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Hand-rearing the critically endangered blue-eyed black lemur (*Eulemur flavifrons*): milk formula, feeding and socialisation protocols

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Abstract
The blue-eyed black lemur (*Eulemur flavifrons*) is critically endangered in the wild and managed by ex-situ programmes in zoos. The breeding success in the European population is low and within the last five years, there have only been three births that survived. To try to increase the rate of infant survival, a systematic hand-rearing protocol was developed in 2013 and used on five infants from two different females that did not properly raise their infants. Milk formula was created with a mix of human newborn formula and kitten replacement milk. The lemur infants were fed ten times a day at the beginning, on a 24-hour round-the-clock basis. Solid food was offered as early as Day 7 and complete weaning was achieved without any medical issues around Day 107. The socialisation protocol consisted of maintaining permanent visual, olfactory and auditory contact with the parents from the day of the birth. First attempts to put the infants on their mother began as early as Day 2, but results varied, including successes with the parents, with conspecifics or lemurs from another *Eulemur* species. More work is needed to develop a feeding protocol which would also include the physiological variations in milk composition during the lactation period. Although many studies and reports have described hand rearing mammals, and more specifically lemurs, none of them describe a successful and complete protocol for five infants of the critically endangered blue-eyed black lemur.

Background

The blue-eyed black lemur (*Eulemur flavifrons*) is an arboreal, cathemeral, generalist and opportunistic feeder lemur (Schwitzer et al. 2007). Its distribution is restricted to the Sahamalaza peninsula, in the north west of Madagascar (Schwitzer et al. 2013). *E. flavifrons* is classified as critically endangered by the IUCN red list (Andriaholinirina et al. 2014). An *ex-situ* conservation programme was established in Europe in 1989, and a European endangered breeding programme (EEP) was created in 2002. The current EEP population is composed of 17 males and 13 females, all descendants of six *E. flavifrons* imported from Madagascar between 1986 and 1991 (Lefaux 2013, 2014). The population is not genetically and demographically sustainable given the current reproduction rate (Lefaux 2013). Only 11 births have occurred in the last five years, and only three infants survived; three were stillborn and five did not survived because of a lack of mother rearing (Lefaux 2013). Thus a systematic hand-rearing protocol was developed in 2013 and used with five infants from two different females. In this paper we describe the nutritional and socialisation protocols used, both key to the survival of a healthy infant and its future breeding ability (Porton and Niebruegge 2006).

Action

Individuals

Three infants (2.1) from Female 1 (Mulhouse 1, Mulhouse 2 and Mulhouse 3) and two infants (1.1) from Female 2 (La Palmyre 1 and La Palmyre 2) were reared following the hand-rearing protocol between 2013 and 2015. All five infants were singletons except Mulhouse 1, whose twin was stillborn.

Female 1 from Mulhouse Zoo was born in Europe in 2003 and was parent-reared. Before the hand-rearing protocol was developed, she had already given birth to five infants who died within their first three days of life. The possible hypotheses

Table 1. Formula composition, dry matter basis, comparison with *Eulemur macaco* natural milk composition (Tilden 1997).

	DM (%)	Lipids (%DM)	Proteins (%DM)	Glucids (%DM)	Ca (%DM)	P (%DM)	Ca/P
Hand-rearing formula used in the study	16.7	22.9	15	56	0.6	0.4	1.5
E. macaco milk	10.1	10.9	14.9	83.2	ND	ND	ND

to explain why she did not rear her infants were 1) a social or environmental stress, 2) a lack of rearing experience, or 3) an anatomical or physiological abnormality of the dam such as a nipple defect or lack of milk production (Coffman 1990; Laidebeurre et al. in press; Porton and Niebruegge 2006). Female 2 from La Palmyre Zoo was born in Europe in 1998 and parent-reared. The hand-rearing protocol was initiated at her very first parturition as no maternal feeding was observed and the infant was not able to cling anymore to his mother two days after his birth.

Female 1 was trained following a protocol developed by Paris Zoo (Laidebeurre et al. in press; Roullet 2013) to take of the infant, before feeding and put it back.

