Journal of Melittology
Bee Biology, Ecology, Evolution, & Systematics

No. 131, 1–9 28 May 2025

65 degrees of bee thermal biology

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Abstract. Addressing global bee declines requires multidisciplinary, coordinated, and collaborative action. This contribution highlights ongoing efforts to build multidisciplinary and international partnerships among researchers from the University of Wyoming, the University of Kansas, and the Universidade de São Paulo, Brazil, spanning nearly 65 degrees of latitude, to explore how bees respond to changing temperatures. This document summarizes key insights from a mini-symposium held on May 12, 2025, and preliminary collaborative studies conducted between May 8 and 15, 2025, at the Universidade de São Paulo. The mini-symposium brought together faculty and researchers from different Brazilian universities, along with both undergraduate and graduate students, creating a dynamic exchange of ideas across institutions and career stages. Emerging themes from the discussions included the inconsistent use of terminology and methods for assessing thermal biology, critical gaps in taxonomic and life-history coverage, restricted access to expensive equipment and the need for more accessible approaches, and the opportunity to incorporate alternative metrics of thermal tolerance in future studies.

Resumo. Ações coordenadas, colaborativas e multidisciplinares são essenciais para enfrentar o declínio global das abelhas. Esta contribuição destaca um esforço atual para estabelecer parcerias internacionais e interdisciplinares entre pesquisadores da Universidade de Wyoming, da Universidade do Kansas e da Universidade de São Paulo (Brasil), abrangendo quase 65 graus de latitude, com o objetivo de investigar como as abelhas respondem às mudanças de temperatura. O documento apresenta os principais insights de um mini-simpósio realizado em 12 de maio de 2025, bem como de estudos colaborativos preliminares conduzidos entre 8 e 15 de maio de 2025, na Universidade de São Paulo. O evento reuniu docentes e pesquisadores de diversas universidades brasileiras, além de alunos de graduação e pós-graduação, promovendo uma troca rica e dinâmica de ideias entre diferentes instituições e níveis de experiência acadêmica. Entre os temas emergentes das discussões destacaram-se: o uso inconsistente de terminologias e métodos na avaliação da biologia térmica, lacunas significativas na cobertura taxonômica e de história de vida, o acesso limitado a equipamentos caros e a consequente necessidade de metodologias mais acessíveis e a oportunidade de incorporar métricas alternativas de tolerância térmica em pesquisas futuras.

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doi: https://doi.org/10.17161/jom.vi131.24009

ISSN 2325-4467

INTRODUCTION

Climate change is a major driver of bee population declines and changes in distribution (Biesmeijer, 2006; Potts *et al*., 2010; Giannini *et al*., 2017; Marshall *et al*., 2020; Soroye *et al*., 2020; Gonzalez *et al*., 2021; Pardee *et al*., 2022). As a result, interest in understanding how bees respond to changing temperatures has grown significantly in recent years (Macías-Macías *et al*., 2011; Oyen *et al*., 2016; Gonzalez *et al*., 2020; Maia-Silva *et al*., 2020; Pimsler *et al*., 2020; Souza-Junior *et al*., 2020; Gonzalez *et al*., 2022, 2024; White & Dillon, 2023; López-Uribe *et al*., 2024). However, the majority of the existing research is phylogenetically and geographically biased, with most studies focusing on honey bees and bumble bees from North America and Europe (Pimsler *et al*., 2020; Martinet *et al*., 2021; Gérard *et al*., 2022; Gonzalez *et al*., 2022; MacQueen *et al*., 2025). Consequently, current findings in bee thermal biology may not accurately reflect broader trends across the global diversity of bees (Carvalheiro *et al*., 2025). Recognizing these limitations, the authors of this contribution initiated efforts to build multidisciplinary and international collaborations to explore how bees respond to temperature variation across diverse taxa and environments. This report outlines the main activities of a week-long meeting held at the University of São Paulo, from May 8 to 15, 2025 (Figs. 1–5). It highlights key insights from a mini-symposium held on May 12, 2025, and initial collaborative research efforts with undergraduate and graduate students. We hope the ideas generated during this meeting and outlined below will help to inspire new directions for future research on bee thermal biology at a global scale.

