OBSERVATIONS ON INVERTEBRATES COLLECTED UP DURING WILD FLOWER SEED HARVESTING IN A HAY MEADOW, WITH PARTICULAR REFERENCE TO THE BUTTERFLIES AND MOTHS

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The forester moth, *Adscita statices* L., is a local moth in Oxfordshire and Buckinghamshire. One of its few remaining sites in these counties is the Bernwood Meadows nature reserve which is a traditional hay-meadow. The moth is fairly common here most years. Several former sites in the area have been destroyed by agricultural intensification. I was therefore concerned when I learned, in 1988, that Bernwood Meadows was to be harvested for wild flower seed on several occasions in June and July 1988 using a large vacuuming device. I was unable to find any information on the effects on butterflies and moths of such an operation so I arranged to follow the machine, make some observations and to find out more about this type of harvesting.

Dr C.W.D. Gibson had made some unpublished observations and recommendations based on observations made on 23.vii.87, the first year in which seed harvesting at Bernwood meadows took place. He has kindly given me permission to incorporate his notes.

THE INCENTIVE TO HARVEST WILDFLOWER SEED

Popular interest in growing wild flower seed took off in the late 1970s and early 1980s and a variety of machines have been designed to collect seed for this purpose. The machine in use at Bernwood Meadows was specially designed to harvest seed from North Meadow, Cricklade, without damaging it and it has been used there for several years. The amount and value of the seed harvest varies from year to year but can be £300 per acre in a reasonable year, at £20 per kg. This is as much as eight times the value of the hay crop per acre (P. Carey pers. comm.). This offers an additional revenue for site owners, for the hay can still be cut after the seed harvest. Seed from a nature reserve or site of special scientific interest can be promoted as such and may help sales. The revenue can be used to fund management work or monitoring studies on reserves so the option is being considered at a number of sites and this may increase as the demand continues.

THE SEED HARVESTING MACHINE

The machine (Figure 1) consists of six rectangular suction heads which are dragged over the sward. These are arranged in a line to give a 4 m swathe. They rest on little wheels and can be set at different heights just above the ground. They were set at 2.5 cm on my visit. The heads lead via tubes into a large drum in which is mounted a fan. The fan creates the suction and is powered directly off the PTO drive of the tractor which tows the machine across the field at about half normal walking speed. On this machine the suction heads are at the rear and the air drawn by the fan is blown out at the front and disturbs the sward. In other designs this arrangement may be reversed.

From the insects' and seeds' point of view the tractor wheels pass first, followed by a blast of air from the fan and then the lesser load of the wheels which support the drum. Lastly the sward is pushed over forwards, is scraped by the blunt blades of the

Fig. 1. Seed harvester in action.

suction heads and suction is applied to the sward mostly after it has been pushed over. Once the machine has passed, the sward springs up to a greater or lesser extent but does not return to the undisturbed condition, at least not on the same day, and this and the tyre tracks show which areas the machine has covered (Figure 2).

To collect the full variety of seed it is necessary for the machine to make several visits spread throughout late June and July (six visits in 1987). The sward must be dry to the touch before harvesting and sunny calm conditions are preferred.

Effects on the invertebrates

Both Dr Gibson and I concentrated on the invertebrates that were collected up by the machine on the day and were not able to investigate the longer-term effects of additional soil compaction and changes in the composition or structure of the vegetation that may or may not result from seed harvesting. Also, we were unable to sample the invertebrates that remained within the sward after the seed harvester had passed. Dr Gibson observed that the suction of the machine at normal power was low compared with standard insect vacuum samplers such as the 'D-vac' and Burkhard 'Univac'. On the basis of his experience with the D-vac he estimates that the catch of insects which he observed was equivalent to 1–3% of the likely fauna present in the area covered by the machine.

In 1988 the machine made three visits between July 15 and early August and I was present on the first of these. The operation was 3 weeks late due to bad weather and most of the buttercup seed was missed. The forester moth had finished flying a fortnight previously (A Saunders pers. comm.) and did not appear in the catch.

