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A growing captive population erodes the wild Red-crowned Cranes (*Grus japonensis*) in China

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Abstract

Background: The Red-crowned Crane (*Grus japonensis*) is an endangered bird species and while the wild population continues to decrease in China, the captive population has dramatically increased over the last two decades. We hypothesized that some of the captive Red-crowned Cranes originated from the wild and that a growing captive population is eroding the wild population in China.

Methods: We surveyed the size of the population and determined the average annual growth rate, reproductive success rate and mortality rate of captive Red-crowned Cranes in 2013 in China. We assessed this erosion effect through mathematical models, in which the size of the captive Red-crowned Crane population was determined from the annual growth rate, the reproductive success rate and the rate of mortality.

Results: We found there were a total of 1520 captive Red-crowned Cranes in 2013 in China, with an average annual growth rate of 7.46%, a reproductive success rate of 9.17% and a mortality rate of 3.6%. We found that approximately 10–27 supplementary Red-crowned Cranes per year and a total of 244, over the 14 year period from 1999 to 2013, were needed to account for the growing captive population in China.

Conclusion: We conclude that the 244 birds probably came from the wild by taking eggs and capturing juveniles or adults and hence accepted the hypothesis. Perhaps more surprisingly, our annual estimate of the number of supplementary Red-crowned Cranes in captive populations is very conservative, with the erosion effect substantially underestimated, because the total number of captive Red-crowned Cranes in 2013 was underestimated, with the annual reproductive success rate in zoos overestimated. The existence of an erosion effect provides a new perspective for the interpretation of why the Red-crowned Crane population in the wild continues to decrease. In our opinion, it is important to understand the consequences of this erosion effect on the management and conservation of this endangered bird species in China.

Keywords: Zoo, Nature reserve, Crane, Captive population, Reproductive success rate

Background

The Red-crowned Crane (RC, *Grus japonensis*) has been listed as an endangered bird species by the International Union for Conservation of Nature (International Union for Conservation of Nature 2014). Its population in the wild has continued to decrease in China in recent years, especially along the western flyway of its continental population (Su and Zou 2012). In contrast to the poor results of in situ conservation, the captive RC population has dramatically increased over the last two decades. The captive population includes birds kept in captivity in enclosed cages or in partially enclosed areas where they are provided with artificial diets. Both zoos and nature reserves have captive RC populations in China, while free-range feeding of captive RCs occurs in some nature reserves. There were only 555 captive RCs in 76 zoos and nature reserves in 1999 (Wu and Zhang 1998; Tian 1999). However, Zhou et al. (2014a) surveyed 141 zoos in China and found that a total of 917

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captive RCs were maintained in 83 zoos in 2013. It should be pointed out that the large captive population in nature reserves, such as Zhalong National Nature Reserve, with more than 300 captive RCs, was not involved in that study. To be sure, the size of the entire captive RC population in China is very large and continues to increase (Wang and Yang 2005; Zhou et al. 2014a).

When captive RCs breed in a controlled environment, such as zoos and crane farms, that is defined as captive breeding, and new-born, captively bred individuals might play an important role in the process of population growth. Tian et al. (2006) found that an average of 43 RCs per year were bred in 1964–2005 at 17 major captive breeding sites, but it is obviously difficult to account for the growing captive population. Although the source of the cranes, coming from the outside, supplementing and supporting the growth of this captive population is unknown, the wild population would seem to be the only source, i.e., through taking eggs and capturing juveniles/adults, but these activities are illegal in China.

We hypothesized that part of the captive RC population in China comes from the wild and that a growing captive population is eroding the wild population, which actually represents a critical threat to the healthy and sustainable development of wild RCs in China. Our objective was to verify the erosion effect through mathematical modeling, allowing the interpretation of our decreasing wild RC population from a new perspective, which should improve considerably the conservation of this endangered species in China and provide advice for its management.

