Asian-Aust. J. Anim. Sci.
Vol. 24, No. 10 : 1473 - 1482
October 2011

www.ajas.info
http://dx.doi.org/10.5713/ajas.2011.11111

Quantified Analyses of Musk Deer Farming in China: A Tool for Sustainable Musk Production and *Ex situ* Conservation

Xiuxiang Meng*, Baocao Gong, Guang Ma and Leilei Xiang
College of Life and Environmental Sciences, Minzu University of China,
27 Zhongguancun Nandajie, Beijing 100081, China

ABSTRACT : Adult male musk deer (*Moschus spp.*) secrete musk, a widely used ingredient in traditional Asian medicine and the international perfume industry. Musk deer are endangered due to historic over-utilization of musk and habitat loss. Musk deer farming, provides an important way of conserving musk deer and ensuring a sustainable musk supply. For over 50 years musk deer farming has been conducted in China with the endangered Alpine musk deer (*Moschus sifanicus*) the predominant farmed musk deer species. To date, few studies have examined the musk production of captive musk deer. This study analyzed musk-extraction data collected from 1997 to 2009 at Xinglongshan Musk Deer Farm, Gansu, China. The musk-extraction ratio (MER) of captive male musk deer was 90.30% (n = 732), while the annual average musk extraction (AME) per animal was 7.90±0.17 g with the range from 0.00 g to 34.20 g (n = 732). The origin of the deer had an influence on AME and MER production, with male wild-captured (WC) individuals recording higher values (AME, 8.76±0.27 g, n = 272; MER, 93.75%, n = 272) than those of captive breeding (CB) males (AME: 7.39±0.22 g, n = 460; MER: 88.26%, n = 460). The origin of an individual's parents, however, did not influence AME and MER. Age also influenced musk production with the MER of 1.5-year-old males being 87.5% with an average musk production of 8.27±0.47 g (n = 96). The peak period for musk production was from 1.5 to 8.5 years of age. The results of our study demonstrate musk deer farming could work as an effective measure to protect musk deer and provide sustainable musk resources, however, the musk production including MER and AME could be improved through optimizing the managing and breeding system in endangered musk deer farming. (**Key Words :** Alpine Musk Deer (*Moschus sifanicus*), Captive Breeding, Musk Production, Average Musk Extraction, Musk Extraction Ratio, Sustainable Musk Supply)

INTRODUCTION

Musk deer (*Moschus* spp.) are small solitary forest ruminants well known for the musk secreted by the adult males (Green, 1987, 1989). Musk deer are distributed in the mountainous regions of East Asian and are classified as endangered owing to historic over-utilization of musk extraction and habitat degradation and loss (Yang et al., 2003; Aryal et al., 2010; Aryal and Subedi, 2011). Currently musk deer exist only in China, Russia, Nepal and India, and are listed in Appendix I and Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and World Conservation Union IUCN Red List. All musk deer species occur in China and are protected as a category I key species under the National Wild Animal Protection Law (Yang et al., 2003).

In China, musk deer farming, is one of the important methods of *ex-situ* protection the species outside their natural habitat. Farming has become an effective measure to protect musk deer and provide sustainable musk resources (Parry-Jones and Wu, 2001). Whilst musk deer farms have been established in Russia, India and Nepal (Sathyakumar et al., 1993; Homes, 1999), large scale farming only exists in China, largely due to the heavy demand of musk in Traditional Chinese Medicine (TCM). TCM is the flagship medicinal system of traditional Asian medicine in which over 400 patent medicines use musk as an ingredient, with an estimated use of 1,000 kg/yr of musk (Parry-Jones and Wu, 2001). With increasing international interest in traditional medicine; ongoing promotion of TCM by the Chinese Government (Qiu, 2007), and the use of musk in the perfume industry, musk usage is expected to increase. Despite being a major consumer of musk, China has ceased the import of natural musk in an attempt to conserve musk

* Corresponding Author : Meng Xiuxiang. Tel: +86-10-6893-2922, Fax: +86-10-6893-8163, E-mail: muskdeer2006@163.com
Received April 21, 2011; Accepted June 22, 2011

deer populations (Yang et al., 2003). Hence, musk deer farming and the extraction of musk from captive animals will become the only legal source of musk for the traditional medicine and perfume industries. A successful musk deer farming and sustainable captive musk production will, therefore, be a prerequisite of developing and continuing these industries throughout the world.

In China, commercial musk deer farming began in the 1950s despite early unsuccessful attempts to keep and breed musk deer in captivity and extracted musk from living males. Currently musk deer farming in China has expanded to the point in which farms no longer need to supplement individual numbers by capturing musk deer from the wild, which is common in wildlife farming (Mockin et al., 2005). This has proved beneficial for the conservation of the species by providing a steady and legal source of musk for medicine and perfume industries (Meng et al., 2006). Despite the operation of over 10 musk deer farms in China totaling approximately 5,000 captive animals and an annual musk production of 20-30 kg, the demand for musk in commercial enterprise has still not been met.

Musk deer farming in China is largely based on the Forest musk deer (*Moschus berezovskii*) and the Alpine musk deer. In recent years, some investors, institutions and a medicinal company have been interested in musk deer farming owing to the reduction of natural musk resources and the high price of musk. It could be expected that more musk deer farms will begin operation in China and other countries such as Russia, Mongolia and India.

