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Review

The non-indigenous fishes in the fauna of Ukraine: a potentia ad actum

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Abstract

This is a review of the literature on non-indigenous fishes in Ukrainian freshwaters and coastal marine waters. Excluding the cases of unsuccessful introductions and occasional findings, the list of established non-indigenous fish species in Ukraine contains 27 species. Nine of these species have been deliberately introduced and are commercially stocked, though natural spawning has not yet been confirmed. The list of successfully naturalized introductions includes 19 fish species, eight of which can be considered as invasive due to their continued range expansion with probable negative influences on aboriginal fauna. The remaining species on the list are restricted in their distribution and form localised populations. Neolimnetics and Mediterranean species were not considered as non-indigenous because of their native status in major Ukrainian rivers, coastal waters, and/or adjacent waters of the Black Sea. This review highlights the major research gaps in the distribution and status of native and non-native fishes in Ukraine, which has considerable implications for the management of biodiversity and aquatic invasive species.

Key words: ichthyofauna, invasive species, Mediterranization, intentional introduction, range expansion

Introduction

Natural range expansion is one mechanism of evolutionary diversification and the maintenance of biodiversity (Parmesan and Yohe 2003). In the past, these processes were natural, and long distance movement of species took place over long time periods (Alimov and Bogutskaya 2004; Alexandrov et al. 2007; Polačik et al. 2008). Facilitated transport of species by humans across different parts of the world has broken down the natural barriers to species spread and distribution (Bij de Vaate et al. 2002; García-Berthou et al. 2005; Hirsch et al. 2016). The expansion of non-indigenous fauna has negative impacts on natural conservation, being one of the greatest threats to biodiversity worldwide (Leppäkoski et al. 2002; Hirsch et al. 2016). Furthermore, knowledge of indigenous fauna in many parts of the world was rather poor even at the beginning of 20th century. Therefore, in some cases it is problematic to evaluate the origin of the species in a particular region, i.e. are they native or non-indigenous?

Knowledge of species ranges in the past can be very useful for new species findings and defining where species are native or non-indigenous (Polačik et al. 2008; Spikmans et al. 2011). However published information on faunal distributions is often incomplete, episodic, or even absent. Moreover, correct species identification is often questionable, especially in cases where modern taxonomic revisions have been provided for the particular taxonomic group (Ahnelt et al. 2001; Diripasko et al. 2008; Neilson and Stepien 2009; Haertl et al. 2012). Different primary languages adopted by different regions provide another barrier to the flow of information on species distributions and origin.

Ukraine is one example of a region for which these issues are highly relevant and a summary of native and non-native fish distributions through time is in particularly high demand, partly due to many

species being introduced from this region to other parts of the world. Faunistic publications for Ukraine started in the 18th century (Kessler 1856); but we restricted the current review to scientific publications, which started in the 1920–30s, to evaluate which species are native for a particular region (Vladykov 1926; Velykokhatko 1929; Beling et al. 1936; Beling 1937; *etc*.). Later, from the 1940s to 1960s, documentation on the "improvement" of fauna and their production were widely provided (Movchan 1954; Vovk 1976). These activities, which included the purposeful introduction of non-indigenous species, resulted in considerable changes to aquatic biodiversity.

Due to its physical-geographic position and economic development, Ukraine is ideally situated to become a primary testing area for controlling the introduction of aquatic alien species (Alexandrov et al. 2007). The Ukrainian coastal waters of the Black Sea and Sea of Azov have low salinities relative to the neighboring Mediterranean, forming a specific zoogeographic region that is inhabited mainly by brackish-water organisms (Slastenenko 1959). Therefore, this region is most suitable for invasion by species that favor brackish conditions, which have the widest distributed on Earth (Vinogradov 1986). For a long historical period in the Holocene (~ 5–7 Ma), the Black Sea was land-locked from the Mediterranean. The Pontian Sea-Lake included the modern Black Sea, Sea of Azov and the Caspian Sea-Lake (Zenkevich 1963). This water body was full of brackish water, which facilitated the development of appropriate fauna. The Black Sea fauna includes several zoogeographical groups distinguished by their origin:

1. Boreo-Atlantic species, which are relicts of the ancient Tethys Sea (from the Upper Miocene) (Zaitsev and Mamaev 1997). In the fish fauna the typical representatives are *Sprattus sprattus* (L., 1758), *Platichthys flesus* (L., 1758), *etc*.
2. Ponto-Caspian species, which are native inhabitants of the Black Sea (including the Sea of Azov), Caspian Sea and their basins. These are relicts of the old brackish Pontian Sea-Lake (Zaitsev and Mamaev 1997; Zaitsev 1998). Therefore, similar fauna is present in the Caspian Sea. The typical representatives are Ponto-Caspian gobies (Actinopterygii: Gobiidae: Benthophilinae).
3. Mediterranean species form another group in the Black Sea fauna, which inhabits the other parts of the Mediterranean basin. The colonization of the Black Sea by Mediterranean species (a process of Mediterranization) started between 7–12 thousand years ago and continues to this day (Miller 1965; Zaitsev 1998; Boltachev and Yurakhno 2002). Representatives include the blennies (Actinopterygii: Blennidae) and gobies, such as *Zosterisessor ophiocephalus* (Pallas, 1814) and annual gobies of *Pomatoschistus* spp.

The process of "Mediterranization" lead to the extirpation of many native species in the Black Sea proper and a restriction in the ranges of Ponto-Caspian species to estuarine and coastal zones. Many of these historically Black Sea species now only survive in rivers and estuaries (called neo-limnetics), which is attributed to competition-induced niche displacement by Mediterranean species (Starobogatov 1970).

Within Ukraine, which incorporates both the Black Sea basin and part of the Baltic basin, there are several important routes for aquatic invasions, such as southern and central corridors (Panov et al. 2009). Terminology related to freshwater fishes in these water routes in Europe was discussed by Copp et al. (2005). However, Copp et al. (2005) focused on the spread of goby fishes and restricted mainly to northern and western Europe. Yet many European aquatic invaders are native to the Ponto-Caspian region. Alexandrov et al. (2007) distinguished groups of geographically distant and neighbouring aliens in Ukraine, but assessment omitted a large proportion of artificially introduced fishes. Therefore, the aim of our work was to clarify the terminology and summarize the documentation in the literature that relate to alien and native fauna in Ukraine and adjacent waters.

Methods

The published data concerning the first records of fishes in Ukrainian freshwaters and adjuscent marine/brackish waters were studied in detail. Over 90 literature sources were studied to characterise the range of fishes in Ukraine, and ~ 30 sources to determine the current distribution of fishes in the whole region. Many of the sources used were rather old and from our personal libraries. Fishes were sorted by current documented presence and introduction history. The date and site of first occurrence and its current range in Ukraine were listed for each fish species, providing the related citations. Taxonomic revisions were taken into account and FishBase provided the current scientific names (Froese and Pauly 2016).

Intentional introduction

The list of intentionally introduced fishes in Ukraine consists of 32 species, including of 23 freshwater species, five anadromous, one euryhaline, and three marine (Supplementary material Table S1). The eastern

mosquitofish, *Gambusia holbrooki* Girarg, 1859, was introduced for biological control (Prendel et al. 1932). All other species were introduced for aquaculture and/or commercial fisheries.

The history of intentional introduction of fishes in Ukraine is characterized by two dominant time periods. The first period started from the first reliable known case of intentional introduction at the beginning of 20th century. At that time rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792), were used for aquaculture in western Ukraine (Pavlov 1980). Mainly European fauna (whitefishes and trouts) were introduced for recreational and commercial fishing. This period lasted throughout the first half of the 20th century. The second period started in the second half of 20th century, when fishes native to far-eastern Asia were introduced (such as silver carps *Hypophthalmichthys* spp., black carp *Mylopharyngodon piceus* (Richardson, 1846), grass carp *Ctenopharyngodon idella* (Valenciennes, 1844), North America buffalo *Ictiobus* spp., and channel catfish, *Ictalurus punctatus* Rafinesque, 1818).

