

Is bedding material a more effective thermal insulator than trap cover for small mammal trapping? A field experiment

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A B S T R A C T

Live trapping is a key technique for conducting ecological studies on small mammals. All-metal live traps are popular in monitoring schemes owing to their tested performance, lightweight design (aluminium) and foldability. However, capture represents a stressful situation for small mammals, particularly during cold seasons, when individuals are susceptible to cold weather starvation resulting from low temperature and insufficient food to maintain body temperature. Metal live traps provide limited protection against cold temperatures, and it is often recommended to use covers to buffer external temperature fluctuations and prevent entry of moisture. Here, we compared the insulative performance of a PVC cover designed for Sherman traps and of bedding material, using data loggers to record temperature and humidity inside traps. We conducted different experiments simulating field conditions (traps at night with a heat source inside) and different treatments (cover, bedding material) to test the thermal insulation capacity of three models of widely used commercial traps: Longworth, Sherman, and Heslinga. Our findings indicated that Longworth and Sherman traps were better insulated against ambient air temperature fluctuations than Heslinga traps (+2.0 °C warmer on average). Bedding material was paramount in reducing relative humidity and increasing thermal insulation capacity of traps (+3.1 °C), an effect that was strengthened when a PVC cover was additionally used (+4.2 °C). The covered traps prevented the direct entrance of rain and dew (reducing damp bedding), provided camouflage (reducing thefts), and improved thermal and humidity conditions of traps (potentially increasing survival of captive small mammals). Our results suggest that using covers and bedding materials can improve thermal and humidity conditions within live traps, thus reducing the metabolic costs of thermoregulation and increasing survival chances for trapped small mammals during cold seasons.

1. Introduction

For small endotherms living in tropical and temperate climates, ambient temperatures have a profound effect on the capacity to maintain body temperature (Ashton et al., 2000; Ruf and Geiser, 2015), and species inhabiting colder climates often need to invest more energy in thermoregulation (Van Der Vinne et al., 2015). Especially during winter, small endotherms have strategies for saving energy, allocating more time to energy-saving behaviours (Oliveira et al., 2016). Metabolic costs of foraging in cold environments can be extreme (Conley and Porter, 1986), and foraging small mammals should minimize heat loss by reducing activity on cold days (Guiden and Orrock, 2020). This can be especially important in non-hibernating small mammals, which are active during winter and need to employ many different behavioural,

anatomical, and physiological mechanisms to cope with cold (Merritt and Zegers, 2002).

Monitoring small mammals can be hampered by the discrete, elusive, and mainly nocturnal behaviour of most species. Live trapping has been considered the key technique for obtaining accurate population estimates in front of other sampling methods (Flowerdew et al., 2004). Some old models of commercial live traps (i.e., Longworth; Chitty and Kempson, 1949) are still used and recommended in monitoring schemes owing to their performance tested during decades of studies from investigators worldwide. Traps with an all-metal construction are recommended (Barnett and Dutton, 1995), and light (aluminium) and foldable traps (Sherman) are strongly advocated when traps need to be transported for long distances such as surveys in remote areas. The use of aluminium (with alloys) in industry is paramount, and this material

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shows important properties like durability and lightness, both necessary in the construction of a trap. However, the high thermal conductivity of aluminium and other metals is undesirable because it poorly insulates animals in the trap from thermal extremes (Sikes and Animal Care and use Committee of the American Society of Mammalogists, 2016). Thus, wooden, metal, and carton covers are recommended for temperature and moisture insulation (Machtinger and Williams, 2020). Some authors adapted commercial traps to increase survival probability using PVC drainage plumbing tubes attached to the Sherman traps (Romairone et al., 2018). Despite that solution being effective, the logistic constraints of transporting this trapping material can be limiting under some circumstances (i.e., walking long distances). Furthermore, commercial live traps made from aluminium makes them more conspicuous (i.e., glinting with the sun) and hence more prone to vandalistic events and thefts. The use of camouflage is recommended to reduce incidents caused by humans and animals visually attracted to traps (e.g. damage or theft) (Jackson and Hutchison, 1985; Machtinger and Williams, 2020; Torre et al., 2022).

Capture is a stressful situation for small mammals (Stromgren and Sullivan, 2014). During cold seasons, trapped individuals are especially prone to cold weather starvation, a combined effect of low temperature and insufficient food to maintain body temperature (Howard, 1951). This problem can worsen when trapping nocturnal small mammals (e.g., wood mouse *Apodemus sylvaticus*), with traps being exposed overnight along the cooler period of the day (Van Der Vinne et al., 2015). In particular, higher trap mortality in shrews (Stephens and Anderson 2014) could be partially linked to the absence of mechanisms of metabolic heat production in some species (e.g., *Crocidura russula*) (Perrin, 1975; Oliveira et al., 2016). Trapping mortality should be avoided at all costs, particularly when sampling in areas with rare or threatened species, where the loss of few individuals can affect the long-term viability of populations.

