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Effects of agri-environment schemes in a long-term ecological time series

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Abstract

We investigated the impact of agri-environment schemes, including organic farming, on contrasting taxa, when the management of a Southern English farm was changed in the middle of a 12 year time series for an ecosystem monitoring programme. Plant species richness, including butterfly larval food plants, increased, whilst grassland productivity decreased. There was no overall difference in butterfly or carabid beetle abundance or species richness after the management changes, but some individual species increased significantly. Moth abundance and species richness significantly increased following changes in management. There were significant longer term increases in butterfly and carabid populations from when monitoring started in 1994, which continued through the change in management. This contrasted with national trends over the same period. Warmer summers generally increased invertebrate abundance, but there was no significant trend in weather variables for the years following the change in management. This study corroborates results from short term comparison of contrasting farms and demonstrates measurable benefits to biodiversity from the implementation of agri-environment schemes, which continue to increase over at least five years.

Keywords: Organic farming, agri-environment schemes, biodiversity, long-term monitoring, UK Environmental Change Network

1. Introduction

The decline in farmland biodiversity over the last 50 years in Europe and North America has been widely attributed to the intensification of agriculture (Krebs et al., 1999; Robinson and Sutherland, 2002; Green et al., 2005). This decline has been addressed by encouraging farmers and landowners to adopt agri-environment schemes (AES), through which they are subsidised to implement less intensive practices. In 2005 AES covered over 25% of farmland in the EU15 countries (EU, 2005) and 13% in England (Defra, 2007). This approach has also included support for organic farming, which accounted for 3.9% of the total agricultural area of the EU (EU, 2007) and 3.0% of England in 2005 (Defra, 2006a).

The monitoring of the impact of European AES has been limited (Whitfield, 2006), and the Environmentally Sensitive Areas (ESA) scheme in the UK resulted in only marginal increases in biodiversity according to Kleijn and Sutherland, (2003) and Wilson et al., (2007). Studies have indicated that organic farming benefits biodiversity (Bengtsson et al., 2005; Fuller et al., 2005), with greater numbers and/or diversity of bats (Wickramasinghe et al., 2003), birds (Chamberlain et al., 1999), butterflies (Rundlöf and Smith, 2006; Feber et al., 2007), carabid beetles (Kromp, 1989; Pfinner and Niggli, 1996) and plants (Gabriel and Tscharntke, 2007; Boutin et al., 2008). However, these studies have mainly been based on comparing organic farms with conventional farms at the same point in time, often using a paired farm approach. Interpretation of these results are complicated by the possibility that organic farms may be predisposed to support higher biological diversity if they have greater habitat heterogeneity and already favourable management compared to other farms (Krebs et al., 1999; Fuller et al., 2005; Rundlöf and Smith, 2006). There has usually been a lack of baseline data and long-term monitoring before, during and after transition (Kleijn and Sutherland, 2003; Hole et al., 2005; Kleijn et al., 2006). A long-term perspective would be valuable because many ecological processes are slow and sensitive to weather conditions that can cause large inter-annual variability in some animal and plant communities.

To our knowledge, no studies have followed a farm through conversion to organic status, quantifying changes in a wide range of biodiversity, with several years data before and after the change. Organic conversion and adoption of agri-environment measures under an ESA scheme at Wytham Estate, Southern England, in the middle of a long-term ecosystem monitoring programme, provided a unique opportunity to do this.

Long-term monitoring of a wide range of variables has taken place at Wytham under the UK Environmental Change Network (ECN) long term monitoring programme (www.ecn.ac.uk) since 1992. ECN was established to detect long-term environmental change at a series of intensively monitored sites across the UK and is part of the International Long Term Ecological Research (ILTER) network. Monitoring includes physical aspects of the environment, particularly climate, hydrology and air pollution, as well as a wide range of organisms and records of land management. Until September 2001, the farmland on the estate was managed as a commercial mixed farm, with no participation in any AES. In 2002, the farm introduced organic management and part of the site was incorporated into an ESA scheme covering the flood plain of the River Thames. This resulted in an increase in the area of grassland, a decrease in livestock numbers and the cessation of artificial fertiliser, herbicide and pesticide applications (Table 1). This reflected a wider trend across the UK where there has been a 14% decrease in head of stock per hectare and a 30% reduction in fertiliser use over a similar time frame (Defra, 2006b). Grasslands have been targeted in AES in a number of European countries, including Denmark, Germany and Switzerland (Kleijn and Sutherland, 2003) and North America (Grassland Reserve Program). In the UK, the Upper Thames Tributaries ESA encouraged arable reversion and rotations using perennial leys – in 2004 70% of the farmland was grass (Philip Riordan, pers. comm.).

