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# Research Article

# Investigation of biological control agents for the invasive plant *Parthenium hysterophorus* L. (Asteraceae) in Southern Oman

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**Abstract.** *Parthenium hysterophorus* L. (Asteraceae) is an invasive alien weed of increasing ecological and agricultural concern in Oman. Surveys in the monsoon-influenced Dhofar region to assess the natural herbivore complex associated with this species resulted in the documentation of fifteen insect taxa representing Coleoptera, Lepidoptera, Diptera, Hemiptera, and Orthoptera feeding on different plant tissues. Thirteen of these species were prioritized for detailed study of their abundance and impact on *Parthenium*. These included stem and leaf feeders (*Nematocerus omanicus* Rheinheimer, 2003; *Chaetocnema tarsalis* Wollaston, 1860; *Aphthona cookei* LeConte, 1859), a folivorous erebid moth (*Hypena* Schrank, 1802), flower- and leaf-feeding dipterans (*Lethyna* Munro, 1957; *Liriomyza* Mik, 1894; *Phytoliriomyza cf. perpusilla* (Meigen, 1830); *Toxomerus floralis* (Fabrícius, 1798) (New World hoverfly)), and several hemipteran sap feeders (*Adria parvula* (Dallas, 1851); *Myzus persicae* (Sulzer, 1776); Dictyopharidae Spinola, 1839; Deltocephalinae Dallas, 1870; *Taylorilygus pallidulus* (Blanchard, 1852), *Phaenococcus* Cockerell, 1902). Orthopteran assemblages were also observed consuming foliage. Abundance and distribution varied across sites, with *Hypena* sp, *Lethyna* sp, and *Liriomyza* sp causing substantial damage to foliage and flowers, indicating potential utility as biological control agents. In contrast, highly polyphagous taxa such as *M.persicae* and *Phaenococcus* sp. appeared less suitable due to their broad host range and associated risks to crops. These findings represent the first comprehensive inventory of herbivores feeding on *P. hysterophorus* in Oman and highlight candidate species for further evaluation. Targeted studies on taxonomy, life history, host specificity, and ecological interactions are required to determine their suitability for integration into biological control programs against *Parthenium*.

**Keywords:** Dhofar region, Native plants, phytophagous insects.

## *Introduction*

Invasive plant species threaten biodiversity by outcompeting native species for resources and disturbing the balanced plant-insect-interactions (Crooks 2002; Levine & D'Antonio 2003; Ehrenfeld 2010; Jeschke et al. 2014). Several studies have been conducted to understand the ecological role of invasive plants through their interactions with native insect communities, including herbivory, pollination, and seed dispersal (Maron & Vilà 2001; Herrera et al. 2002; Davies & Sheley 2007; Martins et al. 2009; Vanparys et al. 2008; Gibson et al. 2013; Pearse & Altermatt 2013). Understanding how invasive plant species interact with native insect communities is crucial for effective management of native plants (Vermeij 1996). Native insects that come across non-native plants may show degrees of adaptation to the defensive compounds produced by invasive plants (Engelkes et al. 2008). The secondary metabolites released by certain invasive plants can either be toxic result in the decline of native insect populations (Harvey et al. 2010) or attractive (Callaway & Ridenour 2004; Harvey & Fortuna 2012), which play an important role in the successful establishment and expansion of non-native plants (Keane & Crawley 2002; Pyšek et al. 2011). Herbivory on invasive plants is a significant phenomenon that can potentially limit plant invasion (Maron & Vilà 2001). The increase in visitation and oviposition may enhance the performance of native insects on invasive plants, potentially leading to a host shift (Carroll 2007). The shift of native insect herbivores towards non-native invasive plants, caused by the massive replacement of native plants, may enable the native plants to grow and establish themselves once again. The results of interactions with invasive plants depend on whether insects use these plants for feeding and laying eggs, as well as whether the plants support the growth and development of their offspring. It is crucial to understand the relationship between insect choices for oviposition, feeding, growth, and larval survival, often described as preference and performance when examining how native insects interact with invasive plants.

