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The tarnished plant bug and strawberry production

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The tarnished plant bug and strawberry production

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PREFACE

This publication is developed from papers previously published or presented at scientific meetings by the contributors and other investigators in recent years. The original papers appeared in different scientific journals but are not always readily available to extension agents as well as growers. This booklet summarizes some of these findings under one cover to help extension agents and growers develop better strategies for managing the tarnished plant bug on strawberries.

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SUMMARY

The strawberry plant has shown considerable genetic adaptability. Worldwide it has been selected and hybridized extensively to suit local needs. Hence, strawberries grow abundantly in hot regions (Mexico) as well as in more temperate regions (Canada). However, once a cultivar has been selected and developed for a specific region, it generally does poorly elsewhere. As a result, researchers have developed many cultivars. Gravity and wind pollination are of chief importance; insects play a secondary role but should be protected.

A key pest of strawberries in eastern Canada is the tarnished plant bug, *Lygus lineolaris* (P. de Beauvois). This polyphagous insect has many hosts—both weeds and economically important plants. When these weeds are disturbed, e.g., by natural drying or by cultivation, the bugs on them migrate into fields of economically important crops including strawberry.

Our knowledge of managing the plant–bug ecosystem is in its infancy, but progress is being made. The abundance of tarnished plant bug nymphs is well synchronized with the phenology of the strawberry plant, and both can be described by temperature-driven models.

The relationship between nymph numbers and strawberry yield in kilograms is sigmoidal. The "damage boundary" is 0.9 nymphs per blossom cluster; beyond that critical level, marketable yield is inversely related to injury. The economic injury level (EIL) is between 0.95 and 0.99 nymphs per blossom cluster. Berries destined for processing can tolerate such a high level of nymphs, but those destined for fresh consumption need a much lower action threshold. An action threshold of 0.26 nymphs per blossom cluster results in no loss in berry weight or quality. However, experience has shown that when control measures are not exercised immediately (because of poor weather conditions), the number of nymphs increases dramatically within a short time, which results in excessive economic losses. Consequently, 0.15 nymphs per blossom cluster is a more pragmatic action threshold.

In our studies, the highest nymphal density during the growing season was 2.5 nymphs per blossom cluster. When nymphs were that numerous, an insecticide applied at an action threshold of 0.15 nymphs per blossom, cluster occurred during bloom in Redcoat and Bounty cultivars. However, this situation was uncommon, and, most of the time, rapid increases occurred after the beginning of petal fall. Therefore, monitoring based on sequential sampling should begin soon after the white bud stage. Control measures should start when the action threshold of 0.15 nymphs per blossom cluster is reached. Nevertheless, individual growers must decide on their acceptable level of crop loss. At 0.15 nymphs per blossom cluster, about 0.2% of the berries would be injured at harvest.

THE STRAWBERRY PLANT

N.J. Bostanian

The modern strawberry, *Fragaria* × *ananassa* Duchesne, is slightly less than 250 years old. This product of the New World was created in Europe in the middle of the 18th century by hybridizing the North American *F. virginiana* Duchesne with the South American *F. chiloensis* (L.). Since then and thanks to systematic hybridizations and selections, the modern strawberry not only has become a delicious dessert fruit but also has exceptional qualities for processing to jams, ice cream, and cake mixes.

Table 1 summarizes strawberry production in several countries. The cultivated strawberry plant adapts well to different environmental conditions. Field and berry quality are affected by the interaction of environmental factors such as temperature, photoperiod, diseases, pests, soil conditions, and fluctuations in air and soil moisture. Although the genus *Fragaria* shows a wide range of regional adaptation, plants of a

Table 1 Strawberry production in selected countries, 1990

Country	Metric tons[a]	Major cultivars
Canada	30429	
Quebec	11386	Kent, Honeoye, Redcoat, Glooscap, Veestar
Ontario	8693	Governor Simcoe, Kent, Veestar, Honeoye, Annapolis
B.C.	5577	Totem, Shuksan, Hood
USA	570300	Chandler, Selva, Pajaro, Commander, Ken Sheehy, Swede, Selva, Dover, Totem, Benton, Shuksan, Honeoye, Kent, Glooscap, Earliglow, Allstar, Raritan, Redchief, Surecrop, Midway, Delite, Cardinal, Apollo[b]
Poland	241284	Senga, Sengana[c]
Japan	215000	Kanto, Chubu, Kyusho[d]
Spain	197950	Chandler, Pajaro[c]
CIS	120000	
Mexico	117000	
Germany	115000	Elvira, Elsanta[c]
Korea Rep.	100000	
Italy	91500	Addie, Dana, Chandler, Pajaro[c]
France	87000	Elsanta[c]
U. Kingdom	55400	Honeoye, Elsanta, Bogota[c]
Yugoslavia	40000	Senga, Sengana[c]
World production	2357756	

a Adapted from Anonymous (1990).
b Adapted from Chandler (1991).
c Adapted from Rosati (1991).
d Adapted from Oda (1991).

particular cultivar may develop satisfactorily in one area but less satisfactorily elsewhere. Nevertheless, the high degree of genetic heterozygosity present in *Fragaria* spp., as well as the dedication and devoted care of generations of strawberry growers, research scientists, and other industry support personnel, are responsible for the present advanced level of production.

Major challenges continue to face the strawberry industry. Progress continues to be made, albeit at a slower pace because many of the easier problems have been resolved in the last 50 years or so. Several challenges remain.

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) is one such challenge. In this bulletin we discuss its biology, dynamics, relation to the development of the strawberry plant, threshold levels, and sampling in strawberry fields in southern Quebec, as well as pollination requirements for the strawberry plant.

STRAWBERRY POLLINATION AND INSECT POLLINATORS OF QUEBEC

C. Vincent and D.D. de Oliveira

Strawberry pollination

Originally the strawberry was a dioecious species (i.e., plants bearing either male or female flowers). However, most modern cultivars (*Fragaria × ananassa* Duchesne) bear hermaphroditic flowers and are self-fertile and typically five-petaled (Darrow 1966). The strawberry bears an aggregate fruit consisting of small fruits (all on a common receptacle) that mature together as a single unit. The receptacle enlarges to form the edible portion. The true fruit of the strawberry are the achenes. If one ovule is not fertilized, the achene remains smaller and nonfunctional. If a group of ovules are not fertilized, this region of the receptacle fails to develop fully and the fruit is misshapen and smaller (Plate I-G). Because stigmas are generally receptive before pollen of the same flower is available, cross-pollination is encouraged (McGregor 1976). Colbert & de Oliveira (1992) showed that berries resulting from cross-pollination of two different cultivars were significantly heavier than berries resulting from pollination within the same cultivar. Cultivars with shorter stamens benefit most from insect pollination (Connor and Martin 1973). This morphological characteristic partly explains the variation in the degree of self-pollination between cultivars (Connor and Martin 1973, Bagnara and Vincent 1988).

Some cultivars attract insect pollinators better than others. In a field study conducted in southwestern Quebec, the cultivar Elvira received twice as many honeybee visits as 'Catskill' (Table 2). Elvira was also the most-visited cultivar by other pollinators.

Pollination studies

Strawberry pollination can be achieved by three distinct but complementary mechanisms, namely, gravity, wind, and insect pollinators.

Gravity Pollination by gravity is responsible for about 72% of fruit weight in 'Midway' (Connor 1972) and 'Redcoat' (Pion et al. 1980) and up to 80% in 'Favourite' (Free 1968).

Wind Pollination by wind is estimated to contribute from 3% (Connor 1972) to 8% (Pion et al. 1980) of the harvest weight; the average degree of pollination was found to be 56% (Connor 1972). Table 3 summarizes the findings of Free (1968), Connor (1972), and Pion et al. (1980).

Insect pollinators Several insect species visit strawberry blossoms (Table 4). In Quebec, at least 45 insect species visited strawberry flowers (Pion 1980, de Oliveira et al. 1991). Between them these species contribute from 20 to 23% to the average fruit weight (Free 1968, Connor 1972, Pion et al. 1980). Little is known about the contribution of each pollinator species. Nye and Anderson (1974) stated that the abundance of a pollinator is a poor measure of their relative importance to strawberry pollination. They proposed a system based on the amount of loose pollen carried on the body of the

Table 2 Frequencies of visits from honey bees and other pollinators on flowers of eight strawberry cultivars

Cultivar	Number of bee visits per flower		Number of other pollinators' visits per flower	
	1984[a]	1985[b]	1984[a]	1985[b]
Catskill	24	42	21	11
Confitura	35	57	31	11
Elvira	74	100	41	14
Gorella	53	68	23	14
Korona	51	92	29	11
Redcoat	47	43	22	11
Scott	35	32	23	11
Veestar	55	46	24	12
LSD (0.05)	14	19	12	8

a Mean for 21 observations × 100; 10 minutes per observation.
b Mean for 8 observations × 100; 10 minutes per observation.
Source: Bagnara and Vincent (1988).

Table 3 Pollination of strawberry: contribution of gravity, wind and insect pollinators

	Quebec, Canada (Pion et al. 1980) Redcoat			England, U.K. (Free 1968) Favourite			Michigan, USA (Connor 1972) Midway		
Conditions	Average fruit weight (g)	% fruit weight*	% poorly pollinated fruit	Average fruit weight (g)	% fruit weight*	% poorly pollinated fruit	Average fruit weight (g)	% fruit weight*	% pollination (achene set)
Gravity + wind (50%[a])	6.1	69	56	6.7	80	48.6	5.4	75	48
Gravity + wind (80%[b])	6.8	77	53	–	–	–	5.9	78	56
Gravity + wind (70%[c]) + bees under cages	–	–	–	8.3	98	20.7	7.7	104	75
Gravity + wind (100% + pollinators (open field situation)	8.8	100	7	8.4	100	15.4	7.4	100	77

* Percentage of average fruit weight in an open field situation.
a, b, c Wind velocity reduced by 50, 20, and 30%, respectively, due to mesh size of cages over plants.
After Vincent, de Oliveira, and Bélanger (1990).

