MORECAMBE BAY REGION AS A LABORATORY FOR CLIMATE CHANGE

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INTRODUCTION

As I write this we are experiencing some of the warmest weather in memory for July. May 2003, we are told, was the warmest since records began, and the last decade of the 20th century was the warmest for 200 years.

There is much talk of climate change and therefore of its consequences to human beings and wildlife. There is no doubt that we are currently experiencing unusual climates. The key question is if this is simply normal variation or should be ascribed to some causal effect such as the accumulation of 'greenhouse' gases as a consequence of human activity, particularly burning fossil fuels and land use changes such as deforestation of tropical trees, both of which occur at increasing rates.

The burning of fossil fuels adds gases like carbon dioxide, sulphur dioxide, oxides of nitrogen, and, as a photochemical derivative, ozone to the atmosphere, which can have direct effects on plant growth, human respiratory problems etc. The indirect 'greenhouse' effect occurs through their accumulation in the atmosphere from both natural events and human activity. This permits incoming, mainly short-wave, radiation to reach the earth but limits outgoing radiation, leading to global temperature rise. It is difficult to be sure that recent climate change is driven by this phenomenon, but sophisticated computer models incorporating measures of atmospheric conditions do predict the kind of changes consistent with this explanation. Whether or not we fully understand the mechanisms involved, it is a matter of observation and measurement that we are currently seeing relatively warm and unstable weather.

SIGNIFICANCE OF THE MORECAMBE BAY REGION

The region around Morecambe Bay happens to be the location for a number of studies of the consequences of these recorded changes. Three institutions in particular have contributed to this: the laboratories of the Centre for Ecology and Hydrology at Grange-over-Sands and Windermere, both soon to move to the campus of the third, Lancaster University.

Professor Terry Mansfield was amongst the first to appreciate the importance to plants of changing atmospheric conditions. As a world expert in the physiology of stomata (the small pores, mainly on the underside of leaves, which regulate gas exchange) he understood that the physiology and biochemistry of all plants would be affected, and with it their growth rates and productivity. This was the start of some 25 years of intensive research at Lancaster into the consequences to living organisms of the accumulation of polluting gases. Much of this was conducted in computer-controlled plant growth chambers (Figure 1) into which minute quantities of polluting gases could be added. A big advantage was the relatively clean air at the university campus, which meant that there had to be little 'scrubbing' of the natural air to provide clean control comparisons with the experimentally treated air.

Figure 1 Experimental chambers at Lancaster University. Image courtesy of R Berry

My interest, as an entomologist, was aroused when a chance infestation of these chambers with the green spruce aphid *Elatobium abietinum* suggested that spruce trees growing in polluted air were much more susceptible to the aphid than those in clean air. Since then we have conducted experiments on a range of insect species by exposing them to sulphur dioxode, nitrogen dioxide, ozone and carbon dioxide alone or in mixtures and at different concentrations. By measuring their feeding rates, growth rates and survival it is possible to detect the effects of concentrations of gases as low as 10 parts per billion (ppb) on the population characteristics of the insects. An example is the common pea aphid, *Acyrthosiphon pisum*, which we exposed, together with the pea plants on which they were feeding, to concentrations of sulphur dioxide from 10 to 300 ppb. We compared the relative growth rates of the aphids (weighed individually on an electro-balance) to those living on plants in clean air (Figure 2). This dose response shows clearly that there is an effect even at the lowest concentrations of pollutants. Their increase in growth rate reaches a maximum at about 100 ppb sulphur dioxide and the added gas does not become toxic (as shown by negative growth compared to clean air) until about 200 ppb. To put this in perspective, the level of this polluting gas in the towns of the industrial north of England might be approximately 100 ppb. Mixtures of the gases have more effect than the sum of the constituent gases. Out of some 65 separate studies of insects, 49 showed increases in abundance in elevated sulphur dioxide or nitrogen dioxide. So parking your car underneath a lime tree in town is far more likely to result in it being spotted with quantities of sticky honey dew than parking it under a tree in the cleaner air of the countryside.

