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Alien invasive fish species in Polish waters: an overview

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A b s t r a c t. For the last 800 years, 35 alien fish species have been introduced, mainly intentionally, in Polish inland waters. The paper reviews the present state of alien fish fauna in Poland, with special attention paid to those considered to be invasive. Till now 26 species have been reported as naturalized, acclimatized or casual and it means that 34% of fish fauna are non-indigenous species. The majority came from North America, Eastern Asia and Siberia or different regions of Europe. More than 65% of all introductions took place in the last 60 years. After the World War II the rapid expansion was noted specially for brown bullhead, *Ameiurus nebulosus* and gibel, *Carassius gibelio*. In the recent decade similar explosive spread has been observed for three *Neogobius* species (round goby, *N. melanostomus*, racer goby, *N. gymnotrachelus*, monkey goby, *N. fluviatilis*), Amur sleeper, *Perccottus glenii* and topmouth gudgeon, *Pseudorasbora parva*. The occurrence of introduced fish species resulted in several negative changes in aquatic environments. Some of them are as follows: hybridisation with native species, destruction of spawning grounds and habitats for many freshwater organisms, decrease of native fish reproduction success due to predation on eggs and offspring and finally the aliens might be vectors for parasites and diseases.

Key words: non-indigenous species, introduction, invasion, impact of exotic species

Introduction

The awareness of threats to biodiversity posed by introduction of non-native species has increased considerably in the recent decades. One of the symptoms of a new approach to the problem was change in terminology. According to electronic surveys, the proportion of papers using the term 'invasive' in the title instead of 'introduced species' has markedly increased after 1990. Particular explosion of the literature on invasive species was noted in the recent ten years mainly for plants but also fishes (Garcia-Berthou 2007). The importance and popularity of the subject are also seen in the rising number of internet data bases and quality of information available there. The Polish base of alien species was created at the Institute of Nature Conservation, Polish Academy of Sciences (INC PAS) in Krakow for the Ministry of the Environment in 1999 (www.iop.krakow.pl/ias/). At the beginning of 2008 it included almost 800 species of plants, fungi and animals. The next step to expand the knowledge of non-native species was "The Book of Alien Invasive Species in Polish Fauna" prepared by the team of experts coordinated by INC PAS in Krakow, till now published only on-line www.iop.krakow.pl/gatunkiobce/default.asp). Out of 302 animal species included in the book, 119 were considered to be invasive or important for other reasons and characterized in more details. It is expected that this list of aliens is incomplete, especially for some poorly studied taxe. Although, non-indigenous

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animals were estimated to constitute about 1% of Polish Eumetazoa fauna, their impact on native ecosystems cannot be judged simply from the number of species as they are not equally dangerous. Moreover, the percentage of 'biological pollutions' is much larger in particular groups. Freshwater fishes have undoubtedly the leading position in this ranking, as 25% of species currently occurring in Polish inland waters in the wild are non-indigenous. It appears that vertebrate fauna, especially taxa of commercial importance (hunting, angling, fishing, ornamental and fur breeding) were particularly altered by presence of exotic species and in prevalence their introductions were purposeful, e.g. 77% of mammals and 59% of freshwater fish were introduced intentionally. It is a worldwide trend considering the fact that in 2003 there were 3 072 reported fish introductions (between countries) in FishBase (Casal 2006). These represented 568 species from 104 families. Most of the introductions (2 904) were in freshwater ecosystems, and in 40% aquaculture was cited as their main cause (Casal 2006).

The objective of this paper is to review the present state of alien fish fauna in Poland, with special attention to species considered as invasive, as well as to discuss possible impacts of non-indigenous species on the native ecosystems. The information presented herein originates from over twenty years of our studies on alien fish species in Poland and literature data.

