



NATIVE DISTRIBUTION, INTRODUCTIONS AND RISK SCREENING OF *Sander lucioperca* (LINNAEUS, 1758) IN THE FRESHWATER ECOSYSTEMS OF BOSNIA AND HERZEGOVINA

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ABSTRACT

Pike-perch *Sander lucioperca* is a native species originally present in the Black Sea basin of Bosnia and Herzegovina. In the 1990s, it was introduced to the Neretva River and its reservoir system, and since 2009 the species has been recorded in Lake Boračko and Buško Blato Reservoir. The aim of this study is to analyse the distribution of *S. lucioperca* in Bosnia and Herzegovina based on literature data (1975–2024) and to define areas where the species has been introduced in order to assess the risk of potential invasiveness. The results indicate that *S. lucioperca* belongs to the high-risk category. Since the same risk ranking has been confirmed in recent studies on aquatic ecosystems in other geographical areas, the conclusion is that pike-perch could soon pose a potential threat to native species and aquatic ecosystems in Bosnia and Herzegovina if mitigation measures are not implemented.

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INTRODUCTION

Pike-perch *Sander lucioperca* (Linnaeus, 1758) is a freshwater fish that typically inhabits aquatic ecosystems with rocky bottoms and moderate to slow water currents. The original distribution area of this species is mainly in Europe and western Asia. It occurs in the basins of the Caspian Sea, the Baltic Sea, the Black Sea and the Aral Sea, as well as in the Elbe (North Sea basin) and Maritza (Aegean basin) drainages (Kottelat and Freyhof, 2007; Säisä et al., 2010). *Sander lucioperca* plays a crucial role as a top predator in freshwater ecosystems. By regulating prey populations, it contributes to the maintenance of ecological balance and the resilience and functioning of aquatic ecosystems.

Previous research on *S. lucioperca* covers various aspects of its biology, ecology, behaviour, fisheries management and conservation: population dynamics (Bayer et al., 2009), reproductive biology (Głowacki et al., 2021), feeding ecology (Copp and Vilizzi, 2018; Łuczynski et al., 2020), habitat use and movement patterns (Carosi et al., 2013), invasive potential (Vejřík et al., 2020), fisheries management (Kestemont et al., 2015), conservation genetics (Lepais et al., 2009) and effects of climate change (Haenel et al., 2020).

Outside its native range, *S. lucioperca* has been introduced into various aquatic ecosystems to enhance fisheries or promote recreational angling. However, the introduction of *S. lucioperca* can have unintended consequences as this species can compete with native species, alter ecosystems and disrupt local fisheries (Schulze et al., 2006). Following the introduction of *S. lucioperca* into waters where it does not naturally occur, a negative impact on local native fish populations has been documented. For example, *S. lucioperca* caused the extinction of three endemic species in Turkey (Crivelli, 1995), while in the brackish waters of southern France, there was a decline in the population of the big-scale sand smelt *Atherina boyeri* (Risso 1810) (Kiener and Spillman, 1969). In England, it led to a decline in the abundance of cyprinid species (Kell, 1985; Manchester and Bullock, 2000). For these reasons, *S. lucioperca* is often considered an invasive species (Fickling and Lee, 1983).

The introduction of *S. lucioperca* into new habitats outside its native range has led to concerns about its potential invasiveness and ecological impact. The species has several traits that may contribute to its success in new environments (Gago et al., 2021; Nolan and Britton, 2018). It is a highly adaptable predator with a diverse diet that includes small fish, crustaceans and insects. Its opportunistic feeding behaviour, coupled with rapid growth and reproduction rates, may contribute to its success in colonising and establishing populations in new environments. As a piscivore, *S. lucioperca* can exert predatory pressure on native fish species, especially on smaller and endangered populations, leading to changes

in ecosystem structure and dynamics (Ribeiro et al., 2021). The species can tolerate a wide range of environmental conditions, including water temperature, pH level, and habitat type. This adaptability allows it to colonize and establish populations in diverse aquatic ecosystems (Argillier et al., 2012; Olin et al., 2023). Additionally, its introductions may result in genetic introgression with native fish populations, potentially leading to hybridization and loss of genetic diversity (Eschbach et al., 2014; Kahilainen et al., 2011; Louati et al., 2016; Salminen et al., 2012).

