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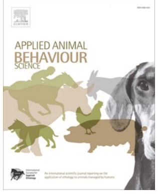

Increasing cage complexity reduces abnormal behaviours in farmed blue foxes

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ABSTRACT

We studied the long-term effects of biweekly rotated enrichment objects and a permanent shelter screen on abnormal behaviour, daily activity, and stress physiology in juvenile female blue foxes (aged 3–9 months). The experiment lasted seven months, from August to February, following a 2 × 2 factorial design with groups of 8–10 foxes. We compared extra enrichment (E) versus basic enrichment (B) and the presence of a shelter screen (S) versus no screen (N). In the final month, we analysed stereotypic and fur chewing behaviours in 38 blue foxes using 48-hour video recordings. Daily activity was measured through instantaneous sampling at 10-minute intervals (IS-10 min), while abnormal behaviours were monitored using IS-1 min during active periods. Faecal cortisol metabolite (FCM) concentrations were analysed from 24-hour faecal samples collected in January. Monthly weighing tracked bodyweight loss towards the spring and breeding season. Scrabbling (scratching/digging) and oral stereotypies were the most common categories of abnormal behaviour, with IS scores of 1.1–1.2 % during active periods. Foxes losing more than 10 % of their bodyweight were scrabbling more, though three individuals with high weight loss exhibited low scrabbling scores, indicating a non-linear association. Enrichment reduced oral stereotypies and inter-individual differences in activity rates. The shelter screen did not influence the occurrence of abnormal behaviours but might have a lowering impact on FCM concentrations. Only cage location had a clear impact on FCMs, whereas other effects might have been obscured by the high individual variation. Overall, our study suggests that providing enrichment objects and avoiding periods of excessive feed restriction can reduce abnormal behaviours in juvenile female blue foxes. Our results highlight the need for category-specific analysis in addition to examining total abnormal behaviours.

1. Introduction

Abnormal behaviour encompasses behavioural indicators of impaired animal welfare (e.g. Fraser, 2008; Mason and Rushen, 2006). These behaviours are linked to neural conditions or environmental factors beyond the individual's control, often driven by thwarted species-specific motivations such as the inability to perform natural behaviours.

In farmed blue foxes (*Vulpes lagopus*), abnormal behaviours include stereotypic behaviours and fur chewing. Stereotypic behaviours are repetitive, unvarying actions lacking an obvious function (e.g. Mason, 1991; Broom, 2014). Studies on blue foxes often group stereotypies as locomotor or oral stereotypies (Korhonen et al., 2001a,b, 2002; Koistinen, 2009; Koistinen et al., 2009), though classification varies across studies. Locomotor stereotypies typically refers to pacing among captive carnivores (Clubb and Vickery, 2006, Blue fox; Korhonen et al., 2001a,b, 2002; Wikman et al., 1999; Koistinen, 2009; Koistinen et al., 2009), but in blue foxes it may also include categories like circling (Korhonen et al., 2001; Koistinen, 2009; Koistinen et al., 2009), jumping (Korhonen et al., 2001; Wikman et al., 1999), and tail chasing (Korhonen et al., 2001ab; Koistinen, 2009; Koistinen et al., 2009). Oral stereotypies involve repetitive biting or licking of cage structures (Korhonen et al., 2001a,b; Koistinen, 2009; Koistinen et al., 2009), with some studies also categorising fur chewing as a form of oral stereotypy (Korhonen et al., 2001a,b). Adopting a more consistent, motivation-based categorisation – such as grouping tail chasing and

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biting under the same fur chewing category as suggested by Wikman et al. (1999) – could clarify the categorisation of stereotypic behaviours in blue fox studies.

Fur chewing, an oral abnormal behaviour, involves the animal damaging its own hair with its teeth, exposing the underfur (Vergneau-Grosset et al., 2021). Fur chewing is predominantly reported in species farmed for their fur, including blue fox (WelFur, 2015), mink (*Neogale vison*, Malmkvist and Hansen, 2001), chinchilla (*Chinchilla lanigera*, Ponzio et al., 2007, 2012), and rabbit (*Oryctolagus cuniculus*, Cheeke, 1987). Similar self-directed hair-damaging behaviours occur in various other species, such as fur-plucking in zoo-housed clouded leopards (*Neofelis nebulosa*, Wielebnowski et al., 2002), self-licking and self-biting in dogs (*Canis lupus familiaris*), and overgrooming in cats (*Felis catus*, Luescher et al., 2003), as well as self-barbering in laboratory mice (*Mus musculus*, Garner et al., 2004).

The most common method for reducing stereotypic behaviours in captive animals is environmental enrichment (Mason et al., 2007). It improves biological functioning by promoting positive states and reducing stress and abnormal behaviours (Newberry, 1995). For farmed blue foxes, items like bones or wooden blocks address gnawing needs (Koistinen et al., 2009; Korhonen and Niemelä 2000) and reduce oral stereotypies (Korhonen et al., 2002; Koistinen, 2009; Koistinen et al., 2009) as well as inactivity (Korhonen and Niemelä 2000). Open platforms, offering a good view of surroundings, are preferred as resting and observation places (Korhonen et al., 1996; Mononen et al., 2001). Finnish regulations mandate both gnawing objects and platforms as part of standard fox housing (Ministry of Agriculture and Forestry Finland, 2011).

Additional enrichment objects that enable gnawing, scratching, play behaviour, and exploration can support natural behaviours and provide long-term welfare benefits for blue foxes. Regularly rotated objects can further maintain the interest in the object as it may decrease over time (Koistinen et al., 2009; Taylor et al., 2023). Items that add environmental complexity, such as retreat structures used for mink (Hansen et al., 1994), or clouded leopard (Wielebnowski, 2002), also improve welfare by enabling social retreat. For blue foxes, the effectiveness of shelter structures remains unverified (Mononen et al., 2001).

Environmental factors can enhance animal welfare by reducing hypothalamus-pituitary-adrenocortical (HPA) axis activity, as demonstrated in mink (Hansen et al., 2007) and large zoo cats (Wielebnowski et al., 2002; Vaz et al., 2017). This can be assessed non-invasively by measuring faecal cortisol metabolites (FCMs), which has been validated for many species (Palme, 2019). FCMs was recently validated in juvenile blue foxes (Ojala et al., 2021), and the method is used here for the first time to study the effects of environmental factors.

