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Geometric Morphometric analysis of *Alosa braschnikowi* (Teleostei, Clupeidae) populations in the southern Caspian Sea

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Abstract
Morphological studies are strong and instrumental for determining discreteness of the similar species and extensively used to identify differences between fish populations. A total of 216 specimens of *Alosa braschnikowi* were randomly collected by beach seine from three fishing regions along the southern Caspian Sea coasts, including some regions of Miankaleh, Sari and Anzali, in the fishing season during 2018-2019. The extracted landmark-points (body shape data) were submitted to a generalized Procrustes analysis (GPA) to remove non-shape data in PAST software. In the present study, the size effect was removed successfully by procrustes action in PAST software. Principal component analysis (PCA) was performed to summarize the variation among the specimens as few dimensions as possible. As a complement to discriminant analysis, morphometric distances among the three localities were inferred to cluster analysis by adopting the Euclidean square distance as a measure of dissimilarity method as the clustering algorithm. The dendrogram derived from cluster analysis of Euclidean square distances showed that the three populations of *A. braschnikowi* were distinct from each other in terms of morphometric characters. The Wilks' lambda tests of discriminant analysis indicated significant differences in morphometric characters of the three populations. The results of the present study demonstrated significant morphological differences between the three populations of *A. braschnikowi*. These differences in the three studied basins were mainly related to the characteristics of head and snout, body height, caudal peduncle, dorsal and anal fin base, which could be related to the hydraulic conditions and diet of the populations.

Key words: *Alosa braschnikowi, Clupeidae, Shape variation, Landmark, Caspian Sea*.

INTRODUCTION

Morphological studies are strong and instrumental for determining the discreteness of the similar species (Mousavi-Sabet *et al.*, 2011; Mousavi-Sabet *et al.*, 2012) and extensively used to identify differences between fish populations (Mousavi-Sabet & Anvarifar, 2013). Morphometrics is a good research method that specialized in shape variation and its covariation with other variables (Bookstein, 1991). Body shape differences not only reflect the genetic characteristics of populations but also environmental parameters (Guill *et al.*, 2003). The morphological characteristics of fish are affected by genetic and environmental factors, which are an important basis for species identification and species classification. The differences between populations of a single species can indicate differences in habitat and behavioral characteristics, because the aquatic organisms, e.g., fishes require to adapt to their environmental conditions for better functioning of their biological

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systems (Webb, 1982) Therefore, morphological adaptations to environmental conditions along with geographical isolation can provide crucial information on the evolutionary trend of these organisms particularly in aquatic ecosystems. Phenotypic differences among fish populations and identifying their causes and consequences may be informative of differences in natural history across a species' geographic range, which would have implications for both theoretical and applied researches in ecological and fishery science (Love and Chase, 2009). Morphometric population differentiation is important from various viewpoints including evolution, ecology, behavior, conservation, water resource management and stock assessment (AnvariFar *et al.*, 2013).

For species like the Caspian shad, investigation on morphometric variations is essential as this species is widely distributed in the Caspian Sea. The family Clupeidae is found in warmer marine waters with some anadromous or permanent freshwater residents. This family has about 200 species in 56 genera worldwide (Coad, 2017), with eight reported species in the Caspian Sea (Esmaeili *et al.*, 2017) and 11 species in the inland waters of Iran (Esmaeili *et al.* 2017). *Alosa braschnicowi* (Borodin, 1904) is an economically important clupeid of the Caspian Sea that widely distributed across this sea. This species is endemic to the Caspian Sea and distributes in the south in winter, moving north to spawn in spring (Coad, 2019).

Geometric morphometrics has been developed in the last decades as a reliable tool concerning size and shape analyses through several studies (Zelditch *et al.*, 2004; Strauss, 2010). As the revolution of morphometrics, geometric morphometric method combined with multivariate statistical analysis could capture the overall morphological changes of shape, avoid the loss of information of specimen's structure and consider the global anatomic context (Rohlf & Marcus, 1993; Adams *et al.*, 2004; Slice, 2007). Geometric morphometrics (GM) is a widely used technique in determining shape variation. Instead of using linear measurements, counts, and ratios, as in traditional morphometrics (Adams *et al.*, 2004), data in GM are recorded in the form of coordinates of landmark points (Rohlf & Marcus, 1993). Landmark-based GM uses the landmark coordinates to extract the shape data (Zelditch *et al.*, 2004) and has been considered as a useful tool to assess phenotypic plasticity. Landmark points are defined as homologous points that bear information on the geometry of biological forms (Bookstein, 1991).

One important advantage of the GM approach to traditional ones is that GM does not need to decide a priori which measurements are likely to display differences (Rohlf and Marcus, 1993). GM also allows to point out the structures better fitted to be used to separate species, which, combined with color patterns in recently captured specimens, may allow adapting catch data to be treated at the species level (Santos *et al.*, 2019). Due to its obvious advantages, GM has widely applied to analyze the relationship between morphology and habitat (Idaszkin *et al.*, 2013; Foster *et al.*, 2015), growth stages and shape morphological differences among geographic populations (Braga *et al.*, 2017), as well as between species or subspecies (Tofilski, 2008; Stange *et al.*, 2016). The body shape is a major component of an organism's phenotype, and it bears important traits of its biological characters such as locomotor performance, feeding efficiency, vulnerability to predators, and reproductive success (Guill *et al.*, 2003). Fish body shape can be the result of evolutionary adaptations to environmental pressures (Winemiller, 1991) Therefore, the body shape differences of populations are considered as essential steps in the process of speciation (Margurran, 1998). Most members of the genus *Alosa* Linck, 1790 in Iran exhibit relatively different body forms. This study was to investigate the body shape the interspecies, among the three populations of *Alosa braschnikowi* (Borodin, 1904) with visualization techniques afforded by the GM approach.