Results and Discussion

History of introductions

During the last 800 years 35 alien fish species have been introduced to Polish inland waters (Table 1). They originate mainly from three donor areas: North America (11 species), Eastern Asia and Siberia (10 species) and different regions of Europe (11 species). Besides, two species have come from Africa and one from South America, but their contribution to the local fish fauna is marginal. Twenty six species have been introduced intentionally from several motivations, well known worldwide (Welcomme 1988, Panov et al. 2009): aquaculture, sport fishing/ angling, improvement in species composition, biological control. The remaining nine species were brought either accidentally, usually as a contamination of stocking material, released by aquarists, or due to the range expansion after liquidation of geographic barriers, facilitated by water transport and human alteration in the environment. In the fish introduction history in Poland three periods might be distinguished: I – since early Middle Ages to the half of the 19th century; II – since half of the 19th c. to the end of the first half of the 20th c.; III – since the half of the 20th c. to nowadays (Witkowski 2002). In the first period only carp, *Cyprinus carpio* was successfully acclimatized in Poland. It was brought by Cistercian monks from the territory of Bohemia and Moravia in the 12–13th century and bred in many ponds at monasteries (Balon 1995). At the beginning of the 19th century the trials failed to acclimatize four other species *Salvelinus alpinus*, *Acipenser ruthenus,* one of endemic forms of coregonids originated from Alps, probably *Coregonus fera* and*, Oncorhynchus kisutsch* (Daszkiewicz 2001). In the next period, the attempts to introduce ten exotic species were undertaken, but they were successful only in the case of six species (i.e. rainbow trout, *Oncorhynchus mykiss,* brown bullhead, *Ameiurus nebulosus,* brook trout, *Salvelinus fontinalis*, pumpkinseed, *Lepomis gibbosus*, large mouth bass, *Micropterus salmoides,* gibel, *Carassius gibelio*), which are found in open waters also in the present day (Witkowski 1989, 2002). In the last 60 years 23 fish species have appeared in Polish waters, which constitute more than 65% of all introductions recorded in Poland (Table 1). Similar pattern in periodical intensity of fish introductions, pathways and fish species composition can be found in the neighboring Czech Republic, where 34 species are listed as introduced and released either in fishponds or directly into natural habitats (Lusk et al. 2010).

Table 1. Fish species introduced to Polish inland waters. Bolded names indicate naturalized and acclimatized species. Pathways of introduction: A – aquaculture, B – game/angling, C – fish fauna enrichment, D – ornamental/aquaristics, E – biological control, F – accidental, G – natural range expansion facilitated by human activities. * – successfully introduced later in 1985.

Year of introduction	Species	Natural range	Pathway
1200-1300?	**Common carp, *Cyprinus carpio* Linnaeus, 1758**	Danube catchment	A
1603?, 1840	Arctic charr, *Salvelinus alpinus* (Linnaeus, 1758)	Alps, boreal regions	B
1837*	Sterlet, *Acipenser ruthenus* Linnaeus, 1758	Siberia, Black & Caspian S.	A
1858-1862	Fera *Coregonus fera* Jurine, 1825	Alps	C
1859	Coho salmon, *Oncorhynchus kisutsch* Walbaum, 1792	North America	B
1881-1889	**Rainbow trout, *Oncorhynchus mykiss*** Walbaum, 1792	North America	B, A
1885	**Brown bullhead, *Ameiurus nebulosus* (Lesueur, 1819)**	North America	B
1889	Chinook salmon, *Oncorhynchus tschawytscha* Walbaum, 1792	North America	B
1890	**Brook trout, *Salvelinus fontinalis* (Mitchill, 1814)**	North America	B
1912?	**Largemouth bass, *Micropterus salmoides* (Lecepede, 1802)**	North America	A, E
1921, 1967	European mudminnow, *Umbra krameri* Walbaum, 1792	Danube catchment	F
1927	**Pumkinseed - *Lepomis gibbosus* Linnaeus, 1758**	North America	D
1930-1933	**Gibel, *Carassius gibelio* (Bloch, 1782)**	Eastern Asia	F
1964	**Grass carp, *Ctenopharyngodon idella* (Valenciennes, 1844)**	Eastern Asia	E
1965	**Silver carp, *Hypophthalmichthys molitrix* (Valenciennes, 1844)**	Eastern Asia	E
1965	**Bighead carp, *Hypophthalmichthys nobilis* (Richardson, 1845)**	Eastern Asia	E
1966	**Peled, *Coregonus peled* (Gmelin, 1789)**	Siberia	C
1966	**Huchen, *Hucho hucho* (Linnaeus, 1758)**	Danube catchment	B
1973	Baikal black grayling, *Thymallus arcticus baicalensis* (Dybowski, 1874)	Siberia	F
1973-1975?	Pink salmon, *Oncorhynchus gorbuscha* (Walbaum, 1792)	North America, E. Asia	C
1984	**Muksun, *Coregonus muksun* (Pallas, 1814)**	Siberia	C
1985	**Siberian sturgeon - *Acipenser baerii* Brandt, 1869**	Siberia	A
1985	**Russian sturgeon, *Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1833**	Black S., Caspian S.	A
1985	**Sterlet, *Acipenser ruthenus* Linnaeus, 1758**	Siberia, Black & Caspian S.	A
1989	**Black buffalo, *Ictiobus niger* (Rafinesque, 1819)**	North America	A
1990	North African catfish, *Clarias gariepinus* (Burchell, 1922)	Africa	A
1990	**Topmouth gudgeon, *Pseudorasbora parva* (Temmick & Schlegel, 1846)**	Eastern Asia	F
1993	**Amur sleeper, *Perccottus glenii* Dybowski, 1877**	Eastern Asia	F
1994	**Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758)**	Africa	A
1990s	**Mississipi paddlefish, *Polyodon spathula* (Walbaum 1792)**	North America	A
1995	**Eastern mudminnow, *Umbra pygmaea* (DeKay, 1842)**	North America	D
1995	**Racer goby, *Neogobius gymnotrachelus* (Kess1er, 1857)**	Ponto-Caspian region	G
1997	**Monkey goby, *Neogobius fluviatilis* (Pallas, 1814)**	Ponto-Caspian region	G
2001	Pirapitinga, *Piaractus brachypomus* **(Cuvier, 1818)**	South America	D
2002	**Round goby, *Neogobius melanostomus* (Pallas, 1814)**	Ponto-Caspian region	F
2008	**Tubnose goby, *Proterorhinus marmoratus* (Pallas, 1814)**	Ponto-Caspian region	G

