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Long-term changes in the biological parameters of wild carp (*Cyprinus carpio carpio*) from the south-eastern Caspian Sea

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Abstract

The populations of wild carp (*Cyprinus carpio carpio*), as a commercially valuable species in the southeast Iranian waters of the Caspian Sea, have been severely declined during last three decades, but there is no comprehensive research available on the biology of this species in this area. The age, growth and reproductive aspects of samples collected during 2009-2010 fishing season were measured and compared with data from previous studies to elucidate changes during the last five decades. The mean total length and weight of sampled carp ranged from 262- 726 mm and 314- 3733 g, respectively. The von Bertalanffy parameters of K and L_∞ for both sexes were 0.24 year $^{-1}$ and 68.13 cm, respectively. The Gonadosomatic index ranged from 6.61 to 20.12% and 1.2 to 7.11% in female and male samples, respectively. The mean fecundity of fish ranged from 33695 in 4 years carp to 1234567 in 12 years samples with mean of 273 thousand in all fish. The oocyte diameters ranged from 0.69 to 1.53 mm with mean of 1.32 mm. Egg size frequency distribution showed that wild carp has asynchronous ovarian development. Comparing the results from 5 decades ago showed that replacing the gill nets with beech seines has had evident impact on the growth and age-composition of wild carp and the observed asynchronous reproduction strategy should be considered for artificial reproduction programs.

***Keywords**: Cyprinus carpio carpio*; biology; age; growth; long-term assessment; south-eastern Caspian Sea

1. Introduction

Common carp (*Cyprinus carpio*) is a very adaptable fish and commonly generates established populations soon after introduction to new biotopes. In areas of introduction huge efforts have been made toward eradication or controling common carp populations, but these are generally not fully successful due to high tolerance of common carp to a wide range of environmental conditions (Brow et al. 2005). In contrast to areas of introduction, the wild populations of common carp have declined in the Caspian Sea basin, where ancestral common carp originated and spread east and west. The Caspian Sea is a brackish water body with salinity ranging from 8-13 ppt in the southern part. In comparison to most fresh waters inhabited with common carp in other parts of the world, the behavior and life cycle of species in the Caspian Sea are different. In this region, common carp (hereafter wild carp) is a semi-anadromous species which migrates from sea to adjacent rivers to spawn and fingerlings migrate back to the sea after complete metamorphosis (Berg, 1948). It is believed that anthropogenic efforts such as regulation of rivers and severe decrease of water levels during peak of spawning season mainly due to agricultural activities are among the main reasons for decline in natural population of wild carp in the south-eastern Caspian Sea area in past decades (Vazirzadeh et al. 2011).

There have been no intensive investigation on the biology of wild carp in the south-eastern Caspian Sea despite its high economic value and fluctuation in annual catch during the last three decades. Genetic studies showed that population of wild carp from south-eastern part of the Caspian Sea differs from wild populations of other parts of the world and needs more considerations for better management of the natural populations (Yousefian 2011; Yousefian and Laloei 2011).

This study aimed to determine the age, growth and reproduction biology of wild carp from the south-eastern Caspian Sea and to evaluate the effects of fishing methods on the biology of fish during the last five decades. The objective of this study was to collect biological information to apply in fisheries management of the fish. The data also could be used in best management of stock

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enhancement of wild carp in this region which has been started since two decades ago (Vazirzadeh et al. 2011).

2. Materials and methods

2.1. Sampling methods

Wild carps were collected from the south-eastern Caspian Sea (Fig. 1) (37 06 42 N and 54 02 37 E) during fishing season 2009- 2010. Samples were randomly selected from those fish catches by commercial beach seine. Totally, 1250 samples were used for biometrical analysis and a subsample of 244 specimens was randomly taken for reproduction study.

