

The re-discovery in Sumatra of a rarely seen moth, *Heterosphacia tawonoides*, and its identification using citizen science platform iNaturalist

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ABSTRACT

Traditional methods of species identification involve the collection and killing of specimens. The associated costs and expertise required are prohibitory. In this paper we describe the first documented record of *Heterosphacia tawonoides* in its natural habitat in Sumatra since 1887, reporting its identification using photographs uploaded to the citizen science platform iNaturalist. Our findings add valuable information to the small body of work on this species and demonstrate the importance of having freely available high-quality tools such as iNaturalist without which this important record would not have been reported and the observation of this rarely seen moth species in Sumatra would have remained unknown.

ABSTRAK

Metode identifikasi spesies tradisional melibatkan pengumpulan dan pembunuhan spesimen. Biaya terkait dan keahlian yang dibutuhkan adalah berupa larangan. Dalam artikel ini kami menjelaskan catatan pertama yang terdokumentasikan dari *Heterosphacia tawonoides* di habitat alaminya di Sumatera sejak 1887, melaporkan identifikasinya menggunakan foto yang diunggah ke platform ilmiah iNaturalist. Temuan kami menambah informasi berharga untuk sejumlah kecil pekerjaan pada spesies ini dan menunjukkan pentingnya memiliki alat berkualitas tinggi yang tersedia secara gratis seperti iNaturalist, tanpanya catatan penting ini tidak akan dilaporkan dan pengamatan spesies ngengat yang jarang terlihat ini di Sumatera akan tetap tidak diketahui.

Keywords: *biodiversity, citizen science, iNaturalist, rediscovery, species identification*

INTRODUCTION

Biodiversity is in crisis with estimates that over 1 million plant and animal species are threatened with extinction (Estrada et al., 2017). Accurate biological species identification is essential and can be used to inform the management and conservation of biodiversity (Austen et al., 2016; Hope et al., 2018; Kürzel et al., 2022). Traditionally species have been identified by describing morphological traits from biological specimens collected in the field. Such 'voucher specimens' are a verifiable representative of a species, often used to describe new species and usually deposited in a curated collection typically of a museum or institution (Ajmal Ali et al., 2014; Turney et al., 2015). The necessity of killing specimens to study them is being called into question and is often subject to controversy (Minteer et al., 2014; Waeber et al., 2017). There are limitations associated with traditional species level identification methods: identification of insects is expensive, time consuming, requires expert knowledge, including of behavioural phenotypes and can be problematic due to the vast number of species (Valan et al., 2019).

Alternative methods of identification are available and include techniques such as DNA sequencing of biopsy or other samples, computer vision/machine learning and behavioural observations (Ajmal Ali et al., 2014; Perring et al 1993; Ronque et al 2016; Spiesman et al., 2021). Such methods might appear supplementary, as voucher specimen collection still seems to be the reference method and museum collections have been recently described as making innumerable contributions to science and society that save governments and taxpayers millions of dollars (Bakker et al., 2020; Suarez & Tsutsui, 2004; Turney et al., 2015).

Citizen science is increasingly used to contribute to scientific research and species identification with databases such as iNaturalist (www.inaturalist.org) and eBird (www.ebird.org) contributing massive amounts of biodiversity data that could not be sourced in any other way (Koch et al., 2022; Sun et al., 2021). iNaturalist, a joint initiative of the California Academy of Sciences and the National Geographic Society, is a freely available, online open access platform that allows users to upload biodiversity photographs, using machine learning methods to automatically suggest an identification which is then verified by community members (iNaturalist 2023 a). Importantly, submissions are curated using open

source software and submitted under a Creative Commons license allowing reuse of data (iNaturalist b, c 2022). As of 20th February 2023 iNaturalist has 127,247,966 observations, 415,739 species, 289,590 identifiers and 2,521,464 observers (iNaturalist 2022 d). The designation ‘research grade’ to an observation requires a photo, date, coordinates and agreement from the community on the taxon which results in high quality datasets (iNaturalist e 2022). As of 12th November 2022 the Global Biodiversity Information Facility website (www.GBIF.org) lists the iNaturalist dataset as having 53,049,459 research grade occurrences and 2,966 citations (GBIF 2022 a).

