

Landscape of Choice: The Influence of Landscape Features on the Behavior of Sport Horses

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Abstract

Understanding how horses interact with landscapes is key to designing environments that support welfare and biodiversity. Yet, little is known about how domestic horses use specific elements within a landscape. This study examined the behavioral interactions of seven Swedish warmblood mares (1–3 years old) with naturally occurring landscape features in the Kumlan Nature Reserve (Sweden) during July and August 2021. HoofStep® sensors continuously recorded equine behaviors, categorized as highly active, active, resting, or eating. Manly Selection Ratios (MSRs) were used to assess landscape feature selection (LFS) relative to availability. A generalized linear model (Gamma distribution, log link) tested the effects of horse, behavior, landscape feature, time of day, temperature, rainfall, and month on LFS. Significant main effects included horse, landscape feature, month, rainfall, and temperature ($p < .001$). Two-way interactions showed that behavior was linked to LFS and that selection was influenced by weather. For instance, tree rows and hedges were preferred during rainfall ($\text{Exp}(B) = 1.17$, $p = 0.01$), but avoided as temperatures rose ($\text{Exp}(B) = -0.51$, $p < 0.001$). Three-way interactions highlighted individual preferences, i.e., Horse A preferred resting on a sandbank ($\text{Exp}(B) = 42.48$, $p < 0.05$), and Horse B in a blackberry patch ($\text{Exp}(B) = 25.22$, $p < 0.05$). Horse C was active on a sandbank with vegetation ($\text{Exp}(B) = 22.57$, $p = 0.01$), while Horse D preferred the pool ($\text{Exp}(B) = 90.44$, $p < 0.001$). Findings suggest that both landscape and weather shape equine behavior, with notable individual variation. Landscape design should incorporate diverse features to meet the behavioral needs of individual horses and to support welfare and biodiversity goals.

Keywords

Equine behavior; biodiversity; welfare; landscape features; sensor technology

1. Introduction

Global biodiversity is declining at an unprecedented rate. With approximately 30% of known species having become endangered or extinct since the 1500s [1], Earth is thought to have entered what is commonly referred to as the "sixth mass extinction" [2]. Integrating biodiversity considerations into how we use and manage land in order to halt additional biodiversity loss has become a critical objective in global and regional policy [1,3–6].

In Europe alone, the equine sector holds a substantial area of land. Approximately six million equids graze about six million hectares of permanent grassland. Yet, historically, equine farms have been largely overlooked in agroecological and conservation initiatives, possibly because they exist at the junction between built-up and rural areas, often combining recreational, ecological, and economic land use [7,8]. Nevertheless, previous studies have demonstrated that equine farms show considerable "biodiversity potential" that, to date, remains underappreciated and largely untapped [9–12]. Even small additions of green or blue infrastructure can

yield outsized ecological benefits. For example, introducing shrubby patches covering <0.5% of pasture area was shown to increase plant species richness by over 40%, alongside notable gains in lichens and insects [13]. By adding small landscape features such as tree rows, wild hedges, buffer strips, trees, and ponds, equine properties can provide habitat heterogeneity that boosts local biodiversity by offering a variety of different microhabitats [12,14].

In addition to these ecological benefits, integrating a diverse range of small landscape features might also enhance levels of equine welfare [15]. Animal welfare science provides a framework for understanding how landscape design can benefit horses themselves. The five domains model identifies physical environment and behavioral interactions as two of the five key domains that determine an animal's welfare state [16]. Beyond minimizing negatives (e.g., hunger, discomfort), animals should be provided with opportunities for positive experiences that fulfill their behavioral and psychological needs [16,17]. For grazing herd animals like horses, such positive welfare inputs include access to varied foraging, freedom of movement, social contact, and shelter, elements that a biodiverse environment with different types of landscape features arguably supplies. The Dynamic Animal Welfare Concept (DAWCon) [18] underscores the importance of an animal's ability to interact with and adapt to its environment as a component of good welfare. Under this dynamic view, an individual is likely in a positive welfare state when it has the ability and opportunity to respond appropriately to both pleasurable and adverse environmental stimuli, thereby coping with challenges and attaining situations it perceives as positive [18]. Both frameworks support the notion that providing horses with a complex, enriched environment that allows them to actively engage with a variety of stimuli may be central to their well-being.

The monitoring of fine-scale movement, habitat use, and even physiological status of horses in real time has been made possible by advancements in integrated sensor technology, including high-resolution GPS, accelerometers, and gyroscopes [19–21]. For example, a three-year GPS tracking study of semi-feral Konik horses on a Polish wetland reserve reported that nearly 68% of the horses' recorded locations were in open habitat types [22]. That study also found that horses made use of multiple habitat types within the reserve, from mown fen meadows to drier mid-forest grassland dunes, with habitat use varying with humidity and weather conditions. This suggests that horses benefit from a mosaic of microhabitats, accessing different resources (e.g., dry ground, lush forage, shade, or shelter) as conditions change [22–24]. Other studies have noted that horses will seek out shade during periods of high solar radiation [25] and biting insects [26], as well as their preference for linear landscape features that might serve as travelling corridors [27].

To date, however, little research exists that explores how domesticated horses interact with different types of small landscape or habitat features. Therefore, the current study aimed to examine the interaction of warmblood horses with naturally occurring landscape features during different environmental conditions at the collective and individual level.

2. Methodology

2.1. Study Area

The study was conducted in the Kumlan Nature Reserve in Sweden, covering a total area of 34 hectares. Within this area, horses primarily utilized 29.07 hectares (290,722.3 square meters), as determined by GPS tracking and spatial analysis. The terrain was highly diverse, consisting of hilly pastures, sand steppes, and swamp forests, with elevation differences ranging from 32.47 m to 79.00 m.

This area had never been grazed by horses before, ensuring minimal pre-existing impact on forage availability and parasite load. Kumlan Nature Reserve is of particular ecological interest due to its sand steppes, a rare habitat type in Sweden that requires specific conditions such as calcareous, well-drained, and fungus-free sandy soils. Due to legal protections for these habitats, grazing was carefully managed to align with conservation goals while providing an optimal environment for the horses.

