



# Compensatory Increase of the Reproductive Capacity of the Red Fox *Vulpes vulpes* (L., 1758) in Sympatric Coexistence with the Golden Jackal *Canis aureus* L., 1758

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**Abstract:** Main reproductive parameters of the most common mesopredators in Bulgaria, golden jackal and red fox, were studied in two regions (Thracian Lowland and South Dobrudzha) where these two species occur in sympatry. The reproductive activity and the average age of the first birth were calculated in both species. Major reproductive characteristics such as gross reproductive rate, net reproductive rate, generation time and the internal rate of population growth were calculated through a life table based on female individuals. The results demonstrated growing populations of red fox and golden jackal in Bulgaria. The testicular weight (g) of the male individuals was measured and the gonadosomatic index was calculated. The breeding percentage of the studied females was 41% for the jackals and 65% for the red foxes. The maximum number of placental scars in jackals was 9 and in foxes was 8. The minimum number of placental scars in jackals was 2 and in foxes 4. The ratio between net reproductive speed and the time between two successive generations was greater for the fox (40.98) than for the jackal (25.16). The gonadosomatic index was lower for the jackal (0.08) than for the fox (0.19), which is a criterion for a higher degree of monogamy for the jackal. The reproductive parameters studied in both species showed a compensatory increase in the reproductive capacity of the red fox in conditions of sympatry with golden jackals.

**Key words:** reproduction, red fox, golden jackal, litter size, sympatry

## Introduction

The golden jackal *Canis aureus* L., 1758 and the red fox *Vulpes vulpes* (L., 1758) are the most common mesopredators of the family Canidae in Bulgaria. In Upper Thracian Lowland and South Dobrudzha, the two species are sympatric. The golden jackal is a highly adaptable species, widespread from Africa to the Arabic Peninsula, reaching central Asia, India and Indochina (SILLERO-ZUBIRI et al. 2004). It has been common in Europe until the beginning of the 20<sup>th</sup> century when population number declined

and the species has gone extinct, mainly due to habitat destruction and predation by other carnivores (DEMETER & SPASSOV 1993, BOSKOVIC et al. 2015). Recent studies indicate ongoing expansion of the jackal population in Europe for the last 25 years, with a particular spread of the Balkan populations towards Central Europe. Data concerning the ecological impact of the recent expansion of golden jackals in Europe are scarce (ARNOLD et al. 2012). The red fox is the most common and abundant carnivore in the world and a common species in Bulgaria. It can be found from the Black Sea coast to the

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subalpine zone. The highest density is in open field habitats, especially in Northern Bulgaria, where it is abundant nearby urban areas (POPOV & SEDEFCHEV 2003). Its diet relationships with other carnivores, land cover changes and land use are the main factors driving fluctuations in population numbers (PASANEN-MORTENSEN et al. 2013).

Wild members of the family Canidae have unique reproductive characteristics, including social monogamy, copulatory lock tie and biparental care. Females have seasonal monoestrous and pseudopregnancy after induced ovulation. According to BEKOFF et al. (1981), jackals' sexual maturity occurs at the age of nine months. However, HERPENTER et al. (1998) have found that females reach sexual maturity at the age of 10-11 months, while males – at the age of 21-22 months. Studies have shown that despite reaching sexual maturity early, the jackals reproduce at least after the second year. Some individuals never reproduce because of the social structure of populations (MOEHLMAN 1989). Red fox reproduction is better studied than that of the golden jackal. CAVALLINI & SANTINI (1996) have investigated the fox reproduction cycle based on placental scars. HERPTNER et al. (1998) have found that female foxes can give birth even before reaching a year old. Red foxes experience severe fluctuations in mating seasonality and fertility due to variations of food sources (HERPTNER et al. 1998). The reproductive characteristics of the two species in conditions of sympatry are not well known.

The present study aimed to establish the main reproductive parameters of golden jackals and red foxes while living in sympatry in the area of Thracian Lowland and South Dobrudzha. The objectives include (i) analysing the breeding status of females; (ii) determining the number of placental scars in uteri as an indicator of number of pups; (iii) establishing the reproductive period through estimating the change in testicular size and calculating the gonadosomatic index (GSI) in males; and (iv) obtaining the generation time and survival for each age class using a static female individuals life table.