Fig. 1. Iranian water of the southern Caspian Sea and sampling area is depicted by black ovals

2.2. Age and growth

Total weight (nearest g) and total length (nearest mm) of sampled fish were measured using electronic balance and biometry board. The age of the samples was determined according to the annual rings of scales. Ten to 15 scales were sampled from the left side the body above the lateral line and below the dorsal fin. The scales were cleaned and annual rings were counted (Fig. 2). Length-weight relationship was studied according to (Brown et al. 2005). The overall sex ratio was calculated and tested with a chi-squared test against the null hypothesis where the sex ratio was 1: 1 (Brown et al. 2005).

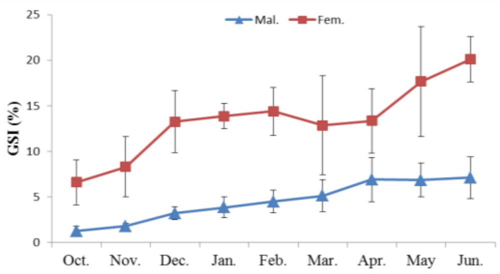

Fig. 2. Monthly changes in Gonadosomatic index (GSI%) as mean ± S.D. of male and female wild carp caught from the south-eastern Caspian Sea

Length-at-age was described by von Bertalanffy's growth model: $Lt = L_\infty (1-e^{-k(t-t0)})$, where L_∞ is the predicted asymptotic length of the fish, K is the body growth coefficient and t_0 is the theoretical age of a zero-length fish. The relative growth and instantaneous growth rates were calculated according to Ricker (1975).

2.3. Reproduction

The gonadosomatic index of the fish was calculated by $GSI= W_g/W_t \times 100$, where W_g is total weight of gonads (g) and W_t is total weight of the fish (g) before removing gonads. To calculate the fecundity of the fish, 3 samples from anterior, middle and posterior sections of both ovaries were taken at tertiary vitellogenesis stage and the number of oocytes in each sample was also counted. Total fecundity of each sample was calculated according to Sivakumaran et al. (2003). At this stage, diameters of 100 oocytes from five individuals (totally 500 oocytes) were also measured to determine size frequency distribution to distinguish the type of the fecundity which could be determinate or indeterminate, according to West (1990).

Ovarian samples from each ovary were fixed in Boudin's solution and after alcoholic dehydration and preparations, 5-7µm sections were prepared for histological studies of the ovarian development (Hinton 1990). The developmental stages of the ovary were analyzed according to the most advanced oocytes regardless of their abundance as described previously for this species (Smith and Walker, 2004).

2.4. Statistical analyses

The normality of data was checked by the Shapiro-Wilk test. Data on reproductive parameters were analyzed using one way ANOVA after arcsine transformation of the percentage data. Statistical significance was accepted at $P \leq 0.05$. Data are reported as means ± standard deviation (S.D.). All statistical analyses were done using the statistical software SPSS 15.

3. Results

3.1. Age and growth

The mean total length and weight of sampled carp ranged from 262- 726 mm and 314- 3733 g, respectively. In studied samples 12 age-classes were observed. Samples were dominated by 4-year-old fish, while there were few fish in excess of 9-years-old. The age composition of fish is shown in

Table 1. According to exponential regression estimation, the *b* parameter for male and female fish was 2.92 and 2.95, respectively which were significantly different from 3 (r^2= 0.99; $P \leq 0.001$). L∞ and K for female, male and total fish were 70.23, 63.21, 68.13 cm and 0.21, 0.32, 0.24, respectively (Table 2).