Table 4 Principal Hymenoptera pollinators frequenting strawberry blossoms in Utah, USA and Quebec, Canada (+ present; - absent)

Insects	Utah, USA	Quebec, Canada	
	1970 and 1972 (After Nye & Anderson 1974)	1978 and 1979 (After Pion et al. 1980)	1987
Hymenoptera			
APIDAE			
Apis mellifera L.	+	+	+
Bombus bifarius Cresson	+	-	-
Bombus centralis Cresson	+	-	-
Bombus huntii Greene	+	-	-
Bombus impatiens Cresson	-	+	-
Bombus rufocinctus Cresson	+	-	-
ANDRENIDAE			
Andrena andrenoides Cresson	+	-	-
Andrena carlini Ckff	-	+	+
Andrena crataegi Robertson	+	+	-
Andrena cressonii Robertson	+	-	-
Andrena integra Smith	-	-	+
Andrena melanochroa Cockerell	-	-	+
Andrena miserabilis Cresson	+	-	-
Andrena nasonii Robts	-	+	+
Andrena (Biareolina) neglecta Dours	+	-	-
Andrena nivalis Smith	-	+	+
Andrena regularis Malloch	-	-	+
Andrena salicifloris Cockerell	+	-	-
Andrena sp.	+	-	-
Andrena wheeleri Graen	-	+	-
Nomadopsis scutellaris Fowler	+	-	-
HALICTIDAE			
Agapostemon texanus Cresson	+	-	-
Agapostemon virescens F.	+	-	-
Augochlora pura Say	-	+	-
Augochlorella striata (Provencher)	-	-	+
Dialictus sp.	+	+	+
Evylaeus sp.	+	+	-
Evylaeus sp. #2	+	-	-
Halictus confusus arapahonum Cock.	+	+	-
Halictus confusus confusus Smith	-	-	+
Halictus ligatus Say	+	-	-
Halictus rubicundus Christ	+	+	-
Halictus tripartitus Cockerell	+	-	-
Sphecodes sp.	+	-	-

(continued)

Table 4 (continued)

Insects	Utah, USA	Quebec, Canada	
	1970 and 1972 (After Nye & Anderson 1974)	1978 and 1979 (After Pion et al. 1980)	1987
MEGACHILIDAE			
Anthidium sp.	+	-	-
Hoplitis fulgida Cresson	+	-	-
Hoplitis producta interior Michener	+	-	-
Osmia indeprensa Sandhouse	+	-	-
Osmia juxta Cresson	+	-	-
Osmia kinkaidi Cockerell	+	-	-
Osmia lignaria Say	+	-	-
Osmia nanula Cockerell	+	-	-
Osmia seclusa Sandhouse	+	-	-
Osmia simillima Smith	+	-	-
Osmia spp.	+	-	-
Osmia trevoris Cockerell	+	-	-
Megachile relativa Cresson	+	-	-
Megachile rotundata F.	-	+	-
Diptera			
SYRPHIDAE			
Asemosyrphus polygrammus (Loew)	+	-	-
Chrysogaster bellula Williston	+	-	-
Chrysogaster paroa Shannon	+	-	-
Dasysyrphus venustus (Mg.)	-	-	+
Eristalis anthophorinus (Fallen)	+	-	-
Eristalis arbustorum (L.)	-	-	+
Eristalis barda Say	-	+	-
Eristalis bastardii Macq.	-	-	+
Eristalis brousii Williston	+	-	-
Eristalis latifrons Loew	+	-	-
Eristalis obscura Lw.	-	-	+
Eristalis sp.	+	-	-
Eristalis sp. #2	+	-	-
Eristalis stipator OS.	-	-	+
Eristalis tenax (L.)	+	-	+
Eristalis transversa Wd.	-	+	+
Eumerus strigatus (Fallen)	+	-	-
Eupeodes volucris Osten Sacken	+	-	-
Helophilus fasciatus Walk.	-	-	+
Helophilus latifrons Loew	+	-	+
Helophilus lunulatus Meigen	+	-	-
Helophilus sp.	+	-	-
Helophilus stipatus Walker	+	-	-
Lejops hamatus (Lw.)	-	-	+

(continued)

Table 4 (concluded)

Insects	Utah, USA	Quebec, Canada	
	1970 and 1972 (After Nye & Anderson 1974)	1978 and 1979 (After Pion et al. 1980)	1987
Merodon equestris (F.)	+	-	-
Metasyrphus sp.	-	-	+
Orthonevra pulchella (Will.)	-	-	+
Platycheirus clypeatus (Mg.)	-	-	+
Sericomyia militaris Walk.	-	-	+
Sphaerophoria sp.	+	+	+
Syritta pipiens (L.)	-	-	+
Syrphus ribesii (L.)	-	-	+
Temnostoma alternans Lw.	-	-	-
Xylota flavitibia Bigot	+	-	-
Xylota (Syritta) pipiens (L.)	+	-	-
BOMBYLIIDAE			
Bombylius major L.	-	+	-
Bombylius pygmaeus Fab.	-	+	-
Bombylius sp.	+	-	-
Villa sp.	+	-	-
Villa utahensis Maughan	+	-	-
CALLIPHORIDAE			
Bufolucilia silvarum (Meigen)	+	-	-
Calliphora sp.	+	-	-
Phaenicia sericata (Meigen)	+	-	-
Phormia regina (Meigen)	+	-	-
Pollenia rudis (F.)	+	-	-
TACHINIDAE			
Gonia spp.	+	-	-
Peleteria iterans (Walker)	+	-	-

insect, body size and hairiness, and contact with stamens and stigmas during visits to the flowers.

The honeybee, *Apis mellifera* L., is a major contributor to strawberry pollination (Nye and Anderson 1974). The contribution of honeybees to berry weight as estimated by experiments with cages, ranged from 18 to 26% (Free 1968, Connor 1972). Connor (1972) stated that although 75% of the ovules were fertilized, 20.7% of the berries were malformed.

In a study conducted in southwestern Quebec on the cultivar Veestar, honeybees visited the flowers four times: these visits totaled about 40 s (Chagnon et al. 1989), with the first, second, third, and fourth visits lasting an average of 25, 9, 4, and 4 s, respectively. After landing, the honeybee moved up and down several times in the centre of the flower to reach for the nectar glands located at the base of the receptacle (Chagnon et al. 1993).

In contrast, some syrphids, andrenids, or halictids are simply too small to have contact with most stamens. Furthermore, some species were seen to sit on a petal for several minutes sucking the nectar without contacting either the stigma or the stamens (Vincent, unpublished data).

The number of visits and the quality of visits (duration and contact with floral parts) affect the degree of pollination. In CIS, Skrebtsova (1957) found a positive relationship between the number of visits and the average fruit weight. Flowers of the cultivar Mysovka that were allowed 1, 6–10, and 21–25 bee visits gave fruit weighing an average of 3.2, 4.1, and 8.1 g, respectively. Skrebtsova (1957) estimated that 16–19 visits by honeybees to flowers are required for complete strawberry pollination (100% fruit set). Given that pollen is available for only 3–4 days and that weather conditions are often unpredictable during the bloom period, the use of honeybees complements the action of native pollinators and maximizes the probability of complete pistil fertilization (Chagnon et al. 1993).

Integrating management programs for pollinators and pests

Studies to date have addressed separately the problems of disease, pest management, and strawberry pollination. At present, the application of insecticides is based on the phenology of the plant and, more recently, on economic thresholds for insect pests. The decision to treat does not take into account our knowledge of the beneficial contribution of pollinators. The design of sound, integrated pest management (IPM) programs should therefore maximize yields by favoring the pollinator's contribution, while minimizing losses caused by pests.

As in any biological management effort, there are limits to the use of honeybees for strawberry pollination. First, bees will not forage if the temperature is below 12°C nor if wind speed is high (Seeley 1985). However, in cases of high wind, the contribution of wind to pollination will be relatively higher. Second, although the contribution made by insect pollinators is known for some cultivars, more research is needed to determine how many beehives are needed per hectare. The optimal number depends on the size of the field and the cultivar (McGregor 1976). Third, pesticides applied on strawberries may not only be toxic to pollinators (native or domesticated) but may also interfere with their activity. For example, pyrethroids are known to repel certain pollinator species.

Therefore with some cultivars, such as 'Redcoat', no insecticide should be applied after the 5% bloom stage until the petal fall of secondary flowers. This strategy is compatible with the threshold approach discussed in this bulletin. The ideal program would be the use of thresholds outside a phenological window (starting at 5% bloom of the primary flowers and ending at the petal fall of the secondary flowers). Such programs are currently used in fruit crops that have obligatory cross-pollination requirements such as apple, plum, and peaches. Because stigmas are receptive for only 2–3 days, an insecticide-free window of about 7 days without insecticide sprays would allow sufficient time for the pollination of primary and secondary flowers. Since, pollinators visit strawberry blossoms mainly between 10 A.M. and 3 P.M. (Petkov 1965, Pion 1980), it is preferable to treat after 1800.

Other pest management practices, such as fungicide treatments, may interfere with pollination processes. Thus, fungicides such as captan and thiophanate-methyl, applied to prevent the development of gray mold, *Botrytis cinerea* Fr., affect pollination by reducing pollen germination (Eaton and Chen 1969a, Khanizadeh and Buszard 1987). These authors found that fungicide use led to an increased percentage of fruit malformations but not to a significant reduction in yield. Sprays of captan either just before or just after pollination caused a decrease in achene set (Eaton and Chen 1969b). Little is known about the effect of fungicides on foraging activity of pollinators.

BIOLOGY OF THE TARNISHED PLANT BUG

G. Mailloux and N.J. Bostanian

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), hereafter referred to as TPB is a cosmopolitan pest of a wide range of seed, vegetable, fruit, fiber, and forage crops (see Appendix). According to Young (1986), this insect may live on more than 300 plant species. It is widespread in North America, from Alaska to southern Mexico. Its potential for causing economic losses is often related to the migratory behavior of the adult and the phenology of the host plant.

