Journal of Agricultural Science; Vol. 15, No. 5; 2023
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Examining the Predatory Relationship Between the Indigenous Firefly (*Aspisoma ignitum*) and the Invasive Giant African Snail (*Achatina fulica*) in Trinidad, West Indies

Marcus N. A. Ramdwar[1], Jesse Harripersad[1] & Shastri Badal[1]

[1] Biosciences, Agriculture, and Food Technologies, The University of Trinidad and Tobago, ECIAF Campus, Centeno, Trinidad and Tobago

Correspondence: Marcus N. A. Ramdwar, Biosciences, Agriculture and Food Technologies, The University of Trinidad and Tobago, ECIAF Campus, Centeno, Trinidad and Tobago. Tel: 1-868-710-6678. E-mail: marcus.ramdwar@utt.edu.tt

Received: January 24, 2023 Accepted: March 27, 2023 Online Published: April 15, 2023

doi:10.5539/jas.v15n5p47 URL: https://doi.org/10.5539/jas.v15n5p47

Abstract

The current study investigates the predatory relationship between the firefly larvae (*Aspisoma ignitum*) and the giant African snail (*Achatina fulica*). The principal objective of this study was to examine the specific predator responsiveness of the firefly larvae against the giant African snails under experimental conditions. This was evaluated using two (2) treatments T1 and T2. T1 investigated giant African snail neonates of size 0.5 cm with a larva to snail ratio of 1:5. In T2, larvae to snail ratio of 3:1 was investigated using 2 cm giant African snail neonates. Control treatments were included in the experimental design with the absence of the larvae. Each treatment was replicated five (5) times. There were 100 % mortality effects for T1 and T2. Commonalities existed in both the spatial and the temporal characteristics to possibly consider the firefly larvae as an idealistic and highly compatible predator for the giant African snail neonates. Ecological engineering strategies to encourage the presence of the firefly will aid in suppressing the giant African snail population. The study concludes that the firefly larvae can be a possible predator for the control of the giant African snail once the firefly populations are encouraged in both crop and non-crop spaces.

Keywords: Firefly, larvae, giant African snail, neonates, predator, bio-control

1. Introduction

Invasive pests are a challenge to manage given the limited predators within the new habitat they now come to occupy. This may be attributed to predators being non-existent or that the newly introduced organism has not yet been desired by existing predators as a new food source. Invasive pests threaten local biodiversity by competing for food and shelter and have been known to adversely impact crop production spaces (Tu, 2009; Lurgi, Ritchie, & Fordham 2018; Naveena et al., 2020). It should be recognized that there is always a dimension of economic loss attributed to the presence of invasive organism introductions (Naveena et al., 2020; Kourantidou et al., 2021). According to Pysek and Ricardson (2010), "*the ability of an alien species to overcome various barriers in the new environment is affected, positively or negatively, by the presence of other species, native or alien, already resident in the area*". The consequent emergence of potential biological controls which emerge naturally overtime or are unnaturally introduced would be useful towards controlling the populations of introduced species.

The giant African snail (GAS) was discovered in Trinidad in 2008 and has now spread to almost all areas (5128 square kilometres) of the island. Given the destructive ecological characteristic of this pest, the Global Invasive Species Database has ranked it among the "100 Worst Alien Invasive Species" (Invasive Species Specialist Group, 2012). The GAS is a notorious generalist that consumes over 500 plant species and ranks consistently among the world's most invasive pests (Lowe, Browne, Boudjelas, & De Poorter, 2000; Simberloff, 2003). According to the International Union for Conservation of Nature (IUCN, 2010), this introduced snail is considered a threat to agriculture and the environment, whereas without natural enemies they consume the flora found crop and non-crop spaces. A study conducted by Prasad et al. (2004) indicated the specific behavioural attributes of this invasive snail enable this species to impede control strategies. As much as control strategies exist the most effective control for this invasive snail are still unknown (Andreazzi, 2017). This is possibly attributed to the swift population resurgence attributed to its high rates of proliferation.

