Coccinellidae as predators of mites: Stethorini in biological control

David J. Biddinger, Donald C. Weber, Larry A. Hull

PII: S1049-9644(09)00149-2
DOI: 10.1016/j.biocontrol.2009.05.014
Reference: YBCON 2295

To appear in: Biological Control

Received Date: 5 January 2009
Revised Date: 18 May 2009
Accepted Date: 25 May 2009

Please cite this article as: Biddinger, D.J., Weber, D.C., Hull, L.A., Coccinellidae as predators of mites: Stethorini in biological control, Biological Control (2009), doi: 10.1016/j.biocontrol.2009.05.014

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.
For Submission to: *Biological Control*

Special Issue: “Trophic Ecology of Coccinellidae”

**Coccinellidae as Predators of Mites: Stethorini in Biological Control**

David J. Biddinger\(^a\), Donald C. Weber\(^b\), and Larry A. Hull\(^a\)

\(^a\) Fruit Research and Extension Center, Pennsylvania State University, P.O. Box 330, University Drive, Biglerville, PA 17307, USA

\(^b\) USDA-ARS, Invasive Insect Biocontrol and Behavior Laboratory, BARC-West Building 011A, Beltsville, MD 20705, USA

*Corresponding author, fax +1 717 677 4112

E-mail address: djb134@psu.edu (D.J. Biddinger)
**ABSTRACT.** The Stethorini are unique among the Coccinellidae in specializing on mites (principally Tetranychidae) as prey. Consisting of 90 species in two genera, *Stethorus* and *Parasthethorus*, the tribe is practically cosmopolitan. The Stethorini are found in a diverse range of habitats, including many agricultural systems such as pome and stone fruits, brambles, tree nuts, citrus, avocados, bananas, papaya, palms, tea, cassava, maize, strawberries, vegetables, and cotton, as well as ornamental plantings, grasslands, forests, and heathlands. Tetranychid mite outbreaks became common in many agricultural systems only after World War II, when widespread use of broad-spectrum insecticides increased. Stethorini were initially appreciated only for their ability to suppress severe outbreaks of tetranychid populations. However, research on their prey searching behaviors reveals that Stethorini use visual and olfactory stimuli to locate small mite colonies in patchy distributions, and can be very effective in regulating their prey at low densities. Moreover, acariphagous coccinellids colonize mite outbreaks earlier, and consume more pest mites, than many other mite predators. Key to the use of coccinellids in conservation biological control programs is the provision of overwintering habitats and refuges from pesticides in and near cropland. When these conditions are fulfilled, Stethorini often play important roles in maintaining suppression of tetranychid populations. Examples of successful biological mite control with Stethorini include apple orchards in Pennsylvania, USA, and citrus in Asia, and the unintended disruption of a tetranychid-based biological control program for the invasive woody weed, gorse, in Australia and New Zealand. The systematics and taxonomy of this group is challenging with many cryptic species, and molecular diagnostic tools are sorely needed. How best to utilize their mite-suppressive potential in diverse settings requires better knowledge of their requirements including utilization of alternative foods, refuges for dormancy and from nonselective pesticides, and host-finding mechanisms.
Key words: Coccinellidae, Stethorus, Acari, acariphagous, tetranychid, spider mites

1. Introduction

The approximately 90 worldwide species of the tribe Stethorini Dobzhansky (genera Stethorus Weise and Parastethorus Pang and Mao) are the only specialist mite predators in the Coccinellidae. Most predaceous Coccinellidae are specialist aphid or scale feeders, but have a wide range of accepted foods that they can utilize for various life processes (Obrycki et al., 2009; Evans, 2009; Hodek and Honěk, 2009; Lundgren, 2009b; all in this issue). Entomophagous coccinellid species (or genera) such as Hippodamia convergens Guerin-Meneville, Coleomegilla maculata De Geer, Harmonia axyridis (Pallas), Olla abdominalis (Say), Adalia, Eriopus, Scymnus, and Psyllobora feed on mites, but these prey are often suboptimal for reproduction (Dean, 1957; McMurtry et al., 1970; Hodek and Honěk, 1996; Rondon et al., 2004), and these taxa are not considered to be primary predators of mites (McMurtry et al., 1970; Hodek and Honěk, 1996).

Within the Stethorini, adults and larvae of Stethorus and Parastethorus spp. are specialists on spider mites (Tetranychidae) and the closely related Tenuipalpididae, which are known as false spider mites or flat mites (Chazeau, 1985), both of which are important agricultural pests worldwide. Many natural enemies within the Coleoptera, Dermaptera, Diptera, Hemiptera, Neuroptera, and Thysanoptera feed on spider mites, but vary in their degree of adaptation to and preferences for this prey and in their abilities to regulate pest mite populations (Helle and Sabelis, 1985). Biological control of spider mites has centered on two groups of biological control agents, the predatory mites in the family Phytoseiidae, and various species of Stethorini (reviews by McMurtry et al., 1970; Helle and Sabelis, 1985; and McMurtry and Croft, 1997).
Our understanding of what constitutes an effective mite biological control agent has changed considerably over the last 50 years. Early research focused on the abilities of acariphagous mites and coccinellids to overcome spider mite outbreaks, and on the abilities of these predators to develop resistance to pesticides applied to control primary pests in highly managed agroecosystems such as apple and citrus. More recently, the potential of some phytoseiid predators to regulate spider mites at low equilibrium densities has become more widely appreciated (Croft, 1990; McMurtry and Croft, 1997; Biddinger and Hull, 2005).

Various species of Stethorini have received considerable attention over the last five decades because of their potential as biological control agents of spider mites. At least 12 species of Stethorini have been imported into the U.S. for this purpose (Gordon, 1985) and many more have been purposefully redistributed throughout the world. Chazeau (1985) summarized information on Stethorini general biology and reported that 40% of the 68 species attacked spider mites of economic importance. This review summarizes disparate sources of information on Stethorus across many different crops worldwide for the first time. We also examine the 40-year case history of Stethorus punctum punctum (LeConte) as the key component of biological mite control in Pennsylvania apple orchards, and the sustainability of using Stethorini as biological control agents in the face of changing pesticide use patterns.

2. Overview of Stethorini

2.1. Taxonomic status. Earlier works placed Stethorus sensu latu in the tribe Scymnini, but recent works placed it in the mongeneric tribe Stethorini Dobzhansky (Chazeau, 1985; Hodek and Honěk, 1996; Giorgi et al., 2009, this volume). Stethorini are unique from all other Scymninae by the convex anterior margin of the prosternum and the truncate clypeus near the
antennal bases (Gordon, 1985). Recently, Ślipiński (2007) raised the subgenus *Parastethorus* Pang and Mao (Gordon and Chapin, 1983) to generic status, which this review reflects. Gordon and Chapin (1983) had earlier placed the following species into what was then the subgenus *Parasthethorus*: Stethorus tuncatus Kapur from Malaysia, S. gutierrezi Chazeau from New Hebrides, S. nigripes Kapur and S. histrio Chazeau from Australia. Five species from Asia are now considered to be in *Parastethorus* as well: S. dichiapiculus Xiao, S. guangxiensis Pang and Mao, S. indira Kapur, S. malaicus Xiao, and S. yunnanensis Pang and Mao (Yu, 1996).

### 2.2. Morphology and life stages

Almost all adults of *Stethorus* are small (1-1.5 mm), pubescent, black with brown or yellow legs and antennae. The pubescence may be an adaptation to aid foraging within the silken webbing of some tetranychids, a feature also seen in some species of Phytoseiidae (Houck, 1985; McMurtry and Croft, 1997). Gender can be distinguished by the small notch in the 8th sternite in male beetles (smooth in females) (McMurtry et al., 1974; Biddinger, 1993). Species cannot be determined without examining the male genitalia; most species cannot be determined in female specimens. The eggs are mostly white to creamy colored, elongated ellipsoids (a few species have pinkish or dark eggs) and are glued longitudinally along the mid-veins of the undersides of the leaves. Larval color differs among species, and is often useful in field identification (Khan et al., 2002; Muma, 1955b; Putman, 1955a; Pasqualini and Antropoli, 1994; Pollock and Michels, 2002, 2003, 2007; Biddinger et al., 2008a, b). There are generally four stadia. Stethorini larvae generally do not consume the entire mite as asserted by Chazeau (1985); instead they pierce the mite eggs or active stages, repeatedly regurgitate and imbibe the prey juices, leaving the crumpled exoskeleton (Cottier, 1934; Fleschner, 1950; Collyer, 1953; Robinson, 1953; Putman, 1955a; Kaylani, 1967; Houck, 1991). Pupae are
uniformly dark brown or black, covered with numerous setae, and affixed to either side of the leaves (Chazeau, 1985; Biddinger, 1993).

The cryptic nature of the adult species characteristics has undoubtely led to species misidentifications in the literature. Their superficial similarity to some species of Delphastus, Scymnus, and Telsimia probably accounts for most reports of Stethorini feeding on scale or aphids. The importance of this group in biological control in many crops throughout the world, and the difficulties in separating species, make it an excellent candidate group for systematic treatment as well as diagnostic taxonomy by molecular barcoding methods.