Owing to the importance of ambient temperature and humidity for small mammal survival within traps (Perrin, 1975), we tested the performance of a PVC cover designed for Sherman traps using data loggers for recording the temperature and humidity inside traps (Orrock and Connolly, 2016). We exposed traps to the environment in cold conditions (winter), the more challenging period for small mammals due to higher metabolic costs (Guiden and Orrock, 2020), performing experiments with different commercial trap models and insulating treatments. We expected the PVC cover could provide accommodation benefits to potential captive small mammals (simulation of a heat source), by reducing humidity and increasing temperatures when compared to outside air parameters and control-treatment traps.

2. Material and methods

2.1. Experimental design

We tested the thermal insulation capacity of a PVC cover specifically designed for *Sherman* traps (Sherman folding small animal trap; 23 × 7.5 × 9 cm; Sherman Co., Tallahassee, FL, USA) by one of the authors (Paco Bustamante). This cover — made from water-proof PVC, 4 mm thick, and around 10€/unit — provided camouflage as well as protection from humidity by preventing the passage of rainwater or dew through the cracks (Fig. 1). For a first experiment, four Sherman traps were placed on a private outside terrace (coastal Barcelona, Spain, 22 m.a.s.l) during two trials of four and two consecutive days, separated 1 m apart and without receiving direct solar radiation. Temperature (°C) and relative humidity (%) were recorded every 10 min with data loggers (Elitech RC-51) situated inside each trap, with the sensor being placed in the nest chamber. Traps were assigned to a treatment as follows: *Cover* (CV), trap with only the PVC cover; *Bedding* (BD): Trap with water-proof cotton wool inside; *Cover + Bedding* (CV + BD): trap with the cover and with water-proof cotton wool inside; *Control* (CN), a conventional trap; Another logger was placed outside to have measures of air temperature



Fig. 1. Camouflage PVC cover designed for medium-sized Sherman traps (design by Paco Bustamante).

(Air). In the case of BD treatment, data loggers were placed inside the cotton.

We then conducted a second experimental session consisting of complete nights (from 19:00 to 07:00) of exposure of traps to different insulating treatments to simulate real field trapping conditions. We expected the cover could retain hot air when a heat source was inside the traps. Relatively small changes in air temperature (1–4 °C) inside traps entailed by captive mice can be recorded by data loggers (Orrock and Connolly, 2016). To avoid ethical concerns related with keeping wild animals trapped for long periods of time, we placed hand-warmer heat pads (*Terratherm*) – with up to 12 h of warmth – within traps to simulate endothermic metabolism generated by a trapped small mammal (Kearney et al., 2011; Griffiths et al., 2017). Despite the covers being designed for Sherman traps, in the trials we also included two other commercial traps used in the SEMICE monitoring programme (Torre et al., 2018), *Longworth* (Longworth Scientific Instrument Co., Oxford, UK), and *Heslinga* (www.heslingatrap.com) for thermal insulation capacity comparisons. The experiments were conducted in two contrasting climatic areas in Barcelona province (coastal, 22 m.a.s.l, and Pyrenees, 650 m.a.s.l), to expand the range of temporal and spatial variation in winter temperatures. We performed 63 trials combining three trap models and three treatments. Traps were placed in similar conditions and submitted to the same CN, BD and CV + BD treatments cited above. The CV treatment (trap with only the PVC cover) was excluded from the second experiment due to its poor performance in retaining temperature and humidity, as demonstrated in the first experimental session (see ‘Results’ section). Furthermore, the CV treatment does not represent a common treatment in small mammal trapping studies. Inside each trap we placed a temperature data logger (iButton, *Thermochron*) protected within an aluminium mesh, an ideal material to house the small temperature

loggers (Orrock and Connolly, 2016). In the Bedding treatments, the mesh was placed inside the cotton. Temperature was recorded continuously every 5 min. To avoid direct heat exchange between the heat pad and the data logger, we placed the heat pad at the end of the trap close to the back door, as far away from the data logger as possible. To quantify the heat output of the heat pads through time, we placed a data logger below a hand warmer in six different trials, recording temperatures every 5 min during a 12 h period. All experiments were conducted during winter 2021.

2.2. Data analyses

We used generalized linear mixed models (GLMMs), which combine linear mixed models (with random effects to deal with random variation) and generalized linear models (Bolker et al., 2009), to test the performance of the PVC cover. The two main response variables in the first experiment were the difference between the temperature (T) and humidity (RH) recorded by every data logger inside traps, and air temperature and air humidity, respectively. We also calculated the temperature of dew point (TDP = T - (100 - RH)/5), that is, the temperature to which air must be cooled to become saturated with water vapor, assuming constant air pressure and water content (Yong et al., 2021). In the second experiment, we also considered temperature rate of change inside traps as a response variable, as follows: $\left(\left(\frac{t_1}{t_{12}} \right)^{\frac{1}{12}} - 1 \right) \times 100$, being t_1 and t_{12} the mean temperature recorded during the first and twelfth hours of the exposure of traps along the night (19:00 to 07:00).

Fixed factors were trap model (Sherman, Longworth, and Heslinga), treatment (CN, BD, and CV + BD), and locality (coastal or mountain), and their interactions. Each trial, consisting in a combination of trap x treatment x locality, was attributed a different identification number (ID). This variable was included as a random factor to account for uncontrolled variability of the heat production of the heat pads within a repeated measures framework (Whittier et al., 2020). The response variables were modelled using the Gaussian error distribution and the identity link function. We constructed models resulting from all combinations of explanatory variables using the dredge function of the MuMIn package for R (Bartón, 2015), and selected models with $\Delta AICc < 2$ as being meaningful. For the selected models, we calculated pseudo-R² values (Nakagawa and Schielzeth, 2013) by means of the R function *r.squaredGLMM* and the delta method for variance estimation. Since the top model always had an $\Delta AICc > 2$ against the second model, we ended up selecting the first model at all times.

