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Alien freshwater fish species in the Balkans—Vectors and pathways of introduction

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Abstract
Fish introductions, particularly in areas of high biological diversity and endemism, represent a major threat for biodiversity. In the Balkan Peninsula, 60 fish species have been introduced to date, of which 36 have become naturalized in inland waters. Since the Balkans are one of the world's 35 biodiversity hot spots, this large presence of alien fish species poses a serious threat for the stability of freshwater ecosystems and the survival of the native ichthyofauna and of aquatic biodiversity in general. The motivation for the introductions, and the historical timeline, varies among the Balkan states. Despite recent attempts to implement and align legislation aimed at preventing the introduction of potentially invasive species, and the implementation of rigorous controls of introductions and increased protection of open waters, the majority of

current introductions remain intentional, primarily via aquaculture. This review article provides a historical overview of freshwater fish introductions, the motivation behind them and the current distribution of alien freshwater fishes in the Balkans. The ecological implications and future perspectives concerning alien fish species in the region are also discussed.

KEYWORDS

Balkan Peninsula, distribution, inland waters, introductions history, invasives, non-native fish

1 | INTRODUCTION

Human-induced biological introductions represent a major threat to global biodiversity, by reducing species diversity and leading to biotic homogenization at large spatial scales (McKinney & Lockwood, 1999; Toussaint, Beauchard, Oberdorff, Brosse, & Villéger, 2016; Villéger, Blanchet, Beauchard, Oberdorff, & Brosse, 2015). In the previous decades, the number of introduced species worldwide has increased exponentially (Hulme, 2009; Vilà et al., 2010) and alien species' invasions are now widely considered to be one of the main threats to biodiversity and the second leading cause of animal extinctions (see MEA, 2005; Clavero & García-Berthou, 2005). Freshwater fish introductions have increased substantially during recent decades, mainly due to the negative socio-economic, evolutionary and ecological impacts of globalization on native freshwater biodiversity (Cucherousset & Olden, 2011; Gozlan, Britton, Cowx, & Copp, 2010; Hulme, 2009; Vitule, Freire, & Simberloff, 2009). More specifically, the introduction of alien species together with anthropogenic habitat loss and degradation, hydrological alteration and pollution often act synergistically towards the reduction or extinction of native freshwater fish species (Arthington, Milton, & McKay, 1983; Dudgeon et al., 2006; Joy, 2014; Kennard, Arthington, Pusey, & Harch, 2005; Olden et al., 2010). Invasive species are often superior competitors in relation to the evolutionary isolated native species populations (Mills, Rader, & Belk, 2004; Townsend, 1996), and they have broader environmental tolerances, being thus able to thrive in degraded habitats (Courtenay & Meffe, 1989; Kennard et al., 2005). Their negative impacts on native species include predation, trophic competition, behavioural interference, hybridization, spread of novel parasites and diseases, alteration of food webs and modification of biochemical cycles (Arthington & Lloyd, 1989; Mills et al., 2004; Keller & Brown, 2008; Kalogianni, Giakoumi, Andriopoulou, & Chatzinikolaou, 2014; for reviews, see Leunda, 2010; Cucherousset & Olden, 2011). However, the invasion process contains a series of stages, from introduction, survival and reproduction to dispersal, with species having to overcome barriers to reach the next step, with differing invasion success (Blackburn et al., 2011). Several attempts have been made to classify alien species according to the magnitude of their environmental impacts, based on the mechanism of impact through which they exert their effect, that is predation, competition, hybridization, disease transmission (see Blackburn et al., 2014). The obvious aim remains a standardized method of impact assessment that would be applicable at a wide range of spatial scales, from global to regional and national. The effects of alien species can range from minimal to massive, and the various stages of the invasion process require different management interventions, with special emphasis on the halting of their secondary spread, following the establishment of isolated populations (see Blackburn et al., 2011; Vander Zanden & Olden, 2008). However, under current climate change scenarios, invasive alien species are expected to accentuate climatic stress effects by reducing the number of native species and/or their functional types within the ecosystem and by increasing ecosystem susceptibility to climatic perturbation (Masters & Norgrove, 2010).

In Europe, lists of alien species have been compiled for several countries [e.g. Spain (Elvira & Almodóvar, 2001), Germany (Gollasch & Nehring, 2006), Italy (Gherardi et al., 2008)], and an inventory of freshwater alien species present in Europe has been compiled by the European Alien Species Information Network (European Alien Species Information Network, EASIN; Katsanevakis et al., 2012); based on this inventory, a recent study provided the first Europe-wide assessment of the major pathways and gateways of first introductions for freshwater alien species in Europe (excluding the Balkans, Nunes, Tricarico, Panov, Cardoso, & Katsanevakis, 2015). Detailed analyses, however, of the invasion history of a single taxonomic group such as freshwater fishes in a specific region of Europe, such as the Balkans, may provide useful insights into patterns and drivers of biological invasions, contributing to the development of local strategies for the management of alien species (Hulme, 2009). Hence, such analyses could provide information on key recipient areas of introduction for the purposes of surveillance and prevention, in line with the requirements of the new European Regulation on Invasive Alien Species (EU 2014), that obliges EU Member States to conduct a comprehensive analysis of the pathways of introduction of IAS in their territory, identifying the pathways that require priority action.

This study focuses on the alien fish species of the Balkan Peninsula, one of the world's biodiversity hot spots (Mittermeier, Turner, Larsen, Brooks, & Gascon, 2011) that possess the highest proportion of range restricted endemic fish species in Europe (Bănărescu, 2004; Barbieri et al., 2015; Kottelat & Freyhof, 2007; Simonović et al., 2013). Recent surveys from several Balkan countries, however, have revealed that 15%–23% of their fish fauna is alien (Barbieri et al., 2015; Piria, Tomljanović et al., 2016; Piria, Povž et al., 2016; Simonović et al., 2013), with certain catchments, such as the Danube River and

Pamvotis Lake (Greece), having an ichthyofauna comprised of more than 50% and 80% of alien fishes, respectively (Leonardos, Kagalou, Tsoumani, & Economidis, 2008; Simonović et al., 2013). Furthermore, owing to the high level of endemism and the great conservational value of the Balkan freshwater fish species, introductions can have severe negative and irreversible impacts on the ichthyodiversity of the Peninsula (Barbieri et al., 2015; Ćaleta et al., 2015; Karapetkova & Zhivkov, 1995; Mrdak, Nikolić, Tošić, & Simonović, 2012; Povž, Gregori, & Gregori, 2015; Snoj, Razpet, Tomljanović, Treer, & Sušnik, 2007; Sušnik et al., 2007). Although there is national legislation in place that regulates fish and other alien species introductions in the Balkans (Piria et al., 2017), and elsewhere in Europe (Copp et al., 2005), this legislation is rarely enforced by national environmental agencies and are practically ineffective. Furthermore, in most Balkans countries, measures to effectively control the introductions or translocations of alien fish species are still lacking. In addition, within the framework of the recent European IAS regulation, several issues related to invasive species control which are by definition cross-border cannot be addressed without a collaboration between the various countries, especially since EU Member States along the EU's borders are potentially at greater risk of new bioinvasions from their non-EU neighbours (EC 2008), since non-EU bordering countries are not obliged to enforce EU laws concerning IAS. Thus, a common framework guiding the implementation of IAS legislation between EU and neighbouring non-EU countries is urgently required (Piria et al., 2017), as well as an alignment of the legal frameworks among the Balkan states. The large number of transboundary rivers and lakes in the Balkans, acting as corridors of dispersal beyond state boundaries, makes this common framework an even more urgent priority. Transboundary agreements, such as the recent one between Greece and Bulgaria for the Nestos River, or the agreement between FYR Macedonia, Greece and Albania for the Prespa Lakes on coordinated management and planning, are positive initiatives towards that goal.

Given the high rate of alien fish species introductions in the Balkans and the threat they represent to the local endemic fish fauna, the identification of the vectors and pathways of their introduction, their current distribution and the ecological implications of their introduction, especially in view of climate change projections, becomes of paramount importance for designing and implementing appropriate control and mitigating actions. However, there are no studies that have followed the invasion of any of the aliens in the Balkan area from their very beginning, and consequently, the initial pathway and subsequent dispersion of many introduced species remain unknown. Similar studies on the introduction (establishment/dispersal) of alien species have been conducted in the Iberian Peninsula. However, the introduction phase remains the least researched and the most underrepresented in the scientific literature, in contrast to other phases of biological invasions that have received wider attention, such as the establishment success (Clavero & García-Berthou, 2005; García-Berthou, 2007). This study attempts to fill this gap in the knowledge about alien species in the Balkans by providing the first comprehensive review of alien species introductions, aiming to advance the knowledge of the history of introductions, current distribution, and present status of alien fish species and their documented impact on native species, based on a thorough review of the scientific and grey literature. Future prospects concerning alien fish dispersal in the Balkans, especially under current climate change scenarios, are also discussed.

2 | STUDY AREA

This review compiled the list of introduced species by collecting all the available information, including peer-reviewed articles, conference articles, grey literature, theses and technical reports. Unpublished survey data from field surveys were also applied in some cases, when the available material was collected by the authors personally in field sampling campaigns. Attention was given to ascertain the validity of each particular record. Hence, the inclusion of a species required at least one reliable source, or after reference cross-checking or to receive confirmation of the authors during field surveys. Translocated species (see Copp et al., 2005 for definition) were excluded from this list. Introduced species were grouped into three categories based on their current status: acclimatized, naturalized or unknown, based on the available information and following the definitions provided by Copp et al. (2005). Additionally, they were categorized using their "status of invasion" according to Blackburn et al. (2011). Fish systematic taxonomy was based on Kottelat & Freyhof, 2007 and Froese & Pauly, 2015. The year or decade of the first discovery of an introduced species was based either on the date of first occurrence or the date of first publication. In the current study, species distributed in all major basins and water bodies of a country (rivers, lakes) are considered widespread, species with a moderate distribution are those found in a single basin of one country, while species with a restricted distribution are present in only closed water bodies (alpine or artificial lakes, reservoirs and isolated small river basins). Unknown distribution includes species found/caught only once, sporadically, or those introduced in the past, but their current status remains unknown.

2.1 | The geography and climate of the Balkans

The study area encompassed the countries of south-eastern Europe that have historically been identified as Balkan countries, within a political and cultural framework. It is roughly delineated to the north by the Danube–Sava–Soča border, excluding a small part of south-eastern Romania. The Balkan Peninsula is bordered by the Adriatic and Ionian Seas to the west, the Mediterranean Sea to the south and the Aegean, Marmara and Black Seas to the east.

The high fish biodiversity is a result of the region's geological and palaeoclimatic history and the geophysical variety of its inland water bodies (Griffiths, Krystufek, & Reed, 2004; Skoulikidis, Economou, Gritzalis, & Zogaris, 2009). The major biogeographical barrier in the Balkans is the Dinarides–Hellenides mountain chain that separates the western and eastern faunas, with the early isolation of the Western Balkans in the Miocene leading to a rich endemic fauna (Bianco, 1986; Ćaleta et al., 2015; Gasc et al., 1997; Skoulikidis et al., 2009). In contrast, the Eastern Balkans have a lower degree of endemicity, but a higher richness of aquatic biota, and are influenced by adjacent biogeographical regions, such as the Black Sea and Western Anatolian regions.

The climatic differences between the various parts of the Balkans further contribute to these biogeographical differences. Climate is generally characterized by a distinct bimodal seasonality and a strong north–south (N–S) gradient, with increasing temperature and decreasing precipitation towards the south–south-east (S–SE) (Skoulikidis et al., 2009). Furthermore, the Eastern Balkans are characterized by much lower precipitation than the Western Balkans. According to Peel, Finlayson, and McMahon (2007), with subsequent corrections by Koutsoyiannis et al. (2008), the modified Köppen-Geiger climate type map of the Balkans shows there are four main climate types in the region (Figure 1a). The dominant climate type by land area is temperate (C, 61.3%), followed by cold (D, 31.1%), polar (E, 5.6%) and arid (B, 2.1%). In contrast, Europe as a whole is dominated by the cold climate type (D, 44.4%), followed by arid (B, 36.3%, Peel et al., 2007). Overall, there are 13 subtypes within the Balkan Peninsula, the majority of which belong to the temperate/mesothermal climates (group C, Figure 1a) with the two dominant temperate types, Csa and Cfa, encompassing more that 50% of the Balkans. More specifically, in the southern Balkan Peninsula (which encompasses most of Albania, Greece and the European part of Turkey (Turkey -Thrace), and part of the Former Yugoslav Republic of Macedonia (FYR Macedonia), the dominant climatic subtype is the hot-summer Mediterranean climate (Csa, 27.7% of the total). The next subtype, mostly in the central Balkans (parts of Bulgaria, Montenegro and Serbia, to north-western Croatia and a small part of Bosnia–Herzegovina), is the humid temperate hot-summer climate type (Cfa, 25.2%). Conversely, major parts of the northern and central eastern Balkans (Bosnia–Herzegovina, eastern Croatia, Slovenia, and areas within Bulgaria, FYR Macedonia, northern Greece and Serbia) are covered by continental/microthermal climates, with the continental warm-summer climate Dfb (20.9%) being dominant. Similar to most of Europe, some climate types in the Balkans extend further south than expected (Peel et al., 2007); for example, in the area of Mt. Triglav (46.38 N, 13.88 E) in Slovenia and Musala (42.18 N, 23.58 E) in Bulgaria, there are regions of the tundra ET climate type, accounting for a total of 5.4%.

2.2 | The river network and the lentic ecosystems of the Balkans

2.2.1 | The inland waters of the Balkan Peninsula

The Balkan Peninsula is characterized by extreme hydrographic fragmentation, with hundreds of autonomous river basins, numerous natural lakes and artificial large and small reservoirs, falling within four major catchment basins: Adriatic Sea, Ionian Sea, Aegean Sea and Black Sea (Figure 1b). The major divide separating the Aegean Sea basin from the remaining three main drainage areas is the peak Drmanska Glava (elevation 926 m) in Kosovo. Abell et al. (2008) proposed the division of the Balkans into seven ecoregions based on their freshwater fish fauna: Gulf of Venice, Dalmatia, south-east Adriatic (Adriatic Sea basin), Ionian drainages (Ionian Sea basin), Thrace, Vardar, Aegean drainages (Aegean Sea basin) and Upper Danube and Dniester–Lower Danube (Black Sea). The Thrace ecoregion shows some overlap between the Aegean Sea Basin and the Black Sea Basin (Table 1).

The Adriatic Sea basin is separated from the Black Sea basin to the east by the Dinaric Mountain Range. According to Abell et al. (2008), it includes three ecoregions: Gulf of Venice, Dalmatia and south-east Adriatic ecoregions. The Gulf of Venice ecoregion, extends into the Balkan Peninsula from the west, is bounded by the Julian Alps in the east and by the Dinaric Alps to the south. In the Balkan part of this ecoregion, the most important river is the Isonzo/Soča River (Italy/Slovenia), which is characterized by a pluvial regime. The Dalmatia ecoregion is characterized by short and isolated river catchments and a karst landscape, with springing and sinking rivers of variable flow regimes with a tendency to dry out, and the common occurrence of connected aboveground and underground flows. The largest river is the Neretva River (BiH/Croatia), which forms a wide delta at its mouth. Other important rivers include the Zrmanja, Krka and Cetina rivers (Croatia) and Trebižat and Trebišnjica (BiH). Due to the permeable karst landscape, lakes are not common. Important lakes include two lakes both called Vransko Lake (Cres Island and Biograd), Baćina Lakes (Croatia) and Buško Lake, Blidinje Lake and Boračko Lake (BiH). Bosnia–Herzegovina has more than 20 natural lakes, including high mountain lakes, that is Idovačko Lake (1,830 m). The south-east Adriatic ecoregion is bounded by the North Albanian Alps, the Eastern Highlands and Pindus Mountains. It includes all of Albania and most of Montenegro and a small portion of the territory of Serbia, Kosovo, FYR Macedonia and northern Greece. The ecoregion is mountainous, dropping to alluvial and coastal terrain as it approaches the Adriatic Sea. The most important catchment is the Drin River (Albania) and its tributary network: White Drim and Plavska (Serbia/Kosovo) and Black Drin (Albania) (Popovska & Bonacci, 2007). Other important river systems are the Morača River and its tributary Zeta (Montenegro) in the north and the Aoos/Vjosë River (Greece/Albania) in the south. The transboundary Bojana/Büna River (Montenegro/Albania) connects Skadar Lake to the Adriatic Sea, where it forms a wide delta. The ecoregion contains a number of transboundary tectonic lakes: Skadar/Shkodra (Montenegro/Albania), Ohrid (Albania/FYR Macedonia) and Prespa Lakes (Albania/FYR Macedonia/Greece).

The Ionian Sea Basin is considered a single ecoregion by Abell et al. (2008), the Ionian drainage ecoregion, bounded to the east by the Pindus Range. Important rivers are the Kalamas, Acheron, Louros, Arachthos and Acheloos in northern Greece that flow into the Ionian Sea and lakes Pamvotis and Trichonis, the latter being the largest in Greece. On the Peloponnese Peninsula, important rivers are the Alfeiós and Evrotas.

