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Effects of Climate Change on the Distribution of the Invasive Stone Moroko *Pseudorasbora parva* (Temminck & Schlegel, 1846) (Actinopterygii: Cyprinidae) in Asian Aquatic Ecosystems

Ali Reza Radkhah[1], Soheil Eagderi*[1] & Erdogan Cicek[2]

[1] Department of Fisheries, Faculty of Natural Resources, University of Tehran, Karaj, Iran
[2] Department of Biology, Faculty of Art and Science, Nevsehir Hacı Bektas Veli University, Nevsehir, Turkey

Abstract: The stone moroko *Pseudorasbora parva* is a non-native species that is distributed worldwide in many freshwater ecosystems. Due to the negative impacts of this invasive species in aquatic ecosystems, it is necessary to study the factors affecting its distribution. The present study was conducted to investigate the impact of climate change on the distribution of the invasive stone moroko in Asian ecosystems. For this purpose, climatic data including maximum temperature of the warmest month (MTWM), minimum temperature of the coldest month (MTCM), mean temperature of the warmest quarter (MTWQ), mean temperature of the wettest quarter (MTWeQ), precipitation of the warmest quarter (PWaQ), precipitation of the coldest quarter (PCQ) and precipitation of the wettest month (PWM) were downloaded from the WorldClim climate data. In addition, the occurrence data (Geographic data, latitude and longitude) of *P. parva* were also downloaded from the GBIF website (www.gbif.org). To evaluate the relationship between climatic data with a Pearson correlation coefficient (r> 0.75), ENMTools v1.3 software was used. In order to identify the most important factors affecting the distribution of *P. parva*, Jacknife test was applied. The results showed that MTWQ, MTWeQ and MTCM had the highest contribution to the distribution of stone moroko in the Asian aquatic ecosystems. According to our results, the distribution of this species is largely affected by temperature and precipitation fluctuations. The findings presented in this study can be used to predict, control and prevent the spread of non-native species such as *P. parva* in freshwater bodies.

Key words: *Pseudorasbora parva*, distribution, climate change, aquatic systems, Asia

Introduction

Climate change is a global phenomenon that has become one of the greatest environmental challenges. It is due to both fluctuations of the temperature caused by natural processes and the impact of human activities (Ipinjolu et al. 2014). External factors that can affect the climate are often referred to as climate forces, including processes such as fluctuations in solar radiation, atmospheric circulations and greenhouse gas concentrations (WGC 2019). Aquatic organisms such as fish are highly susceptible to climate change (Kuczynski et al. 2017). Various studies have already reported the environmental impacts of climate change on aquatic ecosystems. Most studies have examined the effects of

*Corresponding author: soheil.eagderi@ut.ac.ir

climate change on the distribution of marine fishes and there is little information on freshwater fish species. Hence, it is imperative that climatic variables affecting fish distribution in freshwater aquatic systems should be further investigated.

In our days, the introduction of alien species is used as a mean to increase the production in aquatic ecosystems (FAO 2005). In many countries, introduction of exotic species is also targeting at improving the sport fishing, controlling undesirable organisms, etc. (Kottelat & Whitten 1996). Many countries have attempted to introduce non-native species to freshwater ecosystems; however, this has threatened many of the world's waterbodies. In view of this, the introduction of alien species around the world is a frequent event requiring careful examinations.

The family Cyprinidae is the largest freshwater fish group and its members are distributed worldwide (Demirok & Ünlü 2001). This family comprises c. 220 genera and over 2420 species (Coad 2019). So far, many species of this family, such as *Carassius auratus*, *Hemiculter leucisculus* and *Pseudorasbora parva* have been introduced to areas outside their native ranges (Esmaeili et al. 2014, Radkhah et al. 2016, 2017). The stone moroko *Pseudorasbora parva* (Temminck & Schlegel, 1846) is a small fish of the family Cyprinidae, which is native to East and Southeast Asia (Benzer & Benzer 2018). This species was described as *Leuciscus parvus* Temminck & Schlegel 1846 from Japan (Esmaeili et al. 2018, Froese & Pauly 2021). It often prefers well vegetated aquatic habitats to protect itself from predators but is also found in rivers, streams, pools, rarely in lakes' lagging habitats (Coad 2019, Froese & Pauly 2021). It feeds on small insects, fish and eggs. Usually, water-rich habitats are selected for its reproduction. Female fish usually spawn 3–4 times throughout the season (Froese & Pauly 2021). The total length of this fish reaches 110 mm, while in most samples the total length does not exceed 90 mm and the body weight is less than 20 g (Witkowski 2011). Coad (2019) stated that one of the important characteristics of this fish is its high tolerance to contamination. It has been found in frozen waters and in aquatic habitats with summer temperature of c. 30°C. The occurrence of this fish in these environmental conditions can cause it to become an effective and invasive species in aquatic ecosystems (Radkhah et al. 2018).

