Aquacult Int (2016) 24:1527–1541
DOI 10.1007/s10499-016-0029-6

The common carp *Cyprinus carpio* in Croatia (Danube and Adriatic basins): a historical review

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Received: 19 April 2016 / Accepted: 2 June 2016 / Published online: 17 June 2016

Abstract This review provides the first historical account of the ecology and biology of common carp *Cyprinus carpio* in the Danube and Adriatic basins of Croatia, and emphasises the species' economic relevance and management implications. As a semi-native species that is native to the Danube but translocated across the Adriatic Basin, carp plays an important role for aquaculture, recreational and artisanal fisheries. However, original strains have now disappeared, and because of genetic pollution in inland waters there is an increasing demand for restoring populations of the now rare and threatened wild carp, making conservation measures a priority. Translocations of carp across water bodies of the Adriatic Basin mostly for food supply did not prove successful in the long term, as the resulting ecological impacts may have been higher than the expected economic advantages. Measures for the prevention of further (uncontrolled) carp re-stocking are therefore necessary and this will require closer collaboration between scientists and environmental managers.

Keywords Inland waters · Aquaculture · Strains · Translocation · Mediterranean

Introduction

The common carp (*Cyprinus carpio*, also 'carp') is the most widely distributed freshwater fish species across the globe (Froese and Pauly 2016). In some of its non-native areas of distribution such as North America and Australasia, the carp is highly invasive (e.g.

Guest editors: Zuzana Linhartová and Jan Mráz/Carp pond aquaculture, product processing and quality.

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McCrimmon 1968; Moyle 1984; Koehn 2004), but it is also regarded as a (potential) threat in several other regions of Africa, Asia, Europe and South America (e.g. Fernández et al. 1998; Britton et al. 2007, 2010; Clavero and Villero 2014). Conversely, in most of its native areas in Eastern Europe and Asia (cf. Kirpitchnikov 1999), the wild carp (*sensu* Balon 1995) is now listed as 'vulnerable' (http://www.iucnredlist.org/details/6181/0) due to a considerable loss in genetic variability resulting from both natural and human selection pressures (e.g. Mondol et al. 2006).

In Croatia, the carp is semi-native (*sensu* Copp et al. 2009) and represents one of the main warmwater aquaculture species, a traditional food fish (at least in some parts of the country), and an important economic asset for angling and fisheries. Similar to other countries where the carp is semi-native (e.g. Turkey: Vilizzi 2012), contrasting attitude towards this species is to be expected in terms of balancing the economical advantages of its exploitation vs ecological conservation needs (i.e. in its native areas of distribution) as well as measures of management/control (i.e. in its non-native areas). In this respect, for a successful decision-making process it is paramount that literature-based, state-of-the-art reviews on the ecology and biology of this species be implemented whenever feasible. By way of example, at the national level a recent ('near-comprehensive': *sensu* Balon 1989) review of the ecology/biology of carp in Turkey (Vilizzi and Tarkan 2016; Vilizzi et al. 2013, 2014a, b, 2015a, b) has paved the way for better informed management measures and future related legislation (e.g. Gaygusuz et al. 2015).

Despite the numerous translocations across the Adriatic Basin (see *Translocations and dispersal*), data on carp biology are available only from Lake Vransko (Treer et al. 1995, 2003, 2011) and Lake Velo Blato on Pag Island (Domitrović et al. 2007). Data on length-at-age for the Lake Vransko carp population indicate a maximum (estimated) age of 11+ years and a corresponding (back-calculated) total length (TL) of 632.3 mm. Although Lake Vransko is oligotrophic, prolonged feeding seasons due to mild climate conditions favour a 'good' Fulton's condition factor (CF, based on TL) ranging between 1.40 and 1.62 (relative to a mean value of 1.64 for Croatia) and slightly negative allometric growth in the length–weight relationship (LWR) ($b = 2.86$; mean value of 2.895 for Croatia) (Treer et al. 2003, 2008, 2009, 2011). On the contrary, carp from Pag Island shows positive allometric growth in the LWR with $b = 3.0679$ but a lower value of CF ranging between 1.10 and 1.37 (both sexes). Due to the more favourable biological conditions for younger fish (up to age of 2+) in Lake Velo Blato, carp of the same age group from this lake have twice as big length increments than carp from Lake Vransko (Domitrović et al. 2007).

To date, there has been no critical review of the historical and present economic importance of carp in Croatia, nor of its translocation history and potential impacts. To fill this gap, the aim of the present study was to review available literature data of carp in the Danube and Adriatic basins of Croatia with special emphasis on the species' (1) origin and status, (2) aquaculture, (3) fisheries, (4) translocation and dispersal, as well as (5) documented and potential impacts. A critical assessment is also provided on how future research and management may be able to reconcile economic demands with habitat conservation needs.

Study area

Croatia is located at the crossroads of three major eco-regions, namely the Pannonian Plain (Hungarian lowland), the Dinarides (Dinaric Western Balkans) and the Mediterranean Sea. Due to its hydrogeological features, the country is divided into a Pannonian and a karst part that include two basins, namely the Danube and the Adriatic (Fig. 1a), with the former being dominated by the large rivers Sava, Drava and Danube plus their smaller sub-basins. The rivers of the Adriatic Basin are short and isolated, and often flow through deep canyons, where they create waterfalls and lakes (cf. lentic expansions of rivers). These rivers have a seasonal hydrological regime, with abundance of water in autumn and spring, but with some of them drying out completely in summer. The karst rivers of the Adriatic Basin can be divided into immediate river basins, with direct confluence into the Adriatic Sea, and confined basins. The River Cetina (100.5 km) is the largest of the Adriatic Basin and, due to its high hydro-energy production potential, has been heavily impacted by dams, which have led to the formation of four artificial reservoirs along its course. The Krka River (72.5 km) is characterised by the natural presence of travertine barriers and waterfalls (Mrakovčić et al. 2006) and includes four hydroelectric plants but no artificial reservoirs. The Zrmanja River (69 km) is connected via the subterranean karst to the Krka River. The Neretva River is the longest of the Adriatic Basin (225 km), although only its final 22.5 km flow through Croatia, where the river forms a wide delta subjected to high anthropogenic impact, mainly from agricultural activities (Table 1). Due to the specificity of the habitat types present, parts of the Neretva delta were recently declared a protected ichthyological and ornithological reserve (Mrakovčić et al. 2006). Finally, Croatia has several natural lakes located in the Adriatic Basin, some of which of ichthyological and economic importance including Lake Vransko (Treer et al. 2011).

