



研究论文 ORIGINAL PAPERS

基于粪便皮质醇的 野化放归大熊猫应激性研究

杨波[#], 严啸[#], 何胜山, 牟仕杰, 刘晓强,
冯高志, 周季秋, 杨洪, 张大磊, 吴代福, 罗波, 周晓^{*}

(中国大熊猫保护研究中心, 大熊猫国家林业和草原局重点实验室, 成都 610057)

稿件运行过程

收稿日期: 2025-09-28

修回日期: 2026-03-11



摘要

关键词: 大熊猫;

野化培训;

放归;

应激;

粪便皮质醇

Keywords: Giant panda (*Ailuropoda melanoleuca*);
Wildness training;
Translocation;
Stress response;
Fecal cortisol

中图分类号: S865

文献标志码: A

文章编号:

2310-1490(2026)-02-0225-08

DOI: 10.12375/ysdwx.202509022

保护性易位是野生动物保护的重要手段之一,易位过程会给动物带来不同程度的应激压力,可能影响其放归后的健康状态和生存力,在动物保护计划中应充分考虑。大熊猫(*Ailuropoda melanoleuca*)是生物多样性保护的旗舰物种,其放归工作成效显著,但对野化放归大熊猫的应激性研究鲜有报道。本研究收集了2010—2017年出生的12只圈养大熊猫在不同野化培训阶段和其放归后(其中4只)的粪便样品,以及圈养与野生大熊猫的粪便样品,测定并比较粪便皮质醇水平。结果显示:野化放归大熊猫在培训第二阶段的皮质醇水平显著低于第一阶段,放归后显著低于培训第二阶段,且放归后个体与野生个体无显著差异;此外,野化培训个体的皮质醇水平显著低于圈养个体。结果表明,随着野化培训阶段的递进,大熊猫粪便皮质醇水平逐渐降低并趋近野生个体水平。本研究积累了野化放归大熊猫的基础生理数据,对大熊猫野化放归与迁地保护具有指导意义,建议将粪便皮质醇监测纳入野化放归大熊猫的长期监测工作中。

第一作者简介: 杨波(1987—),男,高级工程师;主要从事大熊猫生理与行为学研究。E-mail: yangb_198701@163.com

[#] 共同第一作者: 杨波; 严啸

^{*} 通信作者: 周晓, E-mail: 58339217@qq.com

Stress Response of Wildness Training and Translocation Giant Pandas Based on Fecal Cortisol

YANG Bo[#], YAN Xiao[#], HE Shengshan, MU Shijie, LIU Xiaoqiang,
FENG Gaozhi, ZHOU Jiqui, YANG Hong, ZHANG Dalei, WU Daifu, LUO Bo, ZHOU Xiao^{*}

(China Conservation and Research Centre for the Giant Panda,
Key Laboratory of State Forestry and Grassland Administration on the Giant Panda, Chengdu 610057, China)

Abstract: Conservation translocation is one of the important methods for wildlife protection, and the process of translocation could bring different degrees of stress to animals, which might affect the health status and survival of translocated animals after release, which should be fully considered in animal protection programs. The giant panda (*Ailuropoda melanoleuca*) is a flagship species of biodiversity conservation, with remarkable achievements in wildness training and release, but there are few reports on the stress response of wildness training and released giant pandas. In this study, 12 captive giant pandas born between 2010 and 2017 were studied, and fecal samples were collected from them at different training stages and from four of them after release, as well as from captive and wild giant pandas. Fecal cortisol levels from all samples were measured and compared respectively. The results showed that cortisol level of the giant pandas in the second stage of wildness training was significantly lower than that in the first stage, and that after release was also significantly lower than that in the second training stage, and there was no significant difference between the released and wild individuals. In addition, cortisol levels were significantly lower in wildness training individuals than in captive individuals. The results indicated that with the progress of training and release stages, the fecal cortisol concentration of giant pandas in wildness training and translocation program gradually decreased and approached that of wild giant pandas. This study accumulated basic physiological data of wildness training and released giant pandas, which had guiding significance for the translocation and ex-situ conservation of giant pandas. It was suggested that fecal cortisol concentration be included in the long-term monitoring content of giant panda wildness training and release program.

保护性易位 (conservation translocation) 是野生动物保护的重要手段之一, 其过程通常涉及捕获、饲养、麻醉、体检、运输及环境改变等多个环节, 各环节均可能对动物产生不同程度的应激^{[1]9-10}。当受到外界刺激后, 动物可通过自主神经系统和下丘脑—垂体—肾上腺 (hypothalamic-pituitary-adrenal, HPA) 轴调控多项生理功能和行为表达, 以重建机体内环境稳态^[2-3]。若应激源持续存在, 可能导致动物陷入长期应激状态, 进而产生较高的生理代价甚至直接伤害。因此, 应激是影响易位动物健康、行为和认知能力的重要因素^[4], 甚至可能直接决定个体存活率和易位项目的成败^[5]。如何有效降低应激, 已成为易位项目放归策略的核心内容之一^{[1]9, 19}。

