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www.ufaw.org.uk

Animal Welfare 2015, 24: 345-356
ISSN 0962-7286
doi: 10.7120/09627286.24.3.345

Summertime use of natural versus artificial shelter by cattle in nature reserves

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Abstract

Whether cattle grazing in nature reserves in temperate summers ought to be provided with artificial shelter (man-made), in addition to natural shelter (vegetation), is a topic of debate. We have investigated the effect of heat-load on the use of natural versus artificial shelter (with a roof and three walls) by cattle in eight nature reserves in Belgium. GPS collars were used to monitor use of open area, natural and artificial shelter during one or two summers (per 30 min). Cattle location data were coupled to same-time values of climatic 'heat-stress indices' calculated from local weather stations' measurements of air temperature, air humidity, solar radiation and wind speed. Use of open area decreased as heat-load increased. The strength of the effect, and whether the cattle sought natural or artificial shelter, were associated with the amount and spatial distribution of natural shelter in the reserve. When natural shelter was sparse, a more scattered distribution tempered the increased use of shelter with increasing heat-load. If sufficiently available, cattle preferred natural to artificial shelter. When little natural shelter was available, cattle did use the artificial shelter and especially so with increasing heat-load. Microclimatic measurements indicated that solar radiation was blocked by vegetation at least as well as by artificial shelter, and allowed more evaporative cooling. In conclusion, we found no evidence for the added value of additional artificial shelter to protect cattle from heat-load in temperate nature reserves, as long as adequate natural shelter is available.

Keywords: *animal welfare, artificial shelter, cattle, nature conservation, temperate climate, vegetation*

Introduction

Cattle (*Bos taurus*) kept outdoors are, on occasion, exposed to aversive weather. In (sub)tropical and cold regions, the health, welfare and productivity of cattle can be impaired considerably and at least some form of shelter is obviously needed (Silanikove 2000). In temperate regions, however, the need for shelter against aversive weather conditions has received less attention. In addition, most attention has been directed toward farming settings (see also Van laer *et al* 2014). For example, Graunke *et al* (2011) demonstrated that outdoor-wintered beef cattle on Scandinavian farms sought protection from cold and precipitation in forest on and around their pastures. Roselle *et al* (2013) demonstrated that, in Belgian summers, beef cattle on pasture increased their use of shade (natural vegetation or artificial) with increasing ambient temperature, air humidity and solar radiation.

The thermal comfort and sheltering behaviour of cattle used for grazing management in nature reserves, however, has been studied far less. Year-round grazing management in nature reserves is seldom carried out by dairy cattle, and more so with robust cattle breeds (originally intended as beef or work breeds) such as the Galloway, Scottish Highlander or Aberdeen. These breeds are characterised by low energy demands and a high potential to accumulate fat on a poor-quality diet. As such, they are assumed to be relatively resistant to cold conditions, even under nutritional limitation (Wallis de Vries 1994). However, some characteristics, such as their thick hair coat (Yeates 1955; Finch *et al* 1984), heavy posture or fatness (Brown-Brandl *et al* 2006) and dark colour (Brown-Brandl *et al* 2006) (eg in case of the Aberdeen and Heck), might render them less tolerant to heat-load than other breeds. They may thus be more inclined to seek shelter on warm days, even under temperate summer conditions.

In forested reserves, animals can find shelter under trees and shrubs. But also less vegetated reserves such as riverine areas (eg Wallis de Vries 1994) or marshes (eg Andresen *et al* 1990) are sometimes grazed by cattle. Whether and when additional shelter (in addition to the existing vegetation) must be provided, and whether artificial shelter (man-made) or natural shelter (vegetation) is the best choice, is a topic for debate.

First, people have varying opinions as to which degree of animal discomfort or suffering is ethically acceptable.

Advocates of the concepts of 'rewilding' (ie restoration of natural processes, such as flooding and biological processes such as grazing; Vera 2000) and 'de-domestication' (ie introduction of domesticated animals into 'the wild' with the aim of making them become self-reliant; Gamborg *et al* 2010) justify the suffering and even death of the weaker animals by the utilitarian view that natural selection is needed to increase the fitness and coping ability of the population in the long term. Animal rights advocates, on the other hand, object to suffering of animals which are still in human care during the first stages of de-domestication (Gamborg *et al* 2010). For example, the death by starvation of a part of the population of 'rewilded' Heck cattle and Konik ponies in the Dutch polder reserve De Oostvaardersplassen during an unusually harsh winter came in for intense criticism (Lorimer & Driessen 2013). Yet, also, in less dramatic situations, but when the public judges the weather conditions to be aversive, reserve managers are sometimes confronted with citizens' concern about grazers' thermal comfort and welfare. Little scientific literature is available to deduce whether cattle prefer artificial or natural shelter and which provides the most effective protection against excessive heat-load. Thus, in order to contribute to the debate regarding the need to provide artificial shelter to cattle in nature reserves in temperate areas, the current study aimed to investigate the effect of summer climatic conditions, mainly heat-load, on the use of natural versus artificial shelter by cattle in several, year-round grazing projects in Belgium. We hypothesised that the use of natural and/or artificial shelter, as an indication of thermal discomfort in open area, would increase in increasingly hot conditions. The relative degree of the increase in the use of natural versus artificial shelter, would inform us about the cattle's potential preference for either type of shelter. Alternatively, the lack of a consistent relationship between climatic conditions and the use of freely available (natural or artificial) shelter, would indicate that the Belgian summer conditions are not hot enough to initiate substantial thermal discomfort in the studied cattle in nature reserves.

Materials and methods

Reserves and animals

The study took place during the summers (April–October) of 2012 and 2013 in eight nature reserves in Flanders (northern region of Belgium). All reserves were grazed by cattle year-round. Table 1 provides their location, an overview of the most important characteristics in terms of the vegetation or landscape type, the availability of natural and artificial shelter; and the abbreviations we used throughout this paper for each individual reserve. Sources of drinking water differed between the study reserves, as well. Some reserves contained natural water courses, others permanently submerged patches and some had drinking pools. In some reserves, where natural water sources were scarce, cattle drinkers were provided. Maps of the study reserves are available in the supplementary material to information published in *Animal Welfare*; http://www.ufaw.org.uk/supplementarymaterial.php.

Four reserves already had an existing artificial shelter of which the reserve manager chose the size, design, position within the reserve and orientation of the shelter; in the remaining reserves an identical artificial shelter was placed five to eight months before the start of the first summer in which the corresponding reserve was studied. In one reserve (VV), two artificial shelters were used, one installed by the reserve manager and another installed by us. All shelters that were installed by us, had three closed walls made of wooden planks or boards and a slightly slatted roof made from galvanised steel plates, coated with 25 μm white polyester and insulated with 2 cm of polyurethane foam. In addition, there was an 18-cm gap between the roof and either of the three bearing walls, to allow a minimum of ventilation.

Of the artificial shelters which were installed by the reserve manager, only one had three walls of stone and an insulated gable roof of brick tiles. The three remaining artificial shelters installed by the reserve manager were constructed with three closed walls made of wooden planks and a slightly slatted roof of uninsulated galvanised steel plates (n = 2) or an uninsulated gable roof out of brick tiles (n = 1). All artificial shelters had one open side. Four reserves were grazed by Galloway cattle, two by Aberdeen Angus cattle, one by a local Flemish breed (Oost-Vlaams Wit-Rood), and one by Heck cattle. The maximum number of animals in each reserve, can be seen in Table 1 (see supplementary material to information published in *Animal Welfare*; http://www.ufaw.org.uk/supplementarymaterial.php). In five out of the eight herds, fertile males were present, and thus also calves or young cattle were in the herd during at least a part of the study.

