A review of current knowledge of the forest bug, *Pentatoma rufipes*

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Summary

Forest bug (red-legged shieldbug, *Pentatoma rufipes*) is a commonly occurring and widespread shieldbug species in the UK. It is particularly associated with woodland habitats and may remain in woodlands throughout the year, feeding on tree species such as oak, beech and hazel. However, forest bug also occurs in orchards and is emerging as an important pest of tree fruit in northern Europe. In recent years – particularly since the withdrawal of chlorpyrifos in 2016 – UK top-fruit agronomists have found increasing numbers of forest bugs in and around orchards. Their feeding activity on developing fruits is being linked with pitting and distortion damage to apples and pears. There has been limited scientific research into the ecology and control of this species, but some Belgian, Swiss and German studies provide valuable information on the timing of the life cycle and the effects of plant protection products. No information is available linking UK local population levels and activity with damage at particular times of the year. There has been no UK-based research on the effects of control strategies for forest bug populations or fruit damage. This review highlights several findings concerning the pest and makes specific recommendations for further work.

Main findings

- Damage to top fruit is triggered when forest bugs feed early in the season on developing buds, flowers and fruits (shortly after flowering). This results in later pitting and severe distortion as the fruit develops

- Damage is caused by the overwintering early stage (second instar) nymphs

- Low densities of infestation are sufficient for fruit damage. Economic thresholds for significant fruit damage of just two to three nymphs per 100 sampled branches have been suggested

- Pears are particularly at risk of damage, but damage to apple has also been reported very recently in the South East and West Midlands of the UK

- Trees are likely to become more heavily damaged with age because the rougher bark of older trees provides shelter for overwintering nymphs

- Currently, monitoring is only possible using beating tray sampling. There is no pheromone available and nothing is known about communication signals within the species, either using chemical or vibration cues

- The period of highest risk is before or shortly after flowering. Any control products targeting forest bug should be applied at this time to kill the nymphs as they become active and deform fruit

- Very few control product efficacy studies have been carried out with forest bug. The limited available evidence suggests that while pyrethroids (particularly lambda-cyhalothrin) are effective, thiacloprid has limited efficacy. Natural pyrethrins give some control, particularly at higher pest pressure. Spinosad may also provide effective control

- Very little information is available about the natural enemies of forest bugs in the UK and their effects on pest populations

- Exclusion netting is used to effectively protect tree fruit against damage by another shieldbug species (the invasive brown marmorated stink bug) in Italy. However, such netting is expensive to install and it is not clear whether this strategy could be adapted for cost-effective control of forest bug in the UK

Recommendations for further experimental work

The above findings have been informed through consultation with UK growers and agronomists, in combination with a review of international research on the biology and control of the pest species. The experimental studies carried out on forest bug monitoring and control were confined to pear and apricot production areas in Belgium, Germany and Switzerland. No studies have been done in UK fruit production areas and research is now needed to support growers to take informed and effective action against this sporadic but increasingly important pest. Pear crops are most frequently and severely affected in the UK, yet no UK-based research has been carried out on forest bugs in pear. In addition, despite recent reports of damage to UK apples, no information could be found (from any global regions of apple production where forest bug occurs) on the management of the pest in apple orchards.

The following specific action points are recommended as priorities for further work:

- Monitoring of forest bug numbers in UK apple and pear orchards in autumn (counts of adults and egg masses until after harvest) and early spring (sampling nymphs from before flowering). This will enable a comparison of populations of the pest in pear and apple orchards. It will also reveal the association between pest numbers on trees and levels of damage at harvest, leading to sampling methods and timings that could be used to develop realistic thresholds

- Additional monitoring in woodland and hedgerow sites adjacent to orchards, to help inform whether particular tree host species are likely to be sources of infestation and increase the risk of damage to fruit

- Trials to test the currently accepted best control option (lambda-cyhalothrin) against other active ingredients that are likely to have a lesser impact on beneficial insects (natural enemies and pollinators) in orchards. Such efficacy trials should include spinosad and spirotetramat. Control products would normally be applied from immediately before flowering to coincide with the period that forest bug nymphs start to feed and cause damage. However, autumn/winter clean-up sprays could also be explored because these may have a lesser impact on beneficials, either spraying in autumn to reduce mating and oviposition by adult forest bugs in orchards, or spraying the bark of trees during late winter to target the nymphs as they start to emerge from hibernation

- Research investigating vibration-based communication signals between forest bugs and the potential to exploit these signals in pest management strategies

- Chemical ecology studies with forest bug to investigate the roles of pheromones at different stages of the life cycle and whether there is potential to monitor or control the pest with semiochemicals. Such studies should prioritise the investigation and identification of sex

pheromones, since the pest seems unlikely to rely on aggregation pheromones as part of its life cycle

