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RESEARCH PAPER

Distribution and Abundance of the Endemic Scaleless Tooth-carp, *Aphanius furcatus* Teimori, Esmaeili, Erpenbeck & Reichenbacher 2014 (Teleostei: Aphaniidae) in Iran

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Abstract

Aphanius furcatus-known as scaleless tooth-carp- is a unique species of the genus *Aphanius*, endemic to the drainage of the Hormuzgan, Persian Gulf Basin in southern Iran. This species has not yet assessed in the list of IUCN's Red Data Book. Investigation of the current distribution and estimation of the individual abundance revealed that the abundance of *A. furcatus* is low, and it has low population sizes in their current distribution ranges. In addition, its current habitats are under several threats due to the recent severe drought in southern Iran, contamination and habitat destruction. Therefore, immediate necessary plans should be taking into consideration to conserve this unique *Aphanius* species.

Introduction

The killifish genus *Aphanius* Nardo 1827 (Cyprinodontiformes) is currently composed of approximately 45 species, and widely distributed along the late period Tethys Sea coastlines (Hrbek & Meyer, 2003; Fricke, Eschmeyer, & Van Der Laan, 2018). Within its natural distribution ranges, the greatest species diversity is considered to be in the Near East, especially in Anatolia (Wildekamp, Küçük, Ünlüsayin, & Neer, 1999) and Iran (Hrbek & Meyer, 2003). To date, 16 and 15 *Aphanius* species have been described from Turkey (Yoğurtçuoğlu & Freyhof, 2018) and Iran (Esmaeili, Teimori, Gholami, & Reichenbacher, 2014; Teimori, Esmaeili, Erpenbeck, & Reichenbacher, 2014; Teimori, Esmaeili, Hamidan, & Reichenbacher, 2018) respectively. The Anatolian *Aphanius* species are currently distributed in 15 drainage basins (Yoğurtçuoğlu & Güler Ekmekçi, 2017). In Anatolia, the *A. anatoliae* group with 12 recognised species is the most widespread group (Freyhof, Özuluğ, & Saç, 2017). More than 90% of the Iranian *Aphanius* species are endemic to this country (Esmaeili *et al.,* 2014; Teimori *et al.*, 2014,2018).

For several years, the only information on Iranian *Aphanius* was concerning their distribution, general morphology and few biological aspects (Coad & Abdoli, 2000; Coad, 2009; Esmaeili & Shiva, 2006). The recent extensive studies however improved our knowledge about different aspects of the genus *Aphanius* such as; their distribution (Caod, 2009; Keivany & Ghorbani, 2012; Teimori, Esmaeili, Gholami, Zarei, & Reichenbacher, 2012a; Esmaeili *et al.,* 2014; Valdesalici, Langeneck, Barbieri, Castelli, & Maltagliati, 2015; Englezou, Gücel, & Zogaris, 2018), taxonomy (Teimori, Schulz-Mirbach, Esmaeili, & Reichenbacher, 2012b;

Teimori *et al.,* 2018), phylogenetic relationships (Hrbek, Keivany, & Coad, 2006; Esmaeili *et al.,* 2014; Gholami, Esmaeili, Erpenbeck, & Reichenbacher, 2014; Freyhof, Weissenbacher, & Geiger, 2018; Teimori *et al.,* 2014,2018) and biological properties (Esmaeili & Shiva, 2006; Bibak, Hosseini, Koohani, & Daliri, 2012; Zeinali & Motamedi, 2017; Teimori, 2018).

Nevertheless, few studies have considered the conservation view of the genus *Aphanius* in Iran. Keivany (2013) has pointed out that *A. isfahanensis* Hrbek, Keivany, & Coad, 2006 from center of Iran (Isfahan basin) should be listed in IUCN's Red Data Book due to its restricted distribution and other condition such as destruction of spawning grounds, dam construction, and environmental pollution. Recently, another study by Keivany and Esmaeili (2014) introduced *A. pluristriatus* (Jenkins, 1910), a poorly known species in southern Iran (Mond basin) as threatened fish.