As the ESA scheme and organic conversion were implemented at a similar time it is hard to separate their effects on the biodiversity. However, details of specific schemes differ over time and between different regions and countries. The changes that took place at Wytham are typical of many such schemes and are best interpreted in a generic way, rather than as a test of specific prescriptions.

In this paper we aim to address the following questions:

1. Have there been any changes in the composition or abundance of the monitored taxonomic groups?

2. If so, what evidence is there that the changes can be attributed to changes in land management rather than other factors, such as weather?

The wider series of ECN sites has allowed us to compare Wytham with other sites in the network, which have not experienced the same change in management, using standardised monitoring methods.

2. Materials & Methods

Wytham Estate (1°20'W 51°46'N; National Grid Reference SP 462082) is 5 km northwest of the city of Oxford and is owned by Oxford University. The farmland covers 374ha and is bounded in part by the River Thames, at an altitude of approximately 60 m O.D. The land adjacent to the River Thames is on alluvial soils: Max and Fladbury Series in the England and Wales Soil Survey Classification (Clayden and Hollis, 1984), with much of the rest on heavy clay soils (Folksworth and Denchworth Series). The farmland is partially bounded by a forest area, Wytham Woods, which is also monitored within the ECN programme. Prior to the change in management (1994 to 2001), the area of grassland, crops grown, agrochemical inputs and grazing intensity did not change substantially.

(TABLE 1)

2.1. Monitoring

ECN methods are described in detail by Sykes and Lane (1996); those relevant to this paper are summarised below. The data used in this study were from the beginning of 1994 to the end of 2006.

Grassland productivity was measured in ten 2 x 1.5 m plots using wire cages to exclude grazing. Plots were re-sited at random in March each year, within ten 30 x 25 m grid plots in permanent pasture. The sward was cut four times a year from mid-May to the end of October, the fresh yield weighed for each plot and a sub-sample dried to give dry matter productivity; plant species present in each exclosure plot were recorded each July before the second cut. The grassland received a mean rate of 265 kg N/ha/year previous to 2002. Plant species presence was also recorded in July in three 10 x 10 m vegetation monitoring plots, each containing ten 0.4 x 0.4 m randomly placed, permanently marked quadrats.

Butterfly populations were monitored weekly, from 1 April to 29 September, on a fixed 3.55 km transect, divided into 13 different sections at field boundaries, following the method of Pollard and Yates (1993). All butterflies present within 2.5 m to each side and 5 m in front of the observer were recorded. Transects were only walked in dry weather with temperatures >13°C if cloud cover was less than 60%, or >17°C in more cloudy conditions. The transect comprised of cropped (prior to 2002) and grassland habitats and, in parts, deciduous woodland edge, river bank, hedgerows and a field margin established in 1987. Macro-moths were monitored nightly, between dusk and dawn, using a Rothamsted Insect Survey light-trap (Woiwood and Harrington, 1994), located in a fixed position in the middle of the farm.

Carabid beetle populations were sampled using ten pitfall traps at 10 m intervals on a permanent transect beside a hedgerow, with a track and permanent pasture on one side and a 2 m wide field margin (which was present at the start of the monitoring) and cropped field on the other. The traps (plastic cups sunken to ground level containing undiluted ethylene glycol, with covers and wire mesh to exclude rain and small mammals) were emptied every two weeks from the first week of May to the end of October. The data, an index of activity density, were compared with those from two similar transects in adjacent woodland.

Bats were recorded on an 850 m transect through agricultural fields and compared with another transect (500 m) along a nearby woodland / riverbank boundary. The transects were walked four times each year in four three- week periods between 15 June and 7 September, in dry weather conditions, starting 30 min. after sunset. A Batbox III/Batbox Duet (Batbox Ltd, Steyning, UK) was used to identify the bat calls to species and activity levels measured using the number of bat passes.

