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REVIEW ARTICLE

Arthropod pests of currant and gooseberry crops in the U.K.: their biology, management and future prospects

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Abstract

1 Approximately 10–12 species of *Ribes* plants are cultivated for fruit production, mainly blackcurrants, red- and whitecurrants and gooseberries. These crops are increasingly recognized as rich sources of vitamin C and anthocyanins, with production rising by 24% in Europe subsequent to 1998. To date, research into insect pests of *Ribes* has been fragmented, with little appreciation of how changes in climate and agronomic practices affect biology.

2 We review 12 key pests of currant and gooseberry crops in Northern Europe, with specific emphasis on their biology and current management options. These are blackcurrant leaf curling midge *Dasineura tetensi*, blackcurrant sawfly *Nematus olfaciens*, common gooseberry sawfly *Nematus ribesii*, European permanent currant aphid *Aphis schneideri*, redcurrant blister aphid *Cryptomyzus ribis*, currant–sowthistle aphid *Hyperomyzus lactucae*, European gooseberry aphid *Aphis grossulariae*, woolly vine scale *Pulvinaria vitis*, common green capsid *Lygocoris pabulinus*, winter moth *Operophtera brumata*, clear wing moth *Synanthedon tipuliformis* and blackcurrant gall mite *Cecidophyopsis ribis*.

3 It is anticipated that global climate change could lead to increases in the incidence of some aphids through increased overwintering survival and longer seasonal activity. Moreover, changes in management practices such as increased cropping densities (from 5400 ha^{-1} to 8700 ha^{-1}) and machine harvesting could lead to pest outbreaks through optimal microhabitats and increased susceptibility to pest colonization.

4 Future management options are considered, focusing on integrated pest management approaches, including behaviour-manipulating semiochemicals, predictive models, biocontrol and improved plant resistance through breeding.

Keywords Climate change, integrated pest management, plant breeding, *Ribes glossularia*, *Ribes hirtellum*, *Ribes nigrum*, *Ribes petraeum*, *Ribes sativum*, semiochemicals, soft fruit.

Introduction

Currants and gooseberries belong to the genus *Ribes*, which consists of approximately 150 species distributed predominantly in northern temperate regions (Brennan, 1996). At present, 10–12 *Ribes* species are cultivated for fruit production, the vast majority of which are blackcurrants (*Ribes nigrum* L.), red- and whitecurrants (*Ribes sativum* Syme, *Ribes petraeum* Wulf. and *Ribes rubrum* L.) and gooseberries (*Ribes glossularia* L. and *Ribes hirtellum* Michx.) (Brennan, 2008). *Ribes* is a small but economically high value crop and is increasingly recognized as a rich source of vitamin C and anthocyanins (McDougall *et al*., 2005a, b), both of which are important for human health. In particular, there is growing interest in expanding *Ribes* production to countries and regions that previously did not cultivate *Ribes* crops, such as the U.S.A. (Hummer & Waterworth, 1999). In Europe, which accounts for 99% of *Ribes* cultivation, production has risen by 24% between 1998 and 2007, with Poland being the world's largest producer (FAOSTAT, 2009).

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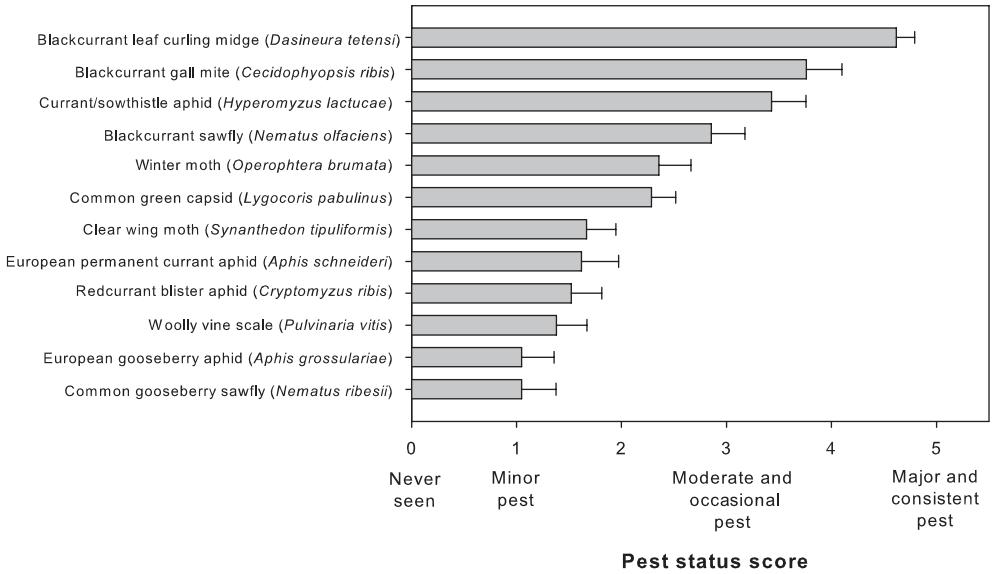

Figure 1 Ranking of *Ribes* pests in terms of pest status from questionnaire responses from major *Ribes* growers in the U.K. Pest scores (mean ± SE) are in the range 0–5 (0 = never observed, 1 = minor pest, 3 = moderate and occasional pest and 5 = major and consistent pest).

Similar to most crops, currants and gooseberries are known to be attacked by a range of insect pests (Alford, 2007). Because *Ribes* is a commercially small crop, however, there has been comparatively little research into such pests, with most of this attention being narrowly focused on one or two species (e.g. blackcurrant leaf curling midge). This is reflected in the literature, with otherwise comprehensive crop entomology textbooks (Blackman & Eastop, 2000) overlooking *Ribes* crops altogether. The scarcity of information about the biology and control of *Ribes* insects could become problematic as *Ribes* cultivation expands, both in terms of production levels and geographic range. Moreover, the potential for many of these insects to reach pest status is exacerbated by the removal of insecticides, either because of increasing consumer demand for residue-free fruit or legislation (e.g. EU Directive 91/414/EEC) that restricts their usage (Gordon, 2008).

The purpose of this review is to synthesize existing knowledge about the key pests of currant and gooseberry crops in the U.K., with specific emphasis on their biology and current management options. Although we focus on the U.K. primarily, much of the information is relevant to the wider area of Northern Europe. It is beyond the scope of this review to cover every insect associated with currant and gooseberry crops because these are summarized in excellent handbooks such as Alford (2007). We focus on 12 of the most serious pests of currant and gooseberry crops and, in addition, identify those which may become more problematic in future. In particular, this review aims to identify future challenges and prospects for sustainable control of pests, and future pests, in commercial currant and gooseberry production.

The pests

Pinpointing which pests cause, or are likely to cause, most damage to currant and gooseberry crops is subjective. Twelve pests in particular were, however, identified using key word searches of research databases (AGRICOLA, BIOSIS, CAB abstracts and Web of Science), questionnaire responses from 21 of the largest commercial growers in the U.K. (Fig. 1) and consultation with representative bodies and researchers in the field. These pests typically cause most concern amongst growers and researchers and represent the substantive majority of research in this area. Survey responses indicated that there were no particular patterns in terms of U.K. geography and particular pests.

Midges and sawflies

Blackcurrant leaf curling midge Dasineura tetensi

The blackcurrant leaf midge *D. tetensi* (Rübsaamen) (Diptera, Cecidomyiidae) was first recorded as a pest in Kent in 1928 (Massee, 1931) and subsequently has spread throughout the U.K., becoming one of the most important pests of blackcurrants (Barnes, 1948). Recently, the incidence and severity of leaf midge has increased in blackcurrant plantations, largely as a result of the withdrawal of control chemicals for blackcurrant gall mite *Cecidophyopsis ribis* Westwood, notably the synthetic pyrethroid fenpropathrin. The replacement control for gall mite consists of sulphur sprays, which do not control leaf midge. The most noticeable stage of this pest is the white larvae, which can turn orange at larger stages and grow to a length of 2.5 mm. The adult is a small (1–2 mm) and short-lived stage with a dark brown to orange body and a paler striped abdomen.

Lifecycle and biology. Midge larvae overwinter in cocoons mostly in the top 0–1 cm of soil (Cross & Crook, 1999) underneath the blackcurrant bush (Fig. 2a). The midges pupate in the spring and emerge as adults, often using the cocoon as an anchor to pull away from the pupal skin (Cross & Crook, 1999).

