CHAPTER 8

Landscape-scale conservation of farmland moths

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> When through the old oak forest I am gone,
> Let me not wander in a barren dream
>
> **John Keats, *On Sitting Down to Read King Lear Once Again*.**

8.1 Scope of agri-environment schemes

Biodiversity has declined substantially throughout much of the European wider countryside. The most promising tools to reverse these declines are widely thought to be agri-environment schemes (AES) (Donald and Evans 2006). These governmental schemes provide financial rewards for 'environmentally friendly' methods of farmland management. However, AES do not always produce significant biodiversity benefits (Kleijn et al. 2006; Batáry et al. 2010). For example, in the UK, the broad and shallow 'Entry Level Stewardship' has often been unrewarding for wildlife (e.g. Davey et al. 2010, but see Baker et al. 2012), but, in many cases, the more targeted 'higher level' scheme has exceeded expectations (Jeremy Thomas, pers. comm.). Indeed, there is great scope for inventively designed AES to make a large impact on biodiversity conservation in regions where intensive agriculture has a dominant footprint; AES can be implemented over enormous areas of land and this matters because intensive agriculture is one of the main drivers of biodiversity declines worldwide (Donald et al. 2001; Benton et al. 2002; Green et al. 2005).

Globally, farmland covers about half of the potentially useable land (Tilman et al. 2001) with farmed crops feeding, dressing and, increasingly, fuelling the growing human population. However, land conversion to farming has brought destruction, degradation, and fragmentation of habitats, landscape homogenization, and pollution. It has not only destroyed the ecosystems converted to farmland, but often also reduced the ecosystem services (such as crop pollination, pest control, water retention, and soil protection) provided by the adjoining non-farmed land. Nevertheless, some biodiversity of the original ecosystems may be retained within farmland ecosystems, its amount heavily dependent on the spatial extent and degree of farmland intensification. Indeed, although species typically 'prefer' one ecosystem, they often occur in, and use resources from, neighbouring ecosystems (Pereira and Daily 2006; Dennis 2010). As such, many species may manage to persist within farmland systems, with at least some of them, such as the speckled wood *Pararge aegeria*, originally a woodland butterfly, adapting to these 'novel' ecosystems (Merckx et al. 2003). As a result, extensively farmed systems can often be characterized by flourishing biodiversity (e.g. chalk grasslands, the Iberian dehesa/montado); hence farmland, in general, has the potential to support biodiversity (Chapter 7, this volume), and all the more so when fostered by effective AES (Whittingham 2011).

Launched during the late 1980s, AES were conceived to reverse the severe declines in farmland biodiversity that were wrought by the techno-boom of agricultural intensification. They reflected a societal desire to restore biodiversity to farmland, and also, increasingly, recognition of the economic value of the ecosystem services they provide (Macdonald and Smith 1991). However, given that they are financed through tax-payers' money, it is essential to ensure AES are effective in delivering their goals (Kleijn et al. 2006; Macdonald et al. 2000, 2007). This could potentially be improved in a number of ways: for example, in regions

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characterized by marginal land or farmland abandonment, ecological restoration may be achieved more cost-effectively by including rewilding approaches, whether or not as part of effective and targeted AES supporting valuable, low-intensity farming practices (Warren and Bourn 2011; Monbiot 2013; Merckx and Pereira 2015). On intensive farmland, cost-effectiveness of biodiversity delivery through AES may be achieved by taking two vital steps: first, by identifying those elements of farmland that benefit biodiversity and can be integrated within intensive farming systems and, second, by managing them appropriately (Merckx et al. 2009a; Fuentes-Montemayor et al. 2011).

8.2 Why moths?

8.2.1 Indicators of farmland quality

With a particular focus on 'larger moths' (i.e. macro-moths), we set out to explore two ways in which the benefits of AES might be optimized. We chose macro-moths principally because of their ability to 'tell' us something about the state of the ecosystems of which they are part. Because of their fast generation turnover (i.e. one to several generations per year), their abundance as a group, their ecological diversity, their functional roles within ecosystems, and their species richness, macro-moths are considered a sensitive indicator group for biodiversity in terrestrial ecosystems (New 2004; Thomas 2005). In other words, they can be viewed as a relatively accessible 'miner's canary' for the health of other terrestrial insects on farmland. Although other groups may be good indicators too (e.g. Odonata diversity is indicative of both terrestrial health and the quality of aquatic habitat resources: Chapter 10, this volume), they are either far less abundant or species-rich, or more difficult to sample and identify (e.g. beetles, fungi). The attraction of moths to light and the fact that they are usually on the wing in high numbers mean that they can be sampled with relative ease using light traps. With around 2500 species in Britain, of which *c*. 900 are macro-moths, and with over 160 000 described and 500 000 estimated species worldwide, Lepidoptera (moths and butterflies) are a highly diverse group of insects that occupy a wide variety of habitats all over the world (Merckx et al. 2013). Their great variety in size, colour, and wing patterns makes the large majority of them easily identifiable. Also, moths are simply beautiful, and they are intriguing leaves of a rich and venerable phylogenetic tree (Mutanen et al. 2010), which has resulted in many fascinating evolutionary, ecological, and life-history aspects, such as pheromone mate-attraction, intricate host plant interactions, varied anti-predator responses, complete metamorphosis (from egg, over several larval stages and pupation, to the adult imago), and complex movement ecology (Young 1997; Chapman et al. 2010).

8.2.2 Population declines

This wealth deserves our attention and timely protection. All the more so since 62 species of macro- and micro-moths have become extinct in Britain during the twentieth century. Moreover, many more species are nationally threatened, and rapid, significant declines in abundance and distribution have been recorded for common and widespread macro-moth species that inhabit farmland in Britain. Of this last group, two thirds (227 of 337 species analysed) show a decreasing population trend over 40 years (1968–2007), with 61 having declined by at least 75% (Fox et al. 2013). For example, the figure of eight *Diloba caeruleocephala* was once a common and well-distributed woodland, hedgerow, and garden moth, feeding as a larva on hawthorn *Crataegus* spp. and blackthorn *Prunus spinosa*, but has declined by 96% over this period. The garden tiger *Arctia caja* has declined by 92% over the same 40 years (Fox et al. 2013). This species is coloured spectacularly and famous for its 'woolly bear' caterpillars that feature prominently in many childhood memories. It seems likely that these trends are part of a widespread loss in insect biodiversity in temperate-zone industrialized regions (macro-moths: Groenendijk and Ellis 2010; butterflies: Van Dyck et al. 2009; carabid beetles: Brooks et al. 2012), not to mention the unrecorded declines and extinctions of many specialist moths all over the world (Merckx et al. 2013).

8.2.3 Ecosystem services

These trends are of concern, as herbivorous macro-moth larvae—because of the huge numbers involved—are significant primary consumers and nutrient recyclers. Anyone who has heard the constant noise of falling 'frass' from winter moth *Operophtera brumata* larvae consuming leaves in temperate oak woodland, knows what we are talking about. Macro-moths are also key prey items, in all life-stages, for a wide range of other taxa (e.g. birds, bats, shrews, parasitoids, spiders, beetles); for example, it is estimated that blue tit *Parus caeruleus* chicks consume at least 35 billion caterpillars in Britain each year (Fox et al. 2006). Another significant ecosystem service to which moths contribute is pollination, with moths dominating both temperate and tropical flower-visitor faunas after dark (Devoto et al. 2011). For example, hawk moths (Sphingidae) are crucial to the pollination of many moth-pollinated plants, whose flowers co-evolved with their pollinators to produce a strong, sweet scent at night, and have long, tubular corollas which only allow long proboscises to reach the nectar produced, to fuel the high metabolic rates needed to power hovering flight; in fact very similar to hummingbird feeding behaviour (Darwin 1862).

8.3 Optimizing agri-environment schemes: field margins and hedgerow trees

Against this background, our AES study had two parts. First, we aimed to elucidate the effects on macro-moths of two prominent farmland elements, wide grassy field margins and hedgerow trees. Both of these farmland features provide habitat for moths, and their restoration and management can easily be implemented as options within AES. Second, we investigated whether implementing AES over larger, landscape-scale areas, rather than applying them to small, field-scale areas, had different consequences for macro-moth populations, and offered more scope for farmland conservation. We tackled these questions by conducting experiments in which we captured 311 species of macro-moth, ranging from the 'primitive' swift moths (Hepialidae) to the fan-foots (Herminiinae), a group of slender noctuid moths. This substantial data base allowed us to document patterns in their ecology on farmland, at a range of spatial scales, which we describe in this chapter. We contrasted species groups categorized with respect to feeding guild, mobility, and conservation status to elucidate the mechanisms underlying these patterns.

