Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 52, No. 2 June 2023
pages (228-239)

sciendo

ISSN 1730-413X
eISSN 1897-3191

Morphological asymmetry in two marine fish species *Acanthopagrus arabicus* (Family: Sparidae) and *Planiliza klunzingeri* (Family: Mugilidae), collected from brackish and freshwater environments in southern Iraq

by

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DOI: **https://doi.org/10.26881/oahs-2023.2.07**
Category: **Original research paper**
Received: **August 9, 2022**
Accepted: **April 11, 2023**

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Abstract

Morphological asymmetry was analysed in two marine fish species *Acanthopagrus arabicus* and *Planiliza klunzingeri,* in brackish and freshwater habitats in southern Iraq. For both species, specimens from the Shatt al-Arab River and Shatt al-Basrah Canal exhibited greater asymmetry values for snout length. In both locations examined, the levels of asymmetry of the physical traits increased as the fish grew. The high levels of asymmetry in the two fish species may be linked to heavy metal pollutants in the two aquatic environments studied.

Key words: Sparidae, Mugilidae, morphology, meristic characters, Shatt al-Arab River, Shatt al-Basrah Canal

online at www.oandhs.ug.edu.pl

1. Introduction

Environmental degradation can create noticeable changes in the biology of individuals and populations, possibly resulting in the extirpation of species (Koprivnikar et al. 2006). Additional indirect effects may result in decreased growth, increased disease vulnerability, and more significant morphological deformities (Jawad & Abed 2020). Rapid alerts to such negative impacts allow scientists and resource administrators to adopt corrective actions that may prevent additional habitat degradation and population failures.

One morphological characteristic associated with habitat changes and environmental impact is fluctuating asymmetry, defined as the arbitrary divergence from normal bilateral symmetry (Van Valen, 1962). The homeostatic regulation of morphological development may be adversely affected when individuals are subjected to either anthropogenic or natural impacts, which may be reflected in the development of bilateral asymmetry. Although no bilateral characters are perfectly symmetric, higher levels of asymmetry may result when organisms are subjected to various environmental impacts during their developmental process (Allenbach 2011). Asymmetry levels may also be affected by biological activities that individuals are subjected to, such as inbreeding (e.g., Leamy & Klingenberg 2005). Quantifying disparities in morphological traits represents a cheap method for defining the overall health rank of populations (Jawad & Abed 2020).

Pollution is reported to be the causative agent for several cases of skeletal deformities in fishes (Härdig et al. 1988). Pollutants can produce abnormal changes in the skeletal system of the fish in two ways, (1) by alteration of the biological processes necessary for maintaining the biochemical integrity of bone, or (2) through neuromuscular effects, which lead to deformities without a chemical change in vertebral composition (Raj et al. 2004). Trace elements such as cadmium and mercury can decrease collagen synthesis (Bhatnager & Hussain 1977). Arsenic binds certain enzymatic sulfhydryl groups, acting as a protoplasmic poison (Luh et al. 1973). Cadmium inhibits the cross-linking (i.e., stiffening) of collagen. It causes pathological bone changes that probably lead to the altered structural integrity of bone (Iguchi and Sano 1982) and reduced proline hydroxylation and collagen biosynthesis (Vistica et al. 1977). Pollutants might also act indirectly, increasing susceptibility to diseases and vertebral damage.

Oil is one source of trace metal pollution in the aquatic environment. Although oil dispersants make oil more bioavailable to oil-eating bacteria (Redmond & Valentine 2012), their short and long-term effects on marine flora and fauna have not been adequately elucidated (White et al. 2012). Rico-Martínez et al. (2013) measured the acute toxicity of dispersed crude oil on rotifers. They found that the combination of oil and dispersant produces higher toxicity than the use of only a single compound at a time (Ralph & Burchett 1998).

The Arabian yellowfin seabream, *A. arabicus,* is a marine pelagic-neritic species generally found at depths down to 50 m (Randall 1995) and ranging from southern Kuwait in the Arabian Gulf southwards to Trivandrum in southwestern India (Iwatsuki 2013) and from Iranian shorelines of the Gulf (Esmaeili et al. 2015). However, several studies have recorded the occurrence of *A. arabicus* from different locations in the freshwater systems of Iraq (Yesser 2016). The leading food of this species is echinoderms, worms, crustaceans, and molluscs (Bauchot & Smith 1984). Klunzinger's Mullet, *P. klunzingeri,* is generally found in marine demersal habitats ranging from the Arabian Gulf to the western coast of India (Randall 1995). However, the species has also been collected from several locations in the freshwater systems of Iraq (Mohamed and Abood 2017). *A. arabicus* and *P. klunzingeri* were selected for the current study because they are commonly found in marine and brackish water environments.

The current investigation aimed to assess the levels of bilateral asymmetry in two common marine fish species found in brackish and freshwater environments in southern Iraq, *A. arabicus* and *P. klunzingeri*. The two locations chosen for this investigation are proved to be heavily polluted (Al-Hejuje et al. 2017, Hassan et al. 2018, Zahraw et al. 2019, Allafta and Opp 2020). Therefore, they are suitable for the asymmetry study.

2.Materials and methods

2.1. Fish specimens

The Shatt al-Arab River and Shatt al-Basrah Canal are well known to be heavily polluted (Al-Saad et al 2015, Al-Hejuje et al. 2017, Hassan et al. 2018) and were therefore selected for the present study. A total of 200 fish specimens of *A. arabicus* and *P. klunzingeri* (Fig. 1) were collected from a fisher operating in the Shatt al-Basrah Canal (brackish water environment) and Shatt al-Arab River (freshwater environment), including 50 specimens for each species from each location (Fig. 2). The fish were taken in gillnets (200 m × 1.30 m, 25-, 40 and 50 mm mesh) at a depth of 12 m between January and September 2018. Water samples were also taken from the same locations.

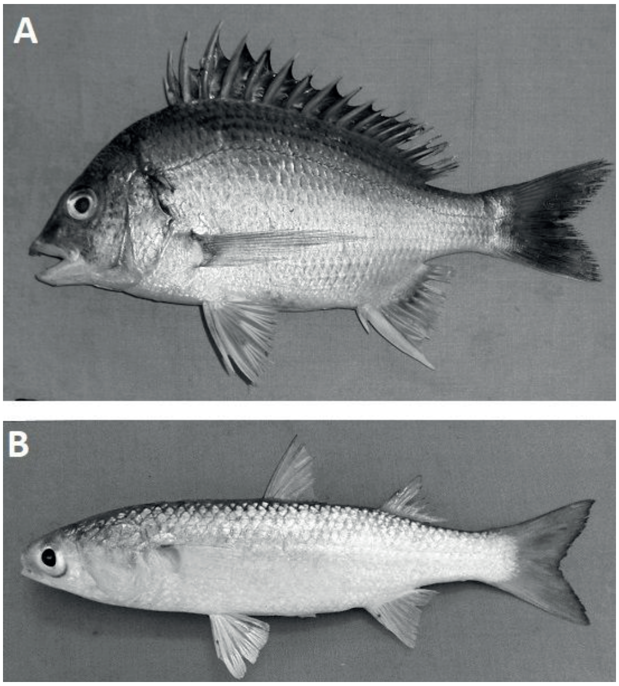

Figure 1

A) *Acanthopagrus arabicus* (176 mm TL) collected from Shatt al-Arab River; **B)** *Planiliza klunzingeri* (180 mm TL) collected from Shatt al-Arab River

