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Original Article

Predatory behavior and predation efficiency of *Sycanus* sp. against *Metisa plana* Walker: Implications for biological control in oil palm

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ABSTRACT

Bagworm (*Metisa plana* Walker) is a major defoliating pest of oil palm, causing significant yield losses during outbreaks. Biological control using predatory insects offers an environmentally sustainable alternative to chemical insecticides. This study evaluated the predatory performance of *Sycanus* sp. against *M. plana* larvae and assessed the effect of predator density on prey suppression under laboratory conditions. A completely randomized design was used with five predator-density treatments (1, 2, 3, 4, and 5 predators per 10 larvae) and ten replications. Predator performance was evaluated based on prey-search duration, handling time, larval mortality, and prey consumption. The initial prey-search duration ranged from 2.11 to 2.25 min, while subsequent searches ranged from 1.69 to 2.04 min. Prey-handling time remained relatively constant across treatments (58.1–59.1 min). Predation by *Sycanus* sp. substantially reduced *M. plana* populations within three days, with the highest mortality occurring on the first day after predator introduction. Predator density significantly increased prey consumption, which rose from 1.26 ± 0.21 larvae at one predator to 4.43 ± 0.19 larvae at five predators. A strong positive relationship was observed between predator density and prey consumption ($y = 0.795x + 0.451$; $R^2 = 0.9531$). Although the highest prey suppression occurred at the greatest predator density, a ratio of two *Sycanus* sp. adults per ten *M. plana* larvae provided a favorable balance between prey suppression and predator deployment efficiency. These findings support the potential use of *Sycanus* sp. as a biological control agent in sustainable oil palm integrated pest management programs.

Key words: bagworm management, biological control, oil palm, predator-prey dynamics

INTRODUCTION

The oil palm (*Elaeis guineensis* Jacq.) has emerged as a pivotal crop in Indonesia, representing a significant investment in the agricultural sector and economic development. Indonesia cultivates more than 16 million ha of oil palm, making it the world's largest producer (BPS 2026). The expansion of oil palm plantations has been accompanied by a remarkable increase in production, with figures rising from 21.14 million tons in 2022 to an anticipated 23.28 million tons in 2023. This growth underscores the importance of effective agricultural practices, particularly pest management, to sustain and enhance productivity.

Pest management in oil palm cultivation is critical, as various pests can significantly hinder plant growth and reduce yields. Among these pests, the bagworm, *Metisa plana* Walker (Lepidoptera: Psychidae) has been identified as particularly damaging, capable of causing substantial economic losses in oil palm plantations (Sigalingging et al. 2025; Thaer et al. 2021). The impact of pests such as the oil palm leaf-eating caterpillar and other members of the Coleoptera and Lepidoptera orders has been well documented, with studies indicating that these organisms can cause production losses of 40% to 60%. The urgency of addressing pest-related challenges in oil palm cultivation is further underscored by *M. plana*'s adaptive capabilities, which enable it to proliferate rapidly and spread quickly through both physical contact and wind (Ikhsan et al. 2024; Egonyu et al. 2022).

Although *M. plana* is known to damage oil palm plantations, there are gaps in the literature regarding its management. Current control measures, such as removal or pesticide use, have been ineffective and are likely to worsen the impact on environmental health and lead to pest resistance. Reliance on chemical control is likely to disrupt the ecological balance and is a major concern for the sustainability of farm systems (Priyanka et al. 2024). For that reason, there is an urgent need to develop new sustainable strategies to manage this pest without compromising ecosystem integrity. Of the many approaches to sustainable pest management, biological control using natural enemies is among the most effective. *Sycanus* sp. may help control *M. plana* and other larvae of Lepidoptera, as this predator feeds through a unique method that sucks the hemolymph of its prey (Hendarjanti et al. 2024; Sucahyono et al. 2022; Yuliadhi et al. 2021).