Most of Croatia has a temperate rainy climate with an average monthly temperature higher than −3 °C and lower than 18 °C in the coldest month (Zaninović et al. 2008). Only the highest mountain areas (>1200 m a.s.l.) are characterised by a snow-forest climate with an average temperature lower than 3 °C in the coldest month. Inland, the warmest month of the year has an average temperature lower than 22 °C, whereas in the coastal area it is higher than 22 °C and more than 4 months in a year have a monthly average temperature higher than 10 °C (Fig. 1b). According to the Köppen–Geiger climate classification system (Peel et al. 2007), the lowland, continental part of Croatia has a Cfb climate (i.e. warm

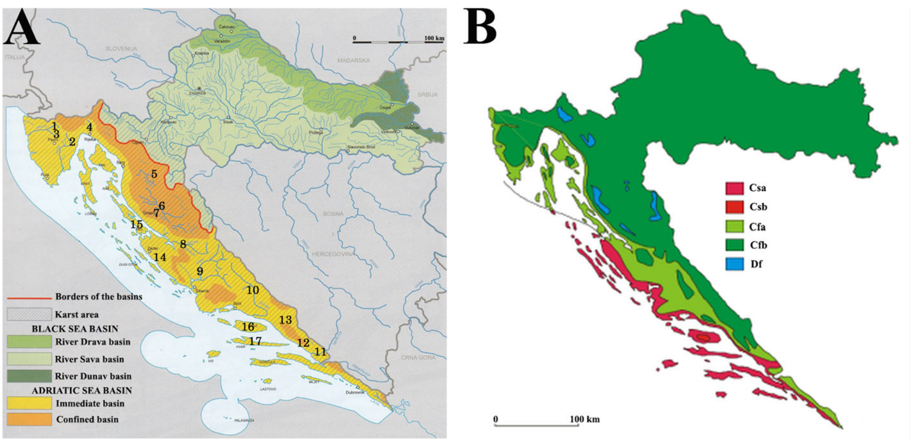

Fig. 1 **a** Hydrographic scheme of Croatia and presence of carp in the Adriatic basin (waterbody codes as in Table 1). **b** Geographical distribution of Köppen–Geiger climate types in Croatia in the 1961–1990 period. Cfa = moderately warm and humid climate with hot summers; Cfb = moderate warm and humid climate with warm summers; Csa = Mediterranean climate with hot summers; Csb = Mediterranean climate with warm summers; Df = humid boreal climate

Table 1 Natural and artificial lakes, rivers and ponds in the Adriatic basin of Croatia and corresponding carp current status according to Copp et al. (2005)

Code	Water body	Status	Reasons of translocation	Date of first translocation
Rivers				
1	Mirna	A	UN	1950s
2	Raša	N	UN	1950s
4	Rječina	N	AN	1990s
5	Gacka	N	AN	1947
6	Lika	N	AN	1937
7	Novičica	N	AN	1933
8	Zrmanja	A	AC	1950s
9	Krka	N	AN	1947
10	Cetina	N	AN	1960s
11	Neretva	N	AQ	1970s
13	Vrljika	N	AN	1950–1960s
Natural lakes				
12	Baćina	N	UN	1949
13	Prološko blato	N	UN	1949
13	Ričice	N	AN	1950–1960s
10	Mišovica	U	AN	1949
14	Vransko	N	AQ, AN	1948
9	Visovac lake	A	AN	1949
Artificial reservoirs				
3	Butoniga	N	AN	1990s
10	Peruća (on the Cetina river)	N	AN	1960s
6	Kruščica (on the Lika river)	N	AN	1940s
Ponds and wetlands				
15	Pag Island (Velo blato)	N	AN	1980s
16	Brač island	U	UN	2000s
17	Hvar island	U	PU	1990s

A absent, *N* naturalised, *U* unknown. Reasons of translocation: *UN* unknown, *AN* angling, *AC* accidental, *AQ* aquaculture, *PU* personal use; Code denotes location of the water bodies presented in Fig. 1a

temperate, fully humid, warm summer), whereas on the islands and in the coastal areas of the Middle and Southern Adriatic there is a prevalent Csa climate (i.e. warm temperate with dry and hot summer).

Origin and status

The wild carp is thought to be comprised of three subspecies: (1) European *C. c. carpio*, (2) Far Eastern *C. c. haematopterus* and (3) the disputed Southeast Asian *C. c. viridiviolaceus* (Kirpitchnikov 1999; see also Chistiakov and Voronova 2009; Vilizzi 2012). Records dating back to 6000–7000 BC indicate that carp is native to rivers draining into the European part of the Ponto–Caspian region (Tsepkin 1995) and that it was the closest to the wild ancestor of all carp breeds reared by man (Kirpitchnikov 1999; Balon 1995). The first carp stocks for aquaculture in Croatia were introduced at the turn of the nineteenth to twentieth century (Treer et al. 2000), and primarily originated from the German mirror carp (Tomljanović et al. 2011). This breed was domesticated from European subspecies (Zhou et al. 2003) and introduced worldwide (Balon 1995). Notably, carp in Croatian inland waters of the Danube Basin and its tributaries is a native species, whereas in the Adriatic Basin and its isolated karst water bodies it is non-native. This causes the species to have 'semi-native' status at the country level.

Aquaculture

Carp breeding has a long history worldwide (Kirpitchnikov 1999). In China, the species has been cultivated for more than 2500 years (Drews 1971) and in Europe since at least the Middle Ages (Hickling 1968). Carp was also the first fish species to undergo selection in Europe (Hulata 1995), resulting in a large number of locally-adapted wild and cultured populations (Komen 1990). By the nineteenth century, the European cultivated carp could be divided into Galician, Bohemian, Franconian, Lausitz and Ayschgrund races (Kirpitchnikov 1999). Research indicates that 'Yugoslav'carp probably originated from the Galician and Ayschgrund races from Germany (Mihajlović-Babuder 1955; Wunder 1955) and differed from the other races in relative body height, growth rate, sexual maturity and ability to adapt to a continental climate (Habeković 1983). In the period before WW2, carp in Croatia displayed different morphological traits depending on fish pond and these traits were mainly related to the presence of low- (Draganić, Poljana and Končanica) and high-back (Našice and Grudnjak) forms (Habeković and Turk 1981). Notably, these features confirm the twofold origin of carp in Croatia (Habeković 1983), i.e. the Končanica carp (with two rows of evenly distributed scales below the dorsal fin) as Galician and the Našice carp (mostly high-back type) as Aischgrund (Safner 1998). After WW2, translocations of carp between fish farms caused the mixing of races with a consequent loss in typical morphological traits amongst fish ponds (Habeković and Turk 1981).