8.3.1 Wide field margins

Moths will make use of many farmland habitats, such as woodland, hedgerows, and scrub. Field margins, defined here as the uncropped strips of land which lie between the boundary feature (such as a hedge) and the field itself (whether arable or grass), can potentially provide nectar sources, larval foodplants, roosting and pupation sites, and protection from farm operations such as pesticide spraying. A first question we posed was whether field margin width affected macro-moth abundance and diversity. To this effect, we contrasted 24 sites characterized by wide (6 m) margins (current AES option; Defra/NE 2012) with 24 sites with standard (1 m) margins (Fig. 8.1). All margins were well-established, tussocky, sown perennial grass strips of variable age, located next to hedges and machine-cut once every two or three years; they were ungrazed and unfertilized, although fertilizer may have drifted into the margin unintentionally. Wide field margins are a popular and important conservation tool, and their management to deliver biodiversity is rewarded by AES payments in a number of EU countries (Chapters 2 and 3, this volume). By early 2011, 67% of the utilizable agricultural area in England was under AES (Defra 2011), and grass/buffer strips on arable land were among the most popular (>116 000 km in 2009) scheme options (NE 2009).

8.3.2 Hedgerow trees

Hedgerow trees are solitary trees emergent from hedgerows. They characterize many European agricultural landscapes and are valuable because of the many ecosystem services they provide, such as shade for livestock, aesthetic value, carbon sequestration, and soil protection. For wildlife, they are a source of fruit and seeds. They also provide shelter from wind, as well as nesting and roosting sites for birds and bats, song posts, hiding places, and both food and mate location sites for many insects. Hedgerow trees can also support diverse invertebrate, lichen, and fungal communities, and they act as stepping stones for mobile organisms to move through otherwise typically bleak agricultural landscapes (Slade et al. 2013). In England, pedunculate oak *Quercus robur*, ash *Fraxinus excelsior*, and formerly elm *Ulmus procera* too, are by far the most common species, but around 20 million elm trees were lost from the English landscape through the Dutch elm fungal disease in the late 1960s. The recent arrival of the ash die-back fungal disease is now threatening to be as damaging to the ash population. From their most abundant in the eighteenth century, when they served as a vital source of timber, hedgerow tree numbers have declined dramatically as a consequence of field enlargements and the mechanical trimming of hedgerows, which drastically affects recruitment. There are now only an estimated 1.6 million, with annual recruitment only half the level required to maintain the current population (Defra 2010). A question we posed was whether local macro-moth abundance and diversity were affected by the presence of hedgerow trees. To this effect, we contrasted 24 sites next to a single open-grown hedgerow tree (minimum height: 15 m, usually pedunculate oak *Quercus robur*) versus 24 sites without any nearby tree (Fig. 8.1).

8.3.3 Joined-up approach

The effects on macro-moth abundance and species diversity were explored with respect to these two key farmland elements—field margins and hedgerow trees. Furthermore, mindful of the generally damaging effects on biodiversity of habitat fragmentation, we investigated whether the impacts on macro-moths of field margins and hedgerow trees differed when the two farmland elements were part of a wider landscape, managed specifically with conservation goals in mind. There is no current policy to encourage neighbouring farmers to join AES and thus increase connections between habitats. We tried a joined-up approach in two experimental areas (hereafter 'targeted' areas of our Upper Thames Project; Macdonald and Feber 2015: Chapter 14). This approach turned out to be successful in terms of uptake. For example, after only two years, the experimentally targeted areas had more conservation management of habitats such as hedges (*c*. 219 km of hedgerows under enhanced management versus 83 km in control areas). We asked whether and to what degree this targeting approach made a difference to the moths we recorded on field margins and next to hedgerow trees, by comparing their numbers in targeted and non-targeted areas.

8.3.4 Moth sampling

During four field seasons (2006–2009) we sampled moths on 16 predominantly arable farms; all located within a 1200 km^2 area of the lowland agricultural landscape of Oxfordshire, UK. Each farm contributed three sites to the total of 48 fixed sampling sites (Fig. 8.1a). In general, these 16 farms had fields characterized by having both standard and wide margins. Within each farm, the number of hedgerow trees per field margin varied from zero to one or more hedgerow trees. Nevertheless, the precise locations of all three sampling sites at a given farm were chosen so that they belonged to only one of four experimental groups (four farms per group), which differed in their combinations of hedgerow tree presence and field margin width: (i) hedgerow tree + wide margin; (ii) hedgerow tree + standard margin; (iii) no hedgerow tree + wide margin; (iv) no hedgerow tree + standard margin (Fig. 8.1b).

We sampled each farm 40 times in discrete fortnightly periods from mid May to mid October, once in each fortnightly period, and in random order within the period. We usually sampled three farms (i.e. nine sites) on any one night. The total of 240 trap nights and 1920 trap events resulted in a sample of almost 72 000 individuals, from 311 macro-moth species. This large quantity of sampled and identified farmland moth individuals, and the space- and timewise intensity of sampling, makes our study unique. While the nocturnal lifestyle of moths makes them challenging to study, their well-known attraction to light means it is relatively easy to sample them. We used battery-run, portable heath pattern actinic light traps (6 W). These were operated from dusk

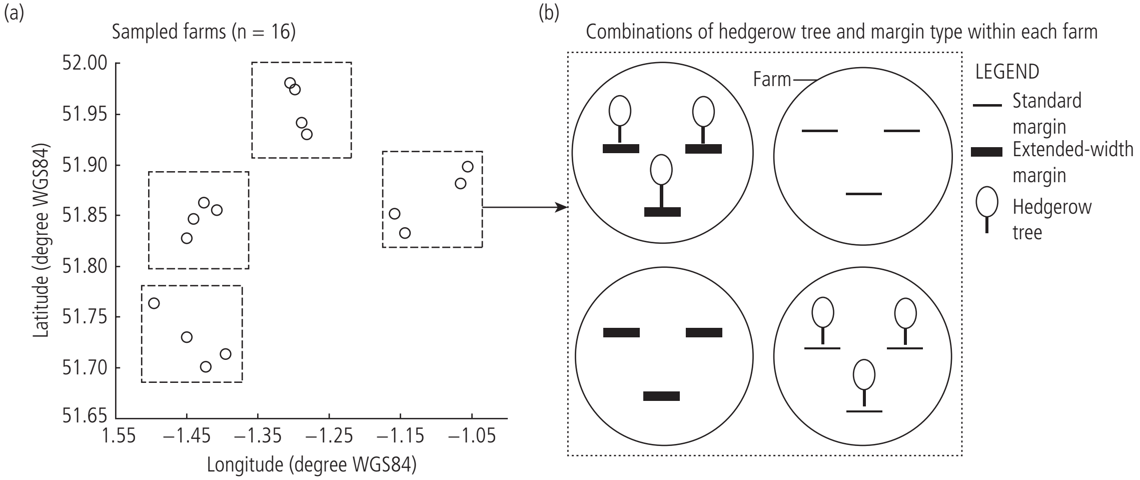

Figure 8.1 (a) Distribution of the 16 sampled farms (open circles) and (b) scheme of the sampling design within each farm (range of minimum, mean, and maximum distances between the three sites per farm: 60–470 m; 190–1290 m; 280–1930 m, respectively). From Merckx et al. (2012). Reproduced with permission from John Wiley & Sons.

until dawn, when the live sample in and on the trap was enumerated and identified to species level, except for five species-pair aggregates of essentially cryptic species. All sampling sites were positioned 1 m away from average-sized hedgerows (2–3 m high, 1.5–2.5 m wide), with both sides bordered by arable land. Sampling sites were at least 50 m away from hedgerow intersections and were at least 100 m apart, which prevented moth attraction radius interference (Merckx and Slade 2014). Traps were placed upon a standard-sized white sheet, which enhanced and equalized trap visibility and enabled us to include all individuals resting on the sheet. Sampling was conducted in similar, sufficiently favourable conditions to minimize bias due to differences in weather-related activity levels.

Apart from the main insights obtained for mostly common and widespread macro-moth species, our sustained trapping effort resulted in some rarer species too. We passed all of our records on to the National Moth Recording Scheme (<http://www.mothscount.org>), whose records help to provide a better picture of each species' national distribution. Perhaps our most fascinating find was the unexpected discovery, on arable farmland, of what is currently the largest known population of the pale shining brown *Polia bombycina*, a rare UK Biodiversity Action Plan (BAP) priority species (see Section 8.7).