2.2. Classification of Landscape Features in ArcGIS

To accurately classify the landscape features within the reserve, the nature reserve's topographical, vegetation, and hydrological features were mapped in ArcGIS using high-resolution GIS layers obtained from official Swedish environmental agencies [28,29]. To help verify and refine the classification of landscape features, photographs and drone footage captured during the study period were used. All identified landscape features were subsequently digitized into polygon layers and categorized based on vegetation type, terrain characteristics, and water sources. The resulting GIS layers were then used to quantify the area covered by each landscape type. The proportionate size, compared to the reference category, Sandbank with vegetation, was also calculated and included for reference purposes (see **Table 1** and **Plate 1**).

2.3. Climate Data

Daily temperature and rainfall data were recorded throughout the study. Temperature values were categorized as cool: <15 °C, moderate: 15–20 °C, and warm: >20 °C. Rainfall intensity was categorized according to the classification system from the National Centre for Hydrology and Meteorology [30] (see **Table 2**).

2.4. Equine Participants

Twelve Swedish warmblood mares, aged 1–3 years, were introduced into the reserve by their owners on May 11, 2021, and remained until October 22, 2021. All horses were inspected daily for signs of distress, injury, or health concerns, and any necessary management adjustments were made. Over the course of the study, no cases of lameness or significant health issues were observed. Two alerts were flagged by the monitoring system but were later deemed inconsequential. Six horses were removed by their owners at various points for reasons unrelated to health or welfare concerns.



Plate 1: Overview of the landscape [31] and identified landscape features.

Table 1: Type of landscape features, including absolute size and proportionate size compared to the reference category, sandbank with vegetation.

Type of landscape feature	Description	Size (m ²)
Individual trees	Several individual trees are set alongside the edge of the forest	465.4
Tree and hedge row	Linear arrangement of trees and hedges dividing or bordering sections of the terrain	10,913.8
Woodland	Densely grown woodland area	88,176.1
Blackberry patch	Circular patch primarily composed of blackberry plants	566.8
Open landscape	Open, unobstructed grassland	106,875
Shaded ridge	Elevated ridge on the north side of the reserve, fenced and sparsely lined with trees	22,900
Grassland surrounded by trees	Grassland enclosed by trees and hedge rows	49,424
Stream	Stream running through the terrain	853.1
Pool	Pool is located within the grassland surrounded by trees	245.1
Sand pit	Indented sandy depression	1,595
Sandbank	Flat sandy area adjacent to an undulating open landscape	4,597
Sandbank with vegetation	Flat sandy area with additional vegetation in the open landscape	4,111

Table 2: Rainfall categories with corresponding precipitation levels [30].

Rainfall category	Precipitation (mm/day)
No rainfall	0 mm/day
Very light rainfall	0.01–0.99 mm/day
Light rainfall	1.0–10.99 mm/day
Moderate rainfall	11.0–30.99 mm/day
Heavy rainfall	>31 mm/day

To maintain consistency in the dataset, only horses that remained in the reserve for the full four-month period (June–September 2021) were included in the data analysis, resulting in a sample of seven horses (three 3-year-olds, three 2-year-olds, one 1-year-old).

The study was non-invasive and reviewed by the Animal Welfare Body of the University of Applied Sciences Van Hall Larenstein (Dossier No. L2414_25).

2.5. Data Collection

All horses were fitted with a Hoofstep® monitoring unit, a lightweight sensor (149 g; dimensions: 96 × 47 × 45 mm), which includes a GPS, accelerometer, gyroscope, and radio transmitter, and has been used in previous behavioral studies [19]. The sensor was mounted on each horse's forehead using softshell headcollars designed to release should a horse get caught somewhere.

The sensor continuously recorded data, which could be stored locally for 24 to 72 hours before being transmitted through a locally positioned base station. From there, the data were uploaded to a cloud-based platform. Using input from both the accelerometer and gyroscope, the system

employed an AI-driven classification algorithm based on a validated equine ethogram [32].

Equine activity was automatically categorized into one of four behavioral categories:

- "Eating" was classified as the time the horse spent chewing or swallowing, in any position or while performing other behaviors.
- "Resting" included any time the horse was stationary and not performing any other activity or behavior. No distinction was made between lying and standing.
- "Active" included any behaviors involving slow locomotion or other types of movement.
- "Highly active" referred to fast locomotory movements (i.e., trot, canter, or jumping/bucking), as well as additional energetic movements such as headshaking or pawing the ground [19].

2.6. Data Curation

Behavioral data were recorded as percentages per hour, reflecting the duration of each unique behavior. Data were provided in .csv format and uploaded into IBM SPSS Statistics, version 29, for further analysis. The preliminary dataset contained 953,002 data points. A total of 111 data points were removed due to implausible duration values, likely resulting from data entry errors or system glitches. These values exceeded biologically feasible durations (e.g., over 24 hours of continuous eating), making their inclusion inappropriate for analysis.

To account for repeated logging of the same behavior in rapid succession, 1,139 duplicate records with identical timestamp values were removed, resulting in a final dataset of 951,752 data points for analysis. The remaining data were examined for sampling frequency per month to ensure an equal distribution (see Table 3).

To ensure appropriate data representation, only the months of July and August were used for the final analysis, resulting in a final dataset consisting of 624,647 data points and representing an average sampling rate of 64.13%.

2.7. Manly Selection Ratios

Manly selection ratios (MSR) were calculated to determine landscape feature selection relative to availability. Selection ratios (w_i) were calculated for horse, behavior, landscape feature, and environmental conditions (month, time of day, rainfall, and temperature) as follows:

$$w_i = u_i / a_i$$

where u_i is the proportion of time the horse spent performing a behavior in landscape feature i relative to its

total time spent performing that behavior under the given environmental conditions, and a_i is the proportion of the total available area made up by landscape feature i .

A ratio greater than 1 indicated selection (i.e., use greater than expected based on availability), a ratio equal to 1 indicated neutral use, and a ratio less than 1 indicated avoidance.

To explore both general behavioral patterns and individual differences in landscape feature selection, a general linear model (GLM) was used, treating horse, behavior, and landscape feature as main factors, and time of day, month, rainfall, and temperature as covariates. Two-way interactions included landscape feature with behavior, landscape feature with rainfall, and landscape feature with temperature, along with a three-way interaction between behavior with landscape feature with horse. This approach made it possible to model overarching trends as well as interactive effects at the individual level.

Due to the skewed nature of landscape feature selection (LFS) data, a gamma probability distribution with a log link function was applied. The reference categories were: horse G; behavior: eating; landscape feature: open landscape; time of day: evening; month: August; rainfall: heavy rainfall; and temperature: warm.

