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The Distribution of Invasive Tilapia Throughout A Tropical Man-Made Lake With Special Reference to Temengor Reservoir, Malaysia

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Abstract

With a surface area of 15, 200 ha, the Temengor Reservoir, in the northwestern state of Perak was selected among other lakes in Malaysia for the development of a large tilapia aquaculture facility within the Aquaculture Industrial Zone (AIZ) in 2008, due to its favourable environmental conditions. Tilapia has never been recorded at Temengor Reservoir prior to the establishment of this facility. However, preliminary observations in a previous study detected tilapia species in the natural waters of this lake, strongly suggesting these were escapees from the floating cages which had invaded the natural waters. Following that, a study was conducted to assess the distribution of these escapees throughout the Temengor Reservoir. The cultured tilapia is easily recognizable with elongated mouth and body, and long caudal fin. The sampling was conducted using gill nets. The distribution of the escaped tilapia throughout the Temengor Reservoir was mapped based on previous and current data on the fish checklist conducted at different sampling points of this lake, and the occurrence (presence/absence) of escaped tilapia was recorded. A comparative analysis was conducted at several points among three sampling areas, according to the radii from the AIZ; <5km (S1), 5-15km (S2), and >15km (S3). The ANOVA showed a significant difference ($p<0.05$) in Catch per Unit Effort (CPUE) weight between the three sampling areas. As tilapia is a highly successful global invasive species, the presence of tilapia at these and other locations at Temengor Reservoir should be rigorously monitored. Complete eradication of tilapia in the lake is of high urgency. We recommend intensive targeted fishing of the species in the vicinity of the cages and biological control by native predators to preserve and conserve the native fish species at Temengor Reservoir.

Keywords: Aquaculture, Escapee, Temengor Reservoir, Catch per Unit Effort (CPUE), Native fish.

1. Introduction

Aquaculture and fisheries sectors are regarded as key drivers of the blue economy for sustainability and food security by most government and the private sectors in developing countries (Aura *et al*., 2021). Furthermore, the expansion of aquaculture provides an answer in overcoming the unsustainable and limited supply of capture fisheries as highlighted by World Fish Center (WFC, 2006). The demand and importance of this sector will continue to accelerate in the future, with an increase in the human population and its function as a major protein source. Freshwater aquaculture contributes a significant part of this industry (Tidwell and Bright, 2018).

Traditionally, freshwater aquaculture in Malaysia has been practiced on a small scale since the early 1900s (Iinuma *et al*., 1999). The sector then emerged as a commercial industry with the extension efforts by the government. As stated by Hamdan *et al*. (2015), the rapid growth of the aquaculture industry in Malaysia was significantly supported by the government through the physical and financial allocations in various aquaculture development projects, primarily through the Aquaculture Industrial Zone (AIZ) projects. For this reason, several lakes and reservoirs in Malaysia have been identified as potential locations for commercial-scale aquaculture facilities within the AIZ (Yusoff, 2015), with Temengor Reservoir being selected due to its suitable water quality and favorable environmental conditions (Adlan, 2009).

As in many other areas of the globe, the non-native tilapia species is widely reared, often in polyculture, pond, and floating cage aquaculture systems in mainland Southeast Asia (Pullin, 1983; Amilhat *et al*., 2009; Meyer, 2015). In Malaysia, tilapia was identified as the major species for the freshwater aquaculture programme under the Third National Agricultural Policy (WFC, 2006). Based on this consideration, the Genetically Improved Farmed Tilapia (GIFT), a strain derived from the several generations of selective breeding of the Nile tilapia, *Oreochromis niloticus* was chosen for culture at Temengor Reservoir, Perak (Jumatli and Ismail, 2021). Besides their high tolerance to poor water quality and environmental variability, this species also exhibits a rapid growth rate which enables it to reach market size within five to seven months (Canonico *et al*., 2005; Zambrano *et al*., 2006; Arthur *et al*., 2010; Gough, 2011; Nico *et al*., 2015).

