. Unlike rods and slides it had a high, and relatively unselective and unvarying collection efficiency (Hirst, 1952). With its use the concentrations and variety of airborne spores trapped, increased out of all recognition: it became possible for the first time to obtain worthwhile estimates of airborne concentrations. At the time I was intent on increasing knowledge of the distribution of *E. graminis* and while doing so was fascinated by the diversity and often large numbers of basidiospores that were caught. Most of the basidiospores were traced to genera within the yeast-like Sporobolomycetaceae that colonize leaf surfaces - phylloplane microbes (Last and Warren, 1972) - but others were attributed to species of *Thelephora*, *Inocybe*, *Lactarius*, *Cortinarius*, *Russula*, *Boletus* and *Amanita* (Fig. 1). At the time - in the 1950s - there was interest in basidiospores as allergens but their relevance to plant growth had still a long way to go before being accepted. In 1995 Newsham *et al.*, articulated a developing consensus. They wrote "Experiments (observations) on non-mycorrhizal plants of species that are usually mycorrhizal are artefactual (unrelated to real life)": plants, of the same species with, or without, mycorrhizas are not the same. The presence of mycorrhizas can facilitate phosphorus and nitrogen uptake, moderate the uptake of cadmium, copper, nickel and zinc, enhance water uptake particularly in drought conditions, strengthen plant defences against herbivores and enhance resistance/tolerance to root pathogens (Newsham *et al.*, 1995). Seven different kinds of mycorrhizal associations have been identified - endo-, ecto-, ectendo-, arbutoid, monotropoid, ericoid, orchid (Harley and Smith, 1983).



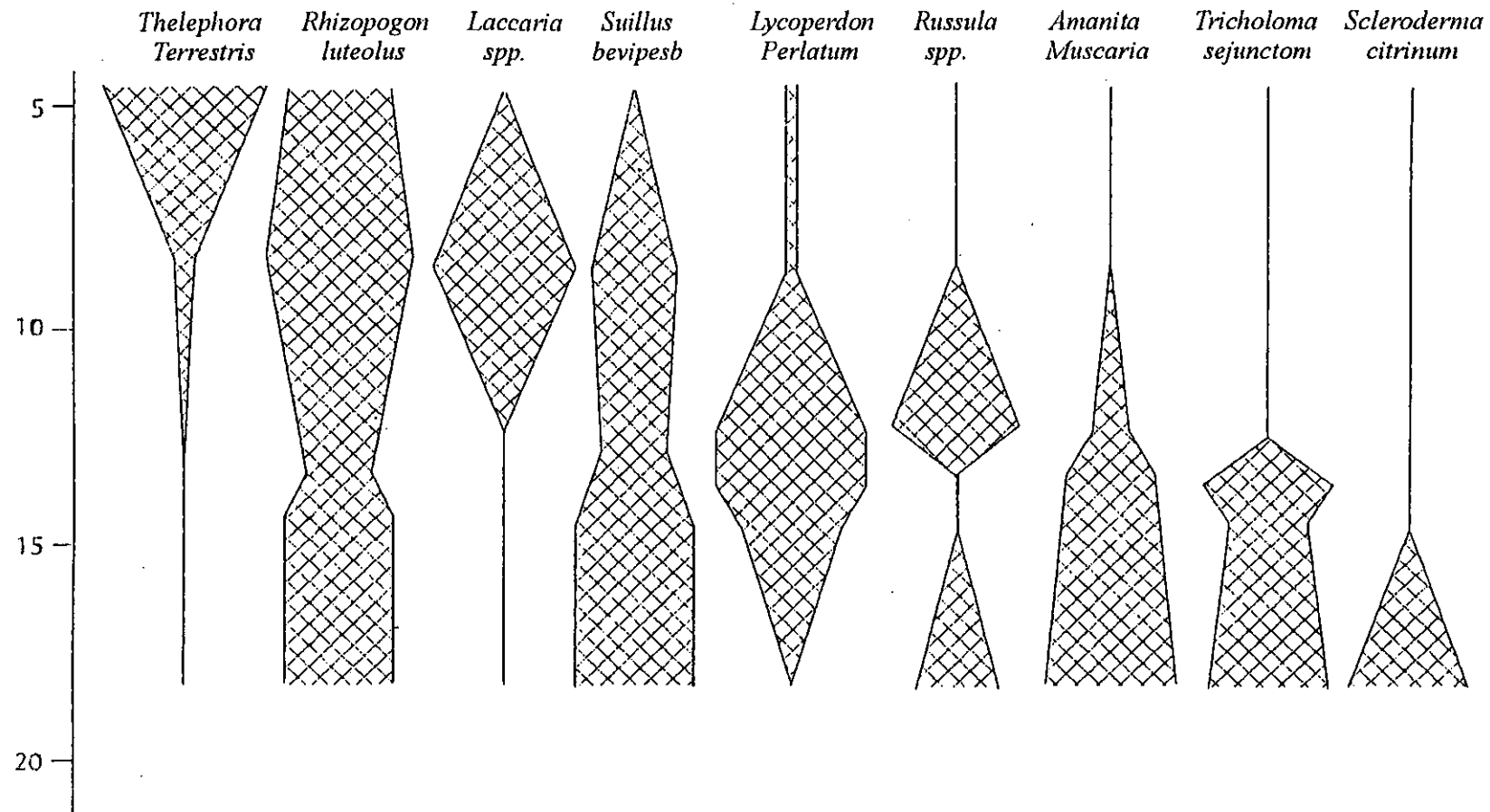
**Fig. 1 Diversity of air-spores. Spores of seven basidiomycetes that form sheathing ectomycorrhizas.** 1, *Thelephora terrestris*; 2, *Inocybe geophylla*; 3, *Lactarius rufus*; 4, *Cortinarius elatior*; 5, *Russula nigricans*; 6, *Boletus scaber*; 7, *Amanita rubescens*. (Drawings made by Maureen Lacey).