Current state of non-indigenous fish species in Poland

At present there are 26 non-native freshwater fish species reported as acclimatized, casual or naturalized in Poland (Table 1). It means that 34% of freshwater fish fauna is composed of non-indigenous species. This value will be different if we consider some exotic species as probably extinct in the wild, e.g. last records of largemouth bass, *M. salmoides* come from the late 1960s (Brylińska 2000) and since then it has not been observed in Poland. Similarly, the presence of European mudminnow, *Umbra kramerii* is disputable as only one record from the 1960s was reliably documented while in two other locations species identification is doubtful and it is supposed that it could have been the eastern mudminnow, *Umbra pygmaea* (Witkowski et al. 1995). Brook trout, *Salvelinus fontinalis* introduced into Poland at the end of the 19th century, inhabited several lakes in the Tatra Mountain region and currently is not recorded in the wild as a self-sustained population (Brylińska 2000), but it is still kept in many breeding centers in different regions of Poland and often penetrates to open waters nearby. Moreover, some exotic species e.g. black buffalo, *Ictiobus niger* or North African catfish, *Clarias gariepinus* are kept in captivity in isolated ponds usually at research institutions and have never been found in the wild. Others were occasionally recorded outside the breeding centers. However, considering their temperature demands they cannot survive the winters, e.g. several individuals of Nile tilapia, *Oreochromis niloticus* were found in the tributary of the upper Oder River below the reservoir, where it was introduced (Kotusz et al. 2000). Mississipi paddlefish, *Polyodon spathula*, sterlet, *Acipenser ruthenus*, Siberian sturgeon, *A. baerii*, Russian sturgeon, *A. gueldenstaedtii* and their hybrids (*A. baerii* x *A. gueldenstaedtii*, *Huso huso* x *A. ruthenus*) are currently cultivated in many fish farms, as well as in "put-and-take" special recreational waters for anglers run out by private owners. Thus, they are sometimes caught in open waters due to escapes (Keszka & Stepanowska 1997, Gessner et al. 1999, Keszka & Heese 2003), but probably without chance to establish a stable population.

The next group that may be distinguished among non-native fishes are acclimatized/ casual species (*sensu* definitions provided by Copp et al. 2005) that, apart from breeding them in captive condition, i.e. in fish farms, were also purposely introduced to numerous locations in the wild. It includes carp, other Asian cyprinids (*Ctenopharyngodon idella*, *Hypophtalmichthys molitrix*, *H. nobilis*) and rainbow trout (*Oncorhynchus mykiss*). Although they are unable to reproduce and sustain populations in Poland without the human support (i.e. stocking), they can significantly influence native ecosystems because of their prevalence in some water bodies. For example, carp is the most commonly introduced and bred alien fish species in Poland. Between 1998 and 2002 it constituted 61% of all stocking fish released to open waters.

The rest of non-native species noted in Poland is naturalized. Some of them established self-sustained populations in the wild but their abundance is on a stable level and distribution is rather limited to particular locations, e.g. pumpkinseed, *L. gibbosus*, after rapid expansion observed in the 1960s now occurs only in the north-west of Poland, where it is particularly numerous in the lower stretch of the Oder River downstream of the 'Dolna Odra' electric power plant (Heese & Przybyszewski 1985); eastern mudminnow, *U. pygmea* was reported only from a few small tributaries in the Oder River system (Witkowski et al. 1995, Kostrzewa 1998).

