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THE NON-INDIGENOUS FRESHWATER FISHES OF POLAND: THREATS TO THE NATIVE ICHTHYOFAUNA AND CONSEQUENCES FOR THE FISHERY: A REVIEW

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Abstract. This paper reviews the history, current state, tendencies, and perspectives of the fish introductions in Poland, as well as the consequences for the native ichthyofauna. The last 800 years witnessed attempts at introducing 37 fish species to territories the of present-day Poland; 19 of them still occur in inland waters of the country. The introductions (deliberate and accidental) reached their peak within 1964–2008, when as many as 24 alien fish species (64.5% of all "acquisitions") were introduced. In most cases, the negative effects on the aquatic environment, native fish species, and other aquatic organisms were noted. Alien helminth parasites (Monogenea, Digenea, Cestoda, and Nematoda), pathogenic fungi, and higher organisms (bivalves, fishes) have been introduced along with the fishes. In terms of the increased fish production and economic profits the aquaculture has been the only section of fisheries that has benefited from acquiring new fish species. Further, detailed studies on the effect of alien species on the native ichthyofauna are necessary.

Keywords: Poland, inland waters, fish introduction, impact, native ichthyofauna, economic profit

Fish introduction on the global scale has a long history. First fish translocations date back to antiquity. Within the last millennium, a total of 3072 cases of fish "import" of 568 species, representing 104 families, were documented in more than 140 countries. The majority of them (2904) were aimed at freshwater ecosystems; the aquaculture was the main target in 1205 cases (ca. 40%) (Froese and Pauly 2012, Casal 2006, Savini et al. 2010). Introductions as a global phenomenon intensified within 1950–1980 (Welcomme 1988, 1992). After that period the rate of introductions substantially decreased. This was associated with the increasing awareness of the negative effects on the native fish communities, other aquatic organisms, and the environment (Krzywosz et al. 1980, Moyle et al. 1986, Wilkońska 1988, Witkowski 1989, 2002, Allendorf 1991, Crossman 1991, Holčik 1991, Krueger and May 1991, Huxel 1999, Manchester and Bullock 2000, Elvira 2001, Perrings 2002, Copp et al. 2005, Gozlan et al. 2005, 2009, García-Berthou 2007, Grabowska et al. 2010, Lusk et al. 2010).

Fish introductions in Poland. In Poland, within the last 800 years, attempts were made to introduce 37 alien freshwater species fishes. The reasons behind their introduction (Witkowski 1996a, 2002, Grabowska et al. 2010) were similar as in the other regions of the world (Welcomme 1988, 1992, Economidis et al. 2000, Elvira and Almodóvar 2001, Copp et al. 2005, Panov et al. 2009), i.e. aquaculture, "improvement" of native species composition, angling, control of undesirable organisms, ornamental aquaculture. Accidental introductions, such as the fish escaping from aquaculture sites and penetration through canals connecting different river systems played a considerable role. A number of the introductions were motivated by more than one reason (Elvira 2001).

The majority of the fish species introduced to Poland (12) came from North America, 11 from Asia including Siberia, 10 from other regions of Europe, and two from each Africa and South America. At present, 19 alien species live permanently in the open waters of Poland, constituting 24% of the country's freshwater ichthyofauna (Witkowski et al. 2009). The prevailing number of the introductions was deliberate and only 14 were accidental. During the last few hundred years the intensity of introductions, like in other countries, depended on the advancement of breeding techniques, possibility of long-distance transport, and the rising popularity of alien species. The whole period of introduction of fishes into inland waters of Poland can be subjectively divided in three stages: 1) from early Middle Ages up to the beginning of the 1860s; 2) from the 1860s to the end of 1959; 3) from 1960 till the end

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of the first decade of the 21st century (Witkowski 1996a, 2002, Grabowska et al. 2010) (Table 1).