MATERIAL AND METHODS

A total of 216 specimens of *A. braschnikowi* were randomly collected by beach seine from three fishing regions along the southern Caspian Sea coasts, including some regions of Golestan Province (Miankaleh) (36°56'46.1"N 53°54'53.3"E; 57 individuals), Mazandaran Province (Sari)

(36°47'27.7"N 52°47'34.8"E; 64 individuals) and Guilan Province (Anzali) (37°30'01.9"N 49°26'44.2"E; 95 individuals), in the fishing season during 2018-2019 (Fig. 1). The specimens were kept in the freezer and transported to the laboratory for further examinations. After thawing, each individual was photographed for digital analysis.

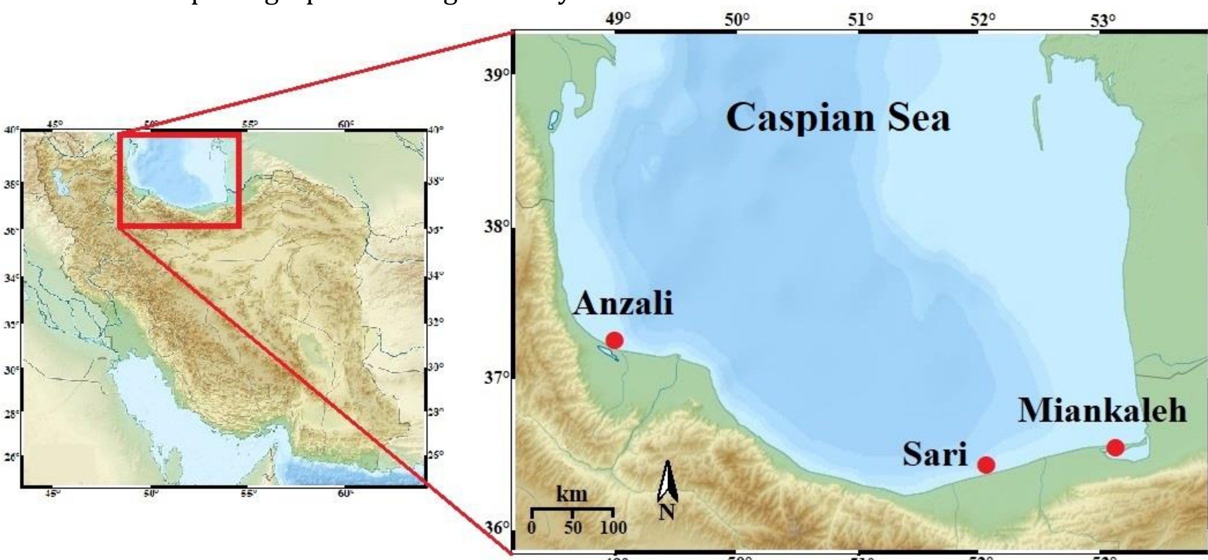

FIGURE 1. Sampling stations in the south Caspian Sea (north of Iran).

Laboratory works

The left side of the specimens (with dorsal and anal fins were held erected using pins) was photographed using a digital camera (Samsung DV150F). Fifteen homologous landmark-points were defined and digitized on 2-D images using tpsDig2 software version 2.16 (Rohlf, 2004). The landmark-points were selected to the best representation of the external body shape (Fig. 2). The landmark-points were chosen at the specific points, in which a proper model of fish body shape was extracted (Bookstein, 1991).

Data analysis

The extracted landmark-points (body shape data) were submitted to a generalized Procrustes analysis (GPA) to remove non-shape data in PAST software. The multivariate analysis of variance/canonical variate analysis (MANOVA/CVA) was used to investigate power of distinction among groups. These morphological differences may be solely related to body shape variation and not to size effects which were successfully accounted for by the allometric transformation. On the other hand, size-related characteristics play a predominant role in morphometric analysis and the results may be erroneous if not adjusted for statistical analyses of data (Tzeng, 2004). In the present study, the size effect was removed successfully by Procrustes action in PAST software. Principal component analysis (PCA) was performed to summarize the variation among the specimens as few dimensions as possible (Klingenberg, 1998). As a complement to discriminant analysis, morphometric distances among the three localities were inferred to cluster analysis by adopting the Euclidean square distance as a measure of dissimilarity method as the clustering algorithm (Sneath & Sokal, 1973). The patterns of taxon's body shape were illustrated in transformation grids relating to consensus configuration of all specimens presented, depicting relative shape differences among the populations (Khataminejad & Bani, 2018).