Methaldehyde is a principal component in many products used to control snails and slugs (Castle et al., 2017; National Center for Biotechnology, 2022). However, as much as this can be useful, the resurgence of snails in areas where it is applied is highly possible much dependant on the formulation which is used. Although metaldehyde formulated molluscicides have proven to be somewhat useful the risk to the environment far prevails over its benefit. Metaldehyde is considered a pollutant which invites problems related to toxicity to the environment, humans and animals (Castle et al., 2017; Saad, Ismail, & Dahalan, 2017; Damalas & Eleftherohorinos, 2011). Given the report threats of this pesticide to the environment there is significance to finding alternative natural approaches which would prove useful in bringing some measure of control. The integration of agroecological principles into pest management is an emerging paradigm for sustainable crop protection practices (Reddy, 2017). This will reduce negative impacts to the environment specifically attributed to pesticide usage.

The identification and nurturing of potential biological organisms to support the population control of the giant African snail would support agroecological pest management strategies. Effective biological approaches to reduce and mitigate pests and pest effects through the use of natural enemies are considered to be environmentally safe (Sanda & Sunusi, 2016). The successful invasiveness of the giant African snail is attributed to the limited existence of identified biological control organisms naturally found in the ecosystem to promote their existence within infested spaces. In a study conducted by Fu and Meyer-Rochow (2013) examined the predator-prey relationship between the larvae of the firefly (*Pyrocoelia pectoralis*) and the land snail (*Bradybaena ravida*). The study concluded that firefly was an effective alternative method of control for the land snail.

The current study examines the predator-prey relationship between the indigenous firefly, *Aspisoma ignitum* and the invasive giant African snail, *Achatina fulica* in Trinidad. The rationale for the study came as a result of an unplanned in-field observation of a larva-type of organism feeding on neonates (snailets) of the giant African snail. Additionally, the need to discover predator-prey relationships for the control of the giant African snail will offer eco-smart pest control alternatives within the eco-system. The specific objectives for the study are:

(1) To characterize the site selection of the organism found displaying targeted predatory behaviour against giant African snail neonates.

(2) To confirm the identity of the larva demonstrating the predatory behaviour.

(3) To examine the specific predator responsiveness of the firefly larva against the giant African snail.

2. Methodology

2.1 Collection Site for the Observed Firefly Larvae Displaying Snail Predation Behaviour

Firefly larvae observed to be feeding on giant African snail neonates were collected from the ground within the proximity of bougainvillea plants located at the ECIAF Campus of the University of Trinidad and Tobago (UTT). Ciomperlik et al. (2013) described the giant African Snail neonate as measuring between 7-20 mm (shell length). The larvae were collected between the hours of 10 a.m. and 12 p.m. during the month of November, 2022. The larvae were most active during and after rainfall events. The authors spent a period of ten (10) days making in-depth direct field observations on the characteristics of the specific area. The identification and selected characteristics of the plants where the larvae were recorded.

2.2 The Identification of the Firefly Larvae and Emerged Adults

The confirmation of the identity of the firefly larvae took the sequential approach of collection, rearing in containment, identification of both the larva and the adult using Google Lens and the subsequent confirmation of the adults' presence at the collection site. The observation of the development of the larvae into the adult under the experimental conditions was crucial for confirmation of the insect. It was reported by Shapovalov et al. (2020), that Google Lens was a suitable means for the identification of insect pests. The confirmation of the adults at the collection site was done by a detailed inspection of the plants as well as by using the sweep net technique as indicated by Jaikla et al. (2020). In this regard, a total of ten (10) larvae were collected on the ground under several *Bougainvillea* spp. plants and divided into two (2) groups of five (5). The average length of the larvae was 1.3 cm. Additionally, a total of ten (10) giant African snail neonates of an average length of 0.5 cm were collected from an active breeding site. Each group of larvae were placed into a 155 cm^3 glass jar. Each jar contained a thin layer of damp soil and a total of five (5) giant African snail neonates. The jars were labelled J1 and J2. The snails were included as a source of food since it was observed that they were being fed upon by the larvae at the collection site. The experimental conditions for light, temperature and humidity was recorded using the LT300 Light Meter and the 3MTM EVM Series Environmental Monitor respectively. The glass jars were covered with a thin permeable cloth that would have provided sufficient ventilation but would have prevented the escape of both organisms. The larvae collected were of all different anatomical and physiological growth stages and as such the transition to the adult stage was expected to vary.