While *S. lucioperca* may exhibit invasive characteristics under certain conditions, it is essential to consider the specific context of its introduction and potential impact on native biodiversity. Despite its invasive potential, the management of *S. lucioperca* populations in non-native environments poses significant challenges. Effective monitoring, control, and mitigation strategies are essential for preventing and minimizing the ecological impact of its introductions. Furthermore, understanding the underlying mechanisms driving the invasiveness of *S. lucioperca*, including its behavioural ecology, population dynamics, and interactions with native species, is of crucial importance for informing management decisions and conservation efforts.

The list of non-native aquatic species that could have potential negative biological, environmental, and socio-economic impact in Bosnia and Herzegovina includes five fish species: *Lepomis gibbosus*, *Carassius gibelio*, *Pseudorasbora parava*, *Ameiurus nebulosus* and *S. lucioperca* in the waters of the Adriatic Sea basin (Đug et al., 2019). Most of the non-native aquatic species are distinguished by specific biological and ecological traits typical of successful invaders and are usually abundant in the watersheds of Bosnia and Herzegovina.

Together with climate change, the introduction of alien species is widely recognized as one of the main threats to aquatic biodiversity and human well-being. The first European legislation on alien species entered into force in 2014 with EU Regulation 1143/2014 on the planning and management of the introduction and spread of invasive alien species. Based on this Regulation, Member States should take measures for routes of unintentional introduction, for early detection and rapid eradication of alien species, and for the management of species that are already widespread in their territory. However, it is still not known whether this regulation has influenced further action in non-EU Balkan countries – although member states are obliged to encourage cooperation with third countries in connection with the Regulation (Article 22). Non-native species and biodiversity are generally of low priority in the political agendas of many countries, and this is especially true for European countries outside the EU. In fact, non-EU countries are not obliged to implement EU laws related to non-native species, which can leave open corridors for invasion.

The introduction of non-native species represents one of the greatest threats to natural biodiversity (Vitousek et al., 1996; Manchester and Bullock, 2000; Clavero and Garcia-Berthou, 2005). Introduced species can exert various pressures on local, native populations, such as predation (Kaufman, 1992), competition (Bando, 2006), hybridization (Huxel, 1999), or transmission of various pathogens (Gozlan et al., 2005). To this end, the Aquatic Species Invasiveness Screening (AS-ISK: Copp et al., 2016) provides guidance on identifying the level of risk posed by non-native aquatic species within a given risk assessment area. The toolkit includes specific criteria for assessing the risk posed by non-native fish species based on factors such as their reproductive capacity, feeding behaviour, habitat preferences, and potential impact on native biodiversity. It facilitates the evaluation of potential ecological, economic, and social impacts associated with the establishment and spread of non-native species, including competition with native species, habitat alteration, and disruption of ecosystem functions. Based on the screening results, the AS-ISK can provide recommendations for management strategies to prevent or mitigate the impact of non-native species. This could include targeted monitoring, regulatory measures, habitat restoration, or control and eradication efforts. Overall, the AS-ISK serves as a decision support tool to assist in informed decision-making regarding the management of non-native species, balancing conservation goals with socio-economic considerations. By systematically applying the AS-ISK framework to assess the invasiveness potential of non-native species, resource managers and policymakers can better understand and address the risks associated with their introduction and establishment in new aquatic environments.

In this paper, along with a review of the previous scientific literature on the invasive characteristics of *S. lucioperca* in Bosnia and Herzegovina, we discuss the ecological implications of its introduction into non-native habitats. The main goal is to detect areas where the species has been introduced and evaluate its risk of invasiveness using the AS-ISK. This will help develop effective management strategies to mitigate the impact of the species on freshwater ecosystems.

