A revised account of the geographical distribution of the endangered freshwater fish *Garra ghorensis* in Jordan and implications for conservation

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ABSTRACT

The spatial distribution of the endangered cyprinid fish *Garra ghorensis* was initially assessed through sampling of 6 riverine sites across Jordan in 2002, with a repeat survey completed in 2010 to detect changes in their distribution. In this latter survey, an additional 8 sites were also sampled in an attempt to fully describe their distribution range, although only one more population was recorded. Comparison of the presence/ absence data in the sites sampled in both 2002 and 2010 revealed no changes in this aspect of their distribution. In 2002 survey, their populations co-existed with either native or invasive species, whilst the population detected in 2010 was in allopatry. Between the two survey periods, however, the physical characteristics of the majority sites had altered with, for example, a series of significant water impoundments constructed. These will potentially result in a loss of longitudinal connectivity in these rivers, leasing to habitat and population fragmentation. Although no detrimental effects of these changes were detected in 2010, given the endangered status of *G. ghorensis,* efforts to minimise potential effects of population fragmentation are recommended.

INTRODUCTION

The causal factors involved in extirpations and extinctions of threatened freshwater fishes include the negative consequences that arise from anthropogenic disturbances including engineering works, industrial and domestic pollution, acidification, fishing and fishery management, and land use practices (Maitland, 1995). Consequently, the successful conservation of freshwater fish is highly reliant on data on their ecology and distribution, and understanding their relationships with their physical habitat (Dudgeon, 2000). Indeed, understanding how species respond to disturbances is important for understanding how human activities affect key habitats, such as spawning and nursery areas (Maitland, 1995). Maintaining habitat connectivity is especially important for species that undertake spawning migrations, with impoundments usually resulting in losses of both longitudinal and lateral connectivity (Falke & Gido, 2006; Fullerton *et al.*, 2010). Data on the consequences of habitat alterations on threatened fishes are, however, often either unavailable or expensive to collect, especially in remote areas and where countries have limited conservation resources (Helfmann, 2007). This can result in conservation efforts often being undermined by insufficient understandings on the ecology and distribution of the species.

The importance of understanding the distribution and ecology of threatened freshwater fishes is highlighted by the genus *Garra* of the Cyprinidae family that has attracted attention and dispute in their taxonomic and biogeographic origins (Hamidan *et al.*, 2014). This genus is encountered across subtropical and tropical Asia, the Middle East and Africa (Menon, 1964), with ten species recognised by Geiger *et al.* (2014) in the Mediterranean basin. Of these ten species, four have a mental adhesive disc, being *Garra variabilis*, distributed in the Orontes and Nahr al Kabir drainages in Syria, *Garra ghorensis*, distributed in the southern tributaries of the Dead Sea basin, but currently only found in in Jordan (Hamidan & Mir, 2003), *Garra jordanica*, distributed in the northern Dead Sea basin of Jordan and Syria, and *Garra rufa*, distributed in the Qweik, Euphrates, Tigris and in rivers in the Persian Gulf south to the Mond River (Hamidan *et al.*, 2014). *Garra ghorensis* was originally described by Krupp (1982) as a subspecies of *Garra tibanica*, an Arabian species closely related to, or even identical with the African *Garra quadrimaculata* (Stiassny & Getahun, 2007). However, recent genetic studies indicate that *G. ghorensis* is of Mediterranean and Mesopotamian origin (Hamidan *et al.*, 2014).

The distribution of *Garra* fishes in Jordan was discussed further by Krupp & Schneider (1989) and Mir (1990). These studies provided a comprehensive account of the fish fauna of Jordan and adjacent areas. These data were used as the basis of a review of the conservation status of freshwater fishes in the Arabian Peninsula, including southern and eastern Jordan, at a conservation assessment and management plan meeting (CAMP) in 2002. The outcome was a conservation plan outlining that three Jordanian fish species, *Aphanius ricardsoni, A. sirhani,* and *G. ghorensis,* were priority species for conservation as they faced an imminent risk of extinction (EPPA, 2002). At that time, *G. ghorensis* and *A. sirhani* were evaluated on the IUCN Red List as a critically endangered species while *A. ricardsoni* as endangered. A recent evaluation has reduced *G. ghorensis* to endangered status due to their area of occupancy not allowing for the classification of critically endangered (Freyhof *et al.*, 2014).