Model fit was evaluated based on convergence criteria and residual distributions. Statistical analyses were conducted using IBM SPSS Statistics, Version 29. The model effects of the final GLM were tested using a Wald chi-square test, and significance levels were set at $p < 0.05$.

3. Results

3.1. Model Fit and Overall Significance

Results demonstrate a good fit of the model, as indicated by the goodness-of-fit statistics: deviance (6494) = 15,821.89; Pearson chi-square (6494) = 5,297.49; AIC = 17,957.07. The omnibus test was significant $\chi^2(349) = 1,466.43$, $p < 0.001$, indicating that the model provided a significantly better fit than the intercept-only model. An overview of the total duration of behavior in hours per factor is included in Table S1 and Table S2 (Supplementary Materials).

Table 3: Total duration of behavior (h) measured per month.

Month	Total hours recorded	Total hours	Sampling frequency (in %)
Jun	1,722.23	5,040.00	34.17
Jul	3,163.12	5,208.00	60.74
Aug	3,516.65	5,208.00	67.52
Sep	2,823.24	5,040.00	56.02
Grand total	11,225.24	20,496.00	54.77

3.2. Main Effects

Based on Wald chi-square statistics, the following predictors of landscape feature selection were significant: horse: Wald $\chi^2(6) = 16.35$, $p < 0.05$; landscape feature: Wald $\chi^2(11) = 119.51$, $p < 0.001$; month: Wald $\chi^2(1) = 13.63$, $p < 0.001$; rainfall: Wald $\chi^2(1) = 14.37$, $p < 0.001$; temperature: Wald $\chi^2(1) = 7.52$, $p < 0.01$. Non-significant predictors were: behavior: Wald $\chi^2(3) = 1.00$, $p = 0.79$ and time of day: Wald $\chi^2(1) = 0.03$, $p = 0.86$.

Compared to the reference category, open landscape, horses showed significantly greater preferences for individual trees, tree rows with hedges, and grassland surrounded by trees. In contrast, the shaded ridge was generally avoided. Preferences also became more pronounced in August and on warmer days (see **Table 4** for significant parameter estimates).

3.3. Two-Way Interaction Effects

Two-way interactions between behavior with landscape features were significant: Wald $\chi^2(33) = 143.21$, $p < 0.001$; landscape features with rainfall (Wald $\chi^2(11) = 158.87$, $p <$

0.001), and landscape features with temperature (Wald $\chi^2(11) = 167.38$, $p < 0.001$) (see **Table 5** for significant parameter estimates).

Results showed that horses were significantly less likely to be highly active in the stream or active in the blackberry patch, resting less often near the stream or individual trees. There was also a near-significant decrease in resting near sandbanks with vegetation (**Figure 1**).

Rainfall was shown to significantly increase the preference for certain landscape features. The heavier the rain, the greater the likelihood of selecting tree rows and hedges, the blackberry patch, sandbanks with vegetation, the shaded ridge, and sand pits, compared to open landscape (**Figure 2**).

Behavioral preferences were also modulated by temperature. As it got warmer, horses were less likely to choose features such as woodlands, tree rows and hedges, individual trees, grasslands surrounded by trees, and sand banks (**Figure 3**).

Table 4: Significant parameter estimates for main effects on landscape feature selection.

Parameter	B			Std. Error	95% Wald confidence interval		Hypothesis test		
		Exp(B)	% Change		Lower	Upper	Wald chi-square	df	Sig.
(Intercept)	-0.74	0.48	-52.41	0.36	-1.45	-0.03	4.22	1.00	0.04
Landscape feature									
Individual trees	6.03	416.54	41,554.23	2.56	1.01	11.06	5.53	1.00	0.02
Tree rows and hedges	1.04	2.83	182.80	0.49	0.08	2.00	4.52	1.00	0.03
Shaded ridge	-2.22	0.11	-89.13	0.64	-3.46	-0.97	12.20	1.00	0.00
Grassland surrounded by trees	1.66	5.25	424.77	0.44	0.80	2.51	14.47	1.00	0.00
Month	0.17	1.19	18.95	0.05	0.08	0.27	13.63	1.00	0.00
Temperature	0.32	1.38	38.31	0.07	0.19	0.46	23.16	1.00	0.00

Table 5: Significant parameter estimates for two-way interactions on landscape feature selection.

Parameter	B			Std. Error	95% Wald confidence interval		Hypothesis test		
		Exp(B)	% Change		Lower	Upper	Wald chi-square	df	Sig.
(Intercept)	-0.74	0.48	-52.41	0.36	-1.45	-0.03	4.22	1.00	0.04
Behavior × landscape feature									
Highly active × stream	-4.11	0.02	-98.35	2.03	-8.08	-0.13	4.10	1.00	0.04
Active × blackberry patch	-3.06	0.05	-95.30	1.33	-5.66	-0.45	5.29	1.00	0.02
Resting × individual trees	-7.38	0.00	-99.94	2.52	-12.31	-2.45	8.60	1.00	0.00
Resting × sandbank with vegetation	-1.94	0.14	-85.70	1.01	-3.92	0.03	3.74	1.00	0.05
Resting × stream	-3.99	0.02	-98.15	1.96	-7.82	-0.16	4.16	1.00	0.04
Landscape feature × rainfall									
Tree rows and hedges × rainfall	0.15	1.17	16.50	0.06	0.04	0.26	7.47	1.00	0.01

Parameter	B			Std. Error	95% Wald confidence interval		Hypothesis test		
		Exp(B)	% Change		Lower	Upper	Wald chi-square	df	Sig.
Blackberry patch × rainfall	0.84	2.32	131.59	0.17	0.51	1.17	24.91	1.00	0.00
Sandbank with vegetation × rainfall	0.37	1.44	44.27	0.07	0.22	0.51	23.92	1.00	0.00
Shaded ridge × rainfall	0.52	1.68	68.49	0.07	0.38	0.66	51.31	1.00	0.00
Sand pit × rainfall	0.51	1.66	66.45	0.08	0.34	0.67	36.75	1.00	0.00
Sandbank × rainfall	0.16	1.18	17.62	0.06	0.04	0.29	6.61	1.00	0.01
Landscape feature × temperature									
Individual trees × temperature	-2.22	0.11	-89.11	0.55	-3.30	-1.13	16.04	1.00	0.00
Tree rows and hedges × temperature	-0.67	0.51	-48.64	0.11	-0.88	-0.45	36.62	1.00	0.00
Woodland × temperature	-0.99	0.37	-62.76	0.11	-1.21	-0.77	79.25	1.00	0.00
Grassland surrounded by trees × temperature	-0.78	0.46	-54.38	0.10	-0.97	-0.60	67.53	1.00	0.00
Sandbank × temperature	-0.47	0.62	-37.71	0.12	-0.72	-0.23	14.47	1.00	0.00