Research on *Sycanus* spp. has focused on predation and prey consumption. Despite numerous studies, predation rates and integrated evaluations that combine prey-search behavior, handling time, temporal mortality dynamics, and density-dependent predation efficiency against *M. plana* remain lacking. The vast majority of studies have focused on *Sycanus dichotomus* Stål, where predation searching behavior, predation and prey-handling times, and patterns of predation and mortality have been poorly studied (Hayati et al. 2024; Jamian & Adam 2018; Ahmad & Kamaruddin 2016). Consequently, information remains limited regarding how behavioral processes influence predation efficiency and biological control potential. A more integrated assessment of both behavioral and quantitative predation parameters is therefore needed to improve understanding of predator–prey interactions and to support the development of effective biological control strategies for *M. plana* in oil palm agroecosystems.

Moreover, methodological variability in predator source and age structure complicates the interpretation of predation capacity. Field-collected predators can present substantial heterogeneity in age, physiological condition, prior feeding history, and reproductive status, potentially confounding estimates of predatory performance. Laboratory-reared, generation-standardized predators, such as first-generation (F1) females, offer a more rigorous framework for assessing intrinsic predatory traits and behavioral characteristics, enabling clearer inferences about predator efficacy in biological control programs (Adhikary et al. 2025; Melketa et al. 2022; Jamian & Adam 2018).

To our knowledge, no previous study has simultaneously evaluated prey-search behavior, prey-handling time, mortality dynamics, and density-dependent predatory performance in laboratory-reared F1 female *Sycanus* spp. targeting *M. plana*. Understanding these elements of predatory dynamics is necessary to assess the effectiveness of predation and is crucial for developing ecologically based pest management strategies for oil palm agroecosystems.

This study provides an integrated evaluation of prey-search behavior, prey-handling time, temporal mortality dynamics, and density-dependent predation of laboratory-reared F1 female *Sycanus* sp. against *M. plana*. By combining behavioral and quantitative measures of predation, this study provides a more comprehensive understanding of predator–prey interactions and the potential application of *Sycanus* sp. in sustainable biological control of bagworms in oil palm ecosystems. Based on ratio-dependent predation theory (Arditi & Ginzburg 1989), we hypothesized that increasing predator density would increase total prey suppression but would reduce per-capita predation efficiency because multiple predators compete for the same prey resources.

This research aims to investigate *Sycanus* sp. predation on *M. plana* and the associated predatory behavior in a controlled laboratory setting. These findings could help to optimize the use of assassin bugs as biological control agents in oil palm plantations and support environmentally friendly integrated pest management.

MATERIALS AND METHODS

The study was conducted between January and September 2024 at the Integrated Pest Management Laboratory, Faculty of Agriculture, Universitas Andalas, West Sumatra, Indonesia.

Collection and rearing of *Sycanus* sp. and *M. plana*

Adult *Sycanus* sp. and *M. plana* larvae were initially collected from oil palm plantations via direct field sampling, following established procedures (Cuthbert et al. 2021). The founder population of *Sycanus* sp. was collected from an oil palm plantation in Labuhanbatu Regency, North Sumatra province, Indonesia (2°09′N, 99°43′E). Adult predators were commonly observed on flowering refugia plants, including *Helianthus annuus*, *Cosmos sulphureus*, *Turnera subulata*, and *Calopogonium mucunoides*. These plants serve as important habitats for natural enemies. To minimize variability typical of field-collected insects, all predators used in the experiment were laboratory-reared F1 *Sycanus* sp. derived from this parental population and used 15 days after adult emergence. *Metisa plana* larvae (third-fourth instars) were collected from smallholder oil palm plantations with active infestations. The larvae were carefully removed from the undersides of oil palm leaflets and maintained under laboratory conditions prior to experimentation.

Experimental design

A laboratory experiment was conducted using a completely randomized design (CRD) to evaluate the predatory interaction between *Sycanus* sp. and *M. plana*. Oil palm seedlings were used as the host plant and food source for *M. plana* larvae throughout the experiment. The experiment consisted of five predator-density treatments, each replicated 10 times, for a total of 50 experimental units (each an individual observation arena). All predators were laboratory-reared F1 female *Sycanus* sp., aged 15 days after adult emergence, standardized to minimize individual variability; only females were used to avoid sex-related behavioral differences and ensure uniform predatory performance. The five treatments comprised 1, 2, 3, 4, and 5 female *Sycanus* sp. (P1–P5, respectively), each with 10 *M. plana* larvae. Predators were then introduced into the units containing the assigned number of *M. plana* larvae, and predation activity and predator–prey interactions were observed.