Despite this conservation prioritisation in 2002, there was a paucity of data on the status of these fishes, including *G. ghorensis.* This presented a major challenge to any efforts to conserve these species in light of potential impacts of anthropogenic disturbances (e.g. impoundments) and climatic events (e.g.

drought). Correspondingly, Hamidan & Mir (2003) assessed the status of *G. ghorensis* in Jordan in 2002, building on knowledge provided by earlier studies of Krupp & Schneider (1989) and Mir (1990). Since this survey, however, there have been substantial alterations to many natural watercourses in Jordan, such as the construction of impoundments that have transformed lotic habitats to lentic in order to meet societal demands for potable water and irrigation. This shift in lotic characteristics, allied with reduced volumes due to water abstraction and the introduction of alien species (e.g. *Oreochromis aureus*), suggest there has been some anthropogenic disturbances that could potentially have impacted the status of populations of *G. ghorensis* since the 2002 surveys (Hamidan & Mir, 2003). Consequently, the aims of this study were to (1) assess the spatial distribution of *G. ghorensis* in Jordan in 2010 and compare it to the distribution recorded by Hamidan & Mir (2003); (2) assess the extent of the increased anthropogenic disturbances at the survey sites in 2010 compared with 2002, and (3) identify the issues that could result in conservation threats to the current status of *G. ghorensis*.

MATERIALS AND METHODS

Study area

Sampling for *Garra ghorensis* in 2010 was conducted in October at 14 riverine sites at the southern end of the Dead Sea in Jordan. Of these sites, 6 had been sampled in 2002, with a further eight sampled here to identify other sites where the species might be present (Fig. 1; Table 1). Of the six sites sampled in both years, four were impounded in their lower reaches where the water used to drain to the Dead Sea. In entirety, the spatial area covered in the 2010 surveys encompassed the distribution range of *G. ghorensis* as reported by Krupp (1982), Krupp & Schneider (1989), Mir (1990), Hamidan & Mir (2003) and Hamidan (2004). It is thus comprised the area from Ein Al-Haditha (31°17'47.74" N, 35°32'35.38"E) at the northern border and extended south to Wadi Khneizerah (30°52'53.79"N , 35°26'1.00"E) app. 50 km to the south of Ibn Hammad. It also extended east to Wadi al-Burbaitah (30°59'1.11"N, 35°40'13.71"E) at the upper tributaries of Wadi Al-Hassa (31° 0'44.95" N, 35°31'19.08"E), and from western site to rivers outlets down to the Dead Sea (Fig. 1). A brief description of each site is provided in Table 1.

Fish sampling

Fish sampling at the 14 sites was completed in October 2010. At all sites, sampling used electric fishing. Where sites were impounded, then the downstream limit of the site would be the impoundment. Sampling was completed at all sites in an upstream direction and continued for 15 minutes before moving 500 m upstream to repeat. This was repeated once more so that a total of 45 minutes fishing was completed per site and over a distance

