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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 infringement of invasive species poses a significant threat to native ecosystems, especially in regions vulnerable to the impacts of climate change. Therefore, this paper aims to find the area that is probably infested with the introduced fish species, Redbelly Tilapia *Coptodon zillii* in Iraq. In case the species ever break out of the aquaculture facilities. Based on the Maxent model, this study identifies the northern Iraq as the most suitable habitat for the invasion of *C. zillii*. This paper goes on to advocate for proactive measures that could prevent establishment in such northern latitudes using of climate projections along with ecological modeling techniques. For example, avoiding attempts at aquaculture in this area so that the possible risk of an accidental release and further ecological disruption will result. It then maps the areas of high susceptibility. This study gives insight for conservation efforts and will therefore inform policy decisions that can be helpful in preserving native ecosystem integrity across regions of environmental change.

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Introduction

Tilapia fishes are a group of freshwater fishes belonging to the family Cichlidae. They are native to Africa, the Middle East and South America, however, tilapia species have been widely introduced into most parts of the world for aquaculture and sport (Fitzsimmons et al., 2011). Usually, they have compressed bodies with a single dorsal fin although various species exhibit different physical features. Their coloration may vary, often hues of silver, gray and brown (Fitzsimmons et al., 2011). The feeding habit of tilapia species is often herbivorous or omnivorous, consuming mainly algae, aquatic plants, and small invertebrates (Adams et al., 1988). Tilapia is by nature adaptive and can live in waters that are either static or flowing, with low oxygen concentration or degraded water quality (Linde et al., 2008; Natugonza et al., 2021; Setiadi et al., 2018), hence being a popular choice for aquaculture.

Coptodon zillii, formerly known as *Tilapia zillii* (Gervais, 1848), is one of the fish species native to Africa (Geletu et al., 2024). It is native to large areas of Africa, this includes the Nile River, Lake Chad, and Lake Victoria. This tilapia species appears to be a medium-sized fish with a laterally compressed body shape. It is astonishingly capable of surviving in a changing environment, from freshwater, brackish to slightly saline waters (Nofal et al., 2019). That has further facilitated the establishment of the species as an invader in many countries around the world. Redbelly Tilapia has been introduced into non-African regions including large areas in Asia, the Americas and Australia (Cassemiro et al., 2018; Geletu et al., 2024). It has fast growth rate and competitive advantages over native fish species, which are reasons for its invasive success. The introduction of Redbelly Tilapia has often resulted in adverse ecological consequences, for example, the displacement of native fish populations and alterations to aquatic ecosystems (Peymani et al., 2022).

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Introduction of species into new environments has severe ecological, economic and social impacts (Vitule et al., 2009; Radkhah et al., 2016; Tabasian et al., 2021). In the case of an introduced species in a new environment to which it has not adapted through evolution, it may lack natural predators, parasites or competitors and thus thrive to possibly outcompete native species. Such incidents include the introduction of Redbelly Tilapia into the Iraqi aquaculture sectors, which is believed to affect the local ecology as it has already established naturalized populations in Iraq's aquatic water bodies (Abdalhsan et al., 2020; Çiçek et al., 2023). The ecological effects following the introduction of Redbelly Tilapia into water bodies of Iraq are discussed below. This species is an invasive species and able to compete with native fishes for both food and habitat, leading to decline or loss of native species. The vast environmental tolerance and rapid fecundity of Redbelly Tilapia (Ishikawa and Tachihara, 2008) may give it an advantage over the native fish species that consequently disrupts the balance of the ecosystem.

There are many studies on the influence of climatic change on species distribution (Bond et al., 2011; Radkhah et al., 2021). Many species have to adapt or face challenges to their survival with increase of global temperature and change of weather patterns. Global warming and climate change may have profound impact on the survival of Redbelly Tilapia across Iraqi aquatic ecosystems. With increasing temperatures, this tropical fish species may reach to areas that were previously considered too cold and also may infest the places that was unable to inhabit before. Warmer waters may then also promote their reproductive success since tilapia tend to exhibit higher reproductive rates in warm conditions (Gu et al., 2018). In addition, it gives an advantage to the Redbelly tilapia compared with freshwater fish species originally inhabiting Iraq.

