impact of land-use changes. More studies are needed, including a comparison of geographical distribution of NNR trends with other upper-air observations, such as rawinsondes and satellites, a more precise definition of the urban and rural observing stations, and the impact of other human activities such as contrails and aerosols that can also reduce the diurnal temperature range[13].

Our method can incorporate updated observations as they become available, can be applied to land stations throughout the world, to other variables such as humidity and winds, detect seasonal trends, and signal changes in station locations that are otherwise difficult to identify. □

Methods

Data

For the surface observations, we use the daily surface maximum and minimum uncorrected surface station temperatures from the National Climate Data Center (NCDC) 'Cooperative Summary of the Day' data set over the 48 contiguous states of the United States for 1950–1999. For the NNR, we use the global daily surface maximum and minimum temperatures gridded on 2.5° gaussian boxes, also for the period 1950–1999.

Analysis

We interpolate linearly the gridded NNR data to each observational site, and only consider the sites that have a total of at least 480 (whole) months of observations. In addition, because the NNR has surface heights different from those of the real locations, and extrapolations underground can introduce errors overwhelming the signal of the real trends (Supplementary Fig. 2), in the computation of the trends we only consider sites with elevations lower than 500 m. There are 1,982 US surface stations satisfying these two conditions. We obtain monthly means by averaging daily data; daily mean temperatures are obtained by averaging maximum and minimum temperatures, and daily temperature ranges by subtracting the minimum from the maximum temperature.

Because the NNR can have systematic differences with observations, especially near the surface, owing to deficiencies in the model forecast or the method of assimilation, we remove the 50-year monthly mean annual cycle for each site from both the observations and the NNR. We are thus comparing anomalies with respect to the 50-year mean annual cycle. In the results we present both comparisons of the 50-year time series and trends. The trends are computed as changes in decadal averages in order to reduce random errors. We only consider two decadal trends: the decade 1990–1999 minus 1980–1989, and 1970–1979 minus 1960–1969. We do not include in the trends the difference between the decades 1960–1969 and 1950–1959, because the observing system during the 1950s was considerably less reliable than in later decades, and it underwent significant scheduling changes during 1958 (ref. 11).

In addition, we have to address changes in the observing systems, especially the introduction of the satellite observing system (of which the most important is the TIROS-N Operational Vertical Sounder, TOVS) starting in 1979. These two major changes are the main reason why trends in the NNR need to be carefully estimated. We therefore do not include the changes 1980–1989 minus 1970–1979. The two decadal changes that we keep correspond to the 1990s minus 1980s (20 years with satellite data), and 1970s minus 1960s (20 years essentially without satellite data). Thus, when we average them we obtain decadal trends from two independent and largely homogeneous 20-year periods.

We compared the 1990s versus 1980s trend of 775 stations classified as urban versus 167 stations classified as rural. The mean surface temperature increased by 0.31 °C for the urban stations and 0.13 °C for the rural stations, with standard deviations of about 0.5 °C each. The difference between urban and rural warming, 0.18 °C, is significant at a 99% level of significance. The trends for the reanalysis station estimates are 0.26 °C for urban and 0.25 °C for rural, with standard deviations of about 0.22 °C, and the difference 0.01 °C between urban and rural is insignificant, showing that the NNR is insensitive to surface effects.

In the time series we compute the 1950–1959 average temperature difference between the NNR and the surface station at each station and subtract it from the NNR. This forces the two time series to have the same 10-year time average during the 1950s and is done for display but does not affect the computation of the trends or correlations.