3. Results

3.1. Thermal performance of cover and bedding

Traps with PVC covers did not differ from control treatments in either temperature or humidity inside the traps when compared with the CN treatment (Sherman traps, Table 1). However, the use of bedding material (waterproof cotton wool) resulted in a temperature increase of 0.3 °C inside the traps and a decrease in relative humidity by 5%. The use of the cover combined with bedding material showed a stronger reduction of relative humidity (-10%), but a similar temperature at night compared with bedding alone (Table 1, Fig. 2). Generally, CN and CV treatments recorded lower relative temperature (except at night) and higher relative humidity (related to air) than BD and CV + BD treatments (Table 1, Fig. 2ab). This resulted in lower temperatures of dew point (TDP) at night with BD and CV + BD treatments, similar TDP with CN, and higher TDP with CV, as compared to air (Table 1, Fig. 2c).

Table 1

GLMMs with relative humidity, temperature offset (difference of each parameter between trap and outside air), and temperature of dew point as response variables; period (Morning, Afternoon, Night), treatment (Control, Cover, Bedding, Cover + Bedding), and their interaction as fixed effects; and day of trial as a random effect. Parameters were recorded every 10 min by data loggers situated inside the four Sherman traps (and one reference outside traps) placed on a private outside terrace (coastal Barcelona, Spain) during two trials of four and two consecutive days of winter 2021, respectively. Bold values highlight statistical significant variables (p < 0.05).

FIXED EFFECTS	RELATIVE HUMIDITY	Estimate	SE	t-value	p-value
	(Intercept)	-2.05	1.24	-1.66	0.14
TREATMENT (Ref: Control)	Bedding	-6.35	0.50	-12.68	0.00
	Cover	-0.59	0.50	-1.18	0.24
	Bedding + Cover	-10.31	0.52	-19.95	0.00
PERIOD (Ref. Afternoon)	Morning	0.30	0.49	0.60	0.55
	Night	-2.29	0.40	-5.75	0.00
TREATMENT X PERIOD	Bedding x Morning	1.48	0.68	2.17	0.03
	Bedding x Night	1.09	0.57	1.93	0.05
	Cover x Morning	-2.01	0.68	-2.95	0.00
	Cover x Night	-0.56	0.57	-1.00	0.32
	Bedding + Cover x Morning	0.13	0.69	0.19	0.85
	Bedding + Cover x Night	0.29	0.58	0.50	0.62
	AICc	15909.18			
	R ² conditional	0.63			
	Num. obs.	2840			
FIXED EFFECTS	TEMPERATURE	Estimate	SE	t-value	p-value
	(Intercept)	0.84	0.39	2.12	0.08
TREATMENT (Ref: Control)	Bedding	0.17	0.09	1.86	0.06
	Cover	-0.07	0.09	-0.80	0.42
	Bedding + Cover	0.04	0.10	0.40	0.69
PERIOD (Ref. Afternoon)	Morning	-0.60	0.09	-6.51	0.00
	Night	0.28	0.07	3.79	0.00
TREATMENT X PERIOD	Bedding x Morning	-0.08	0.13	-0.64	0.52
	Bedding x Night	-0.72	0.11	-6.79	0.00
	Cover x Morning	-0.63	0.13	4.99	0.00
	Cover x Night	0.17	0.11	1.64	0.10
	Bedding + Cover x Morning	0.15	0.13	1.16	0.25
	Bedding + Cover x Night	-0.57	0.11	-5.22	0.00
	AICc	6419.06			
	R ² conditional	0.68			
	Num. obs.	2840			
FIXED EFFECTS	DEW POINT	Estimate	SE	t-value	p-value
	(Intercept)	7.76	1.21	6.39	0.00
TREATMENT (Ref: Air)	Control	-0.59	0.25	-2.40	0.02
	Bedding	-1.19	0.25	-4.74	0.00
	Cover	-0.25	0.25	-0.98	0.33
	Bedding + Cover	-2.49	0.26	-9.59	0.00
PERIOD (Ref. Afternoon)	Morning	-3.97	0.24	-16.77	0.00
	Night	-2.95	0.20	-14.53	0.00
TREATMENT X PERIOD	Control x Morning	0.65	0.33	1.94	0.05
	Cover x Morning	0.19	0.33	0.58	0.56
	Bedding x Morning	0.16	0.33	0.49	0.63
	Bedding + Cover x Morning	0.47	0.34	1.41	0.16
	Control x Night	0.80	0.28	2.89	0.00
	Cover x Night	0.34	0.28	2.89	0.00
	Bedding x Night	-0.15	0.28	-0.53	0.59

(continued on next page)

Table 1 (continued)

FIXED EFFECTS	DEW POINT	Estimate	SE	t-value	p-value
	Bedding + Cover x Night	0.42	0.29	1.43	0.15
	AICc	14885.99			
	R ² conditional	0.77			
	Num. obs.	3551			

