

Review

Mass Trapping as a Sustainable Approach for Scarabaeidae Pest Management in Crops and Grasslands

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Abstract

Soil-dwelling beetles, including native and invasive species such as *Popilia japonica* Newman (Coleoptera: Scarabaeidae), are persistent and damaging agricultural pests worldwide. Mass trapping, using pheromone-, light-, or food-based lures to attract and remove adults, is being developed as an environmentally sustainable alternative within integrated pest management (IPM). Scarab beetles respond positively to attractant-based traps, and large-scale programs against *P. japonica* in North America provide valuable insights for global applications. The efficacy of mass trapping depends on species biology, trap density, environmental conditions and landscape structure. Capturing adults does not always immediately reduce larval populations, as underground stages persist in soil for multiple years. Light traps are effective but often attract many non-target insects, whereas pheromone traps are more selective but require careful optimization of lure composition, release rate and placement. To achieve reliable suppression, mass trapping should be integrated with complementary strategies such as biological control agents (*Beauveria* spp., *Metarhizium* spp.), crop rotation, tolerant crop varieties and soil management. Future research should focus on refining lure design, optimizing deployment, testing predictive models and evaluating multi-bait systems. Overall, mass trapping represents a promising and environmentally sustainable tool that, when incorporated into integrated approaches, can enhance the management of soil-dwelling scarab beetles across diverse agroecosystems worldwide.

Keywords: pheromone lures; light traps; integrated pest management; biological control; cultural practices; invasive species; sustainable agriculture



Academic Editors: Renata Bažok and Emmanouil Roditakis

Received: 26 September 2025

Revised: 12 November 2025

Accepted: 21 November 2025

Published: 21 November 2025

Citation: Adamič Zamljen, S.; Bohinc, T.; Trdan, S. Mass Trapping as a Sustainable Approach for Scarabaeidae Pest Management in Crops and Grasslands. *Agriculture* **2025**, *15*, 2406. <https://doi.org/10.3390/agriculture15232406>

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1. Introduction

Soil-dwelling scarab beetles (Coleoptera: Scarabaeidae), such as the common cockchafer (*Melolontha melolontha* L.) and the invasive Japanese beetle (*Popilia japonica* Newman), pose a significant threat to crops and grasslands across Europe and other temperate regions. Their larvae, known as chafer grubs, feed on roots, leading to severe yield reductions, reduced plant vigor and significant quality losses in both forage and horticultural crops [1,2]. In grasslands, larval feeding often results in sward thinning and bare patches, which in turn decrease forage production and promote weed invasion [3].

The subterranean lifestyle and multi-year developmental cycles of these pests make their control particularly challenging. Recent studies have introduced advanced semiochemical lures and optimized trap designs that enable targeted mass trapping of both males and females. When integrated with biological control agents and cultural practices, these approaches offer enhanced potential for long-term pest suppression [1,4,5].

The effectiveness of conventional insecticides is limited, and increasing restrictions on soil-applied chemicals in many regions, including within the European Union (EU), have further emphasized the need for alternative, environmentally acceptable solutions [6,7].

Mass trapping, which relies on the targeted attraction and capture of adult beetles using pheromone-, light-, or food-based lures, has emerged as a promising environmentally sustainable alternative. For species such as *M. melolontha* and related scarabs, light traps and synthetic attractants have been developed to capture adults prior to oviposition, potentially reducing larval densities in subsequent generations [8,9]. It is important to note, however, that mass trapping is the most effective when it removes a substantial proportion of the reproductive population or directly targets the damage-causing life stage, as demonstrated for the invasive *P. japonica*. Nevertheless, the success of such approaches depends strongly on species biology, population density, trap design and environmental conditions [4].

Integration of mass trapping with other control tactics, such as entomopathogenic fungi (*Beauveria* spp., *Metarhizium* spp.) or nematodes, as well as mechanical soil disturbance and crop rotation, can enhance long-term pest suppression in both arable and perennial systems [1,10].