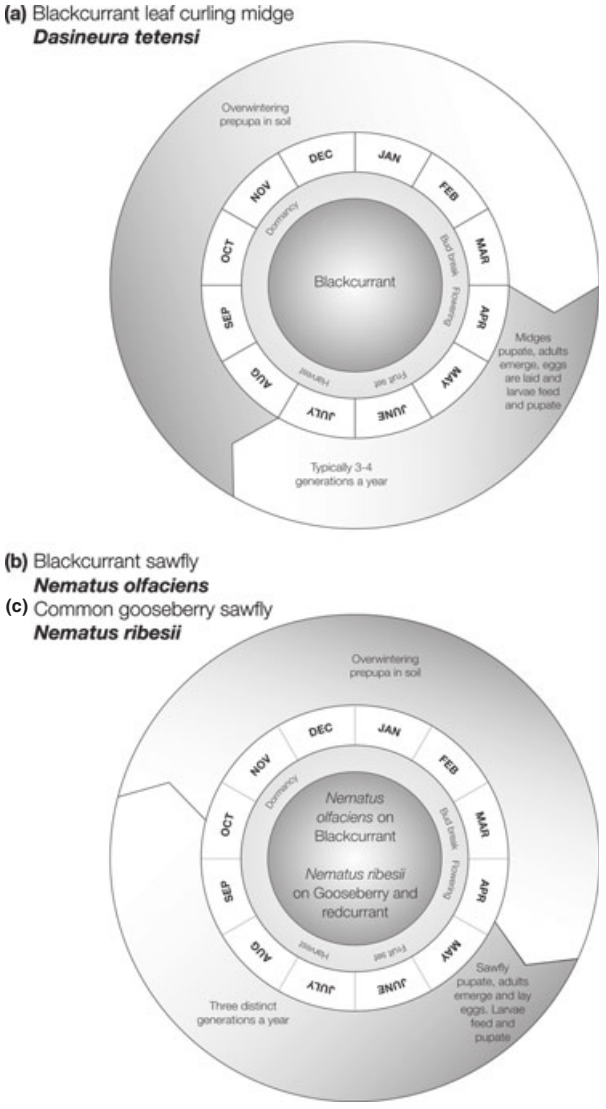

Figure 2 Lifecycles of *Ribes* midge and sawfly pests in the U.K. (a) Blackcurrant midge, the (b) blackcurrant sawfly and (c) the common gooseberry sawfly.

After a very short time, mating occurs and eggs are laid in the folds of young leaves and growing points of young shoots. Usually 4 or 5 eggs are laid per leaf but this can increase to 14 (Greenslade, 1941). After a few days, the eggs hatch and it is the larval feeding on the leaf surface that causes the characteristic symptoms of crinkled and folded leaves that prevents normal expansion of the leaf. Once the larvae are fully fed, they fall to the ground and pupate in cocoons near the soil surface. Development times for eggs, larvae and pupae have been closely studied in the laboratory by Stenseth (1966). At 15 °C, development times were 3.5, 12.4 and 18.4 days, respectively.

Damage. Attacks to the growing shoots (see Appendix, Plate 1a) cause stunting of growth and temporary death of shoots, although the true effect of this pest on yield has not been quantified (Hellqvist, 2005). The midge is most problematic in blackcurrant nurseries where young plants can be so badly damaged that they have to be discarded or completely destroyed if the infestation is severe. The first parts of the plant to show signs of damage are the buds at the base of the plant, which break bud earliest in the season. These parts of the plant are close to the soil and sheltered from the wind (Cross & Crook, 1999). Although the damage is unsightly, control is less important in established bushes that can compensate for damage with extra shoot growth.

Natural enemies. Anthocorid predatory bugs are important predators of blackcurrant leaf midge eggs and larvae (Cross, 2006b). The bugs are often found feeding on eggs in shoot tips and inside leaf galls feeding on larvae. Although large numbers of midge eggs and larvae are consumed, however, the bugs are mainly reactive predators that build up in numbers towards the end of a midge attack and so do not prevent midge outbreaks. The parasitic wasp *Platygaster demades* Walker (Hymenoptera: Platygastridae) is the most important parasitoid of blackcurrant leaf midge (Cross, 2006a). The adult lays its eggs in the eggs of the leaf midge, which hatch when the leaf midge larvae are partially developed. The wasp larva develops inside the mature leaf midge larva and pupa, eventually killing it. Normally, only one wasp egg is laid inside the midge egg but, occasionally, there are two or more. The success of *P. demades* as a parasite of blackcurrant leaf midge is somewhat limited by the parasite's apparent poor synchronization with its host. The parasite also appears to parasitize a number of different midge species, including apple leaf midge *Dasineura mali* (Keiffer) and pear leaf midge *Dasineura pyri* (Bouché) (Cross & Jay, 2001).

Control. In established crops, damage by this pest is relatively unimportant because it does not affect the quality or quantity of the fruit produced. In nurseries, however, infestations can cause unsightly bushes and render cuttings useless. The damage caused by the pest also masks symptoms of the reversion virus (Alford, 2007). Because the midge can go through three to four generations a year, it can be difficult and costly to control (Brennan, 1996). The withdrawal of the synthetic pyrethroid fenpropathrin, which provided good control of leaf midge (Wardlow & Nicholls, 1986), has further exacerbated this problem. Even so, the main method of control still comes from broad spectrum insecticides, which are first applied to coincide with the emergence and oviposition of the first generation of adults. This requires frequent monitoring to optimize the effectiveness of the chemical application (Cross & Crook, 1999) and avoidance of flowering periods when the insecticide adversely affects pollinators. Monitoring can be carried out by visual inspection for the first signs of damage or with a sex pheromone trap (Amarawardana, 2009). Economic thresholds have not yet been determined for the sex pheromone trap but current advice in the U.K. is that an insecticide should be applied a few days after a cumulative catch of 30 midges per trap has accrued at sites with a history of infestation. Currently, synthetic pyrethroids (e.g. bifenthrin, deltamethrin) are the most effective insecticides but several other insecticides, including chlorpyrifos and thiacloprid, give partial control. All these materials are likely

to be harmful to the midge's key natural enemies, including *P. demades* and anthocorid predatory bugs, by analogy with their effects on other similar biocontrol agents (Koppert, 2010).

Differences in susceptibility between blackcurrant species have been shown by Greenslade (1941), Keep (1985) and North (1967). Some genotypes show antibiotic resistance to the midge. This resistance ranges from no gall formation and high larval mortality, to complete gall formation with larvae that survive but develop more slowly (Hellqvist & Larsson, 1998; Hellqvist, 2001). Resistance is controlled by a dominant gene, *Dt*, identified in *Ribes dikuscha* (Keep, 1985). Two strains of the midge have been recorded in Sweden (Hellqvist, 2001): a virulent midge adapted to the resistant host and an avirulent midge that is not. The virulent midge is also found on the susceptible host and appears to perform equally well as the avirulent midge. The virulent strain is dominant despite most of the cultivars grown having a susceptible genotype. These results suggest that it is not possible to rely on the use of resistant cultivars but that other control methods are required. There is also emerging evidence that the limits of geographical range are moving northwards, possibly as a result of warmer winters and a changing climate (Atkinson *et al*., 2005).

Blackcurrant sawfly Nematus olfaciens *and common gooseberry sawfly* Nematus ribesii

The blackcurrant sawfly *N. olfaciens* (Benson) (Hymenoptera, Tenthredinidae) and the common gooseberry sawfly *N. ribesii* (Scopoli) (Hymenoptera, Tenthredinidae) are similar in many respects and so are described together. The adult females are 5–7 mm long and have a black head and thorax, yellow abdomen, blackish antennae, yellow legs and hyaline wings with brown venation. The larvae of the two species can be easily distinguished by the colouring of the head: *N. olfaciens* has a green head, whereas that of *N. ribesii* is shiny black. The larvae can grow up to 20 mm in length and are mainly green in colour (see Appendix, Plate 1b) with the first and the last two segments partly yellow. The larval body becomes arched in a characteristic question mark shape when feeding on the edge of the leaf lamella. Eggs are oval, approximately 1 mm long, and pale green to white in colour.

Lifecycle and biology. Adults emerge from overwintering in soil in late April or May and are particularly active on warm sunny days when they lay sausage-shaped eggs along the veins on the underside of the leaves (Fig. 2b). Throughout May and June, the larvae feed on foliage around the base of bushes, with male and female larvae passing through four or five larval instars, respectively. Once fully developed, the prepupal stage falls to the ground and pupates in the soil after spinning a cocoon. A second generation of adults appears in July and, occasionally, a third generation occurs. The prepupal stage of the final generation overwinters in their cocoons and pupate the next spring.

Damage. The black currant sawfly can attack blackcurrant, redcurrant and gooseberry. The common gooseberry sawfly is a serious pest of gooseberry. Currants (but not blackcurrants) are also attacked. This is a sporadic pest but can be quite damaging if the first generation is not controlled. Larval feeding results in large irregular holes in leaves and disintegrated leaf margins and, in severe cases, larvae can defoliate bushes entirely (see Appendix Plate 1c). If the defoliation occurs near picking then the fruit may be damaged and a severe infestation after picking will stop growth for the year (Anon., 1960). They can also become contaminants in harvested fruit.

Natural enemies. The natural enemy complexes of *N. olfaciens* do not appear to have been characterized, at least in recent (post-1972) literature. The eggs and larvae are likely to be occasional food of a wide range of generalist predators. It is probable that late larvae and pupae in or on the soil are preyed on by carabids and other ground-dwelling predators. Various ichneumonids and some *Trichogramma* spp. are known larval and egg parasitoids of related species respectively (Rahoo & Luff, 1988; Alderete *et al*., 2002) and it is probable that *N. olfaciens* is also subject to such parasitism. In any event, natural enemies do not prevent serious outbreaks of *N. olfaciens* in blackcurrant plantations.