2.3 Estimation of Firefly Larvae Mobility (cm/s)

An estimation of mobility was undertaken to provide an indication of the movement ability of the firefly larvae. A total of ten (10) firefly larvae were randomly selected from the collection site. A 25 cm line was drawn on a sheet of white paper with a dimension 21.6 cm × 27.9 cm. The line drawn had 5 cm sub-divisions measuring 0 cm, 5 cm, 10 cm, 15 cm, 20 cm and 25 cm. Each larva was then placed one (1) at a time at the starting point 0 cm and the time was recorded for the larva to move from 0 cm to 25 cm. The time was also recorded at distances when the larva would have stopped and failed to complete the continuous movement from the 0 cm mark to the 25 cm mark. The larvae were given time to adjust to the experimental conditions before estimating its mobility. The speed (cm/s) was calculated for each larva to give an indication of the larva's mobility.

2.4 Predator Responsiveness of the Firefly Larva Against the Giant African Snail Neonates

The predatory responsiveness by the firefly larvae against the giant African snail neonates was investigated using two (2) ratios for larva and snail combinations, factoring the size of the neonates. In the first evaluation, treatment one (T1) neonates of size 0.5 cm was used in containment jars in a ratio of one (1) larva to five (5) neonates. In the second evaluation, treatment two (T2) a ratio of three (3) larvae to one (1) neonate was used. In the second evaluation, the snails were two (2) centimetres in shell length, hence the justification for increasing the number of larvae used. The snails and larvae were placed in a similar arrangement used for "J1" and "J2" in the identification stage of this study previously reported. However, the damp soil was excluded.

There were two (2) experimental controls used in this component of the study. In the first experimental control (C1) five (5) neonates measuring 0.5 cm were placed in a jar without any larvae. In the second experimental control (C2) a single snail measuring 2 cm was placed in jar without larvae. Each treatment including the control treatments were replicated five (5) times. Only larvae which displayed considerable mobility were selected.

The snails were sourced from an area which had an active breeding population. The experiment was conducted under laboratory conditions of 0.34 Lux, relative humidity 83.9% and with a temperature at 25 ^{o}C. The behaviour of the snails and larvae was monitored for the first hour and after twenty-four (24) hours. The mortality of the snails was determined for each treatment and replicates. Mortality of the 0.5 cm neonates were confirmed using visual inspection and by shining a light through the shell to observe its content. Shells which were empty was an indication of consumption. The mortality of the larger snails was confirmed by visual inspection and further confirmed using the probing procedures as outline by (Ciomperlik et al., 2013). The morality was expressed as a percentage.

3. Results

3.1 Site Characteristics of the Larvae Predatory Behaviour

The larvae were found on the ground within a non-crop area comprised of eight (8) *Bougainvillea glabra* arranged in a linear landscape arrangement. The plants were located between a building on one side and an open savannah-type of field on the other side. The plants were regularly pruned and as such there were minimum floral bracts present on all plants. The area within the drip line of the canopy was bare soil. There were regular rainfall events in the area where these plants were located. The average humidity and temperature within the canopy of the plants were eighty-three (83%) percent and twenty-four (24) degrees centigrade respectively. Table 1 provides a detail description of the dimensions of the plants at the collection site.

Table 1. Dimension characteristics for the *Bougainvillea glabra* plants at the larva collection site

Data parameters	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8
Distance between plants (m)	0	8.77	14.93	22.25	28.65	33.83	38.40	44.19
Diameter of canopy (m)	2.13	2.43	2.13	2.13	2.43	1.98	1.52	1.52
Circumference of canopy (m)	6.69	7.63	6.69	6.69	7.63	6.22	4.77	4.77
Volume of Vegetative canopy (m^3)	4.37	5.70	5.79	5.04	7.82	5.23	3.19	2.92
Distance from concrete (m) walkway	1.49	1.43	1.37	0.94	1.34	1.43	1.31	1.03
Plant height (m)	1.24	1.24	1.64	1.43	1.70	1.70	1.76	1.61
Canopy Length (m)	0.76	0.76	0.73	0.51	0.91	1.066	0.79	0.79
Bare Base* (m)	0.91	0.91	0.73	0.51	0.76	0.60	0.79	0.60

Note. *: Bare base, area of soil without cover within the dripline of a plant.