In the late 1950s, selection began for important economic traits (i.e. growth rate, survival, feed conversion, resistance to adverse environmental factors and disease, later sexual maturity and quality of meat: Habeković 1983). This resulted in the well-known Našice and Poljana strains (Treer and Kolak 1994), which have been preserved from the early 1970s in the Szarvas gene bank of Hungary (Gorda et al. 1995). However, Flajšhans and Gall (1995) argued that by the 1990s the Našice strain had disappeared from its original fish farm due to uncontrolled cross-breeding. This was later confirmed by Tomljanović et al. (2013), who concluded that all well-defined carp strains in Croatia no longer exist. Nowadays, fish farmers are trying to return the Našice and Poljana strains from Sarvash into homonymous fish farms in an effort to certify their strains as genuine Croatian product with the Croatian Chamber of Economy (Božić 2009).

The first data on aquaculture activities in Croatia were recorded in 1817 with reference to specially-equipped ponds covering a total area of 162 acres in the town of Karlovac and to a pond in the town of Bjelovar (Hietzinger 1823). More detailed information about fish production dates back to the Austro-Hungarian Empire, when 'self-aquaculture' practices were developed near monasteries and noble palaces. In that time, the most important fish ponds were established in the towns of Zagorje, Trakošćan, Ivanec, Maruševac, Lukavec, Jastrebarsko and Paly in Končanica plus a pond on Ribnjak stream near Pakrac (Bojčić and Bunjevac 1982). The first real productive fish farm was established in 1897 at Božjakovina on a five-hectare area and included five experimental ponds. Carp juveniles for

Table 2 Locations and dates of establishment of the most important Croatian fish farms in the 1897–1920 period

Name of farm	Latitude	Longitude	Construction year or period
Božjakovina	45°48′53″	16°17′14″	1897
Končanica	45°39′08″	17°07′31″	1903
Našice	43°29′40″	18°05′42″	1903
Jastrebarsko	45°40′11″	15°38′40″	1904–1905
Crna Mlaka	45°36′41″	15°43′47″	1906–1918
Poljana	45°31′10″	16°56′33″	1907
Grudnjak	45°37′34″	18°02′06″	1908–1916
Razbojište, Virovitica	45°48′10″	17°21′27″	1910–1912
Pisarovina	45°34′22″	15°49′57″	1917–1919

Božjakovina farm were imported from the town of Trebon (former Czechoslovakia: Šusta 1898) for commercial purposes with the aim to stock new or existing ponds.

In the period before WW1 (1903–1917), many important Croatian cyprinid fish farms were established (Dujmušić 2000; Table 2), with the first carp stocks being primarily introduced from Germany, the Czech Republic and Hungary (Treer et al. 2000). After the end of WW2, Croatian cyprinid farming and carp production started to rise, and by the late 1960s and early 1970s Croatia experienced a peak in carp production, after which it began to decline and especially so in the 1990s (Turk 1997; Knjaz 2007). In 1968, 1980 and 1986 extremely high rainfalls caused the loss of 90 % carp production (Turk 1997) as well as the escape of feral/domesticated forms of carp together with that of other non-native fish species farmed in polyculture: bullhead *Cottus gobio*, bighead carp *Hypophthalmichthys nobilis* and silver carp *Hypophthalmichthys molitrix* (Turk 1983). After the 1990s and during the Croatian war until 1995, warmwater aquaculture production stagnated (Safner et al. 2000), but it has since increased even though it has not reached levels comparable to those in the 1970s (Kalember 2011).

In Lake Vransko, due to food shortages following WW2, carp translocations occurred between April 1948 and March 1950 with four successive stockings (Fijan 1948, 1949; Treer 1989), and more recently also in the Neretva River (I. Aničić, pers. comm.). However, carp stocking and aquaculture activities in Lake Vransko for the improvement of local fisheries were abandoned more than 20 years ago (Treer et al. 1995), and in 1999 the area became natural park (Mrakovčić 2004). Carp farming in the Croatian part of the Neretva River started with a pilot project in 2001 when fingerlings were introduced for cage farming, but upon completion of the project farming was not continued. More recently, carp has been identified as part of the diverse fish community inhabiting the littoral shallows of the Neretva and Mala Neretva estuaries (Dulčić et al. 2007).

Fisheries

Contrary to marine fish, which are sought after in the Mediterranean part of Croatia, carp is traditionally highly valued as food fish in the country's northern Pannonian region. Besides the carp farms located in this area, catch of this species by recreational and artisanal fishermen is also important. In 2012, carp represented 55.9 % of the commercial production (i.e. combined aquaculture and fisheries catches: Ostroški 2013), and recreational fishing is overall popular throughout the country. Conversely, artisanal fisheries are allowed only in the Croatian section of the Danube (along the border with Serbia) and in the lower section of the Sava River (along the border with Bosnia and Herzegovina). Disputes between recreational and artisanal fishermen arise from time to time, even though investigation of official fisheries data indicates low impacts by intensive artisanal fisheries on fish stocks (Treer et al. 2014, 2015) as well as limited change in carp catches by both groups throughout the years. As commercial fishermen are less selective, the majority of their catches comprise freshwater bream *Abramis brama*, which is the dominant species in these river sections, with an average contribution by carp to the total catch mass equal to 6.86 % in the Danube River and 1.54 % in the Sava River. Conversely, due to the higher selectivity of recreational fishing, the ratio of carp in these catches is higher at 13.37 and 14.83 %, respectively. Also, artisanal fishermen catch on average bigger carp specimens in their nets compared to anglers (Fig. 2). While there are less than 40 artisanal fishermen in both rivers with numbers remaining relatively stable from year to year, the number of anglers instead ranges in the thousands with higher variation. Although not statistically significant, the trend suggests that the higher number of recreational fishermen may result in lower catch per unit effort (CPUE, calculated as kg of carp caught by one angler annually: Fig. 3) (see also Treer et al. 2012).

In the rivers of the north-western part of Croatia (mainly, barbel and trout river zones: Huet 1959), carp is not so abundant (Habeković et al. 1990) and is generally caught in small stagnant water bodies such as gravel pits, and often in catch-and-release form. However, carp plays an important role for recreational angling tourism, even though the contribution to catches in e.g. Vransko Lake dropped from 89.1 % in 1950 to a mere 13.4 % in 2008. In the meantime, other introduced species have become dominant in the lake, including rudd *Scardinius erythrothalmus* (47.1 %), European catfish *Silurus glanis* (23.1 %) and gibel carp *Carassius gibelio* (13.8 %) (Treer et al. 2011). Finally, in several water bodies of the Adriatic region carp has been translocated for angling purposes (Table 1), but data on its catches are not available.