Stone moroko, also known as topmouth gudgeon, is an invasive fish species in Europe (CABI 2019), first recorded in 1961 in southern Romania. Then, its presence was reported in the vicinity of the Danube River from Hungary in 1963. It was recorded in Poland in 1990 and was introduced over time in other European countries (Nowak & Szczerbik 2009). Historical evidence suggests that this species has been transported to several fish-farming areas, along with imported Asian carps such as grass carp *Ctenopharyngodon idella*, bighead *Hypophthalmichthys nobilis* and silver carp *H. molitrix* (Radkhah et al. 2018). This species has been reported in different parts of Europe and Asia and also has been recorded in 32 countries from Central Asia to North Africa (Gozlan et al. 2010, Benzer & Benzer 2018). It should be noted that sev-

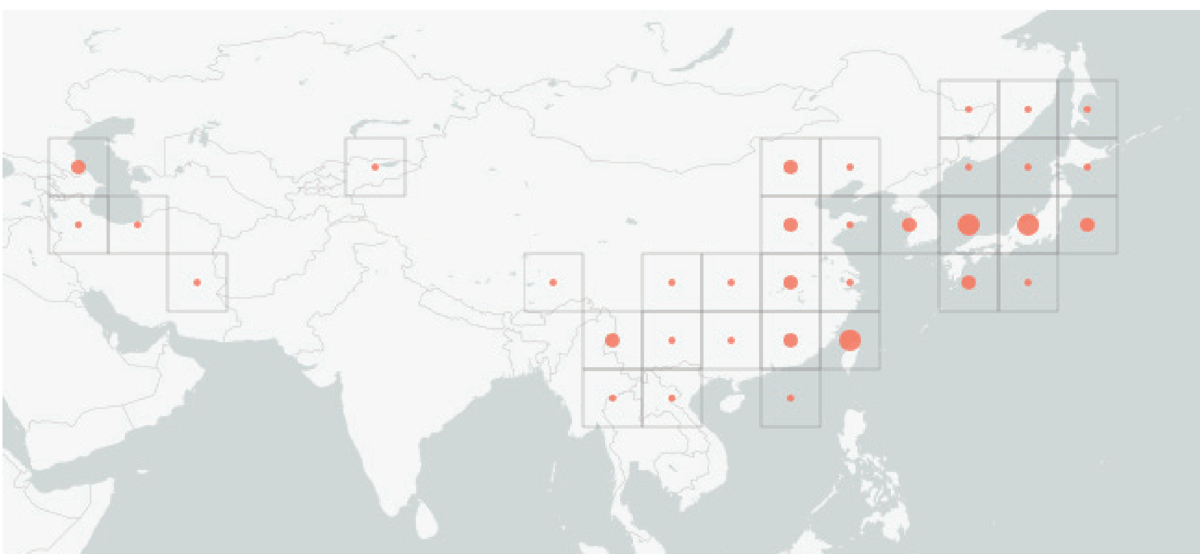

Fig. 1. The geographic distribution map of *Pseudorasbora parva* in the Asian freshwater ecosystems.

eral countries reported harmful ecological impacts of this species (Radkhah et al. 2018, CABI 2019, Froese & Pauly 2021).

According to previous studies, the stone moroko is among non-native and invasive species that have been introduced to different aquatic ecosystems throughout the World and its distribution range is still expanding. Therefore, due to the widespread distribution of *P. parva* in aquatic ecosystems, the present study was carried out to investigate the effect of climate factors on the distribution of this species.

Materials and Methods

Climatic data were used to create a species distribution model for stone moroko (*P. parva*) in Asian aquatic ecosystems. Climatic data were downloaded from the WorldClim version 2 (Global Climate Data, www.worldclim.org). These data were: max temperature of warmest month (°C), min temperature of coldest month (°C), mean temperature of warmest quarter (°C), mean temperature of wettest quarter (°C), precipitation of warmest quarter (mm), precipitation of coldest quarter (mm) and precipitation of wettest month (mm). The occurrence data (Geographic data, latitude and longitude) of *P. parva* were also downloaded from the GBIF website (www.gbif.org, accessed on 2 August 2021.).