## Materials and Methods

### Sampling

The study was carried out in South Dobrudzha (Northeastern Bulgaria) and Thracian Lowland (South Bulgaria) in 2008–2011. These two regions differed from one another by the type of the land use: large fields of monocultures in South Dobrudzha and a mosaic landscape of vegetable, fruit and other plantations, with a well-developed irrigation sys-

tem, in the Thracian Lowland. Samples were collected through hunting by legal methods, using the assistance of organised groups of hunters possessing permits issued by the Environmental Agency and the Ministry of Agriculture, Food and Forestry. Reproductive organs were collected either straight after killing or within 48 hours after that. Until necropsy, the samples were kept in a 3% formalin solution.

Totally, 49 female and 52 male reproductive organs of jackals as well as 23 female and 21 male reproductive organs of red foxes were analysed. Age of animals was determined by growth and tooth wear (HARRIS 1978, LOMBAARD 1971, RAYCHEV 2011). Two age classes were assigned to golden jackals and three age classes to red foxes. The first age class included animals between 10 and 22 months (yearlings), second age class (subadults) – older than 22 months, and third age class (adults) – older than 34 months.

The uteri used for determining the number of placental scars were separated from the ovaries, oviduct, mesometrium and connective tissue and opened longitudinally (LINDSTRÖM 1981, BRAY et al. 2003). They were examined macroscopically and by binocular magnifier in three-time intervals to avoid observers' bias. Staining was not used (in contrast to previous authors) as it was found to make tissues too dark and the placental scars indistinguishable. The dark coloration might result from using formalin solution.

### Females breeding status and placental scars

The number of placental scars showed the number of pups a female can have. Adult females that should either be pregnant or should have distinct placental scars, but did not, were considered as not reproductively active (RUETTE & ALBARET 2010).

### Mean age of primiparity and life tables

The reproductive activity of the two species was calculated based on the average number of placental scars in females from certain species. We calculated the mean age of primiparity as reported by MECH et al. (2016).

A static life table has been made to evaluate survival, based on female individuals in each age class. The following formulas were used:

$$(1) l_x = N_x / N_0$$

$$(2) S_x = N_{x+1} / N_x (= l_{x+1} / l_x)$$

$$(3) E_x = \sum l_x / l_x$$

$$(4) GRR = \sum m_x$$

$$(5) R_0 = \sum l_x m_x$$

$$(6) T = \sum x l_x m_x / \sum l_x m_x$$

$$(7) r \approx \ln R_0 / T$$

where  $x$  is age class,  $N_x$  – number of individuals in that age class,  $l_x$  – survival from birth to age class

$x$ ,  $Sx$  – age-specific survival,  $Ex$  – the average life expectancy of each age class,  $mx$  – fecundity,  $GRR$  – gross reproductive rate,  $Ro$  – net reproductive rate,  $T$  – generation time,  $r$  – internal population growth rate.

**Breeding season based on testicular weight**

Weight of testes has been measured on scales ( $\pm 0.01$  g) after thorough removal of connective tissue and adipose tissue, while other measurements (length, width and thickness) were measured by a caliper ( $\pm 0.01$  mm).

The volume of the testes was calculated according to (CALDEIRA et al. 2010):

$$(8) (4/3) \pi ABC,$$

where  $A=1/2$  the width of the testes,  $B=1/2$  the thickness of the testes,  $C=1/2$  of the length of the testes.

The obtained results are transformed into grams, as the volume density of mammal testes is very close to one.

**Gonadosomatic index (GSI)**

The gonadosomatic index (GSI) was calculated using the weight of both testes as a proportion of the total body weight, which represented the percentage of body mass allocated to the testis (CALDEIRA et al. 2010).

Results were analysed through descriptive statistics and two sampled t-test was used for statistical evaluation.

**Results**

**Females breeding status and placental scars**

The ratio of the breeding red foxes compared to the golden jackal was 65% : 41% (Table 1). For the first age class, the ratio was 69% : 38%. For the second age class, it was 50% : 45%.

The mean number of placental scars in females of the golden jackal was  $4.8 \pm 2.57$  and  $5.0 \pm 2.51$  for the red fox (Table 2). The maximum number of placental scars in the golden jackal was 9 and in the red fox – 8, observed in 10% and 28% of the respective

population.

**Mean age of primiparity and life tables**

The mean age of primiparity (Table 3) was approximately 13 months for the golden jackal and 15 months for the red fox, which seemed realistic given the age of sexual maturity in both species.

