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DATA DESCRIPTOR

A multicontinental dataset of butterfly thermal physiological traits

Sarah E. Diamond¹✉, Carmen R. B. da Silva² & Osmary A. Medina-Báez¹

Butterflies serve as key indicators of climate change impacts such as shifts in emergence timing and shifts in geographic range and distribution. However, the development of commonly used ecological forecasts based on butterfly physiological tolerance of temperature change has lagged behind that of other taxonomic groups. Here, we provide a series of related datasets comprising butterfly thermal physiological traits to enable such forecasts. We compiled data from the literature on butterfly heat and cold tolerance (critical thermal maxima and minima) for 117 species as well as heat resistance (knockdown time) for 45 species. We also present a new dataset comprising heat and cold tolerance and thermal sensitivity of metabolic rate of 28 common North American butterfly species. We envision these data to not only provide foundations for contemporary ecological forecasts of vulnerability to recent climate change, but also to aid in our understanding of butterfly ecology and evolution over historical timescales.

Background & Summary

Datasets of heat and cold tolerance traits have been compiled across large spatial and taxonomic scales¹. These datasets have contributed usefully to our understanding of the ecology and evolution of thermal physiology². They have likewise provided the foundations for forecasts of vulnerability to ongoing climate change³. However, there are substantial biases in taxonomic coverage of thermal tolerance trait data. While butterflies (Papilionoidea) have been widely used to assess the impacts of climate change on natural systems^{4,5}, including as indicators of overall ecosystem health⁶, there are vanishingly few butterfly records in these datasets of thermal tolerance traits. For example, of the 2133 species in GlobTherm¹, none of these species are butterflies (in fact, none are Lepidopterans, i.e. are in the order containing moths and butterflies). Of the 102 species in a dataset of thermal tolerance acclimation capacity, none are butterflies (seven species belong to Lepidoptera, but all are moths)⁷. Indeed, although there are several trait-based syntheses for butterflies, such as LepTraits⁸ and others^{9,10}, they tend to comprise resource breadth, morphology, and life history traits, rather than physiological traits related to climate change resilience.

Recently, butterfly-specific datasets of thermal tolerance traits have begun to accrue, either as a study of a particular assemblage^{11,12} or as cross-study trait compilations¹³. These data will allow for an improved understanding of historical and contemporary drivers of butterfly responses to climatic change. Yet even with these advances, limitations remain. In particular, cross-study comparisons of thermal tolerance traits are often complicated by methodological variation among studies^{13,14}. These differences often have ecologically meaningful effects, as they can lead to qualitatively different conclusions regarding macrophysiological patterns and climate vulnerability¹⁵. Conditions prior to the assessment of tolerance such as developmental acclimation temperature regimes, acute temperature treatments (e.g. heat or cold hardening, initial assay temperatures), and developmental variation such as sex, age, and size, can all affect the estimation of tolerance¹⁶. In addition, whether tolerance is assessed via static or dynamic temperature assays, including differences in the rate of temperature change for dynamic assays, can likewise affect the estimation of tolerance (though some have argued for interoperability between static and dynamic tolerance estimates using thermal tolerance landscapes)¹⁷. On the one hand, these sources of variation in tolerance estimation can be considered a nuisance in that they introduce noise into comparative analyses. On the other hand, they represent the range of conditions over which natural populations interact with climatic variation and therefore can be important for understanding the range of possible

¹Department of Biology, Case Western Reserve University, Cleveland, Ohio, USA. ²School of Natural Sciences, Macquarie University, North Ryde, New South Wales, Australia. ✉e-mail: sarah.diamond@case.edu

responses to climate change. Indeed, intraspecific trait variation is increasingly recognized for its importance in the ability to forecast responses to climate change (especially across climatic gradients)^{18,19}, but is often not captured in large cross-study trait compilations that typically focus on species mean trait values. Relatedly, covariation between multiple traits - not only tolerance, but also metrics of sub-lethal performance and life history traits - are also increasingly recognized as important quantities for forecasting responses to climate change²⁰. However, at present, studies that quantify multiple thermal tolerance and performance traits tend to be focused on single species^{21,22}.

Here we present two related datasets of butterfly physiological traits. Recognizing the tradeoff between enhanced data coverage (spatial and taxonomic) and diminished interoperability of trait values measured with different methods, we have developed a cross-study compilation of butterfly heat and cold tolerance traits from the available literature. These data comprise 279 total individual records among 117 species. As a supplement to these data, we compiled data on butterfly heat resistance (the length of time an organism can withstand a given high temperature environment until loss of motor function), which we converted into heat tolerance (the highest temperature an individual can withstand for a given length of time until loss of motor function); these data comprise 151 total individual records among 45 species. Likewise recognizing the potential importance of intraspecific trait variation, we experimentally assessed heat and cold tolerance traits as well as sub-lethal thermal performance (metabolic rate) and body mass for common North American butterflies. These data comprise 638 total individual records for thermal tolerance and 264 total individual records for metabolic rate among 28 species. Although these data are not spatially diverse, as they are obtained from several locations near the range centroids of these species, they uniquely combine heat and cold tolerance data with metabolic rate assessed at two acute test temperatures and are measured under standardized conditions and protocols. We envision these complementary datasets to be of use to ecological and evolutionary thermal physiologists and researchers interested in forecasting vulnerability to ongoing climate change.