Methods

Survey of population size and reproductive success rate of captive RCs in nature reserves

We synthesized the number of captive RCs in zoos from Zhou et al. (2014a) and surveyed the size of the captive RC population in 16 national nature reserves, i.e., Zhalong, Naolihe, Xingkaihu, Qixinghe, Honghe, Sanjiang, Xianghai, Momoge, Chaganhu, Shuangtaihekou, Dalaihu, Huihe, Tumuji, Dalinuoer, Yellow River Delta and the Yancheng Wetland. These reserves cover the most important breeding, stopover and wintering sites for the wild RCs in China (Fig. 1). We assessed the reproductive success rate of the captive-feeding population in 2011, 2012 and 2013 in five nature reserves (i.e., Zhalong, Xianghai, Momoge, Tumuji and the Yancheng Wetland), which hold most of the captive RCs in these reserves, through consultation with related administrative departments, literature review and field investigations.

Average annual growth rate, reproductive success rate and mortality rate of captive RCs

We determined the average annual growth rate (r) of captive RCs in China using the equation: $r = \sqrt[14]{(\text{total captive RCs in 2013})/(\text{total captive RCs in 1999})} - 1$ (modified from Ranta et al. 2005). The total number of captive RCs in 1999 was 555 (Wu and Zhang 1998; Tian 1999), while the total number of captive RCs in 2013 was obtained as 917 in zoos (Zhou et al. 2014a) and 603 in nature reserves from our survey (Table 1).

We used a weighted mean to calculate the average annual reproductive success rate (μ) of captive RCs in 2013 as follows: $\mu =$ (number of captive RCs in nature reserves/total number of captive RCs in 2013) $\times$ average annual reproductive success rate in nature reserves + (number of captive RCs in zoos/total number of captive RCs in 2013) $\times$ average annual reproductive success rate in zoos. Of these variables, we determined the "number of captive RCs in nature reserves" and the "average annual reproductive success rate in nature reserves" by direct investigation, while the "number of captive RCs in zoos" was obtained from Zhou et al. (2014a). It is difficult to examine directly the "average annual reproductive success rate in zoos" because these facilities are scattered all over the country and the reproductive success rate of captive RCs varies greatly among the various zoos as well as in the same zoo in different years. In addition, the Chinese Association of Zoological Gardens (CAZG), which has the responsibility for RC pedigree management in Chinese zoos, replied through personal communication that it is inconvenient to provide us with RC breeding pedigree information. Based on Zhou et al. (2012), the CAZG found that only 19.8% of all of the captive cranes in zoos are used for breeding and 34.5% for both exhibition and breeding. In other words, 54.3% of captive cranes are involved in captive breeding, a proportion we consider to be applicable to the RCs as the most common captive crane species in zoos in China (Tian 2005; Zhou et al. 2012). We estimated the "average annual reproductive success rate in zoos" to be 54.3% of the "average annual reproductive success rate in nature reserves".

Hartup et al. (2005) found the rate of mortality of all captive cranes in China to be 3.6% based on data from a five-year survey. We also considered this rate to be applicable to the RC, accounting for ~46% of the total number of cranes in zoos in China (Zhou et al. 2012). Thus, we considered the annual mortality rate of captive RCs (ϑ) also to be 3.6%.

