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REVIEW ARTICLE

Ecological consequences of tilapia species on fish biodiversity of Iran and challenges arising from their introduction

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Abstract
This study aimed to review the results of the introduction of tilapia and its impacts and consequences on the biodiversity of inland freshwaters of Iran as a baseline to help ecologists and aquaculturists for making a proper decision in this regard. Up to now, four invasive tilapia species viz. *Coptodon zillii*, *O. niloticus*, *O. aureus*, and *Amatitlania nigrofasciata* have been reported from Iranian inland waters. Introducing tilapia species to the inland waters of Iran will have many severe impacts e.g. it will be possible to hybridize with endemic cichlid species such as *Iranocichla hormuzensis* and *I. persa*. The Iranian Fisheries Organization is executor and supervisor of aquaculture programs. It has implemented the development of tilapia farming regardless of the situation of the inland waters of Iran. Unlike many countries, Iran is an arid and semi-arid country with highly sensitive and fragile aquatic ecosystems which have more than 100 endemic species. Any change in the status of these aquatic ecosystems severely threatens their biodiversity. It is almost impossible to remove invasive tilapia species from Iranian inland waters in the current situation. Hence, the only possible solution in the current situation is to adopt an integrated approach to the management of aquatic ecosystems and close the pathways for the further spread of invasive species. This can be done through continuous and comprehensive cooperation between responsible organizations such as the Iranian Fisheries Organization, the Environmental Protection Agency, NGOs and local people.

Keywords: Tilapia, Invasive species, Hybridization, Ecological niche overlap, Fish biodiversity.

INTRODUCTION

When a species enters a habitat outside its natural range, it is known as exotic. In many cases, exotic species become invasive when are successful in competing with native species due to their high adaptability. As a result, they reduce the population of native species or even extinct them (Khairul-Adha et al. 2013; Esmaeili et al. 2014). Invasive fish are a serious threat to aquatic ecosystems (Radkhah et al. 2021). The family Cichlidae is one of the largest families of fish with 1706 species (Eschmeyer & Fong 2018). The members of this family are distributed worldwide and are found naturally in South America, Texas, India, Africa, Madagascar, Syria, Palestine, Sri Lanka, and Iran (Moreau 1983). Tilapia is a common name given to some taxa of cichlids (Dunz & Schliewen 2013) that are now well-established in many countries e.g. China, Malaysia, Indonesia, Bangladesh, Philippines, Myanmar, and Iran (Rafiee et al. 2017; Eschmeyer & Fong 2018; CABI 2021). China is the largest producer of tilapia in the world producing 1.6 million tons annually (FAO 2020). These fish grow fast and their diet is provided by cheap materials. These characteristics of tilapia make them very affordable food products (Norman-López & Bjørndal 2010). In addition, tilapia species are of the main concerns for their serious consequences for natural ecosystems and ecosystem services. After entering natural ecosystems, tilapia become a serious crisis for the biodiversity of that ecosystem since they are mostly well-established.

The environmental protection organization of Iran, which is in charge of nature conservation and national reference of the convention on biological diversity in Iran, relies on the law and scientific principles of ecology against the breeding, reproduction, and introduction of exotic species in different parts of the country. In contrast, the Iranian fisheries department believes that rearing these fish is easy and low cost and creates employment and food for the country. Therefore, aquaculturists

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believe that the rearing of tilapia should be accepted as a new candidate for the Iranian aquaculture industry.

Based on the above-mentioned background, this work tries to review the results of the introduction of tilapia and its impacts and consequences in other countries as a baseline to help ecologists and aquaculturists for making a proper decision in this regard. In this study, we reviewed articles based on library methods, particularly those works on the Iranian water bodies. For this purpose, first, the biological characteristics of tilapia were investigated; then, based on the available sources, the impacts of this fish on the natural ecosystems and biodiversity of fish were examined. Finally, the necessary strategies to prevent the possible effects of tilapia are presented.

Distribution of cichlids in Iran

The presence of 6 species of cichlids was confirmed in Iranian inland waters, including, *Amatitlania nigrofasciata*, *Iranocichla hormuzensis*, *I. persa*, *Coptodon zillii*, *Oreochromis aureus,* and *O. niloticus* that except the members of the genus *Iranocichla*, others are exotics. The presence of Nile tilapia *O. niloticus* in Iranian inland waters was first reported by Rafiee et al. (2017). Also, despite the unofficial reports of *O. mossambicus*, its occurrence in the Iranian inland waters needs to be confirmed by specimens. Fig .1 shows the distribution map of the species of the Cichlidae family in inland basins of Iran.