Methods

Multicontinental datasets. We performed a literature search to identify studies with heat and cold tolerance data in butterflies. We performed searches in both Web of Science and Google Scholar. The last access date was 12 June 2024. We included peer-reviewed publications and dissertations, but not pre-printed manuscripts. In our main dataset, we focused on estimates of the critical thermal maximum, CT_{max} , and the critical thermal minimum, CT_{min} , as these were the most broadly available estimates measured in a consistent manner across different studies. The estimates include those from thermal tolerance assays where the temperature was dynamically ramped over time and those from thermal death time curves fitted to data from static temperature treatments (four estimates among three species and three studies)^{23–25}. We used the following search terms: “butterfly”, “Papilionoidea”, “Lepidoptera”, “heat tolerance”, “cold tolerance”, “CTmax”, “CTmin”, “critical thermal maximum”, “critical thermal minimum”, “upper thermal limit”, “lower thermal limit”. These search criteria returned several studies that contained data on mortality across different temperatures. However, we ultimately excluded these studies as they would require fitting thermal performance curves and extracting heat and cold tolerance parameters, and most studies lacked sufficient sampling towards high and low extreme temperatures that would allow for robust curve fitting.

We likewise performed a literature search to identify studies with heat resistance data in butterflies. In this companion dataset, we focused on estimates of knockdown time at stressfully high temperatures. Heat knockdown time quantifies the length of time an organism can withstand a high temperature challenge before the onset of heat coma, i.e. when they are knocked down. We used the following search terms: “butterfly”, “Papilionoidea”, “Lepidoptera”, “heat resistance”, “heat knockdown time”, “HKD”, “HKDT”.

To be able to compare the heat resistance data beyond the conditions of a given study, we used thermal death time curves to estimate CT_{max} from knockdown time at a particular temperature²⁶. We emphasize caution here in the interpretation of these CT_{max} values as they rely on the choice of temperature sensitivity coefficient. While this coefficient can be estimated for a particular species or population with multiple static temperature measures of heat knockdown time, this value must be assumed in cases of heat knockdown time at a single temperature. We computed CT_{max} from static single estimates of heat knockdown time based on the median temperature sensitivity coefficient among other butterfly species (median $z = 5.20$; *Bicyclus anynana*, range $z = 4.62–5.72$, $n = 5$; *Pieris napi*, range $z = 4.10–4.11$, $n = 2$; *Pieris rapae*, $z = 5.10$, $n = 1$)^{23–25}. These sensitivity coefficients are generally within the range of values reported for other ectothermic species, range $z = 0.8–5.7$, $n = 41$ ²⁷. Importantly, while there is clearly inter- and intra-specific variation in the temperature sensitivity coefficient, we lack this information for most observations and species in the heat resistance dataset.

Estimates of tolerance or resistance on wild-caught organisms were generally presented as species means and associated error measurements, occasionally with the data reported separately by sex. However, laboratory-based studies generally had multiple subgroups of data including different sexes, life stages, and treatment conditions (e.g. temperature regimes, food resource regimes). In these cases, we followed the presentation of the data by the authors and report means and errors associated with each group. We likewise followed the authors with respect to naming conventions for latin binomial descriptions of genera, species, and subspecies.

To extract data from articles, we used a combination of summary statistics from raw data included as a supplementary file to the article, extraction of values reported in the article text or table display elements, and extraction of values from article figure display elements using WebPlotDigitizer²⁸.

As a minimum criterion for entry into the multicontinental dataset, we required a mean tolerance or resistance value. In a limited number of cases, only medians were available and were used as a summary statistic of central tendency. When possible, we included standard errors associated with mean tolerance or resistance values, either by reporting these directly or by calculating standard errors from other measures of spread such as from standard deviations, interquartile ranges, and sample sizes. We also did not require the tolerance or

