PART IV

EFFECTS of GLOBAL WARMING on PESTS in NORTHERN BRITAIN

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Introduction

The British Isles are often said to have weather but no climate because conditions vary so widely from place to place and from year to year. For this reason it is easier to find examples of the influence of specific weather conditions on pests in Britain rather than identify, except in a broad sense, the effect of climate.

Three inter-related components of climate affect insects; energy, chemical composition of the atmosphere and air movement (Baker, 1972). Raised temperatures resulting from increased atmospheric [CO_2] are likely to have far more serious consequences for insect pests than the raised [CO_2] level itself. Small changes in environmental CO_2 concentration have been shown to affect the host seeking behaviour of many phytophagous and blood sucking insects. The effects of modifications in plant metabolism as a result of projected increases in atmospheric [CO_2] may alter the feeding behaviour of phytophagous insects. Limited studies to date suggest that any increase in leaf consumption on plants grown in CO_2 enriched environments will be offset by increases in the amount of leaf material produced (Nicolas & Sillans, 1989). However, in experiments where caterpillars were fed on plants grown in enriched CO_2 environments, Fajer *et al.* (1989) found that the caterpillars grew more slowly and experienced higher mortality than those reared on low [CO_2] foliage. They suggest that the high [CO_2] foliage was a porrer host because it contained less nitrogen and water. Whilst we should not neglect the contributions of light intensity, day length, pollutants, water vapour (humidity) and air movement to local climate, it is the input of energy as heat that has received most attention because of its influence on metabolic rate and thus insect activity. Temperature exerts a dominant influence on the distribution and rate of development of insects. Most stages develop at rates that are directly proportional to temperature. Units of growth can be defined in terms of the temperature-time integral, thermal time (e.g. Kelvin-days, Kdays) (Baker, 1980). The concept of accumulating "effective temperatures", i.e. temperatures above some theoretical base temperature for development until a defined biological event has been widely applied by entomologists to predict events in insect life cycles, e.g. egg hatching or adult emergence. The method has also been used to determine the risk of non-indigenous insects establishing populations outside their present geographical range (Baker, 1972).

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However, if temperatures rise in Northern Britain, future pest problems will not be predicted solely by reference to the present situation in warmer areas further south. Long-term average temperatures give no indication of variability and have less biological meaning than the short-term changes that they conceal (Messenger, 1959). The same temperature conditions may have different effects depending on whether they occur in spring or autumn and, as Smith (1974) pointed out, rapid rates of temperature change may have much greater effects than the same temperature changes occurring slowly. It is the extreme values, particularly during the winter, which have a greater influence on insect pests. It is important, therefore, to distinguish the effects of temperature increase at different times of the year. Since overwintering survival and the date when activity starts in the spring play a major role in the ecology of many northern pests, particular attention should be paid to the consequences of warmer winters.

In general, pest problems in Northern Britain are likely to become more important as a result of global warming because a warmer climate will:

1. Increase rates of development and the number of generations per year.

2. Enable pests at the margins of their distributions to extend their range.

3. Increase the risk of invasion by migrant pests.

4. Increase the risk of alternative hosts and "green bridge" crops for pest survival through the winter.

IV.1a Effects of Warmer Summer Temperatures on Existing Pests

Insects are usually more abundant in warm summers than cool ones. The number of generations and the population density of many pests, such as aphids, are directly related to temperature before populations are limited by natural enemies and decreasing host plant quality. Aphids are among the most damaging pests of arable and horticultural crops, including cereals, potatoes, sugar beet, brassicas and fruit, in the U.K. They are highly adapted to exploit agricultural crops because of their short generation times and enormous fecundity. They feed in the vascular tissues of plants and cause both direct damage by ingesting plant sap and indirect damage by transmitting plant viruses (Part V). Aphid populations fluctuate rapidly and often unpredictably. Warm summer temperatures increase the rate of population growth and in some years vast numbers of migrant aphids have been produced as a result of population explosions on cereal crops (Dewar, Tatchell & Turl, 1984). Aphids produce successive overlapping generations on crops until their numbers are reduced by migration or increased mortality rates. Insects with more complex life cycles, including most other agricultural pests in the UK, usually have a restricted number of generations per year although some are able to produce extra generations in warm summers. Two-spotted mite, *Tetranychus urticae*, is a pest of raspberries in the Pacific NorthWest States, and in Southern England, but not, at present, in Scotland (Doughty, Crandall & Shanks, 1972; Gordon, Woodford & Barrie, 1989). The raspberry cane midge, *Resseliella theobaldi*, produces 2-3 generations/year in Scotland (Woodford & Gordon, 1977) and Norway (Stenseth, 1977), 3-4 generations in Kent (Pitcher, 1952) and 5 generations in Bulgaria (Stoyanov, 1963). For some pests the influence of summer temperature is less direct, but overrides winter mortality and determines the numbers available to damage crops the following year. Flea beetle damage to brassicas in Scotland is usually unimportant unless it coincides with seedling establishment in dry conditions. Following the flea beetle outbreak in 1977, Foster (1984) monitored adult populations in the West of Scotland. He found that the numbers of *Phyllotreta undulata* developing on brassicas and emerging in late summer was related to summer temperature. Larger numbers were produced in hot summers than cool ones. The damage caused by larvae and the late summer generation of adults is usually unimportant but the number of adults entering the winter determines the number available to damage seedlings in the following spring.