The first stage included several attempts of introduction of alien species, the only successful case being that of common carp, *Cyprinus carpio* L. It is believed that the fish were brought by the Cistercian monks from the Czech and Moravia regions between the 12th and the 13th century (Witkowski 2008), where at that time it was already farmed in many monastery ponds (Balon 1995, 2004). Attempts at introducing further four species: Arctic charr, *Salvelinus alpinus* (L.); sterlet, *Acipenser ruthenus* L.; fera, *Coregonus fera* Jurine, 1825; and coho salmon *Oncorhynchus kisutch* (Walbaum, 1792) have failed (Witkowski 1989, Daszkiewicz 2001).

The second period featured introductions of 9 alien species. Of these only 6—rainbow trout, *Oncorhynchus*

Table 1

A list of fish species introduced into inland waters of Poland

Phase	Species	Year of introduction	Introduction success	Original range	Purpose of introduction	Type of reproduction in Poland
Phase I	*Cyprinus carpio*	1200–1300	S	Europe	A	Ar, Nda
	Salvelinus alpinus	1603?, 1840		Europe	B	N
	Acipenser ruthenus	1837		Europe	A	Ar
	Coregonus fera	1858–1862		Europe	C	N
	Oncorhynchus kisutsch	1859		N. America	B	Ar
Phase II	*Oncorhynchus mykiss*	1881–1889	S	N. America	B, A	Ar
	Ameiurus nebulosus	1885	S	N. America	B	N
	Oncorhynchus tschawytscha	1889		N. America	B	N
	Salvelinus fontinalis	1890	S	N. America	B	N
	Micropterus salmoides	1912?		N. America	A, E	N
	Umbra krameri	1921, 1967		Europe	F	N
	Lepomis gibbosus	1927	S	N. America	D	N
	Carassius gibelio	1930 – 1933?	S	Asia	F	N
Phase III	*Ctenopharyngodon idella*	1964	S	Asia	E	Ar
	Hypophthalmichthys molitrix	1965	S	Asia	E	Ar
	Aristichthys nobilis	1965	S	Asia	E	Ar
	Coregonus peled	1966	S	Asia	C	N
	Thymallus baicalensis	1973		Asia	F	N
	Oncorhynchus gorbuscha	1973–1975?		N. America	C	N
	Coregonus muksun	1984	S	Asia	C	N
	Acipenser baeri	1985		Asia	A	Ar
	Acipenser gueldenstaedti	1985		Europe	A	Ar
	Acipenser ruthenus	1985		Europe/ Asia	A	Ar
	Ictiobus niger	1989		N. America	A	Ar
	Clarias gariepinus	1990		Africa	A	Ar
	Pseudorasbora parva	1990	S	Asia	F	N
	Perccottus glenii	1993	S	Asia	F	N
	Oreochromis niloticus	1994		Africa	A	Ar
	Polyodon spathula	1990s		N. America	A	Ar
	Umbra pygmaea	1995	S	N. America	D	N
	Neogobius gymnotrachelus	1995	S	Europe	G	N
	Neogobius fluviatilis	1997	S	Europe	G	N
	Piaractus brachypomus	2001		S. America	D	Ar
	Neogobius melanostomus	2002*	S	Europe	F	
	Pangasianodon hypophthalmus	2005		Asia	D	Ar
	Pterygoplichthys gibbicens	2006		S. America	D	Ar
	Ameiurus melas	2007	S	N. America	A, F	N
	Proterorhinus semilunaris	2008	S	Europe	G	N

*first found in inland waters (known from the Puck Bay since 1990); S = introduction success (fish established); A = aquaculture; B = angling; C = improvement of wild stocks; D = ornamental fish keeping; E = biological control or biomanipulation; F = accidental; G = penetration through canals connecting different river systems; Ar = artificial; N = natural; Nda = no data available.

mykiss (Walbaum, 1792); brown bullhead, *Ameiurus nebulosus* (Lesueur, 1819); black bullhead, *A. melas* (Rafinesque, 1820); brook trout, *Salvelinus fontinalis* (Mitchill, 1814); pumpkinseed, *Lepomis gibbosus* (L.); and Prussian carp, *Carassius gibelio* (Bloch, 1782)—succeeded in adapting to local conditions and are still encountered in the wild in Poland. (Witkowski 1996b, Nowak et al. 2010). The largemouth black bass, *Micropterus salmoides* (Lacepède, 1802), initially successfully farmed, has not been observed in the Polish waters for over 40 years.