Biology of the pest

Description

The forest bug is one of the larger species of shieldbug found in the UK, with adults typically measuring 12–15 mm long. Adults have a distinctive appearance; several features distinguish this species from other shieldbugs found in the UK (Figure 1).[1]
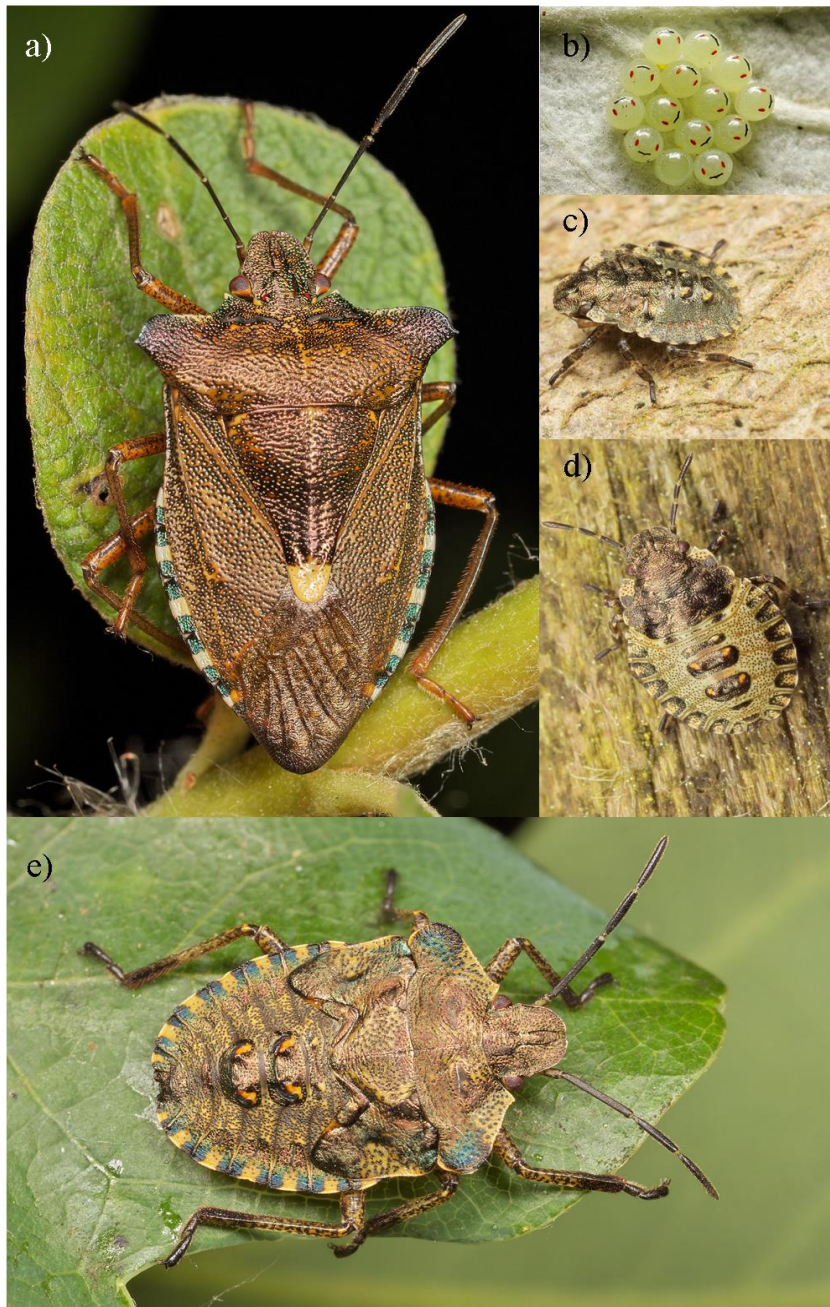

Figure 1. Forest bug life stages: a) adult, b) egg mass, c) second-instar nymph, d) third-instar nymph, e) fifth-instar nymph

Source: Jonathan Michaelson (a, c, d and e) and Tristan Bantock (b)

The dorsal surface of the adult is a glossy dark brown colour, but the legs, tip of the scutellum (the triangular 'shield') and sometimes the basal segments of the antennae are a vibrant orange/red (Figure 1a). The margins of the abdomen are marked with alternating black and cream/orange bands. The hooked front corners of the pronotum ('shoulders') have a tiny pointed barb or tooth on each side of the body, which is particularly characteristic of this species. The adult spiked shieldbug (*Picromerus bidens*) is similar to forest bug in general size and overall appearance[2] and is the only other UK species with pointed projections on each side of the pronotum. However, the large, sharp and thorn-like spines on this predatory species are very different from the tiny points on the sharp corners of the pronotum possessed by *P. rufipes*.[3]

The first-instar nymphs of forest bug are a dark colour, but the nymphs become lighter with age (Figures 1c and 1d). Later nymphal stages are mottled with areas of yellow/green and brown/black (Figure 1e) and can be well camouflaged against tree bark.