In terms of genera and species involved, the diversity of ecto- (sheathing) mycorrhizal fungi is much the greatest. Much has been written in the last 20 years about their ecology and epidemiology. It is clear that there is a diversity of ectomycorrhizal fungi can be associated with natural and man-made (plantations) stands of trees and from the latter there is overwhelming evidence that the occurrence of these fungi can be highly ordered. Critically it has been shown, in many instances, that basidiomes of mycorrhizal fungi above ground reflect the occurrence below ground of mycorrhizas attributable to the same fungus/fungi (see Warcup in Mason *et al.*, 1983) (Table 1). Mohan (1991) in southern India found that earthfans

**Table 1** The relation between (i) fungi isolated from different mycorrhizas and (ii) the occurrence of basidiomes when observations were made on 5 birch saplings of *Betula pendula* during their fourth season after being planted into a brown earth. Warcup in Mason *et al.* (1983)

Tree	Fungi isolated from different mycorrhizas	Basidiomes recorded in association in the autumn
1	<b>Thelephora terrestris</b>	None
2	<i>Hebeloma</i> sp. An unidentified basidiomycete An unidentified ascomycete	<i>Hebeloma</i> sp.
3	<b>Laccaria 'laccata'</b> An unidentified basidiomycete A white ascomycete differing from the unidentified ascomycete ex tree 2.	<b>Laccaria 'laccata'</b>
4	<i>Hebeloma</i> sp. <b>Lactarius pubescens</b> <i>Thelephora terrestris</i> An unidentified ascomycete	<i>Hebeloma</i> sp. <b>Lactarius pubescens</b>
5	<i>Hebeloma</i> sp. <b>Lactarius pubescens</b> <b>Laccaria 'laccata'</b> An unidentified ascomycete	<i>Hebeloma</i> sp. <b>Lactarius pubescens</b> <i>Laccaria 'laccata'</i>