The last 60 years (stage 3; 1960–2010) witnessed the introduction of as many as 24 species which is 65% of all fish species hitherto introduced to Poland (Grabowska et al. 2010). Within the first 30 years (of the above-mentioned period) 12 species (reaching considerable size) were deliberately introduced for aquaculture under controlled conditions and for biomanipulation purposes because of progressing eutrophication of lakes (Opuszyński 1972). Four acipenserid fish species—*Acipenser ruthenus*; Siberian sturgeon, *A. baerii* Brandt, 1869; Danube sturgeon, *A. gueldenstaedtii* Brandt et Ratzeburg, 1833; Mississippi paddlefish, *Polyodon spathula* (Walbaum, 1792); and their hybrids—have been cultured in many pond farms (Kolman 2006), and single escapees are sporadically observed in the wild (Arndt et al. 2000, Keszka et al. 2008).

Further 12 species reached Poland's inland waters in the last two decades (1990–2010); some of them were introduced accidentally—topmouth gudgeon AKA stone morocco, *Pseudorasbora parva* (Temminck et Schlegel, 1846); Amur sleeper AKA Chinese sleeper, *Perccottus glenii* Dybowski, 1877—or as a side effect of ornamental fish keeping—pirapitinga AKA pirapatinga, *Piaractus brachypomus* (Cuvier, 1818); panga AKA striped catfish, *Pangasianodon hypophthalmus* (Sauvage, 1878); and leopard pleco, *Pterygoplichthys gibbiceps* (Kner, 1854) (see: Boeger et al. 2002, Witkowski and Kotusz 2003, Keszka et al. 2008, Nowak et al. 2008, Więcaszek et al. 2009, Witkowski 2009, Półgęsek et al. 2011). The recent decades were also marked by a fast expansion of gobies—racer goby, *Babka gymnotrachelus* (Kessler, 1857); monkey goby, *Neogobius fluviatilis* (Pallas, 1814); round goby, *N. melanostomus* (Pallas, 1814); and western tubenose goby, *Proterorhinus semilunaris* (Heckel, 1837), which penetrated through canal systems connecting the Ponto-Caspian river systems with the Vistula River system (Kostrzewa and Grabowski 2001, 2002, Bij de Vaate et al. 2002, Jazdzewski et al. 2002, Kostrzewa et al. 2004, Grabowska et al. 2008). All these invasive species, of small size, owe their great colonisation success to their effective reproductive strategy (multiple spawning, eggs laid in nests, paternal care) and extreme resistance to adverse habitat conditions (Witkowski 2002, Kostrzewa and Grabowski 2003, Kostrzewa et al. 2004, Grabowska et al. 2009a, b).