ENMTools v1.4.2 software (Warren et al. 2011) was used to investigate the relationship between climatic data with a Pearson correlation coefficient (r> 0.75) after checking the normality of dataset. Maxent software was chosen to create a distribution model for *P. parva*. In the settings of this software, multi-parameter regularisation was 0.5, convergence threshold was set to 0.00001 and maximum number of repetitions was 1000. In order to identify the importance of climatic variables on the distribution of *P. parva*, Jacknife test was used (Phillips et al. 2006, Kurnaz & Kutrap 2019).

Results

The geographical distribution of *P. parva* in the Asian aquatic ecosystems (Fig. 1) was mapped based on GBIF data. The percentage occurrence of this species in different Asian countries (Fig. 2) has shown that the Republic of Korea, Japan and China had the highest distribution of *P. parva*. Frequency of occurrence points of *P. parva* over the past years (Fig. 3) showed that the highest frequency has been recorded in 1984, 1987 and 1993. The frequency of this species was also studied during different months; based on the results, the highest frequencies were recorded in June, May and July (Fig. 4).

The percent contribution of climatic variables on the distribution of *P. parva* in Asian aquatic ecosystems is given in Table 1.

Discussion

The introduction of non-native species is a significant threat to biodiversity and ecosystems and its consequences include the destruction of native populations and the loss of some ecosystem capa-

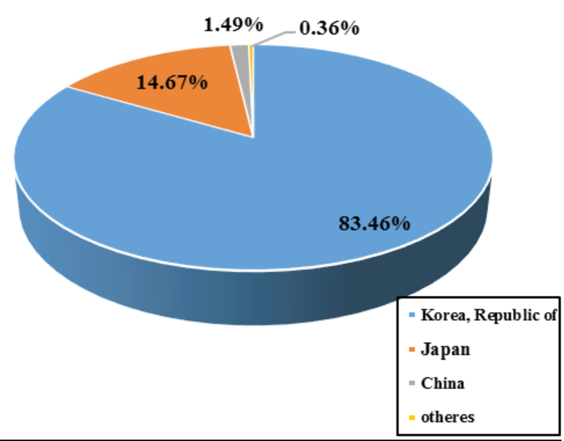

Fig. 2. The percentage occurrence (%) of *Pseudorasbora parva* in different Asian countries.

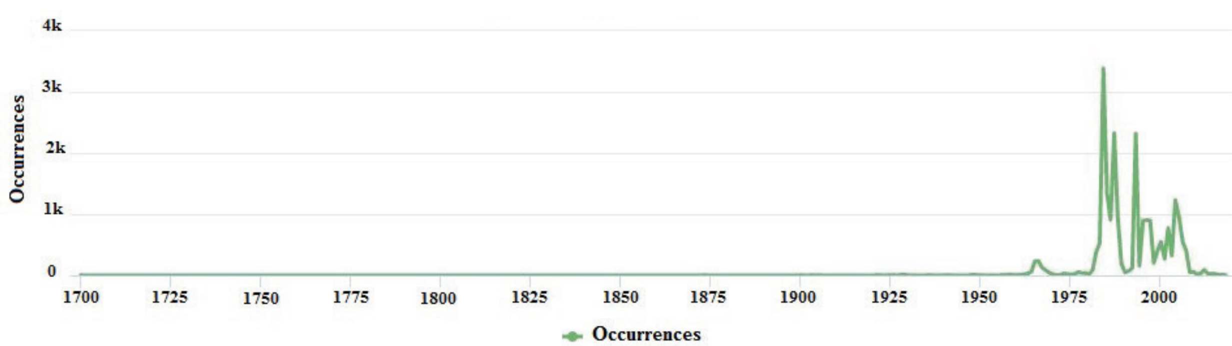

Fig. 3. Occurrences of *Pseudorasbora parva* per year in the studied dataset.

