1991 — 1992
REPORT

Institute of Terrestrial Ecology

Natural Environment Research Council

The ITE mission

The mission of the Institute of Terrestrial Ecology is to understand the science of the natural environment with particular emphasis on terrestrial ecosystems Priority is placed on developing and applying knowledge in the following areas

- the factors which determine the composition, structure, and processes of terrestrial ecosystems, and the characteristics of individual plant and animal species
- the dynamics of interactions between atmospheric processes, terrestrial ecosystems, soil properties and surface water quality
- the development of a sound scientific basis for modelling and predicting environmental trends arising from natural and man-made change
- the dissemination of this research to decision-makers, particularly those responsible for environmental protection, conservation and the sustainable use of natural resources at national, regional and global levels

The Institute will continue to develop long-term, multidisciplinary research to maintain an international reputation, provide training of the highest quality, and attract commissioned projects By these means, ITE will seek to increase scientific knowledge and skills in terrestrial ecology, and contribute to national prosperity and prestige

Front cover illustration
Hedgerows in the landscape – photographer C J Barr

The Reminder Printing Company, Ulverston, Cumbria LA12 7EE

Report of the Institute of Terrestrial Ecology 1991–92

Natural Environment Research Council

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Population ecology

Research in this programme area is concerned mainly with understanding what determines the distribution and abundance of wild plants and animals. It is also concerned with understanding interactions between species, including predator/prey and parasite/host relationships. Knowledge of such matters is essential for the effective management of wildlife populations, whether for reasons of conservation or pest control, and for predicting the effects of human activities on wildlife.

The projects described below are typical of research in this programme. Two are concerned with rare and declining species, which are in urgent need of appropriate conservation action. The work on capercaillie illustrates a familiar problem of how to maintain populations of a valued species in the face of inimical land use practices which destroy or degrade its habitat. This bird thrives in the old pine forests of the Scottish Highlands, and generally shuns the uniform short-rotation plantations favoured by modern forestry. Hopefully, research into habitat needs may suggest ways in which the management of modern plantations might be modified to accommodate this spectacular bird better. As a favoured quarry species, it was once important in the economy of some Highland estates.

The second conservation project is concerned with endangered blue butterflies and their parasitic relationships with ants. Long-term conservation of the butterflies is dependent on the provision of habitat suitable for the butterflies themselves, their gentian foodplants and their ant hosts. Detailed field studies, coupled with mathematical modelling, have helped to elucidate the complex relationships involved.

The interactions between otters and their salmonid prey are described in another project. The work has already indicated that otter numbers are limited by fish stocks, but further work is needed to find whether the reverse is also true, ie whether fish stocks are limited by otters.

The remaining projects are concerned mainly with predicting the effects on wildlife of particular human actions. With developments in genetic engineering, it is only a matter of time before genetically modified organisms become commonplace, perhaps mainly in the form of new crop plants. The project on plant genetics is concerned with assessing some of the risks involved, eg the likelihood of hybridisation between genetically modified plants and their wild relatives, and the rates of gene flow through populations. In due course, such information will be helpful in streamlining screening and regulatory procedures concerning the use of genetically modified organisms.

The fifth project is relevant to predicting the impacts on birds of reclamation schemes for coastal mudflats. Immense numbers of shorebirds overwinter on British estuaries, drawn there each autumn from large parts of the Arctic. On any one coastal flat the numbers of birds depend on the numbers of their invertebrate prey, which in turn depend largely on the types of sediment present. This project is concerned with the feasibility of assessing bird numbers and their distribution from satellite maps of sediments. If successful, the impact on birds of any natural or human-induced event that causes a change in sediment distribution can be rapidly and easily assessed.

Capercaillie habitat evaluation

(This work was partly funded by the Forestry Commission and by Eagle Star Insurance)

Describing complex habitats in simple yet precise terms is a recurring, and difficult, task in ecology and conservation. Complex descriptions may be accurate, but are not easy to understand and use. Botanical classifications based on vegetation types are usually easier to understand, but are often too crude or inappropriate as descriptions of animal habitat. When faced with the need to evaluate capercaillie (*Tetrao urogallus*) habitat, we decided to use the statistical tool of principal component analysis to produce a simple classification of forest types relevant to capercaillie.

The capercaillie, which is the world's largest grouse, is found in Old World boreal and temperate forests. Its range is broadly associated with that of its main winter food, the Scots pine (*Pinus sylvestris*). Populations are, however, also found in other species of pine, and in fir (*Abies* spp), spruce (*Picea* spp) and oak (*Quercus* spp) forests. In Britain, the native capercaillie was confined to the old pine forests of Scotland, but a combination of substantial habitat loss and over-shooting led to its extinction in the late 1700s. It was successfully reintroduced to central Scotland in 1837–38, and is currently found in pine, and mixed conifer forests with pine, from central Scotland northwards. A contraction in range and a decline in numbers through the 1980s following a succession of poor breeding seasons have led to concern over how best to maintain, enhance or create suitable habitat for capercaillie, particularly in the new plantations of exotic conifers which comprise the bulk of our forests.

The capercaillie has a communal display site, the lek, which provides the main focus for the activity of cocks and hens in spring. We used the number of cocks attending each lek to indicate the size of the local population and to find what features, or combination of features, of the forest around a lek best explained the number of cocks present. Leks in Scotland varied in size from a single displaying cock to over 20 cocks, and were spaced at roughly 2 km intervals in continuous forest. This spacing was the same as in Scandinavia, and indicated

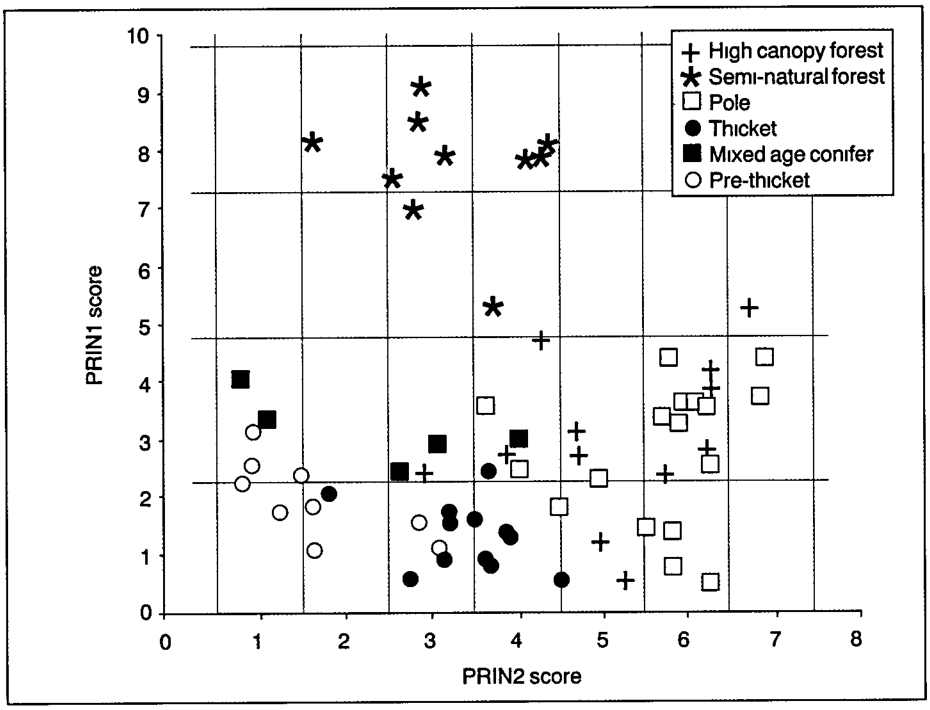

Figure 44 Plot of the first two principal component scores (coded to keep all values positive) for 14 variables in 64 forest plots ranging from pre-thickets to mature semi-natural pine forest The grid, which was imposed empirically, was used to develop a key that allowed approximate scores (the central co-ordinates of each box) to be obtained rapidly for a sample plot of at least ten trees

that the adult cocks' territories typically radiated about 1 km from the centre of the lek Therefore, the number of cocks at each lek was compared with qualities of the forest within 1 km of the lek centre

The value to capercaillie of old forest is well recognised, and our observations confirmed that big leks are usually, but not always, associated with forest older than 45 years This observation, however, did not explain which features of old forest were important, although it has been suggested that the physical structure of such forests determines their suitability If we can determine the structural features of a forest which are critical for capercaillie, then it should be possible to manage a young forest so that it becomes suitable for them

We described the structure of the habitat around 18 leks, and began by measuring 14 variables concerned with tree spacing, dimensions, canopy closure and ground cover of dwarf shrubs and grass (see Picozzi, Catt & Moss 1992) Measurements were made in circular plots which enclosed at least ten trees in stands of different ages The 14 variables were subjected to principal component analysis The first two components (PRIN1 and PRIN2) for 64 sample plots together accounted for 59% of the variability of the data set, and were the components with the most useful biological meaning An increase along the PRIN1 axis represented advance towards an open, unevenly spaced stand, characterised by semi-natural forest with old, spreading 'granny' pines An increase along the PRIN2 axis represented the development of a dense, evenly spaced stand under which all ground vegetation had died The PRIN1 and PRIN2 scores for each sample produced clusters which broadly corresponded to the main stages of forest development, from pre-thickets to mature, high-canopy forest (Figure 44) The classification therefore not only maintained the widely understood distinctions between seral stages of forest development, but had the advantage of being quantitative From this classification, a key based on tree structure was derived to allow stands to be classified rapidly in more extensive survey The key was applied to each stand in the whole forest block within 1 km of each lek in 18 forests Relating the density of cocks to a value for the whole block based on relevant axis scores showed that the more a forest resembled in structure an open, semi-natural forest with a good ground vegetation, the more capercaillie were recorded

In practical terms, the results indicate that the forest management for capercaillie should be based on a thinning policy which allows the dwarf shrub vegetation, in particular blaeberry (*Vaccinium myrtillus*), to be retained Blaeberry is very important for capercaillie chicks because they feed not only on the leaves and berries, but also on the associated invertebrates, notably caterpillars Such thinning is commercially feasible for pine, but much lower stem densities would be required to retain blaeberry under spruce Current practice with spruce usually results in dwarf shrubs dying out as the tree canopy closes Unlike Scots pine and larch (*Larix* spp), spruce has a dense crown and persistent side branches, so making more shade

The two forests in which numbers of capercaillie were greater than expected were particularly instructive One was a mature commercial plantation with Sitka spruce (*Picea sitchensis*) predominant There were large, open, clearfelled areas with profuse ground vegetation Under the older trees, there was little vegetation other than moss, but there were many, small, windblown patches in these stands We are now finding that cocks are living in these patches New shoots growing up from the fallen trunks may provide food in a sheltered yet fairly open environment within the stand The availability of such patches was not considered as one of our variables They are difficult to measure because they are all but impenetrable, for the biologist at least The other forest was a young pine plantation adjacent to a much-disturbed semi-natural pine forest It is possible that birds have moved away from the disturbance These explanations are only tentative as yet

Whatever the reasons, the presence of dense capercaillie populations in commercial forest offers the prospect of managing such forest for capercaillie There seem to be two potential ways of doing this first, as indicated above, managing for a higher GRANNY score, second, replicating the conditions present in the two exceptional forests However, the ecology of capercaillie in these forests is poorly understood, and more study is needed on the birds in these novel habitats Indeed, the birds' requirements may well be changing as they adapt to the new circumstances provided by modern forestry

N Picozzi, D C Catt and R Moss

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A modelling investigation of the population dynamics of a parasitic butterfly (*Maculinea*) and its host ants

Large blue butterflies (genus *Maculinea*) are among the world's most endangered Lepidoptera. Five species live in Europe and they all have high nature conservation priority. Apart from their beauty and rarity, all the *Maculinea* have developed a fascinating parasitic relationship with red ants (genus *Myrmica*).

Plate 13. Maculinea rebeli *caterpillar rearing up and begging for food which would be regurgitated by the* Myrmica *ant*

The adult butterflies lay their eggs on the flower buds of the larval foodplant and the young caterpillars soon develop through three instars, feeding upon the developing flowers. After their third moult, they fall to the ground and wait until they are discovered by a passing *Myrmica* ant, which, mistaking a caterpillar for an ant larva, carries it back to the ant nest. At this stage it is still very small (<2 mg), weighing 1–2% of its final pupal weight (80–130 mg), which is gained during the next ten months while it lives inside the ant nest.

The butterflies have evolved different strategies for living in ant nests; three species simply prey upon the ant larvae, whereas the other two species have a more intimate 'cuckoo' relationship, being fed and looked after by the ants – just like a giant ant larva (Plate 13). The two strategies have different implications for the population dynamics of the butterflies. *Maculinea arion*, the only species of large blue found in Britain, is an example of the predator-type species, and a major study of its population dynamics and successful re-establishment in England has been made by ITE (Thomas 1991).

Maculinea rebeli is one of the two 'cuckoo' species. It lives in hot, dry habitats in continental Europe where it lays its eggs on the cross-leaved gentian (*Gentiana cruciata*) (Plate 14), and is a specific parasite of the ant *Myrmica schencki* (Thomas *et al.* 1989). ITE first established the basics of the life cycle of *Maculinea rebeli* from populations living in the Haute Alpes, France. The early results suggested that this system would be amenable to a mathematical analysis, so a collaborative programme was established with the NERC Centre for Population Biology at Imperial College. The study was then extended to one of the largest metapopulations of *Maculinea* recorded (10^5–10^6 butterflies), located in a valley of the Spanish Pyrenees (Plate 15), and field studies were made in collaboration with Dr M Munguira and Prof J Martin (Universidad Autónoma de Madrid).

The research site was 4 ha of grassland which supported a reasonably discrete population of *M. rebeli* (estimated average 1200 ha^{-1}).

The butterfly population has proved to depend upon a dynamic interaction of the density and the spatial distribution of the gentian foodplants and host ant colonies. We have shown that gentian plants can produce a maximum of one caterpillar per flower. On average, plants have 69 (5–100) flowers and receive 24 eggs (females laying 80 eggs on average). Most of the mortality at this stage results from competition between

Plate 14. Female Maculinea rebeli *laying an egg on a flower bud of the cross-leaved gentian*

Plate 15. Valley in the Spanish Pyrenees which supports one of the largest known populations of Maculinea rebeli

caterpillars. Providing the plant is within the foraging range of a *Myrmica* nest (*c* 2 m), almost all the caterpillars will be adopted by that nest. *Myrmica schencki* colonies compete for nest sites with other ants (usually the congener, *M. sabuleti*) and are often the least abundant of the two species. Both *Myrmica* species will collect caterpillars with equal efficacy (Elmes, Thomas & Wardlaw 1991), but caterpillar survival in the wild is very low for any species other than *M. schencki*. There is a maximum number of caterpillars that a nest can rear (*c* one caterpillar per 40 workers (Elmes, Wardlaw & Thomas 1991)). Most caterpillars survive at lower densities, but at higher densities surplus caterpillars are neglected and starve. Finally, caterpillars are attacked inside the nest by a parasitoid, *Ichneumon eumerus* (Plate 16), which has a very specialised behaviour for seeking out nests of *M. schencki* that contain caterpillars (Thomas & Elmes 1992).