This study focused on determining several forms of abnormal behaviour, their occurrence, and the environmental factors influencing them in juvenile female blue foxes. Environmental factors designed to increase cage complexity included biweekly rotated enrichment objects and a permanent shelter screen. To account for additional influencing factors, the analyses also considered potential genetic predisposition to fur chewing, rate of bodyweight loss toward breeding condition, and cage location in the animal shed. We hypothesised that increasing cage complexity would reduce abnormal behaviours and HPA-axis activity.

2. Material and methods

2.1. Ethical statement

Animals in the study did not undergo handling or procedures other than customary breeding and care practices. Therefore, after consulting the Finnish Animal Experimental Board (ELLA), we agreed that approval from ELLA was unnecessary. The Committee of Animal Welfare at the Natural Resources Institute Finland supervised the study throughout the experimental period, and a field veterinarian working with fur animals approved the list of enrichments for the experiment.

2.2. Animals and housing

The experiment was conducted from August 2019 to February 2020 at Kannus Research Farm Luova Ltd, Finland. All experimental animals were juvenile (aged <1 year) breeding female blue foxes, weaned at 6–8 weeks. Full sisters were avoided with one exception, where two sisters originated from the same litter. These females were divided into different experimental groups (cages 33 and 69, Fig. 1).

The foxes were housed in wire mesh cages (1.2 m^2; width 107 cm, length 114 cm, height 72 cm) in a traditional outdoor shed house where the cage rows were situated on both sides of the middle corridor (Fig. 1). All cages had basic furnishing (B) in compliance with Finnish regulations (Ministry of Agriculture and Forestry Finland, 2011). The furnishing included a wooden block (aspen, length 25–30 cm, cross section 11 × 9 cm) and an observation platform (plastic-coated wire mesh, length 114 cm, width 28 cm) positioned 46 cm above the cage floor and mounted on the outermost wall of the cage (as seen from the corridor). The foxes were fed with commercial fresh food paste produced by a Finnish feed kitchen specialised in fur animal feed. The main ingredients were slaughterhouse offal, fish, fish offal, and cereals.

The daily care of the animals followed standard farm practices. Until late November, the females were pair-housed with juvenile males, a common practice during the growing season to enable social interaction (Ahola, 2002). The foxes were fed once daily in the late morning just before noon. A caretaker delivered the feed using a feeding truck, distributing it to the feeding trays in the cages.

During the pair-housing and growing period, daily feed portions ranged from 1000 g to 1200 g per cage (average 500–600 g per individual). However, due to unequal feed distribution between the cage mates, individual intake was uncertain.

After separation in late November, feed portions were gradually reduced to 300–350 g per day until the end of the study. The reduction is a common practice to slim down young breeding females for the breeding season in March (Kempe, 2018). From October to December, the feed had an average energy density of 2037 kcal/kg of metabolisable energy (ME). This was gradually lowered to 1335 kcal/kg ME from January to February, as the breeding season approached. Despite gradual reductions in energy content, the feed remained mainly consistent, aside from natural day-to-day variations in fresh feed. After separation, the females continued living individually in the same cages, while the males were relocated to a separate shed house.

An automated, non-freezing drinking system with nipples provided *ad libitum* access to water. The farm staff monitored the general health of the animals daily during feeding and other care routines. As part of routine health inspections, the animals were weighed monthly using Tru-Test JR-3000 scale.

2.3. Experimental design

This data is part of a larger project investigating the causes and mechanisms of fur chewing in blue foxes. Only a subset of the collected measures is relevant to this study's objectives. None of the additional measures required extra handling of the animals.

The experiment initially involved 40 foxes in a 2 × 2 factorial design. The factors were extra enrichment objects (E) and shelter screen (S). In addition to basic (B) furnishing, the E group received two enrichment objects rotated biweekly and was given a single-use edible or chewable enrichment every Monday. The S group had a shelter screen installed under the platform, creating a tunnel-like shelter, while the N group had no screen. The experimental groups were BN, BS, EN, and ES (n = 10 per group, Fig. 1, see sheet 1 in supplements S1).

The biweekly rotated enrichment objects were designed to stimulate play, gnawing, digging, scratching, and other exploratory behaviours (sheet 2 in supplements S1. These included items such as a piece of drainage pipe, a wooden box containing an edible treat, and a beef femur bone. Frequent rotation and varied combinations aimed to

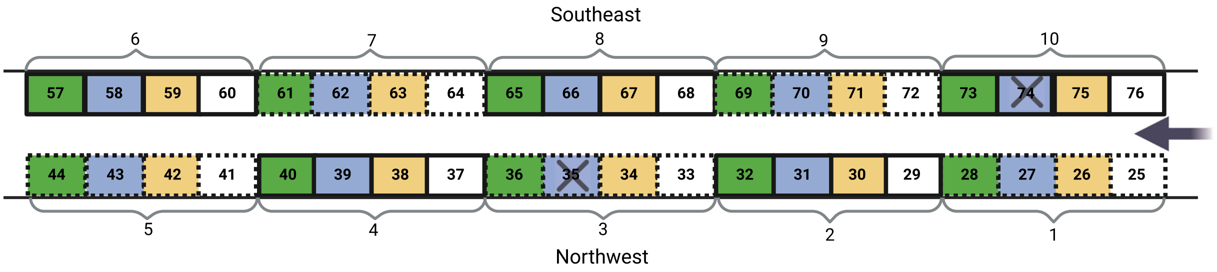

Fig. 1. Experimental Setting. The colours represent the 2 × 2 experimental groups as follows: White = Basic + No Screen (BN), Yellow = Basic + Screen (BS), Blue = Enrichment + No screen (EN), Green = Enrichment + Screen (ES). The experimental cages were allocated into 10 blocks of four cages, with all experimental groups in each block. There were five blocks in each cage row of the shed. The cages with dashed borders housed offspring whose mothers had clear fur damage. The cage numbers correspond to the actual cage numbers within the shed house, which contained a total of 100 cages. Foxes from the cages 74 and 35 died during the study (see text for more details).

maintain the foxes' interest throughout the study. Weekly edible/chewable enrichment treats included items like a dried pig or bull ears and frozen apples, which were typically eaten or destroyed quickly. While the edible/chewable enrichments were single-use, the biweekly objects were reused for the same individual unless more than half was worn out. The worn out objects were replaced with new ones.