FIGURE 1 Study area, (a) Koppen Geiger climate classification system in Balkans; (b) the freshwater rivers and lakes network system in the Balkan Peninsula sensu Abell et al. (2008). with boundaries of the main drainage basins; codes from 1 to 113 are presented in Table 1. [Colour figure can be viewed at wileyonlinelibrary.com]

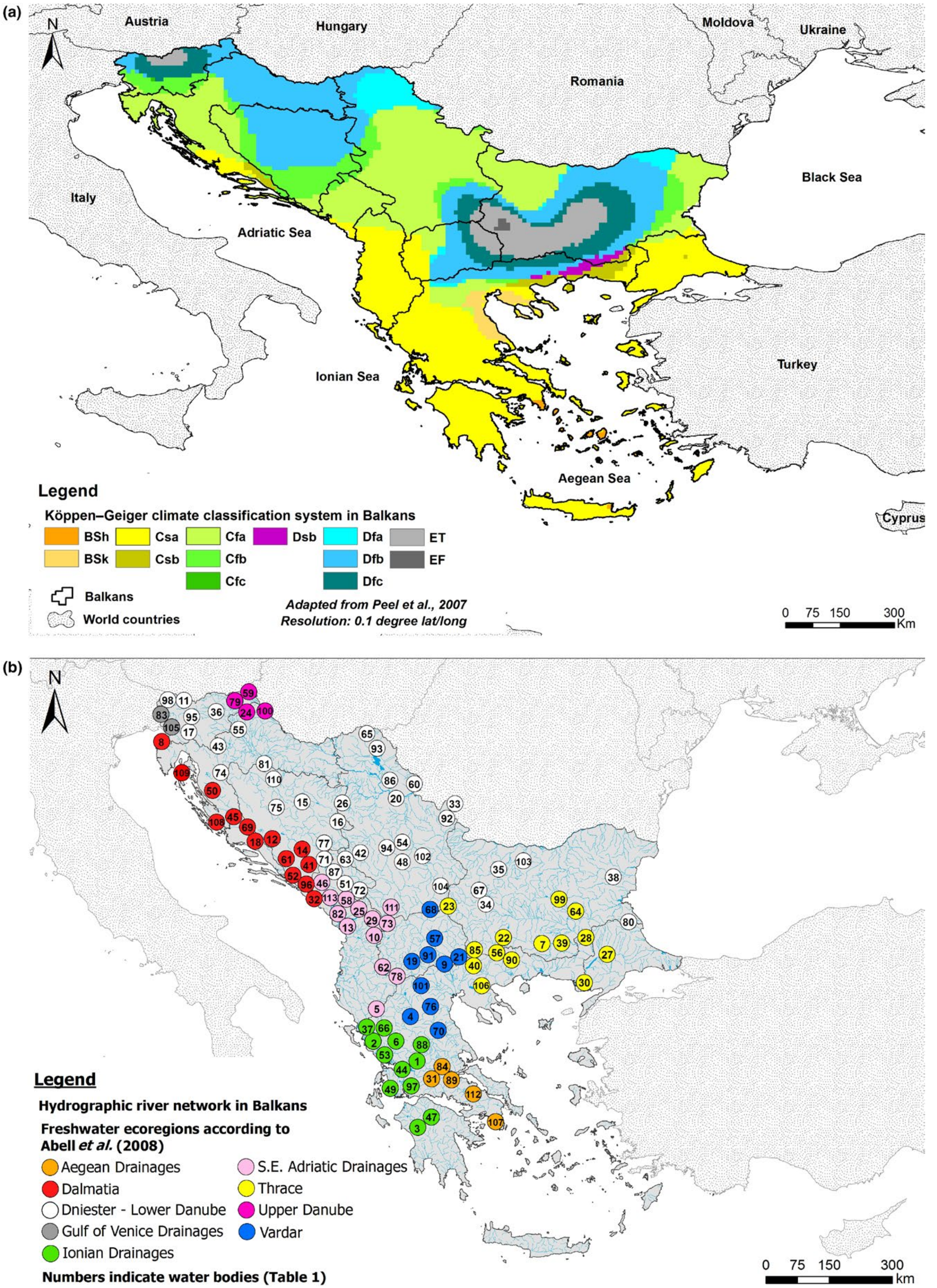
(a)
N
Austria
Hungary
Moldova
Ukraine
Romania
Black Sea
Italy
Adriatic Sea
Ionian Sea
Turkey
Aegean Sea
Cyprus
Legend
Köppen–Geiger climate classification system in Balkans
BSh
Csa
Cfa
Dsb
Dfa
ET
BSk
Csb
Cfb
Dfb
EF
Cfc
Dfc
Balkans
World countries
Adapted from Peel et al., 2007
Resolution: 0.1 degree lat/long
0 75 150 300
Km
(b)
N
Legend
Hydrographic river network in Balkans
Freshwater ecoregions according to Abell et al. (2008)
Aegean Drainages
Dalmatia
Dniester - Lower Danube
Gulf of Venice Drainages
Ionian Drainages
S.E. Adriatic Drainages
Thrace
Upper Danube
Vardar
Numbers indicate water bodies (Table 1)
0 75 150 300
km

TABLE 1 Freshwater ecoregions of the Balkan Peninsula according to Abell et al. (2008) (R. = River; R.s. = Rivers; Res. = Reservoir; Res.s = Reservoirs; L. = Lake; L.s = Lakes)

Code	Water Bodies	Ecoregion
1	Acheloos R.	Ionian Drainages
2	Acheron R.	Ionian Drainages
3	Alfios R.	Ionian Drainages
4	Aliakmon R.	Vardar
5	Aoos/Vjosë R.	South-east Adriatic Drainages
6	Arachthos R.	Ionian Drainages
7	Arda R.	Thrace
8	Aro-Rižana R.s.	Dalmatia
9	Axios/Vardar R.	Vardar
10	Black Drin R.	South-east Adriatic Drainages
11	Bled-Bohinj L.s	Dniester–Lower Danube
12	Blidinje-Buško L.s	Dalmatia
13	Bojana/Büna R.	South-east Adriatic Drainages
14	Boračko L.	Dalmatia
15	Bosna R.	Dniester–Lower Danube
16	Ćehotina R.	Dniester–Lower Danube
17	Cerknica L.	Dniester–Lower Danube
18	Cetina R.	Dalmatia
19	Crna R.	Vardar
20	Danube	Dniester–Lower Danube
21	Doirani/Dojran L.	Vardar
22	Dospat L.	Thrace
23	Dragovištica R.-Lisina Res.	Thrace
24	Drava R.	Upper Danube
25	Drin R.	South-east Adriatic Drainages
26	Drina R.	Dniester–Lower Danube
27	Ergene R.	Thrace
28	Evros/Maritsa/Meriç R.	Thrace
29	Fierza Res.	South-east Adriatic Drainages
30	Gala L.	Thrace
31	Gorgopotamos R.	Aegean Drainages
32	Grahovsko L.	Dalmatia
33	Iron Gate/Djerdap I & II Res.s	Dniester–Lower Danube
34	Iskar R.	Dniester–Lower Danube
35	Iskar Res.	Dniester–Lower Danube
36	Jasenik R.	Dniester–Lower Danube
37	Kalamas R.	Ionian Drainages
38	Kamchiya R.	Dniester–Lower Danube
39	Kardzhali Res.	Thrace
40	Kerkini Res.	Thrace
41	Klinje Res.	Dalmatia
42	Kokin Brod Res.	Dniester–Lower Danube
43	Kolpa/Kupa R.	Dniester–Lower Danube
44	Kremasta Res.	Ionian Drainages
45	Krka R.-Krk L.	Dalmatia
46	Krupac-Slano Res.s.-Liverovići L.	South-east Adriatic Drainages
47	Ladonas R.	Ionian Drainages
48	Lepenac R.	Dniester–Lower Danube
49	Lessini R.	Ionian Drainages
50	Lika R.	Dalmatia
51	Lim R.	Dniester–Lower Danube
52	Lištica R.	Dalmatia
53	Louros R.	Ionian Drainages
54	Lugomir R.	Dniester–Lower Danube
55	Medvednica R.	Dniester–Lower Danube
56	Mesta/Nestos R.	Thrace
57	Mladost Res.	Vardar
58	Morača R.	South-east Adriatic Drainages
59	Mura R.	Upper Danube
60	Nera R.	Dniester–Lower Danube
61	Neretva R.	Dalmatia
62	Ohrid L.	South-east Adriatic Drainages
63	Otilovići Res.	Dniester–Lower Danube
64	Ovcharitza Res.	Thrace
65	Palić-Ludaš L.	Dniester–Lower Danube
66	Pamvotis L.	Ionian Drainages
67	Pancharevo Res.	Dniester–Lower Danube
68	Pčinja R.	Vardar
69	Peruća L.	Dalmatia
70	Pinios (central Greece) R.	Vardar
71	Piva R.-Pivsko Res.	Dniester–Lower Danube
72	Plav L.	Dniester–Lower Danube
73	Plavska R.	South-east Adriatic Drainages
74	Plitvice L.s	Dniester–Lower Danube
75	Pliva L.s	Dniester–Lower Danube
76	Polifitos Res.	Vardar
77	Prača R.	Dniester–Lower Danube
78	Prespa L.s	South-east Adriatic Drainages
79	Ptuj L.	Upper Danube

(Continues)

TABLE 1 (Continued)

Code	Water Bodies	Ecoregion
80	Rezovo	Dniester–Lower Danube
81	Sava R.	Dniester–Lower Danube
82	Skadar L.	South-east Adriatic Drainages
83	Soča/Isonzo R.	Gulf of Venice Drainages
84	Spercheios R.	Aegean Drainages
85	Struma/Strymon R.	Thrace
86	Tamiš R.	Dniester–Lower Danube
87	Tara R.	Dniester–Lower Danube
88	Tavropos Res.	Ionian Drainages
89	Thermopylae hot springs	Aegean Drainages
90	Thisavros Res.	Thrace
91	Tikvesh Res.	Vardar
92	Timok R.	Dniester–Lower Danube
93	Tisa R.	Dniester–Lower Danube
94	Topla Voda R.	Dniester–Lower Danube
95	Trboje L.	Dniester–Lower Danube
96	Trebišnjica R.-Bileća L.	Dalmatia
97	Trichonis L.	Ionian Drainages
98	Triglav/Triglavska jezera L.s	Dniester–Lower Danube
99	Tundzha R.	Thrace
100	Varaždin Res.	Upper Danube
101	Vegoritis R.	Vardar
102	Velika Morava R.	Dniester–Lower Danube
103	Vit R.	Dniester–Lower Danube
104	Vlasina L.	Dniester–Lower Danube
105	Vogršček Res.	Gulf of Venice Drainages
106	Volvi L.	Thrace
107	Vouliagmeni L.	Aegean Drainages
108	Vransko L.s	Dalmatia
109	Vransko L. (Cres Island)	Dalmatia
110	Vrbas R.	Dniester–Lower Danube
111	White Drin R.	South-east Adriatic Drainages
112	Yliki-Paralimni L.s	Aegean Drainages
113	Zeta R.	South-east Adriatic Drainages

The Aegean Sea Basin consists of three ecoregions according to Abell et al. (2008): Vardar, Aegean drainages and Thrace. The Vardar ecoregion includes part of Serbia, FYR Macedonia and Greece and is bounded by the Dinaric Alps and Pindus Range in the west, the Šar Mountains in the north-west, the Osogovska and Maleševske mountains in the east and Mt. Olympus in the south. The most important rivers are the Vardar/Axios River (FYR Macedonia/Greece) and its tributaries: Lepenac and Pčinja rivers (Serbia), Crna and Brejalnica (FYR Macedonia). Other major rivers include the Aliakmon and Pinios (Greece). The Vardar ecoregion includes also the transboundary Doirani Lake (FYR Macedonia/Greece). The Aegean drainages ecoregion lies to the south of the Vardar ecoregion and is bounded by the Pindus range to the west and Mt. Othrys to the north, encompassing south-eastern Greece. The ecoregion is characterized by small intermitted watercourses prone to dry out in summer, with many fed by karst springs. The most important river is the Spercheios, with over 60 tributaries and creating a large delta at its mouth. Other important watercourses are the Assopos and Boeotic Kifissos. The Thrace ecoregion lies to the east of the Vardar ecoregion and south of the Dnieper–Lower Danube ecoregion and spans both Europe and Asia. The rivers of this ecoregion are not limited to the Aegean Sea Basin, as some fall within the Black Sea Basin. The most important rivers in the western part of the ecoregion are Struma/Strymon (Bulgaria/Greece), with its tributaries Dragovištica (Serbia/Bulgaria) and Strumica (FYR Macedonia/Bulgaria), and the Mesta/Nestos River (Bulgaria/Greece). In the Eastern Thrace ecoregion, important rivers are the Maritsa/Evros/Meriç (Bulgaria/Greece/Turkey-Thrace) with its main tributaries Tundzha (Bulgaria/Turkey-Thrace) and Arda (Bulgaria/Greece). The Rezovo River (Bulgaria/Turkey-Thrace) springs in Turkey-Thrace and flows through Bulgaria before draining into the Black Sea. There are more than 40 natural lakes in this ecoregion, including Lake Volvi and Lake Vegoritis in the western part of the ecoregion, and more than 10 natural lakes, including Lake Gala (Balık, 1985) in Eastern Thrace.

The Black Sea Basin includes two ecoregions according to Abell et al. (2008): Dniester–Lower Danube and Upper Danube. The Dniester–Lower Danube ecoregion is a vast area, encompassing many countries, and is primarily a floodplain region. In the Balkan Peninsula, delineated by the Soča-Sava-Danube border to the north, this ecoregion includes Slovenia, Croatia, Bosnia–Herzegovina, Montenegro, Serbia, Bulgaria and Turkey-Thrace. The dominant river in the ecoregion, and in the Black Sea Basin, is the Danube River (in the Balkans: Croatia/Serbia/Bulgaria), which forms a vast delta at its mouth. The Danube is considered to be one of Europe's most important rivers and its catchment encompasses vast areas of the inland water network within the Balkan Peninsula. For example, this catchment drains 81% of Slovenia, 65% of Croatia, 76% of Bosnia–Herzegovina, 51% of Montenegro 92% of Serbia and 43% of Bulgaria (ICPDR 2009). The longest tributary is the Tisa/Tisza River (Romania/Serbia), which forms the largest sub-basin. The transboundary Sava River (Slovenia/Croatia/BiH/Serbia/Montenegro) is the second largest sub-basin and contributes the most water to the Danube, and its main subtributaries are the Krka and Kupa (Slovenia/Croatia), Una (Croatia/Bosnia–Herzegovina), Vrbas and Bosna (BiH), Drina (BiH/Serbia, with main tributaries Tara, Piva and Lim (Montenegro). The Iskar River (Bulgaria) is the largest tributary of the Danube in Bulgaria, followed by the Vit River (Bulgaria). Other independent and shorter rivers drain eastern Bulgaria directly into the Black Sea. There are a number of natural lakes in this ecoregion. Slovenia has lakes of glacial origin, such as the Triglav, Bled and Bohinj, and of karstic origin, such as Cerknica Lake or the numerous smaller *polje* (karst field) lakes. Montenegro has small high mountain glacial lakes, the most important of which is Lake Plav (Popovska & Bonacci, 2007), while in Bosnia–Herzegovina, there is the Great Pliva

Lake. In Serbia, there are the Palić and Ludaš Lakes. Bulgaria has the largest number of natural lakes, about 400 (high mountain glacial lakes, several landslide lakes, Black Sea coastal and Danube riparian lakes/marshes). The Upper Danube ecoregion in the Balkans encompasses only a small part of Slovenia and Croatia and includes the Drava River (Slovenia/Croatia) and its tributary Mura (Slovenia/Croatia). The Drava River forms the fourth largest tributary of the Danube.

2.2.2 | Artificial reservoirs

In Slovenia, damming created the artificial Lake Ptuj (Drava River), the largest in Slovenia, Lake Most na Soči (Soča River) and Lake Trboje (Sava River). In Croatia, there are three large artificial reservoirs on the Drava River and one on the Cetina River. In Bosnia–Herzegovina, there are dams on the Neretva River, although the largest reservoir is Bileća Lake (Trebišnjica River), near the border with Montenegro. In Montenegro, there are several relatively large artificial lakes, in river canyons or river valleys, mostly for electric power production (Pivsko and Otilovići in the north and Slano, Krupac, Liverovići and Grahovsko in central Montenegro). In Albania, most lowland reservoirs are used for aquaculture or irrigation. In FYR Macedonia, there are more than 120 reservoirs (21 large) created for water supply, hydropower production, irrigation and fish farming. In Greece, there are over 160 large reservoirs (ICOLD 2015), mostly in the north that primarily serve for irrigation and drinking water supply, while several large reservoirs are for hydropower production, that is Lake Polyfytos (Aliakmon River), Lake Kremasta (Acheloos River) and Lake Thisavros (Nestos River). In Eastern Thrace, there are ≈70 reservoirs (mostly small) used for irrigation and water supply. In Serbia, several reservoirs have been constructed for hydropower, water supply or erosion control. The largest is the Derdap (Iron Gate) reservoir on the Danube River. In Bulgaria (total surface area of 395 km^2), large reservoirs (>2 km^2) are used for irrigation, hydropower generation, water sources control, fish farming, drinking water supply, flood control and recreation. The 3,000 small reservoirs are used mainly for irrigation and fish farming; the majority are mountain reservoirs (elevation from 600 to 1,800 m; Stefanov, 2007).