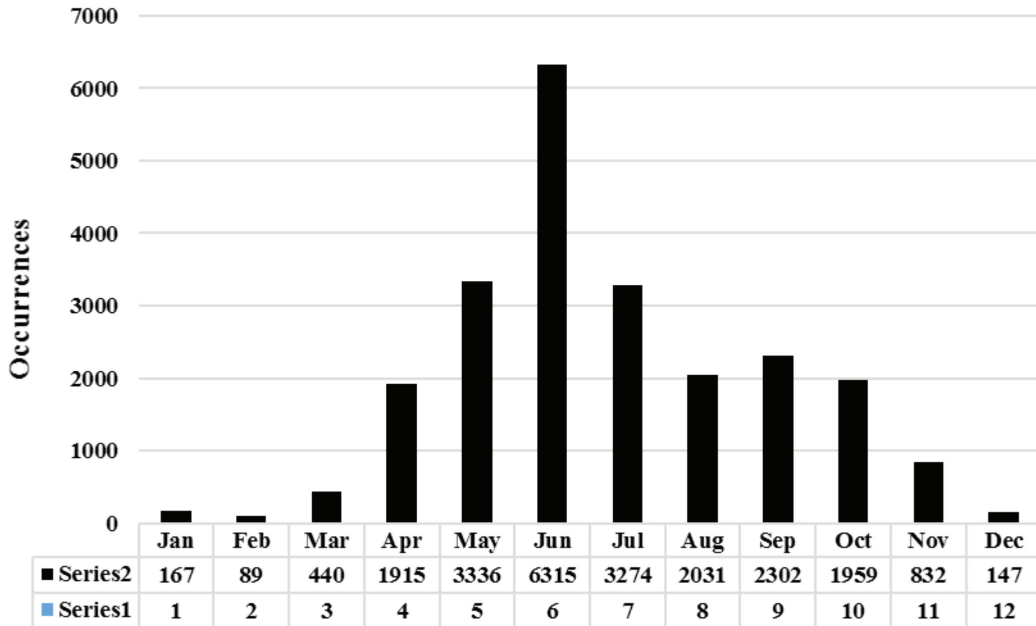

Fig. 4. Numbers of occurrences of *Pseudorasbora parva* per month in the studied dataset.

Table 1. The percent contribution (%) of climatic variables on the distribution of *Pseudorasbora parva* in Asian freshwater ecosystems.

Variables	Abbreviation	Description	Percent contribution (%)
VAR1	MTWM	Max Temperature of Warmest Month (°C)	9.0
VAR2	MTCM	Min Temperature of Coldest Month(°C)	12.1
VAR3	MTWQ	Mean Temperature of Warmest Quarter (°C)	30.6
VAR4	MTWeQ	Mean Temperature of Wettest Quarter (°C)	22.5
VAR5	PWaQ	Precipitation of Warmest Quarter (mm)	10.2
VAR6	PCQ	Precipitation of Coldest Quarter (mm)	8.0
VAR7	PWM	Precipitation of Wettest Month (mm)	7.3

bilities (Hossain et al. 2018; Radkhah et al. 2018). Latini & Petrere (2004) stated that the introduction of exotic fishes has caused major changes in the composition of the fish fauna. E.g., the introduction of unknown species has caused a decline of native freshwater fishes (Strecker 2006, Hossain et al. 2008). The past studies often have indicated that the introduction of invasive and exotic species is a threat to habitats, native species and ecosystems (Shine et al. 2000, Esmaeili et al. 2014, Radkhah et al. 2017). According to the obtained reports, several parasites and diseases have been diagnosed in local fishes that were transmitted to freshwater ecosystems through alien species (Vignon & Sasal 2010). These findings confirm that introduction of non-indigenous species may lead to transmission of diseases and (or) genetic contamination in aquatic ecosystems (Yakupitiyage & Bhujel 2005). Thus, it is necessary to examine the ecological background of species before their introduction to new habitats.

According to previous studies (Benzer & Benzer 2018, Radkhah et al. 2018, CABI 2019, Coad 2019, Froese & Pauly 2021), the invasive stone moroko has been introduced to most water bodies in different parts of the World. This non-native species was introduced into Europe with Chinese carps such as common carp, bighead, silver carp and grass carp (Gozlan et al. 2010). It has been reported from the several European countries including France, Germany, Belgium, Denmark, Poland, Bulgaria, Italy, Czechia, Slovakia and England (Panov 2006, CABI 2019). In the present study, the examination of the geographical distribution map of *P. parva* has shown that the largest distribution range of this species is in East Asia. Witkowski (2011) stated that *P. parva* is native to Japan, China and the Republic of Korea. According to the results obtained**,** it is found in East Asia, including the Amur Basin, Japanese Islands, southern and western regions of Taiwan and Korea (Panov 2006, Gozlan et al. 2010). In addition, this species was introduced into other countries such as Armenia, Afghanistan, Uzbekistan, Azerbaijan, Turkey, Iran, etc. (Radkhah et al. 2018, CABI 2019).