8.3.5 Effects of hedgerow trees, wide field margins, and landscape on moths

Our findings highlighted the importance of hedgerow trees and wide field margins for moth conservation in the wider countryside, as both turned out to be beneficial for moth populations. The presence of hedgerow trees and wide margins each significantly increased macro-moth species numbers locally from *c*. 90 to *c*. 105 species on average, or by around 15% (Merckx et al. 2009a, 2012) (Fig. 8.2). Largest numbers of macro-moths were found at sites characterized by both wide margins and hedgerow trees, which was the result of additive rather than interactive effects. Such sites had, on average, 15% more individuals and ten more species than sites characterized by either one of these farmland elements (mean ± SE: abundance: 1286 ± 181 versus 1117 ± 90; species richness: 110 ± 6 versus 100 ± 4), and they had 33% more individuals and 26 more species than sites lacking both farmland elements (1286 ± 181 versus 965 ± 9; 110 ± 6 versus 84 ± 2.8, respectively).

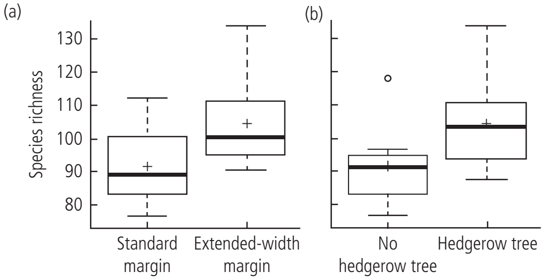

Figure 8.2 Main effects (P < 0.05) of the presence of (a) wide versus narrow margin, and (b) presence of a hedgerow tree at the local scale on macro-moth species richness. A solid line in the boxplots indicates the median, while a cross indicates the mean. From Merckx et al. (2012). Reproduced with permission from John Wiley & Sons.

The species most helped by wide field margins appeared to be the shoulder-striped wainscot *Mythimna comma*, a grass-feeding, common, widespread, but declining (72% national decline over 35 years) UK BAP species: 98% of all shoulder-striped wainscots were sampled in wide field margins. Other nationally declining macro-moth species particularly helped by the wide field margins' likely increase in foodplant quality and amount, and occurring in numbers four to eight times higher on wide versus standard margins, were (i) treble-bar *Aplocera plagiata*, feeding on St John's wort *Hypericum perforatum*, (ii) small phoenix *Ecliptopera silaceata*, a UK BAP species (77% decline over 35 years) feeding on willowherbs *Epilobium* spp., (iii) frosted orange *Gortyna flavago*, whose larvae feed and pupate internally in plant stems, (iv) small dotted buff *Photedes minima*, with tufted hair-grass *Deschampsia cespitosa* as foodplant, (v) feathered gothic *Tholera decimalis*, a grass-feeding UK BAP species (89% decline over 40 years), and (vi) grass rivulet *Perizoma albulata*, a UK BAP species (93% decline over 40 years) whose larvae feed on the hemiparasitic yellow rattle *Rhinanthus minor*. Both the barred rivulet *Perizoma bifaciata*, a local, though widely distributed, moth feeding on another hemiparasitic plant, red bartsia *Odontites vernus*, and the ghost moth *Hepialus humuli*, a species with a worrying national trend (62% decline over 40 years) feeding on the roots of grasses and herbs, occurred exclusively at wide field margins.

Nationally declining macro-moth species not feeding directly on herbaceous field margin species were also found in greater numbers on wide field margins. One possible explanation is that margins buffer hedgerows and trees from pesticide drift (Pywell et al.

2004). Examples of species that were between four and six times as abundant on wide compared to standard margins are: (i) buff arches *Habrosyne pyritoides*, feeding on bramble *Rubus* spp., (ii) beautiful hook-tip *Laspeyria flexula*, whose overwintering larvae feed on bark lichens, (iii) oak hook-tip *Watsonalla binaria*, a UK BAP (78% decline over 40 years) oak-feeding species, and (iv) pale eggar *Trichiura crataegi*, another UK BAP species (90% decline over 40 years), feeding on blackthorn and hawthorn. The declining, tree-feeding lunar-spotted pinion *Cosmia pyralina* occurred exclusively on wide margins.

The poplar grey *Acronicta megacephala*, fairly common and well distributed in England, is a powdery looking, greyish noctuid whose caterpillars feed on poplar *Populus* spp. leaves. Poplar grey appeared to be the species most helped by hedgerow trees—none of them poplars—, occurring almost twenty times more abundantly near hedgerow trees than at sites without hedgerow trees. Nationally (fairly) common and (fairly) well-distributed macro-moth species that were ten times more abundant at hedgerow trees, included: (i) white-spotted pug *Eupithecia tripunctaria*, a small geometrid with larvae on elder *Sambucus nigra* and wild angelica *Angelica sylvestris*, (ii) dingy shears *Parastichtis ypsillon*, whose nocturnal larvae feed on willow *Salix* spp., and (iii) clouded border *Lomaspilis marginata*, a nationally declining delicate geometrid with blackish and white markings, with sallow *Salix* spp. and poplars as foodplants.

Hedgerow trees seemed particularly important for some macro-moth species, 51 of which were only ever recorded at sites with hedgerow trees. These included: (i) pretty chalk carpet *Melanthia procellata*, an attractive but now nationally severely declining (88% decline over 40 years) geometrid, typical of hedgerows containing the climbing shrub traveller's joy *Clematis vitalba*, (ii) the nationally declining, campion *Silene* spp.-feeding, sandy carpet *Perizoma flavofasciata*, and (iii) a whole series of species more typical of woodland, such as satin beauty *Deileptenia ribeata*, large emerald *Geometra papilionaria*, pine hawk-moth *Hyloicus pinastri*, pale oak beauty *Hypomecis punctinalis*, olive *Ipimorpha subtusa*, and leopard moth *Zeuzera pyrina*.

We conclude that paying farmers to protect and establish more hedgerow trees could make a major contribution to halting the decline in moth diversity in 'farmscapes' typified by our study areas, as do existing AES payments for wide field margins. The likely main benefits of a higher density of hedgerow trees and wide field margins on farmland are (i) increased shelter for thermally constrained organisms in the otherwise barren and exposed environment (results from another experiment (see Section 8.4.1) appeared to confirm this), (ii) increased abundance and variety of foodplants, and (iii) increased provision of tree sap, nectar, pollen, and undisturbed roosting areas. Because moths are sensitive indicators for farmland biodiversity in general, and in particular for other terrestrial insects, we expect that these benefits would also benefit other insect groups, such as butterflies and bumblebees (Merckx et al. 2008; Goulson et al. 2011; Haaland et al. 2011).

In addition to the sheltering effect that hedgerow trees have on moths, they also provide larval feeding and female egg-laying resources, at least for some of the shrub and/or tree-feeding macro-moth species (hereafter called 'high-feeders'), although they do not for grass and/or herb-feeders ('low-feeders'). Also, it is likely that hedgerow trees exhibit a stronger attraction to high-feeders in terms of providing adequate roosting sites compared to low-feeders, as the latter may be more likely to roost in vegetation close to the ground (e.g. the highly abundant large yellow underwing *Noctua pronuba* and other common noctuid species, such as *Noctua*, *Agrotis*, *Xestia*, *Mythimna*, *Apamea*, and *Hoplodrina* spp.). In contrast to the stronger benefit of hedgerow tree presence for high-feeders, low-feeders did not benefit any more strongly than high-feeders from the presence of wide margins (Merckx et al. 2012), suggesting that both guilds benefited equally from the presence of wide margins. The positive effect of wide margins can be explained by the fact that they provide a relatively undisturbed breeding habitat and can act as buffer zones against the impact of agricultural chemicals on moth larvae and their host plants (Pywell et al. 2004). As such, this result indicates that wide margins may improve larval habitat quality, both for low-feeding larvae within the margins, and for high-feeding larvae in adjacent hedgerows and lower parts of hedgerow trees, by reducing exposure to pesticides and fertilizers. Another (complementary) explanation may be that floral resources are providing nectar to adults of both guilds. Increasing plant species richness of margins, and optimizing availability of resources through appropriate management, may have benefits for both larval and adult macro-moths, as is the case for other farmland Lepidoptera (Feber et al. 1996).