To account for potential hereditary predisposition to self-inflicted fur chewing (observed e.g. in chinchillas, Gonzáles et al., 2018), half of the animals in each experimental group were offspring of mothers with visible fur damage. This was defined as one or more areas larger than 100 cm^2, where the mother had chewed off fur, as observed in February-March over the previous two years (WelFur, 2015 and unpublished detailed guidelines for WelFur Fox assessors). The other half of the animals were offspring of mothers without observed visible fur damage.

The experimental cages were allocated into 10 blocks based on their location in the shed house, with each block containing the four experimental groups. However, there were exceptions in two blocks: two foxes from the EN group died during the study (28 October and 11 November) and were excluded from the data. Consequently, the final group sizes were 10 for BN, BS, and ES but only 8 for EN (Fig. 1.). The deaths appeared unrelated to the experimental setup. One female was euthanized due to symptoms of hindquarter paralysis, while the other was found dead in its cage without signs of enrichment use (e.g. scratching or bite marks). These foxes were replaced with new juvenile female blue foxes to maintain the social balance in the shed. The replacement foxes, as well as the males from the pair-housing period, underwent all experimental treatments until either separation (males) or the end of the study (replacement females). Data from these were excluded from the study, as their primary role was to standardise social housing conditions for the juvenile females.

2.4. *Measurements of stereotypic and other abnormal behaviours*

2.4.1. *Video recordings*

The behaviour of all experimental animals was video recorded for 48 hours in February. The video material was collected with 10 video cameras (Dahua PoE IP67 surveillance camera + Ubiquiti Cloud Key Gen2 controller, PoE switch and UniFi Controller software), each of them recording two experimental individuals at a time. Thus, to record all 38 animals, the video recordings consisted of two recording periods. The first recording period (cages 25–28, 33–36, 41–44, 61–64, 69–72) occurred from 17 February 8:00 AM to 19 February 8:00 AM, and the second period (cages 29–32, 37–40, 57–60, 65–8, 73–76) from 19 February 12:00 PM to 21 February 12:00 PM.

2.4.2. *Validation of instantaneous sampling time interval*

All behavioural recordings were done by the first author using the CowLog software (Pastell, 2016). The raw data was then entered into IBM SPSS statistics (version 28.0.0.). The preliminary video data included 456 minutes, with a 12-minute period from each of the 38 experimental foxes. We monitored different hours of the day with each 12-minute recording period, starting 72 minutes after the previous period (see sheet 3 in supplements S1). Using *ad libitum* sampling and continuous recording (CR) (Martin and Bateson, 2007), gathered information described the abnormal behaviour categories and was used to validate sampling intervals for further monitoring. CR is a laborious method and we used it only for preliminary observations. For further monitoring, we switched to instantaneous sampling (IS) and calculated IS scores to determine the percentage of observation points with the recorded behaviour out of the total number of observation points.

To find the most practical IS interval for activity recording, we analysed active time periods from the CR data with IS intervals of 1, 2, 3, 5, and 10 minutes (see sheet 3 in supplements S1). We calculated the discrepancies of the IS scores as relative errors (RE) between the real frequency (CR score, RF) and the estimated frequencies (IS score, EF): RE= (EF-RF)/RF. Martin and Bateson (2007) suggest a threshold of 10 %, which we adopted as the acceptable limit for discrepancy, as this provides a good estimation and allows for a more practical approach to monitor behaviour.

With a relative error or 2.7 % (see sheet 3 in supplements S1), we chose a sampling interval of 10 minutes (IS-10min) for monitoring active time periods. Thus, all 48-hour video recordings of 38 individuals were analysed with IS-10min using a simple binary classification of behaviour as 'inactive and 'active' (Table 1). This enabled calculating activity rates (percentage of active observation points out of all 288 observation points) for all individuals. In IS interval validation of abnormal behaviours, we focused only on active periods. The behavioural monitoring of the active time periods for abnormal behaviour observations began with a 5-second interval for 48-hour recording of one blue fox from each treatment group (BN: 37, BS: 38, EN: 65, ES: 66). In most cases, the behaviour needed to be monitored for more than 5 seconds to determine if it falls under the abnormal behaviour categories. Thus, a 5-second interval was frequent enough to determine RF, and we calculated the EF for the same data with intervals of 10, 15, 30, and 60 seconds (see sheet 3 in supplements S1).

The validation process focused on all recorded abnormal behaviour categories (Table 1). Using a rounding rule to the nearest whole percentage, we found that IS-1min was suitable as our final method for recording abnormal behaviour categories (see sheet 3 in supplements S1). With a discrepancy of 60.1 %, 'other stereotypies' exceeded the accepted maximum discrepancy. Since this category was a sum variable of the four least common abnormal behaviour categories (Table 1), it has only descriptive value and we did not include it in the statistical analyses. Finally, after validation, we analysed all active time periods of 48-hour video recordings from 38 foxes with IS-1min for abnormal behaviours. The results are expressed as the percentage of abnormal behaviour observations out of active time points (later IS-score).

Table 1
Ethogram of monitored behavioural categories.

Behavioural category	Description
Inactive	The fox is on the cage floor or platform, lying curled up in a ball or lying immobile on its side with lied-down head. When curled up in a ball, it's head is either hidden inside or lying outside. Monitoring starts after the fox has stayed immobile in lying position for at least 30 seconds. Short instances of head lifting or standing to adjust position are not considered interruptions of this behaviour.
Active	Behaviours other than inactive, including but not limited to: sitting, moving, lying actively with head up, eating, drinking, interacting/playing (with. e.g., neighboring foxes, enrichments, or feeding tray). Abnormal behaviours are included in active behaviour.
Abnormal behaviour categories	
Oral stereotypies	Oral stereotypies are behaviours directed toward cage structures or the feeding tray. These involve a persistent and unvarying routine of biting and/or licking the object. This occurs while the fox is in a standing or sitting position. To avoid confusion with eating behaviour, such as cleaning the feeding tray by licking it, oral stereotypies was not recorded for one hour after the fox received its feed portion.
Scrabbling	The fox uses its forelegs to engage in persistent, high-frequency, and compulsive scratching or digging (referred to as scrabbling, i.e. Dallaire et al. 2011) on cage structures or the feeding tray. This behaviour occurs while the fox is in a standing position.
Fur chewing	The fox displays intensive grooming or chewing of its own body or tail by biting and/or plucking hair off from its fur. This behaviour occurs while the fox is in a standing, sitting, or in lying position. Fur chewing can also include tail chasing, where the fox either circles around, chasing its tail, or lies on its back, attempting to reach the tail with its mouth and front paws.
Other stereotypic behaviours	This category combines the least common categories: • Locomotor Stereotypy: Pacing repetitively along one side of the cage or circling around the cage. • Bury: burying with the muzzle despite the absence of burying material or an object to bury. • Jump: jumping side to side on the cage floor at least three consecutive times, moving the forelegs and upper part of the body.

