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Original Article

Investigating the potential infestation region of Redbelly Tilapia (*Coptodon zillii*, Gervais 1848) in Iraq: Impacts of climate change on distribution

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Abstract: The encroachment of invasive species poses a significant threat to native ecosystems, especially in regions vulnerable to the impacts of climate change. This paper aims to examine the potential infestation region of Redbelly Tilapia (*Coptodon zillii*), an introduced fish species, in Iraq, should the species escape aquacultural facilities. Utilizing a Maxent model, our analysis identifies northern Iraq as the optimal habitat for *C. zillii* proliferation. Leveraging ecological modeling techniques and climate projections, this research emphasizes the need for proactive measures to prevent the establishment of *C. zillii* in these northern regions. Specifically, caution is advised against undertaking aquaculture activities in these areas to mitigate the risk of accidental escape and subsequent ecological disruption. By delineating areas of high susceptibility, this study provides actionable insights for conservation efforts and informs policy decisions aimed at preserving the integrity of native ecosystems in the face of environmental change.

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Introduction

Tilapia fishes comprise a diverse group of freshwater species within the family Cichlidae. Indigenous to various regions worldwide, including Africa, the Middle East, and South America, tilapia species have been widely introduced to numerous other areas for aquaculture and recreational purposes (Fitzsimmons et al., 2011). Exhibiting a range of physical traits depending on the species, they typically feature laterally compressed bodies and a singular dorsal fin. Their coloration varies, commonly including shades of silver, gray, and brown (Fitzsimmons et al., 2011). Tilapia species primarily exhibit herbivorous or omnivorous feeding habits, consuming algae, aquatic plants, and small invertebrates (Adams et al., 1988). Known for their adaptability, tilapia can thrive in both stagnant and flowing water bodies (Linde et al., 2008; Natugonza et al., 2021), exhibiting tolerance to low oxygen levels and demonstrating resilience in areas with compromised water quality (Setiadi et al., 2018), hence making them a favored choice for aquaculture.

Redbelly Tilapia (*Coptodon zillii*, Gervais 1848), formerly classified as *Tilapia zillii*, is a species native to Africa (Geletu et al., 2024). It exhibits a wide distribution across various African regions, including the Nile River, Lake Chad, and Lake Victoria. Redbelly Tilapia typically presents as a medium-sized fish with a laterally compressed body shape. Its remarkable ability to thrive in diverse environmental conditions, ranging from freshwater to brackish and slightly saline water, is noteworthy (Nofal et al., 2019). This adaptability has facilitated its successful establishment as an invasive species in numerous regions globally. Redbelly Tilapia has been deliberately introduced to various areas outside of Africa, spanning parts of Asia, the Americas, and Australia (Cassemiro et al., 2018; Geletu et al., 2024). Its capacity for rapid growth, coupled with its competitive edge over native fish species, has contributed to its invasive success. However, introducing Redbelly Tilapia has often resulted in adverse ecological consequences, including the

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displacement of native fish populations and alterations to aquatic ecosystems (Peymani et al., 2022).

The introduction of species into non-native environments can have significant ecological, economic, and social repercussions (Vitule et al., 2009; Radkhah et al., 2016; Tabasian et al., 2021). When a species is introduced to an ecosystem where it did not evolve, it may lack natural predators, parasites, or competitors, enabling it to thrive and potentially outcompete native species. The introduction of Redbelly Tilapia into Iraqi aquacultural sectors exemplifies such an event, raising concerns about its potential impacts on the local environment as it has already established itself in natural water bodies in Iraq (Abdalhsan et al., 2020; Çiçek et al., 2023). Introducing Redbelly Tilapia to Iraq's water bodies could have several ecological consequences. As an invasive species, it may compete with native fish for food resources and habitat, potentially leading to the displacement or decline of indigenous species. Redbelly Tilapia's capacity to tolerate a wide range of environmental conditions and its rapid reproductive rate (Ishikawa and Tachihara, 2008) could confer it a competitive advantage over native fish species, disrupting the ecosystem's balance.