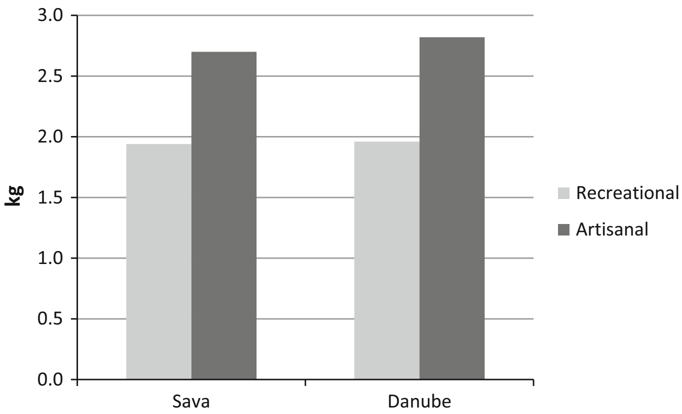

Fig. 2 Average weight (kg) of carp caught by recreational and artisanal fishermen in the Croatian sections of the Sava and Danube rivers

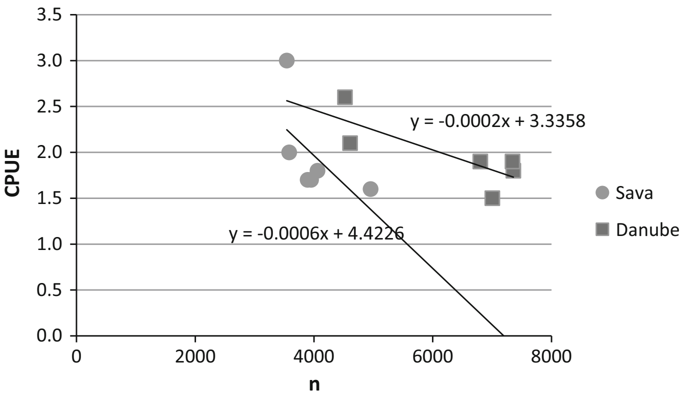

Fig. 3 Correlation between number of recreational fishermen (*n*) and carp catch per unit effort (CPUE) in the Croatian sections of the Sava ($r^2 = 0.361$, $P = 0.208$) and Danube rivers ($r^2 = 0.315$, $P = 0.147$)

Translocations and dispersal

In recent years, there has been increasing concern about genetic pollution of carp stocks. This is because the wide availability of carp from farms across the country has resulted in the stocking of large numbers of fish into Croatian open waters by recreational fishing clubs. As the wild form of carp is included in the Red List of endangered Croatian fish species (Mrakovčić et al. 2006), stocking of open waters is permitted only with carp of this form, with evidence indicating more successful survival relative to feral/domesticated forms. This has been the case of Lake Vransko, where 97.5 % of carp stocked was of farm origin (i.e. both high body depth and mirror variant), but very soon the wild form (elongated and scaled) became predominant (Habeković 1973). Carp released from farms had a standard length to maximum height ratio between 2.20 and 2.31, which in a few generations turned to 3.01 ± 0.19 (or 0.332 ± 0.021 in reverse ratio; Treer et al. 1995). Ankorion et al. (1992) considered carp with a latter index lower than 0.365 as very elongated, and a similar quick change of body form in open waters was also reported by Balon (1995). The form factor (Froese 2006) of wild common carp, was 1.41, describing the body form as midway between elongated and round (Treer et al. 2009).

In addition, a cage culture experiment was performed in Lake Vransko, again with farmed carp from North Croatia, causing several specimens to escape (Ržaničanin et al. 1984). However, in spite of that, almost all of the carp recently caught from the lake were of the wild form (Tomljanović et al. 2011). Following Copp et al. (2005), it can be anticipated that most of these fish are feral (i.e. becoming wild after domestication), although some of them could be descendants of the wild specimens introduced from the Drava River in November 1948 (equal to 2.5 % of all carp introduced in the late 1940s: Treer et al. 2003). Such difficulty to distinguish feral from originally wild carp is further discussed in Krupka et al. (1989).

The first documented translocation of carp from the Crna Mlaka fish farm into Croatian Adriatic freshwater systems occurred in the River Novičica and Lika (natural salmonid water courses) in the 1930s (Plančić 1946; Taler 1952). Translocation to the River Gacka (from the Končanica fish farm) occurred in 1947 and in the same year carp (of unknown origin) were also translocated into the River Krka (Taler 1952). Carp were translocated into

Lake Vransko for aquaculture activities at the beginning of 1948 from Grudnjak and Končanica fish farms (Fijan 1948; Plančić 1948; Treer et al. 1995). Furthermore, a small percentage of wild carp from the River Drava were stocked into Lake Vransko at the end of 1948 to boost fisheries production as a remedy for post-war food shortages (Treer et al. 1995). Sources of these introductions were confirmed by recent research using microsatellite-based genetic methods of five feral and five hatchery-based stocks of carp (Tomljanović et al. 2013). Additional translocations have occurred into many other water bodies of the Adriatic Basin as well as into Croatian islands (Table 1), though mostly without knowledge of their origin. Thus, it is presumed that carp arrival on Pag Island was the result of stocking by recreational anglers in the 1980s, whereas translocation to Hvar Island was the result of stocking into livestock pools by a local person. Due the species' exceptional adaptability (Vilizzi et al. 2015a), the process of naturalisation was successful, with additional translocations having occurred into 20 pools. Due to the small amount of freshwater on the islands, a similar scenario is thought to have occurred also on Brač Island. The main reasons for these introductions were for angling and rearing in private pools (I. Aničić, pers. comm.). Currently, carp is dispersed widely across the Adriatic Basin of Croatia (Fig. 1a), making further research on its potential impact, monitoring and control necessary.

Impacts

Before common carp translocations, Lake Vransko was transparent and inhabited by European eel *Anguilla anguilla* and freshwater blenny *Salaria fluviatilis* together with several saltwater fish species. Since carp translocation, Lake Vransko has become permanently turbid, and this has caused a decrease in freshwater blenny abundance (Mrakovčić 2004) posing a potential threat for the entire native ichthyofauna (Ćaleta et al. 2015). Similarly, translocation of carp in the Lika River caused brown trout relocation towards the river source and changes in water quality from transparent to turbid (Plančić 1948). In the River Gacka and surrounding cold lakes, carp could not adapt very well (Taler 1952). However, in the 1970s the River Gacka was artificially connected to the Lika River following hydropower plant construction and as a result this salmonid water course became populated with additional carp specimens and other (accidentally or intentionally) introduced lower rhithron fish species. All of these factors have caused an increase in turbidity, higher annual water temperatures, and have brought about changes in brown trout spawning time including a decrease in abundance (Štefanac 1986).