The exceptional case is huchen (or Danubian salmon), *Hucho hucho*. The huchen's native range in Poland was restricted to two small rivers (Czarna Orawa and Czadeczka) of the Danube River basin, but because of over-exploitation (mostly illegal) and water pollution it became almost extinct there. In the 1950s it was translocated for conservation purposes to some tributaries of the upper stretch of the Vistula River where it established self-sustained populations (Witkowski 1996). Currently huchen is being stocked also into water courses of the Oder River catchment.

Finally, we have a group of invasive alien species. The term 'invasive alien species' refers to non-native species, subspecies, race or variety (including gamets, propagules or part of an organism that might survive and subsequently reproduce) that does not occur naturally in a geographic area, i.e. that did not previously occur there and then spread, with or without the aid of humans, in natural or semi-natural habitats, producing a significant change in composition, structure, or ecosystem processes, or caused severe economic losses to human activities (Copp et al. 2005). It follows that an alien species is able to reproduce and establish self-sustained population in the wild. According to the above definition eight non-indigenous fish species are presently treated as invasive in Polish inland waters.

Invasive species

Brown bullhead, *Ameiurus nebulosus*

The species was introduced from North America (where it naturally occurs in the Mississippi and Missouri river catchments) to several European countries (e.g. France, Germany, England, Holland, Belgium and Austria) in the second part of the 19th century (Welcomme 1988). The main purpose was improvement of species composition i.e. developing new resources for fishing and angling. In Poland the presence of brown bullhead dates from 1885 when it was first released to ponds in the Western Pomeranian Province (in those times belonged to Germany) (Horoszewicz 1971). Its further expansion is not well documented but apparently it soon penetrated open waters as at the beginning of the 1920s it was reported to be acclimatized in Silesia (SW of Poland) (Pax 1925) and before the World War II it reached the eastern part of Poland (the Bug River drainage). Its natural expansion was assisted by intentional introductions carried out by angling associations, fish pond's owners, accidental admixture to the stocking material of other species and using it as alive bait (Witkowski 2002). At present the species is widely distributed on the lowland territory of Poland: in Pomeranian Province, Mazurian Lake District, middle part of the Oder and Vistula River and their main tributaries e.g. the Warta River, the Bug River, the lower and middle section of the San River (Kolejko 1998, Brylińska 2000). Its preferred habitats are eutrophic lakes, lower courses of lowland rivers, oxbow lakes and ponds, where locally is very numerous, e.g. in some lakes in eastern Poland brown bullhead exceeded 50% biomass of totally caught fish (Kolejko 1998, Kornijów 2001). Till the 1990s it was noted in 22% of Polish rivers (Witkowski 1996). In lastest decades the decrease of brown bullhead abundance and occurrence or even its extinction in some rivers (Kusznierz et al. 1994, Kruk et al. 2001) is observed.

Gibel, *Carassius gibelio*

The history of its introduction in Europe is disputable and unclear due to lack of reliably and unanimous information on dates of first introductions, which results from uncertainty in species identification (Kottelat 1997). The recent studies with molecular markers indicate that the species originates from Far East Asia (Kalous & Šlechtová 2004). According to Bănărescu (1993) it was a very common, pond species commercially bred in China and with increasing popularity of aquaculture in the Middle Ages it was transferred through Islamic countries to eastern Europe. At the beginning of 20th century there were three major centers of its occurrence in Europe from where its invasion began, i.e. the Danube River delta (territory of Romania and Ukraine), bordering part of the Danube between Romania and Bulgaria and the Tisza River system (including parts of Serbia and Hungary) (Holčík & Žitnan 1978). In Poland the first documented records of *C. gibelio* came from 1933, when it was found in ponds northward from Lvov (currently Ukraine) and in southern part of central Poland (Gąsowska 1934). It was probably accidentally introduced with stocking material of carp *C. carpio* from an unknown source (Gąsowska 1934, Witkowski 1989). Its further expansion was not monitored in detail but the frequency of its occurrence and range of distribution continuously increased (Staff

1950). Initially it spread uncontrollably with stocking material of carp (Staff 1950), then it became commercial fish used as accompanying species in carp's ponds. Due to escapes from ponds it sooner or later appeared in open waters and successively penetrated to next drainages. Additionally, its dispersal was accelerated by intentional introductions to lakes and rivers, carried out by angling associations. That practice was especially popular till the 1990s and as a consequence, till that time it was reported from 50% of the main river systems in Poland (Witkowski 1996). Besides, based on investigations from the recent 20 years it has become more abundant and frequent than native crucian carp *Carassius carassius*. Nowadays, it is very common on the whole territory of Poland, particularly numerous in lowland lakes, ponds and rivers, but present also in mountain streams, in sections of slower water current. It is definitely the most abundant and widely spread exotic species in Poland.