3.2 Firefly Larvae Identification and Confirmation

Only two (2) firefly larvae completed the metamorphosis, one (1) from each of the glass jars. Google Lens returned the results as to the identity of the organism to be that of *Aspisoma ignitum.* The adults which emerged may have been from larvae at a more advanced physiological stage of metamorphosis. The Taxonomic Serial Number (TSN) for this organism is 722435 (ITIS, 2022). The firefly larva and emerged adults is shown in Figure 1. The specific organism is coleopteran within the family Lampyridae (Santiago-Blay & Medina-Gaud, 1986). The authors were able to confirm the existence of the adult fireflies within the canopy of the bougainvillea plants.

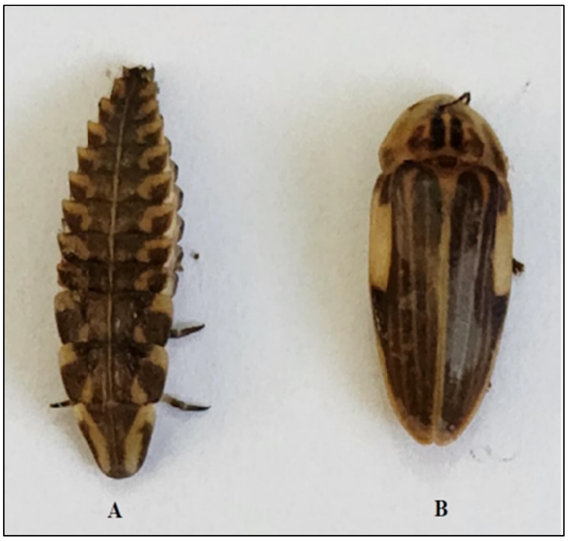

Figure 1. The larva (A) and the adult of the indigenous firefly (B) (*Aspisoma ignitum*)

3.3 Mobility (cm/s) of the Firefly Larvae

There was variability in the speed for each firefly larvae (Table 2). This can be attributed to the age of the individual larva and its physiological stage in relation to entering a stage of quiescence towards pupation. It is envisaged that these speeds would also be different in the larvae's natural habitat. It was noted that the larvae had a faster mobility when exposed to sunlight compared to shaded conditions in its natural habitat. The results presented in Table 2 indicated that the larvae were considerably mobile under experimental assessment and would have a wide seeking range for possible predatory behaviour. The speed varied based on the stage of development of the larva and the sensitivity to measurement procedures and conditions.

Table 2. Speed of fire-fly larvae (cm/s)

Larva Number	**Time** (s)	**Distance** (cm)	**Speed** (cm/s)
1	102	25	0.25
2	55	25	0.45
3	69	25	0.36
4	104	20*	0.19
5	78	25	0.32
6	127	25	0.19
7	96	15*	0.16
8	125	25	0.20
9	47	25	0.53
10	118	25	0.21
Average			0.29

Note. *: Larva stopped at that distance;

Temperature 24.2 °C, Relative Humidity 83.2%, Light 207.2 Lux.

3.4 Predatory Responsiveness of the Firefly Larva

The predatory characteristics of the firefly larvae for both ratio combinations, T1 (1:5) and T2 (3:1), resulted in 100 % mortality against the giant African snail after twenty-four (24) hours (Table 3). Upon the introduction of the larvae with the snails in T1, the larvae were immediately attracted to the snails for all treatment replicates. The larvae and the snail were both present at the base of the jars in T1. In the experimental evaluation T2, the larvae were also attracted to the snails for all treatment replicates. There was marked contrast in the mobility of the snail in T2 when compared to treatment T1. The larger giant African snail neonates used in T2 given its size had greater mobility. In some instances, the snail ascended the jar to occupy a different location away from the larvae. Although, this was observed the snail was eventually compromised by the larvae at the base of the jar. It was observed within twenty-fours (24) hours that the mouth parts of the larvae in all replicated of T1 had burrowed into the exposed tissue of the snail. In a similar manner, the larvae mouth part was burrowed into the tissue of the larger snails in all replicates of T2. It was observed that when the mouth parts of the larvae made contact with the snails' tissue in both T1 and T2 that there was a prolong continuous feeding attachment for both treatments (Figure 2 and Figure 3). In T1, the contents within the shell of all the neonates in each replicate were consumed. In T2, given the size of the snails, the tissue was present but appeared to have a shrunken appearance.