of *Thelephora terrestris* and puff-balls of *Rhizopogon luteolus* were abundant in young (5 years-old) plantations of *Pinus patula* in which they accounted for a significant proportion of the ectomycorrhizas. However in older stands (18 years-old) of *P. patula* in the same locality *T. terrestris*, which was virtually absent, was replaced by, among others, *Suillus brevipes*, *Amanita muscaria* and *Tricholoma sejunctum* (Fig. 2). There is therefore evidence of temporal changes to which can be added a spatial dimension. To the best of my knowledge (Plate 2 in Rayner 1945), Rayner was one of the earliest, if not the earliest, to show that the toadstools of the ectomycorrhizal *A. muscaria* can be found arranged concentrically around trees. By annually observing the occurrence of basidiomes associated with an ageing stand of birch, *Betula pendula*, the spatial and temporal aspects of their occurrence emerged with clarity (Fig. 3). Taken together the evidence indicates that a consideration of the diversity of tree species should not be divorced from a parallel consideration of the diversity of associated mycorrhizal fungi. This conclusion has an added significance because the sparse amount of data available suggests that ectomycorrhizal fungi only produce their basidiomes when, through their mycorrhizas, they can be influenced by the current metabolism of their host trees (Rommell, 1938; Last *et al.*, 1979). Will the diversity of mycorrhizal fungi be affected by climate change? As yet it is not possible to answer this question but the work of Arnolds (1991) is suggestive. He argued that the available evidence in Europe suggests that fewer ectomycorrhizal fungi are producing basidiomes/sporocarps, notably those (*Cortinarius*, *Hydnellum*, *Phellodon*, *Suillus* and *Tricholoma*) associated with trees more than 40 years-old particularly conifers. He argues that their loss is likely to be attributed to the indirect effects of air pollutants in particular to increases in amounts of soil-N and concomittant acidification. But I hardly need stress that nitrogen pollutants are just one of many different groups of greenhouse gases that can directly and indirectly bring about environmental change. Others may have similar or more disruptive effects.



**Fig.2** The occurrence and relative abundance of sporocarps/basidiomes (earth balls, earth fans, puff-balls, and toadstools) of seven sheathing (ecto-) mycorrhizal fungi found in association with plantations of *Pinus patula* (4-19 years-old) in the Nilgiri Hills, Tamil Nadu, India (Mohan 1991). (Explanation: numbers of *Thelephora* earth-fans were maximal in plantations four to five years-old, but they were not observed in plantations 12 or more years of age; puff-balls of *Rhizopogon* were abundant in plantations of all ages and so on.)