Finally, a brief mention should be made of ponds, that is small and shallow lentic water bodies characterized by plant growth, namely rooted plants, as opposed to lakes that are much deeper and larger with no plant growth. Ponds are often the recipients of alien species, similarly to other lentic systems.

3 | VECTORS OF INTRODUCTIONS

This study showed that the two main modes of alien species introduction in the Balkan countries were as follows: (i) intentional, that is for recreational and sport fishing, aquaculture, ornamental trade and biological control) and (ii) unintentional, that is the accidental spread of a species as a consequence of introduction for aquaculture purposes, or the natural spread of a species outside its natural habitat (Figure 2a). Data since the late 19th century indicate that introductions continued at a high rate right up to the 1980s. In the subsequent decades, introductions of both types were reduced substantially (Figure 2b–k). By country, the highest number of unintentionally introduced species over the last 15 years has been recorded in Croatia and Greece (Figure 2e,f). The main vector for introductions, with the highest number of fish species in most Balkan countries, was intentional introduction for aquaculture, except in Serbia and Turkey-Thrace, where most species were introduced unintentionally. Recreational and sport fishing (angling) is another major vector of alien species introduction and dispersal (Figure 2a). In Slovenia, this has been a common practice for more than 100 years (Figure 2j), while in other Balkan countries, recreational fisheries and stocking activities began after World War II. Another important introduction vector was biological control. This practice began in Albania (Figure 2b) and spread throughout the Balkans after the 1960s. It is interesting that no introductions have ever been reported for biological control in Bosnia–Herzegovina and Serbia (Figure 2d,i) or for recreational and sport fishing in Albania, FYR Macedonia and Turkey-Thrace (Figure 2b,h,k). Finally, although it appears that the ornamental trade (Figure 2a–k) is not a highly important vector of introduction, some have warned that this will become an increasing problem in Europe and the Balkans in the future (Chucholl, 2013).

Freshwater aquaculture, which represents a major vector for the interwatershed dispersion of many alien species worldwide (Nunes et al., 2015), has a long tradition in the Balkans, dating back to the 16th and 17th centuries in the case of Slovenia, when fish breeding was performed by the church, monasteries and squires. In Slovenia, the first fish farm for artificial carp breeding was established in 1870, with salmonid farming beginning a decade later (Govedič, 2005). Similarly, in Croatia and Bulgaria, the first trout farms were established in the late 19th century, followed by the first carp farms at the same time in Croatia (Piria, Tomljanović et al., 2016), and in Bulgaria in the 1940s (Uzunova & Zlatanova, 2007). In Greece, in contrast, the freshwater aquaculture sector was very limited until the 1980s (Perdikaris, Gouva, & Paschos, 2010).

Freshwater aquaculture in the Balkans is focused on the production of both warm-water (cyprinid or carp-like) and cold-water (salmonid or trout-like) species, with common carp (*Cyprinus carpio*, Cyprinidae) and rainbow trout (*Oncorhynchus mykiss*, Salmonidae) as the predominant species, respectively.

Indeed, statistics show that common carp dominates warm-water aquaculture production in countries with a large aquaculture sector, accounting for 85%–90% of the total warm-water species production of 8,000–10,000 tonnes in Serbia and over 50% of the production in Croatia (2,100 tonnes of a total of 2,884 tonnes) and Bulgaria (1,736 of a total of 3,248 tonnes–2012 data, FAO 2016). The same is also evident in countries with predominantly cold-water aquaculture, such as Greece.

More specifically, warm freshwater aquaculture in countries with an extensive sector such as Croatia (eight large and several smaller units), Bulgaria (451 fish farms) and Serbia (36 large and several smaller farms) mainly involves the farming of common carp, either in monoculture or in poly-culture with other species, such as grass carp

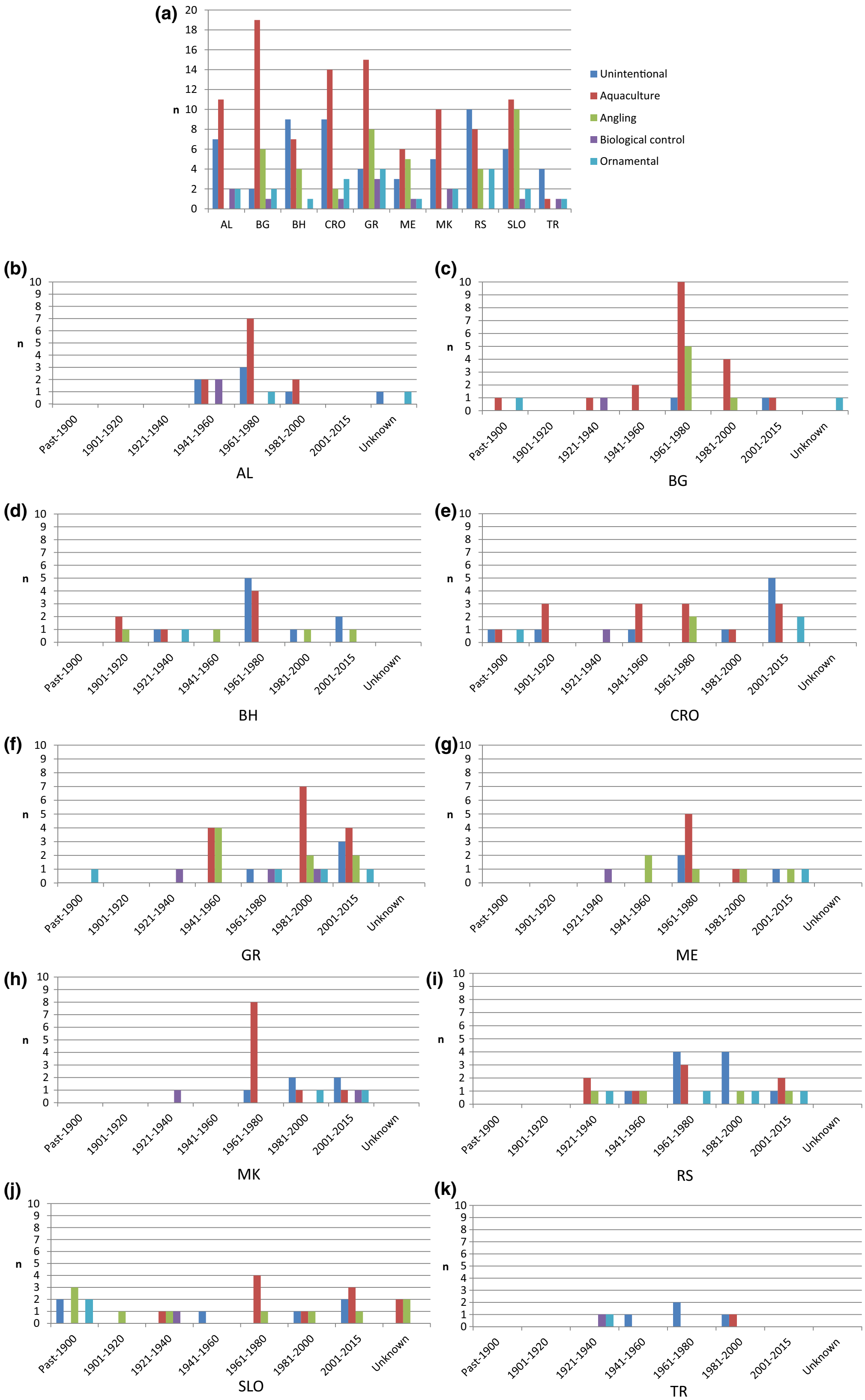

FIGURE 2 Vectors of fish introductions into the (a) Balkan Peninsula (Kosovo excluded), n = number of species (AL, Albania; BG, Bulgaria; BH, Bosnia–Herzegovina; CRO, Croatia; GR, Greece; KS, Kosovo; ME, Montenegro; MK, FYR Macedonia; RS, Serbia; SLO, Slovenia; TR, Turkey-Thrace); (b–k) each country separately, since the beginning of the 20th century. [Colour figure can be viewed at wileyonlinelibrary.com]

(*Ctenopharyngodon idella*, Cyprinidae), silver carp (*Hypophthalmichthys molitrix*, Cyprinidae) and bighead carp (*Hypophthalmichthys nobilis*, Cyprinidae), (FAO 2016). In Bulgaria, channel catfish (*Ictalurus punctatus*, Ictaluridae) is raised in net cages in the cooling lake of the Maritza-Iztok 2 Thermal Electrical Plant, while sturgeons, such as Danube sturgeon (*Acipenser gueldenstaedti*, Acipenseridae), stellate sturgeon (*Acipenser stellatus*, Acipenseridae), beluga (*Huso huso*, Acipenseridae) and starlet (*Acipenser ruthenus*, Acipenseridae), are reared for stocking, together with hybrids, also for human consumption and stocking. Finally, in both Greece and Eastern Thrace, common carp is the dominant species of warm-water aquaculture, together with Danube sturgeon and Nile tilapia (*Oreochromis niloticus*, Cichlidae), which was also stocked in Greece in the past for commercial purposes.

The geographical, climatic and water conditions in certain Balkan countries, such as Slovenia or Montenegro, are more favourable for cold-water fish husbandry, with small-scale fish farms on montane streams and rivers dominating aquaculture in these countries. Cold-water aquaculture in Bulgaria concentrates also mainly on rainbow trout, which accounted for 98% of the total cold-water output of almost 2,800 tonnes in 2012, followed by brown trout (*Salmo trutta*, Salmonidae) and brook trout (*Salvelinus fontinalis*, Salmonidae), and the whitefish species, European whitefish (*Coregonus lavaretus*, Salmonidae) and peled (*Coregonus peled*, Salmonidae). Similarly, rainbow trout dominates cold-water fish farm production in Serbia, with total production varying from 1,600 to 2,500 tonnes, in Bosnia–Herzegovina at 97 farms from 3,000 to 4,000 tonnes, where brown trout and brook trout are also reared in 55 fish farms, in Albania at 57 trout fish farms, in FYR Macedonia at 64 farms and in Eastern Thrace at seven large farms that produce 1,000 tonnes of rainbow trout. The dominance of rainbow trout rearing in the Balkans is more evident in Croatia, where 345 of 351 tons of all salmonid fish produced in 2013 at 27 trout fish farms were rainbow trout (FAO 2016). Finally, in Greece, mostly in its north-western part, the most common cold-water aquaculture species is rainbow trout, followed by coho salmon (*Oncorhynchus kisutch*, Salmonidae), reared in ≈ 80 aquaculture units.

Warm-water aquaculture represents a major source of invasiveness in the Balkans; there is evidence of established self-sustaining populations of the Asian carps based on evidence of sexual maturation and of the increasing number of these species (Janković, 1998). There is evidence of the presence of silver carp and grass carp juveniles (0+ age) in the Bulgarian section of the Danube (A. Apostolou, personal observation). Warm-water aquaculture is also a major vehicle for the interwatershed dispersion of several other highly invasive species, such as the gibel carp (*Carassius gibelio*, Cyprinidae), pumpkinseed (*Lepomis gibbosus*, Centrarchidae) and topmouth gudgeon (*Pseudorasbora parva*, Cyprinidae) (Nunes et al., 2015; Savini et al., 2010; Uzunova & Zlatanova, 2007). Furthermore, alien sturgeon species breeding near the Danube in Bulgarian waters could also impact natural stocks by hybridization, while the possible detrimental effects of paddlefish (*Polyodon spathula*, Polyodontidae) escapees from Romanian fish farms are currently unknown.

Unlike warm-water aquaculture, cold-water aquaculture does not represent a major vector of invasiveness, as alien salmonids do not reproduce naturally in most of the Balkan waters. However, there are documented cases of rainbow trout reproduction dating back to the early 20th century in Slovenia (Franke, 1913; Mršić, 1935) and to the early 1970s in Croatia (MacCrimmon, 1971); for more recent reports, see the review by Stanković, Crivelli, and Snoj (2015). Surprisingly, there are also indications of a reproducing rainbow trout population in a river in southern Croatia (D. Zanella, personal observation) and in southern Greece (Koutsikos et al., 2012). In addition, the impacts of escapees from cold-water fish farms on local biodiversity certainly warrant further studies, as suggested elsewhere (Tarkan, Marr, & Ekmekçi, 2015).

Sport and recreational fishing (angling) is also a major vector of the spread of alien freshwater fishes in the Balkans, through their translocation between watersheds, an activity that is very difficult to monitor. In the past, anglers often engaged in this practice, by intentionally introducing species of fisheries interest in waters considered to have "impoverished" fauna, as is the case of the introduction of northern pike (*Esox lucius*, Esocidae) and of an alien strain of brown trout to Adriatic water systems in Croatia. Similarly, the transfer of alien species, such as the gibel carp, between water bodies in FYR Macedonia or Eastern Thrace is currently also extensive (Aydın et al., 2011), whereas for other countries, such as Bosnia–Herzegovina, information on these activities is lacking. Anglers have also likely been responsible for the spread of many small alien species, using them as live bait and thus transferring them from catchment to catchment. In Croatia and Slovenia, for example, small-bodied fishes from the lower Danube are routinely transported as live bait for angling in Adriatic rivers (Dalmatia and south-east Adriatic ecoregions), despite the prohibition of this practice by law (Pofuk, Zanella, & Piria, 2017). In Greece, in contrast, the scale of angling and commercial fisheries in large lakes and reservoirs is scarce, and thus, the spread of alien species through these practices is rather limited, in comparison with the other Balkan countries. Stocking with alien species has been banned by legislation in many Balkan countries (in 2000 in Serbia; in 2001 in Croatia), although dispersal via the Danube River as a prominent southern Invasive Corridor (Bij de Vaate, Jazdzewski, Ketelaars, Gollasch, & Van der Velde, 2002) continues. However, unintentional introductions of alien fish species and alien trout strains (Simonović et al., 2015) still occur in certain countries, such as Serbia.

The ornamental trade has also been recognized as an important vector for the introduction of invasive species, linked to over 150 species' invasions in natural ecosystems around the world (Fuller, 2003; Padilla & Williams, 2004; Siguan, 2003). The vast majority of the studies on the ornamental trade as a vector have been conducted in North America, with few such studies conducted in Europe (Copp & Fox, 2007; Duggan, Rixon, & MacIsaac, 2006; Maceda-Veiga, Escribano-Alacid, De Sostoa, & García-Berthou, 2013; Padilla & Williams, 2004). For the Balkan region, data collection and monitoring of the ornamental fish trade is virtually non-existent, as no official datasets are available. Recently, Papavlasopoulou, Vardakas, Perdikaris, Kommatas, and Paschos (2014) concluded that the aquarium fish sector is under virtually no control in Greece, given the existence of threatened species, species potentially harmful to humans and species capable of establishing non-indigenous populations, if released into the wild.

To date, the ornamental trade accounts for a limited but steadily growing proportion of fish introductions in the Balkan region (Zenetos et al., 2009). So far, only nine ornamental fish species have been recorded in the fresh waters of the Balkans (Table S1). Only the goldfish (*Carassius auratus*, Cyprinidae) and the pumpkinseed, introduced in the northern Balkans in the 19th century, occur widely in the region, while the rest are restricted to individual basins (Economou et al., 2007). For example, the guppy (*Poecilia reticulata*, Poeciliidae) has only been introduced to Albania, where its current distribution is unknown, to Bulgaria in the artificial Lake Pancharevo on the Iskar River, a tributary of the Danube and to Serbia, in the Topla Voda thermal Stream, which supports a self-sustaining population of the species (Milenković, Žikić, Stanković, & Marić, 2014). Similarly, the Amazon sailfin catfish (*Pterygoplichthys pardalis*, Loricariidae) has only been recorded in the Serbian (middle) section of the Danube River (a first record in the inland waters of Europe, see Simonović, Nikolić, & Grujić, 2010). However, despite the low number of ornamental fish species released in the Balkans, the possibility of more ornamental fish being introduced, either intentionally or unintentionally, and subsequently being established into the wild, with unknown impacts on the native fauna, still remains. Furthermore, there is no knowledge of how these species affect the native fish fauna, as no relevant research has yet been conducted in the region.