Data for butterflies, moths and carabids were compared with national trends. Eight ECN sites with comparable records for the same period of time were used to provide indices of national trends, independent of local changes in management. They include a wide range of agricultural and semi-natural habitats across the UK (www.ecn.ac.uk).

In addition to the standard ECN methods, butterfly larval food plants were recorded in 2001 and 2006. Each of the 13 butterfly transect sections was split into 10 m sub-divisions and the presence of food plant species were recorded to give an objective measure of frequency for each section. To account for varying section lengths, all data recorded on the butterfly transect were scaled to 100 m of section length.

The nomenclature for vascular plants followed Stace (1997), for butterflies Lewington (2003), moths Waring and Townsend (2004), beetles (Duff, 2008) and for bats Jones and Walsh (2006).

2.2. Data analysis

Regression analyses were used to examine temporal changes in grassland productivity, plant species richness, abundance and species richness of butterflies, moths and carabid beetles, and number of bat observations. Analyses were also carried out on all butterfly species recorded and the five most common moth and carabid beetle species.

Three potential types of change were tested:

a) Incremental change following the change in management (linear increase or decrease 2002 – 2006)

b) Step change, following the change in management (change in level between 2001 and 2002)

c) Incremental change independent of change in management (linear increase or decrease from 1994 to 2006)

A structured approach was taken, using four statistical models.

Model 1 tested for

$$y = a + bt + cz + dw \quad (1)$$

y being the dependent variable (for example butterfly abundance), t the year, z a parameter management change, $z = 0$ for $t \leq 2001$ or $= 1$ for $t > 2001$, w a measurement of time lapsed since management change ($w = z * t$), a, b, c, d fitted parameters.

Significant effects of w and level z indicated that there was both a step change and a subsequent incremental change in y following transition. In this case the results of this analysis only are reported.

If Model 1 showed that only w was significant, a second model (Model 2) was used to test for a change in trend since the changes in management in 2001, without a stepped change:

$y = a + bt + cw$ (2)

If only z was significant in Model 1, then Model 3 was used to test for a stepped change, but no subsequent trend:

$y = a + bt + cw$ (3)

Significant results from Models 2 and 3 are reported.

If neither w nor z were significant in Model 1, Models 2 and 3 were checked to see if there were significant effects of w and z without t, and if so, the significant model is reported. If not, Model 4 ($y = a + bt$) was used to test whether there was any significant linear trend with time through the whole data set from 1994 to 2006. Variables that were not significantly related to any variables with any of the models have not been reported.

Trends in air temperature and precipitation for summer (June, July, August) and the previous 12-months (September to August) were investigated using the same models.

Regression analyses were also used to test the relationship between the abundance of the different invertebrate groups and weather variables. The change in number of larval food plant species was tested using a *t*-test. All statistical analyses were performed using Systat 11 (Systat Software Inc., Richmond, CA, USA).

3. Results

3.1 Vegetation

Grassland productivity declined rapidly after nitrogen fertiliser applications ceased to approximately 50% of the yield before 2002 (Figure 1). Regression analysis of biomass showed a significant change in level from 2002 (Model 3, $R^2 = 0.853$, $P = 0.009$). Plant species richness under the exclosure cages increased from a mean of 4.1 species per plot in 2001 to 6.5 in 2006 (Model 2, $R^2 = 0.806$, $P = 0.007$). This trend was also recorded in the three additional plots with mean number of species per plot increasing from 5.7 (1998-2001) to 7.3 (2002-2006) (Model 2, $R^2 = 0.716$, $P = 0.035$).

(FIGURE 1)

The number of larval food plant species on the butterfly transect increased from a mean of 12.6 ±0.8 per section in 2001 to 17.2 ±0.8 in 2006 (t-test, P=<0.001), with 20 species increasing in occurrence and six declining (Table 2). Grass species, in particular *Festuca pratensis*, increased in frequency, as did legumes such as *Trifolium repens* and *Medicago lupulina*. Whilst, *Cirsium arvense* increased in occurrence, other weed species such as *Cirsium vulgare* and *Urtica dioi*ca slightly decreased, as did *Elytrigia repens* and *Poa annua*.