Composition of the catch

The catch of seeds and insects was not simply closed up and removed from the site for later sorting. The operator was in the habit of spreading the seed out on a sheet after every two or three swathes across the field, partly to allow the seed to dry and

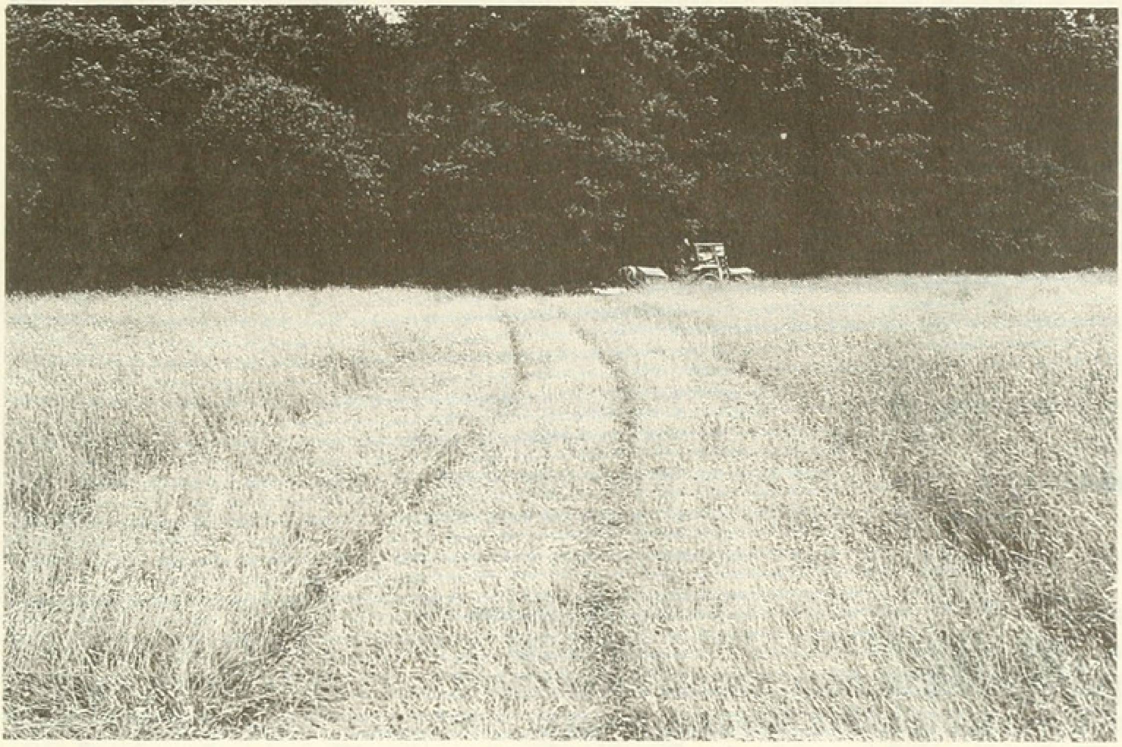

Fig. 2. Hay sward after passage of harvester.

partly to rid it of as many of the invertebrates as could fly or crawl away. The seed was swept out of the floor of the drum with a brush. Apparently at least one frog and one mouse have been collected up by the machine in the past and both emerged unharmed during sweeping out! (P. Carey, pers. comm.). What emerges onto the sheet is a pile of seeds seething with invertebrates, the latter consisting mainly of insects and spiders. Hemiptera (bugs), Collembola (springtails) and the larvae of the Symphyta (sawflies) were present in very large numbers. Adult Diptera and Hymenoptera were well represented. The Coleoptera were mainly represented by cantharids (soldier beetles) and small curculionids (weevils). Orthoptera, both tettigonids (bush crickets) and acridids (grasshoppers), were present in small numbers, as were representatives of other orders such as the Mecoptera (scorpion flies) and Neuroptera (lace-wings). My particular interest was the Lepidoptera, (butterflies and moths) and these were counted individually. I also recorded bees. Paul Hatcher and Bob Brocklehurst assisted with the counting, which had to be done rapidly so as not to hold up the operation. The results are shown in Table 1.