Extracting musk from captive animals has been the focus of research for many scientists and farming practitioners, with a wide number of relevant observations, research and farming practices being developed. In China, however, studies on the captive musk deer and musk production are largely based on descriptive accounts of the general behavior patterns of male deer during musk secretion (Zhang, 1979, 1983; Homes, 1999). Musk secretion is a complicated physiological process and could be influenced by a number of factors such as the physical condition, age, health and endocrine level of the animal in addition to external factors such as forage protein level, farming management practices and even the weather (Dai and Yin, 1990, 1991; Huang et al., 1998). Cheng et al. (2002) reported no significant difference in musk production of male Forest musk deer in regard to the duration of musk secretion. Generally speaking, the studies above are based on relatively small samples taken over short time period, which leads to relatively limited conclusions. Furthermore, the majority of musk production research targets Forest musk deer, with related studies of the Alpine musk deer restricted to descriptive accounts (Jiang, 1998; Kang et al., 2008) with no reported studies of musk production of Alpine musk deer based on long-time monitoring with a large sample size.

This study analyzed the musk production of captive Alpine musk deer from 1997 to 2009 at Xinglongshan Musk Deer Farm (XMDF) in Gansu Province, China, to determine the potential effect of age and origin of animals on the average musk extraction (AME) and the musk extraction ratio (MER), which has important implications for establishing a sustainable musk supply and assist in *ex situ* conservation of this endangered species.

MATERIALS AND METHODS

Study site

This study was conducted at XMDF, located within Qilian Mountain range within Xinglongshan National Nature Reserve, Gansu Province, north-west China (E103°50′; N35°38′). Xinglongshan National Nature Reserve is habitat for wild Alpine musk deer, with the average elevation at XMDF of 2,000-2,100 m and the annual average temperature is 2.5-6.4°C.

Farming practices

XMDF, built in 1990, encompasses 30 ha in area, and contains more than 400 Alpine musk deer. Musk deer were housed in groups of five individuals of the same sex in an enclosure of approximately 100 m^2. Enclosures were separated by brick wall and iron-mesh, which enables olfactory and audio interaction, but prevented physical contact between individuals of different enclosures. Animals were fed a diet of leaves collected from the natural habitat and supplemented by artificial food mix consisting of flour, wheat bran and seasonal vegetables, twice a day. The amount of food provided was held constant and water was provided *ad libitum*. Interaction with the human keeper was limited to five minutes per day, as required for feeding, cleaning and other management duties (Meng et al., 2002).

Musk extraction has occurred at XMDF since 1996 (Jiang, 1998) with musk harvesting usually occurring in October and March, in line with mating periods. To extract musk, the identified male is restrained while the operator uses a sterilized and specialized spoon to extract musk from the musk pod. Musk quantities are then dried on coarse paper to remove water, weighted and transferred to a customized bottle under airtight condition (Zhang, 1983).

Data collection and statistic analyzes

The age of wild-captured individual (WC), is estimated from the animals weight and the growth of the canine teeth (Meng et al., 2003a). Individuals are labeled as not producing musk if they don’t contain the brown powder characteristic of ripe musk. Musk extraction ratio (MER) is calculated for each group annually by dividing the number of individuals with ripe musk by the total number of

Table 1. The MER and AME of captive male Alpine musk deer with different origins

Origin		Frequency	MER (%)		AME (g)	
Wild (N = 272)		257	93.75	93.75	8.76±0.27	8.76±0.27
Captive	313	F1 (n = 363)	86.23	88.26	7.16±0.22	7.39±0.22
(N = 460)	77	F2 (n = 80)	96.25		7.86±0.43	
	16	F3 (n = 17)	94.12		10.02±1.24	

AME showed as the Mean±SE and MER showed as the percentage of groups with different parents' origins.
AME = Average musk production; MER = Musk-extraction ratio.

individuals involved in the musk obtaining process.

Musk deer were grouped according their origin wild-captured (WC) and captive-bred (CB), with CB individuals further divided into groups of different generations such as F1, F2 and F3. Individuals were also grouped according to the origin of their parents. Individuals can be divided into 4 groups: wild father (WF) and wild mother (WM), wild father (WF) and captive mother (CM), captive father (CF) and wild mother (WM), and captive father (CF) and captive mother (CM), all of which can be further divided into WF, WM, CF and CM if only one parent was taken into consideration. As parturition of Alpine musk deer occurs in June (Meng et al., 2003b), while musk extracted occurs in October and March (Jiang, 1998), age groups were based on 0.5 year groups.

Analysis of Variation (ANOVA) was used to explore the effect of individual's origins and parents' origins on musk production (AME) and the differences of musk production among groups with different age. Based on the homogeneity test (Levene), the Least significant difference (LSD) or Games-Howell method was used to conduct potential differences between groups. Cochran Test was used to test the factors with MER. All statistical analysis was conduced using SPSS 11.5 program (SPSS Inc., Chicago, Illinois) with a significance level of p = 0.05.

RESULTS

Musk production

Quantities of musk extracted from 1997 to 2009 were distributed normally (Kolmogorov-Smirnov Test, n = 732, Z = 1.350, p = 0.052>0.05). Total MER of captive male deer at XMDF was 90.30% (n = 732) and the AME (±SE) was 7.90±0.17 g (n = 732) with the range from 0.00 g to 34.20 g.

