

Temporal variations in the air, soil, and fiddler crab (*Austruca perplexa*) burrow temperatures in southern Thailand



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Abstract Fiddler crabs live in an intertidal habitat and face several environmental constraints. Extreme environmental conditions, especially temperature affects their growth and reproduction. They use several strategies to deal with extreme temperatures. Among these, constructing burrows is important. Burrows act as a refuge during very high or low temperatures. This study investigates the temporal variations in air temperature, burrow temperature of large-sized male and female *Austruca perplexa* crabs, and the soil temperature near their burrows in Nakhon Si Thammarat province, southern Thailand (tropical climate). Air, burrow and soil temperatures were measured every 30 min in a day using temperature sensors. We observed that from 8:00 up to and including 17:30, burrow temperature was lower than soil temperature, but other times, burrow temperature was higher than soil temperature. In the case of air temperature, it was lower than soil or burrow temperatures most of the time in a day. When we compared temperatures among air, soil, and burrows at day (6:00 up to 17:30) and night (18:00 up to 5:30), burrow temperature was lower than soil temperature during the day but was higher at night. The air temperature was lower than soil or burrow temperatures on both day and night. This study shows that *A. perplexa* crab burrows can modulate the inside temperature and maintain a suitable temperature for the crabs.

Keywords air temperature, crab burrow temperature, day and night, soil temperature, temperature sensor

1. Introduction

Fiddler crabs are intertidal organisms and they live on various habitats such as muddy sandy flats, salt marshes, and mangrove swamps (Crane 1975). They are among the most abundant organisms in their habitats and their densities may exceed 50 crabs/m² (Bertness and Miller 1984; McCraith et al 2003; Tina et al 2015a, b). Both males and females construct burrows and stay inside the burrows during high tide (Tina et al 2015 a, b). They are active on the surface and show various activities (e.g., feeding, fighting, waving, burrowing, grooming, etc.) during low tide (Tina et al 2016, 2019, Tina 2020; Tina and Muramatsu, 2020).

Their burrowing activity is very important for their habitats since it promotes soil aeration and thus oxidizes hydrogen sulphide. Hydrogen sulphide inhibits plant growth by affecting their nitrogen uptake and growth (Howarth and Teal 1979; Bradley and Morris 1990; Koch et al 1990; Wiessner et al 2005). Crab burrowing activity also reduces salinity by increasing water flow through the sediments. A higher salinity level negatively affects the growth and productivity of mangroves (McKee 1993; Sylla et al 1996; Twilley and Chen 1998). For these reasons, fiddler crabs are known as ecosystem engineers in their habitats (see Jones et al 1994; Kristensen 2008). Moreover, burrows have several advantages for the fiddler crabs. They provide shelters from

predators and environmental extremes (e.g., very high or low temperature), they provide water for physiological needs, and they act as sites for moulting and breeding (Crane 1975; Christy 1982, 1987; Keeratipattarakarn et al 2020).

The intertidal animals live in a dry and open environment and face several environmental constraints (Chapman and Underwood 1996; Thurman 1998; Somero 2002; Schneider 2008; Miller et al 2009; Allen et al 2012). Among these environmental constraints, temperature is the most important since it affects their behaviour, physiology, growth, and reproduction (Weinstein 1998; Ruscoe et al 2004; Resgalla et al 2007; Allen et al 2012). In the case of fiddler crabs, very high or very low temperature affects their metabolic rates, heart rates, haemolymph osmolality, muscle hydration, ovarian development, and egg hatching success (Vernberg and Vernberg 1966; Eshky et al 1995; Matsumasa and Murai 2005; Colpo and López-Greco 2017; Principe et al 2018; Chou et al 2019). They have developed several physiological, morphological, and behavioural adaptations for dealing with the very high or low temperature (Eshky et al 1995; Thurman 1998; Yoder et al 2005; Levinton et al 2015; da Silva Vianna et al 2020). Moreover, their burrows act as a refuge through maintaining a suitable temperature when the outside temperature is very high or low (Powers and Cole, 1976; Wolfrath, 1992; Keeratipattarakarn et al 2020). Suitable burrow temperature is not only important for the

physiology of fiddler crabs; it also influences their egg incubation rate (Christy and Salmon 1984; Eshky et al 1995; Reaney and Backwell 2007).