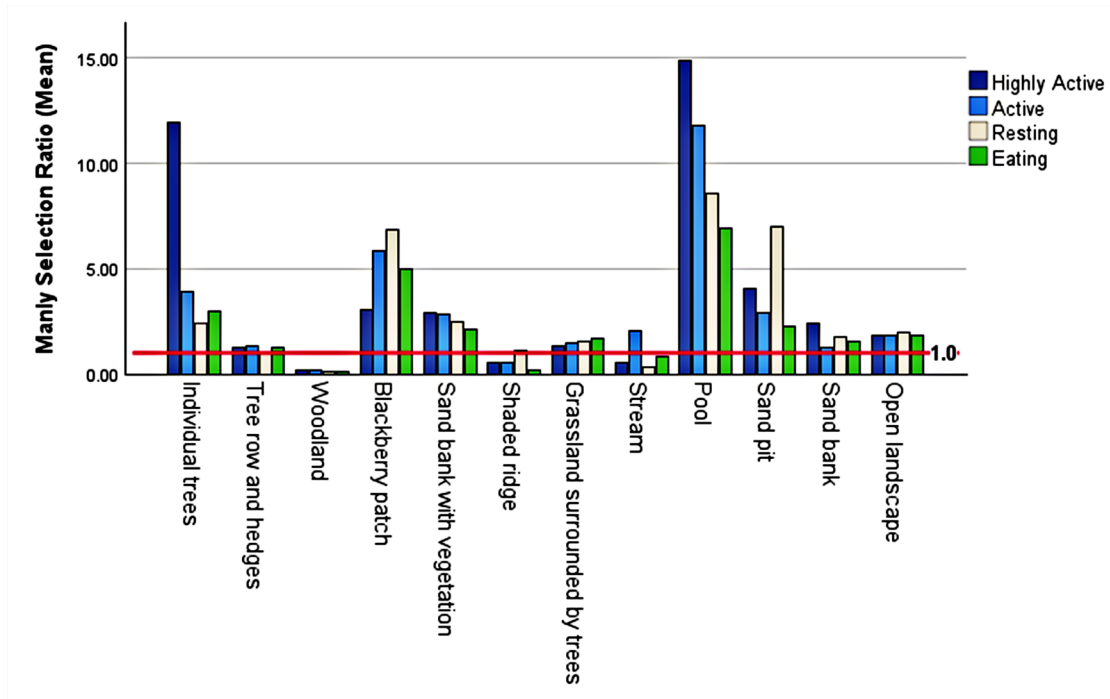


Figure 1: Mean Manly Selection Ratios (MSR) for behavior across different landscape features, with values > 1 indicating preferences, values = 1 indicating neutral use, and values < 1 indicating avoidance.

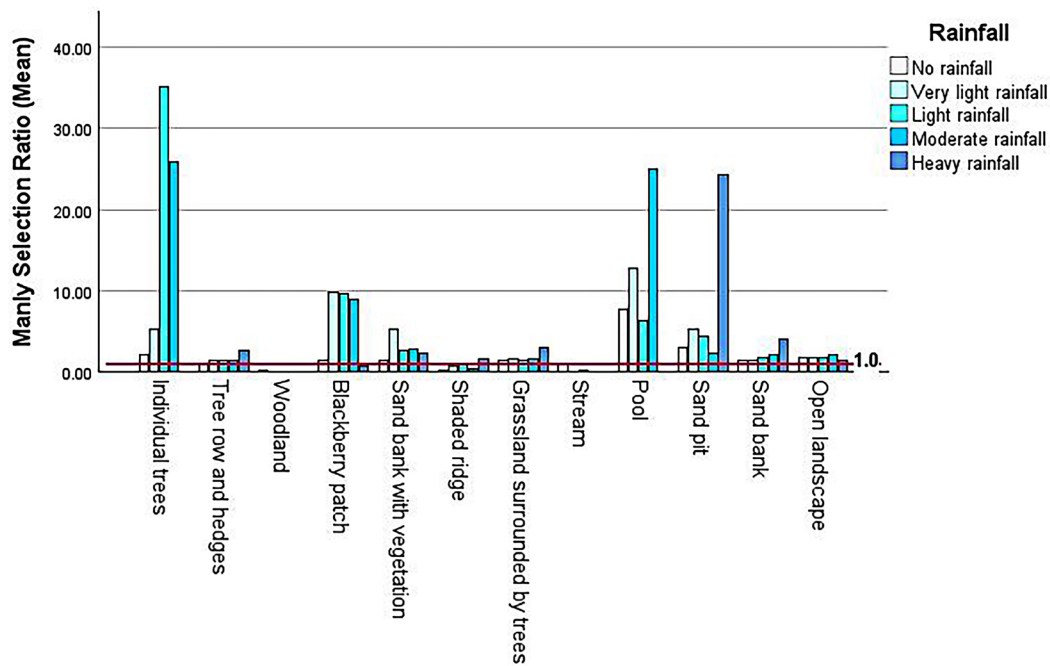


Figure 2: Mean Manly Selection Ratios (MSR) for rainfall across different landscape features with values > 1 indicating preferences, values = 1 indicating neutral use, and values < 1 indicating avoidance.

