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Range extension and conservation status of the bitterling, *Rhodeus sericeus amarus* in Russia and adjacent countries

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A b s t r a c t . The distribution and abundance of the bitterling, a small ostracophilous cyprinid species, is reanalysed on the basis of our records and a review of the recent literature. This fish, recognised as endangered or vulnerable in many European countries, shows a rapid expansion beyond its native geographical range within the limits of the former Soviet Union. In the last decades it has invaded the lower Volga, Kuban and Aras River basins and has recently started to colonise the upper Volga and upper Ural River tributaries. From the early 1980s the number of water bodies and sampling sites where the bitterling is recorded, increases steadily over the entire area examined. At the same time, bitterlings increased in abundance and became a basic species in fish assemblages of diverse water bodies including rivers (both lower and upper reaches), ponds, canals and estuaries. The spread of bitterling outside its historical range results from man-made connections of contiguous waterway systems, from unintentional introductions by aquarists or, more likely, by anglers using bitterlings as bait fish. Independent and synchronous bitterling invasions to geographically distant basins indicate that some global or macroregional factors facilitate its expansion.

Key words: bitterling occurrence, abundance, expansion, conservation, invasion species

Introduction

The common bitterling *Rhodeus sericeus* (Pallas, 1776) is a small ostracophilous fish with disjunctive Eurasian distribution. Until recently, it was considered the only representative of the East Asian cyprinid subfamily Acheilognathinae in Europe (B e r g 1949, H o l č í k 1999). The systematic position and relationships of the European bitterling populations remain questionable and controversial (H o l č í k & J e d l i č k a 1994, K o t t e l a t 1997, H o l č í k 1999), with poor consistency found between morphological and molecular data (B o h l e n et al. 2006). In Europe, East Transcaucasia and Asia Minor it is represented by the subspecies *Rhodeus sericeus amarus* (Bloch, 1782), (*Rhodeus amarus* auctorum) while in the Far East by the nominotypical subspecies *Rhodeus sericeus sericeus* (or, respectively, *R. sericeus*) (Pallas, 1776), although distinguishing further species based on the phylogenetic species concept is likely. Its west Caucasian populations have been re-described as the new species *Rhodeus colchicus* (B o g u t s k a y a & K o m l e v 2001) and Mediterranean populations were raised to a specific level (*R. meridionalis*) in a recent phylogeographic study (B o h l e n et al. 2006) (Fig. 3).

Due to a unique means of the bitterling reproduction (W i e p k e m a 1961, B r e d e r & R o s e n 1966) by laying eggs into unionid mussels, its occurrence is limited largely by the presence of unionids (P r z y b y l s k i & Z i ę b a 2000). Meanwhile this fish is seen as an ideal species for many questions regarding mating tactics (S m i t h et al. 2004), co-evolutionary dynamics (R e i c h a r d et al. 2006) and population consequences of individual behaviour decision (S m i t h et al. 2000, 2006).

The conservation status of the bitterling varies across different parts of its geographic range. In the southern Caspian Sea basin this species is rather common (K u l i e v 1989, K i a b i et al. 1999) and is considered in the conservation category of "least concern" (LR-lc used by IUCN). In the European part of its distribution range, however, the bitterling is mostly seen as a rare and endangered fish (L e l e k 1987) and is considered as a species of high conservation status. Being listed in the Bern Convention (Appendix III) and in the EU Habitats Directive (Annex II) the bitterling is under international protection. This species is recognised as nearly threatened (LR-nt according to IUCN criteria) in Switzerland (K i r c h h o f e r 1997), Slovenia (P o v ž 1996), and Poland (P r z y b y l s k i 2001), vulnerable (VU) in France (K e i t h & M a r i o n 2002), Germany (F r e y h o f 2002), and the Netherlands (d e N i e 2003), or endangered (EN) in the Czech Republic (L u s k 2002). In Austria the bitterling is assessed to be endangered ("gefährdet"), too (S p i n d l e r 1995). Although *R. sericeus* is not on the IUCN Red List, this species is under strict legal protection in some countries, e.g. the Netherlands, Belgium, Germany, and Poland. This species is also included in the regional Red Books or Red Lists of several provinces of Central Russia. However, this commonly accepted view now needs substantial revision.