*Parthenium* weed (*Parthenium hysterophorus* L.) is susceptible to herbivory (Raghu & Dhileepan 2005), but there are no herbivores or pathogens in the introduced ranges that have been identified to significantly affect this invasive plant (Dhileepan & Strathie 2009). Management strategies for *Parthenium* weed include chemical treatments, physical removal, grazing control, and biological methods. Biological control is considered the most effective and economical approach for managing *Parthenium* weed in many situations. Classical biological control using host-specific natural enemies introduced from the plant's native range is the most cost-effective and long-term management strategy for *Parthenium* weed (Page & Lacey 2006). Biological control of *Parthenium* weed began in Australia in 1976, as testing and release of biological control agents continued until 2004, after which these agents were further evaluated and redistributed (Dhileepan et al. 2019). Following successful outcomes in Australia, biological control was later initiated in India, Sri Lanka, South Africa, Ethiopia, Tanzania, and Oceania. Attempts to expand the use of biological control (for example, in East Africa) are currently underway (Dhileepan et al. 2019). A total of approximately 262 phytophagous arthropod species and several fungal pathogens have been catalogued from *Parthenium* weed in the southern USA and Mexico (McClay et al. 1995). In Brazil and Argentina, about 100 insect species have been recorded (Dhileepan & McFadyen 2012).

The situation of *Parthenium* in southern Oman has become catastrophic since its initial invasion in 2010. The plant has spread over vast areas, covering around 3,000 acres across various mountainous terrains, valleys, and plains. Finding solutions to control this invasive species has become urgent, as it competes with native plants and disrupts animal communities in the region.

In Oman, several approaches have been considered for the management of *P. hysterophorus*, yet no management strategies have been effectively implemented at a large scale. Mechanical control, including manual uprooting and slashing, has been practiced locally but is limited by labour intensity and rapid regrowth of the weed. Chemical control through herbicide application has also been implemented; however, environmental concerns, costs, and the need for repeated treatments have prevented its widespread sustainability. Biological control has received attention, with scattered exploratory surveys documenting phytophagous insects associated with *Parthenium*, but no specialized agent has been recommended until now. As a result, management efforts in Oman remain largely fragmented and exploratory, with no sustainable control strategy currently in practice. This study represents the first attempt to survey the plant-eating insects that inhabit *Parthenium* and to examine their effects on the plant and how it responds to them.

## Material and Methods

Field surveys were conducted in September 2024 to investigate phytophagous arthropods associated with *P. hysterophorus* in Dhofar region, southern Oman. Different sites in the region were surveyed including: Samhan Mountain, the coastal plain of Taqah, multiple localities in Rakhyut and Dhalkut, Ateen Mountain, Mughsayl, and Raysut. These sites encompass diverse ecological zones ranging from high-altitude mountains to coastal plains, thereby capturing a broad spectrum of habitats where *P. hysterophorus* occurs.

Sampling was conducted using three complementary methods: (i) sweep-netting with standard entomological hand nets to capture foliar and flying insects, (ii) yellow pan traps placed randomly among *Parthenium* patches to attract small Diptera and Hymenoptera with focusing on nocturnal insects, and (iii) direct hand-picking of visible insects from leaves, stems, and flowers. At each site, *Parthenium* stands were randomly selected, each approximately 20 square meters' strand, and sampling every third to fifth plant encountered in each strand, ensuring coverage of both dense and sparse infestations. Approximately equal sampling effort was applied at each locality to minimize site-level bias. Voucher specimens were preserved for subsequent taxonomic confirmation.

For each collected taxon, relative abundance was estimated using a semi-quantitative scale:

- High (3): consistently abundant (>15 individuals per 10 sweeps or per 10 plants inspected in each strand).
- Moderate (2): occasionally abundant (5-15 individuals per 10 sweeps or plants in each strand).
- Low (1): rarely encountered (<5 individuals per 10 sweeps or plants in each strand).