Depending on the species of the host plant, feeding may cause
- malformation of fruit
- abnormal growth habits
- necrosis
- abscission of fruiting structures
- production of shriveled or embryoless seeds (Tingey and Pillemer 1977).

Life stages

Egg A freshly laid egg is translucent; later it is yellowish. It is oval and slightly curved on one side. One end is obtuse and broadly rounded, whereas the other end is almost squarely truncated. The chorium (hardened egg shell) is smooth. Each is 0.85–1.06 mm long and 0.22–0.28 mm wide (see Plate I-A).

Nymphs The five instars are very similar in form; all are yellowish-green. They walk rapidly and drop readily when disturbed.

First instar The yellowish-green body has a pale orange spot in the middle of the caudal margin of the third abdominal segment. Body length is 0.85–1.10 mm; body width is about 0.40 mm. Width of the head at the eyes is 0.34–0.36 mm (see Plate I-B).

Second instar The body is yellowish to yellowish pea-green. The third abdominal segment exhibits a bright orange–yellow spot with a slightly smaller spot at the posterior margin. Body length is 1.30–1.65 mm; body width is about 0.60 mm. Width of the head at the eyes is 0.45–0.52 mm.

Third instar The body is green. The abdominal gland is indicated by a black spot. Towards the end of this stage, four dark thoracic spots begin to appear. Wing pads also appear and extend on to the second abdominal segment. Body length is 1.7–2.2 mm; body width is about 1 mm. Width of the head at the eyes is 0.58–0.60 mm (see Plate I-C).

Fourth instar Great variation of color exists; green, red, white, and black predominate. The four black thoracic spots are more prominent. The caudal margin of the third abdominal segment bears a large black spot. Two prominent reddish bands appear on each femur. The wing pads extend to the third abdominal segment. Body length is 2.1–2.7 mm; body width is about 1.5 mm. Width of the head at the eyes is 0.78–0.82 mm.

Fifth instar Color is variable, greenish in general. The yellowish head has five longitudinal brownish stripes converging behind but not attaining the posterior margin of the vertex. The thorax and wing pads are yellowish with irregularly marked brown lines. The abdomen is yellowish or greenish yellow. The wing pads extend onto the fifth or sixth abdominal segment.

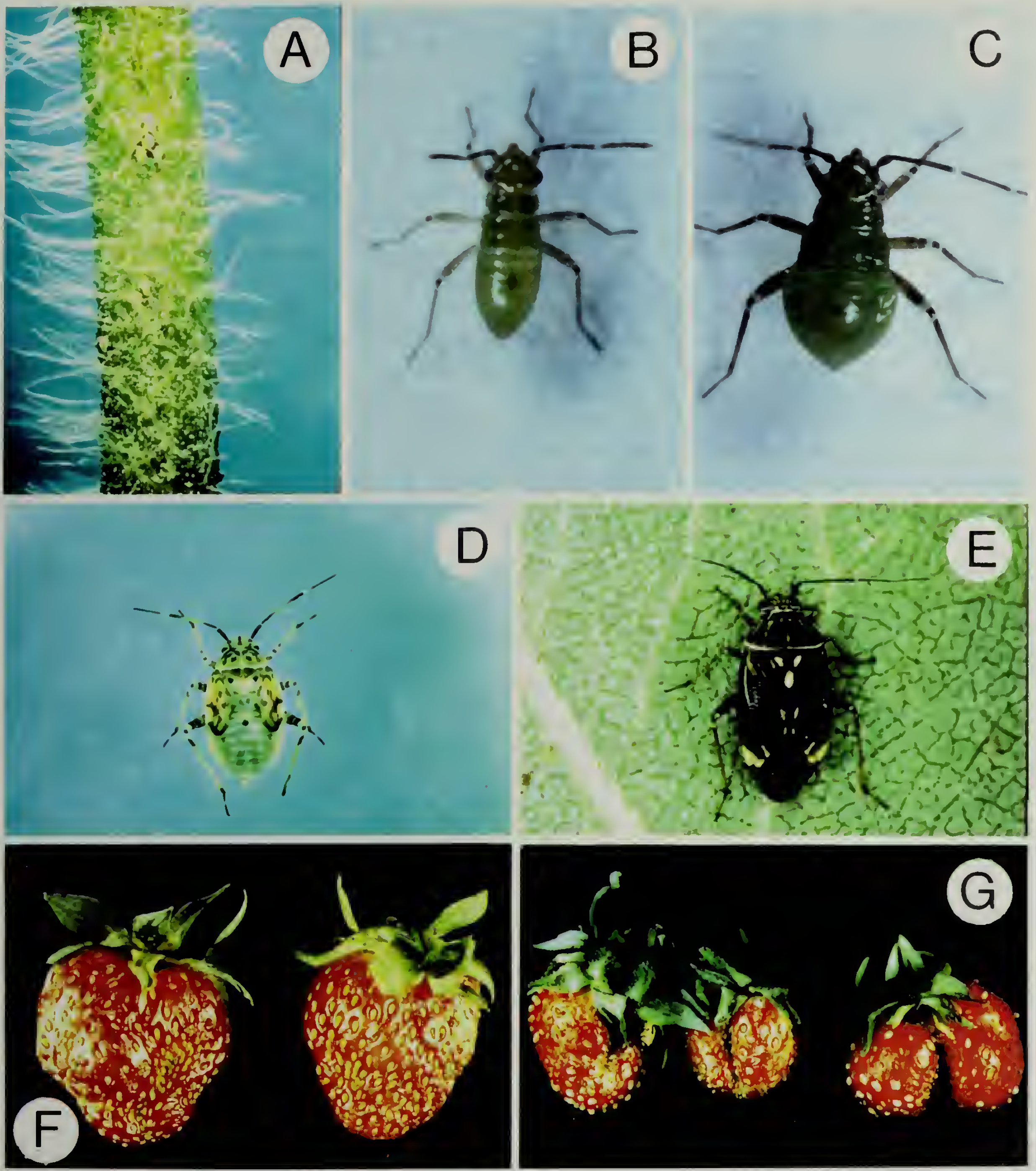

Plate I

A Tarnished plant bug eggs in the pedicel of a young strawberry plant; B First-instar nymph; C Third-instar nymph; note the black spot of the abdominal gland; D Fifth-instar nymph; note the four black spots on the thorax. The wing pads are yellowish with irregularly marked brown lines and extend to the fifth and sixth abdominal segments; E The adult: dark brownish; F Berries showing signs of tarnished plant bug injury; G Berries showing signs of poor pollination (by courtesy of B. Bérancourt).

The veins begin to appear in the pads. Four black spots are conspicuous on the thorax. The dorsal abdominal gland is indicated by a conspicuous black spot on the caudal margin of the third abdominal segment. The legs are variable in color. Body length is 3.2–4.2 mm; body width is about 2 mm. Width of the head at the eyes is 0.94–0.96 mm (see Plate I-D).

Adult The color is very variable; greenish or brownish, with reddish brown markings on the wings. The thorax has five longitudinal dark stripes. The scutellum has two medium and two lateral black or reddish lines. The abdomen is composed of 11 segments, although some of these are considerably modified. The first ventral segment is reduced to an elastic membrane, which joins the abdomen to the thorax. In the female, the seventh segment is named the subgenital plate, as it extends posteriorly in the mid-ventral region to cover the base of the ovipositor. Body length is 4.9–5.7 mm for males and 5.2–6.0 mm for females. Body width is 2.4–2.8 mm for males and 2.4–3.0 mm for females. Furthermore, around the base of the ovipositor on the ventral surface of the abdomen, there is usually a dark brown patch, which may extend to the thorax (see Plate I-E).

Life cycle TPBs overwinter as diapausing adults either beneath plant litter or duff ground cover, or between leaves of plants and long dry grasses.

In piled leaves and rubbish, winter survival is about 29%, whereas in orchard sod it is only 6% (Painter 1929). Overwintering adults start emerging in mid April at temperatures as low as 8°C. These adults feed first on the opening buds of trees such as apple, peach, and shrubs. A little later they migrate to early appearing annual plants. The favorite spring food plants include black currant, *Ribes nigrum* L.; wild currants, *Ribes* spp.; common mullein, *Verbascum thapsus* L.; sheep sorrel, *Rumex acetosella* L.; yellow rocket, *Barbarea vulgaris* R. Br.; and strawberries, *Fragaria* spp.

Overwintering adults gradually disperse on these spring plants as the temperature increases and then migrate to other favorable emerging weeds or cultivated plants. TPBs usually feed on the sap of growing tips or reproductive parts of a plant, such as the buds of flowers or the rapidly growing meristematic tissue of such plants as asparagus, alfalfa, and other forage crops.

TPBs generally migrate to a host only when the plant enters its reproductive growth stage. There is a seasonal succession of hosts as TPBs feed on different plants from spring to fall. Nymphs can disperse long distances (15–20 m) within a short time, and adults can travel at least 5.1 km in sustained flight. Most adults (≈70%) fly no higher than 1 m from the ground, although some adults have been collected at elevations as high as 1500 m. As suitable weed hosts develop, females start to attract males by releasing a sex attractant. The adults mate and the females oviposit in these weeds. Although multiple matings occur, a single mating is sufficient for a female to lay viable eggs throughout her entire life. Overwintering females oviposit from the first week of May to the third week of June (≈50 days). Maximum egg oviposition occurs at the end of May in southern Quebec. Optimal oviposition occurs between 21 and 27°C, and oviposition does not take place below 16°C.

Eggs can sustain low temperatures of 10°C for 15 days without any adverse effect. Eggs are embedded in the stem, in the petioles, or in the midribs of leaves. On strawberries, the eggs are mainly deposited in the pedicel of the flowers (Plate I-A). They may be deposited singly or occasionally in groups of two or three in close proximity. The eggs of the overwintering generation require an incubation period of 18 days (16–22) in southern Quebec.