Finally, only three species have been introduced in the Balkans for biological control: the grass carp, the silver carp and the highly invasive eastern mosquitofish (*Gambusia holbrooki*, Poeciliidae). The grass carp was introduced to control the growth of aquatic vegetation (Economidis, 1991) and the silver carp to control planktonic assemblages (Vuković & Kosorić, 1978), although these introductions had negative implications for inland water communities (Domaizon & Dévaux, 1999; Leonardos, Kagalou et al., 2008). The eastern mosquitofish was introduced in the Balkans and elsewhere in the Mediterranean in the 1920s for mosquito control, with questionable results (Stephanides, 1964). Today, the eastern mosquitofish is the second most widespread alien fish species in the Mediterranean region and the most widespread in Greece, occurring in 49.5% of its river basins (Economou et al., 2007).

4 | PATHWAYS OF FISH INTRODUCTIONS IN THE BALKANS

4.1 | Biogeographical origin of introduced species and current state

The majority of introduced species in the Balkans are of North American origin (25.0%), followed by Asian (23.3%) and Eastern European species (23.3%), which coincides with the chronology of the first introductions (Figure 3). Until the early 1950s, introductions were primarily of North American and Asian species (Copp et al., 2005; Fijan, Petrinec, & Đorđević, 1989; Holčik, 1991; Livadas & Sphangos, 1941; Nežić, 1938; Povž & Šumer, 2005), while the interest for species from Northern and Western Europe arose later (Table S1). Other introduced species originated from Northern Europe (8.3%), South America (5.0%), Asia/Europe (6.7%), Africa (5.0%) and Western Europe (3.3%, Figure 3). It should be noted that since the ichthyofaunal research in Kosovo is sparse (Gashi et al., 2016), only the newest data are presented in Table S1. The historical data for Kosovo are included in the presented data for FYR Macedonia, Montenegro, Albania and Serbia and are not calculated as a separate country due to the lack of data.

In total, 60 fish species have been introduced in the Balkan Peninsula, intentionally, accidentally or by natural dispersal (Table S1). The first introductions were documented in the 19th century in Bulgaria (two species), Croatia (one species) and Slovenia (four species). Known introductions were performed, from 1901 to 1920, in Bosnia–Herzegovina and Croatia, from 1921 to 1940 in Croatia, Serbia, Bosnia–Herzegovina and Bulgaria and after 1940 in Albania, Greece, Montenegro and Serbia. In most countries, the highest number of introductions took place between 1960 and 1980 (Figure 4). Since 2000, Turkey-Thrace has not documented any new alien fish species introductions, as opposed to Croatia, which has recorded the highest number of new alien species since then (Ćaleta, Jelić et al., 2011; Ćaleta, Tutman et al., 2011; Jelkić & Opačak, 2013; Piria, Treer et al., 2011; Piria, Šprem et al., 2011; Safner et al., 2013; Šanda et al., 2013), although this may be the result of intensive ichthyological research in the period after 2000 rather than new introductions (Figure 4).

The majority (38.46%) of species in the Balkan Peninsula have a limited distribution, including alpine lakes (e.g. arctic charr (*Salvelinus alpinus*, Salmonidae) in Slovenia, reservoirs (e.g. pikeperch (*Sander lucioperca*, Percidae) in FYR Macedonia, artificial lakes and reservoirs (e.g. Aristotle's catfish (*Silurus aristotelis*, Siluridae) in Bulgaria and isolated and small river basins (e.g. European grayling (*Thymallus thymallus*, Salmonidae) in Montenegro. In the current study, 33.17% of all introduced fishes were found to be widespread. The most widespread species are gibel carp, pumpkinseed, brown bullhead (*Ameiurus nebulosus*, Ictaluridae), Eastern mosquitofish and topmouth gudgeon, due to their high invasive potential (Perdikaris et al., 2016; Piria et al., 2016b; Simonović et al., 2013). Species with a moderate distribution (15.38%) include the monkey goby (*Neogobius fluviatilis*, Gobiidae) and bighead goby (*Ponticola kessleri*, Gobiidae) in Croatia, the goldfish in Albania and Greece and the silver and bighead carp in most countries. For 12.98% species, their Balkan distribution is unknown, including species found/caught only once (e.g. short-snouted pipefish in the Danube River), sporadically (e.g. Mississippi paddlefish in Serbia, Croatia and Bulgaria) or introduced, but their status remains unknown (e.g. brook trout in Skadar Lake), (Figure 5a). The prevalence of the alien species in the Balkan countries (Figure 5b) suggests that most have become widespread in Serbia, Slovenia, Croatia, Turkey-Thrace and Albania. The majority of these species have a restricted distribution in Greece, Bulgaria, FYR Macedonia and Montenegro. Most introduced fish species in the Balkans have naturalized (Figure 5c), with the exception of Turkey-Thrace, where most introduced fish have acclimatized (Figure 5d). A categorization of alien species status of invasion sensu Blackburn et al. (2011) showed that the highest percentage of species (29%) belongs to the C3 category (individuals surviving in the wild at locations where introduced, reproduction

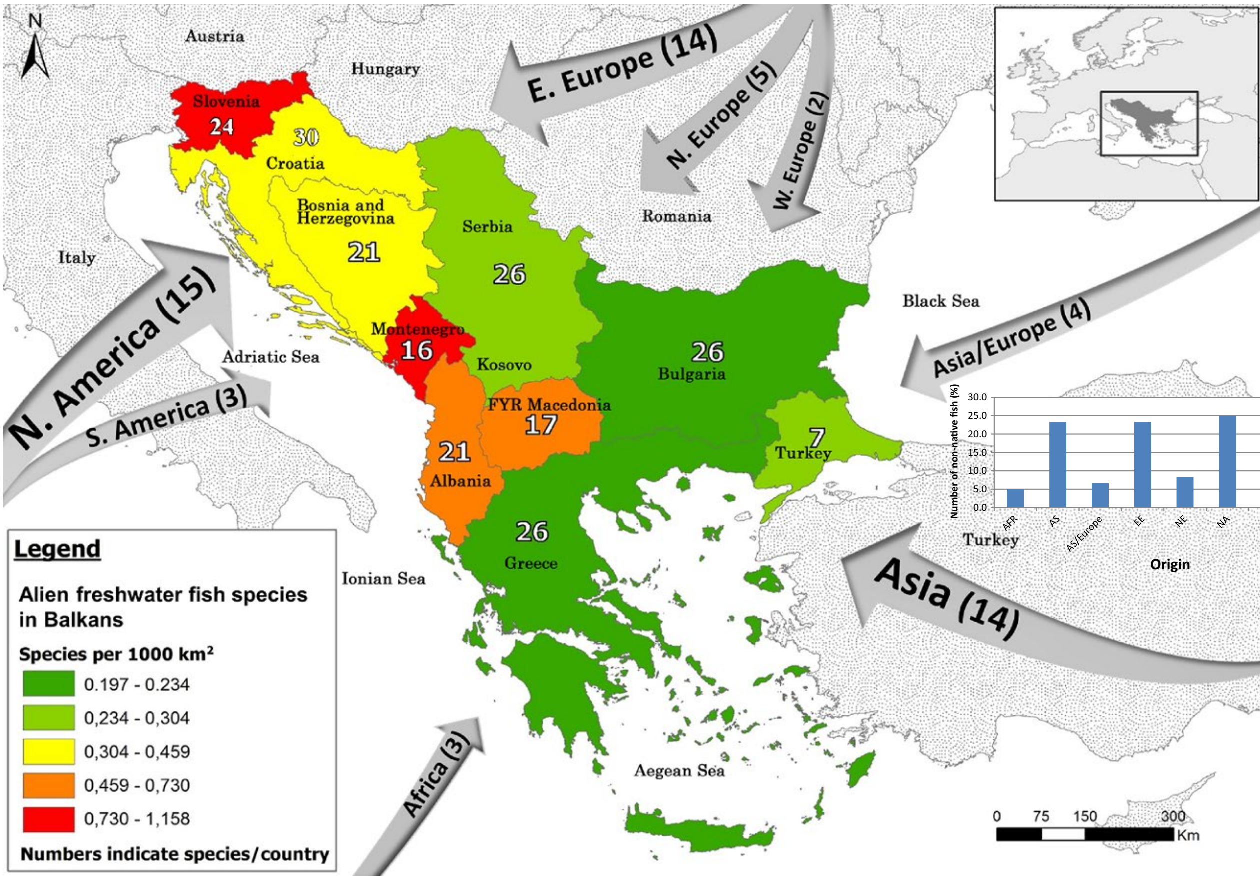

FIGURE 3 Origin of introduced alien fish species in the Balkan Peninsula (AFR = Africa; AS = Asia; EE = Eastern Europe; NE = Northern Europe; NA = North America; SA = South America; WE = Western Europe). Numbers in arrows denote the number of non-native species of varying origins introduced to the Balkans (inset graph shows the percentage contribution of origins). The standard Jenks Natural breaks classification method (ArcGIS, version 10.1) was used to define the class ranges of species per 1,000 km^2 groups. [Colour figure can be viewed at wileyonlinelibrary.com]

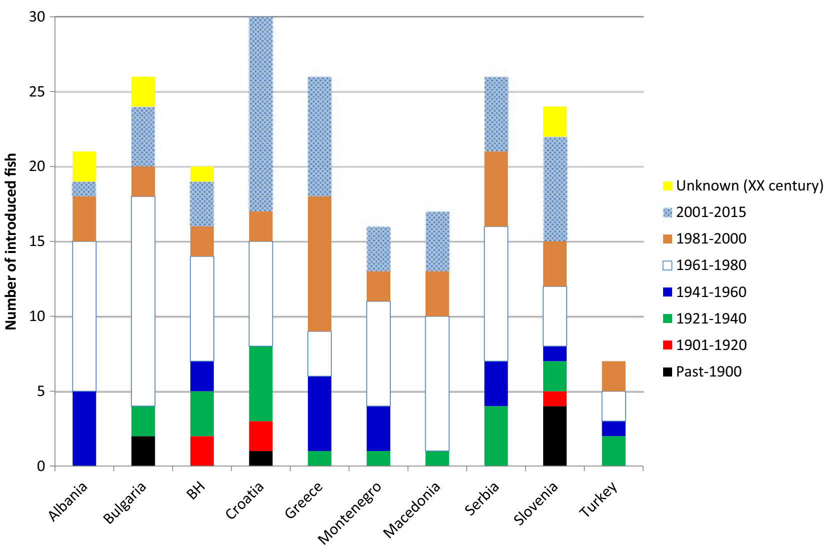

FIGURE 4 Temporal pattern of introduction of alien fish species into Balkan area since the beginning of the 20th century. Period from 2001–2015 represents 14 years. [Colour figure can be viewed at wileyonlinelibrary.com]

occurring and population self-sustaining), 23% belongs to the B3 category (individuals transported beyond the limits of their native range, and directly released into novel environment) and 24% to the E category (fully invasive species, with individuals dispersing, surviving and reproducing at multiple sites across a greater or lesser spectrum of habitats and extent of occurrence). Other species (21%) belong to the C0, C1 and C2 categories which refer to populations that are not self-sustaining (Figure 5e). Only Albania, Bulgaria and Croatia reported the

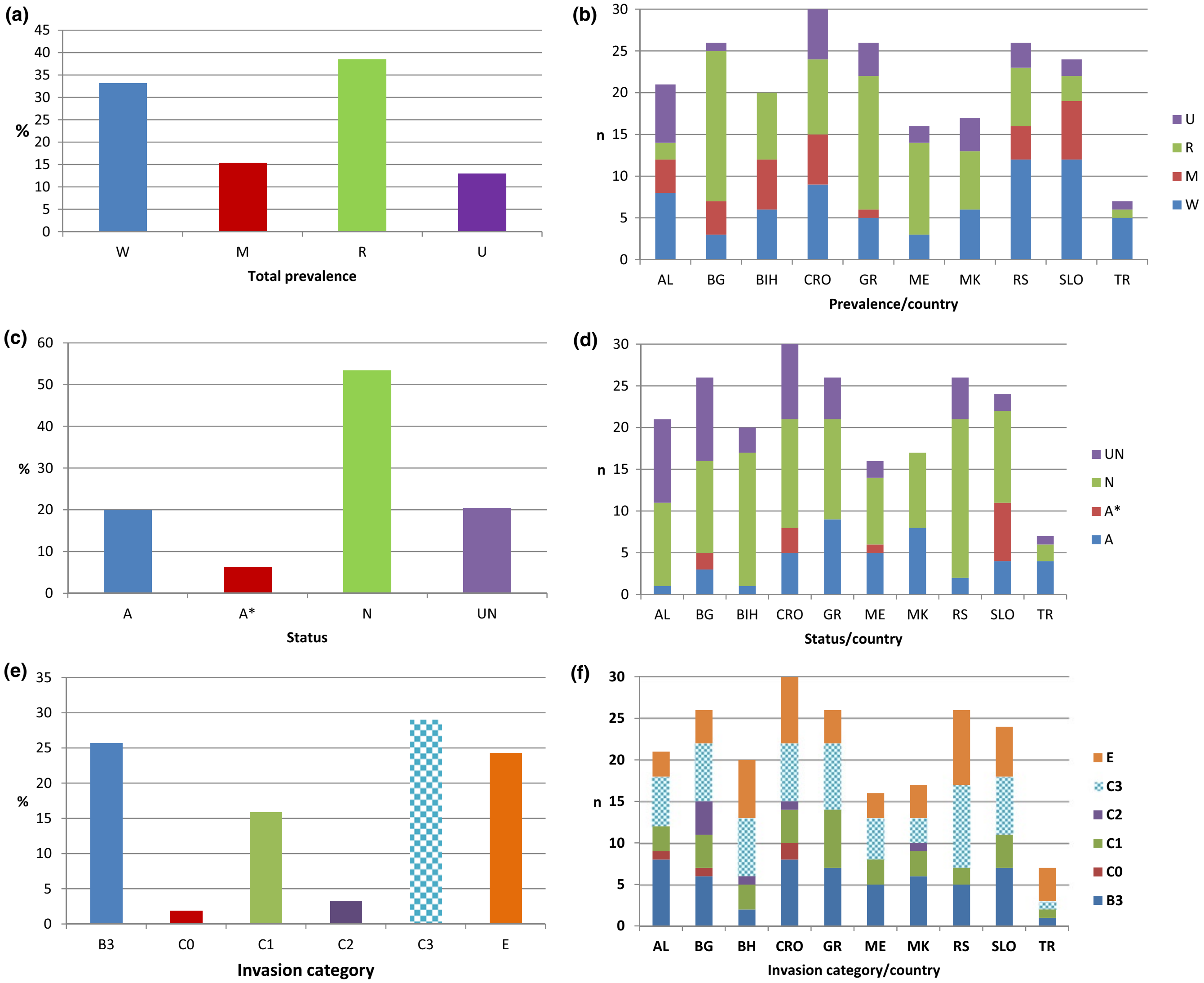

FIGURE 5 Alien species (a) total prevalence; (b) prevalence by country; (c) status of acclimatization; (d) status of acclimatization of introduced species by country, expressed as number of species; (e) invasion category according Blackburn et al., 2011 (for explanation of codes B3, C0, C1, C2, C3, E see Table S1); and (f) invasion category by country; (W, widespread species; M, moderate distribution; R, restricted; U, unknown distribution; A, acclimatized; A*, acclimatized in restricted areas; N, naturalized; UN, unknown status). [Colour figure can be viewed at wileyonlinelibrary.com]

C0 category [individuals released into the wild (i.e. outside of captivity or cultivation) to a location, but were incapable of surviving for a significant period]. The C2 category (individuals surviving in the wild at the site of introduction, reproduction occurring, but population not self-sustaining) was reported Bulgaria, Bosnia Hercegovina, Croatia and FYR Macedonia. The C1 category [individuals surviving in the wild (i.e. outside of captivity or cultivation) at the location of introduction, but without reproduction] was reported in all countries and in total represents 21% (Figure 5e,f).

4.2 | North American introductions

Rainbow trout was the first North American species introduced to the Balkan region. This species was likely introduced first from Germany to the Samokov fish farm in Bulgaria in 1878 (Uzunova & Zlatanova, 2007; Welcomme, 1988), followed by its introduction from Austria in 1883 to the Čabar fish farm in Croatia (Bojčić, 1997), and not in 1894 to the Mt. Medvednica fish pond near Zagreb as previously reported (Stanković et al., 2015). In 1891, eggs were shipped from other Austrian farms to Slovenia (Franke, 1913; Povž & Ocvirk, 1990). The first introductions into open waters were likely conducted in Slovenia in 1893, and in 1895, fish were translocated to the hatchery on Medvednica Stream near Zagreb in Croatia (Stanković et al., 2015). By 1908, rainbow trout were introduced into many suitable waters throughout central Slovenia (Franke, 1913; Stanković & Snoj, 2013) and by 1935 to other areas in the central and Adriatic parts of Slovenia and Croatia (Stanković et al., 2015). At the turn of the 20th century, rainbow trout were introduced from California to Bosnia–Herzegovina in a fish farm at the springs of the Bosna River near Sarajevo (Mršić, 1935). Fry originating from these shipments were used for seed introductions into the River Bosna, Lake Plivsko and Boračko Lake and into several sinking karst streams near Livno and in Trebišnjica River. All these seed introductions were reported as successful (see Stanković et al., 2015). The second wave of introductions began in the 1930s with the first report for Serbia (Lenhardt et al., 2011) and regular imports into Bulgaria (Uzunova & Zlatanova, 2007). The third introduction wave occurred in 1951 with the import of rainbow trout eggs from Switzerland to two state hatcheries in north and north-western Greece (Perdikaris et al., 2010). That same year, rainbow trout stocking began in Montenegro for angling purposes (Drecun, 1951) and later (in 1965) in FYR Macedonia for fish farming (Naumovski, 1995). The most recent introductions were reported from Albania (Shumka, Paparisto, & Grazhdani, 2008) and from Turkey-Thrace (Çelikkale, 2002) in the 1970s. Although the first introductions in Greece and Albania were noted in the 1950s and late 1970s, respectively, the first attempts of introduction must have occurred much earlier, namely in the 1880s, as documented by Holčik (1991).