Milk formula

There are no existing references for the nutritional requirements of *E. flavifrons* infants. Some publications however describe hand-rearing of other lemur species (*Propithecus coronatus*, *P. tattersalli*, *Lemur catta*, *Eulemur coronatus*, *Microcebus murinus*, *Varecia variegata*) (Cartmill 1979; Coffman 1990; Glatson 1981; Hick 1975). We developed our hand-rearing protocol using these references. The substitution milk is a mixture of human newborn formula milk (Milumel Lemiel 1er âge, Milumel, 35370 Torcé, France) and kitten/puppy formula milk (Lait maternisé Biocanina, Biocanina, 63170 Aubières, France). Two grams of Biocanina and eight grams of Lemiel 1er âge are diluted in 50 ml of mineral water. 10 ml of glucose 5% are added in the first week's formula. The formula is composed of 16.7% dry matter (DM) and the analysis (DM basis) is 15% protein, 22.9% fat, 56 % carbohydrates, 0.6% calcium, 0.4% phosphorus, Ca/P ratio=1.5 (see Table 1).

The last two hand-reared infants (Mulhouse 3 and La Palmyre 2) received a formula in which Biocanina was replaced by a different kitten formula milk product (Milkkan chaton, Laboratoires Omega Pharma France, 92321 Châtillon Cedex, France). This change did not affect the overall formula composition.

Nursing protocol

Teats used for the bottle feeding were classic kitten hand-rearing teats that were delivered with the kitten formula milk.

The first two feeds consisted of 1 ml of an electrolyte solution (Biodiet, Elanco Santé Animale, 92158 Suresnes Cedex, France) as a precaution, to rehydrate the infant.

The formula described above is then given as full strength for all the other feeds, with the quantity varying according to the infant's weight at 8 am. At first the infant is given 31% of its body weight over a 24-hour period; this amount is slowly decreased to 19 % around Day 60 (see Table 2).

Frequency of the bottle feeding also decreases over time, with one feed every 2.5 hours at the beginning, decreasing to one daily feed at Day 110 (see Table 3).

The daily formula, divided into portions needed for each meal, is prepared at 0800 and then stored in the refrigerator. Before each feed the milk is warmed, and then any leftovers are discarded.

Solid food is offered as early as Day 7 to help infants become familiar with it and ease transition. Only small pieces of vegetables (cucumber, lettuces, cooked carrots, cooked red peppers) are offered in the first couple of months to promote their steady ingestion, with small pieces of fruits (apple and pear first) added around Day 80. Solid food is offered ad lib after the bottle-feeding. The dish and leftovers are weighed at the end of the day to get an estimate of solid food intake.

Before each feeding time, the infants are gently stimulated in the perineal region with a humid cotton bud, to stimulate urination and defaecation. Then the infant is weighed before and after bottle feeding so that the exact amount of ingested milk is known.

Housing protocol

Just after the infant has been removed from its mother, it is placed on a cotton plush toy (20 cm high) used as a surrogate in

Table 2. Guidelines on the quantity of milk formula to be fed during hand-rearing.

Date	Quantity to be fed (% of body weight) in a day (24 hours)
From day (D) 1 to D7	31 %
D8 to D12	30 %
D13 to D19	28%
D20 to D26	26%
D27 to D31	24 %
D32 to D62	21 %
D63 to D84	19%

Table 3. Changes in the number of bottle-feedings in a 24-hour day throughout the hand-rearing period.

Date	Number of bottle feedings in the day
From D1 to D10	10
D11 to D15	9
D16 to D28	8
D28 to D52	7
D53 to D65	6
D66 to D75	5
D75 to D85	4
D86 to D109	3
D110 to D116	1

Table 4. Data on hand-reared animals' gestation and weights (ND: no data recorded).

	First observed mating of parents	Last observed mating of parents	Date of birth	Estimated gestation length (days)	Birth weight (g)	Sex
Mulhouse 1	01 November 2012	24 November 2012	08 March 2013	130>G>119	75.00	Male
Mulhouse 2	23 October 2013	01 December 2013	01 March 2014	129>G>91	79.20	Female
Mulhouse 3	01 November 2014	12 November 2014	10/ March 2015	127>G>105	69.16	Male
La Palmyre 1	ND	ND	09 April 2013	ND	50.90	Female
La Palmyre 2	ND	ND	13 April 2015	ND	65.00	Male

an incubator. In the beginning the temperature in the incubator is set at 34° C and is then decreased slowly, one degree each week, until Day 40 (following recommendations by Laidebeurre et al. in press). It is then reduced by 0.5° each day until 21° C is reached. At this stage, the infant is increasingly active and is placed in an indoor exercise cage every day (around 20° C), returning to the incubator only for the night. The exercise cage is 60 cm long, 60 cm wide and 80 cm high, with 2x1 cm mesh. Three pieces of bamboo (1.5 cm diameter) are placed in the cage and a 25 cm high tablet (10 x 20 cm) is placed on one side of the cage. Finally, if the weather allows (dry, sunny and above 15° C), the exercise cage is placed outside. Bigger exercise cages are used (up to 100 x 80 x 150 cm) and enrichment is added (ropes, more tablets, larger bamboos, hammocks) throughout the rearing period, according to the behavioural development of the young lemur.