Even though the tilapia is cultured in cages, there is a possibility that the fish could accidentally escape into the wild (Senanan and Bart, 2010; Kour *et al*., 2014). Based on the preliminary observations by Hamid and Mansor (2013), tilapia species has already appeared in the natural waters of this lake. The presence of this species might be due to the "leakage" from the fish cages. Escaped tilapia could threaten native species through competition for food resources, niche displacement, and predation on native species (Kour *et al*., 2014). This competition could reduce the populations of native freshwater fishes (Britton *et al*., 2011; Beatty and Morgan, 2013). Furthermore, predation by tilapia could lead to the extinction of fish resources in the natural environment, as had been observed by Ogutu-Ohwayo (1990), Zafaralla (1999), and Njiru *et al*. (2005).

These previous studies highlight the immense threat to native fishes from the invasive non-native tilapia. Thus, it is vital to assess the occurrence (frequency and distribution) of escaped tilapia throughout the Temengor Reservoir and examine the impacts of tilapia invasion into the wild. Such information is important to plan a management strategy for the protection and conservation of native fish communities at this ecologically important man-made lake.

2. Methods

Study area

Temengor Reservoir is located at the most upper part of Sungai Perak basin in Peninsular Malaysia (Figure 1). This man-made lake covers a surface area of 15, 200 ha and serves as one of the important hydroelectricity sources to Peninsular Malaysia. At Temengor Reservoir, 100 ha has been allocated for Aquaculture Industrial Zone (AIZ) (Hashim, 2015; Jumatli and Ismail, 2021).

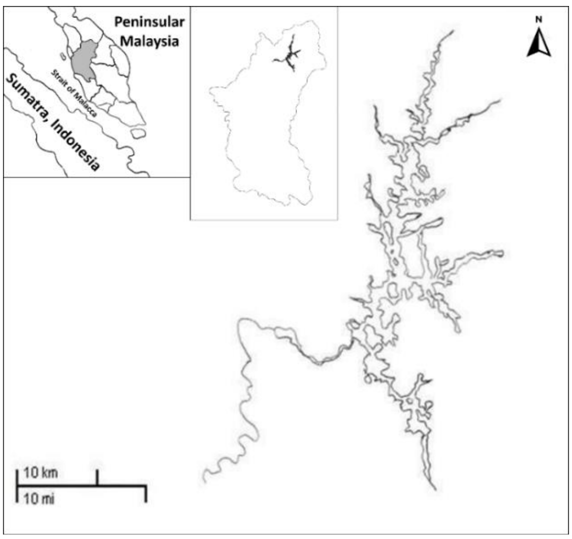

Figure 1. Map of the Temengor Reservoir (Inset: map of Peninsular Malaysia and Perak state)

Fish sampling

A monthly sampling was conducted from January 2014 to May 2015 at Temengor Reservoir. The fish specimens were collected using gill nets. During each sampling excursion, six sets of experimental gill nets (250cm vertical length x 2,976cm total width) comprising five different stretch mesh sizes (3.7cm, 5.1cm, 6.5cm, 7.6cm, 10.2cm) were randomly deployed clustered (Brown and Austen, 1996) at several identified sampling points and left overnight. All captured fish were kept in an ice-chest and taken back to the Pulau Banding Rainforest Research Centre (PBRCC), Perak. The escaped tilapia identification is easily recognizable (Figure 2) as the caged tilapia has distinctive characteristics; elongated mouth and body, and long caudal fin (personal communication with farm manager). The number of individuals per sampling point were counted and weighed to the nearest 0.1 g.