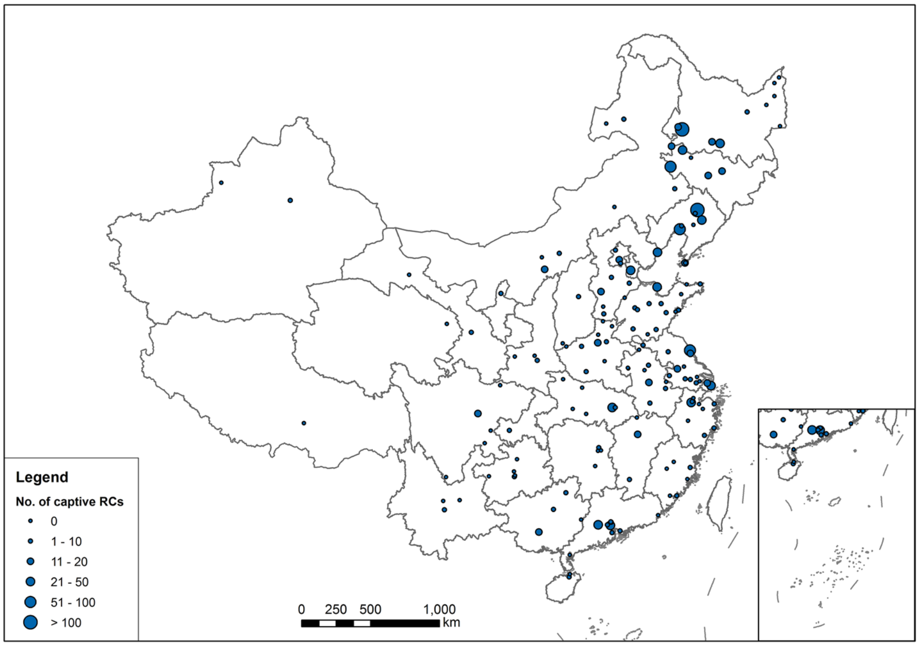

Fig. 1 Number of captive Red-crowned Cranes (RCs, *Grus japonensis*) in 2013 in 141 zoos and 16 national nature reserves in China. Data of zoos from Zhou et al. (2014a)

Assessment of the erosion effect of a growing captive population on RCs in the wild

The size of the captive RC population was determined using the average annual growth rate (r), the annual mortality rate (ϑ) and the annual reproductive success rate (μ). To analyze the erosion effect of captive feeding on the wild RC population, we built the following model:

$$N_s = N_{i+1} - N_i + N_d - N_b \quad (1)$$

where N_s is the number of supplementary RCs in the captive population per year; N_i is the size of the captive population in the ith year; N_{i+1} is the size of the captive population in the $(i + 1)$th year; N_d is the number of deaths per year and N_b is the number of new-born cranes per year. When N_s is equal to or less than zero in a particular year, there is no erosion effect on the crane population in the wild. The cumulative number of supplementary cranes is obtained as:

$$N_{cs} = \sum N_s$$

where N_{cs} also refers to the cumulative erosion effect within a certain period; the larger the value of N_s or N_{cs}, the more serious the erosion effect.

We define the following relationships:

$$N_{i+1} = (1 + r)N_i$$
$$N_d = \vartheta N_i$$
$$N_b = \mu N_i$$

where r = the average annual growth rate, ϑ = the annual mortality rate and μ = the annual reproductive success rate.

Results

Average annual growth rate and reproductive success rate of captive RCs in China

We found a total of 603 captive cranes in eight nature reserves (Table 1). When adding to the 917 birds in zoos, we estimated the total number of captive RCs in China in 2013 as 1520. Based on Eq. (1), the average annual growth rate (r) was 7.46% ($=\sqrt[14]{1520/555} - 1$).

Of the eight nature reserves feeding captive RCs, Zhalong, Xianghai, Momoge, Tumuji and the Yancheng Wetland hold a total of 518 (85.9%) birds, with average annual reproductive success rates of 12.4, 20.9, 7.6, 11.5 and 10.9%, respectively (Table 2). We conclude that, over the 14 year period from 1999 to 2013, the average annual reproductive success rate was 12.7% in

Table 1 Number of captive Red-crowned Cranes (RCs, *Grus japonensis*) in 2013 in 16 national nature reserves in China

Province	Nature reserve	Number of captive RCs
Heilongjiang	Zhalong	306
Heilongjiang	Naolihe	0
Heilongjiang	Xingkaihu	0
Heilongjiang	Qixinghe	0
Heilongjiang	Honghe	0
Heilongjiang	Sanjiang	0
Jilin	Xianghai	96
Jilin	Momoge	36
Jilin	Chaganhu	0
Liaoning	Shuangtaihekou	58
Inner Mongolia	Dalaihu	0
Inner Mongolia	Huihe	2
Inner Mongolia	Tumuji	20
Inner Mongolia	Dalinuoer	0
Shandong	Yellow River Delta	25
Jiangsu	Yancheng Wetland	60
Total		603

nature reserves (Table 2) and estimated that the average annual reproductive success rate in zoos was 6.87% (=12.7% × 54.3%). Based on equation, the average annual reproductive success rate (μ) of the captive RC population in China was 9.17% [=(603/1520) × 12.7% + (917/1520) × 6.87%].