Habitat alternation during recent years has drastically affected the abundance of *Aphanius* individuals and even populations particularly in the southern Iran. Since almost all the *Aphanius* species (exception is *Aphanius stoliczkanus* (Day, 1872)) are geographically restricted to small area in Iran, therefore the monitoring of their conservation should be taken into consideration. Among the *Aphanius* members of Iran, *A. furcatus* is unique because of its complete absence of body scales. It inhabits brackish waters rivers and hot sulpuric springs in Hormuzgan Basin, southern Iran. Our field work observations during last two years indicated that several microhabitats of the species have been drought out, and its abundance has decreased. Therefore, the aim of this study is to investigate the current distribution of *A. furcatus,* and to estimate abundance within its natural distribution ranges.

Materials and Methods

Sampling and Estimation of Individual Abundance

In this study, we collected and examined fish individuals from nine sites. These habitats are in two types; riverine system (Shur river) and hot sulphuric springs (Faryab spring) (Table 1 and Figure 1a & 1b). The physicochemical parameters including water temperature, pH, conductivity, salinity, and dissolved oxygen were measured by a multi measure device, Hach Lange Sension 156 meter in carrying case.

To estimate *A. furcatus* abundance, we used dip net (mesh size of 0.05 cm and 50 cm diameter) with three attempts in one-meter interval along a 100 m transect. We did sampling from all nine sites that were mentioned above between 2nd and 14th of March 2016. All the caught samples were identified, counted and released. This transect assured us that we covered all variable habitat types. These habitat variables (Table 1) were measured directly or were extracted from WorldClim data (Fick & Hijmans, 2017) followed by Mostafavi, Pletterbauera, Coad, Mahini, Schinegger, Unfer, Trautwein, and Schmutz (2014). Not all the *A. furcatus* within the 100 m transect were counted therefore, we employed N-mixture approach for analysing abundance with detection error (here the possibility of not captured) using the package DETECT (Sólymos, Lele, & Bayne, 2012) in R (R Development Core Team, 2017). We followed the method of Dénes, Sólymos, Lele, Silveira, and Beissinger (2017) to estimate the abundance. The method requires a set of covariates that affect abundance and a set of covariates that affect detection probability, and that at least one continuous covariate is unique to each set. The counts of *A. furcatus*

Table 1. Coordinates and some ecological parameters of the localities surveyed for *Aphanius furcatus*. AveMaxWid

Localities	Coordinates	Habitat types	AveMaxWid	AveWetWid	AveSlop	Elevation (m)
Khurgu	56.462417 27.509528	Hot sulphuric spring	112.66	66.91	1.600000	160
Faryab	55.264306 28.160472	Hot sulphuric spring	171	26	0.100000	690
Kol	54.693471 27.637913	Brackish river	22.1	9.4	0.900000	640
Shur	56.469500 27.327111	Brackish river	150	57	0.200000	17
Dehighan-Mehran River	55.272444 26.882056	Brackish river	188	140.88	0.200000	33
Khukherd-Mehran River	54.473444 27.080583	Brackish river	180	48	0.100000	284
Gotab-Mehran River	54.262806 27.144389	Brackish river	38.44	24.79	0.700000	333
Gud-e-Gaz	54.489083 27.291333	Brackish river	494	133.73	0.100000	406
Tang-e-Dalan	55.002544 27.388405	Brackish river	64.8	23.9	0.700000	363