Most of these intentional introductions were unsuccessful (15 fish species, Table S1). The list of unsuccessful introductions consists mainly of freshwater fishes, such as three species of buffalo (*Ictiobus* spp.), eight species of whitefish (*Coregonus* spp.), Sevan trout (*Salmo ischchan* Kessler, 1877), Mozambique tilapia (*Oreochromis mossambicus* (Peters, 1852)), and snakehead (*Chana argus* (Cantor, 1842)). Mozambique tilapia needs artificial support in heated waters, which was not provided so the fish was extirpated (Zhukinskiy et al. 2007). Four fish species were bred artificially and released. Several species from the list were introduced to the Black Sea; an anadromous Asian fish: chum salmon *Oncorhynchus keta* (Walbaum, 1792), far-eastern marine fishes: the suzuki, *Lateolabrax japonicus* (Cuvier, 1828) and the ayu, *Plecoglossus altivelus* (Temminck and Schlegel, 1846), and a North American euryhaline fish, the striped bass, *Morone saxatilis* (Walbaum, 1792) (Zaitsev and Mamaev 1997). The first three of these species were never documented again in the Black sea basin. The Striped Bass was released in the Dnieper Estuary in 1971, and sometime later occurred in the Sea of Azov and Don delta (Volovik and Chikhachev 1998; Movchan 2006), but there are no recent records of this fish in Ukraine. Because natural spawning of these fishes has not been observed in Ukraine and there are no recent documented sightings, we consider the introduction of these species to be unsuccessful.

The group of commercially stocked fish consists of eight species (Table S1). The lack of natural reproduction of these fish species in Ukrainian waters is primarily due to unsuitable habitat and environmental conditions. The list consists entirely of species that are commonly used in the aquaculture trade, such as the American paddlefish (*Polyodon spatula* Walbaum, 1792) and several species of Asian cyprinids (Movchan 2011). Some of these fish species (such as *Hypophthalmichthys molitrix* (Valenciennes, 1844) and *Hypophthalmichthys nobilis* (Richandson, 1845)) are bred artificially and the offspring are released to the natural environment where they persist in some lakes and reservoirs (Vovk 1976; Movchan and Smirnov 1983).

Seven species from the list formed local populations and did not expand their ranges, which is attributed to a lack of suitable habitats or environmental conditions (Table S1). The brown bullhead, *Ameiurus nebulosus* Lesueur, 1819, is represented by two populations, in Shatsk Lakes and in Transcarpathian Ukraine (Movchan 2011). This species has not expanded its range since 1937 when it was first introduced. The kutum, *Rutilus kutum* Kamensky, 1901, was introduced to the Sea of Azov from the Caspian Sea in the 1950s (Diripasko et al. 2011). In 1968, spawning was documented for the kutum in the River Berda in Ukraine (Loshakov 1970), but the species later decreased in abundance. The largemouth black bass, *Micropterus salmoides* (Lacepède, 1802), was introduced to lakes in the Volyn region of Ukraine in the 19th century and its presence was confirmed in 1959 (Zhukinskiy and Balan 1959), but subsequent information about its presence in this region, or in other regions of Ukraine, is absent. Both kutum and largemouth black bass most likely have restricted, localized populations, but cannot be excluded from the fauna. Rainbow trout, *O. mykiss*, and brook trout, *Salvelinus fontinalis* (Mitchill, 1814), are successfully naturalized in several small rivers in upper streams of the Dniester and Tisza basins, and in small rivers in southern Crimea (Movchan 2011).

The eastern mosquitofish was introduced to European waters for mosquito control (Kottelat and Freyhof 2007). In Ukraine, this fish was successfully introduced for the first time to a small pond in the city of Odessa in 1930 (Prendel et al. 1932). Over the next decade, several unsuccessful attempts were made to introduce the species to different parts of Ukraine. Now, local populations of this fish are known in Salgir and Chorna riverine basins in Crimea, in ponds in Yalta, and inland waters adjacent to the Black Sea and Sea of Azov (Movchan 1988; Boltachev et al. 2010).

Because of the long history of introduction for aquaculture purposes, and lack of documentation, it is often difficult to evaluate the origin of species and whether they are native or introduced. A well-known

example is the Prussian carp, *Carassius gibelio* (Bloch, 1782), which has a wide distribution throughout Europe, including Ukraine (Kottelat and Freyhof 2007). This species has been documented in Ukraine since the beginning of the 20th century, as a species that was introduced a long time ago (Kiselyov 1962). This is one of three intentionally introduced fish species that can be considered as invasive in Ukraine. Another species is the channel catfish (*I. punctatus*), introduced from Arkansas in 1972–1973 (Movchan 1988). Recently this species established in some rivers in central and eastern Ukraine, and penetrated to the Siverskyi Donets drainage (Movchan 2011). Our findings confirm the invasive status of both species in Ukraine. First, *C. gibelio*, again introduced in the 1950–60s, has spread widely throughout Ukraine, displacing the local Crussian carp, *Carassius carassius* (L., 1758) (Movchan and Smirnov 1983; Movchan 2011). *Ictalurus punctatus* is still uncommon, but their range expansion is in progress and a negative impact on native fauna has been documented (Movchan 2011).

