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Elucidating the daily foraging activity pattern of *Oecophylla smaragdina* to minimize bite nuisances in Asia large agro-system plantations

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Abstract

Oecophylla smaragdina F., the Asian weaver ant, is one of the oil palm plantation's (*Elaeis guineensis*) potential predators, for the invasive bagworm species *Metisa plana* Walker, but this ant is a nuisance species that irritates plantation workers with their sharp bites. Here we assess the foraging activities (FA) of *O. smaragdina*'s major workers, identify its inactive times and the existence of supervision, a novelty for social insects. Between 2018 and 2022, the pattern of trunk foraging activity was used as a mitigation measure. The relationship between trunk FA and air temperature (AT), relative humidity (RH), air pressure (AP), and rainfall interception (RI) was also investigated. Our results showed that, *O. smaragdina* is a strictly diurnal ant species, has little to no crepuscular activity, and stopped foraging during darkness. Moreover, veteran bigger workers systematically acted as supervisors by monitoring trails, intercepting, and bringing back to nests smaller individuals during heat peaks. In relation to population size relative abundance, all colonies displayed greater intensity during the warmest daily periods with higher mean forager density among the bigger colony, regardless of the dry-rainy intervals corresponded to minimal activity from late scotophase to early photophase and showed a bimodal pattern. Thus, forager activity peaked between 1100–1530 h and 1745–1845 h, and an average two-fold daily sudden decrease in intensity between 1620 and 1650 h as a partial cut-off period (first report). Furthermore, foraging activity, AT, AP showed a significant positive correlation while RH was negative. Finally, we found that from the base palm trunks, defensive territorial layers extended to 5 m on average with different spatial configurations indicating greater foraging density within the first 2 m. Our study shows *O. smaragdina* daily low activity periods, before 1000 h, being the most suitable to avoid forager attacks to facilitate pruning and harvesting tasks. © 2024

Author Keywords

Abiotic data; Ants; Arboreal-ground activity; Diurnal hunters; *Elaeis guineensis*; Foraging behaviors; *Oecophylla*

References

- Blüthgen, N., Fiedler, K.
Interactions between weaver ants *Oecophylla smaragdina*, homopterans, trees and lianas in an Australian rain forest canopy
(2002) *J. Anim. Ecol.*, 71 (5), pp. 793-801.
- Crozier, R.H., Schlüns, E.A., Robson, S.K.A., Newey, P.S.
A masterpiece of evolution *Oecophylla* weaver ants (Hymenoptera: Formicidae)
(2010) *Myrmecological News*, 13, pp. 57-71.
- Exélis, M.P., Idris, A.H.
Studies on the predatory activities of *Oecophylla smaragdina* (Hymenoptera: Formicidae) on *Pteroma pendula* (Lepidoptera: Psychidae) in oil palm plantations in Teluk intan, Perak (Malaysia)
(2013) *Asian Myrmecol.*, 5, pp. 163-176.