Finally, potential impacts of carp on endemic Adriatic roach *Rutilus aula* and Neretva roach *Rutilus basak* from the Neretva River, Illyrian chub *Squalius illyricus*, Istrian chub *Squalius janae*, Makal dace *Squalius microlepis*, Neretva chub *Squalius svallize*, Livno masnica *Squalius tenellus* and Zrmanja chub *Squalius zrmanjae* from several karst rivers in Croatia cannot be ruled out (Ćaleta et al. 2015).

Discussion

The findings of the present study indicate that in both the Danube and Adriatic basins of Croatia carp plays a crucial role both socially and economically. Besides artisanal fisheries and aquaculture, recreational fishing for carp is becoming more and more popular across the country. In recent years, large specimens of carp have become increasingly common in catch-and-release type of angling (see Arlinghaus et al. 2007), which is likely to have contributed substantially to the species' translocation and dispersal across the Adriatic Basin, especially in areas with warmer climate types (i.e. Csa). This is because anglers expect better growth in such areas similar to what recorded for carp in Lake Velo Blato (Domitrović et al. 2007), and this can ultimately represent a hazard for such sensitive karst water bodies.

Introduction of hatchery-reared carp represents a threat for the conservation of wild populations in open waters (Memiş and Kohlmann 2006). This is the case of the section of the Danube Basin within Croatia, where escapees of domesticated forms of carp from hatcheries compounded with heavy stocking by anglers may have led to extinction of wild Danubian carp populations. Evidence in support of this is available for the River Kupa (a tributary of the Danube River), whose population belongs to hatchery carp as indicated by genetic distance (Tomljanović et al. 2013). In Europe, there are relatively few self-reproducing wild carp populations and the species is listed in several areas of central Europe as threatened or endangered, with the Danubian wild form being particularly rare (Krupka et al. 1989) or probably extinct (Murakaeva et al. 2003; Copp et al. 2005).

For countries characterised by a Csa/Csb climate type such as Dalmatia (middle and southern parts of the Adriatic basin), concerns have been expressed over the impact carp on freshwater biota (Vilizzi 2012), even though Croatia is as yet not particularly concerned with this issue. This is likely a result of a combination of the carp's semi-native status in the country combined with a moderate level of invasiveness, overall positive public perception and low–moderate scientific concern, making this species 'low–medium risk' (see Vilizzi et al. 2015c for categorisation). Furthermore, following translocations of many other non-native species (mostly cyprinids) across the country, compounded with the presence of top predators such as catfish *Silurus glanis* and pike *Esox lucius* (Treer 1989), it would be difficult to isolate carp-related impacts only. Regardless, in Croatia there have been so far no attempts for remediation and/or control actions for introduced/translocated fish including carp. This is an issue of special concern given that Croatia's ichthyofauna in the Adriatic Basin is rich in endemic species (Ćaleta et al. 2015), with some of them endangered and limited to very short rivers (Sušnik et al. 2007; Snoj et al. 2008). Clearly, there is a pressing need for Croatia to align with other countries where progress has been made on the management of invasive fish (e.g. Angeler et al. 2003; Britton et al. 2011; see also Vilizzi et al. 2015a).

In the Dinaric mountain areas, which are characterised by a Cfb climate type and mostly oligotrophic ecosystems, carp invasion has not been reported. In this region, following carp introduction 22 more alien species have so far been translocated (Jelić et al. 2016). These include tench *Tinca tinca*, whose presence may have suppressed potential carp dominance (Innal and Erk'akan 2006). An example is the Gacka River, where tench was introduced together with carp at the same time and where a few years later only high abundances of tench were observed, including the presence of pike already naturalised in the system (Taler 1952). In addition, the cold water bodies of this area together with high angling pressure and habitat degradation due to human-induced changes during the last 60 years would not provide suitable conditions for carp invasion (Habeković and Pažur 1988).

In a recent risk assessment of fish translocated into the Adriatic Basin (Piria et al. 2016), carp was categorised as a 'high-risk' species, suggesting that further translocations should be abandoned and management/control measures implemented. Since in the Adriatic region limited attemption has been given to translocated/introduced species and impacts are not well known, management should be focused on the prevention of further replacement/restocking of water bodies with carp together with other high-risk species.

This is because further dispersal of carp could have many direct and indirect impacts on freshwater ecosystems, ultimately compromising traditional amenity values (e.g. sport fishing, tourism industry: Vilizzi and Tarkan 2015) as in the case of salmonid angling tourism in Croatia. Aquaculture is also another important vector of potential carp translocation, so that strategies should focus on the culture of indigenous species as suggested by De Silva et al. (2009).

In both the Danube and Adriatic regions of Croatia there is a need to improve the dialogue between scientists and environmental managers/stakeholders. In the Danube region, research should focus on wild carp and its importance for aquaculture, angling clubs and species conservation. In the Adriatic region, better conservation actions for endemic and other native species should be implemented and further uncontrolled carp restocking and dispersal should be suppressed. Also, a compromise between carp angling clubs and other beneficiaries including fishermen should be achieved.

Acknowledgments This study was supported by the University of Zagreb, Faculty of Agriculture, and by the Ministry of Agriculture, Division of Fisheries.

References

Angeler DG, Chow-Fraser P, Hanson M (2003) Biomanipulation: a useful tool for freshwater wetland mitigation? Freshw Biol 48:2203–2213

Ankorion Y, Moav R, Wohlfart GW (1992) Bidirectional mass selection for body shape in common carp. Genet Sel Evol 24:43–52

Arlinghaus R, Cooke SJ, Lyman J, Policansky D, Schwab A, Suski C, Sutton SG, Thorstad EB (2007) Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from historical, ethical, social, and biological perspectives. Rev Fish Sci 15:75–167

Balon EK (1989) The epigenetic mechanisms of bifurcation and alternative life-history styles. In: Bruton MN (ed) Alternative life-history styles of animals, perspectives in vertebrate science 6. Kluwer, Dordrecht, pp 467–501

Balon EK (1995) The common carp, *Cyprinus carpio*: its wild origin, domestication in aquaculture, and selection as colour nishikigoi. Guelph Ichthyol Rev 3:1–55

Bojčić C, Bunjevac I (1982) 100 godina ribogojstva na tlu Jugoslavije (100 years of fish farming in Yugoslavia). Ribozajednica, Zagreb, pp 154 (**in Croatian**)