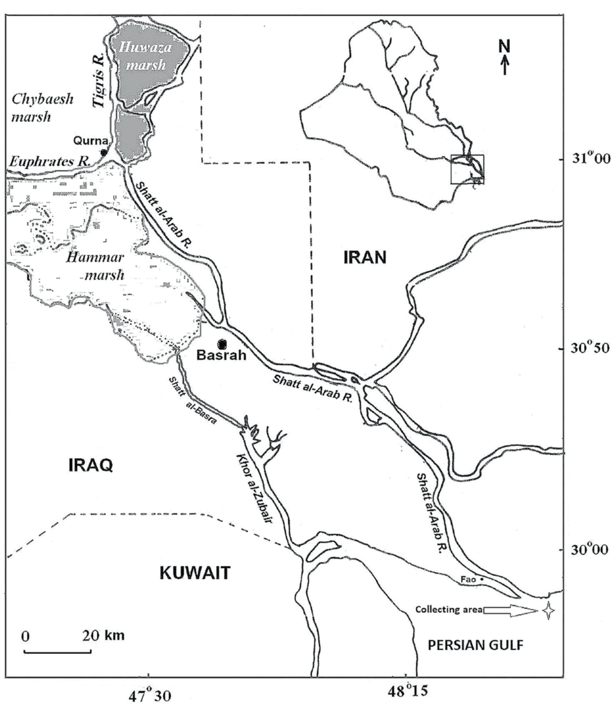

Figure 2

Map showing sampling locations

2.2. Water samples

Since fish live in water, they directly react with this environment which also provides the food that enters their body and is metabolised (Yavuzcan et al. 2017). Therefore, water sampling was selected to indicate pollution in the studied areas. Before use, 5% nitric acid was added to the water sampling bottles and thoroughly washed with distilled de-ionised water. Al-Saad et al. (2015) followed the method for water sampling. Polyethene sampling bottles have been washed at least three times before sampling at each site. Clean polyethylene containers were dipped about 10 cm underneath the water surface. Approximately 0.5 l of water samples were taken at each station. Samples were acidified with 10% HNO_3, cooled with ice on-site, and transported to the laboratory, where they were filtered through a 0.45 μm micropore membrane filter and retained at 4°C pending analysis.

2.3. Sediment samples

As with water, sediment is considered a good indicator of the pollution load at a given location (Hahladakis et al. 2013). Consequently, samples of sediment were collected from the studied areas. Sediment samples were obtained using a grab sampler. They were taken to the laboratory and kept firmly closed at room temperature. Later, sediment samples were crushed and filtered through a 160 μm sieve. The sieved samples were packed in polyethylene bags and stored below –20°C before analysis. Samples were weighed, positioned into digestion bombs with 10 ml of HNO_3/HCl (1:3 v/v), and digested in a microwave digestion system. Sediment analysis was carried out according to the methodology of Binning & Baird (2001).

2.4. Chemical analysis

Fish specimens were taken directly to the laboratory after being caught and kept on ice during the journey. The total length and weight of the fish were noted. All specimens were held at –30°C until analysis. The method of Bernhard (1976) was followed in the preparation and analysis of the fish samples. Before analysis, muscle tissues taken from the area above the pectoral fin were removed and whipped in a mixer, and one gram of the mixed material was digested. A microwave digestion system (CEM Mars 5 ESP 1500 PLUS) was utilised to prepare the specimens for analysis. Recently, microwave digestion procedures have frequently been used in investigations (Kucuksezgin et al. 2001), which involve rapid digestion and fewer chances of impurity throughout the process. Muscle tissues (without skin) were mixed with 5 ml HNO_3 (65%) and 5 ml H_2SO_4 in polypropylene vials. After 10 minutes of mixing, 1 ml H_2O_2 was added, and samples were placed in a microwave (1 hour at 105°C). After digestion, the residues were diluted to 25 ml with HNO_3 (0.3%)

Fe, Cu, Pb, Cr, Ni, and Cd were detected in all samples using ICP–AES (Varian-Terra Model Liberty II). Identification limits are summarised in Table 1. These limits represent the lowermost analytical levels differentiated regarding quality at a definite assurance value from background levels. The accuracy of the analytical method was tested by analysing comparable standard samples (water: SRM-143d, National Institute of Standards and Technology; sediment: CRM-277, Community Bureau of Reference; fish: DORM-2, National Research Council). Recovery rates ranged from 79 to 96% for all components analysed.

Table 1

Spectral lines used in emission measurements and the instrumental detection limit for the elements measured by using ICP–AES

Element	Wave length (nm)	Instrumental detection limit (µg l^{-1})
Cd	227.9	0.001
Cr	268.7	0.006
Cu	325.9	0.013
Fe	258.6	0.07
Ni	230.7	0.05
Pb	221.5	0.05

2.5. Statistical analysis

The body features (Fig. 3) assessed for bilateral asymmetry in the current investigation were previously used in earlier reports (Jawad et al. 2010, 2016; Hechter et al. 2000). These morphological characteristics were proved to be quickly affected by environmental factors such as pollution (Jawad et al. 2010). The characters assessed included external features (4 characters) and meristic traits (2 features): (1) snout length (SnL); (2) eye diameter (ED); (3) head length (HL); (4) caudal peduncle length (CPL); (5) number of the lateral line scales (LLS); and (6) number of pectoral fin rays (PFR). External body features were computed to the nearest 0.1 cm using digital callipers. Lateral line scales were counted for *A. arabicus* only, as there is no lateral line in the mugilid species *P. klunzingeri*. To avoid possible computation errors, all measurements were completed by the same person. The square coefficient of asymmetry variation (CV^2 a) for meristic and morphometric traits was assessed (Valentine et al. 1973) as follows:

$$CV^2\ a = S_{l-r}\ X\ 100/x_{l+r}$$

In the equation, we see this: S_{l-r} is the standard deviation of the signed variance, and X_{l+r} is the character's mean, computed by totalling the absolute scores for both sides and dividing by the sample size. To remove variation related to growth in external traits (non-discrete, measurable), the body's external attributes were divided by a predictable standardising measurement (head length, from the mouth to the posterior edge of the operculum). Every external feature was dealt with similarly, and the squared coefficient of asymmetry was determined. The ANOVA test evaluated the coefficients of asymmetry between the diverse total length groups. Further to the ANOVA test, a Tukey HSD post hoc test was used to assess whether the alterations were significant between couple assessments of length groups (StatSoft, Inc., 1991). Fish specimens were categorised into ranks for every character examined based on their total length. Three- and four-size ranks of fishes of both species were collected from both sampling sites. Coefficients of asymmetry were compared between the fish groups of each species and the collaborative groups using ANOVA tests.

