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A potential case of copper-related sand eating behaviour in Grevy zebras *Equus grevyi* at Kolmården Wildlife Park

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Abstract

In the spring of 2023, a zebra *Equus grevyi* at Kolmården Zoo was euthanized due to colic. During the autopsy, over 20 kg of sand was found in her intestines. During the summer of 2023, it was noted that the black stripes of the rest of the zebra group appeared less dark than usual. Two mares were observed actively eating sand at a specific location for the first time in August; when moved, they were not seen eating sand in other enclosures. When moved back to the original enclosure, they returned to eating sand from the same spot. Analysis of the sand from that specific location, compared to sand from other areas in the enclosure, showed markedly higher levels of copper (Cu), a mineral suggested to be associated with geophagia in horses *Equus caballus* when deficient. This, together with the coat coloring, strengthened suspicions of a Cu deficiency. The total diet had previously contained 9 ppm Cu in dry matter. First, the pellet feed was increased to raise this to 12 ppm; then, the pellet recipe was adjusted so that the diet increased to 14 ppm without further increasing the pellet amount. 30% of the Cu sulfate was replaced with copper chelate to putatively enhance absorption. In the spring of 2024, the amount of pellets was reduced while a Cu and zink chelate supplement was added, so that the total diet contained about 15 ppm Cu, with most of the Cu coming from bioavailable sources. During the summer of 2024, the zebras were not seen eating sand, except for one occasion after the introduction of a new stallion, during which the mares exercised intensively for many days. The results suggests Cu as the underlying cause of the observed behavior, which in turn may indicate nutritional wisdom.

Background

Zebras are obligate herbivores with nutritional needs putatively similar to domestic equids. Colic is a general term for abdominal pain in equids, and several risk factors have been associated with dietary composition. One possible cause of colic is the excessive ingestion of sand (Kaneene et al. 1997). Risk factors for sand colic in horses *Equus caballus* include sandy soil in pastures, feeding directly from the ground in the absence of grass or when grass is short (1–5 cm), and failure to provide supplemental feed during periods of poor grazing (Husted et al. 2005). In some cases, colic can be fatal (Tinker et al. 1997; Hillyer et al. 2001). In a study from France, mortality in horses was reported at 2.47%, with colic being the second most common cause of death, accounting for 21% of cases (Leblond et al. 2000). This underlines the importance of prevention. Among horses monitored over a year for colic, approximately 3% were diagnosed with sand colic (Kaneene et al. 1997).

In addition to unintentional sand ingestion, some horses voluntarily consume soil or sand, a behaviour known as geophagia or pica. The exact causes remain unknown, although the behaviour is reported in both wild and domesticated horses (McGreevy et al. 2001; Abrahams 2012). Aside from boredom (Ralston 1986), several potential causes have been proposed, including compensation for mineral deficiencies. For instance, it has been estimated that sheep can meet up to 50% of their daily requirement for minerals such as copper (Cu), iron (Fe), manganese (Mn), iodine (I), selenium (Se), and sodium (Na) through soil ingestion (Abrahams 2012). Horses may likewise consume sand as an attempt to self-regulate their diet—a concept referred to as nutritional wisdom (Provenza 2018). While horses have been shown, to some extent, to regulate sodium intake through voluntary salt consumption (Schryver et al. 1987), evidence suggests they do not proactively regulate the intake other minerals (Ralston 1986; Niinistö and Sykes 2021). Nonetheless, McGreevy et al. (2001) found that soils selected for consumption by horses contained significantly higher levels of Fe and Cu. Horses engaging in geophagy exhibited, on average, less than half the serum Cu (8.1 vs 18.41 µmol/L) and Fe levels (8.37 vs 18.84 µmol/L) of control animals (Aytekin et al. 2011). These individuals also showed lower hemoglobin concentrations, though the difference was not statistically significant. Similarly, Li et al. (2020) demonstrated lower circulating mineral levels, including lower Cu levels, in horses practicing pica. In a study on sheep, Cu deficiency was prevented with as little as 20 g of soil intake per week (Niinistö and Sykes 2021). A study on buffalo calves demonstrating pica behaviour reported significantly reduced concentrations of serum Cu, Zinc (Zn), Se, Fe, and Mn (Kochan et al. 2023). When testing licks visited by mountain zebras and antelopes and comparing them with surrounding samples, calcium (Ca) was the only element found in higher amounts in all the licks; however, only Ca, Na, magnesium (Mg), potassium (K), and phosphorus (P) were analyzed (Penzhorn 1982). Their results also showed lower levels of Na in all the licks compared with the surrounding samples, suggesting that geophagy is not always triggered by a hunger for salt.