The survival from birth to the next age class, the age-specific survival, the fecundity and the gross reproductive rate were higher for the red fox (Table 4). The difference in the generation time was insignificant –  $T=1.14$  for the golden jackal and  $T=1.15$  for the red fox. The ratio between the net reproductive rate ( $Ro$ ) and the time between two successive generations ( $T$ , generation time) was greater in the red fox (40.98) than in the golden jackal (25.16).

**Breeding season based on testicular weight**

The average weight of the testicles in the males of the golden jackal in October was  $5.1 \pm 2.19$  g, in November –  $4.85 \pm 2.64$  g and increased in December –  $7.82 \pm 2.71$  g, reaching a maximum in January

**Table 1.** Age-dependent fecundity of the golden jackal *C. aureus* (A) and the red fox *V. vulpes* (B) from two regions in Bulgaria.

A. <i>Canis aureus</i>					
Age classes	Total number	Non-breeders		Breeders	
		Number	%*	Number	%*
1	29	18	62	11	38
2	20	11	55	9	45
Total	49	29	59	20	41
B. <i>Vulpes vulpes</i>					
Age classes	Total number	Non-breeders		Breeders	
		Number	%*	Number	%*
1	13	4	31	9	69
2	8	4	50	4	50
3	2	0	0	2	100
Total	23	8	35	15	65

\* from the total number

**Table 2.** Mean number of placental scars in different age classes in golden jackal and red fox females.

Age classes	Species			
	Golden jackal <i>C. aureus</i>		Red fox <i>V. vulpes</i>	
	Number (n)	Mean number of placental scars ( $\bar{X} \pm SD$ )	Number (n)	Mean number of placental scars ( $\bar{X} \pm SD$ )
First age classes	11	$4.45 \pm 2.62$	9	$4.71 \pm 3.25$
Second age classes	9	$5.22 \pm 2.59$	4	$5.75 \pm 1.71$
Third age classes	0	0	2	$4.50 \pm 0.71$
Total	20	$4.84 \pm 2.57$	15	$5.00 \pm 2.51$

**Table 3.** The mean age of primiparity of females of the golden jackal *C. aureus* (A) and the red fox *V. vulpes* (B) in Bulgaria.

A. <i>Canis aureus</i>						
Age classes	Total number	Breeder		First-times breeders		Total Cohort years
		Number	%	%	Number	
1	29	11	38	38	11	11
2	20	9	45	7	1.4	2.8
Total	49				12.4*	13.8*

\*mean age of primiparity (13.83/12.4=1.2 years)

B. <i>Vulpes vulpes</i>						
Age classes	Total number	Breeder		First-times breeders		Total Cohort years
		Number	%	%	Number	
1	13	7	54	54	7	7
2	8	4	50	0	0	0
3	2	2	100	50	1	3
Total	22				8*	10*

\* mean age of primiparity (10/8=1.3 years)

**Table 4.** Survival of the golden jackal *C. aureus* (A) and the red fox *V. vulpes* (B) in Bulgaria ( $x$  – class,  $N_x$  – number of individuals in that age class,  $L_x$  – survival from birth to age class  $x$ ,  $S_x$  – age-specific survival,  $m_x$  – fecundity,  $GRR$  – gross reproductive rate,  $Ro$  – net reproductive rate,  $T$  – generation time,  $r$  – internal population growth rate)

A. <i>C. aureus</i>						
$x$	$N_x$	$L_x$	$S_x$	$m_x$	$Ro$	$x \cdot l_x \cdot m_x$
0	2	1	5.5	0	0	0
1	11	5.5	0.15	4.5	24.75	24.75
2	9	0.81	0	4.8	3.92	7.85
3	0	0		0	0	0
				9.3	28.68	32.60

GRR=9.3; Ro=28.68; T=1.14; r=2.95

B. <i>V. vulpes</i>						
$x$	$N_x$	$L_x$	$S_x$	$m_x$	$Ro$	$x \cdot l_x \cdot m_x$
0	1	1	9.00	0	0	0
1	9	9	0.05	4.7	42.3	42.3
2	4	0.44	1.13	5.8	2.57	5.16
3	2	0.50	0.00	4.5	2.25	6.75
				15	47.13	54.20

