Scientific Reports in Life Sciences 2 (3): 25-38

DOI: http://dx.doi.org/10.22034/srls.2021.245823

An investigation into socio-economic impacts of invasive redbelly tilapia Coptodon zillii (Gervais, 1848): A case study from the Shadegan Wetland, Iran

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Received: 25 July 2021 / Revised: 14 August 2021 / Accepted: 20 August 2021 / Published online: 28 August 2021.

How to cite: Tabasian, H., Abdoli, A., Valikhani, H., Khosravi, M., Dehghan Madiseh, S (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), x-x. **DOI: http://dx.doi.org/10.22034/srls.2021.245823**

Abstract

The cichlid species, *Coptodon zillii* (Gervais, 1848) is one of the invasive tilapia species, but little is known about its ecological and socio-economic effects on freshwater ecosystems. This study aims to understand socio-economic impacts by considering the ecological roots of the invasion success of *C. zillii* in one of the internationally important wetlands, Shadegan Wetland in Khuzestan province, southwest of Iran. For this purpose, the impact of the species occurrence on the local fishing communities and the feeding habits of the fish, which may affect the ecosystem of the wetland, were studied from October 2015 to September 2016. The redbelly tilapia has been observed in large numbers in the daily catchment of fishermen and due to its low price, it has greatly decreased their income. Because of the herbivorous diet, redbelly tilapia might cause ecosystem changes that adversely affect the native species, especially the commercially important fish. The unwillingness of fishermen to catch this fish makes it hard to physically remove it and then to control the population growth. Thus, it is possible to reduce its

population by using incentives and creating new uses for this species, such as fertilizer production, which for this study presents a new method in this regard.

Keywords: Biological invasions, Ecological impacts, Feeding habits, Shadegan International Wetland, Tilapia

Introduction

Invasive alien species (IAS) are defined as species introduced by human-mediated factors outside their native geographical range with remarkable environmental or socio-economic impacts and capable of sustaining a self- recruiting population (Turbelin et al. 2017). Among all types of ecosystems, freshwater ecosystems suffer far more than others by economic and environmental impacts from invasive species (Mills et al. 2003). Native to Africa and the south-western Middle East, tilapias are a group of subtropical to tropical freshwater fish of the family Cichlidae; these species have been intentionally dispersed worldwide for the biological control of aquatic weeds and insects, as well as baitfish, ornamental and commercial purposes (Canonico et al. 2005). These species are tolerant toward wide fluctuations in salinity, dissolved oxygen, temperature and even pollution. Strong tolerance toward environmental variability, high fecundity, rapid growth rates and omnivorous feeding habits allow them to breed and to establish rapidly in various freshwater ecosystems (Martin et al. 2010).

Invasive alien species are categorized as one of the major threats to freshwater ecosystems and biodiversity (Dudgeon et al. 2006). In recent years, tilapia species as IAS have had profound ecological and socio-economic impacts in the Mesopotamia region, Western Asia. This region has high ichthyofaunal diversity with ecologically and commercially valuable endemic species. Some of the neighboring countries in the region (Turkey, Syria, Iraq and Iran) with shared connected water bodies have been faced with a growing threat of tilapia species, from which the redbelly tilapia (*Coptodon zillii* Gervais, 1848) has been introduced to Turkey (Kuru et al. 2014), Syria (BorKenhagen and FreyhoF 2009), Iraq (Al-Zaidy 2013) and Iran (Khaefi et al. 2014). *C. zillii* is typically a macrophyte feeder, and so has been used to control aquatic weeds previously (Crutchfield et al. 1992), suggesting this species may impact plant abundance and species richness.

This study aims to understand some of the ecological and socio-economic impacts of *C. zillii* in one of the most influenced water bodies by the species, Shadegan Wetland (Valikhani et al. 2018) in Khuzestan province, southwestern Iran. This wetland is downstream of the Jarrahi River catchment and one of the largest ones in the country (400,000 ha) registered in the Ramsar Convention (ramsar.org). This body of water provides a wide variety of functions, (e.g. biodiversity support, climate moderation, sediment, nutrient retention and landscape), services (e.g. tourism, research and education, aquaculture) and products (fish, pasture for water buffalo and other livestock, reed for handicrafts). Thus, the Shadegan Wetland plays a key role in the economy and wellbeing of the local communities of the region (CIWP 2011; Lotfi 2016). Approximately 90 villages around the Shadegan Wetland with more than 400,000 households are highly dependent on the resources of the wetland. In 2006, about 5320 people were involved in fishing and 1500 in hunting activities within the wetland (Kaffashi et al. 2012).