2.5. Faecal cortisol metabolites

The analysis of FCMs was based on composite samples collected over a 24-hour period. Personnel from Luova collected the samples using filter cloths placed under the cages from 14 to 15 January. This single sampling during active farm hours minimised disturbance to the animals. The filter cloths strained urine, reducing the risk for contamination. The faeces were collected into plastic bags with plastic spoons and frozen at −20 °C within 30 min of collection. Due to the low temperature (0 ± 4°C) during the collection period, the risk of bacterial degradation was low.

In June 2020, the faecal samples were transported on dry ice from the experimental farm to a Movet Ltd. laboratory in Kuopio, Finland. The samples were stored at −20 °C until pre-treatment. The frozen samples were thawed in a fume cupboard at 60°C for approximately 45 minutes. The thawed samples were then homogenized in plastic bags, and 0.5 g per sample was extracted with 5 mL 80 % methanol. The extraction involved shaking with a hand vortex mixer for 1.5–2 minutes before centrifugation at 2500 × g for 15 minutes (as described by Palme, 2019; Palme et al., 2013). After centrifugation, 0.5 mL per supernatant sample was transferred into Eppendorf tubes and evaporated in heating blocks until completely dry (4–6 hours). The dried extracts were sent to Vetmeduni Vienna for further enzyme immunoassay (EIA) analysis. The dried supernatants were re-dissolved in 0.5 mL 80 % methanol and diluted (1:20) with assay buffer. The supernatants were analysed using a 5-pregnane-3β,11β,21-triol-20-one EIA, first described by Touma et al. (2003). This metabolite was chosen based on the results by Ojala et al. (2021) that demonstrated its suitability for blue foxes.

2.6. Statistical analyses

2.6.1. Preliminary statistics

We used R software (version 4.3.1) for statistical data analysis and graphics. Variance homogeneity was assessed with Levene's test, and normality was checked using the Shapiro-Wilk test. The dependent variables included total abnormal behaviours, scrabbling, oral stereotypies, fur chewing, FCMs, and activity rate. We examined correlations between continuous variables to determine if some dependent variables were associated (see sheet 4 in supplements S1). Since only the activity rate exhibited a normal distribution, we used Spearman's ρ. The independent factors were enrichment (B, E), screen (N, S), mother's fur chewing status (no clear signs, clear signs), block (1−10), house row (Northwest and Southeast), and bodyweight loss (percentage lost from December to February).

Our primary factors of interest in examining effects on abnormal behaviours, FCMs, and activity rate were the enrichment and screen groups. To account for other factors potentially influencing the results, we also considered cage location (block and row), bodyweight loss, and mother's fur chewing status. Since the females were at their heaviest in December, we used individual weight data from December to February to indicate bodyweight loss due to restricted feeding. Complete weight data are presented in sheet 5 (supplements S1).

In addition to simple boxplot (categorical variables) and scatterplot (continuous) comparisons, we tested the single effects of categorical independent factors on continuous dependent variables. These preliminary analyses helped identify factors for further modelling. For examining association between scrabbling and continuous bodyweight loss, we used Spearman's ρ. For two-category variables, we used *t*-tests and for the block variable, we applied univariate analysis of variance (ANOVA). Since only the activity rate was normally distributed, more robust permutation *t*-tests and ANOVA were applied for all other factors. We also used permutation tests to analyse activity rate in enrichment groups, due to unequal variances between groups, as indicated by F-statistics. Unequal variances were further tested with Bartlett's K-squared test. To assess effect sizes, we calculated Hedges' *g* for t-tests and Partial Eta-Square (PES) for ANOVA. When ANOVA showed significant results ($p < 0.05$), Tukey's Post-Hoc tests were used to compare group means. For oral stereotypies and fur chewing, which had a high number of zero values, we used Mann-Whitney U tests for dichotomous variables and the Kruskall-Wallis test for the block variable.

Preliminary statistics showed that mother's fur chewing status did not markedly affect any of the dependent variables, leading to its exclusion from further models. Cage row was only relevant for FCM levels, and bodyweight loss was only associated with scrabbling (see sheet 4 in supplements S1), and therefore neither factor was included in other models.

2.6.2. Statistical models

The models for total abnormal behaviours, scrabbling, FCMs, and activity rate were based on the final selection of factors, evaluated using their metrics such as p-values, effect sizes (PES), small-sample corrected Akaike Information Criterion (AICc), adjusted R-squared (R^2adj), and F-statistics. These metrics were used iteratively to eliminate variables with minimal effects and simplify the models. Predictors with high p-values were prioritised for removal, guided by statistical significance and other fit metrics to balance simplicity and accuracy. R^2adj. and AICc evaluated the models' explanatory power while penalising complexity, favouring simpler models with lower AICc and higher R^2adj. values. PES assessed the relative importance of predictors, helping to eliminate those with minimal effects. The F-statistic and its p-value evaluated the overall significance in each iteration. Variables of primary interest were potentially excluded if they had no effect and their inclusion did not improve model fit. Detailed metrics and elimination rounds are available in the supplementary material (see sheets 6, 7, and 8 in supplements S1).

To meet normality requirements, we used a generalized linear model (permutated LM) to analyse the effects of selected factors on total abnormal behaviours (sheet 6 in supplements S1). Permutation tests were necessary to ensure normality by repeatedly shuffling the data to create different sets, generating a distribution of results under the null hypothesis. This approach provided a more accurate assessment of p-values. Permutation models were implemented using the lmp function from the lmPerm package (Wheeler and Torchiano, 2016). The R code for the final permutated LM was as follows:

1. LM permutated (*total abnormal behaviours*)

lmp(total abnormal behaviours ~ enrichment + screen)

In each model, the model name is specified first (e.g. LM permutated [total abnormal behaviours]) followed by the R package used (lmp) and the dependent factor (total abnormal behaviours). The independent factors are listed after the ' ~ ' symbol.