HPA 轴介导的应激反应可促使动物体内糖皮质激素 (glucocorticoid) 分泌量呈不同程度上升, 该激素

是评估动物应激反应程度的重要指标。与血液、唾液等样品相比, 粪便样品具有非损伤性、易于采集的优势, 已被广泛应用于野生动物的应激研究中^[6-8]。已有研究表明, 大熊猫 (*Ailuropoda melanoleuca*) 粪便皮质醇 (fecal cortisol) 水平可在一定程度上反映个体应激状态^[9-11], 并在圈养和野生种群研究中多有应用^[12-15]。

我国圈养大熊猫野化放归项目始于 2003 年, 截至目前已在小相岭和岷山山系累计放归个体 13 只, 其中 11 只在野外存活^[16], 在大型哺乳动物放归实践中存活率处于较高水平。但这并不意味着其面临的应激压力可以忽视。在圈养条件下, 人为噪声、高温、转运和麻醉等均可造成大熊猫粪便皮质醇水平升高或行为异常^[17-18], 生理应激 (physiological stress) 甚至被认为是造成其繁殖力低下的原因之一^[19-20]。

此外,不同性别、个体之间对应激的敏感度存在差异,圈养管理需在个体水平上予以关注^[21]。与此同时,野外大熊猫种群仍处于濒危状态,其个体同样可能面临食物短缺、寄生虫感染和人为干扰等压力胁迫^[22-25]。因此,圈养大熊猫在野化培训期间及放归后均可能受到不同程度、多样的应激压力,进而引发心理、生理和行为改变,最终影响野外生存能力。然而,目前野化放归大熊猫粪便皮质醇水平尚未纳入长期监测体系,相关应激研究仍处于初步阶段^[26],对其在野化培训和放归过程中应激压力的认识尚不深入。

基于此,本研究收集不同野化培训阶段及放归后大熊猫的粪便样品,测定并比较其粪便皮质醇水平;同时以圈养大熊猫和野生大熊猫作为参照,评估

野化放归个体的压力水平,旨在为野化放归大熊猫的基础生理研究积累基础数据,并为大熊猫野化放归和迁地保护实践提供科学依据。

1 研究方法

1.1 研究对象与研究地点

研究对象为中国大熊猫保护研究中心 2010—2017 年出生的 12 只野化培训大熊猫,个体详细情况见表 1。野化培训地位于卧龙国家级自然保护区,放归地为栗子坪国家级自然保护区。野化放归流程:采用“母兽带仔”野化培训方式,受训个体先在面积较小的第一阶段野化培训圈生活,随后转入海拔更高、面积更大且更接近野外的第二阶段野化培训圈,最后放归野外^[27]。各阶段野化培训圈信息见表 2。

表 1 野化放归大熊猫基本信息和采样情况

Table 1 Basic information and sampling data of wildness training and translocation giant pandas

呼名(谱系号) Name (Pedigree number)	性别 Sex	母亲(谱系号) Mother (Pedigree number)	出生日期 Date of birth	样品份数 Number of samples		
				第一阶段 The first stage	第二阶段 The second stage	放归后 After release
淘淘(777) Taotao(777)	♂	草草(581) Caocao(581)	2010-08-03	—	25	—
张想(826) Zhangxiang(826)	♀	张卡(505) Zhangka(505)	2011-08-20	3	15	52
新媛(843) Xinyuan(843)	♀	龙欣(516) Longxin(516)	2012-07-28	4	7	—
雪雪(850) Xuexue(850)	♀	思雪(625) Sixue(625)	2012-08-15	2	5	—
华姣(866) Huajiao(866)	♀	草草(581) Caocao(581)	2013-07-06	—	25	10
华荣(874) Huarong(874)	♂	华美(487) Huamei(487)	2013-07-18	—	3	—
华妍(888) Huayan(888)	♀	晔晔(495) Yeye(495)	2013-08-14	—	32	—
映雪(955) Yingxue(955)	♀	思雪(625) Sixue(625)	2015-07-12	—	10	6
八喜(956) Baxi(956)	♂	喜妹(511) Ximei(511)	2015-07-26	—	4	4
云儿(1058) Yun'er(1058)	♂	茜茜(476) Qianqian(476)	2017-05-20	1	8	—
冉冉(1062) Ranran(1062)	♀	龙欣(516) Longxin(516)	2017-05-31	8	27	—
潘旺(1064) Panwang(1064)	♀	娜娜(568) Nana(568)	2017-06-02	6	24	—

—. 未采集到样品。
—. No sample was collected.