Understanding the potential impacts of climate change on a non-native species like Redbelly Tilapia, in case of its escape from aquacultural facilities, would be very important for two reasons: first, it could help identify the potential ecological impacts of the successful establishment of this invasive species in freshwater ecosystems, and second, it serves to expose how climate change may interact with the introduction of nonindigenous species in enhancing the magnitude of impacts on native biodiversity. Thirdly, it may help give information to conservation strategies and management practices in order to reduce the potential dangers of climate change and invasive species. It also helps in the identification of high-risk areas or regions that are very vulnerable to invasion and guides the development of proactive measures to prevent or manage their spread (Radkhah and Eagderi, 2020, 2021). This type of research will also help policymakers and resource managers in the field of conservation to make informed decisions in protecting and conserving Iraqi freshwater fish species in view of threats from climate change and invasion. Thus, this work was motivated to look at the possible distribution of *Tilapia zillii*, together with its temporal changes under different climate change scenarios. The results of such a study would indicate which areas would be more at risk of infestation by this species in the case of its entrance into natural freshwater ecosystems in Iraq.

Materials and Methods

Bioclimatic variables: All bioclimatic variables used in the study were downloaded from worldclim website worldclim.org (Table 1). The bioclimatic variables were first checked for collinearity by performing a Pearson's correlation in R version 4.3.1, after which any showing a high level of collinearity was removed. When two variables resulted in a Pearson's correlation coefficient of 0.9 and above, the one that had the highest accumulated correlation with other variables was removed.

Modelling: For modeling species presence, 70% of the presence data was allocated to model training and the remaining 30% was used as test data for model evaluation. The background data were 10,000 data. To find the importance of bioclimatic variables on the presence of C. zillii, a jackknife test was performed. The dismo package in R 3.4.1 was used for Maxent modeling (Hijmans and Elith (2024).

For modeling species presence, 70% of the presence data was allocated to model training and the remaining 30% was used as test data for model evaluation. The background data were made up of 10,000 data. A jackknife test was performed to find the bioclimatic variables that were more influential for the presence of *C. zillii*. Maxent's modeling was conducted through the package dismo using R 3.4.1 as the framework, methodology developed 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. Furthermore, the omission of MTCQ, PCQ and PWQ would decrease the model's gain.

The probability of the presence of *C. zillii* according to the climate scenario SSP126 is shown in Figure 3A, B, and C. The predicted maps indicate the least 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 period from 2021 to 2080.

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°.