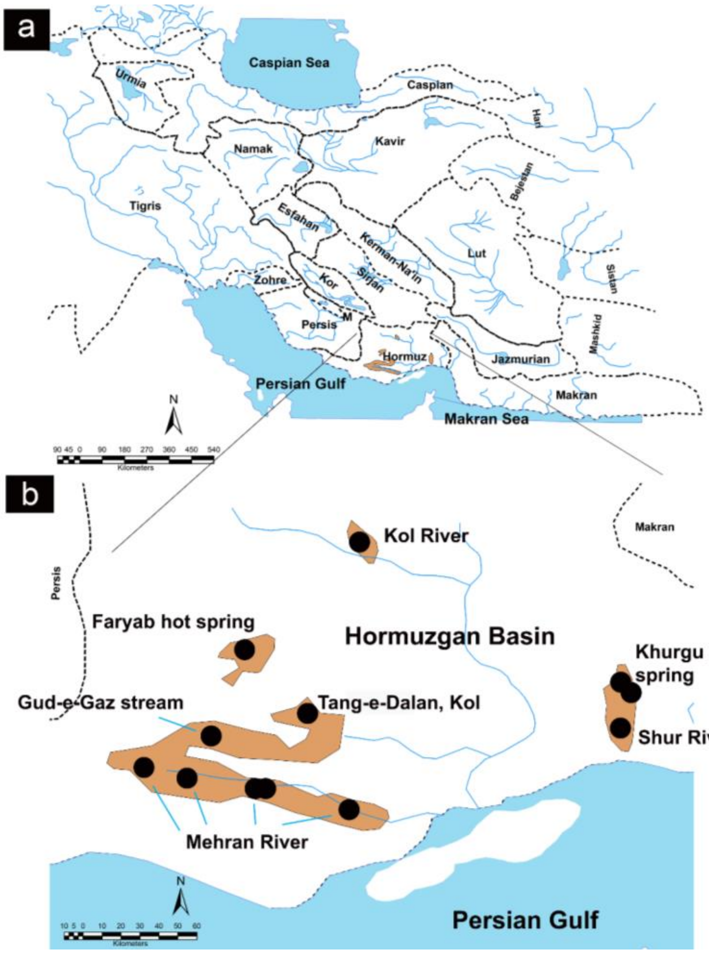

Figure 1. General overview of Iranian drainage basins (a), and the current distribution of the *Aphanius furcatus* in Hormuzgan Basin, southern Iran (b).

Table 2. Model selection results for *A. furcatus* abundance based on the binomial-negative binomial (NB) model

	Model 1	Model 2	Best Model	CI for Best Model
Abundance				
Intercept	-13.48	-2122.00	1.31	0.71, 3.99
Water temperature	0.60	90.64	4.22	1.79, 5.29
Salinity	0.02	1.40	-	-
Detection				
Intercept	8.40	1.86	-3.08	-1.73, -3.16
Average slope	0.89	0.86	-0.07	-1.40, -1.46
pH	-0.86	-	-1.00	-0.53, -1.11
AIC	47.92	38.32	35.46	-
$\bar{p}$	0.84	0.76	0.25	0.07, 0.63
$\bar{\lambda}$	10.99	12.88	41.16	19.91, 68.46

in each transect was the response variable. We used negative binomial (NB) distributions to estimate abundance of the species, and then selected average slope and pH as detection covariates and average water temperature and salinity as abundance covariates. According to Sólymos *et al.* (2012), we started with full model then performed backward stepwise model selection, and eliminated insignificant detection covariates first, and then did the same for abundance covariates.

Results

Identification and Distribution

Aphanius furcatus is unique among the *Aphanius* species distributed in Iran. It is distinguished from all its relatives in Iran by the complete absence of scales; slightly forked caudal fin with the upper lobe slightly longer than the lower lobe; males with dark pigmentation at the base of the four anterior dorsal rays