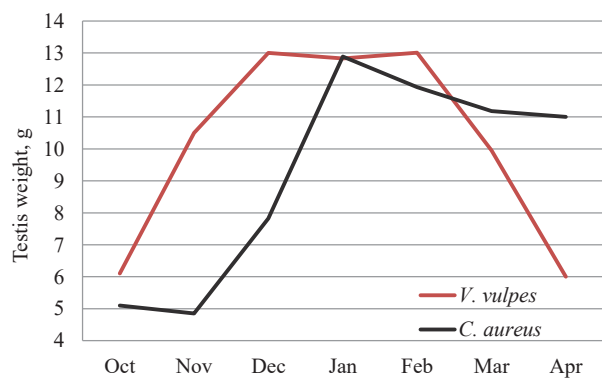
GRR=15; Ro= 47.13; T=1.15; r=3.35

–  $12.82 \pm 3.43$  g. In February, the average size of the golden jackal testicles declined ( $11.93 \pm 2.91$  g) and this lasted until April – March ( $11.18 \pm 3.13$  g), April ( $11.0 \pm 2.95$  g) (Fig. 1).

The maximum measured weight of the testicles of the golden jackal was 18.1 g in January in the

**Table 5.** Bodyweight, testicular weight and gonosomatic index (GSI) of the golden jackal (A) and red fox (B) in Bulgaria (\*Standard Deviation; \*\*Coefficient of Variation)

A. <i>Canis aureus</i> , n=41	Testis weight, g			Body weight, kg	GSI, %
	Left	Right	Total		
Mean	5.00	5.11	9.74	11.98	0.08
± SD*	2.16	2.16	4.23	1.05	0.03
CV**	43.19	42.20	43.43	8.75	42.11
B. <i>Vulpes vulpes</i> , n=21	Testis weight, g			Body weight, kg	GSI, %
	Left	Right	Total		
Mean	5.19	5.31	10.50	5.51	0.19
± SD*	1.99	2.06	4.03	0.76	0.06
CV**	38.31	38.72	38.38	13.76	34.42



**Fig. 1.** Average testis weight (g) of the golden jackal *C. aureus* and the red fox *V. vulpes* in Bulgaria.

Thracian Lowland, and the minimum (2.3 g) was measured in a young jackal in October in South Dobrudzha. In January, a minimum weight of the testicles of the golden jackal was 4.1 g. In February, the maximum weight of testicles was 16.6 g and the minimum weight was 7.1 g (measured in the Thracian Lowland). In March, the maximum weight for the jackals was 14.8 g and the minimum was 5 g (measured in South Dobrudzha). In October, the maximum weight was 9.7 g and the minimum was 2.8 g measured in the Thracian Lowland.

In male red foxes, there was a gradual increase in the average weight of the testicles as early as October ( $6.1 \pm 2.65$  g). The trend continued in November ( $10.5 \pm 5.03$  g) and was particularly pronounced in December ( $13.0 \pm 2.82$  g). In February, the average weight of the testicles in red fox was highest ( $13.2 \pm 3.14$  g), in March decreased ( $9.95 \pm 2.53$  g) and in April it was  $6.01 \pm 2.83$  g.

In males of the red fox, the highest average weight of the testicles ( $13.2 \pm 3.14$  g) was measured in February in the Thracian Lowland and the lowest was on October  $6.1 \pm 2.65$  g in Dobrudzha. In Janu-

ary, the maximum weight of the testicles of red fox was 14.3 g, and the minimum was 10.5 g. In February, the minimum weight of testicles was 9.1 g.

The breeding season of the red fox and the golden jackal are of approximately the same duration but that of the jackal begins later compared to the fox.

### Gonadosomatic index

The average body weight in the male jackals surveyed by us was  $11.98 \pm 1.05$  kg and the calculated GSI was av. 0.8% (Table 5a). The average weight of the male foxes surveyed was  $5.51 \pm 0.76$  kg, and the GSI was calculated on average to 0.19% (Table 5b). The GSI was lower in the golden jackal (GSI = 0.08) than in the red fox (GSI = 0.19).

## Discussion

### Females breeding status and placental scars

According to our results, the red fox has a higher breeding status compared to the golden jackal (Table 1). Such a trend was established in Central Europe, where the percentage of breeding red foxes was greater compared to that of the golden jackal (SZABO 2016). The new data obtained from Bulgaria show smaller differences between the two species compared to data by SZABO (2016).