Collection of animal location data

In each reserve, a Lotek Wildcell M5 GPS collar with GSM communication function (Lotek Wireless Inc, Newmarket, Canada) was fitted onto one animal to remotely monitor terrain use during one summer (2013; in two reserves: KE and VV) or two summers (2012 and 2013; in six reserves: BB, EB, HB, HP, KH and MS). The manufacturer guarantees an accuracy between of 0 and 10 m, with an average of 5 m in open area. This claim was verified by us determining ten times the deviation from a reference point in open area, a reference point under natural shelter (vegetation) and under the artificial shelter in each of the eight study reserves. We found a mean (± SEM) deviation of 3.4 (± 0.4) m in open area, 10.1 (± 0.4) m under natural shelter and 6.8 (± 0.4) m under artificial shelter.

Only one animal was followed per reserve, because the relatively small herds (consisting of about 15 animals maximum) were known to travel through the reserves as a group. The GPS collars were attached when cattle were caught for their annual veterinary check-up. At the end of the study, collars were removed during the first annual check-up following the end date (Table 1; http://www.ufaw.org.uk/supplementary-material.php). We strived to collar animals without obvious ailments or health problems, that were assumed (by the local reserve conservators who carry out regular health and welfare check-ups) to have a dominant (or at least not subordinate) position in the herd hierarchy, so they could be assumed to

Table 2 Overview of climatic heat stress indices used in cattle research to quantify the effects of heat load.

Heat stress index + formula	Associated 'heat stress' threshold
THI = 0.8 × Ta+[(RH/100) × (Ta – 14.4)] + 46.4 (Thom 1959)	68, based on milk production losses (Zimbelman *et al* 2009)
THI_adj = 4.51 + THI – 1.992 × WS + 0.0068 × Rad (2.5) (Mader *et al* 2006)	68, cfr, conventional THI
CCI = Ta + Eq.1 + Eq.2 + Eq.3	25°C, based on elevated respiration rates (Mader *et al* 2010)
Eq.1 = e^([0.00182 × RH + 1.8 × $10^{(-5)}$ × Ta*RH]) × (0.000054 × Ta^2 + 0.00192 × Ta – 0.0246) × (RH–30) Eq.2 = (–6.56)/e^[(1/(2.26 × WS + $0.23)^{(0.45)}$ × (2.9 + 1.14 × $10^{(-6)}$ × $WS^{2.5}$–$\log_{0.3}$ (2.26 × WS + $0.33)^{(-2)}$] – 0.00566 × WS^2 + 3.33 Eq.3 = 0.0076 × Rad – 0.00002 × Rad × Ta + 0.00005 × Ta^2 × $\sqrt{Rad}$ + 0.1 × Ta – 2 (Mader *et al* 2010)	
Tbg = 1.33 × Ta – 2.65 × Ta^0.5 + 3.21 × log (Rad + 1) + 3.5 (Hahn *et al* 2003)	25°C, cfr, upper critical temperature for cows (Van laer *et al* 2014)
HLI = 8.62 + 0.38 × RH + 1.55 × Tbg – 0.5 × WS + $e^{(2.4 - WS)}$ if Tg > 25 HLI = 10.66 + 0.28*RH + 1.3*Tbg– WS If Tg <25 (Gaughan *et al* 2008)	70 (Gaughan *et al* 2008)
WBGT = 0.7 × Twb + 0.2 × Tbg + 0.1 × Ta (Schröter & Marlin 1996)	25°C, cfr, upper critical temperature for cows (Van laer *et al* 2014)

THI = Temperature Humidity Index; THI_adj = adjusted version of the Temperature Humidity Index; CCI = Comprehensive Climate Index in °C; Tbg = Black Globe Temperature in °C; HLI = Heat Load Index; WBGT = Wet Bulb Globe Temperature in °C; Ta = air temperature in °C; Rad = solar radiation in W m^{-2}; RH = % air humidity; WS = wind speed in m s^{-1}.

have access to shelter whenever they felt the need. These animals were usually female and of intermediate age, compared to the rest of the herd. Sex and exact age of collared animals can be found in Table 1 (http://www.ufaw.org.uk/supplementarymaterial.php).

Animal positions were registered every 30 min (around the clock) and were plotted onto digital maps of the reserves, using ArcGis (Esri Headquarters, CA, USA). For each animal position, we determined whether it took place in: (1) open area (= no shelter); (2) natural shelter, including the surrounding 5 m because we assumed cattle would still find protection (eg from wind or solar radiation) within 5 m of trees or shrubs; or (3) artificial shelter (including the surrounding 5 m). These data were coupled to the climatic variables and indices registered by the closest or the most representative weather station, in the 15 min before the animal position was registered. The digital maps of the reserves were based on the most recent, detailed orthographic aerial images available at the Flemish Agency for Geographical Information. The vegetated patches were mapped as natural shelter and the location of the artificial shelters added manually. To correct for potential changes in vegetation after the aerial images were captured, these maps were checked in the field and adapted accordingly. The area of each separate patch of natural and artificial shelter was determined (measured on-site with a tape measure for artificial shelter, and determined with ArcGis for natural shelter) and the sum of the patches of natural shelter was divided by the total reserve area to obtain the percentage of natural shelter per reserve (Table 1; http://www.ufaw.org.uk/supplementarymaterial.php).

Quantification of the spatial distribution of shelter

The cattle's use of the shelter is almost certainly influenced by the amount and spatial distribution of natural and artificial shelter across the reserve. Therefore, we had to quantify the spatial distribution in order to include it into the analysis of the effect of climatic variables and indices on the use of shelter. We used a 'structural diversity index' based on the Shannon Wiener index (H), which is widely used in ecology to assess the diversity of species or habitats in a given area (Magurran 1988). Here, we used it to quantify the spatial distribution of 'areal units' of the three different location types — separate patches open area, natural and artificial shelter, in each reserve — according to Equation (1) below.

The Shannon Wiener index's value ranges from 1 to 4 and increases with an increasing number of and greater scatter of 'shelter units'. However, this value provides little information about the relative differences regarding the spatial distribution of shelter between the different reserves. This is why we used a method equivalent to the calculation of the Shannon evenness measure, traditionally used to quantify the difference in abundance between different species in a given area (Magurran 1988). More specifically, we divided each reserve's Shannon Wiener index (H) by the maximum Shannon Wiener index (for the reserve with the maximum number of shelter units) (Equation 2), to obtain a relative measure per reserve, which we named the 'structural diversity index' (Table 1; http://www.ufaw.org.uk/ supplementarymaterial.php).

$$(1)\ H = -\Sigma_i = 1^s\ [(ni/N) \times \ln (n_i/N)]$$

$$(2)\ S = H/H_{max}$$

where: i = i^{th} unit of the location type (open area, natural shelter and artificial shelter); s = number of location type units; n_i = area of the ith unit of the location type; N = total area of location type; $H_{max} = \ln S_{max}$ and S_{max} = the maximum number of location type units in one reserve.