表 2 野化培训圈信息

Table 2 Information of wildness training enclosures

培训阶段 Stage	地点 Place	海拔 /m Altitude	面积 /m ² Area
第一阶段 The first stage	核桃坪 Hetaoping	1 860	2 400 ~ 3 200
	核桃坪后山 Back mountain of Hetaoping	2 050 ~ 2 500	40 000 ~ 240 000
第二阶段 The second stage	天台山 Tiantaishan	2 400 ~ 3 010	240 000 ~ 480 000

1.2 样品采集

不定期采集野化培训期间和放归后大熊猫的新鲜粪便样品,共计281份(表1)。采样时大熊猫年龄:第一阶段1.2~1.6岁,第二阶段1.2~3.2岁,放归后2.3~4.6岁。圈养亚成体大熊猫粪便样品于2018—2022年采集自中国大熊猫保护研究中心都江堰基地,采样时个体年龄为2.0~3.0岁,每个体采集2~5份,共获得7只(3♀、4♂)个体的23份样品。野生大熊猫粪便样品收集于2014—2023年,采样地点为卧龙国家级自然保护区内的核桃坪、天台山和五一棚区域,每个体采集1~3份,共获得36只野生个体的48份样品。

1.3 粪便样品皮质醇水平测定

1.3.1 样品处理

粪便样品采集后立即装入自封袋,当天置于 -20°C 冻存。在每年度采样工作完成后,采用真空冷冻干燥技术将粪便样品冻干至恒质量,经揉碎粉末化处理后,利用孔径0.50 mm(35目)筛网筛取粪便粉末于 -75°C 冻存。

1.3.2 皮质醇提取与测定

称取约0.1 g粪便粉末,采用90%乙醇萃取其中的皮质醇,具体步骤参照唐丹等^[28]的方法。采用酶联免疫吸附法(enzyme-linked immuno-sorbent assay, ELISA)测定激素水平,所用抗体(CORT-R4866)、辣根过氧化物酶(horseradish peroxidase, HRP)及标准品等试剂均来源于美国加州大学戴维斯分校人口健康与生殖系临床内分泌学实验室^[29]。

1.4 数据处理与统计分析

采用独立样本 t 检验,分析野化培训大熊猫母幼分离前后3个月内粪便皮质醇水平的差异。采用Mann-Whitney U 检验(数据不符合正态分布)或独立样本 t 检验(数据符合正态分布且方差齐性),分别比较野化放归个体在不同阶段(培训第一阶段、培训第二阶段和放归后)的皮质醇水平差异,以及野化培训个体与圈养个体、放归个体与野生个体间的皮质醇水平差异。为排除年龄干扰,仅分析年龄差不超过5个月的同龄个体,显著水平 $\alpha = 0.05$ 。所有统计分析及绘图均采用GraphPad Prism 9.0软件完成。

2 结果

2.1 母幼分离前后粪便皮质醇水平差异

对2.0~2.7岁的野化放归大熊猫,在母幼分离

前后3个月内采集粪便样品测定皮质醇水平。独立样本 t 检验结果显示,野化培训大熊猫在母幼分离前后的粪便皮质醇水平分别为 (239.2 ± 118.6) 、 (238.2 ± 136.1) ng/g(图1),组间均值差值仅为1.0 ng/g(95% CI: $-76.9 \sim 74.9$ ng/g),二者差异无统计学意义($t = 0.027, P = 0.979$)。

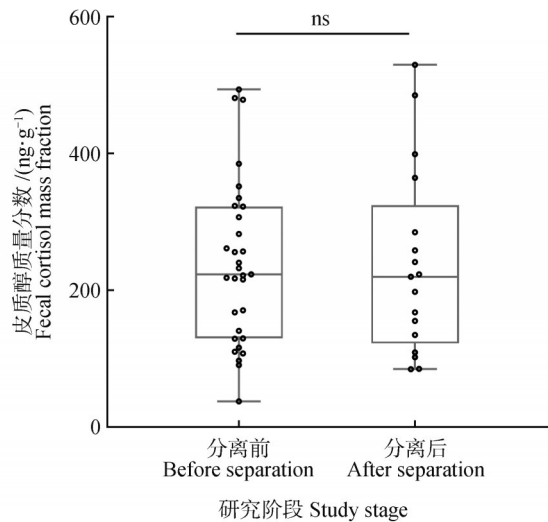


图1 野化培训大熊猫母幼分离前后粪便皮质醇水平比较

Figure 1 Comparison of fecal cortisol levels of wildness training giant pandas before and after separation of mother and offspring

2.2 不同阶段野化大熊猫粪便皮质醇水平差异

在控制年龄相近的前提下, Mann-Whitney U 检验结果(图2)显示,14~19月龄受训个体在野化培训第一阶段皮质醇水平平均秩次为45.95,第二阶段为22.18,二者差异极显著($U = 85, P < 0.001$);28~32月龄放归个体皮质醇水平平均秩次为42.73,极显著低于同年龄段个体在培训第二阶段的65.84($U = 733.5, P < 0.001$)。