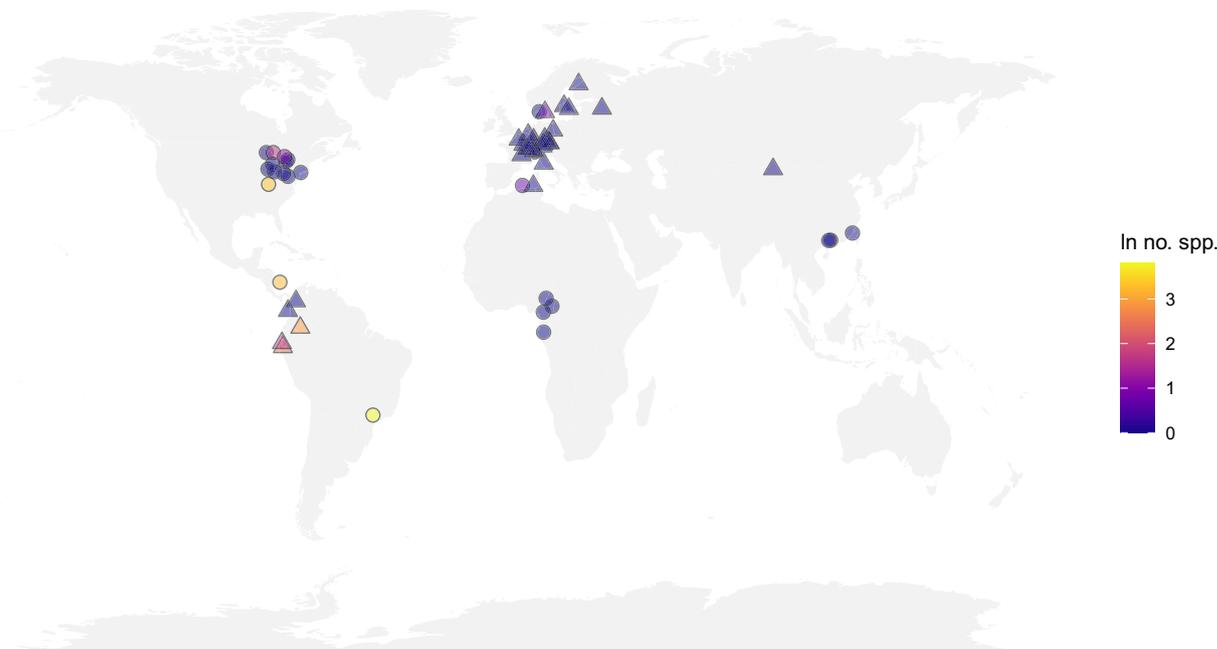


Fig. 1 Sample locations for species in the multicontinental dataset. Each point represents an individual sampling location, with points colored by the natural log transformed number of species measured for thermal tolerance or resistance at each site. Thermal tolerance data are denoted by circles, and heat resistance data are denoted by triangles. Points have been strongly jittered to avoid overlap in some areas, and consequently, sampling locations are approximate on this map. Fourteen species in the heat and cold tolerance dataset and one species in the heat resistance dataset lacked geographic information and are not represented on this map.

resistance data to be georeferenced, though again, we included this information when possible. In some cases, we were able to match an individual tolerance or resistance value to a single geographic location. In other cases, we were only able to match an individual tolerance or resistance value to a group of sites. In these cases, we report the geographic coordinates of all potential collection sites or each individual tolerance or resistance value. Although the combined multicontinental dataset of thermal tolerance and resistance traits contains records from each continent where butterflies are found except Australia, the data are nonetheless sparse in terms of spatial coverage (Fig. 1).

Finally, we incorporated species means and standard errors for CT_{\min} and CT_{\max} among the species comprising our North American dataset (see below) into our multicontinental thermal tolerance dataset. These data are fully georeferenced at the observation level. To include them on a comparable scale to those in the multicontinental dataset, we computed species trait means for each collection location. Sex could not be determined for all individuals, so data were pooled across sexes.

The combined multicontinental heat and cold tolerance trait dataset includes representatives from all six butterfly families (Fig. 2). By contrast, the heat resistance trait dataset includes representatives from only three butterfly families (Lycaenidae, Pieridae, and Nymphalidae; Fig. 3). In our datasets, and as others have pointed out, research on butterfly responses to temperature tends to be biased towards the Nymphalidae family, though this is also the most globally diverse butterfly family²⁹.

North American dataset. Although the North American dataset contributes species (by location) means for CT_{\min} and CT_{\max} to the multicontinental dataset described above, we also provide access to the individual-level data for these traits and others including metabolic rate and body mass. Because thermal tolerance, metabolic rate, and body mass measurements were taken on the same individuals (excepting heat and cold tolerance measurements on the same individual, as these assays were destructive), they can be used to explore intraspecific associations between traits (Fig. 4a,b) in addition to interspecific comparisons of trait means (Fig. 4c).

Collection information. Adult butterflies were collected in northeastern Ohio, USA from 2021 to 2023. Collection sites included Case Western Reserve University (latitude, longitude: 41.5043, -81.6084), Cuyahoga Valley National Park (41.2808, -81.5678), Holden Forests and Gardens (41.6027, -81.3061), Squire Valleevue Farm (41.4979, -81.4240), and private property in the city of Independence (41.3687, -81.6379), though we note that over 95% of the data came from the Squire Valleevue Farm site. Seasonal collections began in May and continued through late September or early October each year.

We used aerial nets (BioQuip, 38 cm diameter) to collect butterflies. For transportation from the field sites to the laboratory, butterflies were placed individually into 90–946 mL containers (with holes for airflow), depending on the size of the butterfly. At the laboratory, butterflies were transferred and housed individually in mesh cages (28 × 28 × 28 cm BugDorms from BioQuip). Butterflies were provided with a paper towel moistened with