In this paper we have summarised our own and literature data on the bitterling occurrence and number to trace recent changes in its geographic distribution, conservation status and to demonstrate that over considerable parts of its European range this species is in fact highly invasive, deserving more likely an impact assessment as aquatic nuisance species, rather than protection.

Material and Methods

Species collections from previous monitoring programmes carried out by the following institutions were reviewed**:** the Hydrochemical Institute, the Federal Service of Russia on Hydrometeorology and Environmental Monitoring, Rostov-on-Don; the Centre of Preparation and Implementation of International Projects on Technical Assistance; North Caucasus Branch, Rostov-on-Don; South Russian Regional Centre for Preparation and Implementation of International Projects, Rostov-on-Don; and Institute of Biology of Inland Waters, Russian Academy of Sciences, considering the European part of the Russian Federation and some regions of the Ukraine in 1973–2003 (Table 1). A total of 62 observations, including replicate samplings in different years, from 23 localities within the bitterling native range, were made during this period (Fig.1). For sampling, we predominantly used 10 m long close-meshed beach seines or, occasionally, 30 or 50 m long regular seines, with 8 mm mesh size in the bag. At each sampling site, multiple samplings were made (ten or more) covering all available microhabitat diversity.

Since it was not possible to perform a direct quantitative estimation of the fish absolute numbers and density at each site in the course of the monitoring, we used a more rough

Table 1. Sampling locations and years of observations, see also Fig. 1.

No	Location	River basin	Year	Material
1	Uzha R. near Dorogobuzh, Smolensk prov., Russia	Upper Dnieper	1990	our catches
2	Desna R. near Shmakovo, Smolensk prov., Russia	Middle Dnieper	1980, 1990	our catches
3	Desna R. near Zhukovka, Bryansk prov., Russia	Middle Dnieper	1990	our catches
4	Desna R. near Novgorod-Severskiy, Chernigov prov., Ukraine	Middle Dnieper	1981, 1985, 1991	our catches
5	Snov R., upper course, Bryansk prov., Russia	Middle Dnieper	2003	our catches
6	Revna R. mouth, Chernigov prov., Ukraine	Middle Dnieper	1986, 1997	our catches
7	Snov R. downstream from the Revna R. mouth, Chernigov prov., Ukraine	Middle Dnieper	1985, 1989, 1994, 1996	our catches
8	Seym R. near Sazonovka, Kursk prov., Russia	Middle Dnieper	2000	our catches
9	Psyol R., upper course, Kursk prov., Russia	Middle Dnieper	1984, 1988, 1994, 1996	our catches
10	South Bug R., lower course, Ukraine	Lower Dnieper	1981, 1984, 1988, 1998, 2001	our catches, local fishermen' catches
11	South Bug estuary near Nikolaev, Ukraine	Lower Dnieper	2002	local fishermen' catches
12	Don R. near Lebedyan, Lipetsk prov., Russia	Upper Don	1980, 1988, 1990	our catches
13	Don R. near Zadonsk, Lipetsk prov., Russia	Upper Don	1990, 2002	our catches
14	Vorgol R., Lipetsk prov., Russia'	Upper Don	1999	our catches
15	Sosna R. near Yelets, Lipetsk prov., Russia	Upper Don	2002	our catches
16	Don R. near Liski, Voronezh prov., Russia	Middle Don	1980, 1985, 1989, 1994	our catches
17	Oskol R. near Chernyanka, Belgorod prov., Russia	Middle Don	1999, 2000	our catches
18	Don R. near Rostov-on-Don, Rostov prov., Russia	Lower Don	1973, 1974	our catches, local fishermen' catches
19	Don R. delta near Azov, Rostov prov., Russia	Lower Don	1976, 1977, 1980, 1983, 1987, 1990, 1995, 2000, 2003	our catches, local fishermen' catches
20	Tson R., middle course, Orel prov., Russia	Oka, Middle Volga	1980, 1993	our catches
21	Ponds near Tula, Tula prov., Russia	Oka, Middle Volga	1998	local fishermen' catches
22	Chapayevka R. near Suchaya Vyazovka, Samara prov., Russia	Lower Volga	1977, 1986, 1998	our catches
23	Volga R. near Syzran, Samara prov., Russia	Lower Volga	1977, 1986, 1989, 1998	our catches
24	Kuban R. near Temryuk, Krasnodar prov., Russia	Kuban	1981, 1985, 1996	our catches
25	Kuban R. mouth, Krasnodar prov., Russia	Kuban	1999	our catches
26	Laba R. near Kurganinsk, Krasnodar prov., Russia	Kuban	1999	our catches
27	Kara-Sal R., Kalmykia, Russia	Lower Don	2002	our catches
28	Malyi Uzen' R. near Piterka, Saratov prov., Russia	Inland	1990	our catches
29	Velya R., Moscow prov., Russia	Upper Volga	2003, 2005	our catches