MATERIALS AND METHODS

Distribution of S. lucioperca in Bosnia and Herzegovina

Species distribution mapping is an important stage in ecological research, conservation planning, and biodiversity management. It entails mapping geographical areas where a species is known to occur and forecasting probable distribution areas based on a variety of environmental conditions. Assessment of the current distribution of *S. lucioperca* in Bosnia and Herzegovina included collecting species occurrence data from various sources such as scientific literature, field surveys, and

existing datasets gathered during the last 50 years, i.e. from 1975 to 2024: Aganović et al. (1975a, 1975b, 1976a, 1976b, 1976c); Habeković et al. (1981); Kosorić et al. (1985); Škrijelj (2002); Škrijelj et al. (2005, 2011a, 2011b, 2011c); Sofradžija (2009); Korjenić et al. (2011, 2013); Pavličević et al. (2014); Mušović et al. (2020).

The distribution database of *S. lucioperca* included information on location coordinates, date of observation, collector, and number of specimens. The study area was divided into 10×10 km UTM grid as the recording unit. QGIS, an open-source Geographic Information System, was used for the species distribution mapping due to its robust set of tools for spatial data analysis and visualization. The final database contained records for 37 UTM 10×10 km cells.

Risk screening

The AS-ISK was applied to identify the level of invasiveness of *S. lucioperca* in the main watersheds of Bosnia and Herzegovina (risk assessment area). The AS-ISK consists of 49 basic questions that examine the biogeographical and biological/ecological aspects of the taxon being screened, resulting in a Basic Risk Assessment (BRA) score. An additional six Climate Change Assessment (CCA) questions require the assessor to evaluate how future climatic conditions are likely to affect the BRA score with regard to the risks of the taxon's introduction, establishment, dispersal, and impact, resulting in a (combined) BRA + CCA score. To achieve a valid screening, the assessor is required to provide for each question a response, a justification for that response, and a confidence level. These three elements ensure that assessor responses are supported, where possible, by bibliographic sources and an explanation of their confidence in each response, which is a reflection of the available knowledge with which to answer the question. Scores lower than 1 suggest that the species is unlikely to become invasive in the risk assessment area. Higher scores classify the species as posing either a medium risk or a high risk of becoming invasive. The distinction between medium and high risk of invasiveness depends upon setting a threshold value. In this study, the threshold was set to 14.7 as provided for freshwater fish (Vilizzi et al., 2021).

RESULTS AND DISCUSSION

Distribution of S. lucioperca in Bosnia and Herzegovina

In Bosnia and Herzegovina, *S. lucioperca* is present in the Black Sea basin, more specifically in the River Sava and the lower reaches of its tributaries (i.e. middle and lower course of the rivers Sana, Spreča, Una, Ukrina, and Vrbas) and in the reservoirs Hazna, Modrac, and Vidara, where it is considered a native species (Fig. 1). From the Black Sea basin, *S. lucioperca* was introduced into the River Neretva and the Neretva Reservoir system in the 1990s from the Adriatic basin (Škrijelj, 2002; Sofradžija 2009).

