JZAR JOURNAL OF ZOO AND AQUARIUM RESEARCH
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Evidence-based practice

Evidence based ex situ strategy for breeding and release management to support European wildcat *Felis silvestris* recovery in Scotland

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Keywords: behaviour, conservation translocations, evidence-based husbandry, ex situ, wildcat

Article history:
Received: 07 Oct 2025
Accepted: 28 July 2026
Published online: 31 July 2026

Abstract

Following a 2019 International Union for the Conservation of Nature (IUCN) status review, the wild population of the European wildcat *Felis silvestris* in Scotland was considered to be non-viable and in need of reinforcement if its extinction was to be prevented. In 2020 'Saving Wildcats' was established as a European partnership project led by the Royal Zoological Society of Scotland and supported by European Union LIFE funding. Saving Wildcats was developed as the first UK project to breed wildcats for release. In 2023, the first releases of captive-born wildcats in Great Britain were carried out and 10 months later post-release survival is estimated at 95% (18/19), with wild reproduction recorded in 2024. A critical tool for this project has been the development of a dedicated "Conservation Breeding for Release Centre", which between 2022-2025, produced 56 offspring, with 51 surviving to a minimum of 6 months old (91%) and 48 individuals surviving to the point of release (1-2 years old; 94%). Here, we present a detailed overview of the ex situ management strategy, focusing on population management, animal husbandry, and remote behaviour monitoring and analysis. We provide summary data on the reproductive and behavioural profiles of the first two years of releases (2023 and 2024, n=32), documenting for the first time individual variation in pre-release behaviour of wildcats through behavioural assessments. These data can now serve as a benchmark for future recovery programmes committed to reintroducing threatened carnivores and help generate long-term understanding of ex situ pre-release behavioural and management factors contributing to individual post-release survival in the wild.

Background

The European wildcat *Felis silvestris silvestris* is the last remaining wild cat species in Great Britain following the extinction of the Eurasian lynx *Lynx lynx* 1500-1800 years ago (Hetherington et al. 2005; Kitchener and Bonsall 1997). Once widespread, the species has been restricted to the Scottish Highlands since the late 19th century (Easterbee et al. 1991; Harris et al. 1995; Langley and Yalden 1982; Taylor 1946), with a heavily fragmented population which has incurred severe declines in the past 150 years due to intense persecution, habitat destruction and fragmentation, prey population declines, and interbreeding (hybridisation) with feral domestic cats *Felis catus* (Breitenmoser et al. 2019; Kilshaw 2015; Macdonald et al. 2004). In 2015 the wild population was estimated at 100 - 400 individuals (Kilshaw 2015; Mathews and Harrower 2018), likely an overestimation (Breitenmoser et al. 2019).

In Scotland, wildcats are therefore critically endangered (Gerngross et al. 2023; Mathews and Harrower 2020). Following the first national conservation action plan (2013) - which included ex situ objectives (Barclay and Senn 2023) - a status review by the International Union for the Conservation of Nature (IUCN) Cat Specialist Group (Breitenmoser et al. 2019) identified that the wildcat in Scotland should be regarded as non-viable and on the brink of extinction, and recommended continuing conservation efforts. Further, it stated that field based (in situ) conservation actions alone would be insufficient to save the species.

In 2018 "Saving Wildcats" (www.savingwildcats.org.uk) was established to implement the first reinforcement approach through captive breeding for release and threat mitigation (SWAforLIFE LIFE18-NAT 000995). This European partnership, led by the Royal Zoological Society of Scotland (RZSS), aims to deliver a first phase (2019-2026) wildcat recovery plan in Scotland and to develop a sustainable approach for long-term conservation action. Since 2015, RZSS also coordinates the UK Conservation Breeding Programme for the captive wildcat population held in zoological collections, wildlife parks and private collections (Species360 2025). Following successful population growth from 64 to 150 individuals, this population was selected as a suitable source for reintroduction into the wild.

While the challenges of captive-bred carnivore translocations are well documented (e.g. Jule et al. 2008; Thomas et al. 2023), with the increase in extinction trends globally, the need for conservation breeding programmes is growing (Conde et al. 2013). When used strategically, ex situ management can be a critical tool for species conservation that supports a long-term insurance policy, increased reintroduction success (Barclay and Senn 2023; IUCN/SSC, 2014) and achieves high welfare standards of captive-bred individuals. Following best practice for translocation management (IUCN/SCC, 2013), a Population Viability Analysis (PVA, see SOM#1) was undertaken to evaluate impact on the source (ex situ) population, with results indicating a sustainable removal from the population for release into the wild. Furthermore, a Long-Term Management Plan (LTMP) for the ex situ population was developed to ensure continuing sustainability and support future recovery efforts. This ex situ strategy complements the Saving Wildcats in situ strategy (Langridge et al. 2025) which details the approach for release site assessments, threat mitigation and post-release monitoring.