Collection of climatic data

Custom-built Campbell Scientific BWS200 weather stations (Campbell Scientific Inc, Logan, Utah, USA) in six out of eight reserves recorded the average air temperature, air humidity, solar radiation, wind speed and total precipitation

Figure 1

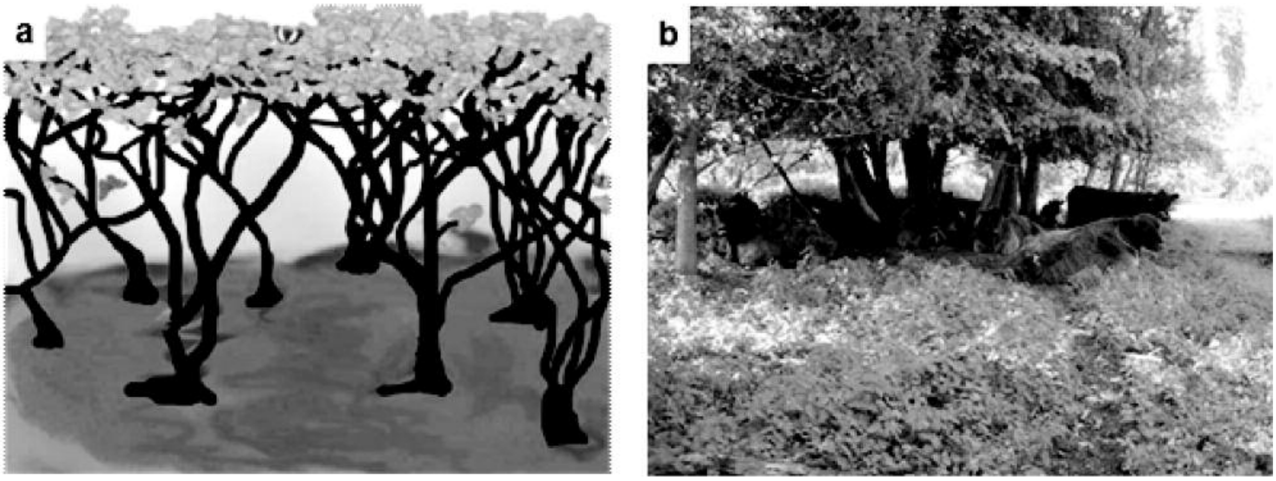


Image (a) showing a typical patch of natural shelter used by cattle as described by Hauck and Popp (2010) and (b) as observed in our study.

every 15 min. For the two reserves without a weather station (MS and BB), climatic variables were used from the closest (max 43 km distance) weather station (KH in 2012, VV in 2013). In livestock heat-stress research and livestock management, the effect of different climatic variables is often combined into a single measure to quantify the degree of discomfort and potential production loss. This has resulted in the development of climatic indices, which are usually associated with risk classes or threshold values reflecting the effect on biological response functions, such as body temperature, respiration rate or milk production (Hahn *et al* 2003).

In our research we used six such heat-stress indices (Table 2), for which we calculated 15-min values based on the measurements of the weather stations.

The Temperature Humidity Index (THI) is, at present, still the most commonly used index for classifying moderate to hot conditions in livestock research and management. In addition, we used more recent climatic indices — such as an adjusted version of the THI, the Heat Load Index (HLI) and the Comprehensive Climate Index (CCI) — which incorporate the effects of temperature, humidity, wind speed as well as solar radiation to improve the assessment of heat stress risk (Table 2). The black globe temperature (Tbg) incorporates the effect of air temperature and solar radiation and the Wet Bulb Globe Temperature (WBGT) incorporates the effect of air temperature and solar radiation via the Tbg and the effect of solar radiation and wind speed via the wet bulb temperature (Table 2).

Effect of natural versus artificial shelter on microclimate

In order to evaluate the effectiveness of natural versus artificial shelter as protection against heat-load we conducted microclimatic measurements on three days of high heat-load in open area ($n = 3$ per day and per reserve), and under natural shelter area ($n = 3$ per day and per reserve) and under artificial shelter ($n = 3$ in the same shelter, per day and per reserve). Within each measurement session (per reserve), we aimed to minimise the time interval in which we took the microclimatic measurements by means of convenience sampling. The order of the nine measurements within a session was thus determined by the order of which we came across suitable patches along our path through the reserve. Patches of open area were selected to lie at least 25 m from the nearest patch of (natural or artificial) shelter. For natural shelter, we selected places that were clearly regularly used by the cattle, as evident from trampling, fouling with excreta and/or the absence of a herb layer and low branches under dense foliage, as also described by Hauck and Popp (2010) and illustrated in Figure 1.

In each artificial shelter, we took three measurements per session, one in the centre of the shelter and two in the inner corners. Air temperature, wet bulb temperature, Tbg and WBGT were measured with Testo 400's WBGT probe (Testo AG Inc, Lenzkirch, Germany). Wind speed and relative air humidity were measured with a Testo 410-1 Pocket Vane Anemometer (Testo AG Inc, Lenzkirch, Germany). These manual measurements were also used to calculate the HLI.

Data analysis

The difference in air temperature, wind speed, Tbg, and HLI measured in open area, under natural shelter and under artificial shelter was modelled by means of a mixed model ANOVA (proc MIXED, in SAS 9.4) to correct for the effect of repeated measurements within each reserve. In *post hoc* tests, Tukey-Kramer adjustments were used to account for multiple comparisons. In addition, we checked the correspondence between the manual measurements of climatic variables in open area (used in the evaluation of the effectiveness of natural vs artificial shelter) with the measurements of the closest weather station at the same time. Therefore, we conducted a mixed model ANOVA (in SAS 9.4, proc GLIMMIX) that compared the average air temperature, Tbg, HLI and wind speed measured (i) manually and (ii) by the closest weather station during the three measurement sessions per reserve. A random factor was used to correct for the effect of repeated measurements within each reserve.

To determine if a certain location type is generally preferred (across all climatic conditions) we compared the expected use of the three location types, ie the expected distribution of GPS registrations over the three location types — with their observed use (the observed distribution of GPS registrations over the three location types), per reserve (n = 8).

Per reserve, the expected use is defined as the proportion of reserve area covered by the location type multiplied by the total number of GPS registrations in the respective reserve. The ratio of observed/expected use can be either between 0 and 1 (indicating avoidance of the location type) or between 1 and infinity (indicating preference for the location type). The closer the ratio is to 0, the stronger the avoidance; the closer the ratio to infinity, the stronger the preference.

To investigate the effect of climatic conditions on the use of open area (as opposed to shelter, natural or artificial), eight mixed model logistic regressions were fitted (in SAS 9.4, proc GLIMMIX), which modelled the use of open area (binomially distributed) in function of rain intensity (in mm per 15 min) and each of the six climatic heat stress indices in Table 2. Each logistic regression modelled the probability of use of open area as a function of: (1) the effect of rain intensity or the heat stress index under focus; (2) the effect of the amount of natural shelter; (3) the effect of the structural diversity index (Table 1); the two-way interaction between (1) and (2); the two-way interaction between (1) and (3); and the three-way interaction between (1), (2) and (3). The amount of natural shelter expressed as deviation (±) from the situation where half of the area is covered by natural shelter, thus theoretically ranging between –50 (if there would be no natural shelter at all) and 50 (if the whole area would be covered by natural shelter). All models included time of day as random factor to correct for repeated measurements per day and were conducted in SAS 9.4 (SAS Institute Inc, Cary, NC, USA). Out of all models, the model with the HLI yielded the lowest pseudo-AICC (Corrected Akaike Information Criterion), and thus the best fit (Table 3). Consequently, we assumed that, out of the six climatic heat-stress indices tested, the HLI was best suited to explain the observed trends in function of climatic conditions, and further only report results of the HLI model.

