Physiological and behavioural impact of trapping for scientific purposes on European mesocarnivores

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Abstract

Wildlife trapping and handling entail multi-level consequences on captured individuals. These impacts may be expressed at the physiological and behavioural levels, starting at capture and potentially waning post-release over a variable period. We investigated the impact of trapping and handling on the physiological parameters of 6 species of southwestern European mesocarnivores from the families Canidae, Felidae, Mustelidae, Herpestidae, and Viverridae. These parameters were quantified in real time during the handling procedures, after the induction of chemical immobilization. Using a time-step approach, we further assessed the impact of trapping on the movement behaviour of a subsample of the mesocarnivores. A total of 195 mesocarnivores were captured with cage traps or neck snares, and aspects of their haematology, and blood chemistry parameters quantified in a subset of the cage-trapped animals. These biomarkers suggested mild dehydration, tissue damage, exertion, and activation of the immune response as consequences of live trapping. Eight European wildcats (*Felis silvestris*), 4 red foxes (*Vulpes vulpes*), and 4 stone martens (*Martes foina*) were also fitted with GPS-VHF radio-collars, and their movements tracked by conventional ground-based VHF and GPS telemetry. Movement behaviour was assessed as the mean distance to trapping sites over each week of monitoring and compared with the value under normal use of their home ranges (set as >12 weeks post-capture). Our results showed evidence of reduced movements for up to 11 weeks post-capture. Selected haematology, serum chemistry, anaesthesia monitoring, and movement behaviour parameters should become standard biomarkers of the reactive homeostatic response to live trapping, offering a finer comparison of live-capture techniques and protocols.

Keywords: Cage-traps; Haematology; Hormones; Immune response; Movement behaviour; Neck snares; Serum chemistry

Introduction

Live capture is an essential tool in the research and management of free-ranging wildlife populations whenever non-invasive methods are not applicable (Bosson et al., 2012; Proulx et al., 2020). However, it induces an acute reactive homeostasis response in captured animals (Dantzer et al., 2014; Iossa et al., 2007). Effectively addressing and minimizing the acute response to trapping and handling is thus imperative on ethical, animal welfare, and conservation grounds (Proulx et al., 2020).

While live-trapping standards are in place, they mostly address the capture efficiency, selectivity, and clinical impacts of different models of live traps, as measured by pathological lesions assessed upon necropsy (Byrne et al., 2015; Proulx et al., 2020). Besides the injuries produced, sub-clinical effects of live trapping have been increasingly shown to affect not only wildlife welfare but also the scientific validity of research (Iossa et al., 2007; Cattet et al., 2008). Sub-clinical effects include reduced post-trapping movements (Santos et al., 2017), decreased body condition (Cattet et al., 2008), and breeding failures (Uher-Koch et al., 2015), among others (reviewed by Soulsbury et al., 2020).

Physiological biomarkers can be used to assess the reactive homeostasis response to live-trapping of wildlife (Powell & Proulx, 2003; Marks, 2010). Comprehensive panels of physiological biomarkers such as hormones and metabolites provide a finer approach to assess the sub-clinical impacts of live trapping, such as dehydration, activation of the immune system, and tissue and cellular damage (Powell and Proulx, 2003; Cattet et al., 2008; Santos et al., 2017). Furthermore, behavioural biomarkers allow assessing the impact of the reactive homeostatic response to live-trapping on the medium-term fitness of captured animals. Movement was shown to be reduced for a variable period after capture in several carnivore species (Cattet et al., 2008; Santos et al., 2017). Furthermore, trapping was shown to influence space use on the vicinity of the capture site in the Egyptian mongoose *Herpestes ichneumon* (Travaini et al., 1993).

This study aimed to investigate the impact of trapping and handling on some of the physiological parameters, measured under anaesthesia, of six species of southwestern European mesocarnivores from the families Canidae: red fox (*Vulpes vulpes*); Felidae: European wildcat (*Felis silvestris*); Mustelidae: stone marten (*Martes foina*), and European polecat (*Mustela putorius*); Herpestidae: Egyptian mongoose; and Viverridae: common genet (*Genetta genetta*). Furthermore, we assessed changes in the post-capture movement behaviour of 6 wildcats, 4 red foxes, and 4 stone martens fitted with GPS-VHF radio-collars.

Materials and Methods

Free-ranging mesocarnivores (*n*=195) from six species were captured between 2003-2017 across the Mediterranean ecoregion (Alcaraz et al., 2006) in the southwestern Iberian Peninsula (Fig. 1): 79 red foxes, 37 Egyptian mongooses, 31 stone martens, 25 common genets, 20 European wildcats and 3 European polecats. Overall, the sample was evenly distributed between sexes (94 females and 100 males) but biased towards adults (119 adults vs 42 subadults and 33 juveniles). Trapping was carried out throughout the year, including captures in all seasons (see seasons definition below).

The dataset here analyzed was generated in the scope of several unrelated studies on the ecology of mesocarnivores (Monterroso et al. 2009; Díaz-Ruiz et al. 2016; Santos-Silva et al, 2017; Ferreras et al., 2016; Santos et al., 2020) and further used to assess the sub-clinical impacts of trapping and handling. This approach follows the 3R's principles of animal research applied to wildlife: replacement by non-invasive methodologies, reduction by maximizing the information obtained from each trapped animal, and refinement by using state-of-art trapping and handling methods (Lindsjö et al., 2016).

Trapping

Trapping was performed by two methods: i) cage-trapping, using double- and single-door cage-traps (Tomahawk ref. 109 106x38x38 cm and ref. 208 106x38x38 cm, USA, and VK1 ref. 150310 66x24x31 cm, Portugal, and three models of metal mesh traps between 95x45x50 cm to 152x45x50 cm, from Spanish suppliers, all with mesh sizes between 2x1.5-5cm); ii) neck-snaring with stop (Collarum® Fox model, Wildlife Control Supplies, EUA). Most animals were captured in the cage-traps, except for 41 red foxes and 2 stone martens captured using Collarum neck snares. Several reward non-live or non-reward live baits, scent lures and their combinations were used as attractants. Traps were checked once or twice daily. No trap-alarms were available, so the time spent on trap is unknown. Whenever weather conditions were predicted to be extreme (maximum daily temperature >35ºC or total daily precipitation >10mm), cage traps and neck snares were deactivated to minimize exposure of the captured carnivores. Traps were always checked early in the morning and set as not to be easily detected by humans to minimize disturbance of the captured carnivores.