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

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

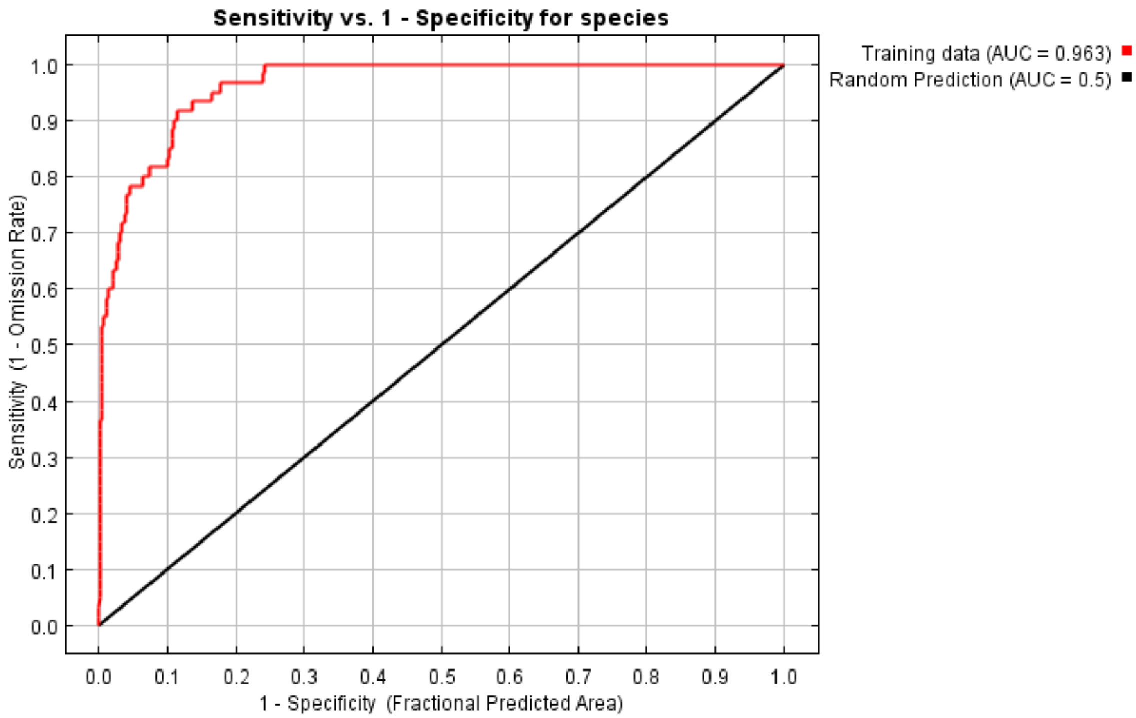

Figure 1. The AUC of the Maxent model.

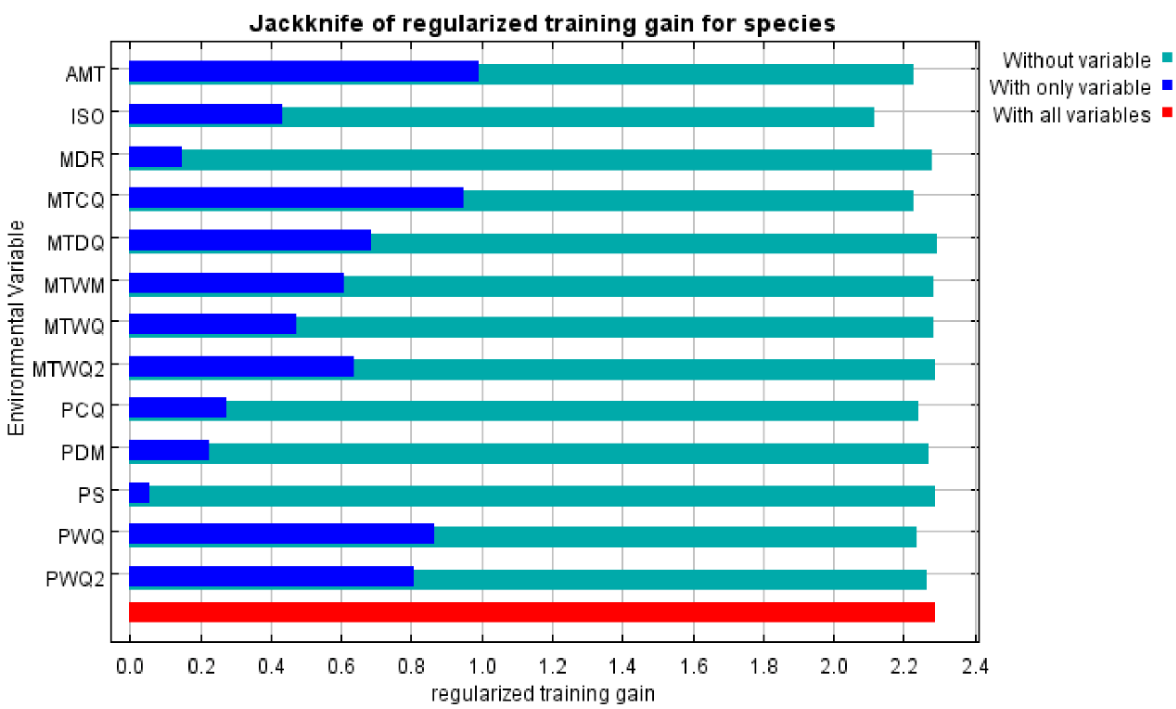

Figure 2. The jackknife test used to find the importance of the bioclimatic variables in the Maxent model.

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 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.