Potentially, the system has considerable scope for stochastic modelling; however, we tried to keep the initial model simple, using a series of phenomenological terms based on well-explored theoretical constructs, to describe the recruitment and survival rates of the butterfly at different points in its life cycle (Figure 45). While the butterfly population was a dynamic variable, the ant and gentian populations and the impact of parasitisation by *I. eumerus* were assumed constant over the relatively short simulated timescale (*c* 5–10 years). This timescale was more reasonable for the perennial gentian population than for the ants: although caterpillars damage gentian seed production, they do not affect the short-term survival of plants, whereas laboratory studies show that the caterpillars can greatly reduce ant brood production, and hence significantly reduce the size and survival of colonies from year to year.

Overall, combining the four rate constants (arrows in Figure 45), we estimated that the number of adult female butterflies in year t+1, expressed as a function of the number in year t, should depend upon seven terms. Assuming a 1:1 sex ratio, these are: half the eggs laid per butterfly (λ) modified by the density-independent survival on gentians (ϕ_G); the average number of gentians per hectare (G) modified by the average number of flower buds per gentian (ε_G); the proportion of caterpillars taken into ant nests (ρ_A) modified by the density-independent survival in ant nests (ϕ_A); the number of ant nests per hectare (A); the average searching area of foraging ants (η – a function of foraging distance); the average maximum survival of caterpillars per ant nest (ε_A); and the proportion that escape parasitism by the icneumonid (ϕ_I).

Field estimates were made for all these parameters (Table 13). As would be expected, simulations based on these parameters showed that the equilibrium level of the butterfly population (N^*) increased with the reproduction (λ), resource (ε_G, G, ε_A, A), ant searching ability (η, ρ_A), and survival (ϕ_G, ϕ_A, ϕ_I) parameters. The Schur–Cohn conditions for local stability reveal that N^* was stable to small perturbations of a realistic range of parameter values (Figure 46). Although small, the simulated perturbations were much larger than any disturbances caused by our studies in Spain. Overall, the results suggested that the interaction, as simulated by our model, is globally stable.

Another important attribute is the persistence (R_0) of the butterfly

Plate 16. Ichneumon eumerus, *a rare and specific parasitoid of* Maculinea rebeli, *laying an egg in a caterpillar of* Maculinea rebeli. *The wasp fights its way into the ant nest to parasitise the caterpillars, which struggle to avoid the attack*

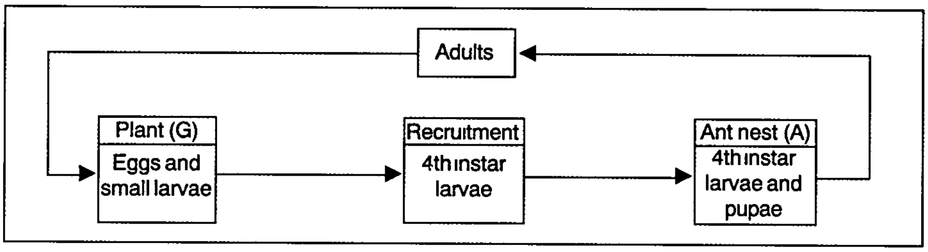

Figure 45 Schematic diagram of the life cycle of Maculinea rebeli *The boxes represent population nodes at different stages in the life cycle and the arrows represent the rate constants calculated from the ten parameters measured*

population We estimated this as the ratio of the female numbers from year to year The sensitivity of the parameters N^* and R_0 were investigated by simulation, and the results (Table 13) showed that those parameters relating to the probability of a caterpillar being found and surviving in the ant nest have the most effect

This model has been published by Hochberg, Thomas and Elmes (1992) Already it has had several important implications for the conservation of *M rebeli* It indicates clearly that, generally, the size and distribution of *Myrmica schencki* ant colonies are much more important than the gentian population to the persistence and abundance of butterflies However, the plants should play a more important role where they are less abundant or the ants are relatively more numerous, the small French sites, where we made our first studies, might be examples of such populations

We are now validating specific predictions of the model by monitoring the Spanish *M rebeli* population over five years (in collaboration with Munguira and Martin) At the same time, we are developing more refined models to understand further the effects of the spatial distributions of ants and plants, and to investigate more realistically how the parasitoid population can influence butterfly population stability We anticipate that these refinements will make significant contributions to the overall theoretical understanding of the ant/butterfly/parasitoid system But, just as importantly, their inclusion will be vital when using the model to formulate site-specific management plans, because different sites can vary greatly in equilibrium population densities and persistence levels

For example, a site might support a population of *Maculinea rebeli* with a high value of R_0 despite a low value of N^*, such a population might appear vulnerable but could in reality persist for a considerable time At another site the reverse situation might result in an apparently robust, large population which would be very vulnerable to small changes in habitat quality At the Spanish site, R_0 was estimated as 6 2, and a drop of 85% in the ant density would be required before the butterflies became locally extinct A decline in ant density of this order within a few years is possible if the site were subjected to radical changes in land management, such as the abandonment of the early summer grazing regimes, or within a few decades if climate changed significantly

Table 13 Field estimates of the various parameters used in modelling the Spanish population of Maculinea rebeli *(see text for interpretation) and their effects upon butterfly abundance* N^{*1} *and persistence* $R_0{}^2$

Parameter	Estimate	(SE)	N^*	R_0
λ	79 5		2	1
ε_G	68 5	(12 4)	1	0
G	2672	(344)	1	0
ε_A	8 06	(1 46)	3	0
A	120	(75 2–166 8)[3]	3	1
η	0 00126		2	1
ρ_A	0 14	(0 0496)	2	1
ϕ_G	0 758	(0 626–0 912)[3]	2	1
ϕ_A	0 88	(0 0328)	2	1
ϕ_I	0 833	(0 0512)	3	1

[1] Qualitative score on scale 1=slightly sensitive 3=very sensitive
[2] Qualitative score on scale 0=not sensitive 1=sensitive
[3] Range of SE

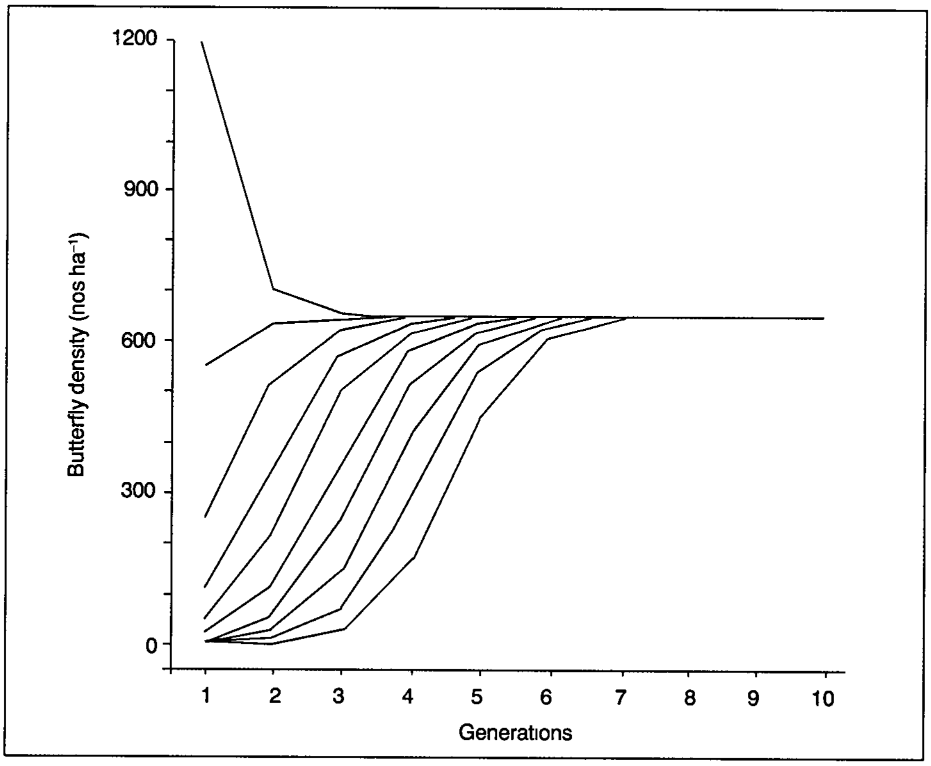

Figure 46 Numerical simulations of the dynamics of Maculinea rebeli *at various starting conditions (numbers ha^{-1}) The equilibrium of 648 butterflies ha^{-1} is always reached within seven generations of the start of a given simulation (for N_i<1)*

This study has demonstrated that it is quite feasible to develop specific population models for very rare species with high conservation value, and that, providing adequate scientific study is undertaken first, these models can be tailored to specific parameters of individual sites Conservationists can then test the probable effects on population numbers and persistence of various management regimes before embarking upon change Furthermore, in the event of wide-scale climatic change, many nature reserves established for particular rare species throughout Europe will become redundant, unless their management can be modified to mitigate the effects of such climatic change Models such as those being developed for *Maculinea* should greatly assist forward planning of species-specific conservation

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Acknowledgement

We are grateful to the British Council and Acciones Integradas (Spain) for support of field work in Spain

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Otter predation on salmonid fishes

The most abundant fishes in most Scottish rivers are salmonids, the brown trout (*Salmo trutta*) and the salmon (*S salar*) They are biologically important in the river because of their high biomass, and they also have considerable commercial value In many of these rivers, otters (*Lutra lutra*) ((Plate 17) probably eat more fish than any other predator, and this report describes recent research on the inter-relationships between otters and salmonid fishes

We estimated population densities, biomass and productivity of trout and salmon in the catchments of the rivers Dee and Don in north-east Scotland Both rivers are over 100 km long, and well known for their salmonid fisheries Twenty-two sections on five tributaries, and three sections of the main stem of the Don were sampled using established electrofishing methods Each site had dense populations of trout and/or salmon, as well as some other species The salmonid populations fluctuated seasonally, for example, the biomass of juvenile salmonids most commonly eaten by otters (ie those of one-year-old or over) increased from 9 2 g m^{-2} in early June to 14 4 g m^{-2} in September in the Beltie Burn, our most intensively studied site, after which it decreased before the following May Other studies in comparable areas showed similar results, and annual salmonid productivity in different areas was closely correlated with biomass – in the Beltie it reached about 15 g m^{-2} yr^{-1}

As expected, there were substantial differences in salmonid populations between sites The narrow tributaries contained a higher biomass of fish than the wider streams, and, despite limited sampling in the larger rivers (Plate 18), there appeared to be a significant, negative exponential relationship between stream width and salmonid biomass

Otter predation on salmonids conspicuously involves large adult breeding salmon We examined this predation in some detail by observing a radio-tagged otter as well as untagged animals, and by studying the remains of adult salmon in otter faeces ('spraints') Apparently healthy adult salmon (mean weight 3 6 kg, range 1 2–6 3 kg) were caught by otters almost exclusively in late autumn and winter (Figure 47) Most (81%) were males, caught when they were traversing riffles between the pools in the stream where the female salmon stayed The radio-tagged male otter killed one large salmon each night during November–January, eating part of it and discarding the rest (Plate 19) Such meals were estimated to weigh about 0 9–1 0 kg, and probably constituted most of an otter's daily food requirement Although otters took a large proportion of the adult salmon present in the tributaries, this was unlikely to have affected the breeding performance of the salmon population because of the sex bias in the kills

Adult salmon may have been the most conspicuous prey of otters, but their diet, as determined by caecal analysis, was dominated by small juvenile fish, 5–13 cm long Otters took these fish in proportion to their availability, although they ignored the very small fry (Figure 48) The animals also ate some eels, and frogs, birds and mammals in spring, but these were far less important than the salmonids Overall, about 90% of otter food consisted of trout and salmon Estimates of actual food intake based on observations of captive otters in captivity and two radio-tagged animals, one in Shetland and one in the River Dee, indicate that otters weighing 6–10 kg eat the equivalent of 12–15% of their body mass each day

Otter numbers and densities are difficult to assess, because animals have very large overlapping home ranges, up to 70 km of river in the Dee and Don, which were used very unevenly Over such large distances, figures of mean biomass for either predator or prey are often irrelevant More meaningful is the total amount of time spent by all otters in restricted areas, in units of 'otter-nights per year per ha of water' An 'otter-night' was defined as one whole nocturnal activity period for one otter, the total estimate for a section of river was derived from radio-tracking data on focal animals injected with a harmless

Plate 17. Adult male otter in Scotland, a frequent predator of adult salmon

Plate 18. River Dee, near Banchory, the widest river in the study

Plate 19. Adult female salmon, killed by otter

radionuclide, Zinc-65. The home range of such otters was calculated for the total time that the animal was followed (up to 13 months), and the proportion of observed time spent by the animal in given sections of river or tributary was assessed. Otter spraints were collected from these areas during the period that the radionuclide remained detectable in the focal otter. The proportion of spraints containing the radionuclide was assumed to be similar to the proportion of total otter time spent in that area by the focal animal. Thus, we were able to calculate the total number of otter-nights per year per hectare of water.

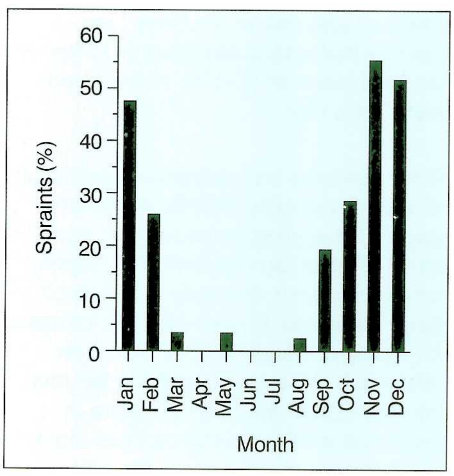

Figure 47. The consumption of large salmonids by otters in the River Dee. The histogram shows the percentage of spraints collected between March 1987 and February 1989 containing remains of salmonids over 30 cm

With these data, and the information on diet and food intake, the total food intake of all otters in specific areas was estimated, and compared with our data on salmonid biomass and productivity. In the Dee and Don, otters consumed fish at a rate of about 8.6–10.8 g m^{-2} per year, or about 53–67% of the annual production of salmonids. Most of this food was taken in narrow streams, where otters spent most of their time, rather than in the wider rivers. We found a negative exponential relationship between stream width and otter-nights per unit area (Figure 49 i). In the few areas where we could measure salmonid biomass and otter presence simultaneously, there was a close association between the two (Figure 49 ii).