The third invasive species from the list is the haarder, *Liza haematocheilus* (Temminck and Schlegel, 1845). This is the only brackish-water/marine fish species which was successfully introduced to the Black Sea for fisheries purposes. Re-stocking of this fish in the Black Sea started in 1968 in two localities: Molochnyi Estuary in the Sea of Azov and Budaki Lagoon in the north-western Black Sea (Starushenko 1976; Kazansky and Starushenko 1980; Starushenko and Kazansky 1996). Now this fish is common throughout the Black Sea, including the Seas of Azov and Marmara (Bilecenoglu et al. 2002; Keskin 2010; Yankova et al. 2014). The low-salinity tolerance of the haarder in the Black Sea has significantly increased and it has started to spawn in much lower salinity (Volya et al. 2003); cases of succesful spawning of this fish were registered in both in the Black Sea and Sea of Azov (Kulik 2001; Movchan 2011). Despite the presence of a commercial fishery for this fish in the Black Sea, it has successfully spread to the Aegean Sea, where it is considered as invasive (Corsini-Foka 2010).

Incidental introduction

This list consists of eight freshwater fishes, one brackish and one marine (Table S2). Some of these fishes have a wide distribution (e.g. *Lepomis gibbosus* (L., 1758), *Perccottus glenii* Dybowski, 1877, *Pseudorasbora parva* Temminck and Schlegel, 1846), but others only occur locally (e.g. *Ameiurus melas* Rafinesque, 1820, *Carassius auratus* (L., 1758), *Carassius langsdorfii* Temminck and Schlegel, 1846, *Gammogobius steinitzi* (Bath, 1971), *Orizias sinensis* Chen et al., 1989, *Poecilia reticulata* Peters, 1859, *Tridentiger trigonocephalus* (Gill, 1859)). The fishes that are considered as invasive generally have a wide range, and those with narrow ranges are spreading rapidly. There are two types of occasional introduction: 1) Hitchhikers to commercially important fishes. Due to the former Soviet Union's program of introduction of Asian phytoplanktivorous fishes, several unwanted fish species were unintentionally introduced to Ukraine (Vovk 1976; Kozlov 1974; Karabanov et al. 2010; Kutsokon et al. 2013, 2014); 2) Released by aquarists. Includes several cases of the release of ornamental fishes with further successful establishment and spread throughout Europe (Andrews 1990) and other ornamental fishes that were not as successful, for example, extirpating after the first frost (Jeschke and Strayer 2005; Półgęsek et al. 2011).

Five fishes were introduced as hitchhikers to commercially important fishes: black bullhead (*A. melas*), gin-buna carp (*C. langsdorfii*), Chinese rice fish (*O. sinensis*), Chinese sleeper (*P. glenii*), and stone morocco (*P. parva*). Those with limited ranges (i.e. less successful) include the Chinese rice fish and two cryptic species of *Carassius*. The Chinese rice fish is only known to occur in the small river Obytochna on the Northern Azov coast (Naseka and Diripasko 2005). The status of *C. auratus* in Ukraine is complex. There are at least three species, diploid *C. gibelio* (see Table S1 for details) and *C. langsdorfii*, and triploid *C. auratus* (Rylková et al. 2013). The goldfish (*C. auratus*) was probably released by aquarists in the 19th century and currently occurs as localized populations in different parts of Ukraine (Movchan and Smirnov 1983; Movchan 2011). *Carassius auratus* is also documented to hybridize with local crussian carp and Prussian carp (Kozlov 1974; Mezhzherin et al. 2009; Kovtun and Manilo 2013). The Japanese gin-buna carp (*C. langsdorfii*) was first recorded in Europe in the River Elbe basin in 2000 and was likely introduced as a hitchhiker to commercial fish introductions, or with ornamental koi carp, *Cyprinus carpio* L., 1758 (Kalous et al. 2007). In Ukraine, the gin-buna carp was first registered in 2010s, but the name of the water body was not provided (Rylková et al. 2013).

