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ORIGINAL ARTICLE

# Model-based assessment of climate change impacts on the distribution of northern pike, *Esox lucius* as an important edible species in the southern Caspian Sea basin in Iran

**Najmeh TABASINEZHAD[1], Hamed MOUSAVI-SABET[*1], Hossein MOSTAFAVI[*2], Mojtaba ZOLJOODI ZARANDI[3]**

[1]Fisheries Department, Faculty of Natural Resources, University of Guilan, Sowmeh Sara, Iran.
[2]Department of Biodiversity and Ecosystem Management, Environmental Sciences Research Institute, Shahid Beheshti University, Tehran, Iran.
[3]Department of Marine Meteorology & Physical Oceanography, Atmospheric Science & Meteorological Research Center, Tehran, Iran.

**Correspondence**
mosavii.h@gmail.com,
hmostafaviw@gmail.com

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**Abstract**
The climate system is changing at an unprecedented rate in the world. Climate change is having significant impacts on freshwater ecosystems and the fish species that inhabit them. The main purpose of this study was forecasting the distribution of northern pike, *Esox lucius* in the Caspian Sea basin under two optimistic (RCP 2.6) and pessimistic (RCP 8.5) scenarios of 2050 and 2080 by the MaxEnt model in R software. Five environmental variables including, annual mean temperature, temperature annual range, annual precipitation, flow accumulation, and slope were used for the modeling. The obtained results demonstrated that the performance of the model in predicting species distribution was "excellent" (0.977) based on the AUC (Area Under the Curve) criterion. Moreover, the results indicate that the distribution range of northern pike is likely to be reduced by 2050 and 2080 under the both optimistic and pessimistic climate change scenarios. In conclusion, the decreasing distribution of this fish, which is a commercially important and interesting species in sport fishing, poses a serious threat to food security and livelihoods. Therefore, policy makers should pay more attention to conservation and stock management of this species in the future.

**Keywords:** Global warming, Species Distribution Modeling, Biodiversity conservation, Food security.

## INTRODUCTION

For millions of years, natural climate change occurring at a rate slower than the current anthropogenic-induced change has caused significant shifts in ecosystems, resulting in the emergence and extinction of species (Pörtner et al. 2014; Pletterbauer et al. 2018). This phenomenon is driven by human activities such as the burning of fossil fuels for energy production and deforestation (Ramanathan 2020). The world's rivers and fish populations that rely on them are being profoundly affected by the negative impacts of climate change (Makki et al. 2023 a,b). Hence, these changes as a source of extreme and unpredictable environmental variation represent one of the most significant threats to freshwater biodiversity (Woodward et al. 2010; Raven 2020; Mostafavi et al. 2021).

The most significant impacts of climate change on freshwater fish are the alteration of water temperature, the volume and timing of flow, and the chemistry of freshwater ecosystems (Olden and Naiman 2010; IPCC 2014; Pletterbauer et al. 2018). Increased levels of carbon dioxide in the atmosphere lead to higher levels of carbonic acid in freshwater systems, which can cause changes in pH levels and affect the ability of fish to absorb oxygen. Changes in pH levels can also affect the growth and reproduction of many fish species (Robertson et al. 2016; Islam et al. 2022). In addition, climate change affects precipitation patterns and water availability, which can have a significant impact on freshwater fish populations. Changes in precipitation patterns can lead to more frequent floods and droughts, which can disrupt fish spawning and migration patterns, alter food availability, and cause habitat destruction (Robertson et al. 2016; Schmutz et al. 2018). Therefore, decision makers and managers should pay more attention to the vulnerability of rivers and aquatic animals to climate change. On the other hand, climate change is leading to the spread of invasive species, which can compete with native fish species for resources and prey on them directly. Changes in temperatures are suitable for some

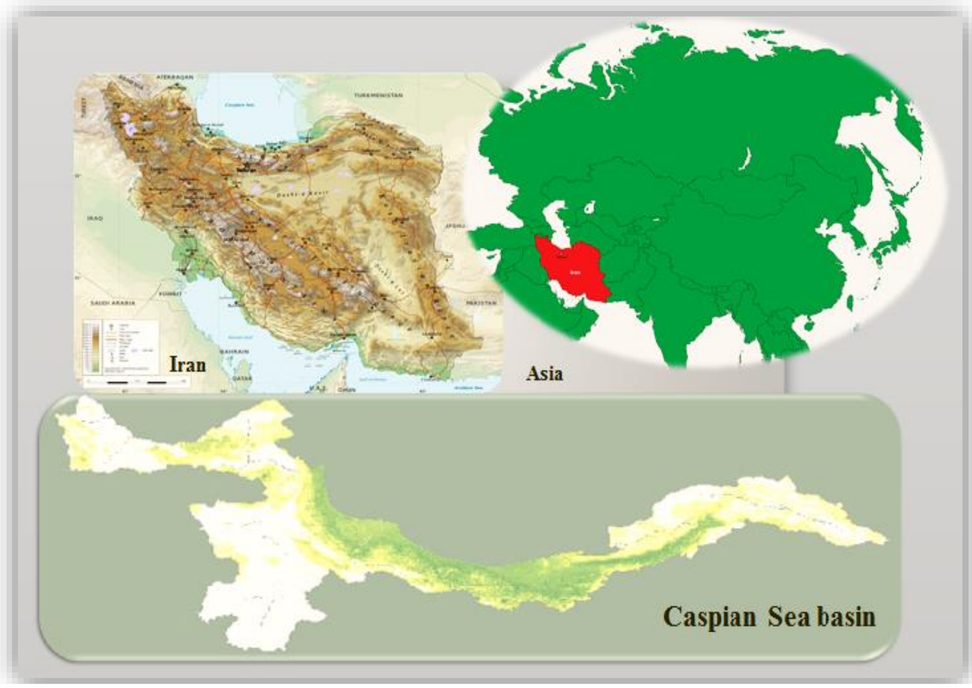


**Fig.1.** Study area of northern pike in this research.

invasive species as their distributions may increase (Bond et al. 2011; Rahel 2013; Mostafavi et al. 2019).

Understanding the effects of climate change on individual organisms, species populations, communities, and ecosystems requires research in laboratories, micro- and mesocosms, field biota or communities, and modeling (Boyd & Hutchins 2012; Pörtner et al. 2014). Modeling is always less complex than original ecosystems. Therefore, we can make predictions about the future events and plan for them with minimal manipulation of the natural environment (Phillips et al. 2017). One of the most important methods for modeling the natural environment is Species Distribution Modeling (SDM), which is a tool to examine the relationship between a species' geographic distribution data (presence or abundance in known locations) and information about its environmental characteristics (Elith & Leathwich 2009).