Psyllium seeds are sometimes used as treatment for sand colic (Hotwagner and Iben 2008). The intended function of psyllium is to form a gel within the intestines, which, in theory, binds sand and facilitates its passage, thereby reducing the risk of accumulation. However, psyllium alone has not been demonstrated to have a positive effect, and in some cases, its use may inadvertently increase the risk of sand accumulation due to a false sense of security following administration (Hammock et al. 1998). A modest beneficial effect has been observed when combined with mineral oil (Hotwagner and Iben 2008); more promising outcomes have been reported with a combination of psyllium and magnesium sulfate (Niinistö et al. 2014). Entwisle and McConnell (2025) administered a combined treatment of psyllium, magnesium sulphate, and paraffin oil to 54 Western Australian equids, resulting in an 81% success rate after four days based on radiologic examination of the abdomen. However, outcomes were less favorable in the miniature pony group, with only 44% showing successful resolution. Complications occurred in 30% of cases but these were considered mild.

Active sand consumption was observed in one group of Grevy's zebras *Equus grevyi* housed at Kolmården Wildlife Park. Due to the potential role of Cu and Fe in such behaviour, these minerals were investigated in the present case. As of spring 2023, Kolmården Wildlife Park held two separate groups of Grevy's zebra. The safari group consisted of two adult females—Lucky (born 2011), and Zawadi (born 2014), along with their two male offspring (both born August 2022). A stallion, Kiru (born 2017), arrived at Kolmården during 2023 and was temporarily housed in the park savannah located one kilometer away from the safari zebras with a castrated male while awaiting the transfer of the foals. Later in 2023 after the death of Zawadi , a new female, Mala (born 2018), was introduced to the collection in the beginning of July.

The main habitat used for the safari zebras is referred to as "the big savannah." This large savannah complex spans six hectares and can be divided into two sections: approximately five hectares on one side and one hectare on the other. The terrain is varied, featuring grassy areas, sandy surfaces, woodland, and rocky outcrops. In addition, there is an adjoining stable with outdoor paddocks, most of which are surfaced with sand, except for one which is predominantly rock and grass. Grevy's zebras are housed in this mixed-species exhibit alongside a range of other ungulates, including giraffe *Giraffa camelopardalis*, blue wildebeest *Connochaetes taurinus*, ankole cattle *Bos taurus watusi*, gemsbok *Oryx gazella*, red lechwe *Kobus leche*, blackbuck *Antilope cervicapra*, and eland *Tragelaphus oryx*.

In spring 2023, Kolmården Wildlife Park experienced the loss of Lucky, one of its adult female Grevy's zebras; necropsy revealed more than 20 kilograms of sand in the large intestines. There were no reported signs of sand ingestion before the colic was discovered, nor were there any signs in the weekly fecal samples. An internal evaluation was conducted to assess the incident, identifying several factors considered relevant for reporting. The zebras always received a certain allotment of a mineral pellet. Two weeks prior to the case, the park had initiated a forage transition from a late-cut silage to an even later-cut hay of significantly lower nutritional value. The animals were fed a 50:50 mix during the first week before being moved entirely to the new hay. In the evaluation, this dietary shift was not considered to be the cause of the sand colic.

It was noted in late June and July 2023 that the remaining safari zebras had paler stripes than usual, with a distinct reddish-brown hue. On 23rd of August, both mares in the group were observed eating sand on the "lower savannah" (Figure 1), prompting the removal of the entire group from the exhibit. After a week, they were reintroduced to the lower savannah, only for both mares to immediately return to the same location and resume sand ingestion. A month later, a supervised trial yielded the same outcome, and it was decided that the group would no longer have access to the lower savannah until a solution was identified. Exceptions were made when the ground was frozen or covered in snow. Notably, while other areas of the enclosure offered access to soil and sand, the zebras returned to two specific spots around the same location to ingest sand. Similar behaviour was not observed on other enclosures used during this time, although minor exploration of soil or moss occasionally occurred. However, this was not equivalent to the active sand ingestion previously recorded.

Action

A task group was formed to investigate the issue, consisting of the veterinary team, the ungulate team leader, the zoo's nutritionist, and a biologist.