Cabbage root fly (*Delia radicum*) is a major pest of brassicas and has been extensively investigated by Finch and colleagues at the Institute of Horticultural Research, Wellesbourne. Finch (1977) showed that the peak activity of adults could be predicted from thermal time above 6°C accumulated from 1 January. He found that three generations developed at Wellesbourne, the adults showing peaks of activity at 227, 601 and 1115 Kdays. The fly requires less calendar time to complete a generation in warmer than in cooler years and can only complete three full generations in warm years (Finch & Collier, 1988). If the first generation develops slowly because of cool conditions in May and June the second generation adults lay eggs during a period when the day length falls below a critical level. The larvae go into diapause in response to declining temperature/daylength and overwinter instead of emerging as adults for the third generation. Diapause is a delay in development which, in many insects from temperate regions, is induced by decreasing temperatures and daylength, and is an adaptation to winter conditions induced in advance of the onset of winter. Diapausing insects are unaffected by rising temperature and do not continue developing until diapause is broken. Thus, warmer conditions may have less impact on insects with an obligatory diapause than on those species which do not enter diapause.

IV.1b Effects of Warmer Winter Temperatures on Existing Pests

The effect of winter temperature on survival and the date when activity starts in the spring plays a major role in the pest status of many crop insects in Northern Britain. For many pests, the timing of activity in relation to plant growth (phenology) determines the extent of damage. On raspberries, for example, there can be considerable annual variation in the dates of spring emergence of *R.theobaldi (Diptera: Cecidomyiidae), Otiorhynchus singularis (Coleoptera: Otiorhychidae)* and *Byturus tomentosus (Coleoptera: Byturidae)*. Early emergence from overwintering sites in the soil increases the damage caused by *O.singularis* because the weevils destroy opening buds rather than browse on elongating lateral shoots, as they do when they emerge later relative to shoot development. On the other hand, *R.theobaldi* is less of a problem when it emerges before the primocanes begin to split because the shortlived females are unable to find oviposition sites (Woodford *et al.*, 1979).

According to the conclusions regarding the predictions of model climates in Part I, we may expect a rise in the United Kingdom of 1-2C° by year 2010. Increases of this magnitude will have important effects on the development of non-diapause insects during the winter. Base temperatures for the development of different insects lie within a range of 4-10°C. In northern latitudes, where spring comes slowly, temperatures fluctuate around these levels for several weeks. Mean temperature increases of 1-2C° could advance the development of overwintering insects by several weeks. Gordon, Barrie & Woodford (1989) used the annual variations in date of oviposition by overwintered *R.theobaldi* to generate a prediction model based on soil temperatures accumulated from March. The late starting date was chosen to avoid problems with larvae in diapause and because temperatures above the base of 4°C were rarely recorded in January and February. The effect of small differences in winter temperature on the development of *R.theobaldi* are already apparent. Pitcher (1952) recorded oviposition in Kent starting in the first two weeks of May. At SCRI oviposition started on average (1977-85) on 30 May and the earliest date was 18 May (1982). At present, there is a delay of about 2 weeks between the predicted start of oviposition in Surrey/Kent and Tayside. In 1988 the differences between mean monthly air temperatures at Wisley, Surrey and SCRI varied from 0.8C° (June) to 2.3C° (May) and calculated mean soil temperatures were between 1.6 and

2.6C° cooler at SCRI between March and May. As a result, the predicted midge oviposition date was 15 days later at SCRI (Table IV.1).

Table IV.1

Comparison of mean monthly air temperatures and calculated mean monthly 10 cm soil temperatures at Wisley, Surrey and the Scottish Crop Research Institute, Tayside, in 1988, and effect on predicted start of oviposition by *R. theobaldi*.