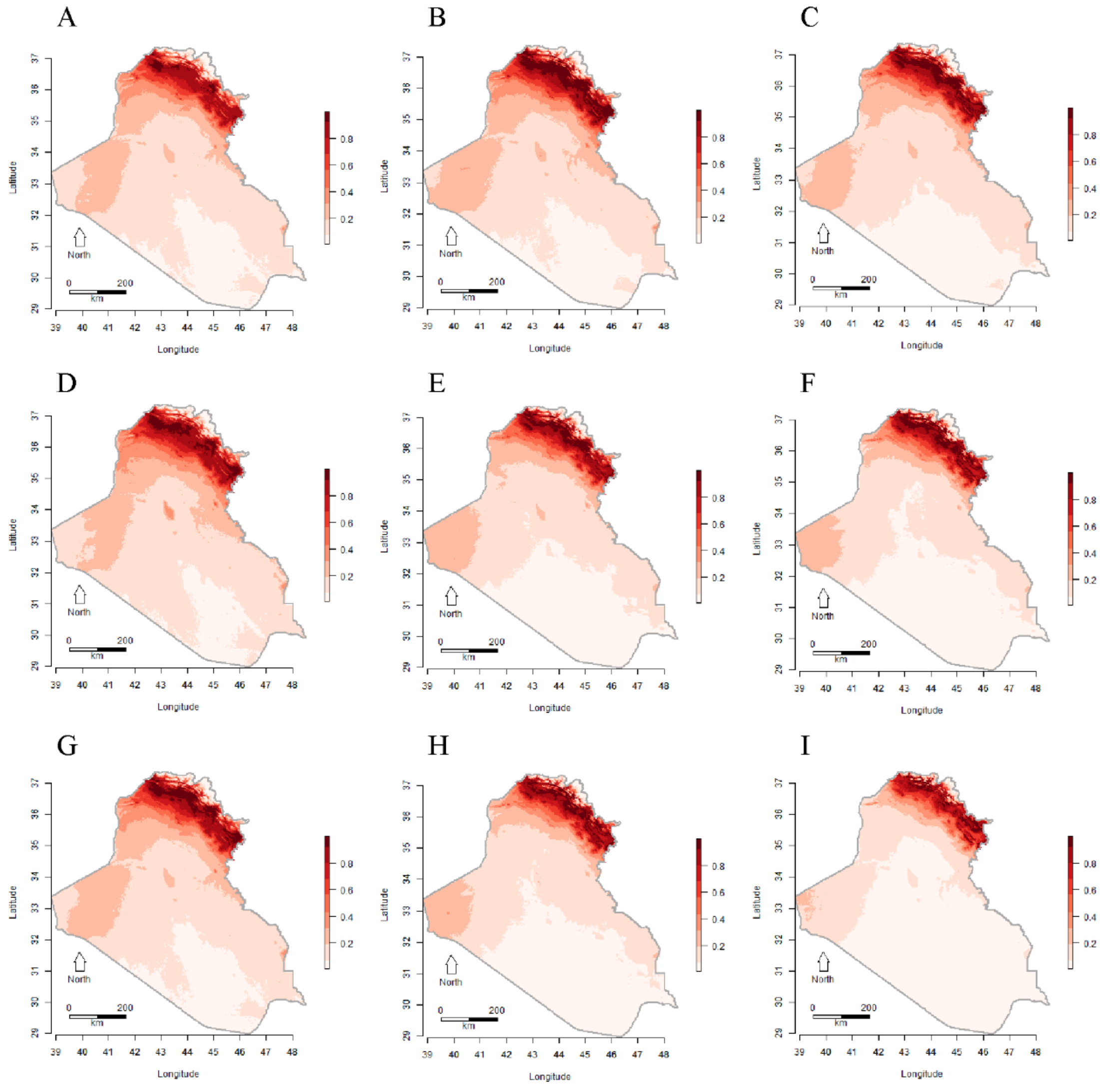

Figure 3. The predicted probability of presence of C. zillii using the maxent model based on SSP126 (A, B, C), SSP245 (D, E, F) and SSP585 (G, H, I) climate scenarios.

Discussions

The present study tries to model how climate change may influence the future distribution of *C. zillii* within inland waters of Iraq as one of the most important issues for the prediction and management of possible invasions. Our results provide deeper insight into the ecological consequence of climate change for this alien species and give recommendations for fisheries management and conservation in Iraq. This study further adds to the rapidly expanding knowledge on species distribution modeling, hence enabling proper decision-making for biodiversity conservation in the wake of fluctuating climatic conditions.