Clearwing moths (Lepidoptera: Sesiidae) are known for their Batesian mimicry of Hymenoptera species and worldwide there are 160 genera with 1452 recognized species (Pühringer 2022). Tropical clearwing moths are rarely encountered in nature and little is known about their behaviour, distribution and ecology and photographic documentation is extremely uncommon (Gorbunov & Severtsov, 2015; M. Skowron Volponi, 2020). *Heterosphaecia* is a genus of moths in the family Sesiidae found in Borneo, Sumatra and South India. There are eight known species with few records, and their conservation status is unknown (GBIF 2022 b; M. A. Skowron Volponi & Volponi, 2017). *Heterosphaecia tawonoides* was first described in 2003 using a specimen collected from an unknown location in Sumatra in 1887 (Kallies, 2003). It was observed and filmed for the first time in its natural habitat in Malaysia 2013 exhibiting puddling behaviour and bee mimicry which are only possible to see on live specimens. (M. A. Skowron Volponi & Volponi, 2017).

In this paper we present the first documented record of *H. tawonoides* in its natural habitat in Sumatra since 1887, reporting its identification using iNaturalist.

METHODS

Observations of *H. tawonoides* were made near Bukit Lawang, North Sumatra on the 20th May 2015 and photographed using Canon EOS 2000d mounted with a 55-250 mm Canon lens. Observations were uploaded onto iNaturalist on 24th February 2022.

Study Area

Bukit Lawang is a tourist focused village located within the Langkat district of north Sumatra (03°32.770’N, 098°07.000’E) on the eastern edge of the Gunung Leuser National Park, adjacent to the Bohorok river. Orangutan are flagship species for conservation of their forest habitat and Bukit Lawang has a very long affiliation with orangutan tourism as well as its associated problems (Molyneaux et al., 2021; Walpole & Leader-Williams, 2002). Whilst Sumatra is a biodiversity hotspot and Bukit Lawang gives relatively easy access to

a wide variety of habitats the tourism in this area is heavily reliant on orangutan and little attention is given to promoting awareness of any other species (Molyneaux 2022).

RESULT AND DISCUSSION

A single specimen of *H. tawonoides* was observed and photographed on the cement block path (Figure 1) of a remote house on the border of Gunung Leuser National Park close to the tourist village of Bukit Lawang. The path is next to an ornamental fish pool but over 100 m from the large, fast flowing Bohorok river. The surrounding habitat (Figure 2) is an overgrown mix of both primary and secondary forest and small scale rubber and palm oil plantations. 6 photographs (Figure 3 a-f) were taken between 13:30-13:35 on the 20th May 2015 and show the moth puddling on the edges of the cement block path.

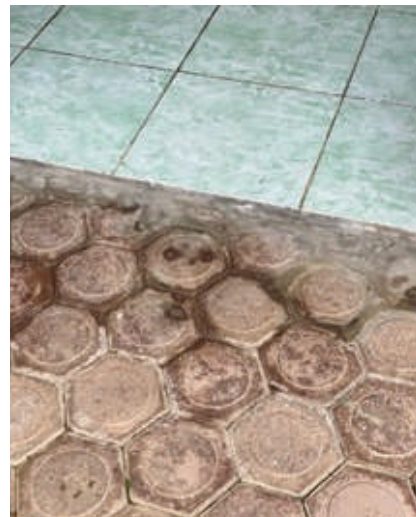


Figure 1. Cement block path of remote house near Bukit Lawang village.



Figure 2. Surrounding habitat of the remote house.

The first 4 photographs (Figure 3 a-d) were uploaded onto iNaturalist on the 24th February 2022 (iNaturalist, 2022) and were submitted with a provisional identification of “genus *Epicharis*, apine bee”. Over a period of several weeks community members suggested refinements of the identification arriving at the suggestion of *H. taxonoides* on 13th March 2022 which was confirmed by user @kallies (who first described the species in 2003) and by 5 other community members (Kallies, 2003; iNaturalist 2022 d). It is the first and currently the only recording of this species on iNaturalist and is a research grade observation. (see Table 1 Species identification sequence on iNaturalist). A comparison with the holotype (Kallies, 2003) and with descriptions of its observation in Malaysia (Skowron Volponi & Volponi, 2017) shows that our observation also has the novel morphological features only visible on a live specimen – blue wing sheen, blue and white hair like scales on all tibia, elongated white hair like scales on hind tibia. (see Table 2 Comparison of documented records of *H. taxonoides*).



Figure 3. a-f *H. taxonoides* observed and photographed on 20th May 2015 near Bukit Lawang village, North Sumatra, Indonesia.

