Acta Herpetologica 8(1): 1-8, 2013

The oogenic cycle of the Caspian bent-toed gecko, *Cyrtopodion caspium* (Squamata: Gekkonidae) in Iran

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Submitted on 2012, 14th June; revised on 2013, 12th January; accepted on 2013, 11th February.

Abstract. The Caspian bent-toed gecko, *Cyrtopodion caspium*, is one of the commonest lizards in northern Iran. It is nocturnal, anthropophile and oviparous. In this study, the reproductive cycle of this species was studied by focusing on oogenesis, from April 5 to October 20, 2011. In total, 70 adult females were obtained from Mazandaran, one of the northern provinces of Iran where the climate is temperate. Ovaries were removed and processed for histological and morphometric studies. The results show that oocyte growth starts in late April and ends in August. Mating starts in spring, especially at the beginning of May, with oviposition occurring from late May to mid August. Females lay 1-2 eggs per clutch with the possibility of producing a secondary clutch later in the season. Maximum reproductive activity occurs in May and peaks in June. There was no significant difference between right and left side of reproductive system. With oogenesis occurring from April through July, *C. caspium* follows an oogenic cycle typical for temperate species.

Keywords. Lizard, gecko, *Cyrtopodion caspium*, oogenesis, ovary, reproduction.

INTRODUCTION

Lizards exhibit three general types of reproductive cycles: associated, dissociated and constant (Pough et al., 2001). Associated and dissociated reproductive cycles are characterized by the presence of a discontinuous mating season. In an associated reproductive cycle, gonadal activity increases immediately prior to the mating period in both males and females simultaneously. In this reproductive cycle, females have no need to store sperm due to it's availability during the reproductive season. This cycle is common in species that live in predictable environments such as in the temperate zones (Diaz et al., 1994), the subtropics (Huang, 1997), and in the seasonal tropics (Censky, 1995a, b). In a dissociated reproductive cycle, gonadal activity is low during the mating period and peaks during the non-mating period. In this type of reproductive cycle, male gonadal activity is shorter than that of females and sperm is stored by the female genital system for some months with fertilization occurring later (Torki, 2006). A dissociated cycle is typically observed in species that live in temperate zones and have a brief mating season (Van Wyk, 1995). A constant reproductive cycle is exhibited by species in which gonadal activity is maintained at nearly maximum level almost year-round. Several species of tropical lizards exhibit a constant reproductive cycle (Jenssen and Nunez, 1994). These relationships between reproductive cycles and climate suggest that reproduction in lizards is affected by environmental variables such as temperature (Marion, 1982), precipitation (Guillette and Casas-Andrew, 1987), and photoperiod (Licht, 1967). Phylogenetic constraints may also play a major role in shaping the reproductive characteristics of lizards (Dunham and Miles, 1985). If so, it may be beneficial to study the reproductive cycles of species within a single diverse and wide-ranging lineage.

ISSN 1827-9635 (print)
ISSN 1827-9643 (online)

The members of the family Gekkonidae display different reproductive patterns, as evidenced by the presence of viviparous and oviparous species (Nogueira et al., 2011). Breeding season is determined by cycles of photoperiod, temperature, rainfall and availability of food (Vitt and Pianka, 1994).

The Caspian bent-toed gecko, *Cyrtopodion caspium* (Eichwald, 1831), is a nocturnal oviparous lizard of the family Gekkonidae (Anderson, 1999) and comprises two subspecies in the Caspian Sea region (Szczerbak and Golubev, 1996; Anderson, 1999). *Cyrtopodion caspium caspium* is widely distributed in the eastern part of the Caucasus, Middle Asia including Turkmenistan, Uzbekistan, southern Tajikistan, southwestern Kazakhstan, northern Afghanistan and Iran (Szczerbak, 2003). The northern border of its range is a line from Komsomolets Bay on the northeastern shore of the Caspian Sea to the northern coast of the Aral Sea and Syr Darya. In Iran it is known to occur in the Mazandaran and Gorgan regions, northern and eastern Khorasan, extending south to Sistan from sea level up to 1700 m (Anderson, 1999). *Cyrtopodion caspium insularis* (Akhmedov and Szczerbak, 1978) occurs on the island of Vulf in the Caspian Sea and is known only from the type locality. It differs from the nominate subspecies in having the first pair of postmental shields usually separated from each other by gular scales, though there may be a tiny dot-like contact, while in the nominate subspecies they are broadly in contact (Akhmedov and Szczerbak, 1978).