Topmouth gudgeon, *Pseudorasbora parva*

The species' native range covers Far East Asia, i.e. the drainages of Amur, Yang-tze, Huang-ho rivers and inland waters of Japan, Taiwan and Korean Peninsula (Berg 1949). It was unintentionally brought to Europe with stocking material of Asian herbivorous cyprinids (*C. idella*, *H. nobilis*, *H. molitrix*). First records of its presence came from southern Romania and Albania, where it was found in ponds in 1961 (Bănărescu & Nalbant 1965, Knezevič et al. 1978). It soon escaped to open waters, including the Danube River system. Spreading either naturally or with stocking material within next 40 years it invaded most European countries. With stocking material of carp imported from Hungary or the Czech Republic topmouth gudgeon was also brought to Poland, where it was first recorded in the fish farm Stawno near Milicz (SW of Poland) in 1990 (Witkowski 1991). In the next year it was found in adjacent open waters i.e. the Barycz River system (the middle part of the Oder River drainage) (Błachuta et al. 1993). From that area it soon expanded across almost the entire territory of Poland. Its spread was partly natural but definitely accelerated by trade of unsorted stocking material and other irresponsible and ignorant practices, e.g. it was reported that 300 kg of that species were released to the Barycz River system after cleaning one pond in 1993. Its present distribution is rather patchy (Fig. 1), mainly connected with fish farms, where it is especially numerous. Through drainage ditches, it also penetrated to small water bodies, lakes and rivers and locally it is a dominant species in abundance, e.g. in a small river in Silesia its abundance in 2005 was a few thousands individuals per 100 m^2 (J. Kotusz, unpublished data).

Amur sleeper, *Perccottus glenii*

Its natural distribution range covers the Russian Far East, north-east China and northern part of North Korea (Berg 1949). Most of this area includes the Amur River basin, where the species inhabits flood plain waters and tributaries (Zeya, Sungari and Ussuri). Its first introduction to Europe dates from 1912 when several individuals were brought near St. Petersburg, kept in aquarium and after four years released to adjacent ponds, where they successfully bred. A similar scenario repeated in 1948 near Moscow. Since that time many other centers of Amur sleeper acclimatization emerged in the territory of the former Soviet Union (Reshetnikov 2004). In most cases its introductions were related to releasing the fish by aquarists, using it as a live bait, or to

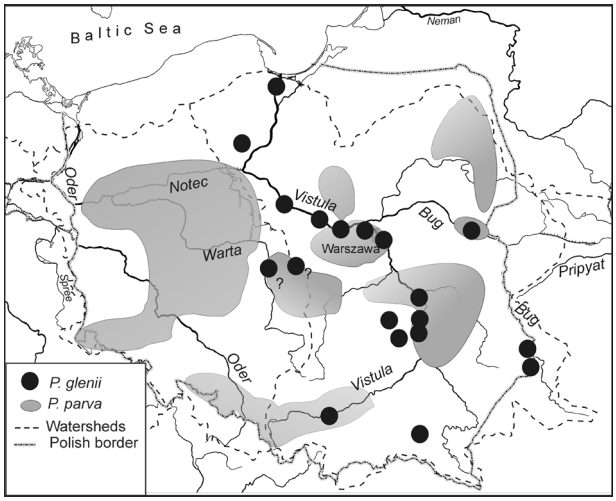

Fig. 1. Distribution of Amur sleeper (*P. glenii*) and topmouth gudgeon (*P. parva*) in Polish waters.

translocation with commercial fish stocking material (Reshetnikov 2004). As a result of these practices and further natural dispersal in adjacent waters Amur sleeper invaded many localities in Eurasia.