	Wisley		**SCRI**	
	Air	**10cm soil**	**Air**	**10cm soil**
March	7.3	6.5	5.3	4.3
April	8.5	9.7	7.5	8.1
May	12.9	14.7	10.6	12.1
June	14.7	16.7	13.9	16.7
Predicted date for start of oviposition	10 May		25 May	

The effects of warmer winters on diapausing insects are more difficult to predict because development at temperatures above the base temperature cannot start until diapause is completed. For insects from temperate regions, several weeks of low temperatures are required to break diapause, e.g. 22 weeks at 0-6°C for diapausing pupae of cabbage root fly (Collier & Finch, 1983) and it is uncertain how such insects would behave if the winters become too mild to provide this stimulus. Once diapause is completed, however, development proceeds at a rate proportional to temperature, and emergence would be earlier in warm springs than in cold ones. It is also possible that non-diapausing races will become widespread if winters become milder and there are suitable host plants available throughout the year. *Tetranychus urticae* and the tortricid moth, *Clepsis spectrana* are two field pests that have become adapted to glasshouses by developing races that no longer respond to diapause-inducing factors (van Lenteren & Woets, 1988).

Winter temperature is a major factor determining the survival and development of many aphid pests in Britain. By controlling the size and timing of spring migration, winter temperature largely determines the potential for outbreaks of cereal aphids in the summer (Sparrow, 1974; Carter, Dixon & Rabbinge, 1982; Walters, Watson & Dixon, 1983; Dewar & Carter, 1984). Variations in the incidence of sugar beet virus in England are closely dependent on winter and spring temperatures because of their effects on the survival and spring activity of vector aphids (Watson *et al.*, 1975). In Scotland, Howell (1973) found similar relationships between the incidence of potato leafroll virus (PLRV) and temperatures in February to April. More recently there was a progressive increase in the incidence of PLRV in Scottish seed potato crops from 1974 to 1976 (Howell, 1977). This increase coincided with a series of mild winters. At SCRI the mean air temperatures in January and February were 1.45C° above average each winter from 1971 to 1976 (Table IV.2). The aphid vectors of PLRV migrated earlier than usual during this period (Taylor & French, 1975; Turl, 1980) and colonised potato crops about a month earlier than normal (Woodford *et al.*, 1977). The risk of virus spread is increased when potatoes are colonised in June because the virus may be transmitted from infected plants before roguing and because young plants are more susceptible to infection than older ones

(Cadman & Chambers, 1960). Relationships between winter temperature and the date of the spring migration (determined from the date of the first alatae caught in the Rothamsted Insect Survey suction traps) have been established for several aphid pests (Turl, 1980; Walters & Dewar, 1986; Bale, Harrington & Clough, 1988), but there are differences between those species, such as the potato aphids *Myzus persicae* and *Macrosiphum euphorbiae*, and the grain aphid, *Sitobion avenae*, which overwinter anholocyclically i.e. asexual individuals survive throughout the year, and holocyclic species, such as the blackberry aphid, *Sitobion fragariae* and northern populations of the oat-birdcherry aphid, *Rhopalosiphum padi*, which overwinter as eggs. Aphid eggs can withstand very low temperatures which kill anholocyclic aphids. Holocyclic species are therefore less affected by cold winters than anholocyclic species. In mild winters alatae of anholocyclic species are produced more rapidly than those of holocyclic species. Walters & Dewar (1986) could not establish a significant relation between winter temperature and the timing of the spring migration of *S.fragariae*.

Table IV.2

Mean of daily air temperatures at the Scottish Crop Research Institute for the months of January to April, 1971-76, compared with the 30 year (1954-83) long term average (LTA)

	Maximum		***Minimum***	
	1971-76	LTA	1971-76	LTA
Januqry	6.8	5.5	1.6	0.0
February	6.8	5.6	1.7	0.0
March	8.2	7.9	1.7	1.7
April	11.1	11.0	3.6	3.3

The vectors of PLRV, *M.persicae, M.euphorbiae* and *Aulacorthum solani* can all overwinter anholocyclically on weeds in Scotland. Their survival depends in part on the severity of winter temperatures (Turl, 1983). Although many aphids can supercool to very low temperatures, pre-freeze processes are ecologically more important. Bale, Harrington & Clough (1988) found that pre-freeze mortality (LT50) of unacclimated *M.persicae* occurred at -8.1°C (first instar) and -6.9°C (adults), and -11.8°C and -11.1°C respectively for acclimated aphids. They showed that variations in the total number of frost days in different winters could produce markedly different levels of winter mortality. The factors influencing winter survival of aphids in the field require further consideration. Harrington & Cheng (1984) found that field mortality was associated with leaf surface wetness as well as low temperatures. It is already apparent that the relation between temperature and anholocyclic aphid overwintering and timing of migration varies in different areas of Britain. In the south west, temperature is less critical and other factors, such as rainfall are more important. In Brittany, where the winters are usually mild, overwintering aphids are controlled by Hymenopteran parasitoids. The potential of natural enemies to regulate overwintering aphids in Northern Britain is an unknown factor which requires investigation.