Cyrtopodion caspium is one of the most common lizards of Iran especially in its northern range. Because no data is available on the reproduction of this species, this project was conducted to characterize its reproductive cycle by focusing on oogenic cycle in northern Iran.

MATERIALS AND METHODS

Study area

The study locality was Sari County (36°32'N, 54°7'E), in the Mazandaran province in northern Iran, located on the southern coast of the Caspian Sea. Sari is situated inland from the Caspian Sea in the semi-tropical coastal plain to the north of the Alborz Mountains. The rainy season lasts about seven months, with an annual precipitation of more than 1,110 mm, giving the countryside a green and lush appearance. The climate of this area is wet and temperate (during this study, the mean temperatures of the coldest and warmest seasons were 1.6 °C and 22.5 °C, respectively), with the most dominant plants being grassy species belonging to the families Asteraceae and Poaceae (Assadi et al., 2005).

Sampling

Sampling took place periodically every 15 days during the activity period of this species from April 5 to October 20, 2011. All specimens were collected by hand, with the aid of a torch, at night time. Most of the specimens were collected from walls of old buildings and gardens. In total, 70 adult and mature females were captured (five specimens per sampling period) and sexed by the presence of preanal and femoral pores in males and their absence in females. Our observations show that females reached sexual maturity at a body length (SVL) about 42 mm, but we tried to capture specimens which had attained a larger SVL to be sure they were sexually mature adults. Some specimens were kept in terrarium in order to study the frequency of clutch deposition.

Methods

The specimens were transferred alive to the zoology laboratory of Islamic Azad University, Damghan Branch and SVL (south-vent length), TL (tail length), HL (head length) were measured. Then they were anaesthetized by chloroform and anatomized. We observed oviductal eggs and vitellogenic follicles simultaneously in most specimens from May to June.

ROD (diameter of right ovary), LOD (diameter of left ovary), ROW (weight of right ovary), LOW (weight of left ovary), ROV (volume of right ovary), LOV (volume of left ovary), RFN (number of right follicles), LFN (number of left follicles), MaxRF (maximum diameter of right follicles), MaxLF (maximum diameter of left follicles), MinRF (minimum diameter of right follicles), MinLF (minimum diameter of left follicles), MRF (mean diameter of right follicles), MLF (mean diameter of left follicles), ROEL (length of right oviductal eggs), LOEL (length of left oviductal eggs), ROEW (width of right oviductal eggs), LOEW (width of left oviductal eggs), ROEWE (weight of right oviductal eggs), LOEWE (weight of left oviductal eggs), ROEV (volume of right oviductal eggs), LOEV (volume of left oviductal eggs), MDFL (mean diameter of follicular layer), MDN (mean diameter of nucleus), MNn (mean number of nucleus) and MDn (mean diameter of nucleolus) were measured. Length, width and diameter were measured by dial caliper with an accuracy of 0.02 mm. Weight was measured by a scale with an accuracy of 0.001 g. Gonads, once removed, were inspected for metric and meristic characters. The number, weight, diameter (length and width) and volume of immature, growing and mature follicles and oviductal eggs were inspected in right and left ovaries separately. After fixing the ovaries in 10% formalin, tissues were dehydrated, cleared in Xylene, infiltrated and embedded with paraffin. Sections were made at 5-7 microns, deparaffinized, re-hydrated, stained (Hematoxylin and Eosin) and mounted. The sections were studied by light microscopy at 100× and 400× magnification. Photographs were prepared by digital camera. Data were analyzed by SPSS 17 software and one-way ANOVA to compare biometric data among monthly samples.

