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RESEARCH ARTICLE

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Barramundi (*Lates calcarifer*) from Iraq: a new record for the Arabian Gulf, with a highlight on it genetic origins and description of two skeletal deformities

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ABSTRACT

The natural distribution of *Lates calcarifer* (barramundi or Asian sea bass), ranges from western India, around Sri Lanka to the Bay of Bengal, and through the whole of Southeast Asia to Papua New Guinea and northern Australia. It is not known to be native to the Arabian Gulf, although the species has recently been introduced for aquaculture production in Iran. In 2019, 12 adult barramundi were caught from freshwater in the Shatt al-Arab River, its estuary and marine waters bordering Iraq. This is the first wild-capture record of this species for Iraq's inland waters and the northern Arabian Gulf. The specimens were morphologically described, while genetic structure analyses indicated that the specimens likely originated from Australian and Thailand genetic stocks and thus probably were aquaculture escapees from farmed populations. Among the *L. calcarifer* collected from the freshwater environment on the Shatt al-Arab River, one specimen exhibited saddleback syndrome, and another showed abnormality in the left operculum. The results are interesting and useful in reminding people to prevent aquaculture escapees. The aim of this study was to morphologically describe the specimens and undertake a genetic analysis to determine the likely provenance of the fish.

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Introduction

Lates calcarifer (Bloch 1790), (commonly known as barramundi in Australia or Asian sea bass) is a euryhaline species that inhabits brackish and nearshore marine waters and prefers living in a demersal habitat (Riede 2004) at a depth range of 1–40 m (Whitehead 1984). This species belongs to the family Latidae, which comprises 14 species in three genera distributed globally (Otero 2004; Fricke et al. 2023). It is characterised by a large body, large scales, and voracious feeding habits (Blaber et al. 2008).

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Lates calcarifer's accepted natural distribution ranges from western India and Sri Lanka to Southeast Asia, Papua New Guinea, and northern Australia (Jerry 2014; Froese and Pauly 2023). The species supports extensive commercial, aquaculture, and recreational fisheries inside its range.

Aquaculture of *L. calcarifer* started in the 1970s in Thailand and swiftly spread to Australia and much of Southeast Asia (Zhu et al. 2006; Yue et al. 2009). Barramundi is farmed throughout most of its natural geographical distribution (Siddik et al. 2016). It is now being introduced for aquaculture to other regions, including the United States of America, Europe, Saudi Arabia, and recently Iran. Iran is considered the only country to have introduced *L. calcarifer* for seacage aquaculture in the Arabian Gulf (FAO 2016; Yue et al. 2023).

Lates calcarifer appears not to be indigenous to the Arabian Gulf, and there are no reliable records of the occurrence of the species in the wild. The nearest location to the Arabian Gulf where this species was reported to naturally occur is from the west coast of India. One specimen from each of the following localities in India was reported, Daman and Diu, Goa, 1st January 1942; Bhidiya Harbour, Gujarat, 10 October 2010; Bharuch Estuary, Gujarat, on 10 and 20 October 2010 (GBIF 2020). However, because the culture of *L. calcarifer* is gaining in popularity, and it is now farmed extensively, both within and outside its natural geographical distribution, individuals caught outside its acceptted distribution are probably aquaculture escapees. When *L. calcarifer* escapes from marine culture systems, they are known to survive for long periods and move substantially from the original location of the farm from which it escaped (Noble et al. 2014).

In 2019, 12 specimens of *L. calcarifer* were caught from the Shatt al-Arab River estuary at Al-Faw City and the upstream station at Abu Al-Khaseeb City (Figure 1), Iraq. These are the first reports of wild-caught *L. calcarifer* from river systems in Iraq and the first for the Arabian Gulf. Given that the species is not recorded from Iraq and is beginning to be farmed in sea cages in other countries bordering the Arabian Gulf, the purpose of this study was to morphologically describe the specimens and undertake a genetic analysis to determine the likely provenance of the fish.

Materials and methods

Sampling locality fish samples

A total of 12 *L. calcarifer* were obtained from two localities, that in the estuary of Shatt al-Arab River, Al-Faw City, southern Iraq, and the other locality far upstream at Abu Al-Khaseeb City, Basrah (90 km from the sea) (Figure 1, Table 1). These specimens collected from the estuary of Shatt al-Arab River at Al-Faw City were obtained in three lots dated November 2018, 2019, and January 2019, while those collected from the freshwater environment at Abu al-Khaseeb City were obtained in five lots, December 2017, January 2018, December 2018, November 2019, and December 2019. There were three specimens from the estuary of Shatt al-Arab River ranging in total length 278–310 mm and nine specimens from the Abu Al-Khaseeb locality at Shatt al-Arab River ranging in total length 218–416 mm. The specimens were obtained from the commercial catch at both Al-Faw and Abu al-Khaseeb, where commercial fishermen used gill and seine nets to catch the fish.

