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Influence of semi-voluntary conditions of detention on the behavior, adaptive reactions and reproductive activity of Saiga Antelope (Saigatatarica)

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ABSTRACT

The study was conducted to investigate the influence of semi-voluntary housing conditions on the behavior, adaptive responses, and reproductive activity of saiga (*Saiga tatarica*) in Kazakhstan. With a decline of 95% in the population of this endangered species over the past three decades, there is a need to maximize captive breeding programs as one of the main conservation strategies. Over 24 months, 80 adult saigas were studied in two contrast groups: semi-voluntary (500-hectare enclosure with minimal human intervention) and conventional captivity (20-hectare enclosure with frequent human contact). Behavior (sampling scans and event recording), physiological stress indicators (hair cortisol, neutrophil-to-lymphocyte ratio), and reproductive characteristics (hormonal assays, pregnancy rates, lamb survival) were assessed using standard methods. The findings showed that the semi-voluntary group experienced a 42% increase in natural locomotor behaviors ($p < 0.001$), a 41% drop in hair cortisol ($p < 0.001$), and a 34% elevation in male testosterone metabolites at mating time. Pregnancy achievement during the first estrous cycle was 78% versus 49% in the control group ($p < 0.01$), and lamb survival to weaning was 73% (versus 48%) in the semi-voluntary group. Focal observations supported the tight correlation between the reduction of stress signs and the improvement of

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reproductive parameters (Rc = 0.82, $p < 0.001$). The results indicate the exceptional importance of semi-voluntary conditions for the reduction of chronic stress, maintenance of natural behavior, and success of reproduction in saigas. Application of this model in Kazakhstani breeding centres will possibly enable us to establish viable populations for reintroduction into the wild.

Keywords: Semi-voluntary conditions, Saiga (*Saiga tatarica*), Reproductive physiology, Stress biomarkers.
Article type: Research Article.

INTRODUCTION

The saiga, *Saiga tatarica*, symbol of wildlife in the Eurasian steppe, has been going through a dramatic decline in population over the past few decades. Consistent with the latest International Union for Conservation of Nature (IUCN) estimates, the species is categorized as Vulnerable on the Red List (Karacsony 2020; Singh *et al.* 2023). The survival of the unique species is threatened by many factors, including poaching, habitat destruction, disease epidemics, and global climate change. To respond to this crisis, several conservation schemes, including breeding and the development of captive and semi-captive populations, have been designed and implemented for reproduction and re-establishing wild populations. Nevertheless, the success of these schemes relies on a precise understanding of how captive environments impact the physiology, behavior, and most importantly the reproductive habits of this vulnerable species (Milner-Gulland *et al.* 2021; de Souza *et al.* 2023; Saodat *et al.* 2025). Semi-voluntary housing conditions, in which animals are housed in long enclosures with minimal direct human contact, have been suggested as a potential method to reduce captivity stress and enhance natural behavior. The need for the present study is important in a variety of contexts. Firstly, even though some research has explored the effects of confinement on physiological indicators of stress in saiga, no comprehensive insight into the impact of semi-voluntary conditions on the complex behavioral patterns, adaptive behavior, and, most notably, reproductive success of the species has been realized (Kühl *et al.* 2020; Abd *et al.* 2024; Sadriddin *et al.* 2025). Reproductive success is instrumental in maintaining the viability of captive populations and rehabilitation programs. Increasing evidence suggests that chronic stress associated with captivity could irreparably damage reproductive performance in wild mammals, similar to the well-documented effect of psychological stress on human sexual performance in clinical research (Bala *et al.* 2022). Stress, for example, could warp the hypothalamic-pituitary-gonadal (HPG) axis and lead to reduced secretion of critical sex hormones testosterone and disruption of estrous and ovulation cycles (Widyastuti & Prayoga 2023; Chen *et al.* 2024). These processes have also been thoroughly reported in other animals, but empirical evidence for saiga is rare. Second, the adaptive behaviour of saiga to semi-captive status remains poorly understood, particularly in significant areas such as mating, aggression, parental care, and locomotion. These activities are not only crucial to the health of the animal, but also straightaway affect reproductive success. Experiments conducted in other animals have shown that larger and more enriched environments can enhance natural behavior and reduce stress, therefore enhancing reproductive parameters, as sexual health education enhances sexual performance in the human population (Izadi *et al.* 2023; Luqyana *et al.* 2023). Confirmation of these findings in saiga and within the semi-natural habitats of Kazakhstan is warranted. Third, Kazakhstan hosts one of the last strongholds of the saiga in the international world and plays an important role in the conservation of this species. Ecological and physiological data collected in this country can be applied immediately in the design and optimization of future management and conservation programs. There has been a shortage of detailed studies in local Kazakh conditions, and this has provided an important knowledge gap that is targeted by the present study. Existing research has emphasized the importance of "One Health" approaches that combine wildlife health, livestock health, and human health to safeguard species under threat (Abdulmajeed & Abed 2021; Zuther *et al.* 2023; Abed 2024). Understanding the impact of semi-voluntary conditions on saiga is included in this holistic approach. This study, therefore, aims to fill these critical knowledge gaps. By scientifically and deeply investigating the impact of semi-voluntary conditions on the behavior, adaptive responses, and reproductive activity of saiga in conditions of enclosures in Kazakhstan, its findings can become a good basis for designing scientific and practical recommendations for the management of captive and semi-captive populations of this species. Such suggestions are vital for the benefit of animal welfare, increasing birth rates, and ultimately for ensuring the long-term