Socialisation protocol

When developing a hand-rearing protocol, it is important to meet both the nutritional and social needs of the infant. All of the hand-reared infants were therefore kept in visual, olfactory and auditory contact with the parents from birth.

Different socialisation options were tried, either with the parents, with animals from the same species or with animals from other *Eulemur* species, and from Day 1, the infant was always kept in visual, olfactory and auditory contact with the parents during the day.

Attempts to put the infant back on the dam began as early as Day 2 (Mulhouse 3, in the dam's training cage). The latest introduction of infant to dam was La Palmyre 2 at Day 60, by opening the exercise cage, which had been placed in the parents' indoor cage since Day 53. When the attempt with the dam failed, attempts were made with other lemurs that were housed separately at the time of the hand-rearing and thus available for the test (Mulhouse 1 and 2). The first trial was made with other *E. flavifrons* and when it failed again, *E. albocollaris* was tested (Mulhouse 3).

Results

In the cases described, gestation length is estimated at between 128 days (first matings observed) and 105 days (last matings observed) (see Table 2).

The average birth weight of the hand-reared *E. flavifrons* was 67.8 g (ranging from 50.9 g to 79.2 g). Birth weights are shown in Table 4. Two individuals presented foot digit agenesis. In Mulhouse 3, right digit II and left digits II and III were missing and in La Palmyre 1, right digits II and III and left digits II, III and IV were missing. No conclusions can be drawn about the relationship between sex and birth weight as the two females had respectively the heaviest and lightest birth weights of the five animals.

The growth curves of the five animals are shown in Figure 1. Daily milk intake is shown in Figure 2, and daily solid food intake in Figure 3. The infants began to play with solid food as early as Day 10 and began to eat solid food steadily at Day 30. To stimulate solid food ingestion, the amount of milk given was limited to a maximum of 88 ml a day in Mulhouse 1 and solid food was offered *ad libitum*. When the animal was visually assessed as being too big, showing a 10% weight gain, solid food offered was limited to a maximum of 60% of the adult daily intake (115 g) until milk feeding was stopped. For Mulhouse 2 and 3 and La Palmyre 1 and 2, solid food was slowly increased after introduction. For Mulhouse 2 and 3, milk intake was limited to 56 ml a day, which is the milk intake of a 1 month old infant which already steadily eats solid food. Except

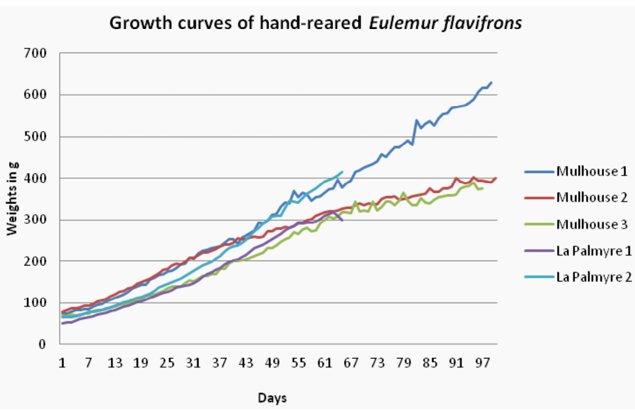

Figure 1. Growth curves of hand-reared *Eulemur flavifrons* from Day 1 to Day 110.