RESULTS

The CVA of standardized morphological measurements exhibited significant differences between groups ($P<0.001$). PCA for all specimens explained 46.69% of shape variations by the first two PC axes extracted from the variance-covariance matrix (PC1 = 28.91% and PC2 = 17.77%). PC1 scores were related to the curvature of the back of the body towards the bottom, the curvature of the snout and caudal peduncle upward, as well as elongation anal fin whereas PC2 scores, were related to decreased head, snout, eyes and dorsal fin size along with shorter caudal peduncle. Separation of the three examined populations showed along the first and second axis, respectively (Fig. 3).

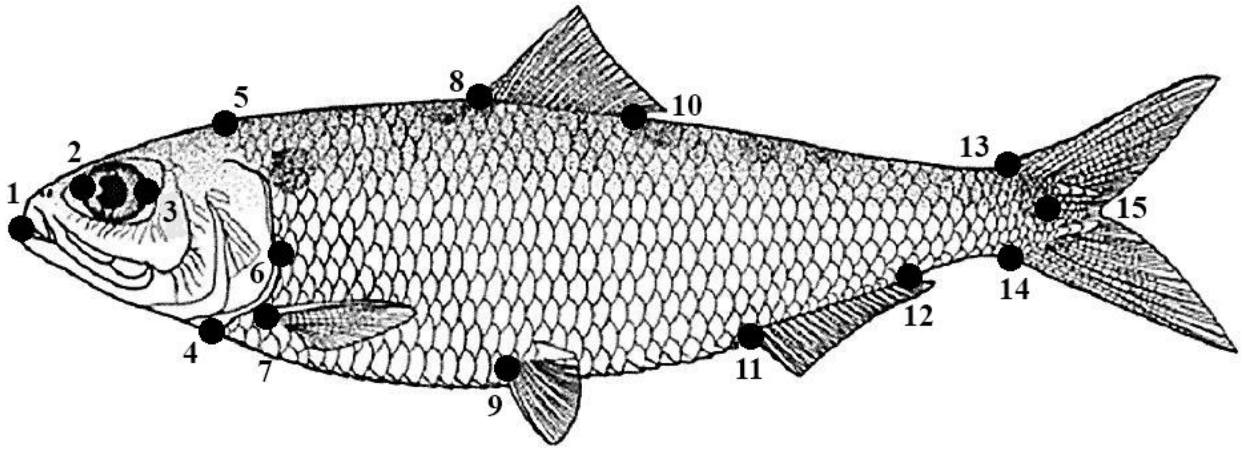

FIGURE 2. Defined landmark points to extract body shape. 1. Anterior tip of the premaxilla; 2. Front of the eye; 3. End of the eye; 4. Beginning of the scales at the dorsal side; 5. The lower beginning of operculum; 6. End of operculum; 7. Base of the pectoral fin; 8. Base of the pelvic fin; 9 and 10. Anterior and posterior insertion of the dorsal fin; 11 and 12. Anterior and posterior insertion of the anal fin; 13. Upper margin of caudal peduncle; 14. Lower margin of caudal peduncle; 15. End of the medial region of caudal peduncle.

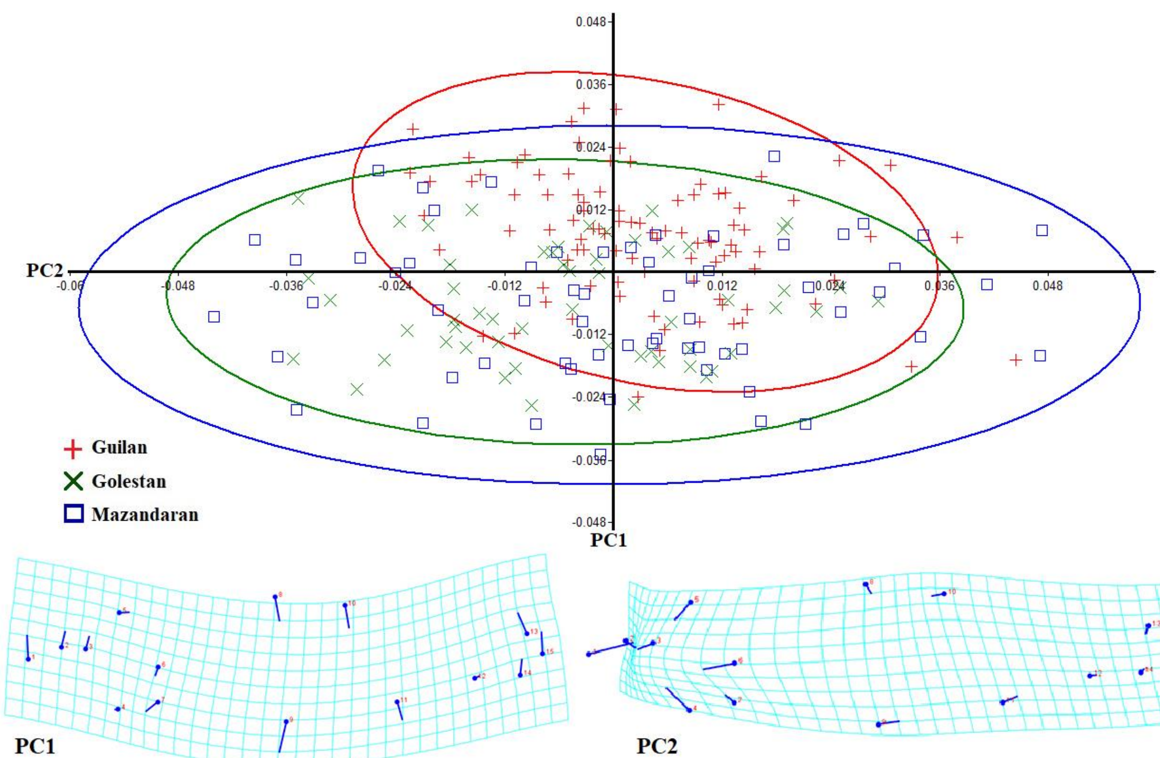

FIGURE 3. The results of Principal Component Analysis (PCA) of three populations of the species *A. braschnikowi* body shape