In this study, we would like to investigate the temporal variations of air, soil, and burrow temperatures of the fiddler crabs (*Austruca perplexa*) in southern Thailand (tropical climate), where the temperature is hot all the year round (average temperature 28-30 °C). Previously, several studies have investigated the burrow temperatures of several fiddler crab species (*Paraleptuca chlorophthalmus*, *Austruca annulipes*, *Gelasimus vocans*, *Leptuca panacea*, *Minuca virens*, *Afruca tangeri*, *Austruca mjoebergi*, and *Tubuca rosea*) in East Africa, Portugal, Texas (U.S.A.), Australia and Thailand (Edney 1961; Powers and Cole 1976; Wolfrath 1992; Reaney and Backwell 2007; Keeratipattarakarn et al 2020). In the case of Thailand, only one study has been conducted on soil and burrow temperatures of *T. rosea* inside mangroves. However, no study has been conducted on the burrow temperature of the fiddler crab *A. perplexa*. Our hypotheses are (1) the temperatures of air, soil and fiddler crab burrows would be different at different times (i.e., hours) in a day, and (2) crab burrow temperature (male/female burrows) would be lower than soil temperature but higher than the air temperature at day but that would be higher than both air and soil temperatures at night.

2. Materials and Methods

2.1. Study site

The burrow temperature of the fiddler crabs (*Austruca perplexa*) was studied in Ban Nai Thung village, Thasala district, Nakhon Si Thammarat province. The population's size is approximately 300 m² and no other fiddler crab species lives in this place. This *A. perplexa* population lives on a muddy-sandy flat. We conducted this study from September to October 2020.

2.2. Biology of *Austruca perplexa*

Both males and females of this species build burrows where males mostly build breeding burrows, and females build temporary refugee burrows. The lengths of male and female burrows are approximately 246 mm and 187 mm, and depths are 192 mm and 140 mm, respectively (Tina et al 2018). They are active on the surface during diurnal low tide. Males wave their major claws towards the wandering females to attract them towards the breeding burrows for mating (Tina et al 2018; Tina 2020; Tina and Muramatsu 2020). If a female selects a male, she approaches the male and enters the male burrow. Afterward, she stays with the male for 4-5 days until she ovulates the eggs. Then the male leaves the burrow and either build another burrow or takes over a burrow from another male through fighting. On the other hand, the female stays inside the male breeding burrow for another 14-15 days for egg incubation. During egg incubation, she rarely comes at the surface for feeding or other activities (Nakasone and Murai 1998).

2.3. Data collection

Forty-two burrows of large-sized (>15 mm carapace width) *A. perplexa* crabs (25 male burrows and 17 female burrows) were randomly selected to measure the temperature from two different locations in their habitat: (1) inside the crabs' burrows and (2) inside the soil near their burrows. We installed two temperature sensors (DS18B20 digital temperature sensor), the first one was installed inside a crab burrow, and the second one was installed inside soil within 10 cm of the burrow perimeter. The installation depth of both sensors was at 5 cm. Previously, temperature sensors were used by Akhter et al (2018), Yue et al (2019), and Keeratipattarakarn et al (2020) to measure the soil temperature. A weather station and a temperature sensor from Davis Company (<https://www.weatherlink.com>) were installed to measure the air temperature (see Kuhapong and Tina 2019 for more details). The air, soil and burrow temperatures were collected every 30 min for 24 hours (see Keeratipattarakarn et al 2020). The same experimental setup was used for all 42 crab burrows. Before installing a sensor inside a crab burrow, the crab was caught to measure its carapace width to ensure that it was larger than 15 mm carapace width. We did not select small-sized crabs as it was difficult to enter the sensor inside small-sized crab burrows. After measuring the crab's body size, it was released to the same place where it was caught.

Each day, only one crab burrow (either male or female) was selected and two sensors were used to measure burrow and soil temperatures. After collecting temperature data from one burrow, the sensor was removed carefully and used for another crab burrow. We made sure that the installation and removal of sensors did not damage the crab burrow. It was not possible to measure male and female burrow temperatures on the same day since we had a lack of sensors. The duration of the day-time was counted as the observations of 6:00 up to and including 17:30, and the duration of the night-time was counted as those of 18:00 up to and including 5:30.

2.4. Statistical analysis

Before analysing data, normality and homogeneity of variances of data were tested using Shapiro-Wilk's and Levene's tests, respectively. Two-way ANOVA tests were used to (1) test the effects of time (24 hours of a day), and location types (air, soil, male/female crab burrows) on the location temperatures and (2) to test the effects of time (day and night), and location types (air, soil, male/female crab burrows) on the location temperatures. Data were reported as mean \pm standard error (SE), and all tests were considered statistically significant at $P < 0.05$.