Table 3. Mortality response (%) for treatments and replicates indicating the fire fly larva predatory characteristics

Treatment 1 Ratio 1:5 (T1)	**Mortality Response (%)**	**Treatment 2 Ratio 3:1 (T2)**	**Mortality Response (%)**	**Control 1 (C1)**	**Mortality Response (%)**
Replicate No.		*Replicate No.*		*Replicate No.*	
1	100 %	1	100%	1	0%
2	100%	2	100%	2	0%
3	100%	3	100%	3	0%
4	100%	4	100%	4	0%
5	100%	5	100%	5	0%
				Control 2 (C2)	**Mortality Response (%)**
				Replicate No.	
				1	0%
				2	0%
				3	0%
				4	0%
				5	0%

Figure 2. The predatory behaviour of the firefly larvae on a neonate giant African snail (GAS) in Treatment 1 (T1) of the study

Figure 3. The predatory behaviour of the firefly larvae on a giant African snail (GAS) in Treatment 2 (T2) of the study

4. Discussion and Conclusion

The firefly larva, *Aspisoma ignitum*, has the potential to be an active biological control for the highly invasive giant African snail (*Achatina fulica*). The firefly, *Aspisoma ignitum* was reported in Trinidad and Tobago by several authors (Santiago-Blay & Medina-Gaud, 1986; Arnett et al., 2002; Lloyd, 2003; Branham, 2006; Peck, 2011; Lloyd, 2018; Global Biodiversity Information Facility, 2020). According to Baral (2022), the firefly larvae exhibits predatory behaviour and can control a wide range of invasive agricultural pests and this can be good from an ecological standpoint. The predatory characteristics of the firefly larvae will be dependent on its stage of development in that there would be a decline in the feeding behaviour as it enters the pre-pupal stage (Danks, 2000; Kaleka, Kaur, & Bali, 2019). It was reported by Tyler (2002) and Walker et al. (2018) that the firefly larvae would pierce the soft-tissue of gastropods and inject a supposedly neurotoxic venom to paralyze their prey. This would be followed by an intricate feeding method as described by Sato (2019).

The fireflies spend most of their lives in the larval stage (Riley, Rosa, & Lima da Silveira, 2021) and given its predatory behaviour may make this organism a beneficial insect for biological control purposes. Albeit, the reduction in feeding closer to the pre-pupal stage the larva has significant potential to control the giant African snail. It would be however critical to ensure that there exist multiple asynchronous stages of the firefly life cycle co-existing simultaneously. Multiple asynchronous stages of the firefly will ensure effective bio-control efficiencies within the snail infested habitats.

The firefly larvae are predominantly nocturnal (Tyler, 2002; Fu & Meyer-Rochow, 2013) and so too is the specific nature of the giant African snails (Bhattacharyya et al., 2014; Mathai, 2014; Lenin & Ummer, 2018). It should also be noted that firefly larvae within the Lampyridae family has been known to occupy a soil based habitat (Wing, 1989). Notwithstanding the limited published research on the firefly larvae and this specific land snail, there exist significant spatial and temporal commonalities to consider the firefly larvae highly compatible predators for the giant African snail.

In the current study, the firefly larvae were effective as a predator for the giant African snail neonates under investigation. Furthermore, it was observed for the larger snail that the larvae exhibited a type of congregation feeding habit. This congregation characteristic was reported by Fu and Meyer-Rochow (2012), and da Silva Nunes et al. (2021). Overtime, indigenous predators may emerge to control invasive pests, however, the time for emergence may be slow on the account of several factors. The observation of the predatory behaviour of the firefly larvae under investigation occurred in a non-crop environment where there was no use of insecticides. In crop type environments, where the giant African snail poses a significant threat to food security, pesticide usage will hinder the possible establishment of this specific predator-prey relationship. This is an immense predictable challenge in crop spaces where insecticides can foster a non-insect type of invasive pest such as the giant African snail from expanding its population. This is as a consequence of the non-target effects of insecticides on possible beneficial insects.