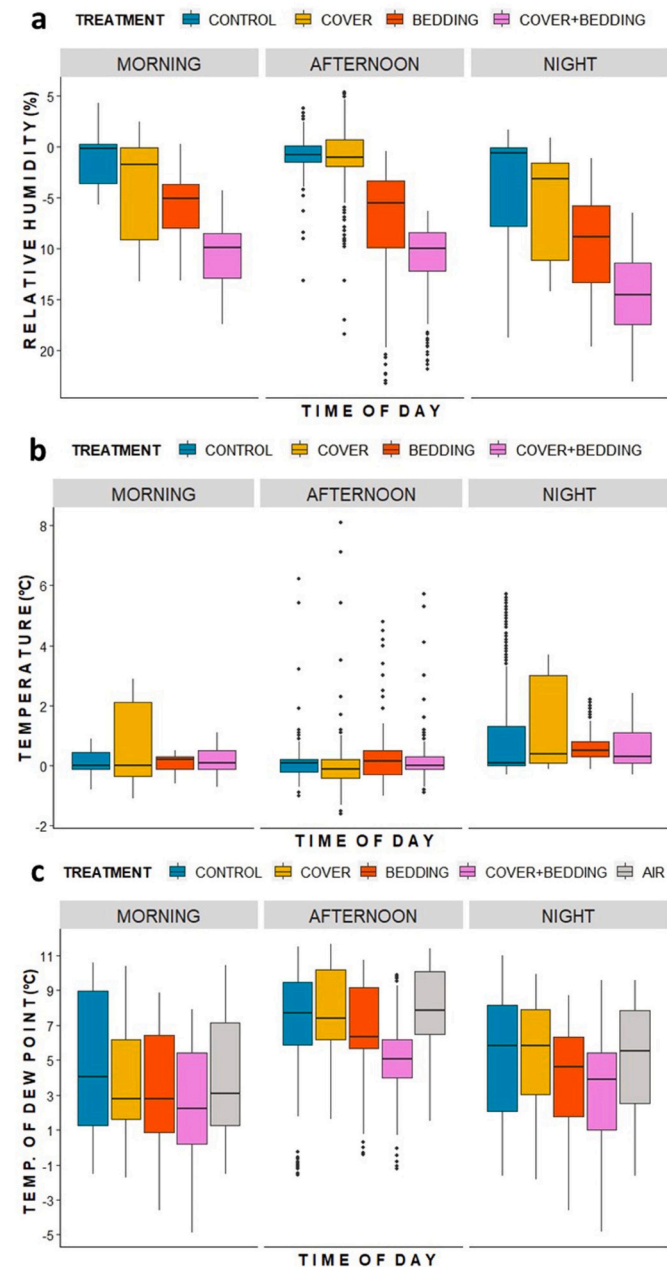


Fig. 2. (a) Median relative humidity, (b) temperature, and (c) temperature of dew point (difference of each parameter between trap and outside air registered every 10 min by data loggers Elitech) inside four Sherman traps placed on a private outside terrace (coastal Barcelona, Spain), according to the insulating treatment (control, cover, bedding, cover + bedding) and period of the day (morning: 8:00–14:00; afternoon: 14:00–20:00; night: 20:00–8:00), during two trials of four and two consecutive days in winter 2021, respectively.

3.2. Thermal performance of traps after simulating the presence of a small mammal inside

The mean air temperature was $12.69\text{ }^{\circ}\text{C} \pm 0.99\text{SD}$ (range 11.5–16.5 $^{\circ}\text{C}$) in the experiments conducted in the coastal area (Litoral) and $2.91\text{ }^{\circ}\text{C} \pm 2.89\text{SD}$ (range -3.0 – $8.5\text{ }^{\circ}\text{C}$) in the mountain area (Pyrenees). Heat pads, used to simulate a heat source similar to that of a small mammal inside the traps, generated a mean temperature of $39.2\text{ }^{\circ}\text{C} \pm 8.77\text{SD}$, with a mean maximum at the start of trials of $50.2\text{ }^{\circ}\text{C}$ and a mean minimum at the end of the trial of $28.2\text{ }^{\circ}\text{C}$. This represented a mean rate of change of temperature exchange of $1.82\text{ }^{\circ}\text{C}$ per hour along the 12 h trials.

The GLMM of the temperature offset recorded inside traps as response variable, and the three fixed factors (*trap*, *treatment*, and *locality*) and their interactions, explained a large amount of variance (R^2 marginal = 45%, explained relative to the whole model = 65%, Table 2). Although the *Heslinga* trap had lower temperature median values in absolute and relative terms than the other two trap models (Fig. 3), this difference was only significant for the Sherman trap. Compared to the *Heslinga* model, the Longworth trap improved thermal insulation when using *BD* and *CV + BD*, and this difference was more evident towards the warmest area (Litoral, Fig. 3). Indeed, temperatures recorded inside *Heslinga* traps were on average $0.92\text{ }^{\circ}\text{C}$ lower than the *Sherman* ($\mu = 10.23\text{ }^{\circ}\text{C} \pm 0.06\text{SE}$ vs. $11.15\text{ }^{\circ}\text{C} \pm 0.04\text{SE}$) and $1.67\text{ }^{\circ}\text{C}$ lower than the *Longworth* ($\mu = 11.90\text{ }^{\circ}\text{C} \pm 0.06\text{SE}$). When temperatures recorded inside traps were expressed as offsets from ambient air temperature, differences were more evident, and temperatures in *Heslinga* traps were on average $2\text{ }^{\circ}\text{C}$ lower than the other two models, but significantly different only when compared to the Sherman traps (Fig. 3b, Table 2).