2.3. Geographical Distribution. Stethorini are present throughout the world in many different climates ranging from tropical rainforests to temperate deciduous forests and plains to colder northern regions of Europe, Canada and Russia (see map, Fig. 1, for distribution of economically important species). Stethorus punctillum Weise has the largest distribution in the group, ranging over most of temperate North America, Europe, and Asia. A major driving force behind the current geographic distribution of Stethorini has been their intentional redistribution by biological control scientists. For example, approximately 12 species (some of which were never formally identified) were introduced into California from geographically diverse areas such as Australia, China, Guatemala, India, Morocco, Pakistan, South Africa, and Turkey (Hall and Fleschner, 1958; Gordon, 1982). Some of the earliest introductions occurred in Hawaii, which apparently has no native species of Stethorini (Swezey, 1925; Fournier et al., 2002). Parastethorus nigripes (Kapur) represents the most recent introduction of Stethorini in North America (Gordon, 1993). This is an important predator of Panonychus ulmi (Koch) and Tetranychus urticae Koch in Australia (Edwards and Hodgson, 1973; Field, 1979).
Parastethorus nigripes established itself in Texas corn where it consumes the Banks grass mite, Oligonychus pratensis (Banks) (Pollock and Michels, 2002), but only after introductions into California almonds failed (Hoy and Smith, 1982). The other recent addition to the North American fauna is P. histrio (= Stethorus histrio), from the Mascarene Islands east of Madagascar (Gordon and Anderson, 1979). It has since been found throughout Australia (including Tasmania), New Caledonia and parts of South America. Aguilera P. (1987) surmised it to be introduced accidentally into central Chile. Gordon and Chapin (1983) extended the range north into the Yucatan (Mexico), but Pollock and Michels (2003) reported it for the first time in the United States feeding on mites in corn, co-occurring with the native species Stethorus caseyi Gordon and Chapin and P. nigripes. Pollock and Michels (2003) found S. caseyi to be relatively scarce and speculated as to whether it had been displaced by these newly introduced species.

Additional introductions of Stethorini have likely established into new geographical ranges; the number is unknown because many species can only be identified by taxonomic experts of the group. The accidental introduction of S. punctillum from Europe into North America completely displaced the native S. punctum from Ontario fruit orchards and other habitats over a 20 year period (Putman, 1955a; Putman and Herne, 1966). In Québec, S. punctillum has been the only species collected from raspberry and apple crops in the past 15 years (pers. comm. with Michèle Roy, MAPAQ Laboratoire de Diagnostic en Phytoprotection).

3. Behavior as predators

3.1. Prey searching behavior. Many early studies of various species of Stethorini concluded that they are “high density predators” unable to regulate spider mite populations at low densities (Fleschner, 1950; Bailey and Caon, 1986; Tanigoshi and McMurtry, 1977). Congdon et al.
(1993) challenged this “high density predator” designation and asserted that high density spider mite populations have become common only since the advent of synthetic insecticides (Huffaker et al., 1970), and that the studies that support the “high density predator” status of Stethorini ignored the spatial context of spider mite populations. While it is true that most Stethorini species do not lay eggs until mite populations are relatively high in comparison to the low mite levels maintained by some Phytoseiidae, the Stethorini have provided economically successful regulation of pest mites in several cases. Reasons underlying these success stories include a) the regulatory potential of the long-lived adults; b) the ability of adults to rapidly immigrate into cropland; and c) the ability of non-pest tetranychid mite populations, non-tetranychid mites, extrafloral nectaries, aphid honeydew, and pollen, to support populations of Stethorini before pest mite populations reach outbreak proportions in crops. The importance of Stethorini species worldwide as biological control agents is also suggested by the over 500 references found in the course of this review.

Congdon et al. (1993) hypothesized that the active discovery of rare and very small prey patches by adult Stethorini was a key element in their natural interactions with spider mites over evolutionary time. Few, if any, predator eggs are laid until mite populations become high enough to support the development of larvae, a common phenomenon in coccinellids (Seagraves, 2009, this issue). Then the impressive numerical response of Stethorini would reduce damaging mite populations later in the season on crops which are often more tolerant of late season mite injury. Pesticides applied for mite control frequently kill Stethorini, and so the natural low-density interactions between predators and pests do not occur. Subsequently, spider mite populations increase, and Stethorini immigrate in response to these ample mite populations.
Thus, there is the illusion that Stethorini function as “high density predators” within pesticide-treated cropland.

Even when insecticides are applied to crops, *Stethorus* can quickly reduce mite populations and may prevent economic injury. Adult *S. punctum* were able to find eight *P. ulmi*-infested apple trees out of a 1-ha orchard, even though these infested trees had fewer than 1 mite/leaf (Hull et al., 1977b). Similarly, *S. punctum* was able to find small patches of pest mites in avocados, citrus, and raspberries (Congdon et al., 1993; McMurtry and Johnson, 1966; Haney et al., 1987). Similar low-density detection of mite prey has also been demonstrated by *S. chengi* in citrus orchards in China (Chen, 1993; Chen & Zhao, 1994). The cues that Stethorini adults employ to find these small populations of mites are poorly understood, but some evidence points to a combination of visual and olfactory cues. The detection of prey by the larval stages is generally thought to be tactile with visual cues being non-existent (Fleshner, 1950; Putman, 1955a, b; McMurtry et al., 1970; Houck, 1985; Houck, 1986).

3.1.1. Visual stimuli. At least some species of Stethorini are visually attracted to white or yellow colors. When spider mite populations are low, sticky traps can be more effective than visual counts in monitoring *Stethorus* populations (Felland et al., 1995; Biddinger and Hull, 1996; Takahashi et al., 2001a; Roy et al., 2005). Readshaw (1975) used white sticky card traps to monitor Stethorini populations in orchards early in the season. Felland et al. (1995) found that yellow sticky card traps captured up to 15 times more *S. punctum* than white traps. Spider mite feeding causes a yellowing (bronzing) of leaves, and like many other coccinellids (Seagraves, 2009, this issue), foraging Stethorini adults may use this color as an indication of prey. *Stethorus*
*punctum* is primarily diurnal (Hull et al., 1977b), which reinforces the hypothesis that vision is an important foraging cue.

### 3.1.2. Olfactory stimuli

Prey-derived olfactory stimuli are another important cue for foraging Stethorini adults. Colburn and Asquith (1970) examined the olfactory response of adult *S. punctum* to *P. ulmi* under choice conditions. The beetles walked preferentially toward prey versus the no-prey treatments in the presence and absence of apple foliage. Later work found that *S. japonicus* and *S. punctillum* also are attracted to the volatiles of tetranychid-infested plants (unpublished data cited in Takahashi et al., 2001b; Lentz et al., 2004). Lentz et al. (2004) went on to show that at least some of the attractive volatiles were produced by infested cucumber and bean plants.

There have been several efforts to identify the prey-associated chemistry that is attractive to Stethorini. James (2003a) and James and Price (2004) found that *S. punctum* was attracted to white traps baited with a synthetic herbivore-induced plant volatiles including methyl salicylate and (Z)-3-hexenyl acetate under field conditions. More *S. punctum* were recovered from beating samples in hop yards treated with time-release methyl salicylate, and the attraction of this and other predators was observed to reduce *T. urticae* numbers dramatically in an unreplicated study. Similar results were obtained with unbaited sticky cards in replicated vineyards treated with time-release methyl salicylate. James (2005) also found cis-3-hexen-1-ol and benzaldehyde to be attractive to *S. punctum* in additional field trials with multiple synthetic plant volatiles.

Although it is clear that olfactory cues are important in attracting foraging Stethorini, beetles do not necessarily respond to specific olfactory stimuli under field conditions. For example, *S. japonicus* was not significantly attracted to sticky traps with plant volatile blends in...
a Japanese pear orchard, perhaps because high *Tetranychus kanzawai* Kishida populations may have obscured the trap-associated volatile attractants (Takahashi et al., 2001a). In another study, infested host odors or other plant cues (e.g., plant location or stature) may have inhibited the attractiveness of mite-infested bean plants to *S. japonicus* (Takahashi et al., 2001b). Gillespie et al. (1997) used potted bean plants infested with *T. urticae* to collect *S. punctillum* and several other mite predators in several habitats in British Columbia, Canada, indicating perhaps that not all Stethorini spp. are equally attracted to the same volatiles.

### 3.2. Trophic Ecology and Life History Parameters.

#### 3.2.1. Relative quality of mites as prey.

As shown in Table 1, Stethorini attack a large number of tetranychid species on many different crops. Although it appears that most feed on multiple tetranychid prey species, some species are more specialized than others and some tetranychid prey are less suitable than others. For example, *S. punctillum* and *S. gilvifrons* do not readily feed on or reproduce on the tetranychid mites of the genus *Bryobia* (Putman, 1955a; Kaylani, 1967). Houck and Strauss (1985) found a weak, but consistent, feeding preference of *S. punctum* for *T. urticae* over *P. ulmi*, but this preference was affected by preconditioning of the predator for specific mite species, and preferences did not persist from larval to adult stages.

Many prey change in their suitability for coccinellids as they age (Hodek and Honěk, 2009, this issue), and mites are no exception. Stethorini adults and larvae often prefer mite eggs over other pest life stages (Houck, 1991; Tanigoshi and McMurtry, 1977), but *S. madecassus* preferred adult mites over eggs as prey (Chazeau, 1974b). Generally, eggs are the most nutritious life stage of a prey item, largely because they contain less water (Lundgren, 2009a). Also, the eggs may be less defended, more apparent to mobile adults, or more abundant than
other life stages. Most studies employ only a single life stage of mite prey (usually adult females or eggs) when they determine the developmental rates of various Stethorini species, and do not examine the nutritional values of the various prey stages or intraspecific competition between predator stages. Houck (1991) speculated that varying the mite stages consumed by *S. punctum* might prevent severe oscillations in both the predator and the prey populations. As with many other coccinellids, Stethorini females often consume more prey than conspecific males (Hull et al., 1977b; Chazeau, 1985).

Some Stethorini utilize non-tetranychid mites as alternative prey in times of starvation. Ullah (2000) compared the suitability of the phytoseiid predatory mite, *Phytoseiulus persimilis* Athias-Henriot, the eriophyid rust mite, *Auclops lycopersici* (Massee), the tenupalpid broad mite, *Polyphagotarsonemus latus* (Banks), and the tetranychid spider mite, *T. urticae* as prey for *Stethorus vagans* (Blackburn) adults. Mating and oviposition of fertile eggs was observed only in *S. vagans* adults that were fed tetranychid or broad mites. However, mating, oviposition and fecundity were much lower with the broad mite diet than with tetranychid prey. Rust mite, but not phytoseiid mite, diets prolonged survival. Hull (pers. obs.) has observed *S. punctum* commonly feeding on both the phytoseiid (most likely *Neoseiulus fallacis* (Garman)) and the eriophyid mite, *Aculus schlechtendali* (Nalepa) early in the season when spider mite populations were very low and the predators were pre-reproductive. Kaylani (1967) and Putman (1955a) observed *Stethorus* spp. feeding on phytoseiids in the field, and Mathur (1969) observed adult *S. gilvifrons* eating a predatory *Anystis* sp. (Acari: Anystidae).