2.3 不同来源大熊猫粪便皮质醇水平差异

Mann-Whitney U 检验结果显示(图3),2岁(23~25月龄)野化个体在第二阶段的粪便皮质醇平均秩次为19.28,同龄圈养个体为28.60,二者差异显著($U = 89, P = 0.036$);3岁(35~37月龄)时,独立样本 t 检验显示二者差异更为显著($t = 2.638, P = 0.013$),野化个体皮质醇水平为 (170.2 ± 81.6) ng/g,圈养个体为 (249.7 ± 87.6) ng/g,差值为 -79.5 ng/g(95% CI: $-141.0 \sim -17.9$ ng/g)。此外,放归后大熊猫与野生大熊猫之间的粪便皮质醇水平差异无统计学意义($U = 2423, P = 0.287$),二者平均秩次分别为87.02和78.44(图4)。

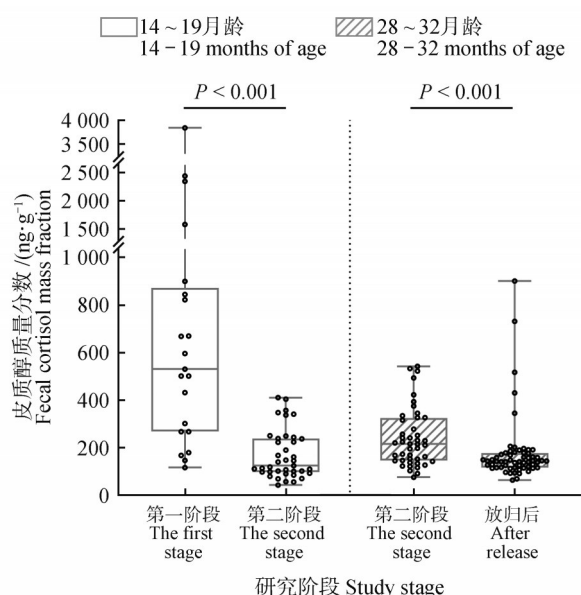


图2 不同年龄大熊猫在野化培训期和放归后粪便皮质醇水平比较

Figure 2 Comparison of fecal cortisol levels of giant pandas of different ages during the wildness training period and after release

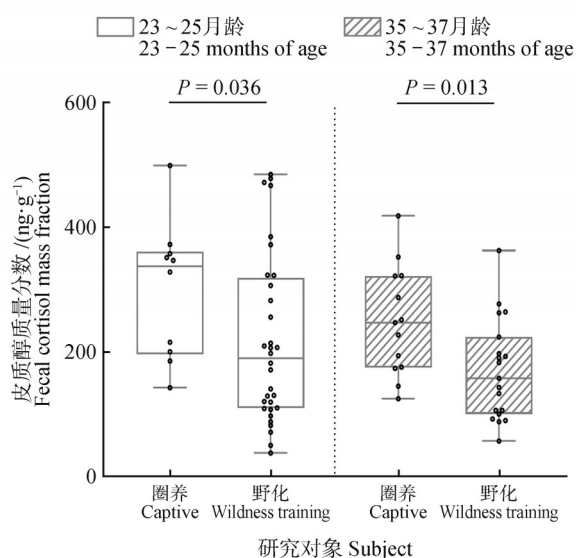


图3 不同年龄圈养和野化培训大熊猫粪便皮质醇水平比较

Figure 3 Comparison of fecal cortisol levels of captive and wildness training giant pandas at different ages

3 讨论与结论

在自然状态下,动物可受多种应激源刺激,皮质醇水平通常反映其综合压力状态。本研究表明,野化放归大熊猫粪便皮质醇水平随培训阶段递进而逐渐降低,放归后进一步下降至与野生个体无显著差异的水平,且野化培训个体皮质醇水平显著低于圈

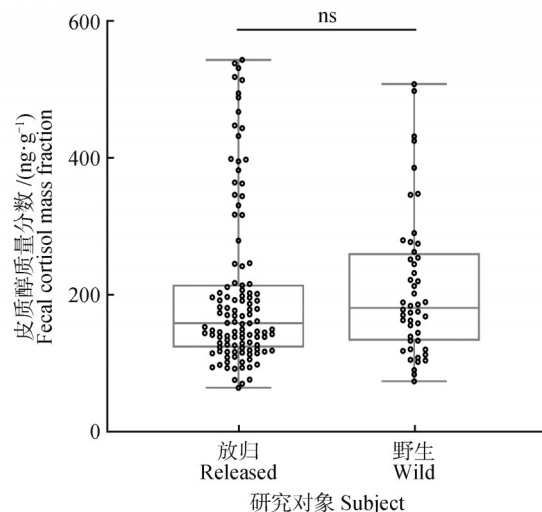


图4 放归大熊猫和野生大熊猫粪便皮质醇水平比较

Figure 4 Comparison of fecal cortisol levels between released and wild giant pandas