Following eclosion, the nymphs feed immediately on the succulent parts of the host plant. They molt five times. The first generation in southern Quebec requires 26–47 days to reach maturity. The duration of the first stage is 5–7 days, 4–8 days for the second stage, 5–9 days for the third stage, 4–9 days for the fourth stage, and 8–13 days for the fifth (last) stage. The choice of the host plant dictates significantly the duration of each stage.

The following equation describes nymphal development:

Days of development = $\beta_0 (T - \beta_1)^{-1}$

β_0 = minimal accumulated temperature for development in excess of β_1

β_1 = minimal threshold temperature for development

T = temperature at which observations are carried out.

The estimate of β_0 and β_1 are 111 ± 8°C (SE) and 12.4 ± 0.2°C (SE), respectively.

Following the fifth nymphal stage, the insect metamorphoses into a teneral adult. Laboratory studies, with the temperature fluctuating irregularly between 17–30°C, showed that female longetivity ranged from 31 to 68 days, whereas male longevity ranged from 19 to 41 days.

Adults of the first generation begin to appear about mid June and reach their maximum abundance toward mid July. During this time, TPB adults migrate in great numbers from June bearing strawberries towards other host plants such as those in the following list:

Raspberry (*Rubus* spp.)

Garden bean (*Phaseolus vulgaris* L.)

Potato (*Solanum tuberosum* L.)

Pepper (*Capsicum annuum* L.)

Turnip (*Brassica napus* L.)

Sugar beet (*Beta vulgaris* L.)

Red clover (*Trifolium pratense* L.)

Celery (*Apium graveolens* L.)

Ox-eye daisy (*Chrysanthemum leucanthemum* L.)

Wild mustard (*Sinapsis arvensis* L.)

Black mustard (*Brassica nigra* (L.) Koch)

Brown knapweed (*Centaurea jacea* L.)

St. John's-wort (*Hypericum perforatum* L.)

Redroot pigweed (*Amaranthus retroflexus* L.)

Lamb's-quarters (*Chenopodium album* L.).

This list is by no means complete, nevertheless on most of these plants, eggs laid by these summer adults produce adults 20–25 days later. We note that, for a given area, the seasonal sequential presence of TPBs on wild plant hosts is practically the same year after year. The first-generation TPB adults start mating when they are 4–6 days old. The pre-oviposition period varies between 9 and 13 days, with individual ranges from 5 to 29 days.

The fecundity may reach up to 140 eggs per female with an average oviposition of 0–3.4 eggs per female per day.

In southern Quebec, the second nymphal generation starts about mid July. The population dynamics of the second-generation nymphs are a function of the immigration time of the adults, the oviposition period of each individual, and the nutritive quality of the different host plants. Fig. 1 summarizes the abundance of TPB nymphs and adults on six different weeds in Canada.

As the season progresses, more and more overlapping occurs between the developmental stages and the different generations of TPB. The overlap results in a smooth exponential growth pattern as opposed to a stepwise pattern. From the end of July to the second week of September, all stages of TPB can generally be found in the field.

First-generation adults that emerge from strawberry fields in mid June oviposit on several hosts and lead to a continuous emergence of second-generation summer adults from the beginning to the end of August. These mid-June adults can live as long as 70 days at 24°C. Survivorship in the field is dependent on

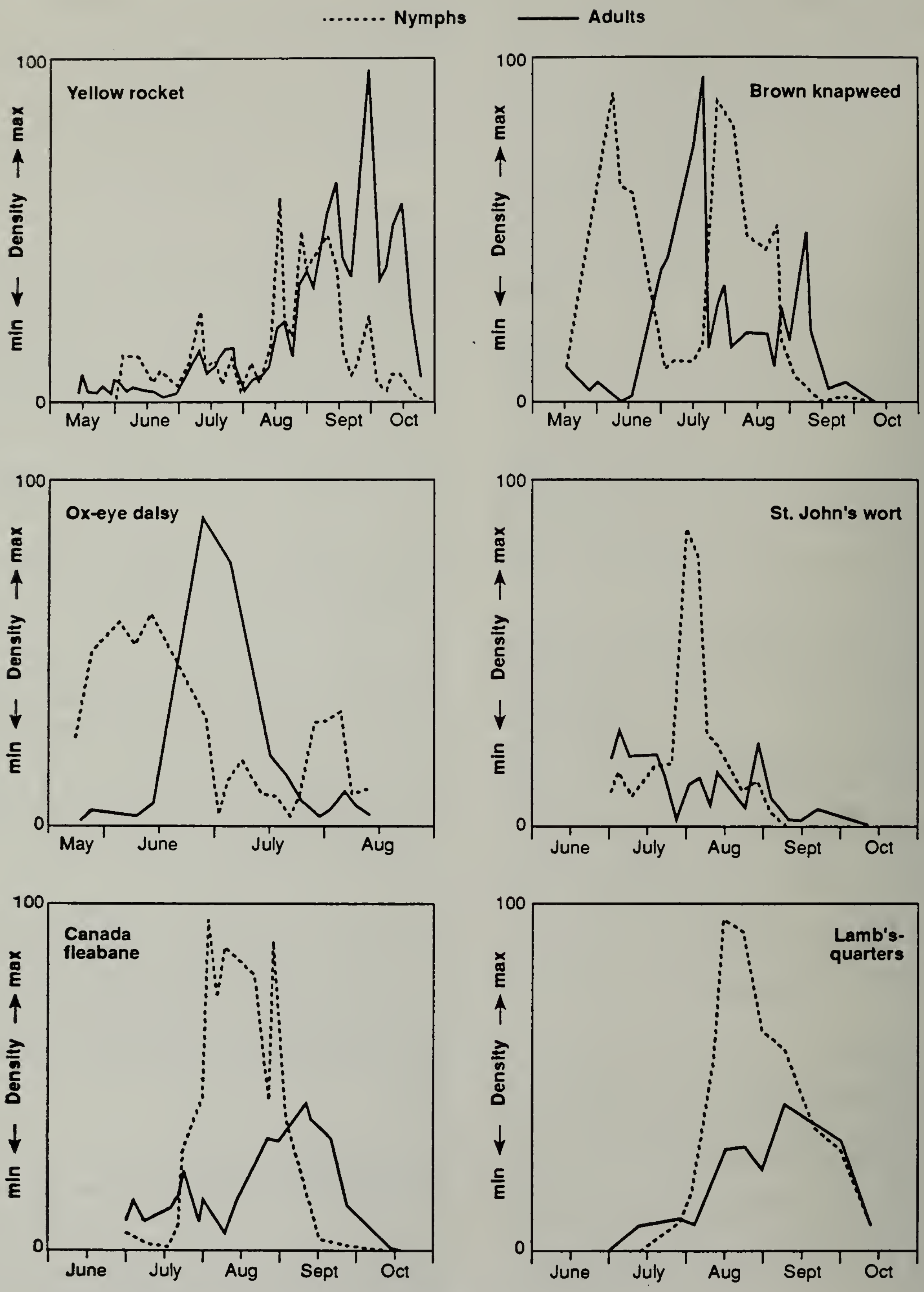

Fig. 1 Seasonal tarnished plant bug abundance on different weeds in Quebec.

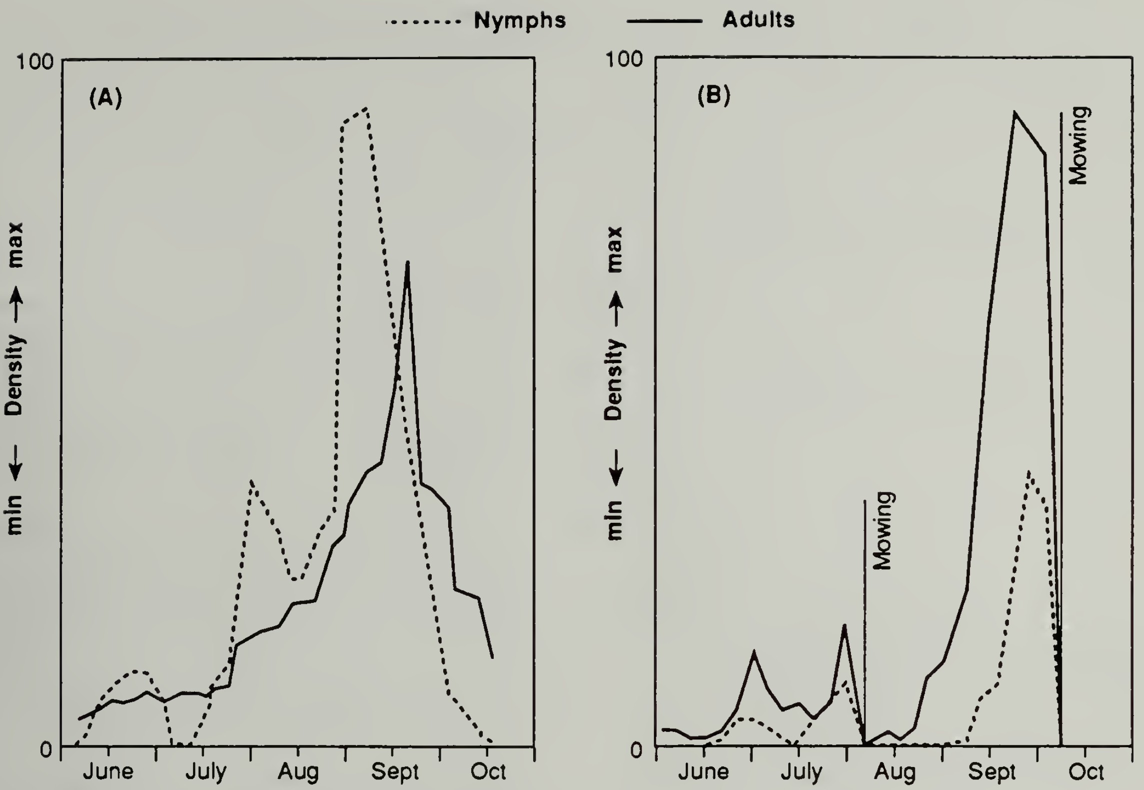

Fig. 2 Seasonal abundance of tarnished plant bug nymphs and adults on alfalfa A) not mowed, B) mowed in early August. (Adapted from Khattat 1978.)

agronomic practices. For example, mowing of alfalfa (compare A to B in Fig. 2) or weed fields could lead to high mortality of eggs and early stages. Late stages walk away to other areas whereas adults fly away within 1 day of mowing. Following mowing, nymphal mortality is a result of lack of food and shelter, low humidity, and high temperatures. Most of the nymphal mortality occurs during the first two stages.