Numbers of Lepidoptera

Bearing in mind that the Lepidoptera were collected from 1.6 hectares (4 acres) the numbers removed are relatively small. Most numerous among the adults was the meadow brown butterfly, *Maniola jurtina* L. at 63 individuals. The numbers of other butterfly species collected were much smaller (Table 1).

As a crude indication of the scale of removal of butterflies from the total in the meadows, the numbers of *M. jurtina* seen on three 90m × 4m transects across the width of the harvested areas as soon as the machine had left the site were 8, 18 and 23 (total 49) compared with similar transect counts adjacent to the area of 38, 11 and 18 (total 67). The high figure of 38 came from the border of the harvested area and could be due to temporary displacement of butterflies from it. Otherwise the transect counts in the two areas are little different, though the possibility exists that the butterflies were quick to move into the harvested area from elsewhere and restored

Table 1. The butterflies, larger moths, bumble bees and larvae of sawflies collected by a wild flower seed harvester from 1.6 hectares of the Bernwood Meadows, Bucks on 15 July 1988.

Butterflies		
Meadow brown	*Maniola jurtina*	63
Marbled white	*Melanargia galathea*	6
Small skipper	*Thymelicus sylvestris*	3
Large skipper	*Ochlodes venata*	2
Gatekeeper	*Pyronia tithonus*	1
Moths		
Narrow-bordered five-spot burnet	*Zygaena lonicerae*	6
Six-spot burnet	*Zygaena filipendulae*	3
Large yellow underwing	*Noctua pronuba*	3
Silver Y	*Autographa gamma*	1
Larvae		
Burnet campanion	*Euclidia glyphica*	} 43
Mother shipton	*Callistege mi*	
Apamea spp. probably rustic shoulder-knot	*A. sordens*	
and clouded-bordered brindle	*A. crenata*	several 100s
Pug moth larvae	*Eupithecia* spp	3
Common wainscot	*Mythimna pallens*	2
Burnished brass	*Diachrysia chrysitis*	2
Sawfly larvae	(Symphyta)	several 100s
Bumblebees		
Bombus spp. including *B. terrestris*, *B lucorum* *B. lapidarius* and others		106

any imbalance. The average densities of adult meadow browns seen in the harvested and unharvested transects are 0.045 and 0.062 adults per m^2. On this basis the estimated population in the harvested area was about 720 adults after harvesting and 783 before, assuming that the number of butterflies entering the harvested area was balanced by the number leaving. This gives a removal rate of 8% which is only approximate because some individuals on the transects may have been counted twice while others may have been overlooked in the grass. The counts in the unharvested transects give an estimated population in 1.6 hectares of 993 individuals, on which basis the removal of 63 represents 6% of the butterflies on the wing in the area at the time of harvest.

The only time that the meadow brown population in Bernwood Meadows has been studied fully throughout the year was by Clarke (1988) who counted the numbers of adults in random 1-m^2 quadrats during 1982. She recorded a peak density of 0.98 adults per m^2 on 29.vi.82 but numbers had declined to 0.35 adults per m^2 on 7.vii.82 and 0.24 adults per m^2 on 16.vii.82. Assuming a similar population size in 1988 and a similar flight period, the peak adult population in the 1.6 hectares covered by the seed harvester would have been 15 680 adults but this would have declined to 3840 adults by the time of the seed harvester's visit. The 63 adults that were collected by the harvester represents 1.6% of the theoretical population on the day and 0.4% of the peak population of the area harvested.

Butterfly populations are known to fluctuate from year to year. If the 1988 population of meadow browns in the meadow was lower than in 1982, the removal rates based on Clarke's data are under-estimates. In Bernwood Forest, adjacent to the meadows, butterfly populations are monitored using the Pollard transect walk method (Pollard 1977). The totals indicate that 1988 was a poor year for meadow browns and that in 1982 nearly three times as many were seen as in 1988. Consequently the actual removal rates in the meadows *might* be nearly three times as high as those given above and about 5% of the adult population of the harvested area on the day. The latter is of the same order as that estimated from the transect walks through the area.