Distribution

The forest bug occurs across Europe and is observed most frequently in Britain, Belgium, the Netherlands, Denmark, Germany, Switzerland, Austria, Czechia, northern France and northern Italy.[5] In the Alps, the bug occurs at high altitude (up to 1500 m).[6] In Britain, the species is widespread, although records in England and Wales are more numerous than in Scotland.[7]

Life cycle, phenology and ecology

There is one generation per year.[4,6] The forest bug has an unusual life cycle (Figure 2).[8] Unlike most other species in the shield/stink bug group (superfamily Pentatomoidea), which overwinter as adults,[9] forest bugs pass the winter as second-instar nymphs (Figure 1c), sheltering on the bark of the main trunk but also on larger branches,[10] probably high in the tree canopy.[4] This is a very unusual overwintering strategy for shieldbugs. Currently, 38 other *Pentatomoidea* species are reported as being established in the UK[1] and nearly all of them overwinter as adults. Only two other British species (*Odonotoscelis fuliginosa* and *O. lineola*) survive the cold months as nymphs,[11] but these two species both feed on a herbaceous plant (stork's bill, *Erodium cicutarium*) close to ground level and are therefore not exposed to such extreme low temperatures in the arboreal environment. Second-instar forest bugs are approximately 3 mm long and can squeeze their small, flattened bodies into the cracks and crevices of tree bark to find some shelter from the cold.[10] This makes them difficult to detect during winter monitoring. With the onset of warmer spring days, they crawl out of winter refuges and begin to sap-feed from buds, flowers and developing fruits. The immature stages continue developing throughout spring and summer.

Populations of forest bugs can be assessed using beating trays as a standardised method for sampling insects from tree canopies.[12] The phenology of forest bug populations has been studied using this method to regularly sample the branches of woodland trees in Britain from spring to autumn,[4] recording life stages and numbers of forest bugs detected (Figure 3). There are no published phenological studies from British orchards, but comparisons with samples of insects beaten from fruit trees in Switzerland[10] and Belgium[13] suggest that the life cycle is consistent at these sites of European commercial horticulture and in British woodlands. The following timings for each stage of the life cycle (illustrated in Figure 2) are largely based on the phenology recorded in Britain, with each life stage typically occurring 1 month earlier in the Belgian and Swiss studies. However, it should be noted that the British survey was carried out over a period of 25 years, based on records starting from 1976. With trends towards milder winters and earlier springs, each life stage may now start to appear earlier in the UK than the months stated. This needs further investigation.
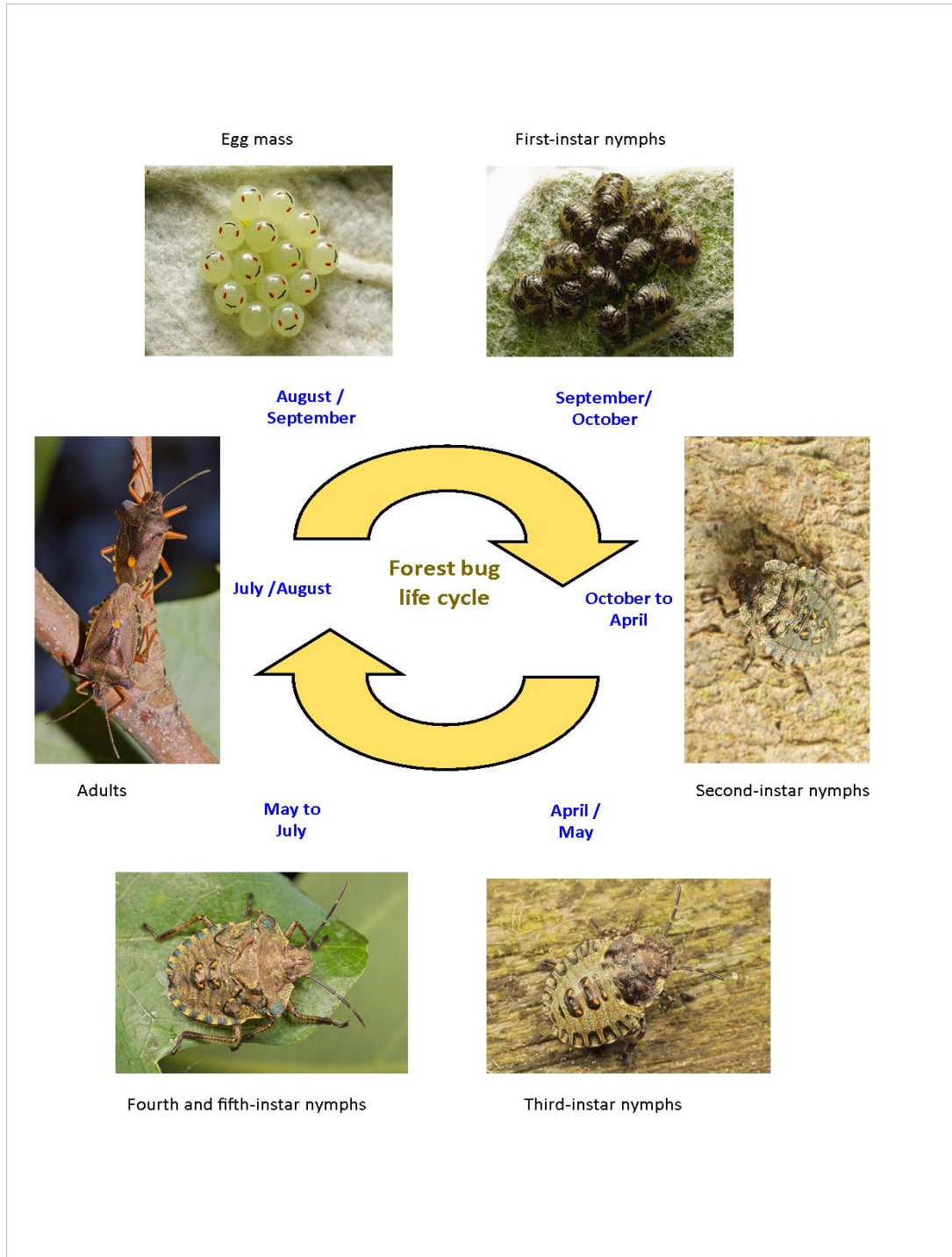
Figure 2. Forest bug life cycle with approximate phenology