The *CN* treatment showed the lowest mean absolute ($\mu = 7.78\text{ }^{\circ}\text{C} \pm 0.09\text{SE}$) and relative temperatures ($\mu = -0.66\text{ }^{\circ}\text{C} \pm 0.05\text{SE}$), but the difference with the other treatments was reduced in the coldest study area (Pyrenees, Fig. 3). Surprisingly, *CN* traps showed negative relative

Table 2

Top ranked model of the GLMMs with relative temperature (i.e., temperature offset between trap and air temperature recorded by data loggers) as the response variable, and the fixed factors trap model (*Heslinga*, *Sherman*, *Longworth*), treatment (cover + bedding, bedding, control), and study area (Litoral, Pyrenees), and their interactions. We performed 63 trials combining three trap models and three treatments during winter 2021. Bold values highlight statistical significant estimates ($p < 0.05$).

FIXED FACTORS	EFFECTS	Estimate	SE	t-value	p-value
	(Intercept)	-1.62	1.06	-1.53	0.13
TRAP MODEL (Ref: <i>Heslinga</i>)	Longworth	-0.39	1.10	-0.35	0.73
	Sherman	2.86	1.10	2.61	0.01
TREATMENT (Ref: Control)	Bedding	1.30	1.22	1.07	0.29
	Bedding + Cover	3.32	1.39	2.39	0.02
LOCALITY (Ref: Pyrenees)	Litoral	-0.62	0.98	-0.63	0.53
TREATMENT X LOCALITY	Bedding x Litoral	4.21	1.27	3.31	0.00
	Cover + Bedding x Litoral	2.34	1.29	1.82	0.07
TRAP X TREATMENT	Longworth x Bedding	2.26	1.13	2.00	0.05
	Sherman x Bedding	-1.14	1.12	-1.02	0.31
	Longworth x Bedding + Cover	3.90	1.55	2.52	0.02
	Sherman x Bedding + Cover	-1.06	1.42	-0.75	0.46
	AICc	39370.65			
	R ² marginal	0.45			
	R ² conditional	0.69			
	Num. obs.	9026			