IV.2 New Pest Problems

The implications of global warming have aroused interest in the "species-energy" hypothesis (Wright, 1983) which claims that, given adequate water supplies, species diversity or "richness" (the number of species in a given area) in terrestrial habitats is a function of the amount of solar energy available, and that it is variations in solar energy that account for observed latitudinal gradients in diversity. The hypothesis is difficult to test because both solar energy and diversity decline with latitude, but day-flying insects provide an interesting example to work with. They require warm air and sunshine because their activity largely depends on being able to maintain their flight muscles at temperatures above ambient. Turner, Gatehouse & Corey (1987) showed that the number of butterfly species present in 900 km^2 areas of mainland Britain is highly correlated with sunshine and temperature during the summer but negatively correlated with winter temperature. They developed a model that predicts that 6.6 species of butterfly are added for every Celsius degree increase in mean temperatures (May-September). An hour of summer sunshine had, on average, a similar effect. Whilst not totally eliminating latitude, the effects of climate had a positive effect on diversity only in the summer months when the insects were active. On an evolutionary time scale, insects and plants have co-adapted through natural selection to occupy areas broadly limited by climate. Many insect pests are migratory and could thus move more rapidly than plants into areas which become favourable as a result of climatic warming. Rhoades (1985) suggested that pest outbreaks would, therefore, become more likely because plants in regions, previously beyond the range of pests, would be more susceptible to attack because they had failed to evolve rapid-defense responses.

This argument is less relevant for recent agricultural crops than for native species because of the rapid dispersal and widespread cultivation of crop genotypes throughout large areas of Britain. Problems with new agricultural pests could develop, however, if climatic change favoured the cultivation of new crops or varieties. This has happened recently in France where the release of new maize cultivars adapted to northern areas has resulted in a considerable increase in this crop. The European Corn Borer, *Ostrinia nubilalis*, which is usually contolled by a parasitic fly in the south of France, has become a pest in the north and east, where it is not controlled by the fly (Robert, 1987).

Warmer conditions also increase the risk of glasshouse pests, e.g. the glasshouse whitefly (*Trialeurodes vaporariorum*), surviving outside. In recent years accidental introductions to Britain of non-indigenous pests have resulted in widespread glasshouse contamination by the agromyzid leafminer, *Liriomyza trifolii*, Western flower thrips, *Frankliniella occidentalis* and the whitefly, *Bemisia tabaci*. There would be serious implications for agriculture if these pests were able to survive outside glasshouses. These insects have wide host ranges, are resistant to many different types of pesticide, and *F. occidentalis* and *B.tabaci* are important virus vectors. Some populations of *M.persicae* that are highly resistant to insecticides and now found throughout Britain may originally have been selected by intensive pesticide use in glasshouses (Dunn & Kempton, 1977). There seems to be little risk of the recently introduced glasshouse species surviving outside at present as they require rather high temperatures to develop. *L.trifolii* has a very long pupal stage (138.7 Kdays above 10.8°C) and present winters are too long for it to survive outside (Miller & Isger, 1985).

Although this review has concentrated on the implications of global warming on insect pests, rising soil temperatures will also have predictable effects on plant parasitic nematodes. There is a larger range of potential nematode pest species in England than Scotland and nematode populations tend to be larger in southern England. The recent distributions of nematode pests in Great Britain (Heath, Brown & Boag, 1977) and Europe (Alphey & Taylor,

1986) have been mapped in detail. The virus vector species *Longidorus elongatus* is found throughout Scotland but *Xiphinema diversicaudatum* has not been found north of Dundee although soil type and moisture content do not appear to be limiting. *Longidorus attenuatus* and *L.macrosoma* (also virus vectors) occur in England and damage a range of crops and could become established in Scotland if soils were warmer. Similarly, *X.diversicaudatum*, which transmits strawberry latent ringspot virus, could extend its range if introduced to strawberry crops in warmer soils in northern Scotland.