TABLE 1. Mahalanobis distance analysis for the three populations of *A. braschnikowi*

Station	Golestan	Guilan
Guilan	4.1320	
Mazandaran	2.2054	3.8742

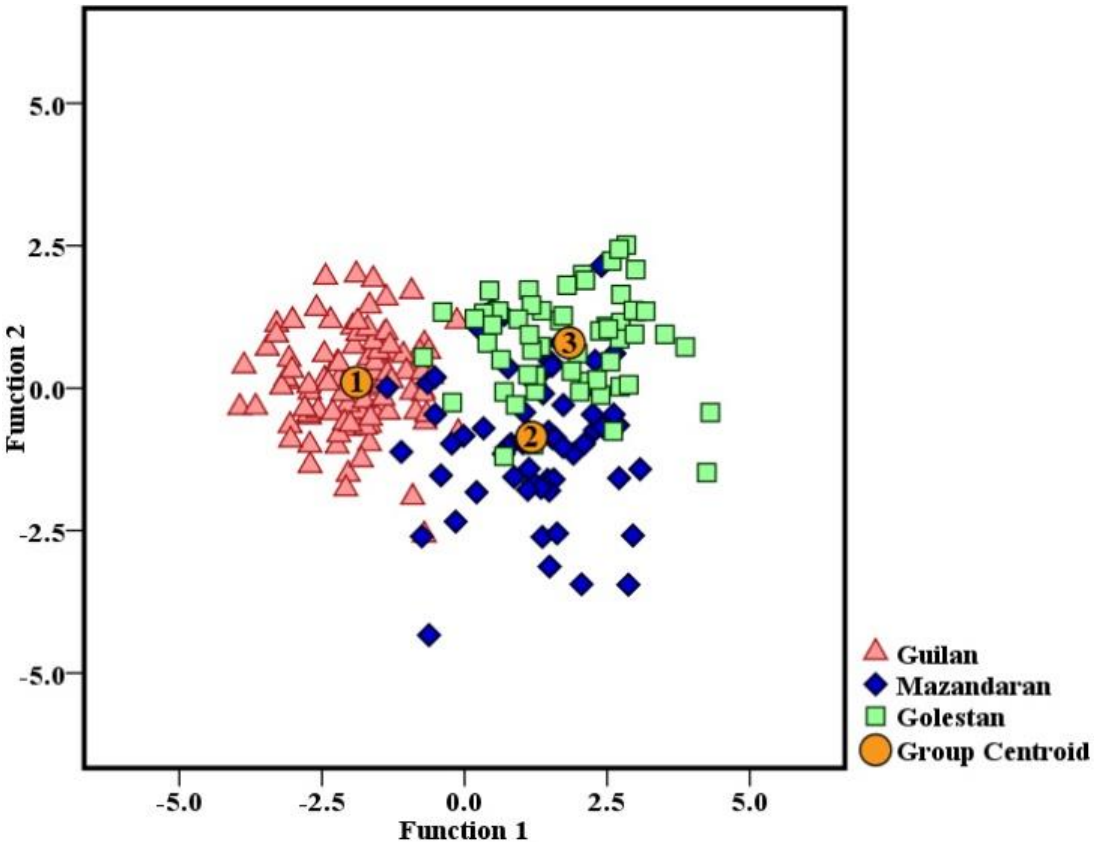

FIGURE 4. Scatterplot of *A. braschnikowi* specimens according to the first two discriminant functions from Geometric morphometrics data analysis.

Mahalanobis distance analysis showed that the most differences were in terms of body shape between Guilan and Golestan populations, while the least differences among Golestan and Mazandaran ones. The Mahalanobis distances among the populations are represented in Table 1.

According to the results of the DFA analysis, the populations were divided into three groups (Fig. 4), which indicates a high degree of differentiation among the *A. braschnikowi* population in the study areas. Grouping related to either uniform component, Mazandaran and Golestan overlap broadly, but Guilan had less overlap with the other populations. There was a high degree of separation in body shape characters between Guilan and the other two provinces, with a slight degree of separation between Golestan and Mazandaran populations (Fig. 5).

The dendrogram derived from cluster analysis of Euclidean square distances showed that the three populations of *A. braschnikowi* were distinct from each other in terms of morphometric characters (Fig. 6). Longer head and snout, large body depth in the midsection, short and depth caudal peduncle, longer dorsal and anal fin bases for Guilan population, while short head and snout, shallow body depth in midsection, longer caudal peduncle, short dorsal and anal fin bases for Golestan one. Short head and snout, short dorsal and longer anal fin base, longer caudal peduncle and large body depth were observed in the Mazandaran population.