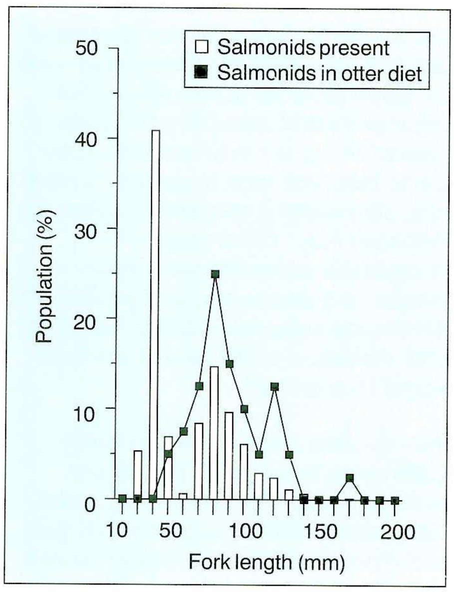

Figure 48. The size of salmonids eaten by otters compared with the size of fish in the Beltie Burn. Atlas vertebrae from spraints were used to calculate the size of fish eaten

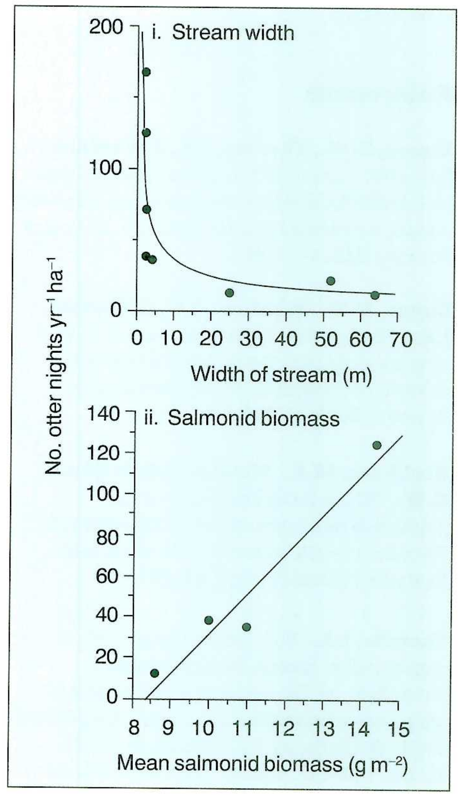

Figure 49. The area of water used by otters, in relation to (i) stream width, and (ii) salmonid biomass

Clearly, otters take a high proportion of the annual fish production, and predation by other piscivores will be additional. It is therefore possible that the availability of salmonids has an important effect on otter populations – a very large part of natural otter mortality occurred when salmonid populations were lowest. This is also the time when otters take what is thought to be sub-optimal food, such as birds (including poultry) and mammals. A major field experiment has been initiated to investigate the influences of fish populations on piscivorous predators, and further study is required to assess whether otters actually limit fish biomass.

H Kruuk, D N Carss and J W H Conroy

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Genetically modified crops and their wild relatives

(This work was partly funded by the Department of the Environment)

The use of genetically modified plants is seen as a major growth area for agriculture within the next decade. Significant progress and continued investment depend, however, on a clear and rapid procedure for approval to release such crops. The release of genetically modified crops is perceived as involving special risks (eg Mooney & Bernardi 1990) and, therefore, present proposals for release are subject to elaborate scrutiny. Streamlining of the regulations for release will develop from analysis of previous releases of modified crops, and from data collected from unmodified crops and their wild relatives. ITE is involved in several projects to collect such data, one of which has been the assessment of the likelihood of genetically modified crops hybridising with related wild plants.

In theory, modern techniques of genetic modification allow any piece of DNA (gene), regardless of source, to be transferred into a plant and to produce novel proteins. This provides plant breeders with an almost limitless gene pool and allows new characters to be incorporated into existing varieties without the need for lengthy backcrossing programmes. Most crop plants in the UK, apart from certain cereals, can be modified genetically and several methods can be employed (Potrykus 1990). The most widely used technique for modification is infecting plants with the bacterium *Agrobacterium tumefaciens*, a plant pathogen that inserts portions of its own DNA into the plant. Introduction of a gene into *Agrobacterium* that has had its pathogenic functions removed ('disarmed') permits its subsequent transfer to plants. Some plant species are unsuitable for *Agrobacterium*-mediated modification, and so other methods have been developed, such as inducing plant protoplasts (cells lacking cell walls) to take up DNA from solution by chemical or electrical treatments, or by firing small DNA-coated pellets into plant cells. Many traits can be altered by genetic modification, and those ripe for early commercial exploitation include insect and viral disease resistances and improvements in the nutritional quality of seeds (Grierson 1991).

Problems over the use of genetically modified crops (apart from possible health implications in the consumption of plants containing novel proteins) are seen as the inadvertent production of new pernicious weeds of agricultural land or the invasion of natural communities by plants possessing the genetic modifications. The increased 'weediness' may arise directly from products of the gene itself, from interaction of the gene with other genes in the plant (pleiotropy), or from changes induced by the process of modification, rather than the nature of the gene.

One possible source of these new weeds is the transfer of genetic material between modified crops and their wild relatives by hybridisation. At present, genetically modified crops are treated very similarly with respect to the possibility of hybridisation with wild relatives. In the few small-scale trial releases that have been carried out, regulatory authorities have often required the removal of flowers before anthesis and other precautions to limit the spread of pollen. Research undertaken by ITE staff for the Department of the Environment suggests that this kind of approach can be simplified somewhat by the recognition of three broad categories of crop, which could be subject to different regulatory requirements.

Group I includes those crops with very closely related, often conspecific, wild relatives in the UK. In almost all cases, the crop is never grown outside the range of the wild relative (see Figure 50, for example) and, therefore, there is a very high probability of gene flow between the crop and the wild species. The major crops are sugar beet (Plates 20 & 21), forage grasses and legumes and cabbage (and other *Brassica oleracea* cultivars); less important crops include plums, blackberries and poplar.

Group II consists of crops with no wild conspecifics in the UK, but with wild

Plate 20. Sugar beet crop growing next to the sea wall in north Lincolnshire

*Figure 50. Distribution maps of sugar beet and wild beet (*Beta vulgaris*) showing that the ranges of the crop and its wild relative overlap. Any genetically modified beet grown in areas near wild beet populations could transfer genetic modifications to the wild populations*

congenerics or feral crop populations. There are different degrees of reproductive isolation in the various crop/crop relative combinations, making generalisations difficult. Crops in this category are oilseed rape, lettuce, raspberry, apple and the major UK cereals.

Group III comprises those crops with no wild relatives, or with relatives from which they are isolated by complete breeding barriers. Included in this category are potatoes, tomatoes, maize, grain legumes and many species of soft fruit.

The results of our research suggest that assessing the risk of hybridisation of crops in group III with wild species could be permitted to be more generalised than for those in group II. Indeed, for crops in this group, risk assessment should concentrate on the possible spread of the crop itself, rather than considerations of hybridisation. This should simplify the release procedures.

*Plate 21. Wild beet (*Beta vulgaris *ssp.* maritima*) plant on the edge of Poole Harbour*

Crops in group II show very different degrees of sexual compatibility with their wild relatives and, therefore, in the near future at least, there seems to be no alternative to proceeding on a crop-by-crop basis. Research and regulatory considerations should concentrate on assessing how much gene flow between the crop and its relatives has occurred in the past, under what conditions hybridisation can occur, and what traits prevent or promote the persistence of hybrids.

Research objectives similar to those given for group II crops will be necessary for those in group I. As the crops and relatives in this group are much more uniform in their levels of sexual compatibility, generalisations may be possible.

Research aimed at improving our knowledge of gene flow within and between crops and their wild relatives, also funded by the Department of the Environment, is under way at Furzebrook with studies of wild beet and *Brassica* populations.

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Satellites, sediments and shorebirds

(This work was funded by the Department of the Environment)

One of the major reasons British estuaries are of immense conservation interest is that the numbers of migratory and overwintering shorebirds, particularly wading birds (Charadrii), are of international importance The birds' presence is due to the rich supplies of their invertebrate prey that occur in the intertidal mud- and sand-flats Not surprisingly, the distribution of shorebirds on their feeding areas is related to that of their prey, while a major determinant of the prey distribution is the particle size composition of the sediment It follows that shorebird distribution will also be related to the sediment type in which their prey occurs

Extensive surveying and sampling in the Wash, on the east coast of England, have enabled us to quantify these relationships (Goss-Custard *et al* 1988, Yates *et al* 1992a), examples of which are shown in Figure 51

The link between shorebirds and sediment type means that maps of the distribution of intertidal sediments provide useful tools by which suitable shorebird feeding areas can be identified It also means that we can assess the impact on shorebirds of any natural or man-made event that causes a change in sediment distribution

Mapping sediments of intertidal areas, especially those the size of the Wash (Figure 52), requires extensive sampling programmes that can pose problems of time and manpower, not least those associated with the safety of working on huge intertidal areas No matter how extensive such programmes are, the accuracy of the result is limited by the need to extrapolate from a relatively small number of sample sites to the whole area, usually by linking similar sites in a series of contours For these reasons, we have explored the use of remote sensing to map sediments This approach depends on each surface sediment type being distinct in its reflectance of light It offers the advantage of large areas being sampled simultaneously, and the possibility of increased efficiency by combining minimal ground sampling with more accurate extrapolation to the whole area

We applied three processing methods to Landsat 5 Thematic Mapper images, taken at low tide, to map intertidal sediments in the Wash Each of the picture elements, or pixels, that make up the satellite images relate to a 30 m square on the ground To attain a similar coverage by ground sampling would require a sample site in every 30 m square – which, for the 270 km^2 of intertidal area of the Wash, means 300 000 sites In the first image processing method, a maximum likelihood classification procedure was used to assign each pixel to either a 'muddy' or 'sandy' sediment class, where muddy areas were those in which the fine sediments (particle size <0 063 mm) exceeded 20%, and sandy areas where the fine content was less than 20% This method is most appropriate in classifying large areas of uniform cover types which have distinct boundaries, and has been successfully used in our first attempt to relate bird numbers to sediments (Goss-Custard & Yates 1992) Typically, intertidal areas do have large areas of uniform sediment types but their boundaries are diffuse Consequently, the other two processing methods were applied because they were able to quantify the amount of a sediment type within each pixel and so improve the precision of the resulting maps A multiple regression method was used to quantify the areas of clay (particles <0 02 mm), silt (particles of 0 02–0 063 mm), medium-fine sand (0 063–0 25 mm) and coarse sand (>0 25 mm) within a pixel by expressing the amount of each sediment category as a function of the light it reflected Similarly, a process known as spectral mixture modelling was used to quantify the area of wet and dry mud and sand in a pixel All processing methods are fully described in Yates *et al* (1992b) The accuracy of each method was

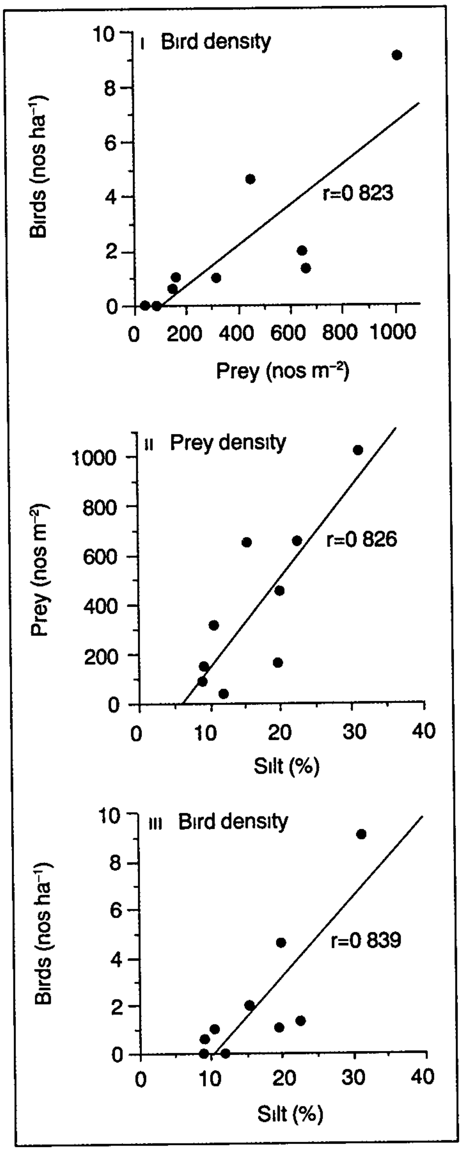

Figure 51 The relationships between the density of knot (Calidris canutus), the density of its invertebrate prey, the Baltic tellin (Macoma balthica), and the sediment type (silt) in which the prey occurs on the south shore of the Wash
i Bird density plotted against prey density
ii Prey density plotted against the proportion of silt
iii Bird density plotted against the proportion of silt
Each data point is the mean of five samples taken at nine shore levels

verified by comparison with the known sediment composition of 192 sample sites and, on a subjective basis, by our familiarity with the area acquired during many visits to survey shorebird distribution

All three methods produced an acceptable description of sediment type, Figure 53 shows a map of muddy (clay and silt) and sandy (medium-fine and coarse sand) sediments produced by the multiple regression method Each

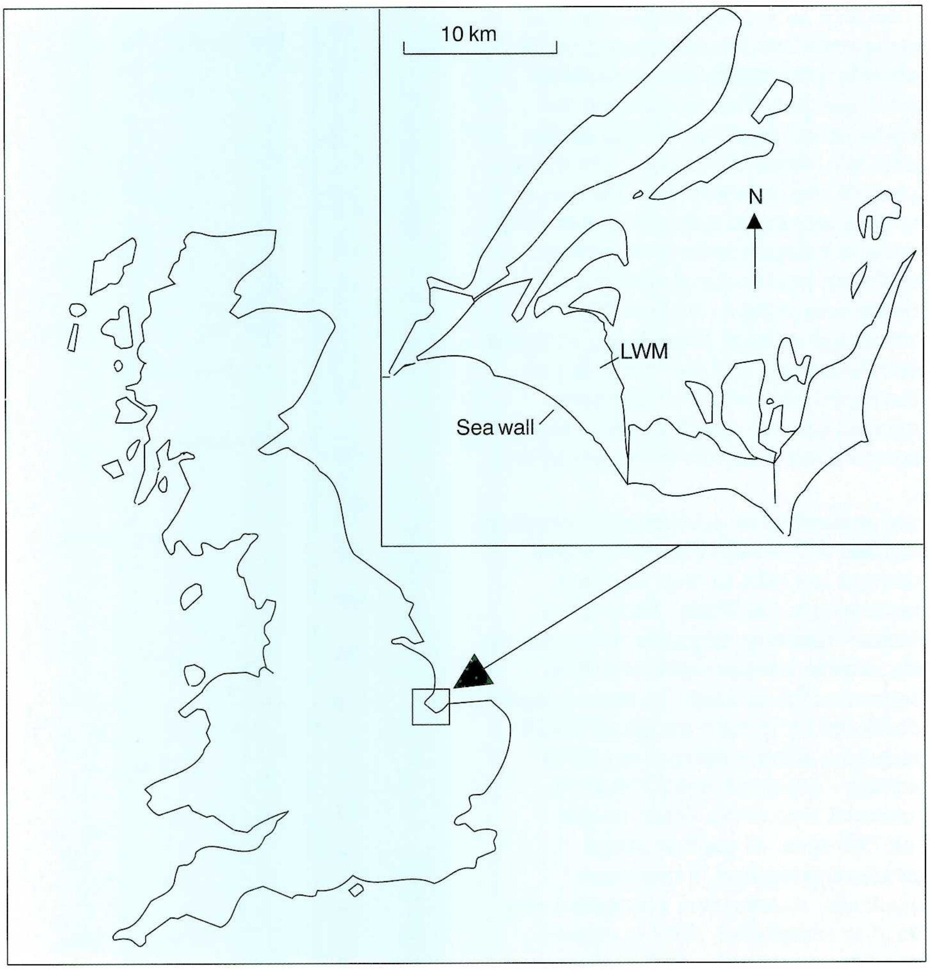

Figure 52. (Above) A map of the Wash showing its geographical location and the extent of its intertidal areas that are exposed at low water of an ordinary spring tide

Table 14. The percentage of 'muddy' and 'sandy' sample sites that were correctly classified by each of the three satellite image processing methods. The total number of sites in each observed sediment category is given in brackets

Processing method	Observed sediment category	
	Muddy	Sandy
Maximum likelihood	83.1 (83)	67.9 (109)
Multiple regression	92.7 (83)	58.7 (109)
Mixture modelling	93.7 (79)	20.8 (101)

method was less accurate in classifying sandy areas than muddy ones (Table 14). This was particularly the case for the mixture modelling method. The most likely cause of this misclassification is that sandy areas may be covered by a veneer of mud, particularly during calm weather when there is little wave action to disturb the sediment surface. Both satellite images used in this study were taken during periods of calm weather.

