

Using mark-release-recapture to investigate habitat use in a range of common macro-moth species

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Summary

1. Substantial declines have been documented in many of the so called ‘common’ macro-moth species in the UK. One cause of this decline is the intensification of agriculture and, in response to this, Environmental stewardship schemes are now offering the opportunity to restore agricultural habitats to provide landscapes for macro-moths and other wildlife.

2. In this study the habitat use of 11 common macro-moth species were compared using ten portable 12 volt actinic light traps. The abundance of moths found in standard arable field margins and wider field margins, of up to 6m were compared and the effect of a tree being present at the site was investigated.

3. The wider field margins had a higher abundance of macro-moths compared to the standard margins, the presence of a tree had no significant affect on moth abundance. It was also found that sites with high nectar availability had a higher abundance of moths. The dispersal ability of each species was looked at and it was found that moths with a greater wing span were found to be dispersing greater distances.

4. The findings in this study suggest that there is great benefit to increasing the size of arable field margins, and in increasing the abundance of flowers and the plant diversity. This may help to combat the increasing decline of many macro-moth species and could help lesson the impact of climate change on moths by reducing the fragmentation of agro-ecosystems currently found in the UK.

Key-words: macro-moths, agri-environment, biodiversity.

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Introduction

Despite the unquestionable importance of invertebrates to the global ecosystem, the research in the area of endangered and common insects lags far behind that of vertebrates (New, 2004). The lack of suitable data means that it is virtually impossible to quantify the declines found in many insect groups, even though recent evidence has suggested that some groups, such as butterflies, may be declining more rapidly than many of our native bird and plant species (Thomas *et al.*, 2005; Cowley *et al.*, 1999).

The Lepidoptera is one of the most commonly studied invertebrate groups in the UK and there are extensive data sets available which give very good indications of population changes over time. The usefulness of these long-term data on species abundance has become greater in recent years, with the escalation of research into climate change and, although their use remains contentious (Hamblen and Speight, 2004), butterflies are now commonly used indicators of climate change.

Macro-moths in the UK also have an extensive data series, and are a more diverse group than butterflies making them potentially more representative of terrestrial insects in Britain (Conrad *et al.*, 2006).

Population data on British macro-moths has been collected since 1968 by the Rothamsted Insect Survey, which is one of the longest running datasets anywhere in the world (Conrad *et al.*, 2006) providing data from a wide range of habitats. Conrad *et al.* (2006) used this data to determine the rate of population change in 337 species of macro-moth and revealed that two-thirds of the species studied had declined and 21% of the species had declined by over 30% in 10 years. This demonstrated that many so called ‘common’ moth species are undergoing severe declines and raised the further possibility that there could be knock-on effects for many bird and bat species that depend on moths for food.

There are many causes for the declines in the biodiversity in the UK. The population changes of many UK butterflies have been in some way attributed

to the intensification of agriculture in the last 40 years (Warren *et al.*, 2001). Since 1945 there has been a 65% decline in the number of farms in Britain, but with a concurrent fourfold increase in yield and since the mechanisation of agriculture, 50% of the hedgerow stock has been removed to make harvesting more efficient (Robinson and Sutherland, 2002). In addition to the intensification of agricultural practices, increased use of pesticides and synthetic fertilizers has also had a major negative impact on the invertebrate communities and on biodiversity in agricultural ecosystems.

In response to the concerns over the loss of biodiversity in agricultural land the EU agricultural policy first addressed the impact of farming practices on the environment in a Green Paper published in 1985 (Kleijn and Sutherland, 2003). This began a new set of measures for protection of environmentally sensitive areas and has led to the agri-environmental schemes of the present day. Within these schemes farmers are encouraged to modify their farming practices in a variety of ways to provide environmental benefits and improve their land for wildlife. These modifications include a number of strategies that may benefit insects, such as hedgerow restoration/creation, altered management of crop margins and the restoration of stone walls.

Within one of the tiered schemes known as Environmental Stewardship, lower tier farmers are encouraged to create 2m, 4m or 6m wide margins around the crop. These margins, which can be managed as fine grass with flowers, natural regeneration or tussocky grass, are intended to substantially increase the current area of field margin habitat and so benefit many wildlife species. This practice has now been reinforced through the introduction of a condition of use of most insecticides which states that spraying is not permitted on the outermost 6 m of arable crops in the summer (Frampton and Dorne, 2007).