Observation and data analysis

Behavioral observations were conducted in transparent plastic containers (20 cm × 15 cm × 15 cm) covered with fine mesh to prevent insect escape while allowing ventilation, at 27 ± 2 °C, 70 ± 10% relative humidity, and a 12:12 h (L:D) photoperiod. Before each observation, predators were individually isolated and starved for 12 h to standardize hunger and feeding motivation (Jamian & Adam 2018). Each arena then received *M. plana* larvae according to the assigned treatment.

Predatory performance of *Sycanus* sp. against *M. plana* was evaluated using both qualitative and quantitative observations: (a) prey search time, determined as the interval from predator introduction to the first successful prey encounter; (b) prey handling time, measured as the interval from initial contact until the prey was completely immobilized; (c) prey consumption, the number of larvae consumed during the observation period; (d) larval mortality, assessed at 24-hour intervals after predator introduction using the formula (Ge et al. 2019):

$$M = \frac{a}{a+b} \times 100, \text{ where}$$

M: mortality of larvae (%); *a*: number of dead larvae; and *b*: number of larvae treated.

Data were analyzed in Microsoft Excel 2016 and SPSS version 23. One-way analysis of variance (ANOVA) tested the effects of predator density on prey search duration, prey handling time, larval mortality, and prey consumption. Where treatments differed significantly, means were separated using Duncan's multiple range test (DMRT) at $P = 0.05$. Linear regression assessed the relationship between predator density and prey consumption.

RESULTS

Prey search behavior of *Sycanus* sp. on *M. plana*

The prey-search behavior of *Sycanus* sp. showed clear temporal patterns throughout the experimental period (Figure 1). The first search was consistently longer than later ones: the initial search for 10 *M. plana* larvae ranged from 2.11 to 2.25 minutes across all predator densities, with no consistent trend as predator density increased. In contrast, subsequent searches were markedly shorter (1.69 to 2.04 minutes) and decreased slightly at higher predator densities. This shortening after the first capture indicates that the predator shifted to a more efficient hunting state, possibly reflecting a higher encounter probability within the confined arena, although the underlying behavioral mechanisms were not directly quantified.

Prey handling time of *Sycanus* sp.

Total handling time for 10 *M. plana* varied across predator densities, ranging from 58.1 to 59.1 minutes (Figure 2). These minimal differences, indicate that predator density did not substantially affect the duration of the prey handling process, suggesting that *Sycanus* sp. requires a relatively constant time to capture, immobilize, and consume prey, regardless of the number of conspecifics present. The mechanism by which *Sycanus* sp. handles *M. plana* involves piercing the larval cuticle with its rostrum and