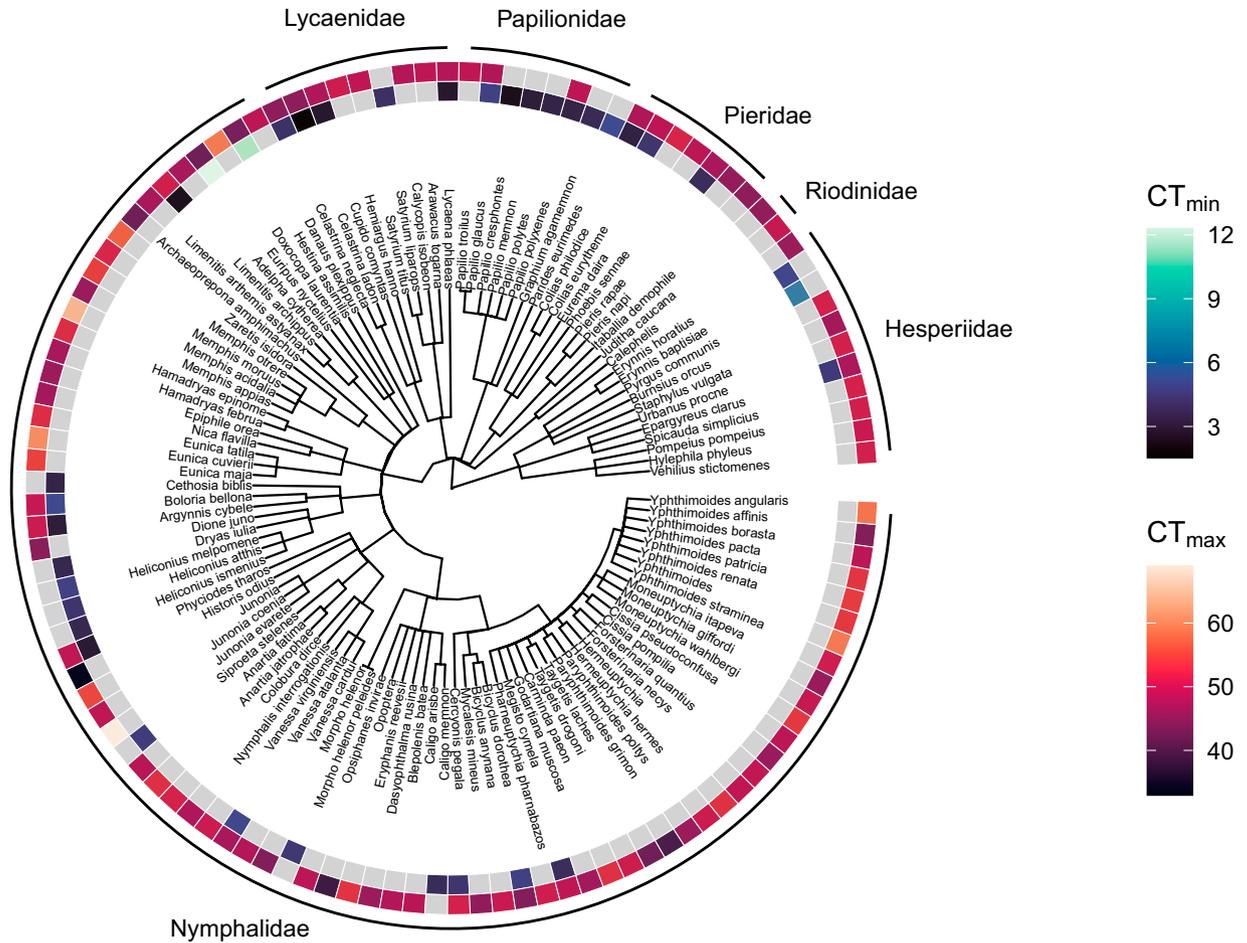


Fig. 2 Heat and cold tolerance trait values mapped onto the NCBI taxonomy. Clade labels highlight the six butterfly families. For species with multiple entries in the multicontinental thermal tolerance dataset, species mean trait value are presented here. One species had no matches in the NCBI database and is represented only at the genus level (*Opoptera sulcius*). For records where individuals could not be identified to species in the original study, we include only the genus name.

tap water (aged at least 24 hours) and a petri dish (60 × 15 mm) containing a sponge and a 10% sugar-water solution.

The butterflies were held for a 24 to 48-hour acclimation period in Percival growth chambers (36-VL) programmed to a constant 25 °C and a 14:10L:D photoperiod cycle. This acclimation period was intended to minimize acute acclimation responses to field environmental conditions prior to the assessment of physiological traits.

Metabolic rate. To assess the thermal sensitivity of routine metabolic rate, we measured the metabolic rate of individuals at two constant acute test temperatures, 20 and 30 °C. Individuals were tested at 20 and 30 °C in a random order. To quantify metabolic rate at each test temperature, we used a CO₂/H₂O gas analyzer (Licor-7000) in push mode that pushed air from the environment (scrubbed of CO₂ and H₂O with soda lime and Drierite) through two flow control meters (Alicat Scientific, MC-200SCCM until July 2021 and MC-1SLPM from July 2021 through October 2023) and then a respirometry flow multiplexer (RM-8). The flow controllers were calibrated (Gilian Gilibrator-2 NIOSH) at both 20 and 30 °C. The respirometry equipment was held within a dark growth chamber (MIR 154 PHCBI for trials performed 2021–2022, and a MIR 153 for trials performed in 2023) set to 20 or 30 °C. The dark environment helped to limit movement during the trials. Butterflies were generally resting, although we could not entirely exclude the possibility of movement during the trials (e.g. walking around the testing chambers). Once placed inside the respirometry chambers, animals were allowed to acclimate at the given test temperature for 15 minutes prior to recording of metabolic rate.