Table 1. Species identification sequence on iNaturalist

Photographs uploaded on 24 / 2 / 2022	
24/02/2022	Genus <i>Epicharis</i> - a member of Apine Bees (withdrawn)
25/02/2022	Kupu-Kupu dan Ngengat - Order Lepidoptera
25/02/2022	Picture-winged Leaf Moths (withdrawn) - Superfamily Thyridoidea
27/02/2022	Clearwing Moths - Family Sesiidae
13/03/2022	Genus <i>Heterosphacia</i> - a member of Clearwing Moths - Family Sesiidae
Species identified and confirmed 13/3/2022	
	Oriental Blue Clearwing <i>Heterosphacia taxonoides</i>

Here we show that high quality photographic records can be used to identify a poorly known and rarely seen species of moth using iNaturalist in the field. Having access to a large network which included an ‘expert’ enabled rapid identification of this species of moth that has not been recorded in Sumatra since 1887. Our findings represent the first ever record of observation of this species in its natural habitat in Sumatra and only the 3rd published record.

The traditional method of obtaining voucher specimens for species identification is subject to controversy with two recent examples relating to a non-endangered goliath bird eating spider and a rarely seen moustached kingfisher. Both species were collected during large biodiversity surveys and the spider was one of 857 voucher specimens!

Both instances received a lot of negative criticism prompting the collectors to publish detailed accounts of their reasons for collecting the specimens. (Naskrecki 2014; Boroff 2015; Filardi 2015; Silber 2015). Scientists have long been polarized about the use of voucher specimens (Funk et al., 2018; Marshall & Evenhuis, 2015) The suggestion that alternative methods of identification should be used in relation to threatened or rediscovered species (Minteer et al., 2014) proved controversial and elicited strong response in support of voucher specimens (Krell & Wheeler, 2014; Rocha et al., 2014). Digital photography, geolocation, open access databases and widespread internet access are enabling wider engagement with the process of collecting and curating primary biodiversity data and pushing access beyond that of professional academic researchers. Species ARE nowadays being identified without voucher specimens and it is recommended that traditional taxonomic scientists engage with this ever expanding network and community (Marshall, 2018; Marshall & Evenhuis, 2015; Wilson et al., 2020).

Table 2. Comparison of documented records of *H. tawonoides*

	Kallies 2003 (holotype)	Volponi 2017	This paper
Date of publication / uploading	2003	2017	24-2-2022
Date of specimen /observation	1887	2013, 2016, 2017	20-5-2015
Country	Sumatra	Malaysia	Sumatra
Habitat	not detailed	primary lowland forest	cement path next to primary/secondary rainforest
Stored location of specimen	Natural history museum, Vienna	British museum of natural history and private collection	n/a
Observed behaviour	not detailed	Mud-puddling on sandy/pebble river bank	puddling on a cement block path
Id methods	not detailed	Photo, pinned for morphological analysis, dissection of male genitalia, DNA barcoding	Photo, iNaturalist
Novel morphological observations	not detailed	strong blue sheen on wings	Yes
		characteristic tufts of hair like scales on all tibia longest on hind legs, alternate shiny blue and white colouration	Yes
		strongly elongated, creamy white hair like scales of hind tibia extend interiorly over folded wings and abdomen in natural resting position	Yes
		resemblance to bees	Yes

With our account we show that it has not been necessary to kill and remove the specimen to a museum or collection to identify it. Our observations show the moth exhibiting puddling behaviour and displaying novel morphological features which are consistent with those described in the only other documented record of this species in its natural habitat (Skowron Volponi & Volponi, 2017). Sessiids have been noted to visit river banks, streams, puddles and wet soil remaining after drying out of flowing water (Gorbunov & Severtsov, 2015; Skowron Volponi, 2020, 2022). A potentially significant difference is that in our observations the moth was puddling on an artificial cement block path far from natural flowing water (but close to a small artificial fish pool) whereas Volponi (2017) documents *H. tawonoides* puddling on a leaf on the riverbank of a lowland dipterocarp forest.

Thus we add valuable information to the small body of work on this species and genus. We demonstrate the

importance of having an open access database and vast community network as without it this important record would not have been reported and the observation of this rarely seen moth species in Sumatra would have remained unknown.