To ensure that they are effective it is important to determine whether conservation strategies, such as the establishment of wide field margins, are actually increasing the abundance and diversity of species within these agricultural habitats. Approximately 4 billion euros are paid annually to farmers through agri-environment schemes, and it is important to determine if this money is being put to good use, or whether the scheme could be adapted or improved.

Studies have shown that wider field margins act as a buffer, protecting the hedgerows from fertilizer and pesticide drift. Margin width has been shown to be positively associated with bank vole abundance, with more bank voles being found in the 6m margins, and that the total small mammal biomass found in the autumn was three times higher within 6m wide margins compared with the conventional arable field edges (Shore *et al.* 2005).

Carvell *et al.* (2007) reported that, for some important pollinator species such as bumblebees, the presence of a wider margin alone may not be enough and that they require a field margin sown with additional nectar sources. Margins sown with a legume based pollen and nectar mixture attracted a higher abundance and diversity of bumblebees, on

average attracting 269 times more bees compared to the crop (Carvell *et al.*, 2007).

It has been demonstrated that insecticides can have direct effects on moths and butterflies while herbicides change the plant composition usually leading to a decrease in the floral diversity (Clausen *et al.*, 2001). In accordance with these findings, strong relationships have been found between the abundance of butterflies in arable land and the degree of shelter, width of non-crop habitat, nectar species abundance and hedgerow structure in the field margins (Pywell *et al.*, 2004). This effect has also been shown in other invertebrates, Meek *et al.* (2002) found that avoidance of the crop was by far the commonest observed response and that the margins showed double or more the number of invertebrates. This effect has been noted in a range of nectar feeding, flying invertebrates where a preference was seen in margins that contained high numbers of wildflowers (Meek *et al.*, 2002).

The specific habitat requirements of many macro-moth species remain to be determined, but it has been speculated that they will also benefit from a widened field margin with many nectar sources, as has been reported for butterflies. Indeed, the restricted use of herbicides in the crop edges has been shown to have a clear positive effect on a wide variety of lepidopteran larvae and so it appears that, in addition to butterflies, altered management of arable field margins may also represent an appropriate strategy for the conservation of macro-moths in agricultural ecosystems.

In this study we have examined the effect that different field margin widths have on the species assemblages and abundance of macro-moths in arable fields in the UK. Furthermore we have used a mark-release-recapture approach to examine the use of different habitats and the dispersal distances of different macro-moth species within the agricultural environment.

It is important to determine the dispersal ability of each moth species as the dispersal patterns affect the dynamics and survival of populations (Conradt *et al.*, 2001). Knowing the dispersal capabilities of moths will allow management plans to be taken in the appropriate areas.

Comparisons were made between 6m wide arable field margins and standard field margins, which usually consist of no more than 2m between the crop and the hedgerow. Furthermore, the presence of mature trees within the margin habitat and the abundance of nectar sources of different types were also investigated to determine whether these factors have any impact on the abundance of moths. The arable fields studied contained a mixture of wheat, potato and oil seed rape crop. The use of the crops themselves as potential macro-moth habitat was also investigated.

Methods

STUDY AREA

The field study was conducted from June-July 2007 within Callow Farm (OS Grid reference: SP 395181), in Oxfordshire. Twenty sites were chosen within four separate fields on the farm. Each field was

Table 1. List of the species studied with the rates of annual population change measured by Conrad *et al*, 2006. Annual change rate = annual rate of population change estimated from the 35yr time series (Conrad 2006). Change status = increasing: change > 0, declining: change < 0, vulnerable: greater than 30% 10yr decline.

| Species | Scientific name | Family | Annual change rate (Conrad <i>et al</i> 2006) | Change status (Conrad <i>et al</i> 2006) |
|----------------------------|------------------------------|------------|--|---|
| Large Nutmeg | <i>Apamea anceps</i> | Noctuidae | -0.058 | Vulnerable |
| Setaceous Hebrew Character | <i>Xestia c-nigrum</i> | Noctuidae | 0.004 | Increasing |
| Rustic Shoulder-knot | <i>Apamea sordens</i> | Noctuidae | -0.027 | Declining |
| Heart and Dart | <i>Agrotis exclamationis</i> | Noctuidae | -0.031 | Declining |
| Treble Lines | <i>Charanyca trigrammica</i> | Noctuidae | 0.007 | Increasing |
| Dark Arches | <i>Apamea monoglypha</i> | Noctuidae | -0.009 | Declining |
| Brown-line Bright-eye | <i>Mythimna conigera</i> | Noctuidae | -0.023 | Declining |
| Common Footman | <i>Eilema lurideola</i> | Arctiidae | 0.010 | Increasing |
| White Ermine | <i>Spilosoma lubricipeda</i> | Arctiidae | -0.041 | Vulnerable |
| Common swift | <i>Hepialus lupulinus</i> | Hepialidae | -0.005 | Declining |
| Buff-tip | <i>Phalera bucephala</i> | Phalerinae | -0.022 | Declining |

chosen to have equal tree density. Out of the four fields, two had wide field margins while the other two fields had standard margins.