Fig. 1. Scheme of bitterling sampling sites. Sample numbers as in Table 1.

and simplified qualitative approach based on available sampling records. To estimate the abundance of bitterlings in a given site a three-level numerical scale was used, i.e. “1” representing “rare” findings, “2” referring to “common, but not abundant”, and “3” – to “abundant” records. The lowest level of abundance corresponding to the “1” score was assumed when the bitterlings occurred sporadically at the given location, i.e. only one or few individuals were caught per series of standard sampling attempts using a 10 m beach seine (or equivalent number for longer ones). The medium level (“2”) was assigned to locations where most sampling attempts were successful but the bitterling was not numerous, yielding on average a few individuals per one sampling attempt, and the highest level (“3”) corresponded to dozens of individuals per one sampling event. In cases where a more precise abundance assessment was impossible, intermediate estimates were used, i.e. 1–2 (= 1.5) or 2–3 (= 2.5). Together with score zero for the category “not found” this resulted in a four-point scale which was applied to measure the bitterling abundance within the study area. In some cases local fishermen, who used non-selective fishing gear were asked to roughly estimate the bitterling abundance using the same scale and their catches were inspected. All scores obtained for all localities in each year were averaged and then pooled in four-years periods for which group means were calculated. The resulting values reflect a generalised population condition within the bitterling's native range, especially, within its primary area where the species is more common. Six sampling sites (NN 24–29, Table 1) lie outside the species' native range and the respective findings mostly refer to our unpublished data. These data were not used for the abundance trend evaluation for accuracy reasons and are only presented as evidence for the bitterling range extension.

Results and Discussion

The changes in the bitterling occurrence from the early 1970s to the beginning of this century are presented in Fig. 2. After a period of consistently low numbers (usually absent or rare, with average score less than 1) in most water bodies up to the late 1980s, a considerable and rapid increase in abundance was observed. For example, in the Don River delta and the lowermost river portion near Azov and Rostov-on-Don, from where the longest series of observations is available, the abundance score dynamics was as follows: 1973–77: "1"; 1980 – 1,5; 1983–87: "2"; 1990–2003: "3". Our observations indicate that since the late 1990s the bitterling became one of the most abundant species in the fish communities of most rivers and estuaries investigated, i.e. the Yuzhny (South) Bug River, South Bug River estuary, Desna River basin, Don River with tributaries and the delta.

The same trend is also apparent from literature data. According to Maslovsky (1956), who reported the occurrence of fish species in the Oskol River (Seversky Donets tributary, Don River basin) in 1953, the bitterling percentage in catches averaged 1.02% (from a total of 9,052 specimens of 27 species, ranging from 0 to 1.93% on different stations). These values, according to the categories used in this work, rather correspond to the score "1". However, in 1999 and 2000 bitterlings were found to be very abundant in