养个体。这一结果为评估野化放归项目的应激调控效果提供了重要的生理学证据。

3.1 母幼分离未对野化大熊猫造成明显应激

急性应激可造成皮质醇水平短暂升高,当应激源消失后,动物通常能较快恢复至正常水平^[30]。人为让大熊猫母兽从幼仔身边离开可视作对幼仔的一种急性应激,这种人工分离如果发生过早,可能使幼仔出现皮质醇水平升高、体质量下降和肠道菌群失调等情况^[31-32],并可能影响其身心健康和行为发育^[33]。在本研究中,对2.0~2.7岁野化培训大熊猫实施人工母幼分离,其分离前后皮质醇水平无显著差异($P = 0.979$),表明该分离节点未对个体造成明显应激刺激。该年龄段与野生大熊猫幼仔脱离母兽的时间相近,此时幼仔已具备独立生存能力,对母兽依赖程度显著降低,因此人工干预的应激影响极小。

3.2 不同阶段野化放归大熊猫应激水平呈梯度下降

年龄是影响动物皮质醇水平的重要因素之一,面对相同环境变化,低龄个体通常表现出更强的应激反应^[34-36],大熊猫也存在此规律^[28,37]。为排除年龄因素的干扰,本研究仅对年龄相近的个体在不同培训阶段的皮质醇水平进行比较。结果表明,野化放归后个体粪便皮质醇水平显著低于野化培训第二阶段,而第二阶段又显著低于第一阶段($P < 0.001$)。此外,处于野化培训中的大熊猫应激水平显著低于圈养个体($P < 0.05$),这与毕温磊等^[37]的研究结果类似。从野化培训第一阶段、第二阶段到放归后,大熊猫应激水平呈动态变化,表明生活环境改变是造

成其长期应激水平差异的主要原因。

3.3 野化培训环境有效缓解个体应激

本研究中,野化培训大熊猫的皮质醇水平显著低于同龄圈养个体(2岁龄, $P = 0.036$;3岁龄, $P = 0.013$)。圈养环境可能对大熊猫产生更显著的长期慢性应激,这与圈养环境的局限性及行为限制密切相关。首先,活动空间受限。野生大熊猫的活动范围通常为 $3.9 \sim 6.2 \text{ km}^2$ (卧龙国家级自然保护区)或 $3.3 \sim 28.9 \text{ km}^2$ (长青国家级自然保护区)^[38];而圈养环境的外运动场面积通常仅为 $100 \sim 200 \text{ m}^2$ ^[39],难以支持其自然行为的充分表达。其次,环境结构单一。圈养条件下隐蔽条件不足、食物供给模式固定,缺少野外取食的挑战性和多样性。此外,圈养大熊猫还时常面临游客参观、体检医疗等人类活动干扰。以上因素均可使圈养个体皮质醇水平在长期或短期内维持较高水平^[17,40]。相比之下,野化培训圈(第二阶段面积可达 $40\,000 \sim 480\,000 \text{ m}^2$)提供了更接近野外的活动空间、更自然的取食模式及更低的人为干扰,显著缓解了野化受训个体的应激反应。

3.4 大熊猫放归后个体应激水平降低并趋近野生状态

不同物种放归前后的应激水平存在差异。部分动物放归后应激水平升高,可能与野外捕食压力大^[41]、营养质量下降^[7]或多因素综合作用有关^[42-43]。另有研究则显示相反趋势,如放归普氏野马(*Equus przewalskii*)应激水平低于圈养个体^[44]。亦有研究并未观察到放归对动物粪便皮质醇水平的长期影响^[45]。圈养动物放归初期常经历环境突变引发的急性应激,随后通过自身调节逐步恢复内环境稳态,该恢复能力存在种间差异^[46]。对欧洲地松鼠(*Spermophilus citellus*)的研究表明,其放归后粪便皮质醇代谢物浓度先升高后快速下降,降至放归前水平后仍持续降低^[47]。对大熊猫而言,放归初期个体活动量较低,提示存在应激性活动抑制,随后活动量逐渐回升^[48]。本研究结果显示,放归后大熊猫应激水平低于野化培训第二阶段,推测主要与环境压力降低有关。监测表明,“淘淘”和“张想”分别于放归后22、14个月建立家域,95%家域面积分别为 $1\,499$ 、 954 hm^2 ^[49],远大于野化培训圈面积。更大的活动范围为个体提供了更丰富的食物资源和更广阔的选择空间,有助于其规避种内竞争与人为干扰。加之放归地通常选择竹子资源丰富、野生种群密度低和周边社区支持

力度高的区域,这些因素共同构成了较低的环境压力,有助于放归个体快速适应野外环境,提高生存率。

本研究还发现,放归后大熊猫粪便皮质醇水平与野生个体无显著差异($P = 0.287$),表明其在资源利用、领域竞争和环境挑战应对等方面的压力状态已与野生个体相近。前期研究证实,为圈养大熊猫提供适宜环境条件,可使其活动模式^[50]、肠道菌群^[51]和免疫力^[52]等逐渐接近野生水平。本研究从生理应激角度得出类似结果,表明野化培训可有效促使大熊猫生理机能逐步向自然状态过渡,避免因环境剧变引发生理应激紊乱。