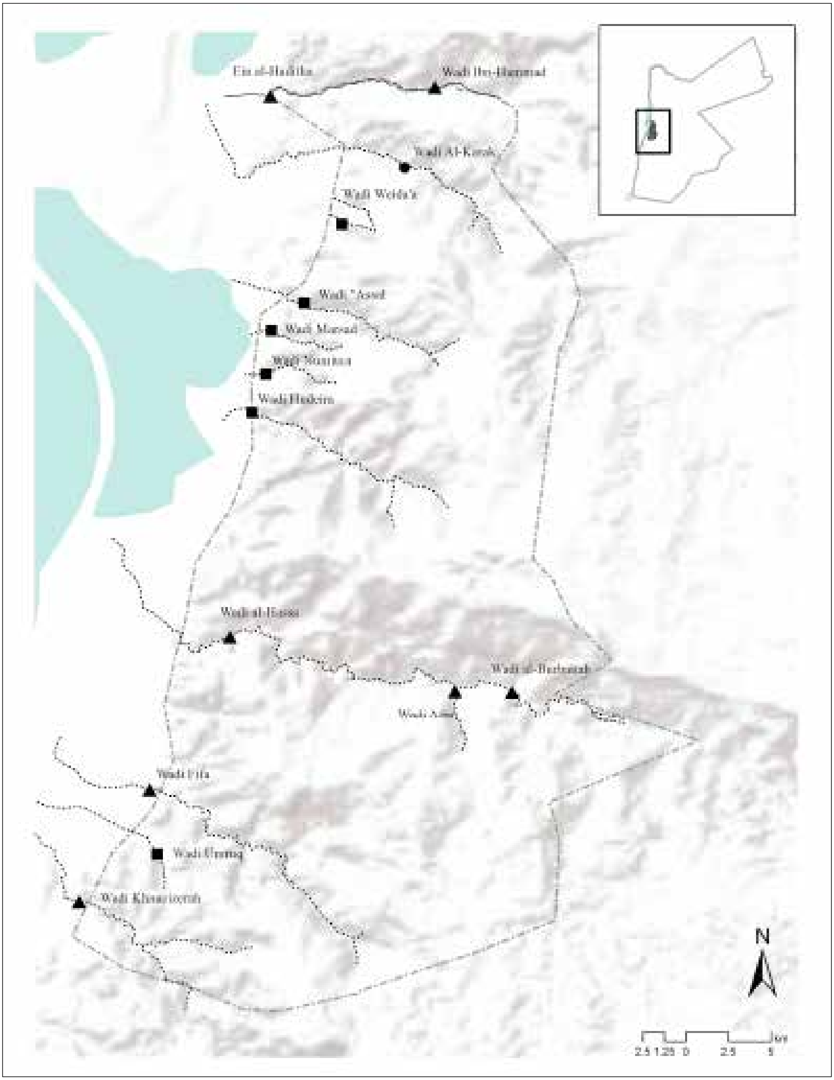

Figure 1. Locations of the sampling sites in Jordan (inset) and in Southern Jordan (main image). Filled triangles represent sites where *Garra ghorensis* was pre sent, filled squares represent sites where they were absent. The filled circle is the site where only *Oxyneomacheilus insignis* was captured. The dashed line marks the limit of the known up to date distribution range of *G. ghorensis* described by Krupp & Schneider (1989), Mir (1990), Hamidan & Mir (2003), and Hamidan (2014).

Table 1. Sample size, sub-sample size and length characteristics of *Garra ghorensis* at the three sites where they were most abundant. Site codes are those referred to in Table 1. Site Codes: Ain al-Haditha (HD), Ibn-Hammad (IB), and Wadi al Burbaitah (BR).

Year	Site code	Number fish sampled	Sub-sample size (n)	Mean length (mm)	Length range (mm)
2002	HD	123	-	57.4 ± 1.3	29.0 - 99.0
2010	HD	15	15	35.1 ± 2.6	20.7 – 48.8
2010	BR	78	15	45.2 ± 2.8	24.9 – 62.0
2010	IB	9	9	32.7 ± 3.4	21.2 – 57.3

of approximately 1500 m river length. The electric fishing equipment was a hand-held Samus 725 MP electro-fishing unit. At each section of each site, sampling concluded before 15 minutes if 15 *G. ghorensis* individuals were captured. This was to prevent excessive numbers of this endangered fish being captured.

