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Invasion of freshwater bodies in the Marmara region (northwestern Turkey) by nonnative gibel carp, *Carassius gibelio* (Bloch, 1782)

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Abstract: The aim of this study was to learn the invasion speed and sex ratio, which would be indicative of invasive character, of a nonnative fish species, gibel carp, by reporting its new localities in the Marmara region of northwestern Turkey. Whether the occurrence of gibel carp in freshwater bodies of the Marmara region was random (i.e. chance element) was tested. The question of population increase since first introduction was also examined. Among 14 new locations for gibel carp found during this study, the majority were in mostly lentic ecosystems. The invasion rate of gibel carp in the Marmara region, since its first introduction in the early 1980s, is approximately 1 new water body per year (1.17; number of sites invaded by gibel carp = 35). Females significantly outnumbered males in 10 out of the 12 populations studied, with the sex ratio deviating from unity (1:1) in all populations except 2. The regional extent of gibel carp occurrence increased with the number of years since first introduction ($y = 1.34x - 2651.1$, $F = 47.41$, $P < 0.001$, $r_s = 0.95$). The implications for conservation of native fishes are discussed.

Key words: Invasion, gynogenesis, distribution, illegal releases, acclimatization

Marmara Bölgesi (Kuzey-Batı Türkiye) içsularının egzotik gümüşi havuz balığı *Carassius gibelio* (Bloch, 1782) tarafından istilası

Özet: Bu çalışma Marmara Bölgesi'nde gümüşi havuz balığı için yeni dağılım alanlarını rapor etmeyi, balığın istila hızını ve istilacı karakterinin iyi bir göstergesi olan cinsiyet oranlarını belirlemeyi amaçlamaktadır. Ayrıca Marmara Bölgesi içsularındaki gümüşi havuz balığı varlığının tesadüfi (şans eseri) olup olmadığı ve zamanla sayısının artıp artmadığı test edildi. Gümüşi havuz balığı için çoğu durgun su ortamı olmak üzere 14 yeni bölge tespit edildi. Gümüşi havuz balığının Marmara Bölgesi'ne ilk girişinden (1980'lerin başı) günümüze kadar geçen sürede her yıl ortalama 1 yeni alanı istila ettiği bulundu (1.17, gümüşi havuz balığı tarafından istila edilen saha sayısı = 35). Çalışılan 12 popülasyonun 10'nunda dişiler erkeklere göre önemli derecede fazlaydı, sadece iki populasyonda cinsiyet oranı eşitti. Gümüşi havuz balığının sayısındaki artış ilk aşılanmasından günümüze kadar geçen zamanla doğru orantılıydı ($y = 1.34x - 2651.1$, $F = 47.41$, $P < 0.001$, $r_s = 0.95$). Yerel türlerin korunması ile ilgili sorunlar tartışıldı.

Anahtar sözcükler: İstila, ginogenez, yayılış, yasadışı aşılamalar, uyum sağlama

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Introduction

Freshwater ecosystems are one of the most threatened and poorly protected ecosystems globally (Saunders et al., 2002; Dudgeon et al., 2006; Abell et al., 2007; Moilanen et al., 2008). Species introductions represent one of the primary threats to the preservation of biodiversity. The entry, establishment, and spread of nonnative species in new environments can cause irreversible ecological impact, major economic damage, and significant public health problems. The impact of invasive species on native species, communities, and ecosystems has been widely recognized for decades (Elton, 1958; Lodge, 1993; Simberloff, 1996), and invasive species are now considered a significant component of global change (Vitousek et al., 1996).