Oreochromis niloticus (Linnaeus, 1758): The native range of *O. niloticus* is North and East Africa. This species is currently considered a non-native species in the inland waters of Iran (Fig. 2). It was first reported by Rafiee et al. (2017) from Dehkan River near Jahrom city in the Persis basin.

Oreochromis aureus (Steindachner, 1864): The native distribution of this species is Africa and Eurasia. At present, there is no documented information on how this species has been introduced to the inland waters of Iran. It is currently considered an invasive species in the inland waters of Iran (Fig. 2). This species has been caught from Karun, Arvand, and Bahmanshir rivers as well as water canals in Khorramshahr, Khuzestan Province (Valikhani et al. 2016).

Coptodon zillii (Gervais, 1848)**:** The range of indigenous distribution of this species is limited to North Africa. It was first reported from the Karun River in 2012 and then reached all rivers and wetlands of Khuzestan Province in southern Iran (Khaefi et al**.** 2014*;* Valikhani et al. 2018) (Fig. 2). *Coptodon zillii* is found in Shadegan and Horalazim wetlands, and Karun, Dez, Karkheh, and Jarahi rivers in the Persian Gulf basin, and Mand River in the Persis basin (Kaefi et al. 2014; Esmaeili et al. 2018).

Amatitlania nigrofasciata (Günther, 1867): This species is native to Lake Amatitlán in Guatemala, Central America (Fig. 2). This species is currently found as an exotic species in Soleymaniyeh Spring in Kashan city (Namak Lake basin) and Golabi spring a headwater of Kol River (Hormuz basin) (Mousavi-Sabet & Eagderi 2016).

Iranocichla hormuzensis (Coad, 1982): This species is endemic in the Mehran River of the Hormuz basin of Iran (Coad, 2021; Esmaeili et al. 2006, 2018).

Iranocichla persa (Esmaeili, Sayyadzadeh & Seehausen, 2016): It is an endemic species in the Shoor, Khorgor, Rudan, and Hassan Langi in the Makran basin of Iran (Rafiee et al. 2017).

General biological characteristics of tilapia

Tilapia species inhabit freshwaters such as rivers, lagoons, and shallow lakes. They can adapt to brackish waters, and some also spawn in seawater. Their optimum growth temperature range is 25-30°C and in this temperature range, they usually reproduce and spawn (Lowe-McConnell 2000). Tilapia can tolerate temperature fluctuations and adverse water conditions such as lack of oxygen, high salinity, and water pollution (Nivelle et al. 2019). They mature and reproduce at four months of age and have a high rate of reproduction. As a result, they can produce thousands of young fish in a short time i.e. in four

