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Review

An overview of the translocated native and non-native fish species in Croatia: pathways, impacts and management

Matija Pofuk[1], Davor Zanella[2] and Marina Piria[1,]*

[1]*University of Zagreb, Faculty of Agriculture, Department of Fisheries, Beekeeping, Game Management and Special Zoology, Svetošimunska 25, 10000 Zagreb, Croatia*

[2]*University of Zagreb, Faculty of Science, Department of Zoology, Rooseveltov trg 6, 10000 Zagreb, Croatia*

**Corresponding author*

E-mail: mpiria@agr.hr

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Editor's note:
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Abstract

Fish introductions and/or translocations, particularly in areas with high biodiversity and endemism, represent a major threat to biodiversity. Fish translocations between the Danube and the Adriatic basins in Croatia have not been well documented, and the origin, pathway or reason for translocation for many species is still not clear. A total of 33 fish species, both native and non-native, were translocated from the Danube to the Adriatic basin, while one non-native species was translocated from the Adriatic to the Danube basin. The first known translocations date back to the 18th century, when pike *Esox lucius* and tench *Tinca tinca* were translocated to Vrana Lake on Cres Island. The largest numbers of translocations were made for recreational and sport fishing activities, or unintentionally. Most translocated species have become naturalized in their new habitats. The recommendation is to reinforce control measures to prevent translocations and to implement enhanced conservation measures for native fish in their native habitat, particularly for the Adriatic region.

Key words: inland waters, aquaculture, autochthonous fish, translocation, Mediterranean

Introduction

Human activities, globalisation, and more recently climate change have seriously increased the movement potential of invasive alien species (IAS), to the point where biological invasions are considered a major threat to biodiversity (Caffrey et al. 2014). Domestication, translocations and introduction of plant and animal species, either intentional or unintentional, date back to ancient times (Diamond 2002), implemented by the Romans (Lightfoot et al. 2012) and intensified from the late 19th century to the late 20th century (Copp et al. 2005; Gozlan 2008; Rowe et al. 2008). In addition to the movement of many animal and plant species, the transfer of fish species beyond their natural range also has been practiced (Balon 1995; Knežević et al. 1978; Lenhardt et al. 2011), and is considered to be potentially one of the most ecologically damaging of human activities (Koehn 2004). Furthermore, the management of alien