Božić M (2009) Plans to add value to carp and eel-products. Eurofish Mag 2:34–35

Britton JR, Boar RR, Grey J, Foster J, Lugonzo J, Harper DM (2007) From introduction to fishery dominance: the initial impacts of the invasive carp *Cyprinus carpio* in Lake Naivasha, Kenya, 1999 to 2006. J Fish Biol 71:239–257

Britton JR, Chucherousset J, Davies GD, Godard MJ, Copp GH (2010) Non-native fishes and climate change: predicting species responses to warming temperatures in a temperate region. Freshwat Biol 55:1130–1141

Britton JR, Gozlan RE, Copp GH (2011) Managing non-native fish in the environment. Fish Fish 12:256–274

Ćaleta M, Buj I, Mrakovčić M, Mustafić P, Zanella D, Marčić Z, Duplić A, Mihinjač T, Katavić I (2015) Hrvatske endemske ribe (Croatian Endemic Fish). Croatian Environment Agency, Zagreb, 116 pp (**in Croatian**)

Chistiakov DA, Voronova NV (2009) Genetic evolution and diversity of common carp *Cyprinus carpio* L. Cent Eur J Biol 4(3):304–312

Clavero M, Villero D (2014) Historical ecology and invasion biology: long-term distribution changes of introduced freshwater species. Bioscience 64:145–153

Copp GH, Bianco PG, Bogutskaya N, Erős T, Falka I, Ferreira MT, Fox MG, Freyhof J, Gozlan RE, Grabowska J, Kováč V, Moreno-Amich R, Naseka AM, Peňáz M, Povž M, Przybylski M, Robillard M, Russell IC, Stakėnas S, Šumer S, Vila-Gispert A, Wiesner C (2005) To be, or not to be, a non-native freshwater fish? J Appl Ichthyol 21:242–262

Copp GH, Britton JR, Cucherousset J, García-Berthou E, Kirk R, Peeler EJ, Stakėnas S (2009) Voracious invader or benign feline? A review of the environmental biology of European catfish *Silurus glanis* in its native and introduced range. Fish Fish 10:252–282

De Silva SS, Nguyen TTT, Turchini GM, Amarasinghe US, Abery NW (2009) Alien species in aquaculture and biodiversity: a paradox in food production. Royal Swedish Academy of Sciences, Ambio 38(1):24–28

Domitrović Ž, Šprem N, Treer T, Piria M (2007) The growth and condition of carp in the lake Velo Blato. Book of abstracts, 42. Croatian and 2. International symposium on Agriculture, Opatija, Croatia 13–16. February, pp 176–177

Drews RA (1971) Raising fish for food in Southeast Asia. In: Borgstrom (ed) Fish as food, vol I. Academic Press, New York, pp 121–142

Dujmušić A (2000) Hrvatsko ribarstvo ispod površine (Croatian fisheries under the surface). Robus media, Zagreb, pp. 215 (**in Croatian**)

Dulčić J, Tutman P, Matić-Skoko S, Kraljević M, Jug-Dujaković J, Glavić N, Kožul V, Glamuzina B, Bartulović V, Skaramuca B (2007) A list of Y-O-Y fish species found in the littoral shallows of the Neretva and Mala Neretva estuaries (Eastern Adriatic, Croatian coast). Acta Adriat 48:89–94

Fernández OA, Murphy KJ, López Cazorla A, Sabbatini MR, Lazzari MA, Domaniewski JCJ, Irigoyen JH (1998) Interrelationships of fish and channel environmental conditions with aquatic macrophytes in an Argentine irrigation system. Hydrobiologia 380:15–25

Fijan N (1948) Prijevoz i nasađivanje šarana u Vransko jezero (Transport and stocking of common carp into the Lake Vransko). Ribar Jugosl 3:45–46 **(in Croatian)**

Fijan N (1949) Godišnjica nasađivanja šarana u Vransko jezero (anniversary of common carp stocking in the Vransko Lake). Ribar Jugosl 4:45–46

Flajšhans M, Gall GAE (1995) Genetics: chairpersons' summary. 1. Selection and hybridization. Aquaculture 129:221–222

Froese R (2006) Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. J Appl Ichthyol 22:241–253

Froese R, Pauly D (ed) (2016) FishBase. World Wide Web electronic publication. www.fishbase.org, version 01/2016

Gaygusuz Ö, Tarkan AS, Aydın H, Dorak Z, Top N, Karakuş U, Vilizzi L (2015) Stocking of common carp (*Cyprinus carpio*) into newly-established reservoirs may create new introduction pathways for non-native fish. Turkish J Fish Aquat Sci 15:833–840

Gorda S, Bakos J, Liska J, Kakuk C (1995) Live gene bank of common carp strains at the Fish Culture Research Institute, Szarvas. Aquaculture 129:199–202

Habeković D (1973) Eksterijer šarana Vranskog jezera (The morphology of common carp from Vransko Lake). Izbor naučnih i stručnih radova Instituta za slatkovodno ribarstvo SRH, Zagreb, pp 93–105 (**in Croatian**)

Habeković D (1983) Literaturni podaci o genetici, selekciji i hibridizaciji šarana (Collected data on carp genetics, selection and hibridisation). Ribarstvo Jugoslavije 38:124–127 **(in Croatian)**

Habeković D, Pažur K (1988) Pike (*Esox lucius* L.), its characteristics and importance. Ribarstvo 56:55–60 **(in Croatian with english summary)**

Habeković D, Turk M (1981) Neki podaci selekcije šarana u SRH (Some data of carp selection in SRH). Ribar Jugosl 36:99–101 **(in Croatian)**

Habeković D, Homen Z, Fašaić K (1990) Ihtiofauna dijela rijeke Save (Ichthyofauna of a part of the river Sava). Ribar Jugosl 45:8–14

Hickling CF (1968) Fish culture. Faber and Faber, London

Hietzinger von CBR (1823) Statistik der Militärgränze des österreichischen Kaiserthums. Zweiter Theil, Zweite Abtheilung

Huet M (1959) Profiles and biology of western European streams as related to fisheries management. Trans Am Fish Soc 88:155–163

Hulata G (1995) A review of genetic improvement of the common carp (*Cyprinus carpio* L.) and other cyprinids by crossbreeding, hybridization and selection. Aquaculture 129:143–155

Innal D, Erk'akan F (2006) Effects of exotic and translocated fish species in the inland waters of Turkey. Rev Fish Biol Fisheries 16:39–50