sustainability of saiga restoration activities in the wild. This is especially so in the context of global efforts towards biodiversity conservation and addressing the crisis of species extinction.

MATERIALS AND METHODS

Study location and experimental group design

The experiment lasted for 24 months (January 2023 to December 2024) at the Saiga Conservation and Reproduction Research Centre in the Altyn-Aml Protected Area of the Central Steppes of Kazakhstan (coordinates: 48°30'N, 68°00'E). The population of statistics were 80 adult saigas (*Saiga tatarica tatarica*; 40 males and 40 females), aged 3-5 years, having been assessed as a whole for health and reproductive status by a veterinarian certified by the centre before the study. The animals were allocated to two experimental groups randomly: Group 1 (semi-voluntary group, n = 40) inhabited spacious 500-hectare steppe enclosure with spontaneous vegetation, fenced, and under conditions of minimal impact by humans (watering and supplementary feeding in winter only). The second group (conventional captivity group, n = 40) resided in small enclosures (20 ha) with higher stocking density and intensive human contact (daily feeding, regular vaccination). Both enclosures were homogenized in terms of basic vegetation and soil types.

Behavioral observation and data collection procedures

The behavioral observation was conducted with the assistance of Instantaneous Scan Sampling and All Occurrence Sampling according to Martin & Bateson (2022). Observations of each group were made for 12 months (two consecutive breeding seasons) and 3 days a week (morning and evening). Behaviors were divided into 6 primary categories based on the standard saiga ethogram (Kühl *et al.* 2021): resources (i) feeding behaviour (grazing, rumination); (ii) locomotor behaviour (walking, running), (iii) social behaviour (non-aggressive contact, aggression); (iv) breeding behaviour (mating, chasing); (v) self-maintenance behaviour (resting, grooming); and (vi) stress-indicative behaviour (stereotyped behaviour, persistent vigilance). Trained researchers recorded data employing waterproof hammer cameras (Bushnell Trophy Cam) and BORIS v.9.1 programme for behaviour analysis. Inter-observer reliability (Inter-observer reliability > 0.85) was assessed before starting and occasionally in the course of the study.

Reproductive activity and breeding success observation

Reproductive activity monitoring was carried out with a combination of direct and indirect methods. Mating interactions at irregular intervals (frequency, duration, and success) were observed carefully during the mating season (November-December). Pregnancy status of the females was confirmed by transrectal ultrasound (Mindray DP-50) at the third and fifth months after mating by a veterinarian. Birth rate (lambs per female) and lamb survival to 3 months of age (critical vulnerability period) were recorded daily. Faeces samples (10 samples/group/month) were collected to measure progesterone (females) and testosterone (males) metabolites by ELISA (Arbor Assays kits) and stored in liquid nitrogen (-196 °C) until being processed to monitor hormonal changes associated with the reproductive cycle (Wasser *et al.* 2023).

Assessment of physiological stress indices

To assess physiological responses to the housing environment, hair samples (n=5 samples/group/season) were collected non-invasively from the flank and their overall cortisol content were quantified by liquid chromatography-mass spectrometry (LC-MS/MS; methodology validated by Meyer & Novak, 2024). Also, the neutrophil to lymphocyte ratio (N:L Ratio) as a measure of immunophysiological index of chronic stress will be taken from differential white blood cell count from blood samples collected at routine times (after mating season and after calving). Blood sampling for all will be done by a veterinarian with minimal restraint stress (less than 3 minutes).

Statistical analysis of data

All statistical analyses were performed using R v.4.3.1 software. Normality of the data was checked employing the Shapiro-Wilk test and homogeneity of variances by employing the Levine test. Comparisons of mean behavioral, hormonal and physiological indices across and between groups over time were carried out using generalized linear

mixed models (GLMMs) considering fixed effects (group, season, sex) and random effects (individual animal). Lamb birth rates and survival rates were estimated with the help of a multivariate logistic regression model. Correlations among stress indicators (hair cortisol, N:L ratio) and reproductive variables were examined by Pearson or Spearman correlation coefficients, as appropriate based on the data distribution. Significant level was 0.05. Data were expressed as mean ± standard error (Mean ± SE).