Conservation biological control can be a useful approach to enhancing natural indigenous predators in fighting against invasive pest. Ecological engineering techniques as described by van Emden (2022) when applied to agroecosystems can be useful to improve the benefits of natural enemies within the environment. Ecological engineering will be useful in reducing the dependence on or elimination of pesticides. The main pesticide used for the control of the giant African snails around the world and in Trinidad and Tobago is metaldehyde. Metaldehyde is known to cause serious environmental problems and has also been banned in the United Kingdom (Castle et al., 2017). Hence, it would be valuable to encourage the presence of fireflies in snail infested crop and non-crop spaces as an agro-ecological crop protection strategy for giant African snail control.

Beetle banks are ecologically engineered spaces which comprises a variety of flora that is protected from pesticides and which encourages the proliferation of beneficial predatory insects. The concept of a beetle bank was described by (Marshall & Moonen, 1998). Although these spaces may also be attractive to the giant African snail, the predatory characteristics of the firefly larvae would become engaged. The study concludes that the firefly (*Aspisoma ignitum*) larvae can be a possible predator for the control of the giant African snail once their populations are encouraged in both crop and non-crop spaces.

Acknowledgements

The authors would like to express their gratitude to the library staff at the ECIAF Campus of the University of Trinidad and Tobago for their assistance with database searches related to this study. The authors would also like to express their gratitude to Mr. Ticquel Mohammed and Ms. Teddi-Ann Lazar for their field assistance.

References

Andreazzi, M. A., Gasparotto, F., Paccola, E. A., Silva, C. N., Rodrigues, A. D., & Lizama, M. D. (2017). Giant African snail, *Achatina fulica* (Férussac, 1821): An environmental and public health problem in the Northwestern of Paraná State, Brazil. *Acta Scientiarum. Biological Sciences, 39*, 301-307. https://doi.org/10.4025/actascibiolsci.v39i3.35569

Arnett, R. H. Jr., Thomas, M. C., Skelley, P. E., & Frank, J. H. (2002). Polyphaga: Scarabaeoidea through Curculionoidea. *American beetles* (Vol. 2). CRC Press LLC. https://doi.org/10.1201/9781420041231

Baral, A. (2022). Firefly: Its importance and an inspiration for innovations. *International Journal of Entomology Research, 7*(4), 126-127.

Bhattacharyya, B., Das, M., Mishra, H., Nath, D. J., & Bhagawati, S. (2014). Bioecology and management of giant African snail, *Achatina fulica* (Bowdich). *International Journal of Plant Protection, 7*(2), 476-481. https://doi.org/10.15740/has/ijpp/7.2/476-481

Branham, M. A. (2006). The fireflies of the Fernando de Zayas Collection, Havana, Cuba with notes on their taxonomic status. *The Coleopterists Bulletin, 60*(1), 49-52. https://doi.org/10.1649/855.1

Castle, G., Mills, G., Gravell, A., Jones, L., Townsend, I., Cameron, D. G., & Fones, G. (2017). Review of the molluscicide metaldehyde in the environment. *Environmental Science: Water Research and Technology, 3*, 415-428. https://doi.org/10.1039/c7ew00039a

Ciomperlik, M. A., Robinson, D. G., Gibbs, I. H., Fields, A., Stevens, T., & Taylor, B. M. (2013). Mortality to the giant African snail, Liss *Achatina fulica* (Gastropoda: Achatinidae), and non-target snails using select molluscicides. *Florida Entomologist, 96*(2), 370-379. https://doi.org/10.1653/024.096.0257

da Silva Nunes, V. C., Lemos de Matos, E. J., Lima, W., Vaz, S. M., Mermudes, J. R., & Lima da Silveira, L. F. (2021). Lights Ahead: Morphology and Life Stages of the Spotted Tortoise Firefly, *Aspisoma sticticum* Gemminger, 1870—Fireflies with a Unique Extra Pair of Lanterns on the Larval Pronotum (Coleoptera: Lampyridae). *Annales Zoologici, 71*(1). https://doi.org/10.3161/00034541anz2021.71.1.007

Damalas, C. A., & Eleftherohorinos, I. G. (2011). Pesticide Exposure, Safety Issues, and Risk Assessment Indicators. *International Journal of Environmental Research and Public Health, 8*(5), 1402-1419. https://doi.org/10.3390/ijerph8051402

Danks, H. V. (2000). Measuring and reporting life-cycle duration in insects and arachnids. *European Journal of Entomology, 97*(3), 285-303. https://doi.org/10.14411/eje.2000.046