The impacts of climate change on species distribution have been extensively documented (Bond et al., 2011; (Radkhah et al., 2021). As global temperatures rise and weather patterns shift, many species are compelled to adapt or face survival challenges. Climate change and global warming may significantly alter the success of Redbelly Tilapia in Iraqi freshwater ecosystems. Increasing temperatures could expand the suitable range of this tropical fish species to previously deemed too cold, enabling its proliferation in previously unsuitable regions. Warmer waters may also enhance their reproductive success, given tilapia's known propensity for higher reproductive rates in warmer environments (Gu et al., 2018). This heightened adaptability to a broader temperature range could confer Redbelly Tilapia a competitive edge over native Iraqi freshwater fish species.

Understanding the potential effects of climate change on a non-native species like Redbelly Tilapia, should it escape from aquacultural facilities, is crucial for several reasons. Firstly, it helps assess the potential ecological impacts of successfully establishing this invasive species in Iraqi freshwater ecosystems. Secondly, it provides insights into how climate change may interact with the introduction of non-native species, exacerbating their impacts on native biodiversity. Thirdly, it can inform conservation strategies and management practices to mitigate the potential threats of climate change and invasive species. Additionally, it can help identify high-risk areas or regions vulnerable to invasion, guiding the development of proactive measures to prevent or manage their spread (Radkhah and Eagderi, 2020, 2021). Such research also aids policymakers, conservationists, and resource managers make informed decisions regarding protecting and conserving native Iraqi freshwater fish species in the face of threats from climate change and invasive species. Therefore, the present study was motivated to investigate the potential distribution of Redbelly Tilapia and its temporal changes under various climate change scenarios. Such a study would help determine the areas at higher risk of being infested by this species if it were to enter natural freshwater ecosystems in Iraq.

Materials and Methods

Bioclimatic variables: The bioclimatic variables utilized in this study were obtained from the worldclim website (worldclim.org) (Table 1). These variables underwent examination for collinearity using Pearson correlation analysis in R version 4.3.1, and variables displaying high correlations were subsequently removed. Specifically, in cases where two variables exhibited a Pearson correlation coefficient of 0.9 or higher, the variable with the highest total correlations with other variables was eliminated.

Modelling: The species presence data were obtained from the Ocean Biodiversity Information System (OBIS, 2024). More than 35 General Circulation Models (GCMs) have been employed to forecast

Table 1. The bioclimatic variables utilized in the present study and were examined for collinearity prior to analysis. The resolution of all variables were 0.008° × 0.008°.

The bioclimatic variables	Acronyms
Annual mean temperature	AMT
Mean diurnal range	MDR
Isothermaliy	ISO
Temperature seasonality	TS
Max temperature of warmest month	MTWM
Min temperature of coldest month	MTCM
Temperature annual range	TAR
Mean temperature of wettest quarter	MTWQ
Mean temperature of driest quarter	MTDQ
Mean temperature of warmest quarter	MTWQ2
Mean temperature of coldest quarter	MTCQ
Annual precipitation	AP
Precipitation of wettest month	PWM
Precipitation of driest month	PDM
Precipitation seasonality	PS
Precipitation of wettest quarter	PWQ
Precipitation of driest quarter	PDQ
Precipitation of warmest quarter	PWQ2
Precipitation of coldest quarter	PCQ

climate factors for future decades. The climate parameter data derived from these models vary and can impact the final prediction. In this study, GCMeval, a web-based program, was utilized to select the most suitable GCM for the Iraq region (Parding et al., 2020).

Initially, 19 bioclimatic data points representing recent annual averages were selected. Variables exhibiting high correlations with others were then removed. Subsequently, a Maxent model was employed to predict the presence of *C. zillii* across Iraq using current bioclimatic data (averaged data over 1970-2000). The Maxent model is recognized as one of the most effective models for modeling presence-only data (Valavi et al., 2019). The quality of the Maxent model was assessed using the area under the curve (AUC) (Kuhn and Johnson, 2013).