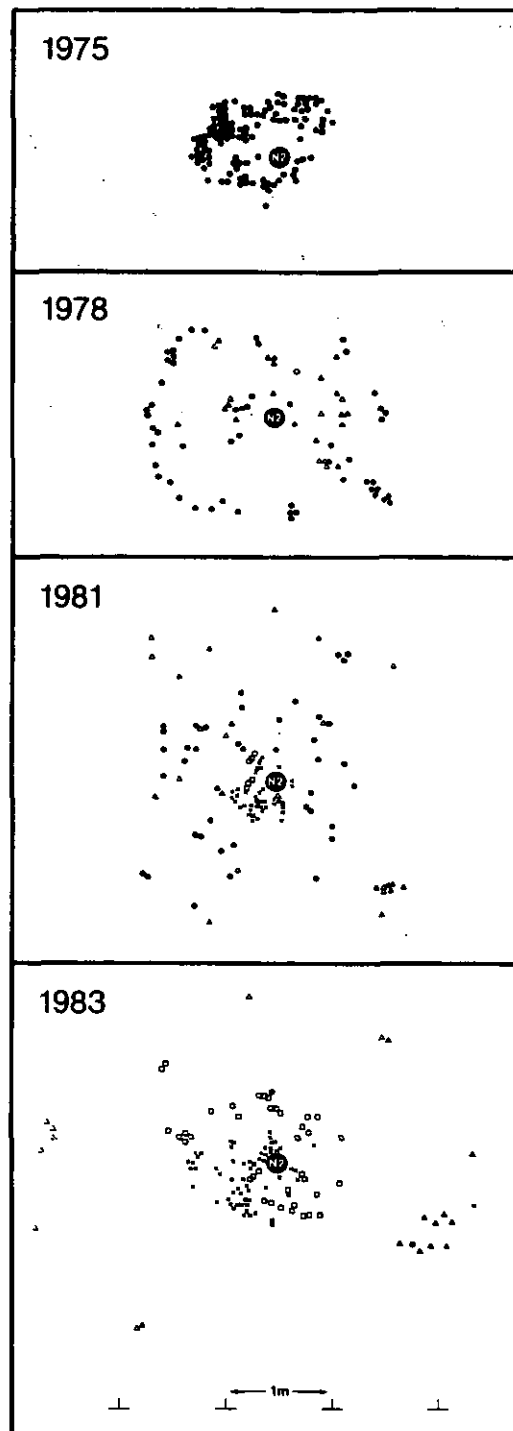


Fig. 3 Positions of basidiomes (toadstools) of sheathing mycorrhizal fungi produced in late summer/autumn of 1975, 1978, 1981 and 1983 around the stem of a specimen (N2) of silver birch (*Betula pendula*) planted as a seedling in 1971 in a former agricultural site. ●, *Hebeloma* spp. (*H. crustuliniforme*, 1975 and 1978; *H. fragilipes*, 1981 and 1983); △, *Lactarius pubescens*; ◆, *Ramaria* sp.; ○, *Leccinum roseofracta*; □, *Russula 'grisea'*; x, *Cortinarius* sp.

## (b) The role of phenology in assessments of plant/animal interactions

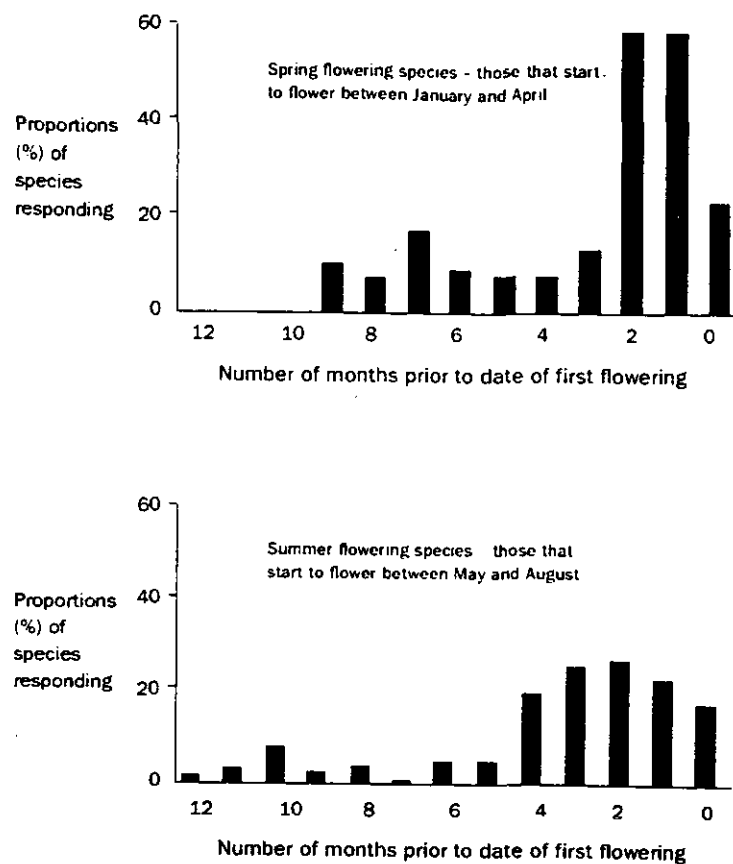
Ornithologists, amateur and professional, have for many years and in many parts of the world, made it their business to monitor systematically the ever-changing populations of birds. Slowly but surely knowledge is being gained of the year-to-year changes that might be attributed to the effects of seasonally different weather. More recently this sort of activity (monitoring) has been widened to include butterflies and moths (lepidoptera) but, with some notable exceptions (terrestrial orchids, see Wells and Willems, 1991), surprisingly little is known, or has been done to acquire knowledge, of the demographic changes of plants. The recruitment of new individuals to populations of many plant species reflects, on the one hand, the damage to foliage, flowers, seeds and roots done by herbivores and, on the other hand, the benefits attributed to pollinators. It is likely that the balance between damage and benefit will be affected if longterm climatic changes were to disrupt the essential synchrony between flowering and the availability of pollinators (see Augspurger, 1981). Regrettably it is not possible to conjecture the magnitude of possible effects - more needs to be known about both the flowering behaviour of plants and the activities of pollinators in relation to weather. By not being proactive a major opportunity has been lost over the years because of the reluctance of institutions to allocate resources to monitoring an activity that has been erroneously regarded by many research workers as unworthy - happily there are signs that the stigma is lessening.