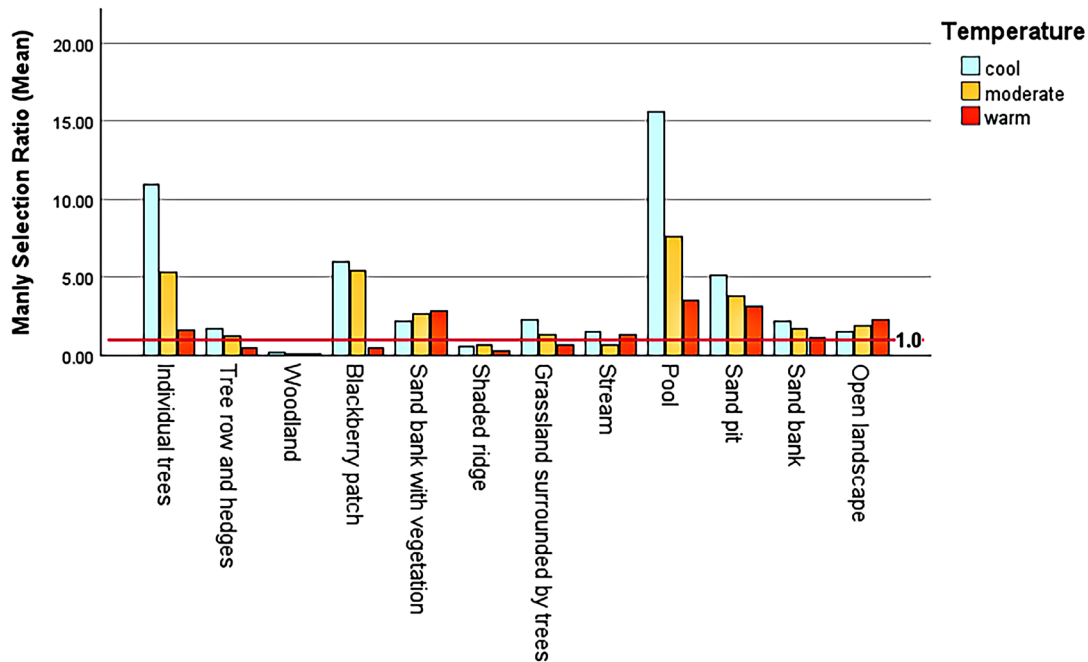


Figure 3: Mean Manly Selection Ratios (MSR) for temperature across different landscape features with values > 1 indicating preferences, values = 1 indicating neutral use, and values < 1 indicating avoidance.

3.4. Three-Way Interaction Effects

A significant three-way interaction between horse, behavior, and landscape feature (Wald $\chi^2(269) = 514.87$, $p < 0.001$) revealed strong individual variation in how horses used their environment. See **Table 6** for parameter estimates and **Figures 4–7** for visual representations of individual behavioral preferences of behaviors across landscape features.

For example, Horse A preferred to rest in woodlands and on sandbanks, and was active in the blackberry patch, but avoided resting near the pool, tree rows, and hedges, and eating near individual trees. Horse B also rested frequently in woodlands, as well as in the blackberry patch, and on the sandbank with vegetation, but avoided being active near the stream and resting near the pool. Horse C was highly active in sandbanks with vegetation and near the pool,

and used the blackberry patch for resting, yet not for high levels of activity. Horse D showed strong preferences for being highly active near the stream and the pool, and for resting in woodlands and the blackberry patch. Horse E also demonstrated preferences for high levels of activity near the

pool, and showed a strong resting preference for sandbanks with vegetation. It avoided being active or highly active near sand pits, and eating near the shaded ridge. Horse F preferred high levels of activity near the pool, resting in woodlands, yet avoided eating in the blackberry patch.

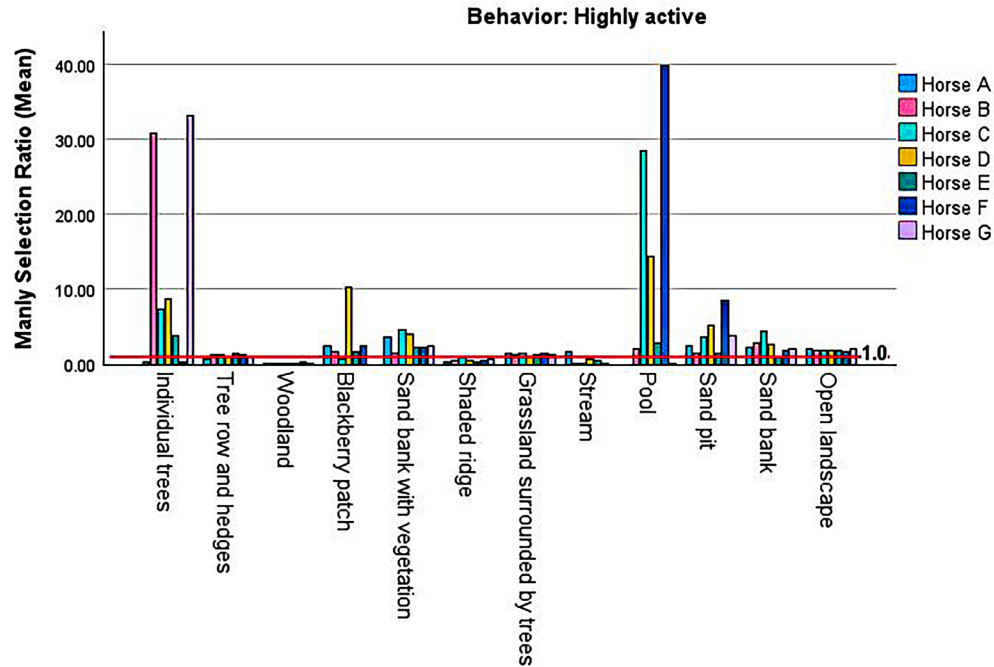


Figure 4: Mean Manly Selection Ratios (MSR) for the behavior "highly active" performed by individual horses across different landscape features, with values > 1 indicating preferences, values = 1 indicating neutral use, and values < 1 indicating avoidance.