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Field sports and conservation in the United Kingdom

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Many natural habitats exist on privately owned land outside protected areas[1], but few governments can afford to enforce or subsidize conservation of this biodiversity. Even in some developed countries, conservation subsidy schemes have only achieved limited success[2–4]. Fortunately, some landowners may be willing to accept management costs in return for other benefits[5], although this remains controversial when it involves the killing of charismatic species. For example, participants in British field sports, such as fox hunting and game-bird shooting, may voluntarily conserve important habitats that are required by quarry species[6–8]. Here we report results from a multidisciplinary study that addressed this issue by focusing on three sites across central England. We found that landowners participating in field sports maintained the most established woodland and planted more new woodland and hedgerows than those who did not, despite the equal availability of subsidies. Therefore, voluntary habitat management appears to be important for biodiversity conservation in Britain. Current debates on the future of field sports in Britain, and similar activities globally, may benefit from considering their utility as incentives to conserve additional habitat on private land.

Private landowners play an increasingly important role in biodiversity conservation[1]. This is especially important where habitats form isolated remnants in an agricultural matrix, and it is politically difficult to establish large protected areas[9]. This is typified by the situation in Britain, where farmland covers 76% of the country and increases in agricultural efficiency have caused great declines in biodiversity[7,10,11]. The British government has responded by introducing legislation to protect important habitats and species on public and private land[12–14], as well as establishing subsidy schemes[11,15]. However, conservation legislation remains unpopular with certain landowners, making enforcement by the statutory agencies difficult[16]. In contrast, subsidised agri-environment schemes do not involve coercion, but receive little funding[17] and can be poorly targeted[4,18]. Nevertheless, many British landowners are interested in conservation and may be willing to accept the costs of maintaining biodiversity[19]. However, research on this topic requires consideration of the role of field sports, which are controversial because of associated animal welfare issues.

Woodland and hedgerows are important habitats and create linkages across agricultural landscapes[20], while also providing important cover for British quarry species[8]. Both habitat types have declined considerably in the past 50 years[21,22], but those elements with high scenic or conservation value now have legal protection through a range of prescriptive legislation[12,13]. In addition, particular subsidies now encourage maintenance and planting of woodland and hedgerows[15], although funding availability is limited[17]. Moreover, uptake of such schemes depends on landowners' conservation values[19] and field sports may play a role in maintaining these habitats[8]. But previous studies have either used self-selecting questionnaires[6,7] or focused on the effects of game management practices on specific taxa[23,24]. We therefore sought to determine whether those who hunt foxes and/or maintain a game-bird shoot on their land voluntarily increase the biodiversity value of their land. We measured the extent of woodland and hedgerows in three study sites in central England, and investigated whether participation in these field sports, as well as farm size, farm type, dependence on income from farming, and membership of a biodiversity advisory group, influenced a landowner's likelihood of conserving habitat (see Methods).

Analysis of aerial photographs showed that landowners who hunt and those who maintain game-bird shooting support more woodland cover than those not involved in field sports (hunt: *F*-test statistical datum $F = 4.004$, $P = 0.05$; shoot: $F = 12.439$, $P = 0.001$), with no effect of study site, farm size or type, income dependence, or advisory-group membership. Landowners who both hunted and maintained game-bird shoots conserved the most woodland cover, around 7% of their farm area (Fig. 1). There was no difference in the proportion of field boundaries consisting of woodland or hedgerow between landowners practising and not involved in field sports (hunt: $F = 0.305$, $P = 0.583$; shoot: $F = 0.956$, $P = 0.332$).

Interviews revealed that landowners who participated in hunting and shooting were more likely to have planted woodland (Area under the Receiver Operating Characteristic curve (AUC) = 0.781; hunt: Wald = 6.050, $P = 0.014$; shoot: Wald = 8.463, $P = 0.004$; Fig. 2), with no effect of study site, farm size or type, or advisory-group membership. These results support an earlier questionnaire study[7], suggesting that involvement in field sports is an important incentive for farmers to create additional woodland. The likelihood of planting will also depend on the landowner's income, as new planting incurs direct and opportunity costs, even with grant support. Indeed, landowners who hunt and maintain game-bird shoots were less dependent on farming income (hunt: $\chi^2 = 4.197$, $P = 0.04$; shoot: $\chi^2 = 7.565$, $P = 0.006$), but wealth alone does not appear sufficient to encourage landowners to plant.