The circumstances of Amur sleeper introduction to Poland are unknown. It was speculated that the species was released by aquarists or brought with stocking material from the East (Antychowicz 1994). First few individuals were caught in an oxbow lake adjacent to the middle section of the Vistula near Dęblin in 1993 (Antychowicz 1994). It rapidly expanded downstream of the river (Kakareko 1999, Kostrzewa et al. 1999, Terlecki & Pałka 1999) and by 2000 it reached almost the river mouth (Wiśniewolski et al. 2001, J. Błażuk, pers. comm.), i.e. within 6-7 years it migrated almost 600 km downstream (Witkowski 2002). Currently the species is reported also from the smaller and bigger tributaries of the Vistula and from some fish farms, but was not found outside the Vistula drainage (Kostrzewa et al. 2004, Nowak et al. 2008) (Fig. 1). The species prefers rather highly vegetated habitats with stagnant water, so it is especially numerous in ponds, reservoirs, floodplain waters of the river valley and oxbow lakes.

Round goby, *Neogobius melanostomus*, racer goby, *N. gymnotrachelus*, monkey goby, *N. fluviatilis* and tubenose goby, *Proterorhinus marmoratus*

All these gobies have Ponto-Caspian origins. They naturally inhabit brackish waters (limans and estuaries) of Black, Azov and Caspian Sea as well as their rivers e.g. Danube, Dnieper, Southern Bug, Dniestr, Don, Kuban and Caucasian rivers (Miller 2003). Their natural distribution in rivers, depending on the species, was more or less limited to lower and middle stretches of these rivers, while in the recent decades the migrations farther upstream were observed (Ahnelt et al. 1998, Gulugin & Kunitsky 1999, Vasil'eva 2003). They spread in Europe through three main invasion corridors described for Ponto-Caspian fauna by Bij de Vaate et al. (2002). The northern corridor consisting of the Volga River, Rybinsky Reservoir, lakes Ladoga and Onega is connected by artificial canals with the Gulf of Finland. The central corridor, goes through the Dnieper and Pripyat rivers (the Black Sea basin), that are connected with the Vistula River system (the Baltic Sea basin) by Pripiat-Bug canal. The southern corridor goes along the Danube to the Rhine River.

Round goby was found for the first time in 1990 in the Puck Bay (part of the Gulf of Gdańsk, the Baltic Sea) (Skóra & Stolarski 1993). The most probable route of its migration to the Gulf of Gdańsk is the northern corridor (Sapota 2004). The species introduction to Polish waters was probably through the ballast waters transport. It soon spread along the whole Polish part of the Baltic coast, colonizing some coastal lakes and the Vistula Lagoon (Sapota 2004). Nowadays it is one of the dominant species particularly in the shallow waters of the Gulf of Gdańsk (Sapota 2004, Sapota & Skóra 2005) and was reported from several other places in the southern coastal waters of the Baltic Sea (Ojaveer 2006) as well as from the North Sea basin (Van Beek 2006). It also entered the Vistula River, where, till 2002, it reached as far as 130 km upstream from the mouth (Kostrzewa et al. 2004). There are several records of this species from the Oder River estuary (S. Keszka, pers. comm.) (Fig. 2). Considering that the species is already present at high abundance in Belarus in the Pripyat River, Pripyat – Bug canal and in the Mukhavets River near Brest (Gulugin & Kunitsky 1999, V. Semenchenko, pers.comm.), its migration into the territory of Poland to the Vistula River system, through the central corridor from Belarus must be expected in the nearest future.

Two other species of alien gobies reached the Baltic basin via the central corridor (Grabowska et al. 2008). Their occurrence in the Vistula River system was preceded by their invasion in the inland waters of Belarus via the Ukrainian part of the Dnieper River (Gulugin & Kunitsky 1999). Racer goby was first recorded in the middle section of the Bug River (Western Bug), the tributary of Vistula River in 1995 (Danilkiewicz 1996) and soon, in 2000, it was noted in the Włocławski Reservoir (lower

Vistula River) (Kostrzewa & Grabowski 2001). Till 2007 it almost reached the Vistula River mouth (J. Błażuk, pers. comm.). The location of the first record of racer goby was in a vicinity of the confluence of the Muchavets River, which connects the Bug River with Pripyat-Bug canal. It indicates the route of invasion. Besides, based on the mitochondrial DNA data, the Dnieper River was identified as a most likely source area for the Vistula River colonization (Ohayon & Stepien 2007). Monkey goby followed the same route of invasion. It was first noted in the same stretch of the Bug River (Western Bug) as racer goby, but two years later, in 1997 (Danilkiewicz 1998). It reached the Włocławski Reservoir in 2002 and then the Vistula River mouth in 2004, thus within seven years it expanded 836 km downstream (Kostrzewa & Grabowski 2002, Kostrzewa et al. 2004) (Fig. 2). Both species also entered some lower parts of the Vistula and Bug rivers' tributaries, but studies conducted in 2003 did not reveal its migration farther to the West, i.e. to the Oder drainage (Grabowska et al. 2008).