RESULTS

In this study, the maximum SVL and TL of females were 68.03 and 91.16 mm, respectively. The maximum HL was 17.56 mm. Body length (SVL) of the smallest mature female was 42.64 mm.

The gecko *C. caspium* in the study area hibernates from late October to early April. Geckos emerge in early April and begin oogenesis and vitellogenesis by mid April, while mating is observed in early May. Oviposition occurs from from late May to early August. In the terrarium, the first egg was observed May 18, and hatching occurred after about 45-50 days post oviposition in July and August, while oogenesis and vitellogenesis stopped by mid August. According to our observations in the field and analyzing the captured animals, oviposition may occur twice a year and clutch size ranges from 1–2 eggs per clutch.

The ovaries are paired and vesicular, consisting of 3-8 follicles (Figure 1A). Three types of follicles were observed: immature, growing and mature. In April, ovaries are white and small with an irregular shape. The growing follicles were observed in late April (Figure 1B). Ovary size increased immediately in May and mature follicles were observed in early May. Ovaries are large in July and August with mature follicles present. Ovary size decreases in September and October until the following April. The follicular layer is multilayered and polymorphic, composed of three cell types: small, intermediate and the large pyriform cells (Figure 1C). The diameter of follicular layer varies between 30-70 μm in mature and immature follicles, respectively. The mean diameter of follicular layer is 50 μm. The diameter of the nucleus varies between 35 to 260 μm in immature and mature follicles, respectively. The nucleoli are very large and distinguishable from April to July and their numbers vary from 2 to 30 in immature and mature follicles, respectively (Figure 1D). The diameter of nucleoli varies between 25 and 70 μm. The activity of nucleoli decreases after July and they disappear in the nucleus. Mature oocytes enter the oviducts, where fertilization occurs. We observed follicullar atresia in some ovaries especially in the post-breeding period. The descriptive statistics of ovarian characters were described in Table 1 and 2. Analysis of variance of shows that weight, SVL and TL of mature females were not significantly different among groups; but ovary weight and volume and mean diameter of follicles were significantly different between groups ($P < 0.05$, Table 3 and 4). There are no significant differences in the ovarian characters between the left and right side of body (paired t-test, $P > 0.05$ in all cases). There is no significant difference between body length (SVL) of mature females and gonadal weight in different months.

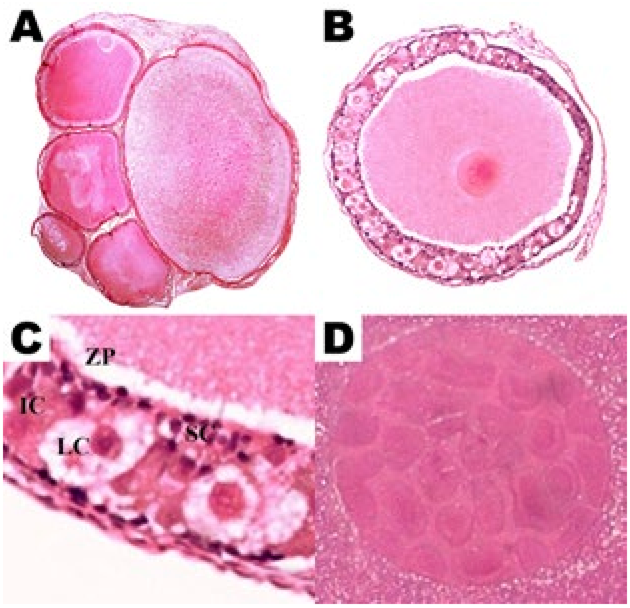

Fig. 1. *Cyrtopodion caspium*: A) ovary with growing follicles; B) growing oocyte; C) follicular layer and D) nucleus with nucleoli. IC = interstitial cell; LC = large pyriform cell; SC = small cell; ZP = zona pellucida. Photos by V. Hojati.