All trapping procedures were licensed by the nature conservation authorities *Instituto de Conservação da Natureza e Florestas*, Portugal (Licenses nr. 395/2011/CAPT/MANUS and 362/2012/CAPT/MANUS) and the Castilla-La Mancha Regional Government, Spain (Licenses nr. 02-227/RN-52, PREG-05-23, and PR-2013-05-04), according to Portuguese (*Decreto-Lei* 113/2013), Spanish (*Real Decreto* 53/2013) and European legislations (Directive 2010/63/EU) and followed international standards on the use of wild animals for scientific research (Sikes and Gannon, 2011; Chinnadurai et al., 2016).

Anaesthesia

The protocol for the manipulation of trapped carnivores was previously described (Monterroso et al., 2009; Santos et al., 2020). Trapped carnivores were transferred to a restraint cage, equipped with a sliding wall, and covered with a dark blanket to reduce stimulus. All trapped carnivores were chemically immobilized by the intramuscular injection of ketamine (Imalgene®, Merial, France) and medetomidine (Domitor®, Merial, France) (Table 1). Immobilization was reversed by the intramuscular injection of atipamezole (Revertor®, Merial, France).

The age of each animal was estimated by the dental eruption and wear, and classified as juveniles (deciduous teeth present), subadults (only permanent teeth, no wear detectable), or adults (slight to moderate wearing of the teeth) (Harris, 1978; Anders et al., 2011). Gender was assessed by inspection of genitalia.

Sample collection and laboratory analyses

Blood samples were collected from a subset of the trapped mesocarnivores by venepuncture of the cephalic or saphenous veins, 4-54 min after administration of anaesthesia and preserved in EDTA and clotting tubes, kept refrigerated and protected from sunlight and excessive agitation.

Whole blood in EDTA (ethylenediaminetetraacetic acid) was analysed for 8 selected parameters (haematocrit, haemoglobin concentration, mean corpuscular volume, erythrocyte, leukocyte counts, neutrophile, and lymphocyte counts – Marks, 2010). The microhematocrit technique was employed for the haematocrit, and the alkaline hematin technique for haemoglobin concentration (Lema et al., 1994). Blood cell counts were performed manually in a haemocytometer after staining with Natt and Herrick's solution, and the differential leukocyte count by identifying 200 leukocytes in Giemsa-stained blood slides (Voigt, 2000).

Serum was analysed for 8 selected parameters (total protein, albumin, glucose, creatine kinase, aspartate aminotransferase, urea, sodium, and chloride – Marks, 2010) in a commercial laboratory (Inno, Braga, Portugal) using a Sysmex XT-2000iV (Sysmex Corporation, Kobe, Japan) haematology analyser and a Mindray BS380 (Mindray Medical International Ltd, Shenzhen, China) clinical biochemistry analyzer.

Haematology and serum chemistry parameters were obtained from 69 animals (28 Egyptian mongooses, 16 red foxes, 14 European genets, 5 stone martens, 3 European wildcats, and 3 European polecats). Results are presented as the average and minimum-maximum values, as the low sample size does not allow to estimate reference ranges. All the mesocarnivores for which haematology and serum chemistry parameters were obtained were captured using cage-traps, not allowing to compare the reactive homeostatic response between the two types of traps employed.

Telemetry

Eight European wildcats (3 adult males, 3 adult females, 2 subadult females), 4 red foxes (3 females, 1 male, all adults), and 4 stone martens (1 female, 3 males, all adults) were also fitted with species-specific radio-collars (88.6g for wildcat, 149.6g for red fox, 66.5g for stone marten). Six wildcats (2 adult males, 1 adult female and 2 subadult females) were tagged with VHF radio-collars (HLPM 3320, Wildlife Materials Inc., Murphysboro, IL, USA). Two adult wildcats (male and female), 4 foxes and 4 stone martens were tagged with VHF-GPS radio-collars (TGB-325315, TGB-318 and TGB-335, Telenax, Mexico).

Tagged animals were located by triangulation of VHF radio signal using directional antennas (4-element Telonicss, Mesa, AZ, USA, model RA-14, and 3-element Yaggi antenna, Biotrack, Dorset, UK) and a portable receiver (Yaesus, Cypress, CA, USA, model FT-290RII, and R-1000, Communications Specialists Inc., Orange, CA, USA), and bearings were determined using either a lensatic or magnetic compass, or a handheld global positioning system unit equipped with electronic compass (GPSMap 60CS and E-Trex Summit, Garmin, Olathe, KS, USA). Triangulations were performed by a single researcher at different times of the day. Occasionally, tracking cycles were performed, during which animals were located at 1 h intervals between mid-afternoon and the end of the morning the following day. Triangulation consisted of at least three azimuths with an angle of no less than 30 degrees between them, obtained within 15 min of each other (Kenward, 2001). Additionally, locations were obtained from the GPS units once radio-collars were recovered from dead or re-captured carnivores. Animals were located 7-90 times (mean XX) by VHF method and 9-3,898 times (mean XX) by GPS unit during radio-tracking periods of 45-275 days (mean 133 days).

Statistical analysis

The effect of trapping, anaesthesia, and handling on the haematology and serum chemistry parameters of mesocarnivores was assessed comparing their descriptive statistics with published reference ranges. One-sample Wilcoxon signed rank test was used to test the differences between the median of the dataset and the measure of central tendency of the published reference ranges.