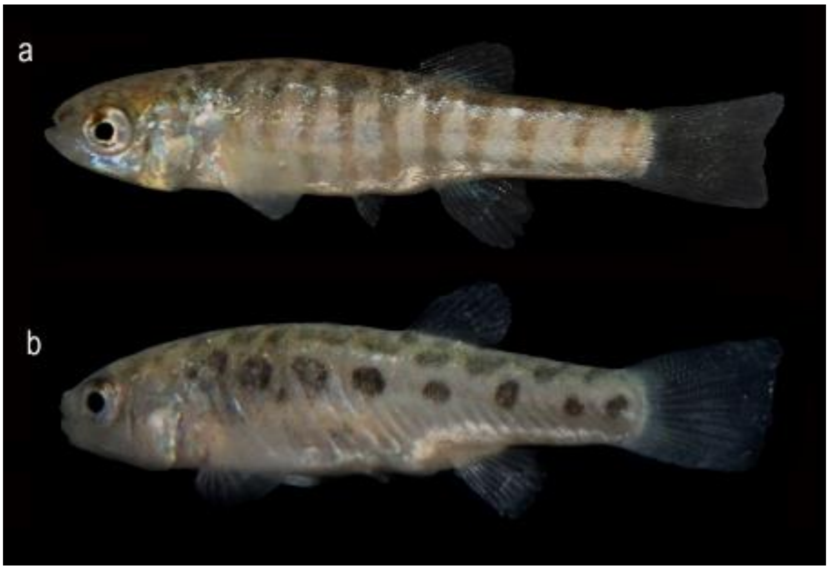

Figure 2. Male (a) and female (b) of *Aphanius furcatus*.

(Figure 2); 26–27 vertebrae of which the neural arches are rather thick (Teimori *et al.,* 2014). Males usually have 7–11 vertical flank-bars, their dorsal, anal, caudal, pelvic and pectoral fins are white but with a dark pigmentation on the base of the 1st to 4th dorsal rays (Figure 2a). Females display 7–9 dark circular blotches on their flanks, starting behind the operculum and extending until the base of the caudal fin. Similar to the males, their dorsal, anal, caudal, pelvic and pectoral fins are white (Figure 2b) (see also Teimori *et al.,* 2014).

The current distribution of the *Aphanius furcatus* is shown in Figure 1. It is restricted to the brackish water rivers and hot sulphuric springs in the Hormuzgan Basin, southern Iran, where it is sympatric with another native brackish water species, *A. hormuzensis* Teimori, Esmaeili, Hamidan & Reichenbacher, 2018 (see also Teimori *et al.,* 2018). The rivers and spring streams in this region are often seasonal. *Aphanius furcatus* individuals are usually inhabit the riversides, where the water is shallow, warm and water flow is slow.

Habitat Characteristics and Estimation of Abundance

Ecologically, this species occurs in habitats with extreme ecological conditions such as low oxygen concentration, mineral warm and salty sulphuric water. From its ten known habitats, two were hot sulphuric springs. The riverine habitats are characterized by shallow water and white salty layers around and within the river (Figure 3a), while the spring-system habitats are characterized by hot sulphuric water, low dissolved oxygen, and muddy bed with algae (Figure 3b). Some ecological parameters of the type locality, Shur River (October 2015) are as follow: water temperature 33.5–36.3°C; water depth 6.25–16.20 cm; pH 8.1; conductivity 3180–3240 µS/cm; salinity 30.1 ppt, dissolved oxygen 8.1 mg/l. Furthermore, the following parameters are listed by Teimori *et al.* (2014) for the type locality; nitrate (NO_3^-) 1.7–2.1 mg/l; nitrite (NO_2^-) 0.014–0.015 mg/l; phosphate (PO_4^{3-}) 0.21–0.36 mg/l; ammonia (NH_3) 2.55–2.66 mg/l.

Ecological parameters of the Faryab hot sulphuric spring (October 2016) are as follow: water temperature 37.2–37.8°C; water depth 4.20–10.12 cm; pH 8.3; conductivity 2158–2420 µS/cm; salinity 25.2 ppt, dissolved oxygen 5.7 mg/l, and for the Khurgu hot sulphuric spring are as follow: water temperature 37.8–38.4°C; water depth 2.45–9.13 cm; pH 8.3; conductivity 3180–3240 µS/cm; salinity 30.5 ppt, dissolved oxygen 4.6 mg/l.