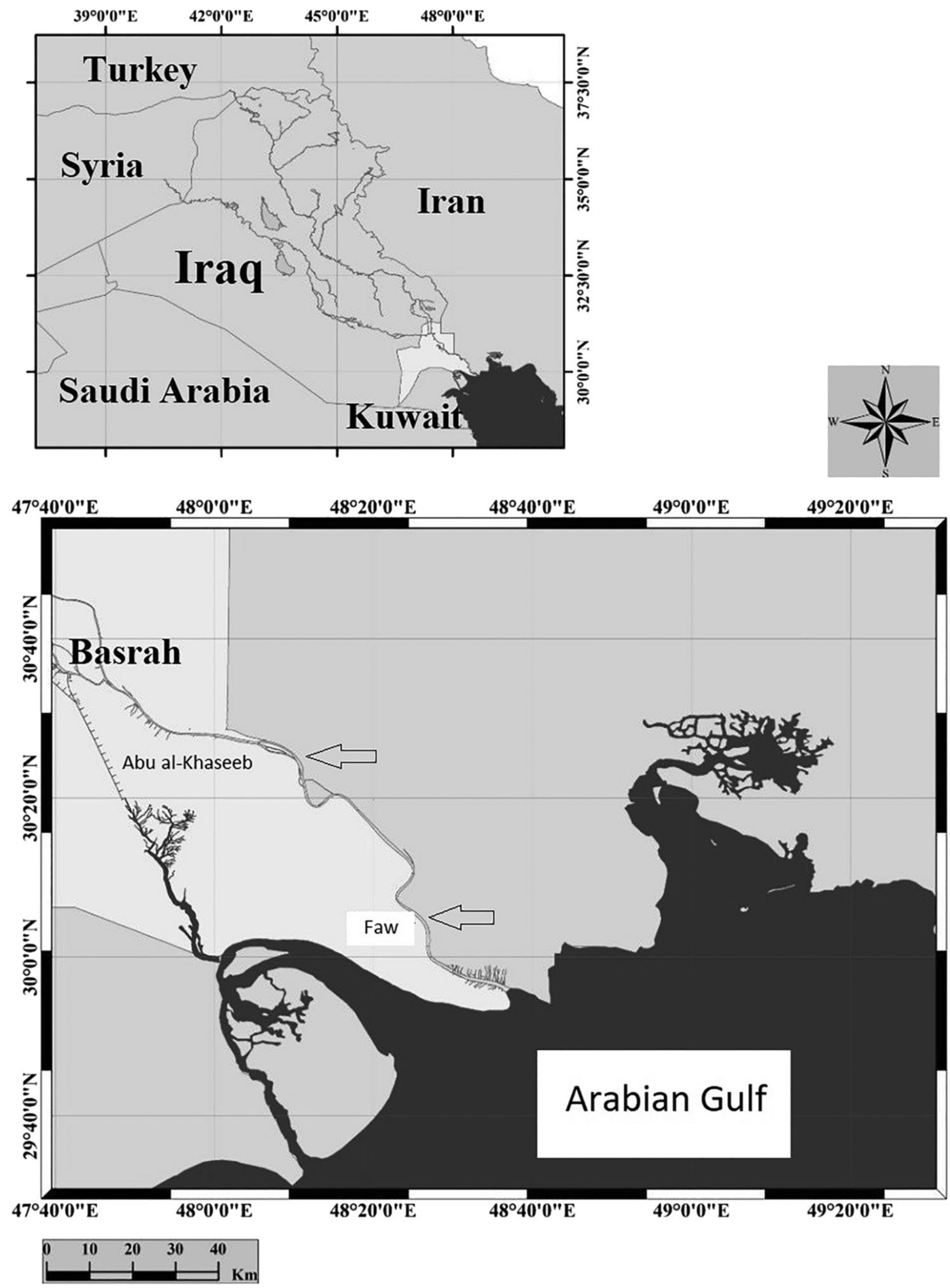

Figure 1. Map showing localities where fish samples of *Lates calcarifer* were collected.

The samples were deposited at the fish collection of the Department of Fisheries and Marine Resources, College of Agriculture, University of Basrah, Basrah, Iraq. Morphometric and meristic characters were recorded following Larson (1999) and are presented in Table 2. Length measurements were determined using dial calipers. After measuring, a piece of fin tissue was taken for genetic analysis. Then specimens were fixed in 10%

Table 1. Statistical data of specimens of Lates calcarifer collected from the Shatt al-Arab River and estuarine environment at Fao City, Iraq.

