Habitat temperatures of the red firebug, *Pyrrhocoris apterus*. Taking a stand for small scale measurement of climate data.

Helmut Käfer, Helmut Kovac, Anton Stabentheiner

helmut.kaefer@uni-graz.at

University of Graz, Institute of Biology, Universitätsplatz 2, 8010 Graz, AUSTRIA

Introduction Ambient temperature (T_a) is a main parameter that determines the thriving and propagation of ectothermic insects. It affects them at all life stages, during egg and larval development, as well as adults' survival. The firebug *Pyrrhocoris apterus* (LINNÉ 1758) is an herbivorous bug species almost ubiquitous in Europe. Its distribution extends from the Atlantic coast to Siberia, north-west China and Mongolia. After introduction it established successfully in the USA, Central America, India and Australia. This ability to spread and establish viable populations in different habitats shows a considerable ability to cope with changing environmental factors. Temperature data (amongst other parameters) can be used to describe the area where a species can survive and thrive, and predict possible routes of dispersal in invasive insects. In order to create accurate models, it is necessary to determine or estimate the temperature which organisms are exposed to as accurately as possible. In this regard, both the spatial and the temporal resolution of the temperature data are crucial. Here we examine how well large-scale temperature data match the temperatures measured directly on site in the (micro)habitat.

Methods Over the years 2014 to 2016 we determined the climatic conditions at a farmhouse in rural Gschwendt (Fig.1; 47.17855 N, 15.5729 E, Styria, Austria, Central Europe) in a habitat where a stable population of *P. apterus* has been observed continuously for decades. We conducted temperature measurements via thermocouples connected to a data logger (Ahlborn ALMEMO 5590-2) in the habitat, and in the microhabitats where individuals could be found during the seasons (linden tree trunk and crown, vine trellis, on the ground nearby the aforementioned places, winter hibernaculum in crevices between cobblestones at a porch). We also measured climate data with a standardized weather station (M00_WSloc) directly on site. The temperature data were set against freely available data from European (ECA&D), and national (ZAMG) organisations (for details see legend in Fig.3). These simulated, gridded climate data sets are commonly used to characterize habitat climate. They, as well as our temperature measurements, were also compared to the thermal limits (critical thermal minimum and maximum; CT_{min}, CT_{max}) of the firebug to determine survivability.