To be continued… The list of non-native species in the Polish freshwaters is not complete; in the near future we can expect other newcomers, mainly due to dispersal from adjacent countries, i.e., places of their previous introduction. The central invasion corridor *sensu* Bij de Vaate et al. (2002) has appeared to be especially important for the recent introduction of alien fish and invertebrates through semi-natural expansion from the Ponto-Caspian region (Grabowska et al. 2008, Karatayev et al. 2008, Rizevskij et al. 2009, Semenchenko et al. 2011). Since the 1990s, three species of gobies have entered the Polish territory, migrating from Belarus through the Pripyat-Bug canal and the fourth one—round goby—has been already recorded in the Belarussian part of the Bug River in Brest, thus it is more than certain that soon it will be reported also from the Polish section of that river (Kostrzewa et al. 2004, Ohayon and Stepien 2007, Grabowska et al. 2008, 2010, Semenchenko et al. 2011). The latter species—*N. melanostomus*—invades Polish inland waters from two directions, i.e., from the north, as it has already entered the Vistula River from the Gulf of Gdańsk (Kostrzewa and Grabowski 2002), and from the east (Semenchenko et al. 2011). The other species which has already been recorded in the Belarussian part of the central invasion corridor is the Black and Caspian Sea sprat, *Clupeonella cultriventris* (von Nordmann, 1840). It was recorded in the central part of the Pripyat River in 1986 (V. Rizevsky and M. Pluta, unpublished data), but has not been found during the 2007 survey (Semenchenko et al. 2011). It is possible that its appearance was associated with an accidental introduction with a ship (ballast waters) entering the Mykashevichy River harbour (Rizevsky et al. 2007). This species, however, occurs in the reservoirs along the Dnieper River (Romanenko et al. 2003) as far as Kiev Reservoir (Ukraine), located 550 km downstream, and its possible expansion in the future can not be ignored. The invasion of alien species through the Belarussian- and then Polish section of the central invasion corridor was preceded by their expansion in the Dnieper River in Ukraine (Smirnov 1986). The large reservoir located on this river seemed to facilitate these earlier invasions of the rather poorly swimming species, since the damming created a limnic ecosystem which was suitable for population establishment, abundance increase, and farther upstream spread along the river system. The Kiev Reservoir is a very likely donor of such invaders. Such alien species as the southern ninespine stickleback, *Pungitius platygaster* (Kessler, 1859); bighead goby, *Ponticola kessleri* (Günther, 1861), black-striped pipefish, *Syngnathus abaster* Risso, 1827; and stellate tadpole-goby, *Benthophilus stellatus* (Sauvage, 1874), are already established there. In 2008 two of them (southern ninespine stickleback and black-stripped pipefish) were found in the Belarussian part of the Dnieper River (upstream from the section of the river belonging to the central corridor) on the border between Belarus and Ukraine (V. Rizevsky and M. Pluta, unpublished data). The black-stripped pipefish is now widely distributed and abundant in all the Dnieper dam reservoirs (Romanenko et al. 2003). The bighead goby also has a large invasive potential, considering its invasive history and fast spread in the Ukrainian part of the Dnieper River as well as in the Danube system (Copp

et al. 2005). The other Ponto-Caspian fish—the stellate tadpole goby—entered the Kiev Reservoir immediately after its construction in the 1980s and recently was found in the reservoir's upstream section (Zimbalevskaya et al. 1989, Romanenko et al. 2003).

The trade of fish stocking material is another source of potential new invaders. The black bullhead was found in a small dam reservoir in southern Poland. The species may have been present in the Polish inland waters much earlier, but was misidentified as brown bullhead (Nowak et al. 2010). Being a common alien fish in many European countries including the adjacent Czech Republik, Slovakia, Ukraine and Germany, the black bullhead seems to be a good candidate for a new invasive species in Poland, and the exchange of stocking material may accelerate its expansion. In recent years the fathead minnow, *Pimephales promelas* Rafinesque, 1820, the species of North American origin, appeared in a few ponds of some western European countries. It is a pet fish kept in aquaria and garden ponds for ornamental purposes; it can be also used as live bait, like in the parts of the USA where it was introduced outside its natural range because of the bait bucket release. It is already recorded in the inland waters of the United Kingdom, Belgium, the Netherlands and possibly also in France and Germany. Its possible continuous spread is monitored (Verreycken et al. 2007, Zięba et al. 2010) as considering its biological features the species seems to have a high invasive potential. The popularity of garden ponds in Poland increases every year thus its appearance in the Polish waters is also possible.

Further species are still being imported for aquaculture purposes. Since 2005 several trout farms in Pomerania have been breeding the Arctic charr, and farming in recirculation aquaculture systems of another species—barramundi, *Lates calcarifer* (Bloch, 1790), started in 2009. It cannot be ruled out that soon also these species, despite being cultured under controlled conditions, may find their way to open waters, as was the case of several other species (Kotusz et al. 2000).

Effects of introduced fishes on aquatic organisms and aquatic environment in Poland. The presence of introduced fishes in Poland has already caused many unfavourable changes, both within the native ichthyofauna and in aquatic ecosystems as a whole (Gliwicz 1963, Wilkońska 1988, Witkowski 1989, 1996a, 2002, Witkowski et al. 2004, 2009). Some examples are given below.