The selected GCM data from the model chosen by GCMeval for Iraq were utilized to predict the presence of fish species in future decades. For modeling species presence, 70% of the presence data was allocated for model training, while the remaining 30% was designated as test data for model evaluation. Background data encompassed 10,000 points. A jackknife test was conducted to identify the most influential bioclimatic variables affecting the presence of *C. zillii*. The Maxent model was implemented using the dismo package in R version 3.4.1, based on the methodology outlined by Hijmans and Elith (2024).

Results

According to the online tool GCMeval, the HadGEM3.GC31 emerged as the most suitable GCM model for the Iraq region and was consequently utilized for modeling purposes. The scenario datasets SSP126, SSP245, and SSP585 were employed due to their availability as downscaled datasets for the GCM HadGEM3.GC31 on the worldclim website. Bioclimatic variables TAR, AP, MTCM, TS, PWM, and PDQ exhibited high correlations with each other and other variables and thus were excluded from the study. The AUC of the Maxent model generated by the training and testing data were 0.963 and 0.835, respectively (Fig. 1).

The jackknife test identified AMT as the most important variable when considered alone (Fig. 2). The subsequent important bioclimatic variables, if considered as the sole independent variables of the model, were MTCQ, PWQ, and PWQ2. ISO was determined as the most significant variable when omitted from the model, indicating its unique contribution of information not present in other bioclimatic variables. Additionally, the omission of MTCQ, PCQ, and PWQ from the model would decrease the model's gain.

The probability of the presence of *C. zillii* based on the climate scenario SSP126 is presented in Figure 3A, B, and C. The predicted maps indicate minimal changes in the presence probability of *C. zillii* from 2021 to 2080 under SSP126. Generally, the presence probability of *C. zillii* will be < 0.4 for most parts of Iraq, with the exception of the southern regions, indicating that most parts of the country are susceptible to *C. zillii* infestation. The most suitable habitats for the species will be in northern and northeastern Iraq, near the border with Turkey and Iran. This favorable habitat extends from northern Mosul and Erbil towards the eastern part of Iraq, encompassing Sulaymaniyah and Halabja, over the

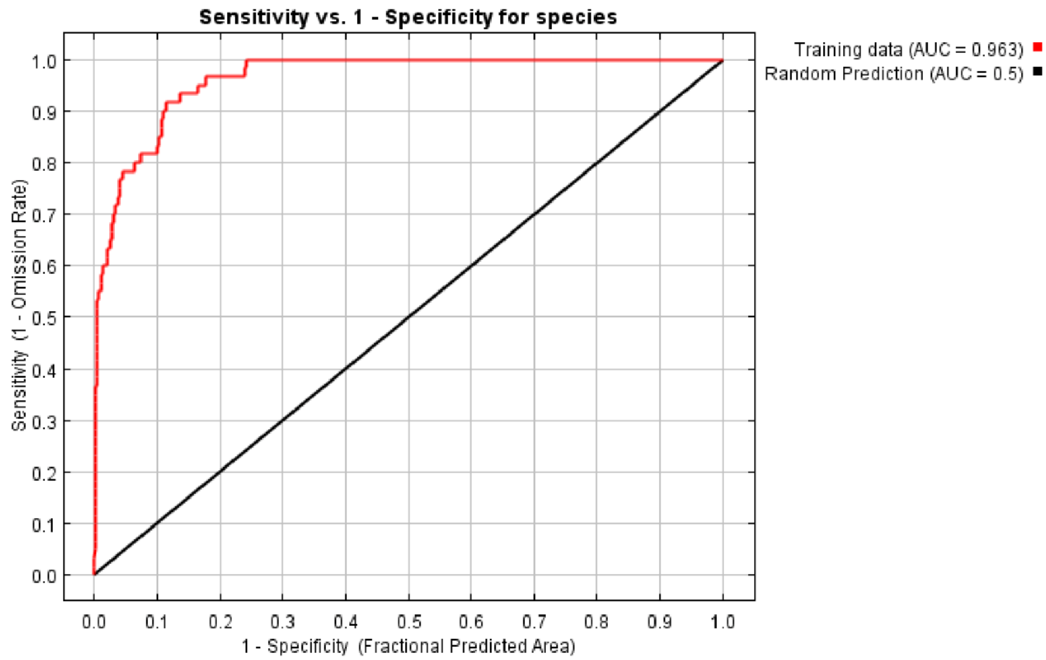

Figure 1. The AUC of the Maxent model.