Although the observed local increase in macro-moth species richness is not, by itself, a measure of ecosystem functioning, evidence suggests that they are positively related (Hector and Bagchi 2007). Increased macro-moth richness is likely to provide a number of economically valuable ecosystem services. First, pollination success and pollination resilience are likely to be facilitated due to higher numbers of pollinating moth species (Devoto et al. 2011). Other pollinating taxa possibly also benefit from the presence of these farmland elements (Power and Stout 2011). Higher pollination success should not only benefit populations of wild plant species, but also increase fruit set and yields of insect-pollinated crops (Holzschuh et al. 2012). Second, moths are important prey for various taxa (see above), which may result in larger, and more stable, populations of a greater diversity of species at these higher trophic levels. In turn, this may provide better and cheaper crop pest control (Winqvist et al. 2011). The resulting increase in functional diversity of field margins and hedgerows will feed back into an improved ecosystem functioning of farmland as a whole via the affected ecosystem services (Cadotte 2011).

Our findings for macro-moths have important implications for AES policy and for delivering the best bangs-per-buck to the tax-payer who funds them. To the extent that we are correct in proposing macro-moths as model animals to inform biodiversity policy on farmland, the chief lesson of our findings is to advocate a policy shift from field- and farm-scale implementation of AES towards connective landscape-scale conservation. While hedgerow trees were found to benefit moths—*c*. 15% overall increase in species richness (Fig. 8.2) and *c*. 20% increase in overall abundance—the best results were in landscapes where we targeted farmers to join AES. In these areas, the abundance of moths was 60% greater at sites with a hedgerow tree than at sites without trees, and macro-moth species diversity was 38% greater at sites with a hedgerow tree (Fig. 8.3). We deduce that the mechanism underlying this striking result is that the higher proportion of land covered by AES in these areas resulted in the joining-up of habitat resources across the landscape. Thus, the *context* of the trees, and the *relationship* of protected areas to each other within a landscape are revealed to be important to delivering effective conservation. Our findings on macro-moths offer a foundation for policy thinking about wildlife on farmland such that, to preserve the biodiversity of agricultural landscapes, it is more effective to implement measures at spatial scales greater than those of individual fields; the most fruitful focus is on strengthening the diversity within landscapes and ecosystems as a whole. Although the financial and societal implications are far-reaching, the lesson of the macro-moths is that it could be beneficial for biodiversity on farmland to complement the entry-for-all approach to AES with a system that targets specific areas and/or landscapes in high nature conservation value farmland (Merckx et al. 2009a).

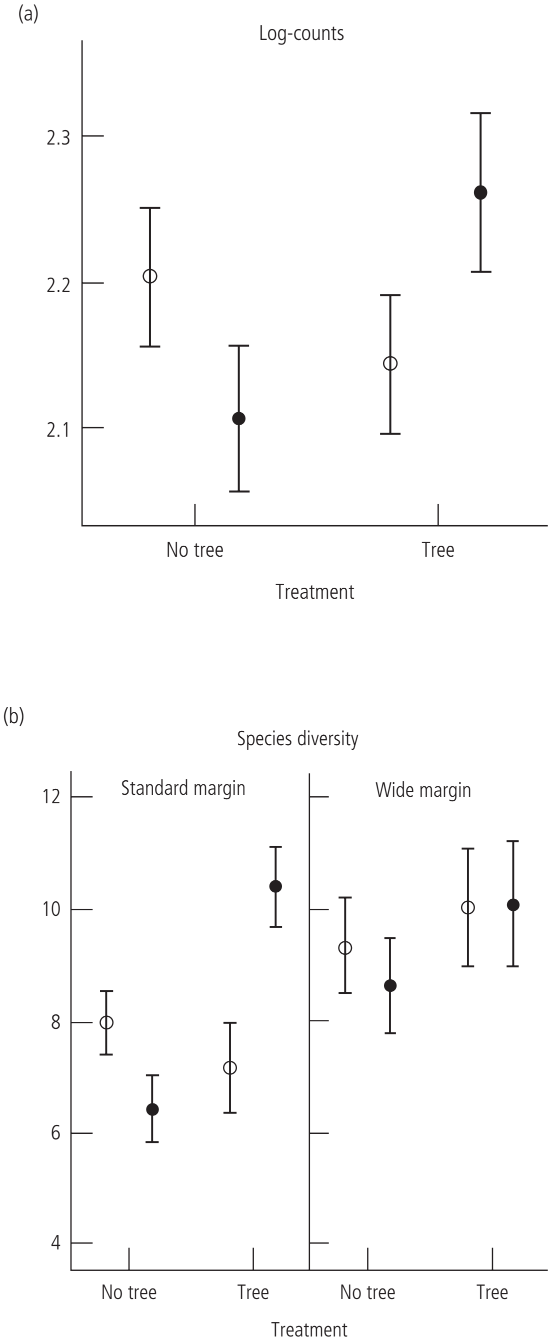

Figure 8.3 Fortnightly (a) individual moth counts (log $N + 1$) contrasting the effects of presence/absence of hedgerow trees on moth abundance, and (b) log-series α indexes of moth communities contrasting the effects of presence/absence of hedgerow trees and wide field margins on moth species diversity, in areas where farmers had (●) and had not (○) been targeted to apply for agri-environment schemes (error bars represent SE). From Merckx et al. (2009a).

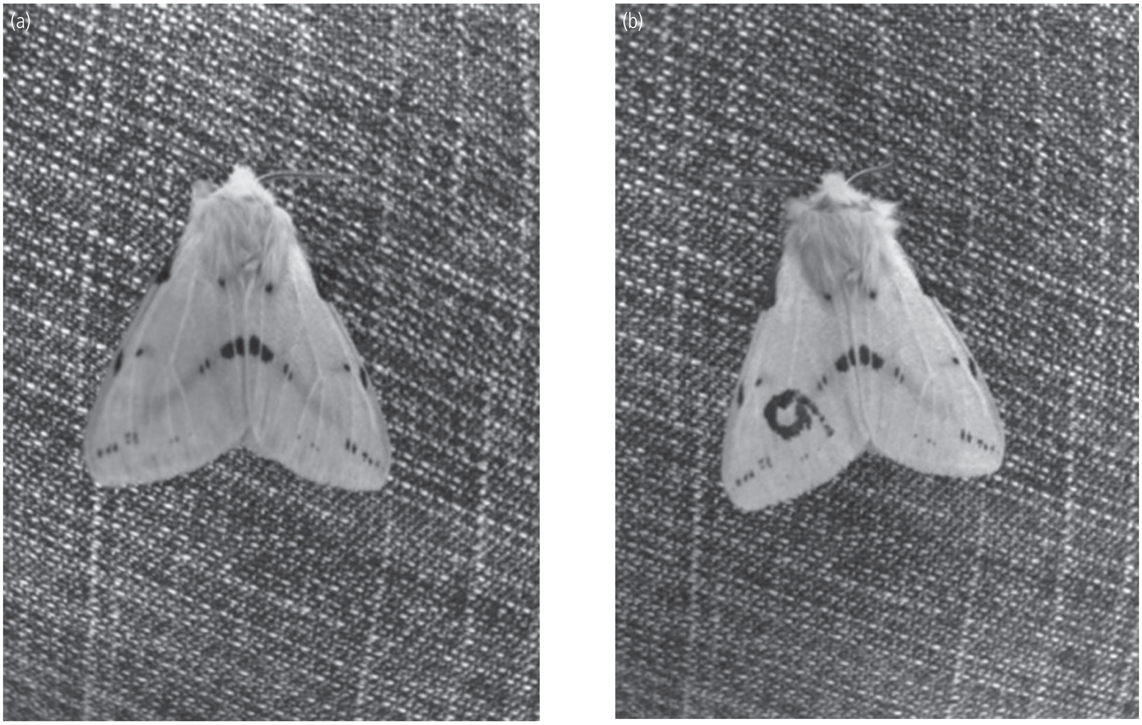

Figure 8.4 (a) Male buff ermine *Spilosoma luteum*, captured with a Heath light trap (Actinic 6 W), which operates on the 'lobster-pot principle', whereby moths are drawn to an actinic tube secured vertically between baffles, fall unharmed down a funnel, and rest on the inside of the trap or on pieces of egg-tray provided. Traps were operated from dusk to dawn, when the live sample of selected species was marked (at first capture) by writing a unique number on the left forewing with a fine (0.4 mm), non-toxic, permanent waterproof marker and released *in situ* into nearby tall vegetation. (b) Same individual marked with a black number '6'. Photographs © Rita Gries.

Figure 8.5 Marked (red number '100') individual of drinker *Euthrix potatoria*, a common but nationally declining Eggar moth (Lasiocampidae). Both its common English name and scientific species name are derived from the larval liking for drinking drops of rain or dew on its foodplants, whereas the genus name refers to the hairy, thickset adults. The larvae too are densely covered in hairs, which gives them protection from being eaten by birds, except cuckoos. Photograph © Claire Mclaughlan.