Specimen	Total length (mm)	Standard length (mm)	Weight (g)	Date of collection	Locality	Body colour
1	232	191	135	January 2019	Fao	Black
2	270	222	254	=	=	=
3	218	179	99	=	=	=
4	278	228	236	November 2018	=	=
5	310	225	326	December 2019	=	White
6	416	343	1023	December 2017	Shatt al-Arab River	=
7	295	236	295	January 2019	Fao	=
8	298	240	305	=	=	=
9	298	236	308	=	=	=
10	315	258	420	=	=	=
11	405	334	842	February 2019	Shatt al-Arab River	=
12	390	323	796	=	Shatt al-Arab River	=

Table 2. Morphometric and meristic characters of *Lates calcarifer* collected from the Iraqi waters. Length ranges in mm (% in SL in brackets).

Characters		
Morphometric	Range mm	Mean mm
Total length	218–416	310.42
Standard length (% TL)	179–343 (82.1–82.45)	253.17
Head length (% SL)	67.5–120.2 (35.1–37.5)	87.79 (36.33)
Snout length (% SL)	12.5–26.2 (6.95–7.63)	16.64 (7.34)
Interorbital length (% SL)	5.8–17.3 (3.24–5.02)	10.47 (4.12)
Orbital diameter (% SL)	11.5–16.9 (5.04–6.77)	13.5 (5.02)
Maxilla length (% SL)	17.2–46.6 (9.54–13.86)	30.68 (11.64)
Postorbital length (% SL)	37.0–78.4 (20.67–22.86)	55.22 (21.74)
Predorsal fin length (% SL)	77.6–213 (43.33–62.08)	113.33 (52.71)
Prepectoral fin length (% SL)	61.0–113.3 (32.20–33.01)	79.2 (32.61)
Pectoral fin length (% SL)	29.7–57 (16.13–16.61)	42.11 (16.35)
Prepelvic fin length (% SL)	61.4–124.8 (34.29–36.36)	85.85 (35.33)
Pelvic fin length (% SL)	36.3–68.6 (18.43–20.25)	51.44 (19.35)
Preanal fin length (% SL)	135–266 (73.63–75.40)	189.33 (74.52)
Caudal fin length (% SL)	39.3–87.9 (21.93–25.63)	59.94 (23.76)
Dorsal fin base length (% SL)	72.7–147.8 (21.51–23.65)	96.19 (22.59)
Ratio of 3rd to 2nd spine of anal fin	1.23–1.67 (0.49–0.65)	1.42
Anal fin base length (% SL)	20.5–47.8 (11.42–19.23)	33.68 (15.33)
Caudal peduncle length (% SL)	29.2–48.9 (16.29–16.81)	42.64 (16.53)
Caudal peduncle depth (% SL)	23.1–58 (12.88–16.87)	36.27 (14.87)
Body depth (% SL)	53.4–110 (29.81–32.04)	75.36 (30.92)
Meristic		
Dorsal fin spine count	7	–
Dorsal fin ray count	10–11	-
Anal fin ray count	8	-
Pectoral fin ray count	16–19	
Pelvic fin ray count	5	-
Caudal fin ray count	17	-
Total number of gill raker on 1st gill arch	20–32	-
Lateral line scale count	46–58	-
Number of serrae on posterior edge of preoperculum	24–32	-
Number of rows of scales in transverse line between base of third dorsal fin spine and lateral line	4.5, 5.5, 6.5	-

formalin, stored in 70% ethanol, and deposited in the fish collection of the Department of Fisheries and Marine Resources, College of Agriculture, University of Basrah, Basrah, Iraq under catalogue number 1923. Fricke et al. (2023) were used for the taxonomic status of the species, the spelling of species names, and taxonomic references.

Genetic analyses

Genetic analyses were conducted according to the methods outlined in Jerry and Smith-Keune (2014) and Loughnan et al. (2015, 2019). Briefly, tissues from the 12 specimens were preserved in 90% ethanol before DNA was extracted using a modified cetyltrimethylammonium bromide (CTAB) chloroform: isoamyl (24: 1) extraction buffer (Adamkewicz and Harasewych 1996). Polymerase chain reactions (PCR) were then used to amplify 17 microsatellite loci in two multiplex reactions (see loci and conditions in Yue et al. 2009). Allelic profiles of each fish were scored using GENEMAPPER software (ver. 4.1, Applied Biosystems). From the 17 loci genotyped in the multiplex, Lca287 has been found previously to deviate significantly from Hardy–Weinberg Equilibrium (HWE) and exhibit the presence of null alleles (Loughnan et al. 2015; 2019); as a result, this microsatellite marker was excluded from subsequent statistical analyses, reducing the number of loci for analyses to 16.

To determine the likely provenance of specimens caught in Iraq, the Bayesian method of individual clustering was applied in Structure ((ver. 2.3.4, see https://web.Stanford.edu/group/pritchardlab/structure_software/release_versions/v2.3.4/html/struvture.html)) (Pritchard et al. 2000). Genotypes from the Iraqi samples were added to the regional structure analysis conducted by Jerry and Smith-Keune (2014), which included *L. calcarifer* from India, Thailand, Vietnam, Indonesia, and Australia. Parameters for analysis were five replicate runs at $k = 4$ (K was initially determined by Structure Harvester (ver. 0.6.94, see http://taylor0.biology.ucla.edu/structureHarvester)), ‘nolocprior,’ an admixture model with correlated allele frequencies, burn-in length of 10,000 iterations and 100,000 Markov chain Monte Carlo repetitions.