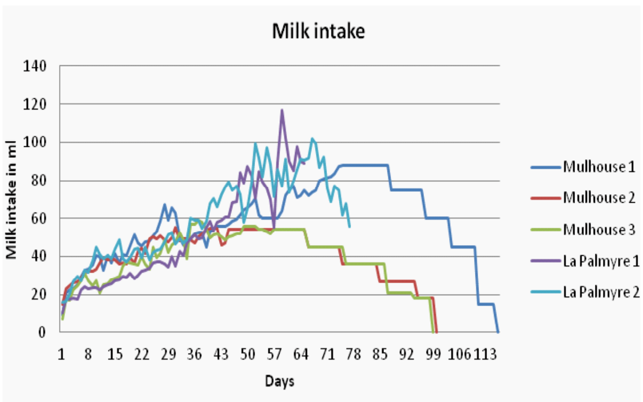

Figure 2. Daily milk formula intake of hand-reared *Eulemur flavifrons.*

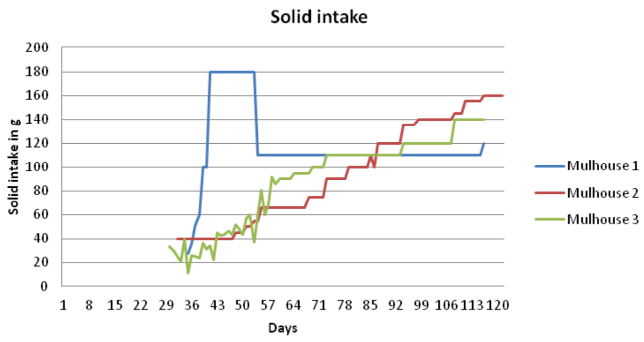

Figure 3. Daily solid food intake of *Eulemur flavifrons.*

for Mulhouse 1, which obviously looked obese, all other infants looked in good body condition, neither thin nor obese, and were very active.

Full weaning of the animals was achieved between Day 100 and Day 115.

Four of the infants survived, but La Palmyre 1 died at Day 66 of acute septicaemia. This death occurred 10 days after a move to a new enclosure with the parents and was associated with bloating, diarrhoea and blood in the faeces. *Klebsiella pneumonia* was cultured from heart blood.

For Mulhouse 1, 2 and 3, attempts to put the infant back on the dam in the training cage were made at Day 15, Day 4 and Day 2 respectively. The mother respectively showed signs of rejecting the infant (restlessness, aggression towards the infant) on the day of, the day after and 19 days after the first introduction. For these introductions, the infant stayed with the mother for sessions of 2 h 30 min, corresponding to the interval between two feedings. Mulhouse 1 and 2 were successfully introduced to a conspecific, at Month 7 and Day 78 respectively. Mulhouse 3 was introduced to a pair of white-collared lemurs (*Eulemur albocollaris*) at Day 109.

La Palmyre 2 was introduced to his parents at Day 60, after the exercise cage had been placed in the parents' indoor cage at Day 53. The female showed signs of aggression towards the infant and received an anxiolytic treatment (zuclopenthixol, 1.8 mg/kg sid, Clopixol 2%, Lundbeck SAS, 92130 Issy-les-Moulineaux, France). This medical protocol allowed for a successful introduction of the infant to the parents. A decrease of 1 drop was made each week and the treatment was stopped completely after six weeks.

Three of the infants reached adulthood and have remained healthy until the present; Mulhouse 1 died in a drowning accident.

Discussion

Birth weights

Mean birth weight for this species in zoos is 82.6g (SD=14.8, n=16). This data comes from all animals born within both the EEP and SSP for which birth weights have been recorded (Lefaux pers. com., Katz pers. com., Zehr et al. 2014). There is currently no data available from the wild. All hand-reared animals were below this mean (see Table 2); the heaviest (Mulhouse 2) weighed 79.2g. Low birth weight mean can be explained by many factors including: maternal nutrition, size of the mother, gestation length, litter size or high levels of maternal glucocorticoid during gestation (Godfrey et al. 1996; Mustoe et al. 2012; Tardif et al. 2001). In our cases, gestation lengths are estimates therefore no links can be drawn between low mean birth weights and gestation length.

In the cases studied, maternal nutrition was controlled and followed recommendations complying with observations from the wild (Gomis et al. 2009). However, specific gestation nutritional needs have not been properly described and might differ from dietary needs during non-pregnant status. The animals studied were all singletons except Mulhouse 1 (75g, stillborn twin weight was 89g), so the size of the litter does not appear to be a factor. Further studies have to be done to check if maternal size and glucocorticoid levels during gestation can explain these low birth weights.