Relationships between sediments and shorebirds were judged subjectively by comparing maps of shorebird distribution with sediment maps. Quantifying the relationships was achieved by regressing bird numbers against the area of each sediment type in 66 contiguous transects, each 1 km wide, arranged around the Wash. Figure 54 shows an example of how shorebird numbers are related to the area of a sediment type within the transects. The fitted regression line gives a method for predicting how bird numbers might change as a result of a change in sediment distribution in the Wash. For instance, a reduction in the amount of muddy sediment is likely to lead to a reduction in the numbers of shelduck (*Tadorna tadorna*) in a given area.

Such relationships will be of far greater predictive value if they are applicable to other estuaries. We are currently testing this possibility be using the same satellite

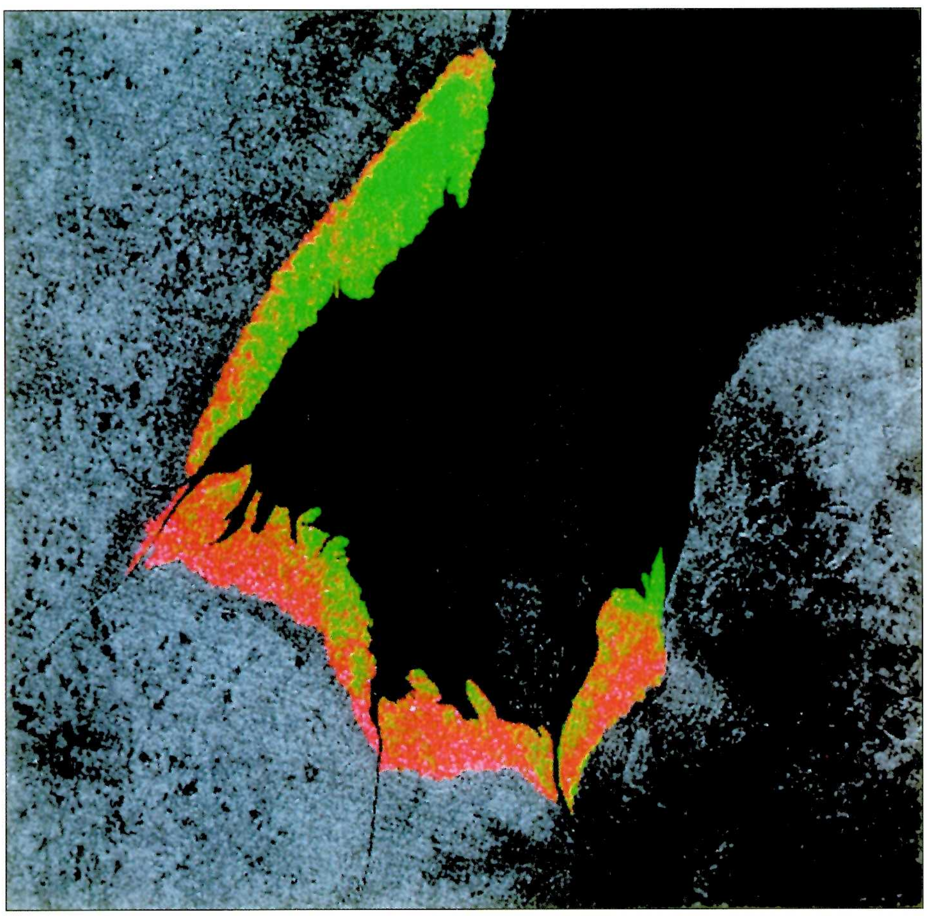

Figure 53. (Right) A processed satellite image of the Wash on which the intertidal area of the inner shore has been classified into its sediment type (red =muddy sediments, green=sandy sediments, yellow=areas with a mix of muddy and sandy sediments)

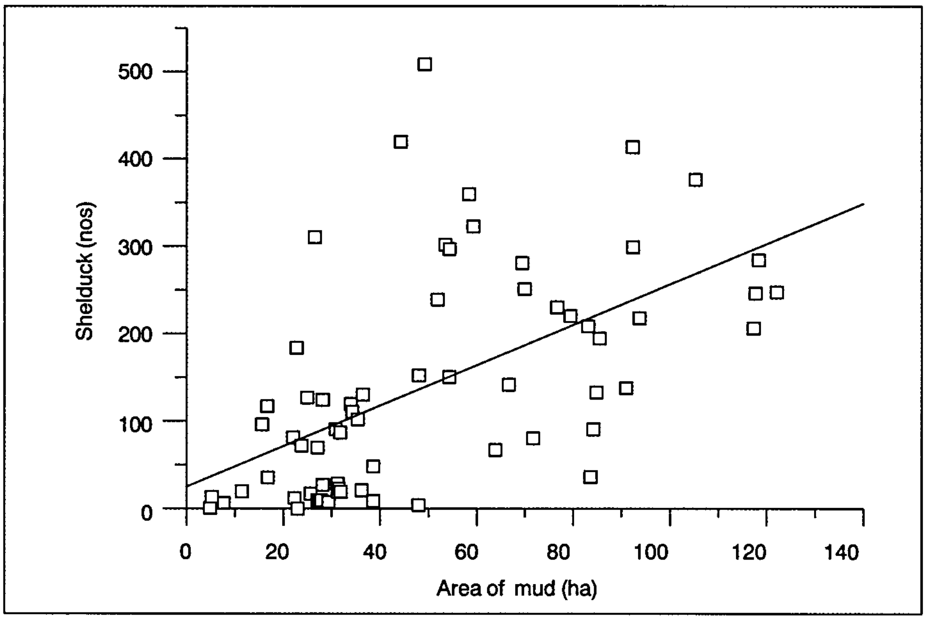

Figure 54 The relationship between the numbers of shelduck and the area, in hectares, of muddy sediment occurring in 66 transects (1 km wide) around the Wash

image processing methods to map the intertidal sediments and to predict shorebird numbers on Dengie and Maplin flats, on the Essex coast

M G Yates and A R Jones

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Community ecology

Research in this programme area aims to understand the complex interactions between, and within, plant and animal communities

Within ITE, community studies involve a range of habitats, from lowland to upland heaths, woodlands and montane areas Emphasis is placed on understanding processes, grazing being an important area of study in three of the research stations Succession is the cornerstone of community ecology, and modelling successional processes is an increasingly important research activity

There is growing demand from land managers for an ability to predict changes at the community as well as at the population level, whether these changes are caused by natural or man-induced perturbations The management of communities is fundamental to conservation and will be a key element in such developing areas of sicence as metapopulation ecology and biodiversity Also, with much land coming out of agriculture, we need to know the likely colonisation of vacant niches and the effects that a reduction in farming practices, such as draining, spraying, etc, will have on colonisation, succession and community structure The role of habitat creation in such areas of changing land use will become more common

The following two papers demonstrate how habitat manipulation can be used for conservation The first, on locating and reconstructing lowland heathland, is investigating the reinstatement of former heath on areas used more recently for agriculture The project uses geographical information systems to provide the basis for survey and assessment, and experimental field studies to discover which type of areas are the easiest and most cost-effective to re-establish The second paper shows how the design of commercial forestry plantations can be used to enhance the conservation value of such woods, in this case for an important group of beetles, the Staphylinidae

Locating and reconstructing former heathland

(This work was partly funded by BP International, ESRC/NERC Joint Programme in Handling Geographic Information, and by a SERC/ESRC Research Studentship)

With an increase in the use of land for agriculture, it is important that key habitats for particular species of plants and animals are identified and maintained, both nationally and locally throughout Britain Indeed, there are now efforts to reconstruct these key habitat types on land which has suitable potential The Countryside Stewardship Scheme is an initiative taken by the Countryside Commission to recreate a number of habitats, including lowland heath For England, ITE is identifying areas of potential lowland heath using the presence of suitable soil types, topographic data and historical maps The ITE land cover map (pp15–19), derived from satellite imagery, is being used to indicate areas where heathland still exists These data, together with information on designated areas which may afford protection to habitats, are mounted on a geographical information system This system provides the basis for detailed survey and assessment of particular areas and a subsequent evaluation of current policies aimed at the conservation of biotopes and species

On a local scale, the Dorset heathlands are a well-documented example Since the early 19th century, the extent of these heathlands has decreased from about

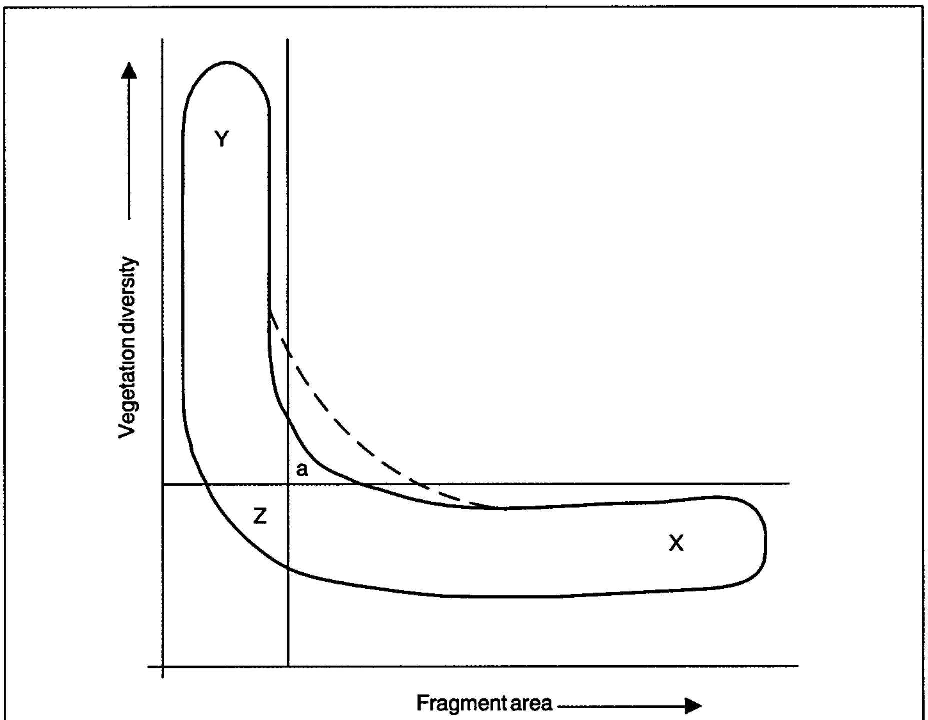

Figure 55 The relationship between plant diversity and heathland area In general, small fragments are very diverse while large fragments have a low diversity characteristic of heathland

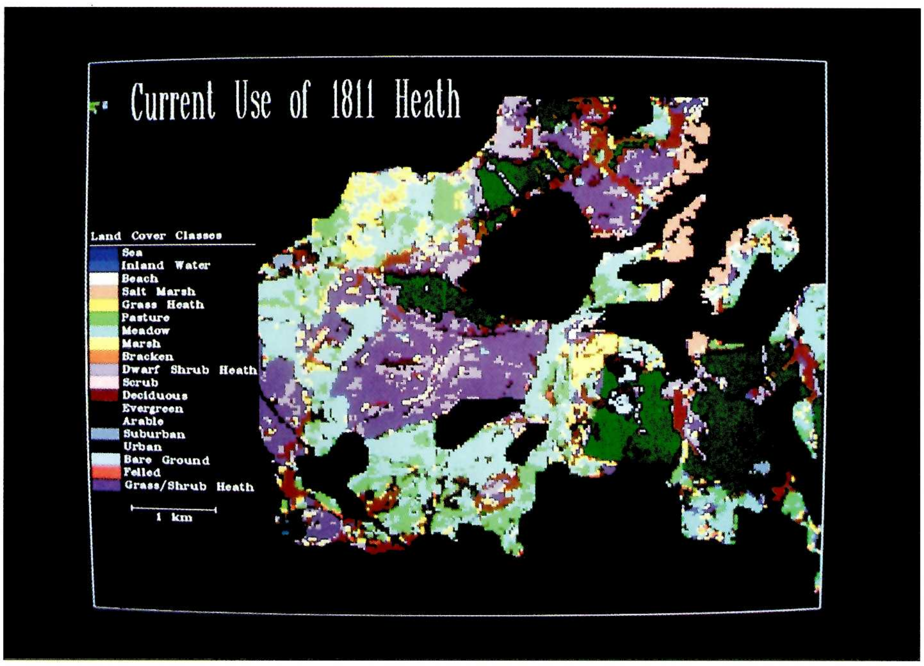

Figure 56. Map of land cover types within the boundary of heathland as it existed in 1811

300 km^2 to about 50 km^2. Much of the former heathland area has been converted to farmland, afforested, or been affected by urban and industrial developments. Up to the 1980s, the losses were mainly to farming and forestry; however, more recent losses have been equally divided between farming and forestry and industrial and urban development (Webb 1990).

Associated with the reduction in area there has been considerable fragmentation, from a few large patches in the early 19th century, which were separated by natural features such as river valleys, to several hundred patches today. Many of the fragments are less than 10 ha in extent while the largest is 479 ha.

The implications of these landscape changes for conservation are considerable. In general, species richness on heathlands is low compared with other biotopes but, nevertheless, there are numerous characteristic species; consequently, these heathlands have a high ecological value. Both the flora and fauna of the remaining small, isolated patches now frequently lack characteristic heathland species (Moore 1960; Webb 1989) and may contain a number of invasive species from surrounding vegetation types, thus elevating species richness above that typical of heathland (Figure 55). Furthermore, the patches may now be too small to maintain viable populations, the chances of extinction will have increased as patch size has decreased, inter-patch distances will have increased, and recolonisation rates will have correspondingly decreased. The rates of succession on patches will have changed as a result of changes in the composition of the surrounding vegetation types, thus creating a strong 'edge effect' on the smaller patches (Webb & Hopkins 1984; Webb & Vermaat 1990).

An aim of current land use policies on these heathlands could be to reconstruct heathland on some of the areas where the land use has changed but where the potential for them to revert to heathland is greatest. This reconstruction would enlarge and link together existing fragments, thereby counteracting the past changes, and improving the biotope by providing additional suitable habitat in both the right place and at the right time for heathland species.