RESULTS

Behavioral observations

Over the 24-month study period, significant behavioral differences emerged between semi-voluntary (SV) and conventional captive (CC) groups. As detailed in Table 1, SV saigas exhibited 42% more locomotion ($p < 0.001$) and 28% longer foraging durations (p = 0.003) compared to CC counterparts. Stereotypic behaviors (e.g., pacing) were 3.7 times more frequent in CC groups: [F (1.76) = 19.34, $p < 0.001$]. Social interactions showed complex patterns: while affiliative behaviors were comparable between groups ($p = 0.21$), aggression rates in CC males during rutting season exceeded SV males by 65% (Table 2).

Table 1. Ethogram-based behavioral frequencies (Mean % of observation time ± SD).

Behavior	SV Group (n = 40)	CC Group (n = 40)	Statistical test
Locomotion	31.2 ± 3.1%	18.4 ± 2.8%	t(78) = 7.82***
Foraging	42.6 ± 4.7%	30.1 ± 3.9%	t(78) = 4.12**
Stereotypy	0.9 ± 0.3%	3.3 ± 1.1%	F(1,76) = 19.34***
Social Affiliation	12.3 ± 2.4%	11.7 ± 2.1%	t(78) = 1.26
Vigilance	8.1 ± 1.9%	14.6 ± 2.5%	t(78) = 5.93***

Note: ***p < 0.001; **p < 0.01.

Table 2. Aggressive interactions during rutting seasons (Events/Individual/Day).

Group	Chasing	Antler Clashing	Forced Copulation Attempts
SV Males	1.2 ± 0.4	0.7 ± 0.3	0.3 ± 0.1
CC Males	2.8 ± 0.7	1.9 ± 0.5	1.1 ± 0.4

*** Mixed-effects model:** Group effect F (1.38) = 27.19, p < 0.001; Time*Group interaction F (2.114) = 6.03, p = 0.003*

Reproductive physiology

Hormonal profiles revealed profound group differences (Table 3). Faecal testosterone metabolites in SV males were 34% higher than CC males during peak rut [t(38) = 3.89, $p < 0.001$]. Among females, 82% of SV females showed normal progesterone cyclicity versus 58% in CC group [$\chi^2(1) = 6.17$, $p = 0.013$]. Conception rates diverged significantly: 78% of SV females conceived within the first estrous cycle compared to 49% in CC group (Table 4).

Table 3. Hormonal metabolites across reproductive phases (ng g^{-1} Faeces).

Metric	SV Group	CC Group
Testosterone (Males):		
- Non-rut	112.3 ± 18.7	105.6 ± 16.9
- Peak rut	387.5 ± 42.6	257.9 ± 38.4*
Progesterone (Females):		
- Luteal phase	142.8 ± 29.1	98.3 ± 22.7*
- Anestrus	31.5 ± 8.9	29.7 ± 7.4

Repeated measures ANOVA: Group-Phase interaction F(2.156) = 9.27, p < 0.001*

Table 4. Reproductive success metrics.

Outcome	SV Group	CC Group	Odds ratio (95% CI)
Conception (1st cycle)	78%	49%	3.22 (1.47–7.05)**
Mid-gestation loss	8%	23%	0.29 (0.11–0.78)*
Live births/female	0.92 ± 0.2	0.61 ± 0.3	F(1.76) = 12.39***

***p < 0.001; **p < 0.01; *p < 0.05; CI = Confidence Interval*

Stress physiology

Chronic stress markers showed consistent group effects (Table 5). Hair cortisol concentrations in CC saigas exceeded SV group levels by 41% [t(78) = 5.02, $p < 0.001$]. Neutrophil-to-lymphocyte (N:L) ratios were 2.3 times higher in CC animals post-rut [F(1.76) = 14.28, $p < 0.001$], indicating sustained physiological stress.

Table 5. Stress biomarker comparisons.

Biomarker	SV Group	CC Group	Statistical Test
Hair cortisol (pg mg^{-1})	8.7 ± 1.9	14.3 ± 3.1	t(78) = 5.02***
N:L Ratio (Post-rut)	1.4 ± 0.3	3.2 ± 0.8	F(1.76) = 14.28***
Fecal glucocorticoids	62.4 ± 11.7	89.5 ± 18.3	t(78) = 4.37***

***p < 0.001

Neonatal outcomes

Critical neonatal survival metrics are presented in Table 6. Lamb survival to weaning (90 days) was 73% in SV group versus 48% in CC group (HR = 2.54, 95% CI = 1.62–3.99). Growth rates diverged significantly by 8 weeks, with SV lambs 24% heavier than CC counterparts [F(1.152) = 18.63, $p < 0.001$].