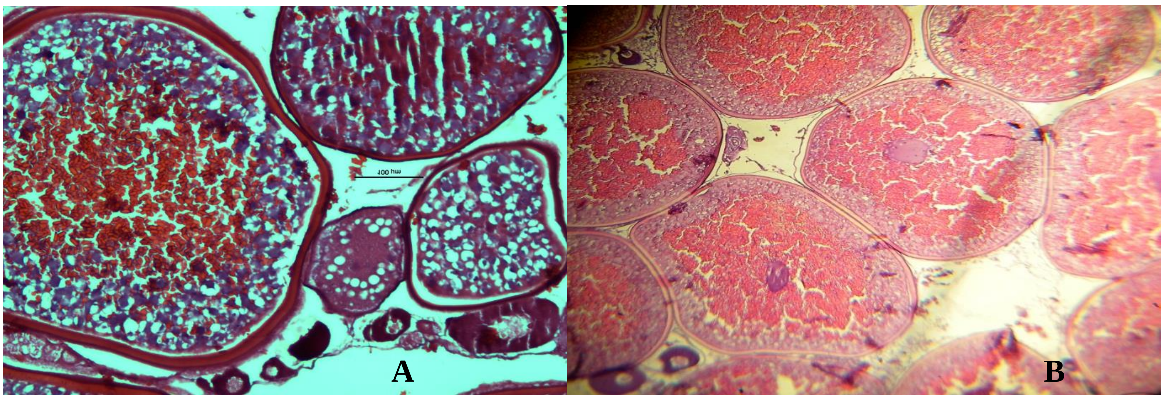

Fig. 3. Five µm paraffin sections of ovary showing asynchronous oocyte development (A) and synchronous oocyte development (B) in female wild carp from southeast coastal Iranian waters of the Caspian Sea

Table 1. Details of growth of wild carp in different age, caught from the southeast Iranian waters of the Caspian Sea

Age	Mean TL (mm)	Mean TW (g)	Instantaneous growth (g)	Relative growth rate (mm)
2	262	314	0.95	371
3	349	811	1.23	267
4	378	1065	0.401	109
5	435	1342	0.323	96
6	471	1678	0.291	56
7	527	1987	0.251	67
8	559	2245	0.212	51
9	583	2678	0.154	46
10	646	2981	0.116	37
11	674	3367	0.092	41
12	726	3733	0.082	32

3.2. Reproduction

GSI of female changed from 6.61% in Oct. to 20.12% in June and was highly variable (Fig. 2). Lower GSI at some sampling times might be due to presence of spent fish among samples. Spent fish were sampled at 6 sampling times. GSI of male fish changed from 1.25 to 7.11% (Fig. 2) and fish with running sperm were observed in 7 sampling times. The histological studies revealed that wild carp show both single and multiple spawning patterns, while the majority of studied fish had asynchronous ovarian developmental pattern. In synchronous fish, ovary contained only two developing oocyte batches, while ovaries of asynchronous fish represented more than two developing batches of oocytes (Fig. 3). Size frequency distribution of five hundred oocytes from 5 individuals at the stage of tertiary vitellogenesis is shown in Fig. 4. It clearly shows that the stage of V (tertiary vitellogenesis) is abundant but the size frequency distribution is continuous and all developmental stages of oocytes before tertiary vitellogenesis also exist. It means that the fecundity of wild carp is indeterminate and it is also clear evidence of the asynchronous development of wild carp ovaries. The details of fecundity and oocyte diameter of wild carp of Caspian Sea are shown in Table 3. Total fecundity of species ranged from 33695 in 4 year old carp to 1234567 in 12 year old samples with mean of 273 thousand. The oocyte diameters ranged from 0.69 to 1.53 mm with an average value of 1.32 mm.

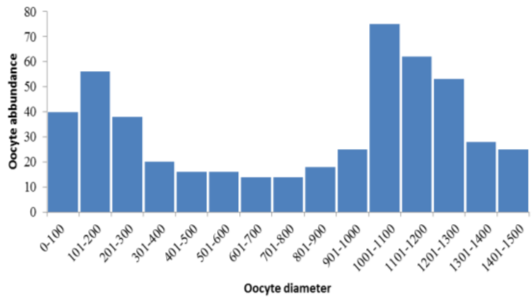

Fig. 4. Size frequency distribution of 500 oocytes pooled from 5 individuals at stage of tertiary vitellogenesis

4. Discussion

As the ancestor of the oldest domesticated species of the fishes (Balon 1995) and because of its high economic value, wild *C. c. carpio* has special importance among the ichthyofauna of the Caspian Sea and Europe.