Results

Collected specimens of barramundi were characterised by the following characteristics: long, compressed body, with broad caudal peduncle area; stout noticeable, with a clear curved dorsal outline in the head; dorsal profile anterior to the base of dorsal fin convex; large upper jaw extending to behind eye; teeth in mouth villiform and absence of canine teeth; maxilla extending behind the posterior edge of orbit; strong spines at the lower edge of the pre-operculum, while the posterior edge is finely serrated; the posterior plate of the upper limb of the cleithrum is exposed, and displays denticulations; spiny and soft parts of the dorsal fin are deeply separated; the short, rounded pectoral fin reaches about the mid of the spiny part of the dorsal fin origin of the pelvic fin is slightly behind that of the pectoral fin; the origin of the anal fin under the 1st-5th dorsal fin rays; the base of anal fin broad and scaly; caudal fin rounded. Presence of large ctenoid scales. The pectoral and pelvic fins are bronzy, and the dorsal, anal, and caudal fins are dark in colour. The eyes are pale and bright. Colour: specimens collected showed two types of colouration (Figure 2A,B), olive-brown on the snout, operculum,

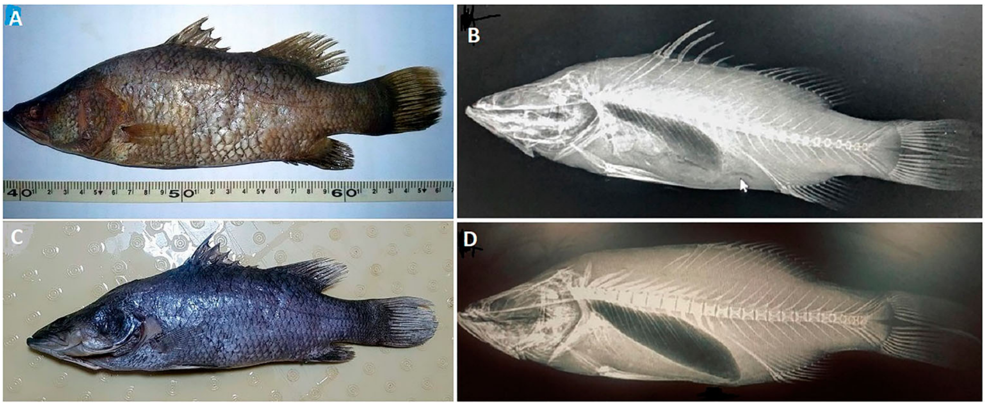

Figure 2. Specimens of *Lates calcarifer*, **A,** olive-brown colour form; **B,** normal specimen; **C,** sliver colour; **D,** specimen showing saddleback syndrome.

upper side of the body, and base of anal and caudal fins, with silver sides and belly observed in one specimen from the estuary of Shatt al-Arab and three specimens from the freshwater environment at Abu al-Khaseeb City, the other colour type is silver all over the body with dark dorsal side and base of both anal, spinous part of the dorsal fin, and caudal fins. This type was found in six specimens from the freshwater environment and three from the estuary environment.

Description of cases of abnormalities

1. Saddleback syndrome

The fish having a saddleback syndrome is missing all or part of their dorsal fin. The expression of this character is quite variable and exhibits a continuous distribution ranging from those that lack only the first spine to those that have no dorsal fin.' Pterygiophores associated with the missing spines or rays also were missing, resulting in a depression in the dorsal profile that inspired the name 'saddleback' (Tave et al. 1983).

Among the fish specimens of *L. calcarifer* collected from the freshwater environment at Abu al-Khaseeb City, one specimen (343 mm TL) showed saddleback syndrome (Figure 3A–C). The x-ray image (Figure 2A,B)) showed five of the seven dorsal fin spines were missing the pterygiophores that support them. The sixth and seventh dorsal spines are present with their pterygiophores supporting them. The pterygiophore of the seventh dorsal spine is lifted upward and laid in a horizontal position posterior to the sixth dorsal spine. The pterygiophores of the first and second dorsal spines are present, while those of the third to fifth dorsal spines are missing. All the soft dorsal rays are present with their pterygiophores, but the pterygiophores of the first and second dorsal rays are displaced anterior-dorsally. Other anomalies that appeared in this specimen are that the centra of the first and second penultimate vertebrae are slightly displaced ventrally.