Effect of origins of males on musk production

The MER for WC and CB (F1, F2 and F3 generation) musk deer groups is shown in Table 1. MER was significantly different between groups (Cochran test, Q = 30.00, df = 3, p<0.01), with a further pairwise comparison showing a highly significant difference between WC and F1 (p<0.01), F2 (p<0.01) and F3 (p<0.01), moreover, the differences between F1 and F3, F1 and F2 were also highly significant (p<0.01). No significant difference was recorded among F3 and F2 groups (p>0.05). Pooling individuals across generations (F1, F2 and F3), the captive-bred musk deer (CB) had a significantly lower MER (88.26%, n = 460) compared to WC individuals (93.75%, n = 272) (t = 3.835, p = 0.001<0.01). The effect of individuals' origin on the AME was significant (ANOVA, $F_{3, 731}$ = 7.29, p<0.01). As the variance of data was homogeneous (Levene test, df_1 = 3, df_2 = 728, p = 0.24>0.05), LSD multiple comparisons indicated differences in AME was mainly due to differences between F1 (7.16±0.22 g, n = 363), WC (8.76±0.27 g, n = 272) and F3 groups (10.02±1.24 g, n = 17) (F1-WC: p<0.01; F1-F3: p<0.05). AME was not significantly different between other groups (p>0.005). The comparison of pooled generations (F1, F2, F3) of CB individuals with WC individuals indicated that AME results for WC (8.76±0.27 g, n = 272) was significantly higher than that of CB (7.39±0.22 g, n = 460) (p<0.01).

Effect of parents' origins on musk production

Comparison of MER for groups based on the origin of parents is showed in Table 2. The effect of parents' origins on musk production was not significant (ANOVA, $F_{3,393}$ = 0.373, p = 0.772>0.05). No significant differences in MER was recorded between the groups, however individuals with a wild father (WF, 92.32%, n = 573) recorded lower MER than those of individuals with a captive father (CF, 93.02%, n = 43) (Cochran test, Q = 3.00, df = 1, p = 0.083>0.05). Furthermore, the MER of males with a wild mother (WM, 92.28%, n = 492) was lower than that of males with a captive mother (CM, 95.56%, n = 90)(Cochran test, Q = 0, df = 1, p = 1.00>0.05).

Comparison of musk production of each year

Total MER recorded between 1997 and 2009 is shown in Figure 1. Significant differences were recorded between years (Cochran test, Q = 21.93, df = 12, p<0.05), with further pairwise comparisons shown in Table 3.

From 1998 (6.07±1.02 g, n = 13), AME levels rose till 2002 (10.88±0.88 g, n = 25), after which it fluctuated from 2004 (6.86±1.61 g, n = 13), through to 2006. From 2006 AME again increased from 6.01±0.50 g (n = 86) to 2009

Table 2. The MER and AME of captive male alpine musk deer with different parents' origins

Parents origins	WF		CF		Total
	AME	MER	AME	MER	
WM	8.28±0.22 (n = 460)	92.17% (n = 460)	8.54±0.80 (n = 30)	93.33% (n = 30)	8.28±0.21, 92.28% (n = 492)
CM	7.77±0.48 (n= 74)	95.95% (n = 74)	8.35±1.15 (n = 13)	92.31% (n = 13)	8.10±0.45, 95.56% (n = 90)
Total	8.19±0.19, 92.32% (n = 573)		8.48±0.65, 93.02% (n = 43)		

AME showed as the Mean±SE and MER showed as the percentage of groups with different parents' origins.
WF = Wild father; WM = Wild mother; CF = Captive father; CM = Captive mother; AME = Average musk production; MER = Musk-extraction ratio.

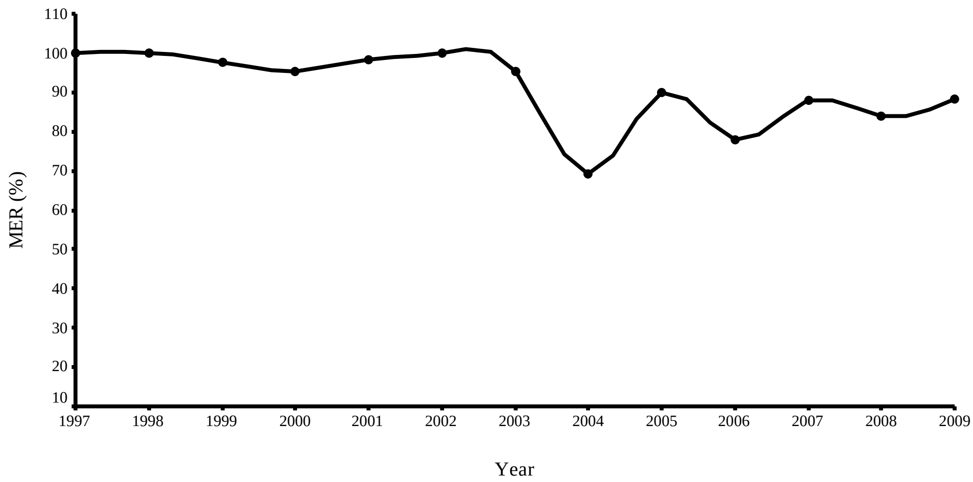

Figure 1. The MER (musk extraction ration) of captive male Alpine musk deer from 1999 to 2009.