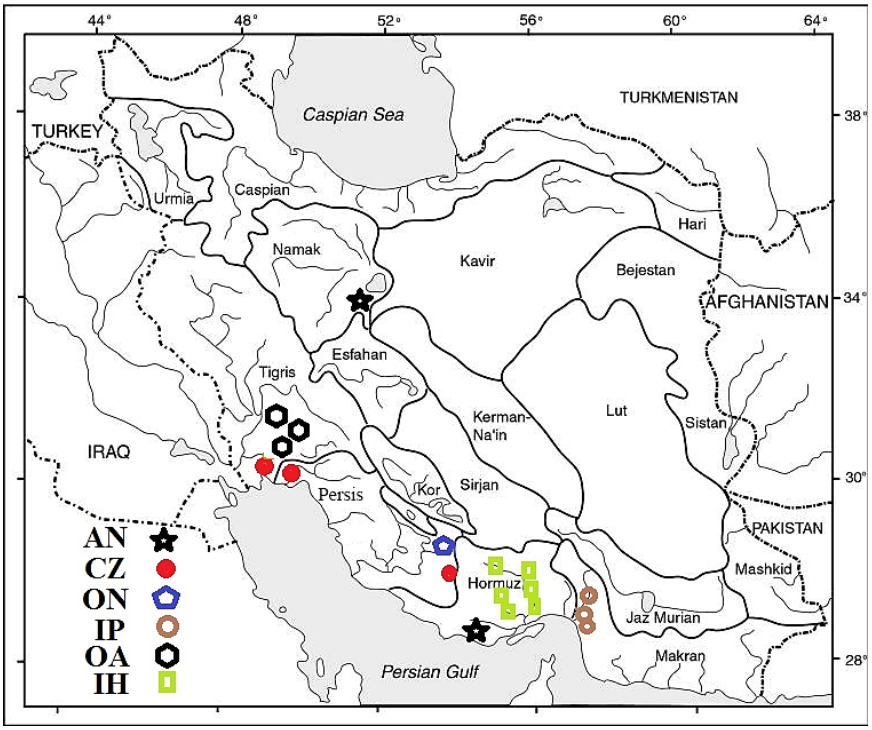

Fig.1. Geographical distribution map of cichlid fish species in inland waters of Iran. AN) *Amatitlania nigrofasciata*; CZ) *Coptodon zillii*; ON) *Oreochromis niloticus*; IP) *Iranocichla persa*; IH) *Iranocichla hormuzensis*; OA) *Oreochromis aureus*.

months. Tilapia can keep eggs in their mouths in times of danger, therefore, the eggs are protected. This behaviour increases the survival rate of tilapia and according to many works is the secret of the explosive increase in the tilapia population (Rana 1988). Tilapia usually feed on microalgae and aquatic plants but are highly adaptable to a variety of food items (Esmaeili et al. 2015).

Threats of tilapia to biodiversity

Tilapia is considered a serious biological threat and its negative ecological effects have been studied in different countries (CABI 2021). Tilapia species can easily be moved to different areas through the natural flow of floods, water canals, and water supply after introduction to a waterbody. They enter natural ecosystems and drinking water reservoirs as well (Martin et al. 2010; Radkhah et al. 2018). Due to their ability to reproduce rapidly, degradation of aquatic plant communities because of their extensive feeding habits, reduction of the population of some native fish through competition for nesting sites, and competition with other aquatic species due to the aggressive behaviour of males during production and transmission of diseases and parasites are happened, hence they are famous as the most important invasive species in the world (Radkhah et al. 2018). Feeding tilapia from other fish larvae is another factor in the extinction of native fishes and the reduction of species richness e.g. introduced tilapia to aquatic ecosystems of Venezuela, Mexico, Nicaragua, and Australia have occupied the habitat of native species, leading to population decline and the gradual extinction of unique and endemic species (CABI 2021).

Tilapia in Iran and its challenges: Tilapia was imported from Indonesia to Iran in 2008 for research purposes and its possible use in the aquaculture industry (Shabanloo 2020). These exotic fish were transferred to the National Center for Saltwater Fish in Bafgh, Yazd (Rahmati et al. 2012), and its breeding and rearing licenses were strangely (because of some political orders) issued only for Yazd and Semnan provinces that do not have access to open waters. So far, four exotic species of tilapia viz. *C. zillii*, *O. niloticus, O. aureus*, and *Amatitlania nigrofasciata* have been reported from the aquatic