Table 2. The von Bertalanffy growth parameters of wild carp caught from the southeast Iranian waters of the Caspian Sea

Sex	No	$L\infty$	K	t_0
Female	148	70.23	0.21	-0.34
Male	96	63.21	0.32	-0.30
Total	244	68.13	0.24	-0.32

In many parts of Europe, as well as the Caspian Sea basin, the natural populations of wild carp are in great danger and it have already become extinct in some regions (Holcik 1996; Lusk, 1996). Despite great variations in annual catches, a decreasing tendency is very obvious in the south Caspian Sea region which is very similar to the situations already reported for the north and west Caspian Sea (Ivannikov 1997). At the present time, the largest population of wild carp inhabits the lower Volga river (north of the Caspian Sea), while it has become least abundant in the south Caspian Sea Kura river. However, in the latter region the fish still maintains its commercial value due to the stock enhancement program of the government (Barus et al. 2001; Vazirzadeh et al. 2011).

Present annual catch of wild carp in southeast Iranian water of the Caspian Sea is near 4000 to 6000 m tones. It is worth mentioning that one of the main rivers of the south-eastern Caspian Sea, Ghara Su (meaning black or dark water), where carps migrate to spawn during spawning season, is named so because of intensive fish migration in spring which changes the color of the river to darkish.

Growth rates for wild common carp in this study fall within the range reported for populations of common carp elsewhere. Younger wild carp showed higher growth rate than the elders ones, as shown by relative and instantaneous growth rates in studied area which was in agreement with the carp populations from France (Crivelli 1981), Spain (Fernández-Delgado 1990), and Turkey (Ozcan, 2008). However the New Zealand Koi carp exhibited similar growth rates during their first and second years, but higher growth rates from about 6 years of age (Tempero et al. 2006). The length range of wild carp in this study was higher than those of wild carp from Turkey (Ozcan 2008), but similar to those of wild carp from Aral Lake and Volga River (Koblitskaya 1977) and Australia (Brown et al. 2005). Nikolskiy (1957) reported the standard lengths of the common carp from the southern part of the Caspian sea for age 1-6 as 147, 200, 359, 437, 504 and 561 mm which were significantly lower than those of carps from the northern part with 175, 310, 455, 540, 620 mm at age 1-5 years. The SLs of wild carp in Lesser Danube were 142, 265, 347, 396, 424, 451, 478, 493, and 526 mm for ages 1-8, respectively. The *K* of wild carp in present study was 0.24 which is similar to those of carps from New Zealand (*K*= 0.21) and the Barmah region of Australia (*K*= 0.17 for female and 0.24 for male), much higher than that of Karamik lake of Turkey (*K*= 0.07). However, it is significantly lower than that of wild carp from the Campaspe region of Australia (*K*= 0.47 for female and 0.37 for male). Berg (1949) reported that the wild carp population in Kura River is the most rapidly growing among those in the Caspian Sea basin. It is also characterized by a delayed maturation that occurs at 4-5 years of age. Differences in growth rate between south-eastern Caspian Sea carp and other wild carp populations may be attributable to different climatic conditions and also genetic variation. The ambient salinity may also be the reason for different growth rate as shown by Wang et al. (1977).

Table 3. Fecundity and oocyte diameter of wild carp caught from the southeast Iranian waters of the Caspian Sea

Age	Oocyte diameter		Total fecundity
4 (n= 41)	Max	1.27	181234
	Min	0.69	33695
	Avg	1.18	85369
5 (n= 26)	Max	1.33	373456
	Min	0.78	42367
	Avg	1.20	130024
6 (n= 16)	Max	1.35	389034
	Min	0.87	56781
	Avg	1.23	154678
7 (n= 16)	Max	1.36	421745
	Min	1.01	67532
	Avg	1.25	212325
8 (n= 15)	Max	1.38	601234
	Min	1.12	98005
	Avg	1.28	321174
9 (n= 25)	Max	1.42	745641
	Min	1.09	321872
	Avg	1.32	532902
10 (n= 11)	Max	1.46	864390
	Min	1.16	632149
	Avg	1.37	591345
11 (n= 7)	Max	1.51	986890
	Min	1.20	721436
	Avg	1.41	763543
12(n= 5)	Max	1.53	1234567
	Min	1.21	876546
	Avg	1.42	925431