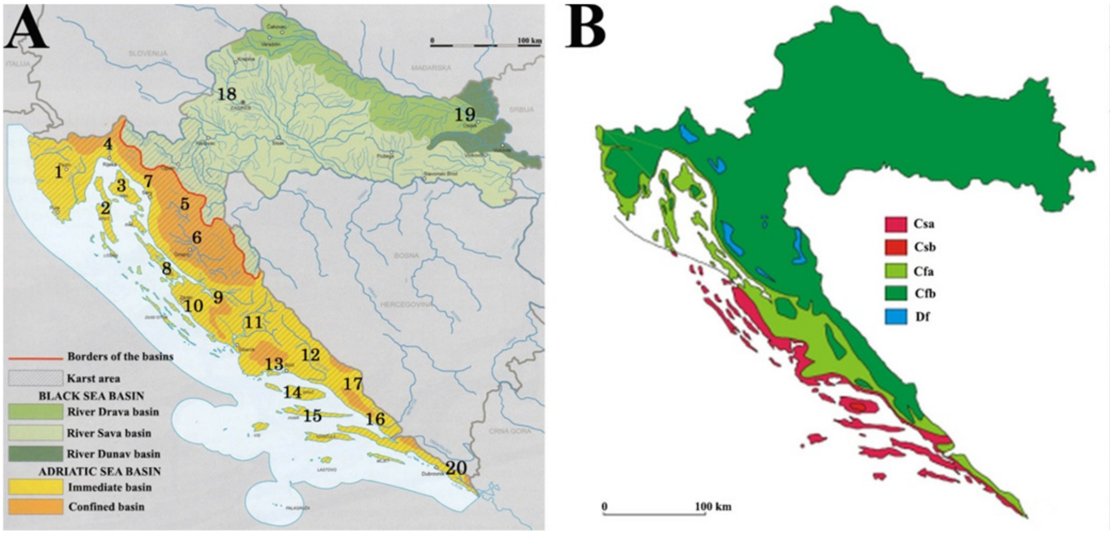

Figure 1. (**A**) Hydrographic scheme of Croatia (waterbody codes as in the Supplementary material Table S1). (**B**) Geographical distribution of Köppen-Geiger climate types in Croatia in the 1961–1990 period. Cfa = moderately warm and humid climate with hot summers; Cfb = moderate warm and humid climate with warm summers; Csa = Mediterranean climate with hot summers; Csb = Mediterranean climate with warm summers; Df = humid boreal climate.

and translocated fish species may be one of the greatest challenges that conservation biologists will face in the coming decades (Sinclair Knight Merz 2008).

Translocation represents the introduction of a species from one part of a political entity (country) where it is native to another part of the same country where it is not native (Copp et al. 2005). Such movements may have notable impacts upon the indigenous populations of native fish in the receiving ecosystem of the translocations, in addition to subsequent social and economic impacts over time (Morgan et al. 2004). In recent years, the most attention has been given to introductions (Copp et al. 2005; Gozlan 2008; Gozlan et al. 2010), while translocations are still a marginalized problem (Piria et al. 2016a, b). Over the past 150 years, freshwater fish introductions, reintroductions and translocations in the Balkan Peninsula, including Croatia, have become very frequent and were carried out by governments, aquaculture, fishery experts and anglers (Cuculić 1949; Kaitner 1932a, b; Kesterčanek 1896, 1909; Lorini 1910; Rössler 1910c; Taler 1953b). The primary reasons were food shortages, depletion of fish stocks, sport fishing, profit and accidentally (Bartulić 1903; Drnić 1896; Fijan 1949; Horvat 1900; Kaitner et al. 1929; Mršić 1935; Plančić 1920, 1946; Rössler 1918; Taler 1931a, 1951a, b; Vukić 1918). In Croatia and its neighbouring countries, fish translocations between basins have not been well documented, and thus the origin, pathway or reason for translocation remains unclear for many species. Thus, the aim of this paper was to review the available literary sources concerning the native and non-native fish species translocated between the Danube and Adriatic basins in Croatia, and to outline: (1) the history of fisheries regulation in Croatia; (2) the first recorded fish translocations and pathways; and 3) to document the possible impacts. A critical assessment is also provided on how future research and management might resolve socio-economic issues and habitat conservation needs.

Study area

Croatia is located at the crossroads of three major eco-regions: the Pannonian Plain (Hungarian lowland), the Dinarides mountain chain (Dinaric Western Balkans), and the Mediterranean Sea (Figure 1A). The Pannonian section of Croatia participates in the Danube catchment area, linking Croatia with the rest of Central Europe. The Dinaric Alps are a typical mountainous area; include the Gorski Kotar region and the karst mountainous basin, the Lika plateau. The coastal region of Croatia, stretching along most of the eastern Adriatic coast, is predominantly characterised by Mediterranean natural features (Bognar 1996) and represents the Adriatic catchment area.

The Danube catchment area is dominated by the large rivers Sava, Drava and Danube with their sub-basins (Figure 1A). The Dinaric region includes rivers that drain into either the Adriatic Sea or the Danube basin. Such a waterbody, draining from the Dinaric region to the Danube basin, is the Una River. It springs at Mt. Stražbenica (Dinaric region of Lika), flows through Bosnia-Herzegovina for most of its course, and drains into the Sava River near Jasenovac (central Croatia). Additionally, the Krbava and Matica streams of the Krbavsko Polje and Koreničko Polje karst fields (notheast Lika) have underground flows that feed the Una River (Jelić et al. 2016). The highland region Gorski Kotar has a dense river network with most of the watercourses feeding the dominant Kupa river (Sava basin, Danube catchment) as the main stream, and a partially flowing, mostly subterranean Ličanka (Fužinarka) stream, which sinks near the village Lič, re-emerges at Vinodol, and with a new name, Dubračina, drains into the Adriatic Sea in the town of Crikvenica.