8.4 Moth mobility: impacting local effects of farmland resources

8.4.1 Hedgerow trees

Motivated to better understand the mechanisms that underlay our finding that hedgerow trees were beneficial to the abundance and species diversity of macro-moths on farmland, we conducted a farm-scale mark-release-recapture (MRR) experiment (Fig. 8.4 and Fig. 8.5; Merckx et al. 2010a). We asked whether hedgerow trees increase moth numbers mainly because they provide shelter, which would be of strongest benefit to slender, sedentary macro-moths, or because they provide food resources for specific tree-feeding species only. If the latter hypothesis prevailed, hedgerow tree options within AES would favour significantly fewer species than if the former hypothesis prevailed, because hedgerow tree species would only benefit a specific suite of insect species adapted to use specific tree species as larval foodplants (or for adult sap-feeding). For example, hedgerow oak trees would only be beneficial to oak-feeders, such as the blotched emerald *Comibaena bajularia*, and not to other species, such as the small emerald *Hemistola chrysoprasaria*, a moth only feeding on traveller's joy. Furthermore, if the predominant importance of hedgerow trees to macro-moths was to provide larval foodplants, then the spatial abundance of not only hedgerow trees in general, but of specific tree species, would need to be taken into account to optimize the biodiversity gain from AES.

We opted for a MRR approach to find out how far individuals of different species travelled on farmland, as well as where the moths were, which gives a strong indication of species' habitat preferences. We were able to do this by individually and harmlessly marking moths with a pen, and by trying to recapture them by applying a continuous trapping effort during 33 nights. We marked and recaptured 23 pre-selected species of moth for which the larval foodplants are well known and which were assigned to one of two feeding guilds (i.e. 13 species of 'high-feeders' versus 10 species of 'low-feeders') using 20 fixed light-trap sampling points within five adjacent arable fields (Merckx et al. 2010a).

We found that hedgerow trees were significantly associated with increased adult moth numbers, even for eight shrub/tree-feeding species which did not feed on the tree species available in the hedgerows at our sampling points. We therefore deduced that the increased adult moth numbers associated with hedgerow trees were likely to have arisen, at least for these eight species, because of the shelter these trees provided in the typically exposed agricultural landscapes. We note that prominent trees do function as assembly points for adult mating in several insect species, providing a possible additional (or alternative) explanation for these higher moth numbers near hedgerow trees. Shelter is also the likely explanation for higher numbers of some 'low-feeders' near hedgerow trees, such as yellow shell *Camptogramma bilineata*, drinker *Euthrix potatoria*, treble lines *Charanyca trigrammica*, rustic shoulder-knot *Apamea sordens*, and shears *Hada plebeja*. This conclusion was corroborated by the observations that the hedgerow tree effect was (a) not significant for the two most mobile species of our set of high-feeders, i.e. scalloped oak *Crocallis elinguaria* and buff-tip *Phalera bucephala*, with mean covered distances above 550 m, and (b) strongest for less mobile species, such as many small geometrids (Merckx et al. 2010a). Sedentary species of macro-moth are believed to be more prone to convective cooling in typically exposed agricultural landscapes (Dover and Sparks 2000; Pywell et al. 2004), so we predicted that they would benefit most from the additional shelter provided by trees (Dover and Sparks 2000). Macro-moths in this category included scorched carpet *Ligdia adustata*, a declining, small geometrid feeding on spindle, as well as the following geometrids feeding on traveller's joy: (i) small emerald, a UK BAP species (82% decline over 35 years), (ii) pretty chalk carpet, and (iii) small waved umber *Horisme vitalbata*. We found these species had covered relatively small mean distances (0–185 m), and were indeed associated, in large numbers (+ 73%), with hedgerow trees.

One plausible idea is that hedgerow trees may act as 'stepping stones' for some species, especially less mobile and woodland species, increasing the opportunity for moths, and other flying insects, to cross barren exposed farmland in search of resources, and facilitating dispersal between patches of semi-natural habitat. Tall hedgerows may serve a similar function; a study on Canadian farmland found 60% more macro-moth species, and in triple the abundance, near 20 m tall hedgerows compared to within fields, and this finding was more pronounced for two low-mobility (sub)families (i.e. Geometridae and Arctiinae) than for the generally more mobile noctuids (Boutin et al. 2011).

In the context of climate change, such stepping stones could facilitate the northward movements through farmland that may enable species to stay within their climatic envelope as the climate changes. This has been shown for butterflies (Hill et al. 2002; Menéndez et al. 2007) and would apply to the many moth species which have southern distributions but are struggling to expand their ranges northwards in response to climate change, due to low intrinsic dispersal capacity and/or the general hostility of the agricultural matrix. For example, although some macro-moths have shown substantial range shifts within Britain (up to 393 km between 1982 and 2009 for the red-necked footman *Atolmis rubricollis*; Fox et al. 2011), such species are very likely to be a small minority. Betzholtz et al. (2013) have recently analysed range margin shifts for all southerly distributed macro-moths and butterflies in Sweden (the analysis for macro-moths in Britain is currently in preparation; R. Fox pers. comm.). The Swedish study shows that 60% of the 282 analysed species had expanded their northern range margin between 1973 and 2010, yet it also shows a huge variation in expansion distance (min–max: 0–850 km; mean: 101 km). What is clear is that range shifts for the majority of thermally constrained insect species are probably happening already, and lagging behind to varying degrees depending on the species. Increasing the functional connectivity of ‘farmscapes’, helped by the establishment of more hedgerow trees providing more shelter, will help to mitigate these time lags. Although we believe that a higher density of hedgerow trees will benefit a majority of species by allowing them to move more easily through agricultural landscapes, we predict this will especially benefit woodland moth species, such as pale oak beauty, white-pinion spotted *Lomographa bimaculata*, slender brindle *Apamea scolopacina*, and oak hook-tip, to name just a few.

Given that most of Europe’s intensive agricultural land was once dominated by forest, hedgerow trees are often the only remaining farmland element linking to this natural climax biotope. As such, it is not surprising that they make a large contribution to the ecological resilience of farmed landscapes. It is hence likely that hedgerow trees are keystone structures, with a disproportionate effect on ecosystem functioning given the small area occupied by any individual tree. Although proactive conservation management of hedgerow trees was not, until recently, rewarded financially in any EU country, it is now a recent addition to the set of general AES options within England (see also the new Scottish Rural Development Priorities), due in part to the results of our studies. These new AES options include the establishment of new hedgerow trees by tagging saplings, and the establishment of protective hedgerow tree buffer strips on both grassland and cultivated land (Defra/NE 2012). Expanding AES support to include these options should increase both the field- and landscape-scale supply of trees that not only provide shelter and stepping stones, but are also visually prominent enhancements of the landscape. Importantly, for the compatibility of food production and biodiversity conservation, the establishment of hedgerow trees, especially when using saplings already present within hedgerows, and the retention of hedgerow trees, have minimal costs to farmers, mainly related to the increased care that needs to be taken while trimming hedgerows, although mature hedgerow trees may very locally compete with crops for light and water.

As a result of the many ecosystem service benefits in return for these minimal costs, we believe that hedgerow trees are highly compatible with intensive farming systems. As such, hedgerow trees may be habitat resources that are spatially compatible within high-production areas, which are otherwise spatially separated from conservation areas in the ‘land sparing’ framework (Phalan et al. 2011). However, once a landowner opts to also provide hedgerow tree buffer strips, which are typically 6 m wide, we come conceptually closer to ‘land sharing’, where conservation and production are spatially integrated (Phalan et al. 2011). It is especially within a ‘land sharing’ context that foregone financial profit (cost of establishment and foregone crop of buffer strip) should be compensated.

Although it is impossible to give advice on a truly ‘optimal’ spacing of hedgerow trees, because such requirements differ from one organism to the other (Van Dyck 2012), we believe that AES advice on this (Defra/NE 2012)—two to three trees over 100 m of hedgerow—will be effective for increasing general farmland biodiversity and functional connectivity of agricultural landscapes. This advice is also in line with the suggestions for more, larger, better, and joined blocks of habitat given by the Lawton report (Lawton et al. 2010). Furthermore, as we have shown that the beneficial effect of hedgerow trees is mainly to be had from the shelter they provide, and only to a smaller extent from species-specific aspects, our only guideline is to use a variety of autochthonous tree species in line with what would be naturally on offer within the region.