Brook trout is native to north-eastern America, from Newfoundland to Hudson Bay in Canada to Georgia in the southern USA, and has been introduced worldwide. According to Holčik (1991), brook trout was introduced to the western Balkans in 1869, which coincides with the Slovenian record in 1884 (Povž & Ocvirk, 1990) when it was introduced to the Ljubljana area for sport fishing and as a food fish (Povž et al., 2015). At the turn of the 20th century, brook trout was introduced to the Sarajevo region (Željeznica, Zujevina, Bosna and Prača rivers) and in 1913 to the karst rivers Sturba and Šuica (Vuković & Kosorić, 1978). In the 1930s, it was imported to Bulgaria alongside rainbow trout. These two species remain dominant in Bulgarian cold-water farming (Uzunova & Zlatanova, 2007). In the period between the two World Wars, brook trout was introduced to Serbia (Vlasina and Lisina Lakes) and successfully reared in the Vrla fishpond at Surdulica (Lenhardt et al., 2011; Simonović, 2006). Much later, brook trout was introduced to FYR Macedonia, between 1965 and 1980 (Naumovski, 1995) and to Montenegro in 1985 (Marić, 1991). In Montenegro, this species was introduced to the Mareza fish farm near Titograd and later translocated to Skadar Lake for cage farming (Marić, 1991), from which many specimens escaped. There is no knowledge on any further restocking or farming activities in Montenegro or Albania, although this species is present in Skadar Lake (Talevski et al., 2009). It is not clear when the introduction of brook trout occurred in Croatia, but this species is farmed (Vardić et al., 2007) in the inland waters of the Dniester–Lower Danube ecoregion (Jelić, Jelić, Žutinić, & Ćaleta, 2012) and also in the south-east Adriatic ecoregion (Muhamedagić, Gjoen, & Vegra, 2010). The latest introduction occurred in Greece when eggs of brook trout were introduced into the Edessa state hatchery for incubation, and fingerlings were subsequently released into Lake Vegoritis and the Tavropos Reservoir (Economidis, Dimitriou, Pagoni, Michaloudi, & Natsis, 2000) during the 1980s, although its establishment in the Tavropos Reservoir is doubtful (Barbieri et al., 2015).

Coho salmon is a non-indigenous species from the Northern Pacific. In the Balkans, it was first introduced for commercial purposes in Serbia in the 1950s (Janković & Raspopović, 1960a,b), in Greece in the 1980s (Crivelli, Catsadorakis, Malakou, & Rosecchi, 1997; Economidis, Dimitriou et al., 2000; Tsekos et al., 1992) and in Slovenia and Croatia (Teskeredžić, Teskeredžić, Tomec, & Hacmanjek, 1989). In Greece, eggs from Canada were imported to the Edessa state hatchery in Northern Greece, while live specimens were released at nearby Lake Vegoritis and Tavropos Reservoir (Acheloos River) in Central Greece in the 1980s and in fish farms in the Gorgopotamos River (Spercheios drainage, Economidis, Dimitriou et al., 2000). Although not established in Greece, escapees or released individuals have been reported in the Tavropos Reservoir, Lake Vegoritis and Gorgopotamos River and in the upper Ladonas River (Alfios drainage) in the Peloponnese (Barbieri et al., 2015). In some cases, such as at Tavropos Reservoir, repeated stocking has occurred in the past (Economou et al., 2001). In Croatia, Serbia and Slovenia, this species has since disappeared.

Brown bullhead and black bullhead (*Ameiurus melas*, Ictaluridae) were introduced at an early date into the Balkans. The first introductions occurred in Croatia in 1905 (Fijan et al., 1989) and from here to other European countries (Movchan, Talabishka, & Velikopolskiy, 2014). It was originally believed that only brown bullhead was introduced to Europe (Fijan et al., 1989; Movchan et al., 2014), although following the discovery of the presence of black bullhead, it became apparent that both bullhead species were introduced at the same time (Holčik, 1991) and were subsequently misidentified (Movchan et al., 2014). The first occurrence of brown bullhead in inland waters was reported in 1926 for the Danube River (Balón, 1964), followed by records from Serbia and Bosnia–Herzegovina since 1930 (Lenhardt et al., 2011; Simonović, 2006; Sofradžija, 2009; Tutman, Glamuzina, Dulčić, & Zovko, 2012; Vuković & Ivanović, 1971) and Slovenia since 1935 (Povž & Ocvirk, 1990). More than 40 years later (in 1978), this species was observed in Montenegro (Knežević, Vuković, & Ražnatović, 1978), FYR Macedonia (between 1970 and 1995, Naumovski, 1995) and Bulgaria in 1975 (Uzunova & Zlatanova, 2007). The lack of reports of brown bullhead in Albania is questionable as this species was reported for Skadar Lake in Montenegro (Knežević et al., 1978), a lake shared by both countries. According to Rakaj and Flloko (1995), black bullhead was indeed introduced into Albania, although there are no data on its current presence. In Greece, a record of brown bullhead from 2012 remains unconfirmed (Barbieri et al., 2015).

The distribution of these two species outside their native dispersal area is not known (Fijan et al., 1989), a fact confirmed by data collected for this article (Table S1). Only four countries have reported the presence of black bullhead (Bosnia–Herzegovina, Croatia, Slovenia and Serbia), with the period between findings in Croatia (Fijan et al., 1989) and Serbia (Cvijanović, Lenhardt, & Hegediš, 2005) extending over 100 years. In Bosnia–Herzegovina and Slovenia, the exact time of appearance is not known (Adrović, Skenderović, Salihović, & Stjepić, 2012; Povž & Šumer, 2005). Recent research in Croatia has confirmed the dominant presence of black bullhead in both basins (Adriatic and Black Seas), while the brown bullhead is restricted only to the Neretva River and its tributaries (Novosel, 2010). In countries bordering with Croatia (Slovenia and Bosnia–Herzegovina), most reports refer to brown bullhead (Adrović et al., 2012; Povž & Šumer, 2005), thus indicating ambiguities and possible misidentifications of these two species.

Channel catfish was introduced more recently in the Balkans, namely to the former Yugoslavia in 1968 (Fijan et al., 1989; Holčik, 1991). This species is only still present in aquaculture in FYR Macedonia, where it has been recorded in the inland waters (Nastova-Gjorgjioska & Kostov, 2000). The introduction of channel catfish to Bulgaria occurred in 1975 for aquaculture purposes (Uzunova & Zlatanova, 2007), with increasing trends of production (Hadjinikolova, Hubenova, & Zaikov, 2010). Due to the sporadic records of channel catfish in inland waters (A Apostolski, unpublished data), it is considered naturalized (Uzunova & Zlatanova, 2007), although its impact is unknown.

Three more species were introduced to the Ovcharitza and Kardzhali reservoirs of Bulgaria in the late 1970s (Holčik, 1991): smallmouth buffalo (*Ictiobus bubalus*, Catostomidae), bigmouth buffalo (*Ictiobus cyprinellus*, Catostomidae) and black buffalo (*Ictiobus niger*, Catostomidae). Their reproduction is assumed to be natural, although their current status is unknown, as there are no known records since then (Uzunova & Zlatanova, 2007).

Pumpkinseed is one the most successful introduced fishes in Europe, with widespread introductions in the late 19th century (Fox & Copp, 2014). According to Holčik (1991), the introduction and establishment of pumpkinseed in several European countries began in 1885. This year could also be the time of introduction into the Balkans, specifically Slovenia (Povž & Šumer, 2005) and Bulgaria (Holčik, 1991). The pumpkinseed has been reported in Greece since 1885 (Holčik, 1991), although the first established population was cited 100 years later by Economidis, Kattoulas, and Stephanidis (1981; Aliakmon River). In Serbia, pumpkinseed was first recorded in the 1930s in the Tisa River (Lenhardt et al., 2011) and in Bosnia–Herzegovina at the same time (Sofradžija, 2009). The species was reported in the Croatian part of the Danube River basin in the 1920s and 1930s (Plančić, 1946). In Croatia, it was translocated from the Crna Mlaka fish farm into the karst Lika River by local fishermen as early as 1937 (Plančić, 1946; Vuković & Ivanović, 1971). Pumpkinseed was first reported in the Turkey-Thrace in the Ipsala Canal-Edirne (Erk'akan, 1983) and Gala Lake in the 1980s (Özcan, 2007) and in the Vardar River in FYR Macedonia at the same period (Kostov, Rebok, Slavevska-Stamenković, & Ristovska, 2010). In the Great Prespa Lake shared by Albania, Greece and FYR Macedonia, pumpkinseed was observed in 1994 (Shumka et al., 2008), while the most recent occurrence of this species in the Balkans was in the Krupac Reservoir in Montenegro in 2003 (D. Milošević, pers obs.). Pumpkinseed dispersal, aided largely by local fishermen using them as bait, has been enhanced with common carp stocking practices (Ağdamar et al., 2015). Pumpkinseed is currently distributed in virtually all the water bodies of the Balkans.

Largemouth (black) bass (*Micropterus salmoides*, Centrarchidae) was introduced repeatedly to the Balkan Peninsula (Povž & Ocvirk, 1990). It was first introduced to Europe and to the Balkans in 1877 (Holčik, 1991) for aquaculture purposes. In Croatia, it was reared at several fish farms until 1935 (Fijan, 1966). At that time, several attempts of adaptation to inland waters were made, all unsuccessful (Fijan, 1966; Povž & Ocvirk, 1990). The first reports in the Danube River basin date back to 1957 (Lenhardt et al., 2011), although in the Serbian part of the Danube, it was not reported until 1984 (Maletin, 1988). In Croatia, largemouth bass were introduced a second time in the late 1980s for aquaculture (M. Piria, personal observation) and were found in 1990 in Varaždin hydropower reservoir, obviously released for angling (Mrakovčić, 1992). For the same purpose, largemouth bass was released in Slovenia in 1993 in the Vogrščck reservoir and likely translocated in 2004 into still water (Prekmurje) (Povž & Šumer, 2005). In Bosnia–Herzegovina, it was found in the Vrbas River in the 2000s (Radević, 2001), although the time and path of introduction is unknown. Although present in the Danube basin, and several closed freshwater systems in the Balkans, it has not achieved success in natural reproduction and expansion (D. Zanella, personal observation). Nevertheless, largemouth bass was observed in 2003 near the estuaries of the Lessini stream in Greece, as a likely escapee and was stated as cause of concern (Corsini-Foka & Economidis, 2007).

The eastern mosquitofish and the common mosquitofish (*Gambusia affinis*, Poeciliidae) were introduced to Europe in the 1920s (Vidal, García-Berthou, Tedesco, & García-Marín, 2010). Their invasion was successful, and negative impacts on native communities have led them to be considered among the 100 worst invasive species worldwide (Cote, Fogarty, Weinersmith, Brodin, & Sih, 2010 and references within). Several hundreds of specimens of eastern mosquitofish, and not only 12 as cited in Vidal et al. (2010), were successfully introduced into Spain (Cáceres province) in 1921 to control mosquito larvae and pupae. In 1922, they were transferred to Lago di Porto, Ostia, Paludi Pontine and Vetralla in Italy (Radošević, 2013) and then to almost every European country, as well as to Asia and the Middle East (Copp et al., 2005; Radošević, 2013) and have since spread successfully to over 40 countries (Welcomme, 1988). The same eastern mosquitofish population from Spain (named *Gambusia patruelis*, Poeciliidae) arrived at Croatia in spring 1924, where introductions began in the Trogir area of Dalmatia. In June 1924, eastern mosquitofish was translocated to the Poreč marsh and the environs of Vrsar, Rovinj and Pula in the Istrian Peninsula and not in Italy as stated by Vidal et al. (2010). In August 1924, eastern mosquitofish were translocated to Krk Island (Radošević, 2013). Twelve specimens of common mosquitofish arrived in 1926 to Rovinj, Croatia directly from the USA, as they were supposed to be more resistant to cold weather than the eastern mosquitofish (Radošević, 2013; Vidal et al., 2010). In Slovenia, mosquitofish (species unknown) arrived in the Koper saltern area in 1927, where they managed to survive (Radošević, 2013).

Recently, a single male common mosquitofish was identified in Slovenia, in a pond between the Rižana and Aro rivers. However, the gonopodium morphology of this specimen, and the variable dorsal fin ray count of other specimens from the same locality, indicates that the common mosquitofish was also introduced and subsequently hybridized with the eastern mosquitofish (Veenvliet, 2007). In North America, these two species hybridize and eastern mosquitofish genotypes tend to outcompete and even replace those of the common mosquitofish where they coexist naturally or by introductions (Vidal et al., 2010; Walters & Freeman, 2000). A recent genetic study suggested that the mosquitofish in Europe should be referred to as eastern mosquitofish;

unless the gonopodium morphology, fin ray counts or genetic identification clearly demonstrates that it is common mosquitofish (Vidal et al., 2010 and references within).

At around the same time as introductions began in Croatia (1924), the eastern mosquitofish also arrived at Bosnia–Herzegovina and soon dispersed throughout the whole territory of the former Yugoslavia (Vuković & Ivanović, 1971), with the exception of Serbia (Lenhardt et al., 2011; Simonović et al., 2013). In FYR Macedonia, eastern mosquitofish were first intentionally introduced into Dojran Lake in 1924 (referred to as common mosquitofish, Apostolski, Petrovski, Popovska, & Sidorovski, 1956). The species spread rapidly to inhabit the largest rivers of FYR Macedonia (Vardar River, Bregalnica, etc.). In Bulgaria, it was introduced in 1924 (Uzunova & Zlatanova, 2007) and the first successful breeding attempts were made near the Tundzha River (Mikov, 2005). These fish were massively bred and introduced as a biological agent to Bulgarian malaria-rich areas, such as swamps, lakes, coastal lakes and wetlands near the Black Sea shore and the Danube River (Zarev, 2012). In Montenegro, eastern mosquitofish were introduced into the marshes around the city of Bar in the 1930s for biocontrol purposes (Tischler, 1950) and not in 1957 when it was first reported (Drecun, 1957), as malaria was virtually eradicated in Europe in the 1950s (Gachelin & Opinel, 2011). According to Shumka et al. (2008), eastern mosquitofish were first introduced to Albania in 1979, although the first introduction likely occurred earlier, in the 1950s, when active eradication campaigns against malaria were conducted (Berger, 2015). The first documented introduction of mosquitofish to Greece was *G. patruelis* from Italy and France, between 1927 and 1937 (Livadas & Sphangos, 1941), appearing also in Eastern Thrace at the same time, also introduced for biological control (Geldiay & Balık, 1988).

Paddlefish is native to the Mississippi River basin in the USA (McClanes, 1974). Burtsev and Gershanovich (1976) and Reshetnikov et al. (1997) reported they were first introduced into Russia for farming and ornamental purposes in 1970 and 1974, respectively. They entered natural waters, although natural reproduction was not recorded (Reshetnikov, 2003a). Paddlefish were recorded in the upper Danube River following introductions for aquaculture in Hungary (1986), Germany (1987) and Austria (1990) (Zauner, 1997), although Holčik (2006) claims this species was released into natural waters by aquarists. In Bulgaria, paddlefish were introduced from 2002 to 2004 (Uzunova & Zlatanova, 2007). In the Serbian stretch of the Danube River, paddlefish were first recorded in the Lower Danube River at rkm 426 in 2000 (Simonović, Marić, & Nikolić, 2006) and downstream of the Iron Gate (Đerdap) II dam (rkm 863) in 2006 (Lenhardt et al., 2006; Simonović et al., 2006). Paddlefish are currently reared at fish farms in Germany, Austria, Czech Republic, Bulgaria, Romania and Hungary (Bogutskaya & Naseka, 2006; Hubenova, Zaikov, & Vasileva, 2005; Prokeš, Baruš, & Peňáz, 2000; Vedrasco, Lobchenko, & Billard, 2001) and were introduced to the Gospič fish farm in Slovenia in 2012, also for farming (Povž, 2012). Vassilev and Pehlivanov (2005) reported the presence of paddlefish fry in the lower Danube, implying their successful acclimatization and possible naturalization. Despite Elvira's (2000) assumption that paddlefish have likely become naturalized in Russian rivers, Holčik (2006) considered that naturalization of paddlefish in the Danube River is highly unlikely due to the scarcity of floodplain zones, oxbow lakes, lagoons and inner deltas in the Upper Danube, and Dniester–Lower Danube ecoregions as favourable habitats for the larger planktonic crustaceans that form the diet of the paddlefish. Despite this, the most recent adult paddlefish specimen was caught in the Croatian section of the lower Danube River at rkm 1418, near the Kopački Rit Nature Park in 2011, without mention of whether this specimen was introduced in an early life stage or developed in nature (Jelkić & Opačak, 2013). In Greece, paddlefish was introduced from Hungary (1995) and the USA (1997) to fish-farm pens near Lake Pamvotis (Ioannina); however, according to Leonardos, Kagalou et al. (2008) was unable to acclimatize and was soon extirpated from the lake. According to Paschos (2002) and Barbieri et al. (2015), there is no evidence of any release of the species in the wild anywhere in Greece.