With the exception the sites Ain al-Hadihta, Wadi Ibn-Hammad, and Wadi Burbaitah, field identification of *G. ghorensis* was completed at the conclusion of the fishing and then all fish were immediately returned to the water to prevent excessive handling and stress associated with capture. As sample sizes at Ain al-Hadihta, Wadi Ibn-Hammad and Wadi Burbaitah were relatively high, then up to 15 individual fish were removed, euthanized (overdose of anaesthetic, clove oil) and taken back to the laboratory for identification and measuring (standard length, nearest 0.1 mm). Permission for removing individuals was granted by licence from the Royal Society for the Conservation of Nature, Jordan.

Across the 14 sites, reporting of *G. ghorensis* was on a presence/ absence basis, with supplementary data only provided for Ain al-Hadihta, Wadi Ibn-Hammad, and Wadi Burbaitah. Qualitative assessment of the extent of anthropogenic disturbance was through noting the additional alterations to the sites since 2002. As length data were available in both 2002 and 2010 for the site at Ein Al-Haditha, differences in the length distribution of *G. ghorensis* between the years were tested using a Mann Whitney U-test, as they were not normally distributed (Shapiro-Wilk test, $P < 0.05$ in both years). In reporting, where error is expressed around the mean, it represents standard error.

RESULTS

In 2002, *G. ghorensis* was detected in all of the six sites that were sampled (Hamidan and Mir 2003). In 2010, all of these sites were still found to have populations, with an additional population detected in one of the eight extra sites fished (Table 1). This was an allopatric population in the lower reaches of Wadi Ibn Hammad (Table 1). The samples collected in 2010 revealed that the seven recorded *G. ghorensis* populations comprised: (i) an isolated population at the lower part of wadi Ibn Hammad; (ii) a population that was sympatric with invasive *O. aureus* in Ein Al-Haditha; and (iii) populations that coexisted naturally with the native *Capoeta damascina* (Wadi Al-Hassa (including Burbaitah and wadi Fifa), and wadi Khneizerah) (Table 1). In the upper part of Wadi Al-Karak, no *G. ghorensis* were sampled, but the nemacheilid loach *Oxyneomacheilus insignis* was found (Fig. 1, Table 1). There were no fish recorded from Wadi Weida'a, Wadi Assal, Wadi Marsad, Wadi Numeira, Wadi Hudeira, and Wadi Umruq (Fig. 1, Table 1).

Across the three sites where samples were recorded in more detail, the number of sampled *G. ghorensis* was the lowest at wadi Ibn Hammad (n = 9) and highest at Wadi al-Burbaitah (n = 78) (Table 2). Data of collected samples at Ein Al-Haditha in 2002, and the three sites in 2010, revealed *G. ghorensis* present in samples from 21 to 99 mm, suggesting a recruiting population comprising of juvenile and mature fish, with mean lengths highest in Ein Al-Haditha and lowest in Ibn Hammad (Table 2). Between the samples collected in 2002 and 2010 at Ein Al-Haditha, their mean standard lengths differed (2002: 55.0 ± 1.2 mm; 2010: 35.1 ± 2.6 mm), with these differences being significant (Mann Whitney U test: $Z = -4.95$, $P < 0.01$).
Additional anthropogenic disturbances were apparent at all sites sampled (Table 1). The primary disturbances were increased impoundment, leading to decreased flows, channel deepening and the potential for increased silt deposition (Table 1). At a large level, a 17 million cubic metres dam, Al-Tannour, was established at the upstream of Wadi Al-Hassa and was operational from 2005, after which seasonal flooding was controlled and non-native fishes introduced into the impoundment (*O. aureus, Cyprinus carpio*, and *Clarias gariepinus*). However, no introduced fish were present in the samples collected downstream.

DISCUSSION

The 2010 surveys revealed that across the range of *G. ghorensis* described by Krupp (1982), Krupp & Schneider (1989), Mir (1990), Hamidan & Mir (2003) and Hamidan (2004), seven populations were detected, of which six had previously been detected in 2002. These populations covered three scenarios: allopatry, present in sympatry with native *C. damascina* and present in sympatry with invasive *O. aureus*. This reveals that *G. ghorensis* is present in fish communities with inherently low species diversity, perhaps due to the often extreme conditions that occur at the sites, including very high summer water temperatures (> 30°C) and low flows, and winter flood events (Hamidan & Mir, 2003). In terms of conservation threat, Hamidan *et al.* (2015) suggested that the coexistence of *G. ghorensis* with these native and invasive fishes did not represent a constraint to their population status due to low evidence for competitive interactions.