Oviductal eggs were observed between May 5 and August 5. The largest egg was observed in the left oviduct of a female with SVL = 60.62 mm in early May. Its size, weight and volume were 13.46 × 12.45 mm, 0.819 g and 0.20 mm^3, respectively. The mean size and weight of oviductal eggs were 10.27 × 8.46 mm and 0.462 g, respectively. There was at least one large oviductal egg in right or left ovary in the adult females, but they usually had two eggs, one in each oviduct (Figure 2A). There were 4 oviductal eggs in a specimen (10.32 × 12.45, 10.70 × 12.48, 5.15 × 5.40 and 5.20 × 5.80 mm) on May 20. Eggs are white and oval shaped and were deposited from late May to early August and they were laid usually in moist and warm holes of the walls of old buildings and gardens as a natural incubator. The egg shells are soft but harden after 8-12 hours after deposition. In this study, the first egg (12.08 × 11.01 mm and 0.755 g) was laid on May 20 and we also observed two additional oviductal eggs (5.83 × 5.42 mm and 12.45 × 12.48 mm) in this female, after dissection.

In this study, the number of laid eggs varied from 1-2 per clutch. We observed the first hatchling in 10 July. These results confirm that the incubation period ranges between 45 and 50 days, as we observed the first oviposition on 20 May and the first hatchling appeared on 10 July. One of the embryos (about 35 days old and with total length = 18.10 mm) was studied in early July (Figure 2B). The body length (SVL) and tail length (TL) of the smallest hatchling were 19.11 and 28.15 mm, respec-

Table 1. Descriptive statistics for the examined characters in *C. caspium*. For abbreviations see Methods.

Character	N	Range	Minimum	Maximum	Mean	SE	SD	Variance
W (g)	70	4.915	2.718	7.633	4.681	0.129	1.084	1.175
SVL (mm)	70	25.390	42.640	68.030	58.500	0.474	3.964	15.716
TL (mm)	70	26.670	64.490	91.160	80.298	0.645	5.399	29.149
HL (mm)	70	9.360	8.200	17.560	11.535	0.239	2.000	4.000
ROD (mm)	70	5.990	2.130	8.120	4.32800	0.158	1.321	1.746
LOD (mm)	70	5.440	2.430	7.870	4.16186	0.131	1.098	1.205
ROW (g)	70	7.335	0.005	7.340	0.16587	0.106	0.882	0.780
LOW (g)	70	0.859	0.006	0.865	0.07200	0.020	0.172	0.030
ROV (mm^3)	70	0.249	0.011	0.260	0.05516	0.005	0.042	0.002
LOV (mm^3)	70	0.210	0.030	0.240	0.05286	0.005	0.040	0.002
RFN	70	5.000	3.000	8.000	5.20000	0.157	1.314	1.728
LFN	70	5.000	3.000	8.000	5.17143	0.132	1.103	1.217
MaxRF (mm)	70	3.800	1.190	4.990	2.407	0.112	0.935	0.875
MaxLF (mm)	70	3.640	1.090	4.730	2.16729	0.097	0.813	0.661
MinRF (mm)	70	1.580	0.340	1.920	0.870	0.0343	0.287	0.083
MinLF (mm)	70	1.220	0.320	1.540	0.890	0.030	0.249	0.062
MRF (mm)	70	2.110	0.830	2.940	1.50857	0.054	0.455	0.207
MLF (mm)	70	1.630	0.720	2.350	1.40586	0.040	0.338	0.114
ROEL (mm)	21	8.170	5.420	13.590	10.674	0.460	2.110	4.448
LOEL (mm)	15	7.630	5.830	13.460	10.4960	0.585	2.267	5.140
ROEW (mm)	21	6.320	5.180	11.500	8.598	0.366	1.677	2.813
LOEW (mm)	15	7.260	5.190	12.450	8.76467	0.559	2.165	4.689
ROEWE (g)	21	0.749	0.069	0.818	0.503	0.054	0.248	0.062
LOEWE (g)	15	0.742	0.077	0.819	0.486	0.067	0.261	0.068
ROEV (mm^3)	21	0.130	0.070	0.200	0.133	0.008	0.038	0.001
LOEV (mm^3)	15	0.140	0.080	0.220	0.136	0.012	0.0475	0.002
MDFL (μm)	70	40.00	30.00	70.00	49.823	0.7861	6.570	43.169
MDN (μm)	70	94.69	35.81	260.50	121.680	2.791	23.352	545.302
MNn	45	28.00	2.000	30.000	14.6647	0.294	1.972	3.888
MDn (μm)	45	45.00	25.00	70.00	32.7498	1.407	9.441	89.125