The results of this study showed that climate variables including mean temperature of warmest quarter (30.6 %), mean temperature of wettest quarter (22.5 %) and minimum temperature of coldest month (12.1 %) had the highest contribution to the fish distribution in Asian aquatic ecosystems. This result suggests that temperature plays a crucial role in the distribution of *P. parva*. Various studies have been conducted on the effects of temperature on fish populations. Neuheimer & Grønkjær (2012) and Tu et al. (2018) stated that as the metabolism of fishes is directly dependent on the environment (Kuczynski et al. 2017) and it changes with the increase of water temperature. This factor increases the growth rate and causes early maturation of fish populations. Rising water temperature affects the physiological processes of fish, thus affecting spawning, feed intake, fish survival, population size, production and yield (O'Gormane et al. 2016). In addition, temperature as a key parameter can affect other biological factors such as oxygen content, acidity, salinity and water density (Summers 2020). Therefore, many ecological changes in aquatic ecosystems can occur due to temperature changes.

So far, many studies have confirmed the role of temperature as an important factor on the distribution of fish. E.g., Swales (2006), in a study that aimed to investigate the factors affecting the distribution and abundance of rainbow trout (*Oncorhynchus mykiss*) in lake and reservoir systems, found that the occurrence of the rainbow trout in lakes and reservoirs is mainly determined by a combination of factors, one of which is the water temperature. Although various fish species have optimal temperatures for migration, spawning and reproduction (Thompson & Larsen 2004) and cannot survive outside the optimal temperature, in the case of P. parva, adaptation is possible due to its high tolerance and wide temperature range (5 °C – 22 °C) (Froese & Pauly 2021). According to the present studies, when the river water temperature increases, the distribution range of *P. parva* will expand because the increase in temperature will provide favourable conditions for improved reproduction and increased fecundity of this species.

The findings presented in this study show that other variables such as precipitation of warmest quarter (10.2 %), precipitation of coldest quarter (8 %) and precipitation of wettest month (7.3 %) can also have significant effects on the geographical distribution of the invasive stone moroko in the Asian aquatic systems. Therefore, it can be explained that, in addition to temperature, precipitation is also an important factor that plays a role in the distribution of fish populations. The effects of this factor can be justified by the fact that rainfall is capable of altering landscape ecosystems and destroying fish habitats by creating severe floods in freshwater environments (Ipinjolu et al. 2014, Talbot et al. 2018). This phenomenon is common in many Asian countries and has led to widespread changes in freshwater ecosystems. Many studies have shown that climate change will be much more severe in aquatic ecosystems as the drought and declines in surface water flows. Ipinjolu et al. (2014) considered that small rivers and shallow wetlands are most sensitive to changes in temperature and precipitation. This suggests that as the earth's temperature rises, the life of aquatic ecosystems will be exposed to more severe changes.

There are various scenarios that can be used to predict the distribution of fish populations. The stone moroko has the highest distribution in East Asian countries such as Korea, Japan and China. Given the occurrence points of this species as well as climate variables, it is anticipated that the distribution range of this species will increase in East Asian aquatic ecosystems in the coming years. A similar result was presented by Kolomytsev & Kutsokon (2012) on the distribution of *P. parva* in Eastern Europe. They predicted that by 2050, in accordance with the baseline IPCC scenario, the distribution range of this species will increase by 40%. According to their reports, the distribution will extend to Ladoga Lake in the north and Ural River in the east.

The present study has shown that *P. parva* is a successful invasive species that can adapt to most freshwater bodies. Therefore, its release can have far-reaching and irreversible consequences on aquatic ecosystems. Given the widespread distribution of *P. parva* in different freshwater bodies, this study suggests that future research has to be conducted in order to control and prevent the spread of invasive species in aquatic ecosystems. Certainly, this goal would not be possible without the cooperation of national and international environmental organisations.

Conclusion

Due to its unique characteristics, *P. parva* is able to compete with other fish species in various ecosystems. It is generally recognised as an undesirable coloniser and even a serious ecological threat to native fish species. This study has shown that the distribution of *P. parva* is largely affected by temperature and precipitation fluctuations. Therefore, there is a high probability of extending its distribution range in freshwater systems in East Asia. Given this situation, it is imperative that management measures, policies and investments have to be used by environmental organisations to prevent its further spread to new ecosystems.

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