(TABLE 2)

3.2 Lepidoptera

A total of 23 butterfly species have been recorded on the transect. Butterfly numbers significantly increased from 1994, the rising trend continuing through the changes in management (Table 3). This result contrasted with the combined data from other ECN sites, which showed numbers peaking in the mid-1990's and declining subsequently (Fig. 2 a). At North Wyke, a lowland grassland ECN site which has not had any recent change in farm management, there has been a significant decrease in numbers since 1994 ($R^2 = 0.406$, $P = 0.026$).

(FIGURE 2)

(TABLE 3)

Butterfly abundance at Wytham showed a positive relationship ($R^2 = 0.604$, $P = 0.002$) with September to August mean air temperature, but not current year summer (June – August) temperature or previous 12-month rainfall.

One new species (*Aricia agestis*) was recorded following 2001. The species richness of butterflies per 100 m section significantly increased (Figure 3) over the whole period from 1994 (Model 4, $R^2 = 0.653$, $P = 0.001$), indicating that species were colonising new areas before and after the land management changes. There has been a significant increase in the populations of five butterfly species since 2001, including *Maniola jurtina* that made up over 50% of the total number of butterflies in 2006 compared with 15% in 2001. *Pieris napi* has shown a significant decrease in abundance since 2001, and *P. brassicae* a stepped decrease. A number of species have shown significant increases in numbers since the start of monitoring in 1994 (Table 3).

(FIGURE 3)

Since 2001 there has been a 9% increase in the number of individual macro moths caught at Wytham (Table 3). The other ECN sites have seen an overall decrease in moth abundance of 23% since 1994, with an 89% decline at North Wyke. Up to 2003 there was a similar pattern in the year to year changes between Wytham and the rest of the ECN sites, for example, a peak in 1995 and 1996. Since 2003 there as been a divergence in the trends (Figure 2b). Moth numbers showed a negative ($R^2 = 0.489$, $P = 0.008$) relationship with 12-month total rainfall.

There has also been a significant increase in the number of moth species since 2001 (Table 3). The abundance of Noctuids significantly increased in the period 2002-2006 compared to 1994-2001, while the number of Geometrids have remained steady, and other macro moth species have shown an increasing trend from the start of monitoring. *Eilema lurideola* was the most common moth caught (7% of the total catch), followed by *Luperina testacea*, *Agrochola lychnidis*, *Omphaloscelis lunosa* and *Idaea aversata*. Of the five most common species, only *O. lunosa* showed a trend of increasing abundance (Table 3) after the management changes.

3.3 Carabids

There was no significant trend following 2001 in the number of individuals (Figure 2c) or species richness of carabid beetles trapped on the farmland at Wytham, although there was a significant increase in number caught from 1994 onwards (Model 4, R^2 = 0.574, P = 0.040). This trend was not seen at other ECN sites, nor in two woodland transects at Wytham. Carabid beetles were caught in higher numbers in warm summers (R^2 = 0.318, P = 0.045). Compared with the woodland transects at Wytham, the farmland traps caught relatively few beetles, although species richness was higher (49 different species trapped since 1994 compared to 22 in ancient woodland). The high numbers caught in 2003 were mostly due to increased *Pterostichus melanarius* which was the most common species caught over the 13 years, followed by *P. madidus, P. cupreus*, *Harpalus rufipes* and *Abax parallelepipedus* (overall accounting for 81% of the catch). Both *H. rufipes* and *A. parallelepipedus* increased significantly after 2001 (Model 2, R^2 = 0.654, P = 0.009 and R^2 = 0.476, P = 0.046, respectively). *P. cupreus* has increased significantly from 1994 (Model 4, R^2 = 0.640, P = 0.001).

3.4 Bats

There has been an increase in the number of bat observations of *Pipistrellus pipistrellus* and *P. pygmaetus* (Model 4, R^2 = 0.440, P = 0.014) since 1994 on the farmland and *Myotis daubentonii* (Model 4, R^2 = 0.552, P = 0.004) on the riverside transect (Figure 4); *Pipistrellus* spp. make up 70% of the total number of bats on the farmland. No significant change has occurred since the management changes started in 2001.