The wetland has high species richness and it is an important ground for spawning, nursery and feeding of different aquatic species. About 111 plant species (three critically endangered), 36 fish species in the marsh and 45 species in the shoreline, 4 species of shrimps in the estuaries and shorelines, 3 species of amphibians, 8 species of reptiles, 174 species of birds and 40 species of mammals are identified in the Shadegan Wetland (CIWP 2011; Kaffashi et al. 2012). *Phragmites australis*, *Cyperus pygmaeus*, *Typha* sp., *Scirpus lariaceae* and *Najas* sp. are amongst the most abundant plants in the area (Ehsani et al. 2011; Valikhani et al. 2020). Despite this significant role, many factors including water depletion, pollution, climate change and drought, overexploitation of resources and the introduction of alien species threaten this important ecosystem (CIWP 2011; Lotfi 2016).

In the first step, we requested the local fishermen to fill out the related questionnaires in order to figure out the impact of the species on the local communities. Then, we sought to investigate some biological parameters including foraging behavior (since it is proven that feeding strategy is a good indicator of invasion success; Tonella et al. 2018) and also reproduction behavior (from the previous study in the wetland) to assess the roots of the invasion success and ecological consequences which lead to the socio-economic impacts of the redbelly tilapia in the Shadegan Wetland.

Finally, as a managing strategy that tries to encourage local fishermen to catch the redbelly tilapia out of Khuzestan province water bodies (physical removal of species), a patent (registered by the first author) which is about producing organic fertilizer using *C. zillii* will be introduced and discussed in the following sections.

Materials and Methods

Study area

Five stations were selected along the entire stretch of the Shadegan Wetland in Khuzestan province, southwest of Iran based on proximity to local community settlements, different habitat conditions and accessibility. The wetland is a vast environmental system comprising fresh and brackish waters as well as the inter-tidal Musa creek and off-shore islands (CIWP 2011). The Shadegan Wetland is surrounded from north by the sugarcane fields and the Azadegan warm-water fish farm, southward by Mahshahr-Abadan road, the entrance of the sugarcane canal and several creeks such as Doragh and Guban, from west by the Karun River and from east by the Jarrahi River and Musa creek (Fig. 1). The climate of the basin is characterized by hot, long and dry summers and short, mild winters (semiarid region of southwestern Iran). The average annual precipitation of the basin varies from 200 mm in the southern coastal areas to more than 800 mm in the higher altitudes of the northern mountains. The main part of precipitation occurs during the late fall through early spring seasons. Pan evaporation ranges from 3,500 mm/year in wetland area to 2,000 mm/year in the Persian Gulf shore-line. The mean annual temperature varies between 20.9 ˚C in northern higher altitudes and 24.8 ˚C in the southern lower altitudes. The maximum and minimum temperature is 51˚C and -1.4˚C, respectively. July and August are the warmest and January and February are the coldest months of the year there. Ninety percent of the water supply is freshwater from the Jarrahi River inflow and the remaining is the tidal saltwater of the Persian Gulf. The average inflow from the Jarrahi River decreased between 1,000 – 1,500 mcm/year because of recent water development projects. The water depth varies from a couple of centimeters to 3 meters. The water quality of the Shadegan Wetland depends on the season; annual precipitation and water supplement range

between 5 and 10 dS/m in wet seasons with good inflows and 25 – 30 dS/m in dry seasons with little or no flows (CIWP 2011; Lotfi 2016).