2.5. Ethical statement

Animal care and handling procedures followed the guidelines of Thailand's Wild Animal Reservation and Protection Act, B.E. 2535 (1992). No animal was harmed or

removed from their habitat, and no animal nest was destroyed. This study does not include any human subject.

3. Results

3.1. The temperature of air, soil, and crab burrows

The maximum, minimum, and mean temperature of the air, soil, and crab burrows are shown in Table 1. In a day, the crab burrow temperature range was narrower than the soil temperature range.

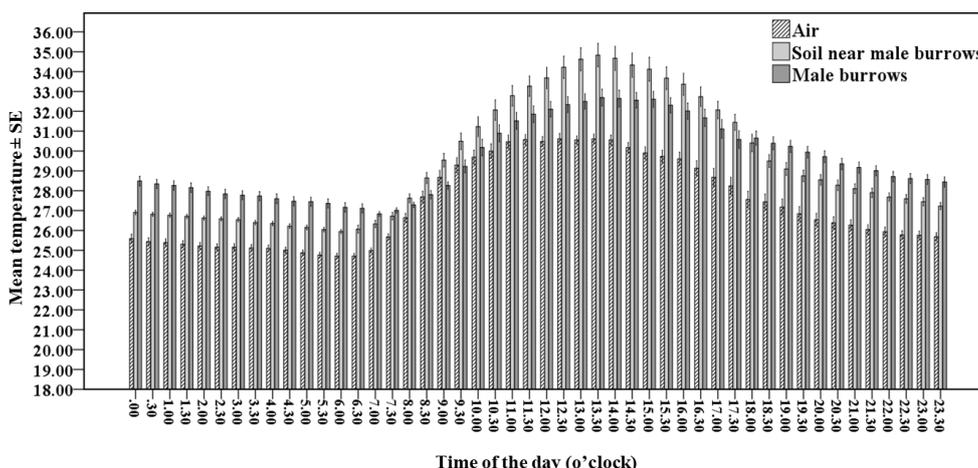
3.2. Variation in air, soil, and fiddler crab burrow (male/female) temperatures in 24 hours of a day

It was observed that air, soil, and male burrow temperatures were different at different time (hours) in a day (time: $F_{47, 3585} = 159.46, P < 0.001$; location types: $F_{2, 3585} = 741.56, P < 0.001$; time*location types: $F_{94, 3585} = 5.93, P < 0.001$) (Figure 1a). Similarly, air, soil, and female burrow temperatures were also different at different hours in a day (time: $F_{47, 2448} = 86.76, P < 0.001$; location types: $F_{2, 2448} = 296.34, P < 0.001$; time* location types: $F_{94, 2448} = 4.12, P < 0.001$) (Figure 1b). Burrow temperature was lower than soil temperature from 8:00 to 17:30, but other times, burrow temperature was higher than soil temperature (Figure 1a and b). Air temperature was lower than soil and burrow temperatures in most of the time of a day (Figure 1a and 1b).

Table 1 Air, soil, and crab burrow temperatures (°C) at day and night.

Day/night	Locations	Maximum temperature	Minimum temperature	Mean ± SE
Day	Air	34.20	23.30	28.53 ± 0.07
	Soil	39.40	25.00	30.67 ± 0.10
	Crab burrows	35.60	25.00	29.74 ± 0.08
Night	Air	30.40	23.20	25.82 ± 0.04
	Soil	33.30	24.40	27.32 ± 0.05
	Crab burrows	33.20	25.60	28.39 ± 0.05

(a)



(b)