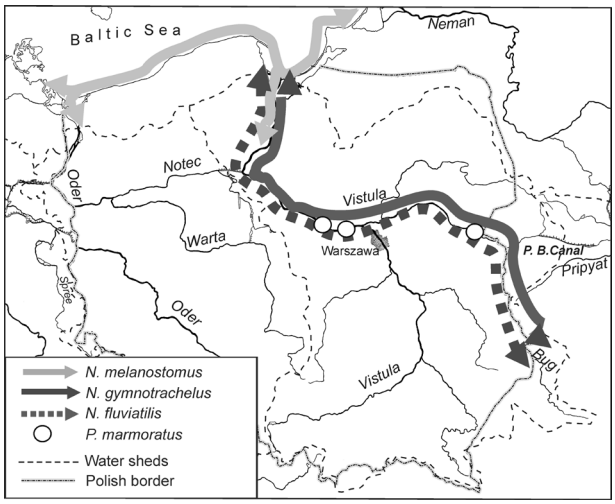

Fig. 2. Distribution of Ponto-Caspian gobies i. e. round goby (*N. melanostomus*), racer goby *(N. gymnotrachelus*), monkey goby (*N. fluviatilis*) and tubenose goby (*P. marmoratus*) in Polish waters; (P. B. canal: Pripyat - Bug Canal).

In 2008 the fourth species of Ponto-Caspian goby *P. marmoratus* was recorded in Poland (Grabowska et al. 2008). Recently, it is postulated that tubenose goby occurring in freshwaters is a separate species and the name *P. semilunaris* should be used to distinguish it from marine *P. marmoratus* (Stepien & Tumeo 2006). It was found for the first time in the Vistula River (backtail of the Włocławski Reservoir) and later also in the Bug River (Fig. 2). Later it was found also at several others locations in the Włocławski Reservoir and the Bug River (Grabowska, unpublished data, T. Kakareko, pers. comm.). It is expected to spread farther as quickly as other Ponto-Caspian gobiies. Most likely it migrated to the territory of Poland through the central corridor (Grabowska et al. 2008), as it has been recently recorded in Belarus in the upper and middle parts of the Pripyat River very close to the Pripyat-Bug canal (Rizevsky et al. 2007).

The invasion of Ponto-Caspian gobies is a combination of natural colonization and passive dispersal due to water transport (Ahnelt et al. 1998), supported by human mediated changes of riverine ecosystems, e.g. damming, alteration of river banks (Copp et al. 2005, Wiesner 2005). Assuming their invasive potential it may be expected that the three *Neogobius* species and tubenose goby present in Polish inland waters can migrate farther to Western Europe through the central corridor but also, as euryhaline organisms, they may invade the southern part of the Baltic Sea.

Impact

The negative impact of alien fish species on native ecosystems in Poland is still speculative rather than proved and needs further studies. One group of threats is related to their foraging behavior. It is usually expected that aliens may compete with indigenous fish species for food resources. Such impact was virtually shown for *A. nebulosus* in the Elbe drainage (Frank 1955, Hensel 1963) and *C. gibelio* in the Danube basin (Holčík 1980, Lusk et al. 2004). The high dietary overlap between native percid fishes and the invading Ponto-Caspian gobies were found in the Danube (Copp et al. 2008). There are not too many studies considering that problem in Polish waters while those dealing with it did not reveal diet overlap e.g. between racer goby and native perch and ruff in the Vistula River