3.Results

Table 2 summarises the water quality constituents at the two sampling sites compared with reference freshwater values. Heavy metal concentrations in the waters of the Shatt al-Arab River and Shatt al-Basrah Canal were reduced in the sequence of Fe > Cu > Pb > Cr > Ni > Cd.

Table 3 summarises the total concentrations of metals in the sediment samples at the two sampling sites compared with other sediments estimates that have been published worldwide. Heavy metal concentrations in the sediments of the Shatt al-Arab River and Shatt al-Basrah Canal were reduced in the sequence of Fe > Ni > Cu > Cr > Pb > Cd.

The average concentrations of these metals in the muscle samples of *A. arabicus* and *P. klunzingeri* are summarised in Table 4. The metal levels in the muscle samples were reduced as Fe > Ni > Cu > Cr > Pb > Cd for both *A. arabicus* and *P. klunzingeri*.

The bilateral asymmetry results for six external body traits of *A. arabicus* and five traits of *P. klunzingeri* are summarised in Table 5. In the two species investigated, the asymmetry levels of the external morphological traits were greater in the Shatt al-Arab

Table 2

The heavy metal concentrations in the waters of the Shatt al-Arab River and Shatt al-Basrah Canal and comparison with guidelines and different literature (Mean ± SD) (mg l^{-1})

Location	Cd	Cr	Cu	Fe	Ni	Pb	Reference
Shatt al-Arab River	0.02 ± 0.002	0.009 ± 0.005	0.01 ± 0.001	0.9 ± 0.4	0.004 ± 0.002	0.03 ± 0.007	Present study
Shatt al-Basrah Canal	0.02 ± 0.012	0.059 ± 0.004	0.01 ± 0.003	0.89 ± 0.95	0.059 ± 0.006	0.025 ± 0.007	
Shatt al-Arab River	3.01	-	2.35	89.45	9.51	7.58	Al-Hejuje et al. 2017
WHO	0.01	0.05	2	-	0.02	0.05	WHO, 1993
EC	5	50	2	0.2	20	10	EC, 1989

Table 3

The heavy metal concentrations in the Shatt al-Arab River and Shatt al-Basrah Canal sediments and comparison with sediment quality guideline and different literature (Mean ± SD) (mg kg^{-1} dry weight)

Location	Cd	Cr	Cu	Fe	Ni	Pb	Reference
Shatt al-Arab River	0.76 ± 0.4	84.47 ± 4.4	28.9 ± 4.7	25272 ± 920	29.71 ± 7.4	2.38 ± 2.1	Present study
Shatt al-Basrah Canal	0.76 ± 0.1	13.41 ± 2.1	22.56 ± 9.8	22732 ± 4084	28.21 ± 6.7	4.03 ± 2.0	
Shatt al-Arab River	0.17 – 2.8	81.8 – 112.4	21.8 – 44.0	5452 – 7584	530 – 811	11.3 – 28.1	Abaychi and Douable 1985
Shatt al-Arab River	0.3	48.1	39.6	6205	57.2	19.0	Abaychi and Al-Saad 1988

Table 4

The heavy metal concentrations of *Acanthopagrus arabicus* and *Planiliza klunzingeri* samples from the Shatt al-Arab River and Shatt al-Basrah Canal (Mean ± SD) (mg kg^{-1} wet weight)

Location/species	Cd	Cr	Cu	Fe	Ni	Pb	Reference
Shatt al-Arab River							
Acanthopagrus arabicus	0.18 ± 0.07	1.19 ± 0.73	3.85 ± 2.18	16.65 ± 6.99	1.28 ± 1.18	2.15 ± 2.09	Present study
Planiliza klunzingeri	0.19 ± 0.06	1.20 ± 0.73	3.90 ± 2.20	16.95 ± 6.89	1.30 ± 1.19	2.17 ± 2.12	
Shatt al-Basrah Canal							
Acanthopagrus arabicus	0.17 ± 0.08	1.18 ± 0.74	3.81 ± 2.16	16.96 ± 6.79	1.29 ± 1.17	2.15 ± 2.10	Present study
Planiliza klunzingeri	0.20 ± 0.05	1.19 ± 0.71	3.85 ± 2.13	16.99 ± 6.69	1.99 ± 6.69	2.17 ± 2.15	
Avşar Dam Lake, Turkey	0.17 ± 0.07	1.18 ± 0.73	3.85 ± 2.18	16.55 ± 6.99	1.27 ± 1.18	2.14 ± 2.09	Öztürk et al. 2009

Table 5

Squared coefficient asymmetry (CV^2a) values and character means (*Xr + 1*) of *Acanthopagrus arabicus* and *Planiliza klunzingeri* collected from Shatt al-Arab River and Shatt al-Basrah Canal, Iraq

	Location	Characters					
		Snout length	Eye diameter	Head length	Caudal peduncle length	Pectoral fin ray count	Number of lateral line scales
Acanthopagrus arabicus							
CV^2a	Shatt al-Arab River	89.371	78.874	63.412	75.981	65.412	77.982
	Shatt al-Basrah Canal	87.964	75.651	64.914	73.912	65.298	74.329
N	Shatt al-Arab River	50	50	50	50	50	50
	Shatt al-Basrah Canal	50	50	50	50	50	50
Character mean (Xr + 1)	Shatt al-Arab River	0.9	1.4	3.65	1.3	12.5	37
	Shatt al-Basrah Canal	0.80	1.29	3.59	1.29	12.40	36
% of individuals with asymmetry	Shatt al-Arab River	83	85	86	89	86	87
	Shatt al-Basrah Canal	81	82	82	86	81	82
Planiliza klunzingeri							
CV^2a	Shatt al-Arab River	92.751	81.376	61.286	79.518	73.298	-
	Shatt al-Basrah Canal	87.251	79.521	69.825	77.538	70.156	-
N	Shatt al-Arab River	50	50	50	50	50	-
	Shatt al-Basrah Canal	50	50	50	50	50	-
Character mean (Xr + 1)	Shatt al-Arab River	0.7	1.95	3.30	1.55	13.5	-
	Shatt al-Basrah Canal	0.6	1.86	3.29	1.53	13.3	-
% of individuals with asymmetry	Shatt al-Arab River	89	87	88	91	89	-
	Shatt al-Basrah Canal	76	74	81	89	87	-

River than in the Shatt al-Basrah Canal. At both locations, asymmetry levels were most significant for snout length and lowest for head length in both species (Tables 5, Figures 1, 3).

Individuals of *A. arabicus* and *P. klunzingeri* from both locations were aggregated into length groups (Tables 6 and 7). Increasing levels of asymmetry were noted for each external body feature investigated.