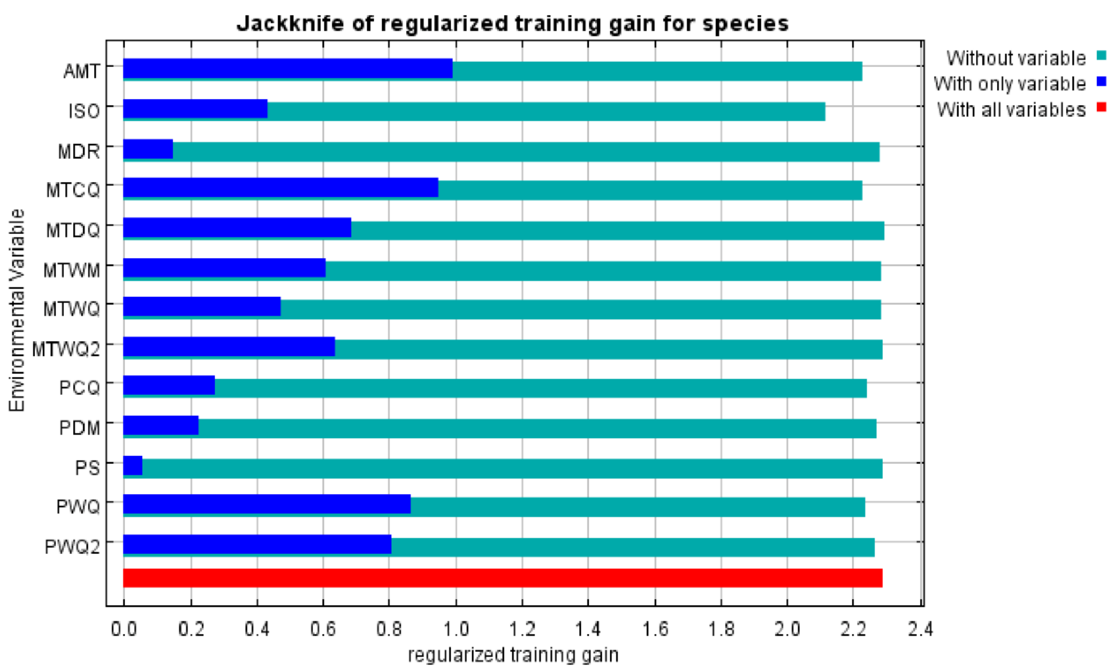

Figure 2. The jackknife test used to find the importance of the bioclimatic variables in the Maxent model.

period from 2021 to 2080.

The predicted distribution of *C. zillii* from 2021 to 2080 based on the SSP245 scenario is expected to be similar to that of the SSP126 scenario. In other words, the most suitable habitat for the species will be concentrated in the northern part of the country (Fig. 3D, E, F). The most notable temporal changes will occur in areas with approximately a 0.4 probability of presence in eastern Iraq, extending towards the Jordanian border over time.

The most significant changes in the probability of the presence of *C. zillii* were predicted based on the SSP585 scenario (Fig. 3G, H, and I). Over time, the areas of suitable habitat for *C. zillii* will change, though they will remain primarily in northern Iraq. The areas of less suitable habitat, with a presence