In addition, the severity of feeding damage on *P. hysterophorus* was visually assessed in situ and categorized as:

- Severe (3): >50% of plant tissue damaged (e.g., defoliation, flower destruction) in each inspected strand.
- Moderate (2): 10-50% tissue damage, localized or patchy feeding per inspected strand.
- Mild (1): <10% tissue damage, scattered or superficial feeding signs per inspected strand.

The study was exploratory, limited by a short sampling period and absence of life cycle or seasonal data. Life stages were not systematically recorded, and temporal fluctuations of herbivore populations remain unknown. Nevertheless, this work provides a baseline inventory, documenting the relative abundance, plant parts targeted, and observable damage caused by herbivorous arthropods on *P. hysterophorus* in Oman. Overall, 15 phytophagous arthropod taxa were recorded, of which 13 species showing higher abundance or clear evidence of feeding damage were prioritized for further ecological assessment.

## Results and Discussion

A total of 15 phytophagous arthropod taxa were recorded feeding on *P. hysterophorus* across seven sites in Dhofar, Oman. Abundance and feeding patterns varied among taxa and sites. Leaf-feeding species, including *Hypena* sp., *Liriomyza* sp., *Chaetocnema tarsalis* Wollaston, 1860, and *Aphthona cookei* LeConte, 1859, were particularly widespread, with *Hypena* sp. and *Liriomyza* sp. causing the most severe foliar damage in eastern Dhofar localities. Flower-feeding species, notably *Lethyna* sp. and *Toxomerus floralis* (Fabrícius, 1798), were abundant on inflorescences, indicating their potential role in reducing reproductive capacity. Sap-feeding hemipterans, including *Taylorilygus cf. pallidulus* (Blanchard, 1852), *Adria parvula* (Dallas, 1851), and *Dictyopharidae*, were moderately abundant and observed on leaves and stems, producing localized feeding effects. *Nematocerus omanicus* Rheinheimer, 2003 adults were found actively consuming leaves and stem tissues, while larvae were not observed. Orthopteran species were moderately abundant and contributed to minor foliar damage.

***Nematocerus omanicus*** (Fig. 1). This species belongs to a periteline genus within *Systates* group. The biology of African Peritelini is similar to *Systates*, but it remains poorly studied. However, some reports state that the larvae of this species feed on roots, while adults feed on leaves. We examined hundreds of *Parthenium* stems and roots, but no evidence of larvae feeding. The adult is eating aggressively in some areas, particularly around Samhan Mountain, as we observed adults were also mating on the plants. The abundance of *N. omanicus* is high in the Samhan Mountain area because we suggest the place is a typical habitat due to the abundance of the "Desert Flower", which is another local food source. The species appears to be polyphytophagus, and feeding on *Parthenium* with the availability of a local host raises a question regarding the host range preference and the ability potential of mouthpart and gut morphological adaptation. Currently, the species seem exophytic, feeding on outer stem cover and leaves, more prevalent in eastren Salalah and poor attendance on westren Salalah. The possible absence of the local food source in some areas may compel larvae to feed on *Parthenium*.

***Hypena*** Schrank, 1802 (Fig. 8). This genus is non-migratory moths, and we guess there are around less than five species from Oman. However, the taxonomy of this morphospecies is unclear to us to detect, it seems to be mostly Afrotropical fauna. The African species is restively diverse and widespread across Africa and southern the Arabian Peninsula. This species caught our attention in feeding on *Parthenium* in large numbers in eastern Dhofar (Samhan, Madinat Al alhaq, Tiwi Ateer) as we guess some areas show more than 60% of the *Parthenium* were infected by this moth. There are some reports that some species of *Hypena* are good agents for invasive plant control. Further studies are required to document its life cycle, as numerical and functional responses are expected within its populations.

***Chaetocnema tarsalis*** Wollaston, 1860 (Fig. 9). The adults of this species feed on the cotyledons and leaves of seedlings. *Chaetocnema* exhibits a feeding behaviour that creates irregular, small holes in the upper leaf layer. In most cases, the feeding damage does not penetrate the leaf entirely, leaving the lower layer intact. We observed this species to be highly prevalent in eastern Salalah (Samhan, Madinat Alhaq, Titam, and Tiwi Ateer), as the symptoms are evident on *Parthenium*. The larval feeding behaviour remains unknown and requires investigation, as understanding this may reveal potential for use in biological control. The population should be monitored to ensure it increases alongside the *Parthenium* community over time.