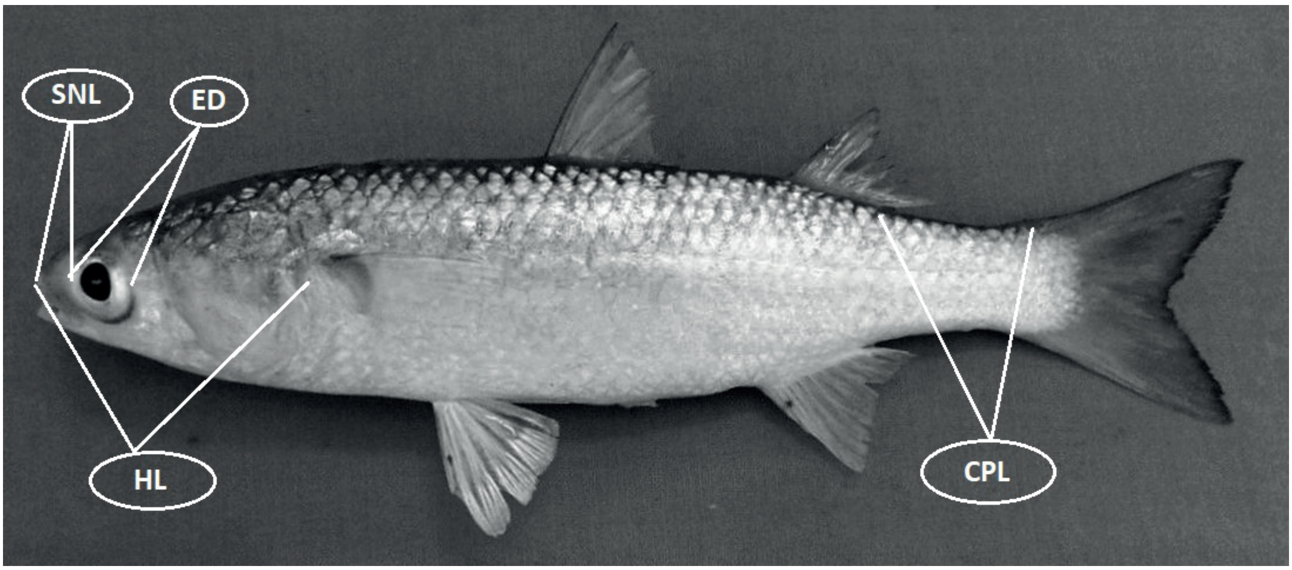

Figure 2

Planiliza klunzingeri (180 mm TL) collected from Shatt al-Arab River showing the morphometric characters used in the asymmetry study. Head length, HL; snout length, SNL; eye diameter, ED; caudal peduncle length, CPL.

4. Discussion

The Cd, Cr, Cu, Fe, Ni, and Pb levels in the water at the two sampling sites were comparable with universal values. Except for Cd, Fe, and Pb, the heavy metal levels in the water samples did not exceed the WHO (World Health Organization, 1993) and EC (European Community 1998*)* guidelines (Table 2). The high Pb, Cd, and Fe levels in the water samples in the Shatt Al-Arab River agreed with previously recorded raised levels (Al-Saffie 2005, Hassan 2007, Al-Hejuje et al. 2017). Mastoi et al. (2008) obtained similar elevated values for Cd, which they attributed to the overflow of chemical fertilisers originating from agricultural areas. The elevated values may also be linked to land-based point of origin releases associated with the rapid development of Basrah city centre (Al-Hejuje 1997). The high levels of Cd may also be due to various human-related effects connected to disparities in population density, wastewater releases, and manufacturing events. The Shatt al-Arab River is widely used for cleaning cars. Indeed, Al-Hejuje et al. (2017) remarked that cities are the primary sources of heavy metals in the river. In general, the variation in the levels of heavy metals could be related to several influences. For example, plankton and other water plants in the river may absorb ionic metals. Sandstorms and high fuel consumption may also be contributory factors, particularly during the summer. Electrical energy production also discharges large quantities of metals, notably lead compounds (Al-Hejuje et al. 2017).

The Cd, Cr, Cu, and Fe levels obtained from the sediment samples at the two sampling sites were either comparable to or exceeded the results previously obtained by other investigators.

The Cd, Cr, Ni, and Pb levels found in the tissue samples of *A. arabicus* and *P. klunzingeri* in the present and other studies (Öztürk et al. 2009) exceedsafe levels, which could represent a health hazard for human consumption.

Since water in the Shatt al-Arab River is widely used for agricultural irrigation, and water from the Shatt al-Basrah Canal mixes with the water in the southern marshes of Iraq, the focus of pollution research should be concentrated on these two water bodies in terms of both environmental impact and public health issues.

High levels of bilateral asymmetry for snout length and eye lens diameter have previously been reported in numerous freshwater and marine fish species (Al-Hassan et al. 1990, Jawad 2013, Jawad et al. 2016, Jawad & Abed 2020). Such agreement in the finding of bilateral asymmetry can clarify the tendency of this characteristic to steer deviations in the niche. Consequently, it can be exploited as an operative stress biomarker in aquatic animal niches. Otherwise, head length displayed lower bilateral asymmetry levels in both fish species examined from both locations investigated, which suggests that this feature may be more vulnerable to ecological impact measures comprising contamination. The lesser bilateral asymmetry levels obtained for head length in both species could be explained on the grounds that the growing time of head length may not coincide with the occurrence of opposing ecological measures (Jawad 2003).

Analysis of variance showed that bilateral asymmetry levels for the external body traits examined diverged significantly between *A. arabicus* and *P. klunzingeri* from the two locations examined ($p < 0.001$). The present results of heavy metals showed a clear difference in the concentrations in the two locations. These results were also supported by several other reports on water, sediments, and fish tissues in both locations investigated (Al-Hejuje et al. 2017). Numerous other writings from around the world have proved that pollution was most likely responsible for high levels of bilateral asymmetry (e.g., Elie & Girard 2014). Generally speaking, the toxicity of frequent trace metals and other chemicals is revealed to surge with the growth in both temperature and salinity (Elie & Girard 2014). The average water temperature in the two areas investigated was shown to be high (Ahmed & Ghazi 2014), which supports this finding. Besides, salinity as an influence augmenting the toxicity of pollutants in this instance could be due to the average salinity level of water in the Shatt al-Arab and Shatt al-Basrah Canal (Ahmed & Ghazi 2014).

Animals living in marine and freshwater habitats globally (Elie & Girard 2014) and in Iraq were influenced by chemical and organic pollution, resulting in external body feature anomalies (Jawad et al. 2017).