Action

The first step in executing the ex situ strategy was the design and construction of the Saving Wildcats Conservation Breeding for Release Centre, CBRC. The CBRC was designed upon review of successful conservation breeding centres for Iberian lynx *Lynx pardinus* (Vargas et al. 2009), European mink *Mustela lutreola* (Maran et al. 2016), and black footed ferret *Mustela nigripes)* (Miller et al. 2003) and is the first large-scale facility of its kind in the UK dedicated to the management, breeding, and pre-release development of wildcats. Situated in a 10-acre (off-show) site at RZSS Highland Wildlife Park, it provides the necessary infrastructure and resources for wildcat management whilst restricting access and disturbances to allow a quiet environment for breeding and pre-release management. CBRC comprises eight breeding enclosures (6W x 15L x 4.5H m), 20 pre-release enclosures (20W x 30L m, Figure 1), biosecurity barriers, CCTV monitoring, and quarantine and veterinary facilities. It has four key objectives, developed in collaboration with expert ex situ advisors: i) establish a wildcat breeding population following best practice husbandry; ii) produce up to 20 offspring per year for release; iii) maintain a minimum gene diversity of 85% within the CBRC population for its duration; and iv) demonstrate a 'no harm to source population' approach. All animal procedures received ethical approval by RZSS Animal Welfare Advisory Group.

After construction, 16 founder wildcats were selected from the UK Conservation Breeding Programme as follows: in 2017 the entire breeding programme was screened for hybridisation using a 35 SNP (single nuclear polymorphism) molecular test, with animals that showed hybrid ancestry of <75% excluded. Additionally, the population's pedigree was molecularly reconstructed using 2230 SNPs resulting in 100% known ancestry (Barclay and Senn 2023; Senn et al 2019). Founder wildcats were selected based on the following criteria: maximum age of four-years old, carried wildcat mtDNA (in addition to passing the 35 SNP hybrid test) and previous history of successful reproduction. Founder selection was further optimised from this pool of animals using Gene Diversity (GD) calculations generated from the pedigree in the Population Management Software (PMx, v. 1.0). Animals were selected to be founders such that their removal from the UK Conservation Breeding Programme to the CBRC would have the greatest positive impact in terms of increased GD on both the newly formed CBRC population and the remaining UK Conservation Breeding Programme. Details on the methodology for genetic sampling/hybrid-scoring and pelage assessment can be found in Senn and Ogden (2015) and Kitchener et al. (2005).

Pairs were introduced between December and February, which is the peak mating season, following close behavioural observations, monitoring vocalisations, scent swapping between enclosures, and gradual introductions. Key reproductive behaviours indicative of mating readiness included female calling, increased scent marking, and lordosis – the reflex posture associated with mating - were monitored closely. Following observed matings, birthing windows that estimated due dates were calculated. Oestrus cycles were visually monitored at 21-days post mating to confirm pregnancy or identify further mating windows. Births were confirmed from direct nest box checks two weeks post-partum. Males were separated from females to increase privacy during rearing and remove risk of further mating and second litters, and introduced back to family groups when kittens were approximately four months old to promote development of social behaviours. At approximately five to six months old, kittens were separated from family groups and transferred to larger, more natural, pre-release enclosures (Figure 1) where they were managed from November-June individually (with the exception of five sibling groups in the first year) with targeted pre-release behavioural monitoring. This process was adopted to follow the natural weaning and dispersal ages for wildcats (cf. Daniels et al. 2002) and promote natural behavioural development prior to release.