Jelić D, Špelić I, Žutinić P (2016) Introduced species community over-dominates endemic ichthyofauna of high Lika plateau (Central Croatia) over a 100 year period. Acta Zool Acad Sci Hung 62(2):191–216. doi:10.17109/AZH.62.2.191.2016

Kalember Đ (2011) Slatkovodno ribarstvo na tlu republike Hrvatske od 1945. Do 2007. Godine (Freshwater fisheries in the republic of Croatia from 1945 to 2007). Stočarstvo 65:147–164 **(in Croatian)**

Kirpitchnikov VS (1999) The origin of domesticated breeds of common carp. 5-9 In: Billard R, Reperant JPR, Ward R (eds) Genetics and breeding of common carp. Hydrobiologie et aquaculture, Institut National de la Recherche Agronomique (INRA), Paris, France, Editions Quae

Knjaz V (2007) Hrvatsko slatkovodno ribarstvo (Croatian freshwater fishery). Ribarstvo 65:111–121 **(in Croatian with English summary)**

Koehn JD (2004) Carp (*Cyprinus carpio*) as a powerful invader in Australian waterways. Freshw Biol 49:882–894

Komen J (1990) Clones of common carp, *Cyprinus carpio*. New perspectives in fish research. Doctoral thesis, Wageningen Agricultural University Wageningen, Netherlands

Krupka I, Meszaros J, Ráb P, Šlechtová V (1989) Toward the preservation of endangered fish gene pools—example of wild Danube carp (*Cyprinus carpio*). Prace Ust Rybar Hydrobiol 18:27–33

McCrimmon HR (1968) Carp in Canada. Bull Fish Res Board Can 165:93

Memiş D, Kohlmann K (2006) Genetic characterization of wild common carp (*Cyprinus carpio* L.) from Turkey. Aquaculture 258:257–262

Mihajlović-Babuder Z (1955) Ispitivanje šarana sa gledišta pravilnog izbora za daljnji uzgoj (Research on the common carp for the good race choice). Ribarstvo Jugoslavije 10:65–69 **(in Croatian)**

Mondol RK, Islam S, Alam S (2006) Characterization of different strains of common carp (*Cyprinus carpio* L.) (Cyprinidae, Cypriniformes) in Bangladesh using microsatellite DNA markers. Genet Mol Biol 29:626–633

Moyle PB (1984) America's carp. Nat Hist 9:43–51

Mrakovčić M (ed) (2004) Kategorizacija i inventarizacija florističkih i faunističkih vrijednosti Parka prirode «Vransko jezero» (Categorisation and inventarisation of floristic and faunistic values of Nature Park ''Vransko Lake''). PMF SUZ, Zagreb, 1–239 (**in Croatian**)

Mrakovčić M, Brigić A, Buj I, Ćaleta M, Mustafić P, Zanella D (2006) Crvena knjiga slatkovodnih riba Hrvatske (Red book of freshwater fish of Croatia). Ministarstvo kulture, Državni zavod za zaštitu prirode, Republika Hrvatska, 253 p (**in Croatian, with English Introduction**)

Murakaeva A, Kohlmann K, Kersten P, Kamilov B, Khabibullin D (2003) Genetic characterization of wild and domesticated common carp (*Cyprinus carpio* L.) populations from Uzbekistan. Aquaculture 218:153–166

Ostroški LJ (ed) (2013) Statistical yearbook of the Republic of Croatia. Croatian Bureau of Statistics, Zagreb

Peel MC, Finlayson BL, McMahon TA (2007) Updated world map of the Köppen–Geiger climate classification. Hydrol Earth Syst Sci Discuss 4:439–473

Piria M, Povž M, Vilizzi L, Zanella D, Simonović P, Copp GH (2016) Risk screening of non-native freshwater fishes in Croatia and Slovenia using FISK (Fish Invasiveness Screening Kit). Fish Manag Ecol 23:21–31

Plančić J (1946) Novonaseljene ribe u rijeci Lici (Introduction of new fish species in the Lika River). Ribar Jugosl 1:31 **(in Croatian)**

Plančić J (1948) Privredni značaj Vranskog jezera (Economic importance of the Vrana Lake). Ribar Jugosl 3:35–38 **(in Croatian)**

Ržaničanin B, Safner R, Treer T (1984) Rezultati prvog kaveznog uzgoja šarana (*Cyprinus carpio* L.) u Vranskom jezeru kod Biograda n/m (Results of the first cage culture of carp (*Cyprinus carpio* L.) on lake Vransko near Biograd n/m). Ribar Jugosl 39:29–31 **(in Croatian with English Summary)**

Safner R (1998) Utjecaj spola na randman četiri populacije konzumnog šarana (*Cyprinus carpio* L.) (The influence of sex on dressing percentage of four common carp (Cyprinus carpio) populations). PhD thesis, University of Zagreb, Faculty of Agriculture, Zagreb, Croatia (**in Croatian with English summary**)

Safner R, Treer T, Aničić I, Piria M (2000) Mogućnosti poslovanja malih obiteljskih ribnjaka (The possibilities of small family fish farms management). Ribarstvo 58:55–62 **(in Croatian with English summary)**

Snoj A, Bogut I, Sušnik S (2008) Evidence of genetically distinct population of Vrljika softmouth trout *Salmo obtusirostris* Heckel evolved by vicariance. J Fish Biol 72:1945–1959

Štefanac M (1986) Neka zapažanja na populaciji potočne pastrve (*Salmo trutta* m. *fario* L.) u rijeci Gackoj (Some observations on the population of brown trout (*Salmo trutta* m. *fario* L.) in the river Gacka). Ribar Jugosl, 41:102 (**in Croatian**)

Sušnik S, Weiss S, Odak T, Delling B, Treer T, Snoj A (2007) Reticulate evolution: ancient introgression of the Adriatic brown trout mtDNA in softmouth trout *Salmo obtusirostris*. Biol J Linnean Soc 90:139–152

Šusta J (1898) Fünf Jahrhunderete der Teichwirtscha zu Wittingau. Stettin. Český překlad Lhotský, O., 1995: Pět století rybničního hospodaření v Třeboni. Carpio, Třeboň, p 212

Taler Z (1952) Dva slučaja prenosa šarana i linjaka u druge vode (Two cases of carp and tench translocation). Ribar Jugosl 7:110–112 **(in Croatian)**

Tomljanović T, Piria M, Treer T, Safner R, Šprem N, Aničić I, Matulić D, Kordić V (2011) Morfološke osobine šaranskih populacija (*Cyprinus carpio* L.) u Republici Hrvatskoj (Morphological parameters of common carp (*Cyprinus carpio* L.) populations in Republic of Croatia). Ribarstvo 69:81–93 **(in Croatian with English Summary)**