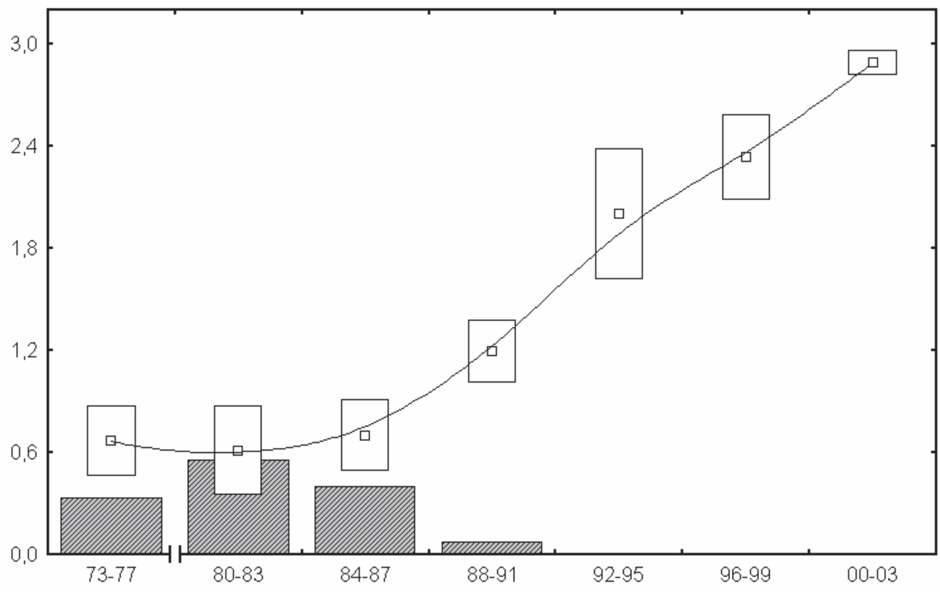

Fig. 2. Abundance score of the bitterling (boxes) and frequency of absence at sampling sites within its historical range (columns) according to time. The box half-height equals to the standard error.

the Oskol River (our data, score “3”). Shatunovsky et al. (1988) defined the species as being “rather rare” in the Moscow province (Oka River basin) whilst, according to Sokolov & Tsepkin (2000), the number of bitterlings in the Moskva River and most of its tributaries had increased dramatically in the recent years. These data are particularly interesting, as the Moscow province is likely the northernmost part of the bitterling range in the whole Caspian Sea catchment area.

In addition to this general trend, the following data deserve further attention. Poltavchuk & Shcherbukha (1988) reported the results of their ichthyological surveys in the Desna River basin between the Chernigov and Sumy provinces (Ukraine) in 1972–73 and found the bitterling locally very abundant and sometimes even dominating their catches. They found this fish in declining numbers in the Snov River and some other Desna River tributaries, down to a complete absence, from the upper course to the river mouth. In contrast, our data on the Snov River show consistently high bitterling numbers in both upper and lower river stretches in 1994–2003. The overall increase in the bitterling abundance is accompanied by its further spread and colonisation of new sites within the native range where it was formerly lacking or reported only occasionally. However, this may be partially explained by a higher probability of capture due to higher fish numbers in the river sections where the bitterling was previously too rare to be found. The percentage of our monitoring stations where bitterlings were absent is indicated in Fig. 2. The percentage dropped from 40–60% in 1970–1980s to 0% throughout the last 15 years. Consequently the spatial distribution of the bitterling is getting less dispersed and more continuous, probably with more diverse habitats being colonised. This process is especially well documented in regions with regular ichthyological surveys, such as the Moscow province (Sokolov & Tsepkin 2000). According to Dgebuadze & Skomorokhov (2002), bitterlings were never recorded in the Glubokoye Lake located about 60 km west of Moscow City until the first record in 2000 when the bitterling was already found to be a common fish in the lake.

Another important aspect of the current bitterling distribution status is the recent but very rapid expansion of this fish beyond the limits of its native range (Fig. 3). In 1999, we simultaneously and independently discovered the bitterling in two different sections of the Kuban River basin situated well apart from each other: the delta and the foothill zone of the Laba River, the largest tributary of the Kuban River (Fig.1, Table 1) (Kozhara & Poznyak 2001, see also Pashkov et al. 2004, Pashkov 2005). Moreover, A. Zhulidov had captured 8 bitterling specimens in the lower Kuban River near Temryuk yet in 1996, but these data remained hitherto unpublished. Although Vasil'eva (2003) considered the bitterling as a new native species for the Kuban River basin, the regional and national checklists of the fish fauna published in Russia until late 1990s show that this species has never been recorded in the Kuban River basin (Berg 1949, Troitsky & Tsunikova 1988, Yemtyl 1997, Reshetnikov 1998, 2003). It is highly unlikely that it might have occurred but was overlooked as the basin is in faunistic respect thoroughly and frequently investigated. The bitterling appeared to be very common in both Kuban sites mentioned above and we therefore suggest that it may have entered the basin even before 1996. This assumption is supported by (a) the great distance between the sampling locations where it was found and (b) our observations (Table 1).