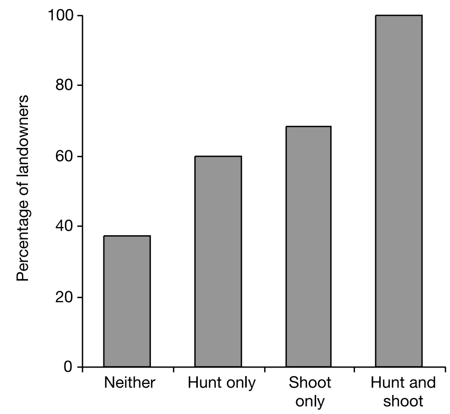

Figure 2 Influence of participation in field sports on the proportion of landowners planting new woodland.

New hedgerow planting was predicted by hunting and advisory-group membership (AUC = 0.752; hunt: Wald = 6.166, $P = 0.013$; advisory group: Wald = 10.657, $P = 0.001$; Fig. 3), with no effect of study site, farm size or type, income dependence, or maintaining a game-bird shoot. Furthermore, hedgerows were generally richer in woody plant species when landowners belonged to an advisory group, although this depended on study site (site × advisory group: $F = 3.637$, $P = 0.007$; Fig. 4), with no effect of farm size or type, income dependence, or participation in field sports. Previous studies have shown that species richness in hedgerows is affected by both hedgerow age and current management[25]. Hence, our findings further emphasize[19] the value of landowners belonging to an advisory group for maintaining species diversity in hedgerows. Moreover, our findings suggest that participating in fox hunting can indirectly support hedgerow conservation through new planting, and supplement the direct support shown by landowners belonging to advisory groups.

Our results suggest that governments in developed countries, such as Britain, could benefit from adopting the sustainable-use and incentive-based conservation policies that they encourage

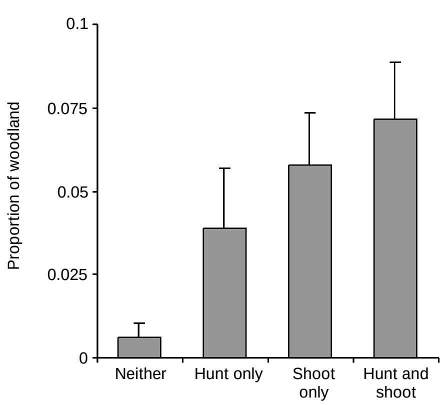

Figure 1 Influence of participation in field sports on the proportion of each farm covered with woodland. Data are mean ± s.e.

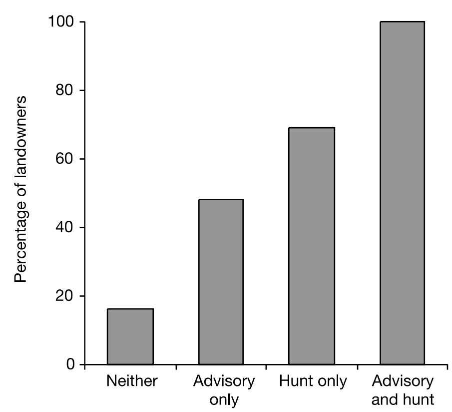

Figure 3 Influence of participation in hunting and membership of an advisory group on the proportion of landowners planting new hedgerows.