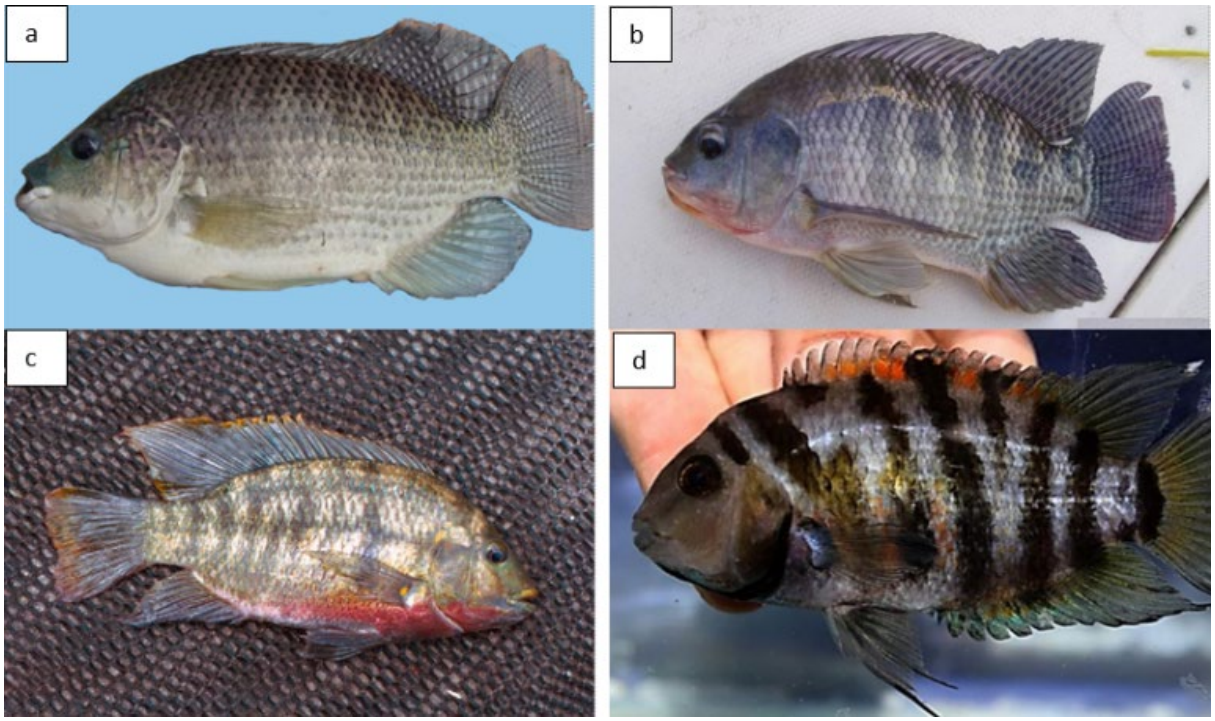

Fig.2. Exotic and invasive species of tilapia in inland waters of Iran (Mousavi-Sabet and Eagderi, 2016; IPM, 2021; U.S. Fish and Wildlife Service, 2021; USGS, 2021; Mexican-Fish, 2021). (a: Blue Tilapia (*Oreochromis aureus*); b: Nile tilapia (*Oreochromis niloticus*); c: Redbelly tilapia (*Coptodon zillii*) and d: Convict cichlid (*Amatitlania nigrofasciata*).

ecosystems of Iran (Valikhania et al. 2016; Rafiee et al. 2017; Esmaeili et al. 2018). The reproduction and accumulation of tilapia in the wetlands of Khuzestan Province have increased to such an extent that it became dominant species in southern Iran and became the main catch of fishermen. For example, 60-70% of the catch in Khuzestan wetlands such as Shadegan are tilapia. The declining population of native species and loss of unique biodiversity of Shadegan Wetland in the south and Hoor Al-Azim in the southwest of Khuzestan have raised concerns about the presence of tilapia in the Iranian Part of the Tigris basin (Valikhania et al. 2016). For legal and logical reasons, the Environment Organization has considered the cultivation of tilapia as an irreparable environmental consequence. First, the organization refused to issue breeding licenses because of well-known experiences in other countries that tilapia is caused severe effects on aquatic ecosystems after its introduction. According to article 3 of the rehabilitation and management of wetlands law, the introduction of invasive and non-native species into wetlands is prohibited (Islamic Parliament Research Center, 2021). Also, according to the sixth paragraph of the regulation on the prevention of irreparable destruction and pollution of wetlands, the import of exotic and invasive plant and animal species is considered as an example of measures leading to irreparable destruction and pollution of wetlands. Despite these official regulations, tilapia is reproduced and reared by the Iranian Fisheries Organization without assessing its risk as an invasive species, and monitoring of its population in the country. Tilapia are currently being reared illegally in many provinces of Iran. The Fisheries Organization has also applied to the Environment Organization for a license to breed this fish in other provinces. However, in some countries, efforts have been made to eradicate them (CABI 2021). Valikhani et al. (2018) investigated the frequency of *C. zillii* and *O. aureus* in Shadegan Wetland and their supply in some fish markets, and some breeding centers in Khuzestan Province. The results showed that the amount of catch of *C. zillii* tilapia was high and it is the dominant species in this Wetland. In this study, *O. aureus* in rivers was also showed a great

abundance increasing in frequency. Also, *C. zillii* has become a pest in some fish farms reducing the production of fish farms. The risk of invasion of Redbelly tilapia, *C. zillii* was assessed by Moghaddas et al. (2020) in Anzali Wetland using AS-ISK model. The results showed a hazard number of 44, which is much of the threshold of this model for Anzali Wetland (11.75) indicating that entry of red-belly tilapia into this Wetland will lead to its invasion. If this process occurs, it will change the biodiversity of this valuable ecosystem through hybridization, predation, and competition for food and space, and habitat destruction.