Reference ranges were not available for all parameters and species and were established mostly from samples collected from captured animals, thus also incorporate the effect of capture. To minimize this effect, we privileged the use of reference ranges obtained from captive animals (Fowler et al., 1986; Kreeger et al., 1990a; Mitchel and Tully, 2008; Marcos et al., 2010; Hein et al., 2012; Matsuda et al., 2015; ZIMS, 2018), or from shot free-ranging animals (Marks, 2010). We expected the impact of capture to be attenuated in captive animals as these are easily accessible, and somewhat habituated to human presence, although their management in captivity could influence the results (Kreeger et al., 1990b). Shot animals probably provide the best approximation to normal values of the physiological biomarkers (Kreeger et al., 1990b; Marks et al., 2010).

The effect of trapping on movement behaviour of captured individuals was assessed separately for each species using log-linear mixed models with ‘distance’ of each location to the capture site as the dependent variable, ‘individual’ animal as a random effect, and ‘sex’, ‘age’, ‘season’, and ‘week’ since capture as categorical fixed effects. The variables ‘age’ and ‘season’ were only included in the European wildcat models, as for the other species only adults were trapped during 1 season (spring). Models including all these variables and their interactions were compared under an information-theoretical approach and the most supported model was selected by the AICc (Burnham and Anderson, 2002). All the independent variables showed Pearson correlations <0.6 between them.

The packages “lme4” (Bates et al., 2014), and “ggplot2” (Wickham, 2016) in R 3.6.1 (R Development Core Team, 2021) were used. The marginal and conditional R^2 of the models were estimated according to Nakagawa and Schielzeth (2013) implemented in the package “MuMIn” (Bartoń, 2015).

Results

Physiology

Trapped mesocarnivores showed evidence of mild dehydration, as a tendency for the serum concentrations of total protein, albumin, and urea to be higher than the published reference ranges for captive animals of the same species (Fig. 2). These tendencies were statistically significant in the red fox. Tissue damage, particularly suggestive of myocyte injury, was consistent with the elevated serum concentrations of creatine kinase and aspartate aminotransferase in trapped carnivores of the 2 species for which reference values were available (Fig. 3). These tendencies were statistically significant in the red fox.

A non-significant tendency for lower erythrocyte counts and higher mean corpuscular volume in all species for which reference values are available is consistent with the increased physical exertion of trapped mesocarnivores (Fig. 4). Changes in haemoglobin and glucose concentrations were inconsistent across species.

A stress leukogram pattern comprising leukocytosis, neutrophilia, lymphopenia, and eosinopenia was present in all the species for which reference values were available (Fig. 5). The differences were only significant in the species with larger sample size, the red fox and Egyptian mongoose.

Movement behaviour

The only species for which a significant effect of the weekly distance to the capture site was found was the European wildcat (Table 2). The European wildcat selected model yielded a conditional R^2=0.684, with the fixed effects accounting for most of the variation (marginal R^2=0.447). Controlling for the effect of the individual European wildcat, sex, and season, the distance from the capture site was significantly lower than in the reference class on the 3rd to 5th week post-capture (Table 3 and Fig. 7).

Discussion

We characterise the homeostatic response to live-trapping and handling procedures on wild European mesocarnivores. We found evidence of sub-clinical impacts on physiological parameters suggestive of mild dehydration, tissue damage, exertion, and activation of the immune system on some of the species studied. Additionally, we found support for restricted movement patterns, likely related to trapping, for one of the species.

Across species, the serum concentrations of total protein, albumin, and urea tended to be elevated compared to the reference range from captive animals of the same species, suggesting dehydration. The differences were only statistically significant in the red fox, possibly due to the larger sample size in this species, although the tendency is similar across species. The haematocrit and serum concentrations of sodium and chloride were within the reference ranges, further suggesting the dehydration was mild (Ilkiw et al., 1989). The high serum urea concentration observed could also be caused by higher protein ingestion in the wild compared to captive mesocarnivores (Santos et al., 2020).

The serum concentrations of creatine kinase and aspartate aminotransferase tended to be higher than in captive conspecifics, sometimes markedly so, supporting that some degree of tissue damage was associated to the capture and handling protocol employed. While aspartate aminotransferase is found in many tissues, creatine kinase is fairly specific to myocytes (Takagi et al., 2001), suggesting the injuries occur mostly in the muscle tissue. Minor physical injuries were observed in the captured carnivores, mostly abrasions and superficial lacerations. Again, the differences were only statistically significant in the red fox (n=16), but not in the European wildcat (n=3).

The erythrocyte count and mean corpuscular volume of trapped mesocarnivores tended to be lower than in captive conspecifics, although the differences were not statistically significant for any of the species for which reference ranges are available. Physical exertion induces oxidative stress in erythrocytes, which can lead to haemolysis and shrinkage of the erythrocytes (Van Beaumont et al., 1981; Oztasan et al., 2004). Haemoglobin and glucose concentration showed no clear pattern across species when compared to the reference ranges.

All mesocarnivore species for which reference ranges were available showed a stress leukogram, with leukocytosis and neutrophilia. The differences were statistically significant only for the species with larger sample size, the red fox and Egyptian mongoose.

We acknowledge that management under captivity in the carnivores used as reference might introduce bias in this analysis, as captive animals usually have access to food and water *ad libitum* and do not need to exercise as much as wild conspecifics. Although there is no way to control for this potential bias, the differences reported are likely informative and a reasonable approach to assess the sub-clinical effect of trapping on wild animals. The time carnivores spend on the trap can influence the reactive homeostatic response, as shown in other species (Santos et al., 2017). Unfortunately, this determinant of the physiological response to trapping could not be assessed in our sample, as no trap-alarms were available, and traps were checked once or twice daily. Furthermore, other factors, such as the anaesthesia protocol employed (Caulket and Arnemo, 2015), can influence the physiological parameters analysed, making the interpretation of the observed patterns particularly challenging and somewhat ambiguous. The lack of published reference ranges for some species further impairs the general use of physiological parameters in the assessment of the homeostatic response to trapping in wildlife. It is necessary to make datasets of individual carnivores' physiological parameters publicly available, including fully characterized capture protocols, allowing the formal statistical analyses to assess differences between wild and captive animals and compare capture techniques and protocols.