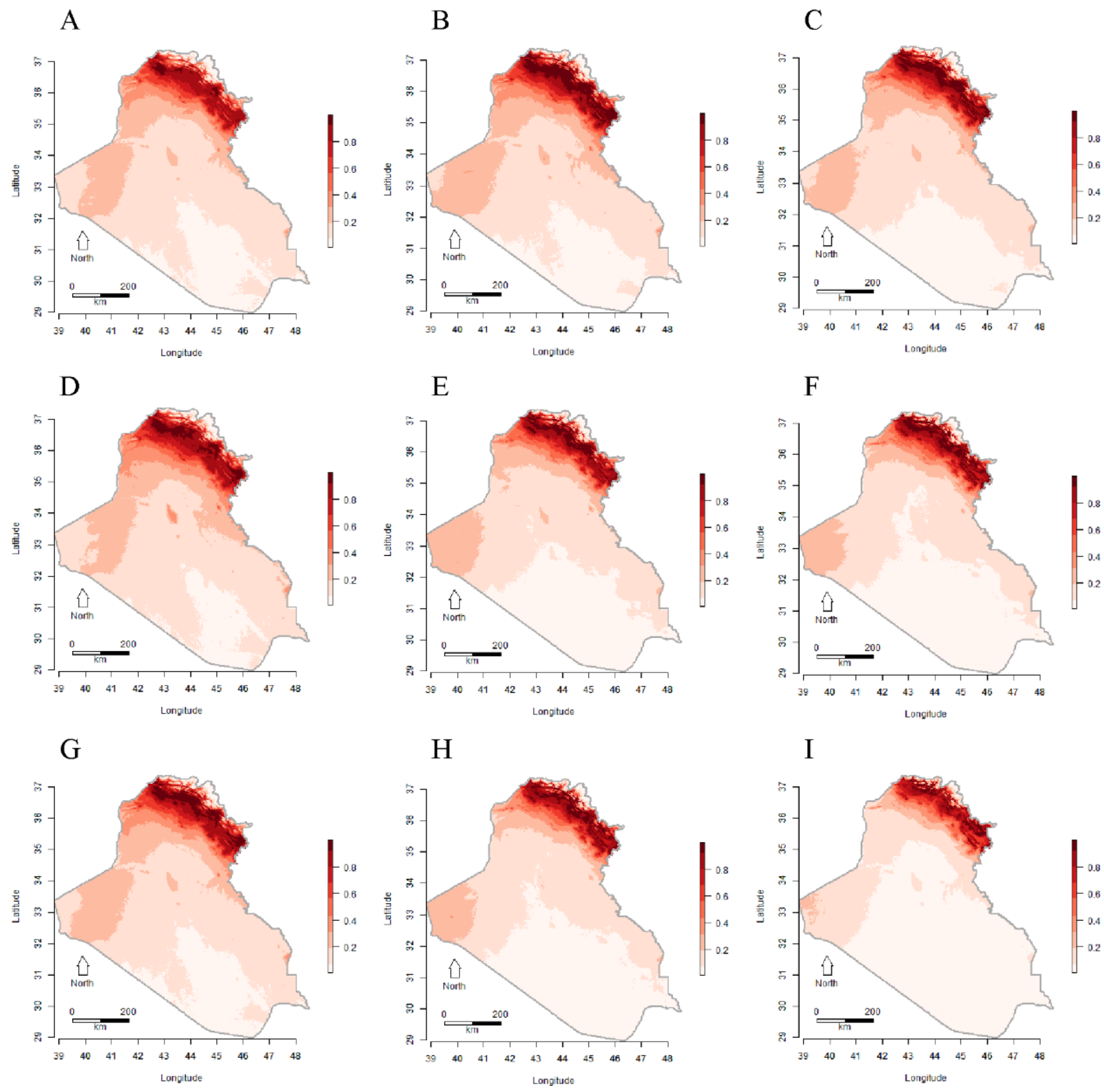

Figure 3. The predicted probability of presence of C. zillii using the maxent model based on SSP126 (A, B, C), SSP245 (D, E, F) and SSP585 (G, H, I) climate scenarios.

probability of < 0.4, are predicted to decrease over time. Specifically, the presence probability of this species will decrease most notably in the western part of the country.

Discussions

This study aimed to assess how climate change could impact the potential distribution of *C. zillii* in Iraq's inland waters. Understanding this is crucial for predicting and managing potential invasions. Our findings provide insights into the ecological consequences of climate change on this non-native species, offering guidance for fisheries management and conservation efforts in Iraq. Additionally, this study contributes to a broader knowledge of species distribution modeling, supporting evidence-based decision-making for biodiversity conservation in a changing climate.