The length range of the carp from the south-eastern Caspian Sea since 1969 is shown in Table 4. It is obvious that the mean length of Iranian carp decreased from 41.5 cm in 1971 to 28.7 cm in 1992 with gradual increase afterwards. The main probable reason for such a pattern is the fishing methods. Before 1994, gill nets were the main fishing tool, which were then replaced by beech seine due to its negative impacts on the population dynamics by catching under size individuals. The age compositions of sampled fish from 1971 to 1997 (Table 5) also clearly show that replacing the gill nets by beech seines resulted in moving the dominant age from 2- 3 years samples during years up to 1993 to older specimens thereafter. Since in condition of study area the maturation of female wild carp occurs in the third year of their life, capturing fish younger than 3 years-old should have drastic impact on the population dynamics of the species.

Table 4. Age-length changes (cm) of wild carp from the southeast Caspian Sea since 1969. Data are presented when reliable information was available. It is worth mentioning that gill nets were replaced by beech nets in 1994

Age	1	2	3	4	5	6	7	8	9	10	11	12	Mean
Year												-	-
1969		34	41	48	54	-	-	-	-	-	-	-	-
1970		31	38.5	46.1	53.5	-	-	-	-	-	-	-	-
1971	-	35.8	41.5	49.2	53.7	63	-	-	-	-	-	-	41.5
1989	22.1	26.9	31.3	35.6	39.4	41.3	54.2	-	-	-	-	-	32
1990	20	24	29	32	36	40	48	51	-	-	-	-	31.8
1991	18	30	35	40	51	-	57	-	-	-	-	-	35.1
1992	21	22.7	26.2	32	41	43.3	46.2	53	-	-	-	-	28.7
1993	22.2	26.2	31	35	35.8	36.5	47.3	-	-	-	-	-	31.9
1994	19.7	27.3	31.4	37.4	47.9	53.2	55.2	-	76.5	-	-	-	36.2
1995	27.3	31.3	36	41	42.4	46.3	53.3	55.6		-	-	-	36.4
1996	23.5	26.8	33	35.8	39.1	42.6	47.9	51.3	54.5	56.5	-	-	37.3
1997	15	23.1	26.7	29.4	35.2	41.1	45.5	49.3	51.1	54	57.1	-	37
Present study	-	26.2	34.9	37.8	43.5	47.1	52.7	55.9	58.3	64.6	67.4	72.6	38.2

There were few samples exceeding age 9^+ in agreement with the McCrimmon's (1968) conclusion that wild carp rarely aged in excess of 20. Vilizzi and Walker (1999) found relatively few common carp older than 12 years from the lower Murray River, Australia, although Brown et al. (2005) reported several 25 years-old or older individuals in mid-Murray River and associated water bodies indicating that longevity is a wide spread phenomenon. The latter authors also reported a 32-year-old male carp from Gippsland that was sampled from a group of fish actively spawning. Old carps do not occur in the Caspian Sea, Probably because of the intensive fishing activities. The oldest specimens in the Ural River were 12 to 14 years-old, while those in Volga Delta were 9 to 10 years-old. Fish aged 7 to 10 years-old constituted more than half of the total catch in the Volga Delta (Kazancheev 1981). The maximum age of the wild carp recorded in Aral Sea is 17 years (Berg, 1949). Barus et al. (2001) stated that some incorrect reports on the long longevity of carp may be due to misinterpretation of the scale annual rings which usually consists of several dozen circuli and were erroneously thought to be the annuli or growth rings.