The parasitoid *Trichogramma* sp. is known to parasitize the eggs of *N. ribesii* but attempts to control the pest in Canada using this insect were not successful (Beirne & Kelleher, 1973). Rahoo and Luff (1988) recorded various ichneumonid parasitoids of both the larval and pupal stages, with *Oetophorus naevius* being the most abundant. A parasitic tachinid fly has also been recorded and has been shown to keep the numbers of sawfly low in some years (ADAS, 1983).

Control. No resistance to the blackcurrant sawfly has been found. The use of chemicals is the only known way of controlling the pests but the larvae can be hard to control because of the overlapping generations and the sporadic and rapid nature of attacks. It is usual that more than one spray application is required. Monitoring the crop is very important to catch the first generation to achieve the best possible control.

Differences in the damage caused by the common gooseberry sawfly have been observed in gooseberry progenies, although the basis of these differences (i.e. genetic or planting location) is unclear (Brennan, 1996). The jostaberry, a gooseberry × blackcurrant hybrid, *Ribes nidigrolaria* (Bauer, 1978) is particularly susceptible to the common gooseberry sawfly. A study has identified possible sources of resistance in other *Ribes* (Brennan, 1996) but gooseberry remains susceptible to attack. A sex pheromone that is attractive to this sawfly has been identified (Longhurst & Baker, 1980) but has not, to our knowledge, been used in traps for control.

Two other sawflies can occasionally reach pest status; the pale-spotted gooseberry sawfly *Nematus leucotrochus* (Hartig) and the small gooseberry sawfly *Pristiphora rufipes* (Lepeletier) (Hymenoptera, Tenthredinidae) (Table 1).

Aphids

There are nine species of aphid (Homoptera, Aphididae) that commonly occur on *Ribes*. This review focuses on four species identified as being the most important (Fig. 1); the European

Table 1 Lesser pests that cause sporadic damage in currants and gooseberries

Group	Pest		Crops affected	References
Midges and sawflies	Pale-spotted gooseberry sawfly	*Nematus leucotrochus*	Gooseberry, and currant but not blackcurrant	Alford (1983) and Anon. (2002)
	Small gooseberry sawfly	*Pristiphora rufipes*	Gooseberry and redcurrant; occasionally blackcurrant	Anon. (2002)
Aphids	Currant-lettuce aphid	*Nasonovia ribisnigra*	Gooseberry, occasionally redcurrant	Cross (1984) and Anon. (2002)
	Currant stem aphid	*Rhopalosiphoninus ribesinus*	Currants	Cross (1984)
	European blackcurrant aphid	*Cryptomyzus galeopsidis*	Blackcurrant; occasionally gooseberry and redcurrant	Cross (1984), Guldemond (1990) and Anon. (2002)
	Gooseberry-sowthistle aphid	*Hyperomyzus pallidus*	Gooseberry	Cross (1984), Anon. (2002)
	Currant root aphid	*Eriosoma ulmi*	Currant; gooseberry	Danielsson (1982), Cross (1984) Anon. (2002)
Weevils	Vine weevil	*Otiorhynchus sulcatus*	Gooseberry and currant; blackcurrant is the most susceptible	Alford (1996)
	Clay-coloured weevil	*Otiorhynchus singularis*	Gooseberry and currant	MAFF (1970)
Other arthropods	Two-spotted spider mite	*Tetranychus urticae*	Gooseberry and currant; blackcurrant is the most susceptible	MAFF (1978) and Anon. (2002)

permanent currant aphid *Aphis schneideri* (Börner), the redcurrant blister aphid *Cryptomyzus ribis* (L.), the currant-sowthistle aphid *Hyperomyzus lactucae* (L.) and the European gooseberry aphid *Aphis grossulariae* (Kaltenbach). The other five species are considered to be sporadic pests of *Ribes* with the potential to increase in pest status (Table 1). These are the currant lettuce aphid *Nasonovia ribisnigra* (Mosley), the currant stem aphid *Rhopalosiphoninus ribesinus* (van der Groot), the European blackcurrant aphid *Cryptomyzus galeopsidis* (Kaltenbach), the gooseberry-sowthistle aphid *Hyperomyzus pallidus* (Hille Ris Lambers) and the currant root aphid *Eriosoma ulmi* (L.). Natural enemies and control strategies tend to be common to all *Ribes* aphid species and are therefore considered collectively.

European permanent currant aphid A. schneideri

The European permanent currant aphid, *A. schneideri* (Homoptera, Aphididae) is frequently found on blackcurrant and redcurrant (see Appendix, Plate 1d). The apterous female is 1.2–2.2 mm in size and dark blue to green in colour with a pale waxy coating.

Lifecycle and biology. Eggs hatch in spring and the wingless aphids feed first on the flower trusses and then, as the colony expands, on the tips of young shoots (Fig. 3a). Winged forms are formed in June, allowing migration to other currant hosts. The wingless offspring of these migrants continue to breed until the autumn when sexual forms are produced. This form lays eggs on the shoots, which stay there until the next spring.

Damage. Attacks on young plants can be particularly devastating. The dense colonies of the aphid on the shoot tips cause the characteristic damage of tight bundles of distorted leaves, which all bend down from where the leaf attaches to the petiole. The leaves remain green. This aphid has been reported as a vector of gooseberry vein banding virus (Brennan, 1996).

Redcurrant blister aphid C. ribis

The redcurrant blister aphid, *C. ribis* (Homoptera, Aphididae) (see Appendix, Plate 1e) is a common pest of redcurrant but is becoming more apparent in blackcurrant. The apterous female is 1.2–2.5 mm in size and has a shiny pale yellow to green body. These aphids are covered with capitate hairs and tend to have long and thin siphunculi.

Lifecycle and biology. Eggs laid on the shoots in autumn hatch during the next spring and colonies build in numbers on the underside of leaves (Fig. 3b). Winged forms are produced in the summer that migrate to *Stachys sylvatica* (Hedge Houndwort) and other closely-related species. The aphids migrate back to currant later in the year.

Damage. The aphid feeds on the underside of the leaves and causes a characteristic blistering and distortion of the leaves near the top of the bush. In redcurrants, the blistering is red to purple in colour and in blackcurrant the blisters are yellowish green. Fruit and foliage can also be contaminated with honeydew and blackened by sooty moulds.

Currant/sowthistle aphid H. lactucae

One of the most abundant aphid species found on blackcurrant and occasionally on redcurrants is the currant–sowthistle aphid *H. lactucae* (Homoptera, Aphididae) (see Appendix, Plate 1f) (Brennan, 1996). The apterous females are 2.0–2.7 mm in size and are green in colour with shortened antennae and longer siphunculi that are swollen in the middle with darker tips.