In Turkey, the stocking of fish into newly established water bodies is very common. Although some species introductions are accidental, many fish species introductions have been intentional, with the aim of increasing fish production and sport fishing. However, as a result of these stocking practices, several nonnative fish species may have also been introduced through unintentional or unauthorized stocking, such as the accidental introduction of gibel carp, *Carassius gibelio* goldfish *Carassius auratus*, eastern mosquitofish *Gambusia holbrooki*, pumpkinseed *Lepomis gibbosus*, and topmouth gudgeon *Pseudorasbora parva*, is the latter species being a contamination of intentional stockings of common carp *Cyprinus carpio* (Özuluğ et al., 2005; Balık and Ustaoğlu, 2006; Tarkan et al., 2006).

One of the most abundant of these nonnative fish species is the gibel carp. It was first introduced into Europe from Asia in the 17th century (Lever, 1996), but did not appear in some parts of Europe (e.g. Poland) until the 20th century. The gibel carp appeared in the European part of Turkey (Lake Gala, Thrace) in 1986 (Baran and Ongan, 1988). A rapid increase in gibel carp abundance and distribution has been reported in many parts of its introduced range (Holčík, 1980). The appearance of gibel carp in some countries may have occurred much earlier, but proper identification was delayed, as it was in Turkey, because of the species' strong physical similarity to native crucian carp *Carassius carassius*. This physical similarity has led to misidentifications in some countries (Copp et al., 2005), similar to those of goldfish for crucian carp in the UK (Wheeler, 2000). As the proper identification of these 2 nonnative species increased, their wider distributions became apparent.

The effect of gibel carp introductions on native species has only recently been recognized. The decline of native cyprinid fish populations in some parts of Europe and Turkey has been associated with habitat degradation due to the introduction of nonnative *Carassius* species (Navodaru et al., 2002; Balık et al., 2003), which also affects the native cyprinid fishes through reproductive interference (Wheeler, 2000; Tóth et al., 2005; Vetemaa et al., 2005; Smartt, 2007). In Turkey, some economically important native and endemic fish species such as *Vimba vimba*, common carp, rudd *Scardinius erythrophthalmus*, and Thracian shemaya *Alburnus istanbulensis* have mostly suffered from these introductions (e.g. Balık et al., 2004; Gaygusuz et al., 2007). The major biological trait responsible for the invasiveness of gibel carp is its reproduction. Invading gibel carp populations are often triploid (e.g. Peňáz et al., 1979; Peňáz and Dulmaa, 1987; Kalous et al., 2004) and composed of almost exclusively triploid gynogenetic females. The gynogenetic females are clonal sperm parasites on cooccurring fish species; they use males of these species for spawning, but the male's sperm merely activates egg development and makes no genetic contribution (Saat, 1990). Other populations are gonochoristic and include both diploid females and males.

The distribution of gibel in Turkey is now thought to include not only the Thrace region (Özuluğ et al., 2004), but the entire Anatolian peninsula, as well (Balık et al., 2003, 2004; Şaşı and Balık, 2003; İlhan et al., 2005). Recent studies show its very fast spread over the country and possible negative impacts on native fish communities (Balık et al., 2003, 2004; Şaşı and Balık, 2003; İlhan et al., 2005; Özcan, 2007). In the Marmara region, where the first introduction of gibel carp occurred (Thrace; Baran and Ongan, 1988), around 20 locations with gibel carp have now been reported (Baran and Ongan, 1988; Özuluğ, 1999; Özuluğ et al., 2004; İlhan et al., 2005; Torcu-Koç et al., 2008). However, the distribution map of this species is poorly understood in the Marmara region and

Turkey. With this study, we report new localities for the gibel carp in the Marmara region of northwestern Turkey and determine its invasion speed and sex ratio, which may be good indicators of its invasive character. Furthermore, we tested whether the occurrence of gibel carp and other nonnative fishes in the studied water bodies is random and increasing over time since their first introduction. Establishment success of nonnative species is usually predicted to be positively correlated with the numbers of individuals introduced and the frequency of their introduction. Hence, the Marmara region was chosen as it was the first region into which gibel carp populations were introduced in Turkey; consequently, it has the oldest gibel carp populations in Turkey.