The comparative analysis of the mean number of placental scars shows no significant differences between the two species ( $t = 0.78$ ;  $DF = 29$ ;  $p = 0.56$ ). More placental scars have been scored for both species in the second age class than in the first age class but with no significant differences ( $t = 0.65$ ;  $F = 21$ ;  $p = 0.52$  for the golden jackal;  $t = 0.58$ ,  $DF = 13$ ,  $p = 0.57$  for the fox). RUETTE & ALBARET (2010) have mentioned similar insignificant differences for the red fox in France. In Hungary, SZABO (2016) has found an average of 5.5 placental scars in the uteri of the golden jackals and 7.5 scars in red foxes. Similarly, VASSILEV & GENOV (2002) recorded 5.6 pups in female golden jackals in Bulgaria.

Our results for the number of red fox pups differ from the previous studies from Bulgaria (GRIGOROV 1987) reporting 4.8 placental scars in Northern and 3.4 in South Bulgaria.

### Mean age of primiparity

The age structure, mortality and reproduction of the red fox depend heavily on persecution (GORTÁZAR et al. 2003). Most of the populations of persecuted red foxes comprise young individuals (HARRIS & SMITH 1987, REYNOLDS 1991). In cases of increased human persecution or competition with hunters of small game species, the number of pups in the red fox

offspring increases and the number of non-breeder females decreases (HARRIS & SMITH 1987, ZABEL & TAGGART 1989, GORTÁZAR et al. 2003). In Bulgaria, the small numbers of small game species, the human persecution and the competition with the golden jackal cause the high breeding activity of foxes.

Generation time (T) is shorter in growing populations but we have found similar values for the golden jackal (1.14) and the red fox (1.15). The relationship between the net reproductive rate ( $R_0$ ) and the time between two successive generations (T) gives information about how long it takes to replace the cohort completely. This ratio is greater in the red fox (40.98) than in the golden jackal (25.16). This difference explains the higher rate of the population growth of the golden jackal despite the high values of the other survival indicators for the red fox.

The obtained data show that the numbers of both species are growing during the period of the study. In the life tables (Table 3),  $R_0$  (net reproductive rate) shows the number of individuals with which a generation is growing, while  $r$  (internal growth rate) is an indicator of population growth. When  $R_0 > 1$  and  $r > 1$ , this is an indication that the population of the species is growing. The internal growth rates ( $r$ ) of the golden jackal and the red fox populations are similar, 2.95 and 3.35, respectively.

### Breeding season based on testicular weight

The main breeding season for the golden jackal is January–February, and for the red fox is December–February. Male foxes with active testicles occur by March and male jackals with active testicles can be detected after mid-April. In both species, mating period continues after February but with low intensity. The observed breeding period of the red fox by the present study corresponds to that described by GRIGOROV (1987). The latter author has reported a period of males being sexually active as determined by the size of the testes: 11.9 g in December, 12.96 in January and 12.3 in February. We have observed that the weight of the testes in male red foxes is bigger during spermatogenesis and vital sperm cells can be found there for two–three months. When the size of the testes decreases, there are no more vital spermatozoa in the reproductive tract (CAVALLINI & SANTINI 1995). The breeding period of the red fox in Bulgaria is longer than reported by CAVALLINI & SANTINI (1995). According to the data obtained, the active breeding season of the golden jackal begins later than that of the red fox and continues until April.

### Gonadosomatic index

According to this criterion, the golden jackal is probably more monogamous than the red fox, in which

the abundance of food increases the degree of polygamy (MACDONALD 1983). This may explain the smaller number of breeding females for the golden jackal compared to the red fox as the dominant female does not allow reproduction for other females (MACDONALD 1983).

## Conclusions

When in sympatry with the red fox, the golden jackal is considered dominating due to its larger body size and more developed social behaviour. The overlapping of the food niches of these two species in sympatry and the shorter time to replace a cohort for the jackal explains its higher rate of population growth, despite the higher breeding rate of the red fox. The higher number of young individuals and the lower number of non-reproductive females of the fox can be interpreted as a compensatory increase in its reproductive characteristics. This gives reasons to continue ecological studies on these two sympatric species. The establishment of interspecies and intraspecific interactions of red foxes and golden jackals in resource-poor habitats is a reliable basis for the future management of these most common mesopredators in Bulgaria.

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