Blood samples were taken, but as the zebras had not been trained for voluntary blood draws and due to logistical constraints, fewer samples were obtained than anticipated. The blood samples were sent to Laboklin in Germany, which has experience analyzing equine blood. For economic reasons, there were limitations on which minerals were analyzed. Previous liver samples from other park animals fed a similar diet were also reviewed for potential clues. Samples of sand from the location where zebra mares were observed consuming sand were sent to Eurofins Agro for analysis, along with a composite sample from other parts of the enclosure for comparison.

The park's animal coordinator also reached out to 54 EAZA institutions housing Grevy's zebras, inquiring whether similar behaviours had been observed, if they had encountered sand colic, whether they used psyllium , and what feeding regimens were used. Of those contacted, 28 institutions responded, though not all provided answers to every question. Responses were compiled to assess whether Kolmården differed in any notable way. Institutions were also asked for general opinions on potential causes and any advice they could offer.

For changes in dietary strategy as well as modifications to the premix composition of the pellets, consultations were held with a specialist from the supplement company Wiromin AB.

We made a list of potential causes of sand ingestion based on the responses of other zoos and our own considerations, excluding

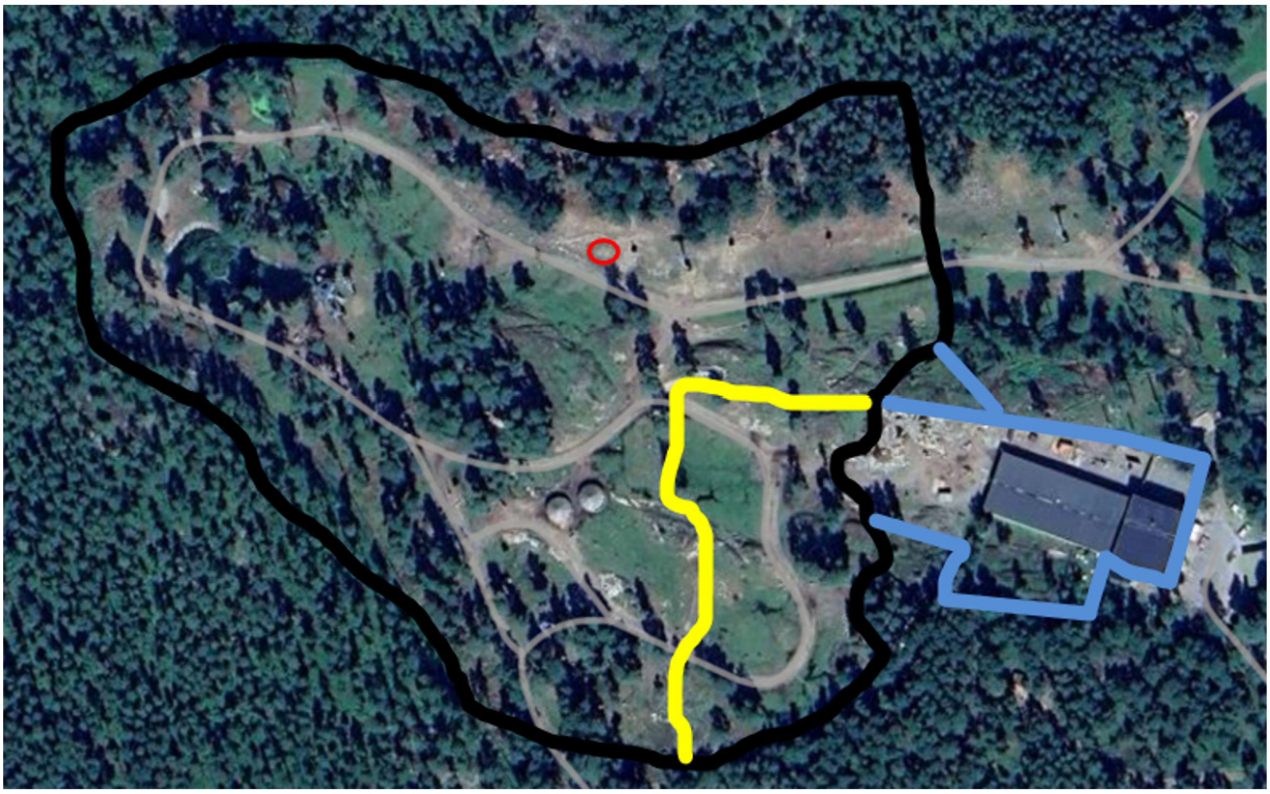

Figure 1. Kolmården's safari savannah where the focal group (safari zebras) lived, sourced from Google Maps. Black lines indicate "the big savannah." The yellow line shows how the savannah can be divided into two by closing two gates; this area is called the "upper savannah". When the savannah is divided, the large area is called the "lower savannah". Blue lines indicate paddocks surrounding the stable—note that not all separation options for dividing into smaller paddocks are visible. The red circle marks the area where the zebras ate sand.

various options and concluding that Cu deficiency was the most likely hypothetical explanation (Table 1).