MINI-SYMPOSIUM

The goal of the mini-symposium was two-fold: first, to provide an overview of the primary research directions across participating institutions and researchers; and second, to promote a multidisciplinary and integrative approach to studying bee thermal biology. We define bee thermal biology as any aspect of behavior, physiology, or ecology of bees that is affected by temperature. This could include the ability of bees to measure and respond to environmental temperatures ("thermal preference"), which has been widely studied in other ectotherms (*e.g*., Dillon *et al*., 2009) but rarely measured in bees (but see, *e.g*., Łopuch & Czekońska, 2025). Behavioral responses may also include shifts in activity in response to temperature, which can be a passive outcome of the effects of temperature on physiological rates or active selection of temperatures that best facilitate key activities related to fitness (Corbet *et al*., 1993). Extreme temperatures also limit function and ultimately fitness; tolerance limits (*e.g*., CT_{min}, CT_{max}) are therefore often linked to current distributions (Sunday *et al*., 2011) and may facilitate predictions of shifts in distributions due to changing climates. Within these extremes, other aspects of physiology may also be temperature dependent, including microbe-mediated digestion (Hammer *et al*., 2021), metabolism (Glass & Harrison, 2024), reproduction (Campion *et al*., 2023), and development (Forrest *et al*., 2019).

The event, entitled "*50 Shades of Thermophysiology*", featured a series of 10 short presentations (10–15 min each) held in the morning, followed by small-group discussions in the afternoon (Figs. 3, 4). Presenters included undergraduate and graduate students, as well as early-career and senior researchers. Talks extended beyond bees to include research on a range of organisms, such as lizards, and salamanders, highlighting shared physiological principles and concepts across taxa. Presentation topics included the effects of biotic and abiotic factors on bee thermal tolerance, heat exposure and its

Figures 1–5. Highlights from the mini-symposium and collaborative research activities held during the week-long meeting held at the Universidade of São Paulo, May 8–15, 2025. **1.** Activities were hosted by Michael Hrncir and his Laboratory of Environmental Physiology of Bees (FIS-A-BEE, Laboratorio de Fisiologia Ambiental de Abelhas) at the Instituto de Biociências. **2.** Group photo of FIS-A-BEE lab members with the authors of this contribution standing at the center back. **3.** Dr. Carlos Navas (Universidade de São Paulo) presenting on the importance of laboratory setups for studying thermoregulation in salamanders, during the mini-symposium on May 12. **4.** One of the small-group follow-up discussions held during the afternoon session. **5.** Michael Hrncir (left) and Michael Dillon (right) examining one of the several stingless bee (Apidae: Meliponini) colonies maintained in the laboratory for physiological and thermal biology studies.

consequences, voluntary thermal maxima in lizards, gene expression in stingless bees in response to environmental change, impacts of heat on sperm viability and quality in stingless bees, advances in thermography, and conceptual and practical challenges in assessing thermal preference in laboratory settings. Although research on bee thermal biology is relatively new, many of the concepts, methods, and techniques were first developed in the 1940s (Cowles & Bogert, 1944) and have since been refined in studies of other animals (reviewed by Lutterschmidt & Hutchison, 1997), yielding large data sets critical for addressing global patterns of thermal traits (*e.g.*, Sunday *et al.*, 2011). For this reason, we intentionally encouraged the participation of researchers working on diverse organisms, recognizing the value of cross-taxa perspectives in advancing the nascent field of bee thermal biology. The mini-symposium was simulcast via Zoom and included the participation of about 50 people from three Brazilian universities from the state of São Paulo, as well as a Canadian and a Spanish university.