Table 2. Temporal measurements for egg and oviductal characters in *C. caspium*.

Characters	April n = 10	May n = 10	June n = 10	July n = 10	August n = 10	September n = 10	October n = 10
Mean diameter of ovary	3.67	4.78	4.42	4.91	3.78	3.84	3.83
Mean diameter of nucleus	152.45	170.46	178.34	118.68	110.52	103.66	101.71
Nucleolus diameter	25-70	25-60	30-60	40-50	–	–	–
Follicles numbers	4-8	4-8	3-7	3-7	4-6	3-6	4-6
Mean diameter of follicles	1.02	1.50	1.74	1.85	1.41	1.59	1.43
Mean size of oviductal eggs	–	12.93×10.83	9.08×7.42	9.71×7.64	9.37×7.97	–	–
Mean weight of oviductal eggs	–	0.801	0.331	0.454	0.262	–	–

Table 3. ANOVA of ovarian macroscopic characters in *C. caspium*. For abbreviations see Methods.

Character	Variance	Sum of Squares	df	Mean Square	F	P
W	Between Groups	20.945	13	1.611	1.500	0.147
	Within Groups	60.161	56	1.074		
	Total	81.106	69			
SVL	Between Groups	149.274	13	11.483	0.688	0.767
	Within Groups	935.105	56	16.698		
	Total	1084.379	69			
TL	Between Groups	306.479	13	23.575	0.774	0.683
	Within Groups	1704.824	56	30.443		
	Total	2011.303	69			
HL	Between Groups	12.612	13	0.970	0.930	0.529
	Within Groups	58.415	56	1.043		
	Total	71.028	69			
ROD	Between Groups	30.161	13	2.320	1.439	0.001
	Within Groups	90.296	56	1.612		
	Total	120.458	69			
LOD	Between Groups	18.645	13	1.434	1.245	0.004
	Within Groups	64.522	56	1.152		
	Total	83.167	69			
ROW	Between Groups	14.790	13	1.138	1.634	0.003
	Within Groups	38.997	56	0.696		
	Total	53.787	69			
LOW	Between Groups	1.092	13	0.084	4.929	0.000*
	Within Groups	0.954	56	0.017		
	Total	2.047	69			
ROV	Between Groups	0.070	13	0.005	5.891	< 0.001
	Within Groups	0.051	56	0.001		
	Total	0.120	69			
LOV	Between Groups	0.065	13	0.005	6.300	< 0.001
	Within Groups	0.045	56	0.001		
	Total	0.110	69			