The brook trout, introduced into rivers where the native brown trout, *Salmo trutta* m. *fario* (Linnaeus, 1758), occurred, contributed to the decrease in abundance of the latter species. Both species spawn at the same time and often hybridise producing infertile offspring (MacCrimmon and Campbell 1969). When introduced to the lakes of Tatra Mountains (Witkowski 1996c) the species caused considerable changes in the structure of planktonic crustacean communities (Dawidowicz and Gliwicz 1983), and probably contributed also to the disappearance of a relic phyllopod—*Branchinecta paludosa* (see Kownacki 2004).

The introduction of peled, *Coregonus peled* (Gmelin, 1789), in lakes where the native European whitefish, *Coregonus lavaretus* (L.), occurred, resulted in hybridisation of the two species. Their hybrids occur in as many as 70% Mazurian lakes (Mamcarz 1992) and it is now difficult to find genetically pure populations of native forms of the whitefish. The process has been intensifying ever since, because peled shows a strong migration drive and invades an increasing number of lakes.

The mass occurrence of the topmouth gudgeon in our waters makes possible hybridisation with the sunbleak, *Leucaspius delineatus* (Heckel, 1843), more likely and consequently may lead to disappearance of this native species (Gozlan and Beyer 2006).

Introducing great numbers of herbivorous fishes caused many deleterious changes in the lake ecosystems. The grass carp, *Ctenopharyngodon idella* (Valenciennes, 1844), exerted an especially negative effect—as a result of consumption of soft- and hard vegetation it destroyed spawning grounds, shelters, and feeding grounds of phytophilous fishes and consequently contributed to the disappearance of several native fish species in the Konin lake complex (Wilkońska 1988). In some of the lakes in Wielkopolska the catches of sander AKA pike-perch, *Sander lucioperca* (L.); northern pike, *Esox lucius* L.; tench, *Tinca tinca* (L.); common bream, *Abramis brama* (L.); roach, *Rutilus rutilus* (L.); silver bream AKA white bream, *Blicca bjoerkna* (L.); and European perch, *Perca fluviatilis*, decreased already a few years after introducing the grass carp (Mastyński et al. 1987). The lakes into which the grass carp was introduced showed a distinct impoverishment of their bird fauna (Krzywosz et al. 1980). Such bird species as coot, *Fulica atra*, or swan, *Cygnus* sp., feeding on soft vegetation, left the lakes permanently. As in the case of the grass carp, the management of the two Asian cyprinids— silver carp, *Hypophthalmichthys molitrix* (Valenciennes, 1844), and bighead carp, *H. nobilis* (Richardson, 1845)—requires control measures. In some cases they can decrease the general productivity of lakes and become a threat to populations of the most valuable native fish species. When studying the effect of the stock of the silver carp and bighead carp on the environmental and biocenotic conditions in carp ponds, Opuszyński (1978, 1997) found that in some cases they could even accelerate eutrophication. They feed on detritus rather than unicellular algae, and eliminate zooplanktonic filtrators, thus accelerating the circulation of the most important biogenic elements—phosphorus and nitrogen—in lake ecosystems.

The round goby which in the conditions of the Baltic bays and gulfs feeds mainly on mussels (*Mytilus trossulus*), contributes to reintroduction of heavy metals that have accumulated in the bivalve's body to the circulation in the ecosystem (Sopota 2005). Because in these areas the goby is mainly consumed by the cormorant *Phalacrocorax carbo* considerable quantities of heavy metals accumulate in the birds' organism (Bzoma 1998).

Introduction of the brown bullhead, *A. nebulosus* distinctly changes the ichthyofauna of some lakes and small water bodies. In such waters the fish can rapidly become a dominant as a result of consuming eggs and fry of other species (Adamczyk 1975, Kornijów 2001).