### 3.2.2. Non-mite foods of Stethorini

Reports of Stethorini feeding on non-acarid prey and non-prey foods challenge the assertion that all species feed and develop only on spider mites.
Al-Duhawi et al. (2006) found *S. gilvifrons* adults and larvae to be very efficient predators of all stages of the *Bemisia tabaci* and, in laboratory trials, found the larvae completed their development on this prey alone. Silva and Bonani (2008) reported *S. minutulus* Gordon and Chapin feeding on the tobacco whitefly on cotton in Brazil as well. However, L.D. Silva (pers. comm.) confirmed that the coccinellid found feeding on whiteflies was actually a species of *Delphastus* (Sticholotidinae); some specimens of *S. minutulus* feeding on mites in the same whitefly colony had been sent for identification by mistake. Mathur (1969) observed that starving larval and adult *S. gilvifrons* ate *Macrosiphum* sp. (Hemiptera: Aphididae) “to a very limited extent,” and Almatni and Khalil (2008) reported this species “fed occasionally” on *Brachycaudus amygdalinus* (Schouteden)(Hemiptera: Aphididae). Massee (1940) noted *S. punctillum* as a predator of *Phorodon humuli* (Schrank)(Hemiptera: Aphididae).

Numerous coccinellid species can utilize pollen, fungal spores, and nectar as alternative food sources (Lundgren, 2009a, 2009b, this issue). Ullah (2000) found that addition of pollen or honey to a water-only diet doubled the longevity of adult *S. vagans*, but beetles did not mate or reproduce on either of these foods. Mathur (1969) found that *S. gilvifrons* consumed aphid honeydew in the lab, and also stated that the larvae “remain adhere [sic] to the sticky secretion.” Pemberton and Vandenberg (1993) reported that *Stethorus* spp. fed at *Prunus padus* L. foliar extrafloral nectaries in South Korea, and Putman (1955a, 1963) found that *S. punctillum*, in the absence of other food, would eat raisins, aphids, aphid honeydew, and peach leaf extrafloral nectar. While all of these foods prolonged adult survival in *S. punctillum*, egg production was greatly reduced or prevented (Putman, 1955a).
3.2.3 Developmental and prey consumption rates. Some attractive characteristics of Stethorini for mite biological control are their prey consumption, longevity and high reproductive capacity (Table 2). Each adult female may consume 30 to 60 mites per day. Total fecundity ranges from 123 eggs in *S. tridens* (Fiaboe et al., 2007), 184 eggs in *S. madecassus* (Chazeau, 1974a, b), 221 in *S. punctum* (Tanigoshi and McMurtry, 1977), 279 in *S. punctillum* (Roy et al., 2003), to a high of 501 eggs in *S. japonicus* (Mori et al., 2005). Developmental times for most species are approximately 17 d at 25°C from oviposition to adult eclosion (Fiaboe et al., 2007; Mori et al., 2005; Putman, 1955a; Roy et al., 2002; Tanigoshi and McMurtry, 1977). The number of Stethorini generations per year varies from 2 to 3 in temperate regions for *S. punctillum* and *S. punctum* (Putman, 1955a; Colburn and Asquith, 1971) to more than 15 per year for tropical species such as *S. siphonulus* and *S. pauperculus* (Puttaswamy and Rangaswamy 1976; Puttaswamy and ChannaBasavanna 1977). Adult longevity is not known for most species, but appears to be longer in temperate species which undergo diapause than in tropical species, and is temperature dependent. Putman (1955a) found *S. punctillum* females in Canada could commonly survive and lay eggs over multiple seasons under field conditions, with an average longevity of over 400 days; males generally die sooner than females. Ullah (2000) found adults of both sexes of *S. vagans* in Australia lived 126 days at 12°C compared to only 27 days at 30°C.

Since the developmental times differ little amongst species of Stethorini, the differences in *r_m* values between species are attributable to differences in reproductive rates (Mori et al., 2005) (Table 2). At 24-25°C the *r_m* values for *Stethorus* species range from 0.100 in *S. punctillum* (Roy et al., 2003) to 0.160 in *S. loi* (Shih et al., 1991); a number of other species have been evaluated and found to fall within this range (Chazeau, 1974a, b; Fiaboe et al., 2007; Mori et al.,...
2005; Richardson, 1977; Tanigoshi and McMurtry, 1977). Sabelis (1985a, b, 1991) calculates that the $r_m$-values for tetranychid mites range from 0.160 to 0.293 at around 25°C. This is significantly higher than the values for Stethorini species listed in Table 2, but their functional response to prey may still allow them to regulate pest populations.

Few studies have calculated the functional response of *Stethorus*. Houck (1991) examined handling time as a component of the functional response of *S. punctum* to *T. urticae*, and found that the handling time of starved beetles for each prey increased due to a greater extraction of body fluids from individual prey. *Stethorus punctum* continued to feed even when satiated with high prey densities and continued to pierce mites, initiate feeding, but then subsequently abandon the prey with minimal extraction of bodily fluids in a classic Type 3 response. This type of response has been observed in other systems as well (Hull et al. 1977a; Haji-Zadeh et al., 1993; Peterson et al., 2000). Type 1 & 2 functional responses have been observed in other *Stethorus* spp. (Hull et al. 1977a; Gotoh et al., 2004).

3.2.4. Diapause and overwintering. All Stethorini in temperate climates overwinter as adults, with a reproductive diapause that is induced by short day lengths and cooler temperatures. *Stethorus punctum* entered reproductive diapause at day lengths of 10 h or less and 21-22°C (McMurtry et al., 1974). *Stethorus japonicus* was induced into reproductive diapause with day lengths shorter than 13 h at 18°C (Mori et al., 2005). Species with large geographical ranges that include both temperate and subtropical climates may hibernate in the colder area but not in the warmer (Collyer, 1964; Kaylanici, 1967). For example, *S. punctum* diapauses in Pennsylvania (Colburn and Asquith, 1971; Colburn, 1971) and in Washington state (Horton et al., 2002), but is
active year round in southern California (McMurtry et al., 1970; 1974). Tropical species seldom
experience diapause (Chazeau, 1985; Hoy and Smith, 1982).

Several studies have shown that *S. punctillum* and *S. punctum* overwinter within fruit
orchards and the adjacent habitat. Putman (1955a) and Felland et al. (1995) determined that both
species moved into overwintering sites as early as mid-summer (July) and population densities
peaked in mid-autumn during apple leaf-fall. In Ontario, Putman (1955a) found that *S.*
*punctillum* only survived the winter in orchards if they were in contact with the soil, likely
because of the insulating effects of snow, whereas dead adults were often observed on the trunks
of peaches during the winter. This agrees with observations of *S. punctum* in Pennsylvania
orchards (Hull pers. obs.). Overwintering Stethorini are often found in aggregations near the
base of orchard trees, but this may be a function of increased survival in these protected areas
(Asquith and Hull, 1979; Colburn and Asquith, 1971; Felland and Hull, 1996; Readshaw, 1971).
Regardless of where they overwinter within a landscape, some North American *Stethorus* spp.
experience substantial mortality during the winter, with spring populations reported as 20 to 28%
of those found in the fall (Felland and Hull, 1996; Putman, 1955a). In areas where winters are
less severe, *Stethorus* may overwinter successfully in less protected sites. For example, *S.*
punctum commonly overwinter in cardboard bands wrapped around tree trunks in Washington
apple orchards (Horton et al., 2002), as does *S. punctillum* in Germany (Berker, 1958).

Spring emergence of *S. punctum* adults in Pennsylvania apple orchards over three seasons
was correlated with tree phenology, ground cover emergence traps, colored sticky card traps,
ambient temperatures, and degree day accumulations (Felland et al., 1995; Biddinger and Hull,
1996). Adults emerged from diapause at 100 and 300 degree days, base 5°C starting 1 March of
each year, with fifty percent emergence occurring at 210 DD$_{5^\circ C}$. Emergence was 2, 47 and 96%
complete by the defined phenological stages of apple as half inch green, pink and petal fall respectively, for the apple cultivar “Yorking.” Most adults emerged on days of average, minimum, and maximum air temperatures of 15-20, 5-15, and 20-30°C, respectively.

3.2.5. Natural enemies of Stethorini. There is surprisingly little information available on the natural enemies of Stethorini species despite numerous reports for other coccinellid species (Riddick et al., 2009, this volume). A species of rickettsial disease (Rickettsiella stethorae Hall and Badgley) from larvae in cultures of Stethorus nr. punctum from Morocco was described by Hall and Badgley (1957). The disease spread rapidly to cultures of S. punctum from Connecticut, S. gilvirfrons from Hong Kong, S. punctillum, and Stethorus sp., possibly S. guatemalensis = S. granum introduced from Guatemala (Hall and Fleschner, 1958). The disease was not found in their prey (six-spotted mite, Eotetranychus sexmaculatus [Riley]). Among the parasitic mites, the Laboulbeniales were found on several S. punctillum adults collected on raspberry plants in Québec (Michèle Roy, MAPAQ Laboratoire de Diagnostic en Phytoprotection, pers. comm.). We could find no records of parasitoids that attack Stethorini. Cannibalism on preimaginal stages of Stethorus is also common (Cottier, 1934; Fleschner, 1950; Robinson, 1953; Chazeau, 1985). It does not appear to be an important cause of mortality except during times of starvation (Collyer, 1953; Putman, 1955a; Kaylani, 1967; Mather, 1969) or when larval densities become very high (Houck, 1991). Biddinger and Hull (pers. obs.) believe the most significant predators to be the older instars of lacewings (Chrysopa spp.) and other coccinellids. Phidippus audax (Hentz), a salticid commonly found in the tree canopy in the late summer and fall, feeds on Stethorus larvae (Biddinger and Hull, pers. observ.). Rosenheim et al. (2004a, b) found the tangle-nest spider, Nesticodes rufipes (Theridiidae), consumed larvae of S. siphonulus, thereby disrupting biological control of the carmine spider mite, Tetranychus
*cinnabarinus*, on papaya in Hawaii. Putman (1955a) observed an unidentified species of *Typhlodromus* feeding on the eggs of *S. punctillum* when confined. Haney et al. (1987) found that *S. punctum* could regulate populations of citrus red mite in California citrus groves at low levels, but in the presence of the Argentine ant, *Iridomyrmex humilis* (Mayr), mite populations flared dramatically. They attributed this to active harassment of adult (and possibly immature stages) *Stethorus* (also documented by Bartlett, 1963), which inhibited the feeding and numerical response of the beetles.