Source: Tristan Bantock (egg mass and first-instars) and Jonathan Michaelson (all other images)

In April/May, the overwintering second-instar nymphs moult to the third nymph stage. This is followed by the fourth stage in May/June and the final (fifth) immature stage in June/July (Figure 3). Adults appear in July/August and typically mate and lay eggs in September. The adults are capable of sustained flight and dispersal over large distances, but it is not known whether the insects tend to stay on the same host tree species on which they developed for mating and egg laying. The flying adults are certainly active high in the canopy of woodland trees; many more forest bugs were caught using flight interception traps placed at high positions (10–30 m) in trees than in traps placed close to ground level.[14] Eggs are deposited in batches of up to 14,[6] glued to the plant surface. They are particularly placed on the undersides of leaves,[2,13] but may also be deposited on stems or fruit.[6] In

favourable weather conditions, individual females may be long-lived and can continue to lay batches of eggs from July/August until October.[15] Eggs hatch in the autumn and first-instar nymphs cluster together (Figure 2), staying close to the egg mass. First instars can be detected between September and October/November, when they moult to the overwintering second stages. Second instars then disperse and seek out overwintering sites on tree bark.

Food sources and host range

Forest bugs are able to feed on various deciduous tree species. Oak is particularly favoured as a host plant,[4] but other tree species are also used, including alder, hazel, beech, apple, pear, cherry, plum and apricot.[7,16–22] Localised populations may become more adapted to feeding on particular host plant species; for example, a survey in Epping Forest, where beech trees are abundant, suggested that forest bugs have a greater preference for beech than oak in this area.[23] Attempts to rear forest bugs in captivity suggest that nymphs predominantly feed by sucking the sap from woody twigs, but may also benefit from access to other sources of sugar and are capable of ingesting honeydew from the surfaces of leaves.[4]

Although forest bugs mainly feed on plant sap, their stylet mouthparts can also be used to attack other insects and ingest a haemolymph meal. Forest bugs are adaptable and opportunistic in their predatory behaviour and can feed on the eggs, larvae, pupae and adults of many insect species.[6] Such carnivorous behaviour has been observed in adult forest bugs;[7] predation by nymphs may also occur. It has been suggested that second-instar nymphs, in particular, may need to switch to a carnivorous diet during the winter months, when access to plant sap is limited on the bare branches of trees.[4] However, this is speculation, not based on field or laboratory observations.

Pentatoma rufipes – number of adults

Pentatoma rufipes – number of last-instar nymphs

Pentatoma rufipes – number of young nymphs (first- to fourth-instar)
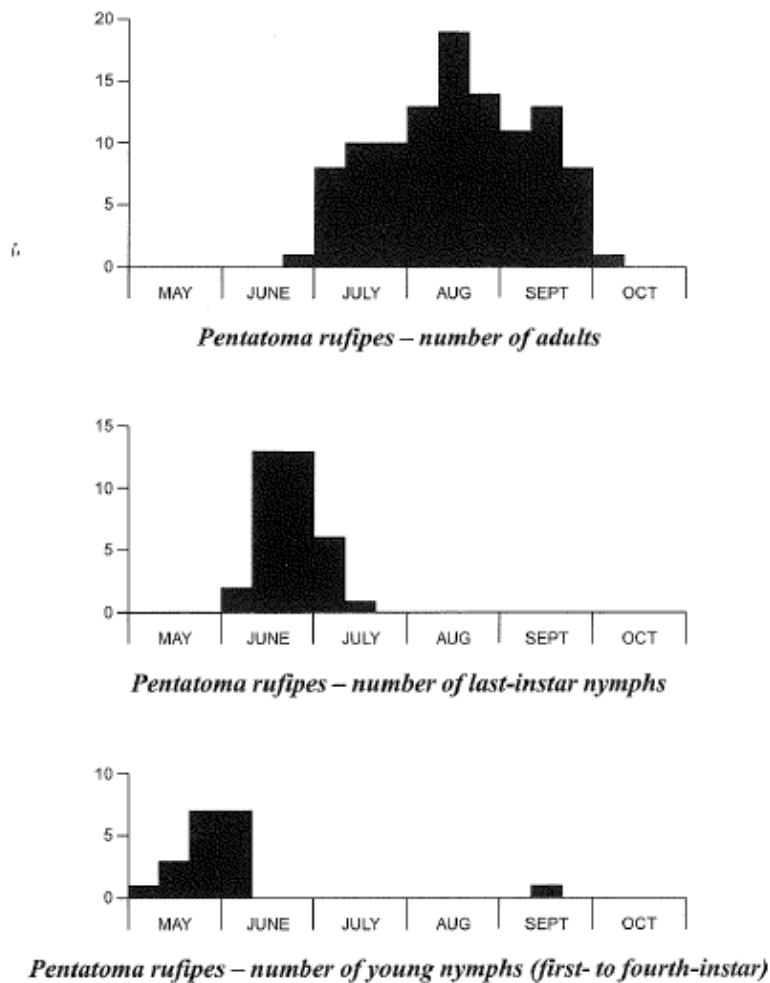
Figure 3. Numbers of forest bugs (*Pentatoma rufipes*) of different life stages sampled from woodland trees in Surrey.[4] A) Adults, B) fifth-instar nymphs, C) young (first to fourth-instar) nymphs