Within each field there were five sites, four of these were in the field margins and one was positioned within the centre of the field, above the height of the crop. Of the sixteen sites within the field margins, half were near a tree and the other half had no tree present. On the first night 2 fields (one wide and one standard margin field) were sampled and on the subsequent night the other 2 fields were sampled. For example:

- Day 1: Field A (Wide) + Field B (Standard)
- Day 2: Field C (Wide) + Field D (Standard).
- Repeat.

It was important to not sample the same sites on subsequent nights because the trapped individuals would not have enough time to disperse.

MOTH TRAPPING

For the initial phases of this study eleven common species were studied. The eleven common species were chosen due to their high local abundance, although recent evidence suggests that even these common species may be in decline. Table 1 shows the species that were studied, as well as data on the population declines found in the last 10 years. Of the eleven species, only 3 are increasing, 2 have been classed a vulnerable (in this case showing a greater than 30% 10yr decline.) and 6 are in decline. It should be noted that in addition to these common species, in the community analyses an additional rare species that was found to occur was also included; the Pale Shining Brown, *Polia bombycina*.

Trapping was performed from the 5th June until the 14th July 2007. Ten portable 12 volt actinic light traps were placed in the late afternoon at the relevant sites. Each trap was placed on a white sheet and tent pegs were used to secure this in place. The traps contained eight egg boxes arranged for the moths to rest upon once caught. The light was connected to the battery which was secured within a water proof bag to protect it from the rain. The following morning the

moth traps were collected approximately one hour after sunrise (5.30am) and the study species were placed within glass collection jars and marked with a fine marker (Staedtler Lumocolor 317, permanent and waterproof) after a short period of cooling within a cool box.

The individual's upper left wing was marked with a number so the individual could be identified if caught again. The moths were marked at site to reduce the chances of miss-labelling and so they could be released immediately at the site they were found. The individuals were released low down in the vegetation and in different areas around the site to reduce the chances of predators becoming habituated to the release sites. Once the traps were emptied and the individuals marked, the traps were collected and the batteries charged for the subsequent night.

Nights that were unsuitable for trapping had to have two of three conditions: wind speed over 13mph, an average temperature of below 9°C or over half of the night with over 60% chance of rain. Nights with two or more of these factors were not sampled as these conditions are not appropriate for moth trapping, as the numbers of moths flying is greatly reduced.

HEDGEROW SURVEY

Within each of the four fields the hedgerows were sampled to calculate the diversity within 10m either side of each site. Within each 10m section the percentage cover of each plant species was calculated. The trees were noted but not included in the percentage cover. The Shannon Index of Diversity was used to give a figure to each site that represented the diversity of plants within that hedgerow, which also gave some indication of the age as more established hedgerows have a higher diversity of plant species.

NECTAR SURVEY

The nectar abundance at each site was calculated by counting all of the flower heads 10m either side of each site along the field margin. Each flower head in the margin was counted and the species identified. The species were then divided into 2 categories - species that are used regularly by moths (rated at high use)

and species that are infrequently used by moths (rated as low-use) (Martin Townsend, *pers. comm.*). To work out the nectar value of each site the flower species rated at high use had the number of flower heads multiplied by 5 (this figure represented the proportion of visits on average made by moths per night compared to the low rated species) and then this figure was added to the number of low rated flower heads. This gave a figure per site, and then this was used to rank the sites in order of the abundance of nectar sources. This nectar index was then used as an indication of the abundance of nectar sources present at the site.

WEATHER CONDITIONS

Each afternoon subsequent to trapping the weather conditions were noted from 21h to 5h using the website www.weather.com. Maximum and minimum temperature, humidity and wind speed were noted, also the average precipitation, cloud cover and wind direction. The sunrise and sunset times for each night were noted as well as the phase of the moon. The interpretation of light trap catches of moths is greatly complicated by the variation in the weather during the trapping period as it affects moth flight activity (Holyoak *et al.*, 1997). As absolute abundances are being measured the effect of weather variation will be treated as a form of sampling error.