The small amount of literature dealing with the effects of season on flowering suggests a very complex set of responses, some unexpectedly large. John Morris monitored, in pictures, the flowering of horse chestnut (*Aesculus hippocastanum*) in Norwich, UK over a period of more than forty years. He found on 1 April that buds were unopened when the mean air temperature of the preceding month had been 3°C, as in 1917, whereas in 1920, when the mean temperature during March had been 9°C, the trees were in leaf and flowering (see Smith, 1968). These observations were, however, predated by a set of records initiated in 1736 and continued until 1947 by members of the Marsham family who, like Morris, lived near Norwich (Sparks and Carey, 1995). In addition to recording the first flowering of *Anemone nemorosa* (wood anemone), *Brassica campestris* (turnip), *Crataegus monogyna* (hawthorn) and *Galanthus nivalis* (snowdrop), the family assessed leafing of 13 species of trees, the first sighting of 4 species of migratory birds, the croaking of frogs etc. Perhaps to the surprise of members of the Marsham family there were very large differences among the first dates of flowering. On average *G. nivalis* started to flower on day 17 (17 January) but in the earliest season it started on day 348 (14 December) in the preceding year (that is 34 days earlier than average) and on day 72 in the latest season a span of 89 days. In the other 3 species the ranges were 71, 55 and 142 days. With such large year-to-year variations it is surprising that time trends have been detected. However it seems that the first date of flowering of *A. nemorosa* may have advanced 0.10 days  $y^{-1}$ . The dates of leafing were similarly variable - 53 days in *Quercus* spp. the least variable and 97 days in *C. monogyna* the most responsive. Further analyses suggest that leafing in sycamore, oak and beech is advanced by warm temperatures whereas in birch it is delayed.