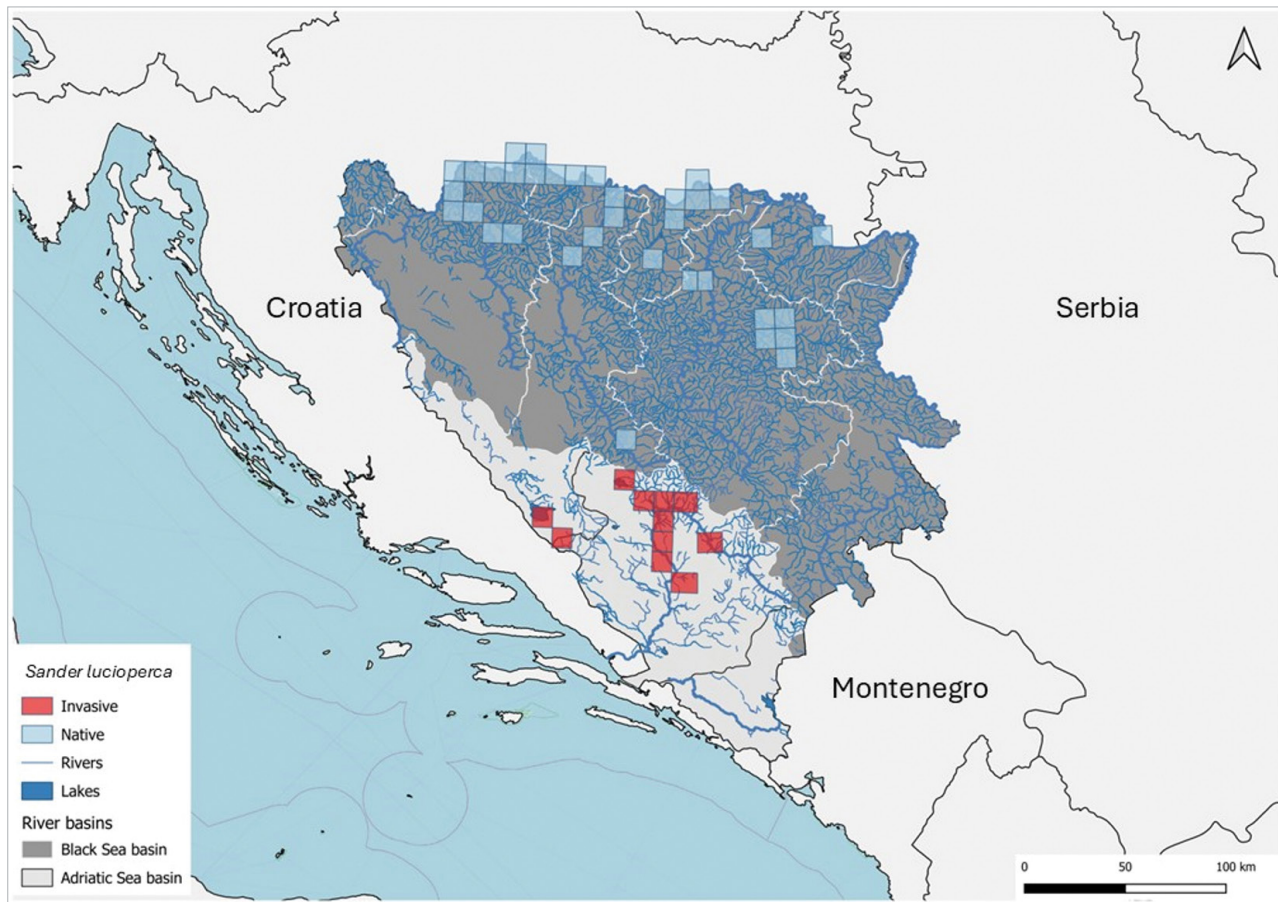


Fig 1. Distribution map of *Sander lucioperca* in Bosnia and Herzegovina

After 2009, for the first time its presence was recorded also in Lake Boračko (Škrijelj et al., 2011) and in Buško Blato Reservoir (Mušović et al., 2020).

The low level of heterogeneity in the Neretva populations of *S. lucioperca* indicates the likelihood that a small number of parental individuals were introduced into this reservoir system, which is reflected in extreme inbreeding. The results of comprehensive analyses of molecular-genetic structure have shown clear genetic differentiation between samples from the Adriatic basin and the River Sava basin (Šljuka, 2016).

As a dominant predator, *S. lucioperca* occupies adaptive zones that normally belong to other predator species, i.e. Salmonidae. The aforementioned factors had profound effects on the native fish fauna, leading to a decline in numbers and posing a significant extinction risk for several crucial species from the Salmonidae family, endemic cephalopods, Neretva softmouth trout, and brook trout. In Bosnia and Herzegovina, *S. lucioperca* continues to expand its range and occupy new ecological niches.

Risk screening

Based on the screening (Table 1), *S. lucioperca* carries a high risk of invasiveness (BRA = 31; BRA+CCA = 37). This indicates a high likelihood and potential for this non-native species to become invasive or cause a severe

impact on native ecosystems, economies, or human health. *Sander lucioperca* may have high dispersal ability, reproductive potential, or ecological impact that increase its risk of invasiveness (Table 1). This species therefore poses a potential threat to native species in the aquatic ecosystems of Bosnia and Herzegovina.

Table 1. AS-ISK results for *S. lucioperca* in Bosnia and Herzegovina

Sector Affected	Commercial	13
	Environmental	13
	Species Traits	15
Score Partition	Biogeography/Historical	11
	Biology/Ecology	20
	Climate Change	6
Scores	BRA	31
	BRA+CCA	37
Level of Confidence	BRA	0.68
	BRA+CCA	0.66

A high risk of invasiveness for *S. lucioperca* was also recorded by Bakiu et al. (2022) in Albanian freshwater ecosystems. This species was ranked as medium risk in a study by Interesova et al. (2020) and as medium-to-high risk for other risk assessment areas (Simonović et al., 2013; Perdikaris et al., 2016; Piria et al., 2016; Li et al., 2017; Tarkan et al., 2017a, 2017b).