Hybridization: One of the major concerns of introducing tilapia is its ability to hybridize with native close species i.e. Hormuz cichlid (*I. hormuzensis*) and Persis cichlid (*I. persa*) of the family Cichlidae (Radkhah et al. 2018). Uncontrolled hybridizations will lead to the loss of genetic diversity, which in turn leads to the gradual extinction of valuable species. Conservation of genetic resources of endemic fish species such as Hormuz and Persis cichlids in the Hormuz basin should be given priority due to the possibility of hybridization with non-native species of tilapia. As tilapia is mostly established in the tropical climate immediately, therefore this is a high alert for the Hormuz basin because of the presence of endemic *Iranocichla* spp. In addition, sex reassignment technology must be used to minimize the possibility of tilapia species hybridizing with endemic species.

Inbreeding: The lower reserves of the fish, the more likely it is that inbreeding will occur. This can create a major problem for endemic fish populations that will delimit to small habitats even they survive from extinction. Inbreeding eventually leads to generation with low growth or growth rate, premature puberty, deformed body, and low survival (Devlin et al. 2015).

Transgenesis: Due to the fact that genetically engineered fish are not easily identifiable in terms of phenotype and behaviour when entering new habitats, they have destructive effects on native species and the environment. Also, with the escape of fish from farms as happened in the case of *O. niloticus* in the Persis basin, the manipulated genes of this fish become part of the natural genetic resources of the ecosystem and artificially increase the genetic diversity of native populations. By mixing with native species, the resulting generation is sterilized and reduces its reproduction (Fujimura & Kocher 2011; Devlin et al. 2015).

Ecological niche overlap: Zengeya et al. (2015) stated that *O. niloticus* reduces the abundance of native species through competitive removal and hybridization in South Africa. Despite these ecological adverse effects, *O. niloticus* is still one of the widely propagated fish species in the aquaculture industry and was planned to be one of the main candidates for Iran as well. Herawati et al. (2020) investigated the effects and interactions between native and introduced fish in the Jatigede Reservoir, West Java, Indonesia. Their results indicated intense competition in food use between the native species and introduced *O. niloticus* showing its negative effects on native species. Gu et al. (2018) confirmed that *T. zillii* can tolerate lower temperatures than *O. niloticus*. However, Nile tilapia had a larger size in field studies, and laboratory experiments showed that Nile tilapia is a stronger competitor in warmer waters due to its larger body size. Champneys et al. (2021) found that *O. niloticus* was more aggressive and showed strong competitive dominance in its interaction with *O. amphimelas*. Based on this evidence, Champneys et al. (2021) stated that *O. niloticus* threaten native species of tilapia by dominating interference competition.

There is no accurate assessment before the introduction of tilapia, and in most cases, the assessment of the ecological hazards of tilapia is done after its introduction. Due to the fact that it will be very difficult to compensate the adverse effects of tilapia in the new habitat, before any introduction and transfer of tilapia, therefore, careful studies and appropriate management mechanisms regarding the breeding of this fish should be considered.

Warnings and solutions for Iran: In Iran, the

Fisheries Organization acts as executor and at the same time as supervisor of aquaculture programs and, therefore, has implemented the development of tilapia farming regardless of the situation of inland waters of Iran. Iran is an arid and semi-arid country with highly sensitive and fragile aquatic ecosystems which consists of more than 100 endemic fish species (Esmaeili et al. 2018). Any change in the status of these aquatic ecosystems severely threatens their biodiversity. Despite the fact that many ecosystems are now extinct due to drought or their water quality is severely affected due to the development of human activities, the justification of the Iranian Fisheries Organization is not recommended that only tilapia species can be exploited in these water bodies, as these aquatic systems can be rehabilitated with proper management and the status of endangered endemic species can be improved.