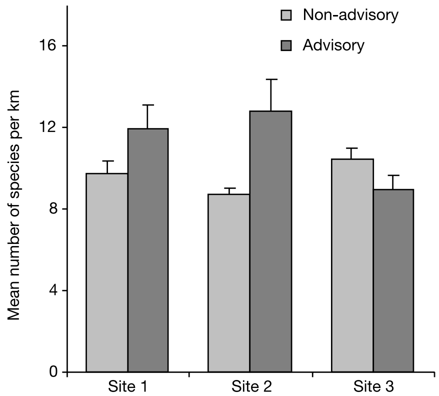

Figure 4 Influence of study site and membership of an advisory group on number of woody plant species in hedgerows. Data are mean ± s.e.

abroad[26,27]. We have shown that landowners participating in British field sports are more likely to maintain established woodland habitat on their farms. More importantly, they are also more likely to undertake new plantings, even though all the farmers have equal opportunities to apply for subsidies that support these activities. Game-bird shooting produced a greater effect on established and planted woodland (Figs 1 and 2), which is unsurprising given the considerable financial return it can generate for landowners. Nevertheless, landowners who hunt with hounds are more likely to conserve woodland habitat (Fig. 1) and plant more woodland and hedgerows (Figs 2 and 3), suggesting that the perceived recreation and social benefits of this controversial activity can produce conservation benefits. However, current debate over the future of fox hunting with hounds predominantly focuses on welfare issues and its uncertain role in population control[28,29], leading to proposed legislation that seeks to balance cruelty against utility of control[30]. Our results suggest an equally valid test of utility could focus on the role of landowners in voluntary habitat conservation. Equally, should hunting, or indeed game-bird shooting, be banned on welfare grounds without concessions for such utility, then additional public funds may be needed to increase subsidies for habitat conservation, together with the strengthened capacity to enforce legislation. □

Methods

Sampling protocol

Three study sites that each fell within one hunt country (an area hunted by an individual hunt) were chosen to represent arable, mixed and pastoral farming areas in central England, an area that has little coverage of formally protected areas. Lists of farmers were obtained at each site from the local foxhunt. Samples of hunting and non-hunting farmers were chosen using a random number generator. All selected farmers agreed to participate in the study, and this produced a total sample size across the three study sites of 65 landowners who owned more than half their farms and had farmed there for 10 years or more. Questionnaire-based interviews conducted with each landowner sought details of the following: farm boundaries; farm type (whether arable, livestock or mixed); farm income dependence (whether or not dependent solely on income from farming); non-productive land management (whether or not new woodland and hedgerows had been planted in the previous 10 years); advisory-group membership (whether or not the landowner belonged to an advisory group such as the Farming and Welfare Advisory Group); and maintenance of game shooting (whether or not farms maintained commercial or non-commercial game shooting on their land). Each selected farm was digitized from 1999/2000 aerial photos, and ArcView v3.2 GIS software (ESRI, Redlands, California) was used to determine its size, area of woodland and length of hedgerows. Hedgerow surveys—undertaken along 1.6 km of hedgerow from eight hedges randomly selected from digitized maps on each sampled farm—sought to determine the number of woody plant species in each hedge.

Statistical analysis

We sought to identify the factors that determine whether landowners conserved woodland and hedgerow habitat, irrespective of study site. Habitat conservation was assessed through five measures on a total of 65 farms: the proportion of each farm covered in established woodland; the proportion of landowners planting new woodland; the proportion of farm boundary consisting of hedgerow and woodland on each farm; the proportion of landowners planting new hedgerows; and, the number of woody plant species per kilometre of hedgerow on each farm. Each of these dependent variables was compared against the following explanatory variables: study site; farm size; farm type; farm income dependence; advisory group member; participation in fox hunting; and maintenance of game shooting on the farm. All of these variables, apart from farm size, were categorical. General linear modelling was used to find the factors determining the following: the proportion of woodland; the proportion of farm boundary consisting of hedgerow and woodland; and the number of woody plant species per kilometre of hedgerow. In order to meet the assumptions of the general linear model, a square-root transformation was applied to the proportion of woodland. Stepwise logistic regression modelling was used to find the factors that determined the probability of landowners having planted woodland and hedgerows. The possible influence of spatial autocorrelation was investigated for each dependent variable within each study site by calculating the Moran's *I* statistic using the CrimeStatII software package (v2.0, Ned Levine & Associates, Houston, Texas) and no significant effect was evident.

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