The rivers of the Adriatic Basin are short and isolated, connected via underground systems and often flowing 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, though some completely dry out in summer. The karst rivers of the Adriatic Basin can be divided into immediate river basins, with direct confluence or subterranean flow into the Adriatic Sea, and confined basins (Figure 1A). The main river systems of the Lika region (i.e. Gacka and Lika) drain into the Adriatic Sea, flowing under Mt. Velebit and emerging as marine springs along the coast. The Lika River (Figure 1A, code 6) has a well-developed and dense network of permanent and intermittent tributaries (e.g. Ričica, Otešica, Jadova, Glamočica), while the Gacka River (Figure 1A, code 5) is fed by ten permanent karst springs. These are considered among the largest sinking karst rivers in Europe (Bonacci and Andrić 2008). The Cetina River (100.5 km) (Figure 1A, code 12) is the longest in the Adriatic Basin of Croatia 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) (Figure 1A, code 11) is characterised by the natural presence of travertine barriers, waterfalls and lentic expansions (lakes) (Mrakovčić et al. 2006) and includes four hydroelectric plants but no artificial reservoirs. The Zrmanja River (69 km) (Figure 1A, code 9) is connected via the subterranean karst to the Krka River. The Neretva River (Figure 1A, code 16) is the longest of the Adriatic Basin (225 km), although only its final 22.5 km flows through Croatia, where the river forms a wide delta subjected to high anthropogenic impact, mainly from agricultural activities (Supplementary material Table S1). 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 are of ichthyological and economic importance, the most prominent of which is Vransko Lake (Figure 1A, code 10) (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) 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 this is higher than 22 °C, and the monthly average temperature is higher than 10 °C more than four months a year (Figure 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 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) (Figure 1B).

Legislation

In the late 19th century, the fisheries legislation and regulation in many European countries already included aspects for aquatic stock protection, such as minimal taking size of fish and crayfish or fishing season closures (Holohač 1908). The first fisheries law in Croatia was adopted by the Parliament of Croatia and Slavonia in 1906 (Holohač 1908), though its implementation was unsuccessful due to a lack of control and due to the socioeconomic background and policy (e.g. Kaitner et al. 1923; Weber and Kaitner 1926; also see Munda 1932). In this period, the majority of present day Croatia was part of the Austro-Hungarian Empire, and aquaculture activities started to develop rapidly, particularly salmonid aquaculture (Bojčić 1997). As such, fish transplantations were not uncommon. Consequently, the first documented fish introductions and/or translocations, are those of salmonids, occurred in Croatia and the surrounding territory (Ivić 1899; Kesterčanek 1896; 1908; Leiner and Povž 1993; Leiner et al. 1995; Lorini 1910; Ocvirk 1985; Rössler 1910a, b; Taler 1951a).

After WWI, depletion of fish stocks and the onset of general poverty (Kaitner 1924, 1926a, b, c, 1929a, 1932a, b, c; Rössler 1918, 1919) led to new restocking and/or translocations (Ribić 1925; Trgovčević 1929). Legislation on freshwater fisheries was first adopted in 1937 (Mužinić 1938; Plančić 1938) and though the stocking of inland waters without prior approval was prohibited (Mužinić 1938), illegal stocking activities were still detected (Plančić 1938). Further intensive stocking activities occurred after WWII, in all countries of the former Yugoslavia, including Croatia, mostly due to food shortages. Stocking was based mainly on prized fish species (i.e. carp and tench), and was implemented by the Ministry of Fisheries and local experts (Fijan 1948, 1951; Plančić 1948; Taler 1953a). Several pieces of legislation were passed in the former Socialist Republic of Croatia in the period between the 1950s and 1973, but due inefficient control (Pažur 1968b), stocking of inland waters continued without adequate enforcement of the regulations (Pažur 1968c). In the period between 1973 and 1995, legislation and enforcement were improved and many aspects of fisheries management were regulated, e.g. prohibition of stocking with unhealthy stocking material (Kalember 2011; Tamhina 1980), though this did not include translocations and/or introductions of fish. In that period, most introductions and/or translocations occurred due to aquaculture activities supported by the state (Marina Piria, unpublished data). Since 1995, no laws or other regulations have been adopted to govern the issue of fish translocations between basins.