Figure 2. The cultured GenoMar Supreme Tilapia (GST), *Oreochromis niloticus* with elongated mouth and body, and long caudal fin captured in the natural waters of Temengor Reservoir (Total length is 27.8cm)

Research design

A comparative analysis of the current data with tilapia occurrence in previous fish checklist data (Kaviarasu *et al*., 2013; Amirrudin and Zakaria-Ismail, 2014; Wardah Nadhirah, 2016; Shah *et al*., 2016a; Ibrahim, 2016) at different sampling points of this lake was conducted. Based on these collection data, a comprehensive list of tilapia from six studies (current study and five previous studies) conducted at different spatial and temporal samplings at Temengor Reservoir (from 2013 – 2017) was compiled and presented (Table 1). The occurrence (presence/absence) of escaped tilapia in the Temengor Reservoir was mapped.

The spatial analysis was categorized based on the radii from the fish cages within the AIZ (Table 2); S1 (<5km; near-cage area), S2 (5-15km; far-cage area), and S3 (>15km; Belum). Belum area is located at the upper section of the Temengor Reservoir. The distance of sampling points from the AIZ was measured based on the approximate water path determined from the Google Earth (http://earth.google.com).

Statistical Analysis

A previous study by Ibrahim (2016) recorded the distribution of tilapia at Temengor Reservoir based on the CPUE weight. Thus, for comparability, all CPUE weights obtained for all sampling points (and temporal scales) in the current study were pooled, and group means for each sampling point were calculated, as according to Kozhara *et al.* (2007).

Based on the lower significance value ($p<0.05$) of the Shapiro-Wilk normality test, the parametric analysis with permutation was performed by selecting the bootstrap option for the datasets, which made the datasets approach a normally distributed dataset. Therefore, a one-way ANOVA with permutation was conducted to assess any significant differences in the distribution of tilapia among the three studied areas based on CPUE weight (kg/night). The analysis was performed using the IBM SPSS version 21 (Arbuckle, 2012).

Table 1. Previous and current records of tilapia at different points and spatial scales (2013 – 2017) at Temengor Reservoir, Perak

	Sampling points	Studies					
		1	2	3	4	5	6
1	Sungai Rokan	+	-	-	+	+	+
2	Sungai Telang	-	-	-	+	+	+
3	Sungai XY	-	-	-	+	-	+
4	Sungai Kuda	+	-	-	+	-	-
5	Sungai Ular	+	-	-	-	+	-
6	Teluk Major	-	-	-	-	-	+
7	Jetty	-	-	-	-	-	+
8	Sungai Semelor	+	-	-	-	-	-
9	Sungai Gadong	-	-	-	-	+	-
10	Sungai Enam	+	-	-	-	-	+
11	Sungai Temin	-	-	-	+	-	-
12	Sungai Kooi	-	-	-	+	-	-
13	Sungai Semelian	-	-	-	+	-	-
14	Sungai Tiang	-	+	+	-	-	-
15	Sungai Purun	-	+	-	-	-	-
16	Sungai Perak	-	+	-	-	-	-
17	Sungai Cha Chor	-	+	-	-	-	-
18	Sungai Mes	-	+	-	-	-	-
19	Sungai Kejar	-	+	-	-	+	-
20	Sungai Ketir	-	+	-	-	-	-

Notes: 1 = Kaviarasu *et al.* (2013), 2 = Amirrudin and Zakaria-Ismail (2014), 3 = Shah *et al.* (2016a), 4 = Wardah Nadhirah (2016), 5 = Ibrahim (2016), 6 = Present study

Table 2. Sampling areas at Temengor Reservoir based on the radii from the Aquaculture Industrial Zone (AIZ)

Sampling area	Distance from AIZ	Number of sampling points
S1 (Near-cage)	Within 5km radius	5
S2 (Far-cage)	Within 5-15km radius	5
S3 (Belum)	>15km radius	10