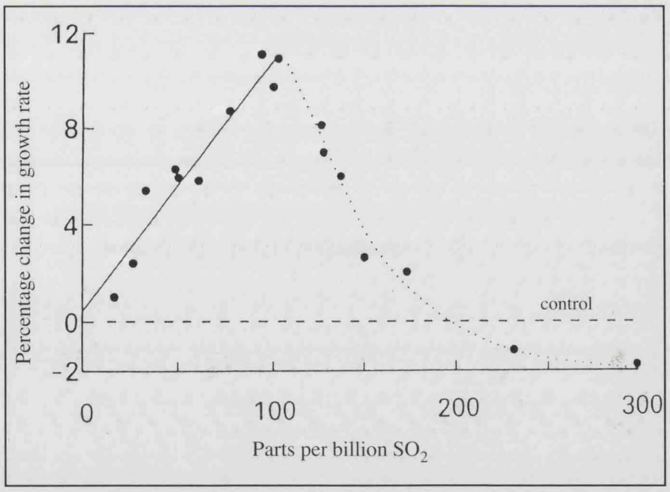

Figure 2 Growth rates of pea aphids in a range of concentrations of sulphur dioxide. Reprinted with permission from Whittaker 2001, Copyright Blackwell Science Ltd.

Figure 3 Protective spittle around larvae of the lined spittlebug, Neophilaenus lineatus. Image by JBW

Fortunately changes in industrial practices and legislation have begun to reduce the emissions of these gases in the UK, but they are still of major concern in developing countries. They might be especially important in, for example, Asia, where it is common for much food to be grown in small allotments and market gardens interspersed with some of the most polluted urban centres in the world.

The decay rates of these gases are different. One which is expected to persist and have an effect even if emissions were cut today, is carbon dioxide. Worldwide atmospheric concentrations of this have risen from about 280 ppm before the industrial revolution to the current 370 ppm. However, responses of insects to this gas are not as predictable as for the other gases mentioned above. A likely consequences is that because the carbon:nitrogen ratios in plant tissues will shift towards greater carbon, herbivorous insects will need to eat more of the plant to grow and reproduce at the same rates.

FIELD STUDIES IN THE NORTHWEST OF ENGLAND

It is commonly assumed that one outcome of the build-up of greenhouse gases will be an increase in temperature. Insects, of course, are poikilotherms, which means that they have a low metabolic rate and high thermal conductance so that their body temperatures change with environmental temperatures and characteristics such as growth and reproduction rates are temperature-dependent. This could mean that the distributions and abundances of insects may change markedly, both locally and globally, in response to elevated temperatures.

This is where the Morecambe Bay region comes into its own as an outdoor laboratory. The three institutions previously mentioned each hold long-term data relating to ecological studies in the region. The importance of these is that they can be re-analysed and correlated with changing environmental variables, permitting modelling of the appropriate species parameters. An example of this are the data which I have collected since 1961 on population fluctuations in the lined spittlebug *Neophilaenus lineatus* (Figure 3). In itself this is not an especially important species although some of its close relatives are major agricultural pests. Its significance lies in the ease of data recording in the field because this familiar 'cuckoo-spit' insect is extremely common, relatively sessile for all its larval life and very visible in the vegetation (grasses and rushes) on which it feeds. For these reasons measurements of its distribution and abundance are likely to be very accurate. It has a widespread distribution from sea level to at least 900m in the Lake District and Pennine hills.