The impact of repeated visits depends on the proportion of the population on the wing at each visit. For six visits (as in 1987) the maximum impact would occur if the whole population was on the wing simultaneously on all six occasions. This would result in about 26% removal in total if 5% were removed each visit. If the population was composed of completely different individuals on each occasion the removal rate would be a maximum of 5%. Clarke (1988) found that males emerged in advance of females and that some individuals of both sexes lived more than 10 days, which is long enough for them to encounter multiple visits of the harvester, so the actual removal rate will be somewhere between the two limits above. The pattern of emergence and the incidence of seed harvesting are likely to vary from year to year, contributing another source of variation. Clarke's results show that the population changes greatly from week to week building to a peak and then declining. With at least a week between harvesting visits only one visit is likely to coincide with the peak population density. The population on a single day at the peak of the flight season might only be a third of the total emergence for the year, based on studies of other grassland butterflies (Thomas 1983). On this basis three visits spread throughout the season, each removing 5% of the butterflies on the day, would result in removal of less than 5% of the total population.

A large population of a common insect such as the meadow brown can survive the maximum harvesting rates given above but annual removals at maximum levels would probably result in a lowering of abundance. The survival of species with smaller populations or with individuals that are more vulnerable than the meadow brown is to the seed harvester could be jeopardized by intensive seed harvesting however.

During the harvesting it was noticeable that many butterflies flew out of the way of the machine before the suction heads arrived. This was greatly assisted by the fact that the blow-out from the fan is 1.5 m in advance of the suction heads. The expelled air rustles the grass and provides the butterflies with an early warning to move. This would not be the case if the suction heads preceeded the blow-out, in which case catches might be higher of insects that presently heed the early warning of the blow-out and fly off.

Burnet moths (Zygaenidae) were less inclined to move and the catch may be a higher proportion of the total population but no estimate of the population is available. None were seen on any of the transect walks, probably because they were resting among the sward. As the burnet moths are similar in shape, size and behaviour to the forester, it is likely that some of these would also have been removed by the harvester had it started on schedule 3 weeks previously.

The weather will affect the tendency of adult Lepidoptera to move off in advance of the machine. On my visit the weather was rather cool and dull until early afternoon and insects were possibly more sluggish than on hot days.

In mid-July most of the abundant moths in the meadow are in the pupal or adult stages. These are principally nocturnal moths and light trap catches reach a peak in late July. These are listed in Waring (1988). The surprise was that only four adult nocturnal moths were collected by the seed harvester. Three were *Noctua pronuba* L., which has a habit of flying up from the grass during the day if disturbed, and the other was a silver Y, *Autographa gamma* L., which is active by day and by night. Some possible reasons for the small numbers of nocturnal moths collected by the harvester are as follows.

1. Few moths had emerged from pupae by July 15. This is unlikely as experience on nearby sites and in other years shows that numbers are already building up in early July.

2. The moths are emerging but they are roosting elsewhere, in hedgerows and the adjacent wood. Moths can move considerable distances from open ground to local woods (eg Waring 1984) but there is no evidence that a mass translocation takes place each day and other meadows far from cover are known to produce large catches of moths at nightfall.

3. It is most likely that the moths are resting low down in the sward and probably head lower still when disturbed by the seed-harvester. If this is the case they will be trapped and held among the bent over grass stems as the harvester passes over. Only a species like *N. pronuba* which flies up quickly, or moths resting on flowers, like the burnets, will be amongst the seedheads when the harvester inlets scrape over them and draw off loose material. Other moths were not seen flying up in advance of the harvester. What happens to moths among the sward when the harvester passes over them is unknown but it would be easy to estimate the survival rate by placing a few specimens in this situation experimentally. Searches for roosting and damaged moths could be made in quadrats within the sward. Less direct would be comparison of light trap catches on the night before and the night after each harvesting visit. This would be worthwhile to see if there is consistently a decline in numbers after each harvesting visit though stable weather conditions would be needed for these can influence the catch greatly.