A single bitterling specimen was captured in the inland Maly Uzen River in the Saratov province in 1990 during our ichthyological survey (Fig.1). As the bitterling was never registered east of the Volga River basin, we assume that it has arrived in the Maly Uzen River via the Volgograd Reservoir through the irrigation canal network. Unfortunately, its

Fig. 3. Geographical distribution of the genus *Rhodeus* in the European part of Russia and adjacent countries. (1) – native range of the bitterling species complex (including the areas of possible expansion before 1980s) according to B e r g (1949), H o l č í k (1999), R e s h e t n i k o v (2003), S h a s h u l o v s k y & E r m o l i n (2005), B o h l e n et al. (2006) and our own observations); (2) – new areas colonised by the species; (3) – sites of bitterling introductions (see text for references).

geographical distribution in Russia has been described rather schematically and sometimes controversially, with extensive areas of unknown bitterling status and this particularly applies to the middle and lower Volga River basin. Contrary to the published data (B e r g 1949, R e s h e t n i k o v 1998, 2003), bitterlings do occur now in the lower Volga River, at least in the Volgograd Reservoir, and have been recorded there well before our own finding in the Maly Uzen River. For example, N e b o l s i n a (1975) listed the bitterling for the Volgograd Reservoir although the aforecited summaries of the Russian fish fauna (B e r g 1949, R e s h e t n i k o v 1998, 2003) ignored this record. According to S h a s h u l o v s k y & E r m o l i n (2005) this species was found in the Volgograd Reservoir since the late 1950s and it is still increasing its abundance. Moreover, S h a s h u l o v s k y & E r m o l i n (2005) do not consider the bitterling as nonindigenous species in this reservoir. Due to first bitterling record in the Volgograd Reservoir soon after construction of the Volga-Don shipping canal in 1952 (see Z h u l i d o v et al. 2005), we believe that the bitterling is unlikely to be a native species in the lower Volga River section and consider this canal as possible invasion corridor.

In 2002, we recorded bitterlings in the upper reaches of the Kara-Sal River, a lower Don River tributary from where it was previously unknown (Fig. 1). This river is characterised by low water discharge in summer and numerous dams built for water accumulation. Despite this, the bitterling has spread upstream successfully. Two damaged bitterling specimens have been reported in 1994 at the water intake of the Konakovo thermoelectric power station near the Ivankovo Reservoir on the upper Volga River (Y a k o v l e v et al. 2001). Presumably bitterlings have penetrated into the upper Volga from the Oka River basin via the Moskva-Volga canal, although this is an upstream migration through a series of dams. It remains unclear, whether this species has formed a self-sustaining population in the upper Volga River. However, in August 2005 the bitterling was sampled in the Dubna River system in the Moscow province (Fig. 1), where it was already rather common if not abundant. Records in the upper Volga basin clearly indicate a passage through the Oka River – upper Volga River watershed which makes a further colonisation of the upper Volga River basin likely.

A similar situation is reported from France where bitterlings rapidly colonised the system of man-made ditches draining the Bourgneufe Marsh near the Atlantic coast (C a r p e n t i e r et al. 2003). While bitterlings were absent in the system during 1987–91, the species reached a density of 61.7±47.0 individuals/100 m^2 and a frequency of occurrence of approximately 70–75% in 1997–2001. Furthermore, the bitterling has been recently registered in small rivers and ponds of the Ararat valley in the Republic of Armenia. Bitterlings presumably have arrived from the Aras River, and seem to continue spreading (P i p o y a n 1996, P i p o y a n & T i g r a n i a n 2002). A very interesting record in its spread is the recent finding of this species in the upper Ural River tributaries (C h i b i l e v 2004). The bitterling had never been known from the Ural River basin (S h a p o s h n i k o v a 1964) and the way of its penetration to this river system remains unclear.

There might be two principal ways of bitterling spread outside its historical range. Firstly, it actively spreads throughout continuous waterway systems, both downstream and upstream, and the general increase in bitterling numbers undoubtedly favour its range extension. In particular, the high abundance of bitterling larvae and early juvenile fish in the drift communities noted in some lowland rivers suggests that drifting can also be a successive way of dispersal across the floodplain (R e i c h a r d et al. 2002). However, countercurrent upstream migration evidently prevails now in the bitterling dispersal throughout Russia and adjacent countries.