4. **Conservation and value in biological control.**

The habitats of Stethorini are diverse, and include many agricultural systems such as tree and small fruits, nuts, citrus, avocados, bananas, papaya, palms, tea, cassava, sugarcane, maize, and various vegetables, as well as ornamental plantings, grasslands, forests, and heathlands. The overview provided by Lo et al. (1989) of tetranychid predators in several crops in Taiwan is an illustration of where acariphagous coccinellids often fit within natural enemy communities. Typically coexisting with several phytoseiid mite predators, the staphylinid *Oligota* and green lacewings (*Chrysopa*), *Stethorus loi* Sasaji is considered an important mite predator in citrus and tea plantations, whereas in mulberry, strawberry, and pear, mite management practices focus completely on phytoseiids. Citrus red mite (*Panonychus citri*) is preyed upon by a number of Stethorini in Asia, frequently resulting in significant population suppression. For instance, Huang et al. (1988) provide an account of inoculation of approximately 20 adult *Stethorus siphonulus* per tree in six citrus orchards in southeastern China, resulting in reduction of *P. citri* to below economic thresholds over the growing season, and drastic reduction in miticide input.
It is difficult to generalize which agroecosystems support Stethorini and/or phytoseiid mites as effective tetranychid predators; this is likely a function of many factors such as pesticide use history, crop phenology and characteristics, proximity to refugia for protection from climatic extremes and agrochemicals, and experience and preference of pest management practitioners. Globally, Stethorini perform best as biological control agents in low-input woody perennial systems. Key to their optimal utilization as biological control agents are the provision of sufficient overwintering habitats or other reservoirs for Stethorini in or near agroecosystems, and their protection from particularly damaging pesticides. Under these circumstances, Stethorini are often important contributors to the suppression of tetranychid populations. Examples are apple orchards in Pennsylvania, USA, citrus and tea in East and South Asia, and in Australian and New Zealand gorse (*Ulex europaeus* L. [Fabaceae]), where they suppressed a tetranychid biological control for this invasive woody weed.

4.1. Case studies of *Stethorus* in IPM systems.

4.1.1. *Stethorus punctum* in Pennsylvania orchards. The best documented and most successful biological control program incorporating Stethorini has been that of *S. punctum* in apple and peach orchards of the eastern USA. Pennsylvania initiated a system for the biological control of mites using *S. punctum* during the 1970s (reviewed in Asquith and Hull, 1979; Chazeau, 1985; Croft, 1990; Hull and Beers, 1985; Tanigoshi et al., 1983). The program reportedly reduced acaricide usage by 1000 metric tonnes of formulated product, realizing a cumulative grower savings of US$20 million over 25 years (Biddinger and Hull, 1996). Key to the success of this program was early development of resistance by *S. punctum* to organophosphate (OP) insecticides such as azinphosmethyl (Colburn and Asquith, 1973), and the
continuous use of this pesticide class in controlling susceptible primary pests (e.g., codling moth and Oriental fruit moth) from the mid 1960s through the mid 1990s (Croft, 1990). The intense selection pressure over decades of using multiple applications of the same insecticides per season undoubtedly contributed to this resistance development, but another factor was a unique method of application known as alternate row-middle spraying (Lewis and Hickey, 1964; Hull and Beers, 1985). In the 1970s this became the preferred method of pesticide application by over 95% of mid-Atlantic fruit growers. Knight and Hull (1992 a, b) demonstrated that, using this method, only ~20% dose of the pesticide is deposited on leaves or fruit on the opposite side of the tree, leaving untreated refugia for Stethorus, even as new insecticides were employed, to which the predator was not resistant (Hull et al., 1976; Hull and Beers, 1985; David, 1985; Biddinger, 1993; Biddinger and Hull, 1996; Biddinger and Hull, 1999).

The usefulness of Stethorus was communicated directly to tree fruit growers through insecticide and acaricide efficacy guides. A series of field studies and a computer simulation model by Mowery et al. (1975) determined the expected efficacy of biological control of P. ulmi based on visual predator and prey counts, information later incorporated into the Penn State Apple Orchard Consultant program, one of the first IPM expert systems (Rajotte et al., 1987; Travis et al., 1992). Pesticide recommendations focused not only on efficacy against primary pests, but on use of products that S. punctum could tolerate: OPs and many acaricides (Biddinger et al., 2008a). To protect S. punctum, pyrethroids, despite being inexpensive and effective on many primary pests, were never recommended in Pennsylvania apples, and are rarely used there after bloom (Hull and Knight, 1989; Hull and Starner, 1983; Hull et al., 1985ab). In contrast, in Michigan and New York apples and in Pennsylvania peaches, S. punctum disappeared with widespread adoption of pyrethroids in the late 1980s (Hull, pers. obs.).
The period of tetranychid mite control in Pennsylvania with *S. punctum* was characterized by a lack of effective miticides. Starting in the mid 1990s, new miticide registrations offered more effective, less expensive materials. Most growers abandoned recommended action thresholds for *P. ulmi*, and miticide use increased dramatically. *Stethorus punctum* began to disappear from apple orchards as lower populations of *P. ulmi* prevented predator reproduction. Of more lasting impact however, was the development of OP resistance in the primary lepidopterous pests of eastern apple orchards, which required adoption of new insecticide chemistries, some of which were very toxic to *S. punctum*. These insecticides include the neonicotinoids, and several of the insect growth regulators, which are toxic to various stages of *S. punctum* (Biddinger and Hull, 1993, 1996, 2005; Hull et al., 1991; Hull and Biddinger, 1991ab), in spite of being classified as “reduced risk,” by the US EPA. James (2003b, 2004) reported similar effects on *S. punctum picipes* in Washington hops. Many of these new insecticides have sublethal effects on pest development and fecundity (Biddinger and Hull, 1999; Sun et al., 2000; Biddinger et al., 2006), which have been demonstrated for *S. punctillum* through feeding on tetranychids on imidacloprid-treated ornamental woody plants (Creary 2009).

Around 2005, biological mite control in Pennsylvania apple orchards shifted to the conservation of the phytoseiid predatory mite, *Typhlodromus pyri* (Schueten) (Biddinger et al., 2008b). *Typhlodromus pyri* can survive on alternative food sources such as rust mites, pollen or fungi when tetranychid mite densities are very low and do not seasonally disperse from trees, as do other phytoseiid predators such as *Neoseiulus fallacis* (Garman) (Nyrop et al. 1998). Biological mite control with *T. pyri* in Pennsylvania apple orchards does not suffer from temporal or spatial asynchrony such as that found in raspberries (Roy et al. 2005). *Stethorus punctum* is now considered a backup option for mite control when *T. pyri* conservation fails due
to the use of toxic insecticides rather than a complement to phytoseiids. Currently, neither S. punctum nor T. pyri are providing significant mite control in Pennsylvania peach orchards because of the heavy dependency on pyrethroid applications for pest control (Hull and Biddinger, pers. obs.).

4.1.2. Pesticide impacts and resistance in other Stethorini species. Nienstedt and Miles (2008) have established a bioassay for pesticide toxicity for S. punctillum, including effects on development and fecundity, and demonstrated its sensitivity using the insect growth regulators fenoxycarb and methoxyfenoside. This species developed resistance to azinphosmethyl in Italian apple orchards under very similar circumstances to that of S. punctum in USA (Pasqualini and Malvolta, 1985; Croft, 1990). The value of this predator has also been reduced as alternative insecticides have been adopted to control azinphosmethyl-resistant primary pests (Pasqualini and Antropoli, 1994). Biological control of mites in Italy is now also more dependent on the phytoseiid predatory mites. T. pyri and Amblysieus andersoni (Chant)(Pasqualini, pers. comm.). McMurtry et al. (1970) reviewed the biology and ecology of several North American Stethorus spp. and noted the impact of orchard spray practices on them. Stethorus bifidus Kapur was the most important insect predator of mites in New Zealand apple orchards, but is susceptible to organophosphate insecticides (Collyer, 1964, 1976). The use of alternate-row middle applications of reduced rates of insecticides was not adopted in New Zealand orchards or in other countries with native species of Stethorini; this may contribute to the absence of insecticide resistance. The introduction of the synthetic pyrethroids into New Zealand apple spray programs severely impacted Stethorini populations and fruit IPM now largely relies on the introduced pyrethroid resistant phytoseiid, T. pyri (Croft, 1990, Marwick, 1988). In Australian
apple IPM programs several species of Stethorini were important in the 1960-70’s, but are now
dependent on phytoseiid predators for biological mite control (Edwards and Hodgson, 1973;
Readshaw, 1975; Walters, 1974, 1976 a, b, c; Bower and Kaldor, 1980).
Álvarez-Alfageme et al. (2008) examined the effect of two different Cry1Ab expressing
transgenic maize cultivars with lepidoptera-specific Bt toxins. The two-spotted spider mite, T.
urticae, retains the Bt toxin but its predator, S. punctillum, degrades it without measureable
effects on fitness or performance. This is consistent with field results comparing Cry1Ab
expressing maize with its isogenic cultivar in Spain, showing no significant differences in
coccinellid numbers, which were predominantly S. punctillum (de la Poza et al., 2005). Güllü et
al. (2004) reported similar results with S. gilvifrons comparing Cry1AB expressing maize with
an isogenic cultivar in Turkey. To our knowledge no specific deleterious findings are available
regarding Stethorus and rootworm-targeted (Cry3) transgenic maize.