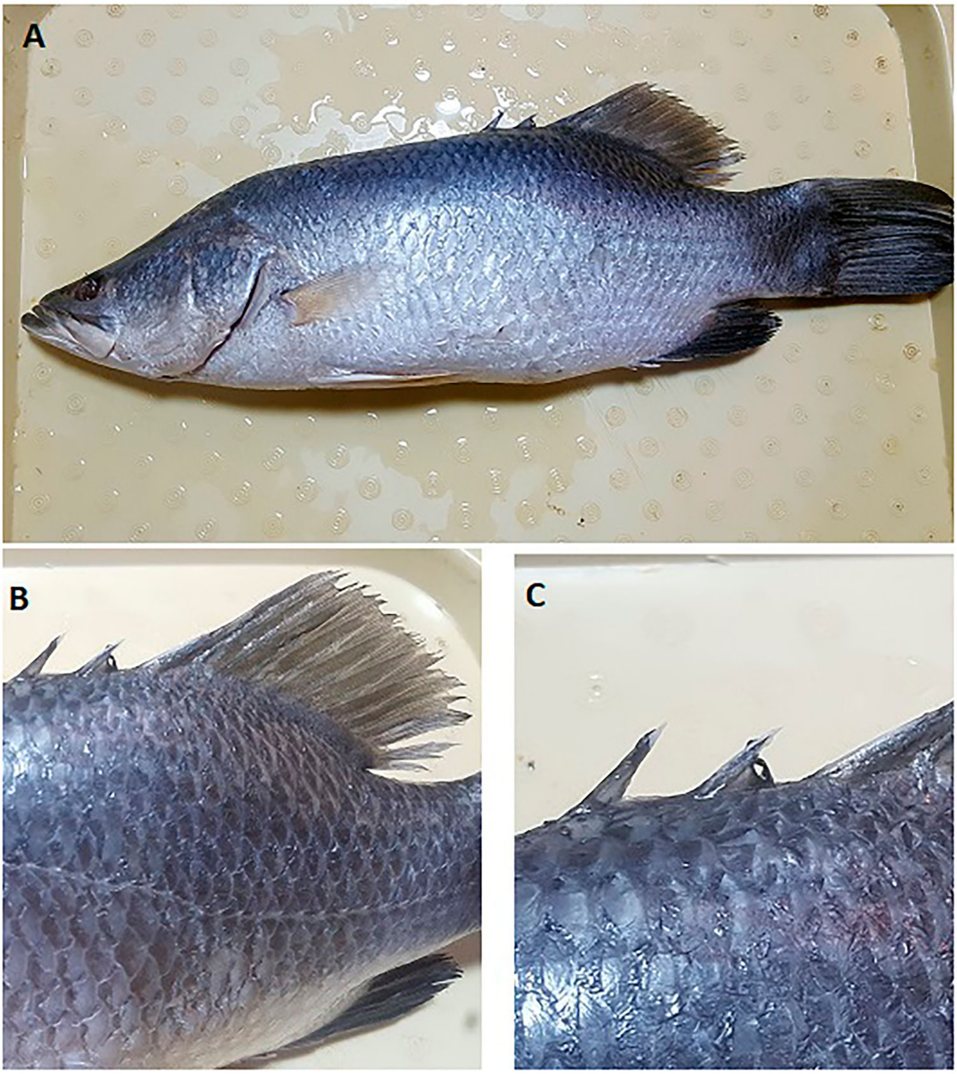

Figure 3. Specimen of *Lates calcarifer*, 416 mm TL, with the saddleback syndrome. **A,** lateral view of whole fish; **B,** close-up view for the deformed area; **C,** close view for the remaining spines of the dorsal fin.

2. Operculum abnormality

One (248 mm TL) out of three specimens collected from the estuarine environment showed abnormality in the left operculum (Figure 4A–D). In this specimen, the operculum and the preopercular were displaced sideways at an angle of 45°. The X-ray image (Figure 4D) showed that the operculum was curved instead of straight. The preopercular was normal. The operculum and preopercular on the right side of the fish appeared normal. Also, the branchiostegal rays were shown to be deformed significantly.

3. Genetic analyses

Due to issues with DNA quality, only seven of the 12 specimens from Iraq could be genotyped for microsatellite analysis. Bayesian Structure analyses placed the seven