To reduce the impacts of climate change, strategies can be developed that take into account the factors that assess the vulnerability of endangered species. In Iran, one of the native and economic species is northern pike, *Esox lucius* (Linnaeus, 1758).Several studies have been conducted on this fish covering topics such as physiology, morphology, molecular biology, etc. (Sattari et al. 2007; Khara et al. 2011; Imanpour Namin et al. 2011; Teimouri et al. 2011; Sakizadeh et al. 2012; Abbasi et al. 2013a,b, 2015; Samiei et al. 2015). Although the modeling of distribution for this fish has not yet been studied in our country, and furthermore it is an important nutritional species, the current study aimed to investigate how climate change will affect the habitat and distribution of northern pike under future climate scenarios (RCP 2.6 and RCP 8.5).

## MATERIAL AND METHODS

**Study area and data occurrence:** The studied area in this research contains rivers in the southern part of the Caspian Sea basin in Iran (Fig. 1). In general, the climate of Iran can be classified as arid to semi-arid, with more than 80% of the country characterized by less than 250 mm annual rainfall (Firouz et al. 1970; Coad 2021). The Caspian Sea basin is one of the most important basins in Iran, with a high level of biodiversity and unique species (Vasil′eva et al. 2015; Abassi et al. 2019; Coad 2021). This basin has more than 100 species out of 292 fish species of the inland waters ichthyofauna of Iran, including 83 native, 10 exclusive endemic, and 17 exotic species (Eagderi et al. 2022). The species occurrence records were obtained from our fieldwork, previous literature, and

**Table 1.** Environmental variables were used for modeling and their estimates of permutation in MaxEnt modeling of northern pike in the Caspian Sea basin.

| Category and Source | Variable | Permutation importance (%) |
|---|---|---|
| Bioclimatic variables (www.worldclim.org) | BIO1 (Annual Mean Temperature) | 1.2 |
| | BIO7 (Temperature Annual Range) | 10.2 |
| | BIO12 (Annual Precipitation) | 67.2 |
| Global hydrography datasets (http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/) | Flow Accumulation | 16.7 |
| Topographic variables (www.isric.org www.worldgrids.org) | Slope | 4.8 |

personal datasets of experts, which were considered as presence points.

**Species introduction:** Northern pike belong to the family Esocidae and is one of the native species in the Caspian Sea basin (Coad 2016; Eagderi et al. 2022), mostly reported from the Anzali Mordab and its drainage canals, tributaries and other rivers (Fazli et al. 2014; Keivany, et al. 2016; Abbasi et al. 2019). The northern pike have the widest distribution range in the Northern Hemisphere (Coad 2016; Arlinghaus et al. 2018), spawning from 24° to 69° in latitude and originally described from Europe (Forsman et al. 2015; Eschmeyer and Fong 2016). It usually migrates to deeper, cooler-water at the height of summer (Abbasi et al. 2015; Coad 2016). Northern pike is an important commercial and sport fish and is found in the lower reaches of rivers along the Iranian shore (Coad 2016; Abdoli et al. 2016). Kiabi et al. (1999), Valipour and Haghighy (2000), and Abdoli & Naderi (2008) concluded that this species is conservation dependent in the southern Caspian Sea basin according to the IUCN criteria. Mostafavi (2007) listed it as conservation dependent in the Talar River, Mazandaran. Zarkami (2012) also provided synopses of biological data and habitat modeling on this extensively studied species.

**Environmental variables preparation:** The environmental layers were extracted from different sites such as worldgrids and worldclim as well as Global hydrography datasets. Layers in the scale of Iran with ArcGIS ver. 10.8 were then standardized. Initially, 8 variables were provided. Afterwards, co-linearity among environmental variables was tested using Pearson's correlation coefficient (r). Finally, some variables were selected for modeling (Table 1). In addition, if two variables were highly correlated ($r > |0.70|$), one of them was excluded according to our expert judgment (Elith et al. 2011). To represent climate change impacts, projected future climate variables for 2050 and 2080 with empirically downscaled bioclimatic data were used. The average of 10 General Circulation Models (GCMs) under optimistic (RCP 2.6) and pessimistic (RCP 8.5) greenhouse-gas emissions scenarios was considered.

**Modeling Technique:** The MaxEnt model (Phillips et al. 2006) was applied to model the species in this study. The MaxEnt model was predominantly used when the data points included presence-only with a limited number of records (Elith et al. 2011; Fois et al. 2018). In addition, for species with few presence records, it fits simpler models (Elith et al. 2011). To predict the potential distribution of northern pike fish, modelling was performed using the "MaxEnt" model (Phillips et al. 2006) in the R package dismo (Hijmans et al. 2017) in R programing (R Core Team 2018). The modeling was evaluated using 10-fold cross-validation according to Valavi et al. (2019). To assess the accuracy of the modeling results, the Area Under the Curve (AUC) (Table 2) of the Receiver Operating Characteristic Curve (ROC) was computed (Lobo et al. 2008). AUC shows the power of the model to discriminate presences from random backgrounds

**Table 2.** Quantitative and qualitative classification of model performance based on the AUC index.

| Model performance | AUC value |
|---|---|
| Very Poor | 0.6–0.7 |
| Poor | 0.7–0.8 |
| Good | 0.8–0.9 |
| Excellent | 0.9 – 1 |