The larval stages of the Lepidoptera were collected by the seed harvester in larger quantities and could be counted in hundreds. The majority of these larvae were early instars of one or more noctuid species of the genus *Apamea* (G. Haggett pers. comm.). Most likely they were the rustic shoulder-knot, *Apamea sordens* Hufn., which feeds on developing grass seeds in July and can be swept from grass heads in large numbers. The clouded-bordered brindle *Apamea crenata* Hufn. is another possibility. The date was too early for the young larvae of most other *Apamea* species (Newman & Leeds 1913).

Forty-three of the lepidopterous larvae were young specimens of either the burnet companion, *Euclidia glyphica* L., or the mother shipton, *Callistege mi* Cl. Both species occur in these meadows and the larvae are very similar in appearance and in the timing of the lifecycle.

A. sordens, *A. crenata*, *E. glyphica* and *C. mi* are regularly seen as adults in the meadows, by day in the case of the latter two species. The small range of species of larvae in spite of the large number of specimens collected is partly a reflection of the time of year and the relative abundance of different species but it also suggests that some species are more vulnerable than others. The other common species with larvae that are present at this time are the small square-spot, *Diarsia rubi* View., and treble lines, *Charanyca trigrammica* Hufn., which forages low down on plantains and other herbaceous plants and the small wainscot, *Photedes pygmina* Haw. which feeds in the stems of grasses. These habits explain why they were not seen in the samples.

The larvae of *A. sordens* feed in the grassheads and the larvae of *E. glyphica* and *C. mi* like to rest stretched out along stems and must be some distance from the ground for they are easily swept with a net. Larvae that feed low down or drop as soon as they are disturbed will be trapped amongst grass stems and will not be extracted very readily by the seed-harvester.

Damage to and removal of invertebrates passing through the seed harvester

The practice of spreading the seed out on a sheet to dry on site during the harvesting process allows some undamaged invertebrates to escape and this is an advantage to the operator for it rids the seed crop of some 'impurities'. Bumblebees (*Bombus* spp.) appeared to be largely undamaged and although 106 of these valued pollinators were collected during the operation, most of these had flown off by the end of the afternoon. Butterflies passing through the harvester were generally damaged in the process and of the total sample shown in Table 1, 60% were unable to fly away afterwards. Grasshoppers (Acrididae) frequently lost hind legs and the larger slender mirid bugs also lost parts of their anatomy but few of the insects were squashed or minced by the harvester, so the samples were useful to the entomologist wishing to identify them. The vast majority of the smaller insects and most of the larvae were still present amongst the seed when it was removed from the site at the end of the day. Those that had crawled to the edge of the sheet were probably more vulnerable to predators because of the concentration of numbers in this spot and they may also be unable to find the appropriate species of food-plant to survive.

Conclusions

Large numbers of insects are collected during the harvesting of wild flower seed and most of these are unlikely to complete their life-cycle once they enter the harvester, either because of damage sustained or because they are subsequently removed from site with the seed. Bumblebees are an exception and are usually at least able to fly away after passing through the machine.

The large numbers of insects harvested need to be seen in the context of the populations present in the fields and the fact that many of these meadows are traditionally harvested for hay a little later during the summer, with dramatic effects on the flora and fauna.

For one species, the butterfly, the meadow brown, the approximate likely population size is known. The number of adults removed by the harvester on a single visit was probably somewhat less than 10% of the total population on the day and would be a much smaller fraction of the total adult population for the year in the area harvested even if the visit had taken place at peak season. Meadow browns and other species of butterfly respond to the advance warning provided by the blow out from the harvester and fly out of the way, thus reducing the number that are collected.

Rough estimates provided by Dr C.W.D. Gibson on the basis of his experience with D-vac samplers, suggest that for the Hemiptera as a group between 1 and 3% of the total number present are removed by the harvester.