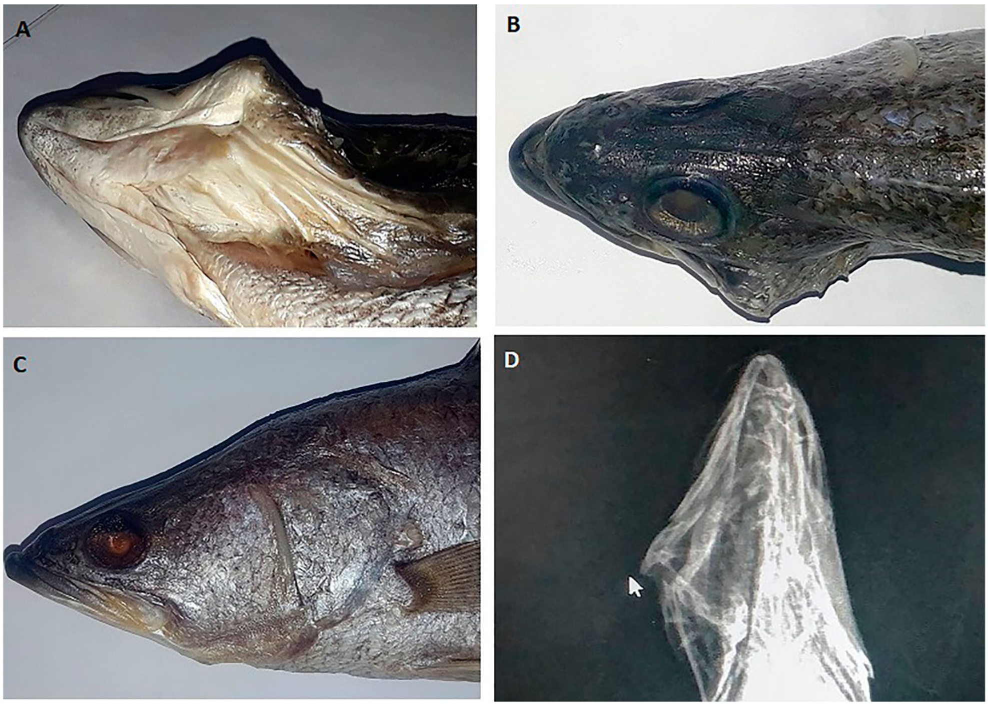

Figure 4. Heads of specimens of *Lates calcarifer* collected from the Iraqi waters. **A,** abnormal specimen showing venter-lateral view; **B,** abnormal specimen showing dorsal view; **C,** abnormal specimen showing normal left side operculum; **D,** an x-ray of the head of the specimen with abnormal operculum.

L. calcarifer specimens with high affinity into the genetic cluster's indicative of fish from either Australia or Thailand/Vietnam (Figure 5). Three specimens had >90% *q*-membership to the Australian cluster, and four specimens had >95% *q*-membership to the cluster that comprised Thailand, Vietnam, and Cambodia. There was no relationship between the location of the sampling of barramundi from Iraq, and the genetic cluster in which they were placed. Due to the strong genetic structure present among populations of *L. calcarifer* across its south-east Asian distribution (Jerry and Smith-Keune 2014), these results indicate that the fish are unlikely to be native to the Arabian Gulf or related to the nearest geographical genetic cluster analyzed of *L. calcarifer* from India.

Discussion

The Iraqi specimens of *L. calcarifer* collected and analysed in the present study represent the first confirmed records of wild-caught fish of this species from the Arabian Gulf. Genetic structure analyses indicated that the fish possess genome ancestry most closely with those from Australia (three specimens) and Thailand/Vietnam (four specimens) and thus confirm that the species is not native to the region and that the specimens likely originated as escapees from farmed populations stocked with fingerlings from these two genetic populations. Additional support for the fish being escapees and not part of a locally breeding population was that barramundi caught at the two locations in Iraq represented a mix of genome ancestry to both Australia and Thailand clusters.

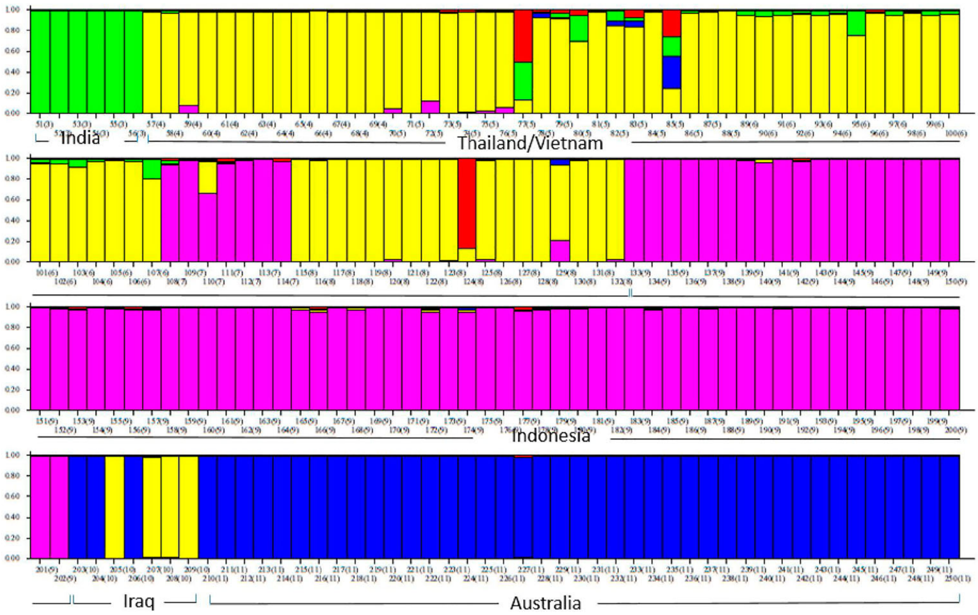

Figure 5. Structure analysis ($k = 4$) of barramundi genotyped at 16 microsatellite loci from India (green cluster), Thailand/Vietnam (yellow cluster), Indonesia (pink cluster) and Australia (blue cluster). Barramundi sampled from Iraq show genome ancestry against either Australian or Thailand/Vietnam genetic clusters. Numbers on x-axis represent sample ID of fish.