Source: Surrey Wildlife Trust, reproduced with permission

Factors affecting mortality

***Biotic factors (natural enemies)* –** Predators tend to avoid shieldbugs and there is very little specific information on the predators and parasites that may exploit forest bugs. The second-instar nymphs of forest bugs seem to be particularly vulnerable to predation by blue tits and other small birds that forage on the trunk and high branches of bare trees during winter, but sources of winter mortality are not known. In spring in Central Europe, the tachinid fly *Phasia hemiptera* reportedly parasitises forest bug nymphs before switching hosts to the green shieldbug *Palomena prasina* for a second generation in autumn.[24,25] Both this parasitic fly species and the green shieldbug alternative host are widespread in the UK,[7,26] but British host records for *P. hemiptera* are not available.[27] Indeed, it is possible that tachinid flies do not significantly regulate populations of forest bug and other species of UK shieldbugs. As part of a 25-year survey of shieldbug populations in Surrey, large numbers of nymphs were collected from the wild and reared to adulthood to identify them. Although several bugs were found with the egg of a parasitic fly attached to their body, it was rare to find an adult fly emerging from a shieldbug host.[4]

In the UK, a species of large solitary wasp (*Astata boops*) specialises in catching shieldbug adults and nymphs, placing them in a burrow to provision its offspring. The wasp lays one egg on each bug and the larva that hatches develops by consuming the shieldbug.[4] *A. boops* occurs in southern England and East Anglia,[28] but no information could be found about the contribution that this species makes (if any) to keeping populations of forest bugs in check.

Egg parasitoid species are often excellent biological control agents and can have large impacts on populations of shieldbug pests.[29] In Switzerland, adult parasitoids of the native European species, *Trissolcus scutellaris* emerged from eggs of forest bugs that were collected in the field and brought into the laboratory.[30] It is therefore possible that *T. scutellaris* helps to regulate forest bug populations in Europe; however, a search of the literature revealed no reports of this species in the UK. The Asian egg parasitoid species *Trissolcus japonicus* has been investigated as promising biological control for the invasive shieldbug *Halyomorpha halys* (the brown marmorated stink bug, BMSB), which has spread to large areas of North America and Europe to become a major pest of numerous crops.[31] Recent host–range studies of native European shieldbug species revealed that *T. japonicus* also readily parasitises forest bug eggs and the parasitoid larvae develop and emerge very successfully.[32] Although *T. japonicus* was originally of interest as a potential candidate for classical biological control of its BMSB host, this tiny wasp has extended its geographical range into global regions invaded by BMSB, including Europe. The invasive parasitoid is now established in Switzerland[33] and could spread to the UK and affect native British shieldbug populations, including forest bug. However, bioclimatic modelling suggests that the UK climate may be only marginally suitable for the persistence of *T. japonicus* populations.[29]

Abiotic factors – Forest bug is unique among British shieldbug species in its ability to pass the winter as cold-hardy nymphs that are positioned high in the canopy of bare deciduous trees exposed to freezing temperatures. Winter temperature, therefore, seems likely to be a major influencer of survival at this time of year. It is possible that the recent increases in forest bug damage to fruit crops are linked with global warming trends and milder winters. While winter weather data can be used to help predict the phenology and effects of other insect pests (e.g.[34]), this has not been explored for forest bug.

Temperature-based phenological models have been developed for other insect pests, including Heteroptera (e.g. BMSB) and can be used to predict pest population growth[35,36] and inform management strategies. Such models are based on estimates of minimum and maximum developmental temperature thresholds and the relationships between temperature and development rates during each insect life stage. As this information is not available for forest bug, laboratory-based studies are needed to provide data and develop models. Unfortunately, forest bugs seem to require a mixed diet for successful development and attempts to rear them in captivity have resulted in high mortality.[4]

Impacts of the pest

Damage

Like many other shieldbug species, forest bugs produce a sticky defensive secretion with a strong smell. This can contaminate soft fruit, rendering the harvested berries unpalatable. Such chemical contamination can be a particular problem for raspberry and cherry harvests.[37] In recent years, the insect has also been observed more frequently in vineyards. Some vineyard managers are becoming concerned that the chemicals released by the forest bug may taint wine. An additional problem is the nuisance that forest bugs cause at harvest time: in years when they are particularly abundant, pickers may be disturbed by their presence on fruit and there have been reports of staff refusing to pick fruits of infested cherry trees.[38]

In soft fruit, the bug is considered to be harmless outside of harvest time. It may even provide benefits to growers through feeding on other pests, such as caterpillars and aphids. However, in top fruit, the effects of forest bug as a pest appear to be increasing. Linked to forest bug, growers and agronomists report increased problems with fruit deformation, particularly since the withdrawal of chlorpyrifos in 2016. Pears are particularly sensitive to damage[21] and this has been a particular problem in the UK, where growers are not likely to apply early-season products because of the risk of affecting the natural enemies that suppress pear sucker populations. Forest bug can also be abundant in apple orchards,[19,39] but the sprays applied for other pests (particularly blossom weevil and sawfly) may have contributed to secondary protection against forest bug. In 2019, for unknown reasons, UK growers reported unprecedented levels of forest bug damage to apples.