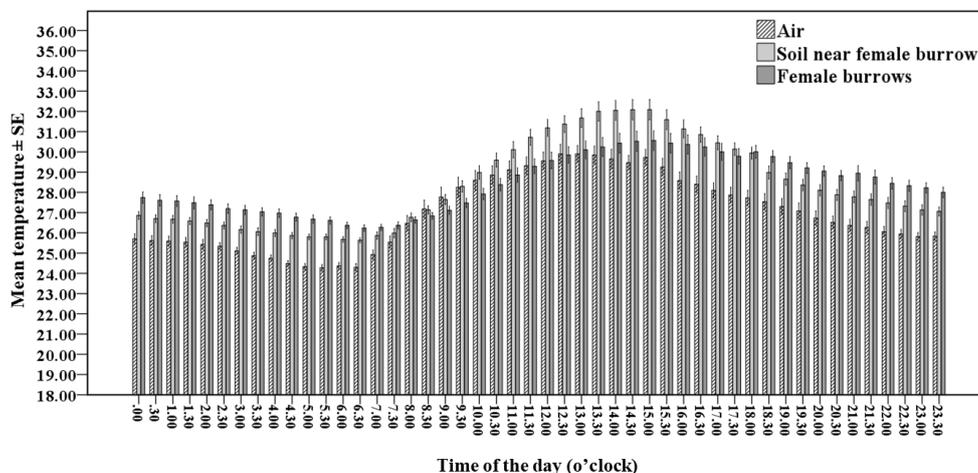


Figure 1 Location types and their temperatures (°C) at 24 hours of a day; (a) air, soil, and male (*Austruca perplexa*) burrow temperatures, (b) air, soil, and female (*A. perplexa*) burrow temperatures.

3.3. Variation in air, soil, and fiddler crab burrow (male/female) temperatures at day and night

Air, soil, and male burrow temperatures were different between day and night (day/night: $F_{1, 3585} = 1320.51, P < 0.001$; location types: $F_{2, 3585} = 296.34, P < 0.001$; day/night* location types: $F_{2, 3585} = 62.37, P < 0.001$) (Figure 2a). Male burrow temperatures were higher than air temperature ($P < 0.001$) but lower than soil temperature ($P < 0.001$) during the day. On the other hand, at night, male

burrow temperatures were higher than air ($P < 0.001$) and soil temperatures ($P < 0.001$) (Figure 2a).

Similarly, air, soil, and female burrow temperatures were different between day and night (day/night: $F_{1, 2448} = 490.76, P < 0.001$; location types: $F_{2, 2448} = 132.43, P < 0.001$; day/night* location types: $F_{2, 2448} = 46.13, P < 0.001$) (Figure 2b). Female burrow temperatures were higher than air temperature ($P < 0.001$) but lower than soil temperature ($P < 0.001$) during the day. However, female burrow temperatures were higher than air ($P < 0.001$) and soil temperatures ($P < 0.001$) during the night (Figure 2b).