This review provides a comprehensive overview of mass trapping strategies for scarab beetles, with particular focus on *Melolontha* spp. and *P. japonica*. The review examines trap design and attractant optimization, evaluates the ecological and economic implications of these strategies, and explores their integration into sustainable pest management frameworks for scarab beetles. It aims to provide practical guidance for implementing effective mass trapping within integrated pest management (IPM) programs worldwide. In this review, we focus completely on the family Scarabaeidae, distinguishing our work from previous reviews that primarily addressed Elateridae and other soil-dwelling larvae of other families. Moreover, we provide a global perspective by including case studies from Europe, North America and Asia, and highlight recent technological and methodological advances in mass trapping, such as female-targeted lures, multi-species trap systems and digital monitoring tools. These aspects have not been comprehensively covered in previous reviews, providing novel insights for sustainable pest management of Scarabaeidae.

2. Biology and Pest Status

Scarabaeidae: Taxonomy, Distribution, Life Cycle and Economic Importance

The family Scarabaeidae comprises numerous species of chafer grubs, i.e., the larvae of beetles such as the common cockchafer (*M. melolontha*), the summer cockchafer (*Amphimallon solstitiale* L.) (Coleoptera: Scarabaeidae), and invasive species such as *P. japonica*. In temperate regions, *M. melolontha* and *A. solstitiale* are among the most economically important native scarabs, while *P. japonica* has become a major invasive pest in both North America and, more recently, parts of southern and central Europe [1,11,12].

The life cycle of scarab beetles varies considerably among species and is influenced by temperature, soil conditions and food availability. The common cockchafer generally completes its development within 3–4 years, while the summer cockchafer typically has a 1–2-year cycle [11,12]. Adult females deposit eggs in the soil, where the larvae (chafer grubs) develop entirely underground (Figure 1E), feeding on the roots of grasses, maize, potatoes, strawberries and forest seedlings [13]. The larvae pass through three instars, spending most of their development in the soil. Mature larvae overwinter in deeper soil layers to avoid frost, with pupation (Figure 1H) occurring in the final year of development. Larval survival and population density depend strongly on soil texture, moisture and vegetation cover. Permanent grasslands and perennial horticultural systems are particularly vulnerable due to the abundance of roots and limited chemical control options [1]. Adults (Figure 1G) emerge synchronously in spring or early summer, often forming large

flight swarms coinciding with favorable temperature and humidity conditions [8]. This synchronized emergence is crucial for the efficient timing of pheromone- and light-based mass trapping programs.