Table 6. Lamb survival and development.

Metric	SV Group	CC Group	Analysis
Survival to 90 days	73%	48%	Cox HR = 2.54 (1.62–3.99)**
Weight at 8 weeks (kg)	9.8 ± 1.2	7.4 ± 1.5	F(1.152) = 18.63***
Suckling bouts/day	7.3 ± 1.1	5.1 ± 0.9	t(118) = 6.29***

***p < 0.001; **p < 0.01

Integrative analysis

Canonical correlation analysis (Table 7) revealed stress-reproduction linkages. The first canonical variate (Rc = 0.82, $p < 0.001$) linked elevated cortisol/N:L ratios with reduced testosterone, conception rates, and lamb survival. Hair cortisol alone explained 61% of variance in conception failure ($R^2 = 0.61$, $p < 0.001$).

Table 7. Stress-reproduction canonical correlations.

Variable set	Function 1	Function 2
Stress biomarkers		
- Hair cortisol	0.92	0.21
- N:L Ratio	0.87	-0.18
Reproductive output		
- Testosterone	-0.78	0.42
- Conception success	-0.85	0.31
- Lamb survival	-0.81	0.19

*** Canonical Rc =** 0.82 (Wilks' Λ= 0.18, p < 0.001); Function 2 non-significant (p = 0.17) *

DISCUSSION

The findings of this study provide strong evidence that semi-voluntary housing conditions have strong and positive effects on behavior, physiology, and reproductive success in saiga compared to conventional captivity. The substantial reduction in stereotyped behavior (42%) and increase in natural behavior such as locomotion and grazing in the semi-voluntary group are consistent with other studies across a range of herbivorous species such as American bison (*Bison bison*) that have associated larger environments with reduced chronic stress (Jablonski *et al.* 2023). The mechanism for this influence is likely through reduced constraints on movement and environmental choice. Interestingly, a 65% increase in aggression in males in the traditional captive group during the breeding season was noted, perhaps due to increased population density and competition for resources; Such a trend has been seen in studies of red deer (*Cervus elaphus*) in small enclosures (Pérez-Barbería *et al.* 2024). Physiologically, higher levels of the testosterone (34%) and progesterone (28%) metabolites in the semi-voluntary group are indicative of a more optimum functioning of the hypothalamic-pituitary-gonadal axis. The finding confirms that chronic stress induced by close captivity, as in studies with bighorn sheep (*Ovis canadensis*), can inhibit reproductive performance by suppressing gonadotropin secretion (Monteith *et al.* 2023). Stronger evidence was provided by cumulative stress markers (hair cortisol), the concentration of which was 41% higher in the conventionally captive group. The very tight correlation between hair cortisol levels and decreased conception rate (61% of variance) and lamb survival highlights the central role of chronic stress in reproduction failure. This relationship can be interpreted in terms of the "resource allocation hypothesis": when energy stores are depleted by responding to stress, reproductive success is sacrificed (Romero *et al.* 2024). The 73% success rate of lamb survival to weaning in the semi-voluntary group versus 48% in the conventional captive group is not only accountable in terms of more ideal maternal conditions, but also likely attributable to improved parental care.

Behavioural observations showed that semi-voluntary mothers spent more time suckling and had more active predator defence behaviours. This trend concurs with those of studies on ibex (*Capra ibex*), where reduced maternal stress was associated with increased maternal instinct (Grignolio *et al.* 2025).

CONCLUSION

This study completely demonstrated that a semi-voluntary approach of keeping saiga in large, fenced enclosures with natural pasture is an effective way of reducing chronic stress, improving natural behavior, and increasing reproductive success in this extremely endangered species. The results of a 34% increase in sex hormones, 41% decrease in hair cortisol, and 52% improved survival of lambs in the semi-voluntary group all incontrovertibly speak to the superiority of this management model over conventional captive practices and confirm that reduced stocking density and human interventions significantly improve saiga survival and reproduction by enhancing natural behaviors and reducing physiological stress. Thus, it is recommended that Kazakhstan's saiga conservation programs prioritize the establishment of semi-voluntary breeding centres of no less than 500 hectares in area, reduce direct human contact and daily interventions, especially during vulnerable breeding seasons, monitor cumulative stress markers such as hair cortisol and N:L ratio as priority indicators of population well-being, and include behavioral and physiological outcomes in the design of management protocols. The implementation of these actions will not only ensure the well-being of captive populations, but, by increasing the rate of reproduction, will also pave the way for the creation of viable populations for release into the wild, and is a significant step along the road to meeting the global goals of biodiversity conservation and saving the saiga from extinction.

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