- Exélis, M.P.
An Ecological Study of Pteroma Pendula (Lepidoptera: Psychidae) in Oil Palm Planta Tion with Emphasis on the Predatory Activities of Oecophylla Smaragdina (Hymenoptera : Formicidae) on the Bagworm
(2015),
Dissertation (Msc) – Universiti of Malaya, Kuala Lumpur Malaysia
- Peng, R., Christian, K., Gibb, K.
The best time of day to monitor and manipulate weaver ant colonies in biological control
(2012) *J. Appl. Entomol.*, 136, pp. 155-160.
- Gordon, D.M., Katherine, N., Dektar, Pinter-Wollman, N.
Harvester ant colony variation in foraging activity and response to humidity
(2013) *PLoS One*, 8 (5).
- Hölldobler, B., Wilson, E.O.
The Ants
(1990), Harvard University Press Cambridge
- Offenberg, J.
Ants as tools in sustainable agriculture
(2015) *J. Appl. Ecol.*, 52 (5), pp. 1197-1205.
- Li, L., Peng, H., Kurths, J., Yang, Y., Schellnhuber, H.J.
Chaos–order transition in foraging behavior of ants
(2014) *Proc. Natl. Acad. Sci. U. S. A*, 111 (3), pp. 8392-8397.
- Devarajan, K.
Correction: the antsy social network: determinants of nest structure and arrangement in asian weaver ants
(2016) *PLoS One*, 11 (7).
- Kolay, S., Boulay, R., d'Ettorre, P.
Regulation of ant foraging: a review of the role of information use and personality
(2020) *Front. Psychol.*, 11, p. 734.
- Vayssières, J.F., Ouagoussounon, I., Adandonon, A., Sinzogan, A., Korie, S., Todjihoundé, R., Goergen, G.
Seasonal pattern in food gathering of the weaver ant Oecophylla longinoda (Hymenoptera: Formicidae) in mango orchards in Benin
(2015) *Biocontrol Sci. Technol.*, 25 (12), pp. 1359-1387.
- Lim, G.T.
Enhancing the Weaver Ant, Oecophylla Smaragdina (Hymenoptera: Formicidae), for Biological Control of a Shoot Borer, Hypsipyla Robusta (Lepidoptera: Pyralidae), in Malaysian Mahogany Plantations
(2007),
Virginia Tech University electronic Doctoral Dissertation
- Dejean, A., Corbara, B., Orivel, J., Leponce, M.
Rainforest canopy ants: the implications of territoriality and predatory behavior
(2007) *Funct. Ecosyst. Communities*, 1, pp. 105-120.
- Offenberg, J.
The use of artificial nests by weaver ants: a preliminary field observation
(2014) *Asian Myrmecol.*, 6, pp. 119-128.
- Sangma, J.S.A., Prasad, S.B.
Population and nesting behaviour of weaver ants, Oecophylla smaragdina from

Meghalaya, India

(2021) *Sociobiology*, 68 (4), pp. 1-11.

- Guénard, B., Silverman, J.
Tandem carrying, a new foraging strategy in ants: description, function, and adaptive significance relative to other described foraging strategies
(2011) *Naturwissenschaften*, 98 (8), pp. 651-659.
- Nene, W., Rwegasira, G.M., Mwatawala, M., Nielsen, M.G., Offenberg, J.
Foraging behavior and preferences for alternative supplementary feeds by the african weaver ant, *Oecophylla longinoda* latreille (Hymenoptera, Formicidae)
(2016) *J. Hymenoptera Res.*, 50, pp. 117-128.
- Barsagade, D.D., Masram, P.P., Nagarkar, D.A.
“Surface ultra-structural studies on antennae in polymorphs of weaver ant *Oecophylla smaragdina*; Fabricius” (Hymenoptera: Formicidae) with reference to sensilla
(2020) *Indian J. Agric. Res.*, pp. 1-8.
A-5411
- Van Mele, P., Cuc, N.T.T.
Evolution and status of *Oecophylla smaragdina* (Fabricius) as a pest control agent in citrus in the Mekong Delta, Vietnam
(2000) *Int. J. Pest Manag.*, 46, pp. 295-301.
- Offenberg, J., Cuc, N.T.T., Wiwatwitaya, D.
The effectiveness of weaver ant (*Oecophylla smaragdina*) biocontrol in Southeast Asian citrus and mango
(2013) *Asian Myrmecol.*, 5, pp. 139-149.
- Peng, R.K., Christian, K., Gibb, K.
The effect of the green ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), on insect pests of cashew trees in Australia
(1995) *Bull. Entomol. Res.*, 85 (2), pp. 279-284.
- Peng, R.K., Christian, K.
The control efficacy of the weaver ant, *Oecophylla smaragdina* (Hymenoptera: Formicidae), on the mango leafhopper, *Idioscopus nitidulus* (Hemiptera: Cicadellidea) in mango orchards in the Northern Territory
(2005) *Int. J. Pest Manag.*, 51 (4), pp. 297-304.
- Allou, K., Doumbia, M., Atta Diallo, H.
Influence de trois facteurs sur le peuplement d'*Oecophylles* dans la lute biologique contre la punaise du cocotier en basse Côte d'Ivoire
(2006) *Agron. Afr.*, 18 (1), pp. 33-40.
- Van Mele, P.
A historical review of research on the weaver ant *Oecophylla* in biological control
(2008) *Agric. For. Entomol.*, 10, pp. 13-22.
- Way, M.J., Khoo, K.C.
Colony dispersion and nesting habits of the ants, *Dolichoderus thoracicus* and *Oecophylla smaragdina* in relation to their success as biological control agents on cocoa
(1991) *Bull. Entomol. Res.*, 81, pp. 341-350.
- Way, M.J., Khoo, K.C.
Role of ants in pest management
(1992) *Annu. Rev. Entomol.*, 37, pp. 479-503.