A scatterplot revealed the non-linear relationship between scrabbling and weightloss (Fig. 2). The generalized additive model (GAM) allowed us to include a smooth term s(weightloss) to flexibly model this non-linearity without assuming a parametric relationship (sheet 7 in supplements S1). This choice was validated by AICc and residual diagnostics. The smooth term captured non-linear patterns without assuming a specific parametric form. Additionally, the Tweedie family distribution was well-suited for handling data with four zero values and overdispersion, ensuring robust model performance. GAMs were implemented using the gam function from the mgcv package (Wood, 2011, 2023). The R code for the final GAM model was as follows:

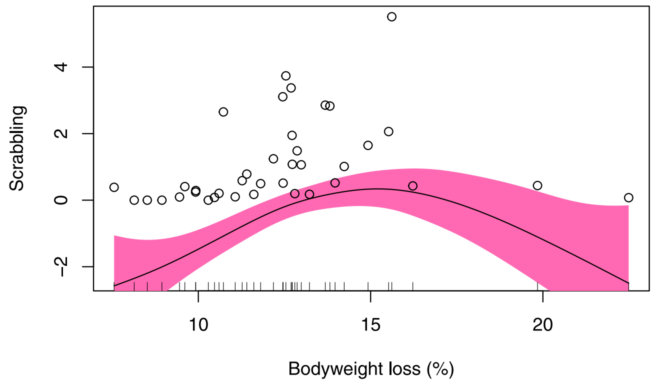

Fig. 2. Scatterplot of observed data and the GAM model visualise the relationship between scrabbling behaviour and bodyweight loss (% from December to February). The GAM model, with weight loss as a smoothed term, indicates a non-linear association between weight loss and scrabbling behaviour. Note that the model operates on a distinct scale compared with observed data. The smooth black line represents the fitted values, while the shaded pink area shows the 95 % confidence intervals of the model predictions. Open circles represent the observed values. The graphic was created using mgcv package (Wood, 2011).

2. GAM (*Scrabbling*)

gam(*scrabbling* ~ s(*weight loss%)* + *block*)

Dependent variables with many zero values, such as oral stereotypies and fur chewing, were analysed using logistic regression (LR) models with binomial distributions (sheet 8 in supplements S1). Factor selection was based on p-values, Nagelkerke's pseudo R^2, and area under the ROC-curve (AUC). Predictors with higher p-values were considered for exclusion to simplify the model. Nagelkerke's pseudo R^2 measured explanatory power, while AUC assessed the model's ability to classify binary outcomes (presence/absence of behaviour). AUC values range from 0.5 (no better than random guessing) to 1.0 (perfect classification). Changes in AUC during iteration provided insights into predictive accuracy. Detailed metrics and elimination rounds are available in the supplementary material (see sheet 8 in supplements S1). Logistic regression was implemented using the glm function (R Core Team, 2023). The final models were as follows:

3. LR (*Oral stereotypy*)

glm(*oral stereotypy~enrichment* + *block*)

4. LR (*Fur chewing*)

glm(*fur chewing* ~ *enrichment* + *block*)

Linear mixed models (LMM) were used to evaluate the effects of selected environmental factors on FCMs and activity rate (sheet 9 in supplements S1). The same metrics applied for LM models, such as p-values, effect sizes (PES), AICc, R^2, and F-statistics, were also used for LMM refinement to assess model fit and eliminate less significant factors. Random effects (block, row) accounted for the experimental design. To normalise residuals, we log-transformed the FCM data. Models were fitted using the lmer function from the lme4 package (Bates et al., 2015). The R codes for the final LMM models were as follows:

5. LMM (*FCMs* log)

lmer(log(*FCMs*) ~ *screen* + (*1* | *block*)

6. LMM (*Activity rate*)

lmer(*activity rate* ~ *enrichment* + *screen* + (*1* | *block*),

In these models, '(1 | factor)' indicates factor as a random factor.

3. Results

3.1. Abnormal behaviours

Of the 38 individuals, 34 exhibited scrabbling, 22 displayed oral stereotypies, 21 engaged in fur chewing, and 18 showed other abnormal behaviours. Among the abnormal behaviours, scrabbling and oral stereotypies had the highest average IS scores (Table 2).

Oral stereotypies correlated moderately with fur chewing ($r_s=0.514$, $p = 0.001$, $n = 38$, see sheet 4 in supplements S1). All three abnormal behaviour categories correlated ($r_s=0.47–0.54$, $p < 0.003$) with total abnormal behaviours. In other cases, the correlation between dependent factors was low, with coefficients varying from −0.182–0.167.

3.1.1. Environmental impacts on total abnormal behaviours

The final model for total abnormal behaviours demonstrated weak explanatory power ($R^2adj.=-0.0059$) and did not reveal effects for the enrichment or screen groups ($F=0.892$, $p = 0.419$, sheet 6 in supplements S1). Although enrichment and screen did not show statistically significant effects ($PES=0.02–0.03$, $p = 0.686–0.804$), they were retained in the model as primary factors of interest. The block variable was omitted ($PES=0.00$, $p = 0.686$). These results suggest that the

Table 2
Average (± SD) FCM levels, activity rate (% of all observation points), and IS scores (% of active observation points) for different abnormal behaviour categories in female blue fox juveniles (n = 38) across categorical factors. *t*-tests (two-categorical) and ANOVA (block) determined the effects of independent factors on FCMs, activity rate, total abnormal behaviours, and scrabbling. For oral stereotypies and fur chewing, we used the Mann-Whitney *U* test and the Kruskal-Wallis test. Note: g = Hedges' g; ES = eta-squared; n.a. = not applicable. Other abnormal behaviours, i.e., sum of the least common abnormal behaviours was not included in the statistical analyses.