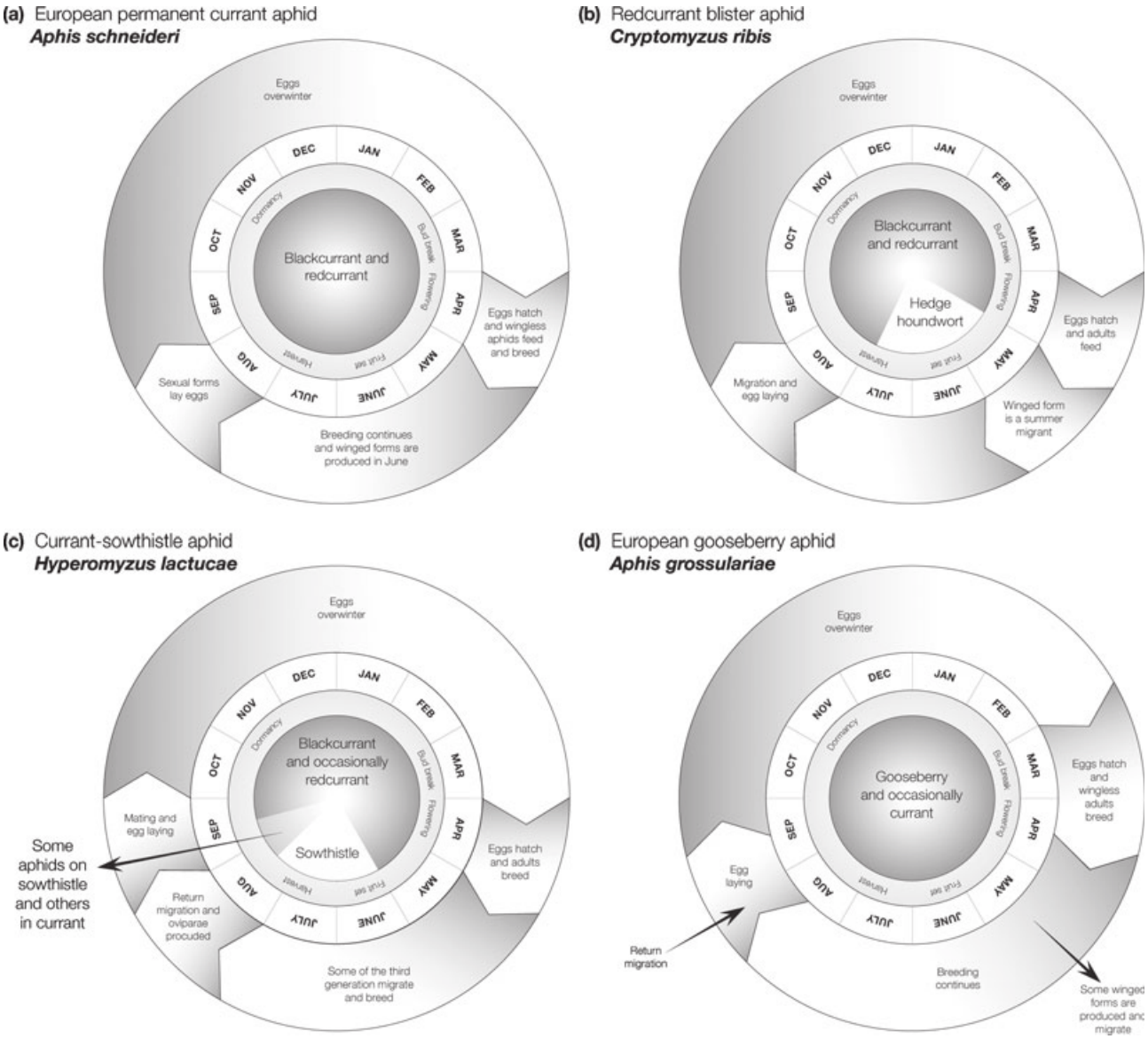

Figure 3 Lifecycles of *Ribes* aphids in the U.K. (a) European permanent aphid, (b) redcurrant blister aphid, (c) currant–sowthistle aphid and (d) European gooseberry aphid.

Lifecycle and biology. The aphids hatch from eggs in March and April and infest nearby buds (Fig. 3c). As the clusters of flower buds unfurl, aphids enter them and remain protected until the late grape stage. By May, the aphids have formed colonies on the shoot tips. Migration to another host is facultative: they may remain on blackcurrant during the summer, especially if they are on young, fast-growing bushes, or they may migrate. The winged aphids of the third generation can migrate to sow-thistle (*Sonchus* spp.) where they breed on the flower heads during the summer months. Other summer hosts include red dead nettle (*Lamium purpureum*) and hemp nettle (*Galeopsis tetrahit*). The females migrate back to currant bushes in the autumn where they produce oviparae that mate with the males returning from the sow-thistle. Eggs are laid in the bud axils.

Damage. Infestations in the spring cause the curling down and yellow mottling of the leaves, particularly on the shoot tips. Shoot growth may also be stunted.

European gooseberry aphid A. grossulariae

The European gooseberry aphid *A. grossulariae* (Homoptera, Aphididae) is present throughout Europe and is a pest of gooseberry and, occasionally, it is present on currant. The females are 1.5–2.2 mm in size and are dark green to greyish-green in colour with a light wax dusting. Siphunculi are typically short in this species.

Lifecycle and biology. Eggs that have overwintered on the shoots hatch in March and early April (Fig. 3d). The first

aphids are wingless and feed on the developing fruit buds. As infestations build up, they spread to the tips of the young shoots. Breeding occurs throughout the summer on gooseberry, although some winged forms are produced and migrate to other summer hosts, such as willowherb (*Epilobium* spp.). These aphids return to gooseberry in the autumn and lay eggs.

Damage. This aphid is a virus vector. Physical damage caused by infestations results in leaf and shoot distortion (see Appendix, Plate 2a). Shoots can be twisted and small with shorter distances between nodes.

Natural enemies of Ribes aphids. A wide range of generalist predators are significant natural enemies of the aphid pests of *Ribes*. These include ladybird adults and larvae, hoverfly larvae, lacewing larvae and anthocorids, as well as other predatory bugs, earwigs and spiders. These can feed voraciously in aphid colonies, sometimes eventually controlling them, although the rate of aphid increase in spring is generally too fast for them to prevent damage. In prolonged periods of mild, wet weather in spring and summer, outbreaks of entomopathogenic fungi (e.g. *Entomophthora planchoniana*) can occur in colonies of currant sowthistle aphid and blackcurrant aphid (Cross & Harris, 2004).

Control of Ribes aphids. It is common grower practice in the U.K. to apply one or more preventive or curative aphicide sprays in the spring, before and/or after blossom. Selective systemic materials are often preferred because they can control aphids inside curled leaves without direct spray interception and they are less harmful to natural enemies. Use of synthetic pyrethroids is discouraged because they are not very effective against aphids and are very harmful to a wide range of natural enemies, and thus are highly disruptive of integrated pest management (Koppert, 2010). To combat this, a single spray of an aphicide in early October can be used to control females on the undersides of leaves before they lay overwintering eggs on the bark. A high degree (>95%) of control of all the most important aphid pests may be achieved at this time, providing that temperatures are adequate for good efficacy (Cross *et al*., 2010). Keep and Briggs (1971) reported different susceptibilities between *Ribes* species and cultivars but, to our knowledge, aphid resistance has not been included in any breeding programmes.

True bugs: scale insects

Woolly vine scale Pulvinaria vitis

Once regarded as a distinct species, *P. ribesiae* (L.) (Hemiptera, Coccidae) has now been reclassified along with *Pulvinaria betulae* (L.) as *Pulvinaria vitis* (Alford, 2007). The wrinkled adult female scale is dark brown, 5–7 mm long and ranging from round to heart-shaped convex shape (see Appendix, Plate 2b). The adult male is only 1.5 mm in length, pink to red in colour and winged. The first-instar nymphs are only 0.5 mm in length, elongated oval in shape and range in colour from brown to dark yellow.

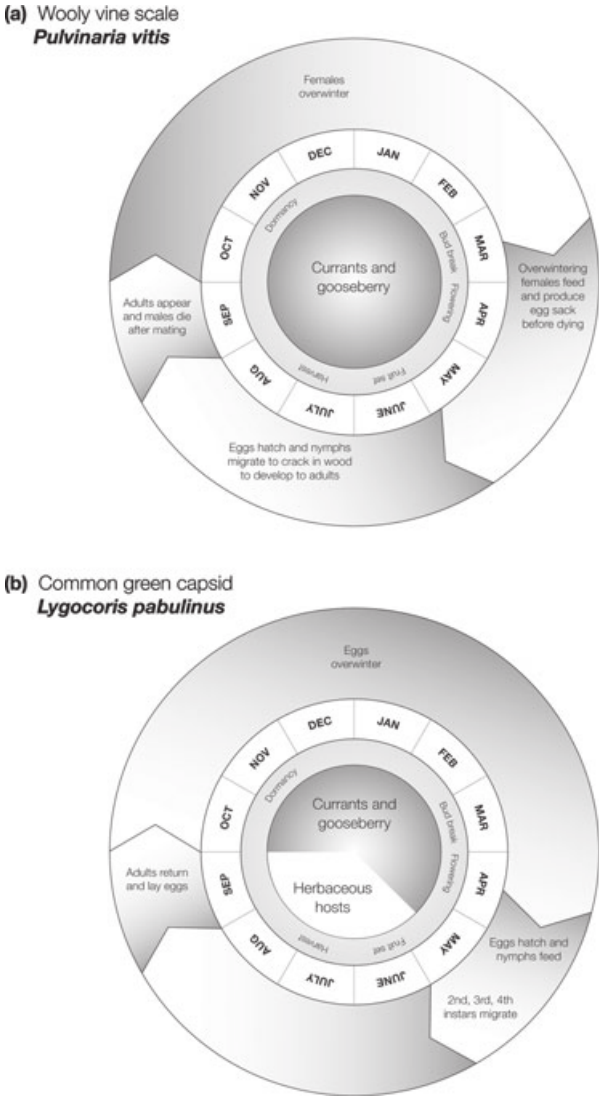

Figure 4 Lifecycles of true bugs on *Ribes* (except aphids) in the U.K. (a) Woolly vine scale bug and (b) common green capsid.

Lifecycle and biology. The adults are observed in the autumn and, after mating, the short-lived males die (Fig. 4a). The females overwinter and start feeding and growing in the early spring. As the females grow, they become convex in shape and darker in colour and eventually their backs harden to form a protective scale. Once fully matured, the female produces a white egg sac containing approximately 1000 eggs. The female dies once egg laying is completed. The egg sac begins to swell pushing up the protective scale. The eggs hatch in late May to June and the first-instar nymphs crawl over the stems and leaves and eventually enter the 1-year-old wood where they go through another two instars before eventually reaching the adult stage in autumn.

Damage. The larvae produce a large quantity of honeydew that can cause sooty moulds to develop. The egg sacs produce woolly secretions that can reduce the harvest quality of the fruit.

In large infestations, they can attack the roots of the plants, weakening them.

Natural enemies. Scale insect populations are host to a complex of natural enemies. The chalcid wasp *Aphytis mytilaspidis* Le Baron (Hymenoptera: Aphelinidae) is a common external parasite of various scale insects. The egg of the parasite, usually one per scale, is laid under the waxy scale, close to the body of the insect. The wasp has two generations per year and can feed on the second nymphal stage as well as on the adult female. Several other species of parasitic wasp also attack scale insects. Natural populations of the parasitic wasps do not, however, constitute a significant or reliable regulatory mechanism (Cross *et al*., 1999a).