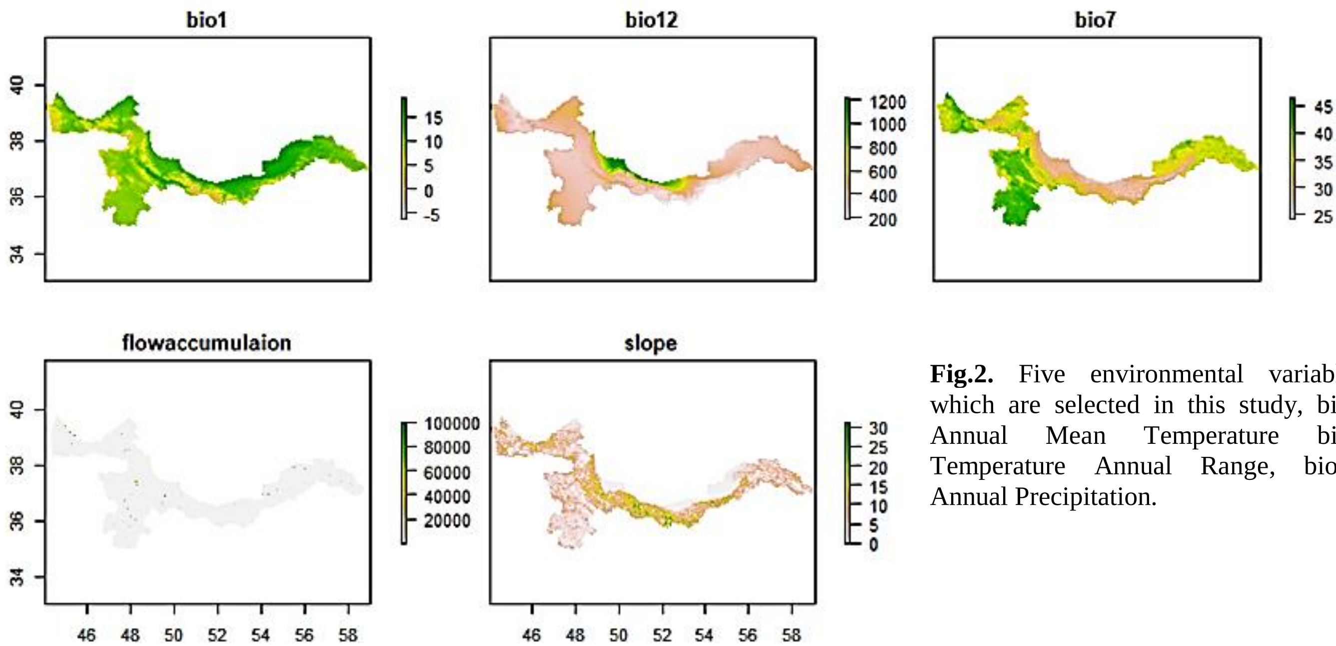


**Fig.2.** Five environmental variables, which are selected in this study, bio1: Annual Mean Temperature bio7: Temperature Annual Range, bio12: Annual Precipitation.

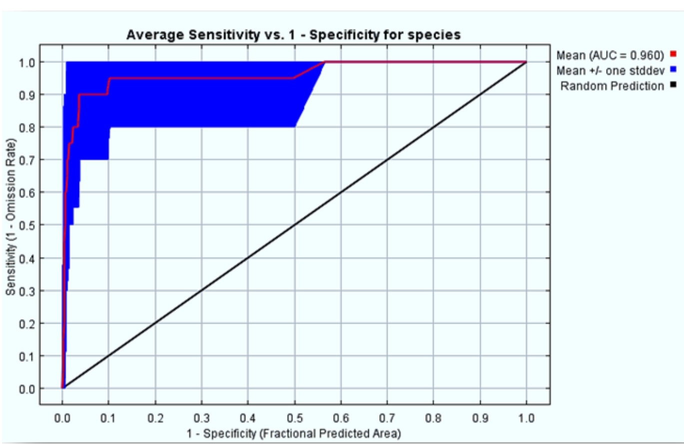


**Fig.3.** Receiver operating characteristic (ROC) curve and AUC index.

(Phillips et al. 2009). The AUC score is a powerful tool for measuring model performance because of its independence from threshold selection. The AUC ranges between 0 and 1, with 0.5 showing a random prediction performance and 1 showing perfect discrimination. Values under 0.5 indicate models worse than random (Elith et al. 2006). The "equal training sensitivity and specificity" of the MaxEnt report was used to determine the suitable threshold for prediction (Liu et al. 2013). For northern pike, the percentage of reduction (% loss), expansion (% gain), and stable sites (% stability) as well as range changes for species were calculated (Makki et al. 2023 a,b).

## RESULTS

After correlation test, five environmental variables i.e., BIO1 = Annual mean temperature, BIO7= Temperature annual range, BIO12= Annual precipitation, Flow accumulation, and Slope were used for modeling (Fig. 2).

The result of evaluating the efficiency of the MaxEnt model using the AUC index (i.e. 0.977) shows that this model has a great ability in predicting the distribution of northern pike (Fig. 3). Also, based on the results, the Annual Precipitation is the most important variable than the other variables in determining the distribution of this species (Fig. 4).

The obtained results of modeling the distribution of northern pike under the influence of climate change indicate that in all the scenarios and time scales studied, the model prediction will show both increase

**Table 4.** Percentage of gain, loss, and range change of species under scenarios for 2050 and 2080.

| Scenarios | Optimistic (RCP 2.6) | | Pessimistic (RCP 8.5) | |
|---|---|---|---|---|
| Time | 2050 | 2080 | 2050 | 2080 |
| Gain | 1.20 | 1.04 | 0.02 | 0.01 |
| Loss | 69.46 | 76.87 | 77.59 | 81.39 |
| Range change | -68.26 | -75.83 | -77.57 | -81.38 |