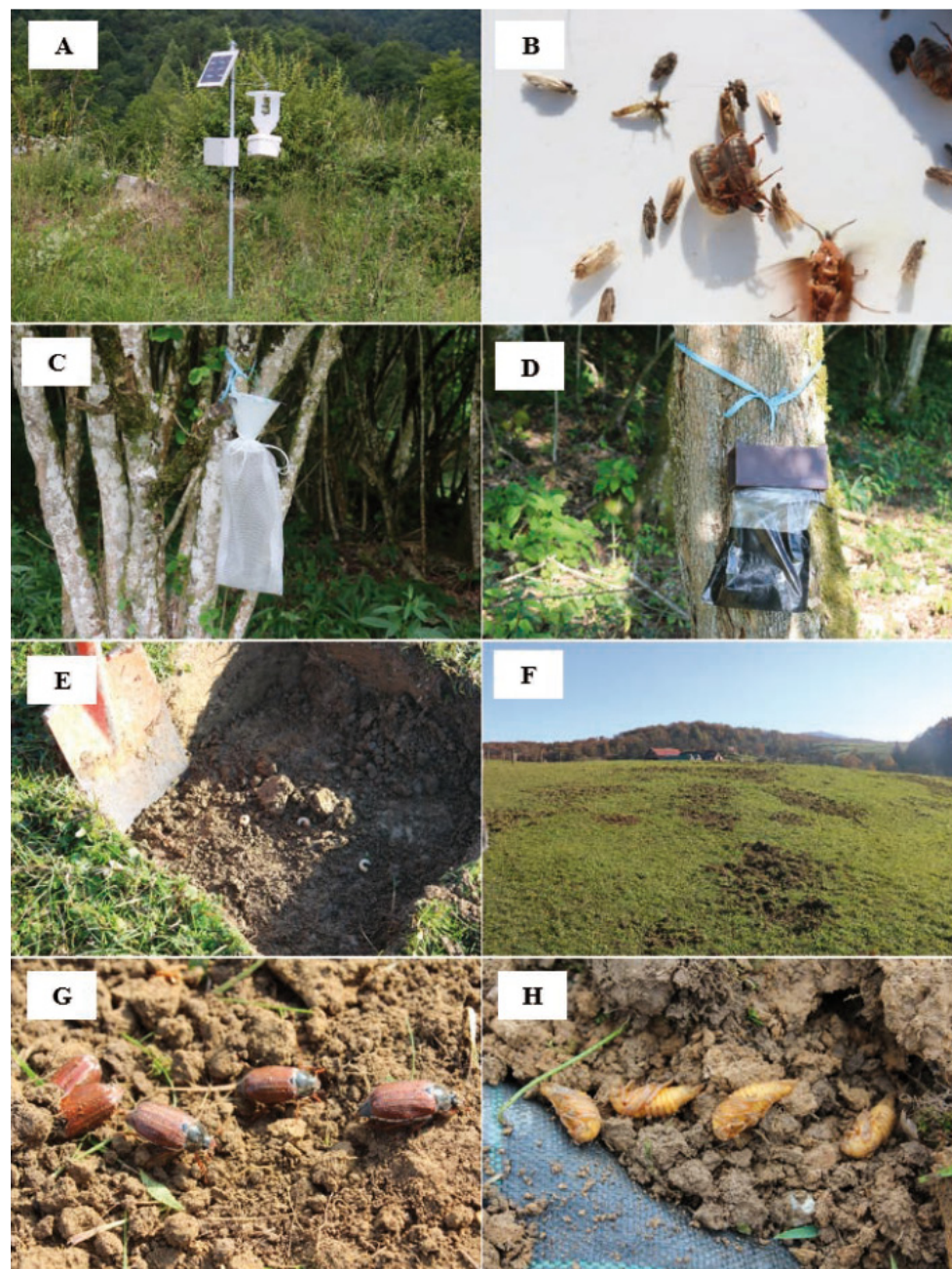


Figure 1. Photos of field trials of mass trapping of summer cockchafer beetles in Kočevsko region, south-eastern Slovenia (A–F) and control of common cockchafer grubs in Gorenjska region, north-western Slovenia (G,H). The photos represent a light trap for adults (A), male and female summer cockchafer beetles from a light trap (B), Gea pheromone trap for adults (C), Econex pheromone trap for adults (D), soil excavation with summer cockchafer L3 grubs (E), rooting in a grassland caused by wild boars feeding on grubs (F), adults (G) and pupae of common cockchafer in the grassland soil (H) (photo: S. Trdan).

The economic impact of scarab beetles is substantial, especially in temperate agroecosystems where *M. melolontha* and *A. solstitialis* are among the most destructive soil pests [14,15]. Outbreaks can cause extensive damage in grasslands, orchards, vineyards, nurseries and various arable crops [8]. Chafer grubs feed on plant roots, reducing water

and nutrient uptake, weakening plant vigor and predisposing crops to drought stress and secondary infections [7,10,11]. Symptoms of infestation include yellowing, wilting, reduced growth, and in severe cases, plant death due to destruction of root system. In grasslands and turf, heavy infestations lead to thinning of the sward, bare patches and significant declines in forage yield [9,16]. Similarly, in maize and other crops, grub feeding weakens the root system, leading to lodging and yield losses [12]. Economic damage tends to accumulate in areas with replanting or reseeded damaged fields [17–19]. In addition to direct feeding damage, secondary effects caused by vertebrate predators, particularly wild boars (*Sus scrofa* L.), can amplify economic losses. Wild boars uproot vegetation while feeding on grubs (Figure 1F), disturbing soil structure and promoting erosion. Studies across Europe and Asia have shown a strong positive correlation between chafer grub density and wild boar damage in grasslands, indicating that indirect effects may even exceed primary root losses in severely infested sites [17,20].

The invasive *P. japonica* represents a rapidly emerging threat in newly colonized regions. It attacks more than 300 host plants, including grapevine, maize, soybean and various horticultural crops [21]. In North America, economic losses associated with *P. japonica* infestations have been estimated to exceed USD 450 million annually [11]. Its continued expansion into new habitats highlights the urgent need for coordinated monitoring and area-wide management strategies to mitigate potential impacts on agriculture and forestry [3].

Chafer grubs are persistent and polyphagous soil pests with long-lived larval stages and broad host ranges. Their concealed lifestyle and overlapping generations complicate both monitoring and control. With increasing environmental concerns and regulatory restrictions on soil insecticides, conventional chemical control is becoming increasingly limited [11,22]. Consequently, alternative strategies, including mass trapping, biological control agents and the use of tolerant crop varieties, are gaining importance. A thorough understanding of the biology, ecology and pest status of scarab beetles are essential for designing effective and sustainable IPM programs [23,24].