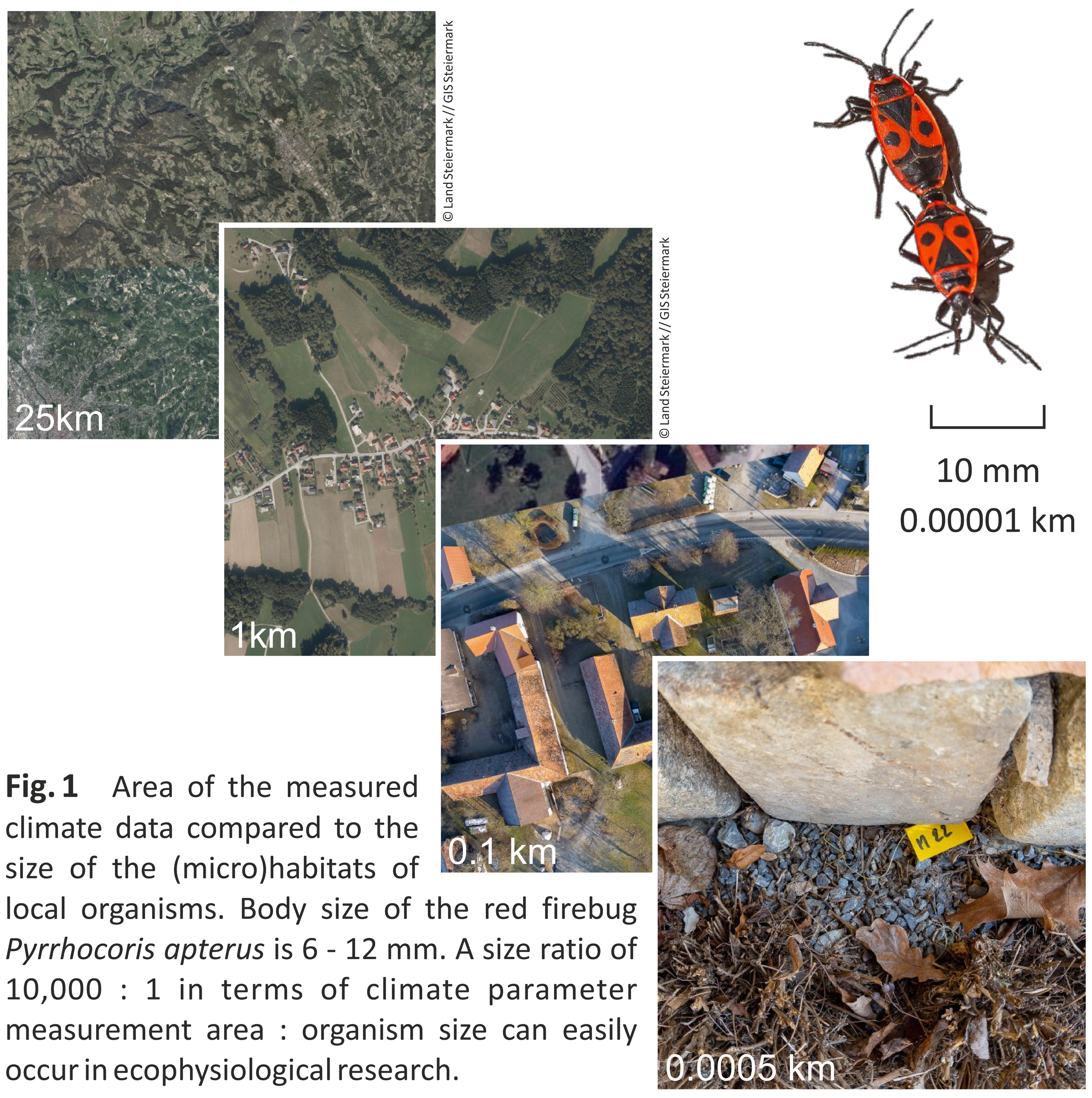

Fig. 1 Area of the measured climate data compared to the size of the (micro)habitats of local organisms. Body size of the red firebug *Pyrrhocoris apterus* is 6 - 12 mm. A size ratio of 10,000 : 1 in terms of climate parameter measurement area : organism size can easily occur in ecophysiological research.