Endemic fish are a valuable treasure of a country's natural heritage, therefore, their protection is very important due to the special geographical conditions of Iran, but fisheries officials, with their way of thinking as aquaculturist, insist the exploitation of aquatic resources as a goal and have no responsibility for protecting the aquatic life. This way of thinking in the past has caused the invasion of various fish species such as crucian carp (*Carassius carassius*), stone moroko (*Pseudorasbora parva*), eastern mosquitofish (*Gambusia holbrooki*), and sharpbelly (*Hemiculter leucisculus*) in all inland waters of Iran (Radkhah et al., 2016; 2018; 2020; 2021). Therefore, it is almost impossible to remove invasive fish in the current situation and there is no proper tool to remove them. Physical removal of these fish using fishing nets is a practical and effective method, but it is difficult and expensive, and probably in extensive drainage basins of Iran is impossible. The use of phytochemicals and chemicals in the management of invasive and non-native fish species in aquatic ecosystems has a long history (Vinson et al. 2010). These toxins can cause the extinction of non-target aquatic species. One of the important ways to control tilapia is to sterilize it (Ibrahim et al. 2020). Sterilization is an efficient method but expensive and not applicable in many areas. One of the most effective ways to eliminate tilapia is to rehabilitate wetlands and their biodiversity (Linde et al. 2008), but in the case of Iranian inland water needs further studies and it is suggested such efforts to eliminate those tilapias already introduced in Iranian inland waters, before any new introductions. Therefore, the only possible solution at the present is to close further expansion paths of invasive fishes. This issue requires the cooperation of people by creating a degree of awareness among them by providing effective educational programs to not only influence public opinion but also to force managers to create a scientific policy in accordance with the environment and to formulate effective inhibitor laws to preserve the country's biological reserves. This can lead to the establishment of a comprehensive and integrated management for the protection of biodiversity in Iran.

CONCLUSION

The natural ecosystems of Iran have been severely damaged in recent years due to the introduction of exotic and invasive species. Non-native species are introduced to nature, and after become problematic, no one takes responsibility for it. Many countries have experienced the severe experience of tilapia introduction and their experiences should be used in Iran as well. Rearing tilapia in Iran has no environmental justification and threatens aquatic ecosystems and biodiversity. In addition, the expansion of tilapia farming increases the possibility of their escape to natural waters that has great diversity with more than 100 endemic species, which certainly have negative effects on them e.g. Hormuz and Persis cichlids due to hybridization.

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مقاله مروری

پیامدهای اکولوژیک گونه‌های تیلاپیا بر تنوع زیستی ماهیان ایران و چالش‌های ناشی از معرفی آن‌ها

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چکیده: این مطالعه با هدف بررسی معرفی ماهیان تیلاپیا و پیامدهای آن بر تنوع زیستی آب‌های داخلی ایران به‌عنوان مبنایی برای کمک به بوم‌شناسان و آبزی‌پروران برای تصمیم‌گیری مناسب در این زمینه انجام گرفت. بر اساس مطالعات قبلی تا کنون، چهار گونه مهاجم تیلاپیا شامل *Coptodon zillii*، *O. niloticus*، *O. aureus* و *Amatitlania nigrofasciata* از آب‌های داخلی ایران گزارش شده است. معرفی گونه‌های تیلاپیا به آب‌های داخلی ایران اثرات بسیار شدیدی بر اکوسیستم‌های آبی خواهد داشت و یکی از اثرات مهم آن‌ها، امکان هیبریداسیون این گونه‌ها با گونه‌های سیکلید بومی شامل *Iranocichla hormuzensis* و *I. persa* می‌باشد. در طی سال‌های اخیر، سازمان شیلات ایران بهعنوان مجری و ناظر برنامه‌های آبزی‌پروری است، توسعه پرورش ماهی تیلاپیا را بدون توجه به وضعیت آب‌های داخلی ایران اجرا نموده است. برخلاف بسیاری از کشورهای دیگر در زمینه آبزی‌پروری، ایران کشوری خشک و نیمه‌خشک با اکوسیستم‌های آبی بسیار حساس و شکننده است که بیش از ۱۰۰ گونه بومزاد دارد. بنابراین، هر گونه تغییر در وضعیت این اکوسیستم‌های آبی به‌شدت تنوع زیستی آن‌ها را تهدید می‌کند. با توجه به این مسئله، حذف گونه‌های مهاجم تیلاپیا از آب‌های داخلی ایران در شرایط فعلی تقریباً غیرممکن است. از این‌رو، تنها راه حل ممکن در شرایط فعلی اتخاذ رویکردی برای مدیریت یکپارچه اکوسیستم‌های آبی و بستن مسیرهای گسترش بیشتر گونه‌های مهاجم است. این امر می‌تواند از طریق همکاری مستمر و همه‌جانبه بین سازمان‌های مسئول مانند سازمان شیلات ایران، سازمان حفاظت محیط‌زیست، سازمان‌های مردم‌نهاد و افراد محلی صورت گیرد.

کلمات‌کلیدی: تیلاپیا، گونه‌های مهاجم، هیبریداسیون، هم‌پوشانی آشیان اکولوژیک، تنوع زیستی ماهیان.