CBRC animal management followed an evidence-based "eyes-on/hands-off" approach focused on minimising disturbance and maximising welfare. This included the avoidance of early and abrupt family group separation that presents a risk for abnormal behaviour development and other welfare issues (Mason 1994)

Journal of Zoo and Aquarium Research 14(4) 2026
http://doi.org/10.19227/jzar.v14i3.1014

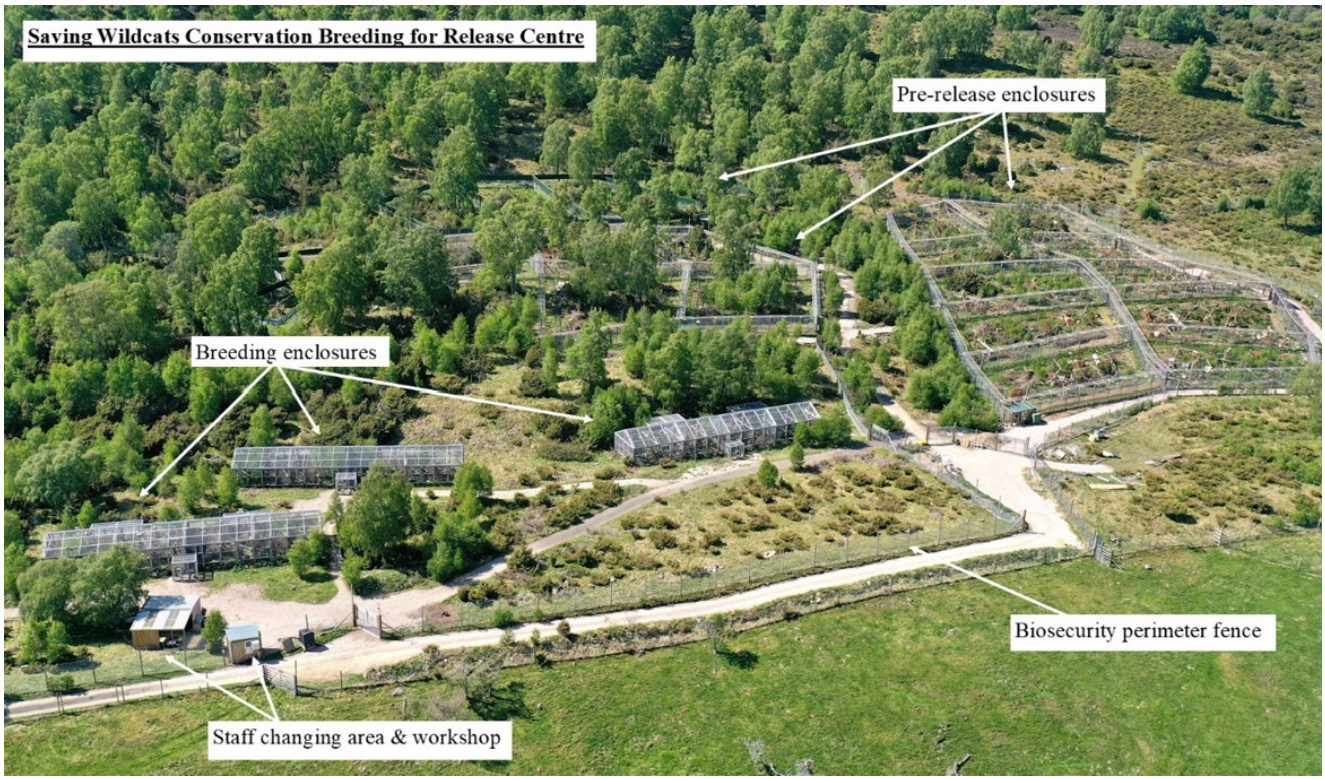

Figure 1. Aerial view of CBRC showing six of eight breeding enclosures (bottom left, two enclosures per building), 20 pre-release enclosures (top right), biosecurity perimeter fence and staff facilities. Photo credit: Saving Wildcats.

and increasing the complexity of enclosures, including providing multiple resources to allow choice and expression of highly motivated behaviours (reviewed in Englund and Cronin 2023). Animal husbandry within pre-release enclosures was designed to promote development of key behavioural competencies to maximise post-release survival, e.g. foraging and navigational skills. This included the provision of dynamic enrichment, complex enclosure design / structures, minimal human contact / presence, a diverse feeding programme and automated feeding and weighing systems.

A critical tool of the CBRC approach was the development of a pre-release strategy and checklist identifying data collection priorities and release criteria (e.g. human avoidance, display of natural behaviours; see SOM#2). This strategy and checklist formed the backbone for all CBRC behavioural observations and only when individuals "passed" the release criteria (see SOM#3) were they selected for release. Data collected during pre-release management included response to humans, hunting behaviours (e.g. pouncing, eating, stalking); general behaviours (e.g. patrolling, climbing, resting; circadian patterns; abnormal behaviours e.g. pacing); and enclosure use.