- Van Mele, P., Cuc, N.T.T., Seguni, Z., Camara, K., Offenberg, J.
Multiple sources of local knowledge: a global review of ways to reduce nuisance from the beneficial weaver ant *Oecophylla*
(2009) *Int. J. Agric. Resour. Govern. Ecol.*, 8 (5-6), pp. 484-504.
- Wood, B.J., Kamarudin, N.
A review of developments in integrated pest management (IPM) of bagworm (*Lepidoptera: Psychidae*) infestation in oil palms in Malaysia
(2019) *J. Oil Palm Res.*, 31 (4), pp. 529-539.
- Wood, B.J., Kamarudin, N.
Bagworm (*Lepidoptera: Psychidae*) infestation in the centennial of the Malaysian oil palm industry—a review of causes and control
(2019) *J. Oil Palm Res.*, 31, pp. 364-380.
- Chong, K.F., Lee, C.Y.
Influences of temperature, relative humidity and light intensity on the foraging activity of field populations of the longlegged ant, *Anoplolepis gracilipes* (*Hymenoptera: Formicidae*)
(2009) *Sociobiology*, 54 (2), p. 531.
- Win, A.T., Machida, Y., Miyamoto, Y., Dobata, S., Tsuji, K.
Seasonal and temporal variations in colony-level foraging activity of a queenless ant, *Diacamma* sp., in Japan
(2018) *J. Ethol.*, 36 (3), pp. 277-282.
- Mishra, M., Bhadani, S.
Daily Activity and Visual Discrimination Reflects the Eye Organization of Weaver Ant *Oecophylla Smaragdina* (*Insecta: Hymenoptera: Formicidae*). bioRxiv
(2017),
- Wielgoss, A., Tschirantke, T., Buchori, D., Fiala, B., Clough, Y.
Temperature and a dominant dolichoderine ant species affect ant diversity in Indonesian cacao plantations
(2010) *Agric. Ecosyst. Environ.*, 135 (4), pp. 253-259.
- Vayssieres, J.F., Sinzogan, A., Korie, S., Adandonon, A.
Field observational studies on circadian activity pattern of *Oecophylla longinoda* (*Latreille*)(*Hymenoptera: Formicidae*) in relation to abiotic factors and mango cultivars
(2011) *Int. J. Brain Cognit. Sci.*, 5 (2), pp. 790-802.
- Wahid, M.B., Abdullah, S.N.A., IE, H.
Oil palm—achievements and potential
(2005) *Plant Prod. Sci.*, 8 (3), pp. 288-297.
- Dislich, C., Keyel, A.C., Salecker, J., Kisel, Y., Meyer, K.M., Auliya, M., Wiegand, K.
A review of the ecosystem functions in oil palm plantations, using forests as a reference system
(2017) *Biol. Rev.*, 92 (3), pp. 1539-1569.
- Tang, K.H.D.
Climate change in Malaysia: trends, contributors, impacts, mitigation and adaptations
(2019) *Sci. Total Environ.*, 650, pp. 1858-1871.
- Mahadi, N.A., Rita, M., Adam, N.A.
Relationship between bagworm *pteroma pendula joannis* (*Lepidoptera: Psychidae*) populations, parasitoids, and weather parameters in oil palm plantation
(2012) *J. Agric. Sci.*, 4 (12).