Materials and methods

Fish were collected between 15-30 June 2009 and 17-30 May 2010 from several small artificial lakes in the Kocaeli Peninsula, the Meriç River, and Lake Karpuzlu (Thrace region). Between March 2008 and January 2009, fish were collected from Lake Taşkısığı, and between May 2009 and April 2010, from Lake Uluabat and Lake Manyas (Marmara region) (Figure 1, Table). Fish were collected using electrofishing (SAMUS 725 MP) and multi-mesh gillnets (length = 50 m, height = 3 m, mesh sizes = 30 and 60 mm from knot to knot). The nets were set from dusk until dawn at the surface in areas where water depth was <10 m. In the laboratory, sex was determined by visual examination of the gonads, by naked eye for larger fish and with the aid of a magnifying lens (16×) for smaller fish. The overall ratio of males to females was examined with chi-square (χ^2) analysis (Zar, 1999), with significance set at $P < 0.05$. For each water body, distance from the nearest residential area (in km), as well as the total water body area (in km^2), was recorded. Available information on these variables and date of introduction of other gibel carp populations in the Marmara region were obtained from published material. The relationship between occurrence of nonnative fishes and distance form nearest city center, the number of nonnative species occurrences and sex ratio in the wild, and number of years since introduction and area of water body were tested using correlation and regression analyses as appropriate.

Results

In the present study, 14 new locations were detected for gibel carp, mainly in lentic ecosystems; only 1 area was a river (Meriç River). Overall, 948 gibel carp specimens were caught and sexed. In total, 35 sites were considered for analyses; however, it was only possible to calculate the sex ratio for 12 locations, as a minimum of 25 individuals were accepted for further analyses. Gibel carp invasion history in the Marmara region was examined using 3 decades as time intervals (1980-1990, 1990-2000, 2000-2010) (Figure 1). A new water body has been invaded by gibel carp approximately once a year since the first introduction of the species into the Marmara region. Recently (i.e. after 2000) its invasion has decreased remarkably (Figure 1), while the manifested area has increased considerably within the same time interval. Of these invaded water bodies, 10 were natural lakes, 6 were streams, and 19 were reservoirs.

Females significantly outnumbered males in 10 out of the 12 populations studied (chi-square test, $P < 0.05$); the sex ratio was 1:1 in only 2 populations (chi-square test, $P > 0.05$) (Table). The regional extent of nonnative fish occurrence increased with the number of years (t) since the first introduction ($y = 1.34x - 2651.1$, $F = 47.41$, $P < 0.001$, $r_s = 0.95$) (Figure 2). Although not as significant as the number of sites with gibel carp, the number of years (t) since first introduction was significantly related with the cumulative area manifested by gibel carp ($y = 31.49x - 6259$, $F = 5.35$, $P < 0.05$, $r_s = 0.65$). However, between 2000 and 2005, the gibel carp remarkably extended its manifested area more than 2 times (i.e. 636 km^2) compared to the previous decades (in total, 331 km^2) since 1980. The relationship between the nearest residential area and the number of nonnative fish species was not significant ($P > 0.05$, $r_s = -0.05$). An insignificant relationship was also found between years since introduction of gibel carp and sex ratio ($P > 0.05$, $r_s = 0.19$).

Discussion

These data for the Marmara region exemplify how the rise in numbers of introductions of native fishes (mostly common carp) for angling and fish production has increased the risk of intentional or