From the composition of the catch it appears that, not surprising, insects which feed on or rest on flower and seedheads or high up on the stems are more vulnerable than those lower down and for the former the percentage removal could be higher than that given above. The forester moth, *A. statices*, a nationally notable insect, is in this vulnerable category. Because of delays in 1988 seed-harvesting took place after the moth had finished its flying season but the closely related burnet moths (2 spp.) were the second most numerous group of adult Lepidoptera in the harvester even though the total population sizes (unknown) are probably smaller, on the basis of adults seen during the year, than for butterflies such as the marbled white and large and small skippers which were also 'harvested'.

Other moths likely to be particularly vulnerable to seed harvesting (Table 2) are

Table 2. List of macro-moth species that could be particularly at risk during seed-harvesting operations on neutral or calcareous herb-rich grasslands, with notes on the most vulnerable stage.

Black-neck, *Lygephila pastinum*, larva—late July to May on tufted vetch (*Vicia cracca*).

Broad-barred white, *Hecatera bicolorata*, larva—late July to September on buds and flowers of hawkweed (*Hieracium* spp.) and hawk's beard (*Crepis* spp.).

Burnet companion, *Euclidia glyphica*, larva—July and August on various clovers and trefoils (*Trifolium* spp. and *Lotus* spp.).

Chalk carpet, *Scotopteryx bipunctaria*, larva—in June on clovers and trefoils. Adult flies up by day in July and August.

Chimney-sweeper, *Odezia atrata*, adult—June and July. Fly during sunny periods. Dependent on pignut (*Conopodium majus*).

Cistus forester, *Adscita geryon*, adult—June and July on flower-heads. Dependent on rockrose (*Helianthemum* spp.).

Five-spot burnet, *Zygaena trifolii*, adult—on flower heads subsp. *Z.t. decreta* July to August, dependent on *Lotus uliginosus*. Subsp. *Z.t. palustrella* May and June dependent on *Lotus corniculatus*.

Forester, *Adscita statices*, adult—June and July on flower-heads. Larva dependent on sorrels, (*Rumex* spp.).

Four-spotted, *Tyta luctuosa*, larva—June to September on field bindweed (*Convolvulus arvensis*). Adult May/June and July/August. Two generations on some sites. Sometimes active by day.

Grass rivulet, *Perizoma albulata*, larva—July and August, feeds on ripening seeds of yellow rattle (*Rhinanthus minor*) which may be depleted by seed-harvesting.

Marbled clover, *Heliothis viriplaca*, larva—August and September on wide variety of flowers and seeds.

Mother shipton, *Callistege mi*, larva—July to September. Either legumes or grasses.

Narrow-bordered five-spot burnet, *Zygaena lonicerae*, adult—late June and July on flower heads. Dependent on legumes.

Scarce forester, *Adscita globulariae*, adult—June on flower heads. Dependent on knapweeds (*Centaurea* spp.).

Shaded pug, *Eupithecia subumbrata*, larva—July to September on a wide variety of flowers.

Small yellow underwing, *Panemeria tenebrata*, larva—June and July on seed capsules of mouse-ears (*Cerastium* spp.).

Straw belle, *Aspitates gilvaria*, adult—July and August. Flies up weakly if disturbed. Local to Surrey, Kent and Ireland.

the grass rivulet. *Perizoma albulata* D.&S. and the small yellow underwing, *Panemeria tenebrata* Scop., the caterpillars of which feed on the ripening seeds of yellow rattle, *Rhinanthus minor* L. and the mouse-ears, *Cerastium* spp. respectively.

All of these insects survive the traditional hay cut which takes place most years between late June and August depending on weather conditions, growth and the wetness of the ground. It is certain that the insects will survive a single harvest of flower seed at this time, using a machine like the one at Bernwood, for this has much less impact than the haycut. However, the impact of multiple visits at different times of the year to get the full variety of seeds is unknown. Six visits were made to part of Brenwood Meadows in 1987 and three in 1988.

Recommendations

The above observations are based on one day watching a flower seed harvester in action and on a general familiarity with the butterfly and moth fauna of the site. My first recommendation would be that more observations are made and published. What are most needed are reliable measures of actual population sizes of particular insects against which the numbers collected by the seed harvester can be compared, followed by long-term monitoring of sites on which seed harvesting is taking place to see if there is evidence of a decline in the species of interest. In the absence of such data Dr Gibson and I recommend the following:

For entomologists

1. Preparation of a list of those invertebrate species that are likely to be especially vulnerable to seed harvesting in hay meadows. For the macrolepidoptera I would suggest that the species shown in Table 2 are included.