In the case of those introduced species (i.e., topmouth gudgeon, Amur sleeper, racer goby, monkey goby, round goby, and tubenose goby) which have recently rapidly invaded new regions of the country there are no precise literature data on their effect on the autochthonous ichthyofauna. They are known to compete for food with native species, and can devour their eggs and juvenile stages (Skora and Rzeznik 2001, Kakareko et al. 2003, Kostrzewa and Grabowski 2003, Wandzel 2003, Grabowska and Grabowski 2005, Grabowska et al. 2009 a, b, Hliwa 2010). The appearance of the Amur sleeper in a small peat bog pond near Sobibór within one year caused a total eradication of the lake minnow, *Rhynchocypris percnurus* (Pallas, 1814) ("*Eupallasella percnurus*" see Wałowski and Wolnicki 2010). Data from other parts of Europe clearly indicate that the appearance of alien species also distinctly contributed to gradual disappearance of some native fishes (Balon 1959, Žitnan and Holčik 1976, Arnold 1985, Jankovič 1985, Kautman 1999, Jurajda et al. 2005). Introduced species were found to bear many parasites which are alien to the native helminth fauna (i.e., *Dactylogyrus aristichthys*, *D. hypophthalmichthys*, *D. lamellatus*, *D. nobilis*, *D. suchengati*, *Gyrodactylus fairporti*, *G. perccotti*, *G. proterorhini*, *Cleidodiscus monticelli*, *C. pricei*, *Paradiplozoon marinae*, *Nippotaenia mogurndae*) (see Prost 1973, Corkum et al. 2004, Ondračková et al. 2012, Popiołek and Kotusz 2007, Dzika 2008, Mierzejewska et al. 2012). Exotic monogeneans (i.e., *Thaparocleidus caecus*, *Mymarothecium viatorum*) were introduced in Poland with non-invasive, "aquarium" species (panga, pirapitinga, and pleco) (Boeger et al. 2002, Więcaszek et al. 2009.

The species which is the most invasive in Europe—the topmouth gudgeon (Gozlan et al. 2010) transmits the rosette agent, *Sphaerothecum destruens* (Dermocystida), a dangerous pathogen which causes mass mortality among many species of salmonids and cyprinids (Arkush et al. 1998, Gozlan et al. 2005). The species is also vector to two flatworm parasites (*Dactylogyrus squameus*, *Diplostomum spathaceum*), one nematode (*Anguillicola crassus*), and a few species of zoosporic fungi (i.e., of the genera *Achlya*, *Blastocladiopsis*, *Leptomitus*, *Pythium*, and *Rheosporangium*) which constitute a threat to the native fishes (Czeczuga et al. 2002). The fish tapeworms *Bothriocephalus acheilognathi* (junior synonym: *B. gowkongensis*) and *Khawia sinensis* were introduced in Poland with the introduced Asiatic herbivorous fishes; they cause considerable losses among the fry of native species and farmed carp (Pańczyk and Żelezny 1974, Pojmańska 1993). Furthermore, several monogenean species (i.e., *Dactylogyrus aristichthys*, *D. hypophthamichthys*, *D. lamellatus*, *D. nobilis*, *D. suchengtai*) (see Pojmańska and Chabros 1993, Niewiadomska and Pojmańska 2004) were introduced in the same way. Similarly, the Chinese pond mussel, *Sinanodonta woodiana* reached Poland with stocking material of Asiatic cyprinids, as a fish gill parasite at the stage of glochodium (Witkowski 2009, Gozlan et al. 2010).

Economic importance of introduced fish species. Farming of only few species introduced in Poland, exclusively under controlled conditions, brought considerable economic profits throughout increased cultured fish consumption.

In this respect, the proportion of the common carp has traditionally been the greatest; its production in 2002–2009 was 20 100–15 600 t per year (mean ca. 17.0 t) though in the last decade a decreasing tendency is observed as a result of increased mortality and the losses caused by parasites and diseases, mainly the koi herpes virus (KHV), piscivorous animals (mainly cormorants), and low water temperature during the farming season (Lirski and Wałowski 2010, Turkowski and Lirski 2010). In the case of rainbow trout the last decade witnessed a very fast increase in production of consumer fish which for a few years was within 14–16 thousand t per year (Bontemps 2008, K. Goryczko personal communication). The commercial value of production of the two species for 2002 was estimated as ca. PLN 300 mln (= ca. EUR75 mln) (unpublished data of the Ministry of Agriculture and Rural Development; Sector Operational Programme Fishing and Fish Processing 2004–2006).