Although not cultivated in Iraq, *L. calcarifer* is farmed in the southern Arabian Gulf in seacages around Bandar Aftab, Hormozgan Province, Iran. For farming operations in Iran, fingerlings are known to have been sourced as seedstock from Australia and Thailand (Nisha Co; http://www.niksa-co.com/partner.html; pers. comm). Although no fish escape events from seacages have been documented in Iran to our knowledge, it is common for *L. calcarifer* to escape from aquaculture cages, survive and establish themselves in the wild (Fraser et al. 2004; Fraser and De Nys 2005, 2011; Noble et al. 2014). Escapees also have been recorded as dispersing from the point of their escape, which may be the source of the specimens caught in Iraq. There are also two prior reports of this species caught in Iran. The first is the presence of two images of this species in the photo section of Fishbase (https://fishbase.cn/photos/ThumbnailsSummary.php?Genus=Lates&Species=calcarifer). These two photos show two men holding *L. calcarifer* fish collected from Iran. After personal contact by one of the authors (LAJ) with the men in the photo, it was stated that the fish they held in the pictures were taken from aquaculture facilities. The other mention was that of Eagderi et al. (2019), which is again based on aquaculture specimens.

No other substantiated reports of *L. calcarifer* occurring in the Arabian Gulf exist. Pethiyagoda and Gill (2012) mentioned the Arabian Gulf in the distribution of *L. calcarifer*; however, they based their assumption on Pusey et al. (2004) and FAO (2011). Checking these two references, it appears that Pusey et al. (2004) mentioned that the species occurred on the eastern coasts of the Arabian Gulf but provided no evidence to back up this occurrence. This report of the species from the locality is considered an incomplete record. At the same time, in the map of the distribution of *L. calcarifer* shown in FAO (2011), the Arabian Gulf is excluded from the geographical distribution of this species. The nearest locality where specimens of *L. calcarifer* were collected is the western coast of India at Daman and Diu, Goa, Bhidiya Harbour, and Bharuch Estuary, Gujarat (GBIF 2020). Such documentation and the recent introduction of barramundi *L. calcarifer* to the Arabian Gulf for aquaculture and genetic structure analyses suggest that the Iraqi records are non-indigenous. *Lates calcarifer* is known to be a near-shore migratory species that will migrate to the mouths of rivers and estuaries to spawn, where after juveniles move upriver to undergo the first phase of their development as males (Russell 2014). Moore and Reynold (1982) reported on an extensive migration performed by *L. calcarifer* individuals in Papua New Guinea to reach their spawning ground. Noble et al. (2014) found that escaped individuals move away from the point of release. Therefore, it is highly possible that *L. calcarifer* caught in Iraqi waters originated from farms in western Iran and migrated northwards along the Arabian Gulf and into the Shatt Al-Arab River estuary for breeding. The putative origin of the barramundi sampled as being non-indigenous escapees from sea-cage aquaculture that then have migrated to regions of the Gulf where estuarine systems are present is of concern, as *L. calcarifer* is a hardy species and has been previously reported to have established feral populations outside the species' natural range in French Polynesia after being introduced for sea-cage aquaculture (Jerry 2014); consequently, further sampling should be undertaken with a focus on new recruits to determine if the species is breeding and now established.

The Iraqi specimens of *L. calcarifer* differ from the specimens of the same species examined by Pethiyagoda and Gill (2012), and the two new species, *L. lakdiva* and *L. uwisara*, described from the Indo-Pacific region recently by the same authors in the following set of characters: several rows of scales in transverse line between the base of third dorsal fin spine and lateral line, number of serrae on the posterior edge of preoperculum and the ratio of 3rd to 2nd spine of anal fin (Table 3). Such differences in the morphological characteristics of the Iraqi specimens of *L. calcarifer* support the suggestion given by Pethiyagoda and Gill (2012) that individuals of this species obtained from different localities may show significant morphological differences (Pusey et al. 2004).

Tave et al. (1983) were believed to be the first to use the term 'saddleback syndrome' to describe the lack of a dorsal fin in tilapia *Sarotherodon aureus*. Several reports of the syndrome in farmed fishes are on record within the literature (e.g. Koumoundouros 2010;

Table 3. Meristic characters comparison between specimens of Lates calcarifer collected from Iraqi waters and those of other species of Lates found in the Indo-Pacific region.