Striped/white bass (*Morone saxatilis* × *M. chrysops*) is a significant hybrid of a striped bass (*Morone saxatilis*, Moronidae) female and white bass (*Morone chrysops*, Moronidae) male, originally cultured in the USA. It was introduced into Europe and Northern Africa as an aquaculture fish (Nelson, 1994). In 2010, a male specimen of the wiper/sunshine bass hybrid was caught by commercial fishing net in the Croatian section of the Danube River and was assumed to have escaped from an aquaculture facility (Safner et al., 2013). However, according to Tate and Helfrich (1998), these hybrids are fertile but can produce only a few offspring, although Hodson (1989) stated that females produce sufficient number of eggs for successful reproduction once a year. Although not currently believed to be a serious threat to the fish community (Safner et al., 2013), caution should remain.

Sailfin molly (*Poecilia latipinna*, Poeciliidae) is a North American species that was introduced to several countries around the world through the ornamental fish trade. In the Balkans, there is only one known population in Greece; it is a female-dominated feral molly population that inhabits the brackish, geothermally heated Lake Vouliagmeni near Athens (Koutsikos et al., 2012). This population was positively identified as the sailfin molly based on meristic traits (N. Koutsikos, unpublished data).

4.3 | Asian introductions

The first fish introductions, in general, began with common carp (Balón, 1995), although their origins remain unknown (Balón, 2006; Copp et al., 2005). Records from 7000 to 6000 BC indicate that this species was native to the rivers draining into the European part of Ponto-Caspian region (Tsepkin, 1995), originally domesticated in Europe by the Romans (Balón, 2006), while it was later translocated between and within Europe and Asia as a food source (Copp et al., 2005). In most Balkan countries, common carp is considered native and is only reported as introduced in Slovenia and Bosnia–Herzegovina (Table S1), while the debate on its origin continues (Govedič, 2005).

The history of goldfish introductions in Europe dates back to 1611 (Copp et al., 2005), although the exact time of introduction to the Balkans is unknown. It was likely first introduced to Slovenia and Croatia in the late 19th century for ornamental purposes (Povž

& Ocvirk, 1990; Povž & Šumer, 2005). Currently, five Balkan countries report this species as present. In some, goldfish are widespread, while its distribution in others is moderate to restricted (Table S1). This suggests three possibilities: (i) they do not spread easily; (ii) there is a lack of data for the Balkan area; or (iii) they are mistaken for gibel carp or crucian carp (*Carassius carassius*, Cyprinidae) as reported by Kalous, Bohlen, Rylková, and Petrtýl (2012). However, for Albania and Montenegro, it is still possible that goldfish is dispersed through the Ohrid-Drin-Skadar system and transported to neighbouring water systems, such as Prespa Lake (Liasko et al., 2010).

Introductions of gibel carp to Europe are linked with releases of common carp imported to Europe from Chinese aquaculture in around 1611–1691 (see Copp et al., 2005), although the history of its introductions, taxonomical status and native distribution is still not clear. Some authors have suggested that gibel carp is common in Danubian marshes (Kovachev, 1922), although gibel carp and crucian carp were mentioned as varieties and not as separate species. This was also stated for Bulgaria (Drensky, 1948), with notes of the presence of both sexes in the Danube and the suggestion that two-year-old females became male (Busnita, 1938; cited by Berg, 1964 as an incorrect hypothesis). Is it possible that the physical similarity of the brown varieties of goldfish, gibel carp and crucian carp resulted in the misidentification of these introduced species for the native crucian carp, as suggested by Copp et al. (2005)? Although it has been debated whether gibel carp is alien in all of Europe (Lusková, Halačka, Vetešník, & Lusk, 2004), new research based on molecular analysis suggests that gibel carp populations in Central Europe and parts of Eastern Europe are native, resulting from natural post-glacial range expansion, while the rest of Europe was colonized anthropogenically (Bohlen, Lamatsch, & Petrtýl, 2013). Based on this, gibel carp in Bulgaria is considered to be a native species, translocated to the Northern Aegean basin, especially Strymon and Nestos rivers. The first findings in this area revealed only the presence of gynogenetic females (Economidis, 1974), while a sex ratio of 3-4: 1 of females: males in Strymon was reported (Apostolou, 2002), indicating that the species is a recent invader in these areas. The arrival of gibel carp in the Dniester–Lower Danube ecoregion is thought to have occurred in 1912 as a consequence of its natural spread down the Danube (Copp et al., 2005; Perdikaris et al., 2012). More than five decades later, in the late 1950s, gibel carp was documented in the Serbian part of lower Danube at the border with Romania (Plančić, 1967), when rapid dispersal into the Balkans began. By the 1980s, it had already spread throughout most of former Yugoslavia, even reaching the Adriatic drainage, and was becoming commercially relevant (Vuković, 1982). There are several suggestions as to how this species was introduced to the freshwaters of Greece (Economidis, Dimitriou et al., 2000; Tsoumani, Liasko, Moutsaki, Kagalou, & Leonardos, 2006). More recent studies suggest that the species was either translocated from Lake Kerkini (Strymon River) to Lake Pamvotis or was introduced from Italy to the same lake during the 1950s or later (Leonardos, Kagalou et al., 2008; Perdikaris et al., 2012).

The most recent find of a new *Carrasius* complex species in the Balkans is the gin-buna carp (*Carassius langsdorfii*, Cyprinidae), first detected in Greece in 2009 (Tsipas, Tsiamis, Vidalis, & Bourtzis, 2009). This species was first reported in Europe in 2000 (Kalous, Šlechtová, Bohlen, Petrtýl, & Švátora, 2007) and seems to have only recently been introduced. The pathways and vectors of its introduction to Europe are not known, but it was most likely an unintended introduction accompanying other cyprinid fishes (Rylková, Kalous, Bohlen, Lamatsch, & Petrtýl, 2013). Genetic data have revealed the existence of at least two lineages among the gin-buna carp that have been introduced to Europe (Kalous et al., 2007; Tsipas et al., 2009), both of which are found in Greece, and one is found in Bosnia–Herzegovina (Rylková et al., 2013).

The invasion of gibel carp coincided with the introduction of the Chinese carps, that is grass carp, silver carp, bighead carp and a decline of the native crucian carp populations, attributed to a shift from clear to turbid water-preferring species in the Danube River (see Copp et al., 2005). The first known introduction for the Balkan area was recorded in Albania (1959), when fingerlings of grass carp and silver carp were imported from China, with reintroduction occurring in 1968 with the imports of bighead carp and likely Wuchang bream (*Megalobrama amblycephala*, Cyprinidae), (Shumka et al., 2008). The same authors mentioned that all these introduced species, including crucian carp, successfully reproduced in 1972. For the majority of the Balkans countries, crucian carp are native fish although they are considered alien for Albania and Turkey-Thrace (Shumka et al., 2008; Tarkan et al., 2015). According to the latest information, crucian carp were unintentionally introduced to Lake Taşkısı in Turkey in the 1950s (S. Tarkan, unpublished data), and not in 1990, as previously reported (Tarkan et al., 2015), as it was obviously misidentified due to its similarity with other *Carassius* species. Reports of crucian carp introductions by Shumka et al. (2008) in Albania could be erroneous due to a lack of data on gibel carp presence. Is it possible that this fish also arrived from China together with other Chinese carps and was mistaken for gibel carp? This was suggested by recent research of Skadar Lake in Montenegro, where an abundant gibel carp population was found, though no crucian carp (Mrdak, 2009).

Due to the role of Asiatic herbivorous fish in increasing production in fish ponds and their commercial significance, grass carp fingerlings were imported to Serbia at the end of 1963 from Hungarian ponds (Mihajlović & Ćirić, 1969). Thereafter, probably in 1964, silver carp were also imported from Hungary to the same fish farm (Vuković & Kosorić, 1978). It is not documented when bighead carp were imported into the Balkans, although it seems that this rather occurred together with silver carp in Serbia (Fijan & Vojta, 1969). In the same period, Chinese carp species were introduced to Bulgarian ponds (Uzunova & Zlatanova, 2007), and several years later, in 1966, also into Croatian fish ponds, also from Hungary (Fijan & Vojta, 1969). In Slovenia, the first introductions were performed from Croatian fish farms (Povž & Ocvirk, 1990; Povž & Šumer, 2005) but after 1966 (Fijan & Vojta, 1969), and not in 1963 as previously reported (Povž & Šumer, 2005; Welcomme, 1988). Fishes were translocated among the former Yugoslav nations without exact known dates (Povž & Ocvirk, 1990). In FYR Macedonia, the first attempts to rear Chinese carp species were in the period 1965–1975 at several fish farms located on the Crna and Vardar rivers, without a known source of introduction (Kostov, Ristovska, Prelić, & Slavevska-Stamenković, 2011). Silver carp and grass carp in Greece were introduced between the 1970s and 1980s for the biological control of plants and planktonic organisms in aquaculture ponds (Zenetos et al., 2009).

Topmouth gudgeon were introduced into Europe (Romania) in the 1960s from the Yangtze River (Wuhan Province) concomitantly with Chinese carp species' imports and then spread through the Danube River basin (Gozlan et al., 2010). It has also been documented that topmouth gudgeon were introduced into Lake Skadar in Albania as a food item for predatory fishes in hatcheries (Wildekamp, Van Neer, Küçük, & Ünlüsayın, 1997), possibly prior to 1970 (Gozlan et al., 2010; Knežević et al., 1978; Wildekamp et al., 1997), which could represent a second source of dispersal. Both sources were mentioned as potential introduction routes for Small Prespa Lake, Great Prespa Lake and the Aliakmon River in Greece in the 1970s (Bianco, 1988), for Šasko Lake in Montenegro in 1977 (Knežević et al., 1978), for the Lugomir River in Serbia in 1978 (Cakić, Lenhardt, Kolarević, Micković, & Hegediš, 2004) and for the Meric River-İpsala in Turkey-Thrace in the 1980s (Ekmekçi & Kırankaya, 2006). A third source of dispersal could be the Ukraine, where Chinese carp species were imported for aquaculture, as the first Bulgarian record in 1976 is thought to be the result of this invasion (Marinov, 1979). The southern Bulgarian population could be the result of invasion from south-east Europe (Albania) (Wildekamp et al., 1997). In Albania, topmouth gudgeon occurred in the period between 1960 and 1970 (Rosecchi, Crivelli, & Catsadorakis, 1993; Wildekamp et al., 1997) and not since 1998 as claimed by Shumka et al. (2008). Later, likely via dispersal within the Upper Danube and Dniester–Lower Danube ecoregions, this species was recorded in the Sava River in Croatia in 1985 (Habeković & Popović, 1991) and in the Jasenek stream near Celje in Slovenia in 1986 (Povž & Ocvirk, 1990). Much later, the presence of the topmouth gudgeon in FYR Macedonian open waters was first recorded in 1996 (Georgiev, 2000), although they were obviously present since the 1970s in the Great Prespa Lake, shared by Albania, Greece and FYR Macedonia (Rosecchi et al., 1993).

In addition to gibel carp, topmouth gudgeon and the Chinese carps, white amur bream (*Parabramis pekinensis*, Cyprinidae) was already introduced to the Great Prespa Lake by the late 1970s (Rosecchi et al., 1993). Thus, they could have also occurred then in Greece and FYR Macedonia, despite a lack of reports. However, they were introduced into Small Prespa Lake much earlier (in 1959) by the Albanians, either intentionally (Crivelli, 1995; Economidis, Dimitriou et al., 2000; Rosecchi et al., 1993), or accidentally as escapees from fish farms (Perdikaris et al., 2010 and references within). Nevertheless, it appears that white amur bream has not become established, since none have been recently caught for several years (Perdikaris et al., 2010) and the status of this species remains unknown (Crivelli, 1995; Froese & Pauly, 2015). Two more Asian species, black Amur bream (*Megalobrama terminalis*, Cyprinidae) and black carp (*Mylopharyngodon piceus*, Cyprinidae), were introduced into Skadar Lake shared between Albania and Montenegro, likely by the Albanians in 1963 (Holčik, 1991) and were recorded in Montenegro in 1973 (Vuković & Knežević, 1978) and 1983 (Knežević & Marić, 1986). In the same period, amur bream was introduced into Bulgaria (in 1964), where it was used for the biological control of the zebra mussel (*Dreisena polymorpha*, Dreissenidae) population in the Ovcharitza reservoir (Uzunova & Zlatanova, 2007) and recently in Slovenia (2004) for aquaculture and angling purposes (Povž, 2009a). Both these species have acclimatized to their new environments, although natural reproduction has not been confirmed.

Chinese sleeper (*Perccottus glenii*, Odontobutidae) is one of the most invasive fish species in Eastern and Central Europe in recent decades (Copp et al., 2005). Chinese sleeper possesses an opportunistic and aggressive behaviour making it the perfect invader (Ćaleta, Jelić et al., 2011). Its accelerated expansion has been documented on several occasions in association with Asian cyprinid stockings (see Grabowska et al., 2011) and this species was introduced on multiple occasions into various parts of Asia and eastern Europe (Bogutskaya & Naseka, 2002; Uzunova & Zlatanova, 2007). Since its first appearance in the catchment of the Tisa River (Hegediš et al., 2007; Koščo, Lusk, Halačka, & Luskova, 2003; Simonović et al., 2006), its spread in the Danube River was only a matter of time (Hegediš et al., 2007; Jurajda, Vassilev, Polačik, & Trichkova, 2006). Its first occurrence in the Balkan Peninsula was in 2003 in the Serbian section of the lower Danube River (Gergely & Tucakov, 2003). It was recorded in the Bulgarian part of the Danube River and its marshes and lakes in 2006 (Uzunova & Zlatanova, 2007), and the latest record was from 2008 from a channel near the Sava River in Croatia (Ćaleta, Jelić et al., 2011). In the early stages of its invasion, high densities of Chinese sleeper were recorded at many locations in Europe (Bogutskaya & Naseka, 2002), although its prevalence in the Balkans remains moderate, as is the case for Serbia (Simonović et al., 2006) and restricted in Bulgaria (Uzunova & Zlatanova, 2007), while in Croatia, following the first findings, its presence was not later confirmed (Ćaleta, Jelić et al., 2011). Although some have predicted that this species will be able to establish a stable population in the near future (Uzunova & Zlatanova, 2007), having an adverse impact on the native ichthyofauna (Reshetnikov, 2003b), and thus strong restrictive measures have been advised (Ćaleta, Jelić et al., 2011), it appears that it has failed to invade the upper part of the Danube basin. According to Koščo et al. (2003), this species is a poor swimmer and it may be expected that its dispersal within a river system would mainly be downstream. However, the possibility that it is still going through the process of acclimatization should not be ruled out (Simonović et al., 2006).

4.4 | European introductions

4.4.1 | Eastern Europe

Five of the Ponto-Caspian (P-C) gobies (Pisces, Gobiidae) have been reported in the Balkans to date: bighead goby, monkey goby, round goby (*Neogobius melanostomus*, Gobiidae), racer goby (*Babka gymnotrachelus*, Gobiidae) and western tubenose goby (*Proterorhinus semilunaris*, Gobiidae). Native distributions of (P-C) gobies were mostly confined to the lower reaches of the Danube River and the littoral zone of the Black Sea; thus, they are native species for Bulgaria and Turkey (Vassilev, Apostolou, Velkov, Dobrev, & Zarev, 2012). The

Djerdap Gorge represented the uppermost range boundary of bighead goby, monkey goby, racer goby and round goby (Miller, 2003). Historically, the western tubenose goby had the farthest range up the Danube of all the Ponto-Caspian Gobies, being found as far upstream as Vienna and the mouth of the Morava River on the Czech/Slovak border (Roche, Janač, & Jurajda, 2013). Thus, the western tubenose goby is considered as native to Croatia (Jakovlić et al., 2015; Polačik et al., 2008), but not to Serbia or Bosnia–Herzegovina (Simonović, 2006). The distribution, invasion and range expansion of these P-C gobies has been well documented (Roche et al., 2013) and they continue to expand their distribution across the European continent (Jakovlić et al., 2015). The most recent record of range expansion was for the bighead goby in the Slovenian part of the Sava River in 2015 (Simonović et al., 2017) and for the monkey goby in the Evros River in Greece in 2011 (Zogaris & Apostolou, 2011). However, caution is needed in accepting an alien status for this record in Greece due the lack of previous ichthyological studies of the Evros River and the close proximity of this river to the species' native distribution range; although it is unlikely that a conspicuous medium-sized fish would go unnoticed (Zogaris & Apostolou, 2011), which may indicate new range expansion in Greece inland waters. P-C gobies are not reported for Albania and Montenegro.