We also report evidence suggestive of a negative effect of capture on the movement behaviour of the European wildcat. Trapped European wildcats tended to stay closer to the trapping site on the first few weeks post-capture, particularly on the 3rd-5th weeks, compared to the reference period (13th week onwards). This effect might be due to the physiological impacts of capture, such as the muscle injuries suggested by the physiology results. Minor physical injuries were observed on some of the captured carnivores, mostly abrasions and superficial lacerations, but not on those fitted with telemetry collars. Given that carnivores in our sample were followed by a mix of conventional VHF and GPS telemetry, we could not use more sensitive measures of movement behaviour, such as daily distances travelled or home range size, relying instead on an admittedly crude measure (distance to the trapping site). Nevertheless, the results generally agree with those on other species of carnivores showing reduced movement for some time after trapping (Cattet et al., 2008; Santos et al., 2017; Gese et al., 2019). Together, these observations suggest that the impact of capture on movement behaviour might be pervasive under current trapping and handling procedures.

The collation of datasets generated in various unrelated studies and their analysis for a different purpose, following the 3R's Reduction principle, allowed to characterize the homeostatic response to live-trapping, anaesthesia, and handling of 6 species of wild mesocarnivores. Nevertheless, to collation of data collected in unrelated studies on the ecology of mesocarnivores as drawbacks, e. g. physiological biomarkers were not available for all the captured animals, and do not allow to compare the types of traps employed. Overall, physiology and behaviour biomarkers suggest mild dehydration, tissue damage, exertion, and activation of the immune response as potential sub-clinical consequences of live trapping for research purposes. Such consequences might be integral to trapping wild animals, but the responses might vary between trapping protocols, underlining the need for further studies specifically on this subject.

Selected haematology and serum chemistry parameters should become standard biomarkers of the reactive homeostatic response to trapping. Other biomarkers could be useful for this purpose, particularly fecal glucocorticoid metabolites which reflect the activation of the hypothalamic–pituitary–adrenal axis in a timeframe compatible with the time carnivores spend on trap. Furthermore, detailed analyses of movement behaviour could be used to evaluate the short-term fitness consequences of live trapping, whenever the animals are followed by telemetry. These biomarkers could provide a finer comparison of different live capture techniques and protocols, following the 3R's Refinement principle.

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Table 1. Summary of anaesthesia for the six species of wild carnivores captured in the Iberian Peninsula. Average ± SD dosage employed for each species, handling time from injection of anaesthetic drugs to injection of antidote, recovery time from injection of anaesthetic drugs to stationary.

Species	**n**	**Ketamine (mg/kg)**	**Medetomidine (mg/kg)**	**Handling time (min)**	**Atipamezole (mg/kg)**	**Recovery time (min)**
Red fox (*Vulpes vulpes*)	79	4.17 ± 1.15	0.06 ± 0.02	35 ± 11	0.21 ± 0.13	65 ± 23
Egyptian mongoose (*Herpestes ichneumon*)	37	4.92 ± 5.38	0.17 ± 0.10	44 ± 12	0.75 ± 0.17	67 ± 18
Common genet (*Genetta genetta*)	25	7.05 ± 3.63	0.13 ± 0.05	53 ± 19	0.59 ± 0.24	94 ± 28
European wildcat (*Felis silvestris*)	20	3.78 ± 1.80	0.08 ± 0.04	31 ± 17	0.35 ± 0.20	46 ± 14
Stone marten (*Martes foina*)	31	10.0 ± 4.72	0.09 ± 0.08	29 ± 13	0.35 ± 0.12	65 ± 39
European polecat (*Mustela putorius*)	3	3.24 ± 0.17	0.06 ± 0.003	28 ± 4	0.27 ± 0.10	33 ± 3

Table 2. Model selection of movement behaviour for each species. 'Individual' carnivore included as random effect. Only models with ΔAICc<2 from the most supported and the null model are shown. Mixed effects included in all the models.

Species	Model	Fixed effects	df	AICc	ΔAICc	Model weight
	1	Intercept + season + sex + week	18	670.9	0	0.218
	2	Intercept + season + sex	5	671.4	0.54	0.166
European wildcat	3	Intercept + sex + week	17	672.5	1.58	0.099
	4	Intercept + age + season + sex + week	19	672.5	1.62	0.097
	5	Intercept	3	678.1	7.16	0.006
Red fox	1	Intercept	3	1,399.5	0	0.694
	2	Intercept + sex	4	1,401.2	1.64	0.306
Stone marten	1	Intercept + sex	4	98.3	0	0.679
	2	Intercept	3	99.8	1.50	0.321

Table 3. Summary of the selected model of the distance to capture site for the European wildcat. 'Individual' carnivore included as random effect. 'Female', 'spring' and 'week>13th' as reference classes. Significant effects in bold.

Fixed effects	β	Standard error (β)	95% confidence interval (β)		df	P-value
			Low	High		
Intercept	7.843	0.381	7.096	8.591	5.264	**<0.001**
Sex						
Male	0.879	0.348	0.196	1.562	4.958	0.053
Season						
Summer	-0.835	0.389	-1.597	-0.073	4.958	0.085
Week since capture						
1st	-0.255	0.134	-0.517	0.007	363.9	0.057
2nd	-0.147	0.149	-0.439	0.145	364.3	0.325
3rd	-0.623	0.145	-0.907	-0.339	363.5	**<0.001**
4th	-0.739	0.151	-1.034	-0.443	362.9	**<0.001**
5th	-0.587	0.187	-0.953	-0.220	361.9	**0.002**
6th	-0.260	0.230	-0.709	0.190	362.5	0.259
7th	0.172	0.322	-0.458	0.802	361.7	0.593
8th	-0.076	0.224	-0.515	0.363	360.2	0.734
9th	-0.103	0.213	-0.520	0.313	361.3	0.627
10th	0.156	0.208	-0.251	0.563	363.0	0.453
11th	0.209	0.170	-0.125	0.543	363.2	0.221
12th	0.009	0.138	-0.262	0.280	361.5	0.947
13th	-0.033	0.148	-0.323	0.256	360.6	0.821