We tested butterflies of small body mass inside 30 mL glass chambers, and butterflies of large body mass in 650 mL chambers (RC and RC-1, Sable Systems International). In the multiplexer, each animal chamber contained one individual, and CO₂ was recorded for 10 minutes, with a two-minute flush, at a constant flow rate, adjusted separately for each test temperature to achieve a volumetric flow rate of 100 mL min⁻¹. Note that there were a total of eight chambers, with one empty chamber to assess the baseline and up to seven animal chambers per trial. For butterflies of large body mass, the larger respirometry chambers required a higher flow rate,

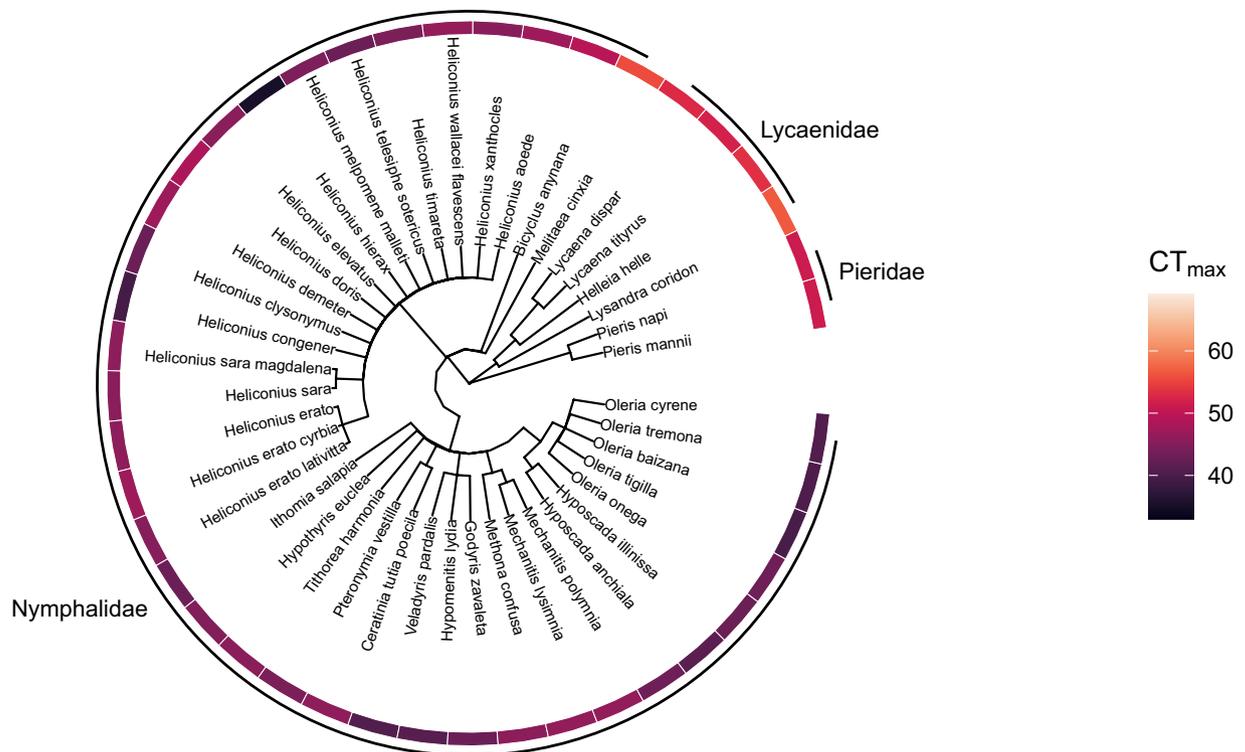


Fig. 3 Heat tolerance estimated from heat resistance (i.e. knockdown time using the median thermal sensitivity coefficient for butterflies of $z = 5.20$) mapped onto the NCBI taxonomy. Note that the color scale for CT_{max} is matched to that of Fig. 2 for comparison. For species with multiple entries in the heat resistance dataset, species mean trait value are presented here. Five species with sub-species designations had no matches in the NCBI database and were promoted to the level of species to be able to extract their taxonomic information. These included *Heliconius clysonymus clysonymus*, *Heliconius elevatus willmotti*, *Heliconius sara sprucei*, *Heliconius xanthocles napoensis*, and *Pieris mannii alpigena*.

adjusted to achieve a target volumetric flow rate of 500 mL min^{-1} , and a longer flush of 14 minutes. CO_2 concentration (ppm) from the animal chambers was compared to the CO_2 concentration (ppm) from the returning control line and recorded by the Licor-7000.