Due to the use of open area being modelled in function of three variables (HLI, amount of natural shelter and structural diversity) it is impossible to plot the relations in one graph. This is why the relationship between the HLI and the modelled use of open area is plotted for specific and existing cases of certain combinations of availability of natural shelter and structural diversity, ie for the eight studied reserves. The modelled relation was plotted on top of the plot of the raw data, ie the mean (uncorrected for repeated measurements) use of the three different location types. As such, we illustrate that an overall model may not always predict specific reserve patterns precisely and roughly sketch the relationships between the relevant climatic index and the use of natural and artificial shelter in the reserves where they were not modelled. Only for the reserves where artificial shelter was used relatively frequently (> 1% of observations), the probability of use of natural shelter and probability of use of artificial shelter were modelled (in SAS 9.4, proc GLIMMIX) as a function of the HLI, per reserve.

Table 3 Pseudo-AICC value (lower = better fit) for the analyses of the use of open area in function of the different heat-stress indices.

Climatic variable or heat-stress index	Pseudo-AICC
THI	266,582
THI_adj	264,510
Tbg	266,450
CCI	264,348
HLI	264,295
WBGT	264,374
Rain intensity	266,298

THI = Temperature Humidity Index; THI_adj = adjusted version of the Temperature Humidity Index; CCI = Comprehensive Climate Index in °C; Tbg = Black Globe Temperature in °C; HLI = Heat Load Index; WBGT = Wet Bulb Globe Temperature in °C, rain intensity in mm per 15 min.

Results

An overview of the climatic conditions measured by the weather stations in the study reserves, is presented in Table 4. The air temperature, Tbg and HLI registered manually were generally higher in comparison with the registrations of the closest weather station at the same time (respectively 3.8°C [$P < 0.0001$], 5.6°C [$P < 0.0001$] and 4.9 units [$P = 0.0204$]). The wind speed registered by the manual measurements vs weather stations did not differ significantly ($P = 0.7236$), though the absolute value of the difference between both averaged 0.6 (± 0.1) m s^{-1}. This difference is probably due to the weather stations' measurements being an average over the entire hour whereas the manual measurement being an average of three instantaneous measurements spread over moments within this hour.

Effect of natural vs artificial shelter on microclimate

The micro-climatic measurements indicate that during high heat-load several climatic parameters and indices differed between open area, natural and artificial shelter (Table 5). The Tbg, which combines the effect of air temperature and solar radiation, was not significantly different between artificial and natural shelter. In open area, however, it was about 8.5°C higher than under natural or artificial shelter. Wind speed was generally highest in open area, lower under natural and lowest under artificial shelter and these differences were all highly significant. The HLI was highest in open area. The difference between open area and natural shelter and the difference between open area and artificial shelter were highly significant and were 12.7 and 9.0 HLI units, respectively.

Table 4 **Overview of climatic conditions measured by the weather stations, across the whole dataset, per reserve.**

Measure	Factor	KH	VV	MS	EB	KE	HB	HP	BB
Minimum	Air temperature (°C)	–3.0	–1.6	–1.6	–2.8	0.0	–4.3	–2.6	–1.6
	Wind speed (m s^{-1})	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Rainfall per 15 min (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	THI	26.6	29.1	29.1	26.9	32.0	24.3	27.3	29.1
	HLI	13.6	34.6	34.6	10.7	35.8	34.6	10.7	34.6
Mean	Air temperature (°C)	15.2	15.6	15.5	15.6	15.1	15.5	15.0	15.6
	Wind speed (m s^{-1})	0.9	0.9	0.8	1.3	0.4	0.9	0.5	0.9
	Rainfall per 15 min (mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	THI	58.5	59.2	58.9	59.4	58.4	59.2	58.4	59.1
	HLI	47.4	56.7	56.7	46.2	59.4	56.3	45.2	56.7
Maximum	Air temperature (°C)	35.3	35.2	35.2	34.1	35.6	33.9	35.8	35.2
	Wind speed (m s^{-1})	6.0	6.3	6.3	6.4	2.9	5.1	3.3	6.3
	Rainfall per 15 min (mm)	5.6	4.0	4.2	4.6	2.8	4.6	5.8	4.8
	THI	83.9	85.1	85.1	84.2	85.7	84.0	85.5	85.1
	HLI	96.7	97.2	97.2	97.3	102.3	95.5	97.5	97.2
Percentage of observations where rainfall (mm) per 15 min > 0		5.70	4.50	4.13	4.76	4.20	5.12	5.15	4.47

KH: Katershoeve; VV: Velpvallei; MS: Molenstede; EB: Ename Bos; KE: De Kevie; HB: Heidebos; HP: Hobokense Polder; BB: Beninksberg; THI = Temperature Humidity Index; HLI = Heat Load Index.

Table 5 **Effect of location type on least square means (± SEM) of three climatic variables: black globe temperature (Tbg), air temperature, wind speed and the Heat Load Index (HLI).**

Shelter type	Tbg (°C)	Air temperature (°C)	Wind speed (m s^{-1})	HLI
OA	35.1 (± 0.9)^{a}	28.8 (± 0.7)^{a}	1.1 (± 0.1)^{a}	84.0 (± 2.2)^{a}
NS	26.5 (± 0.9)^{b}	24.6 (± 0.7)^{b}	0.6 (± 0.1)^{b}	71.3 (± 2.2)^{b}
AS	26.6 (± 0.9)^{b}	25.0 (± 0.7)^{b}	0.1 (± 0.1)^{c}	75.0 (± 2.2)^{c}
P-value	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$

OA = open area; NS = natural shelter; AS = artificial shelter. Least square means without a common superscript differ significantly according to Tukey-Kramer corrected *post hoc* comparisons, $P < 0.05$.