Control. Thiacloprid has been found by U.K. growers to be the most effective insecticide of those approved for use (J.V. Cross, unpublished data). Timing is critical, with the best results occurring when sprays are applied in late June or early July when most or all of the eggs have hatched but when a maximum proportion of the populations is at the first instar (early crawler) stage. Some broad spectrum organophosphate and synthetic pyrethroid insecticides approved for use on blackcurrants are partially effective against woolly currant scale, although these have long term harmful effects on natural enemies (Koppert, 2010).

True bugs

Common green capsid Lygocoris pabulinus

The adult capsid *L. pabulinus* (L.) (Hemiptera, Miridae) is up to 6.5 mm in length and is bright green and shiny in appearance. The nymphs are green with developing wings and red tips on the antennae (see Appendix, Plate 2c).

Lifecycle and biology. Eggs, which are laid in the autumn, survive over winter in the bark of first- or second-year woody branches of various hosts, including *Ribes* (Fig. 4b). They hatch over a period of weeks in April and May and the nymphs feed on the young foliage. At second, third or fourth instar, the nymphs migrate to herbaceous hosts where they develop to the adult stage. Only partial migration to herbaceous hosts was observed by Hill (1952), with many second generation nymphs remaining on *Rubus* hosts. It is considered that woody hosts cannot provide an adequate food source for the developing nymphs and this is the reason for their migration to herbaceous hosts (Blommers *et al*., 1997). For example, Wightman (1969) showed that the first generation could develop on blackcurrant, although there was evidence of nymphs older than third instar feeding on herbaceous weeds. The second generation born on the herbaceous hosts develop into adults before returning to the woody hosts in the autumn to lay eggs and eventually die.

Damage. Salivary secretions from nymphs feeding on shoot tips causes brown spots in the unfolding leaves that lead to lesions (Blommers *et al*., 1997), and large infestations can impair shoot growth, resulting in branching (Hill, 1952). The nymphs emerging in the spring feed on shoot tips and flower buds causing malformed fruit.

Natural enemies. Parasitism of capsids varies between host plant and between generations. Solomon (1969) found no parasitized capsids on apple hosts but 25% parasitized by *Leiophron* sp. (Braconidae: Euphorinae) on nearby nettles. Blommers *et al*. (1997) reared *Peristenus laeviventris* (Ruthe) (Braconidae: Euphorinae) from capsids on potato but never observed parasitized individuals in the summer generation. In years when an epizootic of *Entomophthora* sp. is present, it can cause mortality of capsids (Blommers *et al*., 1997). Arnoldi *et al*. (1991) suggested that generalist predators, such as spiders and predatory beetles, are more effective natural enemies of the capsids in fruit crops.

Control. Although several candidate sex pheromone components of *L. pabulinus* have been identified (Drijfhout & Groot, 2001; Groot *et al*., 2001; Drijfhout *et al*., 2003), an attractive lure has not yet been developed. A sex pheromone trap could be used to monitor capsid numbers during the late summer/autumn when they migrate from herbaceous hosts to blackcurrant crops. Capsid bugs are normally controlled in spring, although potentially they could also be controlled in the autumn before egg laying.

Moths

Winter moth Operophtera brumata

Winter moth *O. brumata* (L.) (Lepidoptera, Geometroidae) has many hosts, including currant and gooseberry (Briggs, 1957). The adult females are dark brown mottled and greyish-yellow and 5–6 mm long. Their wings are reduced to black stubs. The adult male forewings are grey to brown in colour with a wingspan of 22–28 mm and the hind wings are brown to white in colour. Eggs (0.5×0.4 mm in size) occur singly in bark crevices. They are oval in shape and are pale yellowish-green when newly laid and then become orange red with a pitted surface. The larvae are light green and can be up to 25 mm in length (see Appendix, Plate 2d). The larvae have several creamy white stripes along the length of the body plus one dark green dorsal stripe.

Lifecycle and biology. Eggs hatch in the early spring coinciding with bud break (Fig. 5a). The caterpillars feed mainly on the foliage but can also feed on the flowers and young fruitlets. Once fully fed, the caterpillars drop to the ground and pupate in the soil. The adults emerge from October onwards, when they mate and lay 100–200 eggs in the crevices in the bark.

Damage. They feed mainly on foliage but can also feed on flowers and young berries, which can cause significant yield loss, although it does not generally affect fruit quality (Alford, 2007).

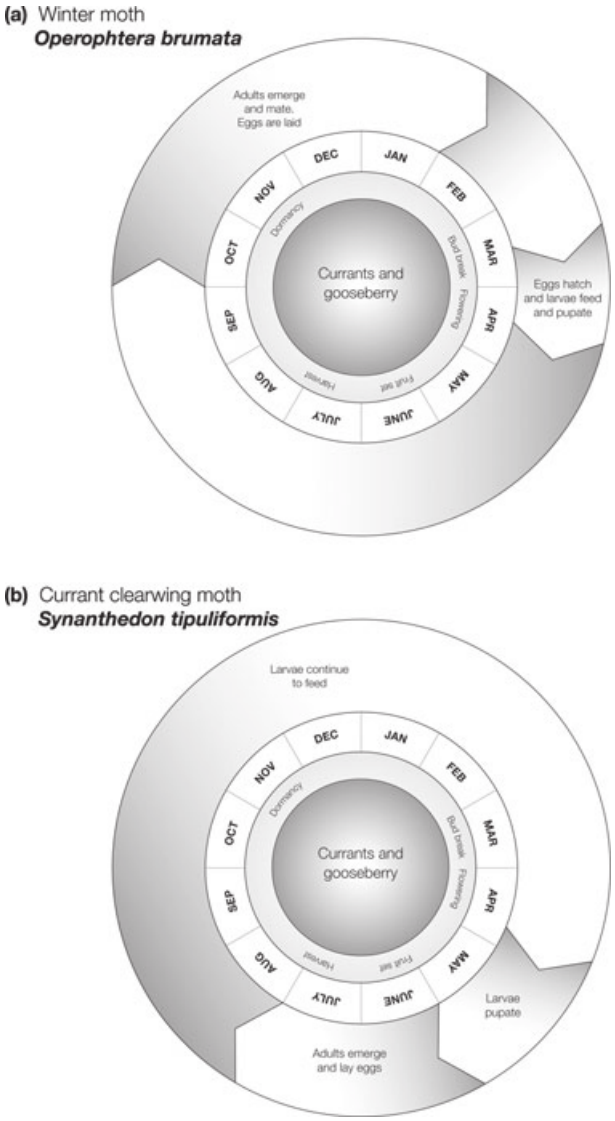

Figure 5 Lifecycles of *Ribes* moths. (a) Winter moth and (b) clear wing moth.

Natural enemies. Insectivorous birds and many species of polyphagous predatory insects feed occasionally on winter moth larvae. Their impact on populations of winter moth larvae in blackcurrant plantations is, however, limited (J.V. Cross, personal observation). Many species of parasitoid attack the larvae or cocoons of the winter moth and these are its most important natural enemies. The tachinid fly *Cyzenis albicans* (Fallén) (Diptera: Tachinidae) is one of the most common (Cross *et al*., 1999a). It lays up to 1000 eggs, which are attached singly to leaves that already have some feeding damage by winter moth larvae. Parasitism rates can be high (30–60%) when the density of winter moth larvae is high, although they are much lower (<5%) in commercial orchards. The ichneumonid parasitic wasp *Agrypon flaveolatum* (Gravenhorst) (Hymenoptera: Ichneumonidae), which attacks winter moth larvae, is another common species that may play a role in reducing populations (Cross *et al*., 1999a). Parasitic wasps are sensitive to broad-spectrum insecticides, which are especially harmful to adults. *Bacillus thuringiensis* (Bt) is a pathogen of winter moth larvae (Zurabova *et al*., 1986) but infections are normally associated with applications of the bacterium as a biological control agent (see section on Control). Nucleopolyhedroviruses and cypoviruses have been recorded from winter moth (Graham *et al*., 2006) but have not yet been exploited for control measures.

Control. Winter moth is a denizen of woodland trees, especially oak. The pest is much less of a problem in crops that are isolated from such woodland and larger hedgerows. Control can also be achieved with sprays of biopesticides or insecticides. One or more sprays of Bt before or just after blossom can control winter moth larvae, providing that temperatures are high enough for the caterpillars to be feeding actively (Hardman & Gaul, 1990). The bacteria, and the crystal toxin produced, have to be ingested so that they can act. The main problem is that caterpillars are often feeding in or amongst the buds or in furled leaves where they are inaccessible to sprays. The bacterium is degraded by heat and ultraviolet light and so is of short persistence. For these reasons, it is probable that more than one spray will be required for a high standard of control. Bt is harmless to bees and may be applied during blossom if necessary (Cross *et al*., 1999b).