STATISTICAL ANALYSIS

Microsoft Excel and Minitab 14 were used for all the statistical analysis and for generating the graphics. GIS ArcMap was used to create the map of the study sites and to measure the dispersal distances. The count data were transformed using \log_{10+1} transformation to make the data more normally distributed.

Results

There were 6 habitat types in this study. Each habitat type was classified according to its landscape features which were the margin width (Wide/Standard/ Middle of field) and the presence or absence of a tree. The habitats were thus: (A) a wide field margin with a tree directly opposite the trapping site, (B) a wide field margin but with no tree opposite the trapping site, (C) a standard field margin with a tree directly opposite the trapping site, (D) a standard field margin with no tree opposite the trapping site, (E) a wide field margin with the trapping site located within the crop, and (F) a standard field margin, with the trapping site located within the crop.

NECTAR AND HABITAT

Firstly it was important to determine whether the 6 different habitat types had different characteristics. This was measured using the 'flower index' as a measure of the abundance of nectar and the 'hedgerow index', which was a measure of the diversity of the hedgerow. To compare the habitats, the sites placed within the middle of field were discounted as they had no flowers or hedges.

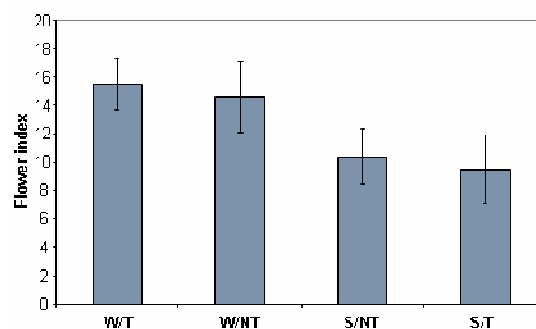


Figure 1. The average flower index (see text for description) for each habitat. (\pm S.E). (W= Wide margin, S= Standard margins, T= Tree present at site, NT= No tree present at site).

As Figure 1 shows, the nectar abundance was found to be the greatest at the sites with a wide margin compared to sites with standard margins ($F_{1,15} = 6.27$, $p < 0.05$). The presence or absence of a tree at the site had no effect on the abundance of flowers at the field sites ($F_{1,14} = 0.00$, $p > 0.05$). When the hedgerow index was compared between the sites there was no significant difference ($F_{1,14} = 0.07$, $p > 0.05$), so the sites had a similar diversity of plants within their hedgerows.

EFFECT OF HABITAT ON MOTH ABUNDANCE

Figure 2A shows the mean number of moths caught in each of the habitat combinations examined during the study. Overall, significantly more moths were caught in the wide field margins than in the standard margins. Furthermore, when the mid-field sites were also included there was an even more significant difference between the standard, wide and middle sites ($F_{2,317} = 10.23$, $p < 0.001$).

The effect of wide margins on mean moth abundance was also observed when the abundances of several of the individual species were studied, with higher mean abundances of 4 species observed within the wide margins compared to standard margins. As Figure 2B shows, the mean abundance of the species Treble lines, *Charanyca trigrammica*, was significantly greater in the wide margins compared to the standard margins ($F_{2,254} = 10.90$, $p < 0.001$). This effect was also found in Heart and Dart, *Agrotis exclamationis* ($F_{2,254} = 3.35$, $p < 0.05$), Brown-line Bright eye, *Mythimna conigera* ($F_{2,254} = 8.85$, $p < 0.001$), and the Common Footman, *Eilema lurideola* ($F_{2,254} = 8.13$, $p < 0.001$) (data not shown).

None of the species studied showed any significant differences in their abundance between the sites with or without a tree.

A two-way ANOVA was performed to look at the effects of margin width, the effect of a tree and whether there is an interaction between the two variables (the mid-field sites were discounted). This showed that there was no significant effect of the presence of a tree, but that there was a highly significant effect of margin width ($F_{1,252} = 7.23$, $p < 0.05$). There is no significant interaction between margin width and presence of a tree ($F_{1,252} = 3.55$, $p = 0.061$), however this result does suggest that further study may reveal that the effect of a wide margin is more pronounced in the sites without a tree.