Translocations and dispersal

Danube basin

The only recorded translocation from the Adriatic to the Danube basin was that of eastern mosquitofish *Gambusia holbrooki* Girard, 1859 (Table S1). During the early to mid-20th century, as in the most Mediterenean countries, eastern mosquitofish was introduced in the Adriatic region for biological control (Nežić 1938; Radošević 2013). Eastern mosquitofish was translocated from the town of Trogir to Osijek and its surroundings (eastern Croatia) in the period 1940–1943, though its present status in eastern Croatia remains unknown (Landeka et al. 2015). Recently, stable populations were recorded in the surroundings of Zagreb due to the inflow of hot water from the Zagreb city heating plant, though their origins remain unknown (Landeka et al. 2015).

Adriatic confined basin – Lika plateau

The geological origin of the Lika plateau (see study area) dates back to the Upper Triassic period (Bognar 1996; Herak 1993), when this region was isolated along with the Dinaric West Balkans. This prevented the colonization of ichthyofauna from the Danube drainage system (Thienemann 1950). Accordingly, the native fish species of the Lika plateau is comprised of species that have become adapted to the sinking and sessional dry regime of the karst waterbodies over their long evolution (Jelić et al. 2016). A very attractive species for sport fishing activities in the Lika region is the brown trout *Salmo trutta* Linnaeus, 1758 (Štefanac 1986). Together with brown trout, northern pike *Esox lucius* Linnaeus, 1758 was found in the Lika region, though its time of introduction is unknown (Rössler 1932). These two species commonly do not live in sympatry in the region (Simonović et al. 2017) and interests in their origin were raised early (Jelić et al. 2016; Karaman 1926). According to Pažur (1979), northern pike and later brown trout from the Korana River were translocated to the Gacka River during the late 19th century. Brown trout was introduced to several sinking karst rivers of the Lika region at the end of 19th century (Habeković et al. 1989), with regular stocking beginning in the early 20th century (Kaitner 1932b). In addition to these records, the huchen *Hucho hucho* (Linnaeus, 1758) was reported in the Gacka River (Hirc 1903) though this may have been a misidentification with brown trout due to their high growth potential in this waterbody (Sabioncello et al. 1970; Taler 1948).

In the period between the 1930s and 1950s, the Lika region was stocked with common carp *Cyprinus carpio* (also "carp") (Piria et al. 2016b). Repeating carp stockings resulted in the accidental translocation of several mostly cyprinid fish species native to the Danube basin: chub *Squalius cephalus* (Linnaeus, 1758), crucian carp *Carassius carassius* (Linnaeus, 1758), (Plančić 1946; Taler 1951a), bleak *Alburnus alburnus* (Linnaeus, 1758), gudgeon *Gobio gobio* (Linnaeus, 1758), roach *Rutilus rutilus* (Linnaeus, 1758), rudd *Scardinius erythrophthalmus* (Linnaeus, 1758), ruffe *Gymnocephalus cernua* (Linnaeus, 1758), European perch *Perca fluviatilis* Linnaeus, 1758, weather loach *Misgurnus fossilis* (Linnaeus, 1758) and common dace *Leuciscus leuciscus* (Linnaeus, 1758), (Habeković et al. 1989; Habeković et al. 1992; Jelić et al. 2016; Table S1).