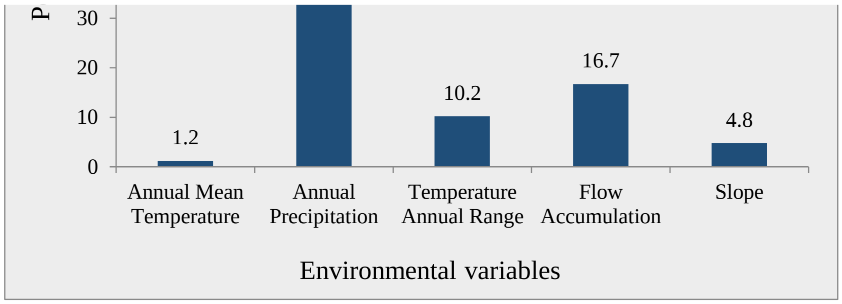


**Fig.4.** Variable importance for distribution of northern pike.

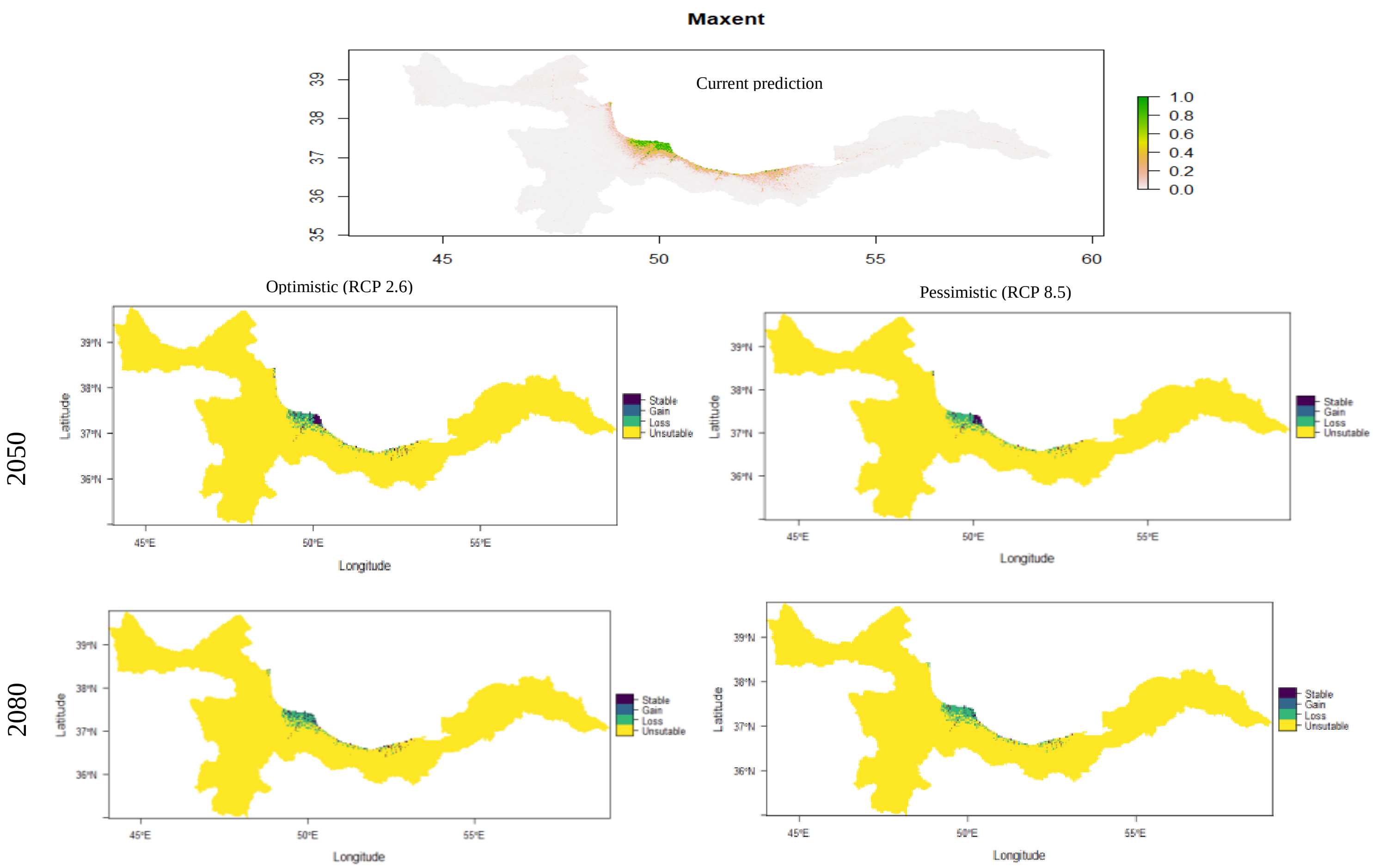


**Fig.5.** Distribution of northern pike under different climate change scenarios for 2050 and 2080.

(gain) and decrease (loss). However, the loss is greater than the gain, and consequently, the range change is negative for all optimistic and pessimistic scenarios (Table 4 and Fig. 5). Moreover, the highest severity is the pessimistic scenario of 2080 (-81.38 %).

## DISCUSSION AND CONCLUSION

Continued emissions of greenhouse gases and climate change will cause disasters worldwide (Lee 2020). Hence, a framework for managing and monitoring the consequences is needed. This framework should encompass a comprehensive range of conservation management actions, from research and development to implementation and public outreach (Dasgupta & Ehrlich 2019). To control the effects of climate change, different strategies must be implemented, such as enhancing our understanding of its impacts on species and ecosystems, creating decision-making tools and adaptation methods, integrating climate change adaptation plans into existing management and research programs, planning and policy-making, and improving the management and restoration of existing species and ecosystems to increase their resilience (Ramanathan 2020; Rahel 2022; Makki et al. 2023a).

The results of this study indicate that the distribution range of northern pike is likely to be reduced by 2050 and 2080 under both optimistic (RCP2.6) and pessimistic (RCP8.5) climate scenarios, thus conservation measures for this species is necessary. Management of freshwater conservation requires the regulation of water, land within the water body (the bed), land within the catchment, and biodiversity in freshwater ecosystems (Robertson et al. 2016; Coad 2021). Policy options for addressing freshwater conservation issues include altering property rights (e.g. purchase of land), implementing regulations (e.g. setting bottom lines, prohibiting activities), establishing directions from the central government, setting scientific and best practice standards, providing tools, and offering additional support for transformation (financial and non-financial), (Schmutz et al. 2018; Pletterbauer et al. 2018).

According to the study of Arlinghaus et al. (2023), there are increasing reports of declines of freshwater fishes. Specifically for pike, multiple causes underlie the decline in the central and southern Baltic Sea. To understand the possible reasons underlying the recent decline in pike abundance and biomass in the lagoons in the southern Baltic Sea, they compiled data and literature emphasizing possible environmental trends, including those related to anthropogenic factors, in the last 10–20 years since about 2000. In another study, potential habitats of northern pike, which are predatory, were predicted in the rivers (Han, Nakdong, Geum, Seomjin and Youngsan) of Korea. The prediction results have shown that the physiological habitat suitability of species was mainly controlled by heat or cold stress, which resulted in biased habitat distribution. Northern pike was predicted to prefer basins at high latitudes (Shim et al. 2023). Khaval et al. (2010) found that pike controlled coarse fish in carp culture ponds, reducing unwanted fishes by 79.3% and 74.3%, respectively, at pike densities of 200 and 500 individuals per hectare. Pike fed mainly on frog juveniles but reduced unwanted fish such as *Carassius auratus*, *Hemiculter leucisculus*, *Alburnus alburnus,* and *Pseudorasbora parva* by 94.0, 88.9, 62.4 and 56.82%, respectively. In studies conducted in Iran, it was found that northern pike mainly feed on *Carassius* sp., *Hemiculter leuciscus, Rhodeus caspius, Alburnus chalcoides, Atherina boyeri, Gambusia holbrooki, Chelon saliens, Alburnus hohenackeri,* and *Ponticola bathybius*. Thus, this fish plays an important role in controlling non-native fish in the region (Abdoli et al. 2022).