- Peng, R., Christian, K., Gibb, K.
How many queens are there in mature colonies of the green ant, *Oecophylla smaragdina* (Fabricius)?
(1998) *Aust. Entomol.*, 37 (3), pp. 249-253.
- Peng, R., Christian, K., Reilly, D.
Using weaver ants *Oecophylla smaragdina* to control two important pests on African mahogany *Khaya senegalensis* in the Northern Territory of Australia
(2013) *Aust. For.*, 76 (2), pp. 76-82.
- Rwegasira, R.G., Mwatawala, M., Rwegasira, G.M., Offenberg, J.
Occurrence of sexuals of African weaver ant (*Oecophylla longinoda* Latreille) (Hymenoptera: Formicidae) under a bimodal rainfall pattern in eastern Tanzania
(2015) *Bull. Entomol. Res.*, 105 (2), pp. 182-186.
- Krag, K., Lundegaard, R., Offenberg, J., Nielsen, M.G., Wiwatwittaya, D.
Intercolony transplantation of *Oecophylla smaragdina* (Hymenoptera: Formicidae) larvae
(2010) *J. Asia Pac. Entomol.*, 13 (2), pp. 97-100.
- Kamhi, J.F., Nunn, K., Robson, S.K., Traniello, J.F.
Polymorphism and division of labour in a socially complex ant: neuromodulation of aggression in the Australian weaver ant, *Oecophylla smaragdina*
(2015) *Proc. Biol. Sci.*, 282 (1811).
- Mildner, S., Roces, F.
Plasticity of daily behavioral rhythms in foragers and nurses of the ant *Camponotus rufipes*: influence of social context and feeding times
(2017) *PLoS One*, 12 (1).
- Davidson, D.W., Cook, S.C., Snelling, R.R.
Liquid-feeding performances of ants (Formicidae): ecological and evolutionary implications
(2004) *Oecologia*, 139, pp. 255-266.
- Peng, R., Christian, K., Gibb, K.
The effect of colony isolation of the predacious ant, *Oecophylla smaragdina* (F.) (Hymenoptera: Formicidae), on protection of cashew plantations from insect pests
(1999) *Int. J. Pest Manag.*, 45, pp. 189-194.
- Floren, A.
How reliable are data on arboreal ant (Hymenoptera: Formicidae) communities collected by insecticidal fogging?
(2005) *Myrmecol. Nachrichten*, 7, pp. 91-94.
- Blüthgen, N., Stork, N.
Ant mosaics in a tropical rainforest in Australia and elsewhere: a critical review
(2007) *Austral Ecol.*, 32 (1), pp. 93-104.
- Dejean, A., Djiéto-Lordon, C., Céréghino, R., Leponce, M.
Ontogenetic succession and the ant mosaic: an empirical approach using pioneer trees
(2008) *Basic Appl. Ecol.*, 9 (3), pp. 316-323.
- **R: A Language and Environment for Statistical Computing**
(2023), R Foundation for Statistical Computing Vienna, Austria
- Durrleman, S., Simon, R.
Flexible regression models with cubic splines
(1989) *Stat. Med.*, 8 (5), pp. 551-561.