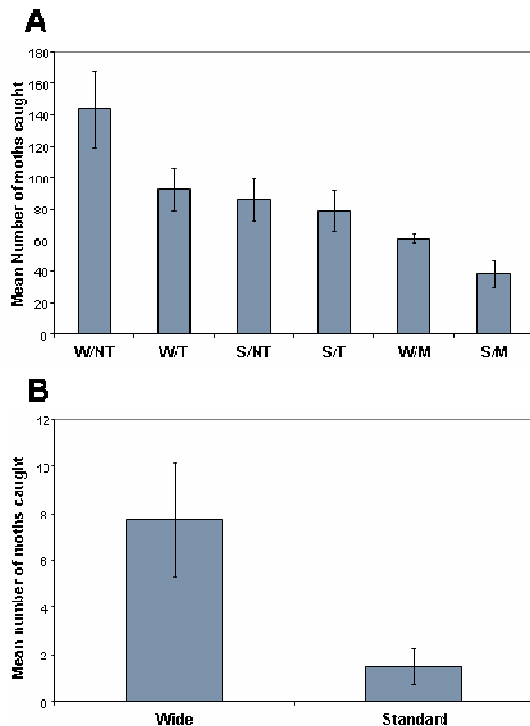


Figure 2. (A) The mean number of moths that occurred in each habitat type (\pm S.E) (W= Wide margin, S= Standard margins, T= Tree present at site, NT= No tree present at site, M= Sites in the middle of the field). (B) The effect of field margin size on the abundance of the species Treble Lines (*Charanyca trigrammica*) (\pm S.E).

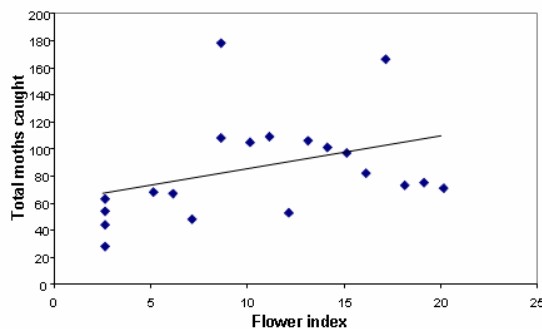


Figure 3. The relationship between the flower index of a site (see text for description) and the total number of moths caught. ($R-Sq= 2.3\%$).

Further examination of the data for wide field margins alone did reveal that mean abundance of moths was significantly greater in sites without a tree in the margin ($T_{1,25} = 2.10$, $p < 0.05$) and this can clearly be seen in Figure 2A. There was, however, no difference, between the sites with and without a tree in the margin when the standard field margins were examined separately (Figure 2B).

Furthermore, when the mid-crop sites were compared there were no differences in mean moth abundance between those in fields with wide margins and those with standard margins (data not shown).

EFFECT OF MARGIN FLORA ON MOTH ABUNDANCE

Figure 3 shows that as the flower index increased the number of moths caught significantly increased ($T_{1,318} = 2.73$, $p < 0.01$, $R-Sq= 2.3\%$). There was no significant relationship between the number of moths caught at each site and the diversity of plants within the hedgerow ($T_{1,318} = 1.92$, $p < 0.1$, $R-Sq= 1.1\%$) (data not shown), although the probability that there is a relationship between mean moth abundance and hedgerow diversity is very high and warrants further study.

COMMUNITY ANALYSIS

Simple correspondence analysis was used to investigate the assemblages of moths caught in the different habitats and to elucidate associations between the different moth species. The over-laid results of these analyses are shown in Figure 4A and indicate that there are potentially associations between the Common Footman, Treble Lines, Buff Tip and Rustic Shoulder Knot moth species both with each other and with habitat features of a wide margin with a tree. Figure 4A also shows that there may be an association between Brown-line Bright-eye and the Pale Shining Brown and between these species and the habitat features of a wide field margin with no tree present.

Figure 4B compares the habitat types according to their macro-moth community compositions. There is a clear difference in community composition between the wide margins with a tree present and the wide margins with no tree present. Both of the habitats with wide margins also have very different community compositions to both of the standard margin habitats and also to both of the mid-crop sites. There appears to be a similar species composition between the sites placed in the middle of the fields.

Figure 4C compares the species according to their occurrence in different macro-moth communities. As the analysis shows, there are some species that are associated with each other in similar communities. The Common Footman, Treble Lines, Buff Tip and Rustic Shoulder Knot appear to be associated with each other in similar communities, indicating that they may be ecologically closer together, while Large Nutmeg, Setaceous Hebrew Character, White Ermine and Dark Arches appear to be associated in a different moth community. In addition, the Pale Shining Brown, Brown-line Bright Eye and possibly Heart and Dart also appear to be associated in terms of the communities in which they occur. The Common Swift is the only species that appears to be less associated with any of the other species.