CONCLUSION

The debate around specimen collection will doubtless continue with strong ethical and conservation concerns being expressed and alternatives proposed (Russo et al 2017). Citizen scientist platforms such as iNaturalist continue to generate vast amounts of increasingly important data with significant contributions, such as rediscovery of species and previously undocumented behaviours, the value of which taxonomic science cannot ignore. (Callaghan et al 2022, Fraisl et al 2022). Citizen science plays a crucial part in species identification and the documentation of biodiversity (Koo et al., 2022; Mueller et al., 2019; Wilson et al., 2020).

Implications for conservation

Information about the distribution of Lepidoptera in Indonesia and particularly Sumatra is limited (Iqbal et al., 2022). Whilst long term field studies and surveys for clearwing moths in this area may be desirable the funds and expertise to carry them out are scarce. Our rediscovery and documenting of a rarely seen moth species, *H. tawonoides*, using noninvasive, easily accessible and affordable yet high quality methods could be used to highlight the importance and conservation of its forest edge habitat. It could be used as an alternative flagship species, to promote biodiversity awareness in Bukit Lawang, an area that relies heavily on tourism focused around orangutan (Molyneaux 2022). We strongly encourage travelers, visitors, residents, scientists and naturalists to take photos of the wildlife they see and upload their observations to iNaturalist in order that biodiversity can be documented and the information accessible to all.

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REFERENCES

- Ajmal Ali, M., Gyulai, G., Hidvégi, N., Kerti, B., al Hemaïd, F. M. A., Pandey, A. K., & Lee, J. (2014). The changing epitome of species identification - DNA barcoding. In *Saudi Journal of Biological Sciences* (Vol. 21, Issue 3, pp. 204–231). Elsevier. <https://doi.org/10.1016/j.sjbs.2014.03.003>
- Austen, G. E., Bindemann, M., Griffiths, R. A., & Roberts, D. L. (2016). Species identification by experts and non-experts: Comparing images from field guides. *Scientific Reports*, 6. <https://doi.org/10.1038/srep33634>
- Kallies, A. (2003). Three new species of *Heterosphecia* LE CERF, 1916, from the Oriental Region (Lepidoptera: Sesiidae, Sesiinae).
- Bakker, F. T., Antonelli, A., Clarke, J. A., Cook, J. A., Edwards, S. v., Ericson, P. G. P., Faurby, S., Ferrand, N., Gelang, M., Gillespie, R. G., Irestedt, M., Lundin, K., Larsson, E., Matos-Maraví, P., Müller, J., von Proschwitz, T., Roderick, G. K., Schliep, A., Wahlberg, N., ... Källersjö, M. (2020). The global museum: Natural history collections and the future of evolutionary science and public education. *PeerJ*, 8. <https://doi.org/10.7717/peerj.8225>
- Boroff, D. (2015). Another Cecil? Researcher for New York museum kills rare bird in name of science, draws outrage from PETA. *Daily News*. <https://www.nydailynews.com/new-york/researcher-ny-museum-kills-rare-bird-science-article-1.2394167>. Accessed on 20th February 2023.
- Callaghan CT, Mesaglio T, Ascher JS, Brooks TM, Cabras AA, Chandler M, et al. (2022) The benefits of contributing to the citizen science platform iNaturalist as an identifier. *PLoS Biol* 20(11): e3001843. <https://doi.org/10.1371/journal.pbio.3001843>
- Estrada, A., Garber, P. A., Rylands, A. B., Roos, C., Fernandez-Duque, E., Fiore, A. di, Anne-Isola Nekaris, K., Nijman, V., Heymann, E. W., Lambert, J. E., Rovero, F., Barelli, C., Setchell, J. M., Gillespie, T. R., Mittermeier, R. A., Arregoitia, L. V., de Guinea, M., Gouveia, S., Dobrovolski, R., ... Li, B. (2017). Impending extinction crisis of the world's primates: Why primates matter. In *Science Advances* (Vol. 3, Issue 1). American Association for the Advancement of Science. <https://doi.org/10.1126/sciadv.1600946>
- Filardi, C. E. (2015). Why I Collected a Moustached Kingfisher. *Audobon*. <https://www.audubon.org/news/why-i-collected-moustached-kingfisher>. Accessed on 20th February 2023
- Fraisl, D., Hager, G., Bedessem, B. et al. Citizen science in environmental and ecological sciences. *Nat Rev Methods Primers* 2, 64 (2022). <https://doi.org/10.1038/s43586-022-00144-4>
- Funk, V. A., Edwards, R., & Keeley, S. (2018). The problem with(Out) vouchers. In *Taxon* (Vol. 67, Issue 1, pp. 3–5). International Association for Plant Taxonomy. <https://doi.org/10.12705/671.1>
- GBIF (2022) a. iNaturalist contributors, iNaturalist (2023). iNaturalist Research-grade Observations. iNaturalist.org. Occurrence dataset <https://doi.org/10.15468/ab3s5x> [accessed via GBIF.org on 2023-02-20.]
- GBIF (2022) b. *Heterosphecia* Le Cerf, 1917 in GBIF Secretariat (2021). GBIF Backbone Taxonomy. Checklist dataset <https://doi.org/10.15468/39omei> [accessed via GBIF.org on 2022-11-12.]
- Gorbunov, O. G., & Severtsov, A. N. (2015). Scientific Note: Clearwing moths (Lepidoptera: Sesiidae) of Laos. I. *Akaisphecia melanopuncta* O. Gorbunov & Arita, 1995 (Sesiidae: Sesiinae: Osminiini). In *TROP. LEPID. RES* (Vol. 25, Issue 2).
- Hope, A. G., Sandercock, B. K., & Malaney, J. L. (2018). Collection of Scientific Specimens: Benefits for Biodiversity Sciences and Limited Impacts on Communities of Small Mammals. In *BioScience* (Vol. 68, Issue 1, pp. 35–42). Oxford University Press. <https://doi.org/10.1093/biosci/bix141>
- iNaturalist. (2022). Oriental Blue Clearwing (*Heterosphecia tawonoides*). <https://www.inaturalist.org/observations/107359556>. Accessed 20th February 2023
- iNaturalist. (2023). a. Frequently Asked Questions. <https://www.inaturalist.org/pages/help#general1>. Accessed on 20th February 2023