The metabolic rate data were processed through a UI-3 data acquisition interface and ExpeData software (Sable Systems International). Once all calibrations were complete, we then converted the raw CO_2 values to the rate of CO_2 production ($\text{VCO}_2 \text{ mL min}^{-1}$) by dividing the values by 1,000,000 to get the fractional CO_2 value, and multiplied this value by the flow rate. We considered the first five minutes as a settling-in period and used the last five minutes of recording to compute the mean metabolic rate over this period. These butterflies breathe continuously and so the five-minute interval is sufficient to get an estimation of metabolic rate, unlike species with discontinuous breathing³⁰. We performed a complementary method to detect the flattest part of the trace using a rolling window analysis (each five-minute interval possible over the 10 minutes of recording) and identifying the lowest slope value. Because calculations of metabolic rate based on this rolling window method were nearly identical to the last five minutes recording approach, we elected to use the latter method for simplicity. While we report the mean metabolic rate for each butterfly at each temperature, we also computed thermal sensitivity of metabolic rate. We standardized the change in metabolic rate across the two test temperatures as Q_{10} values, which describe the increase in metabolic rate for every 10°C increase in temperature.

Heat and cold tolerance. Following assessment of metabolic rate at both the 20 and 30°C test temperatures, individuals were allowed to recover for a 15-minute period on the laboratory bench ($\sim 23^\circ\text{C}$) prior to assessment of thermal tolerance. Individuals were randomly assigned to be assessed for either heat tolerance or cold tolerance. Heat tolerance was assessed by the critical thermal maximum, CT_{max} , and cold tolerance by the critical thermal minimum, CT_{min} . For both tolerance estimates, the loss of wing movement was used to determine the critical temperature.

The CT_{max} and CT_{min} trials were performed using water baths (A40 ARCTIC / SC150, A10 ARCTIC / SC150, or S13 SAHARA / SC150, Thermo Scientific) with a dynamic temperature ramping protocol of 1°C min^{-1} . The temperature ramped upward starting at 35°C for CT_{max} . The temperature was ramped downward starting at 15°C for CT_{min} . At the start of the trial, all individuals were placed in plastic containers plugged with a sponge. We used three different sizes of container based on the size of the butterfly. The containers needed to be large enough to allow the butterfly to fully extend its wings. For small butterflies we used 200 mL containers. For large butterflies, we used 473 mL or 946 mL containers. Butterflies were allowed to acclimate to the starting water bath