(Grabowska & Grabowski 2005). The non-native species are also often blamed for predation on eggs and fry of native ones and due to that decrease of their reproduction success. This kind of prey was not often found in the diet of racer goby and monkey goby in the Włocławski Reservoir (Kostrzewa & Grabowski 2003, Grabowska & Grabowski 2005, Kakareko et al. 2005). The presence of non-native species can lead to native habitats modification. First, if the alien fish is a predator it can profoundly affect the population dynamics of indigenous prey species and result in decline or a depletion of native food resources. The introduction of brook trout to several lakes in the Tatra Mountains resulted in negative alteration in the structure of planktonic crustaceans (Gliwicz 1963) and probably contributed to extinction of relict crustacean *Branchinecta paludosa* (Kownacki 2004). The bad reputation as voracious predator is ascribed to Amur sleeper (Reshetnikov 2003). Effects of the species predation on local aquatic communities in Russia were reported as deleterious, especially in small water bodies inhabited by extremely dense populations of that fish. In Polish waters it feeds on a variety of aquatic invertebrates as well as on fish that become important prey items especially for larger individuals of Amur sleeper (Grabowska et al. 2009). Secondly, the herbivorous fish species e.g. Asian cyprinids are reported to destroy the spawning grounds of native phythophilous fish species through foraging on macrophytes. According to Mastyński et al. (1987) in several lakes the fishing of pikeperch, *Sander lucioperca*, pike, *Esox lucius*, tench, *Tinca tinca*, common bream, *Abramis brama*, roach, *Rutilus rutilus*, white bream, *Abramis bjoerkna* and perch, *Perca fluviatilis* decreased a few years after introduction of grass carp, *C. idella*. Krzywosz et al. (1980) associated the occurrence of grass carp with the depletion of wild fowl fauna, particularly those feeding on soft aquatic vegetation, e.g. coot, *Fulica atra* and swan, *Cygnus* sp. were reported to leave the water bodies stocked with Asian cyprinids.

Next type of impact concerns species integrity. Brook trout was believed to influence the reproductive success of native brown trout, *S. trutta* through hybridization resulting in sterile offspring (MacCrimmon & Campbell 1969). Introduction of peled lead to hybridization with native common whitefish, *Coregonus lavaretus*. Mamcarz (1992) reported that their hybribs occurred in about 70% of lakes in the Mazurian Lake District and genetically pure populations of native common whitefish were hard to find.

Finally, the exotic fish species may be vectors of alien parasites and diseases. For example, together with Asian herbivorous cyprinids two species of non-native tapeworms *Bothriocephalus acheilognathi* (= *B. gowkongensis*) and *Khawia sinensis* were introduced to Poland, causing loss in fry of indigenous cyprinids (Pańczyk & Żelezny 1974, Pojmańska 1993). Similarly, parasitic crustacean *Basanistes huchonis* was brought with translocation of huchen (Witkowski & Błachuta 1980). The latest invaders in Polish waters, i.e. Ponto-Caspian gobies and Amur sleeper, have become another source of alien parasites, e.g. population of monkey goby in the Vistula River is infected by monogenean parasite *Gyrodactylus proterorhini,* while Amur sleeper were host species for *Gyrodactylus perccotti* and *Nippotaenia mogurndae* (Ondračková et al. 2007). Topmouth gudgeon has been recently identified as a vector of disease caused by rosette-like agent (closely related to *Sphaerothecum destruens*) dangerous for European cyprinids, e.g. sunbleak (Gozlan et al. 2005). Formerly, Holčík & Žitňan (1978) found *C. gibelio* as host of two monogenic helmints: *Gyrodactylus shulmani* and *G. sprostona*e originating from Far East in European waters (Danube basin). Till now there is no data indicating that those parasites and disease threat native fish species in Poland.

The exotic fish species are already known to be involved in the trophic structure of native environments, e.g. round goby became an important food component of cormorants in the Gulf of Gdansk (the Baltic Sea, Poland), constituting up to 90% of consumed preys in summer months and up to 50% in winter (Bzoma 1998, Sapota 2005). According to anglers racer goby and monkey goby are

found in stomachs of native fish predators, like pikeperch, burbot and wels.

Conclusions

The number of alien fish species in Poland is continuously increasing. In the recent decades it has mainly been caused by accidental introductions and species range expansion accelerated by several human activities. The introductions of fishes that do not occur in Poland is regulated particularly by the Polish law, although it does not guarantee that the stocking material is not contaminated with unwilling species. At last four new species of Ponto-Caspian origin are expected in the nearest future to migrate to Belarusian part of central corridor which links Black and Baltic see basins through Dniester, Pripyat and Bug rivers (V. Semenchenko, pers. comm.). Their further spread to Poland is probably only a matter of time. Considering non-native fish species already naturalized in Poland there were no attempts to eradicate them from the wild and, assuming their present abundance and wide distribution, it is rather impossible. The ordination of Polish government (January 2003), that forbids to release some species, i.e. Amur sleeper, topmouth gudgeon and brown bullhead to open waters after catching, was intended for reduction of their spread. Unfortunately this regulation seems to be ineffective as it is rather not obeyed by anglers. Apart from legislation the most important issue seems to be the increase of public awareness of threats caused by non-native species and their spread e. g. through using them as a live bait and releasing afterwards.

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