The group discussions involved active participation from both attendees and presenters, including the authors of this report. Five key topics were proposed to guide the conversation: 1) sublethal effects of thermal stress; 2) genetic bases of thermophysiology; 3) lab-based thermophysiology studies as predictors for climate change impacts on species; 4) novel methods and techniques to study thermophysiology; and 5) thermophysiology applied to species conservation. The session also provided an opportunity to revisit and expand upon questions raised during the morning presentations. The lively informal discussions yielded a number of core themes summarized below.

EMERGENT THEMES

METHODOLOGICAL LIMITATIONS. A core theme that emerged across talks and discussions was the often inconsistent application of terminology and methodology used to characterize thermal biology of bees. Building from studies on other organisms, measures of thermal tolerance of bees have increased considerably in the last 5 years: a scholar search on "bee thermal tolerance" yields over 2200 results since 2020, whereas only a handful of papers measuring thermal tolerance of bees existed prior to 2015. This explosion in interest is exciting and promising but has also led to considerable variation in the approaches and experimental conditions employed, often limiting cross-study comparisons. For instance, one of the most commonly used metrics is the upper critical thermal limit, or critical thermal maximum (CT_{max}). However, this measure is highly sensitive to the ramping rate and other methodological considerations (Terblanche *et al.*, 2007) complicating comparisons among studies. Further, the ecological relevance of CT_{max} has been questioned (Telemeco & Gangloff, 2021), potentially limiting its utility for predicting individual, population, and species responses to temperatures in the field. A better fundamental understanding of a diverse suite of thermal traits of bees using standardized approaches will be necessary to better capture the complexity of responses to temperature, thereby facilitating compelling predictions of how current and future temperatures may affect bees.

SUBLETHAL HEAT EXPOSURE. Other areas identified as underexplored are the sublethal impact of heat exposure and the role of behavioral thermoregulation in bees. Only a few works have assessed their impact on survival, body size, and sperm viability (White & Dillon, 2023). One of the talks on heat-induced gasping behavior in lizards, presented by Dr. Melissa Bars Closel from the Universidade Estadual Paulista, Brazil, generated discussion on the potential of incorporating similar individual behavioral indicators into bee research in laboratory settings. Identifying and quantifying thermoregulatory behaviors in bees may offer valuable, ecologically meaningful metrics that complement physiological measurements.

Phylogenetic and geographic cold spots. A core theme and initial motivator for the collaboration/convening/interaction is the clear phylogenetic and geographic biases in existing studies of bee thermal biology. The current literature is disproportionately focused on social and temperate species, especially honey bees and bumble bees. In contrast, data on solitary and tropical bees remain sparse (but see Gonzalez *et al*., 2023; Harano & Hrncir, 2023). Addressing these gaps is critical for developing a comprehensive understanding of bees' thermal physiology. Furthermore, research overwhelmingly centers on adult female bees, and typically foraging individuals, while other life stages (*e.g*., larvae, pupae) are largely ignored. Analyses of a suite of thermal traits in a phylogenetic framework will be critical to better understanding the ecological and evolutionary drivers of variation in bee thermal biology.

Lessons from other animals. The symposium also highlighted the value of researchers looking beyond bees to inform future directions. For example, how might lessons learned in the mature lizard literature inform next steps in the nascent bee field? Amphibian studies are also in their infancy and plagued by different challenges due to life history, such as complex interactions between water balance and temperature, that may similarly be important for bees (*e.g*., Botsch *et al*., 2024).

Leveraging working group diversity. Finally, the geographic breadth of the participant institutions and individuals offers a powerful platform for comparative research on thermal ecology across climates, elevations, and bee faunas. We are excited about the potential opportunities to leverage diverse field sites, local expertise, and complementary resources for future research on how bees respond to changing temperatures. Next steps include the development of official institutional agreements to facilitate international cooperation and promoting regular channels of communications among research groups.

ACKNOWLEDGEMENTS

We are grateful to all the presenters and participants who enthusiastically accepted our invitation and contributed to the success of the mini-symposium. We also thank Claus Rasmussen and an anonymous reviewer for their insightful feedback, which significantly improved this manuscript. MED's participation was supported by the Center for Global Studies and the L. Floyd Clarke Professorship from the University of Wyoming. VHG's participation was supported by the Center for Latin American and Caribbean Studies at the University of Kansas. MH received support from the Brazilian Ministry of Education.