In the present report, the ANOVA test analysis shows that the specimens falling near the upper size limits of *A. arabicus* and *P. klunzingeri* had greater bilateral asymmetry values than those found at the lower size limits ($p < 0.001$). The disparities in the bilateral asymmetry of the six morphometric features of *A. arabicus* and five morphological characteristics of *P. klunzingeri* increased with fish length in both species (Tables 6 and 7). This is because of the result of the decline in fish growth; the characteristic means are often lower in young individual groups than in large individual groups (Valentine et al. 1973). Analogous findings concerning fish species from California, U.S.A., were obtained by Valentine et al. (1973), who

Table 6

Squared coefficient asymmetry (CV^2a) values and character means (*Xr+ 1*) of *Acanthopagrus arabicus* collected from Shatt al-Arab River and Shatt al-Basrah Canal, Iraq

Character	CV^2_a	N	Character mean	% of individuals with asymmetry
Acanthopagrus arabicus				
Shatt al-Arab River				
Snout length				
101 – 130	76.354	10	0.90	70
131 – 150	78.426	25	0.87	86
151 – 180	80.631	15	0.86	92
Eye diameter				
101 – 130	65.981	10	1.40	67
131 – 150	67.421	25	1.38	87
151 – 180	72.332	15	1.40	93
Head length				
101 – 130	77.541	10	3.64	88
131 – 150	79.981	25	3.62	79
151 – 180	81.321	15	3.65	91
Caudal peduncle length				
101 -130	65.552	10	1.29	95
131 – 150	69.442	25	1.30	93
151 – 180	71.332	15	1.28	86
Number of pectoral fin rays				
101 – 130	67.771	10	12.4	88
131 – 150	69.991	25	12.5	79
151 – 180	72.441	15	12.2	95
Number of lateral line scales				
101 – 130	81.932	10	37	93
131 – 150	82.554	25	36	90
151 – 180	84.221	15	35	87
Shatt al-Basrah Canal				
Snout length				
101 – 130	55.221	10	0.79	88
131 – 150	56.551	25	0.80	76
151 – 180	57.112	15	0.78	82
Eye diameter				
101 – 130	61.331	10	1.28	91
131 – 150	61.998	25	1.29	87
151 – 180	62.778	15	1.27	88
Head length				
101 – 130	73.221	10	3.58	77
131 – 150	74.001	25	3.59	43
151 – 180	75.112	15	3.57	88
Caudal peduncle length				
101 – 130	81.239	10	1.28	92
131 – 150	81.998	25	1.29	90
151 – 180	82.552	15	1.29	94
Number of pectoral fin rays				
101 – 130	77.321	10	12.40	89
131 – 150	77.998	25	12.39	85
151 – 180	78.999	15	12.38	84
Number of lateral line scales				
101 – 130	78.8871	10	36	78
131 – 150	78.999	25	36	89
151 – 180	79.932	15	36	95

Table 7

Squared coefficient asymmetry (CV^2a) values and character means (*Xr+ 1*) of *Planiliza klunzingeri* collected from Shatt al-Arab River and Shatt al-Basrah Canal, Iraq

Character	CV^2_a	N	Character mean	% of individuals with asymmetry
Planiliza klunzingeri				
Shatt al-Arab River				
Snout length				
141 – 150	89.751	20	0.70	89
151 – 160	90.332	15	0.68	93
161 – 170	91.256	10	0.70	96
171 – 180	92.665	5	0.69	92
Eye diameter				
141 – 150	81.998	20	1.96	88
151 – 160	83.552	15	1.98	85
161 – 170	84.998	10	1.95	82
171 – 180	85.002	5	1.95	89
Head length				
141 – 150	88.286	20	3.29	78
151 – 160	88.990	15	3.30	77
161 – 170	89.543	10	3.28	75
171 – 180	90.432	5	3.30	86
Caudal peduncle length				
141 – 150	78.998	20	1.49	91
151 – 160	80.442	15	1.54	99
161 – 170	85.678	10	1.55	98
171 – 180	88.965	5	1.53	99
Number of pectoral fin rays				
141 – 150	75.664	20	13.4	77
151 – 160	78.987	15	13.5	69
161 – 170	80.425	10	13.6	89
171 – 180	84.763	5	13.5	98
Shatt al-Basrah Canal				
Snout length				
141 – 150	88.776	15	0.58	77
151 – 160	88.995	20	0.59	86
161 – 170	89.435	10	0.60	87
171 – 180	90.993	5	0.57	89
Eye diameter				
141 – 150	79.998	15	1.85	92
151 – 160	80.554	20	1.87	97
161 – 170	85.667	10	1.86	98
171 – 180	88.798	5	1.84	99
Head length				
141 – 150	68.998	15	3.28	96
151 – 160	69.443	20	3.26	97
161 – 170	71.775	10	3.29	87
171 – 180	72.003	5	3.25	88
Caudal peduncle length				
141 – 150	79.998	15	1.52	84
151 – 160	80.332	20	1.54	85
161 – 170	83.665	10	1.53	88
171 – 180	87.442	5	1.53	89
Number of pectoral fin rays				
141 – 150	80.366	15	13.2	98
151 – 160	83.281	20	13.3	98
161 – 170	84.987	10	13.5	99
171 – 180	87.669	5	13.3	92

recommended that the developmental inconsistencies were linked to a surge in bilateral asymmetry with length (age).

To appraise the values disparity in regularity obtained for the six external body features of *A. arabicus* and *P. klunzingeri*, a valuation was carried out between the report at hand and the levels of the fluctuating asymmetry of fish body external features of other fish species investigated from the same area of the current investigation and other regions around the world (Table 8). The amount of asymmetry of the snout length, the morphometric character with a high asymmetry value, is comparable to that of *Saurida tumbil* obtained from the Arabian Gulf Coast of Iraq (98.77) (Jawad & Abed 2020). On the other hand, it is less than those of *Pentaprion longimanus* (328.29) (Jawad et al. 2011b), *Auxis thazard* (Jawad et al. 2012c), and *Sardinella longiceps* (123.2) (Jawad et al. 2012e). The overall results of this valuation designate that the values of asymmetry in the six and five external body features of *A. arabicus* and *P. klunzingeri,* respectively, are similar in their high value or lower in contrast to other species. Even though the species of fish obtained from various sites stated in this evaluation are dissimilar, the evaluation illustrates the amount of influence of the ecosystem on the body external features of the fish that are vulnerable to the niche's natural status (Jawad et al. 2012e). Built on the outcomes of the current investigation, it is suggested that an administration policy is required to establish an excellent physical environment in the Arabian Gulf waters of Iraq.

Acknowledgements

We thank Declan Quigley of Sea-Fisheries Protection Authority, Eastern Region, Howth, Dublin, Ireland, for checking the manuscript and the English language.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could influence or that could have the appearance of an influence onthe work reported in this paper.

Table 8

Comparison of the coefficient of asymmetry (CV^{2}a) of six and five morphological characters of *Acanthopagrus arabicus* and *Planiliza klunzingeri*, respectively examined in the present study with those of other fish species collected from locations around the world.