Tomljanović T, Treer T, Ćubrić-Čurić V, Safner T, Šprem N, Piria M, Matulić D, Safner R, Aničić I (2013) Microsatellite-based genetic variability and differentiation of hatchery and feral common carp *Cyprinus carpio* L. (Cyprinidae, Cypriniformes) populations in Croatia. Arch Biol Sci 65:577–584

Treer T (1989) Pregled istraživanja Vranskog jezera kod Biograda na moru (Review of the Vransko lake (near Biograd n/m) research. Morsko Ribarstvo 41:135–138 **(in Croatian with English summary)**

Treer T, Kolak A (1994) The research in fish genetics in Croatia and former Yugoslavia. Ribarstvo 52:17–31

Treer T, Aničić I, Safner R (1995) The growth and condition of common carps (*Cyprinus carpio*) introduced into Croatian Vransko lake. Ribarstvo 53:63–73

Treer T, Safner R, Aničić I, Kolak A, Dražić M (2000) Morphological variation among four strains of common carp *Cyprinus carpio* in Croatia. Fol Zool 49:69–74

Treer T, Varga B, Safner R, Aničić I, Piria M, Odak T (2003) Growth of the common carp (*Cyprinus carpio*) introduced into the Mediterranean Vransko Lake. J Appl Ichthyol 19(6):383–386

Treer T, Sprem N, Torcu-Koc H, Sun Y, Piria M (2008) Length-weight relationships of freshwater fishes of Croatia. J Appl Ichthyol 24:626–628

Treer T, Piria M, Šprem N (2009) The relationship between condition and form factors of freshwater fishes of Croatia. J Appl Ichthyol 25:608–610

Treer T, Matulić D, Bogdanović G, Aničić I, Safner R, Piria M, Šprem N, Tomljanović T (2011) The condition of allochtonous fishes in the Mediterranean Vransko Lake. J Appl Ichthyol 27:965–967

Treer T, Suić J, Piria M, Šprem N, Aničić I, Safner R, Tomljanović T, Matulić D (2012) Assessment of the fish communities in large Croatian rivers based on the artisan fishermen and anglers data. Book of abstract, XIV European Congress of Ichthyology, Liege, 3–8 July 2012 (Belgium), 236

Treer T, Kubatov I, Simonović P, Piria M, Nikolić V, Škraba D (2014) Co-existing of recreational and commercial fisheries in the three neighbouring countries on the Danube–Croatia, Hungary and Serbia. Program book, 7th world recreational fishing conference, Campinas, September 01–04 2014, 47–48

Treer T, Piria M, Tomljanović T, Matulić D, Aničić I, Safner R, Šprem N, Suić J (2015) The co-existence of recreational and commercial fisheries in the Croatian section of the Sava River. Book of abstracts, EIFAAC symposium on recreational fisheries, managing freshwater recreational fisheries in an era of change, Lillehammer, Norway, 15–17 June 2015, p 54

Tsepkin EA (1995) Changes of commercial fish fauna of inland water-bodies of Eastern Europe and Northern Asia in the Quaternary period. Voprosy Ikhtiologii 35:3–17

Turk M (1983) Uzgoj mlađa šarana u polikulturi sa bijelim glavašem i amurom (Raising carpfry in polyculture with silver carp and grass carp). Ribar Jugosl 38:121–123 **(in Croatian with English summary)**

Turk M (1997) Hrvatsko slatkovodno ribarstvo u godini 1996 (Croatian freshwater fisheries in 1996). Ribarstvo 55:121–133 **(in Croatian with English summary)**

Vilizzi L (2012) The common carp, *Cyprinus carpio*, in the Mediterranean region: origin, distribution, economic benefits, impacts and management. Fish Manag Ecol 19:93–110

Vilizzi L, Tarkan AS (2015) Experimental evidence for the effects of common carp (*Cyprinus carpio* L., 1758) on freshwater ecosystems: a narrative review with management directions for Turkish Inland Waters. Limno Fish 1(3):123–149

Vilizzi L, Tarkan AS (2016) Bioaccumulation of metals in common carp from water bodies of Anatolia (Turkey): implications for fisheries and human food consumption. Environ Monit Assess 188:243

Vilizzi L, Tarkan AS, Ekmekçi FG (2013) Stock characteristics and management insights for common carp (*Cyprinus carpio*) in Anatolia: a review of weight–length relationships and condition factors. Turk J Fish Aquat Sc 13:759–775

Vilizzi L, Ekmekçi FG, Tarkan AS (2014a) Natural diet of common carp (*Cyprinus carpio* L., 1758) in Anatolia (Turkey): a review. Mediterr Mar Sci 15:216–218

Vilizzi L, Tarkan AS, Ekmekçi FG (2014b) Reproductive biology of common carp (*Cyprinus carpio* L., 1758) in Anatolia (Turkey): a review. Mediterr Mar Sci 15:218–222

Vilizzi L, Tarkan AS, Copp GH (2015a) Experimental evidence from causal criteria analysis for the effects of common carp *Cyprinus carpio* on freshwater ecosystems: a global perspective. Rev Fish Sci Aqua 23:253–290

Vilizzi L, Tarkan AS, Ekmekçi FG (2015b) Parasites of the common carp *Cyprinus carpio* L., 1758 (Teleostei: cyprinidae) from water bodies of Turkey: updated checklist and review for the 1964–2014 period. Turk J Zool 39:545–554

Vilizzi L, Ekmekçi FG, Tarkan AS, Jackson ZJ (2015c) Growth of common carp *Cyprinus carpio* in Anatolia (Turkey), with a comparison to native and invasive areas worldwide. Ecol Freshw Fish 24:165–180

Wunder W (1955) Koje se rase uzgajaju u ribnjacima Jugoslavije (Which races are cultivated in Yugoslavia). Ribarstvo Jugoslavije 10:1–3 **(in Croatian)**

Zaninović K, Gajić-Čapka M, Perčec Tadić M, Vučetić M, Milković J, Bajić A, Cindrić K, Cvitan L, Katušin Z, Kaučić D, Likso T, Lončar E, Lončar Ž, Mihajlović D, Pandžić K, Patarčić M, Srnec L, Vučetić V (2008) Klimatski atlas Hrvatske/Climate atlas of Croatia 1961–1990, 1971–2000. Meteorological and Hydrological Service, Zagreb

Zhou J, Wu Q, Zhen Y, Tong J (2003) Genetic divergence between *Cyprinus carpio carpio* and *Cyprinus carpio haematopterus* as assessed by mitochondrial DNA analysis with emphasis on origin of European carp. Genetica 119:93–97