Redbelly Tilapia is found in southern Iraqi inland waters (Çiçek et al., 2023). However, the present study indicates that northern Iraq is the most suitable habitat for *C. zillii*, which is cooler than other parts. This trend of *C. zillii* preference for northern Iraq has been previously observed (Gu et al., 2018). The identification of northern Iraq as the most suitable habitat for *C. zillii* carries significant implications for both conservation and management strategies. Firstly, the concentration of suitable habitat in this region underscores the importance of targeted monitoring and control efforts to prevent potential invasions. Given the high suitability of northern Iraq for *C. zillii*, it is crucial to implement robust management measures, including enhanced surveillance of aquacultural facilities where this species is currently cultivated (Jawad et al., 2021). Additionally, proactive measures such as early detection and rapid response protocols should be prioritized to prevent the establishment of self-sustaining wild populations. This issue is becoming increasingly important as wild stocks of this species have been reported in Iraq (Al-Okailee et al., 2017).

The areas in northern Iraq, bordered by Turkey and Iran, were predicted to have the highest presence probability. The dominance of northern Iraq as a potential hotspot for *C. zillii* underscores the need for regional collaboration and coordinated management approaches. As invasive species know no geopolitical boundaries, effective management strategies must transcend national borders to address the shared challenges of invasive species spread. Collaborative efforts among neighboring countries, information-sharing mechanisms, and joint monitoring programs are essential for eradicating invasive species threats and enhancing regional resilience to potential invasions (Britton et al., 2011).

A large area of southern Iraq had a presence probability between 0.2 and 0.4 (out of 1). While northern Iraq emerges as the most suitable region for the species, it is crucial to acknowledge that numerous areas across Iraq still exhibit varying degrees of habitat suitability. This nuanced understanding underscores the potential efficacy of concentrating aquacultural hotspots for *C. zillii* in regions with lower habitat suitability. It has been shown that this species prefers colder regions (Gu et al., 2018), thus reducing the likelihood of successful establishment in the event of escape and the establishment of new populations. By strategically locating aquacultural facilities in areas less conducive to *C. zillii*'s survival and reproduction, such as regions with suboptimal environmental conditions or limited habitat availability, the potential for escape events to lead to invasive spread could be significantly mitigated. This approach capitalizes on the variability in habitat suitability across Iraq, leveraging less suitable regions as buffers to contain potential escapees and minimize their ecological impact on native ecosystems. However, finding a compromise between conservation and aquacultural benefits is necessary (Thomas et al., 2021). Selecting less suitable habitats as aquacultural centers may impact the productivity of aquacultural facilities and hence have economic impacts.

Identifying northern Iraq as a hotspot for potential *C. zillii* establishment highlights the urgent need for effective management and monitoring efforts in this region. Strategies to prevent escape events from aquacultural facilities and early detection protocols are critical to minimizing the risk of invasive spread. Additionally, the development of targeted management plans that account for the potential establishment of wild populations will be essential for mitigating the impacts of *C. zillii* on native ecosystems and fisheries, including the potential displacement of native species, alteration of ecosystem dynamics, and impacts on local biodiversity and ecosystem services (Walsh et al., 2016).

The analysis of various climate change scenarios in this study revealed an interesting and somewhat unexpected finding: despite projected changes in climate, the most suitable habitats for *C. zillii* across Iraq remained largely consistent. This observation suggests that the species' habitat preferences may exhibit a degree of resilience to climate variability. One possible explanation for this phenomenon is the complex interplay of multiple environmental variables that influence the distribution of *C. zillii*. While climate undoubtedly plays a significant role in shaping habitat suitability, other factors such as habitat availability, water quality, and anthropogenic factors may exert equally or even greater influence on the species' distribution patterns (Natugonza et al., 2021). Consequently, changes in climate alone may not be sufficient to discern significant shifts in the most suitable habitats for *C. zillii* across Iraq.