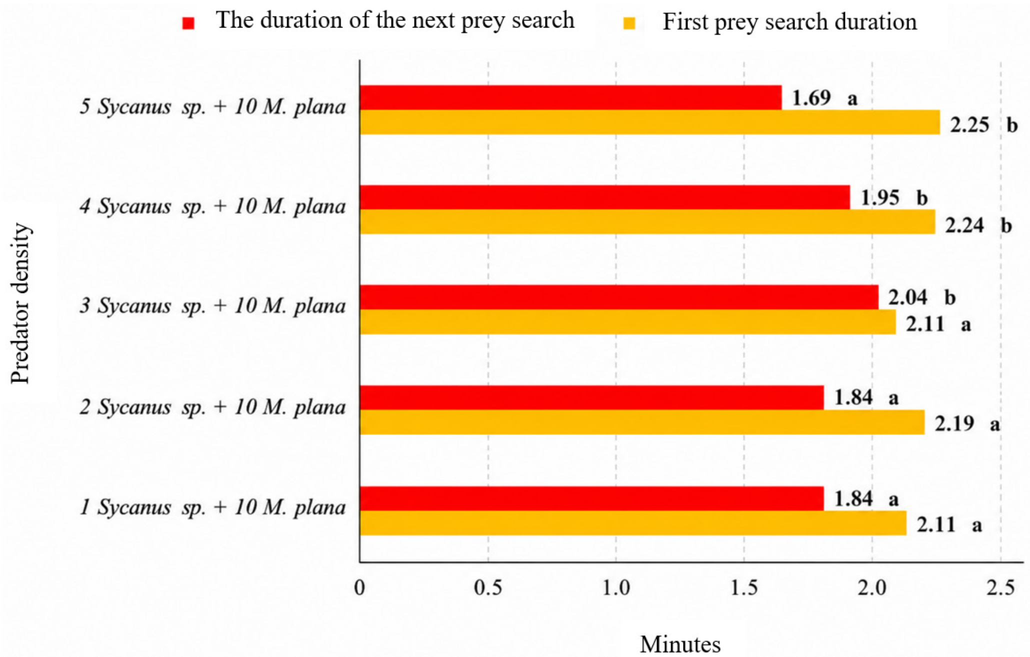

Figure 1. *Sycanus* sp. search time preying on *Metisa plana.* Different letters indicate significant differences (DMRT, $P = 0.05$).

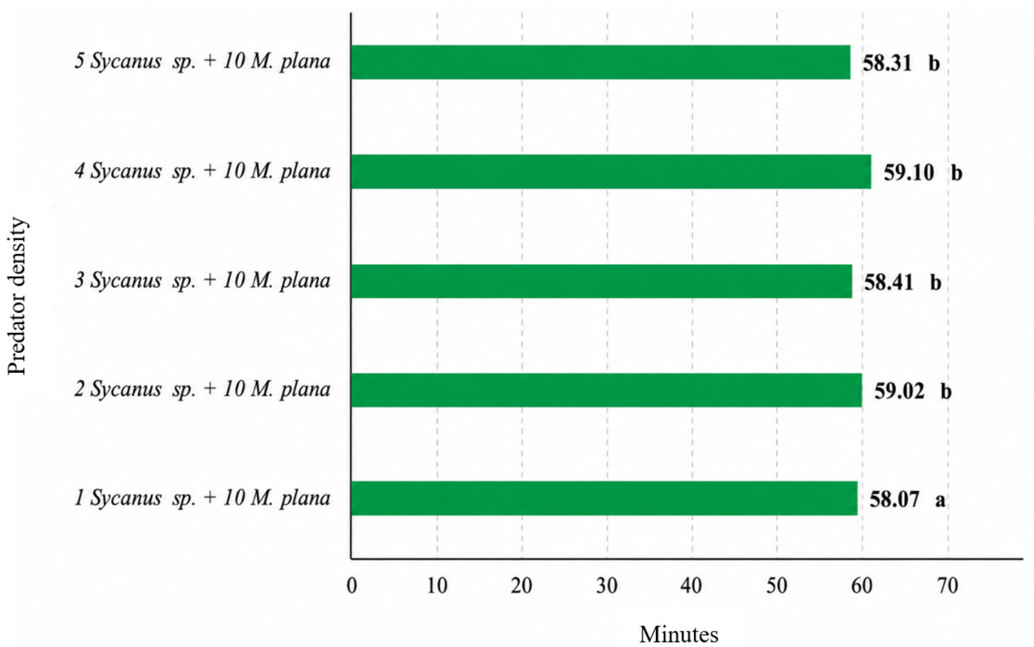

Figure 2. Handling time of *Sycanus* sp. from first attack to immobilization of *Metisa plana*. Different letters indicate significant differences (DMRT, $P = 0.05$).

extracting internal body fluids by sucking, leading to progressive desiccation and eventual death of the larvae. The death of *M. plana* was characterized by the larvae exiting their larval sacs, a clear and reliable indicator of successful predation.

Mortality rates of *M. plana* due to predation by *Sycanus* sp.