Attributes	Categories (n)	FCMs (ng/g)	Activity rate (%)	Total abnormal behaviours (%)	Scrabbling (%)	Oral stereotypies (%)	Fur chewing (%)	Other abnormal behaviours (%)
	Mean ± SD	393 ± 184	40.51 ± 4.69	3.01 ± 3.87	1.20 ± 1.31	1.10 ± 2.61	0.22 ± 0.46	0.48 ± 1.45
	(Min – Max)	115 – 918	29.4 – 52.20	0.16 – 17.80	0.00 – 5.51	0.00 – 9.38	0.00 – 2.27	0.00 – 7.91
Enrichment	B (20)	376 ± 144	39.31 ± 5.66	3.53 ± 4.57	0.91 ± 0.25	1.36 ± 0.62	0.38 ± 0.14	0.87 ± 0.43
	E (18)	412 ± 223	41.86 ± 2.91	2.43 ± 2.62	1.31 ± 0.36	1.02 ± 0.59	0.05 ± 0.02	0.04 ± 0.02
	p-value	*0.546*	*0.102*	*0.385*	*0.393*	*0.009* * *	*0.016* *	
	Effect size(g)	*−0.19*	*−0.55*	*0.28*	*−0.29*	n.a.	n.a.	
Screen	N (18)	449 ± 221	40.79 ± 5.37	3.71 ± 5.00	1.30 ± 0.34	1.34 ± 0.69	0.20 ± 0.09	0.87 ± 0.48
	S (20)	343 ± 129	40.27 ± 4.12	2.37 ± 2.44	0.92 ± 0.27	1.08 ± 0.53	0.24 ± 0.11	0.13 ± 0.07
	p-value	*0.078*	*0.736*	*0.313*	*0.399*	*0.720*	*0.806*	
	Effect size (g)	*0.58*	*0.11*	*0.34*	*0.28*	n.a.	n.a.	
Mother's fur chewing	No signs (19)	412 ± 211	39.27 ± 4.61	3.78 ± 5.02	1.26 ± 0.28	1.67 ± 0.75	0.17 ± 0.09	0.67 ± 0.46
	Signs (19)	374 ± 156	41.76 ± 4.56	2.24 ± 2.10	0.94 ± 0.32	0.73 ± 0.39	0.28 ± 0.12	0.29 ± 0.13
	p-value	*0.532*	*0.102*	*0.229*	*0.498*	*0.780*	*0.450*	
	Effect size (g)	0.20	−0.53	0.39	0.24	n.a.	n.a.	
Block	*p-value*	*0.001* * *	*0.584*	*0.723*	*0.724*	*0.889*	*0.550*	
	Effect size (ES)	*0.51*	*0.42*	*0.18*	*0.46*	n.a.	n.a.	

ns = non-significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

treatment factors had minimal or no impact on total abnormal behaviours.

3.1.2. Environmental impacts on scrabbling

Bodyweight loss was the primary factor explaining scrabbling behaviour (Fig. 2; *PES=0.44, p = 0.0005, dev.expl=0.44,* sheet 7 in supplements S1). The relationship between scrabbling and bodyweight loss was non-linear. Three individuals with the highest bodyweight losses (range 16.2–22.5 %), had scrabbling IS scores close to zero (0.07–0.44 %) (Fig. 2). Block remained in the model *(PES=0.07, p = 0.113)*, while screen and enrichment were sequentially omitted (*PES=0.00–0.05, p = 0.183–0.661*).

3.1.3. Environmental impacts on oral stereotypies and fur chewing

Oral stereotypies was more common in group B than in group E (85 % vs. 28 % of foxes (*odds ratio [OR]=0.042, p = 0.001*, Fig. 3, sheet 8 in supplements S1). A similar trend was observed for fur chewing (70 % vs. 39 %) although the association was weaker (*OR=0.270, p = 0.058*). The model for oral stereotypies included block (*OR=1.413, p = 0.052*), while screen was omitted (*p = 0.752, OR=0.760*). Tukey's post-hoc comparisons did not reveal any significant differences (*p > 0.05*) between the blocks. For fur chewing, both the screen and block were excluded from the final model (*OR=0.933–0.960, p = 0.741–0.933*). Overall, the model for oral stereotypies had strong predictive power (*Nagelkerke=0.512, AUC=0.827*), whereas the model for fur chewing showed weaker predictive performance (*Nagelkerke=0.130, AUC=0.657*).

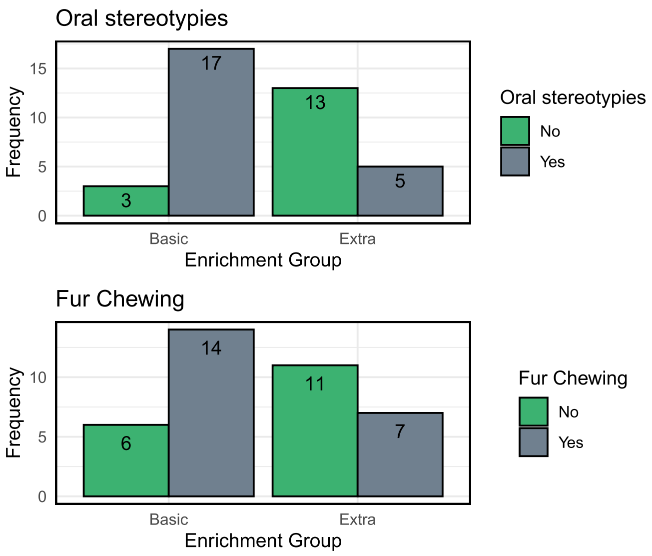

Fig. 3. Barplots representing frequencies of oral stereotypies and fur chewing among enrichment groups. Barplots were created using ggplot2 (Wickham, ham, 2016).

3.2. Environmental impacts on FCM levels

Cage location had the greatest impact on FCM levels, with block as a random factor accounting for 45 % of the variation (sheet 9 in supplements S1). Among fixed variables, which accounted only 6.6 % of the variation, only the screen showed a tendency to influence FCM levels (*PES=0.14, p = 0.048*, Fig. 4). Enrichment did not have an effect (*PES=0.00, p = 0.907*) and was therefore omitted from the model. At the individual block level, post-hoc tests revealed that block 4 (Northwest, highest average 641 ng/g) differed from blocks 9 (198 ng/g, *p = 0.008*) and 10 (235 ng/g, *p = 0.036*) in the Southeast row (Fig. 4).

3.3. Environmental effects on activity rate

The LM model explained 31 % of the variation in activity rate, with fixed factors accounting for 8.1 % (sheet 9 in supplements S1). Enrichment tended to have the strongest effect (*PES=0.13, p = 0.054*), while screen had no effect (*PES=0.01, p = 0.560*). Enrichment reduced variability in activity rates (Table 2), with group B exhibiting higher variance than group E (*Bartlett's* X^2*=7.079, p = 0.008*; Fig. 5).