Table 3. Comparison of MER of captive male alpine musk deer in years

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1997													
1998	a												
1999	ns	ns											
2000	a	a	ns										
2001	a	a	ns	*									
2002	a	a	ns	ns	ns								
2003	a	ns	ns	ns	ns	ns							
2004	ns	*	ns	*	*	*	ns						
2005	ns	*	ns	ns	ns	*	ns	ns					
2006	ns	ns	**	**	**	**	**	ns	ns				
2007	ns	ns	**	ns	**	*	ns	ns	ns	*			
2008	ns	*	**	*	**	**	ns	ns	ns	ns	ns		
2009	ns	ns	*	ns	ns	*	ns	ns	ns	*	ns	ns	

a = The Cochran Test is not performed because all variables are not dichotomous with the same values.
* p<0.05; ** p<0.01; ns: p>0.05.

Table 4. The multiple comparisons (LSD) of AME during 1999 to 2009

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1997													
1998	ns	ns											
1999	ns	ns											
2000	ns	ns	ns										
2001	ns	ns	*	ns	ns								
2002	ns	ns	*	ns	ns								
2003	ns	ns	ns	ns	ns	ns							
2004	ns	ns	ns	ns	ns	ns	ns						
2005	ns	ns	ns	ns	ns	ns	ns	ns					
2006	ns	ns	ns	**	**	**	ns	ns	*				
2007	ns	ns	ns	*	**	*	ns	ns	ns	ns			
2008	ns	ns	ns	ns	*	*	ns	ns	ns	ns	ns		
2009	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	

* $p<0.05$; ** $p<0.01$; ns: $p>0.05$.

(7.50±0.86 g, n = 43). AME was significantly different between years (ANOVA, $F_{12, 718}$ = 4.91, $p<0.01$). As the variances of data was not homogeneous (Levene test, df_1 = 12, df_2 = 718, $p<0.01$), the Games-Howell test was used to test the AME differences between years, with results shown as Table 4.

Effect of musk-extracting time on musk production

MER of males extracted before breeding (90.43%, n = 208) was not significantly different to those extracted after breeding (94.83%, n = 312) (Cochran test, Q = 1.00, df = 1, p = 0.317>0.05). Similarly AME of males with musk extracted prior to the breeding season (8.30±0.31 g, n = 230) was not significantly different those whose musk was extracted after breeding season (8.37±0.24 g, n = 329) (T test, df = 535, t = -0.182, p = 0.856>0.05).

Effect of age on musk production

The MER of musk deer extracted from different age groups is shown in Figure 3. Significant differences in MER between age groups was evident (Cochran test, Q = 31.91, df = 11, p = 0.001<0.01). Pairwise comparison indicated MER of males at 1.5 years of age (87.5%) was significantly lower than that of those aged 2.5-5.5 years ($p<0.05$). Of these 12.5% of 1.5 year old males had not started to secrete musk, however, almost every individual in the ages of 2.5-5.5 years secreted musk. In addition, males older than 9.5 years recorded lower MER than those at 9.5 years of age, 68.18% and 71.43% respectively. Over 28% of males older than 9.5 years did not secreted musk, while only 33% of males aged 12.5 years or more produced musk.

The AME production of males increased from 1.5 years in age (8.27±0.47 g, n = 96) with highest values recorded in the 3.5 year group (9.30±0.34 g, n = 131). AME declined

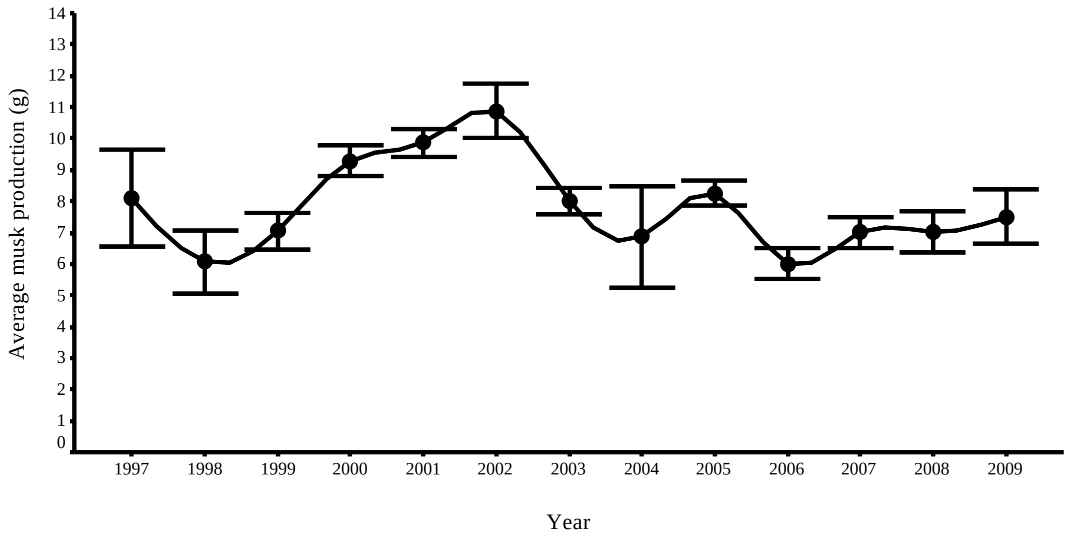

Figure 2. The AME (average musk extraction) of alpine musk deer from 1999 to 2009.