Generally, Redbelly Tilapia are found in the southern inland waters of Iraq (Çiçek et al., 2023). By contrast, this study identified northern Iraq, normally relatively cooler compared to the rest of the country, as the most suitable habitat for *C. zillii*. Similar preference for northern Iraq by *C. zillii* was also identified in findings by a study conducted by Gu et al. (2018). Identification of northern Iraq as the most suitable habitat for *C. zillii* has very significant implications for its conservation and management. First, the concentration of suitable habitat in this region means that targeted monitoring and control will be especially important to prevent potential invasions. Northern Iraq, therefore, appears very suitable for *C. zillii*, and rigorous management actions should be enacted in addition to increased monitoring at aquacultural facilities where this species is already in culture (Jawad et al., 2021). Besides this, proactive measures in the form of early detection and rapid response protocols should be emphasized to avoid establishment of self-sustaining wild populations. This issue is of growing importance due to reports of wild stocks of this species in Iraq (Al-Okailee et al., 2017).

The northern regions of Iraq bordering with Turkey and Iran were predicted to have the highest probability of presence. Its dominance of northern Iraq reinforces regional collaboration and coordinated management approaches that are in great need. Management strategies must likewise transcend national borders if this shared challenge of invasive species spread is to be countered holistically, since invasive species do not observe geopolitical boundaries. These require cooperation, information and joint monitoring among neighbor countries for the elimination of invasive species threats and building regional resilience against potential invasions (Britton et al., 2011).

A vast area of southern region in Iraq showed a presence probability between 0.2 and 0.4 out of 1. While northern Iraq looks very suitable, this study also develops the realization that many areas throughout Iraq have different levels of habitat suitability. This nuanced understanding underlines the efficacy of concentrating aquacultural hotspots for *C. zillii* in regions with relatively lower habitat suitability. It has been stated, on the other hand, that this is a cold-water species (Gu et al. 2018). Therefore, decreasing the risk that in cases of escape a viable invasion stock could be eventually built. The location of the aquacultural facility, although the climate allows successful husbandry, are otherwise suboptimal for *C. Zillii*. It would drastically reduce the likelihood of such an invasive spread of the *C. zillii*, for example, via a network of bad habits, conditions or small fragmented patches around the country in case any of the events which have caused such escapes to occur. It is an approach that takes advantage of the heterogeneity in habitat suitability across Iraq, leveraging the areas with poorer habitat suitability as some sort of buffer zone that might prevent the ecological impacts to native ecosystems if zillii can be allowed to get away. Here, according to Thomas et al. (2021), a trade-off has to be considered between conservation and aquaculture-related benefits. While such choice, with less suitable habitats as centres for aquaculture, might impact productivity from the aquaculture facilities, hence economic consequences, is yet to be seen. Identification of northern Iraq as a hotspot for the potential establishment of *C. zillii* calls for immediate effective management and monitoring activities in this region. The strategies for preventing escape events from facilities and early detection will, therefore, be highly pertinent to the reduction of invasion risk. Management plans that target the establishment potential will, however, be relevant under a mitigation strategy for *C. zillii* on native ecosystems and fisheries, including its possible species replacement of the native ones, alteration of ecosystem dynamics, and impacts on local biodiversity and ecosystem services. Walsh et al. (2016) present some interesting partly unexpected findings from the various analyzed scenarios of climate change. Despite projected changes in climate, the most suitable habitats for *C. zillii* across Iraq remained quite consistent. It could mean that the habitat preference for this species is rather resilient against any form of climate variability. This might partly relate to the distribution of *C. zillii* depends on the interaction of a number of environmental variables in a very complex way. Whereas the climate is undeniably driving this process at a very high pace to alter the habitat suitability pattern in the distribution of the different species of fish, it is equally plausible and more powerful influences that arise in terms of habitat availability, water quality, and other anthropogenic aspects (Natugonza et al., 2021). These would likely be shifted or altered, for instance, and better produce significant changes in *C. zillii* habitats within Iraq. Finally, although the northern part of Iraq has optimum conditions of habitat suitability for *C. zillii*, realization that habitat suitability for *C. zillii* is variable across the country provides an opportunity for strategic concentration of aquaculture hotspots within such areas of poor habitat suitability. It would utilize the less suitable areas as a buffer zone for the eventual escape incidents. This, therefore, becomes pragmatic and proactive in minimizing the risk of invasive spread and the promotion of sustainable aquaculture in Iraq. Further research will go a long way in giving, in greater detail, the ecological demands and interactions of *C. zillii* in these new habitats. This will ensure the establishment of population dynamics, dispersal, and ecological impacts in response to adaptive management. Besides, further modeling that incorporates socio-economic factors will translate into enhanced capacity to predict broader socio-ecological consequences 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.