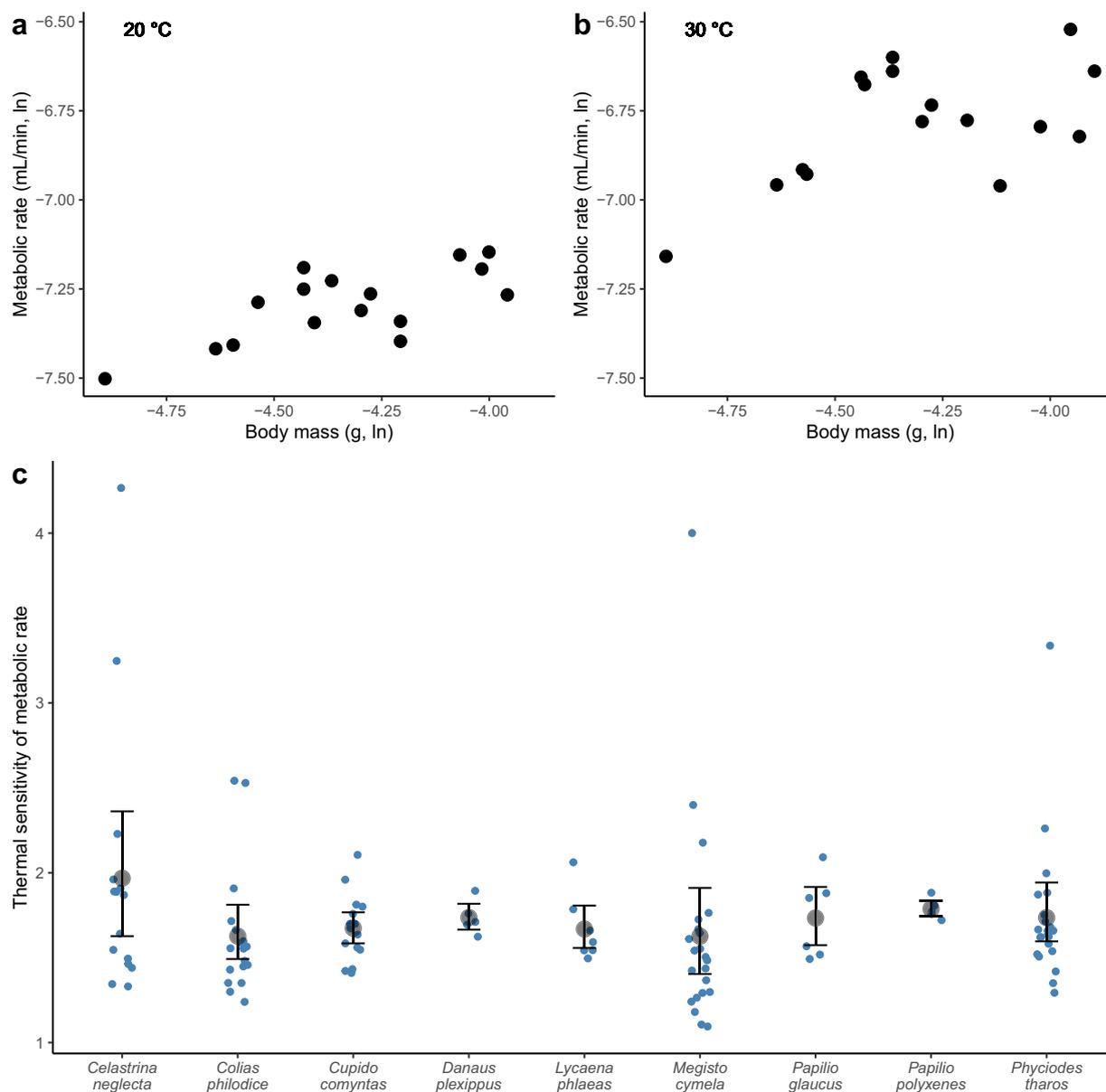


Fig. 4 Metabolic rate as a function of body mass at 20 and 30 °C for *Cupido comyntas* (panels **a** and **b**, respectively); both variables are natural log transformed. Panel **c** characterizes the thermal sensitivity of metabolic rate (as Q_{10} values) for species with at least 5 individuals measured at both 20 and 30 °C. Means, 95% confidence intervals (non-parametric bootstrap), and raw data are shown.

temperature for 15 minutes prior to the start of temperature ramping. After thermal tolerance trials, butterflies were placed into glassine envelopes and frozen at -20°C .

Body mass. Body mass of each individual was recorded multiple times. First, body mass was recorded following collection from the field and prior to being housed in the lab for pre-trial acclimation. Body mass was also recorded just prior to and immediately following the assessment of metabolic rate, and just prior to and immediately following the assessment of thermal tolerance (either CT_{\max} or CT_{\min}). Body mass was recorded to a precision of 0.0001 g (Sartorius MSE124S-100-DA).

Data Records

The multicontinental datasets and North American dataset, collectively referred to as “PapilioTherm” (version 1.0), are hosted on the Open Science Framework³¹ (<https://osf.io/fguxa/>). All data are stored as comma separated value (.csv) files. Metadata are contained in a single text file. Owing to the multicontinental and North American datasets being summarized at different levels, two distinct sets of files house the multicontinental (species or subgroup level) and North American (observation level) datasets. Note that the species-by-site mean trait values of the North American dataset are included in the multicontinental thermal tolerance dataset. Furthermore, the

Variable type	Description
Species and sub-group identity	Full name with genus and species, sex, and life stage at which tolerance was assessed
Tolerance information	Mean and standard error of the thermal tolerance estimate (heat or cold tolerance), sample size, and information on pre-trial and within-trial conditions such as pre-trial acclimation temperature, initial trial temperature, and rate of temperature change during the trial
Data extraction and processing information	Text describing how the data were collected and any conversions that were needed to report the mean tolerance and standard error
Study information	Reference for the source of extracted data and relevant DOI's
Georeferencing information	Decimal degrees latitude and longitude and text descriptions of study sites

Table 1. An overview of the types of variables included in the multicontinental heat and cold tolerance dataset. For complete descriptions, see the meta-data in the online data repository³¹.

Variable type	Description
Species and sub-group identity	Full name with genus and species, sex, and life stage at which tolerance was assessed
Heat knockdown information	Mean and standard error of heat knockdown time, sample size, and information on pre-trial and within-trial conditions such as pre-trial acclimation temperature and the temperature at which knockdown time was assessed; conversion of heat knockdown time to heat tolerance is also provided
Data extraction and processing information	Text describing how the data were collected and any conversions that were needed to report the mean tolerance and standard error
Study information	Reference for the source of extracted data and relevant DOI's
Georeferencing information	Decimal degrees latitude and longitude and text descriptions of study sites

Table 2. An overview of the types of variables included in the multicontinental heat resistance (knockdown time) dataset. For complete descriptions, see the meta-data in the online data repository³¹.

heat resistance (knockdown time) dataset is provided separately from the thermal tolerance dataset owing to the different types of information reported for each trait type.

Multicontinental datasets. The main multicontinental dataset includes CT_{max} and CT_{min} trait data from 14 studies^{11,12,21–25,32–37} including the new data presented here³¹. At a minimum, species or group-level means are reported with standard errors reported when available. Groups can be defined according to combinations of sex, developmental stage, geographic location, and the type of assay performed. We included details of conditions prior to and during the collection of these trait values, including developmental acclimation conditions, initial temperatures for the assessment of heat or cold tolerance, and the rate of temperature change for dynamic ramping assays. We also included details of data extraction and processing to bring them into a standard format of trait means and standard errors. We reported the geographic coordinates of the sampling locations for all but 14 species that were obtained from laboratory stock populations with unknown provenance (Table 1).

The companion multicontinental dataset includes heat resistance (knockdown time) from 13 studies^{38–50}. We used the same inclusion criteria, grouping structure, and georeferencing as described above for our main multicontinental dataset of thermal tolerance traits. We included details on developmental acclimation conditions and the temperature at which knockdown time was assessed. We also estimated heat tolerance (CT_{max}) using thermal death time curves (Table 2).