The Wilks' lambda tests of the discriminant analysis indicated significant differences in morphometric characters of the three populations. In this test, two functions were highly significant

(P≤0.001) (Table 2). Discriminant analysis (DA) on the relative warps classified 84.7% in original data and 81.9% in cross-validation of specimen into the correct groups. Medium classification success rates were obtained for Guilan (95.80%), Golestan (78.90%) and Mazandaran (64.10%) populations, indicating the first one (Guilan population) as a high correct classification of specimens into their populations (Table 3).

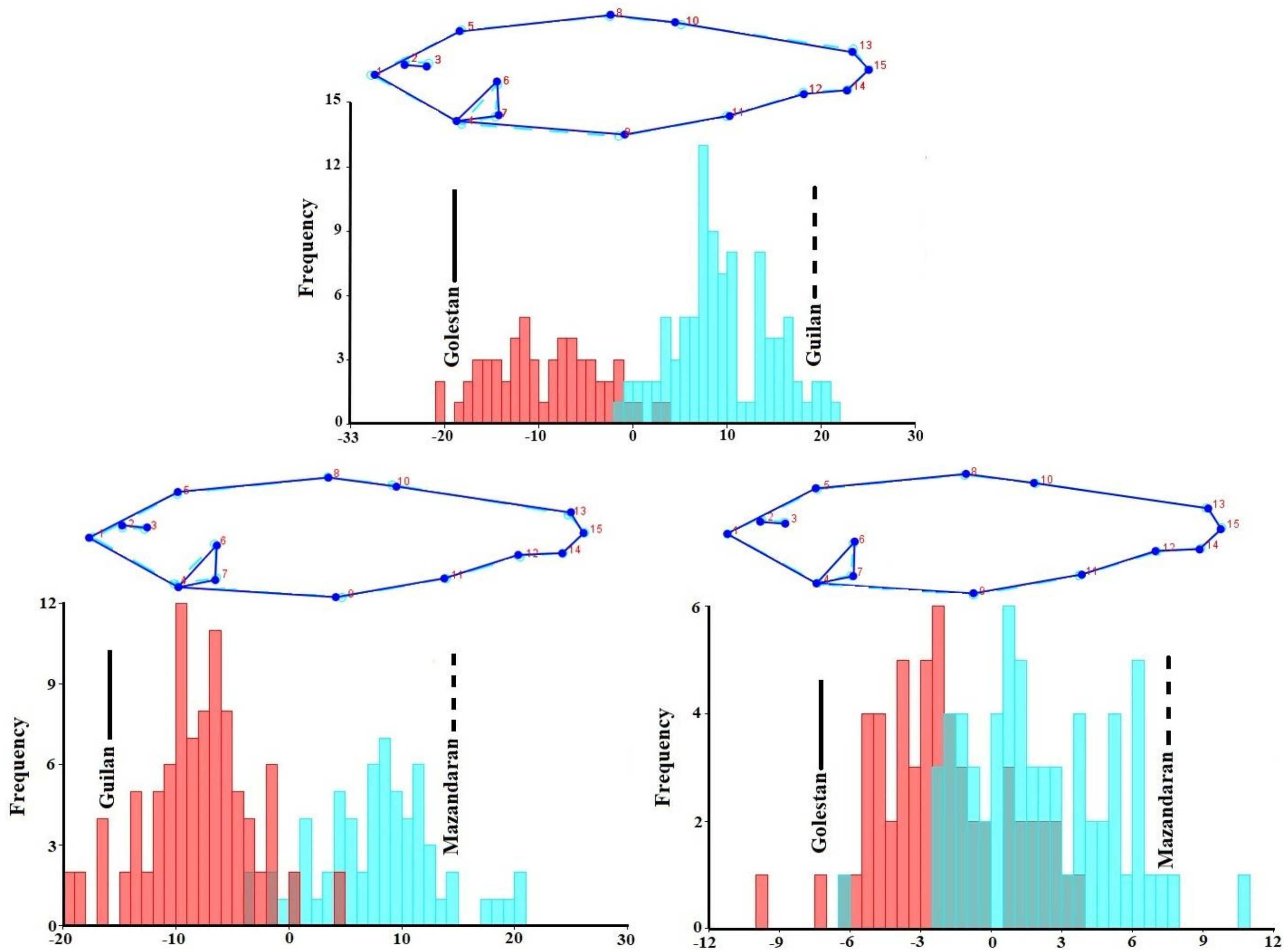

FIGURE 5. Histogram of discriminate analysis (DA) functions of three populations of the species *A. braschnikowi* body shapes in different locations with respect to the first two canonical variables.