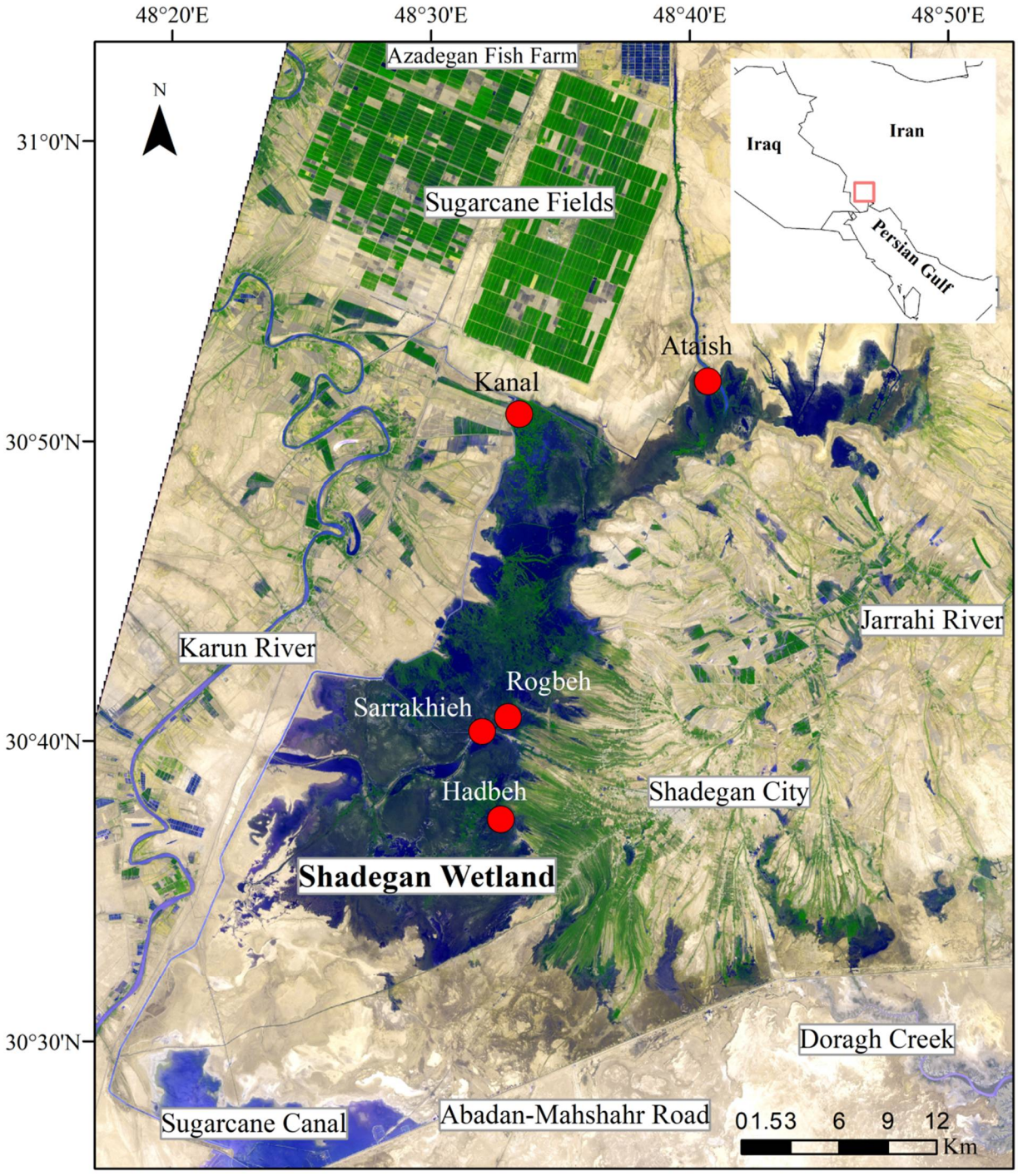

Figure 1: Five surveyed fishing grounds in the Shadegan International Wetland

Questionnaire Survey

To determine the effects of introducing *C. zillii* on the wellbeing of local communities, the related questionnaires were filled out via in-person interviews conducted during the sampling period from October 2015 to September 2016. In this regard, 200 questionnaires were completed in different villages near the sampling stations by the local people (Table 1). During the interviews, the respondents were informed of the objectives of the study. Due to the small and unbalanced number of questionnaires in the northernmost station (Ataish), the information of this location was removed from the analysis.

Table 1 The characteristics of the respondents

Variable			Frequency		Note
			Number	Percent	
Gender	M		153	76.5	Directly or indirectly related to the fishing process.
	F		47	23.5	
Age	Less than 20		16	8	Minimum age was 16 years old.
	20 - 40		126	63	
	More than 40		58	29	
Education	Illiterate		36	18	
	Secondary level		154	77	
	Higher levels		10	5	
Occupation	Fisherman		116	58	
	Manual worker		32	16	
	Fishmonger		28	14	
	Self-employment		14	7	
	Farmer		10	5	
Stations	Sarrakhieh	M	37	74	
		F	13	26	
	Rogbeh	M	44	88	
		F	6	12	
	Kanal	M	38	76	
		F	12	24	
	Hadbeh	M	34	68	
		F	16	32	

Study of Diet and Condition Factor

The study was carried out monthly in the selected stations in the Shadegan Wetland. *C. Zillii* specimens were collected by gillnets with 1.8 - 4.2 cm mesh size during the fieldwork and then transported to the laboratory with dry ice. The total length and weight of each specimen were measured to the nearest 0.1 cm and 0.01 g, respectively. The dietary study of *C. zillii* was performed seasonally. A total of 1422 specimens were examined to check whether the stomach was full or empty, and after putting aside the fish with an empty stomach, 290 specimens were randomly chosen to examine the consumed food items. The stomach contents, between the oesophagus and the pyloric sphincter, were emptied and transferred to a plate-like petri dish for the examination by a binocular microscope. The abdominal content analysis was performed using the following method:

Frequency of occurrence (Ugwumba and Adiaha.2007): The number of stomachs in which a type of food is found is considered as a percentage of non-empty stomachs, indicating the percentage of the population from which a particular food is foraged. To estimate the abundance of food presence or priority in *C. zillii*, the following formula was used, in which Ni is the number of gastrointestinal tubes containing specific nutrient i and Ns is the total number of abdominal contents containing food. According to this formula, if the probability of the prey eaten by the fish species is more than 50%, it will be considered as the main food item, with the numbers 10 to 50 percent as secondary and the numbers below 10 percent as accidental.

$FP=Ni/Ns\times100$

Condition Factor

The condition factor (K) was calculated using the following formula:

$K=100\ W/L^3$

, where W is defined as the total body weight (g) and L is the total length of each specimen (cm) (Froese. 2006).

Chi-square was used to test for the association of stations and gender with sales/consumption satisfaction, income and main problems of the wetland. The data were analyzed using SPSS (version 23) and the graphs were plotted with MS-Excel 2016.

Result

Questionnaire interviews

The study found that 52 percent of people reported between 40 to 60 percent of their daily *C. zillii* catch (Fig. 2). The sale markets for the species were Ahvaz, Shadegan and Abadan with 52, 45 and 3 percent, respectively. According to the interviewees, the highest presence of *C. zillii* in the wetland was in summer (47%), spring (34%), autumn (12%) and winter (7%), respectively. According to the survey, most of the people believed that in recent years, the species had been present in all fishing grounds, but in the southern parts of the wetland, where the water is saltier and the plants such as *Typha* sp. are denser, the abundance of the species is generally higher; in accordance with this result, the minimum daily *C. zillii* catch at the southernmost station (Hadbeh), reported by the fishermen, was 40 percent.

The satisfaction with sales was very low so that 55% of the people were dissatisfied with the redbelly tilapia's sales. Although women are responsible for the sales in the area, a chi-square test of independence shows that there is no significant association between gender and sales satisfaction, χ^2 (3, N = 198) = 3.22, p = .358, and also between stations and sales satisfaction, χ^2 (9, N = 198) = 15.89, p = .069. Satisfaction with the consumption of the species was so low that 60% of people were dissatisfied with the presence of this fish in their food basket. There is a significant relationship between gender, χ^2 (3, N = 200) = 30.39, $p < .001$, and stations, χ^2 (9, N = 200) = 28.05, p = .001, with consumption satisfaction. The women were more likely than the men to consume the redbelly tilapia, and also Hadbeh and Kanal stations had more satisfied people (Fig. 2).