4. Discussion

This study improved understanding of abnormal behaviours in juvenile blue fox females by identifying potential motivations behind the most common abnormal behaviour categories, specifically scrabbling and oral stereotypies. Additional enrichment reduced oral stereotypies. Scrabbling increased in animals with over 10 % bodyweight loss,

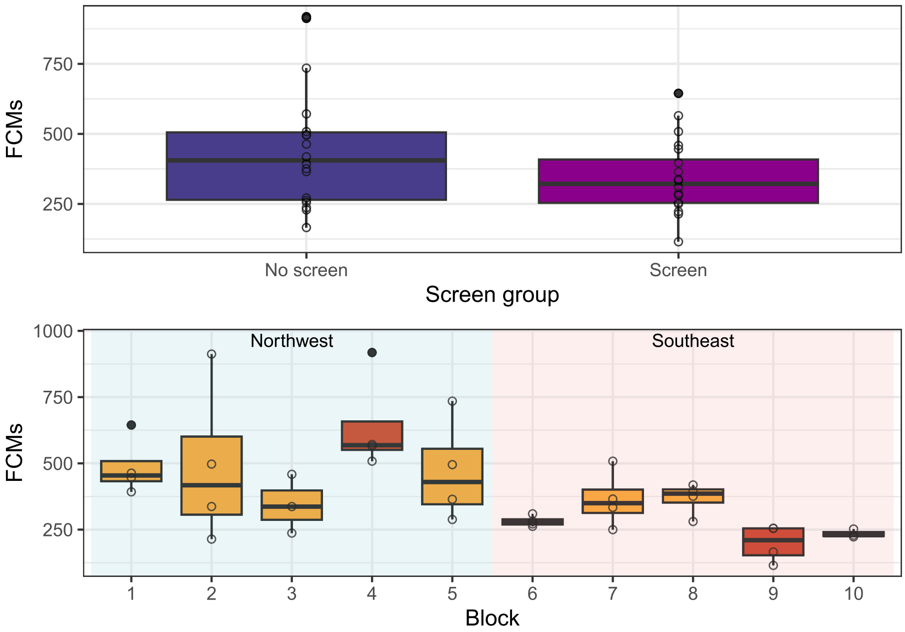

Fig. 4. Boxplots of FCMs in screen groups and blocks, with blocks 1–5 in the Northwest row and blocks 6–10 in the Southeast row. Block 4 differed from blocks 9 and 10 ($p < 0.05$, highlighted in red-orange). Open circles represent observed values. For clarity, the graph uses original data, although statistical analyses were performed on log-transformed FCM levels. The boxplots were created using dplyr (Wickham et al. 2023), ggplot2 (Wickham, 2016), and cowplot (Wilke, 2020) packages.

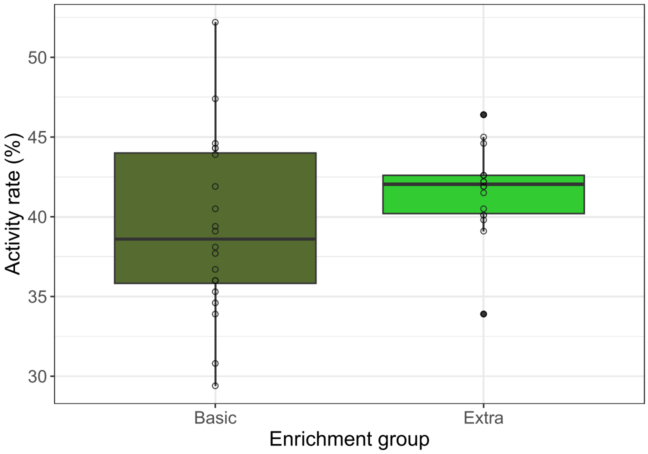

Fig. 5. Boxplots of activity rates in Enrichment groups, created by using dplyr (Wickham et al. 2023) and ggplot2 packages (Wickham, 2016) . Open circles represent the observed values.

although three high-weight-loss individuals had low scrabbling scores, indicating a non-linear relationship. These findings, which were obscured in the analysis of total abnormal behaviours, highlight the importance of assessing motivational-based abnormal behaviours by category (e.g., Mason, 2006).

Although we identified scrabbling as one of the most common abnormal behaviours among juvenile females, it is rarely mentioned in blue fox research. When mentioned (as scratching or digging), it typically falls under locomotor (Korhonen et al., 2001b) or manipulative stereotypies (Wikman et al., 1999). Similar ambiguity exists in mink studies, where the classification of scrabbling is variable (Dallaire et al., 2011; Malmkvist et al., 2024). Malmkvist et al. (2024) suggest that scrabbling might be linked to the presence of a human observer. However, our study did not identify any external cues associated with scrabbling. Instead, we propose that scrabbling is related to hunger. Importantly, scrabbling and interactions with the feeding tray were distinct behaviours: while scrabbling was observed throughout the day, interactions with the tray increased specifically as feeding time approached.

Reduced feeding increases stereotypic behaviours in various species. In mink, reduced feed portions increased the amount of total stereotypies (Damgaard et al., 2004) or mixed stereotypies, such as horizontal side-to-side and vertical up-and-down movement of the anterior body (Bildsøe et al., 1991). Similarly, ‘starve days’ without feed increased locomotor stereotypies in zoo-housed polar bears (Ames, 2000) and large cats (Lyons et al., 1997).

In the wild, arctic foxes gather fat reserves in autumn and naturally lose weight during the winter months, when their energy requirements are lower (Audet et al., 2002). Under farm conditions, restricted feeding is commonly used to slim females before breeding begins in late March (Kempe, 2018). The current breeding scheme has been prioritising larger and heavier animals (Kempe, 2018), which likely increases their appetite. Thus, despite their natural adaptation for fasting, drastically restricted feeding may impair farmed blue fox welfare. Rather than drastically reducing feed portions, we suggest that feeding strategies should maintain breeding animals at an ideal body condition year-round, avoiding excessive fattening before winter.

Interestingly, our GAM model revealed that the three foxes with the most extensive bodyweight loss had near-zero scrabbling IS scores. As part of a small project, we monitored enrichment use from the same video recordings (results not published). Two of these foxes were from group E and had enrichment use IS scores of 17.4 % and 27.5 %. They spent a considerable portion of their active times chewing bones, one of the enrichments during the video monitoring (see sheet 2 in supplements S1 for a complete enrichment list). This behaviour may have redirected hunger-related activities in a more species-appropriate way. The third fox, from group B, had the highest IS score (9.4 %) for oral stereotypies among all experimental animals. Additionally, this individual exhibited burying behaviour (IS score 4.1 %) by attempting to bury the drinking nipple despite the absence of any burying material. The lack of additional enrichments may have been a stronger driver for exhibiting abnormal behaviours other than scrabbling. Although prolonged hunger typically lowers animal welfare, the specific effects can vary widely between individuals (Neave et al., 2018).