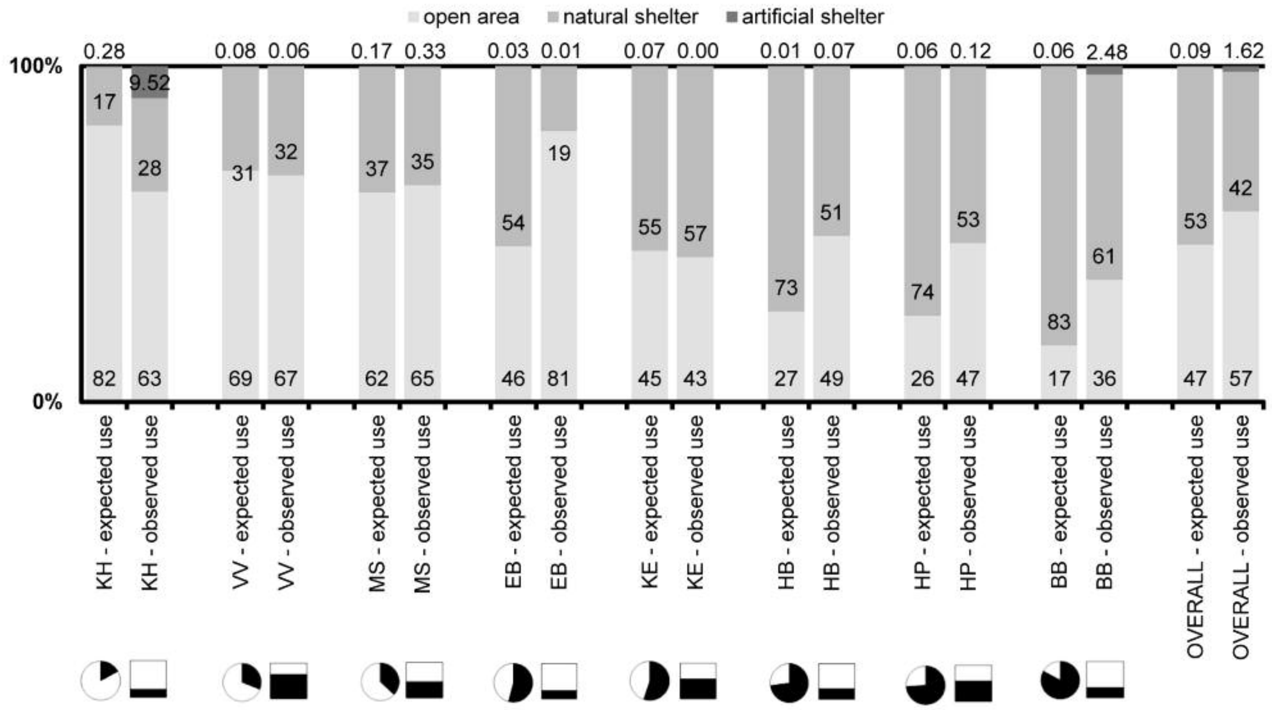
General preferences

In all reserves the artificial shelter covered < 1% of the total reserve area. In six reserves (EB, HB, HP, KE, MS and VV), the artificial shelter was also used ≤ 1% of the time (mean [± SEM]: 0.10 [± 0.05]%), and the ratio of observed use/expected use ranged between 0 and 4.7 (Figure 2). In one of these three reserves, KE, the artificial shelter (including the 5 m around it) was never used at all (Figure 2). Only in two reserves (KH and BB), artificial shelter was used more than 1% of the time. In the most open and least structurally diverse reserve (KH), artificial shelter was used 9.5% of the time (Figure 2) and 34 times more than expected. In one other reserve (though the most vegetated one; (% NS > 80: BB) artificial shelter was used 2.5% of the time (Figure 2) and 45 times more than expected. Natural shelter was slightly avoided (observed use/expected use *circa* 0.7) and open area was preferred, in the three most vegetated reserves (% NS > 60: HB, HP and BB). In the most open and least structurally diverse reserve (KH) open area was avoided and natural shelter was generally (averaged over all climatic conditions) preferred.

Effect of climatic conditions on the use of shelter

Rain intensity did not significantly influence the cattle's use of open area, nor did the interaction of rain intensity with either the amount of natural shelter or the structural diversity or their three-way interaction (Table 6). The effect of HLI on the use of open area was influenced by the inter-

Figure 2



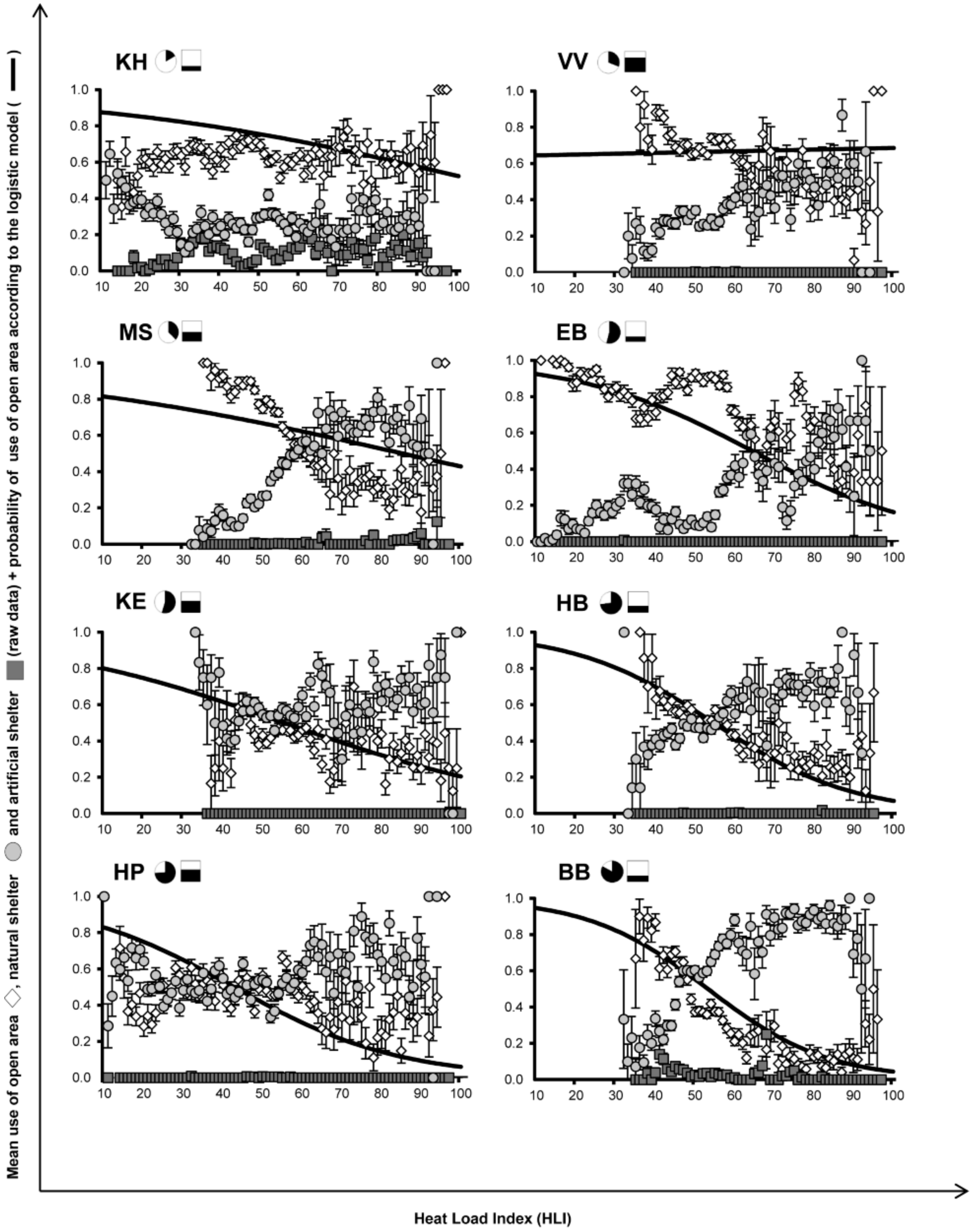
Comparison of the expected use (percentage of the reserves covered by the different location types) with the observed use (percentage of GPS registrations that took place within them), per reserve. KH: Katershoeve; VV: Velpvallei; MS: Molenstede; EB: Ename Bos; KE: De Kevie; HB: Heidebos; HP: Hobokense Polder; BB: Beninksberg. For each reserve, circular symbols represent the percentage of natural shelter and square symbols the structural diversity, with more shading indicating higher values. OVERALL gives the average over all reserves.

Table 6 Effect of rain intensity and the Heat Load Index (HLI) and their interactions with the quantitative availability and spatial distribution (structural diversity) of natural shelter on the use of open area.