In comparison with 2002, the six sites re-sampled in 2010 all revealed additional physical modifications from anthropogenic disturbances, particularly at the lower reaches close to their confluence to the Dead Sea, where the water tended to be impounded and/ or heavily abstracted for domestic and agricultural use. With the exception of the Al-Tannour dam, these schemes tended to be relatively small-scale. As these impoundments are mainly at the lower end of the rivers, then their potential impacts of *G. ghorensis* were likely to relate more to shifting conditions from lotic to lentic, rather than being connected to population fragmentation. Across the seven populations, although no apparent issues were yet apparent for *G. ghorensis* from these impoundments, it should be noted that these surveys were restricted in scope, with a primary focus on their presence/ absence and so restricting further inferences on the effects of habitat change on other aspects of their ecology.

The use of impoundments to manage freshwater availability in water-poor countries such as Jordan is only likely to increase in future. It thus represents an increasing conservation threat to the sustainability of Jordanian freshwater resources and the fish communities they support. Although they might provide some benefits in minimising the harmful effects of annual flood cycles, and especially the damaging effects of stochastic summer flood events, flooding can also play important ecological and engineering roles in river systems (Hamidan & Britton 2014; Kingsford, 2000; Jackson, 1989; Olden & Poff, 2005). Moreover, impoundments tend to provide conditions suitable for the establishment of introduced fishes (Johnson *et al.*, 2008), with non-native fishes such as *Tilapia zillii, O. aureus* and *C. carpio*, and *Clarias gariepinus* already been introduced into some impoundments in Jordan (Hamidan, 2014), primarily for fishery purposes (Khoury *et al.*, 2012). Should these species develop invasive populations then there would be potential for detrimental ecological consequences to develop (Gozlan *et al.*, 2010; Simberloff *et al.*, 2013).

In conclusion, despite a range of additional anthropogenic disturbances across their range, the distribution range of *G. ghorensis* did not decrease between 2002 and 2010, although the habitat changes are likely to have resulted in some ecological and life-history changes (e.g. Hamidan & Britton, 2014). Whilst these data provide some support to their recent downgrading from critically-endangered to endangered on the IUCN Red List, (Freyhof, 2014), given these on-going and increasing disturbances from human activities, then it is suggested that their Red List status remains at endangered for the foreseeable future.

Table 2. The sites sampled in 2010 across the described range of *G. ghorensis*; presented theses refer to sites used in Table 2. Year represents the year(s) the sites were sampled.