Other species on the list are continuing to spread and/or have a documented negative impact, thus can be considered as invasive. Among them is the stone moroko, which is widely distributed in all freshwaters of Ukraine. Two species, the Chinese sleeper and the black bullhead, are actively spreading, though the black bullhead currently has a limited distribution occurring only in the Transcarpathian

Ukraine where it first registered in 2004 (Koščo et al. 2004; Markovych and Kutsokon 2012; Movchan et al. 2014). The black bullhead was probably introduced together with the commercial fisheries introduction of *A. nebulosus*. Since its introduction, *A. melas* has and continues to spread throughout Ukraine (Markovych and Kutsokon 2012; Movchan et al. 2014), whereas *A. nebulosus* has a restricted distribution (Movchan 2011; Table S1). We consider the black bullhead to be invasive despite localized establishment, as it was only recently introduced and is spreading rapidly. Currently, the impact of this species to local ecosystems is unknown, but taking into account its rapid spread, it must be studied.

There are several ornamental fishes that have successfully established in Ukraine and continue to spread throughout Europe (Andrews 1990). One of the best-known aquaria fish, the guppy (*P. reticulata*), is documented for Ukraine only in a heated water pond in Bortnychi, Kiev (Kutsokon et al. 2012), although sporadic findings are registered in other parts of Ukraine, i.e. the Dnieper drainage (Novitskyi 2005). Another well-known example is the pumpkinseed (*L. gibbosus*), first released in France in 1877 (Copp and Fox 2007). In Ukraine this species was first found in lakes of the Danube delta in 1918, believed to be introduced and spread from upper parts of the Danube River (Pavlov and Bilko 1962). This fish then occurred in the Dniester River delta in 1946 (Zambriborshch and Shumilo 1953), and is now distributed in the lower reaches of all rivers of the northern Black Sea coast and in the brackish waters of the North-Western Black Sea (Diripasko et al. 2008; Movchan 2011). Another potential aquarists' introduction is the Chinese sleeper, which was first released in Russia in 1916 (Dmitriev 1971). In Ukraine, it was first introduced with commercial fish (Fedonyuk 2005; Reshetnikov 2013), but the isolated population in northern Ukraine probably has a different origin, which could have been via aquarists or fish farms.

Another case of introduction by aquarists is a small Pacific species, the chameleon goby (*T. trigonocephalus*), which was introduced to the Black Sea fauna. This fish was released by aquarists to Sevastopol Bay in 2006, and then spread along the coast, with documented sightings including the mouth of the Chorna River (Boltachev et al. 2007; Boltachev and Karpova 2012). This fish naturally inhabits brackish and marine waters of south and east China, the Yellow Sea and the Sea of Japan, the Pacific coast of Japan and the Philippines (Courtenay et al. 1986; Meng et al. 1994). The invasion history for this species began in 1960, when it was first recorded into Los Angeles Harbor, California (Haaker 1979). It was later found in San Francisco and San Diego bays, USA (Courtenay et al. 1986; Meng et al. 1994; Matern and Fleming 1996; Pondella and Chinn 2005), also in the Sydney Bay, Australia (Hoese 1973; Pollard 1989). Goren et al. (2009) noted this fish species near the coasts of Israel, eastern Mediterranean, in 2006, probably introduced via ship ballast water.

One fish species, the Steinitz's goby (*G. steinitzi*), is placed in its own category. This is a marine fish, native to the western Mediterranean Sea, especially near the coast of France (Miller 1986). This fish inhabits inland caves and submarine grottoes. Recently, this small and rare fish species occurred in several localities in the eastern Mediterranean, including the Adriatic Sea (Kovačić 1999), Crete coastal waters (Kovačić et al. 2011), and near the western Crimean coast in the Black Sea (Kovtun and Manilo 2013). Because the fish is rare in all places of its occurrence and will likely have a limited impact, we suggest it is not invasive. However, it is included in the introduced fauna in the eastern Mediterranean, including the Black Sea. Kovtun and Manilo (2013) hypothesized that this fish is native to the eastern Mediterranean, and, for the same reasons, we hypothesize that it is also native to the Black Sea. According to this hypothesis, the species penetrated the Karangat Sea ~ 100–150 thousand years ago during Riss–Wurm interglacial period (Zaitsev 1998). However, the fish is absent in the southern region of the Black Sea so it is unlikely that it spread naturally to the northern Black Sea. One possible way it could have been introduced is on the bottom (hull) of water-transport vessels such as yachts. In Ukraine, the fish is currently only found in Cape Tarkhankut, and natural expansion is unlikely due to the lack of suitable habitats (underwater rocky caves) around the cape.