- Pallant, J.
SPSS Survival Manual: A Step by Step Guide to Data Analysis Using SPSS
(2010), fourth ed. Allen & Unwin Book Publishers Australia
- Lei, Y., Jaleel, W., Shahzad, M.F., Ali, S., Azad, R., Ikram, R.M., Lihua, L.Y.U.
Effect of constant and fluctuating temperature on the circadian foraging rhythm of the red imported fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae)
(2021) *Saudi J. Biol. Sci.*, 28 (1), pp. 64-72.
- Prather, R.M., Roeder, K.A., Sanders, N.J., Kaspari, M.
Using metabolic and thermal ecology to predict temperature dependent ecosystem activity: a test with prairie ants
(2018) *Ecology*, 99 (9), pp. 2113-2121.
- Ashikin, N., Hashim, R.
Daily activity patterns of *Platythyrea parallela* in Peninsular Malaysia
(2015) *Asian Myrmecology*, 7, pp. 145-154.
- Tabachnick, B.G., Fidell, L.S., Ullman, J.B.
Using Multivariate Statistics
(2013), pp. 497-516.
seventh ed. Boston, MA: pearson New York Vol. 6
- Laerd Statistics
Ordinal Logistic Regression Using SPSS Statistics”, Statistical Tutorials and Software Guides
(2015),
- Schober, P., Boer, C., Schwarte, L.A.
Correlation coefficients: appropriate use and interpretation
(2018) *Anesth. Analg.*, 126 (5), pp. 1763-1768.
- Akoglu, H.
User's guide to correlation coefficients
(2018) *Turkish J. Emerg. Med.*, 18 (3), pp. 91-93.
- Cohen, J.
Statistical Power Analysis for the Behavioral Sciences
(2013),
Routledge
- Exélis, M.P., Ramli, R., Ibrahim, R.W., Idris, A.H.
Foraging behaviour and population dynamics of asian weaver ants: assessing its potential as biological control agent of the invasive bagworms *Metisa plana* (Lepidoptera: Psychidae) in oil palm plantations
(2023) *Sustainability*, 15 (1), p. 780.
- Lehue, M., Collignon, B., Detrain, C.
Multiple nest entrances alter foraging and information transfer in ants
(2020) *R. Soc. Open Sci.*, 7 (2).
- Ogawa, Y., Jones, L., Ryan, L.A., Robson, S.K., Hart, N.S., Narendra, A.
Physiological properties of the visual system in the Green Weaver ant, *Oecophylla smaragdina*
(2023) *J. Comp. Physiol.*, pp. 1-10.
- Cerdá, X., Retana, J.
Alternative strategies by thermophilic ants to cope with extreme heat: individual versus colony level traits
(2000) *Oikos*, 89 (1), pp. 155-163.

- Villalta, I., Oms, C.S., Angulo, E., Molinas-González, C.R., Devers, S., Cerdá, X., Boulay, R.
Does social thermal regulation constrain individual thermal tolerance in an ant species?
(2020) *J. Anim. Ecol.*, 89 (9), pp. 2063-2076.
- Heylighen, F.
Stigmergy as a universal coordination mechanism I: definition and components
(2016) *Cognit. Syst. Res.*, 38, pp. 4-13.
- Cerdá, X., Renata, J., Cros, S.
Critical thermal limits in Mediterranean ant species: trade-off between mortality risk and foraging performance
(1998) *Funct. Ecol.*, 12, pp. 45-55.
- Guo, F., Guénard, B., Economo, E.P., Deutsch, C.A., Bonebrake, T.C.
Activity niches outperform thermal physiological limits in predicting global ant distributions
(2020) *J. Biogeogr.*, 47 (4), pp. 829-842.
- Exélis, M.P., Ramli, R., Hj Idris, A., Yacob, Z., Ibrahim, W., R, Yaakop, S., Othman, N.W.
The social Organisation of *Oecophylla smaragdina* (Hymenoptera: Formicidae) colonies and their functional activity
(2023) *Preprints.org*,
- Lasmar, C.J., Bishop, T.R., Parr, C.L., Queiroz, A.C., Schmidt, F.A., Ribas, C.R.
Geographical variation in ant foraging activity and resource use is driven by climate and net primary productivity
(2021) *J. Biogeogr.*, 48 (6), pp. 1448-1459.
- Tuck, H.C., Ibrahim, Y., Chong, K.K.
Infestations by the bagworms *Metisa plana* and *Pteroma pendula* for the period 1986–2000 in major oil palm estates managed by Golden Hope Plantation Berhad in Peninsular Malaysia
(2011) *Journal of Oil Palm Research*, 23, pp. 1040-1050.
- Lokkers, C.
Colony dynamics of the green tree ant (*Oecophylla smaragdina* FAB
(1990) *In a Seasonal Tropical Climate. – PhD Thesis*, p. 301pp.
James Cook University of North Queensland Townsville, Queensland
- Dejean, A., Ryder, S., Bolton, B., Compin, A., Leponce, M., Azémar, F., Corbara, B.
How territoriality and host-tree taxa determine the structure of ant mosaics
(2015) *Sci. Nat.*, 102 (5-6), pp. 1-9.
- Roldán, E.L., Beuzelin, J.M., VanWeelden, M.T., Cherry, R.H.
Abundance of the sugarcane borer (*Lepidoptera: Crambidae*) and foraging ants (*Hymenoptera: Formicidae*) in sugarcane grown on organic and mineral soils in Florida
(2020) *Environ. Entomol.*, 49 (2), pp. 473-481.
- Chapuisat, M., Keller, L.
Division of Labour Influences the Rate of Ageing in Weaver Ant Workers
(2002), pp. 909-914.
Proceedings- Royal Society of London B 1494)
- Van Itterbeeck, J., Sivongxay, N., Praxaysombath, B., van Huis, A.
Preliminary observations on gravid queen protection in *Oecophylla smaragdina*: evacuation and retinue function
(2015) *Asian Myrmecol.*, 7 (1), pp. 155-158.