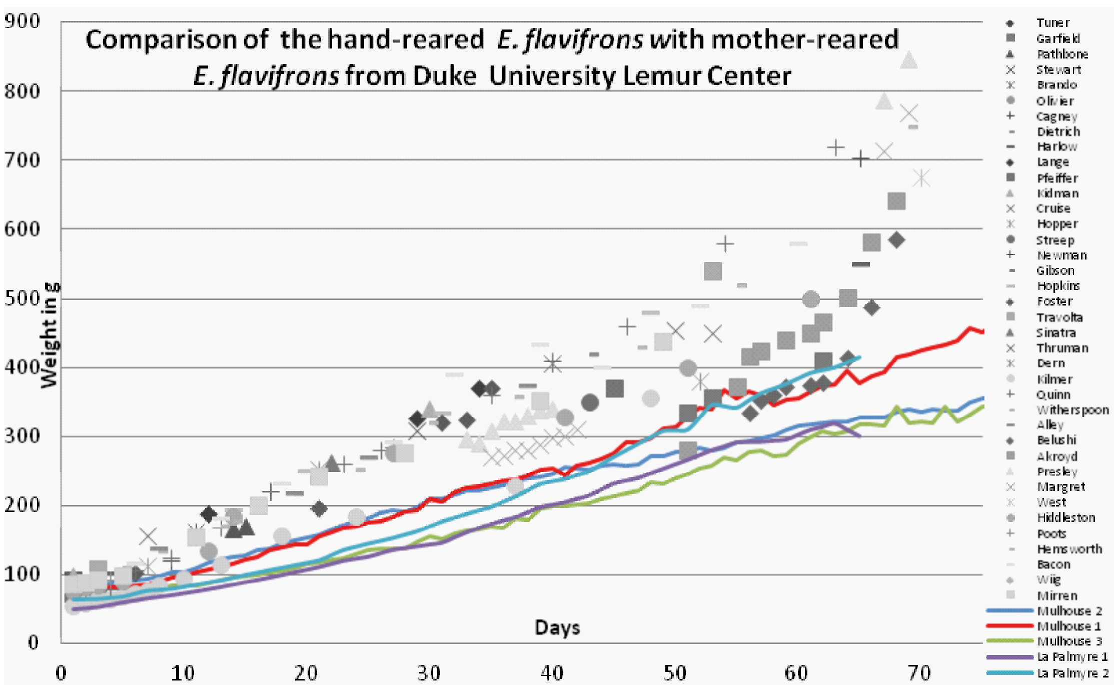

Figure 4. Growth curves of hand-reared *Eulemur flavifrons* and comparison with mother-reared infants from Day 1 to Day 70 (Zehr 2014).

Growth pattern

Growth rate for the five animals (figure 1) showed a similar pattern up to Day 43, with a mean 5% daily weight gain. After Day 43, two males (Mulhouse 1 and La Palmyre 2) maintained a 5% daily weight gain and three animals (1.2) dropped down to a 1.5% daily weight gain. All animals, from either the 5% or 1.5% growth rate, had good body condition. The only exception is Mulhouse 1, which showed a 10% daily weight gain pattern as soon as he was offered solid food *ad libitum*. He looked obese and had a lower activity level. As a result, solid food was restricted so that he returned to a 5% daily weight gain within 20 days and returned to a fit body condition.

When comparing these patterns to growth patterns from mother-reared infants (see Figure 4, data obtained from Zehr et al. 2014), a clear difference can be observed. Mother-reared infants have a daily weight gain close to 5%, when hand-reared infants only have a daily weight gain close to 1.5%. To obtain a 5% growth rate with hand-reared infants, offering more food to animals with lower weight gain could be a solution. However, as these animals were in good body condition (not thin or weak), were very active and socially interactive, one could ask about any real benefit from an increased rate of weight gain. A comparison with growth patterns of mother-reared infants in the wild would be interesting. Moreover, creating a body mass index (including weight and characteristic measurements like torso length) could also help to better evaluate infant development (Mustoe et al. 2012).

Milk composition

The milk formula used in this hand-rearing protocol is composed of 16.7% DM. The milk from *E. macaco,* the closest species for which milk analysis has been done (see Table 1), is 10.1% DM. It is known that there are no major differences among milk composition from closely related species (Hinde and Milligan 2011; Skibiel 2013; Tilden and Oftedal 1997). The replacement milk formula is less diluted in comparison. This more concentrated milk is a good method to counteract the fact that keepers cannot provide formula to the infants *ad libitum* as is the case when infants are mother-reared. *Eulemur* infants spend more than 25% of their time nursing, being carried on their mother (Tilden and Oftedal 1997). *Varecia* or *Otolemur* infants, which are left unattended in a nest for long periods, benefit from more concentrated milk (respectively 14% and 18% DM) than *Eulemur* infants do (Tilden and Oftedal 1997).

Diluted milk is, in the wild, a solution to avoid dehydration in very dry biotopes where infants have high water requirements for thermoregulation (Skiebiel 2013). In incubators where both temperature and humidity are controlled, this is not a problem, and more concentrated milk is not a concern with regards to the infant's hydration.