***Aphthona cookei*** (Fig. 10). The feeding habits of *Aphthona* are similar to those of *Chaetocnema*, making it an important species for weed control in some countries. Although *A. cookei* was found in most surveyed locations, its population density was lower than that of *Chaetocnema*. It may be premature to assess the dynamics of this species on *Parthenium* after only one week, as its population may increase over the following month. Further investigation is necessary for its life cycle.

**Table 1.** Phytophagous arthropods recorded on *Parthenium hysterophorus* in Dhofar, Oman, with relative abundance and observed feeding damage.

| Taxon (Order: Family) | Abundance Level [1] | *Parthenium* Part Target | Feeding Damage [2] | Notes on feeding habit |
|---|---|---|---|---|
| *Nematocerus omanicus* Rheinheimer, 2003 (Curculionidae: Coleoptera) | Moderate (2) | Stem & leaves | Moderate (2) | Adults feed aggressively on leaves and outer stem; larvae not observed |
| *Chaetocnema tarsalis* Wollaston, 1860 (Chrysomelidae: Coleoptera) | Moderate-High (2-3) | Leaves | Moderate (2) | Flea beetle; creates small irregular holes on upper leaf surface |
| *Aphthona cookie* LeConte, 1859 (Chrysomelidae: Coleoptera) | Moderate (2) | Leaves | Moderate (2) | Leaf feeding similar to *Chaetocnema*, less abundant |
| *Hypena* sp. (Erebidae: Lepidoptera) | Moderate-High (2-3) | Leaves | Severe (3) | Folivorous moth; up to ~60% of plants infected in some sites |
| *Lethyna* sp. (Tephritidae: Diptera) | High (3) | Flowers | Severe (3) | Flower-feeding fly; widespread on flowers, potential seed suppression |
| *Liriomyza* sp. (Agromyzidae: Diptera) | High (3) | Leaves | Severe (3) | Leaf miner; causes leaf drying and damage across eastern Salalah |
| *Phytoliriomyza cf. perpusilla* (Meigen, 1830) (Agromyzidae: Diptera) | Moderate (2) | Leaves | Moderate (2) | Leaf miner; less abundant than *Liriomyza*, may compete for resources |
| *Toxomerus floralis* (Fabrícius, 1798) (Syrphidae: Diptera) | Moderate (2) | Flowers | Mild (1-2) | Adults nectaring on flowers; larval feeding suspected but not confirmed |
| *Adria parvula* (Dallas, 1851) (Pentatomidae: Hemiptera) | Moderate (2) | Leaves & stem | Moderate (2) | Sap-feeding bug; adults and nymphs observed feeding on stems and leaves |
| *Myzus persicae* (Sulzer, 1776) (Aphididae: Hemiptera) | Low (1) | Leaves & stem | Mild (1) | Polyphagous sap feeder; low population observed |
| Dictyopharidae sp. (Fulgoromorpha: Hemiptera) | Moderate (2) | Leaves & stem | Moderate (2) | Sap-feeding leafhopper; widespread |
| Deltocephalinae sp. (Cicadomorpha: Hemiptera) | Moderate (2) | Leaves & stem | Moderate (2) | Sap-feeding leafhopper; moderate abundance |
| *Taylorilygus cf. pallidulus* (Blanchard, 1852) (Miridae: Hemiptera) | High (3) | Leaves & stem | Moderate-Severe (2-3) | Sap-feeding; may induce phytoplasma-related phyllody |
| *Phaenococcus* sp. (Pseudococcidae: Hemiptera) | Low (1) | Leaves & stem | Mild-Moderate (1-2) | Mealybug; local aggregation, stunting observed |
| Orthoptera spp. | Moderate (2) | Leaves | Mild (1-2) | Generalist foliage feeder |

[1]**Abundance levels**: Low (1) = <5 individuals per 10 plants; Moderate (2) = 5-15; High (3) = >15. [2] **Damage levels**: Mild (1) = <10% tissue affected; Moderate (2) = 10-50%; Severe (3) = >50%.