2. Continue to record and report the invertebrates of most interest in your local hay meadow sites. If you have the opportunity, follow a seed harvester to see what it collects. The problem here is that the harvest is weather dependent and the decision on when to harvest is often taken at short notice, such as the morning of the day in question.

3. Monitor the numbers of particularly vulnerable species from year to year. Some of the moths in Table 2 can be counted by day.

For the conservation organizations

1. Find out if any nationally uncommon or vulnerable species have been recorded from each proposed seed harvesting site. The site manager and any colleagues and recorders, the local and national biological records centres, any local entomologists known to visit the site and the Invertebrate Site Register of the Nature Conservancy Council should be contacted in that order. If the meadow falls within a site of special scientific interest NCC must be consulted before seed harvesting proceeds and these checks will be made. If there is no invertebrate information see if a selective survey for vulnerable species can be organized. This may be needed in any case to find out exactly where on the site any vulnerable species occur.

2. If there are particularly vulnerable species on the site and if these are localized to certain parts, cordon these off and do not harvest them for seed. If the species are nationally rare and are found over the whole site seed harvesting should not take place until the results of proper studies are available. Other sites can be found to harvest.

3. At this stage I recommend that only part of each site is harvested in any year. Further I would recommend that the seed harvest is confined to the same part each year. If seed harvesting has no effect on the flora and fauna there is no need to harvest on a rotational basis. If there are effects it will be easier to see what these effects are using this system, and the rest of the site will have been spared.

4. No-one can really say what proportion of the field should be seed harvested each year. Figures of one-fourth or less have been suggested. If the site is heterogenous harvesting in strips rather than in a single localized block is better from two points of view. Firstly the seed mix will be more varied and secondly any localized habitat features are less likely to be completely harvested. One advantage of harvesting the same ground every year is that the strips can be marked out permanently. Remarking sites every year on rotation and between passes in the same year will not only be time consuming but it will also make the study of any long-term effects extremely difficult.

Points for the operator

1. The design of this machine with the blow-out in advance of the suction heads gives insects advance warning and butterflies especially fly out of the way at this point.

2. Spreading out the seed on a sheet after each traverse of the field rids the seed of many insects which can fly off. This operation is valuable for bumblebees, the majority of which are apparently undamaged and able to fly away. However, the seed still contains large numbers of insects after several hours of exposure and requires offsite separation of seeds from dead or dying insects. Local entomologists may be interested in the insect material at this stage.

3. In most cases the operator will be the only person on site during seed harvesting and any observations he or she can make on the numbers of butterflies, moths or other large insects left amongst the seed at the end of the day would be much appreciated.

At Bernwood Meadows the above recommendations have been followed with the exception that in 1987 rotational seed harvesting of a single block was recommended and in accordance a different area has been harvested in each of the 3 years. The proportion seed harvested each year has been 22% (1.6 hectares).

The distribution of the forester moth and the host plant of the small yellow underwing have been mapped (Waring, Saunders, Glossler unpublished). So far the seed harvest has not included the area where most foresters are seen, which is also the site of the only record of their larvae from the meadow. This small corner will be left out of the 4-year rotation.

To date none of the vulnerable species of macro-moth have been lost from the meadows and some have been seen in areas previously seed-harvested though no further quantitative studies have been done.

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Corrections — R.G. Warren's exhibit on 28 October 1989 (*Br. J. Ent. Nat. Hist.* 1990: **3:** 74), the following corrections should be noted: (1) *Anacampsis temerella* Zell. was shown to be a very dark form of *Monochroa lucidella* Steph. (gen. det. E.S. Bradford), quite unlike the other example of that species exhibited, also from Crymlyn Bog. (2) *Ypsolopha lucella* F. should be *Y. alpella* D. & S. (det. D.J.L. Agassiz).