In conclusion, while northern Iraq represents the most suitable habitat for *C. zillii*, the recognition of habitat variability across Iraq suggests a strategic opportunity to concentrate aquacultural hotspots in regions with lower habitat suitability. By leveraging less suitable areas as buffers against potential escape events, this approach offers a pragmatic and proactive strategy to minimize the risks of invasive spread while promoting sustainable aquacultural practices in Iraq. Moving forward, further research is needed to refine our understanding of the ecological requirements and interactions of *C. zillii* in its potential new habitats. Long-term monitoring studies can provide valuable insights into population dynamics, dispersal patterns, and ecological impacts, informing adaptive management strategies. Additionally, incorporating socio-economic factors into future modeling efforts can enhance our ability to predict the broader socio-ecological implications of *C. zillii* establishment in Iraq.

References

Adams M.A., Johnsen P.B., Zhou H.-Q. (1988). Chemical enhancement of feeding for the herbivorous fish *Tilapia zillii*. Aquaculture, 72(1-2): 95-107.

Al-Okailee M.T.K., Mutlak F.M., Lazem L.F. (2017). Distribution of red belly tilapia *Coptodon zillii* (Gervais, 1848) larvae in Shatt Al-Arab river and East Hammar marsh, Iraq. Basrah Journal of Agricultural Sciences, 30(1): 2631.

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.

Britton J.R., Gozlan R.E., Copp G.H. (2011). Managing non-native fish in the environment. Fish and Fisheries, 12(3): 256-274.

Cassemiro F.A.S., Bailly D., da Graça W.J., Agostinho A.A. (2018). The invasive potential of tilapias (Osteichthyes, Cichlidae) in the Americas. Hydrobiologia, 817: 133-154.

Çiçek E., Jawad L., Eagderi S., Esmaeili H.R., Atta Mouludi-Saleh A., Sungur S., Fricke R. (2023). Freshwater fishes of Iraq: a revised and updated annotated checklist—2023. Zootaxa, 5357(1): 1-49.

Fitzsimmons K., Martinez-Garcia R., Gonzalez-Alanis P. (2011). Why tilapia is ecoming the most important food fish on the planet. In: Liping L., Fitzsimmons K. (Eds.). The ninth international symposium on tilapia in aquaculture: Better science, better fish, better life. the AquaFish Collaborative Research Support Program, Shanghai Ocean University, Shanghai, China. pp: 8-16.

Geletu T.T., Tang S., Xing Y., Zhao J. (2024). Ecological niche and life-history traits of redbelly tilapia (*Coptodon zillii*, Gervais 1848) in its native and introduced ranges. Aquatic Living Resources, 37(2): 1-11.

Gu D.E., Yu F.D., Xu M., Wei H., Mu X.D., Luo D., Yang Y.X., Pan Z., Hu Y.C. (2018). Temperature effects on the distribution of two invasive tilapia species (*Tilapia zillii* and *Oreochromis niloticus*) in the rivers of South China. Journal of Freshwater Ecology, 33(1): 511-524.

Hijmans R.J., Elith J. (2024). Species distribution modeling. http://www.bayceer.uni-bayreuth.de/mm/de/top/dl/124926/Hijmans_Elith_2014.pdf. Retrieved on 03/01/2024.

Nofal A.I., El-Shaer N.H., Nofal A.E. (2019). Molecular and histological studies of salinity effect on gills and liver of *Coptodon zillii* in Egypt. Egyptian Journal of Aquatic Biology and Fisheries, 23(2): 275-290.

Ishikawa T., Tachihara K. (2008). Age, growth and maturation of the redbelly tilapia *Tilapia zillii* introduced into the Haebaru Reservoir on Okinawa-jima Island. Fisheries Science, 74: 527-532.

Jawad H.J., Alrufaye Z.T.A., Ahmad H.J. (2021). The concentration of some trace metals elements in water and tilapia zilli, *Coptodon zillii*, gills and muscle in rearing ponds of Kerbala region, Iraq. Iranian Journal of Ichthyology, 8: 255-266.

Kuhn M., Johnson K. (2013). Applied predictive modeling. Springer. 600 p.