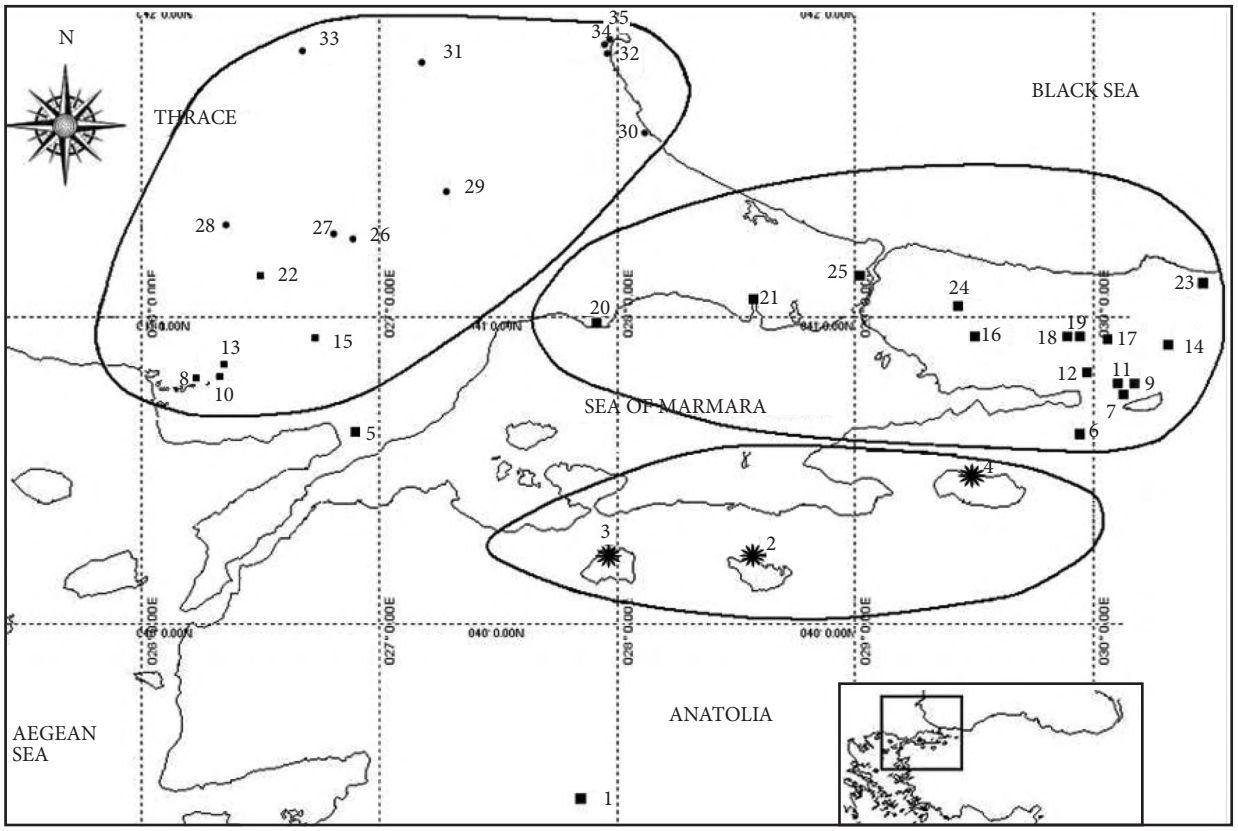

Figure 1. Distribution of gibel carp in the Marmara region: 1) Ikizcetepeler Reservoir, 2) Lake Uluabat, 3) Lake Manyas, 4) Lake İznik, 5) Kavaklı Stream, 6) Yuvacık Reservoir, 7) Kirazoğlu Reservoir, 8) Lake Gala, 9) Ketenciler Reservoir, 10) Lake Pamuklu, 11) Bayraktar Reservoir, 12) Çayırköy Reservoir, 13) Karpuzlu Reservoir, 14) Lake Taşkısığı, 15) Çamlıca Creek, 16) Denizli Reservoir, 17) Davuldere Reservoir, 18) Tahtalı Reservoir, 19) Çağırgan Reservoir, 20) Kınıklı Stream, 21) Büyükçekmece Reservoir, 22) İbriktepe Reservoir, 23) Lake Akgöl, 24) Ömerli Reservoir, 25) İstanbul Technical University Pond, 26) Çöpköy Pond, 27) Bülbüldere Pond, 28) Meriç River, 29) Sarıcaali Pond, 30) Arnavut Stream, 31) Kayalı Reservoir, 32) Lake Saka, 33) Tunca Stream, 34) Lake Hamam, 35) Bulanık Stream. • indicates gibel carp populations introduced between 1980 and 1990, ▪ indicates gibel carp populations introduced between 1990 and 2000, * indicates gibel carp populations introduced between 2000 and 2010.