The full model, included average slope and pH for the detection model, and water temperature and salinity for the abundance model. We dropped salinity because they were not significant based on a Wald test ($P< 0.01$). Based on our final model, the two covariates had impact on detection average of slope and pH, that both had negative effect. Water temperature influenced *A. furcatus* abundance positively. Mean detection probabilities ($\bar{p}$), AIC and mean abundance ($\bar{\lambda}$) per 100 m transect of the best model were 0.25, 35.46 and 41.16 respectively. As results, this species has low population sizes in its current distribution regions.

Discussion

Considering of the ecological conditions of the current habitats for *Aphanius furcatus*, and our field monitoring during recent years, it can be concluded that most of the habitats are in critical status owing to drought and low water capacity. This was clear from the individual abundance during our observation and sampling.

Additionally, estimation of the individual abundance in the present study by the best model with

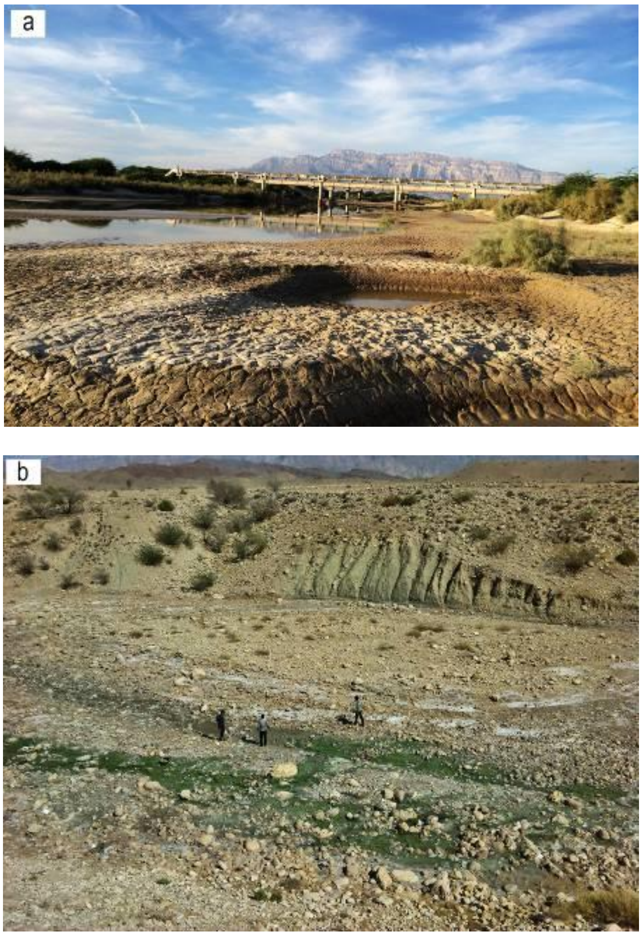

Figure 3. Two known habitat types in Hormuzgan Basin inhabited by the *A. furcatus* populations. Shur River, a reverine system and the type locality of *A. furcatus* (a); Khurgu, a hot sulphuric spring-system (b).

AIC 48.94 indicated mean abundance ($\hat{\hat{\lambda}}$) per 100 m transect of 32.76 individuals for *A. furcatus.* As results, this species has low population sizes in its current distribution regions.

Conservation Recommendation

As it is mentioned above, this species has not yet been assessed in the list of IUCN's Red Data Book, but it should be included due to the low individual abundance, and habitat alternation owing to the recent severe drought (Teimori *et al.,* 2014, this study). Some of the habitats such as Khurgu spring are using by local people, therefore, the effects of anthropogenic threats such as pollution and habitat destruction should be monitored. As results, stopping more anthropogenic activities around at least some of the *A. furcatus* habitats and identifying the possible translocation site are necessary steps that should be taking into consideration.

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Conflict of interest

The authorsdeclare that there is no conflict of interest

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