Linde A.R., Izquierdo J.I., Moreira J.C., Garcia-Vazquez E. (2008). Invasive tilapia juveniles are associated with degraded river habitats. Aquatic Conservation: Marine and Freshwater Ecosystems, 18(6): 891-895.

Natugonza V., Musinguzi L., Kishe M.A., van Rijssel J.C., Seehausen O., Ogutu-Ohwayo R. (2021). The consequences of anthropogenic stressors on cichlid fish communities: revisiting Lakes Victoria, Kyoga, and Nabugabo. In: M.E. Abate, D.L.G. Noakes (Eds.) The behavior, ecology and evolution of cichlid fishes, Springer. pp: 217-246.

OBIS (2024). Ocean Biodiversity Information System. Intergovernmental Oceanographic Commission of

UNESCO. www.obis.org. Retrieved on 03/01/2024.

Parding K.M., Dobler A., McSweeney C.F., Landgren O.A., Benestad R., Erlandsen H.B., Mezghani A., Gregow H., Räty O., Viktor E., El Zohbi J., Christensen O. B., Loukos H. (2020). GCMeval – An interactive tool for evaluation and selection of climate model ensembles. Climate Services, 18: 100167.

Peymani M., Abdoli A., Moghaddas S.D. (2022). Invasiveness risk assessment of non-native species of the redbelly tilapia (*Coptodon zillii*, Gervais 1848) in Shadegan wetland basin. Environmental Sciences, 20(3): 211-226.

Radkhah AR., Eagderi S., Mousavi-Sabet H. (2016). First record of the exotic species *Hemiculter leucisculus* (Pisces: Cyprinidae) in southern Iran. Limnetica, 35(1): 175-178.

Radkhah A.R., Eagderi S. (2020). Investigation on the global distribution of invasive fish species, convict cichlid *Amatitlania nigrofasciata* (Perciformes, Cichlidae) over the past years with emphasis on Iranian inland water Transylvanian Review of Systematical and Ecological Research, 22(3): 45-56.

Radkhah A.R., Eagderi S. (2021). A brief review of the geographic ranges and ecological effects of three major invasive cyprinid species in Iran. Journal of Fisheries, 9(3): 93301-93301.

Radkhah A.R., Eagderi S., Cicek E. (2022). Effects of Climate Change on the Distribution of the Invasive Stone Moroko *Pseudorasbora parva* (Temminck & Schlegel, 1846) (Actinopterygii: Cyprinidae) in Asian Aquatic Ecosystems. Acta Zoologica Bulgarica, 74(2): 317-323.

Setiadi E., Widyastuti Y.R., Prihadi T.H. (2018). Water quality, survival, and growth of red tilapia, *Oreochromis niloticus* cultured in aquaponics system. E3S Web of Conferences, pp: 1–8.

Tabasian H., Abdoli A., Valikhani H., Khosravi M. (2021). An investigation into socio-economic impacts of invasive redbelly tilapia *Coptodon zillii* (Gervais, 1848): A case study from the Shadegan Wetland, Iran. Scientific Reports in Life Sciences, 2(3): 25-38.

Thomas M., Pasquet A., Aubin J., Nahon S., Lecocq T.. 2021. When more is more: taking advantage of species diversity to move towards sustainable aquaculture. Biological Reviews, 96(2): 767-784.

Valavi R., Shafizadeh-Moghadam H., Matkan A., Shakiba A., Mirbagheri B., Kia S.H. (2019). Modelling climate change effects on Zagros forests in Iran using individual and ensemble forecasting approaches. Theoretical and Applied Climatology, 137: 1015-1025.

Vitule J.R.S., Freire C.A., Simberloff D. (2009). Introduction of non-native freshwater fish can certainly be bad. Fish and Fisheries, 10(1): 98-108.

Walsh J.R., Carpenter S.R., Vander Zanden M.J. (2016). Invasive species triggers a massive loss of ecosystem services through a trophic cascade. Proceedings of the National Academy of Sciences, 113(15): 4081-4085.