***Lethyna*** Munro, 1957 (Fig. 11). This is an endemic genus in Africa with seven described species. The species are distributed primarily in the northeast, east, and south, mainly at high elevations. The larvae of this genus develop on the flowers of certain Asteraceae plants. However, the biology and lifecycle of the immature stages remain unknown. It is possible that we have encountered a new document, as there are no recorded instances of this genus in Oman or the Arabian Peninsula. The species seems to thrive in widespread mountain habitats, such as Samhan, Madinat Alhaq, Titam, Tiwi Ateer, and Rakhyuot, which are typical for the genus. We found hundreds of these flies on the flowers of *Parthenium* by sweeping the blooms. They can also be captured using yellow pan traps for those with short stems. We are uncertain about their development on flowers, as we did not find any larvae despite the presence of many dried and damaged flowers. We can suggest that this species serves as a beneficial biological agent on *Parthenium* flowers because of their high abundance and widespread geographic distribution in all the areas we investigated. However, further research is needed to confirm whether it is endemic or introduced and to investigate the host range.

***Liriomyza*** Mik, 1894 (Fig. 2). This leaf-miner morphospecies has notorious occurrence in most localities that we have investigated, particularly in eastern and western Salalah. The species invades nearly all *Parthenium* plants with varying intensity, being particularly aggressive in the east and at medium to low levels in the west. It causes leaf mining, which results in the leaves drying out. The genus *Liriomyza* is found in Oman with fewer than five species, some of which are serious agricultural pests. The exact identity of this species remains uncertain and will be verified using taxonomic references. Its feeding behavior suggests potential as a biological control agent, but further assessment is required.

***Phytoliriomyza c.f. perpusilla*** (Meigen, 1830) (Fig. 3). This is a second species of leaf-mining fly belonging to the Agromyzidae family. The presence of this species is limited compared to the previous one, based on our sweeping and plant leaf investigations, possibly due to competition between the two. Currently, there is only one species of this genus reported in the country, although we suspect there may be others that have not yet been documented. We are uncertain about the biology of this species in comparison to *Liriomyza*, which exhibits multivoltine throughout the year.

***Toxomerus floralis*** (Fig. 4). The genus *Toxomerus* is confined to the New World, ranging from southern Canada to southern Chile and Argentina, with the greatest species richness found in tropical regions. Jordaens et al. (2015) reported the introduction of *T. floralis* in West and Central Africa. Specimens of *T. floralis* were collected by senior author in late August from two sites in Dhofar, specifically from Samhan in 2021 and currently from Rakhyout (Improvv). This species is the only larval feeder on plants among its genus. We observed adults acting as pollinators and nectaring on the flowers of *Parthenium*, but we are uncertain whether the larvae feed on this plant. It is puzzling how this species adapts to the climate of Dhofar, or if there is a potential association with the Neotropical plant "*Parthenium*". The larvae, like the adults, feed on flowers; however, they cannot tolerate high temperatures and tend to feed very early in the morning. They may hide under weeds for shelter as temperatures rise, warranting further investigation.

***Taylorilygus pallidulus*** (Fig. 5). This species is particularly intriguing in relation to *Parthenium*. It is sap-feeding, and some members of the Miridae family exhibit predatory behavior in addition to being herbivorous. We encountered this species in all the investigated areas. It is polyphagous, with a specialization on Asteraceae, and has a significant presence on *Parthenium*, especially in eastern Salalah. Some species in this genus are known to cause phytoplasma infections on *Parthenium*, resulting in phyllody (small flowers), a condition observed clearly in Western Salalah (Shahab Asaib). After assessing the host range of this species and its relationship with the phytoplasma disease, we believe it could serve as an effective biological control agent against *Parthenium*.