There is a longstanding history of translocations of fish species from the Danube basin to the watercourses of the Adriatic basin. This includes species native to the Danube River system, and alien species, such as pumpkinseed *Lepomis gibbosus* (Linnaeus, 1758) (Plančić 1946; Taler 1951a), which was accidentally released, or rainbow trout *Oncorhynchus mykiss* (Walbaum, 1792), (Mršić 1935), which was intentionally released in the Lika region in the 1930s. In the early 1970s, grass carp *Ctenopharygodon idella* (Valenciennes, 1844) was translocated for biological control purposes (Habeković et al. 1989), and silver carp *Hypophthalmichthys molitrix* (Valenciennes, 1844) and bighead carp

Hypophthalmichthys nobilis (Richardson, 1845) were likely stocked for the same reason (Habeković et al. 1989; Jelić et al. 2016). The 1970s represents a period of intensification of fishing activities in Croatia with translocations of attractive sport fishing species from the Danube to the Adriatic basin. Consequently, the Lika River was "enriched" with tench *Tinca tinca* (Linnaeus, 1758) (Jelić et al. 2016), European catfish *Silurus glanis* Linnaeus, 1758 (Habeković et al. 1989; Pažur 2004), and the Gacka River with grayling *Thymallus thymallus* (Linnaeus, 1758) (Pažur 2004; Table S1).

Adriatic immediate basin

Reports on the ichthyofauna of the Istrian peninsula and Dalmatia date back to the 19th and early 20th century (Canestrini 1866, 1870; Faber 1883; Gridelli 1936; Heckel and Kner 1858; Karaman 1929; Largaiolli 1904; Seeley 1886) and indicates a large number of endemic species. The first documented translocations in the Adriatic region were performed by the Republic of Venice and Austro-Hungarian Empire, mostly with carp, tench and brown trout (Aganović 1957, 1979; Ćurčić 1938, 1939a, b; Drnić 1914, 1919; Jedlička 1925; Kaitner 1929b; Kesterčanek 1908; Ribić 1901; Rössler 1910b; Telar 1925; Taler 1931b, 1951a, b, 1953b; Zaplata 1933).

Istria

In the Mirna River, grayling was recorded in the second half of the 19th century (Seeley 1886) and later during the first half of the 20th century (Taler 1944), confirming that the populations were self-sustaining. Furthermore, in the early 20th century, many Istrian waterbodies were stocked with carp (e.g. Lake Čepić, Mirna River, waterbodies of northern Istria and ponds around Rovinj), (see Leiner and Povž 1993; Leiner et al. 1995) and tench (Karaman 1929). During the 1930s, rainbow trout and northern pike were translocated into the Mirna River (Leiner and Povž 1993) and other surrounding rivers (Taler 1953b; Vuković and Ivanović 1971), mostly for sport fishing purposes (Mršić 1935; Table S1).

Dalmatia

The first documented stocking of Dalmatian rivers with species of Danubian origin occurred between 1915 and 1919, when carp and brown trout were translocated into the Neretva Delta (Jedlička 1925; Taler 1951a, b, 1953b). Rainbow trout were transferred to the Cetina and Jadro Rivers in 1930, and to the Ombla River (Mršić 1935) and later in the 1970s to the Žrnovnica River (Krešimir Pažur, pers. comm.). In the period from 1947–1949, carp and tench were released to the Krka River near Knin (Taler 1953a). Both species migrated to the few small lakes in Knin karst area, and after several years, successful spawning was observed in flooded pastures and the polje fields (Taler 1953a). Stocking practices continued in Dalmatia during late 1940s, with carp translocation to: Visovac Lake (Krka River), Mišovica Lake (Cetina Valley), Blata (Imotski Polje field), Bokanjac (near Zadar), the new pond in Raša (Basioli 1958; Fijan 1951; Plančić 1950) and Prološko Blato (Vrljika River catchment) (Debeljak et al. 1990). In 1950, carp was released into the Neretva River and its backwaters, canal and marshland areas along the Norin River, backwaters of the Cetina River, and the Kuti, Modro Oko (around Komin) and Baćina Lakes (near Ploče) (Fijan 1951). Grayling was stocked in the upper Neretva River and Trebišnjica River during 1957–1959 (Vuković and Kosorić 1978) and the upper Cetina River and Ruda River in 1974 (Habeković et al. 1975). In Croatia, arctic charr *Salvelinus alpinus* (Linnaeus, 1758) was introduced from Bohinj Lake to Kozjak Lake (one of the Plitvice Lakes) in 1963 (Pažur 1970). Later, anglers released arctic charr in several inland waters, including the Ruda River in the 1980s (Josip Budinski, pers. comm.), or specimens escaped from farms, though the distribution of this species has not yet been revised (D. Jelić, pers. comm.). It is not clear when the introduction of brook trout *Salvelinus fontinalis* (Mitchill, 1814) occurred in Croatia, but this species is farmed (Vardić et al. 2007) and is found in the inland waters of the Danube River catchment (Jelić et al. 2012) as well as in the lower Neretva River basin (Šanda et al. 2009). The source of the stocked material from the Neretva River remains unknown, and translocation from Croatian fish farms cannot be excluded.