Currant clearwing moth Synanthedon tipuliformis

The currant clearwing moth *S. tipuliformis* (Clerck) (Lepidoptera, Sesiidae) is a sporadic pest of currant and gooseberry in the U.K., although it is a serious pest of blackcurrant and redcurrant in New Zealand (Jermyn, 2002). The adults have a bluish-black body with three (females) or four (males) narrow yellow crossbands (see Appendix, Plate 2e). The hindwings are mostly clear with dark brown veins and borders. The forewings are also mostly clear with an orange–brown section. The larvae, which are often called currant borers, can grow to a length of 18 mm. The body is cream in colour with an obvious central blood vessel located dorsally.

Lifecycle and biology. The adults appear from late May to July and are often seen flying in sunny weather and basking on the foliage (Fig. 5b). The females lay their eggs singly on the bark of the plant close to a side shoot or bud. After 10 days, the larvae hatch and immediately bore into the pith of the plant and start to feed. The larva continues to feed right through to winter, slowly moving through the pith to young shoots and older stems. In late April or May, it chews a channel to the surface of the bark but leaves a protective thin layer of rind at the surface. The larva then spins a cocoon and pupates. After several weeks, the pupa breaks through the rind and is visible on the surface of the bark. After emergence of the adult, the characteristic empty pupa remains in the exit hole.

Damage. Apart from the protruding pupa, the bush may not show many signs of attack, although infested shoots may wilt

and fail to develop. These weakened infested shoots with darkened pith can easily break which can make them vulnerable to fungal pathogen attack.

Natural enemies. The effectiveness of parasitoids for controlling clearwing moth populations appears to vary depending on geographical region, with very little parasitism occurring in the southern hemisphere and up to 10% reduction recorded in the northern hemisphere (Scott & Harrison, 1979). Dead pupae have been recorded with infestations of fungi *Beauveria bassiana* and *Cordyceps* sp. (Scott & Harrison, 1979; Hardy, 1982) and a study in Tasmania found three beetles [*Lemidia subaena* Gorham (Cleridae), an unidentified carabid and a lagriid] that were potential natural enemies (Hardy, 1982).

Control. Control of this pest is problematic because the larva feeds internally in the plant (Anon., 2002; Alford, 2007). Pheromone traps that disrupt mating behaviour (Suckling *et al*., 2005) can also be used to monitor moth emergence and therefore provide a useful prediction of the best time to apply insecticides. Differences between blackcurrant cultivars in susceptibility to the currant clearwing moth have been observed (Cone, 1967; Hummer & Sabitov, 2004). These differences in preference have been linked to plant habit and bush wood hardness (Cone, 1967), the degree of cracking of the bark and machine damage (Yakimova, 1968) and variation in the volatiles released from different cultivars (Jermyn, 2002). The identification of such volatiles would perhaps allow breeding programmes to use parent plants with clearwing moth resistance, although, to date, few sources of genetic resistance to clearwing have been utilized by breeders.

Other arthropods

Blackcurrant gall mite C. ribis

Although 11 of the 12 species identified as major pests of *Ribes* are insects, one arachnid (the blackcurrant gall mite) features in this review because it continues to be one of the most damaging pests. Three species of *Cecidophyopsis* colonize cultivated *Ribes* with *C. ribis* (Westwood) (Acari: Eriophyidae) on blackcurrant being the most important and problematic pest. *Cecidophyopsis ribis* is a small mite with four functional legs and a cigar-shaped body that is characteristic of all Eriophyid mites (de Lillo & Duso, 1996). The adult population consists of mostly females and they can reproduce parthenogenetically, laying up to 50 eggs (Cross & Ridout, 2001). Addtionally, *C. ribis* is recognized as the sole vector of blackcurrant reversion virus (BRV) (Jones, 2002), which is the most serious viral disease affecting the crop.

Lifecycle and biology. The lifecycle of the mite has been extensively studied by Massee (1928), Collingwood and Brock (1959), Smith (1960a, 1961) and Taksdal (1967) (Fig. 6). The annual life cycle of the mites consists of two phases: a free living migration phase and a bud confined phase. Mites

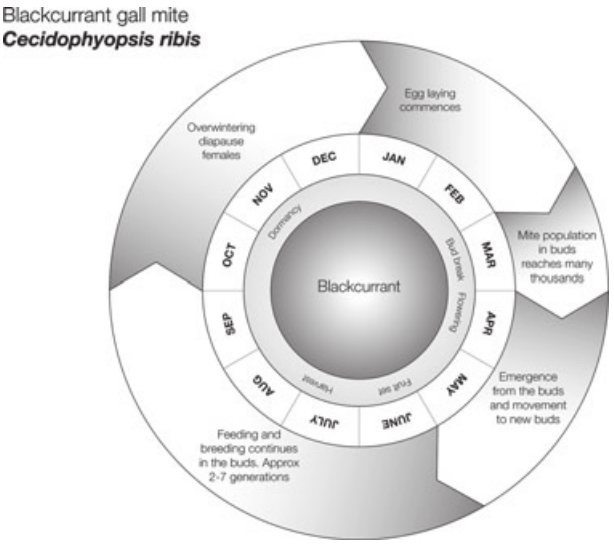

Figure 6 Lifecycle of the blackcurrant gall mite.

overwinter as females in diapause in swollen buds known as 'big buds'. Egg laying by these females commences in January when the temperature rises above 5 °C and the population of mites within the buds reaches a maximum of many thousands by late March. Emergence from these buds starts when the buds begin to dry and open slightly. The timing of this emergence is very much dependent on the development of the host plant and the climate (i.e. temperature) and occurs between early spring and early summer, with emergence being at its greatest during the period of rapid shoot growth and bud formation.

The time that the mite can survive outside the bud is very short (3 days) as a result of desiccation, and it has been estimated that only 1% of mites are successful in penetrating buds (Smith, 1960a, b). There is some uncertainty over what stages are capable of migrating. Smith (1960a, b) states that both nymphs and adults migrate but electron microscopy studies showed that the migrating mites were very similar in size, providing evidence that only adults migrate. During this brief time, the mites crawl towards higher light intensities over short distances in search of new axillary buds where they may aggregate at the base of the petioles and on the leaves before moving inside the bud. Crawling increases with temperature to a maximum of 24 cm/h at 24 °C (Smith, 1960a, b).

Only a small number of mites enter a bud and feed in the green tissue until the next spring. There are two peaks in the number of mites throughout the year, with one occurring in early autumn and a larger one occurring in early spring. Mite migration over longer distances can occur by their use of wind currents or attaching themselves to foraging insects. At temperatures above 10 °C, and when the surface is dry, mites have been observed standing erect on their anal suckers and leaping into the air. Blackcurrant gall mites have been shown to complete between two and seven generations a year (Collingwood & Brock, 1959; Smith, 1961; de Lillo & Duso, 1996).

Damage. The mite infestation causes abnormal and irregular growth of the blackcurrant buds (see Appendix, Plate 2f). The

drying out of these buds in the spring can stop development of the leaves and flowers or can cause leaves to grow malformed. A reduction in yield can not only be a consequence of the damage caused to the buds, but also a result of the transmission of BRV (Jones, 2002).

The virus and the mite are usually found in association and virus infected bushes have been found to be more susceptible to the mite. All instars can acquire the virus after only 3 h of feeding on an infected bush, with an optimum acquisition time at 50 h of feeding. The mite can infect a healthy plant after 48 h of feeding and the mite can retain the virus for up to 25 days (de Lillo & Duso, 1996).

Control. Chemical control of the gall mite is difficult because the mites are inside the galled buds for most of their lives. None of the acaricides available currently in the U.K. have systemic properties and are not able to penetrate the gall to kill the mites inside. It is therefore necessary to protect the new growth during the spring when mites are leaving the galls. Complete protection from mite attack is almost impossible to achieve because the dispersal period of the mites extends over several weeks when the bushes are growing rapidly (Cross & Ridout, 2001). Targeted application of acaricides when the mites are migrating may prevent infestation of new axillary buds and is widely considered to be the best option (Cross & Ridout, 2001). To increase chances of predicting migration and therefore accurately applying acaricides, Cross and Ridout (2001) investigated the emergence of the mites from the buds in spring in relation to meteorological and plant growth conditions. They found that miniature sticky traps were successful in predicting mite emergence, with 5% emergence occurring at the same time each year despite large variation in plant growth stage. This information would help in the development of a predictive model to allow precise timing of acaricide sprays.

Control is currently attempted with two early season sprays of micronized elemental sulphur just before flowering, although sulphur can be phytotoxic to many blackcurrant varieties (Cross, 2006b). The aim is to coat the surface of the plant with a uniform continuous deposit of sulphur. Gall mites emerging from the galls are killed when they pass over the deposit as they walk up the stems seeking new axillary buds to invade. In plantations where gall mite infestation has become established, even at low levels, or where there is a high risk from adjacent neighbouring infested crops, the two early season sprays of sulphur are sometimes supplemented with a spray of tebufenpyrad, applied at or shortly after the peak (= 50%) of gall mite emergence. Unfortunately, tebufenpyrad has a high risk to bees and cannot be applied during flowering (Koppert, 2010).