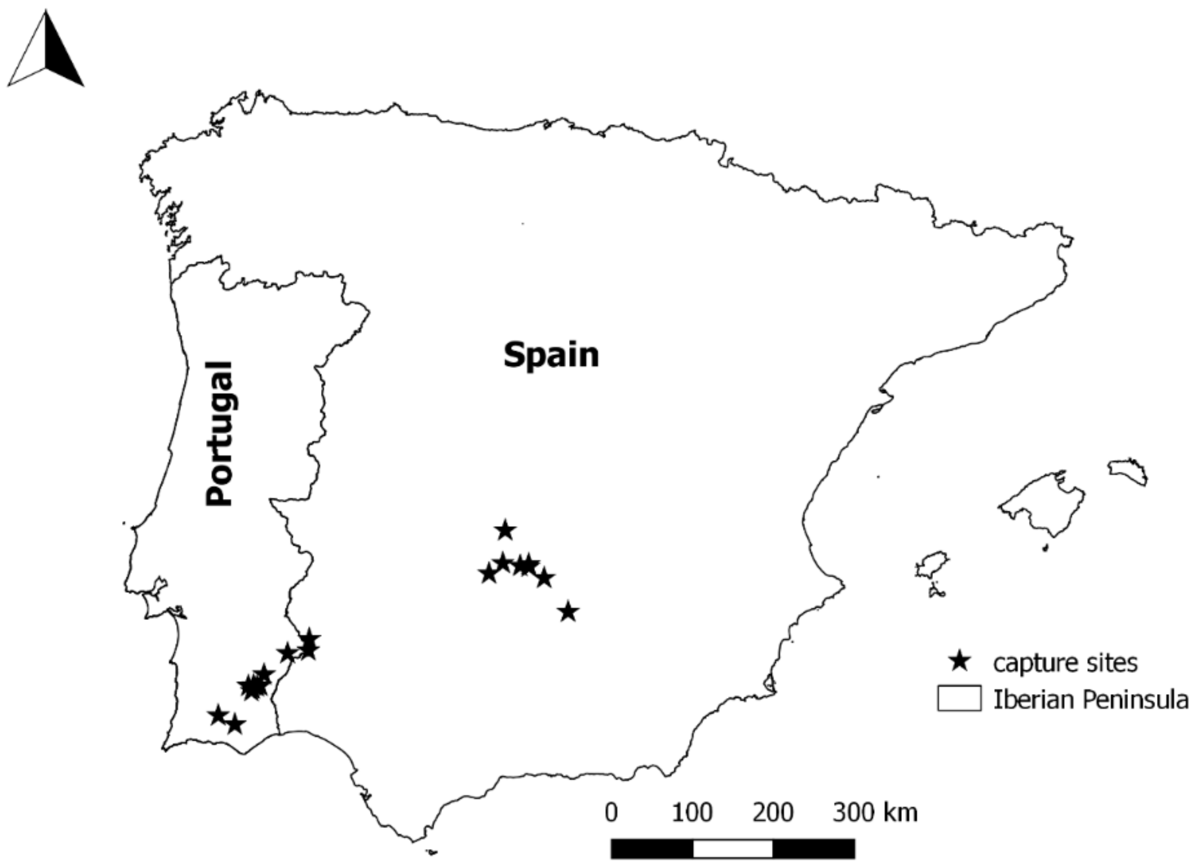

Fig. 1. Location of the capture sites for the 195 mesocarnivores from six species in the Iberian Peninsula, 2013-2017.