- Van Itterbeeck, J.
Prospects of Semi-cultivating the Edible Weaver and *Oecophylla smaragdina*
(2014), Doctoral dissertation, Wageningen University and Research
- Rastogi, N.
Seasonal pattern in the territorial dynamics of the arboreal ant *Oecophylla smaragdina* (Hymenoptera: Formicidae)
(2007) *J. Bombay Nat. Hist. Soc.*, 104 (1), pp. 13-17.
- Mercier, J.L.
Territorialité et agressivité intra- et interspécifique dans les mosaïques de fourmis arboricoles
(1999) *Annee Biol.*, 38, pp. 149-168.
- Van Mele, P., Vayssières, J.F., Van Tellingen, E., Vrolijk, J.
Effects of an African weaver ant, *Oecophylla longinoda*, in controlling mango fruit flies (Diptera: Tephritidae) in Benin
(2007) *J. Econ. Entomol.*, 100 (3), pp. 695-701.
- Kaspari, M., Clay, N.A., Lucas, J., Yanoviak, S.P., Kay, A.
Thermal adaptation generates a diversity of thermal limits in a rainforest ant community
(2015) *Global Change Biol.*, 21 (3), pp. 1092-1102.
- Gintoron, C.S., Mohammed, M.A., Sazali, S.N., Deka, E.Q., Ong, K.H., Shamsi, I.H., King, P.J.H.
Factors affecting pollination and pollinators in oil palm plantations: a review with an emphasis on the *Elaeidobius kamerunicus* weevil (Coleoptera: Curculionidae)
(2023) *Insects*, 14 (5), p. 454.
- Peng, R.K., Christian, K.
Determination and management of weaver ant, *Oecophylla smaragdina* (Fabricius) (Hymenoptera: Formicidae), marks on mango fruit in the Northern Territory of Australia
(2009) *Int. J. Pest Manag.*, 55 (1), pp. 27-30.
- Gonzalez, F.G., Chen, J., Rodriguez-Girones, M.A.
The function of ant repellence by flowers: testing the “nectar protection” and “pollinator protection” hypotheses
(2015) *Evol. Ecol.*, 29, pp. 391-403.
- Rodríguez-Gironés, M.A., González, F.G., Llandres, A.L., Corlett, R.T., Santamaría, L.
Possible role of weaver ants, *Oecophylla smaragdina*, in shaping plant–pollinator interactions in South-East Asia
(2013) *J. Ecol.*, 101 (4), pp. 1000-1006.
- Dorigo, M., Birattari, M., Stutzle, T.
Ant colony optimization
(2006) *IEEE Comput. Intell. Mag.*, 1 (4), pp. 28-39.

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