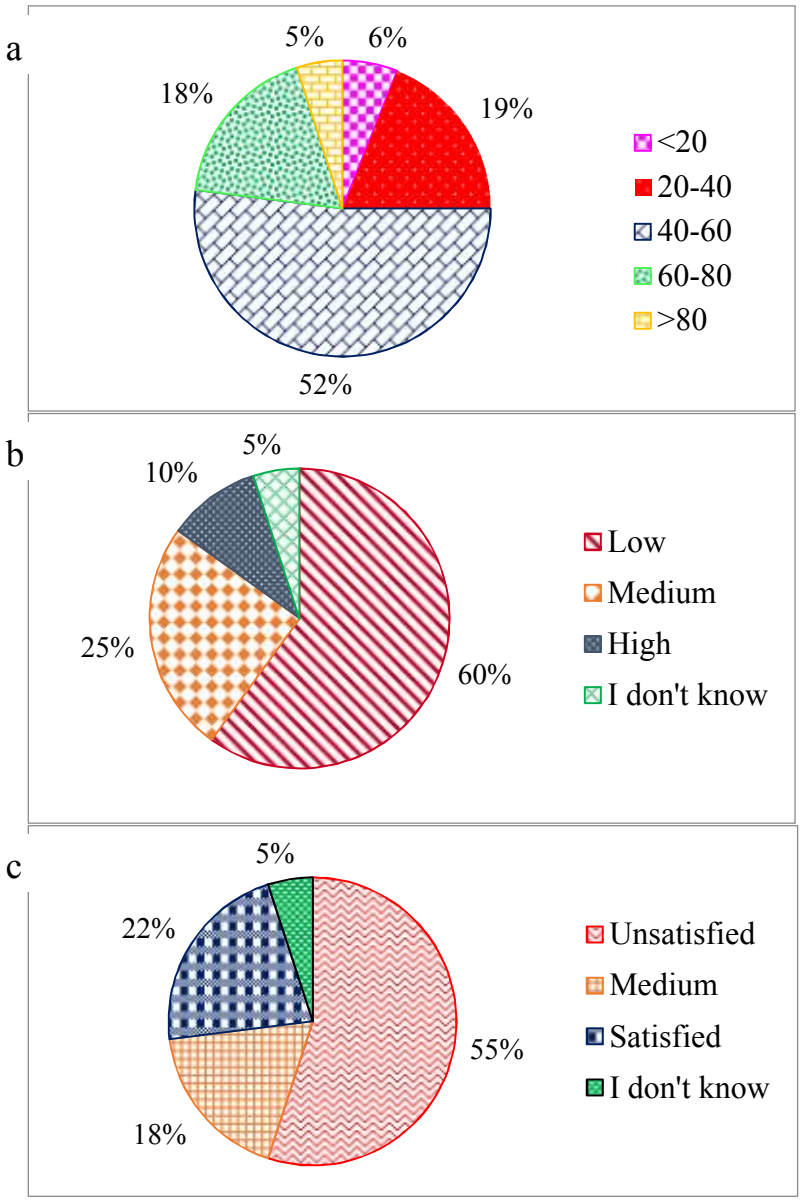

Figure 2: Percentage of the relative frequency of catch (a), consumption satisfaction (b) and sales satisfaction (c) of *Coptodon zillii* expressed by the interviewees

The study found that the effect of tilapia on the incomes of people and fishermen was very evident, so that 53.5% of fishermen earn less than 5,000 thousand Iranian Rials (IRR; considering the rate of inflation at the time of the survey), 32% between 5,000 thousand to ten million IRR and 14.5% more than ten million IRR per month from tilapia. However, according to the results, they would earn an average of 3,000,000 IRR per day from native fish, and the presence of *C. zillii* as the dominant species in their catchment has had a great impact on the income of fishermen's families. The selling price of each kilogram of tilapia by fishermen to brokers was between 10,000 and 20,000 IRR. The significance of the results in stations relationship and income is high, χ^2 (6, N = 200) = 12.77, p = .047. It seems that the income from the redbelly tilapia at Hadbeh and Rogbeh is high and lower than others, respectively.

The acceptable weight of catch had a wide range among the fishermen, varying between 13 and 40 kilos per day. The presence of *C. zillii* in the catchment had caused dissatisfaction among the fishermen. One of the signs of dissatisfaction was the tendency of the fishermen to use nets (mostly gill nets) with large mesh sizes, which led to less catch of the redbelly tilapia.

According to the interviewees' opinions, species that have been in the highest demand at the market during the last 3 years included *Mesopotamichthys sharpeyi* (53%), *Cyprinus carpio* (25%), *Luciobarbus barbulus* (12%), *C. zillii* (6%) and *Carasobarbus luteus* (4%). Based on the interviewees' perspectives, the largest decrease in the abundance of native fish over the past few years included *Arabibarbus grypus* (69%), *Luciobarbus xanthopterus* (14%), *Mesopotamichthys sharpeyi* (12%), *Luciobarbus barbulus* (4%) and *Chondrostoma regium* (1%).

Finally, the main problem of the wetland based on the 47% of the interviewees' perspective was the introduction of *C. zillii*. The following problems were water pollution and shortage, each with 17 percent and other items with 19 percent. There is a significant relationship between stations and type of problem, χ^2 (9, N = 200) = 19.27, p = .023. Although interviewees' perspectives on the main problem of the wetland were different, the highest choice in all stations was tilapia.

Feeding Habits of species

To investigate the dietary habits of *C. zillii*, 290 specimens were examined, of which 258 (88%) had a full and semi-full stomach and 32 (11%) of the digestive tracts contained little or very little food (less than 50%). The samples had a total length and total weight range between 74 - 238 mm and 10.5 - 265 g, respectively. Since the smallest female fish was at the stage of sexual maturation (110 mm), so the study of feeding habits was done for two groups including juveniles (TL less than 110 mm, n = 63) and adults (TL more than 110 mm, n = 227) (Fig. 3, Supplementary Table 1).