4.2. Mass rearing.
Early biological control researchers cavalierly pursued the introduction of many Stethorini
into new regions, and accompanying these classical biocontrol introductions, considerable effort
went into the development of mass production methods using natural diets of mites and factitious
prey or artificial diets. The mass production of Stethorini using prey requires a tremendous
supply of mites. Fleschner (1950) conservatively calculated that S. picipes each required 300
mites for development and oviposition. Several species of mites have been used to rear
Stethorus including Eotetranychus sexmaculatus (Riley), Tetranychus pacificus McGregor, T.
cinnabarinus (Boisduval) (Finney, 1953; Scriven and Fleschner, 1960; Scriven and McMurtry,
1971).
Some host plants may not be suitable for cultures of Stethorini because of hooked trichomes that may kill or impede the movement of larvae and adults. For example, prey mites must be brushed from lima or scarlet runner bean plants before offering them to Stethorini as food since the hooked trichomes on these plants can tear the larval integument, and damage the posterior integument during defecation or oviposition by adults (Putman, 1955a; Walters, 1974; Biddinger, 1993). The smooth-leaved fava bean (*Vicia faba*) proved more suitable for rearing *Stethorus* directly on the plants (Putman, 1955a; Biddinger, 1993).

*Stethorus* can also be reared on alternative foods. Colburn (1971) determined that a modified wheat germ diet with honey greatly increased adult *S. punctum* survival in the laboratory over a two week period compared to sugar water alone. Smirnoff (1958) reared *S. punctillum* and 17 other coccinellids on a diet consisting of cane sugar, honey, agar and royal jelly. Given the limited work done on these non-prey diets, it is difficult to make any firm conclusions at to their value in the mass production of beetles.

Applied Bio-nomics near Victoria, British Columbia, Canada, is the commercial supplier of *S. punctillum* for releases in the United States and Canada. The company recommends *S. punctillum* for release against *T. urticae, P. ulmi*, the spruce spider mite *Oligonychus ununguis* (Jacobi), and the Southern red mite *Oligonychus ilicis* (McGregor). Since the beetles are expensive (US$30-50 per 100 adults), they are sold only in modest numbers compared to phytoseiid mite predators, particularly for interior landscapes, conservatories, and greenhouses with ornamental and vegetable crops, as well as for occasional field use on small fruits and ornamental shrubs (Raworth et al., 2002; Jan Dietrich, Rincon-Vitova Insectaries, and Brian Spencer, Applied Bio-nomics Corporation, pers. comms. with D. Weber, both on 5 Dec. 2008).
4.3. Research on releases in urban, greenhouse and interior environments.

Several studies have focused on using *Stethorus* for controlling spider mites in greenhouse crops. Raworth (2001) found that releases of *S. punctillum* established and reproduced in peppers and cucumbers but not in tomatoes. This study underscores yet again that the prey’s host plant can inhibit predators. Rott and Ponsonby (2000) found in UK glasshouse vegetables, that simultaneous releases of *Neoseiulus californicus*, *S. punctillum*, and *P. persimilis* controlled spider mites better than did *P. persimilis* alone; no intraguild predation was noted, and predator performance varied by crop type. Combined releases of phytoseiids and *S. punctillum* have shown success in greenhouses, interiorscapes, and urban shade tree IPM programs in Europe (Gorski and Fajfer, 2003; Jäckel et al., 2000, 2008; Pöhle et al., 2002). These efforts are testing combinations of releases of phytoseiid mites with *S. punctillum* with habitat modifications, e.g. on shade trees increasing ground residue and providing shelterbands for overwintering. Interior environments with low humidity and artificial lighting pose special challenges that are difficult to overcome (Pöhle et al., 2002). Ornamental pest management is also seen as a possible niche for *S. punctillum* releases in Denmark (Svendsen and Hansen, 2002).

4.4. Inhibition of gorse biocontrol.

*Stethorini* may suppress desirable mites that are biological control agents of invasive weeds. *Gorse*, *Ulex europaeus* L. (Fabaceae), is a thorny woody shrub native to Europe, which was widely re-distributed throughout the world as a living hedge to confine livestock. This plant is also appreciated for its value as browse for stock, and for its abundant yellow flowers. By the early 20th century, the dangerously weedy nature of gorse was recognized in New Zealand, southern Australia, Tasmania, Chile, northwestern USA and Hawaii. Beginning about 20 years
ago, efforts turned toward classical biological control using two foliage-feeding arthropods, the
gorse spider mite, *Tetranychus lintearius* Dufour (of British and Iberian origin) and gorse thrips,
*Sericothrips staphylinus* Haliday (of English origin). *Tetranychus lintearius* has been released in
New Zealand, Australia, Chile, and in the USA (Washington, Oregon, California, and Hawaii).
Established gorse spider mite populations grow to spectacular numbers with webbing that
envelops gorse plants. But several regions have seen steep population declines due to predation
by Stethorini and phytoseiids. In New Zealand, the native *S. bifidus* and less commonly the
exotic *P. persimilis* suppress gorse spider mite populations to the extent that “after several years
populations decline rapidly, and never outbreak again” (Hill et al., 2000). Peterson et al. (2000)
found that *S. bifidis* can regulate *T. lintearius*, based on its functional response in laboratory
arenas.
In Australia, predation on gorse mite by the native *Parastethorus histrio* as well as by the
exotic phytoseiid *P. persimilis*, was detected soon after initial releases in Tasmania and Victoria,
where “it is expected that both predators will significantly restrict its impact” (Ireson et al., 2003;
2004). Davies et al. (2007) estimated that 36% reduction in gorse biomass occurred in
Tasmanian plots, where both *Parastethorus histrio* and *Phytoseius persimilis* were common.
Without these predators, they estimated a 44% biomass reduction would have occurred, and this
magnitude of effect was considered important in the context of gorse competition with other
plants.
In northwestern USA, *P. persimilis* has significantly reduced gorse mite colonies 3 to 4 years
post-establishment (Pratt et al., 2003), and *S. punctillum* “has also caused severe declines”
(Coombs et al., 2004), although the magnitude of the effect on the target weed is uncertain. The
situation in Chile was more favorable for gorse mite populations, where, in spite of the presence
of *Parastethorus histrio* in Chile (Aguilera P., 1987), the native staphylinid predator *Oligota centralis* (Solier) was the only gorse mite predator commonly found, and its impact on *T. lintearius* was not strong (Norambuena et al., 2007).

Predation on gorse mite populations by Stethorini, which in at least two of the four regions has had a major impact on this classical weed biocontrol effort, should not come as a surprise. In fact, this so-called biotic resistance was observed in Europe by Schroeder and Zwölfer (1970) in endemic gorse habitats, predicted by Ireson et al. (1999), and continues in the UK, where *S. punctillum* and phytoseiid predators limit gorse mite outbreaks (e.g., Kirby, 2005).

5. Conclusions and directions for future work.

Stethorini occur in association with spider mites in a variety of habitats throughout much of the world. Although considered specialist predators, many species function as ecological habitat generalists, able to disperse to multiple plants and to feed on multiple mite species. We have little understanding, however, of these beetles’ interaction with their environment other than with their essential prey mites. The clear contributions of Stethorini to population regulation of herbivorous mites in less-disturbed systems (e.g., the disruption of tetranychid-based gorse classical biological control) contrasts with numerous observations that the intense management of cropland exacerbates mite outbreaks by disrupting natural predators. The current and potential roles of Stethorini in biological control can be strengthened by targeting research at several key knowledge gaps.

(1) The role of alternative foods is little known, but may play an important role in population dynamics, diapause, and migration, as with other coccinellids (Lundgren 2009b, this issue).

Stethorini consume alternative non-tetranychid mite prey, extrafloral nectar and pollen. They are
sensitive to plant characteristics and thus cultivar choice and vegetational diversity may increase or hinder their efficacy.

(2) The vision and olfaction of Stethorini are apparently acute, yet their role in prey location remains poorly explored. Research to address the sensory contributions to their impressive dispersal abilities, and to investigate their response to spatially dynamic prey, is likely to be particularly fruitful. Related to this, the regulatory functional responses that appear to prevent tetranychid outbreaks merit further attention.

(3) There is a strong need for systematics research on the group, and for molecular tools to distinguish cryptic species. Stethorini introductions have been common (both accidental and intentional) and careless, and non-target considerations (including the dissemination of entomopathogens and displacement of native species) now dictate a more responsible course. This history of redistribution and the likelihood of significant numbers of yet unnamed species (particularly in Asia) compel the advancement of Stethorini systematics.

(4) Habitat management shows potential for increasing the impact of Stethorini on pest populations. The broad prey and host plant ranges of many species make non-crop habitat valuable sources for predators that can rapidly deploy to colonize and protect crops. These refuges can assist overwintering success in temperate systems, and provide safe havens from pesticides. In milder climates, perennial reservoirs may serve as refuges within diversified annual plantings (e.g., the role of the perennial castor bean, common in Indian farmlands, which serves as a reservoir for *Stethorus gilvifrons and S. pauperculus* [Mathur, 1969; Puttaswamy and ChannaBasavanna, 1977]). Use of chemical control, even pesticides that have novel selectivity (e.g. insect growth regulators) or are organic-approved (e.g. elemental sulfur) can be very harmful to Stethorini and other biological agents. These effects are often seen only after
registration and widespread use; the breadth of pre-release non-target screening should be broadened (e.g. with method of Nienstedt and Miles, 2008) to include the Stethorini.

The full potential of Stethorini as predators of spider mites will only be realized when cultural and chemical farm management practices are truly integrated with biological controls based on farm-scale scientific experimentation. Where proper conditions have come together, such as in Pennsylvania apple orchards, in Asian citrus and tea, and in several other tropical systems, Stethorini play an important role -- sometimes the most important role -- in suppressing tetranychid populations.