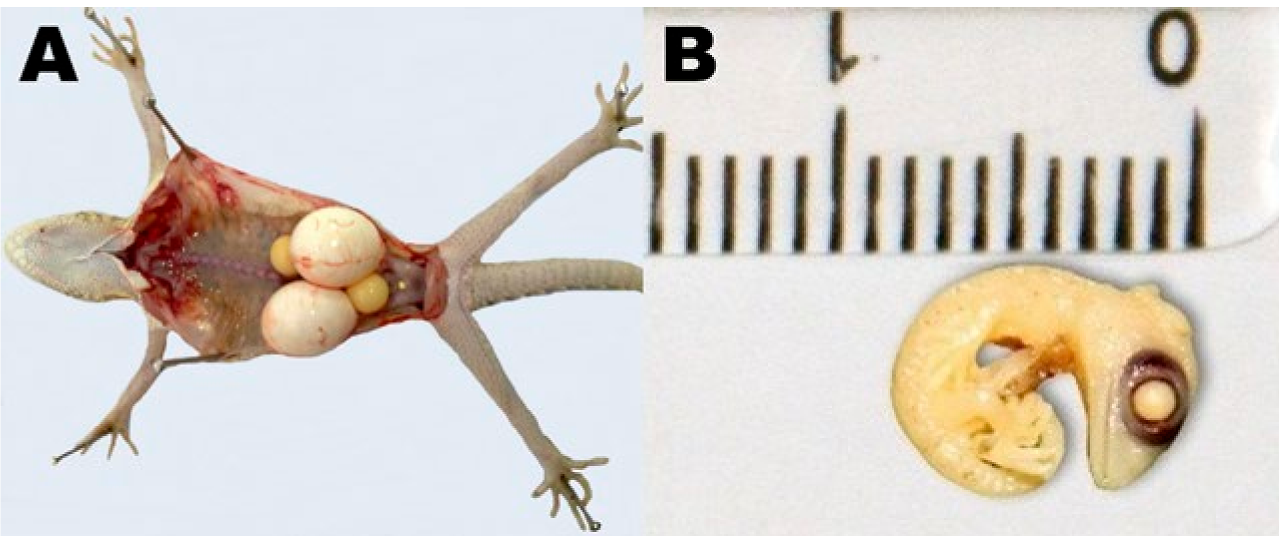

Fig. 2. *Cyrtopodion caspium*: A) oviductal eggs and mature follicles and B) 35 days old embryo. Photos by V. Hojati.

Table 4. ANOVA of ovarian microscopic characters in *C. caspium*. For abbreviations see Methods.

Character	Variance	Sum of Squares	df	Mean Square	F	P
RFN	Between Groups	43.200	13	3.323	2.449	0.010
	Within Groups	76.000	56	1.357		
	Total	119.200	69			
LFN	Between Groups	29.543	13	2.273	2.339	0.014
	Within Groups	54.400	56	0.971		
	Total	83.943	69			
MRF	Between Groups	4.582	13	0.352	2.033	< 0.001
	Within Groups	9.709	56	0.173		
	Total	14.291	69			
MLF	Between Groups	4.299	13	0.331	5.164	< 0.001
	Within Groups	3.587	56	0.064		
	Total	7.886	69			
MDFL	Between Groups	1702.264	13	130.943	5.745	< 0.001
	Within Groups	1276.426	56	22.793		
	Total	2978.690	69			
MDN	Between Groups	25266.383	13	1943.568	8.806	< 0.001
	Within Groups	12359.438	56	220.704		
	Total	37625.821	69			
MNn	Between Groups	146.298	8	18.287	26.575	< 0.001
	Within Groups	24.773	36	0.688		
	Total	171.071	44			
MDn	Between Groups	2984.285	8	373.036	14.329	< 0.001
	Within Groups	937.228	36	26.034		
	Total	3921.513	44			

tively. The juveniles were commonly observed in July and August. The mean SVL and TL of hatchlings were 22.38 and 30.20 mm, respectively. The maximum activity of oogenesis occurs in May.

DISCUSSION

Since oogenesis occurred from April through August, the pattern followed an associated reproductive cycle typical of species from temperate areas. The results of our study on the oogenic cycle of *C. caspium* are reported for the first time from Iran and west southern Asia. The largest female body length in this study was 68.03 mm, whereas in previous studies, it has been reported to be 59.80 mm, in northern Afghanistan (Anderson, 1999). A female collected from northern Afghanistan in mid-April had an oviductal egg about 5 mm long, whereas in the present study we observed oviductal eggs only in early May. This difference is probably due to the different climates of the two regions. All oocytes grow but only some of them enter vitellogenesis and reach the maximum size to later become shelled eggs. The weight, diameter and volume of the ovaries and oocytes increase between May and July and the females are heavier in mid-and-late spring due to the presence of eggs. Clutch size was similar to other gekkonid lizards, such as *Cyrtopodion scabrum* (Anderson, 1999). The smallest juvenile collected in this present study had a SVL = 19.11 mm in early August, whereas Anderson (1999) reported the smallest juvenile with a SVL = 20.7 mm in late August.