The pelleted feed used at Kolmården is a custom formulation developed in collaboration with a local mill, allowing for tight control over composition. However, batches are produced in quantities of at least 3 tons, and the pellet called "Mineral" fed to the zebras is consumed on a four- to five-month cycle. This meant that, although a new recipe had been developed earlier, the

Table 1. Different reasons suggested for geophagia with comments on how the Kolmården team involved with the case reasoned. *Are suggestions via e-mail from other Grévy's zebra holders.

Suggested reason	Thougths from Kolmården
Tooth problems – Worn-down teeth can cause the animal to eat soil in an attempt to correct this itself. *	Lucky sedated for hoof trimming on August 15 2023– no comments regarding teeth. However, this should be an individual issue, not a group-level one.
Hunger – or an unfulfilled need for eating and chewing can result in animals eating soil. There is no benefit to this behaviour; the animal needs more food.*	They have ad lib forage and straw beds
Stress or boredom - can result in the animal choosing to eat soil. This is not healthy; the animal's behavioural and safety needs must be addressed.*	Nothing noticeable. We are better nowadays at providing environmental enrichment.
Lack of fiber – often results in coprophagy or pica. Also seen as gnawing on trees and wood.*	About 60% NDF in the feed ration + the straw that they eat. More than most provide. Gnawing on wood or walls or coprophagy is not observed.
Lack of silica - The soil can have a lot of silica*	Our feed ration consists mainly of grass which should contain a lot of silica. Therefore, they shouldn't be lacking in silica. The sand they ate clearly had more silica than other sand. Our literature search did not provide definitive answers; however, this line of inquiry would have been pursued further had other interventions failed. As the behaviour ceased, no further investigation was conducted.
Low haemoglobin - could be a sign of low copper or iron. A correlation was found between lower serum haemoglobin levels in horses that ate soil, even though the levels were still not too low (Aytekin et al. 2011).	Lucky's hemoglobin was within the reference range but on the low side. Her value: 11.6 g/dL Reference range: 11.4–18.1 g/dL (Species360 Zims 2024)
Copper and iron deficiency - A correlation was found between lower serum of copper and iron for horses that ingested soil (Aytekin et al. 2011)	Our zebras appeared more sun-bleached than usual, which can be a sign of copper deficiency (Hearing 2011; Bennett and Lamoreux 2003). The serum copper level was also around the range reported for horses with similar behaviour (Aytekin et al. 2011). The sand they ate had much more copper.

updated pellet only reached the zebras in January 2024 (Table 2).

Feed formulas are normally adjusted annually after the park's various forage analyses are completed. In this case, changes were also made in light of the suspected Cu deficiency. Because Cu and Zn can interact negatively (Shenkin et al. 2024), the decision was made to administer a combined supplement to reduce the risk of imbalance. The dietary targets for Cu and Zn were raised, see end results in Table 2, while Se levels were reduced. The adjustment of Se was made with the yaks in consideration, as they had, as shown in Table S2, reached levels within the toxic range. Additionally, 30% of the Cu and Zn sources were changed from sulphates to chelates derived from protein hydrolysate to improve bioavailability (Wu et al. 2024). Later, a Cu and Zn supplement composed entirely of chelates was also introduced to further support absorption. The change of the estimated diet nutrient composition over time is displayed in Table 2.

Throughout the autumn 2023, winter, and early spring 2024, the zebras were managed in alternative enclosures rather than on the main savannah. Exceptions were made when the ground was frozen or covered in snow. On some occasions, signs of digging through snow in search of sand were observed. Minor soil ingestion was also noted at one of the other enclosures in February 2024, but only sporadically. One week per month, the zebras were fed psyllium seeds in the hope that it would help carry out any ingested sand. Adult zebras voluntarily consumed approximately 50 g of psyllium seeds each (≈0.14 g/kg BW). This represented the maximal amount they would ingest voluntarily, as any excess offered was refused. Consequently, the effective dose was substantially lower than the veterinarian's recommended dose of 0.33g/kg BW.