Species	Coefficient of asymmetry (CV^2_a)						Reference
	Snout length SnL	Eye diameter ED	Head length HL	Caudal peduncle length CPL	Number of pectoral fin ray PFR	Number of lateral line scales LLS	
Acanthopagrus arabicus Shatt al-Arab River	89.371	78.874	63.412	75.981	65.412	77.982	Present study
Shatt al-Basrah Canal	87.964	75.651	64.914	73.912	65.298	74.329	
Planiliza klunzingeri Shatt al-Arab River	92.751	81.376	61.286	79.518	73.298	81.297	
Shatt al-Basrah Canal	87.251	79.521	69.825	77.538	70.156	80.312	
Saurida tumbil	98.77	87.48	91.92	88.74	79.69	89.96	Jawad and Abed (2020)
Callionymidae *Callionymus margaretae*	19.10	65.00	18.57	-	31.58	-	Al-Mamry et al. (2011b)
Carangidae *Carangoides caeruleopinnatus*	5.65	18.29	2.87	-	10.04	-	Jawad et al. (2011a)
Decapterus russelli	18.37	21.36	-	-	11.55	14.05	Jawad et al. (2010)
Cichlidae *Coptodon guineensis*	20.7	58.3	-	-	-	48.7	Jawad et al. (2016)
Coptodon zillii	33.48	56.09	-	-	15.85	-	Jawad (2002)
Sarotherodon melanotheron	28.4	49.4	-	-	-	48.7	Jawad et al. (2016)
Claroteidae *Chrysichthys auratus*	61.3	60.4	62.8	-	62.1	-	Jawad and Gnohossou (2019)
Clupeidae *Sardinella longiceps*	123.2	125.3	98.4	-	178.7	-	Jawad et al. (2012e)
Gerreidae *Pentaprion longimanus*	328.29	92.90	50.50		478.98		Jawad et al. (2011b)
Hemiramphidae *Rhynchorhamphus georgii*	2.44	121.30	0.51	-	24.20	-	Al-Mamry et al. (2011a)
Leiognathidae *Leiognathus equula*	25.76	0	17.03		3.25		Al-Mamry et al. (2011a)
Mugilidae *Mugil cephalus*	62.2	59.6	58.4	-	60.1	-	Jawad and Gnohossou (2019)
Mullidae *Upeneus doriae*	1.35	0	25.81	-	4.47	-	Jawad et al. (2012d)
Pinguipedidae *Parapercis alboguttata*	59.64	-	12.39	-	34.70	6.81	Jawad et al. (2012a)
Scombridae *Auxis thazard*	154.57	55.74	12.11	-	47.33	-	Jawad et al. (2012c)
Rastrelliger kanagurta	12.19	35.30	-	-	35.30	-	Jawad et al. (2001)
Siganidae *Siganus rivulatus*	24.62	47.08	8.84	-	80.75	-	Al-Mamry et al. (2011–2012)
Siluridae *Heteropneustes fossilis*	95.78	-	-	-	87.24	-	Al-Hassan et al. (1990)
Sparidae *Boops boops*	3.03	23.98	-	-	36.69	-	Jawad (2003)
Diplodus annularis	35.49	18.60	-	-	10.43	-	
Diplodus vulgaris	28.14	9.53	-	-	-	-	
Lithognathus mormyrus	26.31	35.30	-	-	-	-	
Tetraodontidae *Lagocephalus sceleratus*	74.88	22.8	9.677	-	39.7	-	Jawad (2013)

References

Abaychi, J., & Al-Saad, H. T. (1988). Trace elements in fish from the Arabian Gulf and the Shatt al-Arab River, Iraq. *Bulletin of Environmental Contamination and Toxicology, 40*, 226–232. https://doi.org/10.1007/BF01881043 PMID:3349193

Abaychi, J., & Douabul, A. A. Z. (1985). Trace Metals in Shatt Al–Arab River, Iraq. *Water Research, 19(4)*, 457–462. https://doi.org/10.1016/0043-1354(85)90037-5

Ahmed, H. K., & Ghazi, A. H. H. (2014). Rotifers diversity at Shatt Al-Arab River and Shatt Al-Basrah canal, South of Iraq, during the abnormal rising of water salinity. *Mesopotamian Journal of Marine Science, 29*, 145–154.

Al-Hassan, L. A. J., Al-Dubaikel, A. Y., Wahab, N. K., & Al-Daham, N. K. (1990). Asymmetry analysis in the catfish, Heteropneustes fossilis collected from Shatt al-Arab River, Basrah, Iraq. *Rivista di Idrobiologia, 29(3),* 775–780.

Al-Hejuje, M. M. (1997). Distribution of heavy elements in water and sediments from Al-Ashar and Al-Khandak canals connected with Shatt–Al-Arab River and their effects on Algae, M.Sc. Thesis, University of Basrah, college of science, Biology Department, pp. 104

Al-Hejuje, M. M., Hussain, N. A., & Al-Saad, H. T. (2017). Applied heavy metals pollution index (HPI) as a water pollution indicator of Shatt Al-Arab River, Basrah-Iraq. *International Journal of Material Science, 7(35),* 353–360. https://doi.org/10.5376/ijms.2017.07.0035

Allafta, H., & Opp, C. (2020). Spatio-temporal variability and pollution sources identification of the surface sediments of Shatt Al-Arab River, Southern Iraq. *Scientific Reports, 10(1)*, 6979. https://doi.org/10.1038/s41598-020-63893-w PMID:32332795

Ali, A. H., & Khamees, N. R. (2018). Comparative Taxonomy of Two Species of Acanthopagrus Peters, 1855 (Pisces: Sparidae) with the First Record of *A. sheim* Iwatsuki, 2013 from Iraq. *Basrah Journal of Agricultural Sciences, 31*, 36–43. https://doi.org/10.33762/bagrs.2018.160131

Allenbach, D. M. (2011). Fluctuating asymmetry and exogenous stress in fishes: A review. *Reviews in Fish Biology and Fisheries, 21*, 355–376. https://doi.org/10.1007/s11160-010-9178-2

Al-Mamry, J. M., Jawad, L. A., Al-Bimani, S. M. H., Al-Busaidi, H. K., Al-Marzouqi, M. S., & Al-Habsi, S. H. (2011). Asymmetry analysis study on *Callionymus margaretae* Regan, 1906 collected from the Arabian Sea coasts of Oman. *Croatian Journal of Fisheries: Ribarstvo, 69(1),* 3–9.

Al-Mamry, J., Jawad, L. A., Al-Busaidi, H. K., Al-Alawi, A., Al-Gharabi, S., Al-Hasani, L., Al-Marzouqi, S., Al-Ruwaihi, I., Al-Yarubi, J., Al-Zahli, A., Al-Marzouqi, M., & Al-Habsi, S. (2011-2012). Asymmetry study in *Siganus rivulatus* Forsskal, 1775 (family: Siganidae collected from the Arabian Sea coasts of Oman. *Quadrini del Museuo State Naturale de Livorno, 24*, 1–5.

Al-Saad, H. T., Alhello, A. A., Al-Kazaeh, D. K., Al-Hello, M. A., Hassan, W. F., & Mahdi, S. (2015). Analysis of water quality using physico-chemical parameters in the Shatt Al-Arab Estuary, Iraq. *International Journal of Material Science, 5(49),* 1–9. http://ijms.biopublisher.ca

Al-Saffie, A. G. A. (2005). Study of some of heavy elements in water, sediments and phytoplankton in Shatt Al-Arab River, M.Sc. Thesis, University of Basrah, College of Science, Biology Department, pp. 85

Bauchot, M.-L., & Smith, M. M. (1984). Sparidae. In W. Fischer & G. Bianchi (Eds.), FAO species identification sheets for fishery purposes. Western Indian Ocean (Fishing Area 51) (Vol. 4). FAO. pp. 1-11

Bernhard, M. (1976). Manual of methods in aquatic environment research, part 3: sampling and analyses of biological material. FAO Fish Tech Paper No. 158, UNEP Rome.