(FIGURE 4)

4. Discussion

The data clearly show enhancements in some aspects of biodiversity following changes in land management. There is a problem of interpreting the results of long-term monitoring programmes without a ‘control’. This is not, however, unique to this sort of study and has perhaps been best studied in the context of climate change (Rosenzweig et al., 2007). It is necessary both to demonstrate that results are consistent with the effects which would be expected on the basis of theory and that there is no alternative, plausible explanation. In this case we can also compare the results of this study with others in which farms with contrasting management have been compared over shorter periods of time. Neither approach is perfect but the evidence is considerably strengthened when their results are consistent. There have been no other major perturbations which offer a plausible alternative explanation for all the changes at Wytham. The most likely is an effect of climate, and some groups do show relationships to weather variables. However, there have been no significant change in air temperature and rainfall since 2001 and substantial inter-annual variability. Other incidental changes in management were much smaller than the changes in 2001 and more localised.

An increase in plant species richness has been shown in a number of other studies on organic farms (Hald, 1999; van Elsen, 2000; Bengtsson et al., 2005; Boutin et al., 2008), with the increases in species richness probably the result of the cessation of fertiliser and herbicide applications (Hyvönen & Salonen, 2002). In permanent grasslands this increase was primarily due to higher numbers of broad-leaved perennial plants, as has also been found in arable field studies (Hald, 1999; Boutin et al., 2008). The change in larval food plants recorded on the butterfly transect partly reflects the composition of the sown conservation grass seed. The increase in legume species colonising the grass sward is consistent with organic conversion (Van Elsen, 2000), resulting in reduced grassland productivity, because of a decline in available soil nitrogen.

National monitoring schemes for butterfly (Fox et al., 2006) and moth populations (Conrad et al., 2006) have shown declining trends, similar to those for the other ECN data. The difference between the local Wytham and national trends is consistent with an effect of changing management. All the butterfly species that have increased since 2001 are widespread and common, but agricultural intensification has been implicated in the decline in many of these common species (Fox et al., 2001). *L. phlaeas* is one such species which anecdotal evidence suggests has now benefited from set-aside (Mike Wilkins, pers. comm.). *M. jurtina* is likely to have profited from the increased area of grassland and more extensive grazing providing greater food plant resources and improved breeding area. The increase in *P. icarus* reflects the increase in its leguminous food plants. *A. agestis* has probably expanded on to the agriculture fields from populations on the old field margins. The stepped decline in *P. brassicae* density from 2001 to 2002 is most likely because oilseed rape stopped being grown on the farm (Feber et al., 1997). The increase in *O. lunosa* at Wytham may be a response to the increased grassland area and grass species.

The greater moth abundance at Wytham is not likely to have benefited *Pipistrellus* spp. which feed on smaller prey. Wickramasinghe et al. (2003) reported higher bat activity on organic than conventional farms, but no difference in *Pipistrellus* spp. activity.

There is some evidence of a divergence in trends between carabids on the Wytham farm transect and other ECN sites and Wytham woodland transects which, together with the increases in some species after 2001, suggest a beneficial effect of AES. Purtauf et al. (2005) found no difference in carabid species richness or activity density between organic and conventional farms. However, Andersen and Eltun (2000) found *H. rufipes* increased with organic conversion. It is primarily a seed predator, notably of grass seeds, and the increase in grassland might explain the increased catch numbers. Pitfall trapping is widely used for monitoring carabids and there is evidence that it is a robust technique (Standen, 2000). It does however reflect activity as well as population size and the transect at Wytham covers only a small part of the farm, making results susceptible to small-scale changes in vegetation structure around the transect itself.

An increasing temperature trend could potentially explain the longer term trends as many invertebrates are promoted by warm (and dry) conditions (Morecroft et al., 2002). Temperature has generally increased in recent decades, however the increase from 1994 to 2006 was not significant because of several warm years towards the start of the period. If temperature were a major factor, the increases in invertebrate abundance would also be expected to be across ECN, but this has not been the case.

The ECN monitoring at Wytham has provided a unique record of important aspects of farmland biodiversity, before, during and after the adoption of AES and organic management. There have been increases in the abundance and species richness of a number of the biological variables, which are best explained as a consequence of the changes in management. In other cases increasing trends have continued in contrast to other ECN sites. Other aspects of ECN monitoring, such as climate, provide no alternative explanation for these enhancements to the biodiversity of the site. These data also show that responses can be detected within a few years of a change in management and continue to increase over at least a five year period.