For fish, temperature is the master abiotic factor that controls and limits fish physiology (hemato-physiology, metabolism, immune system) at all stages of the life cycle, and is also a key factor affecting species redistribution (Khaval et al. 2010; Schmutz et al. 2018). When water temperatures even slightly increase, it can cause stress, reduce growth rates, and increase mortality in many freshwater fish species that are adapted to specific temperature ranges (Rahel 2022). An increase in water temperature due to climate change can cause physical changes that have ecological implications, such as a decrease in the viable habitat, altering species distribution ranges, decreased availability of food and nutrients, and reduced habitat connectivity (Robertson et al. 2016; Mostafavi et al. 2021; Islam et al. 2022). Whereas, freshwater fishes cannot disperse without connections of the freshwater systems, if the rivers are disconnected and they do not enter suitable habitats, they may face destruction (Pletterbauer et al. 2018; Makki et al. 2023a).

Accordingly, adaptive management should be maintained as a fail-safe, given the delayed detectability of a climate change signal, which could mean that adjusting freshwater management practices based on empirical observations may come too late to be useful. We need to further investigate ways to evaluate the resilience of ecosystems to effectively direct conservation efforts toward the most vulnerable or fragile habitats, or alternatively, strengthen the stability of those ecosystems (Robertson et al. 2016; Pletterbauer et al. 2018; Dasgupta 2021). Managers have three options for responding to these changes: "Resist" change to maintain or restore historic abiotic and biological conditions; "Accept" change and manage within the new conditions; or "Direct" change to produce new conditions considered desirable by humans (Rahel 2022). In order to ensure the survival of freshwater ecosystems and the species within them, "Protecting" and "Restoring" critical habitats, such as rivers, wetlands, and lakes, are two approaches that can be taken to ensure the continued survival of fish species (Ferraro et al. 2015; Muhar et al. 2018).

Finally, the impact of climate change on freshwater fishes is a growing concern that requires urgent attention and action. Importantly, the main action for controlling climate change is to reduce greenhouse gas emissions and slow the rate of temperature increase. To reduce greenhouse gas emissions, strategies such as increasing the utilization of renewable energy sources, enhancing energy efficiency, encouraging sustainable land management practices, halting deforestation, transforming transportation systems, and initiating reforestation should be employed (Dasgupta et al. 2021). Additionally, policies and regulations can be implemented to limit the introduction and spread of invasive species, as well as to promote sustainable fishing practices that minimize the impact on fish populations. According to the results of the current study, it is expected that the range of distribution of northern pike will decrease in the future. However, this species is an important economical species that provides nutrition for people, and anglers catch this species in rivers along the Caspian Sea shore; thus, across its distributional range, the species has high fisheries value, and regionally for commercial fisheries. Based on the above, a decrease in the distribution of this fish as a nutritional species is a threat to food security, and decision makers should pay more attention to the conservation of this species.

## REFERENCES

Abbasi, M.; Mosavi-Sabet, S.H.; Bani, A. & Heidari, A. 2013b. The comparison of morphological and numerical characteristics in pike (*Esox lucius* Linnaeus, 1758) from Anzali and Amirkelayeh wetlands in the southern Caspian Sea basin. Journal of Applied Ichthyological Research 1(4): 39-52.

Abbasi, M.; Bani, A.; Moradinasab, G. & Mosavi-Sabet, S.H. 2013a. The comparison some of growth characteristic in pike (*Esox lucius* Linnaeus, 1758) from Anzali and Amirkelayeh wetlands. Journal of Applied Ichthyological Research 1(3): 49-62.

Abbasi, M.; Bani, A.; Hadavi, M. & Mosavi-Sabet, S.H. 2015. Study of gonadal pathology pike (*Esox lucius* Linnaeus, 1758) in Anzali wetland and its comparison whit Amirkelayeh wetland. Journal of Animal Environmental 8(2): 125-131.

Abbasi, K.; Moradi, M.; Mirzajani, A.; Nikpour, M.; Zahmatkesh, Y.; Abdoli, A. & Mousavi-Sabet, H., 2019. Ichthyo diversity in the Anzali Wetland and its related rivers in the southern Caspian Sea basin, Iran. Journal of Animal Diversity 1(2): 90-135.

Abdoli, A. & Naderi M. 2008. Fish biodiversity in the southern Caspian Sea. Abziyan Scientific Press, 242 p.

Abdoli, A. & Naderi, M. 2009. Biodiversity of Fishes of the Southern Basin of the Caspian Sea. Abzian Scientific Publications, Tehran. 243 p.

Abdoli A. 2016. Field guide of fishes of inland waters of Iran. Iranshenasi Publisher. 276 p.

Abdoli, A.; Valikhani, H. Nejat, F. & Khosravi, M. 2022. Non-native freshwater fishes of Iran (Identification, Impacts, Management). Department of Biodiversity and Ecosystem Management, Environmental Sciences Research Institute, Shahid Beheshti University, Tehran, Iran. 280 p.

Arlinghaus, R.; Rittweg, T.; Dhellemmes, F.; Koemle, D.; Gemert, R.; Schubert, H.; Niessner, D.; Moller, S.; Droll, J.; Friedland, R.; Lewin, W.CH.; Dorow, M.;

Westphal, L.; Ehrlich, E.; Strehlow, H.V.; Weltersbach, M.S.; Roser, PH.; Braun, M.; Feldhege, F. & Winkler, H. 2023. A synthesis of a coastal northern pike *(Esox lucius*) fishery and its social-ecological environment in the southern Baltic Sea: Implications for the management of mixed commercial-recreational fisheries. Journal of Fisheries Research Volume 263, Article 106663.

Boluki, Z.; Dehghani, Tafti, E.; Abbasi, R.H. & Sadeghinezhad, J. 2015. Anatomical, histological and histomorphometric study of the intestine of the northern pike (*Esox lucius*). Iranian Journal of Veterinary Medicine 8(9): 207-211.

Bond, N.; Thomson, J.; Reich, P. & Stein, J. 2011. Using species distribution models to infer potential climate change-induced range shifts of freshwater fish in south-eastern Australia. Marine and Freshwater Research 62(9): 1043-1061.