3.5 研究意义与展望

粪便皮质醇作为评估动物应激状态的有效指标,其在大型濒危野生动物放归监测中的价值已得到广泛认可。该指标已成功应用于细纹野马(*Equus grevyi*)从捕获、易地圈养到放归后的长期监测中^[53]。基于本研究结果,建议将粪便皮质醇监测纳入大熊猫野化放归常规工作体系,作为评估放归个体野外适应能力的核心生理指标之一,为放归时机选择、个体筛选和放归效果评估提供科学依据。

参考文献:

- [1] IUCN/SSC. Guidelines for reintroductions and other conservation translocations. Version 1.0. [M]. Gland: IUCN Species Survival Commission, 2013.
- [2] SAPOLSKY R M, ROMERO L M, MUNCK A U. How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory, and preparative actions [J]. Endocrine Reviews, 2000, 21(1): 55-89.
- [3] BOONSTRA R. Equipped for life: The adaptive role of the stress axis in male mammals [J]. Journal of Mammalogy, 2005, 86(2): 236-247.
- [4] TEIXEIRA C P, DE AZEVEDO C S, MENDEL M, et al. Revisiting translocation and reintroduction programmes: The importance of considering stress [J]. Animal Behaviour, 2007, 73(1): 1-13.
- [5] JENNI L, KELLER N, ALMASI B, et al. Transport and release procedures in reintroduction programs: Stress and survival in grey partridges [J]. Animal Conservation, 2015, 18(1): 62-72.
- [6] AGUILAR-CUCURACHI M A S, DIAS P A D, RANGEL-NEGRÍN A, et al. Preliminary evidence of accumulation of stress during translocation in mantled howlers [J]. American Journal of Primatology, 2010, 72(9): 805-810.
- [7] GELLING M, JOHNSON P J, MOORHOUSE T P, et al. Measuring animal welfare within a reintroduction: An assessment of dif-