Secondly, an unintentional introduction of this species may be assumed. The bitterling is a popular object of aquaculture and, moreover, it is of some importance for anglers as a bait fish (A s l a n i d i & S h a v k i n 1999, S o k o l o v & T s e p k i n 2000). Bait transport may be responsible for short-distance spread between isolated water bodies and for "spread" across migration barriers such as river dams. D g e b u a d z e & S k o m o r o k h o v (2002) supposed bait as introducing vector of the bitterling into the Glubokoye Lake (Moscow province). The release from hobby aquaria may be another "transport vector" which could especially be important for long distances dispersal; this is the most plausible explanation of the bitterling introduction to the USA (B a d e 1926), Britain (W h e e l e r & M a i n t l a n d 1973) and other European countries where it has been successfully established in the wild.

A bitterling establishment in new water bodies together with a general tendency to increase in abundance is especially noteworthy as it is thought to be a rather stenotropic species, with a narrow range of tolerance to the fluctuation of environmental parameters (G r a n d m o t t e t 1983). The bitterling is commonly considered as typical limnophilous freshwater fish (S c h i e m e r & W a i d b a c h e r 1992), mainly confined to such lentic stations as backwaters (river bays with no current or back current), oxbow lakes or canals. Furthermore, it was believed that the bitterling is closely tied to alluvial wetlands and has no proper adaptations to successfully live in canalised rivers (H o r á k et al. 2004). However, we found it to be very common and abundant in typically riverine conditions, including small and large rivers or upper and lower river sections (Table 1). On the other hand, the bitterlings reach high numbers in estuarine habitats, i.e. in the South Bug estuary and in the Don River delta near Azov in a zone with frequent brackish water inflow (see also K o u t r a k i s et al 2000). In the coastal zone of the Azov Sea, the water salinity ranges from 3,4 to 10,1 g dm^{-3} in spring and from 5,6 to 12,3 g dm^{-3} in autumn (our unpublished data). A migration from the Don River delta through the brackish water of the Azov Sea and its small estuaries may explain the bitterling colonisation of the Kuban River basin.

An important feature in bitterling spread may be its ostracophilous mode of reproduction although it seems to constrain its expansion potential. The distribution and dispersal of this fish is restricted to the range of bivalve species used for oviposition, namely *Unio*, *Anodonta*, or *Pseudanodonta* spp. (K r y z h a n o v s k y 1949, H o l č í k 1999, S m i t h et al. 2004), North American native unionids (B r e d e r 1933) and also some margaritiferids (Z h u ľ k o v & N i k i f o r o v 1988, S m i t h & H a r t e l 1999). However, the host specificity is low (S m i t h & H a r t e l 1999) and recent studies (R e y n o l d s et al. 1997, S m i t h et al. 2004, R e i c h a r d et al. 2007) indicated that in regions where bitterlings are established native unionid mussels were used for oviposition. Thus the bitterling´s reproductive specialisation does not stop this fish to increase its number and to further spread.

This rapid bitterling expansion appears to take place quite independently and synchronically in geographically distant basins: in the upper and lower Volga River basin, the Kuban River in Russia and the Aras River drainage basin in Armenia. Therefore, we assume that a global or macroregional factor triggers the spread of the bitterling. Since the geographical distribution of this species suggests that its dispersal northwards and eastwards is limited by low temperatures, we speculate that the climate change in Europe may be one possible factor to support its spread.

The colonisation of water bodies outside its native range is known also for Western Europe and the USA. In Europe, bitterlings are considered as an introduced species in England (W h e e l e r & M a i n t l a n d 1973, L e v e r 1977), Denmark (M ø l l e r & M e n n e 1998), northern Italy (C o n f o r t i n i 1992), and Greece (E c o n o m i d i s et al. 2000). It is noteworthy that in countries where the bitterling is native it is protected. However, in some other countries, such as the United Kingdom, the species has established successfully and is already considered as potential threat to local species (see R e i c h a r d et al. 2006, 2007). For example, in the United Kingdom the bitterling is subject to the Wildlife and Countryside Act 1981 (WCA) regulating the cultivation and release of non-native fish species into the wild.

In summary, we presented the evidence that the bitterling currently increases its abundance in many freshwater system in the former Soviet Union area (Russia, Ukraine, Armenia) and also that it colonises new localities within as well as outside its native range. This species is not as stenobiotic as it was believed and its invasive potential seems to have been underestimated until now. Its rapid and synchronous expansion is probably controlled mostly by global or macroregional environmental factors although in many cases human activities may facilitate this process.

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