Metisa plana mortality was recorded daily for three days predator introduction (days after application, DAA) until few or no larvae remained (Figure 3). Across all predator-to-prey ratios, mortality was highest on the first day (DAA = 1) and declined thereafter. On DAA = 1, the 5:10, 4:10, 3:10, 2:10, and 1:10 ratios recorded killed 9, 8, 7, 6, and 5 larvae, respectively; mortality then fell sharply to 1–3 larvae on DAA = 2, and by DAA = 3 only 0 to 1 *M. plana* larvae remained. Most predation therefore occurred soon after *Sycanus* sp. introduction, with the 5:10 ratio being most effective in achieving early elimination of *M. plana*.

Density-dependent effects on predation efficiency

Predator density had a strong positive effect on prey consumption. The mean number of larvae consumed rose steadily with density from 1.26 ± 0.21 larvae at one predator to 2.05 ± 0.18, 2.74 ± 0.17, and 3.64 ± 0.20 larvae at two, three, and four predators, and 4.43 ± 0.19 larvae at five predators per 10 larvae (Figure 4). Linear regression confirmed a significant positive relationship between predator density and prey consumption, ($y = 0.795x + 0.451$; $R^2 = 0.9531$), indicating that predator density explained about 95% of the variation in prey consumption.

DISCUSSION

Prey search behavior

The search behavior of *Sycanus* sp. during the initial phase – longer durations at first, then progressively shorter intervals – in line with the previous studies on predatory insects, which report that predators often search longer while familiarizing themselves with their environment and the spatial distribution of prey. The rapid decline in search time across subsequent prey encounters suggests that, once the predator located and captured its first prey, it finds additional targets more efficiently in the same arena. This pattern is in line with optimal foraging theory,

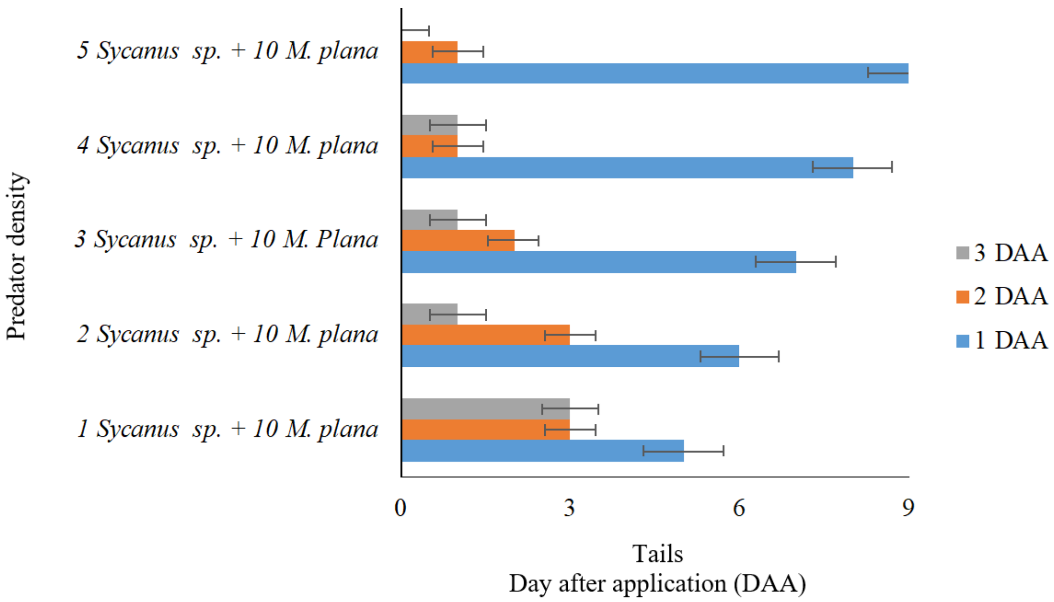

Figure 3. Daily mortality of *Metisa plana* from predation by *Sycanus* sp.