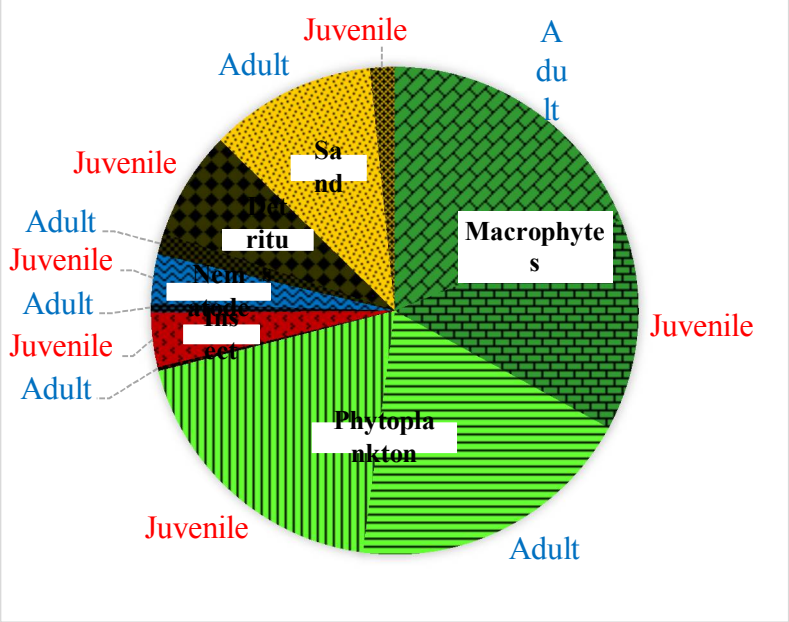

Figure 4: The chart demonstrating main foraged items by the adult and juvenile redbelly tilapias, *Coptodon zillii*, in the Shadegan Wetland according to the frequency of occurrence method. The detailed results regarding all consumed materials are presented in the Supplementary Table 1.

Condition Factor (K)

The condition factor (K) calculated in the present study showed a similar trend between both sexes, with the average 2.09 [median (IQR) = 2.05 (2.17-1.93), n = 401] and 2.07 [median (IQR) = 2.05 (2.17-1.94), n = 660] in males and females, respectively. The highest and lowest condition factor values were 3.78 and 1.34 in males and 3.66 and 1.42 in females, respectively. It peaked in July with average values of 2.28 for males and 2.22 for females (Fig. 4).

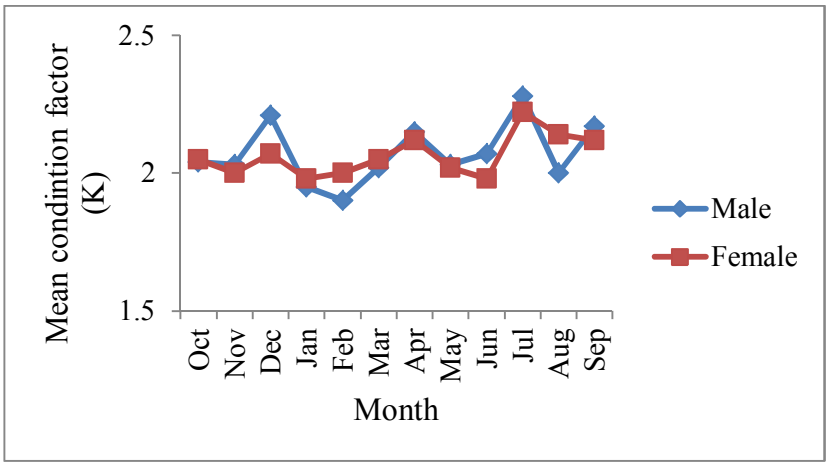

Figure 5: Mean condition factor (K) values of *Coptodon zillii* according to sex and different months in the Shadegan Wetland (September 2015 to August 2016).

Discussion

The primary objective of this study was to investigate the attitude of local communities toward the invasion of the redbelly tilapia (*C. zillii*) into the Shadegan Wetland and then try to find the magnitude of this invasion using the analysis of foraging behavior. Finally, it will suggest a new consumption market for this species to control its population growth.

The situation of the Redbelly Tilapia in the Shadegan Wetland and Perspective of the Local Communities Regarding the Issue

Invasive plant and animal species are more likely to establish in areas affected by human activities (Elton 1958). Unsustainable development in the area has led to further expansion of aquatic exotic species. In recent decades, large dam construction, irrigation plans, water transfer projects, long periods of drought, mass and unsustainable agricultural and aquaculture activities, large volumes of untreated wastewater have had destructive impacts on the Shadegan Wetland (CIWP 2011; Hashemi and Ansary 2012; Lotfi 2016). These conditions have resulted in the reduction of water volume, increased pollution and habitat destruction, having thus provided suitable conditions for the establishment of exotic species like tilapias which are tolerant of the mentioned conditions and accordingly threat the biodiversity of the region including commercial and beneficial species.