3. Results and Discussion

Information on the tilapia distribution from 2013 – 2017 is shown in Table 3. At the near-cage area which is within a 5km radius from the AIZ, three points recorded the presence of tilapia, namely Sungai Telang, Sungai Rokan, and Sungai Ular. The highest CPUE weight of tilapia were documented in Sungai Telang and Rokan at 66.41 kg/night and 24.14 kg/night, respectively (Ibrahim, 2016), while the current study recorded much lower values of 2.18 kg/night and 1.16 kg/night, respectively. Sungai Ular recorded 12.96 kg/night CPUE weight of tilapia (Ibrahim, 2016). At the far-cage area where the distance ranges from 5-15km radius from the AIZ, two points recorded the presence of tilapia, namely Jetty and Sungai Gadong, with CPUE weight at 6.33 kg/night and 1.14 kg/night, respectively. Out of 10 points at the farthest area-Belum, with a distance >15km radius from the AIZ, only a single point (Sungai Kejar; Ibrahim, 2016) recorded the presence of tilapia at 1.82 kg/night CPUE weight. The ANOVA with permutation showed a significant difference ($p<0.05$) in CPUE weight between the three sampling areas (Figure 3).

There were eight overlapping sampling points among the six studies namely Sungai Rokan, Sungai Telang, Sungai XY, Sungai Kuda, Sungai Ular, Sungai Enam, Sungai Tiang, and Sungai Kejar (Table 1). Earlier studies, i.e. studies 1-4 (Table 3) had not recorded any tilapia at these points. However, more recent studies, i.e. studies 5-6 have documented the presence of tilapia at four points, namely Sungai Rokan, Sungai Telang, Sungai Ular, and Sungai Kejar.

The occurrences of tilapia throughout the Temengor Reservoir are shown in Figure 3. Both Sungai Rokan and Sungai Telang, where the escaped tilapia had been recorded in this study, are located within 3km from the AIZ. Escaped tilapia was also observed at several points close to the fish cages (<15km radius from the AIZ) at the lower part of Temengor Reservoir (referred to as Temengor). No tilapia was recorded in the Belum area in 2013 (Amirrudin and Zakaria-Ismail, 2014). Apparently, the tilapia had not migrated upstream during this period. However, in 2016, it was recorded at Sungai Kejar (Ibrahim, 2016), which is about 40km from the AIZ within the Belum area (Figure 4; Table 3).

Table 3. A complete list of tilapia occurrence from six studies (2013 – 2017) conducted at different sampling points with different sampling gears at the Temengor Reservoir, Perak

Sampling area	Sampling points	Distance from AIZ (km)	Occurrence	CPUE weight (kg/night)
Near-cage	Sungai Rokan	3	No [1,4] Yes [5,6]	24.14[5] 1.16[6]
	Sungai Telang	3	No[4] Yes[5,6]	66.41[5] 2.18[6]
	Sungai XY	3.5	No[4,6]	
	Sungai Kuda	5	No[1,4]	
	Sungai Ular	5	No[1] Yes[5]	12.96[5]
Far-cage	Teluk Major	6	No[6]	
	Jetty	10	Yes[6]	6.33[6]
	Sungai Semelor	11.5	No[1]	
	Sungai Gadong	14	Yes[5]	1.14[5]
	Sungai Enam	15	No[1,6]	
Belum	Sungai Temin	23	No[4]	
	Sungai Kooi	27	No[4]	
	Sungai Semelian	31	No[4]	
	Sungai Tiang	32	No[2,3]	
	Sungai Purun	32	No[2]	
	Sungai Perak	33	No[2]	
	Sungai Cha Chor	35	No[2]	
	Sungai Mes	37	No[2]	
	Sungai Kejar	40	No[2] Yes[5]	1.82[5]
	Sungai Ketir	46	No[2]	

