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Review

Coccinellidae as predators of mites: Stethorini in biological control

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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, avocadoes, 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.

1. Introduction

The approximately 90 worldwide species of the tribe Stethorini Dobzhansky (genera *Stethorus* Weise and *Parasthethorus* 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, 2009a,b). 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; 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

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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 US 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 Stethorini 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). 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 Stethorini 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, 1955b; 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 undoubtedly 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

Fig. 1. Recorded geographic distribution of Stethorini on agricultural crops. * Denotes introduced or suspected introduced. See Table 1 and Kapur (1948).