- iNaturalist. (2023). b. Licensed to Share! <https://www.inaturalist.org/posts/58298-licensed-to-share>. Accessed on 20th February 2023.
- iNaturalist. (2023). c. iNaturalist Computer Vision Explorations. https://www.inaturalist.org/pages/computer_vision_demo. Accessed 20th February 2023.
- iNaturalist. (2023). d. Observations. <https://www.inaturalist.org/observations>. Accessed 20th February 2023.
- iNaturalist. (2023) e. FAQ: What is the data quality assessment and how do observations qualify to become "Research Grade"? <https://www.inaturalist.org/pages/help>. Accessed on 20th February 2023.
- Kirilov, P., Pormansyah, P., Setiawan, D., Pragustiandi, G., Setiawan, A., & Yustian, I. (2022). Range extension of the endemic Sumatran admiral *Vanessa samani* (Hagen, 1895) (Lepidoptera: Nymphalidae) in Sumatra, Indonesia. *Indonesian Journal of Applied Environmental Studies*, 3(1), 30–33. <https://doi.org/10.33751/injast.v3i1.4602>
- Koch, W., Hogeweg, L., Nilsen, E. B., & Finstad, A. G. (2022). Maximizing citizen scientists' contribution to automated species recognition. *Scientific Reports*, 12(1). <https://doi.org/10.1038/s41598-022-11257-x>
- Koo, K. S., Oh, J. M., Park, S. J., & Im, J. Y. (2022). Accessing the Accuracy of Citizen Science Data Based on iNaturalist Data. *Diversity*, 14(5). <https://doi.org/10.3390/d14050316>
- Krell, F. T., & Wheeler, Q. D. (2014). Specimen collection: Plan for the future. In *Science* (Vol. 344, Issue 6186, pp. 815–816). American Association for the Advancement of Science. <https://doi.org/10.1126/science.344.6186.815>
- Kürzel, K., Kaiser, S., Lörz, A. N., Rossel, S., Paulus, E., Peters, J., Schwentner, M., Martínez Arbizu, P., Coleman, C. O., Svavarsson, J., & Brix, S. (2022). Correct Species Identification and Its Implications for Conservation Using Haploniscidae (Crustacea, Isopoda) in Icelandic Waters as a Proxy. *Frontiers in Marine Science*, 8. <https://doi.org/10.3389/fmars.2021.795196>
- Marshall, S. A. (2018). Digital Photography and the Democratization of Biodiversity Information. <http://carabidae.org/>
- Marshall, S. A., & Evenhuis, N. L. (2015). New species without dead bodies: A case for photobased descriptions, illustrated by a striking new species of *Marleyimyia* Hesse (Diptera, Bombyliidae) from South Africa. *ZooKeys*, 2015(525), 117–127. <https://doi.org/10.3897/zookeys.525.6143>
- Minteer, B. A., Collins, J. P., Love, K. E., & Puschendorf, R. (2014). Avoiding (re)extinction. In *Science* (Vol. 344, Issue 6181, pp. 260–261). American Association for the Advancement of Science. <https://doi.org/10.1126/science.1250953>