A SPANS geographical information system (GIS) has been used to analyse the ITE land cover map of Great Britain to identify areas of former heathland which might be suitable for reconstruction. First, the extent of the Dorset heaths in 1811 was defined from the first edition of the Ordnance Survey maps and digitised boundaries were created for both this and the present boundary of the heathlands. Next, a classification of the land use lying between the present-day heathland boundary and the 1811 boundary was derived from the ITE land cover map. This map was derived by classifying Landsat Thematic Mapper imagery into 25 land cover types (Fuller 1991) (Figure 56). These land cover types were then reclassified in terms of their potential for reconstruction as heathland. Using this procedure it was possible to classify all of the land lying between the present and the 1811 heathland boundaries in terms of its

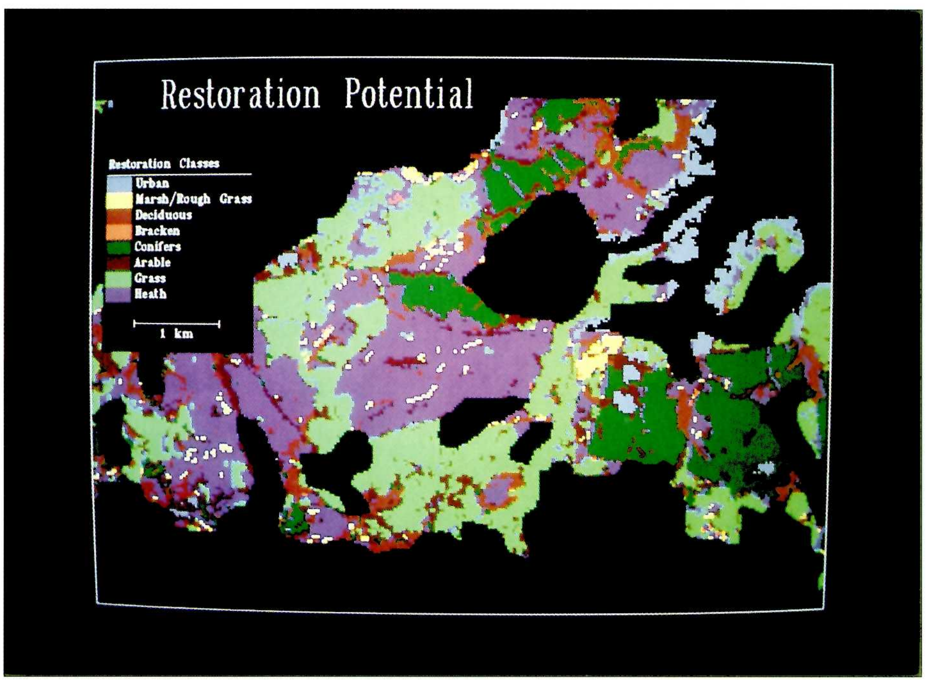

Figure 57. A reclassification of the land cover types in Figure 56 to indicate their potential as heathland. The purple land is existing heathland, the green is semi-improved grassland, and the dark green is coniferous woodland

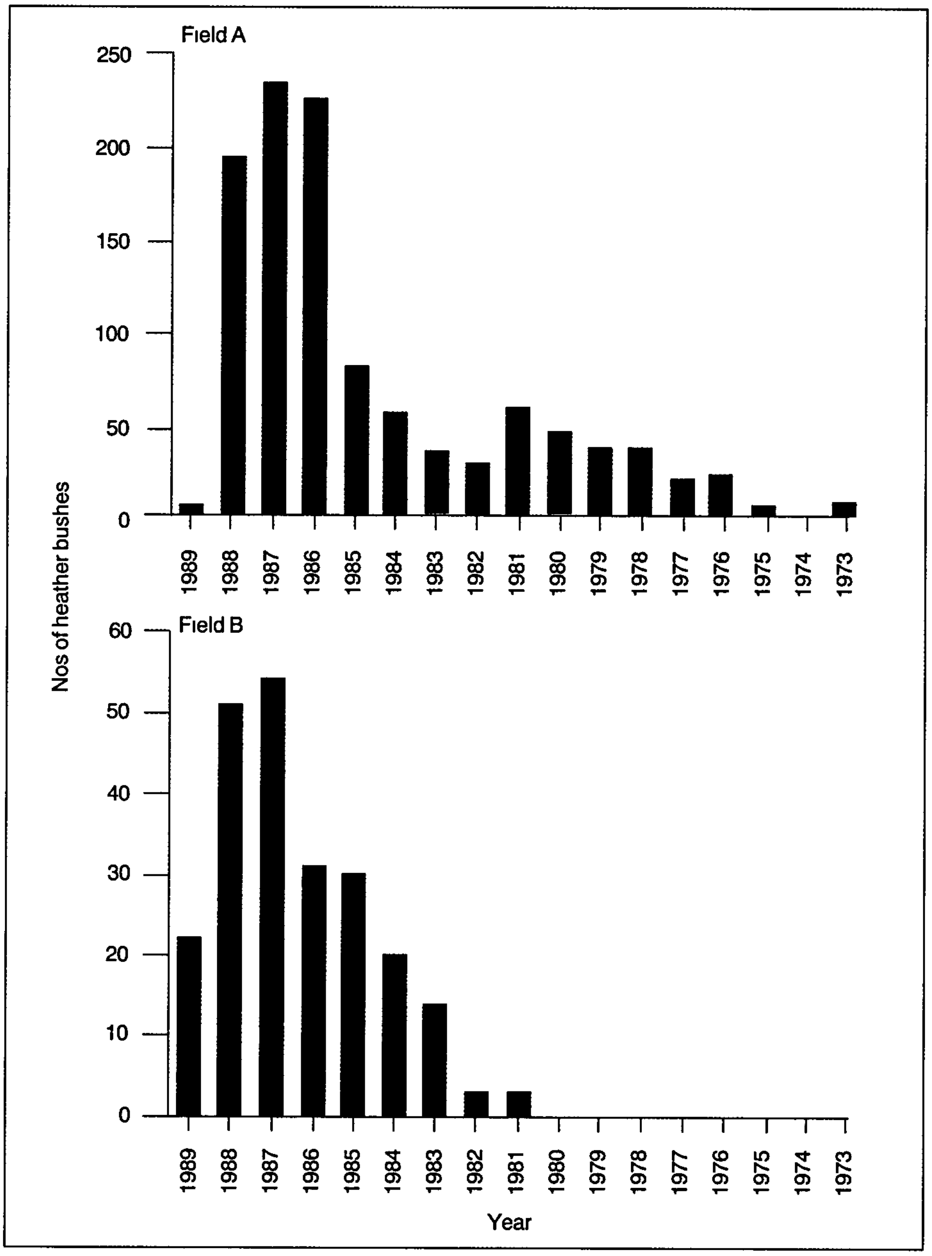

Figure 58 The age structure of heather bushes in two semi-improved fields

suitability for reconstruction, and to calculate the areas of the various types of land with potential for reconstruction (Figure 57) For instance, some 56 km^2 of grassland and 53 km^2 of coniferous woodland currently exist between the two heathland boundaries

To obtain the greatest ecological benefit, the reconstructed heathland needs to be adjacent to existing heathland, both to enlarge patches and to link patches An analysis of the land types at the edges of the existing heathland and for a 100 m zone around the heaths has indicated areas with a high potential for reconstruction Currently, 20% of the existing heath edge and 30% of the land within the 100 m zone is grassland

The potential of a given area for reconstruction as heathland depends largely on soil fertility, which needs to be low for heathland to establish successfully Thus, it is easier to reconstruct heathland on semi-improved grasslands and coniferous woodlands than on improved grasslands, arable land or deciduous woodlands

Figure 57 illustrates a typical case This area of grassland, at Three Barrows, Dorset, which lies between two existing patches of heathland (both National Nature Reserves), was converted from heathland in the late 1960s The northern half of the site, Field B, was farmed more intensively, with continuous cereal cropping, whereas the southern half of the site, Field A, was cropped only occasionally In 1976–77, both fields were sown as permanent pasture until 1979, when they were abandoned Heather (*Calluna vulgaris*) has slowly re-established in these fields over a period of 10–15 years An analysis of the age structure of the regenerating heather plants in these fields reflects the different intensities of farming (Figure 58) Field B was colonised earlier than Field A, and has a higher density of heather bushes Increasing numbers of heather plants were recorded in both fields during the late 1980s, probably as a result of falling levels of soil nutrients in the years following abandonment, making the grasses less competitive, together with the increasing supply of heather seed from established bushes

Despite cultivation, the fields have retained a seed bank of heather from the former heathland, although much of the

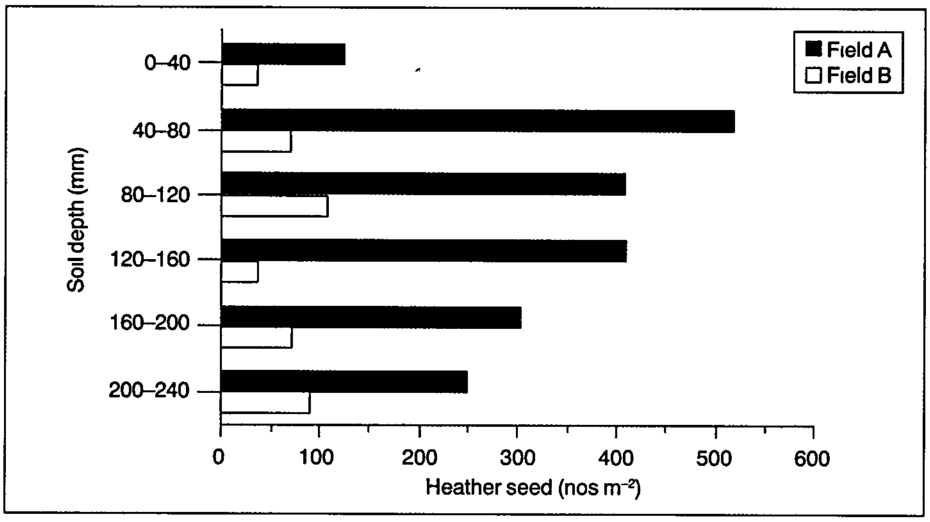

Figure 59 The number and distribution of heather seeds within the soil profile in a semi-improved grassland field

seed lies more deeply within the profile than on heathland (Figure 59). Experimental trials in these fields have shown that heather can be successfully re-established from the buried seed bank by turf stripping (Smith, Webb & Clarke 1991). Other methods of heathland restoration are being investigated for sites without a heather seed bank. These methods include the addition of heather seed capsules mown from existing areas in the course of their routine management, or the addition of heather litter and topsoil.

The current research on the Dorset heathlands is proceeding in two directions. First, it is identifying areas with a high potential for reconstruction by use of the land cover map in combination with extensive survey data (the Dorset Heathland Survey). Second, cost-effective procedures are being developed for the restoration and reconstruction of heathland. Target areas are expected to be of an easily restored vegetation type and located where they produce the maximum extension to the area of existing heathland. This strategy will ensure the maintenance of viable populations and enhance dispersal between heathland patches. Once located, detailed restoration prescriptions for these areas will be developed, based on current experimental studies.

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Afforestation, rove beetles and conservation

(This work was partly funded by the Forestry Commission and the former Nature Conservancy Council)

This study was part of a wide-ranging investigation (Good, Williams & Norris 1990) into the effects of conifer forest design, structure and management on nature conservation. The field work was done in Kielder forest (Plate 22) in northern England (National Grid reference NY6690), and focused on the effects on soils, vegetation, reptiles, amphibians and invertebrates. It compared habitats within the forest with adjacent rides, riversides, roadsides, restocked sites, moorland, lowland meadow and woodland.

There are almost 1000 British species of rove beetle (Coleoptera: Staphylinidae). Such diversity suggests that they would be useful environmental indicators, but few studies have been made of their communities.

Rove beetles (Plate 23) feed on decaying animal and vegetable matter, living animals, fungi, algae and plants (Tottenham 1954), which suggests that they might be habitat generalists – a characteristic confirmed in the Welsh uplands (Buse 1988).

The rove beetle communities

A total of 119 species of rove beetle was recorded by pitfall trapping and heat extraction of turves. Although many species in Kielder forest were habitat generalists, others could be shown to be significantly associated with particular habitats (Table 15). The relationship between the 48 commoner species, from upland to lowland and drier to wetter habitat requirements, is demonstrated by

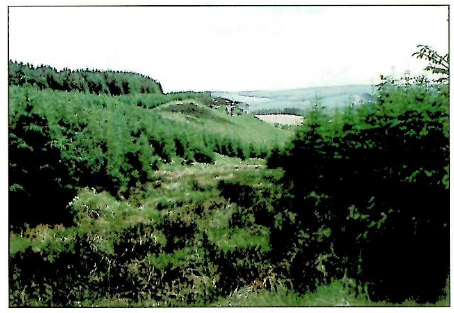

Plate 22. Kielder forest

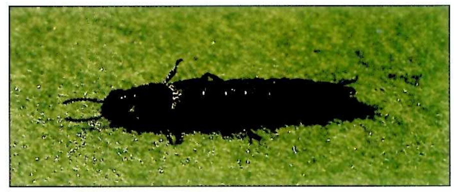

Plate 23. A rove beetle — Staphylinus aeneocephalus

an ordination using DECORANA (Hill 1977) (Figure 60). The species were distributed in a continuum, partly due to wet habitats occurring throughout this area of high rainfall. However, three groupings into upland wetland species (Group A), species associated with dead leaves in woods and forest (Group B), and lowland grassland species (Group C) can be seen from the analysis.

Table 15. Comparisons of the catch size of individual species between pairs of contrasted sites (Mann-Whitney test). Only significant results are shown (significant at P<0.05, + significant at P<0.1, T= turf samples, P= pitfall samples)*

Comparison	Species	Significance
Unplanted *vs* forest	*Omalium rugatum* (P)	+
	Atheta hypnorum (P)	*
	Aloconota gregaria (T)	+
	Myllaena brevicornis (T)	+
Wet *vs* dry	*Acidota crenata* (P)	+
	Lathrobium brunnipes (P)	*
	Lathrobium fulvipenne (T)	*
All other *vs* forest	*Omalium rugatum* (P)	*
	Atheta hypnorum (P)	+
	Othius myrmecophilus (T)	+
Lower pH *vs* higher pH	*Omalium rugatum* (P)	+
	Syntomium aeneum (P)	*
	Quedius fuliginosus (P)	+
	Liogluta nitidiuscula (P)	+
	Atheta triangulum (P)	*
	Ocalea picata (P) +	
	Oxypoda annularis (P)	*
	Arpedium brachypterum (T)	*
	Othius angustus (T)	*
	Othius punctulatus (T)	+
	Sipalia circellaris (T)	*