IV.3 Invasion by Migrant Pests

Small numbers of exotic migrant pests often reach Britain during the summer. The extent of synoptic movement of insects from the Continent of Europe is occasionally very noticeable when mass migrations of insects result in widespread outbreaks. Such events require the juxtaposition of several biological and meteorological factors: favourable conditions for the mass synchronised production and flight of migrants from the country of origin; sustained high level air movements to carry the migrants over Britain; and changed meteorological conditions or insect behaviour resulting in deposition. Such conditions have occasionally resulted in mass invasions of Scottish crops. In 1958, vast numbers of the diamond-back moth, *Plutella xylostella*, suddenly appeared along the east and north coasts of Britain in late June carried on an easterly air stream from areas to the east of the Baltic Sea (Shaw, 1962). Such events could become more frequent if the breeding areas of exotic migrants came closer as a result of global warming. Two major pests, *Helicoverpa armigera* and *Spodoptera literalis* overwinter in Spain but cannot survive winters further north. As temperatures rise, the distributions of these species are likely to move further north and invasions of Britain from the Continent become more frequent.

Migration is a key factor in the present absence from Britain of the Colorado potato beetle (*Leptinotarsa decemlineata*). The beetle has extended its range through much of Europe since its accidental introduction to the Bordeaux area of France in about 1919 and was firmly established in the coastal areas of north west France and Belgium by about 1939. Climate plays an important role in its distribution (Hurst, 1975). The present climate in England is marginal for the continuous development of Colorado potato beetle but two climatic factors have prevented its establishment. It is a weak flyer requiring warm sunny weather, and young larvae are very vulnerable to heavy rain. High temperature (25°C) is the most important meteorological factor for flight. Temperatures over the sea are usually too low to permit successful flights across the Channel and the main risk at present comes from the importation of infested vegetables. The risk of Colorado potato beetle infestations to the Scottish seed potato industry would increase if the beetle were to become established in England.

IV.4 Alternative Host Plants and "Green Bridges"

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The introduction of new crops or cultivars could have unexpected implications for pests and diseases of existing crops. The introduction of the new maize cultivars to northern France is thought to have been partly responsible for the recent outbreaks of Potato Virus Y (PVY) in Brittany because of the large increase in overwintering sites for cereal aphid vectors of PVY (Robert, 1987). Similarly, the recent increase in the area of winter-sown cereals and oil seed rape in Scotland provides new overwintering sites for aphid vectors and increases the risk of aphid-borne viruses such as barley yellow dwarf virus and PVY (Woodford, 1988).

It has also been suggested that oil seed rape increases the risk from cabbage root fly because it provides a large reservoir of plants to support development in spring and autumn (Lamb, 1984; Finch & Collier, 1988).

At the time of writing, the development of barley yellow dwarf virus (BYDV) in winter barley has been widely reported throughout Scotland. Following the mild winter of 1988/89, large numbers of the vector aphid, *Sitobion avenae,* multiplied rapidly in spring and migrants transmitted BYDV to spring sown crops. The migration coincided with the emergence of seed potato crops and increased the risk of spread of PVY.

IV.5 Conclusions

The significance of global warming for pest problems in northern Britain lies not just in the magnitude of the temperature rise that is predicted, but in the rapidity with which these events are likely to occur (Part I). New pest problems are likely, but they will not simply duplicate the present pest problems in warmer areas further south. Aerial transport of pests (and disease organisms), or their importation by man to northern Britain will cause particular problems because these migratory movements can occur rapidly and may outpace our attempts to control them.

The production of healthy planting material makes an important contribution to agriculture in Scotland. The effect of the environment in limiting the spread of pests and diseases has facilitated the development of clean stock (certification) schemes for potato, narcissus and soft fruit in Scotland. A temperature rise of 1-2C° will have predictable effects on the survival and development of insect and nematode pests, and jeopardise the existing methods of producing healthy planting material in Scotland. Finally, the consequences of altered rainfall patterns on pest activity are harder to predict. Increased rainfall would probably decrease pests; decreased rainfall would increase the damage sustained by crops as a result of pest feeding.

The above review has highlighted the serious consequences for agriculture in Northern Britain of the increased risk of aphid outbreaks as a result of global warming. Three major causes have been identified: new "green bridge" crops to maintain local populations; lower winter aphid mortality; larger summer populations.

IV.6 Recommendations for Further Research.

1. Role of winter cereals and oilseed rape in aphid overwintering.
2. Contribution of these crops to the epidemiology of BYDV and potato viruses.
3. Overwintering strategies for predators and parasites of aphids.
4. Effects of temperature on virus transmission by aphids.
5. Effects of CO_2 concentration on rates of virus translocation in plants.

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To end