Notes:
[1] = Kaviarasu *et al.* (2013). Smith-Root electro-shocker Model 20-D
[2] = Amirrudin and Zakaria-Ismail (2014). Smith-Root electro-shocker model LR 24
[3] = Shah *et al.* (2016a). Experimental gill nets with multiple stretch mesh sizes; 2.5cm, 5.1cm, 7.6cm, 10.2cm
[4] = Wardah Nadhirah (2016). Experimental gill nets with multiple stretch mesh sizes; 1.5”, 2.5”, 4.5”
[5] = Ibrahim (2016). Gill nets with multiple stretch mesh sizes; 1.5”, 2.0”, 2.5”, 3.0”, 3.5”, 4.0”, 4.5”, 5.0”, 6.0”, 7.0” and cast net
[6] = Present study. Experimental gill nets with multiple stretch mesh sizes; 3.7cm, 5.1cm, 6.5cm, 7.6cm, 10.2cm

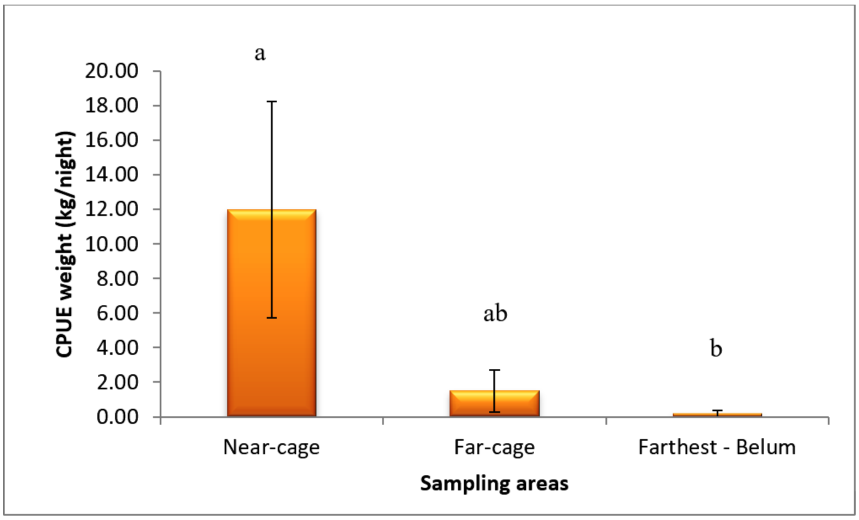

Figure 3. The CPUE weight (kg/night) of tilapia at three sampling areas (mean ± s.d.) with different radii from the Aquaculture Industrial Zone (AIZ) at Temengor Reservoir, Perak

The distribution of tilapia throughout Temengor Reservoir indicated that tilapia appeared to be very common in both Sungai Rokan and Sungai Telang. Higher CPUE weights (kg/night) of tilapia by Ibrahim (2016) at sampling points near the fish cages were observed, as compared to this study. One possible reason for this is the influence of gill net sizes. Ibrahim (2016) utilized nets of mesh sizes 4.0 – 7.0 inches which were more efficient. However, in the present study, mesh sizes from 3.7 – 10.2 cm (1.5-4.0 inches) were used, resulting in a lower yield than Ibrahim (2016). In addition, the additional gear usage (cast net) by Ibrahim (2016) increased the possibility of obtaining more specimens.

As there were no tilapia recorded before the aquaculture development at Temengor Reservoir by Zainudin (2005), Hashim *et al.* (2012) and Shah *et al.* (2016b), the current data deserves further attention. The findings showed that tilapia has invaded the lower Temengor Reservoir and has recently started to colonise the upper part (Belum) as well. The Temengor Reservoir was divided into two parts during the construction of the 124km east-west highway, built in the late 1970s and officially completed in 1982 (Abdullah *et al.*, 2011). The record of tilapia at Sungai Kejar by Ibrahim (2016) showed that the escaped tilapia could migrate up to 40km distance from the fish cage. This indicated that escaped tilapia could conquer almost all parts of lakes in a short time, as Ibrahim (2016) highlighted. The protected Belum Forest is a pristine area, and it was rather unexpected to find tilapia at Sungai Kejar, even though only two individuals were recorded in 2016. Based on this evidence, it is possible that tilapia has invaded other rivers of Belum. Nevertheless, it remains unclear whether this species has formed a self-sustaining population in the upper Belum. It should be noted that the occurrence of tilapia within the 40km distance is possible due to its high adaptability to environmental variation, such as oxygen and pollution levels, and can migrate for long distances (McKaye *et al.*, 1995), supporting its widespread distribution. The presence of tilapia at these and other locations at Temengor Reservoir should be periodically monitored.