To evidence and quantify these behavioural criteria, a detailed wildcat ethogram was produced, modified from Stanton et al. (2015), and data collection monitoring protocols were established (see SOM#3). Behaviour was recorded remotely (after intra and interobserver reliability checks were performed, through a CCTV monitoring system (Hanwha Systems 2022). All enclosures were fitted with at least two cameras. Network video recorders (NVRs) and monitoring screens were situated in a dedicated CCTV control room. Cameras were positioned to maximise field of view across each enclosure; however all had some "blind spots" that could not be covered averaging <10% of field of vision. Additional blind spots were created from dense vegetation, den boxes / barrels and other enclosure features. These were variable between enclosures and potential presence of cats in these areas recorded as 'out of sight'. Data on overall time budgets, enclosure use, and behavioural frequencies e.g. food acquisition, use of resources, and social interactions, were collected using scan and continuous focal sampling (Bateson and Martin 2021, full details in SOM#3). This included daily remote visual checks to monitor overall welfare i.e. individuals located with no visual health issues (e.g. limping), as well as six other scans during peak active and inactive periods based on assumed natural activity patterns e.g. predominantly crepuscular activity pattern (Jiménez-Albarral et al. 2021; Urra 2003). Scan number was selected after pilot tests to determine a frequency of scans that would yield representative data while accounting for observers' time constraints. Over 30,000 data points were recorded across both years from CCTV observations. To obtain data on enclosure use, pre-release enclosures were divided into six grids (A1-C2) and presence of wildcats in those areas recorded per scan. In addition, hourly scans were conducted for 8.5 days on average within that period to obtain 24h circadian activity patterns. Response to human presence was tested upon entry of keepers during feeding. This was selected as the most conservative measure as wildcat motivation to approach humans at this time would be highest, as would be familiarity with keepers. Responses were recorded on a scale from 1: 'actively avoids keeper' to 8: 'actively approaches keeper and makes contact' (see SOM#3). Continuous monitoring - 15-minute sampling instances for a total of 60-120' per individual across the observation period

- was also used to capture key event behaviours (such as stalking, foraging, kill bite) for which scan sampling is not adequate (Bateson and Martin 2021). Following a review of the release strategy and data collection protocol (2023-2024) updates were made for the 2024 release season, which included personality monitoring recording behavioural responses to novel objects both in the breeding enclosures and pre-release enclosures e.g. duration to approach novel objects and latency to enter a new environment. A personality index representing a composite/ integration of behaviours shown by the wildcats in response to different personality tests was calculated.

To support adaptive management, data were collected for food intake, food preference, seasonal appetite and body condition (breeding enclosures only), and seasonal weights. A veterinary health assessment was carried out for each individual following completion of the behavioural criteria and prior to transfer to soft release enclosures. These veterinary assessments included physical examination, blood sampling for biochemistry, haematology and genetics (for hybrid testing), thoracic and abdominal radiographs, body condition scoring (Laflamme 1997), pelage scoring (to monitor hybridisation traits), morphometrics including body length and weight and fitting of GPS-radio collars, as informed by disease risk analysis (Bacon et al. 2025). Full details on veterinary assessments and GPS collaring can be found in Langridge et al. (2025). Pelage scores and genetic (hybrid) scores for all released cats from 2023 and 2024 can be seen in SOM#4.

Following completion of the pre-release checklists (see SOM#2) individuals were transferred to soft-release management enclosures (3.6W x 4.8L x 2.5H m) at the release site. Soft-release enclosures were sited in groups of two to four inter-spaced approximately 5-10 m apart. Release cohorts were selected primarily based on level of kinship to avoid high levels of relatedness among cats in the same release group and in a sex ratio of one male with two to three females that replicated natural social structures (one male home range overlaps 2-3 female home ranges; Beugin et al. 2016) where possible. Animals were managed individually and held for an average of 4.3 days (range 1-7 nights; Langridge et al. 2025) prior to release. Keepers visited the enclosures for daily feeding and health and behaviour assessments from trail camera footage recorded inside the enclosures.

Consequences

Conservation translocations of captive-bred carnivores can be problematic (Jule et al. 2008). To maximise best-case scenario outcomes, Saving Wildcats adopted a best practice project management approach through robust strategic planning, strong network of partners and stakeholders, secure funding and the development of an expert project team and advisory group. It also incorporated key ex situ elements of some of the best-known successful carnivore conservation breeding-for-species-recovery projects including construction of a dedicated breeding centre, maximising behavioural development through evidence-based husbandry and management, and detailed recording and sharing of outcomes. The overall outcomes and conservation impact of the first two years of the first wildcat reintroduction in Great Britain carried out by Saving Wildcats are summarised in Table 1. During this period (2022-2023) a total of 36 kittens were born in the CBRC with an average survival at six months of age of 97%.