***Phaenococcus*** Cockerell, 1902 (Fig. 6). This is a sap-feeding mealybug that primarily affects the thicker parts of *Parthenium*, particularly the stems. It was observed at a single locality in the Samhan Mountains, particularly in a wadi habitat. The infested plants exhibited stunting and dwarfing, with individuals forming dense aggregations under high temperatures. Typically, mealybugs prefer moist conditions, which is why we found this species in a wadi with a high density of *Parthenium*. While *Phaenococcus* sp. could serve as a potential control agent, its polyphagous nature and uncertain origin (native or introduced) require cautious evaluation.

***Adria parvula*** (Fig. 7). This sap-feeding bug is herbivorous and found on various plants. It is an African species, and we discovered both adults and nymphs on *Parthenium* plants, which strongly indicates feeding on these plants. Although this species may not be an effective control agent, its widespread presence warrants attention.

***Myzus persicae*** (Sulzer, 1776) (Fig. 12). This sap-feeding hemipteran is polyphagous, affecting a variety of agricultural crops. We observed a very low population of this species from one location in the Samhan mountains.

Australia has established one of the most successful classical biological control programs against *Parthenium hysterophorus.* Several specialist bioagents especially insects have been released, including leaf-feeding beetle - *Zygogramma bicolorata* Pallister (1953), stem-galling moth - *Epiblema strenuana* (Walker, 1863), stem-boring weevil - *Listronotus setosipennis,* and seed-feeding weevil - *Smicronyx lutulentus.* The genus *Epiblema* Hübner, 1825 is present in Oman, represented by several species especially in Dhofar region. The species *Smicronyx rufipennis* Tournier, 1874 is the only species reported from northern Oman (Al-Jahdhami et al. 2021).

The bioagents identified in this study are generalist herbivores, and therefore their application as biological control of *P. hysterophorus* is not suitable under the current circumstances due to potential non-target risks. This includes non-target damage by shifting general feeders to include economically important crops and native flora in their diet, leading to reduced agricultural productivity (McFadyen 1992). The general feeders may cause ecological imbalance by feeding on multiple species which may disrupt plant community structure and indirectly affect pollinators and other higher trophic levels (Shrestha et al. 2015). The releasing of wide dietary bio-agents may reduce biocontrol efficacy, as feeding behavior is distributed across many host plants, pressure on *Parthenium* populations may be insufficient to suppress its spreading (Kaur et al. 2014). Once released, generalist herbivores may lead to long-term irreversibility, which is difficult to manage, and the negative effects may persist for decades (Dhileepan & McFadyen 2012).

## Conclusion

In future, studies should extend temporal and spatial surveys to capture seasonal dynamics and multivoltine species, document the life cycles and developmental stages of dominant herbivores, reproduction and population structure. Also, quantifying the impacts of herbivory on plant growth and investigating interactions among herbivores to assess