The tilapia is a highly invasive species throughout the globe. The tilapia escapees have established well in the habitat where these fish have become abundant. Anderson (2004) documented that escapees of blue tilapia from two aquaculture facilities have become established in the Everglades National Park, Florida, and other waterways. Crutchfield (1995) noted that the redbelly tilapia *Tilapia zilli* became the fourth most abundant species in a reservoir in North Carolina just within the first three years after its accidental introduction, and corresponded with a significant reduction in native fish populations. A study by Peterson *et al.* (2005) reported that the escape of non-indigenous Nile tilapia into Mississippi wetlands resulted in established populations in coastal Mississippi. Based on the evidence of healthy reproductive populations, they postulated that these populations would expand even more. Based on these examples, the establishment of tilapia populations at Temengor Reservoir is unfortunately inevitable.

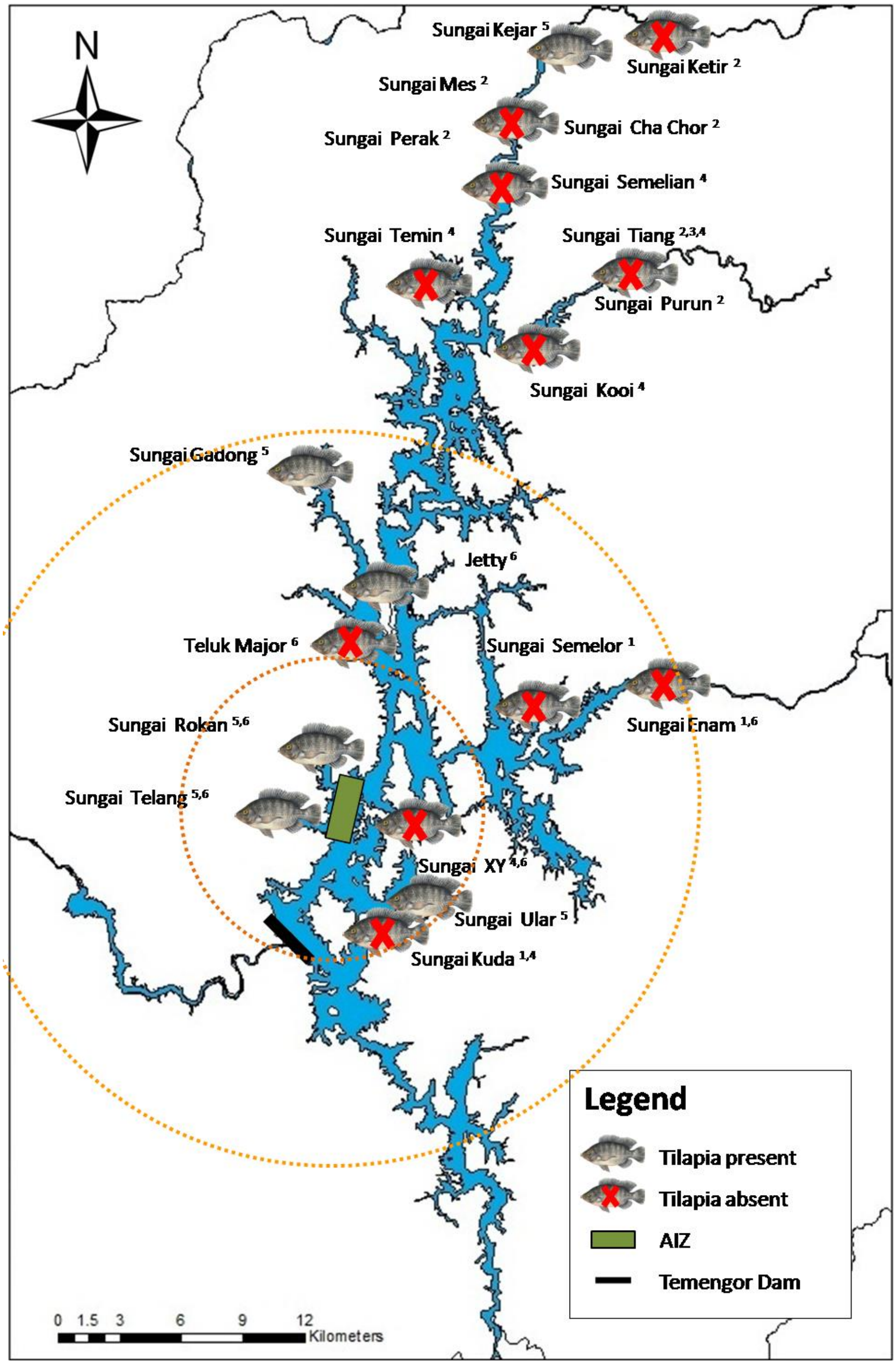

Figure 4. The distribution of tilapia escapees throughout Temengor Reservoir during the study period. Orange circle showing radius; small circle showing a 5km radius from the AIZ (near-cage area) whereas larger circle showing 5-15km radius from the AIZ (far-cage area)

Notes:
1 = Kaviarasu *et al.* (2013), 2 = Amirrudin and Zakaria-Ismail (2014), 3 = Shah *et al.* (2016a), 4 = Wardah Nadhirah (2016), 5 = Ibrahim (2016), 6 = Present study

This study also detected the presence of female tilapia, although this should not have been the case. The cultured tilapia at Temengor Reservoir undergoes oral hormone treatment for sex reversal from female to male in order to produce an all-male (monosex) population. However, it has been documented through several studies that the success rate varies. An experiment conducted by El-Greisy and El-Gamal (2012) showed 95% success after a 75-day treatment period in producing an all-male tilapia population at 60 mg/kg feed with synthetic steroid 17 α–methyltestosterone (MT). In another study, Barry *et al.