Of the 31 individuals selected for release, 28 passed the pre-release assessments and were subsequently released. No cats failed the pre-release assessment based on behavioural criteria. Three cats failed pre-release assessment based on veterinary criteria due to low body condition scores.

Results generated from CCTV behaviour monitoring data collected during the pre-release management periods in 2023 and 2024 are as follows:

Table 1. Wildcats born and released at CRBC (2022, 2023)

Details	Number (first year, second year)
Total kittens born in CBRC[^]	36 (22, 14)
Total surviving at 6 months of age	35 (22, 13)
Total kitten survival % (at 6 months)	97% (100%, 93%)
Number selected for release	31 (22, 9)
Number of individuals to pass pre-release checklist	28 (19, 9)
Number of animals released[§]	28 (19, 9)
Total post-release survival (6 month)[*§]	89%[*] (100%, 78%)
Confirmed kitten births post-release Year 1 (2023)	0
Confirmed kitten births post-release Year 2 (2024)	24

[^]Checked at two weeks postpartum

[*]Post-release survival assumed for some cats (6 month+) due to potential dispersal from release site

[§]Number of animals released and post-release survival is only reported for captive-bred wildcats (one released individual was a wild-caught adult female, see Langridge et al. 2025)

Circadian activity patterns

Overall, all wildcats displayed a predominantly crepuscular/ nocturnal activity pattern that mirrored that of wild living wildcats (Jiménez-Albarral et al. 2021). Wildcat activity in pre-release enclosures, on average, peaked before dawn (between 0400-0600 hr) and was most sustained around dusk (1600-2100 hr) (Figure 2a).

General behaviour

Wildcats were observed performing behaviours in all the key behavioural categories informed by the checklist (see SOM#2). When the wildcats were visible i.e. discounting out of sight instances, the highest percentage of observations included wildcats exhibiting several active behaviours e.g. patrolling, climbing, playing, etc. as well as inactive behaviours (resting, sleeping) (Figure 2b). Stereotypic pacing behaviour accounted for an average of 5% of total observations across all enclosures, which is below the average reported for zoo felids and similar to other small felids (e.g. Bandeli et al. 2023; Lyons et al. 1997; Marinath et al. 2019).

Food acquisition

Wildcats were observed performing all key food acquisition behaviours with the exception of kill (bite) which was only observed on one occasion. Stalking and pouncing were observed the most (Figure 2c). It should be noted that wildcats were not provided with live prey as it is illegal in the UK. However, wildcats were observed displaying opportunistic predation e.g. of wild rodents that entered the pre-release enclosures.