Forest bug nymphs feed on developing fruits shortly after flowering; this early stage of fruit development is particularly sensitive to damage (see below). The damage only becomes apparent long after feeding by the pest, when growing fruits become distorted and pitted and the pulp becomes discoloured (Figure 4). Brown lesions develop in the fruit pulp at the original site of forest bug stylet insertion, saliva injection and feeding. These lesions harden, giving the fruit a 'stony' texture at harvest.[40] In the course of this review, several UK growers and agronomists were asked about their experiences with forest bug. In Suffolk, Cambridgeshire, Herefordshire, Essex, Sussex and Kent, losses of 10% at harvest were commonly reported and, occasionally, much higher levels of damage (up to 50%). Growers are particularly concerned about increasing damage levels (particularly over the last 3–4 years), the lack of available treatment threshold and the emergence of damage to apple. Some of the damage is not detected at harvest and pitted/distorted fruit are now being reported in storage as a result of forest bug attack. A very high level (up to 40%) of damage to stored pears was reported on one Herefordshire farm following the 2019 harvest.

Forest bug damage is similar to the symptoms of pear stony pit virus infection, which leads to fruit deformities.[41] However, the sunken pits caused by forest bug feeding (Figure 4) are typically deeper and more distinct. Boron deficiency can also lead to deformed, cracked and pitted fruit[42] and can potentially be confused with forest bug damage. In addition, it can be difficult to distinguish forest bug damage from that caused by capsid pests or other shieldbug species that may be present in orchards, such as hairy shieldbug (*Dolycoris baccarum*) or common green shieldbug (*P. prasina*). However, forest bug is a particularly abundant shieldbug species in orchards and is the only shieldbug to have been detected in orchards throughout the year.[16,21]

Figure 4. Samples of UK apple and pear fruits reportedly damaged by *Pentatoma rufipes*. Mixed fruit showing surface pitting (top left) and cut to show internal lesions (top right). Pre-harvest damage to Comice (middle) and post-harvest damage to Gala (bottom).

Source: Michelle Fountain (top images), Ralph Hayter (middle image) and Andy Bull (bottom image)

Timing and thresholds

In German pear orchards (Bavendorf-Ravensburg region) in 2013, beating tray sampling revealed forest bug to be the only sap-feeding insect present at the time of early season damage to fruit.[6] In the same region of Germany, numbers of forest bugs sampled from trees during the winter and spring of 2008/09 were compared with the extent of fruit damage assessed in July 2009.[40] Regression analysis revealed a clear, positive correlation between numbers of bugs beaten from trees and the percentage of damaged fruits (r^2 = 0.765; $P<0.001$). Based on this regression, a provisional threshold for significant fruit damage of two to three nymphs per 100 sampled branches was suggested.[40]

In addition to this strong circumstantial evidence associating forest bug with fruit damage, controlled experiments carried out in Switzerland[21] provide a more precise demonstration of how damage to fruit is linked to prior feeding by known densities of forest bug nymphs at specific time points. In April 2009, forest bug nymphs were confined to branches of pear and apricot trees in Swiss orchards. A bag, which was constructed of fabric netting (muslin), was wrapped around one inflorescence of each tree used in the experiment. Three forest bug nymphs were released into some of these cages and confined for a 2-week period, before applying control products. Other control cages remained empty. This was repeated from early flowering until fruit development, to investigate the phenological stage of tree growth most susceptible to forest bug damage. For pear, the phenology of the flowers and fruits exposed to forest bugs corresponded with stages 67–75 on the BBCH scale;[43] in other words, from the point at which flowers faded with most petals fallen, until fruits had reached about half of their final size. Fruits were collected shortly before harvest and assessed for level of bug damage (deformation).

Apricots showed only marginal levels of damage in this experiment, but pears were often clearly misshapen. Levels of pear fruit deformity were particularly high if forest bugs had access to branches shortly after flowering. The highest levels of fruit damage (with at least 80% of harvested fruit showing strong or moderate deformation) were recorded from branches previously exposed to forest bugs at BBCH growth stage 71 (fruit size up to 10 mm) and stage 72 (fruit size up to 20 mm). Replication was very limited in this study, but no damage was recorded for pear fruits picked from control branches (i.e., those caged but without forest bugs present). Overall, Kehrli and Pasquier's study[21] provides valuable evidence linking forest bug feeding shortly after flowering with fruit deformity.