Consequences

The available blood samples indicated serum Cu levels closer to that of horses displaying pica (8.1 ±3.6 µmol/L) than horses not displaying pica (18.4 ±1.0 µmol/L) (Aytekin et al. 2011; Table S1). The paler-than-usual stripes of our zebras matched literature reports that associate this appearance with copper deficiency (Hearing 2011; Bennett and Lamoreux 2003). Although copper deficiency has not been formally demonstrated to cause this specifically in horses, dark-coated individuals exhibiting a reddish tint in the mane have shown positive responses to Cu and Zn

Table 2. Displays the different diets provided to Kolmården's zebras over time; concentrations per dry matter. DMI = dry matter intake. *Proposed diets for zebra and white rhinoceros (Lintzenich and Ward 1997).

kg diet items	2022 (400kg) 5.6 Hay 5.3 Silage 0.5 Mineral	Jan 2023 (350 kg) 8.2 Hay 0.5 Mineral	25 Aug 2023 (350 kg) 6.2 Hay 3.3 Fresh grass 0.8 Mineral	Jan 2024 (350 kg) 8.0 Hay 0.8 Mineral	4 Apr 2024 (350 kg) 8.2 Hay 5 g Cu & Zn 0.5 Mineral	17 Jul 2024 (350 kg) 8.0 Hay 0.8 Mineral	NAG* Zebra
DMI %BW		2.2	2.2	2.2	2.2	2.2	
Starch %	0	0	1	1	0	1	
Sugar %	6	10	10	11	11	11	
Crude fibre %	2	2	1	2	2	2	
Crude protein %	6	7	8	9	9	9	
NDF %	64	61	60	55	56	55	
Vitamin A IU/g	1.2	1.1	1.8	1.8	1.3	1.8	1.2-2
Vitamin D IU/g	0.6	0.5	0.8	0.8	0.6	0.8	0.3-0.5
Vitamin E IU/kg	127	77	126	127	95	127	100-160
Ca:P	2.2	1.6	1.9	1.9	1.8	1.9	
Ca %	0.67	0.51	0.72	0.79	0.65	0.79	0.55-0.63
P %	0.30	0.31	0.39	0.42	0.36	0.42	0.30-0.38
Mg %	0.17	0.16	0.20	0.21	0.18	0.21	0.16-0.19
K %	1.53	1.60	1.44	1.58	1.60	1.58	1.4-1.8
Na %	0.07	0.06	0.10	0.10	0.08	0.10	0.07-0.12
Fe mg/kg	110	81	83	99	93	99	73-84
Zn mg/kg	58	63	83	86	91	86	44-71
Cu mg/kg	10	9	12	14	15	14	8-14
Mn mg/kg	46	47	49	58	55	58	40-55
Se mg/kg	0.25	0.23	0.37	0.21	0.16	0.2	0.10-0.16
I mg/kg	0.2	0.2	0.3	0.3	0.2	0.3	0.2-0.4

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supplementation (Layton 2014).

Liver analyses of wild ruminants with partially similar diets to the zebras did not reveal a clear pattern (Table S2); however, the Cu levels found in two individual antelope species (sable *Hippotragus niger* and eland *Taurotragus oryx)* were considered at the lower range of reference values. Zinc values were low across most individuals investigated.

Mineral analyses for sand and soil indicated a distinct difference in the Cu level between the spots where zebras had been observed ingesting sand compared to sand and soil from other locations in the enclosure (Table 3). Notably there was no higher Fe content in the sand that the zebras chose to eat, which led the team to assume that Fe was not the driving factor behind the behaviour.

Thirteen zoos provided sufficiently detailed dietary information to be used for comparison. Only one included a fully calculated ration with forage analysis. The remaining 12 offered approximate guidelines such as "1 kg of pellet X and ad lib hay." We performed a comparison of the Kolmården Grevy zebra diet with that of other holders in Europe, applying assumptions about total dry matter intake. In calculating the nutrient composition, it was assumed that all institutions that did not report forage analysis were feeding hay similar to an earlier batch of hay previously used at Kolmården. Consequently, the actual feed composition across institutions could differ considerably from what is presented here. The following assumptions were made. The average weight of the zebras was assumed to be 350 kg—lower than typical for adult Grevy's zebras to include smaller and growing individuals—with a total dry matter intake estimated at 2.2% of body weight (BW) originating from our own observations and estimations. Pellets were assumed to have a dry matter content of 90% unless otherwise specified. Reported pellet quantities were subtracted from the total dry matter intake to calculate hay consumption. This allowed for estimation of daily nutrient supply across institutions for comparison with Kolmården. The results did not indicate specifically low Cu levels at Kolmården (Table S3). The diet provided at Kolmården met the levels recommended for zebras by the Nutrition Advisory Group (NAG; Lintzenich and Ward 1997). When converted and compared with the recommended intake levels for horses, the Cu intake of 0.2 mg/kg body weight (BW) exceeded the equine recommendation of 0.1mg/kg BW (Wichert et al. 2002), and similarly, the Zn concentration of 1.4 mg/kg BW was higher than the recommended 1 mg/kg BW for horses (Wichert et al. 2002).