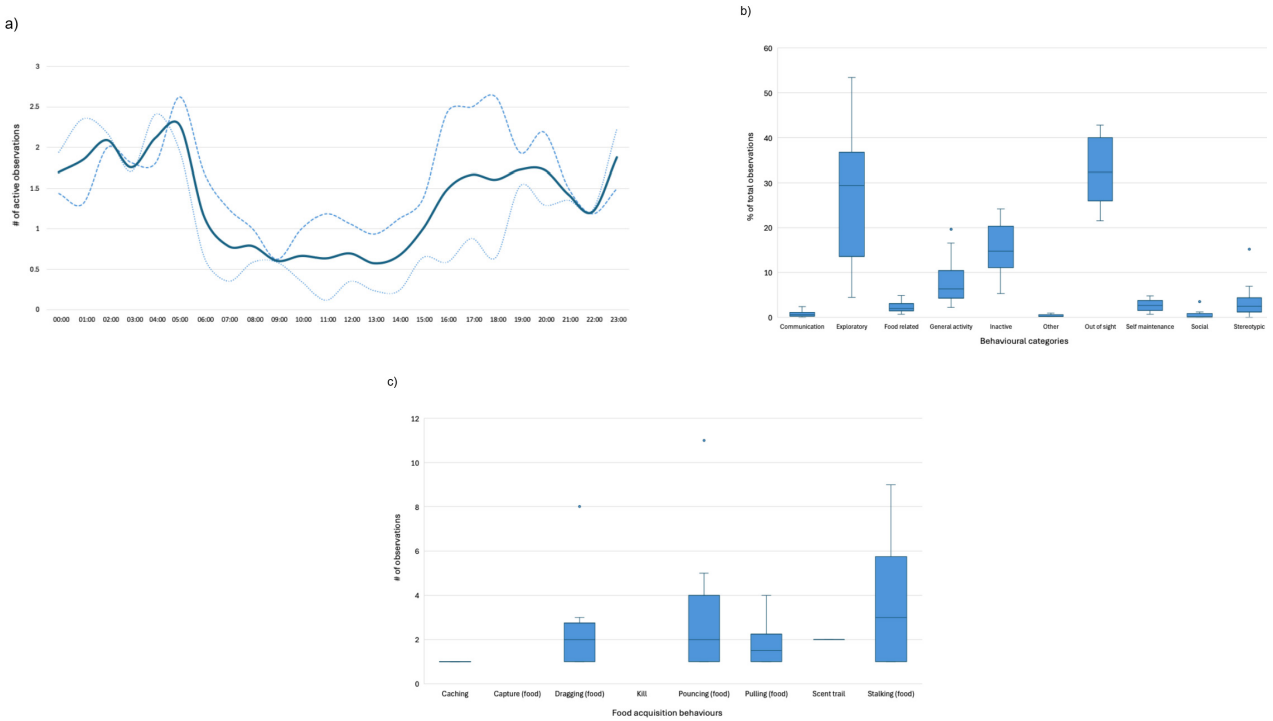

Figure 2. Behaviour displayed by wildcats released in 2023 and 2024 (n=28) during CBRC pre-release management. a) Circadian activity patterns dark blue line: average of active observations across 24h scans for all 28 individuals, light blue dotted line: mean for 2023 individuals, light blue dashed line: mean for 2024 individuals. b) combined diversity of behaviours grouped by behaviour categories as % total time observed; bars = standard deviation. c) total count of all observed food acquisition behaviours (excluding "eating", as pre-release management focused primarily on development of appetitive behaviours rather than consummatory ones).

Enclosure use

All areas of the pre-release enclosures were used to some extent by all cats, although there were clear preferences for specific areas within each of the enclosures (Table 2). Further analysis of the factors contributing to enclosure use continues to assess whether specific resources/locations are drivers of the activity performed in each area.

Response to humans

Of the 22 wildcats monitored, none displayed seeking behaviour towards the keepers i.e. a score of eight/close contact with keeper (Figure 3a). The average response per enclosure across all trials was three, with most wildcats either not changing their behaviour upon the keeper entering the enclosure or actively moving away. There was no evidence from these observations that habituation towards keepers increased during pre-release management. Observations from four enclosures recorded cats approaching keepers within 5m (a score of 6 or 7), but for these cats a "deterrent" i.e. loud noise and / or shouting (Reeves et al. 2013) was implemented which resulted in reduced approach behaviour in subsequent trials.

Personality

Wildcats showed individual variation in personality covering the shy to bold continuum (Figure 3b). Overall, more cats exhibited shy personality e.g. longer latencies to touch a novel object than bold within the pre-release enclosures. Continuing work will assess correlations with post-release survival and behaviour.

Conclusions

By September of 2024 a total of 28 wildcats was released into the Cairngorms National Park in the Highlands of Scotland that had passed the pre-release strategy checklist (behavioural, genetic and health assessments). At the time of writing (May 2025): four mortalities have been reported from released individuals; 18/28 are confirmed living and 6/28 are presumed living; reproduction of seven female wildcats has been confirmed; overall high-site fidelity has been recorded during the release period 2023-2025. The pre-release strategy and management approach presented here likely contributed to the post-release outcomes; further analysis and correlation of ex situ and in situ data will provide a greater understanding of this link.

The ex situ management strategy detailed in this paper highlights the critical role of conservation breeding for release in

Table 2. Enclosure use as % time spent in each enclosure area, of all 2023 and 2024 released cats during CBRC pre-release management. A1-C2: each of the six areas in which the enclosure was divided. PR1-19: enclosure number (not all enclosures or the same enclosures were used on both years). Please note that camera positioning within the enclosure might have affected visibility in some areas leading to underestimation of observations).