While standard enrichments like wooden blocks (Korhonen et al., 2002) or bones (Koistinen et al., 2009) already reduce oral stereotypies, the welfare of farmed blue foxes could be further improved with varied enrichment. In farmed mink, enrichment objects like tubes, pull-ropes, and tennis balls reduced stereotypic behaviours and chewed tails (Hansen et al., 2007), and balls and plastic chains reduced chewed fur coats (Meagher et al., 2014). It is important to note that our enrichment setup was not economically viable, and enrichment preferences should be assessed to identify the most effective and practical enrichment options. Nonetheless, various manipulatable objects, such as straw (Korhonen et al., 2002), sand (Korhonen et al., 2003; Koistinen, 2009) or wooden box and drainage pipe piece (personal observations) – would likely enhance blue fox welfare. Regular rotation of these objects could help maintaining interest over time (e.g. Taylor et al., 2023; Koistinen et al., 2009).

We analysed oral stereotypies and fur chewing behaviour separately, but the reducing effect of enrichment on fur chewing was too weak to draw firm conclusions. Combining oral stereotypies and fur chewing in blue fox studies, as done by Korhonen et al. (2001a,b), seems reasonable, as these abnormal behaviours were similarly associated with the same factors. However, as these behaviours differ from each other, and fur-chewing is less-studied subject in blue foxes, it is preferable to monitor them separately.

In mink, early weaning age is a risk factor for fur chewing, which partly resembles suckling movements (Mason, 1994). In blue foxes, we observed self-grooming behaviour unrelated to abnormality; this often occurred when foxes were curled up and preparing to sleep, possibly representing natural fur-cleaning behaviour. In contrast, fur-chewing foxes distinctly removed hair by plucking tufts or breaking it with their teeth. Therefore, fur chewing in blue foxes may be linked to other factors than weaning age.

Based on our observations oral stereotypies and fur chewing in blue foxes resemble movements typical of feeding behaviour. Bergeron et al. (2006) suggested that oral stereotypies may increase with a diet composed largely of concentrated feed. In ocelots (*Leopardus pardalis*), hair-plucking behaviour ceased when they began receiving whole chickens, allowing them to redirect plucking behaviour toward prey (Hancocks, 1980). Moreover, chunky feed (increased size of animal parts in the feed) in minks reduced fur chewing (Malmkvist et al., 2013). Fur animals typically receive concentrated food paste, which they consume quickly. In our video recordings, feeding lasted only few minutes, and often included or was followed by licking the tray clean. Overall, the impact of less processed feed on the occurrence of oral stereotypies and fur chewing in blue foxes should be investigated further.

E foxes tended to be more active and showed less inter-individual variation in activity than B foxes. Similar findings have been reported in maned wolves (Cummings et al., 2007) and laboratory mice (Hobbiesiefken, 2021), where enrichment increased activity levels. In mice, enrichment also reduced stereotypies and variability in activity patterns. Malmkvist et al. (2024) linked low activity with impaired welfare. In our study, the activating effect of enrichment likely benefited the most passive individuals, leading to less varying activity rates across individuals.

Our findings suggest that locomotor stereotypies are not common among blue foxes. To avoid confusion, we recommend not using this term as a general label for all non-oral abnormal behaviours. Locomotor stereotypies in previous blue fox studies include pacing (Korhonen et al., 2001a,b; Korhonen et al., 2002; Wikman et al., 1999; Koistinen, 2009; Koistinen et al., 2009), circling (Korhonen et al., 2001; Koistinen, 2009; Koistinen et al., 2009), jumping (Korhonen et al., 2001; Wikman et al., 1999), head twirling (Korhonen et al., 2001a; Koistinen et al., 2009), tail chasing (Korhonen et al., 2001a,b; Koistinen, 2009; Koistinen et al., 2009), scratching (Korhonen et al., 2001b), and biting (Korhonen et al., 2001b). The IS sampling interval was either unjustified (Korhonen et al., 2001a,b; Korhonen et al., 2002) or based on a validated interval for total stereotypies by Jauhiainen and Korhonen (2005), Koistinen (2009) and Koistinen et al. (2009). Martin and Bateson (2007) advice selecting an interval suitable for all behaviours, achieved by the accepted maximum discrepancy between the continuous and the IS-sampled record of all behavioural categories separately. Estimating frequencies improves behavioural monitoring accuracy. Therefore, a preliminary validation of sampling methods and motivation-based grouping of abnormal behaviours is recommended before final data collection.

FCM levels are sensitive to various factors, with individual variation playing a significant role (Palme, 2019, blue fox; Ojala et al., 2021). This, combined with relatively small group sizes, may have limited our ability to detect group-specific differences. Since time of day does not significantly impact excreted FCMs (Ojala et al., 2021) and our focus was on long-term stress, 24-hour composite samples provided comprehensive information. Shorter, repeated sampling intervals risk disturbing the animals and can increase the number of missing samples due to lack of faeces. The shelter screen tended to affect FCM levels, possibly reflecting an increased sense of control by allowing foxes to hide or retreat (e.g. Mason et al., 2007). The sense of environmental control may also explain the impact of cage location, as environment outside the cage can affect fox behaviour (Rekilä et al., 1996). Foxes in cages 9 and 10 of the southeast row had better visibility of approaching people, such as farm personnel, compared to those in the back corner of the northwest row, which had limited visibility (Figs. 1 and 4). Thus, the foxes in blocks 9 and 10 may have perceived a stronger sense of environmental control.

5. Conclusions

This study found that the most common abnormal behaviours in juvenile blue fox females were scrabbling and oral stereotypies. Environmental enrichment reduced oral stereotypies, while scrabbling, likely driven by hunger, could be mitigated through a balanced feeding plan that avoids drastic feed changes. Providing shelter screens may reduce stress, but further research is needed to understand factors influencing individual FCM levels.

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CRediT authorship contribution statement

Ojala Eeva Auroora: Writing– review & editing, Writing– original draft, Visualization, Software, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Valros Anna:** Writing– review & editing, Supervision, Conceptualization. **Mononen Jaakko:** Writing– review & editing, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors consulted Copilot and ChatGPT for editing R-codes of the statistical models and visual graphs in R software. In addition to grammar check, the authors used Copilot to reduce characters in the Introduction. After using these tools or services, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2025.106559.

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