Mediterranization and Neo-limnetic spread

This complicated group consists of 23 fish species of different zoogeographic origin. Recently, range expansion has been recorded for Ponto-Caspian (benthophilins) and Boreal-Atlantic (*Gasterosteus aculeatus* L., 1758) relicts, and Mediterranean species. The group of Mediterranean species can be divided into two subgroups: 1) The Brackish/euryhaline species that are present as natives to the Black Sea and have spread to freshwaters (*Atherina boyeri* Risso, 1810, *Syngnathus abaster* Risso, 1826), and 2) Brackish/marine species that are present and native to adjacent waters of the Black Sea and have recently spread to Ukrainian Black-Sea waters. The first group, together with some spreading Ponto-Caspian and Boreal-Atlantic relicts, are called neolimnetics and consists of 12 species (Table S3).

We exclude two fish species from this list: the Don tadpole-goby, *Benthophilus durrelli* Boldyrev and Bogutskaya, 2004, and the pictured goby, *Pomatoschistus pictus* (Malm, 1865). The Don tadpole-goby was recently documented in the River Siverskyi Donets in Ukraine (Shandikov and Goncharov 2008). This species was present in the rivers of the Don drainage in the past but described as *B. stellatus* Boldyrev and Bogutskaya 2007 and is considered to be native to Ukraine. The pictured goby, was known from the Russian coast of the Black Sea (Slastenenko 1939, 1956), and later mentioned for the Crimean and Turkish coasts (Boltachev et al. 2009). The species is excluded from the list of Ukrainian and Turkish fish, and confirmed only for the Russian coast (Yankova et al. 2014).

Neolimnetic expansions

Range expansion refers to the resettlement of organisms to their nearest localities, which can happen naturally and/or be facilitated by anthropogenic transport vectors. The degradation of natural habitats has catalyzed the natural spread of species during the last century (Copp et al. 2005). This increases the implications of facilitated transport, which is sometimes conducted intentionally for commercial purposes (high propagule pressure), and is sometimes unintentional or incidental (generally low propagule pressure). For aquatic organisms, transportation via ship (hull fouling or within ballast water) plays an important role, especially in Europe, where multiple freshwater routes connect the different sea basins (Copp et al. 2005; Panov et al. 2009). The typical representatives of spreading fishes are Ponto-Caspian gobiids, which are expanding upstream of the Danube River and have penetrated the Rhine River drainage in the North Sea basin (Jurajda et al. 2005; Borcherding et al. 2011).

The alien fauna in Ukraine can be divided into two groups: distant aliens, which never previously inhabited the Black Sea-Azov basin, and neighboring aliens, which are inhabitants of the Black Sea-Azov basin (Alexandrov et al. 2007). The construction of a cascade of reservoirs on the Dnieper River has created suitable habitats for many neolimnetics, including fishes (Alexandrov et al. 2007; Panov et al. 2009). Subsequently, species such as Ponto-Caspian gobiids, syngnathids and gasterosteids have a wide range throughout many reservoirs of the Dnieper basin (Pinchuk et al. 1985; Zimbalevskaya et al. 1989). However, these fishes are currently described as indigenous to Ukraine fauna as they are native to the lower reaches of the Dnieper River. They were also likely present in middle flows in the past, although they are not numerous due to the lack of habitats. For example, the black-striped pipefish (*S. abaster*) was registered in some tributaries of the Middle Dnieper basin in the 1920–30s (Beling 1923). This species is now abundant throughout the Dnieper, including northern Ukraine near Kiev, and tributaries such as Desna and Prypiat (Movchan 2011, 2012).