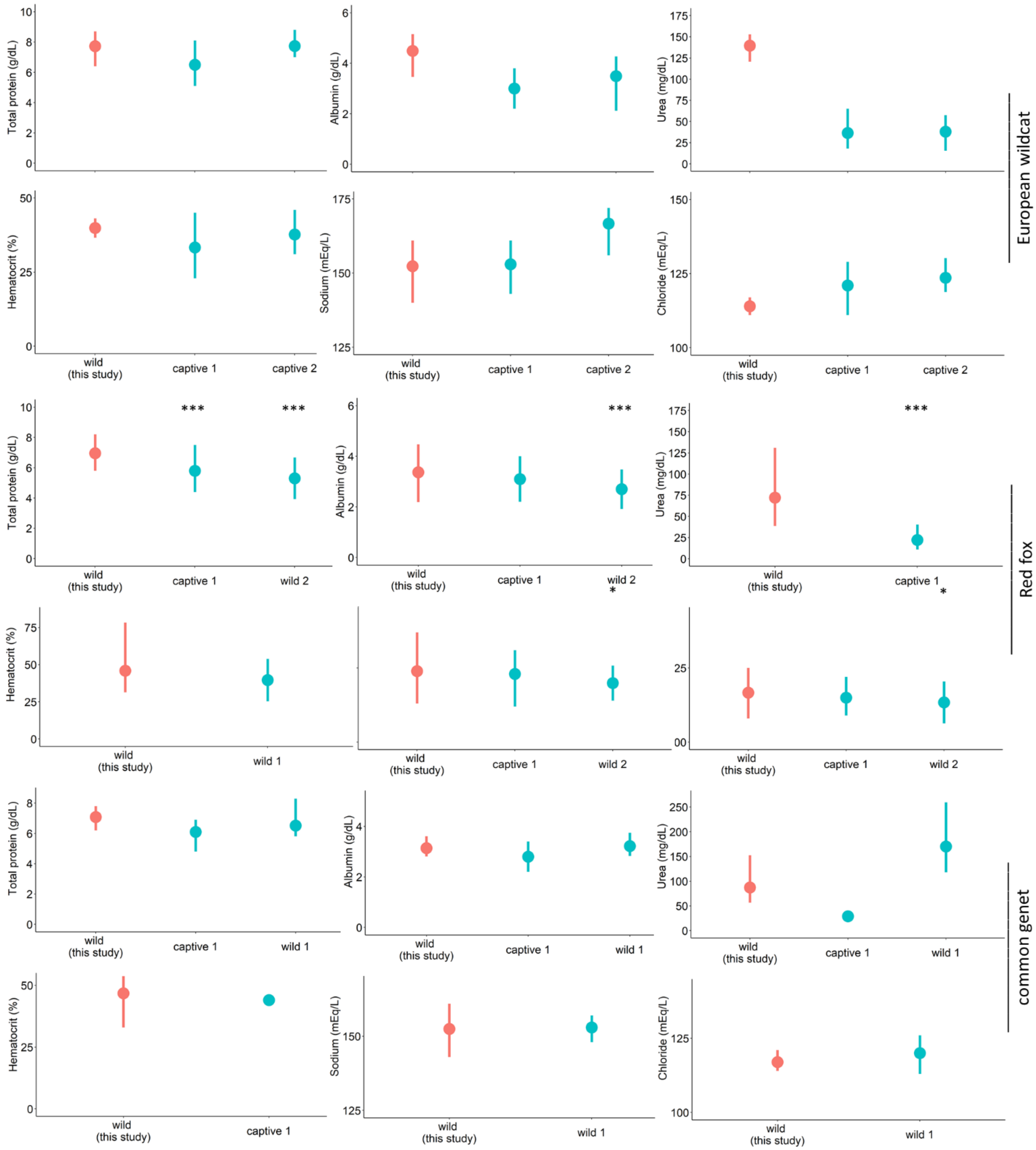

Fig. 2. Physiological biomarkers of dehydration in the European wildcat, red fox, and common genet. Mean and range from this study (red), mean and reference range from captive and wild animals (blue). Captive 1: ZIMS (2018); captive 2: Marco et al. (2000) for the European wildcat; wild 2: Marks (2010) for the red fox, Millán et al. (2015) for the common genet.

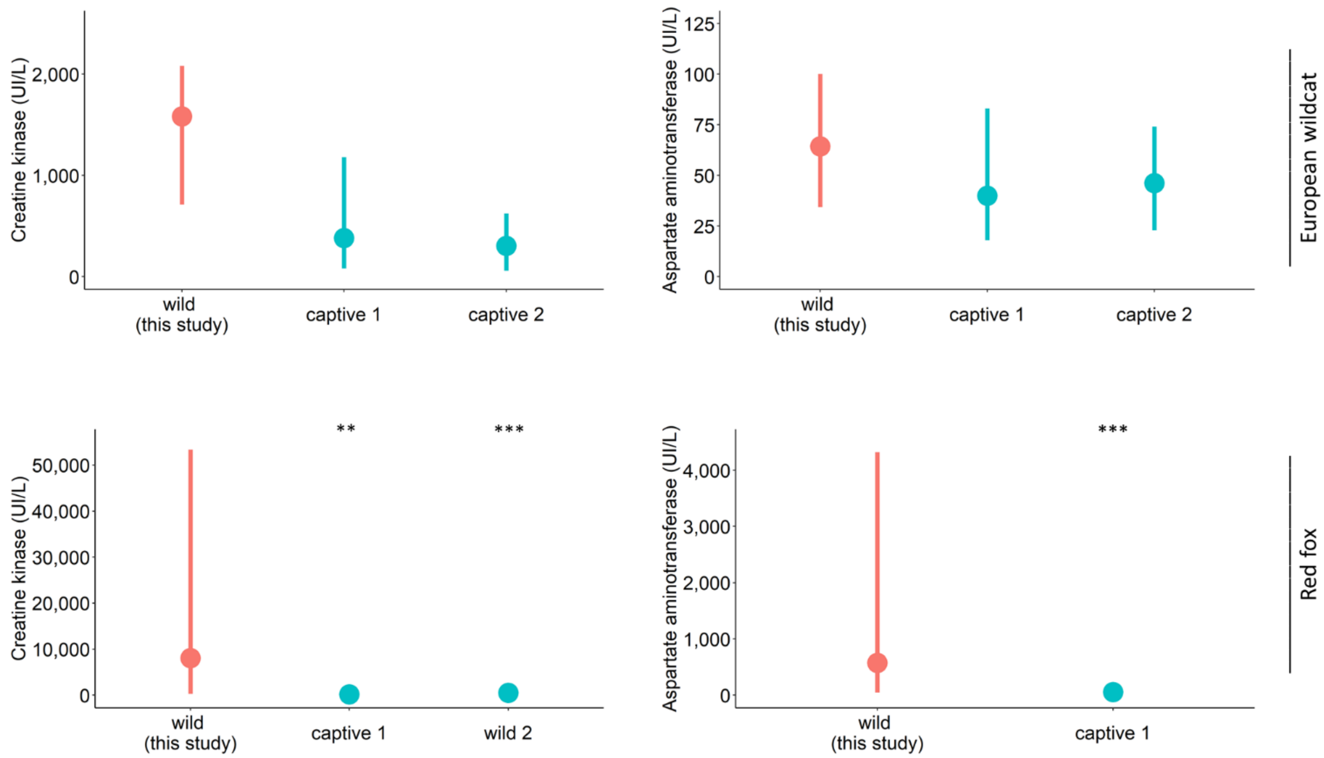

Fig. 3. Physiological biomarkers of tissue damage in the European wildcat and red fox. Mean and range from this study (red), mean and reference range from captive and wild animals (blue). Captive 1: ZIMS (2018); captive 2: Marco et al. (2000) for the European wildcat; wild 2: Marks (2010) for the red fox.