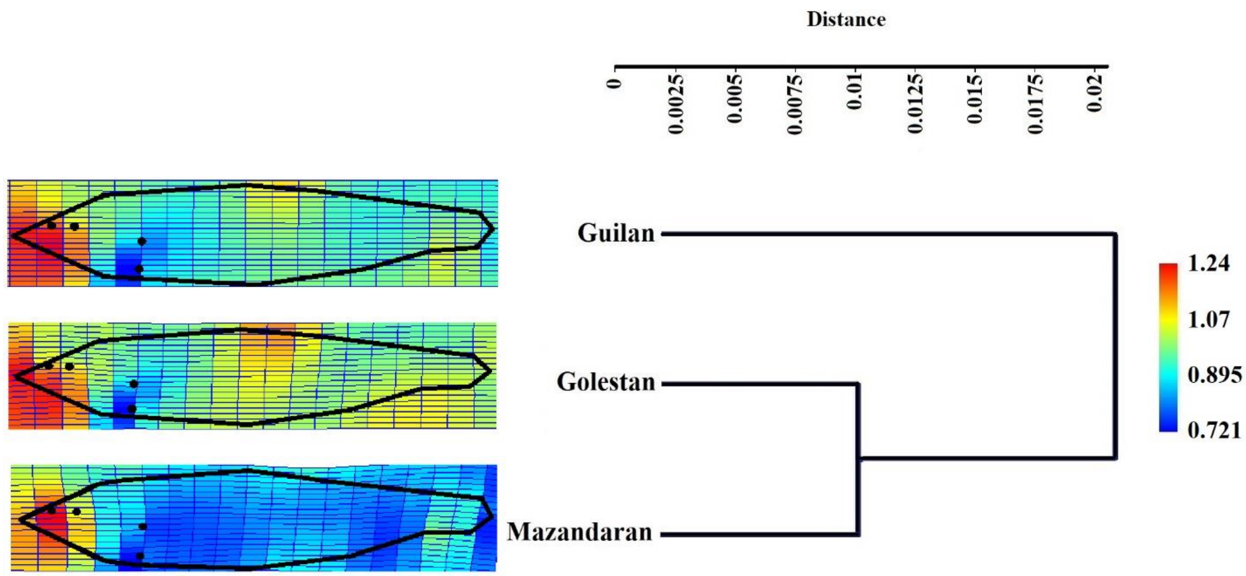

FIGURE 6. Dendrogram derived from cluster analysis of morphometric variables on the basis of Euclidean distance of the three populations of *A. braschnikowi* in Iran. Mean shape of species in relation to consensus shape of the three populations of *A. braschnikowi* are represented.

TABLE 2. Wilks' lambda test for verifying difference among three populations

Test of Function(s)	Wilks' Lambda	Chi-square	Df	Sig.
1 through 2	0.18	353.69	22	0.00
2	0.71	69.38	10	0.00

TABLE 3. Classification matrix showing the number and percentage of individuals that were correctly classified

	Guilan	Mazandaran	Golestan	Total
Original (%)				
Guilan	**96.8**	2.1	1.1	100.0
Mazandaran	7.8	**68.8**	23.4	100.0
Golestan	3.5	14.0	**82.5**	100.0
Cross-validated (%)				
Guilan	**95.8**	3.2	1.1	100.0
Mazandaran	7.8	**64.1**	28.1	100.0
Golestan	3.5	17.5	**78.9**	100.0

The causes of morphological differences between populations are often quite difficult to explain (Poulet *et al.*, 2004) but it has been suggested that the morphological characteristics of fish are determined by genetic, environment and the interaction between them (Poulet *et al.*, 2004; Pinheiro *et al.*, 2005). Prevailing environmental factors are important in the early stages of development because larvae are very effective at these stages (Pinheiro *et al.*, 2005). Body shape differences between two habitats often reflect variations in the swimming and feeding of fishes (Langerhans *et al.*, 2003; Tahmasebi *et al.*, 2014; Haghighy *et al.*, 2015). Different prey resources for larvae and juveniles may lead to different adult body shapes, suggesting that there is a phenotypic plastic response to resource availability (Wimberger, 1990). Morphological changes induced by environmental factors may help a better understanding of the phenotypic plasticity process as a result of induced factors (Mohaddasi *et al.*, 2013; Jalili *et al.*, 2015).

DISSCUSSION

The results of the present study demonstrated significant morphological differences between the three populations of *A. braschnikowi*. These differences in the three studied basins were mainly related to the characteristics of head and snout, body height, caudal peduncle, dorsal and anal fin base, which could be related to the hydraulic conditions and diet of the populations (Chapman *et al.*, 2008). Differences in dorsal and anal fins and caudal peduncle are considered as pivotal variations associated with motion. Differences in body height and dimensional dimensions can be considered as adaptations related to hydrodynamic or nutritional conditions (Fisher & Hogan, 2007). The *A. braschnikowi* population in Guilan had a longer head and snout, short and depth caudal peduncle, longer dorsal fin base that was different from *A. braschnikowi* populations in Mazandaran and Golestan. However in the population of Guilan and Mazandaran, large body depth in the midsection and longer anal fin base were observed, and the population of Golestan was shallow body depth and short anal fin base. Essentially, the large body depth suggests adaptability for quick maneuverability and can help find food (Langerhans *et al.*, 2003). Inland populations, must cope with long and energetically demanding migrations, thus selection should favor a more fusiform body shape that minimizes energy expenditure. Differences in head and snout shapes of Guilan population of *A. braschnikowi* with other populations of *A. braschnikowi*, can be considered as reflective of differences in feeding resources, selection of food items and direction of feeding (Langerhans *et al.*, 2003). Environmental factors through natural selection can increase the efficiency of a phenotype among the members of a population and thus is led to morphological isolation in different habitats (Keeley *et al.*, 2007).