Effect	Estimate	SE	*P*-value
Intercept	0.823	0.064	< 0.0001
Rainfall (mm per 15 min)	–0.067	0.208	0.746
Availability NS	–0.020	0.001	< 0.0001
Structural diversity	–0.892	0.150	< 0.0001
Rainfall × availability NS	0.013	0.008	0.098
Rainfall × structural diversity	–0.608	0.533	0.254
Rainfall × availability NS × structural diversity	–0.045	0.023	0.055
Intercept	3.855	0.204	< 0.0001
HLI	–0.056	0.004	< 0.0001
Availability NS	0.024	0.003	< 0.0001
Structural diversity	–4.157	0.491	< 0.0001
HLI × availability NS	≤ 0.001	< 0.001	< 0.0001
HLI × structural diversity	0.056	0.009	< 0.0001
HLI × availability NS × structural diversity	≤ 0.001	< 0.001	< 0.0001

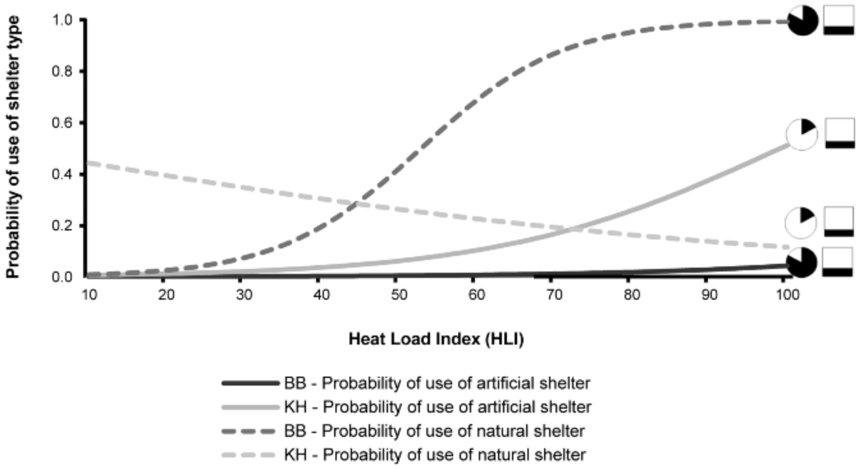
OA = open area; NS = natural shelter; AS = artificial shelter.

Figure 3



Plots of uncorrected (for repeated measures) means (± SEM) of the use of open area (OA; ◊), natural shelter (NS; ○) and artificial shelter (AS; □) and the probability of use of open area predicted by the logistic model (taking the amount and spatial distribution of natural shelter into account), at rounded values of the Heat Load Index (HLI), per reserve. KH: Katershoeve; VV: Velpvallei; MS: Molenstede; EB: Ename Bos; KE: De Kevie; HB: Heidebos; HP: Hobokense Polder; BB: Beninksberg; For each reserve, circular symbols represent the percentage of natural shelter and square symbols the structural diversity, with more shading indicating higher values.

Figure 4



The relation between the Heat Load Index and the use of artificial and natural shelter predicted by the logistic regressions for the two reserves where artificial shelter was used for more than 2% of the time. KH: Katershoeve; BB: Beninksberg. For each reserve, circular symbols represent the percentage of natural shelter and square symbols the structural diversity, with more shading indicating higher values.

Table 7 Effect of the Heat Load Index (HLI) on the use of natural and artificial shelter in Katershoeve (KH) and Beninksberg (BB).

Reserve	Use of natural shelter			Use of artificial shelter		
	Effect	Estimate (± SEM)	*P*-value	Effect	Estimate (± SEM)	*P*-value
KH	Intercept	–0.027 (± 0.124)	*P* < 0.0001	Intercept	5.447 (± 0.245)	*P* < 0.0001
	HLI	–0.022 (± 0.004)	*P* < 0.0001	HLI	0.055 (± 0.004)	*P* < 0.0001
BB	Intercept	–5.808 (± 0.242)	*P* < 0.0001	Intercept	7.378 (± 0.681)	*P* < 0.0001
	HLI	0.112 (± 0.004)	*P* < 0.0001	HLI	0.043 (± 0.011)	*P* < 0.0001

actions with the amount of natural shelter and the structural diversity (Table 6). The use of open area decreased with increasing HLI (estimated effect of HLI is negative; Table 6) but a positive effect of the interaction between the HLI and structural diversity was found as well (Table 6). Thus, if natural shelter was more clustered, the use of open area remained higher than if the structural diversity was high. Compare, for example, EB (lower structural diversity) and HP (higher structural diversity) in Figure 3. The availability of natural shelter had a positive effect on the use of open area (Table 6) but also the three-way interaction between HLI, the availability of natural shelter and structural diversity had a negative effect on the use of open area (Table 6). Thus, if natural shelter was more sparse, the decrease of use of open area with increasing heat-load was less pronounced or even absent when the structural diversity was high (Table 6). Compare, for example, EB (lower structural diversity) with KE (higher structural diversity) and MS (lower structural diversity) with VV (higher structural diversity) in Figure 3. However, the effects were associated with rather large standard errors (Table 6), which is not surprising when comparing the predicted probability of use of open area with the raw data (Figure 3).

In six reserves, the probability of use of artificial shelter could not (reliably) be modelled, as there were ≤ 1% of observations in the artificial shelter. For these reserves, probability of use of natural shelter can be assumed to be as good as complementary to the probability of use of open area, so it would be redundant to model. For the other two reserves (BB and KH) — where artificial shelter was used > 1% of observations — the probability of both artificial and natural shelter use was modelled in function of the HLI. In both reserves, the use of artificial shelter increased with increasing HLI (Figure 4 and Table 7). In the most vegetated reserve (BB), however, an increasing HLI was associated with a greater increase in the use of natural shelter than artificial shelter. In KH the use of natural shelter decreased with increasing HLI (Figure 4 and Table 7).

Discussion

In order to contribute to the debate about the need to provide artificial shelter to cattle in nature reserves in temperate areas we investigated: (i) the effectiveness of natural and artificial shelter against heat load; and (ii) the changes in the use of open area versus (natural or artificial) shelter according to climatic conditions in eight nature reserves in Belgium. The results do not provide conclusive evidence that additional shelter is needed to protect (adult, healthy) cattle from heat in temperate nature reserves as long as adequate natural shelter is available.

Our measurements of microclimatic conditions in open area and under natural and artificial shelter during high heat-load point out that sufficiently dense natural shelter blocks solar radiation quite well, as the black globe temperature was usually not higher under natural than under artificial shelter. At the same time, natural shelter allows more evaporative cooling as compared to artificial shelter, owing to increased air circulation (higher wind speed). In open area, wind speed was generally higher than under natural and artificial shelter. Therefore, when solar radiation is a less-important contributor to heat-load, eg in cloudy but warm weather conditions or during warm nights, this higher wind speed may provide for a better cooling environment in open area. This might be one of the reasons why we observed large variations in the use of open area at elevated HLI values.

Most cattle in our study did not seem to show a clear preference for artificial shelter either. Artificial shelter was in most reserves (EB, HB, HP, KE, MS and VV) used very rarely (≤ 1% of all observations). Consequently, we had an insufficient number of observations to model it in function of heat-load in these reserves. Only in the smallest and least vegetated reserve (KH), did the use of artificial shelter increase markedly and the use of natural shelter decrease with increasing HLI. In conclusion, only the cow in the least vegetated reserve preferred artificial shelter for protection against heat-load.

Although cattle's tendency to use or avoid the artificial shelter might also depend on previous experience (Bateson 2004), we did not observe that the time the cattle had known the shelters before the start of the study was related to the general tendency to use the artificial shelter. Of the two artificial shelters that were used more than 1% of the time, one (in BB) was installed more than ten years before versus the other (in KH) only seven months before the start of the study. In the one reserve where we had one recently installed and one older (more than ten years old) artificial shelter (VV), both were hardly used. Furthermore, animals' preferences are not only influenced by experience in a quantitative but also in a qualitative sense, thus by the association between a given choice and a pleasant or unpleasant consequence. For example, Grandin *et al* (1994) found that cattle resisted altering a choice once they had learned to associate one given option with restraint in a squeeze chute. But the opposite is also possible. In our study, in the most vegetated reserve (BB), cattle were occasionally fed hay inside the shelter, at times when the reserve manager judged natural feed availability to be too low (eg during prolonged snow cover). Although hay was never provided during the study period, the association with feed might still have contributed heavily to the observed general preference for the artificial shelter. Nevertheless, at high heat-load, the cow in this reserve did not seek the artificial shelter but rather used natural shelter for protection against heat.