Erosion effect of a growing captive population on RCs in the wild

Based on the total number of captive RCs in 1999 (555 birds) and 2013 (1520 birds) and the average annual growth rate (7.46%), we found the number of new captive cranes increased from 41 in 1999–2000 to 105 in 2012–2013. The cumulative increase was 965 RCs during the 1999–2013 period (Table 3). The number of new-born cranes from captive breeding rose from 51 to 130 per year and the cumulative number of new-born birds reached 1186 during this 14 year periods (Table 3), while the number of dead birds rose from 20 to 51 per year with the cumulative number of dead cranes at 466 (Table 3).

We determined that approximately 10–27 supplementary cranes (N_s) per year were required to account for the increasing captive RC population in China and a total of 244 supplementary cranes (N_{cs}) were needed from 1999 to 2013 (Table 3). The 244 birds probably came from the wild, which led to the erosion effect on the RCs in the wild.

Discussion

The size of the captive RC population was determined on the basis of the average annual growth rate, the mortality rate and the reproductive success rate. These three parameters were used to build a model to examine whether a growing captive population is eroding the wild RCs in China. Our results show that the number of new-born cranes, bred in captivity, was insufficient to account for the increasing captive population with a gap of 10–27 birds per year and a total of 244 for the entire 14 year periods from 1999 to 2013. Thus, we accept the hypothesis that part of the captive RC population in zoos and nature reserves came from the wild, through taking eggs and capturing juveniles/adults. In the context of a self-sustaining captive population, our results provide a new perspective on the continuing decline of the RC population in the wild in China.

The erosion effect received little attention in previous studies of captive RCs which generally focused on genetic variation (Zou et al. 2007), blood biochemical indices (Zeng and Xu 2012), behavioral ecology (Cao and

Table 2 Reproductive success rates of captive Red-crowned Cranes (*Grus japonensis*) in 2011–2013 in five national nature reserves in China

Nature reserve	Annual reproductive success rate (%)			Average annual reproductive success rate (%)
	2011	2012	2013	
Zhalong	9.7	12.1	15.4	12.4
Xianghai	13.7	22.9	26.0	20.9
Momoge	8.9	8.3	5.6	7.6
Tumuji	8.0	–	15.0	11.5
Yancheng Wetland	10.7	10.0	12.1	10.9
Mean	12.7			

Data of the five nature reserves in 2011 obtained from literature review by Liu et al. (2011); data from Zhalong, Xianghai and Momoge nature reserves for 2012 and 2013 acquired through consultation with related administrative departments; the 2013 data from the Tumuji nature reserve obtained from the literature review by Zhou (2013) but not available for 2012; data from the Yancheng Wetland in 2012 and 2013 was acquired through field investigations

Table 3 Number of increased, new-born, dead and supplementary Red-crowned Cranes (RCs, *Grus japonensis*) per year and the number of cumulative supplementary RCs in captive populations during the 1999–2013 period in China

Year	Size of estimated captive population (N_i)[a]	Increase in the number of RCs per year (N_{i+1}–N_i)[b]	Number of new-born RCs per year (N_b)[c]	Number of dead RCs per year (N_d)[d]	Number supplementary RCs per year (N_s)[e]	Number of cumulative supplementary RCs (N_{cs})[f]
1999	555	41	51	20	10	10
2000	596	44	55	21	11	21
2001	641	48	59	23	12	33
2002	689	51	63	25	13	46
2003	740	55	68	27	14	60
2004	795	59	73	29	15	75
2005	855	64	78	31	16	92
2006	918	69	84	33	17	109
2007	987	74	90	36	19	128
2008	1061	79	97	38	20	148
2009	1140	85	105	41	22	169
2010	1225	91	112	44	23	192
2011	1316	98	121	47	25	217
2012	1414	105	130	51	27	244
2013	1520	–	–	–	–	–
Total	–	965	1186	466	244	–

[a] Estimated captive population size (N_i): $N_{i+1} = (1+r)N_i$, where *i* refers to year; for example: $N_{2000} = N_{1999} \times (7.46\% + 1) = 555 \times 1.0746 = 596$, $N_{2001} = N_{2000} \times (7.46\% + 1) = 596 \times 1.0746 = 641$

[b] Increase in number of RCs per year $= N_{i+1} - N_i$; for example: the increase in number of birds between 1999 and 2000 $= N_{2000} - N_{1999} = 596 - 555 = 41$