Bhatnager, R. S., & Hussain, M. Z. (1977). Interference with steps in collagen synthesis: A test for pulmonary toxicity of environmental agents. Conference Proceedings, Fourth Joint Conference on sensing of Environmental Pollutants, American Chemical Society, Washington DC (pp. 527–531).

Binning, K., & Baird, D. (2001). Survey of heavy metals in the sediments of the Swartkops River Estuary, Port Elizabeth South Africa. *Water S.A., 27(4),* 461–466. https://doi.org/10.4314/wsa.v27i4.4958

Elie, P., & Girard, P. (2014). La sante des poissons sauvages: les codes pathologie, un outil d'evaluation. Association Sante Poissons Sauvages. Acheve d'imprimer sur les Presses d'AVL diffusion, Montpellier (France). (Pages: 286 pp.).

Esmaeili, H. R., Masoudi, M., & Mehraban, H. R. (2015). Assignment of *Acanthopagrus* populations in the Persian Gulf drainage system of Iran to *Acanthopagrus arabicus* Iwatsuki, 2013 (Perciformes: Sparidae). *Iranian Journal of Ichthyology, 1(1),* 23–28.

EC (European Commission) (1998). Council Directive 98/83/. EC of 3 November 1998 on the quality of water intended for human consumption. L 330/32, 5.12.98.

Härdig, J., Andersson, T., Bengtsson, B. E., Förlin, L., & Larsson, A. (1988). Long-term effects of bleached kraft mill effluents on red and white blood cell status, ion balance, and vertebral structure in fish. *Ecotoxicology and Environmental Safety, 15(1),* 96–106. https://doi.org/10.1016/0147-6513(88)90046-2 PMID:3359960

Hahladakis, J., Smaragdaki, E., Vasilaki, G., & Gidarakos, E. (2013). Use of Sediment Quality Guidelines and pollution indicators for the assessment of heavy metal and PAH contamination in Greek surficial sea and lake sediments. *Environmental Monitoring and Assessment, 185*, 2843–2853. https://doi.org/10.1007/s10661-012-2754-2 PMID:22821321

Hassan, W. F. (2007). Geochemical and hydrochemical study at Shatt Al-Arab Canal sediments and overlying water, PhD. Thesis, College of Agriculture, University of Basrah, pp. 205.

Hassan, A. A., Dawood, A. S., & AL-Mansori, N. J. (. (2018). Assessment of Water Quality of Shatt Al-Basrah Canal using Water Pollution Index. *IACSIT International Journal of Engineering and Technology, 7*, 757–762. https://doi.org/10.14419/ijet.v7i4.19.27994

Hechter, R. P., Moodie, P. F., & Moodie, G. E. E. (2000). Pectoral fin asymmetry, dimorphism and fecundity in brook stickleback, *Culaea inionstans. Behaviour, 137(7),* 999–1009. https://doi.org/10.1163/156853900502394

Iguchi, H., & Sano, S. (1982). Effect of cadmium on the bone collagen metabolism of rat. *Toxicology and Applied Pharmacology, 62(1),* 126–136. https://doi.org/10.1016/0041-008X(82)90109-0 PMID:6121393

Iwatsuki, Y. (2013). Review of the *Acanthopagrus latus* complex (Perciformes: Sparidae) with descriptions of three new species from the Indo-West Pacific Ocean. *Journal of Fish Biology, 83(1),* 64–95. https://doi.org/10.1111/jfb.12151 PMID:23808693

Jawad, L. A. (2003). Asymmetry in some morphological characters of four sparid fishes from Benghazi. Libya. *Oceanological and Hydrobiological Studies, 32(1),* 83–88.

Jawad, L. A. (2013). On the asymmetry of some morphological characters of the silvercheeked toadfish *Lagocephalus sceleratus* (Gmelin, 1789) collected from the Sea of Oman. *Water Resources Management, 3*, 25–30.

Jawad, L. A., & Abed, J. M. (2020). Morphological asymmetry in the greater lizardfish *Saurida tumbil* (Bloch, 1795) collected from the marine waters of Iraq. *Marine Pollution Bulletin, 159*, 111523. https://doi.org/10.1016/j.marpolbul.2020.111523 PMID:32768671

Jawad, L. A., & Gnohossou, P. (2019). Asymmetry in *Chrysichthys Auratus* (Geoffroy Saint-Hilaire, 1809) (Siluridae) and *Mugil cephalus* Linnaeus, 1857 (Mugilidae) from Lake Aheme (Benin, West Africa). *Thalassia Salentina, 41*, 33–46. DOI https://doi.org/10.1285/ i15910725 v41p33.

Jawad, L. A., Al-Mamry, J. M., & Al-Shuaily, S. (2012a). Bilateral asymmetry in some morphological characters of *Parapercis alboguttata* (Günther, 1872) (Family: Piguipedidae) collected from the Arabian Sea coasts of Oman. *Romanian Journal of Biology and Zoology, 57(1),* 51–62.

Jawad, L. A., Gnohossou, P., & Tossou, A. G. (2016). Bilateral asymmetry in certain morphological characters of *Sarotherodon melanotheron* Ruppell 1852 and *Coptodon guineensis* (Gunther 1862) collected from Lake Aheme and Porto-Novo lagoon Benin, West Africa. *Marine Pollution Bulletin, 103*, 39–44. https:// doi.org/ 10.1016/ j.marpolbul.2015.12.049

Jawad, L. A., Jayabalan, N., & Jawad, H. L. (2017). Unilateral microphthalmia and slow growth rate in a natural population of the marine teleost *Pampus argenteus* (Actinopterygii: Perciformes: Stromateidae). *Bulletin of Fish Biology, 17(1),* 39–44.

Jawad, L. A., Taher, M. M. A., & Nadji, H. M. H. (2001). Age and asymmetry studies on the Indian mackerel, *Rastrelliger kanagurta* (Osteichthyes: Scombridae) collected from the Red Sea coast of Yemen. *Indian Journal of Fisheries, 30*, 180–182. http://nopr.niscair.res.in/handle/123456789/4620

Jawad, L. A., Al-Mamry, J. M., Al-Kharusi, A. A., & Al-Habsi, S. H. (2010). Asymmetry in some morphological characters of the carangid species, *Decapterus russelli* collected from Lema coastal area, north of the Sea of Oman. *Oceanological and Hydrobiological Studies, 39(1),* 55–62. https://doi.org/10.2478/v10009-010-0019-3

Jawad, L., Al-Mamry, J., Al-Sharyani, L., & Al-Dhaouri, N. (2012b). Study of the asymmetry in *Auxis thazard* (Lacepede, 1800) (family: Scombridae) collected from the bay of Oman. *Biological Journal of Armenia, 64(1),* 19–25.

Jawad, L. A., Al-Mamry, J. M., Al-Bimani, S. M., Al-Ghafari, F. K., & Al- Mamary, D. (2011a). On the asymmetry of some morphological characters of *Carangoides caeruleopinnatus* (Ruppell, 1830) (Family Carangidae) collected from the sea of Oman. *Romanian Journal of Biology, 1*, 179.