As also discussed in Van laer *et al* (2014), cattle's preference for a certain type of shelter may be influenced by anti-predatory or vigilance behaviour. Although the domestication process may have reduced bovine sensitivity to predators in the strict sense, vigilance against predators in a wide sense remains relevant. For example, visual obstruction by vegetation in grazing allotments has also been shown to increase vigilance in Angus × Hereford cross-bred cows (Kluever *et al* 2008). Welp *et al* (2004) showed that dairy cows increase vigilance in a novel feeding enclosure and in response to a dog or a person who had handled them aversively. Thus, vigilance may also be a factor influencing cattle's apparent preference for more open natural shelter, versus an artificial shelter with three closed sides. Furthermore, closed walls hinder air movement, and thus allow less convective cooling and more heat accumulation than an open type of shelter (Mader *et al* 1999). This was also reflected in our microclimatic measurements under artificial versus natural shelter, during high heat-load. Consequently, if our study would have used artificial shelters with a more 'open design' (eg without walls), we might have obtained different results, with regard to the micro-climatic measurements as well as the cattle's use of the artificial shelter.

We used artificial shelters with three closed walls, because they were also used in a study into cattle's sheltering behaviour during winter (in the same eight nature reserves; Van laer *et al* 2015), in which the three walls were meant to provide protection against 'wind chill', ie the combined effect of low air temperatures and high wind speed. Indeed, micro-climatic measurements in cold winter conditions, demonstrated that the artificial shelters with three closed walls, provided better protection against wind chill and thus better thermal comfort, than the surrounding natural shelter. Despite this finding, only in the most sparsely vegetated reserve (out of the eight reserves studied), did the use of the artificial shelter rather than the use of natural shelter, increase significantly as the apparent temperature decreased below 0°C (Van laer *et al* 2015).

In the current summertime study, the heat-load threshold at which cattle start to seek (natural or artificial) shelter and thus decrease their use of open area, as well as the strength of the effect, was associated with the amount of natural shelter and its spatial distribution across the grazed area. When natural shelter was abundant, the use of open area decreased notably and gradually with increasing heat-load, but if natural shelter was less abundant, a greater scatter of it seemed to buffer the decrease of use of open area. At first glance this may seem counter-intuitive. If shelter is highly scattered, cattle in an open area are usually closer to shelter than they would be were shelter more clustered, and thus they could be expected to make use of it more easily. But if open area and shelter regularly alternate when an animal is moving through the terrain (at random or in function of motivations other than shelter seeking), the animal may have less opportunity to accumulate heat-load and thus its motivation to seek shelter may remain lower. Moreover, the structural diversity in the terrain may influence its thermal dynamics. Air temperature is higher in open area than in vegetated patches (as confirmed by our microclimatic measurements). But this might be more extreme in large patches than in small patches of open area sharing more edge surface with vegetated patches. In urban environments, this is known as the 'heat island' effect (Santamouris 2001). For example, a vegetated patch of 60 × 60 m has a cooling effect of 2.9°C on the immediate, non-shaded surroundings, and even cools 1.1°C at a distance of 40 m (Shashua-Bar & Hoffman 2000). This can be another possible explanation why grazers would be less-motivated to seek shelter in areas with highly scattered vegetation as heat-load increases.

It must be mentioned that the above effects and trends are associated with rather large standard errors and variation. This is inherent to observational studies such as this, since many hard-to-avoid differences between reserves or individual cows may influence the relationship between climatic conditions and use of open area, natural and artificial shelter. For example, different breeds were used in different reserves, but not enough replicates were available to allow a proper between-breeds comparison. On the other hand, there is little indication for differing susceptibilities to heat-load between the breeds used in the present study. Another factor that potentially influences cattle's sheltering behaviour is the use of specific locations for activities with greater priority than shelter-seeking, such as drinking or grazing. For instance, Gaughan *et al* (1998) unexpectedly found cattle preferred shade from an iron roof over shade from trees or vine leaves due to its proximity to water and feed troughs. Water is known to be one of the most important factors determining grazers' terrain use (eg Senft *et al* 1987; Stuth 1991). However, motivational priorities are not fixed (Bateson 2004). The degree to which terrain use is determined by the location of water or feed sources, can increase when heat-load and, thus, the motivation to seek shelter, declines. Furthermore, physical barriers to animal movement, such as steep slopes, impenetrable vegetation, or water courses potentially influence use of shelter (Stuth 1991). The presence of water courses and pools (which also varied among the study reserves) can also lessen the motivation to seek shelter from heat-load because cattle are known to partially submerge themselves in water to cool off (eg Clarke & Kelly 1996).

In spite of the multiple other factors which may have influenced terrain use of the cattle we studied, our research does confirm that, even in temperate summers, across all studied reserves, heat-load made cattle avoid open area and increase their use of the available (natural or artificial) shelter. As these relations were gradual, a general threshold value at which the cattle start to seek shelter could not be identified.

Animal welfare implications

A decrease in the use of open area cannot readily be translated in terms of 'need for shelter' or 'reduced animal welfare in absence of shelter', even in these specific reserves. On the other hand, application of the precautionary principle does argue in favour of providing additional shelter to avoid any potential welfare derogation in sparsely vegetated reserves. Our study indicates that cattle would prefer natural shelter (additional vegetation), but new plantations need time to grow and may not always be appropriate for a number of reasons (expense, practical feasibility, management of the reserve, etc). In these cases, one or several well-designed artificial shelters placed in strategic locations can also provide heat-load relief.

Conclusion

Our findings indicate that, even in a temperate climate such as Belgium, cattle in nature reserves increasingly avoid open area and seek shelter at high heat-load in summer. The strength of this response differed between nature reserves and was associated with the amount and spatial distribution of natural shelter across the reserve. Furthermore, this study documents that sufficiently dense natural shelter (vegetation) blocks solar radiation quite well, and at the same time allows more evaporative cooling as compared to an artificial shelter with three closed walls and one open side. In the current study, the (healthy and adult) cattle rarely used this type of artificial shelter as protection against high heat-load, except in one nature reserve that contained little natural shelter. If sufficiently available, cattle preferred natural shelter to artificial shelter. Therefore, this study provides no evidence for added value of such an artificial shelter to protect (healthy and adult) cattle from heat-load in nature reserves in temperate climate zones, as long as adequate natural shelter is available.

Acknowledgements

The authors thank the many people who helped with the field work for this study, including employees and local volunteers of Natuurpunt and the Government of Flanders' Agency for Nature and Forest (ANB), the ILVO staff who built the artificial shelters, and especially Thijs Decroos (ILVO Animal Sciences Unit). Furthermore, we thank the Research Institute for Nature and Forest for helping to recover a lost GPS collar and Professor Maurice Hoffmann for sharing his useful ideas concerning data analysis. Thanks to Miriam Levenson (ILVO) for English-language editing. This study was funded by the Federal Public Service of Health, Food Chain Safety and Environment (contract RT 10/13 Pastress). The experiment was approved by ILVO's Ethical Committee (EC 2011/148 and EC 2011/148bis).