Boyd, P.W. & Hutchins, D.A. 2012. Understanding the responses of ocean biota to a complex matrix of cumulative anthropogenic change. Marine Ecology Progress Series 470: 125-135.

Coad, B.W. 2021. Freshwater Fishes of Iran. Updated 1 January 2021. [Cited 1 January 2021]. Available from: www.briancoad.com.

Coad, B.W. 2016. Review on the pikes of Iran (Family Esocidae). Iranian Journal of Ichthyology 3(3): 161-180.

Dasgupta, P.; Ramanathan, V.; Raven, P.; Sorondo Mgr, M.; Archer, M. & Crutzen, P.J. 2015. Climate change and the common good: A statement of the problem and the demand for transformative solutions. Vatican, Rome: The Pontifical Academy of Sciences and the Pontifical Academy of Social Sciences.

Dasgupta, P. & Ehrlich, P.R. 2019. Why we are in the Sixth Extinction and what it means to humanity. In Dasgupta, P., P.H. Raven., P.H., & Anna McIvor (eds.), Biological extinction: New perspectives (pp. 262-284). Cambridge, UK: Cambridge University Press.

Dasgupta, P. 2021. The Economics of Biodiversity: The Dasgupta Review. (London: HM Treasury).

Eagderi, S.; Mouludi-Saleh, A.; Esmaeili, H.R.; Sayyadzadeh, G. & Nasri, M. 2022. Freshwater lamprey and fishes of Iran; a revised and updated annotated checklist-2022. Turkish Journal of Zoology 46(6): 500-522.

Elith, J.; Graham, C.P.; Anderson, R.; Dudík, M.; Ferrier, S.; Guisan, A.E. & Zimmermann, N. 2006. Novel methods improve prediction of species' distributions from occurrence data. Journal of Ecography 29: 129-151.

Elith, J. & Leathwick, J.R. 2009. Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution, and Systematics 40: 677-697.

Elith, J.; Phillips, S.J.; Hastie, T.; Dudík, M.; Chee, Y.E. & Yates, C.J. 2011. A statistical explanation of MaxEnt for ecologists. Diversity and Distributions 17: 43-57.

Eschmeyer, W.N. & Fong, J.D. 2016. SPECIES BY FAMILY/SUBFAMILY. (http://researcharchive. Calacademy.org/research/ichthyology/catalog/Spec iesByFamily.asp).Electronic version accessed 27 July 2016.

Esmaeili, H.R.; Coad, B.W.; Mehraban, H.R.; Masoudi, M.; Khaefi, R.; Abbasi, K.; Mostafavi, H. & Vatandoust, S. 2014. An updated checklist of fishes of the Caspian Sea basin of Iran with a note on their zoogeography. Iranian Journal of Ichthyology 1(3): 152-184.

Fazli, H.; Kor, D.; Daryanabard, G. & Tavakoli, M. 2014. Distribution and biodiversity of fishes in bottom trawl in Iranian part of the Caspian Sea. The Second Iranian Conference of Ichthyology, Faculty of Natural Resources, University of Tehran, Karaj, 7-8 May 2014.

Ferraro, P.J.; Hanauer, M.M.; Miteva, D.A.; Nelson, J.L.; Pattanayak, S.K.; Nolte, C. & Sims, K.R.E. 2015. Estimating the Impacts of Conservation on Ecosystem Services and Poverty by Integrating Modeling and Evaluation. Proceedings of the National Academy of Sciences 112(24): 7420-7425.

Filipe, A.F.; Markovic, D.; Pletterbauer, F.; Tisseuil, C.; Wever, A. & Schmutz, S. 2013. Forecasting fish distribution along stream networks: brown trout (*Salmo trutta*) in Europe. Diversity and Distributions 19(8): 1059-1071.

Forsman, A.; Tibblin, P.; Berggren, H.; Nordahl, O.; Koch-Schmidt, P. & Larsson, P. 2015. Pike *Esox lucius* as an emerging model organism for studies in ecology and evolutionary biology: a review. Journal of Fish Biology. 87, 472-479.

Fois, M.; Cuena-Lombrana, A.; Giuseppe, F.; Cogoni, D. & Bacchetta, G. 2018. Does a correlation exist between environmental suitability models and plant population parameters? An experimental approach to measure the influence of disturbances and environmental change. Ecological Indicators 86: 1-8.

Haines, A. 2020. Good Health in the Anthropocene Epoch: Potential for Transformative Solutions, in Al-Delaimy, W.K.; Ramanathan, V. & Sánchez Sorondo, M. eds., Health of People, Health of Planet and Our Responsibility (Cham: Springer).

Hijmans, R.J.; Phillips, S.; Leathwick, J.; Elith, J. & Hijmans, M.R.J. 2017. Package 'dismo.' Circles 9(1): 1-68.

Imanpour Namin, J.; Mohammadi, M.; Heydari, S. & Monsef Rad, F. 2011. Heavy metals Cu,Zn, Cd and Pb in tissue, liver of *Esox lucius* and sediment from the Anzali International Wetland - Iran. Caspian Journal of Environmental Sciences 9(1): 1-8.

IPCC, 5AR. 2014. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, Pachauri RK, Meyer LA (Eds.)]. Geneva, Switzerland. Report number: AR5.

Islam, M. J.; Kunzmann, A. & Slater, M. J. 2022. Responses of aquaculture fish to climate change-induced extreme temperatures: A review. Journal of the World Aquaculture Society 53(2): 314-366.

IUCN, 2011. IUCN Red List of Threatened Species. Version 2011.2. IUCN 2011. IUCN Red List of Threatened Species. Downloaded in November 2011.

IUCN, 2015. The IUCN Red List of Threatened Species. International Union for the Conservation of Nature, Gland, Switzerland (http://www.iucnredlist.org/).

Keivany, Y.; Nasri, M.; Abbasi, K. & Abdoli, A. 2016. Atlas of Inland Water Fishes of Iran. Iran Department of Environment Press, Tehran, Iran. 234 p.

Khara, H.; Sattari, M.; Nezami, S.; Mirhasheminasab, S.F.; Mousavi, S.A. & Ahmadnezhead, M. 2011. Parasites of some bonyfish species from Boojagh wetland in the southwest shores of the Caspian Sea. Caspian Journal of Environmental Sciences 9(1): 47-53.

Khaval, A.; Abbasi, K. & Valipour, A. 2010. Biological role of northern pike, *Esox lucius* (Linnaeus 1758) in control of aquatic pests in carps culture ponds. Iranian Scientific Fisheries Journal 19(2): 39-50.