* (2007) reported that over 95% of the population was masculinized after 21–28 days, when 30-60 mg/kg feed with 17a-MT was consumed by the tilapia larvae (7–12 days of age). Therefore, the probability of having female tilapia in the culture at the AIZ of Temengor Reservoir, is relatively high considering the total number of larvae produced, i.e., 5%. Moreover, there is a great risk of female escapees, especially during the transfer of juveniles from the smaller cages to the larger ones as females tend to grow slower than males; the metabolic energy in males is allocated towards growth and uniform size, whereas in females, the allocation is also shared with reproduction (Mair and Little, 1991; El-Greisy and El-Gamal, 2012; Gómez-Márquez *et al.*, 2015). Therefore, female fish will have a smaller size. If a single batch/cohort comprising of slower-growing females and their larger male relatives are not precisely graded in the transfer process, the female may escape through the net mesh that is larger than their body size.

Ibrahim (2016) reported that out of 180 fishes caught at Temengor Reservoir, 65 were females. As any single tilapia could carry more than 1000 eggs at a time in their mouth, the spread of tilapia throughout Temengor Reservoir would be phenomenally disastrous. The mouth-brooding habit of this species allows it to nurture and carry its young over long distances to invade habitats far from the original site of fish cages (Costa-Pierce, 2003; Iq and Shu-Chien, 2011). *Oreochromis niloticus* is long-lived, surviving approximately nine years (Froese and Pauly, 2016). Furthermore, its ability to spawn multiple broods throughout the year could have an irreversible adverse impact on the native fish diversity of Temengor Reservoir.