A third generation of nymphs could occur on some cultivated hosts such as alfalfa and asparagus (Fig. 3) and on wild plants such as common ragweed *(Ambrosia artemisiifolia* L.), Canada goldenrod *(Solidago canadensis* L.), rough goldenrod *(Solidago rugosa* Mill.), tall white aster *(Aster simplex* Willd.), stinging nettle *(Urtica dioica* L.), Canada fleabane *(Erigeron canadensis* L.), and red-stemmed aster *(Aster puniceus* L.).

In autumn, the life cycle of TPB requires 25–30 days for completion. It is generally difficult to separate second and third generations of TPB. For example on lamb's-quarters, second- and third-generation adults and larval populations are found on the same plant at the same time. Continuous germination of this weed provides a season-long supply of lush growth and food for TPBs. Hence, the extended vegetative and flowering period of this weed contributes to the build-up of TPBs in adjacent fields.

Despite some variations, the sex ratio is generally 1 : 1 irrespective of the host plant. TPBs are mainly phytophagous, however, they can sometimes feed as facultative predators on soft-bodied arthropods such as aphids and mites (Lindquist and Sorensen 1970, Wheeler 1974), or as scavengers on dead nymphs and adults of their own species (Taksdal 1961).

As fall progresses, TPBs enter adult diapause characterized by atrophy of the ovaries or testes. Exposure of nymphs of the first four stages (the

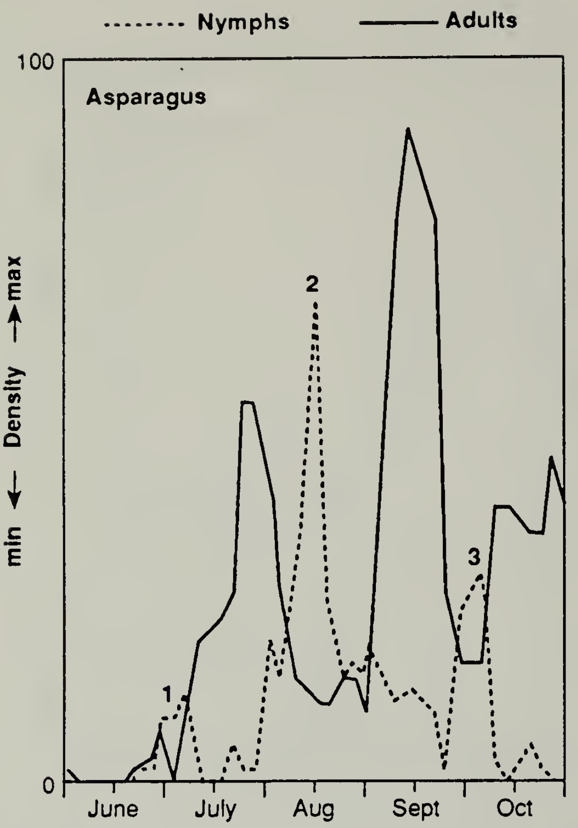

Fig. 3 Seasonal abundance of tarnished plant bug on asparagus; note the three generations (1, 2, and 3) of nymphs on this host plant.

photosensitive stages) to photoperiods of 12.5 h or less induces diapause in the adult stage. Rearing these nymphs to a photoperiod of 13.5 h or more prevents the diapause and the adults will be reproductive. Continuous light prevents diapause in young adults and terminates diapause in diapausing adults. Fifth-instar nymphs and adults are not sensitive to diapause-inducing photoperiods.

Low photoperiod could induce diapause for 75–80 days under laboratory conditions at 21–27°C. In Canada south of 50° latitude, TPB has at least two generations a year with about 70–80% of summer adults not diapausing. Progressively northward, a smaller proportion of summer adults become reproductive. North of latitude 55°3', no summer adults become reproductive in the same year and the species is univoltine (Craig 1983).

Host plant sources and TPB infestations

Under northern field conditions diapausing adults are also subject to late fall temperatures, which induce TPBs to hibernate until the following spring. A partial list of plant species known to be hosts of TPB is presented in the Appendix. Management practices to control TPB in fields must consider plant hosts as reservoirs for the build-up of adults and nymphs in the vicinity of cultivated fields. Taksdal (1961) indicated that TPB is highly polyphagous, feeding on more than 120 plant species representing 30 plant families.

Generally any inflorescent plant could attract TPB, with few exceptions such as dandelions, sowthistle, milkweed, and dogbane, which are all sap latex-type plants. Goldenrod is one of the rare latex-type sap plants, which is very attractive in autumn to field populations of TPB.

Plant hosts range from very attractive to TPB to resistant. Plant resistance to *Lygus* has been reported in some cultivars of celery (MacLeod 1933), alfalfa (Aamodt and Carlson 1938), cotton (Gwynn 1938), beans (Taksdal 1963), and carrots (Scott 1977). Some plants do not seem to interest TPB at all, for example, it has never been reported on wheat, rye, and turf grass.

Although TPB is able to develop on a wide range of hosts, field observations show that some weeds support consistently much higher population densities of TPB than others. Management of selected hosts at particular growth stages over a short time, i.e., before the nymphs of TPB become adults, may result in lowering TPB populations in crop agro-ecosystems. Sites with ephemeral, lush, and *Lygus*-prone growth that dry out quickly provide a release of *Lygus* bugs of immediate concern during the cropping season. For example, management of yellow rocket *(Barbarea vulgaris* R. Br.) would affect TPB populations in early spring cultivated hosts such as strawberry. In uncultivated fields, weeds growing in sequence and acceptable to TPB development usually retain their bug populations throughout the year, without any activity of

Table 5 Known parasitoids of *Lygus* bugs (see text on page 16)

Parasitoid name	Family	Target	Comments
	Indigenous species		
Polynema pratensiphagum Walley	Mymaridae	Egg	72% *Lygus* mortality in Quebec (Sohati et al. 1989)
Anaphes iole Girault	Mymaridae	Egg	
Anaphes ovijentanus Crosby & Leonard	Mymaridae	Egg	50–85% *Lygus* mortality widespread (Day 1987)
Erythmelus miridiphagus Dozier	Mymaridae	Egg	
Telenomus spp.	Scelionidae	Egg	
Peristenus pallipes (Curtis)	Braconidae	Larvae & adults	First generation May–June (Loan 1969); second generation Aug.–Sept. (Loan 1969) combined 15–20% *Lygus* mortality in Quebec (Lim & Stewart 1976); 38% in Ontario (Loan 1965) and 22% in Saskatchewan–Alberta (Loan and Craig 1976)
Alophora opaca (Coquillett)	Tachinidae	Adults	7% *Lygus* mortality in Quebec (Painter 1929)
Alophorella sp.	Tachinidae	Adults	0.8% *Lygus* mortality in Ontario (Clancy & Pierce 1966)
	Imported species		
Peristenus stygicus Loan (USA, Sask., & Alta.)	Braconidae	Larvae	Diapausing race from France and a nondiapausing race from Turkey; polyvoltine (Drea et al. 1973)
Peristenus rubricollis (Thomson) (USA)	Braconidae	Larvae	From Poland; univoltine (Drea et al. 1973)
Peristenus digoneutis Loan (USA, Sask., & Quebec)	Braconidae	Larvae	From France (potato, alfalfa & rye fields); released in alfalfa field in New Jersey 1979–1988; 36% parasitism of first generation and 29% parasitism of second generation (Day et al. 1990); released in seed alfalfa, Saskatchewan, and strawberries, Quebec, in 1991, 1992; bivoltine; population at maximum abundance about same time as TPB populations; attacks early stage nymphs of TPB

dispersion towards the surrounding crop lands, as long as the site is not disturbed or dried up.

Generally, undisturbed sites, such as roadsides and ditch banks, present a minimum hazard for TPB populations. In contrast, instability is created when the weeds along ditch banks, roadsides, and wasteland are disked. In such a situation, many of the weed seeds germinate, the weeds survive and the TPB cycle is repeated. Mowing the weeds is better than destructive tillage. Any management practice directed towards restoring stability in the vegetation of uncultivated land helps TPB management.

Natural enemies

Table 5 summarizes the known parasitoids of TPB. To-date, it seems that natural enemies, other than few species of insect parasitoids, are not capable of checking a TPB population once it begins to build-up to the fullest extent. Nevertheless, endemic populations of *Lygus* bugs are under tremendous environmental pressure that checks their populations. In such instances, natural enemies play an important role. We do not yet have quantitative analyses of the intricate relationships between prey (TPB) and their natural enemies.

In addition to parasitoid Diptera and Hymenoptera, an unidentified species of nematode has been reported to rarely parasitize adults of TPB in Quebec (Painter 1929, Stewart and Khoury 1976). Furthermore, several polyphagous predators are known to prey on *Lygus* bugs. The following is a short list of such predators:

- damsel bugs (*Orius* spp., Anthocoridae)
- leaffooted bugs (Coreidae)
- stink bugs (Pentatomidae)
- lacewings (Chrysopidae)
- solitary wasps (Spheridae)
- robberflies (Asilidae)
- lady beetle larvae (Coccinellidae)
- spiders (Oxyopidae, Tetragnathidae, and Thomisidae).