Characters	*Lates calcarifer* Pethiyagoda and Gill (2012)	*Lates lakdiva* Pethiyagoda and Gill (2012)	*Lates uwisara* Pethiyagoda and Gill (2012)	*Lates calcarifer* Present study
Number of rows of scales in transverse line between base of third dorsal fin spine and lateral line	6	5	7	4.5, 5.5, 6.5
Number of serrae on posterior edge of preoperculum	16–26	31–34	26–34	24–32
Ratio of 3rd to 2nd spine length of anal fin	2.1–2.8	3–3.5	1.42–1.52	1.23–1.67

Jawad and Al-Mamry 2012; Yue et al. 2022), and it has also been described in fishes in the wild (Koumoundouros 2008; Diggles 2013; Pollock 2015).

Saddleback syndrome has always been related to an abnormality of the dorsal fin, which leads to missing spinous and soft parts of the fin's rigid spines and probably the lepidotrichia. According to such deformity, the pterygiophores supporting the spines and rays usually appeared with severe abnormalities (Tave et al. 1983; Koumoundouros et al. 2001; Koumoundouros 2008; Cobcroft et al. 2001; Diggles 2013). In the specimen examined, saddleback has been shown to affect the anterior part of the dorsal fin (Tave et al. 1983). Such results agree with those of Diggles (2013), Pollock (2015), Koumoundouros et al. (2001), and Jawad and Ibrahim (2018). The results also showed that the lack of the spinous part in the examined specimen is not necessarily linked to abnormalities of the subjacent pterygiophores. A similar result was obtained by Fragkoulis et al. (2017) on the European sea bass *Dicentrarchus labrax*.

The first criterion fish consumers usually look for in the fish they want is the general shape of the fish's body. If the body shape is affected by skeletal anomalies, severe or minor alterations might deter the buyer from buying such specimens. The continuous range and discontinuous effects are two categories that can result from the alteration of the fish's body shape, which both depend on the severity of the anomaly. The continuous range is expressed through the haemal lordosis (Sfakianakis et al. 2006), while the discontinuous effects can be represented in the gill-cover abnormalities or the saddleback syndrome since their presence may be associated with other severe morphological alterations (Koumoundouros et al. 1997a; Setiadi et al. 2006). The abnormal specimen does not show signs of physical injury or healed scarring in the dorsal area of any saddleback-affected sites. This suggests that physical injuries were not the cause of saddleback deformities. Those physical injuries are caused by trapping fish in gill nets, an assumption that was deemed at the time of the emergence of this deformity in some parts of the world (Browder et al. 1993).

Tave et al. (1983) found that saddleback in tilapia, *Oreochromis aurea*, had a genetic basis and might be due to developmental deformities. On the other hand, Browder et al. (1993) believed a gene hypothesis is improbable for wild fish populations due to their large population sizes compared to aquaculture populations. Instead, Browder et al. (1993) suggested environmental factors; their observations showed that ten fish species belonging to different groups contributed to outbreaks of a saddleback anomaly within certain contaminated areas in Biscayne Bay. Environmental factors during early hatchery phases can impact swim bladder inflation and bone mineralisation resulting in saddleback abnormality. This mechanism was proposed by Browder et al. (1993) and Koumoundouros et al. (2001). In the wild, the saddleback deformity has been related to environmental contamination (Browder et al. 1993; Koumoundouros et al. 2001). Pollution from anthropogenic activities may directly influence fish's early life history stages (Browder et al. 1993; Gagnon and Rawson 2009). Indirect effects may be through increased disease rates (Sindermann 1996) or bone development disorder by exposure to other anthropogenically mediated emphases such as hypoxia or pH fluctuations (Witten and Huysseeune 2009).

On the other hand, cases of deformities in the operculum are mainly observed in aquaculture (Galeotti et al. 2000), and larval stages of fishes (Gapasin et al. 1998; Yue et al.

2022), but their presence in the wild is sporadic (Divanach et al. 1996; Jawad and Ibrahim 2017).

Koumoundouros et al. (1997a) found that gill-cover deformity was mainly caused by an inside folding of the operculum and/or suboperculum, rarely by bone atrophy, and was frequently correlated with malformations of the branchiostegal rays. The branchiostegal rays in the present case of *L. calcarifer* were deformed. Therefore, the suggestion of Koumoundouros et al. (1997b) can be applied here. Operculum deformity has been shown to increase the sensitivity to oxygen stress and a predisposition to mycobacterial infections (Paperna 1978). In contrast, during the larval stage, their incidence has been shown to correlate negatively with the growth rate of the fish (Koumoundouros et al. 1997b).

The only records on the presence of abnormalities in *L. calcarifer* originated from aquaculture specimens as with the case of any other fish species used in aquaculture practices, and such cases are related to larval stages of the fish (Fraser et al. 2004; Fraser and De Nys 2005, 2011).

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Disclosure statement

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