North American dataset. *Physiological trait data.* The North American physiological trait dataset contains individual-level, temporally and spatially referenced data on CT_{max} , CT_{min} , metabolic rate at 20 and 30 °C, and body mass at capture and prior to and following each physiological trait assay (Table 3). Summary statistics of these individual-level data were incorporated into the multicontinental dataset of heat and cold tolerance.

Physical specimens. Butterfly specimens are stored in the Diamond lab at Case Western Reserve University. Specimens are stored individually within glassine envelopes at –20 °C. Whole specimen loans or other sample requests (e.g. leg for DNA extraction) should be sent to the corresponding author and will be considered on a case-by-case basis.

Technical Validation

Multicontinental datasets. All extracted data were rechecked at least once following the initial extraction. Geographic coordinates were verified against collection locality names and by visualization of collection coordinates on a global map.

North American dataset. Specimens were identified to species at the time of collection, prior to performance of the physiological trait assays. Species identity for each individual was confirmed or updated on these specimens following the physiological trait assays and subsequent storage at –20 °C. Genus and species (including subspecies) names followed the Integrated Taxonomic Information System (ITIS).

Variable type	Description
Individual, species, and sub-group identity	Unique alphanumeric accession for each individual, full name with genus and species, and sex
Physiological traits	Heat tolerance, cold tolerance, metabolic rate at two acute test temperatures, thermal sensitivity of metabolic rate, and body mass at capture and prior to and following assessment of each trait
Field collection information	Decimal degrees latitude and longitude and text descriptions of field collection sites; dates of collection from the field are also supplied for each individual

Table 3. An overview of the types of physiological trait variables included in the North American intra-specific comparative dataset. For complete descriptions, see the meta-data in the online data repository³¹.

Electronic data comprising heat and cold tolerances were checked against the original paper records and either confirmed or amended. Electronic data comprising metabolic rates were visually inspected on an individual basis. In cases of obvious equipment failures, i.e. leaks in tubing connections that resulted in negative metabolic rates, we excluded those trials from further consideration.

Usage Notes

The PapilioTherm datasets provide a first step in synthesizing information on butterfly thermal physiological traits. As data continue to accumulate in this area, PapilioTherm version 1.0 will be updated with subsequent versions on the Open Science Framework³¹. Ideally, the inclusion of new data will help to fill existing gaps in the dataset, both in terms of taxonomic representation and geographical distribution, which are currently limited (Figs. 1–3). Specifically, greater representation of species in families other than the Nymphalidae are needed, as are data from the tropics and the Global South.

Although there are many potential applications of these data, which we enumerate below, we first point out a few areas of caution when using these data. In an analogous manner to other such syntheses of thermal physiological traits, there are limitations on comparing across traits assessed under different conditions and with different protocols⁵¹. Furthermore, converting single-value heat knockdown time values to estimates of heat tolerance likewise require caution owing to inter- and intra-specific variation in the thermal sensitivity coefficient determining the relationship between knockdown time and intensity of thermal exposure²⁷. Finally, we emphasize caution in the interpretation of tolerance and resistance traits measured on laboratory stock populations, as inadvertent selection in these environments could bias physiological trait values relative to those of natural populations⁵².

That said, we highlight several areas for potential use of these data:

- (1) These data could be used to answer fundamental research questions on drivers of biogeographic patterns of occurrence in butterflies. For example, physiological trait data can be used to understand extant relationships between species (potential) climatic niches and species range and distribution⁵³.
- (2) These data can likewise be important for understanding phenotypic correlations between traits and the ecological and evolutionary constraints that might shape those relationships⁵⁴. For example, in many ectothermic species, heat tolerance is more evolutionarily constrained compared with cold tolerance, which is more strongly shaped by current climatic conditions², but this pattern has not yet been explored in butterflies.
- (3) These data could be used to answer more applied research questions on species conservation in the face of global change. With many butterfly communities declining in abundance and species diversity in association with climate change and land-use change^{55–57}, forecasting their vulnerability to ongoing change can provide much needed aid in targeting species for conservation and land management interventions⁵⁸. Heat and cold tolerance data can be used to inform the degree to which species might be buffered under future climatic warming in place⁵⁹, and the capacity to track suitable habitat in space and time^{60,61}. Both the trait data and physical specimens provide a baseline against which future sampling can be compared. Such resampling studies have provided valuable insights into capacities of populations to cope with changes in their environment^{62,63}.
- (4) Finally, the datasets and meta-data themselves might provide useful templates for future data collection in this area, highlighting the importance of information on collection sites, collection timing, pre-assay conditions, and details on the physiological trait assays themselves.

Code availability

An R⁶⁴ script file used to develop the plots for this data descriptor is provided at the Open Science Framework page housing the datasets³¹.

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Author contributions

S.E.D. conceived of the idea for data collection, developed protocols, compiled data (North American and multicontinental datasets), and wrote the first draft of the manuscript. C.R.B.d.S. provided advice on respirometry data collection and data processing for the North American dataset and reviewed entries for the multicontinental dataset. O.M.B. refined protocols and performed field collections and physiological trait assays (metabolic rate, thermal tolerance) for the North American dataset. All authors contributed to revising the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Correspondence and requests for materials should be addressed to S.E.D.

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