Year	Enclosure	Enclosure area					
		A1	A2	B1	B2	C1	C2
2023	PR1	9.9	5.0	36.6	18.3	24.8	5.4
	PR2	8.8	0.0	38.2	47.1	2.9	2.9
	PR3	15.8	5.6	43.5	6.2	26.1	2.8
	PR4	33.5	7.0	18.4	22.8	10.8	7.6
	PR5	37.1	34.5	4.1	13.5	7.1	3.7
	PR6	20.9	14.7	13.6	31.1	8.2	11.6
	PR7	22.8	4.2	19.2	18.0	21.6	14.4
	PR8	20.6	14.4	11.9	13.8	31.9	7.5
	PR9	30.7	19.0	13.1	3.1	27.3	6.8
	PR11	5.8	58.1	2.3	18.6	3.1	12.0
	PR12	20.8	11.1	12.7	35.2	13.0	7.2
	PR13	19.3	17.0	12.5	14.8	15.9	20.5
	PR14	4.1	14.2	45.9	20.9	8.8	6.1
	PR15	10.8	14.8	45.8	9.8	4.8	14.0
	PR17	5.3	4.1	43.5	19.9	18.3	8.9
	PR18	12.6	28.8	16.8	36.0	1.5	4.3
	PR19	6.4	7.1	27.0	31.9	6.9	20.6
2024	PR3	27.8	14.9	10.8	33.2	12.2	1.0
	PR4	32.5	3.7	40.0	21.4	7.8	4.7
	PR5	38.3	22.0	12.2	3.1	3.7	1.7
	PR6	6.8	7.8	11.5	49.2	6.4	7.5
	PR7	19.7	4.7	14.9	17.6	8.8	17.3
	PR8	13.9	5.8	18.0	23.1	11.5	7.8
	PR9	28.1	3.7	19.0	12.5	36.3	15.9
	PR10	13.9	9.2	18.3	27.1	12.5	10.2
	PR11	16.6	16.9	5.1	10.2	11.9	22.0
	PR12	7.5	15.9	16.9	6.8	18.3	19.7
	PR14	8.1	23.7	22.0	14.2	9.2	5.1
	PR15	7.1	15.9	18.3	14.2	8.5	9.8
	PR17	11.9	13.2	8.1	12.2	7.8	2.0
	PR17	16.6	5.8	18.6	28.5	5.1	13.9
	PR18	20.3	16.9	32.2	29.5	2.0	13.6
	PR19	7.5	15.9	11.2	35.3	7.8	14.2

the recovery of wildcats in Scotland. The behaviour monitoring approach demonstrates that systematic data collection from ex situ observations can allow for effective analysis and assessment of individuals for release. Further analyses of how ex situ behaviour links to post-release outcomes and survival will not only enhance our understanding of the integrated approach of ex situ and in situ conservation but also encourage replicability and transferability of the breeding for release approach for other projects across the zoo and wider conservation community. In this way, the work carried out by the ex situ team can act as a model and blueprint to inform future recovery projects for endangered carnivores across the world.