Tilapia is now generally considered to be pests; even juveniles have been documented to feed on other fishes (de Moor *et al*., 1986; Eldredge, 2000; Zambrano *et al.*, 2006). The most effective management is the complete isolation of individuals from natural waters to prevent re-invasion. Therefore, a complete removal or eradication of tilapia outside of the cages should be done to preserve and conserve the native fish species at Temengor Reservoir. However, removal from natural water resources where they have been established is impossible through traditional methods such as angling. Established populations will require an intensive fishing to prevent overpopulations from affecting native populations (GISD, 2015).

Non-chemical control and eradication approach can be employed in various ways, such as removals using casting nets, gill nets, traps, and electrofishing (Knapp and Matthews 1998; Copp *et al.*, 2007; Marr, 2008). However, controlling the non-native fishes is difficult, mainly because overall physical and mechanical methods have been known to be ineffective in large ecosystems or for species with high reproductive rates (Garcia-Berthou, 2007). A study by Knapp and Matthews (1998) reported that it took approximately two years to completely eradicate the non-native brook trout *Salvelinus fontinalis*, and three years for the rainbow trout *Oncorhynchus mykiss* by gill netting from Maul Lake, California (1.6 ha of Maul Lake *vs.* 15,200 ha of Temengor Reservoir). But it will be an uphill task to eradicate the tilapia at Temengor Reservoir. Based on the Maul Lake experience, it may take a longer time since Temengor Reservoir is much larger than the Maul Lake.

In a study conducted by Britton and Brazier (2006), chemical piscicide rotenone was applied to the recreational fishery in Northwest England. The non-target species were transferred to somewhere else prior to the rotenone application in the lake to eradicate the invasive top mouth gudgeon *Pseudorasbora parva*. No more gudgeon was present during the post-application fish sampling. However, the use of rotenone and antimycin should be treated with extra caution due to their lethal effects on non-target organisms and possible short-term/long-term retention in the ecosystem (Knapp and Matthews, 1998; Sato *et al.*, 2010).

It is also comforting to observe that the protection of the Temengor Reservoir from this super-invader could come from a biological element. The presence of top predators such as the snakeheads; the giant snakehead *Channa micropeltes* (toman) and striped snakehead *C. Striata* (haruan), and other carnivorous fish like the Hampala barb *Hampala macrolepidota* (sebarau) (Hamid and Mansor, 2013), are likely to be an advantage where they consume tilapia and help maintain their numbers in relatively undisturbed environments (Senanan and Bart, 2010). The snakehead is a mouthbrooder, hence their eggs could be protected and could not be eaten by tilapia. During the sampling excursions, fingerlings of toman and sebarau were observed, showing the high presence of these carnivorous fishes. Based on the ecology of these native species, it is recommended to apply this biological control to reduce the population of tilapia outside of the cage.

A study by Yi *et al.* (2004) on the efficiency of snakeheads in controlling the overpopulation of *O. niloticus* in ponds in Thailand proved that the snakeheads were able to completely control Nile tilapia recruitment. Adult snakeheads are predators of many species, including crustaceans, frogs, smaller reptiles but have a preference for other fishes. Even as juveniles, snakeheads feed on fry of other fishes in addition to zooplanktons, insect larvae, and small crustaceans (Munshi and Hughes, 1992). Based on its piscivorous (fish-eating) nature, Hoffman (2002) recommended that the snakeheads, particularly *C. striata* and *C. micropeltes*, be used as a control for tilapia populations in the aquaculture facilities. Thus, based on the examples described, the use of the native carnivorous snakeheads would be an effective tool in controlling the overpopulation of tilapia at Temengor Reservoir.

4. Conclusion

The present and previous findings have shown that the tilapia has invaded the lower part of Temengor Reservoir and has recently started to colonise the upper part (Belum). Based on its tolerance to a wide range of environmental conditions, it is postulated that tilapia could successfully become established in the Temengor Reservoir and even beyond. If left unmanaged, the situation could deteriorate with adverse consequences on the biodiversity of the lake. Mitigation measures such as physical removal through intensive fishing and biological control by native predators are suggested.

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