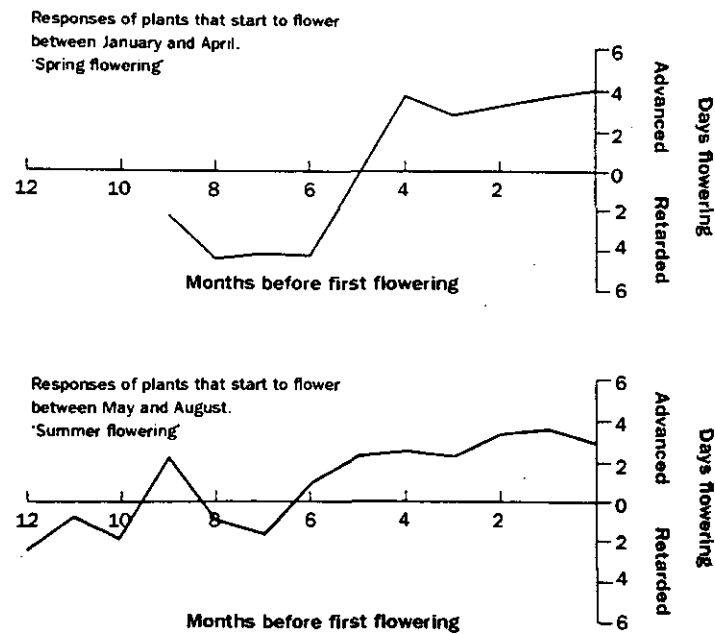
More recently Fitter *et al.*, (1995) have published data restricted to first dates of flowering but of an extended range of spring- and summer-flowering species numbering 267 in total. Both groups were strongly influenced by temperatures in the month of flowering and those 1 and 2 months earlier in the case of spring-flowering species and 1, 2, 3 and 4 months earlier in the case of summer-flowering species (Fig. 4). An increase of 1°C during these months advanced flowering by 3 to 4 days per degree per month. To an extent these effects on spring-flowering species could be offset by the retarding influence of warmer temperatures 5 or more



months prior to flowering: effects of this sort were much less with summer flowering-species (Fig. 5).



**Fig. 4 Proportions of Plant Species whose flowering was affected by air temperature changes at different intervals before flowering. After Fitter *et al.* (1994)**



**Fig. 5 Effects of 1°C changes in mean monthly air temperatures on the first dates of flowering of either spring or summer flowering plants. After Fitter *et al.* (1994)**

These observations made by Fitter *et al.* indicate some of the problems that may be involved when predicting effects of climatic changes. They have been confirmed and extended by observations that I have made over 23 years on 650 species and cultivars growing in the garden attached to my home in the coastal plain to the east of Edinburgh, Scotland. Some species are very responsive to temperature changes while others, such as *Malus domestica* (apple) and *Lunaria annua* (honesty), are not. With observations made once a week *L. annua* has never started to flower before wk.15 (mid-April) nor later than wk.17: the comparable data for apple are wks.17 and 20 - differences of 2 to 3 weeks. In the group of responsive species the differences between the earliest and latest dates of first-flowering are commonly 10 or more weeks apart. In *Choisya ternata* (Mexican orange blossom, an evergreen shrub) the difference is 16 weeks; *Doronicum austriacum* (Leopard's bane, perennial), 14 weeks; *Muscari* sp. (grape hyacinth, bulb), 11 weeks and *Skimmia japonica* (evergreen shrub), 13 weeks. Whereas Fitter *et al.*, found, with their selection of plants, that warmer than average late summer/autumn temperatures delayed flowering in the following year of summer-flowering plants I have many examples, all related to woody species (for example *Azalea* spp., *Forsythia* x *intermedia*, *Lonicera tellmanniana*) in which there is a suggestion that warm periods 12 and 24 months earlier accelerate flowering, the effects appearing to be cumulative.

These observations made in Europe illustrate the complexity of interpreting the changes that one attribute of climate change - air temperature - may trigger. Throughout, the different authors have been unable to identify simple relationships with genera, plant families, growth forms - generalisations are likely to be ill-founded except in so far as events in Japan seem to have their parallels with those in Western Europe. Kai *et al.*, (1996) calculated that *Camellia japonica*, *Prunus Mume*, *Prunus yeodoensis* and *Taraxacum* sp. would flower 7.2, 6.8, 3.0 and 4.1 days earlier in association with a 1°C rise in the mean air temperature during the immediately preceding period of 4 weeks (Fig. 6).