The breeding of mite resistant cultivars is the only long-term solution to the gall mite problem (Brennan, 1996). The most robust source of resistance is the gene *Ce* derived from gooseberry (Knight *et al*., 1974), which was introduced into commercially acceptable blackcurrant germplasm through the development of resistant allotetraploids followed by a lengthy backcrossing programme (Brennan, 2008). In *Ce*-gene carrying plants the mites cannot penetrate the buds. Another source of resistance comes from *Ribus nigrum* var. *sibiricum*, which is controlled by a single dominant gene, *P* (Anderson, 1971). The mites can infest but not survive in buds of these genotypes with this gene, although they survive long enough to transmit the reversion virus (Jones *et al*., 1998). A newly-released commercial cultivar, 'Ben Finlay', which was bred at the Scottish Crop Research Institute (SCRI), has resistance to gall mite and hence the reversion virus through the *Ce* gene. Recent work to develop a polymerase chain reaction-based molecular marker linked to the *Ce* resistance gene by Brennan *et al*. (2009) now enables breeders to select resistant germplasm at the seedling stage without the need for long-term replicated testing in infestation plots.

Although considered to be much less serious than blackcurrant gall mite, the two-spotted spider mite *Tetranychus urticae* (Koch) (Acari, Tetranychidae) is widely considered as having potential to become a more prevalent pest (Table 1), and the incidence is increasing as a result of the warmer summers experienced by European growers in recent years.

Future challenges and perspectives

Climate change

Predictive models suggest that the climate in Northern Europe is likely to undergo major changes in the next 75–100 years (Meehl *et al*., 2007). In particular, the growing season for currants and gooseberries (March to August) in Northern Europe may be up to 2–4 °C warmer and 50% drier, whereas overwintering conditions are predicted to up to 3 °C warmer and 40% wetter (Meehl *et al*., 2007). To our knowledge, no studies have yet explored how these changes will affect insect pests of *Ribes*, and so predictions are currently difficult to make. It appears, however, very likely that aphids such as *A. schneideri*, *C. ribis* and *H. lactucae* may become more of a problem through enhanced overwintering survival and longer seasonal activity, widely predicted in other species (Harrington *et al*., 1995; Zhou *et al*., 1995). Similarly, aphids, such as *C. galeopsidis*, which are not currently considered a major pest, may become more problematic because of such effects on aphid phenology. Addtionally, the northern limits of distribution for certain pests, notably leaf curling midge, appear to be extending even further north in recent years, probably as a result of warmer conditions (Atkinson *et al*., 2005). Interestingly, predicted increases in atmospheric carbon dioxide concentrations (from ambient levels of 375–700 p.p.m.) were seen to reduce vine weevil *Otiorhynchus sulcatus* abundance by 33% when feeding on blackcurrant (*R. nigrum*) roots (Johnson *et al*., 2011), and so some insects may also become less problematic in currants and gooseberries.

Changes in cultivation and management

The control of insect pests has altered significantly in recent years as pesticides change or disappear and new sources of resistance are identified and deployed by breeders. Changes in agronomic practices can also have significant effects on the incidence of insect pests and their control.

For example, the planting density for blackcurrants in U.K. production has increased from approximately 5400 ha^{-1} in the 1970s (Anon., 1973) to 8700 ha^{-1} (GlaxoSmithKline, personal communication) at the present time, with a reduction in inter-row spacing. This creates a denser canopy that both encourages a high-humidity microclimate and also restricts the penetration of control chemicals. Localized climate change can alter the phenology of pests such as vine weevil (*Otiorhynchus sulcatus*) in raspberry (Johnson *et al*., 2010), so it appears likely that similar patterns could be seen in other bush fruit, such as blackcurrant. In addition, hand-harvesting is still widely used for redcurrants and gooseberries, and almost all U.K. blackcurrants are machine-harvested. This can, in some instances, lead to increased wounding of the bush stems, giving an entry point for pests and pathogens.

In general, blackcurrant growers no longer carry out annual pruning during the winter months as a result of the high cost and also the more upright habit of modern blackcurrant cultivars. Most plantations are now maintained by minimal hedge-type pruning, followed by the flailing-down to ground level during autumn or early spring every 5–7 years. This practice removes infested bushes and thereby sources of further infestation for many pests, although this is in some respects balanced by the availability of new growth in the year after flailing-down, which provides an ideal site for pests such as leaf midge to become established.

Future management options

Devising strategies for managing *Ribes* pests is becoming more urgent as the option of insecticides becomes less available, either because of consumer demand for residue-free fruit or more restrictive legislation concerning their usage (Cross & Easterbrook, 1998; Gordon, 2008). Novel strategies that involve several approaches in an integrated pest management framework appear to be inevitable. There are broadly five approaches that may contribute to any such framework: (i) manipulating behaviour with semiochemicals; (ii) targeting existing control measures using predictive models; (iii) using natural enemies of the pest either by exploiting existing populations or introducing them as a biopesticide; (iv) improved plant resistance through breeding; and (v) cultural control via planting and husbandry.

Semiochemicals (or info-chemicals) are chemicals that modify the behaviour of the pest and can be used for monitoring of pest numbers with baited traps or controlling them directly through mate disruption, lure and kill techniques, and mass trapping (Dent, 1995). These techniques are becoming increasing popular in many areas of agriculture, including currants and gooseberries. For example, mate disruption pheromones for the clearwing moth have been used successfully in Europe (Szocs *et al*., 1991) and other parts of the world (Szocs *et al*., 1998; Suckling *et al*., 2005).

Accurately forecasting the emergence of the pest insect using predictive models that take into consideration meteorological data and plant growth conditions has become a realistic goal for some of the pests of currants and gooseberries. Cross and Ridout (2001) collated emergence data and meteorological data to develop a model to predict when the blackcurrant gall mite would emerge from the overwintering galls. Development rate values of the blackcurrant leaf curling midge were used to construct a computer-based phenological forecasting model to predict the first emergence of the adults in the spring (Cross & Crook, 1999). If developed further, these models would allow a more accurate timing of insecticide sprays.

The use of natural enemies to control pest species has received a great amount of interest (Cortesero *et al*., 2000; Delfosse, 2005; Hajek *et al*., 2007) and has been considered in currant crops (Cross & Easterbrook, 1998). The success of the natural enemy is, however, very dependent on the accurate timing of release and the ability to control the environmental conditions. The open field cultivation methods used for currant and gooseberry means that this strict regulation is not possible and very little effort has been put into using natural enemies to control pests of currants and gooseberries. A better understanding of the fundamental biology of such pests may aid this approach in the future.

From the growers' perspective, plant resistance is the simplest form of pest control. Plant breeders generally try to use morphological (e.g. surface waxes, toughness and pubescence) or biochemical characteristics (e.g. secondary metabolites) for the basis of the plant resistance (Dent, 1995). Reliance on plant resistance alone can be risky in the long term, however, because the rapid reproduction in some insects results in resistance being overcome as they adapt. In raspberry, for example, resistance has broken down relatively quickly to the large raspberry aphid *Amphorophora idaei* (McMenemy *et al*., 2009), which may even be exacerbated by predicted climate change (Martin & Johnson, 2010). Plant resistance is therefore best used in combination with other control strategies. In blackcurrant, a single gene conferring resistance to the blackcurrant gall mite, *Ce* (Knight *et al*., 1974), is used in the breeding programme at SCRI, and resistant cultivars of commercial quality have been developed (Brennan, 2008). The *Ce* gene has shown durability over approximately 40 years and, although the strong expectation is for this to remain the case, the additional pressure on the gall mite pest concerned as the cropping area of *Ce*-containing cultivars increases may conceivably prove problematic in the longer term. As a result, breeding strategies for the identification of alternative sources of resistance are well-advanced.

A single dominant gene, *Dt* (Keep, 1985), has been shown to confer resistance to blackcurrant leaf curling midge through larval antibiosis (Crook *et al*., 2001), and this has been transferred into commercially-acceptable backgrounds. Further work on this strategy is in progress as the incidence of this pest increases.

Control of pests through cultural methods includes the adoption of good plant hygiene, including the growing of only material derived from certified stocks and the careful roguing and disposal of infested bushes for pests such as gall mite. Lengthening the period between crops can reduce the levels of many soil-borne pests (Gordon *et al*., 1993), and their incidence can also be reduced by appropriate pruning of bushes to maintain an open canopy structure and thereby improve penetration of control sprays. Weed occurrence within plantations has generally reduced in recent years with the

deployment of grass strips between cropping rows, and this too can reduce pressure from pests with a wide host range, such as *Tetranychus*, and, at the same time, increase the biodiversity within plantations and provide suitable habitats for beneficial arthropods (Thomas *et al*., 1991).

Conclusions

Interest in growing currant and gooseberry crops is on the increase, yet systematic information about the biology of pests that attack these crops is scarce compared with other soft fruit crops (McMenemy *et al*., 2009). It is likely that these pests will become more problematic as chemical control measures become less available, either through increased consumer demand for residue-free fruit or increasingly stringent legislation (Gordon, 2008). Changes in the global climate (e.g. milder winters) and agronomic practices (e.g. more dense planting) could exacerbate such problems through increased overwintering survival and the creation of optimal microhabitats, respectively. Integrated pest management, involving multiple control strategies, appears to be the best prospect for protecting currant and gooseberry crops. Depending on the pest, these could include manipulating behaviour with semiochemicals, targeting control measures using predictive models, deploying natural enemies of the pest and improving plant resistance with crop breeding programmes. Developing these methods will rely increasingly on a robust understanding of pest biology, together with an appreciation of how this will be affected by future changes in the climate and crop propagation.