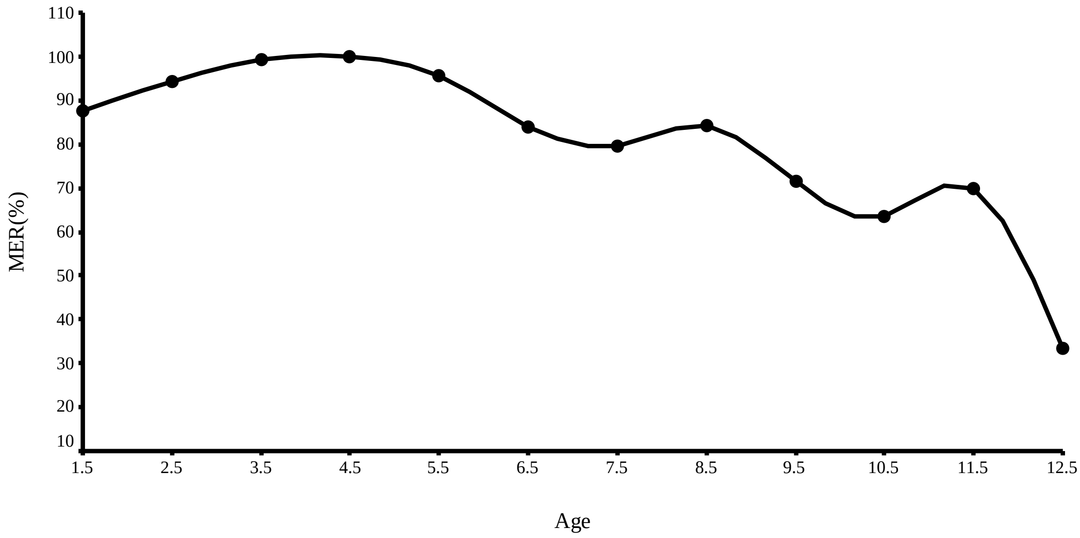

Figure 3. The MER (musk extraction ration) of captive male alpine musk deer with ages.

inversely with age as recorded at 8.5 years (5.59±0.67 g, n = 38), 9.5 years (4.61±0.88 g, n = 28) and 12.5 years (1.14±0.76 g, n = 2), (Figure 4). The effect of age on AME was significant (ANOVA, $F_{11, 719}$ = 9.481, p<0.01). As the Variance was not homogeneous (Levene test, df1 = 11, df2 = 719, p<0.01), the Games-Howell test was applied to conduct pairwise comparison (Table 6).

DISCUSSION

Musk secretion is a complex physiological process. Studies on captive species indicate a number of factors may determine musk secretion such as the deer species, physiological characteristics, health, food supply, managing system and weather (Zhang, 1983; Yan, 1985; Dai and Yin 1991; Huang et al., 1998; Meng et al., 2006; Sheng and Liu, 2007). Sheng et al. (2002) reported that the AME of captive Forest musk deer varied with geographic region, with the musk production of Forest musk deer from Anhui Province (10.8 g) was higher than those from Shanxi Province (7.8 g). Cheng et al. (2002) also reported the average musk production of captive Forest musk deer from Sichuan Province.

The present study indicated that the AME of captive Alpine musk deer in Xinglongshan Musk Deer Farm was 7.90 g, lower than the 8.8 g reported in previous captive musk deer studies (Kang et al., 1998). The variation in reported values can be attributed to a number of factors. In many reported values MER is not calculated, resulting in annual musk extraction values (AME) based only on males who produced musk. In this study, however, the MER of musk deer was 90%, hence 10% of captive males did not secreted ripe musk. Musk sample preparation method may also contribute to the variation in AME values as the

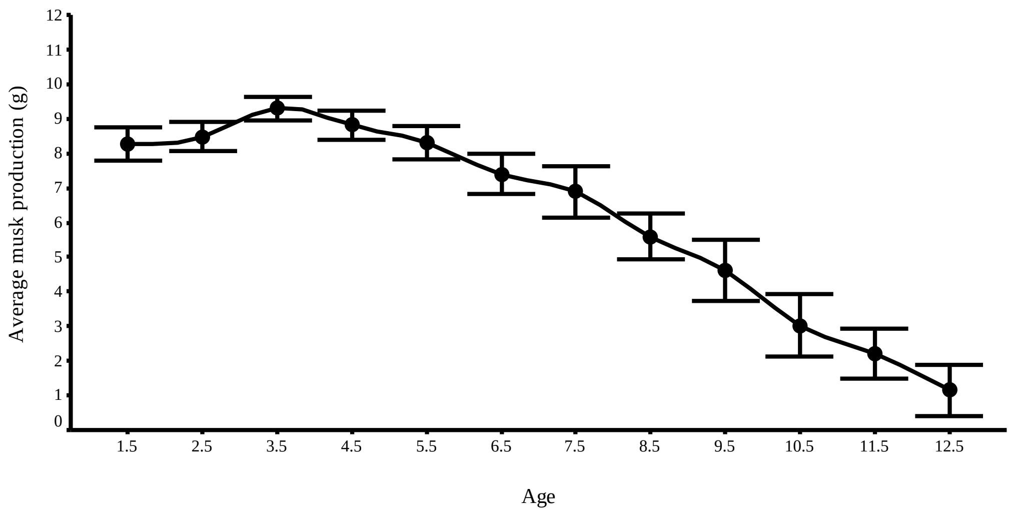

Figure 4. The AME (average musk extraction) of alpine musk deer with different age-classes.