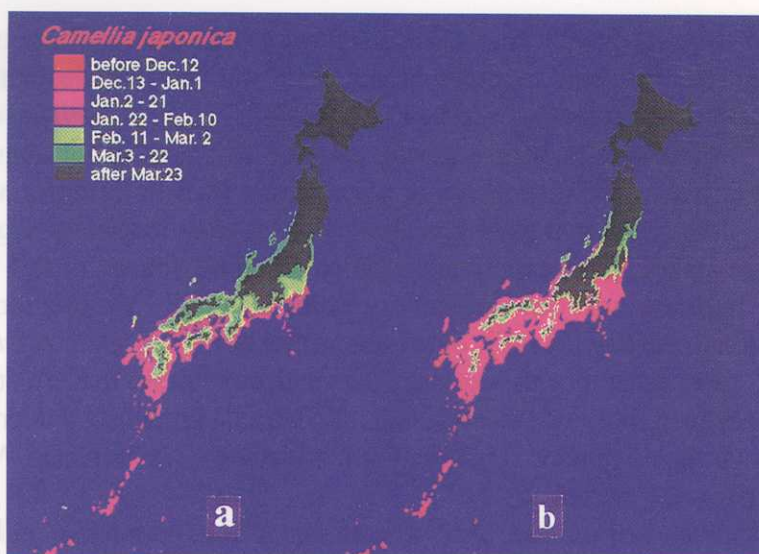
In summary, the effects of temperature changes on dates of flowering are complex. Some species are responsive, some are unresponsive. Temperature increases in the months immediately before the onset of flowering of spring- and summer-flowering species accelerate flowering but comparable changes 8 or 9 months previously may retard it although flowering of woody species may be accelerated with the effect building if there is more than one summer with above average temperatures. Without possessing detailed observations it seems that populations of plants and their pollinators have had sufficient resilience in the past to overcome the often dramatic but ephemeral environmental changes from one season to the next. But will projections based on events of this sort indicate the likely impacts of much smaller and insidious changes that are expected if the emission of greenhouse gases continues without abatement? To understand the effects of longterm climate changes on plant demography, including the composition of plant assemblages, there is a strong argument in favour of starting, without delay, longterm projects **monitoring in parallel** the performance of plants (flowering, seed-set, competitive ability in addition to biomass production) and associated pollinators and predators.

### (c) Nitrogen and defoliation: Their effects on the competitive abilities of *Calluna vulgaris* and *Nardus stricta*

During the 1970s and 80s interest in airborne N-pollutants was first focussed on their role, together with SO<sub>2</sub>, in the production of symptoms of foliar damage and then with acidification, the former being primarily related to dry deposition and the latter to wet deposition. Since



A.



B.

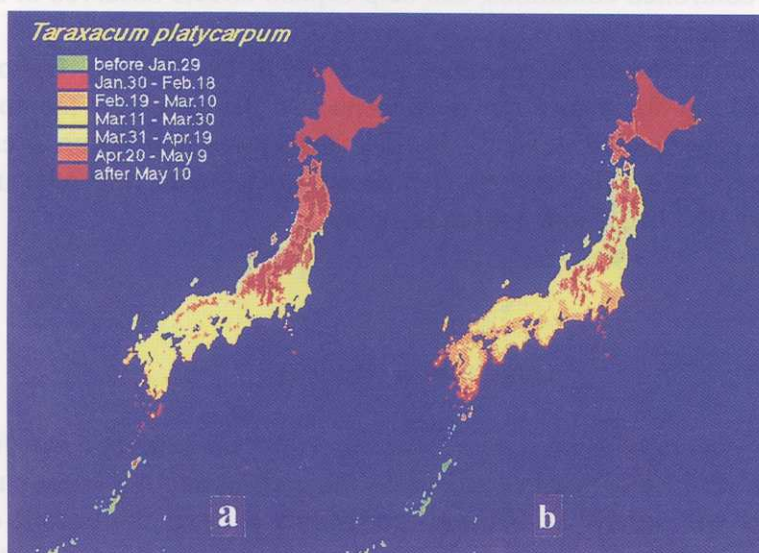


Fig. 6 Flowering of A. *Camellia japonica* and B. *Taraxacum* sp. Kai *et al.* (1996).