Site name	Location	Alt.*	Year	Brief description
Ibn-Hammad (IB)	31° 18` 4.25`` N, 35° 37` 47.36`` E	81	2002, 2010	Deep cliff, shallow water (30-10 cm), fast running (app. 1.2 m/s). Width of sampling site: 4-2 metres, and depth is less than 10 m.
Ain al-Haditha (HD)	31° 17` 47.74`` N, 35° 32` 35.38`` E	-316	2002, 2010	Local impoundments, natural water pond at the spring head (app. 28 m Length by 8-4 m width), deep (3 m), artificial concrete collection ponds, and a fast running (1.3 m/s) open channelled water between the natural and artificial ponds.
Wadi al-Hassa	31° 0` 44.95`` N, 35° 31` 19.08`` E	-184	2002-2010	Drainage system for several tributaries and springs extending along the Karak Mountains.
Afra hot spring	30° 59` 2.97`` N 35° 38` 24.96`` E	180	2002-2010	Originated from Wadi al-Hassa, sulphuric hot spring with temperature of almost 40° C originated from the main Afra hot spring 2.6 km from the confluence point with Wadi al Burbaitah. Fast running wadi (1.3 m/s), with long gorge, narrow 1 m width to wide edges 20 m width especiall at the lower part.
Wadi al Burbaitah (BR)	30° 59` 1.11`` N, 35° 40` 13.71`` E	250	2002-2010	Originated from Wadi al-Hassa at the confluence point with Afra hot spring. Fast running water
is Wadi Fifa	30° 55` 52.57`` N, 35° 28` 46.55`` E	-260	2002-2010	Fust running (1.4m /s) narrow width 3-1m wadi.
Wadi Khneizereh	30° 52` 53.79`` N, 35° 26` 1.00`` E	-256	2002-2010	A narrow wadi surrounded by hills of sandstone and limestone with large boulders, Fast running water (1.3 m/s) water depth varies from 50- 10 cm depth)
wadi al-Karak	31° 15` 32.11`` N, 35° 36` 50.68`` E	-51	2010	Fast running river (0.9 m/s) water depth is 30-15 cm, wadi width is varied from 1 m water width to 12 m at the eastern side.
Wadi Weida'a	31° 13` 45.29`` N, 35° 34` 51.67`` E	50	2010	perennial shallow and slow running stream (0.3 m/s)
Wadi 'Assal	31° 11` 16.40`` N, 35° 33` 39.98` E	-190	2010	perennial shallow and disconnecting water flow.
Wadi Marsad	31° 10` 24.81`` N, 35° 32` 38.02`` E	-250	2010	little, shallow, and slow running (0.1-0.3 m/s) streams of water that is not extended over the wadis
Wadi Numeira	31° 8` 59.69`` N, 35° 32` 9.91`` E	-266	2010	
wadi Hudeira	31° 7` 49.81`` N, 35°32` 1.73`` E	-245	2010	Slow running (0.3m/s) and low amount water that is extended to a dead end
wadi Umruq	30° 54` 7.14`` N, 35° 28` 51.69`` E	-150		Thick and heavy riparian vegetation that is covering the little amount of water along of the wadi

from north (Ibn-Hammad) to south (Wadi Khneizereh). In site name, codes in paren

	Human impact		Fish species
	2002	2010	
	Minimum number of visitors with no facilities. Water extraction for agriculture at a local scale.	Over visit especially in summer, tourism facilities Agricultural encroachment on the wadi beds, and water extraction.	*G. ghorensis*
	Impoundment Water extraction for agriculture, recreation, and invasion with *O. aureus*.	Large scale water extraction to apply the growing demand of agriculture, invasion with *O. aureus*, grazing around the natural ponds and livestock drinking, and recreation.	*G. ghorensis* *Oreochromis aureus*
	Tourism activities, water extraction.	Large scale dam up stream, Tourism facilities, Over visiting at both Afra and Burbita site. Enlarged agricultural scheme, water extraction, and river diversion especially at the upper reaches.	*G. ghorensis* *Capoeta damascina*
			G. ghorensis (Only juvenile fish were found close to the confluence point with wadi Burbaitah)
			G. ghorensis *C. damascina*
	Domestic use of water.	Water impoundment, large scale water extraction to apply the expanded agricultural demand on water, recreation activities including over visiting, grazing and livestock drinking.	*G. ghorensis* *C. damascina*
	Domestic use of water. Water extraction for agriculture. Impoundment at the down stream. Tourism.	Increased water extraction to apply the expanded agricultural demand. Over visiting / recreation.	*G. ghorensis* *C. damascina*
	Water extraction for agriculture.	Increased water demand, that block the water to reach the downstream leaving behind a dry wadi of 1.5 km river length, the wadi became over visited by tourists at local and national levels.	*Oxyneomacheilus insignis*
	Tourism activities.	Tourism activities.	-
	Tourism activities.	Tourism activities and grazing around the site.	-
	Tourism activities.	Tourism activities and grazing around the site.	-
	Tourism activities.	Tourism activities, grazing around the site, and water collection in artificial ponds for domestic and agricultural use.	-
	Water extraction for agriculture. Local tourism.	Large water extraction for agricultural purposes, High tourism activities at national level.	-

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