EFFECT OF WING-SPAN ON DISPERSAL

To examine the dispersal of macro-moth species within the agricultural landscape a mark-release-recapture study was performed. In total 70 individuals were recaptured and the total recapture rate was 3.88% of the population. The furthest distance travelled by a single individual was 1169.52m (a Setaceous Hebrew Character) and 54% of the individuals recaptured had not dispersed and were caught at the original trap site.

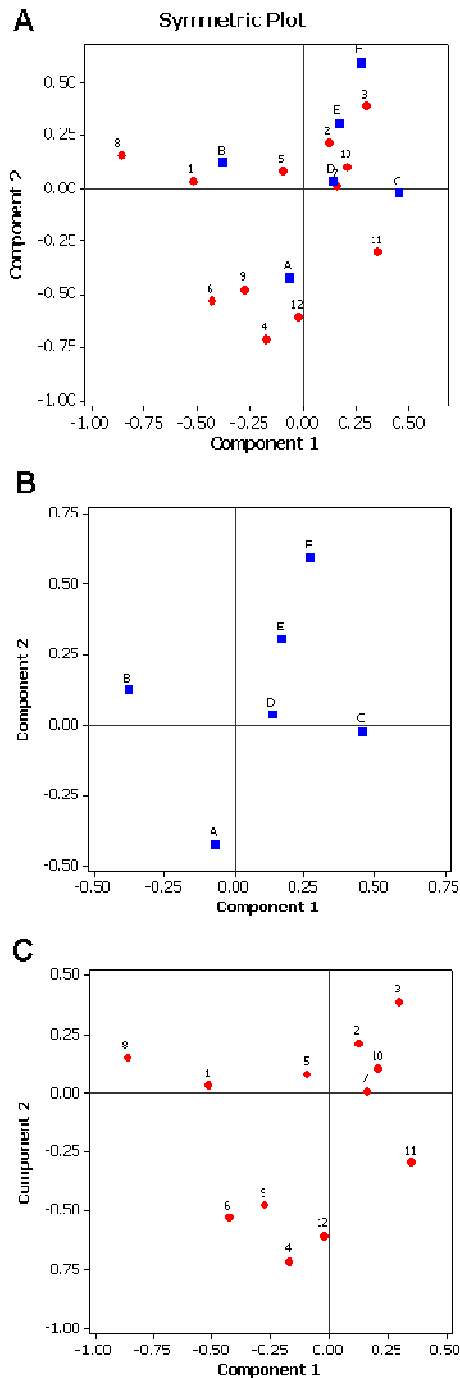


Figure 4. Correspondence analyses to examine moth communities present in different habitats and moth species that occur in similar communities. (A) Symmetric plot showing moth species and habitats on the same axes. (B) Correspondence plot showing ecological distances between habitats. (C) Correspondence plot showing ecological distances between moth species. Moth species shown are: 1 = Pale Shining Brown, 2 = Large Nutmeg, 3 = Setaceous Hebrew Character, 4 = Rustic Shoulder Knot, 5 = Heart and Dart, 6 = Treble lines, 7 = Dark Arches, 8 = Brown-line Bright-Eye, 9 = Common Footman, 10 = White Ermine, 11 = Common Swift, 12 = Buff Tip. Habitats show are: A = Wide/Tree, B = Wide/No tree, C = Standard/No tree, D = Standard/Tree, E = Wide/Middle, F = Standard/Middle.

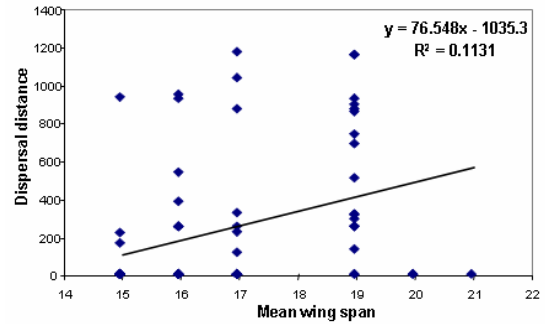


Figure 5. The mean wing span (cm) plotted against the average dispersal distance (m). The equation for the relationship and the value of R^2 are given.

It was speculated that dispersal distance was related to the wing-span of the moth species in question and so mean dispersal distance was correlated with mean wing-span. As Figure 5 shows there was a significant positive relationship between the mean wing span of a macro-moth species and the average dispersal distance of that moth species ($T_{1,68} = 2.94$, $p < 0.01$, $R-Sq = 11.3\%$).