8.4.2 Field margins

As with hedgerow trees, we also quarried into our findings regarding field margins, in order to try to uncover the mechanisms that caused their beneficial effects on the abundance and diversity of macro-moths. For example, these effects might stem from an enhanced habitat quality offered by the margins (e.g. a diverse mixture of native pollen/nectar-rich wildflowers; Haaland et al. 2011), or because the margins are configured as a ramifying *rete* which enhances connectivity at the landscape scale (e.g. Rundlöf et al. 2008). To explore these possibilities, we selected nine widespread moth species that, as larvae, mainly feed on various grasses and low-growing herbaceous plants. From the 1699 individuals that we marked, by far the three most common species, accounting for 73% of all observations, were the noctuid species heart and dart *Agrotis exclamationis* and large nutmeg *Apamea anceps*, and common swift *Hepialus lupulinus* (with root-feeding underground larvae like most ‘swift’ moths). We undertook a field-scale MRR light trapping study over 32 nights in four adjacent arable fields, which were bordered with hedgerows scattered with hedgerow trees throughout (Merckx et al. 2009b). Fields either had surrounding wide or standard-width margins and within each of the four fields, we sampled five sites: the field centre and one site at each margin; two of these margin sites were positioned near a hedgerow tree. Our goal was to discover whether the overall positive effect of grassy, wide field margins (reported previously) was dependent on species-specific mobility, as had transpired with the hedgerow tree effect. Although all nine species are common and widespread, two of them (white ermine *Spilosoma lubricipeda* (Fig. 8.6) and large nutmeg) are severely declining species, the latter having declined by 93% over 40 years (Fox et al. 2013).

Overall, light traps captured almost twice as many moths on field margins compared to field centres. For all but one species, field margins were more abundant in terms of moth individuals than field centres. For instance, all 56 trapped common footman *Eilema lurideola* were trapped in field margins. The only exception was the relatively mobile (see below) setaceous hebrew character *Xestia c-nigrum* (characterized by a dark and distinctive C-shaped mark in the centre of the forewings), which was actually 27% more abundant in field centres than in margins (average trap abundance: 6.75 versus 5.31 individuals, respectively). Moreover, wide field margins had significantly more moths overall (+ 40%) compared to standard-width field margins. For example, 78 brown-line bright-eye *Mythimna conigera* moths (relatively sedentary noctuids), were caught at wide field margins, compared to just seven on standard-width margins (four were caught in the field centres).

Figure 8.6 White ermine *Spilosoma lubricipeda*—A common, widespread 'tiger' moth, which has nevertheless declined nationally by 70% over 40 years, and is hence listed as a UK Biodiversity Action Plan priority species (IUCN category: vulnerable). Its common English name refers to the black-spotted white fur, obtained from the winter skin of the stoat *Mustela erminea*, which is historically associated with royalty and high officials, whereas the scientific name refers to the bold spots on the abdomen of the adult and to the swift-footed, speedy gait of the larva, respectively. Photograph © Maarten Jacobs.

We also measured the abundance of nectar sources and found that flower heads were significantly more abundant (250–300%) on wide versus standard field margins, though not significantly so per unit area. Wide margins also offered a greater area and better quality of breeding habitat (relatively undisturbed larval habitat, increased larval food resources, foodplants, and larvae better buffered from agrochemicals: Pywell et al. 2004). Nectar sources were absent from cereal fields. Furthermore, there was no consistent difference in the nectar-producing characteristics of hedgerows that adjoined standard as opposed to wide margins, so this is unlikely to have confounded our results. Remarkably, the abundance of macro-moths at field centres was 60% higher for those fields bordered with wide margins than those bordered by standard margins. A plausible explanation is that the better habitat provided by wider margins increased the resource base and thus the abundance of moths that could spread from this source to the adjoining impoverished field centres. Some individuals captured at the field centres had indeed been caught and marked previously in a nearby field margin (Fig. 8.7), illustrating the tendency of these moths to make exploratory movements (Van Dyck and Baguette 2005).

In practical terms, our findings suggest that habitat quality of wide field margins could be improved by: (i) altering commercial seed mixes so that these contain more nectar-producing plants and more foodplants for Lepidoptera; and (ii) modifying their management from annual cutting (a common regime for grass and wildflower sown margins) to cutting once every two–three years (Kuussaari et al. 2007), which can be done by an annual rotation where half to a third of margins are cut every year. Summer cutting in particular should be avoided. Annual cutting, particularly in high summer, makes it difficult for moths, especially univoltine species, to complete a full life cycle, as is also the case for butterflies (Feber and Smith 1995).

Figure 8.7 Map showing the four study fields (grey); the two fields with wide field margins are outlined in bold. Sampling sites near a hedgerow tree are indicated with a square; sites lacking hedgerow trees are indicated with a circle. Observed individual movements (> 0 m) are contrasted between the species groups with opposite effects for the variable 'margin'. Individuals within the group of species where the statistical evidence for an effect of 'margin' was absent covered longer distances and were less frequently recaptured at the site of first capture than the group of species where the effect of 'margin' was stronger (bold dashed lines; large nutmeg *Apamea anceps*, setaceous hebrew character *Xestia c-nigrum*; $N_{\text{total}} = 21$; $N_{\text{recaptured at site of first capture}} = 4$ versus slim dashed lines; treble lines *Charanyca trigrammica*, brown-line bright-eye *Mythimna conigera*, heart and dart *Agrotis exclamationis*, common footman *Eilema lurideola*, common swift *Hepialus lupulinus*; $N_{\text{total}} = 43$; $N_{\text{recaptured at site of first capture}} = 29$, respectively). One of the bold dashed lines and one of the slim dashed lines cover the movements of two individuals each. From Merckx et al. (2009b).

Having discovered an interaction between a hedgerow tree effect and species-specific mobility, we found that differences in mobility among species had an impact on the effect of wide field margins too. The statistical evidence of our main effects was negatively correlated with the observed mobility of the nine species studied. For instance, species that were relatively mobile (seldom recaptured at site of capture; typical average distance covered between capture and first recapture: 450–600 m), such as setaceous hebrew character and large nutmeg, were at least as abundant in field centres and standard field margins as they were in wide field margins. In contrast, relatively sedentary species (frequently recaptured at site of first capture; typical average distance: 50–300 m), such as treble lines and brown-line bright-eye, benefited from the presence of wide field margins (Fig. 8.7). These correlations between species mobility and the species-specific statistical strength of the effect of wide field margins, and hedgerow trees too, raise the possibility that the standard, field-scale uptake of AES may be effective only for less mobile species.

8.5 The need for landscape-scale implementation of habitat resources

We have seen that the variation in response of macro-moths to the presence of hedgerow trees and wide field margins corresponded well to species mobility: the abundance of more sedentary moths increased near hedgerow trees and at wide margins, but not the abundance of more mobile moth species. We believe that these more mobile species, such as the severely declining large nutmeg, are not responding well, in terms of individual moth numbers, to these tree and margin resources because these extra resources were provided at a field or farm scale only. Mobile moths typically fly relatively large distances, up to several kilometres (Slade et al. 2013), and hence move around in search of resources on a landscape scale. For such mobile species, field-scale measures on an individual farm will consequently only make a relatively small, and often trivial, contribution to population levels (Fig. 8.8). As such, only sedentary species (i.e. species where the large majority of individuals move only a few hundred metres) are likely to benefit locally from a local, field-scale increase in habitat resources, such as the establishment of wide margins around an arable field. In order to benefit populations of relatively mobile species too, wide field margins and hedgerow trees will need to be established around a majority of fields in whole landscapes (see also Hambäck et al. 2007), rather than—as is currently still often the case—around single fields, diffusely scattered within inhospitable landscapes, composed mainly of fields with narrow margins and a low density of hedgerow trees (Fig. 8.8).