a) Mean dates of first flowering (1951-1980), b) Projected dates of first flowering should the mean air temperatures be increased by 3°C from December to April inclusive.

then emissions of  $\text{NO}_x$  have continued to increase globally but the rate of increase is relatively smaller (even decreases are recorded) in Europe and North America than in South East Asia with its rapidly expanding economies. At the present time the annual emissions of reduced-N ( $\text{NH}_3$ ) nearly match those of oxidised-N - about 50TgN compared to 55TgN. Within the UK, and elsewhere, the annual deposition of N differs among a variety of vegetation types growing in different environments. The deposition to forest, moorland, grassland and arable is estimated at 33, 16, 15 and 16KgN  $\text{ha}^{-1}$  respectively with reduced-N accounting for 55% to 78% (Fowler, 1999). In relation to forest and moorland ecosystems it is thought that these amounts are equal to or greater than, the *critical loads* as defined by the United Nations Economic Commission for Europe - a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on sensitive elements of the environment do not occur according to present knowledge. If this is so, how might these amounts of predominantly reduced-N affect the competitive abilities of the different elements of moorland vegetation? Hartley and Amos (1999) have been doing a series of pot and field experiments

focussing on *Calluna vulgaris* (heather) and *Nardus stricta* (mat-grass). In pots supplied with amounts of N thought to be about 4 times larger than both current deposition inputs and critical loads for heather moorland (Grennfelt and Thornelof, 1992), *N. stricta* responded more in the presence of *C. vulgaris* than with a similar number of plants of its own kind. On the other hand *C. vulgaris* was more responsive in pure stands than in mixtures with *N. stricta*. Taken together these data suggest that N-greenhouse gases may indirectly trigger substantial changes in competitive ability. This experiment yielded further evidence of this type of change when the effects of periodic artificial defoliation were analysed. Defoliation prevented *C. vulgaris* responding to added-N whereas it didn't inhibit the N-responses of *N. stricta*.

When, however, this research was extended to field conditions the effects were not so unequivocal. In the absence, but not the presence, of 'natural' grazing, by deer and sheep, *C. vulgaris* in mixed swards responded positively to added-N. In contrast *N. stricta* only responded when swards were grazed.

These results, which are not unique, carry a warning. Pot experiments, and other sorts of experiments done in controlled conditions, can help explain effects observed in the field but by themselves they can mislead.

In an earlier section of this paper reference was made to the obligate relationship between trees and ectomycorrhizal fungi and the dependence of the latter on the formers' current metabolism. In the experiments done by Hartley and Amos defoliation greatly decreased amounts of *C. vulgaris* root colonized by *Hymenoscyphus ericae*, the relevant mycorrhizal fungus, from 18.6 and 19.7 to 2.9 and 3.4 cm soil core<sup>-1</sup>.

### Concluding remarks

When preparing this contribution about *Environmental Change and Biodiversity* I chose to take three case studies each of which emphasizes the need to adopt a holistic approach. It is known that few trees will survive in 'natural' conditions without the benefit of mycorrhizal associations. Because trees with and without mycorrhizas are not the same, studies on them should take careful note of mycorrhizal status and to be of relevance to the real world mycorrhizas should be present. Because of their importance, knowledge of the biodiversity of mycorrhizal fungi should be accorded priority.

The second case-study was concerned with plant performance in terms of flowering instead of the usual arbiter, biomass. How will flowering respond to climate change? The few observations available, some dating to the 18th century, indicate that the responses are varied and complex. For this reason greater credence should be given, than heretofore, to the fruits of longterm monitoring. As with trees and mycorrhizas the benefits of monitoring flowering would be very greatly enhanced by parallel observations of pollinators and pests also pathogens. The third case-study continued the dominant theme - namely the interaction of plants with other biota: in this instance the indirect influence of greenhouse gases on the interplay between plants and herbivores. Very importantly attention was drawn to the need to avoid unrealistically extrapolating from relatively simple controlled experiments to multifaceted field conditions.

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