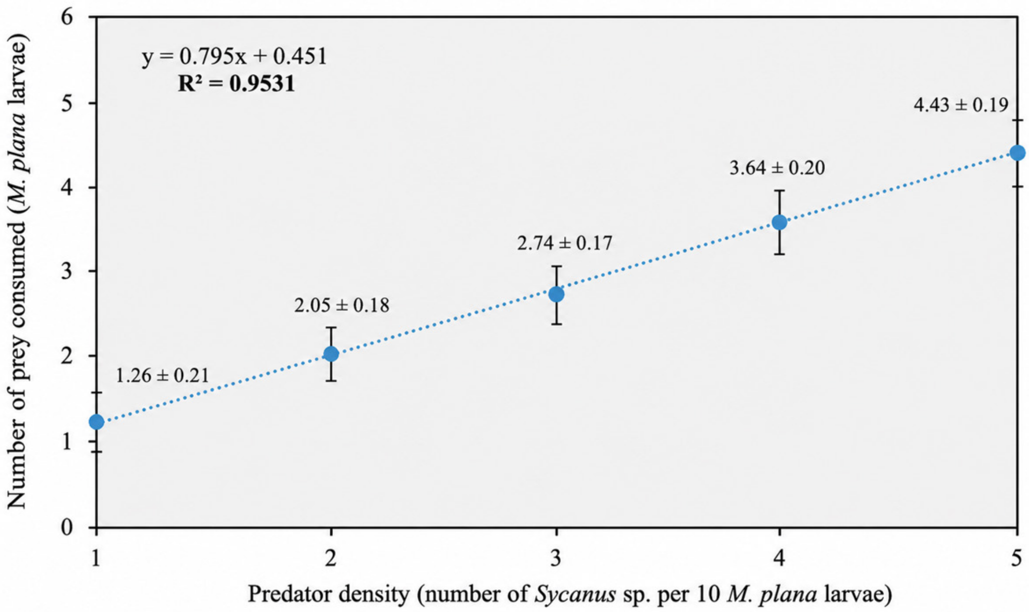

Figure 4. Relationship between predator density and prey consumption by *Sycanus* sp. Values are presented as mean ± SE (n = 10).

which holds that predators adjust their search tactics according to previous encounters and environmental cues (Yuliadhi et al. 2021; Srikumar et al. 2014).

The ability of *Sycanus* sp. to adjust its search strategy upon detecting *M. plana* could strengthen its role in biological pest control in oil palm plantations. Such flexibility is likely important in agricultural systems, where fluctuating pest populations may demand varied predation strategies (Jamian et al. 2017). Because a predator's search behavior can shift with environmental complexity and with successive prey encounters, further should examine how prey density and habitat affect search efficiency; more complex environments, in particular, may hinder prey detection and lengthen the search process (Ahmad et al. 2020).

The initial search time is a useful indicator of predator's potential to control a pest. The shorter search times at higher predator densities may reflect density-dependent interactions among predators, although these were not measured directly. Such effects are likely more pronounced in confined laboratory settings than in the field, where predators and prey are distributed more heterogenously (Stone et al. 2023; Jamian et al. 2017).

Prey handling time

The narrow range of handling times across all predator densities (58.1–59.1 minutes for 10 *M. plana*) indicates that prey handling in *Sycanus* sp. is governed mainly by physiological and behavioral traits intrinsic to the predator, rather than by external factors such as intraspecific competition (Ullah et al. 2019; Srikumar et al. 2014). The mode of prey immobilization employed by *Sycanus* sp.—piercing the larval cuticle and extracting body fluids through rostral sucking—is characteristic of the Reduviidae family and matches the mechanisms documented for other harpactorine assassin bugs (Ullah et al. 2019; Hwang & Weirauch 2012). This piercing-sucking action causes progressive desiccation and death, and the emergence of *M. plana* larvae from their sacs provides a reliable behavioral indicator of successful predation.

The stability of handling time across predator densities contrasts with reports of density-related behavioral effects in some predatory insects, where prey exploitation varies with predator abundance. This constancy suggests that prey capture and consumption are constrained mainly by the physiological processes of immobilizing and feeding on prey rather than by predator density (Ullah et al. 2019). This is also seen in other reduviid predators in which handling time remains relatively constant across different prey densities (Yuliadhi et al. 2021; Ahmad et al. 2020).