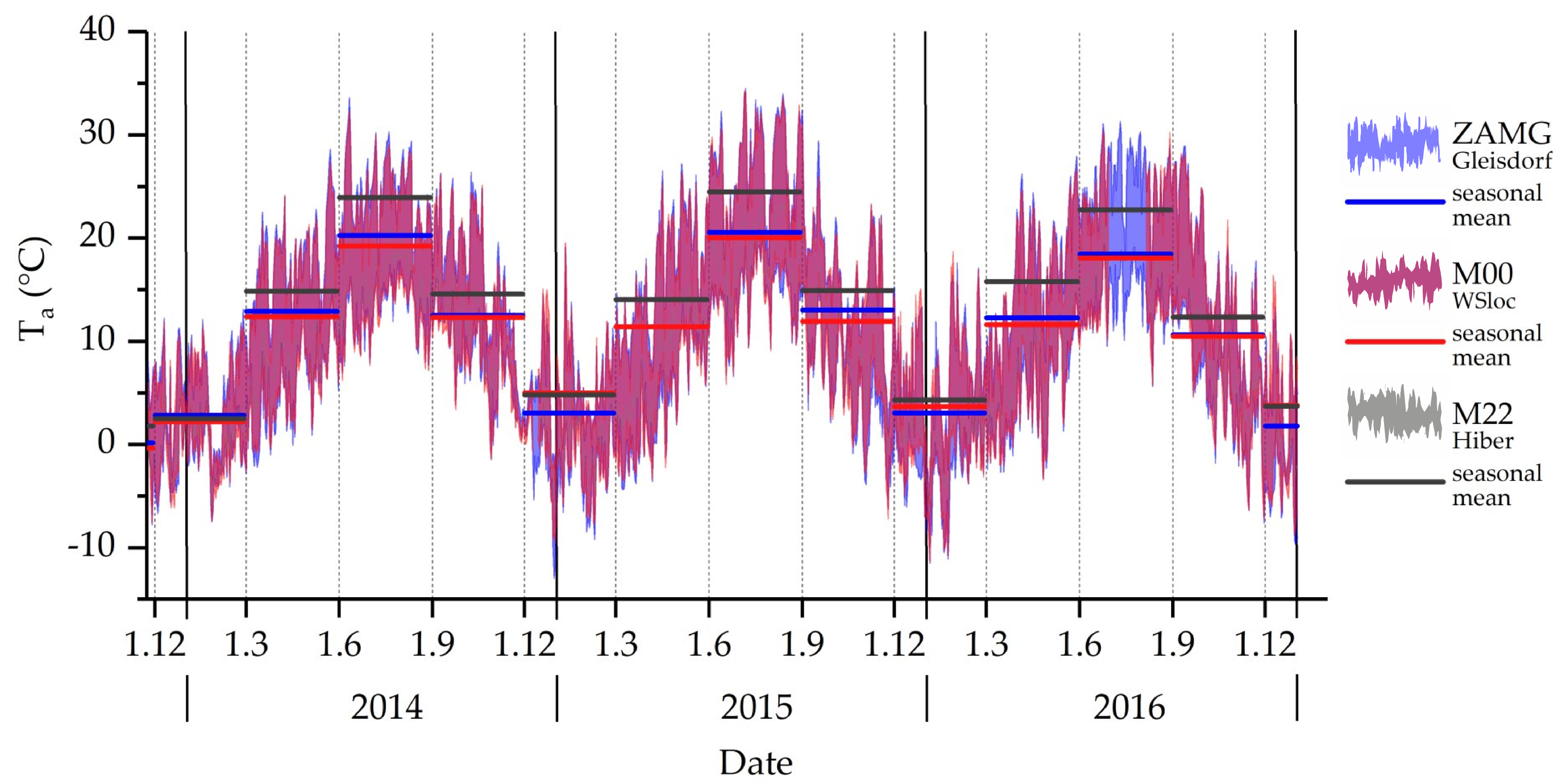

Fig. 2 Ambient temperature (T_a) measurements over the years 2014 - 2016. Calculated daily means (curves) and seasonal means (bold horiziontal lines) from the spatially nearest ZAMG weather station (Gleisdorf), as well as our own standardized weather station on site (M00_WSloc), and microhabitat temperatures in a known winter hibernaculum (M22_Hiber). Temperature data differed depending on location as well as temporal resolution.

Results & Discussion Our measurements of the habitat and microhabitat temperatures obviously deviated from the freely available, processed temperature data (Fig.2; daily calculated means and calculated seasonal means) which, for example, underestimated the temperatures in the hibernacula of the bugs (Fig. 2, winter seasons).

Daily means from ECA&D and ZAMG did not adequately depict the daily temperature curves (Fig. 3). In summer, differences of up to 7.5°C (and even ~22°C in direct sunlight) to measured values during the hottest hours of the day could be observed (Fig. 3A). These high T_as, which could well be above the species' CT_{max}=46.0±0.5 °C, accordingly affected the behavior of the bugs, as they seeked out cooler areas in the habitat . In winter, ambient air temperatures can and do fall below the critical thermal minimum of *P. apterus*, but still the bugs thrive and propagate at the sample site. The provided temperature data did not match the microhabitat temperatures by up to 15°C, and also our own measurements (M00_WSloc) underestimated temperatures, e.g. in the bug hibernacula (Fig. 1) by ~7.5°C (Fig. 3B). These discrepancies may and will influence predictions on winter mortality of the population, when temperatures near the individuals are incorrectly assumed to be below the species' CT_{min} = -4.0±0.6 °C.

Obviously, individuals sought out areas with favorable temperatures in summer as well as in winter (behavioral thermoregulation). These tiny areas in particular are not (always) represented in large scale climate tables, leading to possible misinterpretation of the future distribution in a changing environment or dispersal behavior of invasive species. The calculated ZAMG INCA_L 15-minute values matched our own measured WS_{local} T_a values surprisingly well, highlighting the value of a small temporal resolution in climate measurements, where appropriate.