3. Principles and Methods of Mass Trapping

This section focuses only on the application of mass trapping strategies to soil-dwelling Scarabaeidae, highlighting pheromone- and light-based methods, trap design, environmental considerations and integration within IPM programs. Mass trapping is a pest management strategy that relies on deploying a large number of attractive lures or traps to suppress pest populations below economically damaging levels. Unlike monitoring, which typically requires only a limited number of traps, mass trapping aims to capture a substantial proportion of adults, thereby reducing the reproductive potential, and indirectly, larval populations [25,26]. Historically, some of the most successful examples of large-scale mass trapping have been achieved against tropical rhinoceros beetles (*Oryctes rhinoceros* L.), where pheromone-baited traps substantially reduced damage in palm plantations [27,28]. These examples demonstrate the potential of semiochemical-based control in Scarabaeidae and provide a useful precedent for similar approaches in temperate regions.

3.1. Pheromone-Based Mass Trapping

Research into pheromone communication in Scarabaeidae has advanced significantly, particularly for invasive species such as *P. japonica*, where attraction of both males and females greatly enhances mass trapping efficiency [2,5,21]. For European species such as *M. melolontha*, semiochemical studies have identified anisole derivatives, phenols and other aggregation pheromones as promising attractants [4,8,29]. Recent developments include female-targeted pheromone lures, multi-attractant trap systems and area-wide

trap deployments, which improve capture rates, facilitate early detection and contribute to population suppression across larger management units [5,25]. Integration of pheromone traps with light traps, food baits and biological control agents has also been shown to enhance the sustainability and effectiveness of mass trapping programs [1,4].

The efficiency of pheromone-based trapping is influenced by trap design, lure composition, placement density, environmental conditions and species-specific behaviors. Adaptive management strategies, continuous monitoring and integration into landscape-scale IPM programs are therefore critical to maximize suppression and minimize unintended aggregation effects [5,30]. Consequently, pheromone-based mass trapping represents a promising, environmentally sustainable tool for the management of soil-dwelling scarab pests, with potential applications across Europe, North America and Asia, particularly when combined with complementary control methods [21,27,28].

Trap Design and Density

Trap efficiency depends on lure type, trap design, placement and deployment density. For scarab beetles, light traps, bucket traps and panel traps baited with pheromones have been tested, with results suggesting that trap placement along field borders (Figure 1C,D) may be optimal for intercepting immigrating adults [8,11]. Effective mass trapping generally requires between 6 and 10 traps per hectare, providing a balance between efficiency and cost, while higher densities of 20–30 traps per hectare may achieve greater population reductions under heavy infestations [5,30,31].

3.2. Light Trapping

Light traps exploit the strong phototactic behavior of adult Scarabaeidae (Figure 1A). Mercury-vapor lamps have been used to attract beetles such as *M. melolontha*, *A. solstitialis* and *Anomala albopilosa* (Hope) (Coleoptera: Scarabaeidae), achieving notable reductions in local adult abundance [8,32] (Figure 1B). More recently, LED-based traps have been developed, offering improved energy efficiency, longer operational lifespan and the possibility to fine-tune light wavelengths to optimize attraction for target species [9]. Light traps can operate continuously throughout the night or be programmed to activate during peak flight activity, enhancing capture efficiency. Placement along field edges or in high-emergence areas maximizes interception while reducing the total number of traps required [8]. In addition to suppression, light traps serve as effective monitoring tools, providing data on population dynamics, flight periods and phenology [33].

A notable limitation of light trapping is its low selectivity, as many non-target insects, including pollinators and natural enemies, are also attracted to light sources [34]. Environmental factors such as moonlight, cloud cover, temperature and humidity also strongly influence capture efficiency, with higher catches typically observed on warm, humid nights with minimal ambient light [33,34]. Despite these limitations, light traps remain a practical and widely accepted component of IPM for scarab beetles, especially when combined with pheromone traps or biological control methods [5,8].