The milk formula used (DM basis) is: 15% protein, 22.9% fat, 56% carbohydrates, 0.6% calcium, 0.4% phosphorus, Ca/P ratio=1.5. The protein level is very close to what is found in *E. macaco* natural milk but it is higher in lipids and lower in glucids (Tilden and Oftedal 1997), and thus some adjustments have still to be made.

Improvements in milk formulas should also integrate a shift in formula composition over the course of hand-rearing. Even though no data exist for *Eulemur* milk, it is well known that variations occur in milk composition during mammals' lactation periods (Abbondanza et al. 2013; Skibiel 2013). Most studies of milk analysis focus on mid-lactation milk, but there are important initial and final changes (Oftedal and Iverson 1995; Skibiel 2013; Tilden and Oftedal 1997). More studies need to be done on the changes in *Eulemur* milk composition during lactation to improve the formula used during hand-rearing and thus ensure that infant development will be the same as that of mother-reared infants.

Socialisation

Although no statistical analysis could be done, the results tended to show that the sooner the infant is put back with the mother, the longer she tolerates it. It is also very important to put the infant with the dam every day, otherwise there is a higher risk that the dam will reject the infant. This was the case for Mulhouse 3 who for internal reasons could not be put back on the dam at Day 17 and 18. This two-day interruption is the suspected reason for failure at day 19. The aggressive behavior of the La Palmyre mother might be linked to food. She underwent a severe diet restriction on arrival in La Palmyre as she was obese and is still overweight (3.7 kg on arrival, 2.7 kg now), and feeding time still remains a cause of tension in the pair. However, the aggressive behaviour continued without food present. Only the anxiolytic treatment allowed the successful introduction to the parents.

Congenital malformation

Two of the five hand-reared infants presented foot digit agenesis. In Mulhouse 3, right digit II and left digits II and III were missing and in La Palmyre 1, right digits II and III and left digits II, III and IV were missing. High levels of congenital limb malformation (CLM) have only been described in two cases: in a free-ranging *Macaca fuscata* population in Japan, where 14.2% of the infants in the population were born with malformation, affecting the limbs and digits, and a wild *Hylobates lar* population where 15.9% of the population presented CLM (Schultz 1944; Turner et al. 2005). Many other studies have found CLM rates below 1% (Turner et al. 2005). Here the rate is 40%, but the sample size is low. If we include the other infants born in the EEP between 2013 and 2015, the rate is 30%. In the Mulhouse and La Palmyre breeding pairs, the inbreeding coefficient (F) is 0.0625 (Lefaux 2012). The detrimental effects of inbreeding are well documented in captive and free-ranging populations for a diverse set of taxa (Hedrick and Kalinowski 2000; Keller and Waller 2002). The high level of inbreeding in the two pairs studied could explain this high rate of congenital malformation. This issue is being addressed through a global management approach, involving exchanges of *E. flavifrons* between Malagasy zoos, the American SSP and the EEP (Katz pers. comm.; Lefaux 2013). This global management will help reduce inbreeding and consequently the risk of congenital malformation.

Congenital malformation may be a reason why mothers reject their infants. However, to our knowledge, all studies tend to show that mothers take better care of CLM infants, compensating for their clinging defect (Turner et al. 2005).

Very few studies have been done on the social consequences of disabilities in non-human primates. One study on Japanese macaques showed little evidence of conspecific care toward disabled animals and for social selection against disability (Turner et al. 2014). Another study on chimpanzees in Uganda showed that adult non-vulnerable animals were attentive to disabled conspecifics when crossing roads (Cibot et al. 2015). More studies are needed in lemurs to evaluate the effect of malformations on infant survival.

Conclusion

The hand-rearing protocol in this study has been used to raise five healthy blue-eyed black lemurs (*E. flavifrons*) through to weaning. The socialisation protocol enabled one infant to stay with its parents, two others with conspecifics and one with lemurs of another species. Even though attempts at mixing with conspecifics or with lemurs from other species proved to be successful, first attempts should always be made with the parents or another breeding pair of the same species. This allows the young hand-reared animal to experience the potential natural rearing of the mother the year after. This helps to mimic the most "natural" maternal education possible. If this is not possible, introduction to a conspecific should be tried, and as a last resort, introduction to an individual from another species (behaviourally as close as possible to *E. flavifrons*). More research is needed to get a better approximation of the composition of natural lemur milk, and the natural variation in milk during lactation. Further investigation is also needed to understand why the two dams did not properly care for their infants, with special attention given to possible stress during gestation, and the inbreeding coefficient of the pairs.

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