Studies on the possibility of farming of Asiatic herbivorous cyprinid fishes in Poland conducted by the Inland Fisheries Institute showed that these species, when kept together with carp, could increase the fishery yield of the ponds by ca. 30%. The Asian cyprinids which destroy vascular plants and feed on phyto- and zooplankton and detritus have a favourable effect on the carp pond ecosystem. They contribute to a decrease in the costs of vegetation control and increase the effectiveness of mineral fertilisation (N, P) (Opuszyński 1972). Due to the increased production of Asian herbivorous cyprinids was noted in Poland, i.e., the production of grass carp, silver carp and bighead carp in ponds and lakes in 2009 was 277.3, 177.5, and 224.4 t, respectively, and the total production for the period 2007–2009 was 1902.5 t (Lirski and Wałowski 2010, Wołos et al. 2009). Because these species do not reproduce naturally under our climatic conditions, they can be regarded as relatively safe for the native ichthyofauna provided that there will be no massive introductions into natural lakes.

Farming the acipenserids, most of which are threatened with extinction, is the only method of their preservation and regular provisioning of the market with their valuable caviar (Kolman 2006). Their production in 2005–2010 had an increasing tendency and was 1320 t per year (mean: 220 t per year), while the caviar production was 50–600 kg per year (mean 290 per year) (R. Kolman, personal communication).

Catches of peled, *Coregonus peled*, and muksun, *C. muksun* (Pallas, 1814), from lakes are at a low level; by

the end of the 20th century the catch was ca. 25 t per year (Szczerbowski 1985, 2000), and recently it is not even reflected in the statistics (Ministry of Agriculture and Rural Development, unpublished data).

Among warm water species, farming the Nile tilapia, *Oreochromis niloticus* (L.), is still at an experimental stage, while further attempts at farming the black buffalo, *Ictiobus niger* (Rafinesque, 1819), were abandoned (A. Lirski, personal communication). Only the production of the north African catfish, *Clarias gariepinus* (Burchell, 1822), shows an increasing tendency. In recent years it reached ca. 500–600 t per year. The recently started farming of the barramundi yields at present 100 t, and is expected to reach 1500 t per year (R. Marciniak, personal communication), while that of the Arctic charr—90 t per year (K. Goryczko personal communication).

CONCLUSION

The presence of alien fishes in Poland has already caused many deleterious changes in the aquatic ecosystems. They are increasingly often recognised both in Poland (Witkowski 2002, Grabowska et al. 2010) and in other regions, but their complete and objective assessment is not always possible (Cowx 1997, Bartley and Casal 1998, Cowx and Gerdeaux 2004, Van Zyll de Jong et al. 2004, Casal 2006, Uzunova and Zlatanova 2007, Gozlan 2008, Lusk et al. 2010). Moyle et al. (1986) termed the impact of introduced fishes on native species the "Frankenstein effect". Hence, further, detailed studies on the effect of alien species on the native ichthyofauna are necessary.

In the case of introduced commercial species kept in aquaculture, the distinct increase in fish production observed in Poland is reflected by measurable financial value (Szumlicz, unpublished*). The situation is quite different in the open waters where the introduced species are no longer under control. Hence, all the plans for introduction of yet another species should be analysed in great detail, while the associated culture and studies should be conducted in well isolated water bodies and institutions to prevent the fish escape and spread.

Finally, the pros and cons of fish introductions should be considered here: do the economic profits from the introductions compensate for the losses in the native ichthyofauna and aquatic environment? The answer will probably not be possible for many years, till the effects of the introductions become clearly marked, but then the losses may already be irreversible, while introductions are increasingly often termed a "crime against biodiversity" (Courtenay and Moyle 1992).

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