Based on the results of the questionnaire survey, the abundance of *C. zillii* is high, which is consistent with the previous studies in the wetland (e.g. Valikhani et al. 2018) while the native commercial fish abundance has significantly declined in recent years. Therefore, on one hand, the catch of native fish

should be decreased and, on the other hand, stock enhancement programs should be implemented to increase the population of the species. In this regard, the population of the predator species such as *Silurus triostegus* and *Leuciscus vorax* that could act as a biological control for the tilapia species should be managed. The species-selective catch (physical removing) is very effective, especially before breeding season in minimizing the impact of *C. zillii*. However, the fishing procedure and tools used by the local fishermen are specific to the native commercial fish species with a larger size relative to the redbelly tilapia. In addition, it is not applicable to catch the species out of the water, with the fishermen's low tendency for the catch of *C. zillii* as another factor worsening the situation, which in turn helps this species to survive in the Shadegan Wetland and hence leads to an increasing population trend.

According to the results obtained from the questionnaire survey, the fishermen and consumers' tendency for the redbelly tilapia and its price is low despite its high catchment frequency. The main reasons for this reluctance are small size, strange appearance, and unfamiliarity of the species for the local people and the presence of annoying thorns that harden the fishing process (separating of nets) and cleaning to cook.

The low income resulting from the redbelly tilapia fishing along with the constant increase of inflation make the local fishermen and their families seek for other jobs and considering the high unemployment rate in the region, this can oblige them to turn to illicit businesses or migrating to the outskirts of the surrounding cities, which have a profound effect on their wellbeing. Therefore, new methods must be considered to increase the motivation for catching this fish.

How the invasion of the redbelly tilapia is successful in the wetland and what are the roots of the significant impact on the local communities?

The results of the present study are consistent with other studies that surveyed dietary habits of *C. zillii* in Africa and the Middle East and predictably, this species mainly feed on plant material (Wanink and Joordens 2003; Mahomoud et al. 2011; Dadebo et al. 2014). With detailed attention to the gut content of surveyed samples (Fig. 3; Supplementary Table 1), some implications can be drawn. First of all, there are somehow slight differences between feeding habits of juveniles and adults since juveniles seem to have a greater tendency toward animal food items (Nematode and Chironomid larvae) than adults and accordingly there is an ontogenetic shift from being omnivorous to herbivorous during their growth. This diet ontogeny has been observed in close species (e.g. *Coptodon randalli*; Zaganini et al. 2012) and may decrease intraspecific competition between adults and juveniles and increase invasion success (Zaia Alves et al. 2020). Based on the previous studies, omnivorous herbivorous species can be one of the most successful invaders (Romanuk et al. 2009). In spite of the large amount of sand grains seen in the digestive tract of adults in the species, it can be implied that adults show benthic herbivorous behavior (Prasad and Anvar Ali 2008) and this may impact submerged aquatic vegetation more than anything else.

According to the results obtained by Shalloof and El-Far (2009), the redbelly tilapia seems to have more tendency toward feeding on plant material than other tilapia species and should be considered as voracious herbivorous fish. The herbivory of this species could have drastic effects on the native species, especially the native fishes like the commercially important species, *Mesopotamichthys sharpeyi* which fiercely depend on macrophytes for feeding, reproduction and shelter utilization (Coad 2020). Apart from this, the whole ecosystem of the Shadegan Wetland will be in turmoil as the result of removing macrophytes. In the broad sense, aquatic plants play significant roles in wetlands including primary

production, nutrient and energy fluxes, oxygen production and gas exchange, habitat complexity and heterogeneity of the environment (Alhashemi et al. 2011; Rejmankova 2011; Thomaz and Cunha 2010). In the narrow sense, submerged macrophytes play important specific roles such as reducing erosion and water flow, settlement of suspended sediment, increasing water clarity and quality, food and nest supplement for water birds as well as oxygen balance and their specific decomposition rate (due to their soft tissue compared to emerged macrophytes) (Kosten et al. 2009; Miller et al. 2018; Rejmankova 2011). Removing macrophytes as well as phytoplankton by the redbelly tilapia could disturb the production and cycles of materials and energy not only in the Shadegan Wetland but in the adjacent marine and terrestrial ecosystems. This phenomenon can also reduce habitat complexity, which increases intra-and interspecific competition for food and space (considering the high aggressiveness of *C. zillii*) (Cucherousset and Olden 2011; Nico et al. 2020; USFWS 2019). As the result of this disruption in energy fluxes in the Shadegan Wetland and its neighborhoods, ecosystem services and products like fish supply, grazing field of water buffalo and other livestock, agriculture and reed production (which is the important primary material for local handicrafts) and also aesthetic and recreational services as well as flood control will reduce. Subsequently, considering the invasion of *C. zillii* along with other synergic threats of the Shadegan Wetland, the fragile economy of the region will collapse.