Discussion

HABITAT PREFERENCES

The results of this study suggest that there was not a random distribution of moths in all habitat areas and that some habitats may have a higher abundance of macro-moths. This study has shown that the management of arable field margins has a significant effect on macro-moth abundance. The wider field margins with a higher abundance of nectar sources attracted a higher abundance of moths.

When both field margin types were considered the placement of a tree was not an important factor affecting abundance, but when the wide field margins were investigated separately, a higher abundance of moths were found in sites that did not have a tree. This is a surprising result as it was expected that the total abundance would be greater in the sites that had a tree present due to the benefit of a tree providing a form of shelter. Many previous studies have found that shelter provided by features such as trees and hedgerows are an important predictor of high numbers of butterfly species and abundance due to the benefit of a warmer microclimate (Pywell *et al*, 2004). The areas that provided shelter should allow activity to continue as the more exposed sites become unsuitable. The effect found in this study could be due to a form of sampling bias due to the tree blocking the light from the trap and so reducing the ability to catch as many individuals as the sites that do not have a tree. A study by Weibell and Ostman (2003) found that the habitat explained most of the variation in the butterfly composition within the studied sites, the landscape features and farm management explained far less of the variation found. This shows how important it is on a landscape scale to preserve as many different

habitats as possible, including the field margins which form most of the habitat available for wildlife.

The crop has a very different species composition and plant structure to the non-crop areas, such as the field margins. The margins offer a more stable microclimate for over-wintering and are vital for maintaining populations of moths and butterflies (Pywell *et al.*, 2004). This may be an important factor in explaining why there were significantly less moths caught in the middle of the fields compared to the field margins. It can be concluded that the species studied are not utilising the crop as a habitat and may have been caught while dispersing to another field margin.

The abundance of nectar at a site had a strongly positive relationship with the abundance of moths. This was an expected result as most moth species require an abundant and constant nectar supply. The higher abundance of moths at sites with a wider margin is therefore likely to be related to the higher nectar abundance found at these sites. The wider margins have a higher and more abundant diversity of grasses and flowers and are very important for the less mobile species that cannot move easily between margins. Nectar has been found to be important in the longevity and fecundity of butterflies (Dover, 1996) and it is likely that this is the case for nectar feeding moths. The intensification of agriculture has changed the balance of field margins, with a reduction of flower rich perennial plants and an increase of annual weed species. Some of these weeds, such as old mans beard, *Clematis vitalba*, were very common in the standard field margins in this study and have been shown to 'swamp' hedgerow shrubs (Dover, 1996). Cow parsley, *Anthriscus sylvestris*, may have similar effects, although both plants do have numerous flowers and could be considered as nectar providing species. The best margin therefore should contain a diversity of plant species that will provide nectar for the whole season. A study by Matter and Roland (2002) found that the male butterfly studied of the species, *Parnassius smintheus*, were actively immigrating into higher quality meadows (measured by quality of nectar resources) which suggests that the butterflies were assessing the quality of the meadow, and this may occur in moths although this needs further study to determine how they sample a habitat and if olfactory clues are used.

The diversity of the hedgerow flora had no significant effect on the abundance of moths, but this does not necessarily mean that moths do not respond to the diversity of a hedgerow. In this study all of the hedgerows in the different habitat types had very similar species diversity and thus the true impact of hedgerow diversity could not be resolved effectively. Feber *et al.* (1996) also found that the presence of a hedgerow did not significantly predict the abundance of any butterfly species, although movements of some species are affected by the degree of shelter provided by hedgerows. Some hedgerow species also act as a nectar resource, although this may not be as important as other nectar sources found in the field margin.

Any restoration or improvement to the standard field margins is likely to benefit a range of macro-moth species. These benefits can include making the

margin wider or increasing the floral diversity within the margin. Both these will benefit moth abundance and diversity.

HABITAT-MOTH COMMUNITY ASSOCIATIONS

We have demonstrated through community analyses that there may be some significant associations between the species studied and the habitats. The species, White Ermine and Dark Arches appear to have an association with the standard field margins, while the Pale Shining Brown and Brown-line Bright-eye appears to have an association with the wider field margins that have no tree present. There may also be an association between the wider margins, with a tree present and the Common Footman, Treble lines, Rustic Shoulder Knot and Buff Tip. It is not completely clear as to why these associations have been found, although some species associations may be explained by their larval food plant. For example the Buff Tip was strongly associated to sites that had a tree present. This could be due to their larval food plant being the bark from trees, and the adults are commonly found in woodland areas. Some of the larvae of the species studied feed on grasses, such as Dark Arches which seemed to have an association with the standard field margins which would contain many dominant grasses as opposed to the nectar rich flowering plants. This needs further study to determine what other factors may influence a species association with a habitat feature.