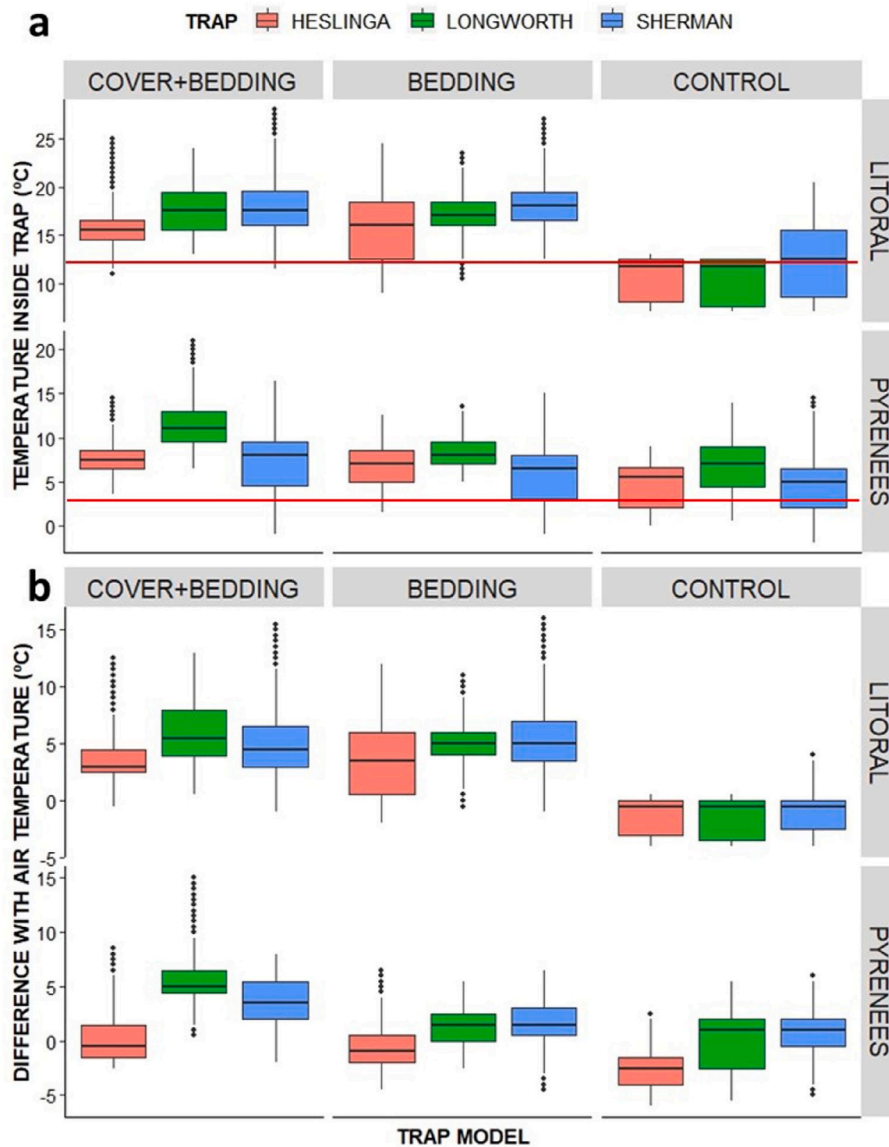


Fig. 3. (a) Median absolute temperature (°C) registered by data loggers (Thermocron) with a heat pad (Terratherm) inside each trap model (Heslinga, Longworth, Sherman) according to the insulating treatment (Cover + Bedding, Bedding, Control) along the 12 h sampling periods (19:00–07:00) in the two study areas (Litoral-coastal and Pyrenees-mountain), and (b) the same for the median difference of temperature in front of air temperature (relative temperature). The red line in the upper panel indicates the mean air temperature during the experiments, and black points indicate outliers.

values, indicating they retained cold air inside (“fridge effect”). *CV + BD* showed the highest differences in relative temperatures ($\mu = 4.22 \text{ }^\circ\text{C} \pm 0.05\text{SE}$), followed by *BD* ($\mu = 3.08 \text{ }^\circ\text{C} \pm 0.05\text{SE}$). The coefficient of variation (SD/μ) of temperatures recorded inside traps was lower with insulated treatments (*CV + BD* = 37%; *BD* = 47%; *CN* = 57%), suggesting that cover and bedding damped the temperature oscillation. Relative temperature was lower in the Pyrenees, implying the capacity to retain heat inside traps was inversely related to air temperatures (Fig. 3). Indeed, the capacity of heat retention inside traps when using *BD* and *CV + BD* was only evident in the warm coastal area. Heat loss along the night was rather similar between trap models (Fig. 4), despite the strong differences in absolute median values registered by each trap model. This was also confirmed by the GLMM using temperature rate of change as response, since all the trap models showed similar regression slopes of the variable against temperatures recorded inside traps (Fig. 5). When *treatment* was considered, there was an evident difference between *CN* and the other two treatments. Rate of temperature change was more pronounced in the former (steeper slope, Fig. 5), but *locality* was

the only factor affecting temperature rate of change within traps ($t_{1, 45} = 2.12, p = 0.04$), indicating that the capacity to retain temperatures inside traps was inversely related to ambient temperatures.

4. Discussion

In this article we analysed the thermal insulation capacity of three widely used commercial small mammal live traps when supplemented with bedding and a PVC cover. We found that adding bedding significantly improves thermal insulation of traps, regardless of trap model. Adding cover in addition to bedding provided further thermal benefits, particularly under moderately low temperatures. These results have important ethical implications for small mammal trapping by ensuring trapped animals are thermally comfortable and trap mortality due to cold weather starvation is reduced (Howard, 1951).

Our results suggest that use of bedding material (cotton wool) increases thermal comfort inside all traps by raising internal temperatures (+3.1 °C) and reducing relative humidity. The use of a PVC cover