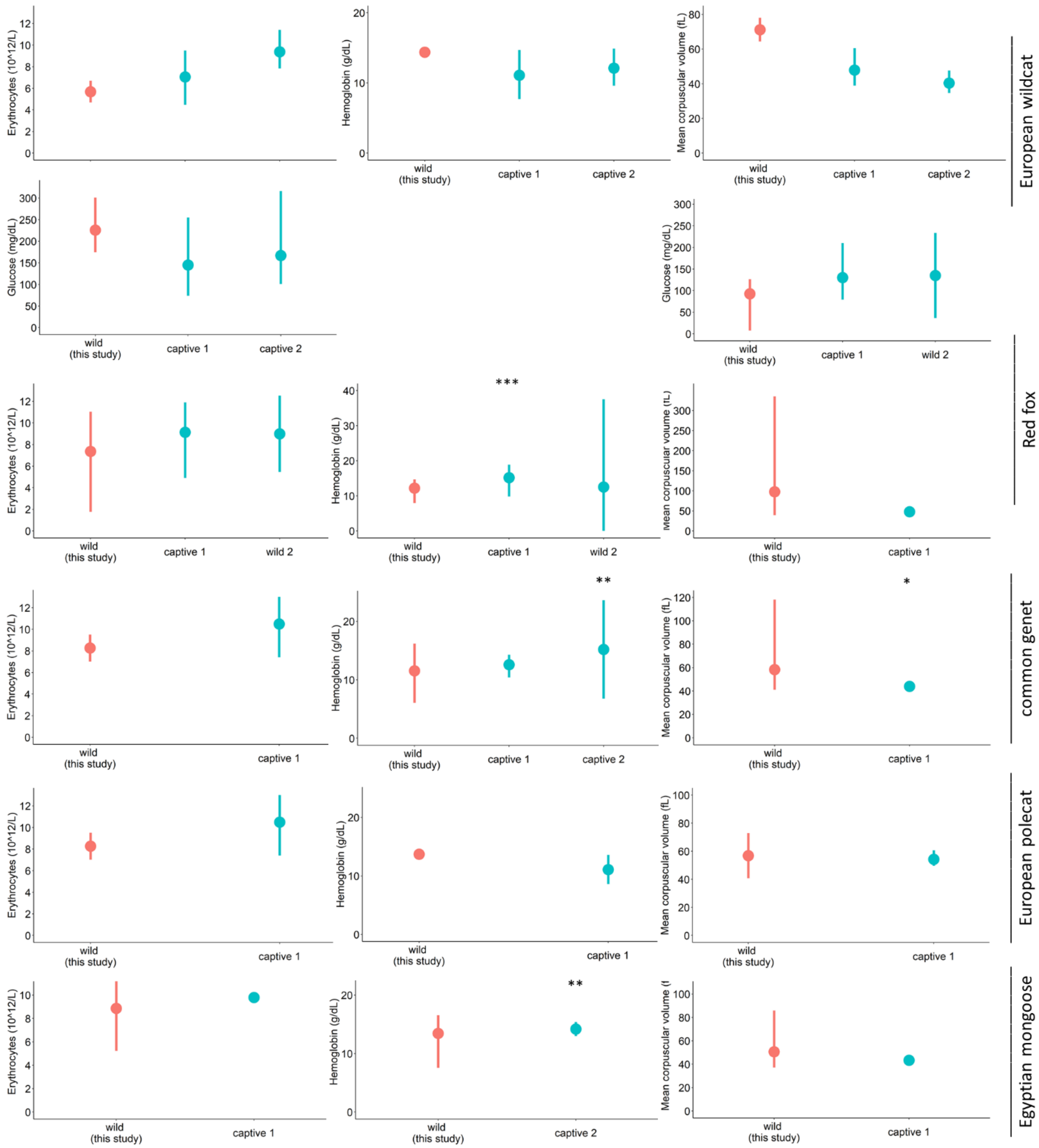

Fig. 4. Physiological biomarkers of exertion in the European wildcat, red fox, common genet, European polecat, and Egyptian mongoose. Mean and range from this study (red), mean and reference range from captive animals (blue). Captive 1: ZIMS (2018) for all species except the European polecat (Mitchel and Tully, 2008) and Egyptian mongoose (Fowler et al., 1986); captive 2: Marco et al. (2000) – European wildcat, Marks (2010) - red fox, Hein et al. (2012) - European polecat.