The results of Mahalanobis distances and cluster analysis showed a closer distance between the *A. braschnikowi* populations of Mazandaran and Golestan, which could indicate a greater similarity in their body shape compared to the *A. braschnikowi* population of Guilan. The results revealed the relationship between the geographical distance and the differentiation of various populations of the *A. braschnikowi* region (Bibak *et al.*, 2013). Mazandaran is located in the southern part of the Caspian Sea, Golestan in the southeastern part of the Sea and Guilan in the southwest of the Sea. Different environmental conditions of Mazandaran, Golestan and Guilan may affect morphological differentiation among these three populations. Geographical separation can affect the growth and reproduction strategy of fish, the importance of these factors in morphological differentiation is known in fish species (Yamamoto *et al.*, 2006). Langerhans *et al.* (2003) found that the distance between habitats correlated positively with the level of divergence in body shape among conspecific populations of two Neotropical fish species. According to Cadrin & Silva (2005), the geographic variation in adult morphology for *Limanda ferruginea* may be explained by differences in ontogenetic rates among local populations if morphology is a product of ontogenetic history. Turan *et al.* (2011) examined systematic relationships among four genera and nine species of the Mugilidae family in the Mediterranean Sea, and in all species except *L. chelon* and *L. oedalechilus*, a significant degree of morphological differentiation was detected. Costa & Cataudella (2007) found that shape differences were related to trophic ecology for several species of the family *Sparidae*, thus indicating local adaptation and possibly ecological radiations (Langerhans *et al.*, 2003). If the shape is related to either environmental influences on larval development (Cadrin & Silva, 2005) or diversifying selection and ecological adaptation at a trophic level (Costa & Cataudella, 2007), then spatially or latitudinal different environmental factors (e.g., temperature and resource availability) may explain the variations in body shape among the studied species.

The phenotypic variability may not necessarily reflect population differentiation at the molecular level (Bookstein, 1991). Apparently, different environmental conditions can lead to an enhancement of pre-existing genetic differences, providing a high inter-population structuring (Mousavi-Sabet and Anvarifar, 2013). Abdolhay *et al.* (2012) showed the high inbreeding that happened in *Rutilus kutum* population, can lead to low genetic variability in four populations of

Rutilus kutum in southern shores of the Caspian Sea. Franssen *et al.* (2013) evaluated shape differences between stream and reservoir populations of *emerald shiners* and also found inconsistent patterns in divergence. Morphometric studies of Turan & Basusta (2011) showed that there is significant heterogeneity among the populations of *Alosa fallax* in Turkish waters. Meng *et al.* (2018) analyzed geometric morphometry among three Lenoks of *Brachymystax* in China. Their results showed that the shape variation of specimens between high- and low-altitude habitat is a significant difference (P<0.0001), in other words, they belonged to three different categories. The results of Paknejad *et al.* (2014) on the morphological diversity of the *A. braschnikowi* population using the truss system showed that there were various morphological populations on the southern Caspian coast. In general, the morphological characteristics of fish are more intra-and inter-species variation and are more sensitive to environmental changes, so the effects of some environmental factors such as temperature, salinity, food availability, or migration distance can potentially be effective on morphological distinctions (Turan *et al.*, 2006). Temperature plays a vital role during the early development of a green swordtail by the alternation of its body shape to provide its biological requirements to survive and decrease the adverse effect of resulted pressures (Bibak *et al.*, 2012; Bibak *et al.*, 2013).

The existence of morphology differences among populations of a species is a common phenomenon due to differences in the characteristics of habitat on the path to their evolutionary history (Antonucci *et al.*, 2009; Bertrand *et al.*, 2008), which is achieved through the directional selection in the habitats and can increase the chance of sustainability and survival in their habitat (Torres-Dowdall *et al.*, 2012). Morphological analysis could improve our knowledge of species stock structure, as the stock is considered as a group with unique phenotypic attributes (Paramo and Saint-Paul, 2010). The present study shows that there is a difference in the shape of the body of the *A. braschnikowi* in the south of the Caspian Sea, which it is suggested to use biochemical and molecular genetic methods in future studies to confirm the morphological. Specifications obtained based on the shape body of the *A. braschnikowi* can provide an identification key that is useful for distinguishing species, also can be considered for the programs of exploitation, management, and conservation programs in the Caspian Sea.

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RESEARCH ARTICLE **Open access**

Identification of three cephalopods from the Iranian waters of the Gulf of Oman (Continental shelf area)

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Abstract
This study aimed to find new species of cephalopods in the Iranian waters of the Gulf of Oman. Two species of Oegopsida (*Abralia steindachneri* Weindl, 1912 and *Joubiniteuthis portieri* (Joubin, 1916)) and also one species of Sepiida (*Sepia omani* Adam & Rees, 1966) were identified. Samples were collected in March and April 2019, using a Myctophidae trawler. To capture *A. steindachneri* a two-panel bottom trawl (codend mesh size (A) equal to 60 mm) was used, while for *J. portieri* and *S. omani* a four-panel midwater rope trawl (codend mesh size (A) equal to 90 mm) was applied. Taxonomic studied on these rare cephalopods, in this region, would be helpful for protecting their stocks as well as safely exploitation them.