Aristotle's catfish is a species endemic to the lower Acheloos River system (western Greece, Economidis, 1991) listed in the IUCN Red List of Threatened Species as data deficient (Crivelli, 2006). Populations occur in the Trichonis, Lysimachia, Ozeros and Amvrakia Lakes (Lower Acheloos basin), as well as the Pamvotis, Volvi and Yliki Lakes via translocation (Barbieri et al., 2015; Leonardos, Tsikliras, Batzakas, Ntakis, & Liousia, 2009). Recently, two specimens of Aristotle's catfish were identified from a small artificial lake in the Montana district (northwest Bulgaria), which is the first find outside Greece. In all likelihood, the species was introduced to Bulgaria as a seeding fish from Macedonia (northern Greece, Pehlivanov & Atanasov, 2007).

Pikeperch was introduced in the Mladost reservoir in FYR Macedonia in 1967 along with carp offspring from Croatia (Georgiev & Naumovski, 1982), where they successfully reproduced. Its distribution is restricted only to this reservoir. In the 1980s, pikeperch was also introduced to Fierza Lake in Albania for aquaculture, also from the former Yugoslavia, although its current status is unknown (Shumka et al., 2008).

Eurasian perch (*Perca fluviatilis*, Percidae) was introduced to Fierza Lake in Albania at about the same time and for the same purpose as pikeperch (Shumka et al., 2008), with populations becoming naturalized in the inland waters of Albania.

Short-snouted pipefish (*Syngnathus abaster*, Syngnathidae) is native to the Mediterranean and Black Seas and to the Atlantic coast from Gibraltar to the southern Bay of Biscay. The first record of the short-snouted pipefish in Serbia was in 1998 (Sekulić, Cakić, Lenhardt, Vucić, & Budakov, 1999). This introduction was likely via ballast water originating from the Black Sea (Cakić, Lenhardt, Mićković, Sekulić, & Budakov, 2002). A study on the fish communities of the lower Danube River (Djerdap reservoir) revealed an increase in the abundance of short-snouted pipefish in grassy littoral habitats (Simić & Simić, 2004), although their dispersal remains limited and their impact insignificant (P. Simonović, personal observation).

Common bream (*Abramis brama*, Cyprinidae) is native to most of Europe (including the Balkan Peninsula) and western Asia but not to FYR Macedonia (Kostov et al., 2015 and references within) where 22 specimens were first captured in the Tikvesh Reservoir, Crna River (Vardar River basin), in 2014. Common bream was possibly introduced from Bulgaria or Serbia, accidentally imported with cages from Bulgaria between 2006 and 2008 or with fry from Serbia for stocking sport and recreational fisheries in 2008 (Kostov et al., 2015). The impact of common bream on native fish populations and ecosystems in FYR Macedonia is still unknown.

European grayling is native to the Black Sea drainage area and to the Dalmatia ecoregion, including Slovenia and Croatia (Froese & Pauly, 2015; Mrakovčić et al., 2006), but not to the south-east Adriatic ecoregion, that is Albania and Montenegro. European grayling was introduced to the Skadar Lake drainage area in the 1960s (Drecun, 1962; Knežević, 1981) and is present in the inland waters of Montenegro (Morača River) and may also be present in Skadar Lake (Talevski et al., 2009). In Bulgaria, European grayling was also introduced in the 1970s in a small highland reservoir (Uzunova & Zlatanova, 2007) but it is assumed to have since disappeared.

Tench (*Tinca tinca*, Cyprinidae) is native to most of Europe, but not to Albania. This species was introduced to this country in the late 1980s for aquaculture purposes (Rakaj & Flloko, 1995; Shumka et al., 2008) and has since become established in the transboundary Prespa Lake (Shumka, Aleksi, Sandlund, Cake, & Mali, 2013).

Letnica trout (*Salmo letnica*, Salmonidae) was introduced to Serbia and Greece from Lake Ohrid. In Greece, it was introduced to the transboundary Prespa Lakes (Crivelli et al., 1997) in the 1950s, where it may have hybridized with the local endemic trout *Salmo peristericus* Karaman, 1938. Its current status within Greek territory is unknown (Barbieri et al., 2015); however, a single individual was caught again in 2011 in Great Prespa Lake (Koutseri, 2012). Introductions to Serbia began in 1953 and 1954, when fry (10^6 each year) were stocked (Janković & Raspopović, 1960a). Afterwards, fertilized roe was transferred to the new hatchery set on the Lake Vlasina reservoir for the establishment of a commercial trout fishery there. Since the late 1960s, roe was reintroduced almost every year, since it seems that this species did not naturalize in the reservoir, despite its fast growth and great yield. It is not known whether this species hybridizes with the native brown trout, but from the regular roe imports over a long-term period, it appears that letnica trout were feral there and diminished after the cessation of reservoir stocking.

4.4.2 | Northern Europe

Five fish species from Northern Europe have been introduced to the Balkans, that is European whitefish, peled, vendace (*Coregonus albula*, Salmonidae), Arctic charr and Atlantic salmon (*Salmo salar*, Salmonidae).

The first known introduction of the *Coregonus* genus dates back to 1937, when larvae of *Coregonus* sp. was imported from Austria to the

Plitvice Lakes in Croatia (Habeković, 1978). This introduction was not successful, but one year later, a new shipment of larvae was imported and released (Plančić, 1938). It is not known whether this introduction succeeded (Taler, 1949), although *Coregonus* sp. forms part of the ichthyofauna of the Plitvice Lakes (D. Zanella, personal observation). The second introduction in Croatia was carried out in 1977 and 1978, when larvae of European whitefish and peled were imported from the former Czechoslovakia and introduced to the Draganići fish farm and Peruča reservoir on the Cetina River (Habeković, 1978; Jevtić, 1991). Between these two introductions in Croatia, there was a successful introduction to the Tavropos reservoir in Greece in the 1950s, likely for angling purposes (Petridis & Sinis, 1993). For the same reason, vendace in 1964, peled in 1970 and European whitefish in 1978 were introduced to Bulgaria and successfully adapted to the conditions of the larger and deeper Bulgarian upland reservoirs. Two of these species, peled and European whitefish, naturalized in several very large mountain lakes, such as Iskar and Dospat (Uzunova & Zlatanova, 2007). Much later, peled was introduced to Serbia in the Drina reservoir in 1991 for aquaculture and later for angling purposes (Simonović, 2006) but the current status of this species in Serbia is unknown. The same year, European whitefish was recorded in the Slovenian part of Drava River, following its downstream movement from the Austrian part of the river, and it has since been found continuously (Povž & Šumer, 2005). The most recent introduction of peled, in 1999, occurred in Bosnia–Herzegovina during the restocking of Boračko Lake. This introduction was successful, as confirmed by recent angler catches (Hamzić, Muhamedagić, & Lelo, 2011).

The first known introduction of charr in the Balkans likely dates back to 1928, when *Salvelinus* sp. from Italy was introduced to Krnsko Lake in Slovenia. The second introduction to Slovenia from Austria occurred in 1943 in Bohinj Lake for sport fishing purposes (Povž & Ocvirk, 1990). However, for both Slovenian records, it is unclear whether the species introduced were Arctic charr or lake charr (*Salvelinus umbla*, Salmonidae) as both scientific names have been used in the literature (Piria et al., 2016b; Povž & Ocvirk, 1990; Povž & Šumer, 2005; Povž et al., 2015). The native range of lake charr are the Alpine and subalpine lakes in Italy (Trentino, Alto Adige), France (Lake Bourget), Switzerland, Germany and Austria, while the European range of Arctic charr extends from the northern Atlantic southward to southern Norway, Iceland and southern Greenland, including isolated populations in the Northern UK, Scandinavia, Finland and the Alps (Froese & Pauly, 2015). According to Englbrecht, Schliewen, and Tautz (2002), the alpine populations of Arctic charr were usually included into *S. alpinus*, but were later revised to *S. umbla* (Kottelat, 1997). Could the source of the Slovenian populations be *S. umbla* from alpine populations or *S. alpinus* introduced to Italy or Austria? In Croatia, the introduction of arctic charr is referred to as *S. alpinus*, which 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 or specimens escaped from farms, although the distribution of this species has not yet been revised (D. Jelić, personal communication). Recently, arctic charr was recorded in the Peruča reservoir and Neretva River (J. Budunski, personal communication). It may occur in the Neretva River due to the restocking of several rivers in the Neretva catchment, e.g. Lištica River. This was confirmed by Škrijelj (2002), who stated that the Neretva hydropower reservoirs were repeatedly restocked with this species. Furthermore, arctic charr was first introduced to the waters of Bosnia–Herzegovina in 1943, as *S. alpinus* to Pliva Lake near Jajce, and this species soon populated several reservoirs in the catchments of the Drina, Neretva and Trebišnjica rivers, and Klinje Lake (Sofradžija, 2009). The Serbian literature also refers to *S. alpinus* as an introduced species, first in Kokin Brod reservoir in 1943, then later in Vlasina Lake (Simonović, 2006), while Montenegrin data suggest that *S. alpinus* was introduced in 1955 (Drecun, 1960; Marić, 1991). In contrast, Welcomme (1988) suggested 1928 as the year of *S. alpinus* introduction from Switzerland and Austria to Serbia and Montenegro.

The first introduction of Atlantic salmon in Croatia occurred in the 1980s for experimental hatchery purposes in the estuary of the Krka River, although this was not successful (Skaramuca, Teskeredžić, & Teskeredžić, 1997). The next record in Croatia dates from the 2000s in the Drava River, when anglers caught several specimens of Atlantic salmon (N. Šprem, personal communication), their origin remaining unknown. Atlantic salmon was introduced to Greece in 1985 for rearing in the Edessa hatchery in northern Greece and to hatcheries in central Greece, Peloponnese and Crete (Economidis, Dimitriou et al., 2000).

4.4.3 | Western Europe

The three-spined stickleback (*Gasterosteus aculeatus*, Gasterosteidae) is a small teleost fish considered to be one of the most widely distributed freshwater fishes in the world (Froese & Pauly, 2015). In the Balkans, it is native to the rivers of the Adriatic, Ionian and Aegean basins of Slovenia, Croatia, Montenegro, Albania and Greece (Barbieri et al., 2015; Zanella et al., 2015) and to the Danube River mouth and Black Sea coast of Bulgaria (Biserkov et al., 2015). The first record of the three-spined stickleback in Serbia was in the Danube River at rkm 92 in 1995 (Cakić, Lenhardt, & Petrović, 2000), although there are unverified earlier records (Lenhardt et al., 2011). The species is present in the Mura River (Upper Danube) in Slovenia (Povž et al., 2015) and was recently recorded in the Croatian part of the Mura due to downstream spreading following a flood event (Lisjak et al., 2015). The populations of the Mura and Drava rivers in Slovenia and Croatia are of central European origin, as confirmed by genetic analysis (L. Zanella, unpublished data). Ahnelt, Pohl, Hilgers, and Splechtna (1998) reported that aquarists were responsible for the introduction and spread of the three-spined stickleback in the Danube river system at the end of 19th century, although the possibility that this species had already existed in the Danube cannot be excluded. The species has no economic value, and its impact on native fish species has not yet been investigated (Lenhardt et al., 2011).

Brown trout is one of the most attractive recreational salmonid species. It was first introduced to the Soča River (Gulf of Venice ecoregion) in 1906 (Ocvirk, 1989; Povž & Ocvirk, 1990), where it hybridized successfully with endemic salmonids (Crivelli, 1995). In the late 1980s, only eight genetically pure (i.e. not introgressed) marble trout (*Salmo marmoratus*, Salmonidae) populations were identified in the upper

Soča basin (Fumagalli et al., 2002), whereas all other populations were found to be introgressed with alien trout of Danubian and Atlantic origin (Berrebi, Povž, Jesenšek, Cattaneo-Berrebi, & Crivelli, 2000; Snoj et al., 2000). Stocking of brown trout of Atlantic lineage has also taken place in the Jadro River in Croatia (Dalmatia ecoregion), likely in the 1990s, in the habitat of the highly endangered endemic population of softmouth trout (*Salmo obtusirostris*, Salmonidae), thought to be of ancient origin (Snoj et al., 2007). Population-specific microsatellite allele profiles indicate hybridization between brown trout of Atlantic lineage and Jadro softmouth trout (Sušnik et al., 2007). This has raised concerns that introductions of brown trout of Atlantic and Danube linages into the Adriatic basin catchment may lead to the extinction of endemic trout species (Mrdak et al., 2012; Snoj, Bogut, & Sušnik, 2008). Supportive evidence for this can be found in the Danube River basin, that is introgression of alien At1 haplotype of Atlantic brown trout (Marić, Sušnik, Simonović, & Snoj, 2006), which caused the loss of intraspecific variability, following the introduction of alien strains and a change in genetic composition of native brown trout stock of Danube lineage (Simonović et al., 2014). Considering the impact of introduced foreign-sourced brown trout on native brown trout stocks in Serbia, brown trout of the Atlantic lineage was found to be the most invasive alien brown trout strain in Serbia (Simonović et al., 2015). Introductions of brown trout of Atlantic origin in the Balkans were reported in the 2000s for most countries (Table S1), although introductions likely began with early angler activities and restocking with foreign lineages, such as in Croatia in the 1970s (Jadan, Čož-Rakovac, Topić Popović, & Strunjak-Perović, 2007). Despite heavy stocking with alien strains of trout (Snoj et al., 2009), no haplotypes of Atlantic or Danubian brown trout phylogenetic lineages were found in Albania.

4.5 | African introductions

African species have only recently been recorded in the Balkan Peninsula. The first introduction with Nile tilapia occurred in Greece in the 1980s, into fish farms near the towns of Epidavros (Peloponnese), Arta and Nafpaktos (western Greece, Katsaros & Fousekis, 1997; Perdikaris et al., 2010) and the Kremasta Reservoir (western Greece, Perdikaris et al., 2010; Barbieri et al., 2015). Nile tilapia in Greece is a potential new candidate species for the diversification of conventional warm-water aquaculture production, as local environmental conditions in geothermal waters give excellent potential for its acclimatization (Perdikaris et al., 2010). Its overwintering and survival in deep ditches have already resulted in established populations in the lower part of Arachthos River (near Arta, western Greece, Perdikaris et al., 2010) and in the Thermopylae hot springs catchment (central Greece, Barbieri et al., 2015). A similar situation was reported for Slovenia, where Nile tilapia was introduced into the geothermal system of the Topla struga channel near Brežice in 2008 where it has become established (Povž, 2009b). The impact of this species could be adverse on self-recruiting native species due to the strong competition of its high-density populations and dominant behaviour at spawning grounds (Perdikaris et al., 2010). Slovenian populations could be a potential source for dispersal of Nile tilapia via the Sava River system to the Lonjsko Polje floodplain area in Croatia, where they were recorded in 2008, although this might be the result of unintentional release from home aquaria (D. Zanella, personal observation). Mozambique tilapia (*Oreochromis mossambicus*, Cichlidae) was introduced into the Ovchariza reservoir in Bulgaria in the 1990s (Uzunova & Zlatanova, 2007). Recently, only isolated specimens of Mozambique tilapia could be found in Bulgaria (Uzunova & Zlatanova, 2007), although the actual population size is unknown (A. Apostolou, personal observation).

North African catfish (*Clarias gariepinus*, Clariidae) have occurred in Slovenia since 1997 in gravel pits near the Hungarian border, likely as a consequence of sport fishing activities (Povž, 2007), and in 2007, they were recorded in the Ovcharitza Reservoir in Bulgaria (Uzunova & Zlatanova, 2007), although the source and status of both introductions are unknown. The most recent introduction of North African catfish occurred in 2010 at the Draganići fish farm in Croatia for aquaculture purposes (Mislav Šarić, personal communication).

4.6 | South American introductions

The pirapitinga (*Piaractus brachypomus*, Serrasalmidae) is a tropical fish characteristic of the Amazon and Orinoco basins, where it inhabits large flooded rivers and lakes (Jégu, 2003). Outside its natural distribution range, the pirapitinga is most common in the open waters of the USA, due to aquarium related releases and fish farm escapes (Nico & Fuller, 2010). Pirapitinga have also been recorded in Europe: in Spain (Leunda, 2010), Slovakia (Hensel, 2004), Poland (Nowak, Szczerbik, Tatoj, & Popek, 2008), Croatia (Ćaleta, Tutman et al., 2011), Montenegro (D. Mrdak, personal communication) and Greece (2012), where it was possibly misidentified as red piranha *Pygocentrus nattereri* Kner, 1858 (Perdikaris et al., 2016), which still requires clarification (L. Vardakas, pers comm). All these individuals are assumed to have been released by aquarists, and their establishment and impact are completely unknown (Froese & Pauly, 2015).