Table 5. Comparison of the MER of captive male alpine musk deer with ages

Age	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
1.5												
2.5	*											
3.5	**	*										
4.5	**	*	a									
5.5	*	ns	ns	ns								
6.5	ns	*	**	**	**							
7.5	ns	ns	**	**	*	ns						
8.5	ns	ns	*	*	ns	ns	ns					
9.5	ns	*	**	**	*	ns	ns	ns				
10.5	ns	ns	*	*	*	*	*	*	ns			
11.5	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns		
12.5	*	*	*	*	*	*	*	*	*	ns	ns	

The Cochran test is not performed because all variables are not dichotomous with the same values. * $p<0.05$; ** $p<0.01$; ns: $p>0.05$.

proportion of water retained in the musk sample varied between studies (Zhang, 1983; Sheng and Liu, 2007). Moreover, factors such as species (forest vs. alpine), geographic region and the management and husbandry of the individual farms are also likely to have an effect on final AME of captive musk deer.

In further studies, identical data collection methods and calculations of musk volume would assist in the comparison of musk production based on variation in farming practices. By comparing musk production from different farms, captive management and husbandry can be optimized to improve the musk production and assist in future conservation of the species.

The musk deer is a small solitary forest ungulate, in which the male musk deer are strongly territorial and defend an area of approximately 20-30 ha exclusively (Green, 1987; Yang et al., 1996; Aryal et al., 2010; Aryal and Subedi, 2011). Due to high farming costs and traditional domestic practices, musk deer farming in China still adopts an intensive group enclosing system established in the initial musk deer farming, in which, several musk deer (usually 5-7 individuals) are enclosed in a limited area (approximately 100 m^2) (Homes, 1999; Meng et al., 2006). As a result, musk deer endure high levels of stress not only from captive environment (limited area, artificial feed, and close human contact) but also the social stress of high density enclosure (Shrestha, 1998). These factors are likely to influence the endocrinological state of the animal, which is directly related to musk secretion of male musk deer (Bi et al., 1985). The response of an individual to captive stress will also relate to the animals' origin, age and even different managing system hence different musk production patterns of captive musk deer populations would be expected.

Musk production and the origin of individual and its parent

In the late 1990's, the captive population of musk deer at XMDF was established by capturing Alpine musk deer of all ages from the wild under authorized approval (Sheng and Liu, 2007). This study indicated MER and AME of WC

Table 6. The multiple comparisons (LSD) of musk production among ages

Age	1	2	3	4	5	6	7	8	9	10	11	12
1.5												
2.5	ns											
3.5	ns	ns										
4.5	ns	ns	ns									
5.5	ns	ns	ns	ns								
6.5	ns	ns	ns	ns	ns							
7.5	ns	ns	ns	ns	ns	ns						
8.5	ns	*	**	**	ns	ns	ns					
9.5	*	*	**	**	*	ns	ns	ns				
10.5	**	**	**	**	**	*	ns	ns	ns			
11.5	**	**	**	**	**	**	**	ns	ns	ns		
12.5	**	**	**	**	**	**	**	**	ns	ns	ns	

* $p<0.05$; ** $p<0.01$; ns: $p>0.05$.

Alpine musk deer was significantly higher than those of CB individuals, with 6% of WC individuals not secreting ripe musk and 8 g of musk recorded as AME compared with 11% of CB deer not secreting musk and an average AME of 7 g. Despite these results, it is hypothesized that induced stress caused by captivity would result in a reduction in musk production as compared to wild musk deer in their natural habitat. If the sustainable musk-extraction from the wild musk deer (Wood et al., 2008) could be conducted in China, the above hypothesis can be tested.

Similar to captive Forested musk deer (Dai and Yin, 1990), this study also showed no significant association between musk production and the origin of an individual's parents, indicating musk production at XMDF may not be genetically determined.

On the bases of the results of this study, when building the founder population on a musk deer farm aimed at conserving and releasing into the wild, an individual's origin should be taken into consideration in order to optimize the genetic diversity and behavioral diversity (Meng et al., 2006b). However, if musk deer farming just aims to maintain captive populations and harvest musk, since individual origin does not affect the musk secretion of their offspring, origin should not be looked as a factor in determining mating males a during breeding season. This could avoid some wild-captured males or males with high annual musk production being used for mating too often mating resulting in reduced mating efficiency and success. Furthermore, in the practice of musk deer farming, it is not necessary for the farm to capture wild deer to improve the musk production of subsequent generations, which would reduce the numbers being removed from the endangered wild musk deer population.

Musk production and managing system

The annual musk production of captive musk deer was different with age (Sheng and Liu, 2007). This study showed that patterns of AME and MER in captive Alpine musk deer populations at XMDF varied with age. Similarly, Kang et al. (2008) and Cheng et al. (2002) reported annual differences in AME in captive Alpine musk deer and Forested musk deer.

As a complicated physiological process, the musk production of captive animals is likely to be affected by the management system of in the farming facility (Zhang, 1983). At XMDF, captive deer were taken from the wild between 1996 and 1997. Since 2008, the managing personnel and keepers were changed frequently with three different owners between 2005 and 2008. Consequently, the whole farming system including keeping system, veterinary system, and even the fodder ingredients changed dramatically, which would have effected the musk secretion of the captive population, with certain time lag, and can be seen in the AME and MER production. Furthermore, the effects on AME is expected to be bigger than on MER on account of a reduction of musk secretion is more likely than the complete cessation of musk production (Meng et al., 2006). Optimistically, as shown in this study, musk production (MER and AME) of captive Alpine musk deer at XMDF continues to rise under the present managing system.