Fu, X., & Meyer-Rochow, V. B. (2012). An investigation into the morphological and behavioral adaptations of the aquatic larvae of Aquaticaleii (Coleoptera: Lampyridae) to prey upon fresh water snails that serve as intermediate hosts for the liver fluke. *Biological Control, 62*(3), 127-134. https://doi.org/10.1016/j.biocontrol.2011.12.007

Fu, X., & Meyer-Rochow, V. B. (2013). Larvae of the firefly *Pyrocoelia pectoralis* (Coleoptera: Lampyridae) as possible biological agents to control the land snail *Bradybaena ravida*. *Biological Control, 65*(2), 176-183. https://doi.org/10.1016/j.biocontrol.2013.02.005

GBIF (Global Biodiversity Information Facility). (2020). *Aspisoma ignitum* (Linnaeus, 1767) in GBIF Secretariat (2022). *GBIF Backbone Taxonomy*. Retrieved from https://www.gbif.org/species/1162741

Invasive Species Specialist Group. (2012). *Achatina fulica* (Mollusc). *Global invasive species database* (Version 2012.2). Retrieved from http://www.issg.org/database/species/ecology

ITIS (Integrated Taxonomic Information System). (2022). *Aspisoma ignitum (Linnaeus, 1767)* (Taxonomic Serial No. 722435). Retrieved from https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=722435&print_version=SCR&source=from_print#null

IUCN (International Union for Conservation of Nature). (2010). *Impact of nature's invading aliens measured for first time*. Retrieved January 22, 2010, from http://www.gisp.org

Jaikla, S., Lewis, S. M., Thancharoen, A., & Pinkaew, N. (2020). Distribution, abundance, and habitat characteristics of the congregating firefly, Pteroptyx Olivier (Coleoptera: Lampyridae) in Thailand. *Journal of Asia-Pacific Biodiversity, 13*(3), 358-366. https://doi.org/10.1016/j.japb.2020.06.002

Kaleka, A. S., Kaur, N., & Bali, G. K. (2019). Larval development and molting. In H. Mikkola (Ed.), *Edible Insects* (Chapter 3, pp. 17-20). Intech Open. https://doi.org/10.5772/intechopen.77835

Kourantidou, M., Cuthbert, R. N., Haubrock, P. J., Novoa, A., Taylor, N. G., Leroy, B., … Courchamp, F. (2021). Economic costs of invasive alien species in the Mediterranean basin. *NeoBiota, 67*, 427-458. https://doi.org/10.3897/neobiota.67.58926

Lenin, N., & Ummer, N. (2018). *Giant African snail menace in crops and its management*. Retrieved from https://www.researchgate.net/publication/329590657_GIANT_AFRICAN_SNAIL_MENACE_IN_CROPS_AND_ITS_MANAGEMENT

Lloyd, J. E. (2003). On research and entomological education VI: Firefly species and lists, old and now. *The Florida Entomologist, 86*(2), 99-113. https://doi.org/10.1653/0015-4040(2003)086[0099:ORAEEV]2.0.CO;2

Lloyd, J. E. (2018). *A naturalist's long walk among shadows: Of North American Photuris—patterns, outlines, silhouettes ... echoes* (p. 477). Self-Published, Gainesville, FL, USA.

Lowe, S., Browne, S. M., Boudjelas, S., & De Poorter, M. (2000). *100 of the world's worst invasive alien species: A selection from the global invasive species database*. The Invasive Species Specialists Group of the Species Survival Commission of the World Conservation Union. Hollands Printing, Auckland.

Lurgi, M., Ritchie, E. G., & Fordham, D. A. (2018). Eradicating abundant invasive prey could cause unexpected and varied biodiversity outcomes: The importance of multispecies interactions. *Journal of Applied Ecology, 55*(5), 2396-2407. https://doi.org/10.1111/1365-2664.13188

Marshall, E. J. P., & Moonen, C. (1998). *A review of field margin conservation strips in Europe* (p. 92, A Report for the UK Ministry of Agriculture, Fisheries and Food). IACR Long Ashton Research Station, Bristol, UK.

Mathai, R. S. (2014). The Snail Spurt—An Issue of Concern. *Internafional Research Journal of Environment, 3*(6), 88-91.