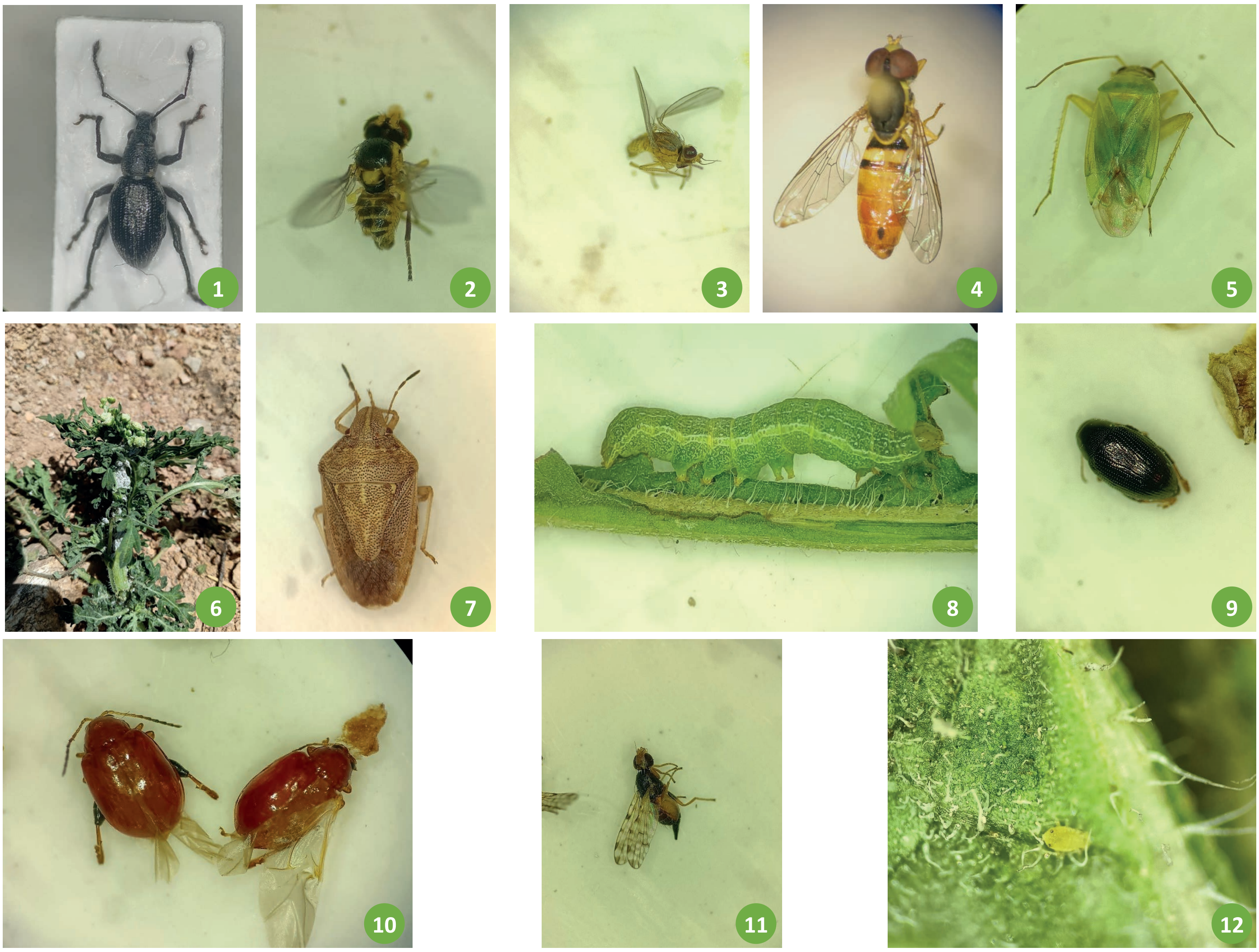


**Figure 1-12**. Arthropod biological agents associated with *Parthenium hysterophorus* L. (Asteraceae) in southern Oman. (1) *Nematocerus omanicus* Rheinheimer, 2003; (2) *Liriomyza* sp Mik; (3) *Phytoliriomyza cf. perpusilla* (Meigen, 1830); (4) *Toxomerus floralis* (Fabrícius, 1798); (5) *Taylorilygus cf. pallidulus* (Blanchard, 1852); (6) *Phenacoccus* sp.; (7) *Adria parvula* (Dallas, 1851); (8) *Hypena* sp.; (9) *Chaetocnema tarsalis* Wollaston, 1860; (10) *Aphthona cookie* LeConte, 1859; (11) *Lethyna* sp.; (12) *Myzus persicae* (Sulzer, 1776).

cumulative effects on *Parthenium* populations. Gathering these efforts will provide the most comprehensive understanding of herbivore-plant interactions and support evidence-based management strategies.

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## Authors' Contributions

AAA-J: Supervision, Methodology, Writing – original draft, Formal analysis, Data curation, Resources, Software, Validation, visualization, Conceptualization, Investigation, Project administration, Funding acquisition, Writing-review & editing; AMA-S: Supervision, Resources, Software, Validation, visualization, Conceptualization, Investigation, Project administration, Funding acquisition, Writing-review & editing; MAA: Supervision, Resources, Software, Validation, visualization, Conceptualization, Investigation, Project administration, Funding acquisition, Writing-review & editing; AKA-W: Resources, Software, Validation, visualization, Conceptualization, Investigation, Project administration, Funding acquisition, Writing-review & editing.

## Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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