REFERENCES

Biesmeijer, J.C. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313: 351–354. https://doi.org/10.1126/science.1127863

Botsch, J.C., Daniels, J.D., Bujan, J., & K.A. Roeder. 2024. Temperature influences desiccation resistance of bumble bees. *Journal of Insect Physiology* 155: 104647. https://doi.org/10.1016/j.jinsphys.2024.104647

Carvalheiro, L.G., Cordeiro, G.D., Marques, B.F., Menezes, P.P., Consorte, P.M., & T.C. Gianinni. 2025. Challenges for quantifying knowledge shortfalls on tropical pollinators in the face of global environmental change – Brazilian bees as a case study. *Sociobiology* 72(2): e11276. https://doi.org/10.13102/sociobiology.v72i2.11276

Campion, C., Rajamohan, A., & M.E. Dillon. 2023. Sperm can't take the heat: Short-term temperature exposures compromise fertility of male bumble bees (*Bombus impatiens*). *Journal of Insect Physiology* 146: 104491. https://doi.org/10.1016/j.jinsphys.2023.104491

Corbet, S.A., Fussell, M., Ake, R., Fraser, A., Gunson, C., Savage, A., & K. Smith. 1993. Temperature and the pollinating activity of social bees. *Ecological Entomology* 18(1): 17–30. https://doi.org/10.1111/j.1365-2311.1993.tb01075.x

Cowles, R.B., & C.M. Bogert. 1944. A preliminary study of the thermal requirements of desert reptiles. *Bulletin of the American Museum of Natural History* 83(5): 261–296. http://hdl.handle.net/2246/1237

Dillon, M.E., Wang, G., Garrity, P.A., & R.B. Huey. 2009. Thermal preference in *Drosophila*. *Journal of Thermal Biology* 34(3): 109–119. https://doi.org/10.1016/j.jtherbio.2008.11.007

Forrest, J.R.K., Cross, R., & P.J. CaraDonna. 2019. Two-year bee, or not two-year bee? How voltinism is affected by temperature and season length in a high-elevation solitary bee. *The American Naturalist* 193(4): 560–574. https://doi.org/10.1086/701826

Gérard, M., Amiri, A., Cariou, B., & E. Baird. 2022. Short-term exposure to heatwave-like temperatures affects learning and memory in bumblebees. *Global Change Biology* 28: 4251–4259. https://doi.org/10.1111/gcb.16196

Giannini, T.C., Costa, W.F., Cordeiro, G.D., Imperatriz-Fonseca, V.L., Saraiva, A.M., Biesmeijer, J., & L.A. Garibaldi. 2017. Projected climate change threatens pollinators and crop production in Brazil. *PLos ONE* 12(8): e0182274. https://doi.org/10.1371/journal.pone.0182274

Glass, J.R., & J.F. Harrison. 2024. A thermal performance curve perspective explains decades of disagreements over how air temperature affects the flight metabolism of honey bees. *Journal of Experimental Biology* 227(7): jeb246926. https://doi.org/10.1242%2Fjeb.246926

Gonzalez, V.H., Hranitz, J.M., Percival, C.R., Pulley, K.L., Tapsak, S.T., Tscheulin, T., Petanidou, T., & J.F. Barthell. 2020. Thermal tolerance varies with dim-light foraging and elevation in large carpenter bees (Hymenoptera: Apidae: Xylocopini). *Ecological Entomology* 45: 688–696. https://doi.org/10.1111/een.12842

Gonzalez, V.H., Cobos, M.E., Jaramillo, J., & R. Ospina. 2021. Climate change will reduce the potential distribution ranges of Colombia's most valuable pollinators. *Perspectives in Ecology and Conservation* 19(2): 195–206. https://doi.org/10.1016/j.pecon.2021.02.010