- ferent indices of stress in water voles *Arvicola amphibius* [J]. PLoS One, 2012, 7(7): e41081.
- [8] BABIC N L, JOHNSTONE C P, RELJIĆ S, *et al.* Evaluation of physiological stress in free-ranging bears: Current knowledge and future directions [J]. Biological Reviews of the Cambridge Philosophical Society, 2023, 98(1): 168–190.
- [9] DICKENS M J, DELEHANTY D J, MICHAEL ROMERO L. Stress: An inevitable component of animal translocation [J]. Biological Conservation, 2010, 143(6): 1329–1341.
- [10] CYR N E, ROMERO L M. Fecal glucocorticoid metabolites of experimentally stressed captive and free-living starlings: Implications for conservation research [J]. General and Comparative Endocrinology, 2008, 158(1): 20–28.
- [11] MILLSPAUGH J J, WASHBURN B E. Use of fecal glucocorticoid metabolite measures in conservation biology research: Considerations for application and interpretation [J]. General and Comparative Endocrinology, 2004, 138(3): 189–199.
- [12] YU X J, HU D F, JIN X L, *et al.* Non-invasive determination of fecal steroid hormones relating to conservation practice in giant panda (*Ailuropoda melanoleuca*) [J]. Animal Biology, 2011, 61(3): 335–347.
- [13] 马凯, 吴存哲, 尹峰, 等. 贮存温度和时间对大熊猫粪便样品皮质醇浓度的影响 [J]. 兽类学报, 2014, 34(2): 188–192.
- MA K, WU C Z, YIN F, *et al.* Effects of storage temperature and duration on cortisol concentration in feces of giant pandas (*Ailuropoda melanoleuca*) [J]. Acta Theriologica Sinica, 2014, 34(2): 188–192.
- [14] 杨波, 赖燕舞, 周强, 等. 大熊猫粪便皮质醇激素分布与取样对策[J]. 野生动物学报, 2022, 43(4): 1094–1099.
- YANG B, LAI Y W, ZHOU Q, *et al.* Distribution of fecal cortisol in giant panda and sampling strategies[J]. Chinese Journal of Wildlife, 2022, 43(4): 1094–1099.
- [15] YAN Z, LIU X Y, LIU H Q, *et al.* Assessment of stress levels and reproductive condition in giant pandas: Insights from hair, faecal and saliva samples [J]. Conservation Physiology, 2024, 12(1): coae044.
- [16] LIU J B, YU J J, BI W L, *et al.* Genetic status assessment and future development forecast for an isolated giant panda population [J]. Global Ecology and Conservation, 2025, 57: e03423.
- [17] OWEN M A, SWAISGOOD R R, CZEKALA N M, *et al.* Monitoring stress in captive giant pandas (*Ailuropoda melanoleuca*): Behavioral and hormonal responses to ambient noise [J]. Zoo Biology, 2004, 23(2): 147–164.
- [18] 陈艳, 王永峰, 魏荣平, 等. 圈养大熊猫应激的研究进展 [J]. 畜牧兽医科技信息, 2019(2): 15–17.
- CHEN Y, WANG Y F, WEI R P, *et al.* Research progress on stress of captive giant pandas [J]. Chinese Journal of Animal Husbandry and Veterinary Medicine, 2019(2): 15–17.
- [19] MARTIN-WINTLE M S, KERSEY D C, WINTLE N J P, *et al.* Comprehensive breeding techniques for the giant panda [J]. Advances in Experimental Medicine and Biology, 2019, 1200: 275–308.
- [20] WANG X Y, YUAN B, HUANG H, *et al.* Abnormal expression of natural mating behaviour of captive adult giant pandas is related to physiological stress [J]. Conservation Physiology, 2024, 12(1): coae061.
- [21] SWAISGOOD R R, OWEN M A, CZEKALA N M, *et al.* Evaluating stress and well-being in the giant panda: A system for monitoring [J]. Giant Pandas: Biology, Veterinary Medicine and Management (ed. DE Wildt), 2006: 299–314.
- [22] NIE Y G, ZHOU W L, GAO K, *et al.* Seasonal competition between sympatric species for a key resource: Implications for conservation management [J]. Biological Conservation, 2019, 234: 1–6.
- [23] ZHOU W L, GAO K, MA Y J, *et al.* Seasonal dynamics of parasitism and stress physiology in wild giant pandas [J]. Conservation Physiology, 2020, 8(1): coaa085.
- [24] WEI F W, SWAISGOOD R, HU Y B, *et al.* Progress in the ecology and conservation of giant pandas [J]. Conservation Biology, 2015, 29(6): 1497–1507.
- [25] DENG H Q, JIN X L, HU D F, *et al.* Fecal cortisol content of wild giant pandas (*Ailuropoda melanoleuca*) to monitor human disturbance level in natural habitats [J]. Animal Biology, 2014, 64(1): 75–86.
- [26] 毕温磊. 大熊猫(*Ailuropoda melanoleuca*)粪便类固醇激素检测方法及其在放归种群中应用的初步研究 [D]. 长沙: 中南林业科技大学, 2014.
- BI W L. The preliminary study of fecal steroid hormone analysis and its application in giant panda (*Ailuropoda melanoleuca*) [D]. Changsha: Central South University of Forestry & Technology, 2014.
- [27] 张和民, 李德生, 黄炎, 等. 圈养大熊猫野化培训与放归研究 [M]. 北京: 科学出版社, 2013: 20–21; 30–31.
- ZHANG H M, LI D S, HUANG Y, *et al.* Study on the wildness training and release of captive giant pandas [M]. Beijing: Science Press, 2013: 20–21; 30–31.
- [28] 唐丹, 杨波, 张志忠, 等. 运输对圈养大熊猫应激影响初探 [J]. 野生动物学报, 2019, 40(3): 753–757.
- TANG D, YANG B, ZHANG Z Z, *et al.* Assessing transport stress on captive giant pandas by fecal steroids assay [J]. Chinese Journal of Wildlife, 2019, 40(3): 753–757.
- [29] KERSEY D C, WILDT D E, BROWN J L, *et al.* Rising fecal glucocorticoid concentrations track reproductive activity in the female giant panda (*Ailuropoda melanoleuca*) [J]. General and Comparative Endocrinology, 2011, 173(2): 364–370.
- [30] CINQUE C, DE MARCO A, MAIRESSE J, *et al.* Relocation stress induces short-term fecal cortisol increase in Tonkean macaques (*Macaca tonkeana*) [J]. Primates, 2017, 58(2): 315–321.
- [31] AHMED S, HEMAYET M A, RAHMAN M H, *et al.* An assessment on the impact of weaning stress on the weaning age in black