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Tables

Table 1 Land management and livestock changes on the study farm

Year	Land management	Stocking
Pre 2002	94 ha permanent grass, 60 ha grass leys, 220 ha cropped land (wheat, barley, oilseed rape and maize).	150 dairy cows, 30 replacement heifers, 1000 ewes.
Since 2002	52 ha designated ESA permanent grassland (Option 1A), 102 ha ESA reversion of arable land to extensive permanent grassland (Option 3A), 42 ha permanent grass, 142 ha grass leys, 36 ha cropped land (wheat, oats, beans and maize). Fertiliser, herbicide and pesticide use ceased.	120 beef suckler cows, 850 ewes, 20000 free range chickens.
2005	Land obtained organic status.	

Table 2 Difference in mean frequency occurrence of larval food plants on the transect sections between 2001 and 2006 survey on the butterfly transect. * Species sown in conservation grass seed mix

Larval food plant species		% change
*Festuca pratensis**	meadow fescue	63
Arrhenatherum elatius	false oat grass	26
Holcus lanatus	yorkshire fog	25
Brachypodium sylvaticum	wood false-brome	22
*Cynosurus cristatus**	crested dog’s-tail	15
*Poa trivialis**	rough meadow-grass	17
Dactylis glomerata	cocksfoot	13
Lolium perenne	perennial rye-grass	2
Poa annua	annual meadow-grass	-24
Elytrigia repens	couch	-13
Trifolium repens	white clover	37
Medicago lupulina	black medick	37

Hedera helix	ivy	23
Cirsium arvense	creeping thistle	18
Sisymbrium officinale	hedge mustard	14
Trifolium pratense	red clover	14
Brassica napus	rape	13
Humulus lupulus	hop	7
Thlaspi arvense	field penny-cress	7
Lotus corniculatus	common bird's-foot-trefoil	6
Ribes uva-crispa	gooseberry	5
Cardamine pratensis	cuckooflower	2
Cirsium vulgare	spear thistle	-9
Urtica dioica	common nettle	-8
Alliaria petiolata	garlic mustard	-4
Capsella bursa-pastoris	shepherd's-purse	-2

Table 3 Trend in Lepidoptera species abundance and richness before and after management changes. Only species showing significance in one of the models have been reported. *** P ≤ 0.001, ** P ≤ 0.01, * P ≤ 0.05, ns = not significant

		Stepped from 2002 (Coeff. of z)	Trend from 2002 (Coeff. of w + t)	Yearly trend from 1994 (Coeff. of t)
Butterfly abundance		ns	ns	59*
Species richness		ns	ns	0.07***
Aphantopus hyperantus	ringlet	ns	ns	18.5**
Aricia agestis	brown argus	-12.7*	7.1***	1.3*
Lycaena phlaeas	small copper	ns	5.7*	2.5*
Maniola jurtina	meadow brown	ns	121.9*	ns
Melanargia galathea	marbled white	ns	ns	3.5**
Pieris brassicae	large white	-32.0*	ns	ns
Pieris napi	green-veined white	ns	-26.2*	ns
Polygonia c-album	comma	ns	ns	1.3**

Polyommatus icarus	common blue	ns	11.8***	3.0*
Vanessa atalanta	red admiral	ns	5.3*	2.0*
Moth abundance		ns	132*	ns
Species richness		ns	8*	ns
Noctuid abundance		ns	106*	ns
Geometrid abundance		ns	ns	ns
Other macro moth species		ns	ns	8*
Omphaloscelis lunosa	lunar underwing	-106***	26**	6*

Figures

Figure 1 Yearly grassland productivity and mean number of plant species recorded under the exclosure cages