Handling time has important implications for biological control. Rapid, predictable handling lets *Sycanus* sp. process prey quickly and sustain a high predation rate, even in the highly modified environments of oil palm plantations, which supports its integration into an oil palm pest management plan (Wood 2019). Optimizing the density and release timing of the predator could further improve prey suppression. As reported, for other harpactorine reduviids such as *Cydnocoris gilvus* (Burmeister) preying on *Helopeltis antonii* Signoret, in which handling time was a key determinant of predation efficiency (Srikumar et al. 2014).

Temporal dynamics of predation and mortality

The mortality of *M. plana* peaked on the first DAA and decline steadily across all predator-to-prey ratios, mirroring the acclimatization of *Sycanus* sp. after introduction to the experimental arena. The peak was more pronounced at the highest-density, where *Sycanus* sp. consumed nine *M. plana* larvae on the first day. This early surge likely results from a combination of hunger (from the 12 h pre-experimental starvation) and the stimulus of newly presented prey in a novel setting, which together trigger exploratory and predatory behavior (Imboma et al. 2020; Ullah et al. 2019).

The subsequent decline in feeding is consistent with reports that predators feed less after initial prey exposure, owing to satiation or reduced prey availability (Yuliadhi et al. 2021; Ullah et al. 2019). This "predation surge" – elevated predation rates immediately after introduction, followed by stabilization into a more sustainable feeding rhythm– has been described for other biocontrol agents (Ullah et al. 2019; Jamian et al. 2017). It indicates *Sycanus* sp. Exerts its strongest suppression right after release.

Density-dependent effects on predation efficiency

Our results indicate predator density had a strong positive effect on the consumption of *M. plana* larvae by *Sycanus* sp. As predicted by ecological theory, more predators produced greater total prey mortality, indicating substantial potential for *Sycanus* sp. to suppress bagworm populations in oil palm systems at adequate densities (Siallagan et al. 2022; Jamian et al. 2017). However, the increase was not proportional; prey consumption rose about 3.5-fold across a fivefold increase in predator density, suggesting density-dependent interactions among predators that may influence prey consumption at higher densities. The regression, which explained over 95% of the variation in prey consumption, indicates a highly predictable predator–prey response under the tested conditions and suggests practical value for anticipating suppression from predator abundance in managed habitats (Adhikary et al. 2025).

Our findings are in line with previous work on reduviid predators, including *Sycanus dichotomus* Stål and *Cosmolestes picticeps* (Stål), in suppressing bagworm populations in oil palm ecosystems (Ahmad 2020), and with reports in other predatory Hemiptera where higher predator density enhances encounter rates and prey mortality. Because the per-capita gain diminished at higher densities, the highest prey mortality (at the 5:10 ratio) did not translate into proportionally greater consumption. The intermediate ratio of 2:10 may therefore offer a practical compromise between suppression and the number of predators deployed, although this requires field validation. From a management perspective, maintaining adequate populations of *Sycanus* sp. could enhance *M. plana* suppression and support the integration of this predator into sustainable integrated pest management (IPM) programs to reduce reliance on insecticides (Ikhsan 2024; Wood 2019; Priwiratama et al. 2018).

CONCLUSION

Sycanus sp. showed effective predatory performance against *M. plana* under laboratory conditions: search efficiency improved after first prey encounter, handling time remained relatively constant across densities, and mortality was highest on the first day after exposure. Increasing predator density enhanced both prey mortality and consumption, though individual consumption rates declined at higher predator densities. Among the densities tested, a ratio of two *Sycanus* sp. adults per ten *M. plana* larvae offer a practical balance between prey suppression and predator use. These findings clarify the behavioral mechanisms underlying predation by *Sycanus* sp. and support its potential as a biological control agent for sustainable bagworm in oil palm plantations. Further field-based studies are needed to validate these laboratory findings.

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