- Bengal goat kids [J]. *Journal of Advanced Biotechnology and Experimental Therapeutics*, 2024, 7(3): 472.
- [32] ST-PIERRE B, PEREZ PALENCIA J Y, SAMUEL R S. Impact of early weaning on development of the swine gut microbiome [J]. *Microorganisms*, 2023, 11(7): 1753.
- [33] NAPOLITANO F, DE ROSA G, SEVI A. Welfare implications of artificial rearing and early weaning in sheep [J]. *Applied Animal Behaviour Science*, 2008, 110(1/2): 58–72.
- [34] TAKESHITA R S C, MENDONÇA R S, BERCOVITCH F B, *et al.* Developmental changes in the endocrine stress response in orangutans (*Pongo pygmaeus*) [J]. *Journal of Comparative Physiology B*, 2019, 189(6): 659–672.
- [35] LOPEZ M, SEIDL A, PHILLIPS K A. Cortisol levels across the lifespan in common marmosets (*Callithrix jacchus*) [J]. *American Journal of Primatology*, 2024, 86(4): e23597.
- [36] ROMERO L M. Physiological stress in ecology: Lessons from biomedical research [J]. *Trends in Ecology and Evolution*, 2004, 19(5): 249–255.
- [37] 毕温磊, 侯蓉, 费立松, 等. 迁入都江堰野放中心的大熊猫野化放归个体皮质醇水平变化初步研究 [J]. *四川动物*, 2014, 33(1): 8–12.
- BI W L, HOU R, FEI L S, *et al.* Variation of fecal steroid hormone level of giant panda between Chengdu research base of giant panda breeding and Dujiangyan research center [J]. *Sichuan Journal of Zoology*, 2014, 33(1): 8–12.
- [38] 魏辅文, 张泽钧, 胡锦矗. 野生大熊猫生态学研究进展与前瞻 [J]. *兽类学报*, 2011, 31(4): 412–421.
- WEI F W, ZHANG Z J, HU J C. Research advances and perspectives on the ecology of wild giant pandas [J]. *Acta Theriologica Sinica*, 2011, 31(4): 412–421.
- [39] 国家林业局. 大熊猫饲养管理技术规程: LY/T 2015—2012 [S]. 北京: 中国标准出版社, 2012.
- State Forestry Administration of the People's Republic of China. Technical regulation of husbandry and management of the giant panda: LY/T 2015—2012 [S]. Beijing: Standards Press of China, 2012.
- [40] 崔媛媛, 胡德夫, 张金国, 等. 黄金周游客干扰对圈养大熊猫应激影响初探 [J]. *四川动物*, 2009, 28(5): 647–651.
- CUI Y Y, HU D F, ZHANG J G, *et al.* Fecal steroids assay for tourist disturbance on captive giant pandas during may day golden week [J]. *Sichuan Journal of Zoology*, 2009, 28(5): 647–651.
- [41] ZIDON R, SALTZ D, SHORE L S, *et al.* Behavioral changes, stress, and survival following reintroduction of Persian fallow deer from two breeding facilities [J]. *Conservation Biology*, 2009, 23(4): 1026–1035.
- [42] LÈCHE A, VERA CORTEZ M, DELLA COSTA N S, *et al.* Stress response assessment during translocation of captive-bred Greater Rheas into the wild [J]. *Journal of Ornithology*, 2016, 157(2): 599–607.
- [43] 赵星, 马锐, 吴蔚, 等. 不同生活环境下小熊猫皮质醇和肠道微生物的变化规律 [J]. *兽类学报*, 2024, 44(4): 427–435.
- ZHAO X, MA R, WU W, *et al.* Changing patterns of cortisol and gut microbiota in *Ailurus fulgens* under different living environments [J]. *Acta Theriologica Sinica*, 2024, 44(4): 427–435.
- [44] 曹婷婷. 圈养和放归普氏野马应激水平的非损伤性研究 [D]. 北京: 北京林业大学, 2008.
- CAO T T. Physiological stress assays with non-invasive method in captive and released Przewalski horse [D]. Beijing: Beijing Forestry University, 2008.
- [45] BOSSON C O, PALME R, BOONSTRA R. Assessing the impact of live-capture, confinement, and translocation on stress and fate in eastern gray squirrels [J]. *Journal of Mammalogy*, 2013, 94(6): 1401–1411.
- [46] JACHOWSKI D S, SLOTOW R, MILLSPAUGH J J. Delayed physiological acclimatization by African elephants following reintroduction [J]. *Animal Conservation*, 2013, 16(5): 575–583.
- [47] KACHAMAKOVA M, KOSHEV Y, MILLESI E. Resident European ground squirrels exhibit higher stress levels than translocated individuals after conservation reinforcement [J]. *Mammalian Biology*, 2021, 101(2): 127–136.
- [48] HE L Y, DAI Q, YANG Z S, *et al.* Assessing the health status of released, captive-bred giant pandas (*Ailuropoda melanoleuca*) through activity patterns [J]. *Folia Zoologica*, 2019, 68(2): 72–78.
- [49] YANG Z S, GU X D, NIE Y G, *et al.* Reintroduction of the giant panda into the wild: A good start suggests a bright future [J]. *Biological Conservation*, 2018, 217: 181–186.
- [50] 朱洪民. 人工繁育大熊猫放归后对自然环境的响应 [D]. 南充: 西华师范大学, 2019.
- ZHU H M. The response of captive-bred giant pandas to the natural environment after release [D]. Nanchong: China West Normal University, 2019.
- [51] 汤静思. 野化培训与放归大熊猫肠道菌群研究 [D]. 温江: 四川农业大学, 2019.
- TANG J S. The gut microbiota of giant pandas in wild training and reintroduction [D]. Wenjiang: Sichuan Agricultural University, 2019.
- [52] YANG M, HUANG Y, WU H L, *et al.* Blood transcriptome analysis revealed the immune changes and immunological adaptation of wildness training giant pandas [J]. *Molecular Genetics and Genomics*, 2022, 297(1): 227–239.
- [53] FRANCESCHINI M D, RUBENSTEIN D I, LOW B, *et al.* Fecal glucocorticoid metabolite analysis as an indicator of stress during translocation and acclimation in an endangered large mammal, the Grevy's zebra [J]. *Animal Conservation*, 2008, 11(4): 263–269.