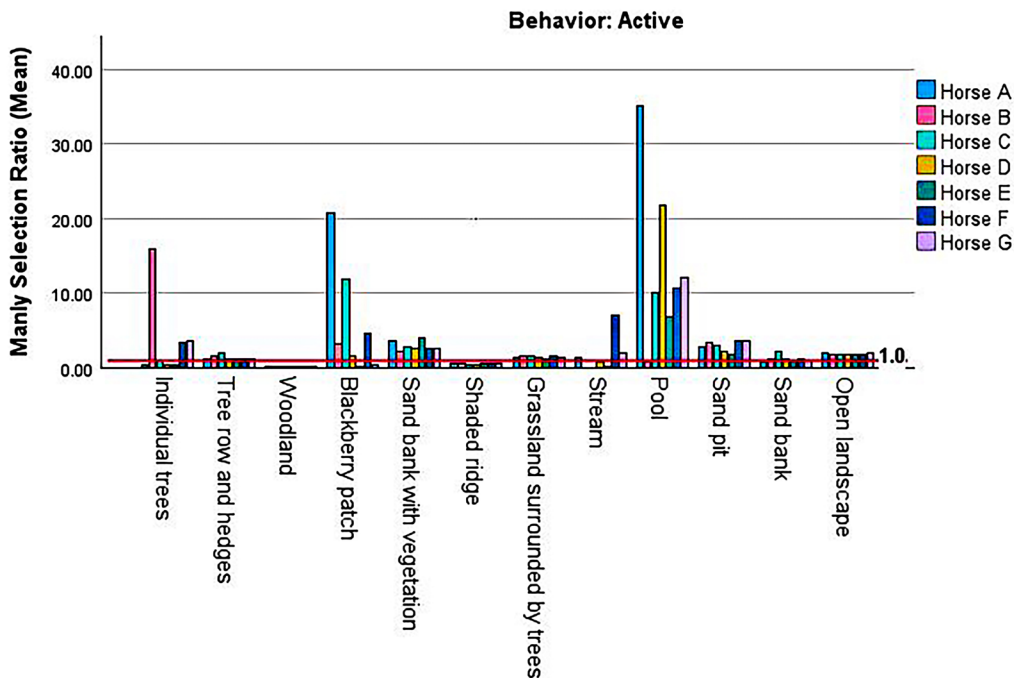


Figure 5: Mean Manly Selection Ratios (MSR) for the behavior "Active" performed by individual horses across different landscape features, with values > 1 indicating preferences, values = 1 indicating neutral use, and values < 1 indicating avoidance.

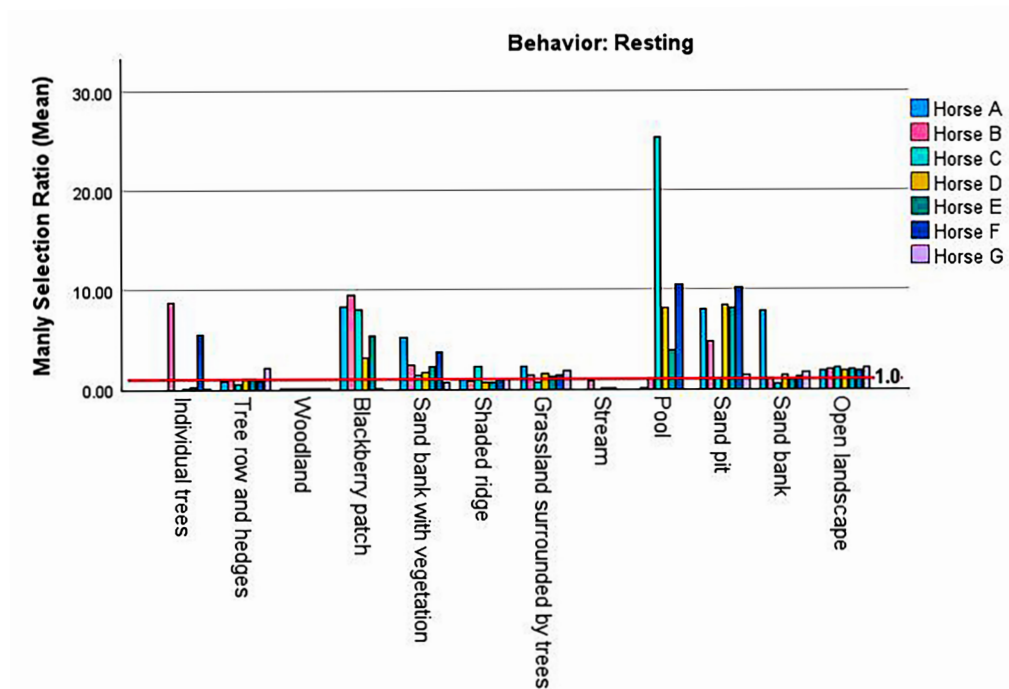


Figure 6: Mean Manly Selection Ratios (MSR) for the behavior "Resting" performed by individual horses across different landscape features, with values > 1 indicating preferences, values = 1 indicating neutral use, and values < 1 indicating avoidance.

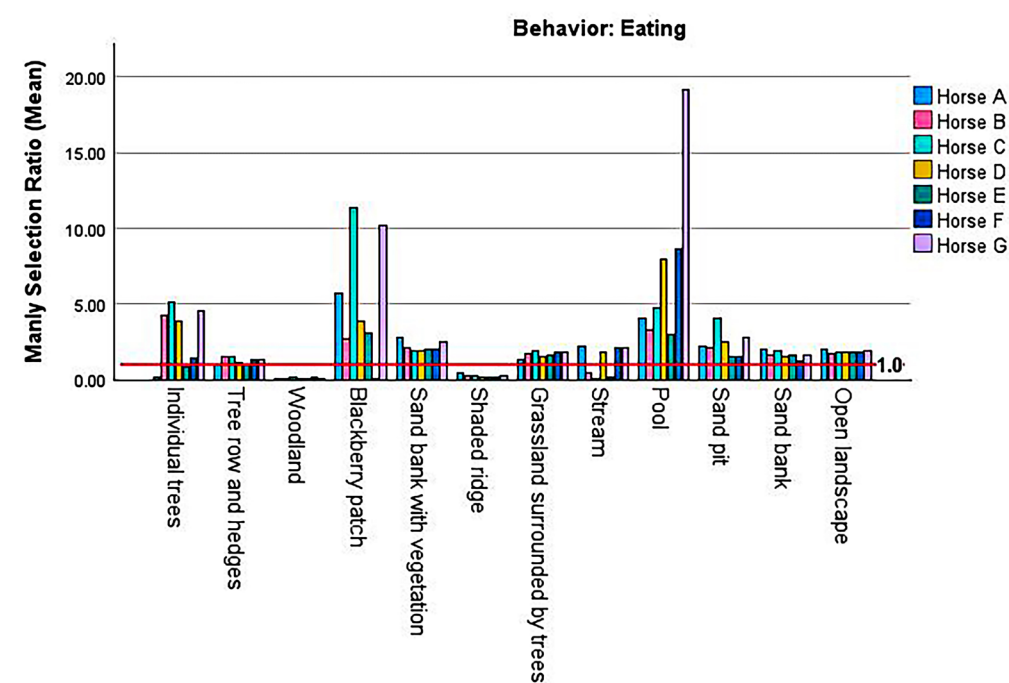


Figure 7: Mean Manly Selection Ratios (MSR) for the behavior "Eating" performed by individual horses across different landscape features, with values > 1 indicating preferences, values = 1 indicating neutral use, and values < 1 indicating avoidance.

Table 6: Significant parameter estimates for three-way interactions on landscape feature selection.