This principle most probably applies to other species groups and other semi-natural farmland elements, at least for structurally simple landscapes typified by low habitat heterogeneity (containing < 20% semi-natural habitat), such as intensive farmland. For instance, while

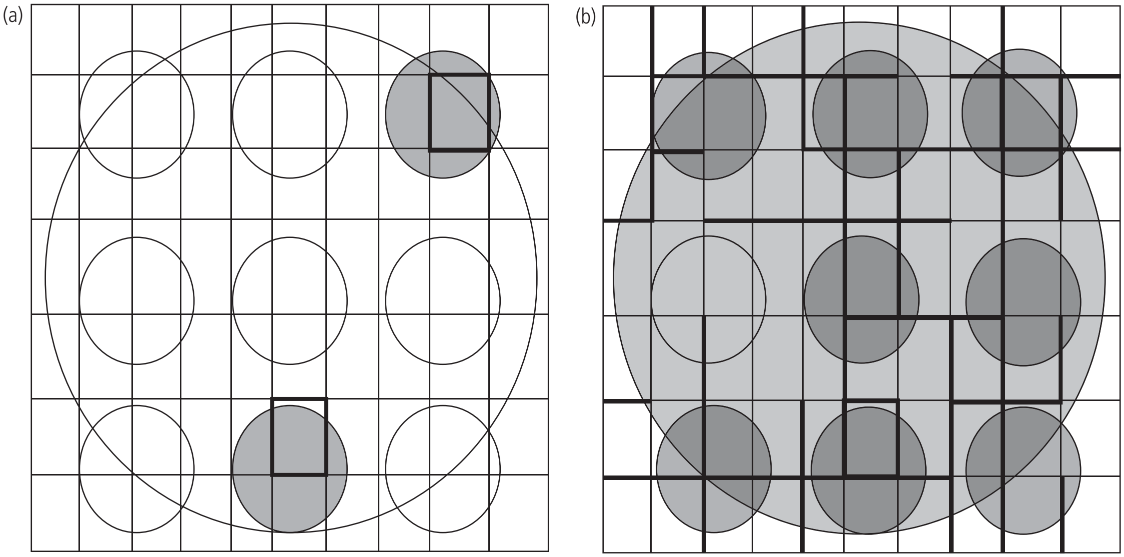

Figure 8.8 Schematic representation of two landscapes under intensive agricultural use, with fields represented as rectangles. Field margins covered by AES options (e.g. 6 m-wide strips) are shown in bold. Small circles represent populations of a sedentary species, whereas the large circle represents a population of a relatively mobile species. Filled circles represent populations benefiting from AES. We contrast (a) scattered, field-scale uptake with (b) landscape-scale uptake of AES. The first scenario does not meaningfully benefit the mobile species, and only benefits a couple of populations from the sedentary species, because whilst the two enhanced fields significantly improve overall habitat quality for two highly local populations of the sedentary species, they only represent a small proportion of the relatively large 'home range' of the mobile species. The second scenario does benefit the population of the mobile species, and also benefits all but one of the sedentary species' populations.

some sedentary woodland moth species, such as maiden's blush *Cyclophora punctaria*, black arches *Lymantria monacha*, and nut-tree tussock *Colocasia coryli*, do occur in small (a few hectares) farm woodlots, mobile woodland specialists, such as the lobster moth *Stauropus fagi*, appear to be restricted to larger (> 5 ha) woodland fragments only (Slade et al. 2013). Depending on their species-specific dispersal characteristics and corresponding differences in landscape-wide resource use, different species operate and experience the landscape at different spatial scales (Steffan-Dewenter et al. 2002; Van Dyck 2012) (Fig. 8.8). As a result, population densities of relatively mobile species will be affected by the surrounding landscape quality at large spatial scales only, whereas populations of low-mobility species will be affected at smaller scales (e.g. diameters of 6 km, 3 km, and 0.5 km for honeybees, bumblebees, and solitary wild bees, respectively; Steffan-Dewenter et al. 2002). This means that, while low-mobility species suffer more from locally adverse conditions than do mobile species, favourable local conditions within adverse landscape conditions will mostly benefit low-mobility species only (Tscharntke et al. 2005) (Fig. 8.8). In line with these findings, Thomas (2000) and Rundlöf et al. (2008) concluded that relatively mobile butterfly and bumblebee species are more affected by habitat fragmentation than low mobility species (although species at the very high end of the mobility spectrum, like the small white *Pieris rapae* butterfly, are generally surviving well).

We have argued that macro-moths are revealing models for understanding patterns of animal communities on farmland and the ways in which AES may be tailored to deliver the best compromises for conserving biodiversity alongside food security. A key lesson from these model organisms is that AES should be devised to take account of the spatial scales at which populations of wider-countryside species use the agricultural matrix and the mosaic of semi-natural habitat within this matrix: although a field-scale uptake of AES options may bring significant benefits to low-mobility species, only a landscape-scale uptake is likely to benefit the whole set of wider-countryside species, inclusive of the high-mobility species (Fig. 8.8). This is important because, for agricultural landscapes characterized by intensive farming systems, mobile, generalist species are a key group in terms of ecosystem functioning for two reasons. First, plant-pollinator networks are highly dependent on the abundance of a core group of generalist species (Devoto et al. 2011) and, second, highly mobile, large-scale species influence food-web interactions more than small-scale species, as the latter are characterized by dispersal limitation (Tscharntke et al. 2005). In practical terms, we advocate that field margin options, and indeed other AES options, should be targeted and implemented at a landscape scale (rather than at the current, standard field or farm scale). By adopting our recommendations, AES options should not only benefit sedentary species, as they do now, but also more mobile species (Fig. 8.8).

In short, while small-scale AES may advantage less mobile species but not more mobile ones, landscape-scale AES will benefit both, and thus deliver more to the tax-payer and policy-maker. Delivering this outcome might involve, for example, encouraging contiguous farms to take up AES options in order to reduce habitat fragmentation and maximize habitat linkages, as in our experimental 'targeted' landscapes (Macdonald and Feber 2015: Chapter 14). This approach was also successfully implemented in the Chichester Plain, UK, where pro-active targeting of farms created a landscape-scale network of managed buffer strips along water courses, resulting in significant increases of the endangered water vole *Arvicola amphibius* (Macdonald et al. 2007; Dutton et al. 2008; Chapter 15, this volume). In England, 67% of the utilizable agricultural area was covered by AES in 2011. However, only 8.1% of the area was under the Higher Level Stewardship (HLS) scheme, which aims to deliver significant environmental benefits in priority areas (Defra 2011). Moreover, HLS remains discretionary, and may be less appealing to farmers because of the commitment to more complex environmental management.

In summary, we argue that a more effective repayment for investment by society in nature on farmland is likely to be delivered by the use of relatively simple existing and new AES prescriptions, but—importantly—implemented over large (landscape-scale) areas.

8.6 Landscape-scale impacts of agricultural intensification

Farms, while separate economic enterprises, are not ecological islands. To what extent does the fate of biodiversity on a farm, or the effectiveness of AES implemented on it, depend on the management of the neighbouring farms (Gabriel et al. 2010; Batáry et al. 2011)? Insofar as our findings about macro-moths pushed our perspective towards the scale of landscapes, and thus ecological patterns and dynamics that embrace several adjoining farms, we expected that AES options would have larger effects on biodiversity in settings typified by increasing intensification, simplification, and homogeneity of landscapes (Tscharntke et al. 2005). Moving on from the discovery that two elements of the 'farmscape' (i.e. wide field margins and hedgerow trees) were associated with increased abundance and diversity of macro-moths, we went on to test whether their effect was moderated by the amount of intensively managed agricultural fields in the surrounding landscape (Merckx et al. 2012). While we expected that a greater expanse of arable land would generally result in lower overall moth abundance and species richness, we predicted that the positive impact of wide field margins and hedgerow trees on both abundance and richness would be stronger in the context of a landscape more dominated by arable land.

Using a Geographic Information System (GIS, ArcMap 9.2), five circles (radii: 200 m, 400 m, 800 m, 1600 m, and 3200 m) were mapped around each of the three sampling sites of each of the 16 farms (Fig. 8.1). Using recent land-use data, we calculated the percentage of arable land within each of these circles. The five spatial scales were selected to cover roughly the extent of foraging movements for a gradient of low- to high-mobility species of macro-moths (Slade et al. 2013), whereas the variable 'percentage arable land' was chosen because it is considered to be a good indicator of the degree of agricultural intensification (Tscharntke et al. 2005).

Our original expectations were not fulfilled. The amount of arable land in the surrounding landscape did not affect overall species richness and abundance at any of the five spatial scales, and did not modify the effect of the local factors (i.e. there were no significant statistical interactions with hedgerow tree and wide margin). In practice, this means that wide field margins and hedgerow trees have an effect (increasing both overall abundance and species richness of macro-moths) no matter the degree of arable land cover on adjoining farms and irrespective of the spatial scale on which the landscape is viewed (at least for the range tested in our study—200–3200 m).