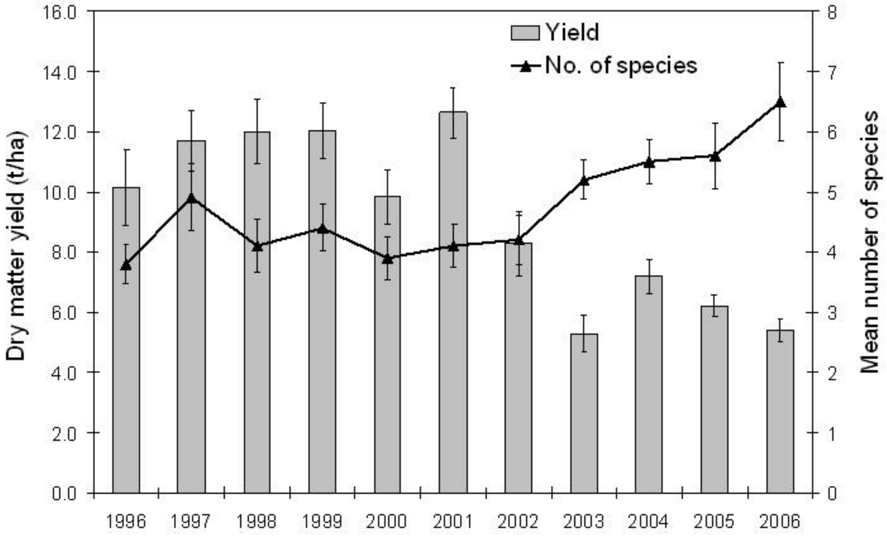
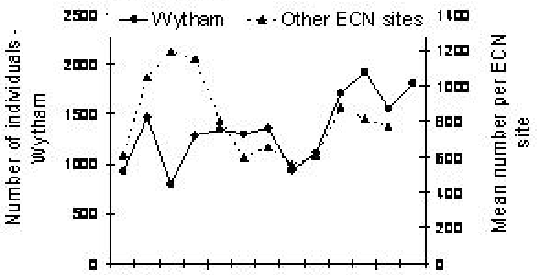
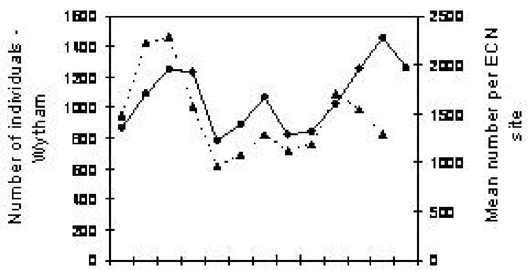


Figure 2 Comparison of changes in abundance for (a) butterflies; (b) moths; (c) carabid beetles between Wytham and the Environmental Change Network. Data for the Network are only available up to 2005

(a) Butterflies



(b) Moths



(c) Carabid beetles

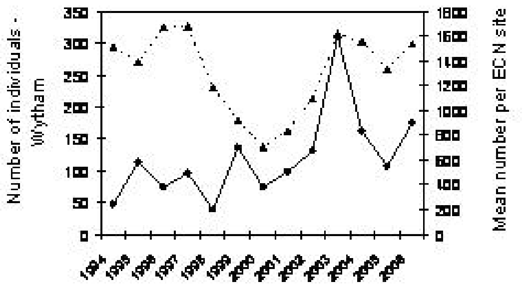


Figure 3 Mean number of butterfly species per 100m transect section at Wytham. Fitted line equations, $y = 0.067x + 2.89$

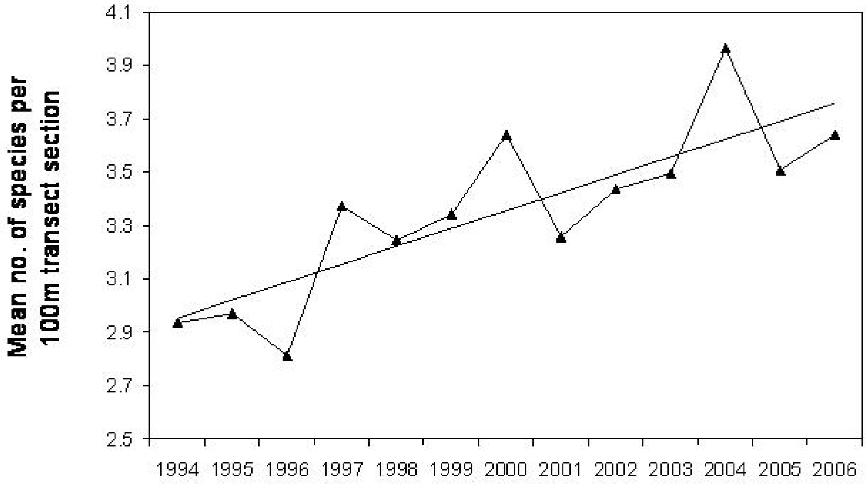


Figure 4 Number of pipistrelle bats recorded at Wytham on farmland transect compared to daubentons on river transect