3.3. Environmental and Ecological Considerations

The efficacy of mass trapping is strongly influenced by environmental and ecological conditions. High wind speeds can disperse pheromone plumes, reducing trap efficiency, while dense pest populations may overcome the trapping effect [26]. Similarly, long-term suppression typically requires area-wide implementation over consecutive seasons, which can increase costs compared to monitoring or localized trapping [25]. For scarab beetles, light traps are most effective on warm, humid evenings that stimulate adult dispersal flights, whereas unfavorable weather can sharply reduce captures [1,33,35]. Untreated surrounding habitats may serve as sources of recolonization, limiting the effectiveness of

local suppression [11,14,36]. Ecological concerns primarily relate to non-target captures: pheromone traps are relatively specific, whereas light traps can attract a broad range of nocturnal insects, including beneficial species [34]. Adjustments in trap design, wavelength and placement can mitigate such risks [8]. Mass trapping should therefore be employed as part of an IPM framework. When combined with biological control agents, crop rotation or tolerant crop varieties, these approaches become more effective and sustainable. Long-term monitoring and adaptive management are essential to ensure reliable suppression [11,37].

4. Mass Trapping of Scarabaeidae

Mass trapping of scarab beetles primarily targets highly mobile adults to reduce subsequent pressure from root-feeding larvae. In Europe, efforts have mainly focused on native Melolonthinae—particularly the common cockchafer, the garden chafer *Phyllopertha horticola* L. (Coleoptera: Scarabaeidae) and the June beetle (*A. solstitialis*)—using light traps and semiochemical lures at varying scales [4,8,9]. These case studies provide valuable insights into how attractant-based strategies can be incorporated within IPM frameworks [1,25].

4.1. Native European Species (*Melolontha*, *Phyllopertha*, *Amphimallon*)

These species cause severe damage through their root-feeding larvae, while the mobile adults represent a feasible stage for intervention. Various trapping approaches have been tested, particularly light traps and semiochemical lures. Early studies demonstrated that pheromone-alcohol blends and synthetic attractants could reliably capture large numbers of *M. melolontha* adults, resulting in short-term local population reductions [8,38]. Similarly, *P. horticola* adults are highly responsive to light cues, and trapping during peak dispersal periods has shown potential to suppress flight activity [9,14].

Despite these promising results, several limitations have emerged. The efficacy of light traps is strongly influenced by environmental conditions such as temperature, humidity and even atmospheric ozone levels [33]. Because scarab beetles are capable of long-distance dispersal, immigration from surrounding untreated areas can rapidly offset local trapping effects [12,13]. Pheromone-based methods also face constraints, since attractants developed for *M. melolontha* remain less effective than those available for invasive scarabs such as *P. japonica* [4,39]. Another concern relates to ecological side effects. Light traps are non-selective and may capture a wide range of non-target insects, including pollinators and natural enemies, raising concerns about their use in diversified agroecosystems [32,34]. Conversely, pheromone-based systems are highly specific, though their large-scale application can be limited by lure replacement and trap maintenance requirements [25].

Given these constraints, mass trapping of native European scarabs should be regarded as a complementary tactic rather than a stand-alone solution. Studies integrating trapping with entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* have demonstrated enhanced suppression of chafer grub populations [1,10]. Agronomic practices including crop rotation, soil management and maintenance of healthy swards further reduce larval survival and improve system resilience [11]. Overall, experience with *M. melolontha* and related species shows that light- and semiochemical-based trapping can contribute to local reductions in adult abundance and provide valuable monitoring data [8,29,40].

4.2. Japanese Beetle—Lessons from Area-Wide Programs

The Japanese beetle is an invasive scarab that has rapidly spread across North America and more recently into Europe, serving as a key case study for large-scale mass trapping [36,41]. Unlike native European scarabs, *P. japonica* reaches exceptionally high adult densities, making local trapping insufficient for effective population control. Recent

developments in female-targeted pheromone lures and multi-attractant trap systems have significantly improved trapping efficiency, demonstrating that area-wide programs can reduce adult populations and subsequent larval damage when integrated into comprehensive IPM strategies [4,5,25].

Advancements in semiochemical lure development have enabled the capture of both male and female scarab beetles. Field trials demonstrate that female-targeted pheromone lures can significantly enhance trapping efficiency and contribute to long-term suppression of adult populations, thereby improving the effectiveness of area-wide management strategies [21,31,36,42].