Parameter	B			Std. Error	95% Wald confidence interval		Hypothesis test		
		Exp(B)	% Change		Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-0.74	0.48	-52.41	0.36	-1.45	-0.03	4.22	1.00	0.04
Horse × behavior × landscape feature									
Horse A × highly active × tree rows and hedges	-1.85	0.16	-84.28	0.73	-3.28	-0.42	6.47	1.00	0.01
Horse A × active × blackberry patch	3.68	39.73	3,872.74	1.05	1.63	5.73	12.40	1.00	0.00
Horse A × resting × tree rows and hedges	-1.53	0.22	-78.27	0.54	-2.59	-0.46	7.88	1.00	0.01
Horse A × resting × woodland	2.40	11.08	1,007.81	1.03	0.38	4.43	5.41	1.00	0.02
Horse A × resting × pool	-5.65	0.00	-99.65	1.75	-9.08	-2.22	10.43	1.00	0.00
Horse A × resting × sand bank	4.41	81.98	8,097.98	1.86	0.76	8.05	5.62	1.00	0.02
Horse A × eating × individual trees	-5.31	0.00	-99.50	2.24	-9.69	-0.93	5.64	1.00	0.02
Horse B × highly active × woodland	-1.09	0.34	-66.27	0.56	-2.18	0.01	3.80	1.00	0.05
Horse B × highly active × pool	3.47	32.08	3,107.55	1.68	0.17	6.76	4.26	1.00	0.04
Horse B × active × blackberry patch	2.94	18.93	1,793.41	1.10	0.78	5.10	7.12	1.00	0.01
Horse B × active × shaded ridge	2.19	8.89	789.19	1.10	0.03	4.34	3.96	1.00	0.05
Horse B × active × stream	-4.31	0.01	-98.65	1.40	-7.05	-1.56	9.47	1.00	0.00
Horse B × resting × individual trees	7.96	2,876.10	287,510.08	2.00	4.04	11.89	15.83	1.00	0.00
Horse B × resting × woodland	2.88	17.78	1,678.21	0.94	1.03	4.73	9.30	1.00	0.00
Horse B × resting × blackberry patch	3.23	25.22	2,422.40	1.40	0.49	5.97	5.33	1.00	0.02
Horse B × resting × sandbank with vegetation	1.93	6.87	587.24	0.87	0.22	3.64	4.87	1.00	0.03
Horse C × highly active × blackberry patch	-3.54	0.03	-97.10	1.32	-6.13	-0.96	7.21	1.00	0.01
Horse C × highly active × sandbank with vegetation	3.12	22.57	2,157.18	1.18	0.80	5.44	6.94	1.00	0.01
Horse C × highly active × pool	6.55	701.18	70,017.80	2.50	1.65	11.46	6.86	1.00	0.01
Horse C × resting × blackberry patch	3.85	46.93	4,593.17	1.89	0.14	7.56	4.14	1.00	0.04
Horse C × eating × stream	-4.80	0.01	-99.17	1.90	-8.53	-1.06	6.35	1.00	0.01
Horse D × highly active × stream	3.48	32.41	3,141.12	1.75	0.05	6.91	3.94	1.00	0.05
Horse D × highly active × pool	4.50	90.44	8,943.51	1.53	1.51	7.50	8.67	1.00	0.00
Horse D × resting × woodland	2.21	9.12	812.25	0.87	0.51	3.91	6.48	1.00	0.01
Horse D × resting × blackberry patch	5.03	153.59	1,5258.75	1.98	1.16	8.91	6.49	1.00	0.01
Horse D × eating × shaded ridge	-1.37	0.25	-74.56	0.63	-2.60	-0.14	4.73	1.00	0.03
Horse E × highly active × pool	4.27	71.27	7,026.77	1.67	0.99	7.54	6.53	1.00	0.01
Horse E × highly active × sand pit	-1.53	0.22	-78.43	0.66	-2.84	-0.23	5.33	1.00	0.02
Horse E × active × sand pit	-1.15	0.32	-68.38	0.59	-2.30	0.00	3.83	1.00	0.05
Horse E × resting × sandbank with vegetation	3.42	30.63	2,962.63	1.29	0.89	5.95	7.02	1.00	0.01
Horse E × eating × shaded ridge	-1.38	0.25	-74.87	0.63	-2.63	-0.14	4.73	1.00	0.03
Horse F × highly active × pool	5.67	290.11	28,910.73	1.68	2.38	8.96	11.43	1.00	0.00
Horse F × resting × woodland	2.02	7.54	654.14	0.88	0.29	3.75	5.23	1.00	0.02
Horse F × resting × sand pit	3.10	22.11	2,111.28	1.59	-0.02	6.22	3.78	1.00	0.05
Horse F × eating × blackberry patch	-6.26	0.00	-99.81	1.43	-9.06	-3.46	19.24	1.00	0.00

4. Discussion

The aim of this study was to investigate how warmblood horses interact with naturally occurring landscape features and to explore how these interactions were influenced by weather conditions at the collective and individual levels. Current findings show that, taking availability into account, horses indeed have strong preferences for certain landscape features and will be selective in their use. While much research has focused on horses seeking shelter in hot weather to mitigate solar radiation and insect harassment [33,34], current findings indicate that shelter is also valued during colder or wetter conditions. Rainfall, too, moderated landscape use, with horses showing a preference for tree rows and hedges, including the blackberry patch, likely to seek shelter [35]. Horses also tended to frequent sandy features more often, most likely to roll and encourage coat health [36].

Findings further indicated that climatic conditions amplified existing preferences, both in August, when colder days became more frequent, and as temperatures rose. Even though the changes observed in the present study were minor, they may support the notion that horses will strive to achieve allostasis, i.e., the balancing of energetic costs of existence with the rewards of daily activities and routines [37–39]. As environmental conditions become more extreme, energetic demands associated with behaviors necessary to cope with these changing conditions also likely increase. Behavioral choices are likely to be maximized to achieve the greatest effect with the least energetic load [39]. It could be argued, therefore, that a heterogeneous environment is preferable, as it provides horses with a greater variety of options and thus the opportunity to engage in their preferred coping strategy. This is further supported by the significant differences in individual behavioral choice. For example, some horses showed clear preferences for resting in more sheltered areas, such as woodlands and individual trees, while others preferred engaging in high levels of activity in areas that might be argued to provide additional stimulation, such as the pool, stream, or sand pits. Just as humans vary in environmental preferences, horses appear to exhibit personal inclinations that influence how they use the space available to them. These significantly different individual preferences support the notion that horses possess at least a modicum of self-awareness, enabling them to demonstrate choice [40].