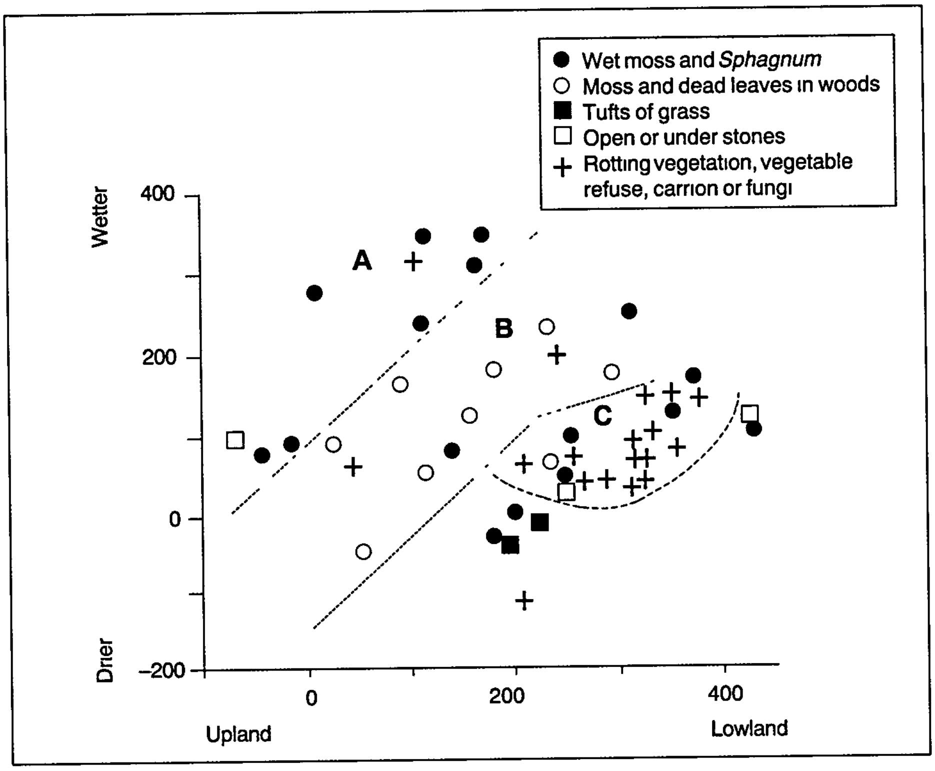

Figure 60 The relationships between the staphylinid species, showing the three groupings obtained by ordination analysis

The sites form similar groups (Figure 61) The unplanted sites tend to be at the extremes of the plot of the ordination, ie upland/more acid soils at one end of axis 1 (Group A) and lowland/more basic soils at the other (Group B) Similarly, the drier sites are at the lower end of axis 2 and the wetter sites at the other These are all unplanted sites they are survivors of the original staphylinid communities before planting

Effects of trees

The group of tree-planted sites is in a central position, but towards the drier part of the ordination (Figure 61) This shows that the sites still have similarities with their original communities before planting, in addition to being afforested Some of the beetle species are new, being directly associated with trees, whereas others are associated with the original habitats and have survived Many other species, being habitat generalists, would not have specific habitat requirements

Fencing, ploughing, draining and tree planting directly affect the original habitats Trees also dry out the soil indirectly, by intercepting a large proportion of the rainfall, thus explaining the position of the afforested sites in the drier part of the ordination Another indirect effect is the suppression of ground flora by shading and dead leaf accumulation this suppression will increase as the forest ages Such stages affect the rove beetles' habitats and thus the rove beetle communities

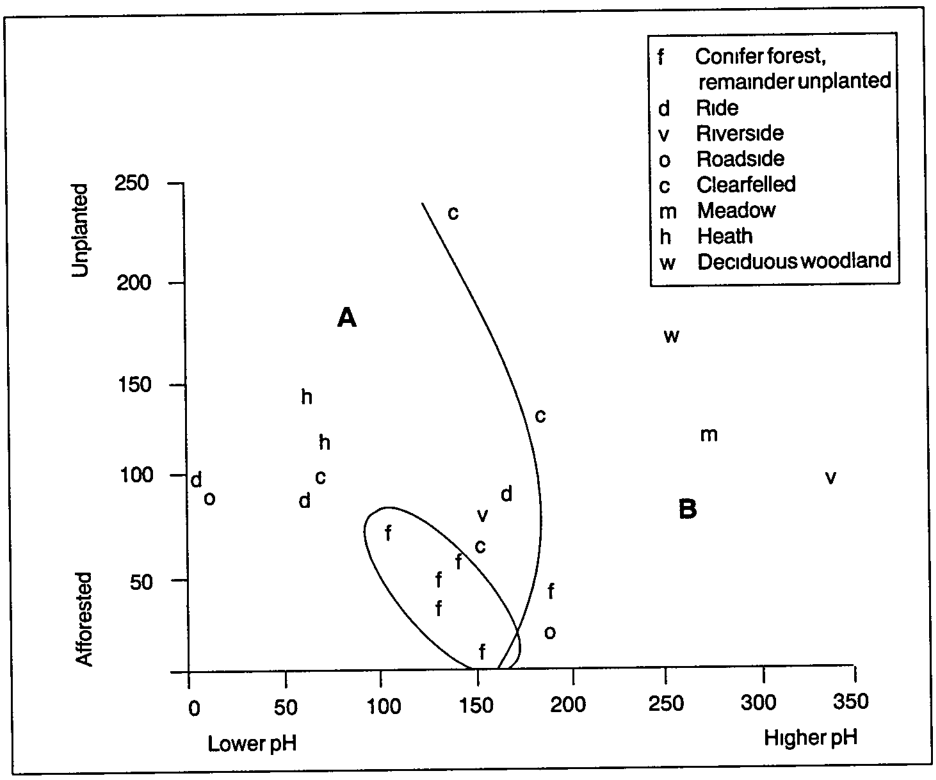

Figure 61 The relationships between the sites as shown by ordination analysis

Conservation implications

The beetle fauna of spruce (*Picea* spp) forest is less abundant and species rich than that of the open habitats it replaces, so the overall diversity per unit area has decreased since planting However, the new habitats of forest, roadside and ride have increased habitat diversity, and hence increased rove beetle species diversity Thus, the 5% area of the forest comprising rides, roadsides and riversides is of disproportionate importance for conservation because of the dispersed distribution of these linear habitats through the forest

The habitat and associated faunal diversity of conifer plantations, mainly associated with the unplanted areas, have arisen as much by chance as by good commercial forestry practice Much greater diversity can be achieved by design in which conservation of flora and fauna is taken into account at all stages of the forest growth cycle Restructuring which involves the creation of greater structural diversity, particularly by varying tree species and age class, and with more intimate juxtaposition of different habitats, would favour the dispersion of rove beetles throughout the forest

Leaving areas of the full range of different vegetation types unplanted at all times will help conserve assemblages of species which might otherwise be lost High-altitude mire communities will benefit especially, particularly because of the adverse drying effects associated with afforestation However, protected areas need to be large enough to hold sustainable populations of beetles Further research is needed to determine the minimum sustainable areas for different assemblages of species Active management, such as grazing, cutting or burning, might be necessary to sustain the floral and faunal diversity of the unplanted areas Again, research is needed to determine the most beneficial management regimes

It is likely that edges between habitats are particularly suitable for high invertebrate densities as they favour the species from both adjacent habitats Thus, reducing forest coup size and creating smaller units within the forest would be beneficial and would have the accompanying 'knock-on' effect of increased bird and small mammal densities as a result of increased food supplies Land along watercourses, especially if it contains a proportion of broadleaved woodland and scrub, is likely to be particularly rich for beetles, and should receive high priority for positive management to maintain habitat diversity

A Buse and J E G Good

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Scientific services

The natural environment is highly variable For example, soils can vary significantly over small distances giving rise to very different plant cover Similarly, different individuals of the same species of plant or animal in the same place respond differently to a given stimulus In addition, all environmental observations are subject to change with time on scales varying from microseconds to millennia In order to make sense of this complexity, research workers in the environmental sciences rely heavily on the assistance of service personnel who are specialists in disciplines which, generally, require too much detailed knowledge for a research scientist to acquire in addition to his or her own specialism The services devise equipment to collect samples, to analyse them and to reduce the resulting, often highly variable, data into usable information As a result, the analytical services, statistical and computing services, and instrument workshops are a vital link in the study of natural systems

The scientific service departments also carry out research in their own right Most departments are involved in studies, often involving international co-operation, to develop the range and quality of techniques available to the wider community of environmental scientists For example, quality assurance standards are being developed for a wide range of chemical substances in different environmental matrices (plants, soils, etc) for use in assessing the reliability of results in laboratories throughout the world Similarly, ITE service scientists are making a significant contribution to both the improvement of the statistical reliability of sampling strategies for forestry studies in developing countries and the transfer of knowledge to local users Further examples will be found in the following reports

Developments in environmental chemistry

Ecologists need consistent, reliable chemical data to enable them to quantify the chemical status of natural and managed ecosystems The Analytical Chemistry Group, based at ITE Merlewood, provides the expertise to meet this need, both for scientists within ITE and for a range of other organisations

Over recent years there has been a change of emphasis in the type of sample submitted to the laboratory for analysis, and in the range of elements requested Ten years ago soil and vegetation samples predominated Ecologists were interested in quantitative measurements of the nutrient content of each component within the ecosystem The number of determinations per sample was usually between five and eight, rising to 12 for a few projects Since then, there has been an increased interest in land management, water quality and transfers within ecosystems, and this interest has been reflected in a change in the balance of sample types submitted (Figure 62) Water samples now predominate, and include bulk precipitation, throughfall, stemflow, soil solutions, lysimeter and streamwaters The usual suite of elements per sample has also increased to between 12 and 16, rising to 25 for some projects

Notable amongst projects submitting samples to the laboratory during 1991–92 have been studies of the impact of sulphur and nitrogen pollutants in forests, nutrient cycling in European forests (Cape *et al* 1990), and nitrogen dynamics in Welsh forests (Fahey *et al* 1991a, b) More recently, research on the effects of enhanced atmospheric carbon dioxide levels on soil microbiology and litter decomposition, the dynamics of atmospheric carbon in cloud water, and on the impact of global warming on carbon turnover in upland soils has produced large numbers of water, soil and vegetation samples for chemical analysis

To accommodate increased sample numbers and the wider range of determinands, the inductively coupled plasma-optical emission spectrometer (ICP-OES), ion chromatograph and continuous flow analysers in the laboratory are regularly set up for overnight runs Software has also been developed to allow automatic data transfer from the ICP-OES and the ion chromatograph to the station mainframe VAX computer, where all chemical data are processed A similar facility is planned for transferring data from the laboratory's continuous flow systems in 1992–93

Studies into transfers of environmental ^{137}Cs from vegetation to sheep highlighted a need to quantify soil contamination of forage and faeces Titanium was used as an indicator of soil contamination because it is present in mineral soils but only occurs in very

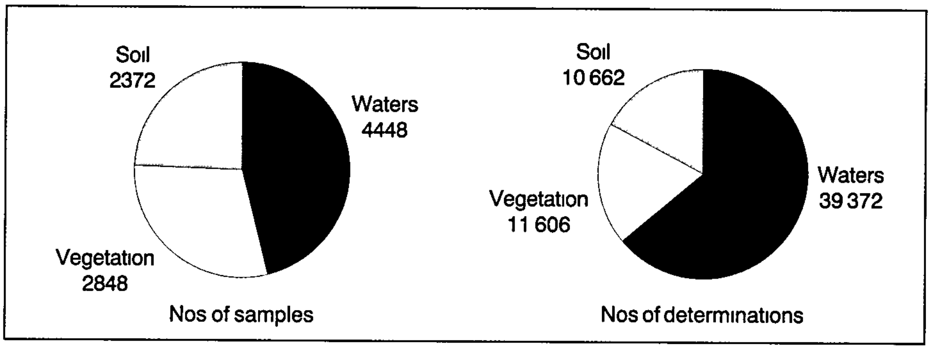

Figure 62 Summary of the work of the Analytical Chemistry Group in 1991–92

Table 16 Improved digestion procedures for measuring nutrient and trace element concentrations in environmental samples

Digestion procedure	Elements determined
Sulphuric acid/hydrogen peroxide digestion with a selenium catalyst	Na K Ca Mg Fe Mn P N
Modified nitric/perchloric mixed acid digestion	Cu Zn Al Pb Cd Mo Co Ni Se Cr V S

small amounts in vegetation ($\mu g\ g^{-1}$) A simple hydrofluoric/perchloric/sulphuric acid digestion procedure was developed, and about 1000 vegetation and faeces sample digestion solutions were analysed for titanium by ICP-OES The Group has also contributed to studies of the effect of potassium nutrition on ^{137}Cs uptake in two upland species (Jones *et al* 1991)

The increased analytical demand for a wide range of trace elements on the same sample identified the need for a digestion solution that could be analysed for a large suite of elements, rather than using a number of different digestion solutions for different elements To meet this challenge, an improved nitric/perchloric mixed acid digestion procedure has been developed so that a wider range of trace elements and sulphur can be analysed, by ICP-OES, using the same digestion solution (Table 16) This work also resulted in a more reliable digestion procedure for measuring selenium levels in environmental samples (Haygarth *et al* 1991)

A similar type of problem was encountered for environmental samples generated by research to assess the contribution of canopy leaching to sulphate deposition on soils in a Scots pine (*Pinus sylvestris*) forest (Cape *et al* 1992) This study involved measuring SO_4 and ^{35}S in rainfall, throughfall and stemflow solutions, aqueous needle and soil extracts, and total sulphur in soil and needle digestion solutions Solution preparation procedures were developed so that stable and radioactive sulphur fractions could be measured by liquid scintillation counting, ion chromatography and ICP-OES instrumental methods, using the same sample solution (Rowland *et al* 1992) (Table 17)

Quality control

The integrity of all results supplied by the Analytical Chemistry Group is maintained by rigorous internal quality control checks, by regular participation in inter-laboratory comparison exercises (Table 18), and by the use of certified reference materials to verify new methods for vegetation and soil analysis Laboratory procedures ensure that all laboratory methods are validated before implementation, that all results are traceable, and that results are similar to those produced by other laboratories participating in inter-laboratory comparison exercises

The Group regularly participates in analytical programmes to establish certified values for international standard reference materials (SRMs) for the Commission of the European Community (CEC) Bureau of Reference (BRC) In previous years, beech (*Fagus sylvatica*) leaves, spruce (*Picea* spp) needles and white clover (*Trifolium repens*) samples have been analysed These samples are now designated SRMs, each with certified values for a specific range of elements This year synthetic rainwater has been analysed and accepted as an SRM, and should soon be generally available

The Analytical Chemistry Group is also acting as the co-ordinating laboratory (co-ordinator A P Rowland) for the quality control of chemical analysis for three of the biggest projects in the CEC Science and Technology Programme (STEP) These are

i ENCORE – environmental network of catchments organised for research on the environment

ii EXMAN – experimental manipulation of ecosystems

iii NITREX – nitrogen saturation experiments

International conference on water analysis

A highlight of 1991–92 was the Group's participation in the organisation and running of an international conference entitled *Chemical analysis of natural waters in environmental research analytical solutions to current problems* The meeting arose from discussions in the Terrestrial and Freshwater Sciences Directorate of NERC and was designed to bridge the gap between the requirements of field-based scientists and state-of-the-art laboratory developments in analytical techniques

Table 17 A summary of new solution preparation procedures for the sulphur project

Sample type	Solution preparation	Analytical technique
Rainwater Throughfall Stemflow	Remove subsample for IC analysis Concentrate (400 ml) by heating in an air-circulated oven at 85°C for ^{35}S with dilution to 10 ml	SO_4 by IC Beta counting
Needle extracts	10 g fresh material extracted for 10 sec with chloroform, re-extracted with 50 ml deionised water (extr 1) A further 100 ml water added to the foliage residue, then soaked for 1 h (extr 2)	SO_4 by IC Beta counting for ^{35}S
Soil extracts	5 g soil shaken for 1 h with 50 ml deionised water, settled for 0 5 h, decanted to filter (extr 1) and extracted twice further using the same procedure (extr 2 and 3)	SO_4 by IC Beta counting for ^{35}S
Needles	Oxygen pressure bomb 1 g sample in 25 ml solution	SO_4 by IC Beta counting for ^{35}S
Soil residue after extraction	Nitric acid digestion – 1 g soil digested in 5 ml conc HNO_3 overnight at room temperature, diluted, filtered and made up to 50 ml	S by ICP-OES Beta counting for ^{35}S

Table 18. Inter-laboratory comparison exercises in which the Analytical Chemistry Group has participated

Organising body	Sample type	Elements
Warren Spring Laboratory Stevenage, UK	Synthetic rainwater	Na K Ca Mg NO_3-N NH_4-N Cl SO_4-S
University of The Netherlands Wageningen, The Netherlands	Vegetation Soil	Na K Ca Mg Fe Al Mn Cu Zn P N S pH LOI Extractable (Na K Ca Mg PO_4-P) Total (P N)
CEC Bureau of Reference Brussels, Belgium	Vegetation (needles) Vegetation (clover) Synthetic rainwater	Total (Na K Ca Mg Mn P N) Total (Se I Mo) Na K Ca Mg Fe Al NO_3-N Cl SO_4-S
	(Part of reference certification exercise)	
Analytical Chemistry Group Grange-over-Sands, UK	Vegetation Soil	Total (Na K Ca Mg C P N) pH LOI acidity Cation exchange capacity Exchangeable (Na K Ca Mg Al PO_4-P Total (C P N)
	Waters	pH conductivity alkalinity Na K Ca Mg Al PO_4-P NO_3-N+NO_2-N NO_3-N Cl SO_4-S DOC Total N

The aims were two-fold:

i. to facilitate the transfer of technological advances in instrumental analysis to real problems in aquatic environmental science;

and

ii. to draw attention to the difficulties in funding these developments.