THRESHOLD LEVELS AND SEQUENTIAL SAMPLING PLANS FOR TARNISHED PLANT BUG ON STRAWBERRIES

N.J. Bostanian and G. Mailloux

Action threshold levels

Before any discussion on thresholds can be made, deformity caused by TPB nymphs should be distinguished from deformity caused by other factors so as to minimize errors. Misshapen strawberries have been referred to in the literature as "catfaced" or "buttoned" (Schaefers 1980). The descriptions may be attributed to several causes.

Unpollinated achenes do not enlarge, therefore areas of the berry with incomplete pollination and fertilization are always associated with small undeveloped achenes (Plate I-G). The achenes are usually greenish and have a hair or two sticking out of them. As the berries mature, unpollinated achenes look collapsed and remain green until the fruit is almost ripe, at which time they turn straw color.

Achenes attacked by TPB nymphs may be small and large; often TPB injury is on the side or top of the berry (Plate I-F). Large achenes, albeit empty ones, close to each other and sometimes in a slightly depressed area suggest TPB attack. Achenes injured by TPB nymphs turn straw color also long before the berries ripen. Finally, a berry may have injuries caused by TPB nymphs as well as poor pollination.

Field studies showed that TPB activity in strawberry fields cause two types of loss at picking. A decrease in yield measured in kilograms per hectare and a loss in quality. The relationship between TPB nymphs and yield loss, shown in Fig. 4, is not linear but sigmoidal, where the strawberry plant tolerates low injury levels (0.9 nymphs flower cluster) without a noticeable reduction in marketable yield. Beyond a critical level (Fig. 4), marketable yield is inversely related to injury. The critical point where the upper plateau curves has been called "threshold level," "carrying capacity," "tolerance

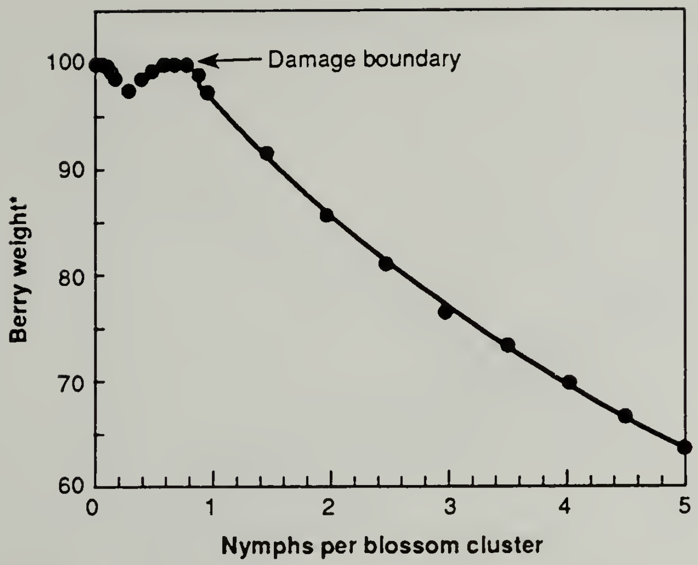

Fig. 4 Relationship between numbers of tarnished plant bug nymphs per blossom cluster and strawberry weight. Smoothed berry weight values (•) and predicted values (——) shown by the curve.

* *The berry weight was standardized by dividing the total weight from each plot by the mean weight of the noninfested check replicates and multiplying the quotient by 100. (Adapted from Bostanian and Mailloux 1990.)*

limit," "damage threshold," and "damage boundary."

Based strictly on decrease in yield and the cost of protection, the economic injury level (EIL), defined as the minimal population density of pest that will cause economic damage, is between 0.95 and 0.99 TBP nymphs per blossom cluster. As soon as the density of TPB nymphs is above this threshold, then economic losses will occur. However, the EIL is based on weight and the cost of protection; if we take berry quality into consideration, then at that threshold we have 13% injured berries. For the processing industry, where berry quality is not important, such a high level of injured berries may be tolerated. On the other hand, 13% injured strawberries are unacceptable for strawberries destined for the fresh market. Therefore, a much lower injury level should be established. Examination of Fig. 5 shows that at zero nymphs per blossom cluster, the upper limit of injured fruit was calculated to be 4.4% and the lower limit 0.3%. However, the upper limit of injured fruit at zero density also corresponds to the lower injury limit of 0.26 TPB nymphs per blossom cluster. Thus, the 95% confidence band of injured fruit between 0 and 0.26 TPB nymphs per blossom cluster overlaps, and a 5% significant difference cannot be distinguished between these two density levels with respect to the injury they may cause to the berries (Fig. 5). Therefore, a significant proportion of injured berries will be observed above 0.26 TPB nymphs per blossom cluster, and control measures should then be exercised. At 0.26 TPB nymphs per blossom cluster, about 3.6% of the berries would show signs of injury above the intercept value at harvest. This level of injury would not be recognized easily by consumers, and berries would be sold in the fresh market without being down-graded during inspection.

Therefore, as there is no loss in berry weight and no appreciable reduction in berry quality, then 0.26 TPB nymphs per blossom cluster is an appropriate action threshold (AT) at which to initiate control measures. However, experience has shown that if control measures are not exercised immediately (because of poor weather

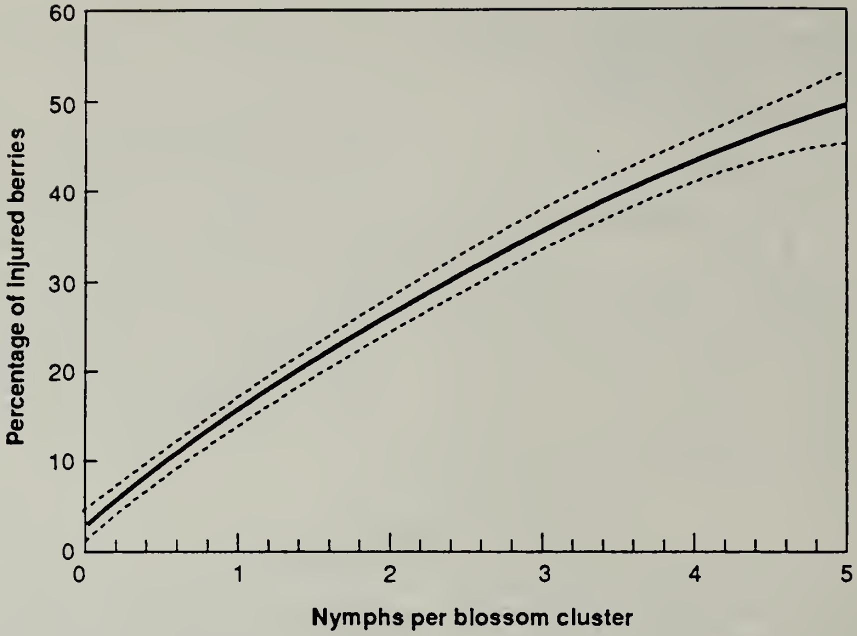

Fig. 5 Relationship between the density of tarnished plant bug nymphs per blossom cluster and percentage of injured berries (adjusted values). The dotted curves represent the upper and lower 95% confidence limits. (By courtesy of Bostanian and Mailloux 1990.)

conditions) nymph numbers may increase within a very short time and cause unaceptable levels of injury. Therefore, a more pragmatic approach would be to use an AT of 0.15 TPB nymphs per blossom cluster. Such an approach permits growers to plan their control measures and take appropriate action before 0.26 TPB nymphs per blossom cluster is attained.

Nevertheless, in the final analysis, acceptable levels of crop losses remain the individual growers' choice and at 0.15 nymphs per blossom cluster, 2% of the berries will be injured at harvest.

Sequential sampling

The traditional way to monitor TPB nymphs is by tapping 100 blossom clusters twice in a 2-L plastic container. The 100 clusters are sampled by walking a "W" pattern across the field and randomly selecting a blossom cluster every 30 paces. Following this sampling, the number of displaced nymphs in the 2-L container is recorded, and the average number of nymphs per blossom cluster is calculated. Then this average is compared with the AT = 0.15 nymphs per blossom cluster. If it has reached the AT, control measures are initiated immediately. If it is below the AT, then the sampling procedure is repeated within 48 hours. No samples are collected from the edges and all sampling is preferably carried out on sunny days between 10 A.M. and 2 P.M.

A short cut to this procedure is to use a bionomial or presence-absence sequential sampling program. The same sampling technique (tapping and walking a "W" pattern) is used except fewer samples are collected. After examining five samples (blossom clusters), the counts are tallied, and the cumulative number of infested clusters is recorded and plotted on the graph (Fig. 6). The sampling procedure is repeated until the points fall outside the sampling band. The same conclusion can be reached by using Table 6.

According to the average sample number curve (Mailloux and Bostanian 1989), a decision would be reached before 50 blossom clusters are

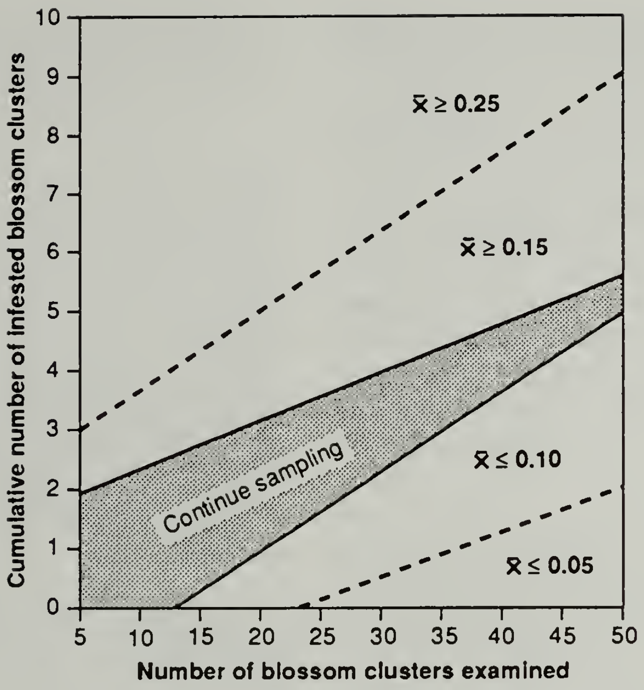

Fig. 6 Sequential decision lines relating cumulative number of TPB-infested blossom clusters to the number of sampled blossom clusters. (By courtesy of Bostanian and Mailloux 1990.)