Recent records indicated the presence of common bream *Abramis brama* (Linnaeus, 1758) in the Neretva River basin, likely transferred by anglers (Bartulović et al. 2010). Top predators, pikeperch and northern pike, occur in the Neretva and Cetina River basins, and were likely translocated in the period between 1985–1991 (Pavličević et al. 2015; Šanda et al. 2009; Škrijelj et al. 2011; Table S1).

Though the first record of stocking Vransko Lake (Biograd) with carp dates to 1948 (Fijan 1948, 1949; Piria et al. 2016b), there are indications of a biological study between 1909 and 1914 on alien marine fish species (Kesterčanek 1909; Rössler 1910b) that refers to the existence of carp ponds there between 1911 and 1917 (Croatian State Archives 2016). A total of 12 non-native fish species was translocated into Vransko Lake (Piria et al. 2016b), all of which have become naturalized (Mrakovčić 2004; Table S1).

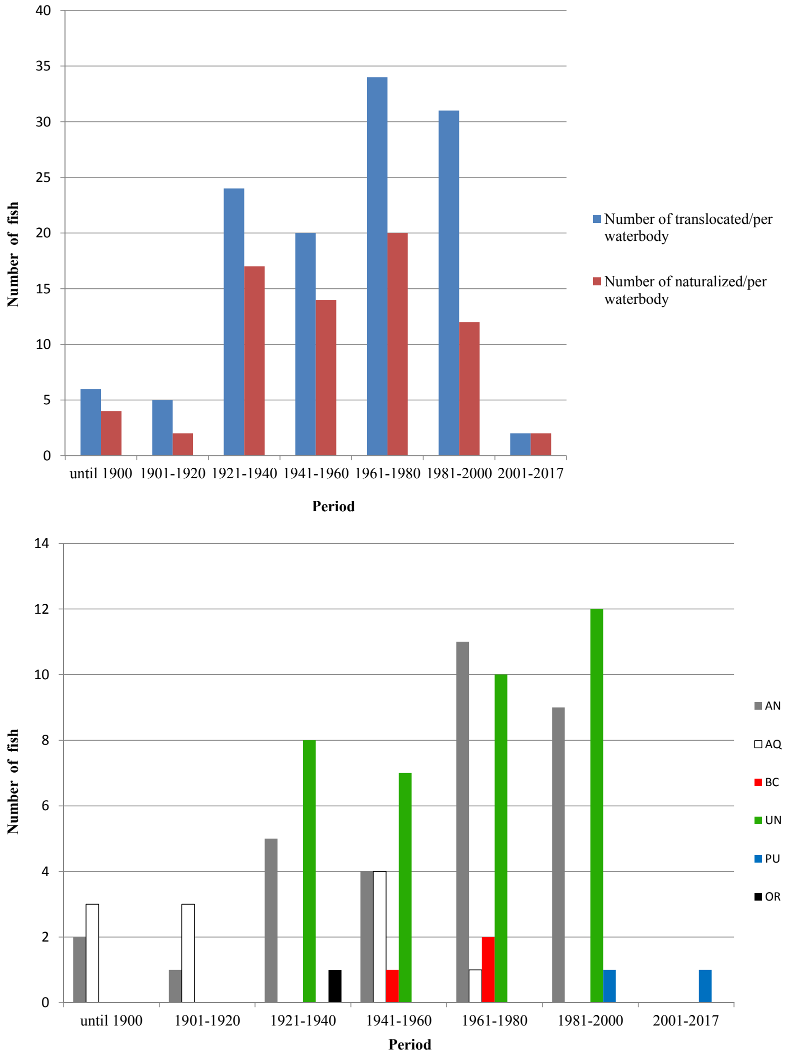

Figure 2. Dynamics of fish translocations from the Danube Basin to the Adriatic Basin (A) Number (n) of translocations and number of naturalized fish species per waterbody (B) Number (n) of fish translocated by pathway of introduction (AN, angling; AQ, aquaculture, BC, biological control; UN, unintentional; PU, personal use; OR, ornamental)

The earliest translocation on the islands of the Adriatic region in Croatia were recorded during the 18th century, around 1750s, when tench and pike were stocked in Vrana Lake on Cres Island (Bašić 2006; Fortis 1778). Carp (Lorini 1910) and an unknown salmonid (*Salmo* spp.) (Ocvirk 1985) were also recorded in the same lake. In the early 20th century, tench and pike were recorded in Ponikva Lake on Krk Island (Karaman 1929). On other islands, Pag, Brač and Hvar, recent stocking with carp has been observed (Piria et al. 2016b; Table S1).

Pathways