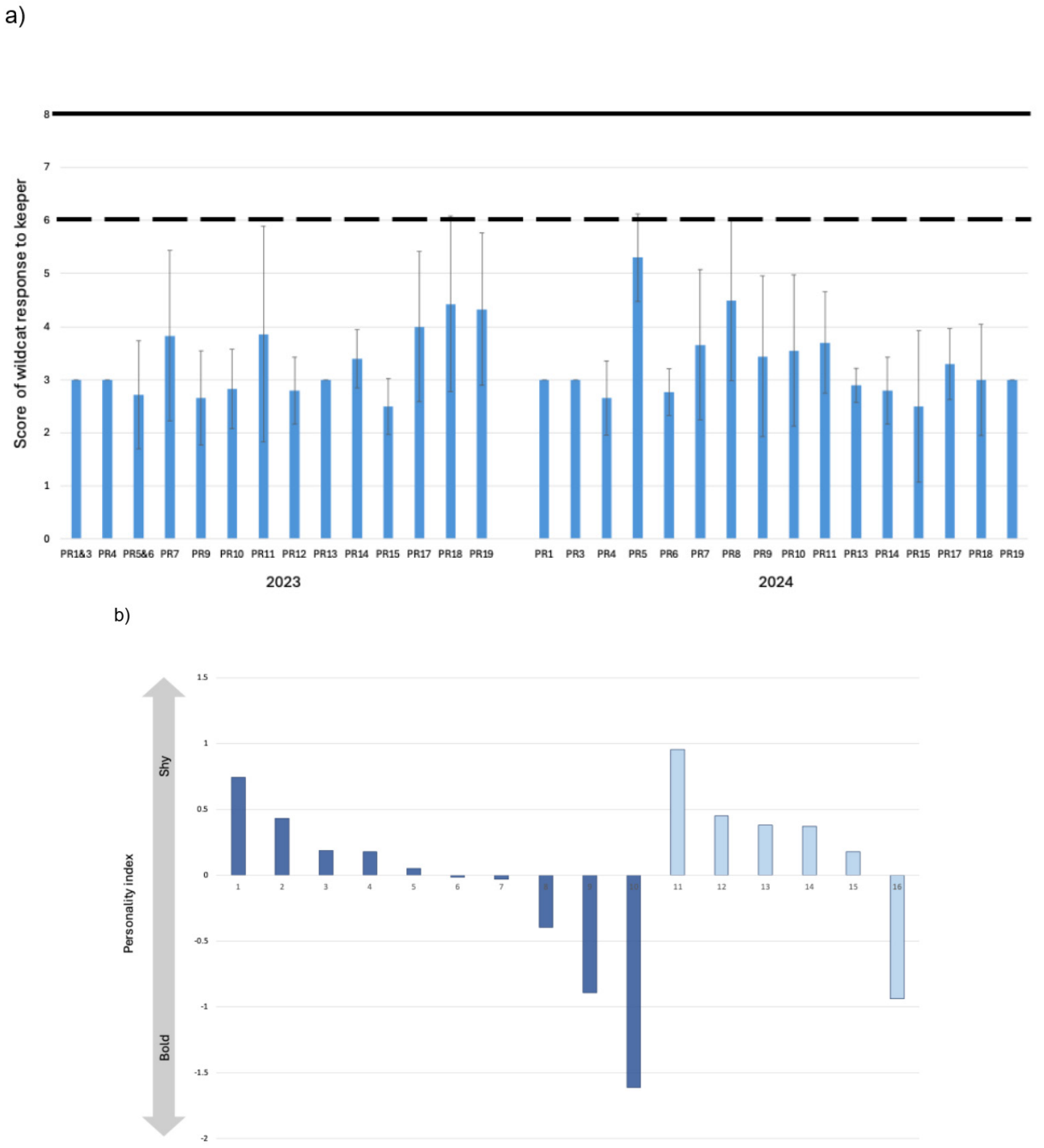

Figure 3. Wildcat behaviour in response to external stimuli. a) Average response scores to keeper presence (up to 7 tests per enclosure) from all 2023 and 2024 released cats during CBRC pre-release management (n=28). Error bars = standard deviation. Black solid bar indicates a score of 8 (i.e. contact with keeper and thus a fail on checklist criteria). Black dashed bar represents threshold of acceptable responses (1-5); scores of 6 or 7 resulted in use of deterrent. b) Personality profiles as index score (z-scored, where the mean response across tests for one individual is standardised relative to the population mean and standard deviation; positive value indicates the score is above the population mean, negative below the mean), for all release candidates in 2024 during CBRC pre-release management (n=16, with between 2-6 independent tests per individual). Dark blue bars: female wildcats; light blue bars: male wildcats.

Acknowledgements

We are extremely grateful to all the ex situ volunteers (2022-2024) who helped conduct CCTV monitoring, data recording, and animal husbandry support; their efforts have contributed to ensure this evidence-based approach to wildcat breeding for release. We are also incredibly grateful for the support, guidance and expertise given by the Saving Wildcats Technical and In situ advisory group members whose contribution to the delivery and implementation of the wider strategy has been critical to promote project success. We would also like to thank our colleagues, Elmar Fienieg and Marie Corlay, from the European Association of Zoos Aquaria (EAZA) for their support in the development of the Captive

Breeding Programme's Long-Term Management Plan. Saving Wildcats is made possible thanks to the work of the wider Saving Wildcats team (past and present): L. Hughes, A. Scurrah-Price, L. Semple, J. Sneddon, H. Parsons, C. Bell, G. Shooter, I. Simpson, R. Amos, L. Byford, Dr S. Girling, S. Rainey, Dr K. Kilshaw. We would also like to thank the WildGenes technician team, E. Heap and M. Butowska.

This work was funded by the European Union LIFE programme and project partners and funders of whom we are incredibly thankful to. We are also very grateful to the two anonymous reviewers whose comments helped improve the manuscript.

Finally, we are thankful to the individual wildcats themselves that have inspired us and continue to motivate our efforts to help the recovery of this species in Scotland and Great Britain.

Supplementary On-line Materials can be found at https://doi.org/10.5281/zenodo.21627259

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