Gonzalez, V.H., Oyen, K., Aguilar, M.L., Herrera, A., Martin, R.D., R. Ospina. 2022. High thermal tolerance in high-elevation species and laboratory-reared colonies of tropical bumble bees. *Ecology and Evolution* 12(12): e9560. https://doi.org/10.1002/ece3.9560

Gonzalez, V.H., Manweiler, R., Smith, A.R., Oyen, K., Cardona, D., & T.W. Wcislo. 2023. Low heat tolerance and high desiccation resistance in nocturnal bees and the implications for nocturnal pollination under climate change. *Scientific Reports* 13: 22320. https://doi.org/10.1038/s41598-023-49815-6

Gonzalez, V.H., Herbison, N., Robles Perez, G., Panganiban, T., Haefner, L., Tscheulin, T., Petanidou, T., & J. Hranitz. 2024. Bees display limited acclimation capacity for heat tolerance. *Biology Open* 13(3): bio060179. https://doi.org/10.1242/bio.060179

Hammer, T.J., Le, E., & N.A. Moran. 2021. Thermal niches of specialized gut symbionts: The case of social bees. *Proceedings of the Royal Society B: Biological Sciences* 288: 20201480. https://doi.org/10.1098/rspb.2020.1480

Harano, K-I., & M. Hrncir. 2023. Big in the tropics-Are there thermal advantages of large body size for carpenter bees in hot climates? *Ecological Entomology* 48(3): 358–370. https://doi.org/10.1111/een.13230

López-Uribe, M.M., Appert, M.K., Delgado, A.X., Herrera-Motta, A.F., Jimenez, A., Martín-Rojas, R.D., Ramos-Abensur, V.M., Riaño-Jimenez, D.A., Cure, J.R., Fuentes, J.D., Duque, L.O., & Gonzalez, V.H. 2024. Critical thermal maxima differ between groups of insect pollinators and their foraging times: Implications for their responses to climate change. *Journal of Melittology* 122: 1–8. https://doi.org/10.17161/jom.vi122.22505 . Czekońska. 2025. Thermal preferences of honey bee drones at different ages, depending on the rearing temperature. *Apidologie* 56(2):30. https://doi.org/10.1007/s13592-025-01162-3

Lutterschmidt, W.I., & V.H. Hutchison. 1997. The critical thermal maximum: Data to support the onset of spasms as the definitive end point. *Canadian Journal of Zoology* 75(10): 1553–1560. https://doi.org/10.1139/z97-782

Macías-Macías, J.O., Quezada-Euán, J.J.G., Contreras-Escareño, F., Tapia-Gonzalez, J.M., Moo-Valle, H., & R. Ayala. 2011. Comparative temperature tolerance in stingless bee species from tropical highlands and lowlands of Mexico and implications for their conservation (Hymenoptera: Apidae: Meliponini). *Apidologie* 42: 679–689. https://doi.org/10.1007/s13592-011-0074-0

MacQueen, S.A., Stanley, D.A., & J.M. Yearsley. 2025. Thermal limits of bumblebees and honeybees are modulated by different functional traits: Predictions of a mechanistic model. *PLoS ONE* 20(5): e0320038. https://doi.org/10.1371/journal.pone.0320038

Maia-Silva, C., da Silva Pereira, J., Freitas, B.M., & M. Hrncir. 2020. Don't stay out too long! Thermal tolerance of the stingless bees Melipona subnitida decreases with increasing exposure time to elevated temperatures. *Apidologie* 52: 218–229. https://doi.org/10.1007/s13592-020-00811-z

Marshall, L., Perdijk, F., Dendoncker, N., Kunin, W., Roberts, S., & J.C. Biesmeijer. 2020. Bumblebees moving up: Shifts in elevation ranges in the Pyrenees over 115 years. *Proceedings of the Royal Society B: Biological Sciences* 287: 20202201. https://doi.org/10.1098/rspb.2020.2201