Data collected since the late 19th century have shown that an increased number of translocations occurred between 1920 and 2000. Of these, 38–70% of species have since become naturalized in their new habitats (Figure 2A). Two main pathways of translocation were determined, i.e. (1) intentional (recreational and sport fishing, aquaculture, ornamental trade, biological control), and (2) unintentional (accidental escape of species following the intentional translocation). The majority of species were translocated for sport and recreational fishing purposes, while improper handling has caused the majority of accidental transfers of fish species (Figure 2B). This reveals that the motives for translocations differ from those for fish introductions. Introductions have primarily been focused on species applicable to aquaculture, while the introductions for sport and recreational fisheries have been considerably less important (Uzunova and Zlatanova 2007).

Impacts

Lika region

Since the first translocation of typical lower rhithron fish species in the waterbodies of the Lika basin, there has been a gradual decline of species presumed to be native to the area (Kaitner 1931, 1932a; Rössler 1932; Trgovčević 1908) (e.g. European eel *Anguilla anguilla* (Linnaeus, 1758) (Plančić et al. 1953). During the 1970s, the Gacka and Lika Rivers were artificially connected in hydropower plant construction, establishing a new introduction pathway (Piria et al. 2016b), and consequently new fish species were recorded in tributaries that were not the natural habitat (e.g. European catfish in the Gacka basin) (Krešimir Pažur, pers. comm.). The resulting increase in water temperatures altered the ecological conditions in the Gacka River, including altering the flow regime and increasing turbidity, thus impacting the spawning of the native brown trout and opening new niches for invaders (Plančić 1946; Štefanac 1986). Translocation of high risk (*sensu* Piria et al. 2016a) non-native fish species into the Lika region significantly changed the water quality and consequently the fish assemblage structure (Habeković et al. 1989, 1992; Ocvirk 1984; Pažur 1968a; Plančić et al. 1953; Taler 1951a). Recent research suggests declining abundance of the endemic fish fauna, with a share of populations retreating and taking refuge in the upper parts of small tributaries and underground cave systems (Jelić et al. 2016).