Table 6 Sequential sampling form for field use in classifying infestation levels of the tarnished plant bug, *Lygus lineolaris*, in strawberry plantations

	Cumulative number of infested blossom clusters		
	Do not treat	Treat	
		Low threshold	High threshold
Number of clusters examined	$\bar{x} \leq 0.10$ nymphs per cluster $\alpha = 0.10$ $\beta = 0.15$	$\bar{x} \geq 0.15$ nymphs per cluster $\alpha = 0.15$ $\beta = 0.10$	$\bar{x} \geq 0.25$ nymphs per cluster $\alpha = 0.10$ $\beta = 0.15$
5	ND	2	3
10	ND	3	4
15	0	3	5
20	0	4	5
25	1	4	6
30	2	4	7
35	3	5	7
40	3	5	8
45	4	6	9
50	5	6	9

ND = No decision.
Source: Mailloux and Bostanian (1989).

examined. If after the examination of 50 samples, no decision can be made, the investigator would make a management decision by using the mid point between the computed decisions line limits as a reference point. Thus with an AT of 0.25 nymphs per blossom cluster, if the cumulative number of blossom clusters infested were eight or more, the strawberry field would be treated; if it were seven or less, then the field would not be treated and it would be inspected again 2 or 3 days later. Since the development of this plan, experience has shown that an average of only 15 blossom clusters were required to reach a conclusion.

A comparative study between sequential sampling and the traditional sampling showed that 88% of the time sequential sampling gave the same results as traditional sampling.

POPULATION DYNAMICS OF THE TARNISHED PLANT BUG

N.J. Bostanian, M. Binns, and G. Mailloux

Insect population dynamics along with infestation/yield loss relationships and the economics of insect pest management are the corner stones for integrated pest management (IPM) programs and or the proper use of chemical insecticides. These programs are the means by which an insect is judged a pest, they are the ultimate criterion by which the efficacy of control measures is assessed, and they are the basis for decision making in management programs. Here we discuss the dynamics of TPB in strawberries.

Overwintering adults migrate into strawberry fields during the last 2 weeks of May. By the 2nd week of June, the adults virtually disappear and

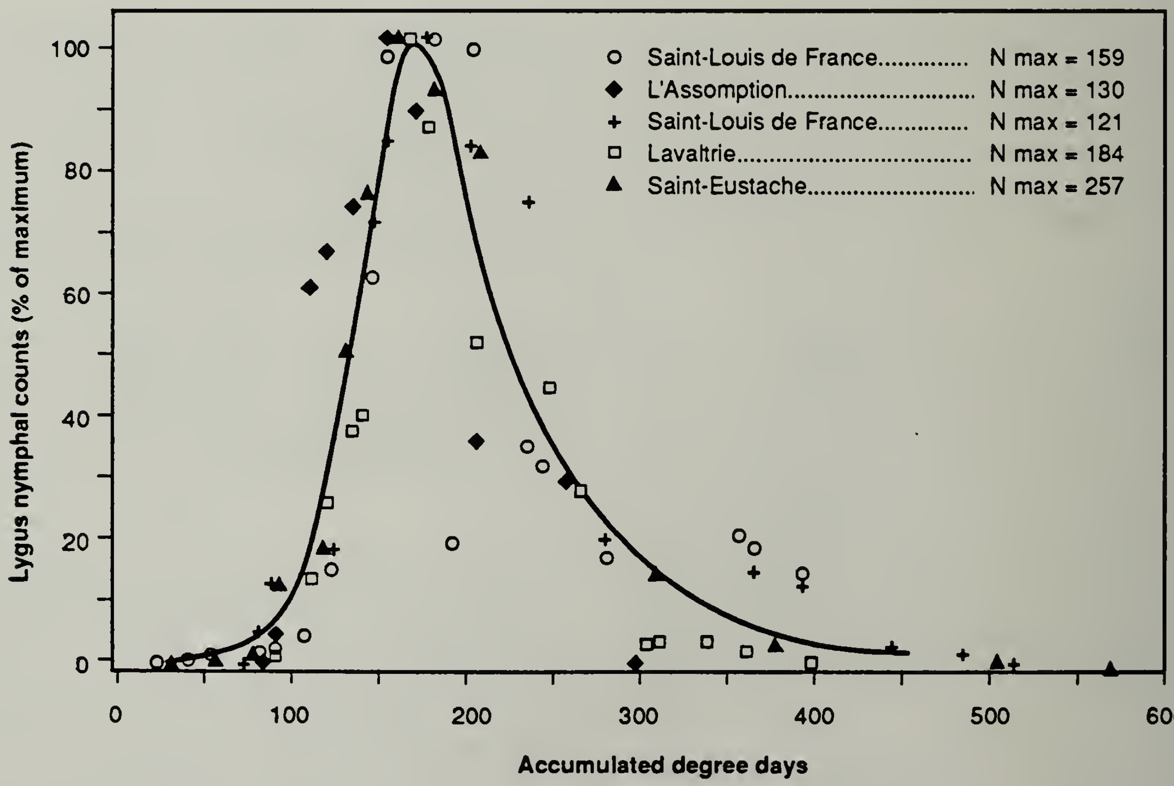

Fig. 7 Lygus abundance data transformed to percentages for five locations in 1985 and overall fitted model, using a lower threshold temperature of 12.4°C. (By courtesy of Bostanian et al. 1990.)

most of the TPB population are young nymphs. These nymphs feed on strawberry buds and, depending on their density, cause slight to severe injury to the berries.

Extensive field observations showed pronounced differences in calendar days for the appearance and build-up of TPB nymphs in different localities across Quebec (Bostanian et al. 1990). However, when calendar days were substituted by degree-days (DD), a pattern was obtained (Fig. 7). Degree-days were calculated from April 1 according to Baskerville and Emin (1969), and the lower and upper thresholds of development were set at 12.4 and 33°C, respectively, (Roberts 1982).

The abundance curve (Fig. 7) was obtained by fitting nymphal counts and DD to the following equation:

$$\text{TPB abundance} = \frac{1}{c_1 + \exp[-(a_2 - DD)/b_2] + \exp[(a_3 - DD)/b_3]} \qquad (1)$$

The value of the parameter c_1 estimated by nonlinear least squares was 2.4×10^{-3} and for practical purposes, it can be ignored. When $c_1 = 0$ then $a_2 = 468.6$, $b_2 = 60.7$, $a_3 = 55.5$, and $b_3 = 19.6$. Closer scrutiny of the curve (Fig. 7) indicates that TPB nymphs make their first appearance on strawberries when 40 DD (threshold of development = 12.4°C) have been accumulated from April 1 and maximum abundance occurs at 173 DD.

The study (Bostanian et al. 1990) also showed that the highest nymphal density per blossom cluster was 2.5 nymphs. However, 2.5 nymphs per blossom cluster was a rarity and it corresponded about to 6% of the maximum relative TPB abundance. On the other hand, 0.4 nymphs per blossom cluster was more common, which corresponded to 38% of the maximum relative TPB abundance.

PHENOLOGICAL DEVELOPMENT OF THE STRAWBERRY PLANT AND ITS RELATION TO THE POPULATION DYNAMICS OF THE TARNISHED PLANT BUG

N.J. Bostanian and G. Mailloux

The effect of temperature on plant development is easily recognized in the field and permits the scheduling of agronomic activities. This section describes a temperature-based phenological model for the strawberry plant and its relation to TPB dynamics.

Plate II shows that the continuum of plant development can, for practical purposes, be divided into nine phenological stages (phenophase), each assigned a number. The vegetative phenophase (stage 1) is characterized by leaf formation, whereas the reproductive phenophases (2–7.5) are identified by bud, flower, and fruit development. A unit difference between each stage is used except the first ripe fruit because that stage is nearer to the first pick than the previous stage 6. The legend of Plate II describes each stage.

Any developmental stage of the strawberry plant can be estimated according to the following equation:

$$\text{Dev. stage} = 9.090 \exp[-\exp(1.620 - 0.0039\, DD)] \quad (2)$$

DD, which represents accumulated degree-days, can be calculated according to Arnold's (1960) equation as follows (the threshold of development (TD) for strawberries is 0°C):

$$DD = \frac{\text{max. temp°C} + \text{min. temp°C}}{2} - TD$$

The Table 7 summarizes the relationship between the nine phenological stages of the strawberry cultivars Redcoat, Bounty, and cumulative degree-days calculated from April 1.