Many authors have concentrated on the effect of extraction frequency and time on AME (Zhang, 1983; Dai and Yin, 1990; Cheng et al., 2002), however the potential influences of these factors on MER has been largely overlooked. This study showed no relationship exists between the musk extraction time and musk production. In practice, many musk deer farms extract musk from non-mating males before the mating season (November, Meng et al., 2002a), but from mating males after the season (March, Meng et al., 2002a), owing mainly to management logistics. As this study showed the mating of males did not affect the musk production (AME and MER), therefore, the musk extraction could be conducted collectively after the mating season, in order to reduce the deer-handling times and the stress from the musk extraction, which will benefit musk deer farming, musk production and *ex situ* musk deer conservation.

Musk production and the age of Alpine musk deer

This study found age to be a factor in musk production with similar effects on MER and AME of captive males. At XMDF, most males (87.5%) begun to secrete musk at 1.5 years of age with AME on 8.27±0.47 g. Reports from other captive farms indicate both Forest musk deer and Alpine musk deer secreted musk at a similar age (1.5 yrs) with maximum AME recorded at 11.58 g and 10.3 g respectively (Cheng et al., 2002; Kang et al., 2008). Because the MER of Alpine musk deer was taken into consideration in this study, the AME of captive Alpine musk deer with the age of 1.5 was lesser than that in the other studies above. Although male deer can reach sexual maturation at 1.5 years, the physical maturation and related physiological processes relating to musk production is not fully completed until 2.5 years old (Homes, 1999; Sheng and Liu, 2007). Hence the musk production of 1.5 year of deer was relatively lower than older age-classes in this study. Furthermore, despite strong reproduction synchronization and timing in both wild and captive alpine musk deer, 12.5% of births occurred after the peak month of June (Zhang, 1983; Meng et al., 2003a, 2003b). Hence these late borne individuals would be expected to be even less mature and have in lower levels of musk production. A similar pattern was also reported in captive Forest musk deer, in which the MER of 1.5 year old males were 87.27% and 89.74% respectively (Dai and Yin, 1991; Cheng et al., 2002).

Musk deer can secrete musk up to 20 years of age, but peak musk secretion occurred prior to 10 years of age (Zhang, 1983; Yan, 1985; Parry-Jones and Wu, 2001). The peak period of musk secretion of captive Forest musk deer was 2.5-7.5 years, with only 68% of males older than 8.5 years able to secrete ripe musk in Maerkang Musk Farm in western China (Dai and Yin, 1991). The MER of male Forest musk deer older than 9.5 years was only 68% in Dujiangyan Musk Deer Farm (Cheng et al., 2002). Likewise, the peak age of musk production at XMDF was between 1.5 and 8.5 years. MER of males younger than 8.5 years was over 84.21%, which means that most of the male musk deer at this peak age period produce ripe musk, and overall AME was greater than 5.5 g (the AME of males aged 8.5 years was 5.59±0.67 g). After the peak age period, the MER levels declines to 71% males aged over 9.5 years, while the AME was reduced to under 5.0 g. Similar to this result, the peak age period of Himalayan musk deer (*M. chrysogaster*) and Siberian musk deer (*M. moschiferus*) was suggested to be 3-9 years old (Yan, 1985; Green, 1989).

The relevance of musk production (including AME and MER) and age was directly related to the physiological growth of captive musk deer (Zhang, 1983; Cheng et al., 2002). Normally, captive musk deer reach sexual maturity at the age of 1.5 years, and physical maturity at 2.5 years of age, hence between the age of 2.5-8.5 (especially 2.5-5.5) individuals have completed endochronological development, resulting in peak musk secretion during this age period. As males grow older, the effect of physical decline, illness and a reduction in androgen secretion (Dai and Yin, 1991), result in a cessation or decline in musk secretion leading to decreasing trend of AME and MER.

In this study, MER and AME both peaked during the 1.5-8.5 years old range. Therefore, to pursue high musk production and improve the benefits of musk deer farms that are focused on musk production, the captive population should mainly consist of males younger than 9 years, and those males older than 9.5 could be removed from the farm and released into the wild habitat to rejuvenate the endangered wild population.

ACKNOWLEDGMENTS

This research was supported by Nature Science Foundation of China (30970374, 30770286), the “985 Project” of Minzu University of China (MUC985-9) and Program for New Century Excellent Talents in University (NCET-08-0596).

REFERENCES

Aryal, A. and A. Subedi. 2011. Conservation and potential Habitat of Himalayan Musk deer Moschus chrysogaster in the protected areas of Nepal. International Journal of Conservation Sciences 2(2):127-141.

Aryal, A., D. Raubenheimer, S. Subedi and B. Kattel. 2010. Spatial Habitat overlap and Habitat preference of Himalayan Musk deer ‘Moschus chrysogaster’ in Sagarmatha (Mt. Everest) National Park, Nepal. Current Research Journal of Biological Sciences 2(3):217-225.

Cheng, J. G., Y. Luo, M. P. Qiao, Y. H. Cai and D. Z. Wang. 2002. The factors affecting musk secretion quantity in Moschus berezovskii. Special Wild Economic Animal and Plant Research 3:15-18(In Chinese with English abstract).