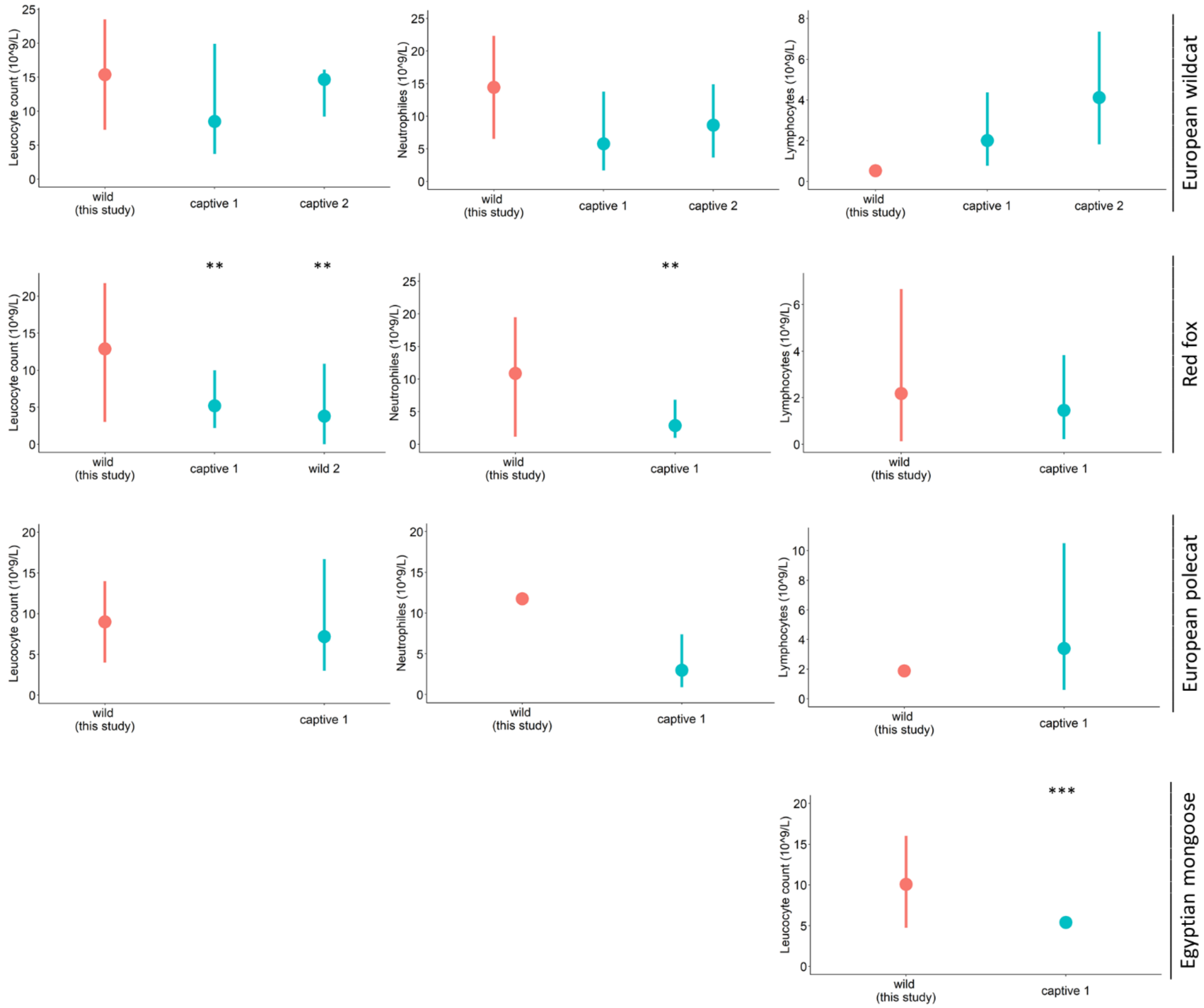

Fig. 5. Physiological biomarkers of immune system activation in the European wildcat, red fox, European polecat, and Egyptian mongoose. Mean and range from this study (red), mean and reference range from captive animals (blue). Captive 1: ZIMS (2018) for all species except the European polecat (Mitchel and Tully, 2008) and Egyptian mongoose (Fowler et al., 1986); captive 2: Marco et al. (2000) for the European wildcat, Marks (2010) for the red fox, Hein et al. (2012) for the European polecat.

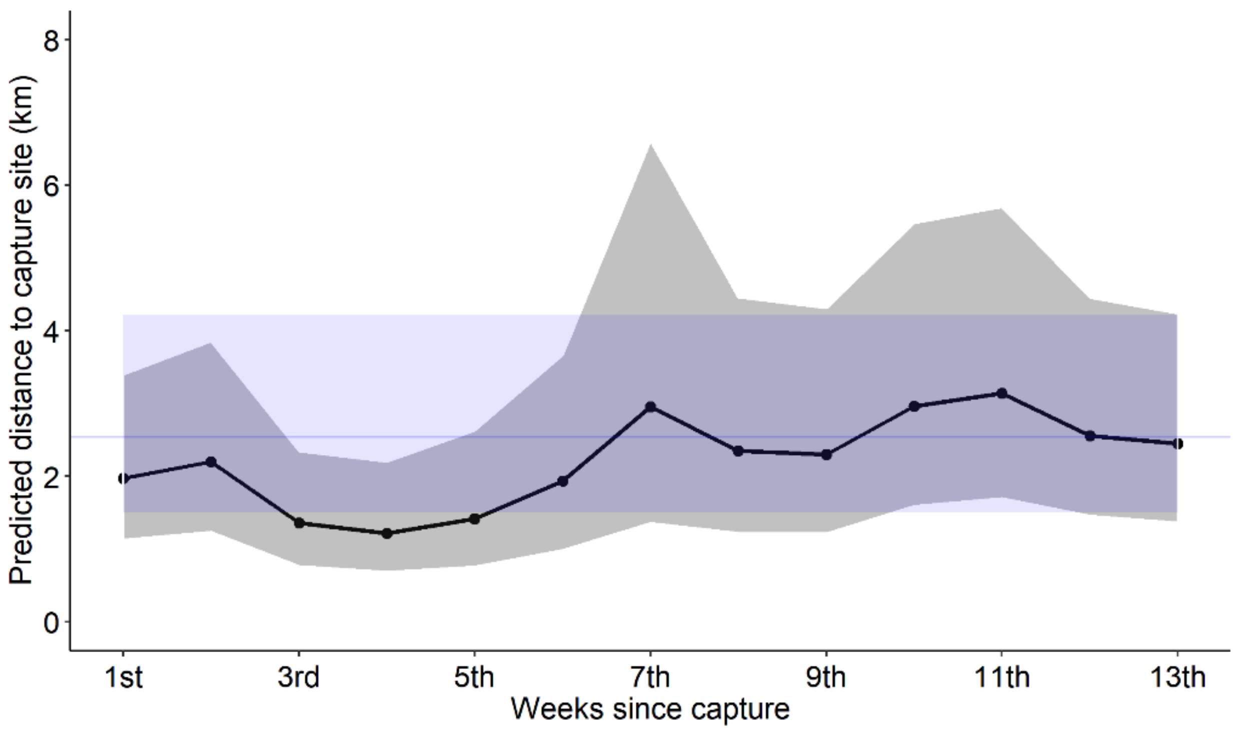

Fig. 6. Predicted weekly distance to the capture site for the European wildcat. Average weekly distance of locations to the capture site with 95% confidence interval (grey) predicted by the log-linear mixed model controlling for the individual carnivore, sex, and season. Average weekly distance of locations to the capture site from the 13th week onwards with 95% confidence interval (blue).