Acknowledgments

We are grateful to Jon Lundgren and Michèle Roy and to two anonymous reviewers, for helpful comments on an earlier draft. Michael Athanas of IIBBL, Long Zhang of China Agricultural University, Michèle Roy of MAPAQ Laboratoire de Diagnostic en Phytoprotection, and the staff of the National Agricultural Library, located a number of the publications consulted. Meiling Z. Webb of IIBBL, Tina Trenczek of University of Giessen, Germany, Hazem Abdelnabby of Benha University in Egypt, and Hossein Hosseini Moghadam of Gent University in Belgium, provided very useful translations. Mention of any proprietary products does not constitute endorsement by the USDA.
References


Biddinger, D.J., 1993. Toxicity, stage specificity, and sublethal effects of abamectin and several classes of insect growth regulators to *Platynota idaeusalis* (Lepidoptera: Tortricidae) and


Butcher, F.G., 1951. Some observations on various insects found on fruit and ornamentals in the Miami area. Proceedings of the Florida State Horticultural Society 1951, 251-254.


Entomophaga 32, 49-57.


Ireson, J.E., Gourlay, A.H., Kwong, R.M., Holloway, R.J., Chatterton, W.S., 2003. Host
specificity, release, and establishment of the gorse spider mite, *Tetranychus lintearius*
Dufour (Acarina: Tetranychidae) for the biological control of gorse, *Ulex europaeus* L.
(Fabaceae) in Australia. Biological Control 26, 117–127.

Progress on the biological control of gorse (*Ulex europaeus*) in Australia. In: Cullen, J.M.,
Briese, D.T., Kriticos, D.J., Lonsdale, W.M., Morin, L., Scott, J.K. (Eds.), Proceedings of
the XI International Symposium on Biological Control of Weeds, Canberra, Australia, 27

antagonist of spidermites in the city (abstract). Mitteilungen aus der Biologischen
Bundesanstalt für Land- und Forstwirtschaft 370, 291.

von Nütlingen an Stadtbäumen. Pflanzenschutzamt Berlin, internal report.

James, D.G., 2003a. Synthetic herbivore-induced plant volatiles as field attractants for beneficial

James, D.G., 2003b. Pesticide susceptibility of two coccinellids (*Stethorus punctum picipes* and
*Harmonia axyridis*) important of biological control of mites and aphids in Washington
hops. Biocontrol Science and Technology 13, 253-259.

James, D.G., 2004. Effect of buprofezin on survival of immature stages of *Harmonia axyridis*,
*Stethorus punctum picipes* (Coleoptera: Coccinellidae), *Orius tristicolor* (Hemiptera:
Anthocoridae), and *Geocoris* spp. (Hemiptera: Geocoridae). Journal of Economic
Entomology 97, 900-904.


Mora Morin, J., 1991. *Stethorus utilis* (Coleoptera: Coccinellidae) pequeña cotorrita que se alimenta de acaros tetraniquidos que atacan a los citricos. Comunicacion corta. Centro Agrícola (Cuba) 18, 83-84.


Plaut, H.N., 1965. On the phenology and control value of Stethorus punctillum Weise as a predator of Tetranychus cinnabarinus Boisd. in Israel. Entomophaga 10, 133-137.


Roy, M., Brodeur, J., Cloutier, C., 2005. Seasonal activity of the spider mite predators Stethorus punctillum (Coleoptera: Coccinellidae) and Neoseiulus fallacis (Acarina: Phytoseiidae) in raspberry, two predators of Tetranychus mcdanieli (Acarina: Tetranychidae). Biological Control 34, 47-57.


Swezey, O. H., 1923. The Hawaiian planter’s record 27, 4-7.

Swezey, O. H., 1925. The Hawaiian planter’s record 29, 369-376.


Figure 1. Recorded geographic distribution of Stethorini on agricultural crops. *Denotes introduced or suspected introduced. See Table 1 and Kapur (1948).
Table 1. Stethorini as predators of tetranychid and tenuipalpid mites on various plant hosts. The referenced publications describe the predator as preying on prey listed; records with "Stethorus sp." are not listed.

<table>
<thead>
<tr>
<th>Predator and prey</th>
<th>Crop or plant</th>
<th>Region</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parastethorus guangxiensis (Pang &amp; Mao)⁵</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Panonychus citri</em> (McGregor)</td>
<td>Citrus</td>
<td></td>
<td>Li et al. (1990)</td>
</tr>
<tr>
<td>China (Guangxi)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parastethorus gutierrezi (Chazeau) ⁶</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Oligonychus</em> sp.</td>
<td>Coconut palm</td>
<td></td>
<td>Chazeau (1979)</td>
</tr>
<tr>
<td>New Hebrides</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parastethorus histrio (Chazeau) ⁷</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Brevipalpus chilensis</em> Baker</td>
<td>Grape</td>
<td></td>
<td>Prado (1991)</td>
</tr>
<tr>
<td>Chile</td>
<td></td>
<td></td>
<td>Citrus</td>
</tr>
<tr>
<td><em>Eutetranychus orientalis</em> (Klein)</td>
<td></td>
<td></td>
<td>Dhooria (1981)</td>
</tr>
<tr>
<td>India</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Oligonychus thelytokus</em> Gutierrez</td>
<td></td>
<td></td>
<td>Lychee, Plumeria</td>
</tr>
<tr>
<td>New Caledonia</td>
<td></td>
<td></td>
<td>Chazeau (1979)</td>
</tr>
<tr>
<td><em>Oligonychus vitis</em> Zaher &amp; Shehata</td>
<td>Table Grapes</td>
<td></td>
<td>Prado (1991)</td>
</tr>
<tr>
<td>Chile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Oligonychus yothersi</em> (McGregor)</td>
<td>Avocado</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Oligonychus</em> sp.</td>
<td>Pine tree (<em>Pinus sp.</em>)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Panonychus citri</em> (McGregor)</td>
<td>Citrus</td>
<td></td>
<td>Houston (1980)</td>
</tr>
<tr>
<td>Chile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Panonychus citri</em> (McGregor)</td>
<td>Citrus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peru</td>
<td></td>
<td></td>
<td>Guanilo and Martinez (2007)</td>
</tr>
<tr>
<td><em>Panonychus ulmi</em> (Koch)</td>
<td>Apple</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tetranychus kansawai</em> Kishida</td>
<td>Bindweed (<em>Convolvulus</em> sp.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tetranychus lintearius</em> Dufour</td>
<td>Gorse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tetranychus neocaledonicus</em> Andre</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Caledonia</td>
<td></td>
<td></td>
<td>Chazeau (1979)</td>
</tr>
<tr>
<td><em>Tetranychus urticae</em> Koch</td>
<td>Various vegetables</td>
<td></td>
<td>Chazeau et al. (1974)</td>
</tr>
<tr>
<td>Reunion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tetranychus urticae</em> Koch</td>
<td>Papaya</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tetranychidae</td>
<td>Apple</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Zealand</td>
<td></td>
<td></td>
<td>Chazeau (1979)</td>
</tr>
</tbody>
</table>
1318  Tetranychidae  
1319  USA (Texas)  
1320  Parastethorus indira (Kapur)  
1321  Tetranychidae  
1322  India  
1323  

**Parastethorus nigripes (Kapur)**

1324  *Oligonyches pratensis* (Banks)  
1325  USA (Texas, Oklahoma)  
1326  *Panonychus citri* (McGregor)  
1327  Australia  
1328  *Panonychus ulmi* (Koch)  
1329  Australia  
1330  *Tetranychus lambi* Pritchard & Baker  
1331  Australia  
1332  *Tetranychus urticae* Koch  
1333  Australia  
1334  *Tetranychus urticae* Koch  
1335  Australia  
1336  *Tetranychus urticae* Koch  
1337  Australia  
1338  *Stethorus aethiops* Weise  
1339  *Mononychellus tanajoa* (Bondar) complex  
1340  Kenya  
1341  *Tetranychus lombardinii* Baker & Pritchard  
1342  Kenya  
1343  *Tetranychus neocaledonicus* Andre  
1344  Kenya  
1345  *Tetranychus urticae* Koch  
1346  Kenya  
1347  *Stethorus aptus* Kapur  
1348  *Panonychus citri* (McGregor)  
1349  China (Guangxi)  
1350  *Stethorus bifidus* Kapur  
1351  *Bryobia* sp.  
1352  New Zealand  
1353  *Panonychus ulmi* (Koch), *Tetranychus urticae* Koch  
1354  New Zealand  
1355  *Tetranychus lambi* Pritchard & Baker  
1356  New Zealand  
1357  *Tetranychus linearius* Dufour  
1358  New Zealand  
1359  *Tetranychus urticae* Koch  
1360  New Zealand  
1361  *Stethorus caseyi* Gordon & Chapin  
1362  *Oligonyches pratensis* (Banks)  
1363  USA (Texas)  
1364  *Stethorus chengi* Sasaji  