National Center for Biotechnology Information. (2022). *PubChem Compound Summary for CID 61021, Metaldehyde*. Retrieved from https://pubchem.ncbi.nlm.nih.gov/compound/Metaldehyde

Naveena, N. L., Shashank, R. P., Raghavendra, D., & Jeer, M. (2020). Invasive insect pests in India: Current scenario and future perspective. *Indian Entomologist, 1*, 23-31.

Peck, S. B. (2011). The diversity and distributions of the beetles (Insecta: Coleoptera) of the northern Leeward Islands, Lesser Antilles (Anguilla, Antigua, Barbuda, Nevis, Saba, St. Barthélemy, St. Eustatius, St. Kitts, and St. Martin-St. Maarten). *Insecta Mundi, 159*, 1-54.

Prasad, G. S., Singh, D. R., Senani, S., & Medhi, R. P. (2004). Eco-friendly way to keep away pestiferous Giant African snail, Achatina fulica Bowdich from nursery beds. *Current Science, 87*(12), 1657-1659.

Pyšek, P., & Richardson, D. M. (2010). Invasive Species, Environmental Change and Management, and Health. *Annual Review of Environment and Resources, 35*(1), 25-55. https://doi.org/10.1146/annurev-environ-033009-095548

Reddy, P. P. (2017). *Agro-ecological approaches to pest management for sustainable agriculture* (pp. 29-41). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-10-4325-3

Riley, W. B., Rosa, S. P., & Lima da Silveira, L. F. (2021). A comprehensive review and call for studies on firefly larvae. *PeerJ, 9*, e12121. https://doi.org/10.7717/peerj.12121

Saad, A. M., Ismail, S. W., & Dahalan, F. A. (2017). Metaldehyde toxicity: A brief on three different perspectives. *Journal of Civil Engineering, Science and Technology, 8*(2), 108-114. https://doi.org/10.33736/jcest.444.2017

Sanda, N. B., & Sunusi, M. (2014). Fundamentals of biological control of pests. *International Journal of Clinical & Biological Sciences, 1*(6), 1-11. https://doi.org/10.13140/RG.2.2.19011.20002

Santiago-Blay, J. A., & Medina-Gaud, S. (1986). Notes on the Biology of *Aspisoma ignitum* (L.) (Coleoptera: Lampyridae): A New Firefly Record for Puerto Rico. *The Florida Entomologist, 69*(2), 440. https://doi.org/10.2307/3494957

Sato, N. (2019). Prey-tracking behavior and prey preferences in a tree-climbing firefly. *PeerJ, 7*, e8080. https://doi.org/10.7717/peerj.8080

Shapovalov, V. B., Shapovalov, Y. B., Bilyk, Z. I., Megalinska, A. P., & Muzyka, I. O. (2019). The Google Lens analyzing quality: An analysis of the possibility to use in the educational process. *Educational Dimension, 53*(1), 3844. https://doi.org/10.31812/educdim.v53i1.3844

Simberloff, D. (2003). How Much Information on Population Biology Is Needed to Manage Introduced Species? *Conservation Biology, 17*(1), 83-92. https://doi.org/10.1046/j.1523-1739.2003.02028.x

Tu, M. (2009). Assessing and Managing Invasive Species within Protected Areas. In J. Ervin (Ed.), *The Nature Conservancy. Protected Area Quick Guide Series* (p. 40). Arlington, VA.

Tyler, J. (2002). *The Glow-worms*. Sevenoaks: Tyler-Scagell.

Van Emden, H. F. (2022). Conservation biological control of insect pests. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 17*(024), 1-11. https://doi.org/10.1079/cabireviews202217024

Walker, A. A., Robinson, S. D., Yeates, D. K., Jin, J., Baumann, K., Dobson, J., … King, G. F. (2018). Entomo-venomics: The evolution, biology and biochemistry of insect venoms. *Toxicon, 154*, 15-27. https://doi.org/10.1016/j.toxicon.2018.09.004

Wing, S. R. (1989). Energetic costs of mating in a flightless female firefly, *Photinus collustrans* (Coleoptera: Lampyridae). *Journal of Insect Behavior, 2*(6), 841-847. https://doi.org/10.1007/bf01049405