For spreading neolimnetics, we mainly list Ponto-Caspian species, such as the Ukrainian stickleback, *Pungitius platygaster* (Kessler, 1859) and seven gobiid species (*Babka gymnotrachelus* (Kessler, 1857), *Benthophilus nudus* (Berg, 1898), *Neogobius fluviatilis* (Pallas, 1814), *Neogobius melanostomus* (Pallas, 1814), *Ponticola kessleri* (Günther, 1861), *Ponticola ratan* (Nodmann, 1840), *Proterorhinus semilunaris* (Heckel, 1837)). Three brackish species of Mediterranean origin (*A. boyeri*, *S. abaster*, *Knipowitschia caucasica* (Berg, 1916)) and one Boreal (*G. aculeatus*) have also expanded their ranges throughout rivers of the Black Sea basin. However, distribution is sparse and generally restricted to drainages of the same rivers, therefore, we continue to list them as indigenous.

Mediterranization

The Mediterranization of the Black Sea started in the early Pleistocene, either during the Earlier Würm/ Main Würm interstadial about 12,000 years ago (Flint 1957), or around 7,000 years ago (Zaitsev 1998). In Russian-language literature the term “Mediterranean immigrants” was widely used for all Mediterranean species inhabiting the Black Sea basin. Sometimes, this “immigrant” group includes Boreal-Atlantic species that occur in the Black Sea fauna, but this group was never considered as “non-indigenous”, so the term “immigrants” is probably inappropraite. The Black Sea is a part of the Mediterranean basin, which has some zoogeographic and ecological significance (Slastenenko 1956; Miller 1965). Similar Post-Glacial immigrations are known from the Baltic Sea, where massive introduction was observed about 10–15 thousand years ago (Ojaveer 2010). These “immigrants” prevail as relict species and only a single endemic is known in the Baltic Sea at this time.

There are ten Mediterranean fish species that were first recorded near Ukrainian coasts during last several decades (Table S3). For recently documented Mediterranean colonizers, we suggest there are two groups, species that are either absent or present in adjacent waters to the southern Black Sea, Sea of Marmara and/or the Aegean Sea. The first group consists of those that are now geographically

separated from their source populations (i.e. the Black Sea populations are isolated and their ranges do not overlap with their source). These species can be recognized as introduced and grouped together with other non-indigenous species, such as the Steinitz's goby, *G. steinitzi* (Kovtun and Manilo 2013; see Table S2).

The introduction of species with natural ranges in adjacent Mediterranean waters into the Black Sea fauna, could be considered as a continuation of Mediterranization. We distinguish representatives of this group found in Ukrainian waters to two sub-groups: a) species that were recently documented in the Black Sea for the first time, and b) species that are already documented in other parts of the Black Sea. In the latter case, range expansion in the Black Sea tends to occur step by step from the southern coast to the northern coast.

Several species were erroneously noted as non-indigenous in the Black Sea. For example, the greater pipefish (*Syngnathus acus* L., 1758) was found in the estuary of the Chorna River, Sevastopol, in 2006 (Boltachev et al. 2009). This was noted as new occurrence, but this species was first recorded in the Black Sea by Kessler in 1877 and misidentified as *Syngnathus variegatus* Pallas, 1814 (Boltachev et al. 2010). Later, this species was also confirmed for the Bulgarian, Romanian, Turkish and Russian coasts of the Black Sea (see Yankova et al. 2014).