Kiabi, B.H.; Abdoli, A. & Naderi, M. 1999. Status of the fish fauna in the South Caspian Basin of Iran. Zoology in the Middle East 18: 57-65.

Lee, Y.T. 2020. Challenges and Opportunities for a Sustainable Planet. In Al-Delaimy, W.K.; Ramanathan, V. & Sánchez Sorondo, M. eds., Health of People, Health of Planet and Our Responsibility (Cham: Springer).

Liu, C.; White, M. & Newell, G. 2013. Selecting thresholds for the prediction of species occurrence with presence-only data. Journal of Biogeography 40(4): 778-789.

Lobo, J.M.; Jiménez-Valverde, A. & Real, R. 2008, AUC: a misleading measure of the performance of predictive distribution models. Global Ecology and Biogeography 17: 145-151.

Makki, T.; Mostafavi, H.; Matkan, A.A.; Aghighi, H.; Valavi, R.; Chee, Y. E. & Teimori, A. 2023a. Impacts of climate change on the distribution of riverine endemic fish species in Iran, a biodiversity hotspot region. Freshwater Biology In Press.

Makki, T.; Mostafavi, H.; Matkan, A.A.; Valavi, R.; Hughes, R.M.; Shadloo, S.; Aghighi, H.; Abdoli, A.; Teimori, A.; Eagderi, S. & Coad, B.W. 2023b. Predicting climate heating impacts on riverine fish species diversity in a biodiversity hotspot region. Scientific Reports 13: 14347.

Mostafavi, H. 2007. Fish biodiversity in Talar River, Mazandaran Province. Journal of Environmental Studies 32(40): 127-135.

Mostafavi, H.; Schinegger, R.; Pinter, K.; Kremser, H.; Bakhtiyari, M.; Abdoli, A. & Vatandost, S. 2015. Comparison of human pressures and fish assemblages in the salmonid and cyprinid streams of the southern Caspian Sea basin. Iranian Journal of Ichthyology 2(1): 20-34.

Mostafavi, H.; Teimori, A.; Schinegger, R. & Schmutz, S. 2019. A new fish based multi-metric assessment index for cold-water streams of the southern Caspian Sea Basin in Iran. Environmental Biology of Fishes 102, 645-662.

Mostafavi, H. & Kambouzia, J. 2019. Impact of climate change on the distribution of brown trout, *Salmo trutta* Linnaeus, 1758 (Teleostei: Salmonidae) using ensemble modelling approach in Iran. Iranian Journal of Ichthyology 6(1): 73-81.

Mostafavi, H.; Mehrabian, A.R.; Teimori, A.; Shafizade-Moghadam, H. & Kambouzia, J. 2021. The Ecology and Modelling of the Freshwater Ecosystems in Iran. In: Jawad, L.A. (eds) Tigris and Euphrates Rivers: Their Environment from Headwaters to Mouth. Aquatic Ecology Series, vol 11. Springer, Cham.

Muhar, S.; Sendzimir, J.; Jungwirth, M. & Hohensinner, S. 2018. Riverine Ecosystem Management, Aquatic Ecology Series 8.

Naderi Jolodar, M. & Abdoli, A. 2004. Fish Species Atlas of South Caspian Sea Basin (Iranian Waters). Iranian

Fisheries Research Organization, Teheran.110 p. In Farsi and English.

Olden, J.D. & Naiman, R.J. 2010. Incorporating thermal regimes and landscape heterogeneity into the selection of riverine conservation corridors. Freshwater Biology 55(1): 76-94.

Paighambari, S.Y.; Moradinasab, A.; Raeisi, H.; Daliri, M.; Parsa, M. & Kamrani, E. 2014. Effect of colour of fyke-net on CPUE and species composition of fishes in Anzali Wetland. The Second Iranian Conference of Ichthyology, Faculty of Natural Resources, University of Tehran, Karaj, 7-8 May 2014.

Phillips, S.J.; Anderson, R.P. & Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. Ecology. Modell, vol. 190, nos. 3-4, pp. 231-259.

Phillips, S.J.; Dudík, M.; Elith, J.; Graham, CH.; Lehmann, A.; Leathwick, J. & Ferrier, S. 2009. Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. Ecological Applications 19: 181-197.

Phillips, S.J.; Anderson, R.P.; Dudík, M.; Schapire, R.E. & Blair, M.E. 2017. Opening the black box: an opensource release of Maxent. Ecography 40(7): 887-893.

Pletterbauer, F.; Melcher, A.; Ferreira, T. & Schmutz, S. 2015. Impact of climate change on the structure of fish assemblages in European rivers. Journal of Hydrobiology 744, 235-254.

Pletterbauer, F.; Melcher, A.H. & Graf, W. 2018. Impact of climate change on the structure of fish assemblages in European rivers. Journal of Hydrobiologia 744, 235-254.

Pörtner, H.O.; Karl, D.M.; Boyd, P.W.; Cheung, W.W.L.; Lluch-Cota, S.E.; Nojiri, Y.; Schmidt, D.N. & Zavialov, P.O. 2014. Ocean systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 411-484.

Raat, A.J.P. 1988. Synopsis of biological data on the northern pike *Esox lucius* Linnaeus, 1758. Food and Agriculture Organization, Rome, Fisheries Synopsis 30, Rev. 2: 178.

Rahel, F.J. & Olden, J.D. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22(3): 521-533.

Rahel, F.J. 2013. Intentional fragmentation as a management strategy in aquatic systems. Journal of BioScience 63: 362-372.

Rahel, F.J. 2022. Managing Freshwater Fish in a Changing Climate: Resist, Accept, or Direct. Journal of Fisheries 47 (6): 245-255.

Ramanathan, V. 2020. Climate Change, Air Pollution, and Health: Common Sources, Similar Impacts, and Common Solutions, in Al-Delaimy, W.K.; Ramanathan, V. & Sánchez Sorondo, M. eds., Health of People, Health of Planet and Our Responsibility (Cham: Springer).

Raven, P.H. 2020. Biological Extinction and Climate Change, in Al-Delaimy, W.K.; Ramanathan, V. & Sánchez Sorondo, M. eds., Health of People, Health of Planet and Our Responsibility (Cham: Springer).

R Core Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing.

Robertson, H.; Bowie, S.; Death, R. & Collins, D. (Eds) 2016. Freshwater conservation under a changing climate. Proceedings of a workshop hosted by the Department of Conservation, 10-11 December 2013, Wellington. Department of Conservation, Christchurch. 87 p.