Eighty-eight participants from six different countries and a wide variety of academic backgrounds took part. Many of the papers presented at this meeting have been refereed and will appear in a special issue of *Science of the Total Environment* to be published in 1992. Two members of the Analytical Chemistry Group, A P Rowland and V H Kennedy, were members of the editorial committee.

J A Parkinson, V H Kennedy, A P Rowland and J D Roberts

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Climate change research facilities at ITE Bangor

Models of global climate change give a general consensus that there will be a doubling of present atmospheric carbon dioxide (CO_2)concentrations (from 340 $\mu l\ l^{-1}$ to 680 $\mu l\ l^{-1}$) coupled with a 2–5°C increase in mean surface air temperatures within the next 100 years (Department of the Environment 1991). These changes in climate are likely to have a profound effect on existing semi-natural plant communities. Staff in the Pollution/Climate Change Section at ITE Bangor have developed a range of experimental facilities in which to investigate the effects on plant growth and competition.

The major new development has been the transfer of a large-scale Solardome exposure system from Leatherhead, following the closure of the National Power research laboratories (NP-TEC). The facility is being resited at the University College Farm, Aber, Gwynedd.

The Solardome facility has been running at Leatherhead for several years to study the long-term effects of exposing plants to acidic gaseous pollutants. It was operated without air temperature control but with charcoal and purafil filters on the fresh air input to remove ambient pollutants.

Just prior to the closure of NP-TEC, the system was modified for climate change research, adjusting it for use with CO_2 and giving temperature control of the air passing into the domes. The pollutant filters on the air inlets were removed.

Eight 4.4 m diameter Solardomes (hemispherical glasshouses) are laid out in an east–west line to form the system (see Plate 24). Sanalux glass is used in the domes to extend the light

Plate 24. Solardome exposure system at the Aber site

transmission into the ultraviolet region. The floor of each dome is divided into two separate semi-circular areas on either side of a central path. Each area is dug out to a depth of 1 m, lined with Butyl rubber and filled with gravel. A vertical pipe rises from the bottom of each pit allowing drainage water to be pumped out.

Experiments can be undertaken using a factorial design, having two levels of CO_2 treatments (ambient and ambient plus about 340 ppm), two levels of temperature (ambient and ambient plus about 3.5°C) and two replicates for each CO_2 x temperature combination.

A Macsym 350 computer controls the operation of the facility, handling all the data logging, CO_2 control, dome air heating and cooling, fan speeds and safety monitoring functions (see Plate 25).

In the modified system, air is drawn through a particulate filter and over either an electrical heater or a heat exchanger by a variable speed fan. For high CO_2 domes, CO_2 is injected at this point before air streams are ducted underground to emerge vertically from a 60 cm diameter opening just above ground level, in the centre of the domes. A bulk liquid CO_2 supply with vaporiser is used as the source of CO_2, and the supply to each dome is controlled by a mass-flow controller under computer control. The air is aimed upwards at a deflector suspended over the opening. The deflected air then moves downwards and outwards across the plants and out of 14 vents arranged around the perimeter of the dome, just above ground level. Air flow into each dome is monitored by a Pitot tube inserted into the ducting. Fan speeds are preset via the computer and can be adjusted to give a range of air flow rates.

The Solardomes operate under a small positive pressure, with 3.7 air changes

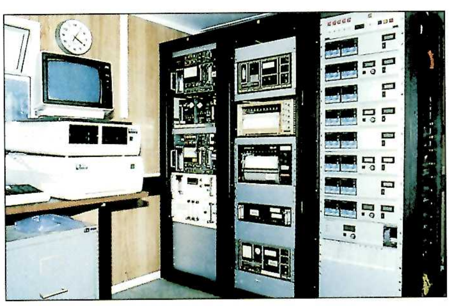

Plate 25. Control system for Solardome exposure facility

per minute (78 m^3 min^{-1} air flow rate). Even with this air exchange rate, solar heat gain within the Solardomes will cause air temperatures to be greater than ambient. To counteract this, the air for the ambient temperature domes is first cooled by a heat exchanger with water at 5°C circulating through it. This water is cooled by a refrigeration unit, the rate of circulation being controlled by a computer-operated valve.

The elevated temperature domes are run at about 3.5°C above ambient. Solar heat gain by itself is unlikely to cause this temperature to be exceeded, and there is no provision for cooling in the elevated temperature domes. Electrical heaters provide the extra heat input to maintain the 3.5°C temperature differential when there is insufficient solar heat gain.

Originally, temperature control problems were experienced using temperature sensors in a closed-loop control system. These were overcome by the National Power group using a computer-run algorithm, based on solar radiation measurements, to control the dome air temperatures. Successful dome temperature control was achieved during the period July–October 1991. The temperature rise in a dome was found to be related to solar radiation by the following relationship.

$$Tr=a+bSr+cSr^2+dSr_m^2$$

where:

Tr = predicted temperature rise
Sr = current solar radiation value
Sr_m = moving mean of solar radiation over previous hour
a,b,c,d = constants

Air from inside each dome is sampled through PTFE sample lines by a gas handling unit, housed inside the instrument building. Gas analysers monitor CO_2, H_2O, NO, NO_2, SO_2 and O_3 levels in the sampled air, and data are recorded on chart and logged via the Macsym computer. For safety reasons, an additional CO_2 analyser monitors levels within the instrument building. Temperature, relative humidity and solar radiation are monitored continuously inside the domes, together with ambient conditions, and the data are logged.

Initially, the system will be used for the continuation of National Power's contract with the European Programme on Climatology and Natural Hazards (EPOCH), to study the effects of CO_2 and temperature on grassland species. This work was part of a collaborative programme in which the Pollution/Climate Change Section, at ITE Bangor, was already participating with open-top chamber studies. The Solardome facility will also be used for collaborative projects within the Terrestrial Initiative in Global Environmental Research (TIGER) programme. A possible future option is to use the system to carry out combination experiments with CO_2, acidic pollutants and temperature.

The new facility will supplement and expand the range of systems already developed at ITE Bangor for pollution and climate change research. These systems include four Solardomes for gaseous pollutant studies (Rafarel & Ashenden 1991) and a polythene tunnel misting system for work on the effects of acidic mists (Ashenden, Rafarel & Bell 1991).

Initial studies on the effects of elevated CO_2 have been conducted using open- and closed-top field chambers, designed at Bangor (Baxter & Ashenden 1991; Ashenden, Baxter & Rafarel 1992). These chambers have recently been developed further with the incorporation of a prototype temperature control system. The temperature of the air blown into the chamber is controlled by a commercially available air handling unit, as used for air conditioning, operated in conjunction with a water chiller unit. A closed-loop temperature controller is being developed to control the system.

Two new Fisons PC660 growth cabinets fitted with a CO_2 control system (PP Systems) have been set up and will be utilised to study the mechanisms of plant response to elevated CO_2 under precisely controlled environmental conditions.

C R Rafarel and T W Ashenden

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Analysis of soil and sediments for polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a group of man-made or naturally occurring organic chemicals that are formed during the incomplete combustion of organic substances in forest fires, electricity generation and petrol engines A few PAHs are used in producing drugs, dyes, plastics and pesticides Other sources of PAHs are oil spills, industrial effluent and biosynthesis They are found throughout the environment in soil, water and air, usually in mixtures of two or more compounds

There are over 100 different PAH compounds with varying chemical and physical properties and health effects Chemically, they consist of three or more benzene rings arranged in a linear, angular or cluster structure The following are representative of the group acenaphthene $C_{12}H_{10}$, anthracene $C_{14}H_{10}$, benzo(a)pyrene $C_{20}H_{12}$, chrysene $C_{8}H_{12}$, fluorene $C_{13}H_{10}$, pyrene $C_{16}H_{12}$

PAHs are transported through the atmosphere in the gaseous state or adsorbed on to soot and dust particles They are insoluble or have extremely low solubility in water, and are usually attached to suspended solids or sediments They can move through soils by leaching and partitioning They are degraded in soils, air and water by bacterial action, photo-oxidation or chemical oxidation, the rate of degradation in sediments decreasing with reduced oxygen levels In the environment they generally have a half-life of 30 days

PAHs can be absorbed by inhalation, ingestion and through the skin They pass to all tissues that contain fat and are stored mostly in the liver, kidneys and fat Most PAHs leave the body in a few days, with half-lives in rats varying from five minutes to 12 weeks However, bioaccumulation has been shown in fish The toxicity classification of PAHs ranges from 'not harmful' to 'dangerous' Some PAHs have been found to be carcinogenic and mutagenic (US Department of Health and Human Services (USDHHS) 1988, Eisler 1987) Studies in animals have shown that PAHs can cause harmful effects on skin, body fluids and the immune system after both long- and short-term exposure Mice fed high levels of benzo(a)pyrene during pregnancy had difficulty reproducing and the offspring showed birth defects and decreased body weight Synergistic and/or antagonistic effects occur between mixtures of PAHs, and between PAHs and other pollutants such as the polychlorinated biphenyls (PCBs) (USDHHS 1988)

Because of current interest and requests from internal and external sources, particularly with reference to contaminated land, the Analytical Chemistry Group at ITE Monks Wood has developed a method for the analysis of PAHs in soil and sediments, covering all those compounds listed above

This method relies on the extraction of the PAHs from the soils or sediments with organic solvents After concentration and clean-up by alumina column chromatography, the sample is analysed by a capillary gas chromatograph fitted with a flame ionisation detector (GC-FID) (Figure 63) PAHs are identified and quantified by reference to a mixed PAH standard The method uses the same extraction technique and chromatographs as those for the determination of organochlorine pesticides and PCBs in soil and sediments, so both determinations can be carried out from the same sample extract To switch from one method to the other requires only minor modification to the instrument and minimum downtime The method will be validated using the USA's National Bureau of Standards reference samples

The method employing GC-FID is the first step in creating a service that will cater for wide-ranging research into the effects of PAHs The aim is to develop methods for determining PAHs in animal tissues, vegetation, air and water, to cover a wider range of PAHs, and to reach detection limits below parts per trillion GC-FID is not sensitive enough in cases where concentrations of PAHs are extremely low or where only a very small sample is available The FID responds to a very wide range of compounds Even with rigorous clean-up, the solvent extract of a sample may contain hundreds of non-PAH components to which the FID may

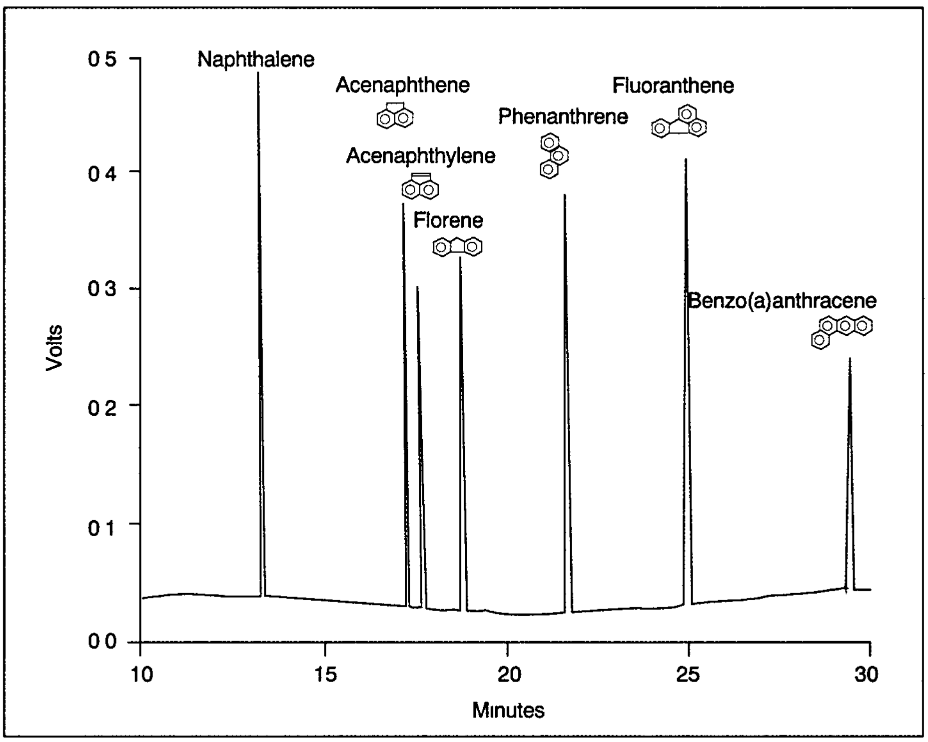

Figure 63 Chromatogram showing a selection of PAHs

respond, thus making accurate identification more difficult. A method will be developed using high-pressure liquid chromatography (HPLC) with either an ultraviolet detector or a spectrofluorophotometer. This technique will provide lower detection limits and greater selectivity. Where PAH concentrations are sufficiently high, both methods can be used to increase the accuracy of identification still further.

J Wright and M C French

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Geographical information systems in the terrestrial life sciences

The past decade has seen the evolution of geographical information systems (GIS), from the realm of esoteric computer science research to operational tools, widely used in a range of applications which require the manipulation of geographically referenced data. Among the users of GIS can now be counted agencies with responsibilities as diverse as defence, cartography, national and local planning, utilities management, nature conservation and environmental research.

Early digital mapping systems were principally intended for editing, updating and manipulating cartographic data obtained, for example, by digitising paper maps or by direct entry at a computer work-station. Such systems allowed the same map to be plotted at different scales or on different projections, using symbolism chosen to meet the requirements of the particular application. More significantly, quantitative measurements could be

Plate 26. Laserscan HORIZON GIS in use in EIC for ecological applications

performed on the digital map representation. Areas and boundary lengths could be readily computed, coincidence established by means of polygon overlay, and estimates of proximity between map features could be made.