At study sites on the Moor House National Nature Reserve near Cross Fell this insect has fluctuated between fewer than 5 per metre square of vegetation to more than 150 over the last 40 years. Most of this is explained by a computer model based on measured insect and climate parameters (Figure 4). We can tweak this model to test what might happen if we were to have, for example, a 2°C rise, which is roughly what is predicted over the next 50 years. It predicts between 50 and 100% rise in the numbers of this insect[1]. How much confidence can we place in this? The great value of the northwest open-air laboratories is that measurements of insect populations can easily be made along montane transects from low to high altitude ie from higher to lower temperatures. In fact, 300m of altitude or four degrees of latitude equate to 2°C temperature shift. So we can test the effect of changing field temperatures on both distribution and abundance by observing the situation along these transects and by experimentally moving insects from one part of the transect to another. The development period of the lined spittlebug relates to these latitude and altitude shifts (Figure 5). The appearance of adults is delayed by 30 days, for example, at 720m, compared with 280m, which represents a difference of 3.4°C. Interestingly, a recent analysis of 143 studies world wide has shown that the average date of spring phenological events for a wide range of

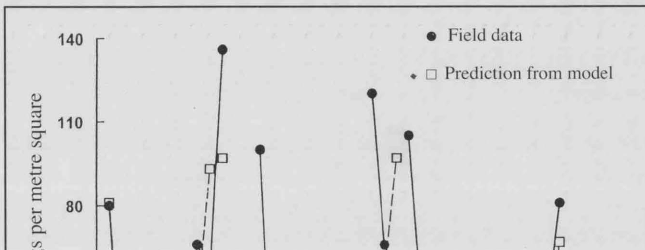

Figure 4 Population density of the lined spittlebug at the Moor House National Nature Reserve 1961 to 1997. Reprinted with permission from Whittaker 2001, copyright Blackwell Science Ltd.

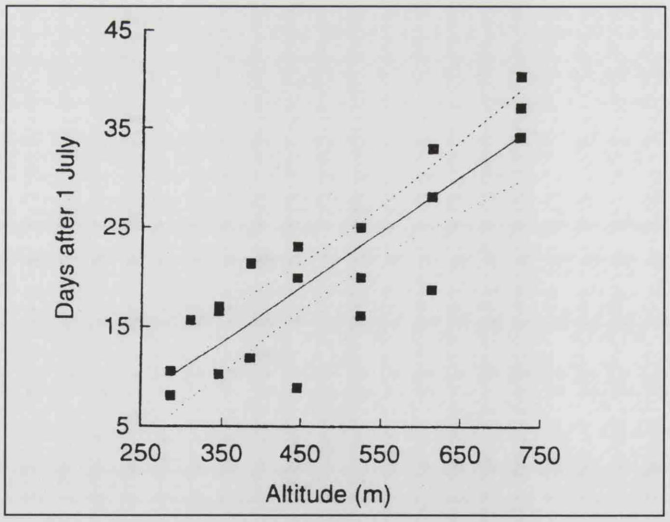

Figure 5 Date of appearance of adult lined spittlebugs at different altitudes on Little Dun Fell (Moor House National Nature Reserve). Reprinted with permission from Whittaker 2001, copyright Blackwell Science Ltd.

temperate species has moved forward by 5.1 ± 0.1 days over the last decade[2] during which we have seen an average temperature rise of about 0.3 degrees. Combining all this information we can predict both the numerical and the distributional changes to be expected in periods of climate change. On Ben Lomond, for example, the lined spittlebug has shifted its upper altitudinal limit by more than 350m during the last decade (Figure 6).