According to Balon (1995) the spawning of wild carp may occur two times during spring when appropriate conditions are available. Spawning may last several days and each fish may have two to three consecutive spawning. Male and female wild carp may spawn each 8 and 25 days, respectively according to McCrimmon (1968). Our observation also showed that overall sex ratio of male: female was 1:1.54 which was significantly different from 1:1, indicating that females had more communion in spawning and each male may mates with more than one female as already reported by Balon (1995) in wild carp of Danube river and adjacent water bodies. This means that male carp have shorter interval between consecutive spawning than females (McCrimmon 1968). In contrast to our result, Brown et al. (2005) reported a 1:1 sex ration for Australian wild carp.

Table 5. Age compositions of annual catches of wild carp from the south-eastern Caspian Sea since 1971. Dominant ages are shown in italics

Age	1	2	3	4	5	6	7	8	9	10	11
Year											
1971	-	21.4	59.4	15.8	2.6	0.8					
1989	25.5	21.6	27.1	17.9	5.21	1.9	0.8				
1990	0.9	8.4	29.9	31.8	22.1	4.6	0.4	0.1			
1991	4.7	9.5	49.6	27.7	6.6	-	1.9	-			
1992	2.4	32.6	33.1	13.2	11.6	5	1.6	0.3			
1993	1.4	18.2	40.8	25.2	8.8	4.2	1.5	-			
1994	1.1	6.1	37.1	41.5	8.6	4.3	1.1	-	0.3		
1995	6.6	25.8	39.9	14.6	8	2.8	0.9	1.4	4.1		
1996	0.3	0.8	19.4	41.6	24.4	7.3	4.8	0.6	0.3	0.6	
1997	4	3.5	13.1	12.9	11.9	23.7	19.1	8.2	1.7	0.3	0.8
present study	-	6.2	13.5	41.5	15.3	11.12	5.75	4.21	1.2	0.6	0.2

According to GSI changes and the presence of spent fish, multiple spawning of wild carp was recorded in study area. In the previous studies it was mentioned that the spawning period of wild carp typically commences when the water temperature is 15 ºC (Stuart & Jones 2002) or more (McCrimmon 1968; Smith and Waker 2004; Brown et al. 2005). Our results surprisingly showed that some individuals are able to spawn even when the water temperature is below 15°C after heavy rains and spawning ground inundation. Wild carp of the Amur River are also known to spawn at lower temperature starting at 15 ºC (Kryzhanovskyi et al. 1951, in Barus et al. 2001). These findings show that common carp is able to adapt its reproductive strategy to take advantage of local environmental conditions and it may also show that appropriate spawning grounds may be of more importance compared to water temperature. This event may also reflect the adaptation of common carp to the environmental condition of the study area with higher fluctuations in temperature in terms of weekly cycles mainly during the spring and autumn seasons and its struggle to tackle the undesirable condition for spawning including deconstruction of spawning ground and water withdrawal for agriculture irrigation purpose. It is important to note that by our sampling schedule it was not possible to determine the precision spawning time of the spent fish and due to the rapid change of temperature in the studied area in a short period, it is also possible that spent fish shed their oocytes in the days prior to sampling though the temperature was higher than 15 °C. In condition of south-eastern Caspian Sea, the temperature of water in spring is more suitable for spawning of wild carp than other seasons, but most of the fresh water rivers are subjected to heavy agricultural activities resulting in highly decrease of water level and even drying of rivers before connecting to the sea. Therefore it seems that some individuals spawn in water temperature below 15-16 °C to take advantage of the local condition (Yousefian 2011). Our results also showed that wild carp spawn at least over 6 months of the year with two peaks in autumn and spring, however, the latter is much longer and of more importance. Berg (1949) also described a wild carp migration from the Caspian Sea into the Volga during summer and autumn. Kazancheev (1981) stated that migrations of wild carps into the Kura River were formerly very intensive and prolonged and in addition to the spring run in April and May, a second spawning migration was observed during summer and autumn, from August through October.