Although oocyte growth was accompanied by changes in the granulosa layer, zona radiata and thecal layers, the zona pellucida remained unchanged throughout. Based on work on the gecko *Hemidactylus mabouia*, the small cells of the granulosa layer are differentiated into three distinct cell types: small, intermediate and the large pyriform cells (Moodley and Van Wyk, 2007). Similar to most other squamates, the intermediate and pyriform cells at the onset of vitellogenesis regressed to a single cuboidal epithelium. Following ovulation, the granulosa layer hypertrophied forming laical tissue (Moodley and Van Wyk, 2007). The theca layer differentiated into two layers and septal invasion of the corpus luteum took place. At the time of oviposition, corpora lutea regressed to form ovarian scars (corpora albicantia). Follicular atresia occurred in previtellogenic follicles (hydration stage) and seldom in vitellogenic follicles. The highest incidence of atresia occurred in the post-breeding period (Moodley and von Wyk, 2007) while atretic follicles were replaced by new growing follicles recruited into the follicular size hierarchy (Jones et al., 1978).

The gross morphology, oogenesis and folliculogenesis of the ovaries of *C. caspium* correspond to the general squamate pattern described for oviparous reptiles (Moodley and Van Wyk, 2007). The ovarian stroma was characterized by follicles in different stages of development, and may contain corpora lutea, and corpora atretica. The follicular epithelium of the lizard oocytes undergoes structural and morphological modifications throughout oocyte growth. During this process the number of follicle cells increases and the epithelium acquires a multilayered and polymorphic organization which is characterized by the appearance of large follicle cells including intermediate and pyriform cells. The number of large cells also increases during oocyte growth and this increase parallels that of small cells. However, another study indicates that large follicle cells arise from the differentiation of small cells (Filosa et al., 1979).

In *C. caspium*, there was a germinal bed (GB) in each ovary. The germinal bed containing oogonia, oocytes, and primordial follicles, was most active during the vitellogenic period. In this species, the number of laid eggs varied from 1-2 per clutch. Another advantage of geckos for comparative analysis of egg shape is that female geckos of all species lay invariant clutches of one or two eggs (Shine and Greer, 1991). Consequently, female geckos have no more than one developing egg in a single ovary at a time. The egg shells harden soon after deposition, thus they undoubtedly offer a better protection against invertebrate predators and desiccating environmental conditions than a soft shell. In squamate reptiles, the generally flexible and poorly mineralized parchment-like egg shell is clearly plesiomorphic, with hard shells occurring only in the gecko family Gekkonidae (Andrews, 2004). Four gekkotan families (Carphodactylidae, Diplodactylidae, Eublepharidae and Pygopodidae) lay soft-shelled eggs, while their close relatives (Gekkonidae) lay hard-shelled eggs (Doughty, 1997). This highly mineralized egg shell is much more costly to produce, as calcium is a limiting element for most terrestrial organisms. However, within gekkonids, small species lay more elongated eggs than larger species (Kratochvil and Frynta, 2005).

In this study, we report more than one egg clutch per year. Our results show that the reproductive cycle of *C. caspium* is of the associated type and occurrs during the well defined period in which oocytes were not found in the ovaries all year round.

ACKNOWLEDGEMENT

Collecting permits and legal requirements were prepared by Department of Environment of Mazandaran Province of Iran. The authors wish to thank professor S.C. Anderson, from University of the Pacific and Dr Raul Diaz from University of Kansas, Natural History Museum and Biodiversity Research Center for a revision of the English and helpful comments. Special thanks are also due to two anonymous reviewers.

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