However, this unexpected generalization obscured different answers when our results were considered for species with different natural histories and, in particular, their conservation status. This became clear when we classified species into three classes based on

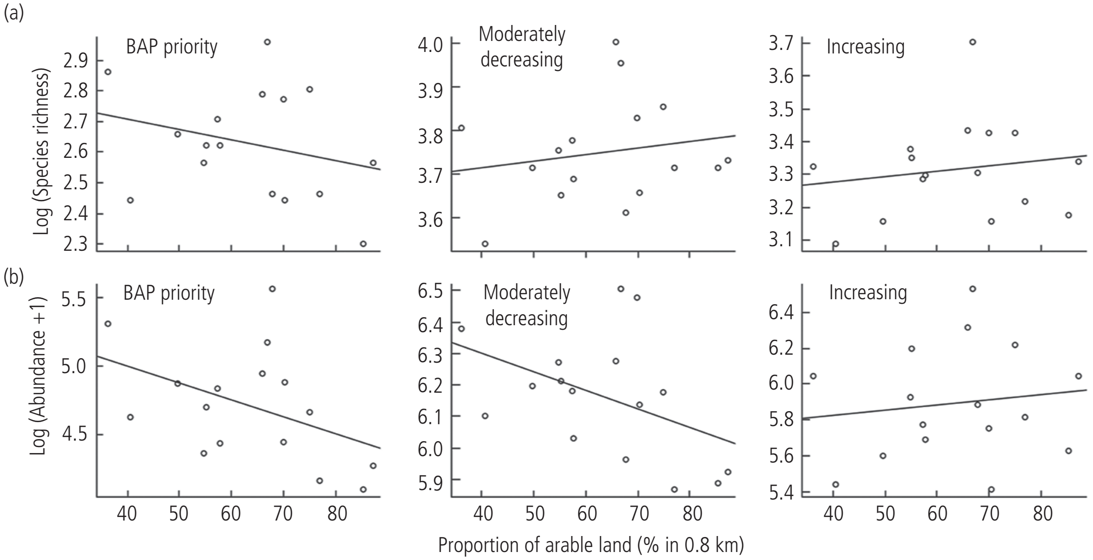

Figure 8.9 Effects of the cover of arable land in the landscape (% within 0.8 km radius) on (a) macro-moth species richness, and (b) macro-moth abundance, separately for severely declining species (i.e. UK BAP priority species), moderately declining species, and increasing species. From Merckx et al. (2012). Reproduced with permission from John Wiley & Sons.

national abundance trend data over 35 years (Conrad et al. 2006): (a) severe decline (70–99%; i.e. UK 'BAP' priority species, N = 44); (b) moderate decline (0–69%; i.e. 'declining' species, N = 106); and (c) increase (> 0%; i.e. 'increasing' species, N = 76). Typical examples for each of the three classes respectively are: (a) white ermine (Fig. 8.6); (b) drinker (Fig. 8.5); and (c) dingy footman *Eilema griseola*, which is nationally on the increase like most other moth species feeding on lichens/algae (Conrad et al. 2006). Species for which the national trend is unknown were not retained in the analysis. All three groups reacted positively in terms of abundance and species richness, whatever the degree of agricultural intensification, to wide margin and hedgerow tree presence. So, these farmland elements delivered a positive overall effect, and they did so at all spatial scales.

Our study showed that nationally declining species became less abundant with increasing levels of agricultural intensification in the surrounding landscape, especially so at the intermediate spatial scale of 0.8 km radius (Fig. 8.9b). Our study is the first to show that this may be the result of direct negative impacts of landscape intensification on these nocturnal insects. As such, this indicates that agricultural intensification may be the factor that explains most of the recent, extensive decline of many macro-moths, such as dusky thorn *Ennomos fuscantaria*, lackey *Malacosoma neustria*, and garden tiger (98%, 93%, and 92% declines over 40 years in Britain, respectively) (Fox et al. 2013). These negative effects of agricultural intensification on the abundance of both nationally severely (UK BAP priority) and moderately declining species did translate into a negative effect with regard to species richness for the UK BAP priority species group only (Fig. 8.9a). The observation that agricultural intensification did not seem to affect the species richness levels for the nationally moderately declining species group may be due to considerable time lags between population declines and resulting local extinctions. We also show that the group of species that are nationally increasing is actually positively impacted with increasing levels of agricultural intensification (Fig. 8.9). This may possibly be a result of reduced competition with species that are declining or going extinct as a result of agricultural intensification.

8.7 Widespread versus localized species: the case of the pale shining brown

We have shown that general AES options are able to benefit widespread moth species, but there is little information on the extent to which rare, more localized, species may also benefit. During our main light-trapping experiment, we caught 88 individuals of the pale shining brown (Fig. 8.10) during the first year alone. This was an exciting, and all the more interesting, find as it meant the discovery of a population of a rare UK BAP priority species on farmland. The species was widely and well distributed in southern and southeast England until the mid 1970s but, since then, has undergone a massive decline. Since 2000, the vast majority of sightings have been from Salisbury Plain, an area known for its rich biodiversity, but the population is thought to be small. The Oxfordshire population we (re)discovered appears therefore to be the strongest currently known in Britain (Townsend and Merckx 2007).

The discovery provided a good opportunity to test whether AES options aimed at increasing general biodiversity would also benefit a highly endangered moth without species-specific tailoring. Since basic but much needed autecological (e.g. foodplant) information is lacking for this species, we tackled this by assessing the effects of wide field margins and hedgerow trees on the abundance of pale shining browns, both using light traps at the landscape scale and MRR (also with light traps) at the farm scale (Merckx et al. 2010b). Based on the generalizations that we had previously demonstrated, we predicted that abundance of this rare species would be highest where field margins were wide and where hedgerows included emergent trees. We also expected that, if hedgerow trees conferred a positive effect, individual pale shining brown moths would be more likely to follow hedgerows than to cross exposed fields while on the move. These expectations were fulfilled: individuals were 8.5 times as abundant at sites with a hedgerow tree than at sites without a hedgerow tree (93 versus 11 individuals, respectively). Numbers were also higher at wide margins, but this was not statistically significant. No individuals were caught at field centres and, judging from the recorded movements, individuals may prefer to move within the sheltered space provided by hedgerows and hedgerow trees.

So, at least in the case of the rare pale shining brown, AES prescriptions designed to benefit the generality of farmland species, appeared to be beneficial to a rare and localized species too. This umbrella effect

Figure 8.10 Pale shining brown *Polia bombycina*—a rare and localized UK Biodiversity Action Plan (BAP) priority species. The population which is currently the largest in the UK was unexpectedly discovered—on farmland—during our light trap research programme. Photograph © Maarten Jacobs.

is encouraging, but obviously may not apply to many specialists because of their specialist life-history and habitat demands. Still, it would be helpful to explore which other rare UK BAP priority species fall inside the protective umbrella offered by specific AES options. For instance, the barberry carpet *Pareulype berberata* is limited to a few small sites in England. Barberry *Berberis vulgaris*, its foodplant, is a plant associated largely with hedgerows. Hence, well-designed hedgerow management options within AES, such as planting, protecting, and joining up stands of barberry, are likely to benefit remaining populations.

We are eager to promote conservation that is fit for purpose to protect priority endangered species, but the greater the extent to which several species can be protected by the same intervention, the more cost-effective it will be (a principle we have applied to widely different taxa; Macdonald et al. (2012)). There is scope for an integrative, biotope-focused approach going hand in hand with species-specific prescriptions where and when the precise ecological requirements of certain species of high conservation concern (and high charisma) are known.

8.8 Key recommendations for management and policy

In summary, what practical lessons for farmland conservation can be gleaned from our research? We propose the following:

1. Hedgerow trees and wide field margins are prominent features of farmland that can easily be integrated within effective AES. The presence and establishment of both hedgerow trees and wide field margins within intensive farmland offer substantial benefits to macro-moths overall, and are likely to benefit other flying insects too. This will positively impact on other trophic levels (e.g. birds/bats), on pollination levels, and other ecosystem services.
2. As the standard, field-scale uptake of AES options may be most effective for sedentary species, a move to a targeted, multi-farm, landscape-scale approach for AES implementation will additionally benefit more mobile species, which are a key group in terms of ecosystem functioning within agricultural landscapes.
3. A two-tier landscape restoration approach is needed, with increased investment in both (a) species-specific conservation measures for highly endangered specialist species with known resource requirements, and (b) biotope-specific conservation measures for mitigating declines in the large number of (once-) common and widespread species, as well as more localized species with poorly known ecological requirements.
4. We have shown that agricultural intensification results in negative effects on nationally declining and priority species, and that this is most pronounced at a spatially intermediate landscape scale (0.8 km radius). Our results hence suggest that the presence of wide field margins and hedgerow trees, promoted by AES targeting their implementation at this spatial scale, may help mitigate negative effects of agricultural intensification on macro-moths. A wide range of other taxa are dependent on macro-moths and may therefore benefit from these farmland features too. Nevertheless, taxa differ widely in their mobility. Consequently, measures mitigating biodiversity loss may need to be targeted at multiple spatial scales to maximize their effectiveness for multiple taxa.

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