[c] Number of new-born RCs per year (N_b) $= \mu N_i$; for example: N_b in 1999 $= N_{1999} \times 9.17\% = 555 \times 9.17\% = 51$, N_b in 2000 $= 596 \times 9.17\% = 55$

[d] Number of deaths per year (N_d) $= \vartheta N_i$; for example: N_d in 1999 $= N_{1999} \times 3.6\% = 555 \times 3.6\% = 20$, N_d in 2000 $= 596 \times 3.6\% = 21$

[e] Number of supplementary RCs per year (N_s) $= N_{i+1} - N_i + N_d - N_b$; for example: N_s in 1999 = (increase in number of RCs in 1999) + (N_d in 1999) − (N_b in 1999) $= 41 + 20 - 51 = 10$. When N_s is equal to or less than zero in a particular year, there is no erosion effect on the RC population in the wild

[f] Number of cumulative supplementary RCs (N_{cs}) $= \sum N_s$; for example: N_{cs} between 1999 and 2001 = sum of the N_{cs} in 1999, 2000 and 2001 $= 10 + 11 + 12 = 33$

Wu 2013) and population surveys (Tian et al. 2006; Zhou et al. 2012). Regarding the enormous size of their captive population, zoos and nature reserves maintain that they caught RCs and took eggs from the wild at the very beginning of the establishment of a captive population, while all captive RCs are currently produced through captive breeding (Wang et al. 2011a). However, this statement is untenable. We found the N_s is greater than one in each of the 14 year periods from 1999 to 2013, which suggests that a supplementary number of cranes are needed to support this growing captive population. Moreover, the import of RCs from abroad is almost impossible because it is listed as an Appendix I species by CITES. Thus, we conclude that part of the captive RC population can only come from the wild. It should be noted that zoos and nature reserves with large captive RC populations generally are adjacent to wild crane areas, which facilitates the transition of RCs from the wild to become captive birds. Of course, it is permissible to pick up eggs and capture juveniles/adults from the wild for ex situ conservation purpose. The establishment of captive population through capturing wild birds is a successful case for the recovery of wild Crested Ibis (*Nipponia nippon*) population (Ding and Li 2005). We hold that the emphasis in similar cases is the rational number of captured wild birds. Currently, the population size of captive RCs was nearly three times as high as that in the wild. Under this circumstance, it is obviously unreasonable and illegal to fill the gap of the growing captive RC population through capturing birds from the wild, and releasing the captive birds to the wild would be the right way, just like the case of the Crested Ibis.

This study found that a total of 244 cranes were needed to supplement the captive population during the 1999–2013 period, an average of 17.4 per year period. However, we believe the real number to be higher because the total number of captive RCs in 2013 was underestimated and the annual reproductive success rate in the zoos overestimated. Based on the population survey of zoos by Zhou et al. (2014a) and that of nature reserves in this study, we found a total of 1520 captive RCs in China. This is the most extensive survey to date, providing the largest estimate of the size of the captive population. However, these data are still incomplete, for the size of captive RC population in wildlife or crane farms is unclear. Hence we are sure that the total number of captive RCs in China is greater than 1520. This underestimate of the total number of captive RCs would lead to an equal underestimate of the average annual growth rate and thus, an underestimate of the erosion effect. We calculated the average annual reproductive success rate in zoos based on the rate in nature reserves. Compared with the number of captive cranes in zoos, the birds in nature reserves have larger populations and a better living environment, such as a more natural habitat with less human disturbance, which helps to increase their mating chances and improve their rate of reproductive success in captivity. Because of this and the fact that only about half of the cranes are involved in breeding programs in zoos, we conclude that the average annual reproductive success rate in zoos is probably overestimated. Zhou et al. (2012) found that only 80 birds from 12 captive crane species were new-born in 2011, with an annual reproductive success rate of about 4.4%, much less than our estimate of 9.17%, providing indirect evidence of an overestimation of the annual reproductive success rate of captive cranes which, in turn, leads to an underestimate of the erosion effect. In our opinion, the estimate of N_s in this study is very conservative and the erosion effect substantially underestimated. All the same, about 0.4–1.0% of wild RCs in the world, i.e. about 2800 birds (Su and Zou 2012) are annually lost because of the erosion effect. Considering only the western subpopulation of the RC in the wild, about 560 birds (Zhou et al. 2014b) wintering primarily at Yancheng, 1.8–4.8% of wild cranes were lost per year, which represents a great loss for this endangered species and is sufficient to push it to the edge of extinction. We suggest that it is necessary to enhance efforts to determine the size and reproductive success rate of RC populations in zoos, as well as the mortality rate of these captive cranes in China and to conduct a more accurate assessment of the erosion effect on the growing population of RCs in captivity.