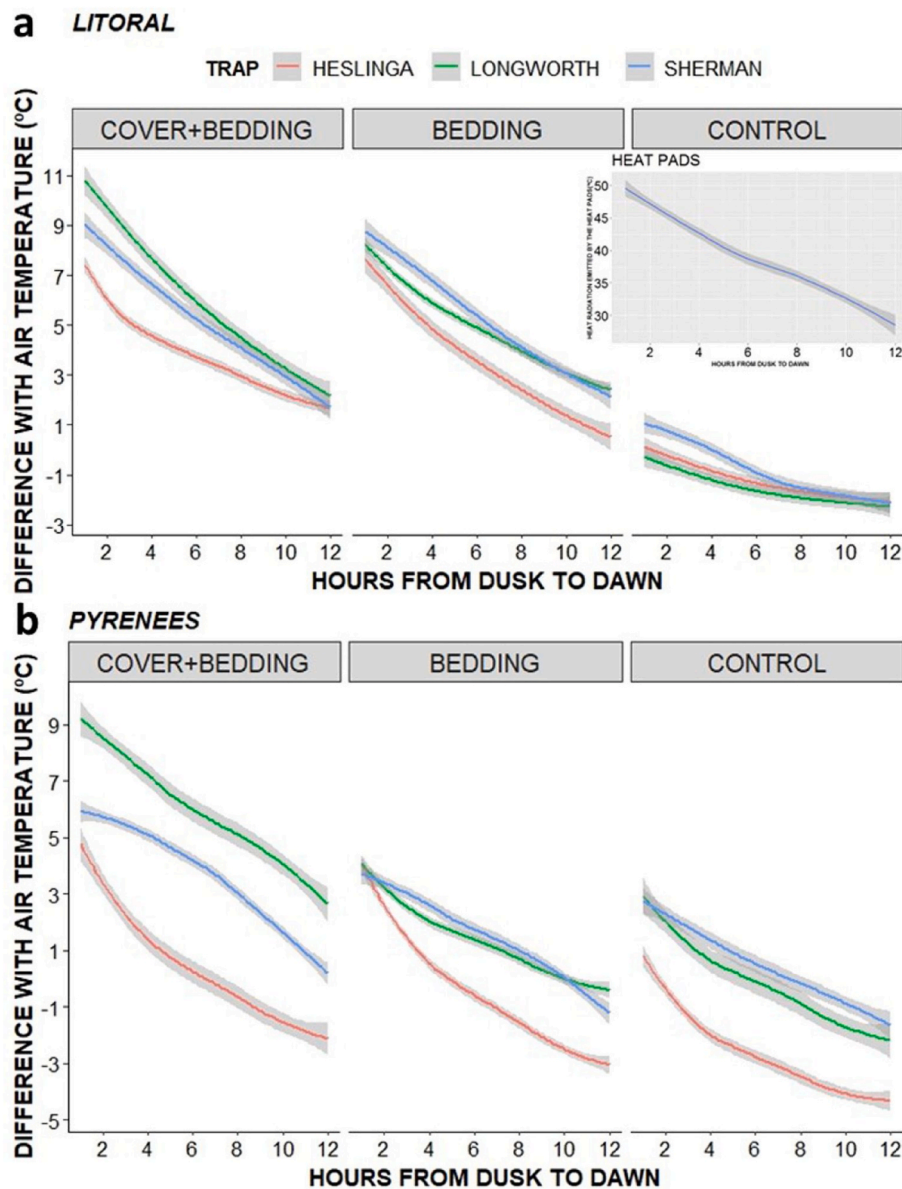


Fig. 4. Trend of the mean temperature difference (\pm CI95%) registered by data loggers with a heat pad (Terratherm) inside each trap model (Sherman, Heslinga, Longworth) in front of air temperature, according to the insulating treatment (control, bedding, cover + bedding) along the 12 h sampling periods (19:00–07:00) in the two study areas (litoral-coastal and Pyrenees-mountain). Lines are regressions and shaded areas are CI95%.

specifically designed for Sherman traps showed an additive effect to bedding ($+4.2$ °C), further reducing relative humidity inside traps and damping temperature oscillations, resulting in lower temperatures of dew point. Surprisingly, the covered traps without bedding material showed similar median temperature and humidity values to control traps without cover. These results agree with the lack of effects of insulating commercial materials (e.g. Koozie) on small mammal hypothermia and mortality (Lohr and Dalby 2000). Still, the covered traps showed two advantages over the control, uncovered traps: 1) prevented the direct entrance of rain and dew, which reduces damp bedding (Machtinger and Williams, 2020), 2) provided camouflage, thus potentially reducing sampling interferences such as those caused by animals or human theft (Jackson and Hutchison, 1985; Machtinger and Williams, 2020; Torre et al., 2022). Natural materials (i.e., litter, bark) can be used as an alternative to a PVC cover. However, while natural materials can provide some insulation and concealment, they cannot completely avoid damp bedding (Machtinger and Williams 2020).

Our results showed comparable thermal insulation capacity between

Longworth and Sherman traps, but a lower one in Heslinga traps. Thermal insulation capacity of traps can be directly related to thermal conductivity of the material used for construction and the capacity of temperature exchange with the air (Orrock and Connolly, 2016). The three trap models were composed of aluminium, but the Heslinga traps had thick, green-painted aluminium walls. Differences in thermal insulation capacity between models is thus surprising and should warrant further investigation. Advantages of using dark colours that add camouflage to the traps could be hampered by modifications to the thermal conductivity of the materials (Flaquer et al., 2014; Bideguren et al., 2019). Indeed, when exposed to the colder temperatures of the Pyrenees, the Heslinga trap retained lower temperatures inside (“fridge effect”), potentially increasing small mammal thermal stress when compared with the other two trap models.

Another reason for these differences in thermal insulation is that heat loss rate may have been affected by differences in the surface/volume ratio of each trap model. Furthermore, our covers were initially designed with Sherman traps in mind, and did not fit perfectly when suited into