Area-wide programs in the United States have shown that pheromone-based traps, often combined with floral or food attractants, can suppress adult populations and reduce larval damage when deployed at high densities across management units [16,21,25]. However, inadequate trap density or poor spatial coverage may instead concentrate beetles and increase crop damage [2]. Adaptive management and continuous monitoring are therefore essential to optimize trap placement and lure composition.

In Europe, experience remains limited, yet lessons from North America underscore the importance of early detection, rapid response and coordinated stakeholder action. Integrating semiochemical lures with light or food-baited traps, supported by cultural practices and biological control agents, can help prevent widespread establishment. Mass trapping of invasive scarabs such as *P. japonica* is most effective when implemented within a landscape-scale IPM framework that combines ecological knowledge with complementary pest management measures [2,39].

4.3. Environmental, Ecological and Design Consideration

The efficacy of mass trapping for scarab beetles depends strongly on environmental and ecological conditions. Climatic factors such as temperature, humidity and wind affect adult activity and trap performance: pheromone plumes disperse in strong winds, while light traps perform best during warm, humid evenings that coincide with peak of adult flights [8,33,35]. Landscape context is equally important, since untreated areas act as reservoirs for recolonization, highlighting the need for coordinated, area-wide management [43].

Ecological impacts must also be considered. Pheromone traps are highly species-specific, whereas light traps attract many non-target nocturnal insects, including pollinators and natural enemies [9,34]. Adjusting trap height, wavelength and placement can reduce bycatch while maintaining efficiency [8]. Trap design further influences capture success. For pheromone traps, lure composition and release rate are key factors, while for light traps, lamp type, intensity and operating time determine capture efficiency [21,32].

4.4. Practical Guidance for European Contexts

Implementing mass trapping for scarab beetles in Europe requires consideration of local pest species, their flight dynamics and surrounding habitats. For *M. melolontha*, *P. horticola* and *A. solstitialis*, pheromone and light traps have been used to monitor and reduce adult populations, although suppression is often temporary due to recolonization from untreated areas, emphasizing the need for coordinated, area-wide deployment [8,9].

Trap placement should reflect species-specific flight behavior and habitat preferences, with density adjusted to optimize lure efficiency. Multi-bait systems and the use of both male and female pheromone attractants can improve capture rates, especially in sympatric species complexes [4,8]. Similarly, perimeter trapping with species-specific attractants has been successfully applied for *Anomala* spp., demonstrating substantial reductions in adult captures and providing practical insights for trap deployment in European contexts [44,45].

Light traps can effectively capture large numbers of adults, but their deployment requires careful timing and design to minimize non-target impacts [34]. Monitoring data should guide adjustments in trap deployment. For sustained suppression, mass trapping must be integrated with complementary strategies. Soil-applied biocontrol agents such as *Beauveria* spp. and *Metarhizium* spp. can reduce larval populations, while crop rotation and the use of tolerant varieties can lower pest pressure [1,10].

5. Comparative Insights and Implications for Scarabaeidae Mass Trapping

The results of mass trapping within the family Scarabaeidae varies considerably among genera such as *Melolontha*, *Phyllopertha*, *Amphimallon* and the invasive *P. japonica*. These differences largely reflect species-specific behavioral ecology, dispersal capacity and life cycle dynamics [8,9,16,21]. Native European species such as *M. melolontha* and *A. solstitialis* exhibit synchronized adult flights that occur over a relatively short period, providing a narrow but predictable window for trapping interventions [8,14]. In contrast, invasive species such as *P. japonica* are characterized by prolonged flight periods and extremely high adult densities, which necessitate intensive, area-wide trapping programs to achieve measurable suppression [21,25].

Trap responsiveness and attractant preferences also differ markedly among species. While *Melolontha* and *Amphimallon* respond well to light-based attractants, *P. horticola* and *P. japonica* are more strongly influenced by semiochemical and floral cues [2,9]. This highlights the need for species-specific optimization of trap type, lure formation and deployment strategy. Furthermore, *P. japonica* exhibits attraction to a combination of pheromone and floral volatiles, enabling efficient capture of both males and females, which is an important advantage over systems that target males only [2,21].

Economic and operational factors further distinguish these systems. For native Scarabaeidae, light trapping remains a cost-effective tool for localized population reduction and monitoring, but recolonization from surrounding untreated areas often limits its long-term effectiveness [8,11]. In contrast, large-scale pheromone-based trapping of *P. japonica* in North America has proven both effective and economically justified when implemented across extensive areas and complemented with biological control [16,25]. These experiences suggest that mass trapping is most viable for invasive or outbreak-prone scarabs where adult densities are high and coordinated management is feasible.