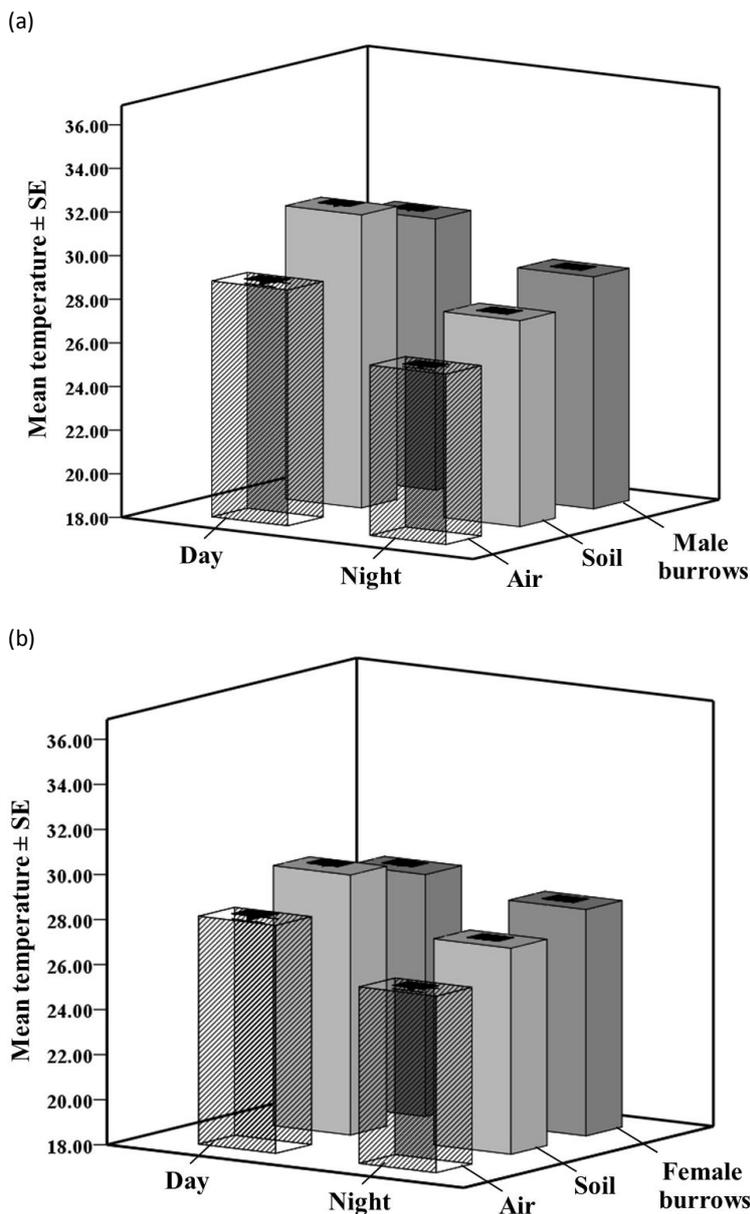


Figure 2 Location types and temperatures (°C) at day and night; (a) air, soil, and male (*Austruca perplexa*) burrow temperatures; (b) air, soil, and female (*A. perplexa*) burrow temperatures.

4. Discussion

In this study, the crab burrow temperatures were lower during the day and higher at night than the soil

temperature. It indicates that *Austruca perplexa* fiddler crabs use their burrows as a refuge during high temperatures in the day and low temperatures at night. In Nakhon Si Thammarat province, the climate is tropical, and soil temperature

fluctuates frequently. The soil temperature range was 24–39 °C. However, the burrow temperature range was 25–35 °C. It shows that the burrow temperature range was narrower compared to the soil temperature range. Moreover, though the maximum soil temperature was 39 °C, which was very high, burrow temperatures did not exceed 35 °C. A few previous studies (Powers and Cole 1976; Wolfrath 1992; Keeratipattarakarn et al 2020) also showed that crab burrows maintained a suitable temperature during extreme temperatures.

Temperature fluctuation shows effects on the capacity of the crabs to live in an open and harsh habitat (Thurman 1998; Principe et al 2018). Extremely high temperature creates a potentially lethal problem to the fiddler crabs living in a tropical environment. For example, it affects the heart rate of the fiddler crabs; producing 100 beats/min from 20 to 25 °C, 140 beats/min at 35 °C, 180 beats/min at 40 °C, and then heartrate steeply declines to near zero when the temperature becomes 50 °C (Levinton et al 2020). It indicates that the heartrates of fiddler crabs are temperature sensitive. Not only heartrates but also ventilator and cardiac performance of the crabs are affected by extreme temperature. Frederich and Pörtner (2000) observed that temperature higher than the optimal peak reduced the ventilator and cardiac performance of crabs. Furthermore, in fiddler crabs, a higher temperature reduces the hepatosomatic index, which means using energy reserves increases during high temperatures (da Silva Vianna et al 2020). For these reasons, crabs require maintaining a suitable body temperature and they can do it by using several mechanisms. Smith and Miller (1973) found that moving into the shade, keeping bodies wet, changing body colour, or orienting to the sun or wind are effective ways for the fiddler crabs to maintain a suitable body temperature. Eshkey et al (1995) observed that evaporation is an effective cooling method for fiddler crabs. However, constructing burrows and staying inside the burrows is another effective way to control body temperature (Smith and Miller 1973; Powers and Cole 1976; Wolfrath 1992; Eshkey et al 1995). Fiddler crab burrows are effective enough to maintain a suitable temperature during day and night (Wolfrath 1992; Powers and Cole 1976; Keeratipattarakarn et al 2020). When fiddler crabs return to their burrows, their body temperature closely follows the burrow temperature, with a slight difference between the burrow temperature and the crab's body temperature (Edney 1961; Eshky et al 1995).

5. Conclusions

This study shows that burrows of fiddler crabs (*Austruca perplexa*) on a muddy sandy flat can keep temperature cooler during the day and warmer at night compared to the soil temperature in a tropical environment. This study also shows that the burrow temperature range was narrower than the soil temperature range. It indicates that fiddler crab burrows act as a refuge through maintaining a suitable temperature all day. When the temperature is very

high or low, *A. perplexa* fiddler crabs may control their body temperature by frequently returning to their burrows and staying inside the burrows. Further study should investigate the temporal variations of air, soil, and fiddler crab burrow temperatures in other habitats (e.g., mangroves and salt marshes).

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Conflict of Interest

The authors declare no conflict of interest.

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