unintentional introductions and, as a consequence, the regional distribution of the nonnative species as a function of time since introduction. The recorded occurrence of gibel carp in the wild appears to be a function of time since introduction (b = 1.34; Figure 2). The present study clearly indicates the rapid invasion of gibel carp, given that 35 populations have been recorded since the beginning of the 1980s (i.e. the first report of gibel carp in Thrace). This phenomenon was also supported by the remarkable increase in area manifested by gibel carp, especially in last 10 years (after 2000, more than twice the area as compared to the manifested area between 1980 and 2000). Indeed, an arbitrary observation of the distribution map of gibel carp in the Marmara region revealed that there were 3 different time intervals for the spread (i.e. 3 decades: 1980-1990, 1990-2000, and 2000 to date), and its move into Anatolia occurred mainly after 1990 (Figure 1). Similar reports on the rapid increase and distribution of gibel carp have been given from many parts of its invaded range in Europe (Holčík, 1980; Abramenko et al., 1997; Paschos et al., 2001; Witkowski, 2002; Vetemaa et al., 2005) and Turkey (Balık et al., 2004; İlhan et al., 2005; Gaygusuz et al., 2007; Özcan, 2007).

As a thermophilic water species, gibel carp is known to prefer eutrophic waters with dense vegetation (Vetemaa et al., 2005). However, this

Table. Study sites with their descriptive features, including number of nonnative fish species and distance to nearest residential area, year of introduction, number of individuals (n), and sex ratio of gibel carp.