Maize, redbud tree (*Cercis*)  
Pollock & Michels (2003)  
Taro  
Kapur (1950)  
Corn  
Pollock & Michels (2002)  
Citrus  
Beattie & Gellatley (1983)  
Apple  
Walters (1976a)  
Banana  
Houston (1980)  
Apple  
Edwards & Hodgson (1973)  
Soya  
Houston (1980)  
Alfalfa seed crop  
Bailey & Caon (1986)  
Cassava  
Yaseen et al. (1982)  
Cassava  
Yaseen et al. (1982)  
Cassava  
Yaseen et al. (1982)  
Cassava  
Yaseen et al. (1982)  
Citrus  
Li et al. (1990)  
Apple  
McMurtry et al. (1970)  
Apples, plums, pears  
Collyer (1964)  
Apple  
McMurtry et al. (1970)  
Gorse  
Peterson et al. (1994)  
Raspberry  
Thomas & Burnip (1984);  
Maize  
Pollock & Michels (2003)
<table>
<thead>
<tr>
<th>Page</th>
<th>Species</th>
<th>Location</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1365</td>
<td><em>Panonychus citri</em> (McGregor)</td>
<td>Citrus</td>
<td>China Chen &amp; Zhao (1994)</td>
</tr>
<tr>
<td>1366</td>
<td><em>Tetranychus urticae</em> Koch</td>
<td>Papaya</td>
<td>Wen and Lee (1981)</td>
</tr>
<tr>
<td>1367</td>
<td><em>Stethorus comoriensis</em> Chazeau</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1368</td>
<td><em>Oligonychus coffeae</em> (Nietner)</td>
<td>Plumeria</td>
<td></td>
</tr>
<tr>
<td>1369</td>
<td><em>Tetranychus neocaledonicus</em> Andre</td>
<td>Breadfruit</td>
<td></td>
</tr>
<tr>
<td>1370</td>
<td><em>Comoro Islands</em> Chazeau</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1371</td>
<td><em>Stethorus darwini</em> (Brethes)</td>
<td>Cassava</td>
<td>Yaseen et al. (1982)</td>
</tr>
<tr>
<td>1372</td>
<td><em>Mononychellus caribbeanae</em> McG., <em>Mononychellus</em></td>
<td>Apple</td>
<td></td>
</tr>
<tr>
<td>1373</td>
<td><em>Guyana, Surinam</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1374</td>
<td><em>tanajoa</em> (Bondar) complex, various Tetranychidae</td>
<td>Tomato</td>
<td></td>
</tr>
<tr>
<td>1375</td>
<td><em>Panonychus ulmi</em> Koch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1376</td>
<td><em>Brazil</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1377</td>
<td><em>Tetranychus evansi</em> Baker &amp; Pritchard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1378</td>
<td><em>Brazil</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1379</td>
<td><em>Stethorus expectatus</em> Chazeau</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1380</td>
<td><em>Oligonychus, Panonychus, Schizotetranychus</em> spp.</td>
<td>Various crops</td>
<td></td>
</tr>
<tr>
<td>1381</td>
<td><em>New Guinea</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1382</td>
<td><em>Tetranychus fijiensis</em> Hirst</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1383</td>
<td><em>New Guinea</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1384</td>
<td><em>Tetranychus lambi</em> Pritchard &amp; Baker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1385</td>
<td><em>New Guinea</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1386</td>
<td><em>Stethorus exsultabilis</em> Chazeau</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1387</td>
<td><em>New Guinea</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1388</td>
<td><em>Tetranychus fijiensis</em> Hirst</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1389</td>
<td><em>New Guinea</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1390</td>
<td><em>Stethorus fenestralis</em> Houston</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1391</td>
<td><em>Tetranychus kanzawai</em> Kishida</td>
<td>Bindweed (<em>Convolvulus</em> sp.)</td>
<td>Houston (1980)</td>
</tr>
<tr>
<td>1392</td>
<td><em>Australia</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1393</td>
<td><em>Tetranychus lambi</em> Pritchard &amp; Baker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1394</td>
<td><em>Australia</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1395</td>
<td><em>Tetranychus urticae</em> Koch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1396</td>
<td><em>Australia</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1397</td>
<td><em>Stethorus fijiensis</em> Kapur</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1398</td>
<td><em>Tetranychidae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1399</td>
<td><em>Stethorus fuerschi</em> Chazeau</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1400</td>
<td><em>Oligonychus chazeaui</em> Gutierrez</td>
<td>Palm tree</td>
<td></td>
</tr>
<tr>
<td>1401</td>
<td><em>Madagascar</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1402</td>
<td><em>Tetranychus roseus</em> Gutierrez</td>
<td>Palm tree</td>
<td></td>
</tr>
<tr>
<td>1403</td>
<td><em>Madagascar</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1404</td>
<td><em>Stethorus gilvifrons</em> (Mulsant)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1405</td>
<td><em>Eutetranychus hirsti</em> Pritchard &amp; Baker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1406</td>
<td><em>Eutetranychus orientalis</em> (Klein)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1407</td>
<td><em>Oligonychus afrasiaticus</em> (McGregor)</td>
<td>Tea</td>
<td></td>
</tr>
<tr>
<td>1408</td>
<td><em>India</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1409</td>
<td><em>Oligonychus coffeae</em> (Nietner)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1410</td>
<td><em>India</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1411</td>
<td><em>Eutetranychus hirsti</em> Pritchard &amp; Baker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1412</td>
<td><em>Eutetranychus orientalis</em> (Klein)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1413</td>
<td><em>Oligonychus afrasiaticus</em> (McGregor)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1414</td>
<td><em>Oligonychus coffeae</em> (Nietner)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1415</td>
<td><em>India</em></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
1416 *Oligonychus sacchari* (McGregor) Sugarcane Iran
1418 *Panonychus ulmi* Koch Apple Iran
1419 *Tetranychus turkestani* Ugarov & Nikolski Strawberry Iran
1420 *Tetranychus turkestani* Ugarov & Nikolski Various ornamentals Iran
1421 *Tetranychus urticae* Koch Castor bean Mathur (1969)
1422 *Tetranychus urticae* Koch Cucumbers, beans Iran
1423 *Tetranychus urticae* Koch Various crops McMurtry et al. (1970)
1424 *Stethorus griseus* Whitehead Apple Chazeau (1979)
1425 *Stethorus japonicus* Kamiya Citrus McMurtry et al. (1970)
1426 *Stethorus japonicus* Kamiya Mandarin orange Tsuchiya (2005)
1428 *Stethorus jejunus* Casey Tea, hydrangea Mori et al. (2005)
1429 *Stethorus jejunus* Casey Apple, citrus Mori et al. (2005)
1432 *Tetranychus kanzawai* Kishida Tea, hydrangea Yaseen et al. (1982)
1433 *Tetranychus lombardini* Baker & Pritchard Cassava Yaseen et al. (1982)
1434 *Tetranychus neocaledonicus* Andre Cassava Yaseen et al. (1982)
1435 *Tetranychus viennensis* Zacher Cassava Yaseen et al. (1982)
1436 *Stethorus madecassus* Chazeau Areca nut palm, coconut Puttaswamy &
1437 *Stethorus madecassus* Chazeau Jujube Wen et al. (1993)
1438 *Stethorus loi* Sasaji Papaya Wen and Lee (1981)
1439 *Stethorus loi* Sasaji Carambola Chang & Leu (1986)
1466 Tetranychus neocaledonicus Andre
1467 Madagascar
1468 Tetranychus spp., Oligonychus spp.
1469 Madagascar
1470 Stethorus par семпunctatus Puttarudrian & ChannaBasavanna
1471 Rapiella indica Hirst (Tenuipalpidae)
1472 India
1473 Stethorus parapausculatus Pang
1474 Tetranychus piercei McGregor
1475 China (Hainan)
1476 Tetranychus urticae Koch
1477 China
1478 Stethorus pauperculus Weise
1479 Oligonychus indicus (Hirst)
1480 India
1481 Oligonychus neocaledonicus Andre
1482 India
1483 Tetranychus ludeni Zacher
1484 India
1485 Stethorus pauperculus Weise
1486 India
1487 Tetranychus ludeni Zacher
1488 India
1489 Stethorus punctillum Weise
1490 Eotetranychus buxi (Garman)
1491 USA (Maryland)
1492 Eotetranychus carpini (Oudemans)
1493 Italy
1494 Eotetranychus tiliarium Hermann
1495 Germany
1496 Oligonychus afrasiaticus (McGregor)
1497 Algeria
1498 Oligonychus bicolor (Banks)
1499 Italy
1500 Oligonychus ununguis (Jacobi)
1501 Canada
1502 Oligonychus ununguis (Jacobi)
1503 USA (Pennsylvania)
1504 Panonychus citri (McGregor)
1505 China
1506 Panonychus ulmi (Koch)
1507 Canada
1508 Panonychus ulmi (Koch)
1509 Europe
1510 Panonychus ulmi (Koch)
1511 Italy
1512 Panonychus bioculatus (Wood-Mason)
1513 Bangladesh
1514 Panonychus cinnabarinus (Boisduval)
1515 Israel
1516 Cotton
1467 Chazeau (1971a)
1468 Various crops
1469 Chazeau (1971a)
1471 Coconut palm
1472 Gupta (2001)
1473 Banana
1474 Chen et al. (2005)
1475 Cassava
1476 Lin & Chen (1984)
1477 Sorghum
1478 Kapur (1948)
1479 Papaya, castor bean, and
1480 Puttaswamy &
1481 Various crops
1482 Eggplant
1483 Puttaswamy &
1484 Waterhyacinth
1485 Ansari & Pawar (1992)
1486 Boxwood (Buxus sp.)
1487 Creary (2009)
1488 Grapes
1489 Laffi (1982)
1490 Linden trees (Tilia spp.)
1491 Jäckel et al. (2000)
1492 Date palm
1493 Idder & Pintureau (2008)
1494 Chestnut
1495 Cinti et al. (1995)
1496 Chinese Chestnut
1497 Putman (1955a)
1498 Various ornamental spruces,
1499 Wheeler et al. (1973)
1500 pines, cedars & Arborvitae
1501 Citrus
1502 Tian (1995)
1503 Fruit trees
1504 Putman (1955a)
1505 Fruit trees
1506 McMurtry et al. (1970)
1507 Apple
1508 Pasqualini & Antropoli (1994)
1509 Marigold
1510 Taleb & Sardar (2007)
1511 Cotton, apple, watermelon
1512 Plaut (1965)
1517  \textit{Tetranychus mcdanieli} McGregor  
1518  Canada  
1519  \textit{Tetranychus shoenei} McGregor  
1520  USA (Maryland)  
1521  \textit{Tetranychus urticae} Koch  
1522  Canada  
1523  \textit{Tetranychus urticae} Koch  
1524  Israel  
1525  \textit{Tetranychus urticae} Koch  
1526  Netherlands  
1527  \textit{Tetranychus viennensis} Zacher  
1528  Turkey  
1529  \textit{Stethorus punctum picipes} Casey  
1530  \textit{Oligonychus punicea} (Hirst)  
1531  USA (California)  
1532  \textit{Panonychus citri} (McGregor)  
1533  USA (California)  
1534  \textit{Tetranychus tumidus} Banks  
1535  Cuba  
1536  \textit{Tetranychidae}  
1537  USA  
1538  \textit{Stethorus punctum punctum} (Leconte)  
1539  \textit{Panonychus ulmi} (Koch) and other tetranychids  
1540  North America  
1541  \textit{Tetranychus mcdanieli} McGregor  
1542  Canada  
1543  \textit{Tetranychus pacificus} McGregor  
1544  Canada  
1545  \textit{Stethorus siphonulus} Kapur  
1546  \textit{Eutetranychus banksi} McGregor  
1547  Hawaii  
1548  \textit{Oligonychus exsiccator} (Zehntner)  
1549  Hawaii  
1550  \textit{Panonychus citri} (McGregor)  
1551  China (Fujian)  
1552  \textit{Tetranychus cinnabarinus} (Boisduval)  
1553  Hawaii  
1554  \textit{Tetranychus neocaledonicus} Andre  
1555  French Polynesia  
1556  \textit{Tetranychus piercei} McGregor  
1557  China (Guangdong)  
1558  \textit{Tetranychus tumidus} Banks  
1559  Hawaii  
1560  \textit{Tetranychus urticae} Koch  
1561  Hawaii  
1562  \textit{Stethorus tridens} Gordon  
1563  \textit{Panonychus citri} McGregor  
1564  Peru  
1565  \textit{Tetranychus cinnabarinus} (Boisduval)  
1566  Colombia  