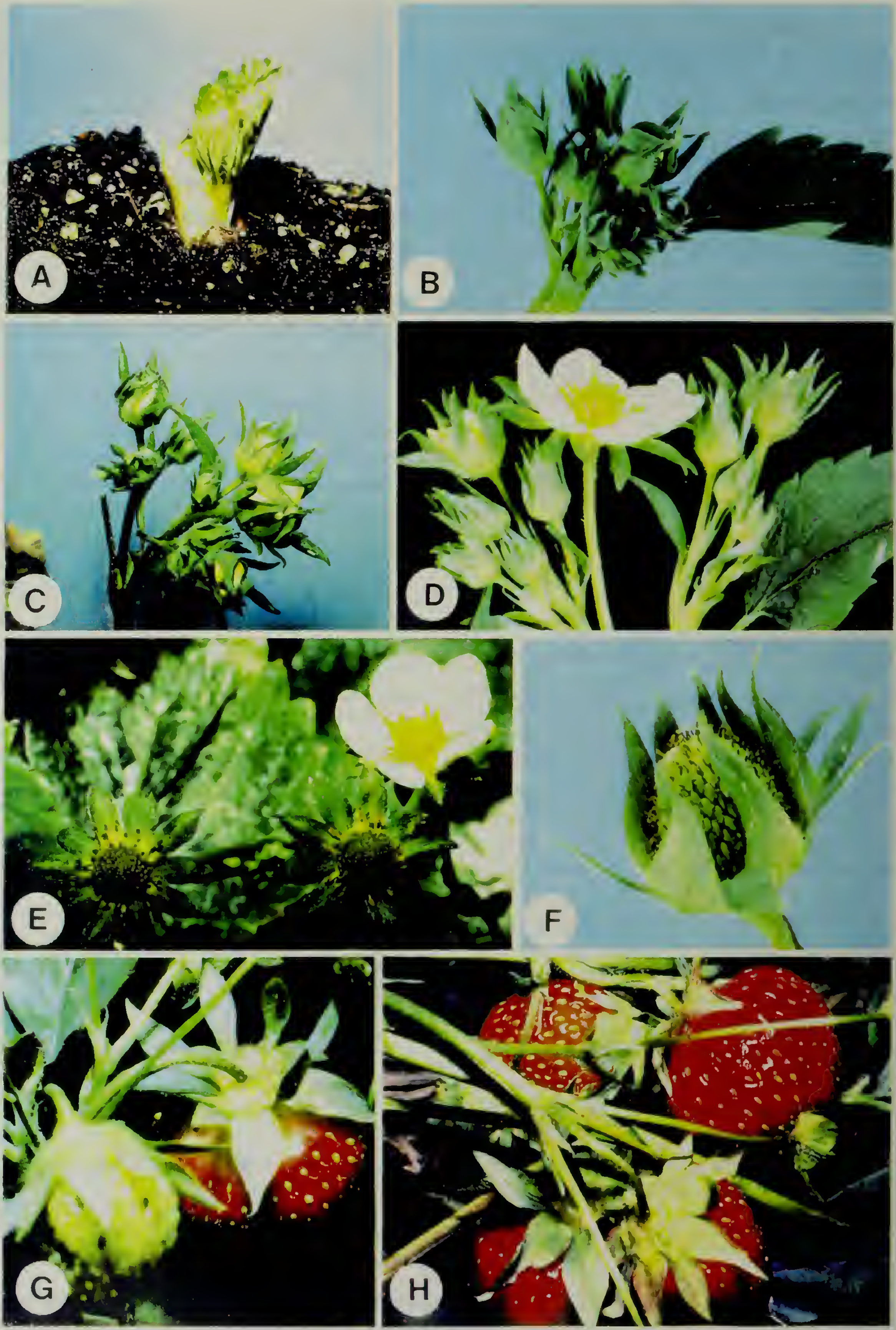
A
B
C
D
E
F
G
H

Table 7 Different phenological stages of Redcoat and Bounty strawberry cultivars in relation to cumulative degree-days. Degree-days > 0°C were calculated and added up from 1 April (Arnold 1960)

Phenological stages	Description	Redcoat $\bar{x}$ ± SE	Bounty $\bar{x}$ ± SE
1	Onset of vegetative growth	177 ± 20	355 ± 33
2	Green bud	315 ± 7	361 ± 22
3	White bud	390 ± 6	460 ± 21
4	First bloom	450 ± 7	492 ± 29
5	Beginning of petal fall	534 ± 8	570 ± 13
6	First green fruit	598 ± 8	625 ± 25
7.5	First ripe fruit	877 ± 8	954 ± 39
8	First pick	955 ± 9	1073 ± 33
9	Last pick	1331 ± 19	1503 ± 65

After Mailloux and Bostanian (1991).

A slight modification of equation 1 from the previous section related the abundance of TPB nymphs to the different strawberry phenophases (Mailloux and Bostanian 1991). This is summarized in Fig. 8 which shows that TPB nymphs appear when Redcoat and Bounty are at the green to white bud stage and the populations increase to reach maximum numbers when the first red berry (7.5) is noted in the field. Thus, TPB development continues during the entire reproductive period of the strawberry plant. As noted in Fig. 8, rapid increases of nymph populations occur at the beginning of petal fall (beyond stage 5). Hence, in most instances treatments are not required during bloom, which, as discussed earlier, may adversely affect bees and their pollination activity. From a practical point of view, monitoring for TPB nymphs can commence immediately after white bud (phenophase 3) and control measures applied when the action threshold is reached.

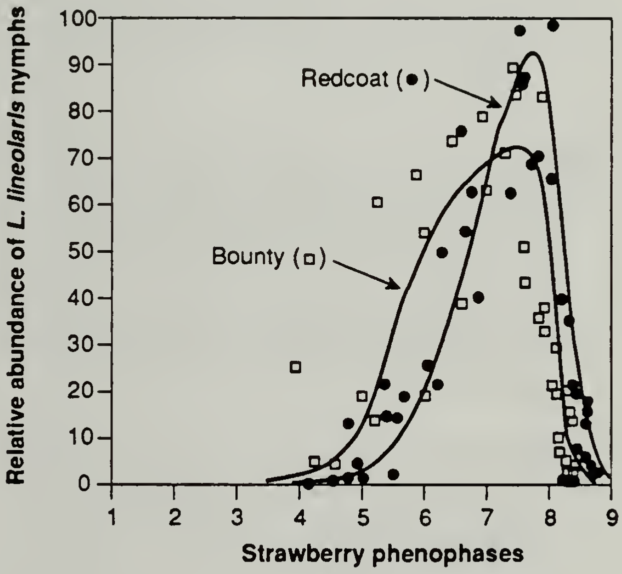

Fig. 8 Relative abundance of tarnished plant bug nymphs in relation to the phenological development of Redcoat and Bounty strawberry cultivars. The solid lines are model predictions. (By courtesy of Mailloux and Bostanian 1991.)

◀ ***Plate II (Opposite)***

A Onset of vegetative growth: first appearance of leaf buds and rudimentary leaves (stage 1); B Green bud: first appearance of flower buds among the rudimentary leaves (stage 2); C White bud: peduncle longer than 2.5 cm in more than 10% of plants in the field (stage 3); D First bloom: first appearance of a flower in bloom in the inflorescence (stage 4); E Beginning of petal fall: most of the petals of the first flower are shed and the first berry is set (stage 5); F First green fruit: small green berries visible on more than 10% of the vines (stage 6); G First ripe fruit: first berry 100% red and physiologically ripe (stage 7.5); H First pick: first cluster of berries ready to be picked (stage 8). (After Mailloux and Bostanian 1991.)

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APPENDIX

LIST OF PLANTS ATTACKED BY TPB

Forest trees (nurseries)

- Bare-root pine and container nurseries
- Conifers
- Douglas-fir
- Larch

Fruit trees

- Apple
- Cherry, prune
- Grape, peach,
- Pear, pecan
- Plum, quince

Small fruits

- Blackberry
- Currant, grape
- Raspberry
- Strawberry

Commercially grown flowers

- Aster
- Bachelor's button
- Bleeding heart
- Calendula
- Carnation
- Chrysanthemum
- Cosmos
- Dahlia
- Garden balsam
- Geranium
- Gladiolus
- Golden glow
- Hollyhock
- Impatiens
- Iris
- Marigold
- Nasturtium
- Peony
- Poppy
- Rose
- Sage
- Salvia
- Shasta daisy
- Snapdragon
- Stock
- Strawflower
- Sunflower
- Sweet pea
- Verbena
- Zinnia

Garden crops

- Asparagus
- Beet
- Broccoli
- Cabbage
- Carrot
- Celery
- Cucumber
- Eggplant
- Endive
- Escarole
- Horseradish
- Lettuce
- Lima beans
- Mustard
- Onion
- Pea
- Pepper
- Potato
- Radish
- Snap beans
- Spinach
- Squash
- Swiss chard
- Tomato
- Turnip

Forage crops

- Alfalfa
- Birdsfoot trefoil
- Clover
- Soybeans

Other crops

- Oilseed rape
- Seed heads of wheat and other grasses
- Sunflower
- Sweet corn
- Tobacco

Weeds

Spring

Annual fleabane : *Erigeron annuus* (L.) Pers.
Common mullein : *Verbascum thapsus* L.
Common ragweed : *Ambrosia artemisiifolia* L.
Garden sorrel : *Rumex acetosa* L.
Wild strawberries : *Fragaria* spp.
Yellow rocket : *Barbarea vulgaris* R. Br.

Summer

Black mustard : *Brassica nigra* (L.) Koch
Boneset : *Eupatorium perfoliatum* L.
Brown knapweed : *Centaurea jacea* L.
Lamb's-quarters : *Chenopodium album* L.
Narrow-leaved hawk's beard : *Crepis tectorum* L.
Ox-eye daisy : *Chrysanthemum leucanthemum* L.
Pineappleweed : *Matricaria matricarioides* (Less.)
Redroot pigweed : *Amaranthus retroflexus* L.
Shepherd's-purse : *Capsella bursa-pastoris* (L.)
St. John's-wort : *Hyperium perforatum* L.
Tansy : *Tanacetum vulgare* L.
White mustard : *Sinapsis alba* L.
White sweet-clover : *Melilotus alba* Desr.
Yellow sweet-clover : *Melilotus officinalis* (L.) Lam.
Wild carrot : *Daucus carota* L.
Wild mustard : *Sinapsis arvensis* L.

Autumn

Canada fleabane : *Erigeron canadensis* L. (=*Conyza canadensis* (L.) Crong)
Canada goldenrod : *Solidago canadensis* L.
Canada thistle : *Cirsium arvense* (L.) Scop.
Common ragweed : *Ambrosia artemisiifolia* L.
European stinging nettle : *Urtica dioica* L. subsp. *dioica*
False ragweed : *Iva xanthifolia* Nutt.
Narrow-leaved goldenrod : *Solidago graminifolia* (L.) Salisb.
Red-stemmed aster : *Aster puniceus* L.
Rough goldenrod : *Solidago rugosa* Mill.
Tall white aster : *Aster simplex* Willd.