The reproductive success rate of captive RCs was nearly twice as high in nature reserves as in zoos. We suggest that the captive population in nature reserves is both capable to maintain itself and to produce extra birds, which actually violates the original intention of nature reserves. In contrast, the captive RCs in zoos have a low reproductive success rate and thus have difficulty maintaining sustained growth. More specifically, we can say the illegal removal of cranes from the wild by zoos and nature reserves has a clear erosion effect on the RC population in the wild. In addition, we speculate that some of the captive RCs in zoos came from nature reserves through trade, but the number of these extra birds cannot completely meet the needs of zoos. The number of supplementary RCs coming to zoos are probably from the wild, but the zoos are isolated from the wild RC population. So the question arises as to how the zoos obtain wild RCs. In contrast to the zoos, nature reserves can more easily obtain wild RCs because they function as breeding, stopover and wintering sites. In fact, we have found and heard that some nature reserves caught cranes in the wild, turned them to be the "captive" population and then sold or rented them to other captive-feeding establishments (such as urban zoos, wildlife parks, wetland parks and crane farms) for profitable ends. The famous illegal wildlife trading case, i.e., the “bird king” Wu Liu Case, provides some direct evidence for this erosion path (Lu et al. 2015). As well, some facilities, such as the Shenyang Forest Zoological Garden and Zhalong National Nature Reserve, hold more than 100 captive RCs. Why these facilities need such a large captive population of cranes is a question worth pondering.

Previous studies of RCs in the wild generally focused on the negative effects of habitat loss or degeneration (Ma et al. 2000; Jiang et al. 2012), climate change (Wu et al. 2012; Peng et al. 2014), the effect of human disturbance on behavioral ecology (Wang et al. 2011b; Ge et al. 2011; Li et al. 2013), fire (Kong et al. 2007) and pollution from heavy metals (Luo et al. 2013, 2014). Direct human disturbances also play a non-negligible role in the decline of populations in the wild (Harris and Mirande 2013). For example, Zhou et al. (2014b) found that approximately 2.1% of the RC population in the wild is lost each year due to poisoning, poaching, becoming entangled in fish nets and flying into power lines. In this study, we first quantified the erosion effect of a growing captive population on RCs in the wild in China, which elucidated the source of captive cranes and provide a new perspective on the continued decline of the RC population in the wild.

Regarding the conservation of our wild cranes, we first suggest controlling the size of the captive-feeding population in zoos and nature reserves, especially in zoos, to reduce the need for supplementary birds. Secondly, it is necessary to enhance the supervision of captive feeding in nature reserves. For example, the impacts of taking eggs from the wild should be assessed. It is possible that free-ranging captive RCs would mix with cranes from the wild which poses a health risk to both (Feare 2007; Boyce et al. 2009). More importantly, nature reserves should focus on the protection of natural habitats and wild populations, rather than hold large captive populations. In third place, we recommend that the management of the captive RC population in zoos, especially in small zoos, be further strengthened. Due to the small population, the limited number of potential mates, the living conditions and their inability to prevent diseases, it is difficult for the RCs to be healthy and breed under stable conditions in small zoos. The resulting high mortality rate and low breeding success in zoos would probably lead to an increased demand for supplementary birds, which would exacerbate the erosion of the RC population in the wild. Finally, we should strictly enforce the newly revised Law of Wildlife Protection of the People’s Republic of China, which clearly stipulates that hunting national key protected animals is illegal and will be fined or investigated for criminal responsibility.

Authors’ contributions

DZ and MJ conceived the study and secured funding. WX, ZQ, XX and ZW collected the data on population size and reproductive success rates of the Red-crowned Cranes in nature reserves. DZ led the data analyses with the help of HZ and JG. DZ wrote the manuscript and JG offered some pertinent comments which improved the text. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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