Long spawning period of wild carp has also been reported in Australia by Sivakumaran et al. (2003), Smith & Walker (2003) and Brown et al. (2005) and in New Zealand (Tempero et al. 2006). Such discrepancies might be attributable to latitude, temperature and prevailing condition of spawning sites.

Majority of common carps showed asynchronous ovarian developmental pattern, although synchronous ovaries were also observed. Sivakumaran et al. (2003) and Brown et al. (2005) also reported the existence of synchronous and asynchronous ovaries in Australian carp, while Smith and Walker (2004) reported asynchronous pattern for the same fish. It is believed that in unpredictable environmental conditions, fish prefer to have multiple spawning strategy to avoid competition for habitat and food and increasing off-springs survival in stochastic changing environments (Rinchard and Kestemont 1996).

Table 6. Absolute fecundity of wild carp from different parts of the Caspian Sea: (Volga River, Banarescu, 1969 and Berg, 1949) and south-eastern Caspian Sea (present study)

Age range	SL range (mm)	Mean fecundity (Banarescu, 1969)	Mean Fecundity (Berg 1949)	Corresponding SL (mm) ranges in the present study	Mean Fecundity (present study)
2-3	310-350	101000	162000	349-378	-
3-4	360-400	274000	222000	371-435	85369
4-5	410-450	357000	278000	436-471	130024
5-6	460-500	450000	365000	472-527	154678
6-7	510-550	550000	508000	528-559	212325
7-8	560-600	-	810000	560-583	321174

Our personal observations also indicated that some individuals are resident to the sea and spawned in coastal waters without migrating to rivers. In Lake Aral, it is already reported that wild carp usually spawns in a large range of salinities reaching as much as 10 ppt (Berg, 1949). He also reported two ecological forms of wild carp in the Volga-Caspian basin: a resident, non- migratory form and a migratory or the semi-migratory form inhabiting parts of the estuaries and regularly migrating upstream for spawning (Berg, 1949).

The total fecundity of wild carp in the south-eastern Caspian Sea was similar to other reports for the species. Common carp in Victoria, Australia, had high fecundity (120000 to 1540000 oocytes per fish) (Sivakumaran et al. 2003), but New Zealand common carp showed lower fecundity (299000 oocytes per fish) (Tempero et al., 2006).The maximum GSI value recorded for a female wild carp is 23.47% and absolute fecundity in a female reached a maximum of 1900000 eggs (Banarescu 1964, in Barus et al. 2001). Berg (1949) found that the fecundity ranged from 9300 to 1664000 eggs. The maximum number of eggs (1.7 kg eggs) was found in a female with 920 mm TL and 10.8 kg TW. Kazancheev (1981), in the same river, found that mean fecundity of specimens ranging from 410 to 600 mm in SL was 363000 eggs, and that of the specimens, 710 to 800 mm reached 650000 eggs. Fecundity values lower than these were also reported by Kazancheev (1981) in Atrek River, where the range was 16000 to 543000 with the mean of 125000 eggs. The mean absolute fecundities of wild carp from the Volga River and south-eastern Caspian region are compared in Table 6. Our results show that the mean absolute fecundity of the species is between those of wild carp of the Kura and Atrek rivers.

The mean diameter of mature oocytes ranged from 1.18 in 4 year-old fish to 1.42 in 12 year-old specimen (0.69–1.53 mm) which includes the mean mature oocyte diameter reported for carp (Sivakumaran et al. 2003; Tempero et al. 2006). The poly modal distributions of yolked oocyte diameters indicate that multiple spawning females are present in the population and the fecundity of carp is indeterminate. This observation is another indication of multiple-spawning behavior of wild carp in the study area. Sivakumaran et al. (2003) and Tempero et al. (2006) also found multiple spawning behaviors using oocyte size frequency distribution. West (1990) suggested that size frequency distribution study is a simple and reliable procedure to determine the spawning frequency and also the type of fecundity (i.e., determinate or indeterminate).

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