Sakizadeh, M.; Esmaeili Sari, A.; Abdoli, A.; Bahramifar, N. & Hashemi, S.H. 2012. Determination of polychlorinated biphenyls and total mercury in two fish species (Esox lucius and Carassius auratus) in Anzali Wetland, Iran. Environmental Monitoring and Assessment 184(5): 3231-3237.

Samiei, M.H.; Norouzi, M.; Ravaei, A.; Behrooz, M. & Nazemi, A. 2015. Genetic structure in Anzali wetland's pike (*Esox lucius*) using microsatellite molecular method. Journal of Biodiversity and Environmental Sciences 6(3): 91-99.

Sattari, M.; Mokhayer, B.; Khara, H.; Nezami, S. & Shafii, S. 2007. Occurrence and intensity of parasites in some bonyfish species of Anzali wetland from the southwest of the Caspian Sea. Bulletin of the European Association of Fish Pathologists 27(2): 54- 60.

Sattari, M.; Khara, H.; Nezami, S.; Roohi, J.D. & Shafii, S.

2005. Occurrence and intensity of some nematodes in the bonyfish species of the Caspian Sea and its basin. Bulletin of the European Association of Fish Pathologists 25(4): 166-178.

Schmutz, S.; Hein, T. & Sendzimir, J. 2018. Riverine Ecosystem Management, Aquatic Ecology Series 8.

Schneider, K. & Hook, T.O. 2010. Climate change and freshwater fish. Journal of Fish Biology 77(9): 1935-1954.

Shim, T.; Kim, ZH. & Jung, J. 2023. Predicting Habitat Suitability of Carnivorous Alert Alien Freshwater Fish. Ecology and Resilient Infrastructure. ISSN: 2288-8527 (Online) pp. 11-19.

Stocker, T.; Qin, D.; Plattner, G.; Tignor, M.; Allen, S. & Boschung, J. et al. 2013. IPCC 2013: Climate change 2013: The physical science basis. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 1535). Cambridge, UK and New York, NY: Cambridge University Press.

Teimouri, B.; Safaeian, S. & Nabavi Seyed, M.B. 2011. Comparison of PCBs concentration in skin and muscle tissue of *Esox lucius* and Cyprinus carpio with PCBs concentration in Anzali Wetland (Abkenar) in autumn and winter 2009-2010. Journal of Animal Environment 3(2): 25-32.

Valipour, A. 1998. An investigation on feeding habits of northern pike of Anzali Lagoon. Iranian Journal of Fisheries Sciences 7(3): 75-90.

Valipour A. & Haghighy D. 2000. Study on changes in fishing in Anzali Lagoon (1992-1996). Iranian Journal of Fisheries Sciences 8(4): 73-88.

Vasil′eva, E.D.; Mousavi-Sabet, H. & Vasil′ev, V.P. 2015. *Ponticola iranicus* sp. nov. (Actinopterygii: Perciformes: Gobiidae) from the Caspian Sea basin. Acta Ichthyologica et Piscatoria 45(2): 189-197.

Woodward, G.; Perkins, D.M. & Brown, L.E. 2010. Climate change and freshwater eco-systems: impacts across multiple levels of organization. Philosophical Transactions of the Royal Society B 365: 2093-2106.

Zarkami, R. 2012. Habitat suitability modelling of northern pike (*Esox lucius*). Fish habitat modelling as a tool for river management. Lambert Academic Publishing, Saarbrücken. 260 p.

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**مقاله کامل**

# ارزیابی مدل‌محور اثرات تغییر اقلیم بر پراکنش اردک ماهی، *Esox lucius* به‌عنوان یک گونه مهم خوراکی در حوضه آبریز جنوبی دریای خزر در ایران

**نجمه طبسی‌نژاد[۱]، سید حامد موسوی‌ثابت[۱*]، حسین مصطفوی[۲*]، مجتبی ذولجودی زرندی[۳]**

[۱]گروه شیلات، دانشکده منابع طبیعی، دانشگاه گیلان، صومعه‌سرا، ایران.
[۲] گروه تنوع زیستی و مدیریت اکوسیستم، پژوهشکده علوم محیطی، دانشگاه شهید بهشتی، تهران، ایران.
[۳]پژوهشگاه ملی اقیانوس‌شناسی و علوم جوی، تهران، ایران.

**چکیده**: در سراسر جهان، سیستم اقلیم به‌شکل بی‌سابقه‌ای در حال تغییر است. این روند تغییر اقلیم بر اکوسیستم‌های آب شیرین و گونه‌های ساکن در آن‌ها تأثیرات قابل‌توجهی خواهد گذاشت. مطالعه حاضر با هدف پیش‌بینی گستره پراکنش اردک‌ماهی در حوضه آبریز خزر تحت سناریوهای اقلیمی خوش‌بینانه (RCP 2.6) و بدبینانه (RCP 8.5) در سال‌های ۲۰۵۰ و ۲۰۸۰ با استفاده از مدل مکسنت در نرم‌افزار R انجام پذیرفت. پنج متغیر شامل، میانگین دمای سالیانه، محدوده دمای سالیانه، میزان بارش سالیانه، جریان تجمعی و شیب برای انجام مدل‌سازی استفاده شدند. با توجه به نتایج به‌دست آمده، عملکرد مدل در پیش‌بینی پراکنش گونه براساس معیار AUC (Area Under the Curve) عالی (۰/۹۷۷) ارزیابی شد. به‌علاوه، نتایج مدل‌سازی نشان داد که احتمالاً پراکنش این گونه در تمامی سال‌ها و سناریوهای خوش‌بینانه و بدبینانه، به‌صورت قابل‌توجهی کاهش پیدا خواهد کرد. با توجه به اینکه اردک‌ماهی یک گونه با ارزش اقتصادی-خوراکی به‌شمار می‌رود و در سبد غذایی جوامع محلی از جایگاه ویژه‌ای برخوردار است، از این‌رو کاهش پراکنش آن در آینده می‌تواند تهدیدی برای امنیت غذایی و معیشت جامعه محسوب گردد. در نتیجه، سیاست‌گذاران و تصمیم‌گیران باید در خصوص حفاظت از این گونه با ارزش و مدیریت ذخایر آن توجه و اهمیت بیشتری قائل شوند.

**کلمات‌کلیدی:** گرمایش جهانی، مدل‌سازی پراکنش گونه، حفظ تنوع‌زیستی، امنیت غذایی.