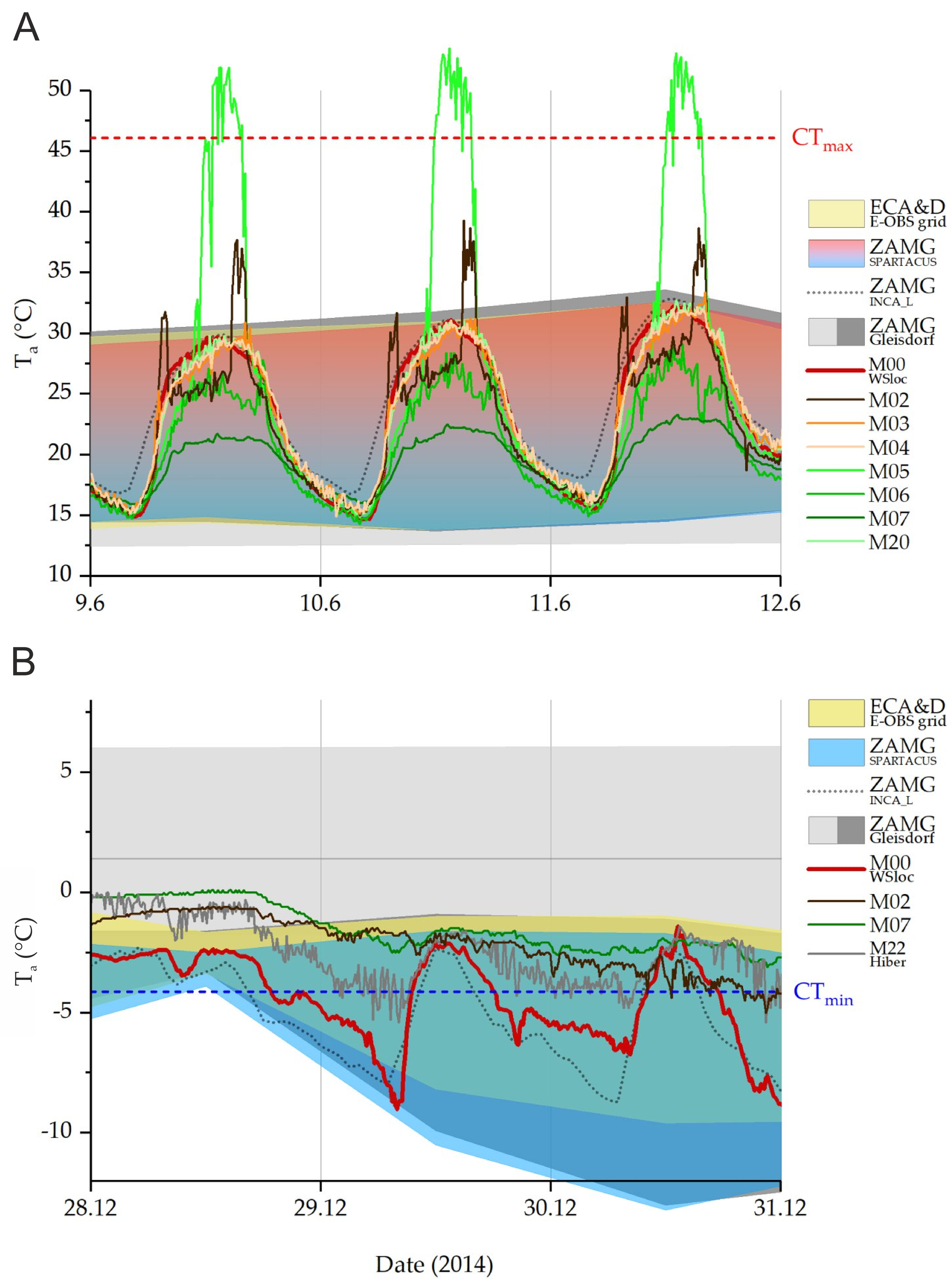

Fig. 3 Ambient temperatures on the hottest (A) and coldest (B) days of 2014. Calculated daily data from ECA&D, ZAMG_SPARTACUS, and ZAMG_Gleisdorf, 15-minute estimates from ZAMG_INCA_L, and 10-minute measurements from our own standardized weather station (M00_WSloc) as well as from sensors in the microhabitats (brown=Linden tree, e.g. M02=roots; green=trellis post, e.g. M07; M22=crevices, winter hibernaculum). CT_{max} and CT_{min} are plotted as the limits of the survivable temperature range. The "real-time values" sometimes deviate considerably from the daily averages. The monthly average of the spatially nearest weather station ZAMG_Gleisdorf is shown as a light gray area for comparison.

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