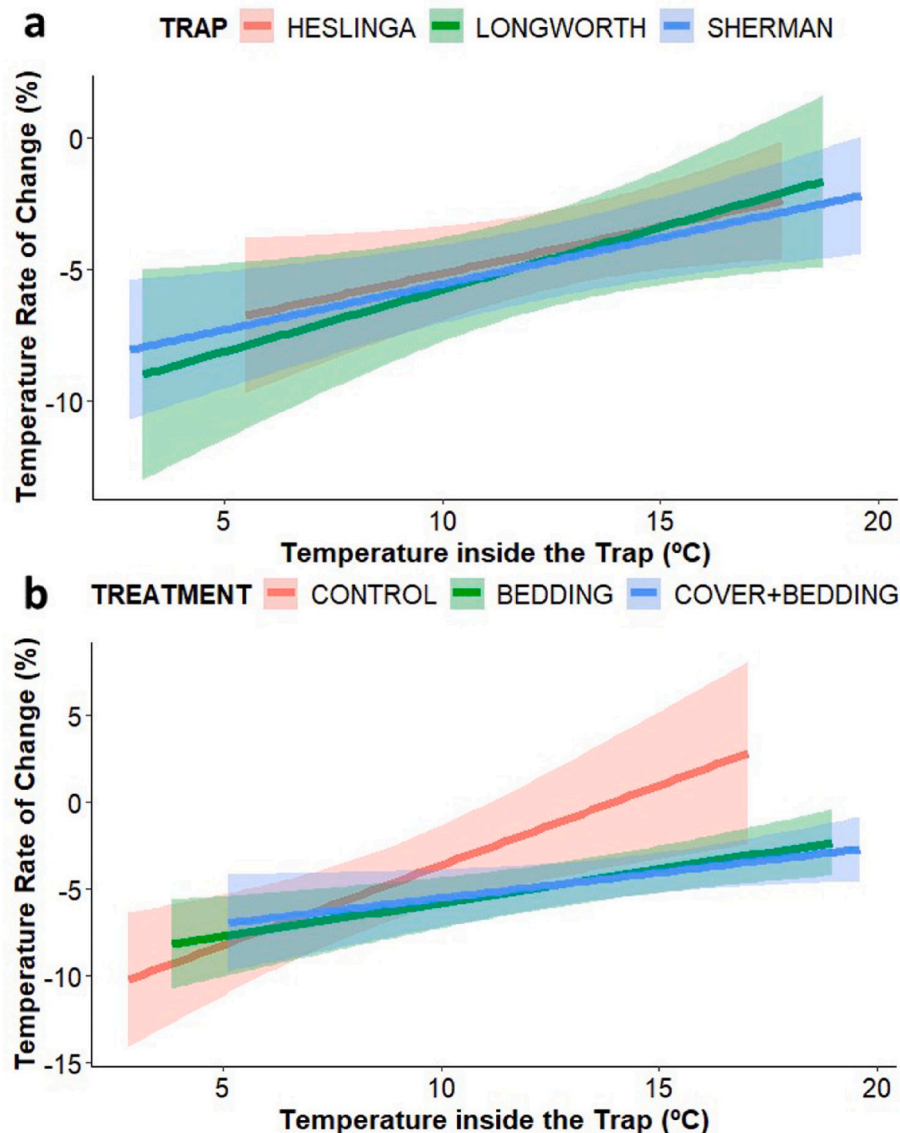


Fig. 5. Rate of change of temperature along the 12 h sampling period (19:00–07:00) in front of the temperature registered inside (a) each trap model (Sherman, Heslinga, Longworth) and (b) insulating treatment (control, bedding, cover + bedding). Lines are regressions and shaded areas are CI95%.

Longworth and Heslinga traps. We acknowledge these factors may have biased the thermal insulation comparison between trap models. Nonetheless, our findings remain meaningful and informative as there were large and statistically significant differences observed between cover and bedding treatments in all trap models.

Minimizing trapping mortality is essential to uphold fieldwork research to the highest ethical standards and ensure the least amount of disturbance to natural wildlife behaviour (Sikes and Animal Care and use Committee of the American Society of Mammalogists, 2016). Still, depending on available logistics and material to researchers, compromises may need to be arranged when planning trapping surveys (Read and Kearney, 2016). Our study provides quantitative evidence that adding bedding to traps significantly improves their thermal insulation properties. When trapping under cold weather, adding a cover further boosts the traps' thermal insulation and avoids damp bedding (Machtinger and Williams, 2020). Considering cold weather starvation is one of the leading causes of trap mortality (Lemckert et al., 2006), applying both treatments should considerably reduce animal mortality. Moreover, bedding and cover are relatively cheap to acquire and can be reused in further surveys. Another method is to use traps composed of

better insulating material, such as wooden-box live traps (Rychlik et al., 2012). These are cheaper than aluminium traps and blend in better with the environment, but are harder to clean and more heavy, which makes them less suitable for surveys that involve considerable walking distances.

To the best of our knowledge, this is the first study quantifying the thermal insulation capacity of commercial small mammal live traps. Based on our results, we recommend that researchers give preference to Longworth or Sherman traps with bedding inside and an external cover when trapping in habitats or seasons where night air temperatures can reach less than 10 °C. Heat pads were used for ethical reasons to simulate the heat produced by the presence of a small mammal inside a trap (Griffiths et al., 2017; Kearney et al., 2011), and we acknowledge they are not a true replacement for a live animal to test thermal insulation. Still, we believe the empirical data presented here should not deviate significantly from tests with live animals and can be used to improve the survival of small mammals during surveys and monitoring programs. In future studies, we recommend addressing two additional variables that can potentially enhance survival rates. Firstly, the composition of bait should be considered, aiming for a balanced mixture that appeals to the

targeted species as well as bycatch species, providing both a lure and a food source. Secondly, the frequency of trap checks should be adjusted based on weather conditions and the behavior of the trapped species. For example, when shrews are present and temperatures are low, traps should be checked every two to three hours (Do et al., 2013; Stromgren and Sullivan, 2014).

CRedit authorship statement

Ignasi Torre: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Roles/Writing - original draft, Writing - review & editing.

Paco Bustamante: Conceptualization, Investigation, Resources.

Carles Flaquer: Data curation, Investigation, Methodology, Project administration, Supervision, Writing - review & editing.

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Declaration of competing interest

The authors declare no conflicts of interest.

Data availability

The dataset produced in this study can be accessed in Zenodo: <https://doi.org/10.5281/zenodo.8032062>.

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