Debby, Ng and Elizabeth A. Burgess. 2005. Against the grain: trade in musk deer products in Singapore and Malaysia. TRAFFIC Southeast Asia.

Green, M. J. B. 1986. The distribution, status and conservation of Himalayan musk deer (*Muschus chrysogaster*). Biol. Conserv. 35:347-375.

Green, M. J. B. 1987. Diet composition and quality in. Himalayan musk deer based on faecal analysis. J. Wildl. Manage. 51:880-892.

Green, M. J. B. 1989. Scent-marking in the Himalayan musk deer (Moschus chrysogaster). J. Zool. 1:721-737.

Harris, R. 1991. For musk deer and other wildlife in southern Qinghai, China. Mt. Res. Dev. 11(4): 353-358.

Homes, V. 1999. On the scent: Conserving Musk deer - the uses of musk and Europe’s role in its Trade. TRAFFIC Europe.

Huang, B. J., H. L. Sheng and H. F. Xu. 1998. The effect of feed nutrition on musk production and quality of Dwarf musk deer. Zoological Research 19(4):296-00 (In Chinese with English abstract).

Jiang, Y. 1998. The reproduction of the captive alpine musk deer. Chinese Journal of Zoology 21(4):23-25 (In Chinese with English abstract).

Meng, X., Q. Yang, L. Xia, Z. Feng, Y. Jiang and P. Wang. 2003a. The temporal estrous patterns of female alpine musk deer in captivity. Appl. Anim. Behav. Sci. 82:75-85.

Meng, X., Q. Yang, L. Xia, Z. Feng, Y. Jiang and P. Wang. 2003b. Timing and synchrony of parturition in alpine musk deer. Folia Zool. 52(1):39-50.

Meng, X., C. Zhou, J. Hu, C. Li, Z. Meng, J. Feng, Y. Zhou and Y. Zhu. 2006a. The musk deer farming in China. Anim. Sci. 82: 1-6.

Meng, X., Q. Yang, Z. Feng, L. Xia, J. Feng and Y. Zhou. 2006b. Behavioral diversity of captive alpine musk deer in Xinglongshan musk deer farm. Acta Zoologica Sinica 52(6):1026-1033 (In Chinese with English abstract).

Mockin, M. H., E. L. Bennett and D. T. LaBruna. 2005. Wildlife farming: A viable alternative to hunting in tropical forests? WCS Working Paper No. 23. Wildlife Conservation Society, New York.

Parry-Jones, R. and J. Y. Wu. 2001. Musk deer farming as a conservation tool in China. Hong Kong: TRAFFIC, East Asia.

Qiu, J. 2007. China plans to modernize traditional medicine. Nature 446:590-591.

Sathyakumar, S., S. N. Prasad and S. Walker. 1993. Status of captive Himalayan Forest musk deer Moschus c. chrysogaster in India. Int. Zoo Yb., 32:32-38.

Sheng, H. and N. Ohtaishi. 1993. The status of deer in China. In Deer of China: biology and management (Ed. N. Ohtaishi and H. Sheng). pp. 14-29. Elsevier Science Publishers, Amsterdam.

Sheng, H. L. and Z. X. Liu. 2007. The musk deer in China. Shanghai Scientific and Technical Publishers.

Shrestha, M. N. 1998. Animal welfare in the musk deer. Appl. Anim. Behav. Sci. 59:245-250.

Wood, J., D. Knowler and O. Gurung. 2008. Assessing the prospects for community-based wildlife management: the Himalayan musk deer (*Moschos chrysogaster*) in Nepal. Human Dimensions of Wildlife 13(1):16-30.

Yan, Y. 1985. A preliminary study on the factors affecting musk deer production in Siberian musk deer. Journal of Chinese Medicinal Materials 2:11-13 (in Chinese with English abstract).

Yang, Q. S., Z. J. Feng, Z. W. Wang, W. L. Liu, X. C. Li and O. Z. Silang. 1998. Home range of the alpine musk deer in the southeast area of Tibet autonomous region. Acta Theriologica Sinica 18(2):87-94 (In Chinese with English abstract).

Yang, Q. S., X. X. Meng, Z. J. Feng and L. Xia. 2003. Conservation status and causes of decline on musk deer in China. Biol. Conserv. 109:333-342.

Yin, S. Y. and W. G. Dai. 1991a. Experimental study about the physiology effect of Androgen on the second musk secretion of male dwarf musk deer. Acta Theriologica Sinica 11(1):9-12 (In Chinese with English abstract).

Yin, S. Y. and W. G. Dai. 1991b. The relevance of age and musk secretion of male musk deer. Chinese Journal of Zoology 26(6):45-48 (In Chinese with English abstract).

Zheng, S. and N. Pi. 1984. The musk sac, musk, quanyity and hunting of alpine musk deer (*Moschus sifanicus*). Acta Theriologica Sinica 4(1):35-42 (In Chinese with English abstract).

Zheng, S. and N. Pi. 1979. Study on ecology of the musk deer (*Moschus sifanicus*). Acta Zoologica Sinica 25(2):176-186 (in Chinese with English abstract).

Zhang, B. 1979. The farming of musk deer in China. Agriculture Press, Beijing (in Chinese).

Zhang, B. 1983. Musk-deer, their capture, domestication and care according to Chinese experience and methods. Unasylva 35:16-24.