- Molyneaux, A., Hankinson, E., Kaban, M., Svensson, M. S., Cheyne, S. M., & Nijman, V. (2021). Primate Selfies and Anthropozoonotic Diseases: Lack of Rule Compliance and Poor Risk Perception Threatens Orangutans. *Folia Primatologica*, 92(5–6), 296–305. <https://doi.org/10.1159/000520371>
- Molyneaux, A. (2022). Bukit Lawang and Beyond: Primates and Tourism from a Provider's Perspective. In: Gursky, S.L., Supriatna, J., Achorn, A. (eds) *Ecotourism and Indonesia's Primates. Developments in Primatology: Progress and Prospects*. Springer, Cham. https://doi.org/10.1007/978-3-031-14919-1_3
- Mueller, M. A., Drake, D., & Allen, M. L. (2019). Using citizen science to inform urban canid management. *Landscape and Urban Planning*, 189, 362–371. <https://doi.org/10.1016/j.landurbplan.2019.04.023>
- Naskreki, P (2014). Involuntary Bioslaughter and Why a Spider is Dead. *The Smaller Majority*. <https://thesmallermajority.com/2014/10/08/the-sound-of-little-hooves-in-the-night/>. Accessed 20th February 2023.
- Perring TM, Cooper AD, Rodriguez RJ, Farrar CA, Bellows TS Jr. Identification of a whitefly species by genomic and behavioral studies. *Science*. 1993 Jan 1;259(5091):74-7. doi: 10.1126/science.8418497. PMID: 8418497.
- Pühringer, F. (2022). Checklist of the Sesiidae of the world (Lepidoptera: Ditrysia). <http://www.sesiidae.net/Checklist.htm>. Accessed 20th February 2023.
- Rocha LA, Aleixo A, Allen G, Almeda F, Baldwin CC, Barclay MV, Bates JM, Bauer AM, Benzoni F, Berns CM, Berumen ML, Blackburn DC, Blum S, Bolaños F, Bowie RC, Britz R, Brown RM, Cadena CD, Carpenter K, Ceríaco LM, Chakrabarty P, Chaves G, Choat JH, Clements KD, Collette BB, Collins A, Coyne J, Cracraft J, Daniel T, de Carvalho MR, de Queiroz K, Di Dario F, Drewes R, Dumbacher JP, Engilis A Jr, Erdmann MV, Eschmeyer W, Feldman CR, Fisher BL, Fjeldså J, Fritsch PW, Fuchs J, Getahun A, Gill A, Gomon M, Gosliner T, Graves GR, Griswold CE, Guralnick R, Hartel K, Helgen KM, Ho H, Iskandar DT, Iwamoto T, Jaafar Z, James HF, Johnson D, Kavanaugh D, Knowlton N, Lacey E, Larson HK, Last P, Leis JM, Lessios H, Liebherr J, Lowman M, Mahler DL, Mamonekene V, Matsuura K, Mayer GC, Mays H Jr, McCosker J, McDiarmid RW, McGuire J, Miller MJ, Mooi R, Mooi RD, Moritz C, Myers P, Nachman MW, Nussbaum RA, Foighil DÓ, Parenti LR, Parham JF, Paul E, Paulay G, Pérez-Emán J, Pérez-Matus A, Poe S, Pogonoski J, Rabosky DL, Randall JE, Reimer JD, Robertson DR, Rödel MO, Rodrigues MT, Roopnarine P, Rüber L, Ryan MJ, Sheldon F, Shinohara G, Short A, Simison WB, Smith-Vaniz WF, Springer VG, Stiassny M, Tello JG, Thompson CW, Trnski T, Tucker P, Valqui T, Vecchione M, Verheyen E, Wainwright PC, Wheeler TA, White WT, Will K, Williams JT, Williams G, Wilson EO, Winker K, Winterbottom R, Witt CC. Specimen collection: an essential tool. *Science*. 2014 May 23;344(6186):814-5. doi: 10.1126/science.344.6186.814. PMID: 24855245.