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Appendix

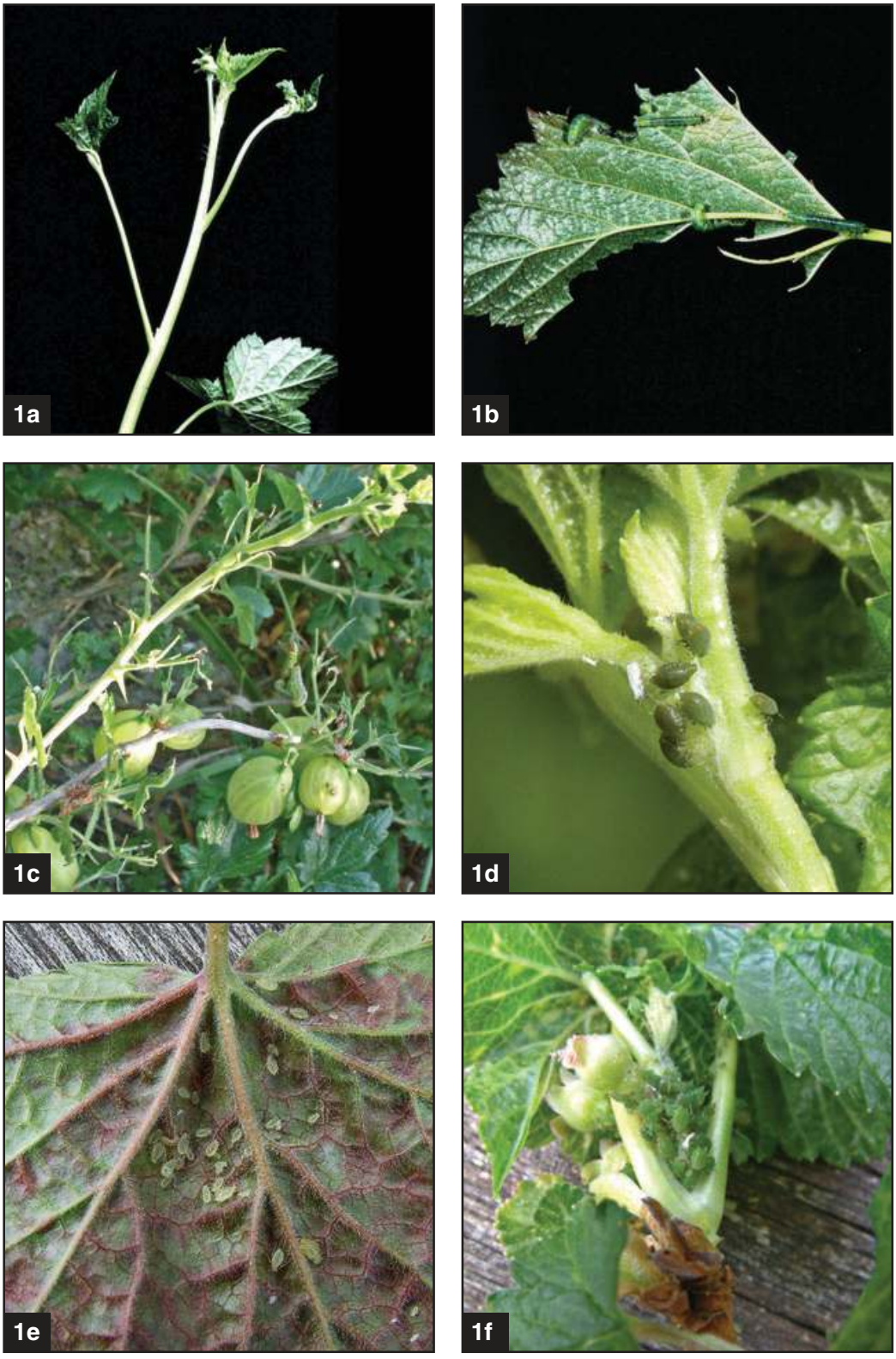

Plate 1 (a) Damage caused by leaf curling midge (*Dasineura tetensi*). (b) Blackcurrant sawfly (*Nematus olfaciens*) and damaged leaves. (c) Common gooseberry sawfly (*Nematus ribesii*) with damaged leaves (d) European permanent currant aphid (*Aphis schneideri*). (e) Redcurrant blister aphid (*Cryptomyzus ribis*). (f) Currant–sowthistle aphid (*Hyperomyzus lactucae*).

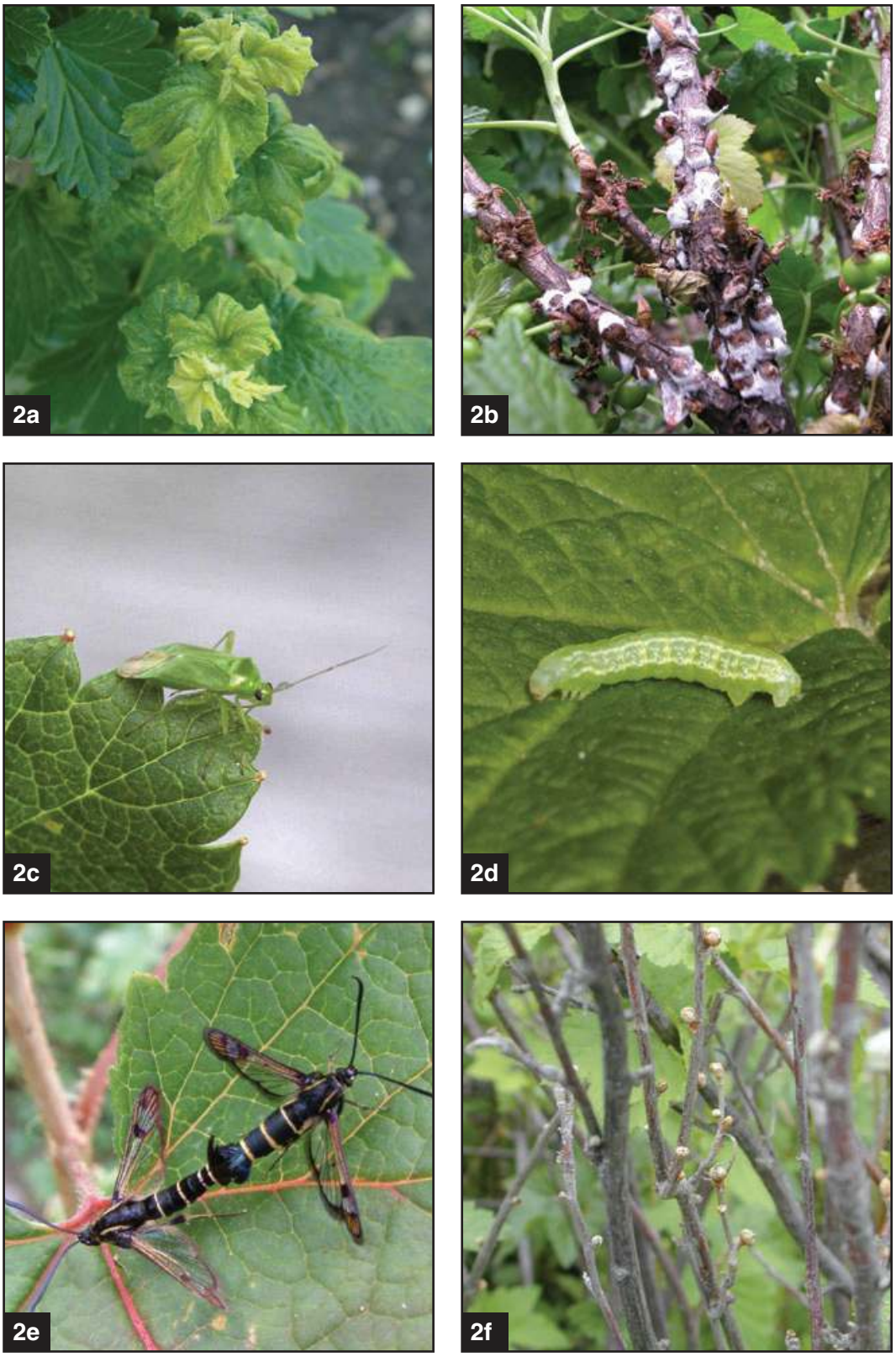

Plate 2 (a) Distorted leaves caused by feeding by the European gooseberry aphid *Aphis grossulariae*. (b) Woolly vine scale *Pulvinaria vitis* with white eggs. (c) Common green capsid *Lygocoris pabulinus* adult. (d) Winter moth *Operophtera brumata* larva. (e) Currant clearwing moth *Synanthedon tipuliformis* adults mating. (f) Galls caused by blackcurrant gall mite *Cecidophysis ribis* in spring.

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