Locality	Lat.	Long.	Area (km^2)	Year of introduction	Distance to the residential area (km)	No. of nonnatives	n	Sex ratio (F:M)	Reference
Ikizcetepeler Reservoir	39°29 ′	27°56′	9.60	1991	1.5	1	14	-	Torcu-Koç et al. (2008)
Lake Uluabat	40°10′	28°35′	160	2001	0.9	1	459	1:0.40*	Present study
Lake Manyas	40°12′	27°56′	178	2000	0	1	3	-	Present study
Lake İznik	40°26′	29°32′	298	2003	0	3	344	1:0.80	Tarkan et al. (2006)
Kavaklı Stream	40°36′	26°52′	-	1998	0	1	1	-	Özuluğ et al. (2004)
Yuvacık Reservoir	40°38′	29°56′	2	1999	6.6	1	30	1:0.23*	Present study
Kirazoğlu Reservoir	40°45′	30°06′	0.40	1991	5.7	2	27	1:1	Present study
Lake Gala	40°46′	26°11′	7.70	1986	9.8	1	4	-	Özuluğ et al. (2004)
Ketenciler Reservoir	40°46′	30°08′	0.40	1991	9.4	2	9	-	Present study
Lake Pamuklu	40°47′	26°16′	2.50	1983	4.4	1	1	-	İlhan et al. (2005)
Bayraktar Reservoir	40°47′	30°05′	0.29	1990	4.6	3	4	-	Present study
Çayırköy Reservoir	40°48′	29°59′	0.41	1990	1	1	5	-	Present study
Karpuzlu Reservoir	40°49′	26°18′	28.68	1989	1	1	50	1:0.35*	Present study
Lake Taşkısığı	40°52′	30°23′	0.90	1998	1.2	1	32	1:0.30*	Present study
Çamlıca Creek	40°52′	26°40′	-	1988	0	1	9	-	Özuluğ et al. (2004)
Denizli Reservoir	40°53′	29°33′	1.20	1995	0.7	1	103	1:0.53*	Present study
Davuldere Reservoir	40°54′	30°02′	0.29	1994	2.5	3	45	1:0.03 *	Present study
Tahtalı Reservoir	40°54′	29°54′	1.60	1990	2.7	2	114	1:0.02 *	Present study
Çağırgan Reservoir	40°54′	29°57′	0.17	1990	0.4	1	25	-	Present study
Kınıklı Stream	40°58′	27°55′	-	1998	0	1	2	-	Özuluğ et al. (2004)
Büyükçekmece Reservoir	41°01′	28°34′	28.47	1995	0	2	487	1:0.05*	Saç (2010)
İbriktepe Dam	41°01′	26°28′	3.90	1988	1.6	1	1	-	Özuluğ et al. (2004)
Lake Akgöl	41°03′	30°34′	0.20	1998	1	1	1	-	İlhan et al. (2005)
Ömerli Reservoir	41°05′	29°25′	21.40	1998	0	1	258	1:0.12 *	Tarkan et al. (2006)
İstanbul Technical University Pond	41°06′	29°01′	0.04	1999	0	1	3	-	Özuluğ et al. (2004)
Çöpköy Pond	41°12′	26°50′	0.06	1988	0.6	1	1	-	Özuluğ et al. (2004)
Bülbüldere Pond	41°13′	26°42′	0.55	1988	7	1	2	-	Özuluğ et al. (2004)
Meriç River	41°13′	26°19′	-	1982	1	2	42	1:0.31*	Present study
Sarıcaali Pond	41°22′	27°13′	0.35	1988	1.5	1	3	-	Özuluğ et al. (2004)
Arnavut Stream	41°35′	28°08′	-	1983	0	1	4	-	İlhan et al. (2005)
Kayalı Reservoir	41°47′	27°07′	10.19	1988	14	1	1	-	Özuluğ et al. (2004)
Lake Saka	41°48′	27°59′	13.45	1983	26	1	5	-	İlhan et al. (2005)
Tunca Stream	41°49′	26°32′	-	1983	3	1	4	-	Özuluğ et al. (2004)
Lake Hamam	41°49′	27°57′	0.19	1984	14	1	153	-	Erdem et al. (1994)
Bulanık Stream	41°51′	27°58′	-	1983	0	1	7	-	İlhan et al. (2005)

* = $P < 0.05$

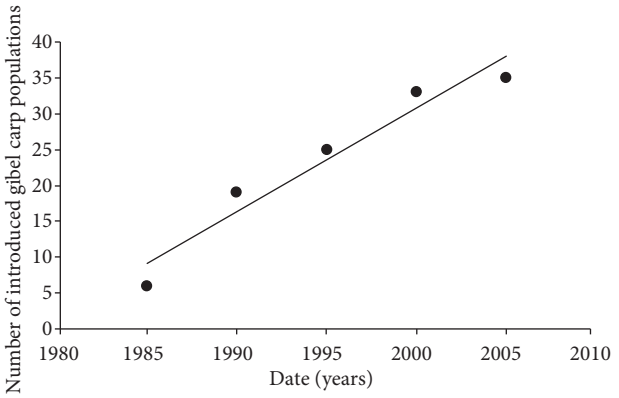

Figure 2. Cumulative number of gibel carp populations introduced to Marmara region since 1980. The data are fitted with a linear equation (y = 1.34x – 2651.1, F = 47.41, P < 0.001, r_s = 0.95).

species has established viable populations in some large, deep mesotrophic waters (i.e. Lake İznik and Ömerli Reservoir) that have relatively poor vegetation (Özuluğ et al., 2005; Gaygusuz et al., 2007). Indeed, it is a very robust species and able to survive and thrive under adverse environmental conditions in which other species rarely survive (Holčík, 1980; Muus and Dahlstrom, 1999). Therefore, this species is considered a very successful colonizer for almost all types of water systems (e.g. Vetemaa et al., 2005; Özcan, 2007). Previous introduction success in a species is considered a good indication that the species in question will have a high probability of establishing itself (e.g. Marr et al., 2010). Multiple introductions of gibel carp in the same water body after its first establishment would have facilitated its invasion success and dispersal (e.g. Keller and Taylor, 2010). This was confirmed by local authorities and fishermen for the majority of the water bodies in the present study.