Geographical information systems enhance the potential of digital cartography by integrating computer-based mapping with data base management functions. Using such systems, it is possible to associate information about the characteristics of land units, such as experimental sites, protected areas, vegetation units, field boundaries, survey quadrats, etc, with the digital representation of those features in space. The recorded characteristics might comprise lists of species, soil type, depth and chemistry, a history of cultivation or land management, and so on. The GIS hardware and software allow such data bases to be interrogated both in terms of the recorded attributes (eg select all herb-rich grasslands on calcareous soils) and by their geographical context (eg retrieve woodlands within 20 m of a river course). The capacity of GIS for spatial analysis can be used in a wide diversity of applications, including terrain modelling and visualisation, change detection, proximity mapping, and network processing (eg to trace the environmental fate of pollutants).

The availability of new data sets at global and regional scales (particularly those

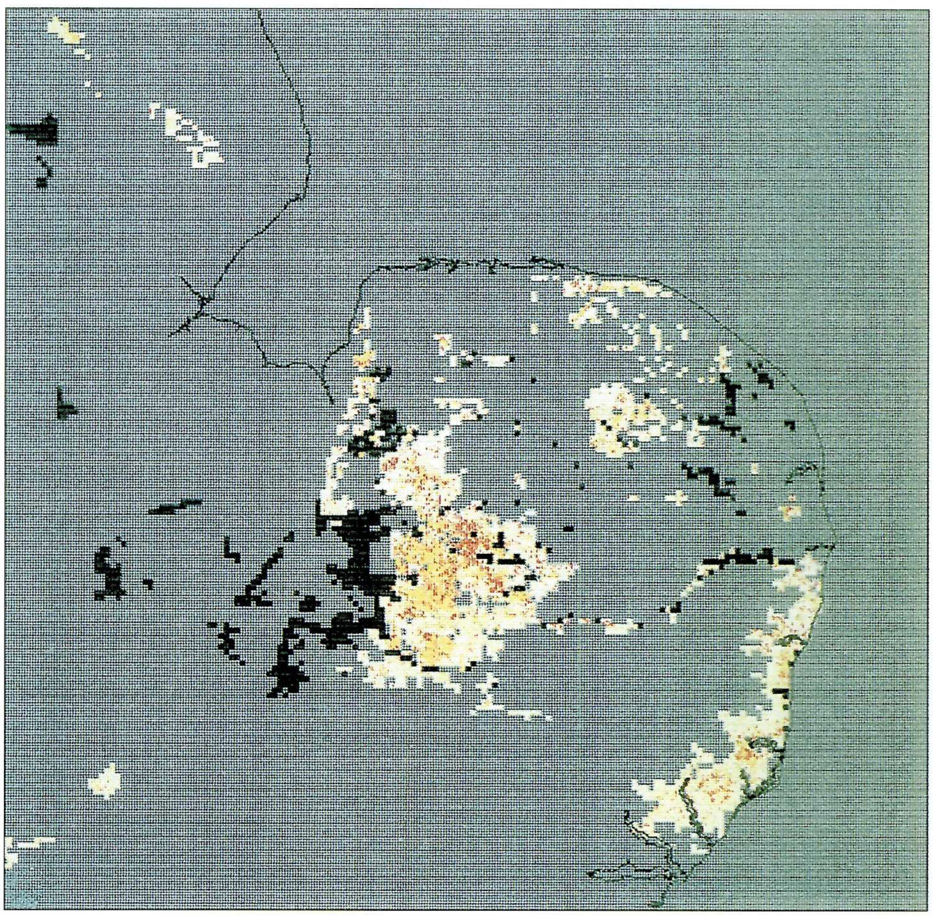

Figure 64. Potential areas of lowland heath in East Anglia, determined on the basis of soil characteristics. Windows define soils, such as podzols and sandy soils, which are characteristic of lowland heaths. Within these windows, present land use is mapped in four categories (red=high, white=low). The black mask indicates the presence of peaty soils

derived from space-based earth observation systems) has further expanded the requirement for sophisticated and powerful computer-based systems for managing and interpreting geographically referenced data.

GIS in the Natural Environment Research Council (NERC)

NERC was among the pioneers of the use of computers in cartography: in 1967, the Experimental Cartography Unit was established to develop computer-based mapping techniques in support of the environmental sciences. Following the report of the Chorley Committee on handling geographic information (Chorley 1987), NERC formed a working group on geographic information, which recommended, *inter alia,* that NERC should adopt a national responsibility for the management and stewardship of geographically referenced environmental data, that there should be new investment in GIS infrastructure, and that corporate arrangements should be put in place for the integrated management of these data sets and to ensure their accessibility. In particular, the group recommended the establishment of Geographic Information Centres within each of NERC's Science Directorates.

Figure 65. Use of digital maps of field survey to assess the accuracy of land cover mapped from remote sensing. The Figure corresponds to 1 km square near Newmarket, Suffolk. The remotely sensed land cover map appears as the coloured gridded underlay (brown=arable land, light green=grassland, dark green=coniferous woodland, buff= deciduous woodland, yellow=heathland, grey=buildings). The linear overlay results from digitising landscape features mapped in the field. Accuracy assessment involves comparing the contents of the digitised land parcels (held separately in a data base) with the remotely sensed map, and drawing up a matrix to compute the degree of correspondence between the two

Environmental Information Centre

Many of these recommendations have now been acted upon. In the Terrestrial and Freshwater Sciences Directorate, the Environmental Information Centre (EIC) at ITE Monks Wood has been designated as the corporate data centre for terrestrial and freshwater ecology, with responsibilities for developing the roles envisaged by the NERC working group. ITE has installed (or is in the process of installing) GIS at each of its sites; EIC provides the focus for research in the application of these systems to meet the needs of the Institute's scientific programmes (Plate 26).

These steps represent a logical development of earlier interests in ITE which, for many years, has been active in digital mapping (eg Fuller, Brown & Mountford 1986). The motivation is self-evident; the Institute is heavily involved in ecological survey, which often generates large volumes of spatially referenced data.

Information on plant communities and animal populations must be interpreted in the context of the physical environments which they occupy. Manual methods for the analysis of mapped data are laborious, inflexible and error-prone, so the adoption of computer-based approaches has obvious attractions.

Applications

Geographical information systems are increasingly being used in the Institute as the vehicles for analysing data from ecological survey and management, and representative examples of recent and current applications of GIS are described below. Other instances of ecological applications occur elsewhere in this Report (pp66–69). A particular area of interest is the integration of data from satellite and airborne earth observation systems with ground-based data sets.

Key habitats

The Directorate of Rural Affairs in the Department of the Environment is concerned to assess the present national distribution of 'key habitats' in relation to their potential extent and to areas designated for the protection of wildlife and countryside. The habitats of immediate interest comprise five landscape types designated under the Countryside Stewardship Scheme of the Countryside Commission, *viz* lowland heaths, chalk and limestone grasslands, waterside landscapes, coastal areas, and uplands. ITE has been commissioned by the Department to carry out a study to survey the national extent and quality of these habitats.

ITE is using GIS to manipulate digital maps recording a variety of the environmental conditions which determine the potential extent of each of these habitat types; for example, potential areas of heathland and calcareous grassland are determined largely by soil, terrain and drainage (Figure 64), while waterside landscapes can be delineated with reference to the river network. In all these cases, their potential extent can be modified by reference to land cover, for example, mapped from remotely sensed data. These maps will be used to assist in the planning of field surveys to assess the quality of the various habitats.

Remotely sensed land cover data will also be employed to identify current land use within regions which have the potential to sustain each of the habitats of interest. Finally, digital boundaries of protected areas such as Sites of Special Scientific Importance and Environmentally Sensitive Areas will be digitally overlaid on the habitat maps in order to assess the extent of protection presently offered.

Countryside Survey 1990

Information on land surface cover and the manner in which this changes over time is needed for a variety of applications in research, planning and management. Data from space-borne earth observation offer a means of generating, over extensive areas, consistent and cost-effective information in digital form, suitable for overlay with other geographically referenced data sets or for incorporation directly into numerical models. ITE is currently engaged in the compilation of a digital map of national land cover at a field-by-field scale, using remotely sensed data, as described elsewhere in this Report (pp15–19). The work forms part of Countryside Survey 1990, a broader survey of the rural environment which draws on a programme of field observations carried out at 512 sites dispersed throughout Great Britain, and forming a stratified random sample of the range of landscapes encountered nationally (Barr 1990).

Ground-based data and results from the remote sensing mapping programme complement each other in ways described by Fuller *et al.* in more detail. The field data provide an independent source of reference information against which to calibrate the remotely sensed map. Additionally, the two data sets can be used in combination: the remotely sensed product provides insights into the spatial variability of the sampling regime employed by the field survey, while, conversely, the field data can be used to

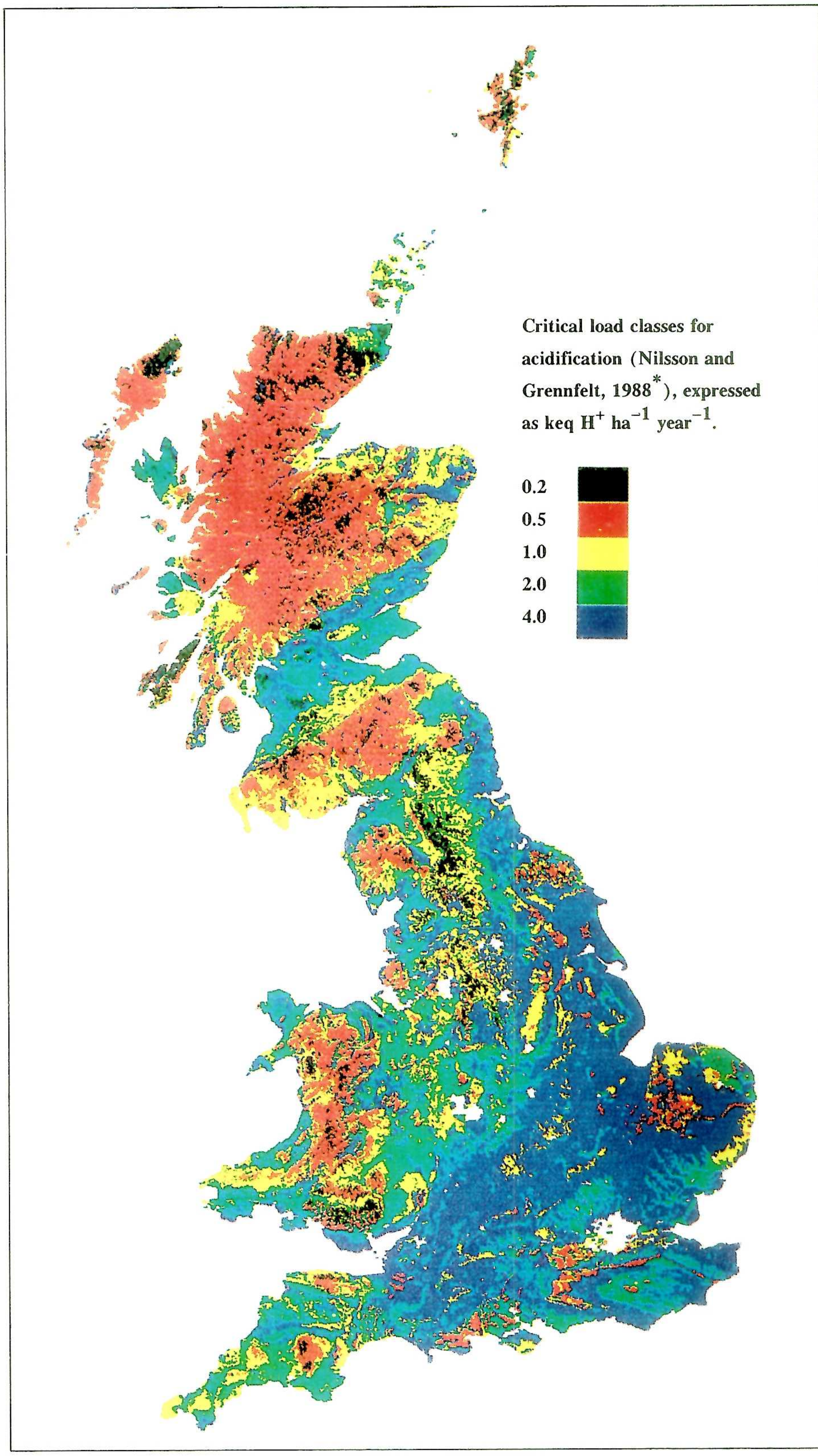

Figure 66. Provisional map of the critical loads for acidity of soils in Great Britain. The map is drawn by allocating each 1 km square of the National Grid to a critical load class on the basis of the mineralogy of the dominant soil unit, but with modification to allow for current agricultural management

infer information in the remotely sensed map (such as the species composition of vegetation types) that is not directly apparent from the multispectral imagery alone GIS is being employed as the means of integrating these two important data sets Figure 65 illustrates the use of digitised data from field survey for validating remotely sensed land cover maps

Maps of critical loading on the environment from atmospheric pollutants

Knowledge of the sensitivity of ecosystems to pollutants allows the determination of the 'critical load' – the maximum pollutant load which will not cause long-term damage (Hornung 1991) The Critical Loads Advisory Group of the Department of the Environment is estimating critical loads of acidic pollutants throughout the UK, to identify those parts of the environment which are susceptible to acidic deposition This work is being co-ordinated by the National Critical Loads Mapping Centre, within the Environmental Information Centre at ITE Monks Wood, where national data and maps are compiled and incorporated into European maps of critical loads, prepared under the United Nations Economic Commission of Europe Convention on Long Range Trans-boundary Air Pollution for application to future international pollution abatement strategies

By the application of internationally agreed procedures to soil units mapped by the Soil Survey Land Research Centre, at Silsoe, and by the Macaulay Land Use Research Institute, at Aberdeen, national maps have been prepared showing critical loads for each 1 km cell of the British National Grid (Figure 66) These data are held at Monks Wood on a GIS so that they can be modified to include critical loads for peats (determined at the University of Aberdeen) and to allow for the effects of land use (by reference to the ITE land classification system) These maps of critical loads may be compared with pollutant deposition data, interpolated from national monitoring networks, to derive maps showing areas where the deposition load exceeds the critical load

A similar approach is being adopted to generate maps of the sensitivity of freshwaters to acidification, by overlaying soils, geology and land use information within the GIS These maps will be used to define a sampling programme aimed at measuring chemical parameters for calculating the critical loads of freshwaters in the most sensitive regions

Terrestrial Initiative in Global Environmental Research (TIGER)

In 1991, NERC announced its initiative in global environmental research Within this programme, ITE expects to make extensive use of GIS to understand and model the direct responses of natural ecosystems to climate change and the indirect impacts of changes in soils, hydrology and land use, brought about by climate change These studies will be undertaken in co-operation with a number of centres in Higher Education Institutes and research establishments, and will include, on the one hand, patch-scale studies of ecosystem response and, at the other extreme, studies of changes in nationally or regionally extensive landscapes and of the responses of global biomes These studies will be heavily dependent on access to the extensive geographically referenced data bases of climate, soils, hydrology and land use held by the participating institutes or generated from satellite earth observation systems EIC will have an important role in integrating these data bases and in making them generally accessible to the TIGER community,

B K Wyatt, K R Bull and N J Brown

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ISBN: 1 85531 075 9

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