The condition factor's results indicate that the individuals of *C. zillii* in the Shadegan Wetland were in such a good condition that the average values were even higher than some native ecosystems for the species such as the Asejire Lake, Nigeria (Ajagbe et al. 2016). The values of K increased in winter until April (the first peak in the gonadosomatic index, GSI) as a result of gonad development when feeding intensity is low while in the spawning period during spring, they decreased (the results of the reproduction biology of the species in the wetland have been presented in Tabasian et al. (2020) (Unpublished Manuscript). The highest values were observed in July when the species experiences the second peak of GSI (Tabasian et al. 2020, Unpublished Manuscript) and also high feeding intensity. But in general, the variations in this factor were low.

A New and Promising Marketing to Increase Demand for the Redbelly Tilapia

The aforementioned patent as registered by the first author is titled "Organic Fertilizer Using the Redbelly Tilapia Under Cold Process" with the international classification code CO5F 5/00, seeking to define a new consuming market for this species to control the intensive increasing of its populations and promote sustainable agriculture (avoiding chemical fertilizers) in Khuzestan province, Iran. Fish-based fertilizers contain remarkable proportions of amino acids and scarce mineral elements with the ability of absorption by plants which have positive impacts on soil biology and crop health. 100 grams of tilapia's meat contains about 20.1 grams of protein (Mjoun et al. 2010). The high frequency of this species in the freshwater ecosystems of the region, simple accessibility, its low price and having meat rich in amino acids make it a good raw material for producing fertilizer. To produce the fertilizer, a fish hydrolysate was made by a non-alcoholic fermentation procedure using tilapia fish as the primary material and protein supplier, sugarcane molasses as an energy supplier for fermentation, water as solvent and *Lactobacillus* bacteria as fermentation factor, with the whole compost incubated in 28˚C for 1 month. The results demonstrated that the fertilizer contains essential and conditionally essential nutrient which includes a total nitrogen of 15/4 gr/lit, organic carbon of 48 gr/lit, phosphorous of 2 gr/lit, ash of 20 gr/lit,

sodium and potassium of 28 and 125 meq/lit, respectively and electrical conductivity is about 23 µS/cm in acidic phase (~pH 4.5). The reported BOD value was 470, which is in the standard range. Also, the microbial phase contained *Lactobacillus*. This product is cost-effective compared to the similar imported ones while having a little foul odor makes it usable for indoor plants beside the other various types. The durability of this fertilizer is high, specifically when preserved from freezing and high temperature. This product improves soil quality and rehabilitates its structure, which guarantees plant and soil's health. And it also increases soil's beneficial bacteria and other microorganisms and enhances its microbial activity. All the mentioned properties of the introduced fertilizer can be considered as the innovations of the patent.

Conclusions

The redbelly tilapia is established in the Shadegan Wetland in high abundance. The species may compete for food and space with the native fish species and removing macrophytes and phytoplankton, which leads to ecosystem-level changes in the wetland. These changes have also affected the fisheries' income and quality of fish consumption in the region which may cause future cascading effects such as migration of people dealing with the Wetland. An ecosystem approach should be developed and implemented as a managing principle for the restoration of the wetland since human activities in the basin can be detrimental. Besides, the authorities and managers are highly recommended to find alternatives for the potential utilization of the species, such as economic incentives for the removal and establishment of fish manure production facilities in the region.

Acknowledgements

We deeply appreciate all of the authorities, fishermen and local people who helped us in the fieldwork and also the experts of the South of Iran Aquaculture Fishery Research Center, Ahvaz, Iran for helping in the diet survey. The authors thank Dr. Gholamhossein Moravej (Department of Plant Protection, Faculty of Agriculture, Ferdowsi University of Mashhad, Iran) and Dr. Patrick Gentry for their help and invaluable guides to analyzing the patent .The final product (fertilizer) has been evaluated by a trusted lab of the Food and Drug Department of Ahvaz Jondishapur University of Medical Sciences, Standard Administration, Provincial Department of Environment of Khuzestan and Danesh Azmoon Parham Jonoub (ISO17025).

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