Adriatic region

Decades of stocking with non-native fish species, dam construction and water abstraction for agricultural purposes may have inflicted serious impacts on the endemic ichthyofauna of Dalmatian rivers (Ćaleta et al. 2015), as these factors are considered to be the main threats to Mediterranean fish biodiversity (Ribeiro and Leunda 2012). These rivers were formerly rich in endemic salmonid species (Heckel and Kner 1858; Karaman 1926, 1932; Rössler 1931; Taler 1953b; Vuković and Ivanović 1971), though river regulation has resulted in declining numbers (Habeković et al. 1975, 1980, 1982, 1985, 1988). Furthermore, the high risks of genetic pollution, dietary overlap and competition for microhabitats between native and non-native salmonids have been reported in Croatia (Snoj et al. 2007) and elsewhere in the Mediterranean basin (Crivelli 1995). The introduction of top predators (e.g. pike-pearch) into the Mediterranean basin could cause a decline and extermination of endemic fish species (Crivelli 1995; Ribeiro and Leunda 2012), while European catfish may increase predation pressures on native fish species in natural waterbodies (Ribeiro and Leunda 2012). Recent field observations in the Cetina basin by anglers indicated a decline of the endemic Illyrian chub *Squalius illyricus* Heckel and Kner, 1858 and minnow-nase *Chondrostoma phoxinus* Heckel, 1843 due to pike predation (J. Budinski, pers. comm.). Certain species can have a negative effect on the native fish assemblage structure, and non-native zooplanktivorous, benthivorous and herbivorous fishes could reshape environmental features, food web composition and function of the recipient aquatic ecosystem through bottom-up and top-down trophic cycles (Dibble and Kovalenko 2009; Ribeiro and Leunda 2012).

Discussion

The findings of this study indicate that sport and recreational fishing has played a very important role for translocations of non-native fish species in the Danube and Adriatic basins of Croatia, both socially and economically. In the legislation, no term for translocation has been defined, i.e. as the movement of fish species from one water body where it is native to another in the same country where it is not, as opposed to introductions, which involve the introduction of alien species from outside the national borders. Over the past 20 years, expert groups and new legislation for the improvement and development of management plans for sport fishing association in Croatia have been established, though the issue of translocation remains unresolved. Still, the introduction/translocation from/to different basins is possible, resulting in "legal" translocations. There have been no attempts to date to remediate and/or control actions for introduced (Piria et al. 2016b) or translocated fish species.

Though just one fish species has been transferred from the Adriatic to the Danube Basin (Table S1), this does not exclude similar attempts over time. Many fish species from the continental climate could successfully be adapted to the Mediterranean mild climate and even could have better growth conditions than in the native habitat (Treer et al. 2011). In the Csa/Csb climate type, including Mediterranean area such as Dalmatia, concerns have been expressed over the impacts of several fish species native to the Danube region, such as carp, crucian carp or European catfish (Vilizzi 2012; Almeida et al. 2013) on the native freshwater biota. In Croatia, concerns regarding the translocation of brown trout and its effect on native endemic salmonids have been confirmed (Snoj et al. 2007). The Istrian peninsula and northern Islands (Krk, Cres and Pag Island) belong to the Cfa/Cfb climate type, thus for fish species originating from the Danube Basin, the climate is suitable. Concerns over impacts for this region were expressed in terms of threats of introductions/translocations on endemic fish species, e.g the introduction of gudgeon could endanger the endemic Italian gudgeon *Romanogobio benacensis* (Pollini, 1816) due to possible interbreeding (Ćaleta et al. 2015). However, there is no evidence or research to confirm these concerns. In the Dinaric mountain area, characterised by a Cfb climate type and mostly oligotrophic ecosystems, invasion of translocated Danubian species has not been reported due to the unsuitable environmental conditions (Piria et al. 2016b; Jelić et al. 2016).

In a recent risk assessment of fish native to the Danube basin and translocated into the Adriatic Basin (Piria et al. 2016a), European catfish was categorised as a "very high risk" species, and pike perch, carp, common bream, rudd and pike as "high-risk" species, suggesting that further translocations should be abandoned and management/control measures implemented.

The recommendation is that the issue of translocation should be addressed in the Croatian legislation, to reinforce control measures to prevent translocations, to implement enhanced conservation measures for native fish in the native habitat, and to suppress further uncontrolled non-native species restocking and dispersal, particularly for the Adriatic region.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Species and common names of the freshwater fishes (native and non-native) translocated in Croatia.

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