References

Andresen H, Bakker JP, Brongers M, Heydemann B and Irmler U 1990 Long-term changes of salt marsh communities by cattle grazing. *Vegetatio 89*: 137-148. http://dx.doi.org/10.1007/BF00032166

Bateson M 2004 Mechanisms of decision-making and the interpretation of choice tests. *Animal Welfare 13*: 115-120

Brown-Brandl TM, Eigenberg RA and Nienaber JA 2006 Heat stress risk factors of feedlot heifers. *Livestock Science 105*: 57-68. http://dx.doi.org/10.1016/j.livsci.2006.04.025

Clarke MR and Kelly AM 1996 Some effects of shade on Hereford steers in a feedlot. *Australian Journal of Experimental Agriculture 21*: 235-238

Finch VA, Bennett IL and Holmes CR 1984 Coat colour in cattle: effect on thermal balance, behaviour and growth, and relationship with coat type. *Journal of Agricultural Science 102*: 141-147. http://dx.doi.org/10.1017/S0021859600041575

Gamborg C, Gremmen B, Christiansen SB and Sandøe P 2010 De-domestication: ethics at the intersection of landscape restoration and animal welfare. *Environmental Values 19*: 57-78. http://dx.doi.org/10.3197/096327110X485383

Gaughan JB, Goodwin PJ, Schoorl TA, Young BA, Imbeah M, Mader TL and Hall A 1998 Shade preferences of lactating Holstein-Friesian cows. *Australian Journal of Experimental Agriculture 38*: 17-21. http://dx.doi.org/10.1071/EA97039

Gaughan JB, Mader TL, Holt SM and Lisle A 2008 A new heat load index for feedlot cattle. *Journal of Animal Science 86*: 226-234. http://dx.doi.org/10.2527/jas.2007-0305

Grandin T, Odde KG, Schutz DN and Behrns LM 1994 The reluctance of cattle to change a learned choice may confound preference tests. *Applied Animal Behaviour Science 39*: 21-28. http://dx.doi.org/10.1016/0168-1591(94)90012-4

Graunke KL, Schuster T and Lidfors LM 2011 Influence of weather on the behaviour of outdoor-wintered beef cattle in Scandinavia. *Livestock Science 136*: 247-255. http://dx.doi.org/10.1016/j.livsci.2010.09.018

Hahn GL, Mader TL and Eigenberg RA 2003 Perspective on development of thermal indices for animal studies and management. In: Lacetera N, Bernabucci U, Khalifa HH, Ronchi B and Nardone A (eds) *Interactions Between Climate and Animal Production* pp 31-44. Wageningen Academic Publishers: The Netherlands

Hauck M and Popp A 2010 The effects of cattle browsing on woody vegetation in large-scale pastures of the Thuringian Rhoen and the South Black Forest. In: Plachter H and Hampicke U (eds) *Large-Scale Livestock Grazing, A Management Tool for Nature Conservation* pp 128-143. Springer-Verlag: Germany

Kluever BM, Breck SW, Howery LD, Krausman PR and Bergman DL 2008 Vigilance in cattle: the influence of predation, social interactions, and environmental factors. *Rangeland Ecology & Management 61*: 321-328. http://dx.doi.org/10.2111/07-087.1

Lorimer J and Driessen C 2013 Bovine biopolitics and the promise of monsters in the rewilding of Heck cattle. *Geoforum 48*: 249-259. http://dx.doi.org/10.1016/j.geoforum.2011.09.002

Mader TL, Dahlquist JM, Hahn G and Gaughan JB 1999 Shade and wind barrier effects on summertime feedlot cattle performance. *Journal of Animal Science 77*: 2065-2072

Mader TL, Davis MS and Brown-Brandl T 2006 Environmental factors influencing heat stress in feedlot cattle. *Journal of Animal Science 84*: 712-719

Mader TL, Johnson LJ and Gaughan JB 2010 A comprehensive index for assessing environmental stress in animals. *Journal of Animal Science 88*: 2153-2165. http://dx.doi.org/10.2527/jas.2009-2586

Magurran AE 1988 *Ecological Diversity and Its Measurement*. Princeton University Press: UK. http://dx.doi.org/10.1007/978-94-015-7358-0

Rosselle L, Permentier L, Verbeke G, Driessen B and Geers R 2013 Interactions between climatological variables and sheltering behavior of pastoral beef cattle during sunny weather in a temperate climate. *Journal of Animal Science 91*: 943-949. http://dx.doi.org/10.2527/jas.2012-5415

Santamouris M 2001 Heat island effect. In: Santamouris M (ed) *Energy and Climate in the Urban Built Environment.* James & James: UK

Silanikove N 2000 Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production Science 67*: 1-18. http://dx.doi.org/10.1016/S0301-6226(00)00162-7

Schröter RC, Marlin DJ and Jeffcott LB 1996 Use of the wet bulb globe temperature (WBGT) Index to quantify environmental heat loads during three-day-event competitions. *Equine Veterinary Journal 28*: 3-6. http://dx.doi.org/10.1111/j.2042-3306.1 996.tb05025.x

Shashua-Bar L and Hoffman ME 2000 Vegetation as a climatic component in the design of an urban street: An empirical model for predicting the cooling effect of urban green areas with trees. *Energy and Buildings 31*: 221-235. http://dx.doi.org/10.1016/S0378-7788(99)00018-3

Senft RL, Coughenour MB, Bailey DW, Rittenhouse LR, Sala OE and Swift DM 1987 Large herbivore foraging and ecological hierarchies. *Bioscience 37*: 789-799. http://dx.doi.org/10.2307/1310545

Stuth JW 1991 Foraging behaviour. In: Heitschmidt RK and Stuth JW (eds) *Grazing Management: An Ecological Approach* pp 65-83. Timber Press Inc: Oregon, USA

Thom EC 1959 The discomfort index. *Weatherwise 12*: 57. http://dx.doi.org/10.1080/00431672.1959.9926960

Van laer E, Ampe B, Moons CPH, Sonck B and Tuyttens FAM 2015 Wintertime use of natural versus artificial shelter by cattle in nature reserves in temperate areas. *Applied Animal Behaviour Science 163*: 39-49

Van laer E, Moons CPH, Sonck B and Tuyttens FAM 2014 Importance of outdoor shelter for cattle in temperate climates. *Livestock Science 159*: 87-101

Vera FWM 2000 *Grazing Ecology and Forest History*. CABI Publishing: UK. http://dx.doi.org/10.1079/9780851994420.0000

Wallis de Vries MF 1994 *Foraging in a landscape mosaic: diet selection and performance of free-ranging cattle in heathland and riverine grassland.* PhD Thesis, Wageningen University, The Netherlands.

Welp T, Rushen J, Kramer DL, Festa-Bianchet M and de Passillé AM 2004 Vigilance as a measure of fear in dairy cattle. *Applied Animal Behaviour Science 87*: 1-13. http://dx.doi.org/10.1016/j.applanim.2003.12.013

Yeates NTM 1955 Photoperiodicity in cattle I. Seasonal changes in coat character and their importance in heat regulation. *Australian Journal of Agricultural Research 6*: 891-902. http://dx.doi.org/10.1071/AR9550891

Zimbelman RB, Rhoads RP, Rhoads ML, Duff GC, Baumgard LH and Collier RJ 2009 A re-evaluation of the impact of temperature humidity index (THI) and black globe humidity index (BGHI) on milk production in high producing dairy cows. In: Collier RJ (ed) *Proceedings of the Southwest Nutrition and Management Conference* pp 158-169. 26-27 February 2009, Arizona, USA