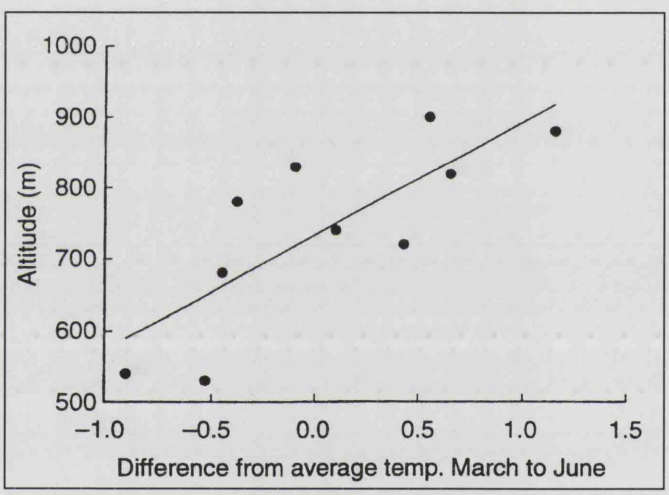

Figure 6 Maximum altitude reached by the lined spittlebug on Ben Lomond from 1986 to 1995 at a range of spring temperatures. Reprinted with permission from Whittaker 2001, copyright Blackwell Science Ltd.

The humble lined spittlebug is only a convenient example of what we might expect. But studies of this kind provide the intellectual basis for predictions of movements and numerical changes in agricultural pests (the pea aphid and green spruce aphid for example) and carriers of human diseases such as mosquitoes and tsetse flies. Many of these are known to be expanding their ranges in temperate regions, but, by experiencing elevated temperatures in their present habitats, may actually be contracting there as environmental conditions become sub-optimal at the upper ranges of their tolerances.

As yet, we do not know which species may prove to be the better adaptors to change but there is emerging evidence that it will not necessarily affect closely related species or even members of the same species equally. An even more common insect, the meadow spittlebug, *Philaenus spumarius,* which lives in all our gardens around Morecambe Bay, is a very good example of this because it exists in about 12 distinct genetic colour morphs in the same species (Figure 7). We expect these to respond differently to temperature change because their variation from light straw colour to jet black offers a range of quite different radiating bodies. Shifts in the frequencies of these colour forms are therefore an excellent indicator of differential adaptation to climate change and are being carefully monitored at nine sites in the UK through the Environmental Change Network programme based at the Centre for Ecology and Hydrology, Grange-over-Sands.

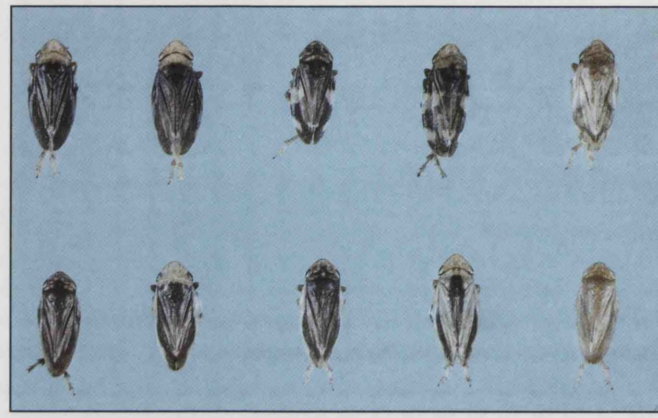

Figure 7 Colour morphs of the meadow spittlebug, Philaenus spumarius. Image by JBW.

CONCLUSIONS

Most insects are not very visible. We tend to judge natural history events in relation to conspicuous species such as butterflies. Forister and Shapiro have recently demonstrated that the average first spring flight of 23 butterfly species in California has advanced by up to three weeks over the last 31 years and that this correlates with warmer temperatures[3]. Indeed in the last decade many of our butterflies have been recorded many miles further north than in recent times. The comma, *Polygonia c-album*, which is widespread in Europe, was confined to the southern half of this country but has now reached the Scottish borders, and migrating species are more noticeable. But several, like the Scotch Argus, *Erebia aethiops* and Mountain Ringlet, *Erebia epiphron,* are at, or near, the southern edges of their distributions around Morecambe Bay. One species' territorial gain with climate change may be another's loss. The picture is complex and we still do not understand enough about most species to be confident about predicting change in distribution or abundance. But we can be sure that changes will occur and that they will not only affect the attractive, harmless species but also many with agricultural or medical significance.

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3 Forister ML, Shapiro AM. Climatic trends and advancing spring flight of butterflies in lowland California. Global Change Biology 2003;9:130-1135