Martinet, B., Dellicour, S., Ghisbain, G., Przybyla, K., Zambra, E., Lecocq, T., Boustani, M., Baghirov, R., Michez, D., & P. Rasmont. 2021. Global effects of extreme temperatures on wild bumblebees. *Conservation Biology* 35(5): 1507–1518. https://doi.org/10.1111/cobi.13685

Oyen, K.J., Giri, S., M.E. Dillon. 2016. Altitudinal variation in bumble bee (*Bombus*) critical thermal limits. *Journal of Thermal Biology* 59: 52–57. https://doi.org/10.1016/j.jtherbio.2016.04.015

Pardee, G.L., Griffin, S.R., Stemkovski, M., Harrison, T., Portman, Z.M., Kazenel, M.R., Lynn, J.S., Inouye, D.W., & R.E. Irwin. 2022. Life-history traits predict responses of wild bees to climate variation. *Proceedings of the Royal Society B: Biological Sciences* 289: 20212697. https://doi.org/10.1098/rspb.2021.2697

Pimsler, M.L., Oyen, K.J., Herndon, J.D., Jackson, J.M., Strange, J.P., Dillon, M.E., & J.D. Lozier. 2020. Biogeographic parallels in thermal tolerance and gene expression variation under temperature stress in a widespread bumble bee. *Scientific Reports* 10: 17063. https://doi.org/10.1038/s41598-020-73391-8

Potts, S.G., Biesmeijer, J.C., Kremen, C., Neumann, P., Schweiger, O., & W.E. Kunin. 2010. Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution* 25(6): 345–353. https://doi.org/10.1016/j.tree.2010.01.007

Soroye, P., Newbold, T., & J. Kerr. 2020. Climate change contributes to widespread declines among bumble bees across continents. *Science* 367(6478): 685–688. https://doi.org/10.1126/science.aax8591

Souza-Junior, J.B.F., Teixeira-Souza, V.H. da S., Oliveira-Souza, A., de Oliveira, P.F., de Queiroz, J.P.A.F., & M. Hrncir. 2020. Increasing thermal stress with flight distance in stingless bees (*Melipona subnitida*) in the Brazilian tropical dry forest: Implications for constraint on foraging range. *Journal of Insect Physiology* 123: 104056. https://doi.org/10.1016/j.jinsphys.2020.104056

Sunday, J.M., Bates, A.E., & N.K. Dulvy. 2011. Global analysis of thermal tolerance and latitude in ectotherms. *Proceedings of the Royal Society B: Biological Sciences* 278: 1823–1830. https://doi.org/10.1098/rspb.2010.1295

Telemeco, R.S., & E.J. Gangloff. 2021. Introduction to the special issue–Beyond CT_{Max} and CT_{Min}: Advances in studying the thermal limits of reptiles and amphibians. *Journal of Experimental Zoology A Ecological and Integrative Physiology* 335: 5–12. https://doi.org/10.1002/jez.2447

Terblanche, J.S., Deere, J.A., Clusella-Trullas, S., Janion, C., & S.L. Chown. 2007. Critical thermal limits depend on methodological context. *Proceedings of the Royal Society B: Biological Sciences* 274: 2935–2943. https://doi.org/10.1098/rspb.2007.0985

White, S.A., & M.E. Dillon. 2023. Climate warming and bumble bee declines: The need to consider sub-lethal heat, carry-over effects, and colony compensation. *Frontiers in Physiology* 14: 1251235. https://doi.org/10.3389/fphys.2023.1251235

Journal of Melittology

A Journal of Bee Biology, Ecology, Evolution, & Systematics

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The *Journal of Melittology* was established at the University of Kansas through the efforts of Michael S. Engel, Victor H. Gonzalez, Ismael A. Hinojosa-Díaz, and Charles D. Michener in 2013 and each article is published as its own number, with issues appearing online as soon as they are ready. Papers are composed using Microsoft Word® and Adobe InDesign® in Lawrence, Kansas, USA.

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ISSN 2325-4467