Jawad, L. A., & Al-Mamry, J. M. AL-Bimani, S., AL-Ghafri, F., & AL-Marzouqi, M. (2012c) Asymmetry of some morphological characters of *Upeneus doriae* (Osteichthyes: Mullidae) collected from the sea of Oman. *Thalassia Salentina, 34*, 3–10. https://doi.org/10.1285/i15910725v34p3

Jawad, L. A., Al-Mamry, J. M., Al-Hinai, A. M., Al-Rashidi, M. A., & Al-Busaidi, H. K. (2011b). Preliminary study on asymmetry in morphological characters of *Pentaprion longimanus* (Osteichthyes: Gerridae) from the sea of Oman. *Annales, Series Historia Naturalis, 22*, 1–6. UDK 591.159:597.556.33(535).

Jawad, L. A., Al-Mamry, J. M., Al-Busaidi, J., Al-Mamari, A., Al-Mamry, S., Al-Owisi, K., & Al-Rubiey, M. (2012d). Asymmetry in some morphological characters of Indian oil sardine, *Sardinella longiceps* Valenciennes, 1847 collected from Muscat waters on the Sea of Oman. *Water Resources Management, 2*, 61–64.

Koprivnikar, J., Baker, R. L., & Forbes, M. R. (2006). Environmental factors influencing trematode prevalence in grey tree frog (*Hyla versicolor*) tadpoles in southern Ontario. *The Journal of Parasitology, 92(5),* 997–1001. https://doi.org/10.1645/GE-771R.1 PMID:17152940

Kucuksezgin, F., Altay, O., Uluturhan, E., & Kontas, A. (2001). Trace metal and organochlorine residue levels in red mullet (*Mullus barbatus*) from the eastern Aegean, Turkey. *Water Research, 35(9),* 2327–2332. https://doi.org/10.1016/S0043-1354(00)00504-2 PMID:11358315

Leamy, L. J., & Klingenberg, C. P. (2005). The genetics and evolution of fluctuating asymmetry. *Annual Review of Ecology, Evolution, and Systematics, 36(1),* 1–21. https://doi.org/10.1146/annurev.ecolsys.36.102003.152640

Luh, M. D., Baker, R. A., & Henley, D. E. (1973). Arsenic analysis and toxicity-a review. *The Science of the Total Environment, 2(1),* 1–12. https://doi.org/10.1016/0048-9697(73)90002-8 PMID:4804487

Mastoi, G. M., Shah, S. G. S., & Khuhawar, M. Y. (2008).

Assessment of water quality of Manchar Lake in Sindh (Pakistan). *Environmental Monitoring and Assessment, 141(1-3),* 287–296. https://doi.org/10.1007/s10661-007-9895-8 PMID:17929187

Mohamed, A. R. M., & Abood, A. N. (2017). Compositional change in fish assemblage structure in the Shatt Al-Arab River, Iraq. *Asian Journal of Applied Science, 5(5),* 944–958.

Öztürk, M., Özözen, G., Minareci, O., & Minareci, E. (2009). Determination of heavy metals in fish, water and sediments of Avsar Dam Lake in Turkey. *Journal of Environmental Health Science & Engineering, 6(2),* 73–80.

Raj, A. J. A., Seetharaman, S., & Haniffa, M. A. (2004). Skeletal deformities in few freshwater fishes from Bhavani River, Tamil Nadu. *Zoos' Print Journal, 19*, 1628–1629. https://doi.org/10.11609/JoTT.ZPJ.1145.1628-9

Ralph, P. J., & Burchett, M. D. (1998). Impact of petrochemicals on the photosynthesis of *Halophila ovalis* using chlorophyll fluorescence. *Marine Pollution Bulletin, 36(6),* 429–436. https://doi.org/10.1016/S0025-326X(97)00207-5

Randall, J. E. (1995). Coastal fishes of Oman. University of Hawaii Press.

Redmond, M. C., & Valentine, D. L. (2012). Natural gas and temperature structured a microbial community response to the Deepwater Horizon oil spill. *Proceedings of the National Academy of Sciences of the United States of America, 109(50),* 20292–20297. https://doi.org/10.1073/pnas.1108756108 PMID:21969552

Rico-Martínez, R., Snell, T. W., & Shearer, T. L. (2013). Synergistic toxicity of Macondo crude oil and dispersant Corexit 9500A(®) to the *Brachionus plicatilis* species complex (Rotifera). *Environmental Pollution, 173*, 5–10. https://doi.org/10.1016/j.envpol.2012.09.024 PMID:23195520

StatSoft Inc. (1991). Complete Statistical System: Statistica, Version 3.0. StatSoft. Inc.

Valentine, D. W., Soule, M. E., & Samollow, P. (1973). Asymmetry in fishes: A possible statistical indicator of environmental stress. *Fish Bulletin, 71(2),* 357–370.

Van Valen, L. (1962). A study of fluctuating asymmetry. *Evolution; International Journal of Organic Evolution, 16*, 125–142. https://doi.org/10.2307/2406192

Vistica, D. T., Ahrens, F. A., & Ellison, W. R. (1977). The effects of lead upon collagen synthesis and proline hydroxylation in the Swiss mouse 3T6 fibroblast. *Archives of Biochemistry and Biophysics, 179(1),* 15–23. https://doi.org/10.1016/0003-9861(77)90081-9 PMID:190947

White, H. K., Hsing, P. Y., Cho, W., Shank, T. M., Cordes, E. E., Quattrini, A. M., Nelson, R. K., Camilli, R., Demopoulos, A. W., German, C. R., Brooks, J. M., Roberts, H. H., Shedd, W., Reddy, C. M., & Fisher, C. R. (2012). Impact of the Deepwater Horizon oil spill on a deep-water coral community in the Gulf of Mexico. *Proceedings of the National Academy of Sciences of the United States of America, 109(50),* 20303–20308. https://doi.org/10.1073/pnas.1118029109 PMID:22454495

WHO. (World Health Organization) (1993) Guidelines for drinking water quality. Recommendations, vol. 1, 2nd ed., Geneva.

Yavuzcan, Y. H., Robaina, L., Pirhonen, J., Mente, E., Domínguez, D., & Parisi, G. (2017). Fish welfare in aquaponic systems: Its relation to water quality with an emphasis on feed and faeces—a review. *Water (Basel), 9(1),* 1-13. https://doi.org/10.3390/w9010013

Yesser, A. K. T. (2016). Impact of feeding levels on growth performance and food conversion of *Acanthopagrus arabicus* cultivated in concrete tanks at Basrah province. *Iraqi Journal of Aquaculture, 13(2),* 109–124. https://doi.org/10.21276/ijaq.2016.13.2.2

Zahraw, Z., Maktoof, A. A., Al-Obaidy, A. H. M. J., Kareem, L. M. A., Shakir, E., & Hassan, S. M. (2019). Estimation of heavy metal concentration for sediments of Shatt Al-Basrah canal by using ecological indices. *Indian Journal of Public Health Research & Development, 10(1)*, 970-974. https://doi.org/10.5958/0976-5506.2019.00213.4