DISPERSAL DISTANCES

We have demonstrated a significant relationship between the wing span of a moth and the average dispersal distance. This finding is in accordance with the findings of Nieminen *et al.* (1999), who found that the abundance of a species and its body size largely determined the migration rate and distance travelled, and has consequences for moth conservation as the fragmentation of habitats may adversely affect smaller species due to their reduced dispersal capabilities. Most moths recaptured (54%) did not disperse, and the recapture rate was relatively low at 3.88% of the total number caught. The furthest distance travelled in this study was 1170m, which shows the capable dispersal distance although this may not be representative of the furthest a moth is capable of travelling. Similar dispersal capabilities were found in the six spot burnet moth, *Zygaena filipendulae*. A study found that most of the six spot burnet moths moved only small distances and only 6% of movements were over 100m (Menendez *et al.*, 2002).

In this study the dispersal distance does not represent the farthest distance that an individual can travel, but could give an estimate of the average distance for an exploratory movement. MRR is a very useful tool to estimate the dispersal distance of individuals but it causes a dilemma, called the 'Heisenberg' effect (Yamamura *et al.*, 2003). In any MRR study a large number of traps are needed to yield a precise estimate of mean dispersal distance, but the individuals, had they not have been intercepted, may have dispersed further. Thus the mean dispersal distance has become smaller than the actual dispersal

distance. Yamamura *et al.* (2003) have proposed a possible solution for this sampling bias, by placing the traps in a uniformly lattice pattern and by assuming random movement. Although it has not been confirmed in any macro-moth species, some butterfly species have been shown to disperse in a non random fashion (Conrad *et al.*, 2001). A smaller number of traps would reduce this bias, but this makes the experimental design subject to larger sampling errors and so less reliable. It has also been suggested that MRR studies may suffer from behavioural biases, as catchability is likely to differ among different types of movement and some individuals may be more likely to be caught than others (Van Dyck and Baguette, 2005). There are two different types of movement that have been suggested by Van Dyck (2005), the first is as the by product of routine movements, like foraging and the second is directed movements designed for displacement. It is likely that MRR studies have a bias to catch individuals in routine movements. These differences need to be explored further to understand the possible effect that fragmentation may have on populations of macro moths.

It has been suggested that the species richness of butterflies within field margins is due to dispersal from larger semi-natural grassland fragments (Ockinger and Smith, 2007). This was not looked at in this study but it might be an important factor in the conservation of macro-moths. If dispersal is occurring then conservation action should be increased in the grassland areas adjacent to the farmland, as they could form the population source, rather than the field margins themselves.

IMPLICATIONS FOR AGRI-ENVIRONMENT SCHEMES

This study looked at the effects of increasing the width of the standard arable crop field margins found in most farms across Britain. The relationship between climatic change and the fragmentation of habitats is very important for the future understanding of Lepidoptera populations. Insects are predicted to be very sensitive to climate change and most data suggests that species distributions will shift northwards (Hill *et al.*, 1999). It is possible butterfly distributions may not be able to shift in response to climate change if the new habitats are too fragmented and isolated (Hill *et al.*, 1999). This may also be true for many of the less mobile macro moth species. The improvement of agro-ecosystems could help to reduce the fragmentation of the landscape and allow for the shift in species distributions.

The long term sustainability of agricultural ecosystems is dependent on the conservation of farmland biodiversity. The recent increase in organic farming has been suggested as being the future of farming in the UK, as the reduced levels of pesticides and inorganic fertilizers have been shown to lead to an increase in butterfly diversity and abundance (Rundlof, 2006) and there is hope that this trend will be found in moths too. Some evidence suggests that the increase of biodiversity within organic farms may not be totally due to the reduced levels of pesticides, but that the restoration of habitat heterogeneity may be a more significant effect (Rundlof, 2006).

Therefore more emphasis should be put on restoring the heterogeneity of the farm environment, and improving the field boundaries is an important part of this. This study has shown that there is an increased abundance of moths in the wider field margins and this effect has been found in many other species (Frampton and Dorne, 2007, Shore *et al.* 2005, Carvell *et al.* 2007 and Meek *et al.* 2002). The benefits of improving the arable field margins are great and wide ranging, and making improvements to the standard margins should be encouraged across the country as part of the current agri-environment schemes.

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