Unsuccessful introductions/data deficient

The list of unsuccessful/data deficient ichthyofaunal introductions includes nine fish species, common to marine waters (Table S4). All these species have one or two recorded sightings/introductions to the Black Sea, but were apparently not able to survive in brackish water. This list includes modern and historical findings. Several species were documented near the Ukrainian coast in the 19th – beginning of the 20th centuries. For example, the European conger, *Conger conger* L., 1758, was found in the Gulf of Yalta more than 100 years ago but was never recorded again. The circumtropical pilot fish, *Naucrates ductor* (L., 1758), the semi-obligate commensal shark (Cervigón et al. 1992), was noted for the Gulf of Odessa in 1870 (Svetovidov 1964). In some cases, occasional findings were described as native fauna of Mediterranean origin. Traditionally, the European conger, the twait shad, *Alosa fallax* Lacépède, 1800, the flying gurnard, *Dactylopterus volitans* L., 1758, and the butterfly blenny, *Blennius ocellaris* L., 1758, were described as Mediterranean colonizers in the Black Sea fauna (Rass 1987). The flying gurnard is known only from two occurrences near the Ukrainian coast (Zambriborshch 1985; Boltachev et al. 2013), but the other two species are also known from southern coasts of the Black Sea (Yankova et al. 2014). Several recently occurring species are considered as non-indigenous: blue whiting, *Micromesistius poutassou* (Risso, 1827), the blue ling, *Molva* sp., pennant coralfish, *Heniochus acuminatus* (L., 1758), and red barracuda, *Sphyraena pinguis* (Günther, 1874) (Boltachev et al. 1999; Boltachev and Yurakhno 2002; Boltachev and Astakhov 2004; Boltachev and Karpova 2013; Boltachev et al. 2013). The presence of blue whiting, blue ling, red barracuda, and dog-tooth grouper (known from the Mediterranean Sea) in the Black Sea could be explained by occasional unsuccessful natural spread from the Mediterranean basin, whereas the occurrence of the Indo-West Pacific pennant coralfish in the Black Sea can be attributed to aquarists' release as it is a popular ornamental fish species.

Unsuccessful occasional introductions of exotic fish (probably released by aquarists), such as porcupine fish, *Diodon histrix* L., 1758, pirapitinga, *Piaractus brachypomus* (Cuvier, 1818), piranhas (*Pygocentrus nattereri* Kner, 1858, *Pygocentrus* sp.), oscar, *Astronotus ocellatus* (Agassiz, 1831), leopard pleco, *Pterygoplichthys gibbiceps* (Kner, 1854), have recently been recorded in different European fresh waters and could also occur in Ukraine (Ellis 2006; Półgęsek et al. 2011). In the Black Sea, there have also been several incidental findings of sharks, such as the smooth hammerhead, *Sphyrna zygaena* (L., 1758), spotted near the coasts of Romania in the 19th century, and the blue shark, *Prionace glauca* (L., 1758), near the Turkish coast in the 1960s (Svetovidov 1964; Geldiay 1969). Sporadic findings of ornamental fishes, such as guppy, swordtail, *Xiphophorus hellerii* Heckel, 1848, stinging catfish, *Heteropneustes fossilis* (Bloch, 1794), are registered in Ukraine in the Dnieper drainage (Novitskyi 2005). The likelihood of future sightings of these fishes in Ukraine is low due to the current unsuitable habitat and environment conditions. However, patterns in the distribution of species in general are complicated by the current and projected rapid changes in climate at a global level. Documenting and summarizing the historic and current species distributions is essential for supplementing our ability to predict the distribution of species in the future, and associated impact to ecosystems and economy. Based on the current literature, the fishes in this category are deemed as unsuccessfully established from unintentional introductions. This includes the sightings for the Black Sea that are occassional and cannot be considered as non-indigenous or native species at present.

Conclusions

1. Excluding the cases of unsuccessful introductions and occasional findings, there are 27 non-indigenous fish species in Ukraine. Eight species are commercially stocked and cases of natural spawning have not been confirmed.
2. The list of successfully naturalized introducents includes 19 fish species. Seven of these can be considered as invasive with expanding ranges and negative influence on aboriginal fauna. The rest of the listed species have localised populations.
3. The neolimnetics and Mediterranean species are not considered as non-indigenous because of their native status in a large number of Ukrainian rivers, coastal waters, and/or adjacent waters of the Black Sea. The border between native and expanded ranges is unclear because of lack of published data.
4. Four species were excluded from the list of non-indigenous introductions and moved to the category of unsuccessful introductions/data deficient. This category includes another five species previously considered to be native to the Black Sea. All these species are known in Ukrainian waters from rare sightings. The status of these species in Ukrainian waters is particularly debateable because of deficient data about their spread and historic distributions in the region.

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Supplementary material

The following supplementary material is available for this article:

Table S1. The list of fish species, intentionally introduced in Ukraine with commercial or other purposes

Table S2. The list of incidentally introduced fish species in Ukraine

Table S3. Fish species exhibiting range expansion in Ukraine

Table S4. The list of unsuccessfully introduced/data deficient fish species with accidental finding in Ukraine

Appendix 1. List of references for annotated checklist.

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