Initial invasion of gibel carp in the Turkish waters may have been caused in 2 ways: they may naturally disperse through river systems from Thrace, or humans may have introduced them. The latter seems to be more likely, as fish stocking of natural lakes and rivers is very common in Turkey. Although stocking practices are generally confined to the intentional stocking of common carp with the aim of increasing fish production and recreational angling, some nonnative fish species may have been introduced this way (e.g. accidental introduction of gibel carp, goldfish, and Eastern mosquitofish, associated with the intentional stocking of common carp) (Özuluğ et al., 2005; Balık and Ustaoğlu, 2006; Tarkan et al., 2006). The accidental transfer and release of gibel carp within these translocations of native cyprinids for aquaculture characterizes the primary pathway of gibel carp introduction into its expanded range. Other secondary pathways have also been responsible for secondary spread; this species may have been introduced by humans because these water bodies have been used as recreation areas and receive many visitors throughout the year, especially in the spring and summer months. Discussions with local inhabitants indicate that humans (e.g. anglers) are probably responsible for these introductions, as they consider some nonnative fishes, mainly gibel carp, to be particularly well suited for newly created lakes. Establishment success of nonnative freshwater fish species has been predicted to be positively correlated with the number of individuals introduced and the frequency of their introduction, and this is driven by socioeconomic factors (Williamson and Fitter, 1996). Indeed, it has been reported that the distributions of nonnative fish species have been positively correlated with human population density and the proportion of developed areas (Shea and Chesson, 2002; Meador et al., 2003).

Humans are indeed the main active agents in the dispersal of gibel carp in the water bodies of the Marmara region. Expansion of these nonnative species by natural pathways (i.e. channels and rivers) is not likely, as most of the studied water bodies are closed areas and not connected to each other. This is corroborated by the fact that gibel carp cannot disperse naturally into the Anatolian part of Turkey because of salt water barriers (i.e. the İstanbul and Çanakkale straits). Our analyses showed that the occurrence of nonnative fishes was not related to distance to the nearest city center or area of the water body, suggesting that the dispersal of nonnative fishes mostly occurred through government-sponsored aquaculture. Undeniably, most of water bodies invaded by nonnative gibel carp in the present study were man-made artificial lakes, into which it is the first priority of the government to introduce fish.

Gibel carp populations in the Marmara region were dominated by females in most cases and the

proportion of males was very low (approximately 17%), suggesting the presence of gynogenetic females. Indeed, invading European freshwater populations of gibel carp seem to be predominantly gynogenetic (Peňáz et al., 1979; Peňáz and Kokeš, 1981; Pihu et al., 2003). The predominance of females to males in gibel carp has also been reported in Turkish waters in other regions (Şaşı and Balık, 2003). These variations in sex ratio may be due to either environmental conditions or to the length of time since introduction. Vetemaa et al. (2005) reported the predominance of females and gynogenetic reproduction in freshwater populations, but near-unity sex ratios in mildly saline waters. However, the gibel carp population invading the middle River Danube was initially dominated by females (i.e. gynogenetic; Černý and Sommer, 1994) and shifted to sexual reproduction within a decade of its appearance. This was not the case for the gibel carp populations in the Marmara region, given that an insignificant relationship between year of introduction and sex ratio was evident. The area of the water body was furthermore not significantly related to sex ratio variations. However, these provisional conclusions should be used with caution due to the relatively small sample. The dependency of sex variations on length of time since introduction and size of the water body requires further study, involving a larger number of water bodies and long time series datasets with information on the introduction dates of gibel carp and the catchment area of the study site.

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