Risk factors

Bailey et al.[44] found that intensive management of apple orchards (particularly characterised by more frequent mowing and applications of fungicides and insecticides) tended to reduce the abundance of forest bug. Organic orchards are at particularly high risk of economically important losses.[16] Proximity of orchards to woodlands may be an additional risk factor for forest bug damage:it is possible that the mobile adult stages move from woodland host trees to orchards for mating and oviposition activities in late summer. This may lead to greater numbers of damaging second-instar nymphs overwintering and causing fruit damage in the following year (Figure 2). Trautmann and Wetzler[40] suggest that fruit from orchards located close to woodland is more likely to be damaged by forest bug, although no data has been published regarding the role of woodlands or other features of surrounding habitats on the pest pressure in orchards. It would be useful to carry out a UK-based study to assess the factors contributing to forest bug damage risk, including size, proximity and species assemblage of local woodlands and the size, age and management history of each orchard.

Tree age is likely to be important for determining forest bug damage risk. In southern Germany, older trees supported higher numbers of forest bugs and had greater fruit damage than younger trees.[40] It has been suggested that this difference is related to the change in texture of the tree bark as the trees age. The rougher bark of older trees may offer more cracks and crevices for the overwintering second-instar nymphs to shelter from the cold and rain, whereas forest bug winter mortality is likely to be higher on younger trees with relatively smooth bark.[10,40]

Pears are particularly susceptible to forest bug damage. Although damage to apple, plum and apricot has also been reported, it usually has less economic impact than the damage caused to pear.[10,20] Within one tree crop species, it is also possible that particular varieties are more sensitive to forest bug damage. Although no quantitative studies could be found to support this, UK growers and agronomists who contributed to this review by sharing their experiences with forest bug reported that,

while any varieties of apple and pear may be affected by the pest, Gala seems to be a particularly sensitive apple variety. Comice may be more susceptible than other pear varieties.

Potential monitoring strategies

Beating tray sampling

In orchards, it is assumed that forest bug nymphs remain sheltered in the bark of fruit trees through the winter, but move up to twigs and smaller branches in February. At this point, they pierce the woody plant tissue with their mouthparts and start to feed on the rising sap before bud burst. The second-instar nymphs are therefore already present on orchard trees and are ready to feed on flowers and developing fruit in spring. However, experimental work is needed to investigate whether numbers of nymphs sampled in late winter/early spring can reliably indicate fruit damage levels within an orchard. Phenological studies of forest bug are usually initiated in March/April (Figure 3),[4,10,16] but it could be valuable to begin beating tray sampling earlier (well before flowering), on warm spring days, to allow sufficient time to assess numbers. Trees might also be treated before bloom, when natural enemies are not as prevalent in the orchards.

Numbers of nymphs sampled in February/March will be linked directly with damage risk – and this is recommended as a starting point for UK monitoring work. Other possible strategies for monitoring include sampling for adults/eggs from August to investigate whether numbers recorded correlate with damage levels in the following season. It has also been suggested that fruit damage risk may be predicted based on damage levels at the previous year's harvest,[6] although such a correlation has not been quantified. Future investigations into pest numbers and fruit damage levels are needed to provide the foundation to build on future monitoring strategies and action thresholds for agronomists and growers.

Pheromone-based monitoring

Pheromones have been identified for other pentatomid pests and are successfully used to monitor stink bug populations gs in North America. For example, the male-produced aggregation pheromone components released by BMSB have been identified and synthesised and have been used in combination with a pheromone synergist compound and traps of various designs to monitor populations.[45] Combining pheromone lures and monitoring traps is particularly effective for BMSB because it enables both adults and nymphs to be captured throughout the crop-growing season.[46] Management strategies linked to pheromone-based monitoring have been developed, allowing the application of control products based on cumulative thresholds of adult BMSB catches in traps.[45]

The potential for pheromone-based monitoring has also been considered for forest bug; however, no specific pheromone is currently available for this species.[47] Pheromone-baited traps are effective for other shield/stink bug pest species, but – unfortunately – no sex/aggregation pheromones have been identified for forest bug. In laboratory studies, an olfactometer was used to investigate the possible responses of forest bug adults and larvae to candidate attractive volatile signals.[6] The stimuli tested included pheromone components known to be attractive to several other stink bug species (($2E$,$4E$,$6Z$)-2,4,6-decatrienoate and other isomers of this compound),[45] but forest bugs showed no clear attraction towards these volatiles over clean air.[6] In further experiments, insects were presented with the odour of fresh pear shoots or groups of live forest bugs. However, no behavioural responses to the odours released from the host plant or from conspecifics were detected.[6]

The study reported briefly by König[6] is the only chemical ecology investigation of forest bug that could be found when preparing this review. Based on the ecology and life cycle of the pest, it seems unlikely that forest bugs release an aggregation pheromone that is homologous with that identified for BMSB and other pentatomid pest species showing gregarious behaviour. By contrast, with the large aggregations formed by BMSB (most notably by overwintering adults, although nymphs and adults also aggregate when feeding),[48] the natural behaviour of forest bug does not suggest that aggregation pheromone signals are important in this species. Although first-instar forest bugs aggregate next to the egg mass after hatching (as is the case for most pentatomid species), second instar nymphs and

all subsequent life stages are solitary until the adults pair for mating. Future studies investigating the chemical ecology of forest bug are more likely to succeed in discovering and identifying sex pheromones than aggregation pheromones.