Integrating mass trapping within IPM frameworks is essential for all scarab beetles. For native European species, combining trapping with biological control agents such as *Beauveria* and *Metarhizium* spp., as well as crop rotation and soil management practices, enhances sustainability and promotes long-term suppression [1,10]. Overall, understanding interspecific differences in ecology, attractant response and dispersal capacity provides the foundation for optimizing mass trapping as a strategic component of the integrated Scarabaeidae pest management.

6. Future Perspectives

Mass trapping of Scarabaeidae beetles is evolving through advances in semiochemical lures, light trap design and deployment strategies. Novel pheromone blends, including female-targeted lures and multi-species attractants, promise to broaden attraction ranges and improve capture efficiency across sympatric scarab species [2,21]. Innovations in controlled-release substrates, such as biodegradable granules or polymer matrices, may enable longer-lasting and more environmentally sustainable lure deployment [26,46].

Climate change poses both challenges and opportunities. Rising temperatures and altered precipitation patterns can shift beetle phenology, dispersal and population dynamics, potentially expanding the geographic range of invasive scarabs such as *P. japonica* [39]. Pre-

dictive modelling and adaptive management will be essential to optimize trap placement, density and timing under variable environmental conditions. Integration of digital monitoring technologies represents a transformative opportunity for mass-trapping systems. Camera-equipped traps and AI-based insect recognition can provide real-time data on adult beetle flight activity, reduce labor costs and enhance decision-making for area-wide IPM deployment [26]. Remote sensing, automated trap monitoring and AI-driven population modelling further enable precision management, supporting proactive interventions before pest outbreaks reach economically damaging levels [47–49].

Future research should focus on refining landscape-scale approaches, evaluating cost-effectiveness and minimizing non-target impacts across diverse agroecosystems, ensuring that mass-trapping becomes a more effective and sustainable component of integrated pest management for Scarabaeidae.

7. Conclusions

Mass trapping is an effective component of IPM for controlling soil-dwelling Scarabaeidae beetles, reducing adult populations and indirectly limiting larval damage. Its success is highly species-specific and influenced by population density, trap design, environmental conditions and landscape-level deployment. For invasive species such as *P. japonica*, effective control requires large-scale, coordinated implementation combining biological, cultural and agronomic strategies. Practical limitations include high material and labor costs for trap installation, lure replacement and maintenance, as well as variability in trapping success across species, regions and years due to behavioral and environmental factors. Minimizing non-target impacts, especially light traps, remains a key ecological consideration.

Future research should focus on improving lure composition, controlled-release formulations and multi-bait systems, including female-targeted traps, to enhance capture efficiency across sympatric species. Evaluating cost-effectiveness, automation options, predictive modelling, remote sensing and long-term monitoring will support adaptive management and optimized trap deployment. Landscape-level studies can further inform optimal trap density and spatial arrangement for different species and cropping systems.

In conclusion, mass trapping alone is rarely sufficient for complete suppression of soil-dwelling beetles. Its full potential is realized when integrated into a comprehensive, landscape-level IPM approach that combines ecological knowledge with biological, cultural and agronomic measures. By addressing economic, technical and ecological constraints, mass trapping can evolve from an experimental method into a practical and sustainable alternative to conventional chemical control.

Author Contributions: Conceptualization, S.A.Z. and S.T.; methodology, S.A.Z. and S.T.; software, S.A.Z.; validation, S.A.Z., T.B. and S.T.; formal analysis, S.A.Z.; investigation, S.A.Z.; resources, S.T.; data curation, S.A.Z.; writing—original draft preparation, S.A.Z.; writing—review and editing, S.A.Z. and S.T.; visualization, S.A.Z., T.B. and S.T.; supervision, S.T.; project administration, S.T.; funding acquisition, S.T. All authors have read and agreed to the published version of the manuscript.

Funding: This review paper was written as a part of the V4-2414 research project, which received financial support from the Slovenian Research and Innovation Agency (ARIS) and the Ministry of Agriculture, Forestry, and Food of the Republic of Slovenia (MKGP).

Data Availability Statement: No new data were created or analyzed in this study.

Acknowledgments: During the preparation of this manuscript no Generative Artificial Intelligence (GenAI) tools were used.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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