- Ronque M.U.V., Azevedo-Silva M, Mori GM, Souza AP, Oliveira PS (2016). Three ways to distinguish species: using behavioural, ecological, and molecular data to tell apart two closely related ants, *Camponotus renggeri* and *Camponotus rufipes* (Hymenoptera: Formicidae), *Zoological Journal of the Linnean Society*, Volume 176, Issue 1, Pages 170–181, <https://doi.org/10.1111/zoj.12303>
- Russo, D., Ancillotto, L., Hughes, A. C., Galimberti, A., & Mori, E. (2017). *Collection of voucher specimens for bat research: conservation, ethical implications, reduction, and alternatives*. *Mammal Review*, 47(4), 237–246. doi:10.1111/mam.12095
- Silber, E. (2015). Moustached Kingfisher Photographed for First Time. Audubon. <https://www.audubon.org/news/moustached-kingfisher-photographed-first-time>. Accessed 20th February 2023.
- Skowron Volponi, M. (2020). A vivid orange new genus and species of braconid-mimicking clearwing moth (Lepidoptera: Sesiidae) found puddling on plecoptera exuviae. *Insects*, 11(7), 1–9. <https://doi.org/10.3390/insects11070425>
- Skowron Volponi, M. (2022). Hidden jewels of Malaysia: two new genera and species of remarkable clearwing moths (Lepidoptera: Sesiidae: Osminiini). *European Zoological Journal*, 89(1), 579–589. <https://doi.org/10.1080/24750263.2022.2061613>
- Skowron Volponi, M. A., & Volponi, P. (2017). A 130-Year-Old Specimen Brought Back to Life: A Lost Species of Bee-Mimicking Clearwing Moth, *Heterosphacia tawonoides* (Lepidoptera: Sesiidae: Osminiini), Rediscovered in Peninsular Malaysia's Primary Rainforest. *Tropical Conservation Science*, 10. <https://doi.org/10.1177/1940082917739774>
- Spiesman, B. J., Gratton, C., Hatfield, R. G., Hsu, W. H., Jepsen, S., McCornack, B., Patel, K., & Wang, G. (2021). Assessing the potential for deep learning and computer vision to identify bumble bee species from images. *Scientific Reports*, 11(1). <https://doi.org/10.1038/s41598-021-87210-1>
- Suarez, A., & Tsutsui, N. D. (2004). The Value of Museum Collections for Research and Society Orchid-Orchid Bee Systematics View project. <https://www.researchgate.net/publication/261795120>
- Sun, C. C., Hurst, J. E., & Fuller, A. K. (2021). Citizen Science Data Collection for Integrated Wildlife Population Analyses. *Frontiers in Ecology and Evolution*, 9. <https://doi.org/10.3389/fevo.2021.682124>
- Turney, S., Cameron, E. R., Cloutier, C. A., & Buddle, C. M. (2015). Non-repeatable science: Assessing the frequency of voucher specimen deposition reveals that most arthropod research cannot be verified. *PeerJ*, 2015(8). <https://doi.org/10.7717/peerj.1168>
- Valan, M., Makonyi, K., Maki, A., Vondráček, D., & Ronquist, F. (2019). Automated Taxonomic Identification of Insects with Expert-Level Accuracy Using Effective Feature Transfer from Convolutional Networks. *Systematic Biology*, 68(6), 876–895. <https://doi.org/10.1093/sysbio/syz014>
- Waerber, P. O., Gardner, C. J., Lourenco, W. R., & Wilme, L. (2017). On specimen killing in the era of conservation crisis - A quantitative case for modernizing taxonomy and biodiversity inventories. *PLoS ONE*, 12(9). <https://doi.org/10.1371/journal.pone.0183903>
- Walpole, M. J., & Leader-Williams, N. (2002). Tourism and flagship species in conservation. In *Biodiversity and Conservation* (Vol. 11).
- Wilson, J. S., Pan, A. D., General, D. E. M., & Koch, J. B. (2020). More eyes on the prize: an observation of a very rare, threatened species of Philippine Bumble bee, *Bombus irisanensis*, on iNaturalist and the importance of citizen science in conservation biology. *Journal of Insect Conservation*, 24(4), 727–729. <https://doi.org/10.1007/s10841-020-00233-3>