These findings underline the importance of taking individual preferences into account and underscore the need for welfare assessments and spatial design to be flexible and horse-specific [26,41].

These significant interactions between behavior, landscape features, climatic conditions, and individuality suggest that horses perceive their environment as a composite of functional spaces. Much like a house with different rooms, each landscape element appears to serve a distinct purpose in the daily lives of these animals. This idea is further supported by the fact that even though larger-scale landscape features might account for more bouts of equine activity in absolute terms, comparatively speaking, smaller-sized landscape features are just as important. A heterogeneous environment, therefore, allows horses to self-select locations based on their needs at any given moment, such as

thermoregulation [25], refuge from insects [26,42], or social resting [43,44]. As a result, landscape variety becomes not merely a luxury but a necessity for promoting equine agency and welfare.

Recognizing and accommodating such differences can contribute meaningfully to enriched, natural behavior and, by extension, individualized welfare. These results add quantitative depth to previous qualitative observations and confirm that horses actively engage with their surroundings in selective and meaningful ways. They do not merely exist in the landscape; they interact with it, interpret it, and respond to it, often in individually distinct patterns. This aligns with the Dynamic Animal Welfare Concept (DAWCon), which emphasizes the importance of allowing animals to respond and adapt to environmental stimuli to achieve positive welfare states [18].

From a neuropsychological perspective, these results are consistent with the Generalized Unsafety Theory of Stress (GUTS), which proposes that organisms remain in a default state of stress unless clear signals of safety are present [45]. Within this framework, the availability of environmental features that provide safety cues, such as visibility, shelter, or social proximity, becomes essential in mitigating background stress. Moreover, the interpretation of these cues is likely highly individualized, with some horses preferring to rest in open environments, such as on sandbanks, while others prefer more shaded areas, such as woodlands or the blackberry patch. To each of these horses, the landscape features likely provided different cues (i.e., openness vs. shelter), considered more or less important to the individual. As a result, the various landscape features likely function as external modulators of their behavioral response. The landscape thus becomes more than a backdrop; it acts as a co-regulator of the physiological and psychological states of horses. Practical implications are that equine environments should be designed with sufficient diversity to accommodate a range of behavioral strategies of individuals. The integration of green-blue infrastructure through small landscape features into equine yard design, therefore, acts as a means of enhancing both biodiversity and equine welfare [12,15,46,47]. Small-scale interventions, such as planting hedgerows, maintaining shade trees, or creating access to sand pits and water sources, can significantly improve habitat complexity as well as offer behavioral choice for horses. While minimal increases in landscape heterogeneity can yield disproportionate ecological benefits [13,14], current findings suggest that they may also offer substantial welfare advantages at the collective and individual levels.

As such, the current study contributes to a growing body of evidence suggesting that animal welfare and biodiversity conservation are not mutually exclusive but can be pursued simultaneously through thoughtful environmental design. The equine sector, with its significant land footprint across Europe, has untapped potential to contribute to landscape-level conservation goals while at the same time improving the quality of life for horses. Therefore, rather than viewing welfare and biodiversity as competing priorities, they should be seen as complementary: a win-win opportunity that benefits both horses and the ecosystems they inhabit.

5. Limitations

To be able to place the current results into the relevant context, several limitations should be acknowledged. First, the sampling rate used for GPS and behavioral data collection, while sufficient to provide a solid and representative overview of landscape use, was not continuous. As a result, a fully detailed picture of what the horses did throughout the entire day could not be obtained. This introduces a degree of uncertainty regarding short-term behaviors or interactions that may have occurred between sampling intervals.

Second, to ensure data quality and consistency, only the two most robustly sampled months were retained for analysis. While this decision strengthened the reliability of the findings, it also meant that seasonal variation could not be assessed. Consequently, potential changes in behavior or landscape use across spring, summer, and autumn were not captured.

Lastly, while grouping equine behavior into four broader categories was necessary for interpretability and statistical modeling, it inevitably resulted in a loss of behavioral nuance. More granular behavior categories might have revealed even stronger or more complex interactions between horse behavior, landscape features, and environmental conditions. Similarly, the aggregation may have masked subtle patterns in collective behavior or social dynamics within the herd. Further studies could address these aspects by applying continuous sampling methods and retaining finer-grained behavioral classifications.

6. Future Directions

Future research should explore the physiological correlates of landscape use in horses, including stress hormone levels and heart rate variability, to further elucidate the connections between environmental engagement and welfare outcomes. In addition, longitudinal studies examining how horses adapt to newly introduced small landscape features over time would provide valuable insights into learning, habituation, and resilience. Ultimately, a richer understanding of equine-environment interactions can inform more ethical, sustainable, and ecologically sound practices across the equine sector.

7. Conclusion

The present study highlights the capacity of domestic horses to navigate, interpret, and selectively engage with a range of natural landscape features. Behavioral patterns varied not only by environmental conditions but also by individual horse preferences, pointing to the necessity of designing equine environments that offer both diversity and choice. These findings reinforce the potential of small landscape features to act as a bridge between biodiversity conservation and animal welfare, offering benefits to both horses and their surrounding ecosystems. By recognizing the role of the environment as an active contributor to equine well-being, this research provides a compelling case for integrating ecological and ethological principles in the design and management of equine properties.

Supplementary Materials

Table S1 provides an overview of the total duration of behavior (in hours) per horse per landscape feature.

Table S2 presents an overview of the total duration of behavior (in hours) per month and weather condition.

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Authors' Contributions

IW: Conceptualization, Formal analysis, Validation, Writing – Original draft, Writing – review & editing. TE: Methodology, Software, Data curation, Visualization. ML: Methodology, Data curation. KF: Software, Validation, Resources.

Data Availability

Data storage was conducted in accordance with the Research Data Management policy framework of the University of Applied Sciences Van Hall Larenstein. Data management adheres to the principles of Open Science, and the data are accessible upon request.

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Conflicts of Interest

ML and KF were employed at HoofStep during the time of the study and provided the raw data for statistical analysis. IW and TE have no conflicts of interest to declare.

Ethical Approval

The study received ethical approval from the Animal Welfare Body of the University of Applied Sciences Van Hall Larenstein (Dossier No. L2414_25), and it followed the guidelines of the Declaration of Helsinki.

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