Vibration signals for monitoring

Pentatomid bugs communicate using vibrational communication. Both sexes produce vibration signals by contracting the muscles of a 'tymbal-like organ' within the first and second abdominal segments and additional whole-body oscillations.[49,50] Species-specific vibrational pulses are produced,[51] which are transmitted along plant stems[49] and detected by receptor structures in the legs.[52] Such signals are important in mate-finding and courtship behaviours and can potentially be exploited for pest management. It may be possible to produce vibrating traps that mimic the natural signals of the pest and improve attraction for monitoring, or to use continuous release of interference vibrations to mask the natural signals and disrupt pest mating in crops.[53] Forest bug has a well-developed tymbal-like organ[54] and is therefore able to produce vibration signals. However, no research reports could be found relevant to the specific vibration signals produced by forest bug or their exploitation for pest management.

Control strategies

Plant protection products

Current approvals for UK apples and pears include a variety of active ingredients with different modes of action, particularly spirotetramat (Batavia), spinosad (e.g., Tracer), flonicamid (e.g., Mainman), lambda-cyhalothrin (e.g., Markate and Hallmark) and the neonicotinoids acetamiprid (e.g., Gazelle) and thiacloprid (e.g., Calypso). Pyrethrins (Pyrethrum 5 EC) are also currently available, but have a final use date of 31 May 2020. Very few studies have been carried out to investigate the efficacy of control products against forest bug. In a laboratory-based study,[21] groups of second-instar nymphs were placed in Petri dishes with plant food, sprayed directly with control products at their recommended field rates and monitored for survival over the following 2 weeks. Lambda-cyhalothrin and pyrethrins had particularly effective and rapid actions, leading to 100% mortality within 1 day. Thiacloprid and azadirachtin-A were among the less effective treatments tested in this experiment.[21]

These laboratory results are consistent with published field trial data – and with observations made by UK growers. The synthetic pyrethroid lambda-cyhalothrin was reported to give good control of forest bug on pears, whereas thiocloprid gave only moderate control.[15,40] Based on experiences of heavy forest bug infestations in Suffolk pear orchards, growers and agronomists report that Calypso (thiacloprid) applications have had little effect, whereas Hallmark (lambda-cyhalothrin) applied after petal fall has provided very effective control.

Spinosad (Tracer) has also been tested in forest bug field efficacy trials in Belgium and has potential for use against the pest in the UK. Both spinosad and pyrethrum (the latter applied in combination with the synergist piperonylbutoxide, PBO) reduced pest numbers and fruit damage, with repeated applications of each treatment (before and after flowering) giving the best levels of protection.[13] Spinosad was also effective in the laboratory experiment reported by Kehrli and Pasquier.[21] Nymphs exposed to spinosad died more slowly than those treated with lambda-cyhalothrin or pyrethrins, but mortality was above 80% after 5 days and 100% efficacy was achieved after 8 days.[21] While these published studies suggest that spinosad may provide effective control, Suffolk pear growers have tried applying Tracer for forest bug and report disappointing results compared with Hallmark. Products containing a mix of natural pyrethrins have also been tested in field trials and provided significant protection against fruit damage. Applications of Spruzit or Piretro Verde both reduced the proportion of damaged pears at harvest to 18%, compared with 85% of fruit damaged in control plots.[6] In another experiment, Spuzit treatment was followed by reduced forest bug damage to the pear varieties Conference, Alexander Lucas and Williams Christ (37%, 52% and 65% reduction, respectively, compared with damage levels in control plots).[6] Spruzit was found to have highest efficacy when applied on farms with the greatest pest pressure.[6]

Growers and agronomists should check the approvals status before applying plant protection products because these can change.

For pentatomid pests showing pheromone-mediated aggregation behaviour, synthetic pheromones can be combined with control products to develop effective pest management strategies. An 'attract-and-kill' approach has shown some promise for controlling BMSB[55] but, as for the pheromone-based monitoring strategies described above, this is not currently possible for forest bug.

Exclusion netting

Nets can be used within orchards to reduce damage to fruit caused by stink bugs. Although they are expensive to purchase and deploy, using such nets is considered to be a cost-effective control strategy.[56] In nectarine and apple orchards in Italy, nets provided effective exclusion of BMSB: netted plots had reduced fruit damage compared with untreated controls and with plots treated with control products.[56] The exclusion nets in this Italian study were installed at petal fall and removed at the end of harvest. While this approach is effective for reducing colonisation of trees by BMSB, this timing of net installation would not work with forest bug because nymphs are already present on trees before flowering. However, nets might effectively exclude adult forest bugs from trees, if they are put in place in the late summer/early autumn. Effective exclusion of adults, if possible, would keep egg masses at very low levels in orchards and therefore minimise populations of early-instar nymphs and fruit damage in spring. Research is needed to demonstrate the optimal timing of placing such nets for protection from forest bug. Research is also needed to determine whether it is feasible to put nets up after harvest has finished to effectively reduce egg-laying on fruit trees by forest bug females.

Acknowledgements

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