Raspberry  
Roy et al. (2002)  
Elm (\textit{Ulmus americana})  
Creary (2009)  
Beans  
Putman (1955a)  
Sugar beets  
Plaut (1965)  
Greenhouse crops  
McMurtry et al. (1970)  
Apple & other fruits  
Yigit & Uygun (1986)  
Avocado  
McMurtry et al. (1969)  
Citrus  
McMurtry et al. (1970)  
Banana  
Perez et al. (2004)  
Walnuts, melon, apple  
McMurtry et al. (1970)  
Fruit trees  
McMurtry et al. (1970)  
Fruit trees  
Robinson (1953)  
Fruit trees  
Robinson (1953)  
Ornamentals  
Raros and Haramoto (1974)  
Sugar cane  
Raros and Haramoto (1974)  
Citrus  
Huang et al. (1988)  
Papaya  
Rosenheim et al. (2004b)  
Custardapple (\textit{Anona} sp.)  
Chazeau (1979)  
Papaya  
Lui & Lui (1986)  
Papaya  
Raros and Haramoto (1974)  
Papaya  
Raros and Haramoto (1974)  
Citrus  
Guanilo and Martinez (2007)  
Cassava  
Gordon (1982)
1567 *Tetranychus evansi* Baker & Pritchard  
1568 Brazil  
1569 *Tetranychus urticae* Koch  
1570 Colombia  
1571 Tetranychidae  
1572 Colombia  
1573 *Stethorus utilis* Horn  
1574 *Eotetranychus hicoriae* (McGregor)  
1575 USA (Southeast)  
1576 *Eotetranychus sexmaculatus* (Riley)  
1577 USA (Florida)  
1578 *Eutetranychus banksi* (McGregor)  
1579 USA (Texas)  
1580 *Mononychellus caribbeanae* (McGregor), *Mononychellus tanajoa* (Bondar) complex, various Tetranychidae  
1581 Colombia, Nicaragua, Trinidad  
1582 Oligonychus pratensis (Banks)  
1583 USA (Texas)  
1584 *Tetranychus urticae* Koch, *Panonychus citri* (McGregor)  
1585 Cuba  
1586 Tetranychidae  
1587 USA (Florida)  
1588 Stethorus vagans (Blackburn)  
1589 Bryobia praetiosa Koch  
1590 Australia (Tasmania)  
1591 Oligonychus exsiccator (Zehntner)  
1592 USA (Hawaii)  
1593 Oligonychus thelytokus Gutierrez  
1594 New Caledonia  
1595 Oligonychus sp.  
1596 New Caledonia  
1597 Oligonychus sp.  
1598 Australia  
1599 Panonychus ulmi (Koch)  
1600 Australia  
1601 Tetranychus lambi Pritchard & Baker  
1602 Australia  
1603 New Caledonia  
1604 Tetranychus lambi Pritchard & Baker  
1605 Australia  
1606 Tetranychus marianae McGregor  
1607 New Caledonia  
1608 Tetranychus marianae McGregor  
1609 New Hebrides  
1610 *Tetranychus neocaledonicus* Andre  
1611 New Caledonia  
1612 Tetranychus urticae Koch  
1613 New Caledonia  
1614 Tetranychus urticae Koch  
1615 Stethorus vinsoni Kapur  
1616 Australia  
1617 *Stethorus utilis* Horn  
1618 Brazil Britto et al. (2009)  
1619 *Tetranychus urticae* Koch  
1620 Gordon (1982)  
1621 Eggplant  
1622 Stethorus utilis Horn  
1623 Tedders (1983)  
1624 Citrus  
1625 Stethorus utilis Horn  
1626 McMurtry et al. (1970)  
1627 Citrus  
1628 McMurtry et al. (1970)  
1629 Cassava  
1630 *Stethorus utilis* Horn  
1631 Yaseen et al. (1982)  
1632 Sorghum  
1633 Ehler (1974)  
1634 Citrus  
1635 Mora Morin (1991)  
1636 Lychee  
1637 Butcher (1951)  
1638 Stethorus vagans (Blackburn)  
1639 Clover  
1640 Evans (1943)  
1641 Sugar cane  
1642 Swezey (1923)  
1643 Lychee  
1644 Chazeau (1979)  
1645 Coconut palm  
1646 Chazeau (1979)  
1647 Pine tree (*Pinus* sp.)  
1648 Houston (1980)  
1649 Apple  
1650 Walters (1976a)  
1651 Cassava  
1652 Chazeau (1979)  
1653 Papaya  
1654 Houston (1980)  
1655 Castor bean  
1656 Chazeau (1979)  
1657 Ornamentals  
1658 Cassava  
1659 Chazeau (1979)  
1660 Vegetables  
1661 Chazeau (1979)  
1662 Soya and beans  
1663 Houston (1980)
<table>
<thead>
<tr>
<th></th>
<th>Taxon</th>
<th>Host Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1618</td>
<td><em>Tetranychus evansi</em> Baker &amp; Pritchard</td>
<td>solanaceous plants</td>
</tr>
<tr>
<td>1619</td>
<td>Mauritius</td>
<td>Mouitia (1958)</td>
</tr>
</tbody>
</table>

a Syn.: *Stethorus, Parastethorus* gen. nov. Ślipiński 2007.
c Reported as fed upon by Syn.: *Stethorus loxtoni* Britton & Lee
d Syn.: *Stethorus ogloblini* Nunenmacher (Gordon 1982).
e Syn.: *Stethorus picipes* Casey (Gordon 1985).
f Syn.: *Stethorus atomus* Casey (Gordon 1985).
Table 2. Some biological parameters observed for six species of *Stethorus* predators of tetranychid mites (mean / range in italics)

<table>
<thead>
<tr>
<th>Predator</th>
<th>S. punctillum</th>
<th>S. punctum picipes</th>
<th>S. tridens</th>
<th>S. japonicus</th>
<th>S. loi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prey</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weise, on</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Casey, on</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chazeau, on</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gordon, on</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kamija, on</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sasaji, on</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Prey species</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. mcdanieli</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O. punicae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. evansi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. urticae</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T. kanzawai</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>McGregor (Hirst)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andre</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roy et al.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanigoshi and</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chazeau 1974a, b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiaboe et al. 2007</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mori et al. 2005;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shih et al. 1991</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002, 2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>McMurtry 1977</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th><strong>Temperature (°C)</strong></th>
<th><strong>Development time (days)</strong></th>
<th><strong>Length of pre-oviposition period (days)</strong></th>
<th><strong>Total progeny (eggs)</strong></th>
<th><strong>Longevity of female (days)</strong></th>
<th><strong>R₀/rₘ/T</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24/16-32</td>
<td>17/49-12</td>
<td>1.2/4.0-0.8</td>
<td>280/7-47</td>
<td>70/112-19</td>
<td>43.6/10-134</td>
</tr>
<tr>
<td></td>
<td>24.5/22-27</td>
<td>17/15.8-19</td>
<td>5.6/4-6</td>
<td>221/12-391</td>
<td>90.0/75-243</td>
<td>103.3/0.121/38.3</td>
</tr>
<tr>
<td></td>
<td>25/20-30</td>
<td>17/28-11</td>
<td>4.2/3-7</td>
<td>184/20-</td>
<td>69/128-</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>15.3</td>
<td></td>
<td></td>
<td></td>
<td>R₀ = net production, rₘ = intrinsic rate of natural increase per day; T = mean generation time (days)</td>
</tr>
<tr>
<td>R₀/rₘ/T</td>
<td>-0.100/</td>
<td>-0.025/</td>
<td></td>
<td></td>
<td></td>
<td>103.3/0.121/38.3</td>
</tr>
<tr>
<td></td>
<td>92.4/0.155/29.2</td>
<td>53/0.104/38</td>
<td></td>
<td></td>
<td></td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>271/0.156/51.1</td>
<td>50/0.160/24.4</td>
<td></td>
<td></td>
<td></td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>123</td>
<td>184°</td>
<td></td>
<td></td>
<td></td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>491/303-754°</td>
<td>361/325-379°</td>
<td></td>
<td></td>
<td></td>
<td>66</td>
</tr>
<tr>
<td>Prey consumed during development</td>
<td>239b</td>
<td>361/325-379°</td>
<td></td>
<td></td>
<td></td>
<td>66</td>
</tr>
<tr>
<td>Prey consumed by ovipositing females (mites per day)</td>
<td>66.3/52-87°b</td>
<td>35.9/32-44°e</td>
<td>46.8/11-80°f</td>
<td>67.8°e</td>
<td>294°f</td>
<td></td>
</tr>
</tbody>
</table>

\[ a \] Prey = various instars and adults
\[ b \] Prey = proto- and deutonymphs.
\[ c \] Prey = eggs only
\[ d \] Prey = adult females
\[ e \] Prey = eggs only, but averaged for only the first 20 days after adult female eclosion
\[ f \] Prey = deutonymphs only
\[ g \] Prey = eggs only, but averaged for only the first 20 days after adult female eclosion
\[ h \] Adult beetles, males and females, fed