Compared to the mean of the responding zoos, Kolmården was rather similar in the percentage that the pelleted feed made up of the estimated total diet (Table S4). Sand colic in the species had been observed in two facilities, and the same two facilities reported applying psyllium when detecting sand in their zebras' feces (Table S4).

Only two individuals had repeated blood samples—Kiru and Zambezi (Table S1). Neither of these individuals had been observed eating sand. During the period of concern, Kiru was housed at a separate facility and received a different roughage source. No notable changes in his serum profile were detected. Zambezi, however, was on the same diet as the mares observed ingesting sand. His first blood sample from February 2024 was taken shortly after the new pellet formulation had been introduced. The second sample, about a month later, showed a general improvement across all values, including Se, despite a recent reduction in Se content in the feed.

The stripe coloration of the zebras gradually returned to its characteristic black appearance. On 7 March 2024, the foals were transferred to other parks. On 16 April 2024, Kiru was introduced to the mares on the large savannah. During the initial days of this introduction, sand ingestion was observed briefly on a few occasions but has not been reported since. A few anecdotal reports of moss-eating have been reported.

The case presented here demonstrates how a variety of considerations – rather than the simple reliance on blood values, or calculated dietary values – led to a series of intervention that appears, so far, to have resolved a situation interpreted as a mineral deficiency causing geophagy, which in turn caused colic. Notably, the thought to simply fence off the spot of soild ingestion was not considered at the time, as the team was not

Table 3. Diet compositions: Kolmården compared with other Grevy's zebra holders in Europe, based on survey responses and assumptions. *Proposed diets for zebra and white rhinoceros (Lintzenich and Ward 1997).

	Average	Median	Lowest	Highest	Kolmården	NAG*
Ca %	0.37%	0.34%	0.26%	0.57%	0.51%	0.55-0.63
P %	0.16%	0.14%	0.11%	0.30%	0.31%	0.30-0.38
Mg %	0.11%	0.10%	0.08%	0.21%	0.16%	0.16-0.19
K %	1.4%	1.4%	1.3%	1.9%	1.60%	1.4-1.8
Na %	0.05%	0.03%	0.01%	0.11%	0.06%	0.07-0.12
Fe PPM	101	90	78	193	81	73-84
Zn PPM	30	19	11	69	63	44-71
Cu PPM	6	4	3	14	9	8-14
Mn PPM	40	33	23	68	47	40-55
Se PPM	0.13	0.03	0.01	0.84	0.23	0.10-0.16
I PPM	0.28	0.09	0.01	1.43	0.2	0.20-0.40
Vitamin A IU/g	1.5	0.6	0.2	7.0	1.1	1.2-2.0
Vitamin D IU/g	0.22	0.09	0.02	0.97	0.5	0.30-0.50
Vitamin E IU/kg	52	36	4	173	77	100-160

focused on preventing pica, but at resolving the underlying issue. Interestingly, Mala exhibited sand ingestion behaviour shortly after her arrival at Kolmården. It is conceivable that any deficiencies—if nutritional in origin—were already present prior to her transfer. It is also possible that she had not displayed geophagia at her previous facility simply due to the absence of access to sand or soil containing the substances she was seeking.

This raises the possibility that more zebras across Europe may be at risk than currently appreciated, obscured by facility-specific environmental variables. While it is to some extent considered that horses can regulate their sodium intake (Schryver et al. 1987), no experimental evidence has demonstrated similar regulatory behaviour for other minerals. In hindsight, the cessation of sand ingestion following dietary modifications suggests a causal link to a mineral imbalance. Such a finding would lend support to the hypothesis that equids—including zebras and horses—may possess a limited but functionally relevant degree of nutritional wisdom specifically with respect to Cu regulation. Should this interpretation hold, it would indicate that achieving appropriate Cu levels in managed diets plays a preventive role in the development of sand colic in zebras. We recommend that other institutions observing similar signs — including sand ingestion and coat bleaching — assess the copper status of their zebras to contribute additional data to test this hypothesis.

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Conflict of interest

No conflicting interests to declare.

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