The guppy is one of the most popular aquarium fishes. Its viable populations have become established in many hot springs or warm effluents of power plants in many European countries (Hanel et al., 2011). In the Balkans, it is present in Pancharevo Lake near Sofia, Bulgaria (Uzunova & Zlatanova, 2007), with an unknown date of introduction. Several authors mention its presence in Albania (Hanel et al., 2011; Shumka et al., 2008), but without any other information. The current status, distribution or potential impact of the guppy in both countries is unknown. However, recent research in Serbia suggests that the guppy (found in 1970) has become naturalized in a thermal stream, together with other ornamental organisms, allochthonous plant species (*Vallisneria spiralis*, *Elodea canadensis* and *Lundwigia repens*) and the alien snail *Melanoides tuberculate* (Milenković et al., 2014).

The Amazon sailfin catfish, native to the Amazon River Basin of Brazil and Peru, is a new non-indigenous fish species recorded in the Serbian section of the Danube River at river km 1026, making this the first report for the inland waters of Europe (Simonović et al., 2010). The status of this species in the Danube is unknown, although it may negatively impact the aquatic food base and native invertebrate and vertebrate species (Nico & Martin, 2001).

4.7 | Multiple origin introductions

Eurasian ruffe (*Gymnocephalus cernua*, Percidae), which is native to the Caspian, Aral, Black, Baltic and North Sea basins, Siberia (Petriki, Naziridis, Apostolou, Koutrakis, & Bobori, 2014), occurs in the Balkan countries situated in the Danube River Basin. This species has been recorded in several aquatic ecosystems outside of its native range, both in Europe and in North America (Brown, Selgeby, & Collins, 1998; Hume, Adams, Bean, & Maitland, 2013). In FYR Macedonia, Eurasian ruffe was first found in the Tikvesh reservoir connected with the Crna River in 1997. It may have been an unintentional release from fish pond stocking with common carp near the middle and upper reaches of the Crna River in Pelagonia (Georgiev & Kostov, 1998). The most recent record was for the Strymon River Basin, shared among Bulgaria, Greece, FYR Macedonia and Serbia, with two specimens found in Kerkini Lake in 2012. It was hypothesized that the species has not yet established large populations in this river system (Petriki et al., 2014). However, it is considered an efficient invader due to its adaptability and tolerance to a wide range of environmental conditions, as well as its high fecundity and strong reproductive potential (Lorenzoni, Pace, Pedicillo, Viali, & Carosi, 2009).

Sterlet was introduced to the Tikvesh Reservoir, FYR Macedonia prior to 2006 (Kostov, Georgiev, Nastova-Gjorgjioska, & Naumovski, 1998). There are two possible reasons for this introduction, that is it was introduced along with carp stocking from Bulgaria, or it was imported from Serbia in 1997 for ornamental fish breeding, and then released into the waters of the Crna River (Kostov et al., 2011).

Danube sturgeon and Siberian sturgeon (*Acipenser baerii*, Acipenseridae) were imported to Greece from Russia in 1997 as eggs to the Lake Pamvotis hatchery for rearing in closed systems (Economidis, Dimitriou et al., 2000). Danube sturgeon was also imported to FYR Macedonia in the 2000s from Bulgarian hatcheries for aquaculture purposes (Kostov, 2008). According to Leonardos, Tsikliras et al. (2008), there is a record of the release of *A. baerii* in Pamvotis Lake (north-western Greece), while according to Paschos (2002) and Barbieri et al. (2015), there is no evidence that Siberian sturgeon were ever released (intentionally or accidentally) to the wild in Greece. Recently, in September 2016, Siberian sturgeon was released into the Sava and Mura rivers in Slovenia, due to misidentification of the species with sterlet (M. Povž, personal observation).

5 | ECOLOGICAL IMPLICATIONS

The introduction of new species can have unexpected negative consequences (Gozlan, St-Hilaire, Feis, Martin, & Kent, 2005), it may not have any reported ecological impact on the native ecosystem (Gozlan, 2008), or the species may disappear without causing any ecological impacts (Lehtonen, 2002). In the Balkans, there are few reports on the ecological impacts of introduced fishes. Most publications are studies outlining the general risks associated with the introduction of alien fish species (Vilizzi, 2012). It has been postulated that many introduced alien species cause adverse effects (Britton, Gozlan, & Copp, 2011; Copp et al., 2005; Economidis, Koutrakis, & Bobori, 2000; Economidis, Dimitriou et al., 2000; Gozlan et al., 2005, 2010), although there is an ongoing scientific debate about whether, instead of causing significant disturbances in the ecosystems, the introduction of alien species can result merely in an increase of biodiversity (Gozlan, 2008), or can even have positive impacts on native species (Rodriguez, 2006; Schlaepfer, Sax, & Olden, 2011). In some natural lakes (and reservoirs) with an impoverished fish fauna or no fish fauna, the introduction of alien species through concerted state-sponsored stocking programmes and private initiatives could be deemed beneficial, by increasing fisheries production or by contributing to the ecological balance of eutrophic lentic ecosystems (for Greece, see Economidis, Dimitriou et al., 2000). In many other lentic systems, however, introductions of alien species have dramatically altered their ecological communities. Extensive stocking, mainly for commercial purposes and sport fishing, coupled with unintentional introductions, have radically affected the fish fauna of those aquatic systems, leading even to the extinction of native species. An example is the Tikvesh Reservoir, the largest artificial lake in FYR Macedonia, where of a total of 20 fish species, seven are now alien, and the non-indigenous brown bullhead has become dominant in the lake (Kostov et al., 1998, 2011). The same is also true for natural lakes, such as Skadar Lake, which was extensively stocked by Albanian authorities to support commercial fishing. Another example is Lake Pamvotis (Greece), an acute example of the combined effects of rapid degradation of ecological quality and alteration of the trophic complexes on a lentic ecosystem due to stocking; the numerous and largely uncontrolled introductions in this lake for extensive stocking, along with several accidental introductions, resulted in the severe decline or near extinction of native species (Leonardos, Kagalou et al., 2008; Zenetos et al., 2009). The fish fauna of the lake currently consists of 20 introduced (including translocated) and only four native species, of which at least one, the local endemic Epirus minnow (*Pelasgus epiroticus*, Cyprinidae), is near extinct or most likely extinct, while the population of Albanian barbel (*Luciobarbus albanicus*, Cyprinidae) in the lake has already collapsed (Leonardos, Paschos, & Prassa, 2007; Leonardos, Kagalou et al., 2008). In the past, mountain streams and rivers were also stocked, usually with trout species for angling, as is the case in Montenegro, where virtually all rivers were stocked with rainbow trout and brook trout (D. Mrdak, personal observation).

In addition to other negative impacts of alien species on freshwater ecosystems, the introduction of alien infectious agents represents one of the greatest risks associated with this global movement and introduction of species (Britton et al., 2011). As such, topmouth gudgeon in Europe is a carrier of several pathogens (Gozlan et al., 2005), posing a risk not only to freshwater aquatic species, as this threat has also expanded to marine fishes, for example as with the transfer of the *S. destruens* pathogen to European seabass (*Dicentrarchus labrax*, Moronidae), (Ercan et al., 2015). From the perspective of the entry of pathogens into Balkan freshwaters, few studies have given reports (Nikolić & Simonović, 2002; Nikolić, Simonović, & Karan Znidaršić, 2007), and none has focused on the consequences and/or impact mechanisms on native populations. Little is still known about the consequences of the introduction of freshwater fishes and of various pathogens, indicating the need for future monitoring and research efforts concerning this issue (Britton et al., 2011). On the other hand, due to climatic reasons, several alien species have rare to no natural reproduction in the Balkans and as a result, dispersion is often limited. For example, Asian carps breed naturally only in the Danube River, and only in those years when higher water levels concur with higher temperatures (Janković, 1998). However, tolerant species such as the eastern mosquitofish, pumpkinseed and topmouth gudgeon occur in most river courses, plain reservoirs and lakes of the Balkans. Similarly, the Mediterranean and sub-Mediterranean climate in the Adriatic Sea basin can provide appropriate environmental conditions for introduced species, such as the North African catfish, first reported in Slovenia in 1997 and currently found in fish farms in that country (Povž, 2007). Although the species is widely tolerant of extreme environmental conditions (Froese & Pauly, 2015), it is unable to survive winter conditions in the continental part of these areas, when water temperature falls below 10°C. Nevertheless, a potential translocation of this species to thermal spring habitats constitutes a threat, as seen by the adaptation of Nile tilapia in Slovenia (Povž, 2009b).

Under current climate change scenarios, impacts on Balkan freshwater biodiversity are expected to increase as a general rule, since the number of alien species involved is growing and the vulnerability of ecosystems to invasions is increasing. Rising water temperatures will particularly affect freshwater fishes (Cochrane, De Young, Soto, & Bahri, 2009) and the problem is expected to be severe, for example, in Greece, where 39% of all native fish species are already classified as threatened (Barbieri et al., 2015). Moreover, changes in the sea level with the consequent flooding, erosion and salinization of coastal lowlands and estuaries (Handisyde, Ross, Badjeck, & Alisson, 2007) can cause further alterations in the balance of aquatic systems and create opportunities for tropical and subtropical alien species to invade fragile Balkan coastal wetlands, lagoons and spring-fed pools, which host strictly endemic species with highly localized distributions. One such example is Greece, with the endemic species almiri toothcarp (*Aphanius almiriensis*, Cyprinodontidae), Corfu toothcarp (*Valencia letourneuxi*, Valenciidae) and others. On the other hand, the high degree of intermittency in the freshwater resources of the southern Balkans may possibly be a restrictive factor for the spread of invasive species. For instance, the Adriatic Sea basin is characterized by small isolated river basins, many of which are subject to extreme hydrographic fragmentation, which could reduce the range expansion of newly introduced freshwater fish species. Nevertheless, climate change-induced alterations of ecosystem conditions, that is in the large number of large-scale transboundary river basins in the Balkans, may enable the spread of invasive species and favour the creation of habitats and conditions suitable for newly introduced invasive species (EPA, 2008). Indicative of that, is the finding that the majority of freshwater alien species in the inland waters of Greece have been recorded in Northern Greece, where most lentic and lotic systems are transboundary. Thus, climate change may either create additional opportunities for invasion or, alternatively, conditions unsuitable for certain invasive species, thus the relative importance of climate change impacts on invasive freshwater fish species in the Balkans depends primarily on the ichthyoregion considered and the traits of each fish species.

6 | DISCUSSION AND CONCLUSIONS

The findings presented here indicate that the Balkan Peninsula had common routes of introduction of many species in the past, occurring in several waves. The first introductions took place between 1883 and 1891, not only in the Balkans, but also throughout Europe (Holčik, 1991). These were primarily aimed at introducing various salmonid species from North America (Povž et al., 2015; Stanković et al., 2015), which did not succeed in securing self-sustaining populations at all localities (Povž & Ocvirk, 1990). In addition to the salmonids, the brown bullhead was also considered a very attractive species for breeding, which later proved incorrect due to its poorer growth in Europe (Fijan et al., 1989; Ivančić, 1946) and its high invasive potential (Novomeská & Kováč, 2009). Following World War I, the second wave of introductions took place, in the period from 1924 to 1937, which continued with the introduction of North American species, primarily salmonids. Those species that failed to form sustainable populations in the first wave experienced repeated introductions (Povž & Ocvirk, 1990).

After World War II, there was a true boom of introductions of a wide range of fish species in the Balkan Peninsula, from various parts of the world. This wave continued until the 1980s. One of the most important reasons for introduction was a shortage of food, and aquaculture played a significant role in resolving this issue. During this period, significant advances were made in aquaculture (Stickney & Treece, 2012), with increased production of native and alien species (Turk, 1997). However, problems arose with the escape of farmed fish into open waters and the subsequent invasions of certain species (Vuković & Kosorić, 1978). Thus, brown bullhead became one of the main invaders in open waters (Novomeská & Kováč, 2009), and the gibel carp, with its gynogenetic reproduction, became a threat not only to wild cyprinids, but also to freshwater aquaculture production in most Balkan countries (Perdikaris et al., 2012; Povž & Šumer, 2005; Savini et al., 2010; Simonović et al., 2013).

As a consequence, primarily of aquaculture activities but also other motives for introduction, such as angling, biological control and to a lesser degree the ornamental trade, there was recently an increase in the number of the total fish species in each country of the Balkan Peninsula suggesting an ongoing process of biotic homogenization. Studies of alien fish introductions in Mediterranean-climate regions have emphasized the loss of faunal uniqueness, albeit with a concurrent increase in the total number of fish species. A 7% average increase in taxonomic and functional similarity of freshwater fish fauna has been documented as a result of human activities (Marr et al., 2013). All Mediterranean regions around the world are displaying taxonomic and functional homogenization in more than 50% of their catchments, with the exception of the south-western Cape, Central Anatolia and the Aegean Sea drainages (Marr et al., 2013). Overall, catchments exhibiting taxonomic homogenization are also homogenized in terms of their functional trait composition, which may have important consequences for the functioning of these ecosystems (Olden, Lise, & Giam, 2016). These studies on biotic homogenization, however, also included translocated species, which may possibly play a stronger role than exotic species (Villéger, Grenouillet, & Brosse, 2014), but were not considered in the current study. Thus, the temporal changes in genetic, taxonomic and functional dissimilarities for freshwater fishes in the Balkans could be even greater and further research on this topic is certainly required.

For the Csa climate type, which is the predominant type in the Mediterranean regions of most of the Balkan countries, as well as Spain and Italy (Peel et al., 2007), concerns have been expressed over impacts on freshwater biota (Vilizzi, 2012). Furthermore, the Balkan Peninsula is the locality with the largest number of endemic species (Oikonomou, Leprieur, & Leonardos, 2014) that are directly threatened by the introduction of alien species (Ćaleta et al., 2015; Piria et al., 2016b; Ribeiro & Leunda, 2012; Snoj et al., 2007). The Cfa climate type is also found in Asia and North America, where the Dfb climate type is also significantly represented (Peel et al., 2007). It is from the Cfa and Dfb climate areas of North America that the pumpkinseed, brown bullhead, black bullhead and Eastern mosquitofish originate (Froese & Pauly, 2015), and therefore, the climatic conditions in the Balkans are suitable for their acclimation and naturalization (Fox, Vila-Gispert, & Copp, 2007; Movchan et al., 2014; Vidal et al., 2010). Most of Northern and Western Europe are characterized by the Dfa and Cfb climate types (Peel et al., 2007), which also corresponds to part of the Balkan Peninsula, and therefore, the introduced species from these areas are also capable of naturalization, as seen in the case of European whitefish and peled (Hamzić et al., 2011; Uzunova & Zlatanova, 2007). In contrast, the African and South American climate types do not correspond to the climatic conditions in the Balkans. Therefore, the survival of species of that origin is limited to thermal waters, such as the Nile tilapia in Slovenia (Povž, 2009b), although there is a realistic threat of naturalization in Csb areas, for example, the Nila tilapia in Greece (Barbieri et al., 2015; Perdikaris et al., 2010). Pursuant to this, it would be desirable to prioritize the Balkan Peninsula for the purpose of actions to remediate and/or control introduced/translocated fishes, which has been lacking, following the example of countries where progress has been made in the management of invasives, for example of common carp in Australia or topmouth gudgeon in England and Wales. Nonetheless, these attempts demonstrate that eradication may not be possible, although management efforts can aim to control their distribution and dispersal in the environment and reduce their impacts on native species and ecosystems (Britton et al., 2011).

The current study has shown that a large proportion of alien species in the Balkans are widespread and are fully invasive species by the criteria of Blackburn et al. (2011). Major corridors for their spread are the transboundary rivers and lakes, such as Ohrid-Drin-Skadar river system draining a number of countries in the Balkans, or the Danube River draining a large section of Central and Eastern Europe. In the Balkans, most major rivers and lakes are transboundary, creating conflicts of interest since water resources are unevenly distributed among the countries. There is a strong need for coordination in river management issues, such as pollution control, hydroelectric energy production and the control of alien fishes. The current study has also revealed the true extent of the gaps in the knowledge on the current state, distribution and impacts of many alien species in the Balkans. These gaps should be targeted through coordinated research that could assist effective conservation efforts.

In the Balkan Peninsula, there remains an immeasurable wealth of freshwater fish diversity, despite the fact that there are very few freshwater ecosystems left intact by introduction, translocation or stocking with alien genetic material. Above all, there is a great obligation and responsibility to preserve these unique ecosystems for future generations, which can be saved only through rational and joint long-term conservation actions.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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