The levels of confidence (BRA = 0.68; BRA+CCA = 0.66) indicate a moderate to high degree of certainty and reliability in the screening results. The screening is based on robust data, well-established methodologies, and consensus among experts. Consequently, decision-makers can have confidence in the accuracy and validity of the present screening outcomes.

Recommendations for mitigation measures

Management strategies should be developed and implemented to prevent or mitigate the spread and impact of *S. lucioperca* in the waters of Bosnia and Herzegovina. This may include targeted monitoring programmes, regulatory measures, public awareness campaigns, and control or eradication efforts, as necessary. Encouraging cooperation and communication among relevant stakeholders, including government agencies, researchers, nature protection organizations, and local communities is of great importance in order to effectively address the potential invasiveness of *S. lucioperca* in the risk assessment area. By systematically conducting these steps, policymakers and resource managers can better understand and address the potential risks associated with the introduction and establishment of *S. lucioperca* in the aquatic ecosystems of Bosnia and Herzegovina.

To prevent a species from becoming at high risk of invasiveness, it is crucial to implement a systematic and regular monitoring programme for the habitats it occupies. Such monitoring programmes should consist of the following key components: distribution mapping, population assessment, and impact assessment. For species like *S. lucioperca* these monitoring activities are essential for gaining a comprehensive understanding of the species population status, distribution, and its effects on native fish communities.

Managing *S. lucioperca* involves the availability of distribution mapping. This process is fundamental in tracking where populations are located and how their range might be expanding over time. Field surveys need to be conducted to record data on the presence of *S. lucioperca* across various water bodies. To achieve this, techniques such as electrofishing and gill netting could be utilized throughout the year. These methods allow researchers to estimate population sizes, densities, and distribution patterns effectively.

In conclusion, the present results have shown a clear differentiation between *S. lucioperca* individuals from the Adriatic and River Sava basins. Based on the results of the risk screening, it can be concluded that there is a high potential that *S. lucioperca* could become invasive or

cause a severe impact on native ecosystems, economies, or human health. Since the same has been confirmed in recent research on aquatic ecosystems in other geographical areas, the conclusion is that *S. lucioperca* could soon represent a potential threat to native species and aquatic ecosystems in Bosnia and Herzegovina if adequate measures are not taken. Overall, we recommend including targeted monitoring programmes, regulatory measures, public awareness campaigns, and control or eradication efforts, as necessary.

ZAVIČAJNA I UNESENA DISTRIBUCIJA TE IDENTIFIKACIJA RIZIKA VRSTE *Sander lucioperca* (LINNAEUS, 1758) U SLATKOVODNIM EKOSUSTAVIMA BOSNE I HERCEGOVINE

SAŽETAK

Smuđ (*Sander lucioperca*) je zavičajna vrsta izvorno prisutna u slijevu rijeka Crnog mora u Bosni i Hercegovini. Unesena je u rijeku Neretvu i njezin sustav akumulacija tijekom 1990-ih godina, a nakon unosa prisutnost vrste zabilježena je u Boračkom jezeru i u Buškom Blatu. Cilj rada bio je analizirati distribuciju smuđa u Bosni i Hercegovini na temelju literaturnih podataka (od 1975. do danas) i definirati područja u koja je vrsta unesena kako bi se identificirao rizik od potencijalne invazivnosti. Rezultati upućuju da *S. lucioperca* pripada kategoriji visokog rizika. Budući da je isto rangiranje rizika potvrđeno u recentnim istraživanjima vodenih ekosustava drugih geografskih područja, zaključuje se da bi *S. lucioperca* mogla predstavljati potencijalnu prijetnju zavičajnim vrstama i vodenim ekosustavima u Bosni i Hercegovini, ako se ne provedu odgovarajuće mjere ublažavanja.

Ključne riječi: AS-ISK, strane vrste

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