Key words: *Abralia steindachneri, Cuttlefish, Joubiniteuthis portieri, Sepia omani, Squid.*

INTRODUCTION

Cephalopods are the smartest and the most complex invertebrates. Cephalopods have been living on the planet for about 500 million years and have fascinated humans for thousands of years (Hanlon *et al.*, 2018). The class Cephalopoda is subdivided into two subclasses named Coleoidea and Nautiloidea (Kröger *et al.*, 2011). Undoubtedly, subclass Coleoidea is more species-diverse and species-evolved in the class Cephalopoda (Kröger *et al.*, 2011; Voss *et al.*, 1998a; Voss *et al.*, 1998b); also, they have been become more interested in fishery purpose (Roper *et al.*, 1984). Coleoidea includes all living octopods, squids, and cuttlefishes, and also extinct forms such as belemnites (Hanlon *et al.*, 2018).

Cephalopods are an important component of both marine food webs and fisheries (Hunsicker *et al.*, 2010). As exploitation of commercial fish is increasing worldwide, low-harvest marine resources, such as Cephalopoda, are considered by many countries (Salahi-gezaz *et al.*, 2016). Moreover, Current demands have no historical precedent and ecosystems in which cephalopods are highly exploited as a targeted resource and as an ecological support service should be further evaluated to prevent the unsustainable development of marine fisheries within them. (Hunsicker *et al.*, 2010). In recent years, the three orders of Coleoidea Including Oegopsida, Myopsida, and Sepiida have participated in more than 50% of total cephalopods capture in the world (FAO website (online query), 2018). Therefore, the focus of researchers on these three orders indicates their importance (Adam & Rees, 1966; Rosa *et al.*, 2013a; Rosa *et al.*, 2013b). However, between 1997 and 2007, Cephalopods had been composed only one percent of RECOFI (Regional Commission for Fisheries including Islamic republic of Iran, Iraq, Bahrain, Qatar, Kuwait, Oman, UAE, and Saudi Arabia) captures in the Gulf of Oman and four percent in the Persian

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Gulf (FAO, 2010). So, this study aimed to find new species of cephalopods in the Iranian waters of the Gulf of Oman. The present study reports the first records of three cephalopods species from Iranian water bodies. These three species include *A. steindachneri* and *J. portieri* from the order Oegopsida and *S. omani* from the order Sepiida.

MATERIAL AND METHODS

The sampling was done in March and April 2019. The specimens were captured by a Myctophidae trawler (namely Aria-Jahan). Its specifications were 40 meters LOA, 8.60 meters beam, 3.50 meters bow draft, 4.40 meters stern draft, 396 tones GRT, 149 tones NRT, and 1200 Hp power. Used net to capture *A. steindachneri* was a two-panel bottom trawl and for capturing *J. portieri* and *S.omani* four-panel midwater rope trawl due to net rip was used. Codend and cover mesh size of two-panel bottom trawl were 60 and 120 millimeters (A), But Codend and cover mesh size of four-panel midwater rope trawl were 90 and 160 millimeters (A), individually. The geographic coordinates of the hauling for *A. steindachneri*, *J. portieri* and *S. omani* were 25°35.400' N-57°11.459' E (start) & 25°29.600' N-57°03.740' E (end), 25°34.000' N-57°12.500' E (start) & 25°26.585' N-57°02.802' E (end), and 25°35.567' N-57°12.272' E (start) & 25°29.200' N-57°04.166' E (end), respectively (Fig. 1). Google Earth Pro software was applied to draw the studied area maps. *A. steindachneri*, *S. omani, and J. portieri*, were found at 3-31 meters above the bottom (depth of the trawl activity) where the average bottom depth was 220.5, 230.5, and 264 m, respectively. Hauling period for *A. steindachneri* was 3 o'clock after 12 noon, while for *J. portieri* and *S. omani* was about 4 o'clock before 12 noon. The geographical direction domain of the hauls was between 220 and 245 degrees.

S. omani and *J. portieri* were identified using valid identification keys, the first volume of Cephalopods of the world (Jereb & Roper, 2005) and the second volume of Cephalopods of the world (Jereb & Roper, 2010), respectively. Whereas *A. steindachneri* either for its small size or difficult to identify was initially preserved in 5% formalin, thoroughly washed with fresh water after returning to the laboratory, and transferred to 70% ethanol (Urbano & Hendrickx, 2018). Then, the aquatic genus was determined in the Tree of Life web project (Young & Tsuchiya, 2018). Next, species were identified by examining tentacle clubs, eye photophores, and integumental photophores (Tsuchiya, 2009). Finally, weight, mantle length, fin length, tentacle length, head length, arm length, and the round of body of all species were measured (plus sexuality). The latest taxonomy of each species was written, according to WoRMS's website (2019).

SST (°C) and CHL-a (mg/m^3) data, were provided through the INCOD policy for Ocean and marine data management of the Iranian National Institute for Oceanography and Atmospheric Science same INIOAS (http://incod.inio.ac.ir). These parameters had been obtained from MODIS-Aqua atlas (since 2010). Wind velocity (m/sec), wind direction (Deg), wave height (m), and wave direction (Deg) were observed from Iranian waves estimation database of Port and Maritime Organization same PMO (http://77.77.77.42 in Persian). These parameters had been estimated by a suitable offshore wave buoy about 25°07' N-57°45' E. Concerning SST and CHL-a of the study area, the average of their monthly data was considered in the last decade (March also April). Besides, wind velocity, wind direction, wave height, and wave direction were taken into account when capturing operations of each species (daily average).

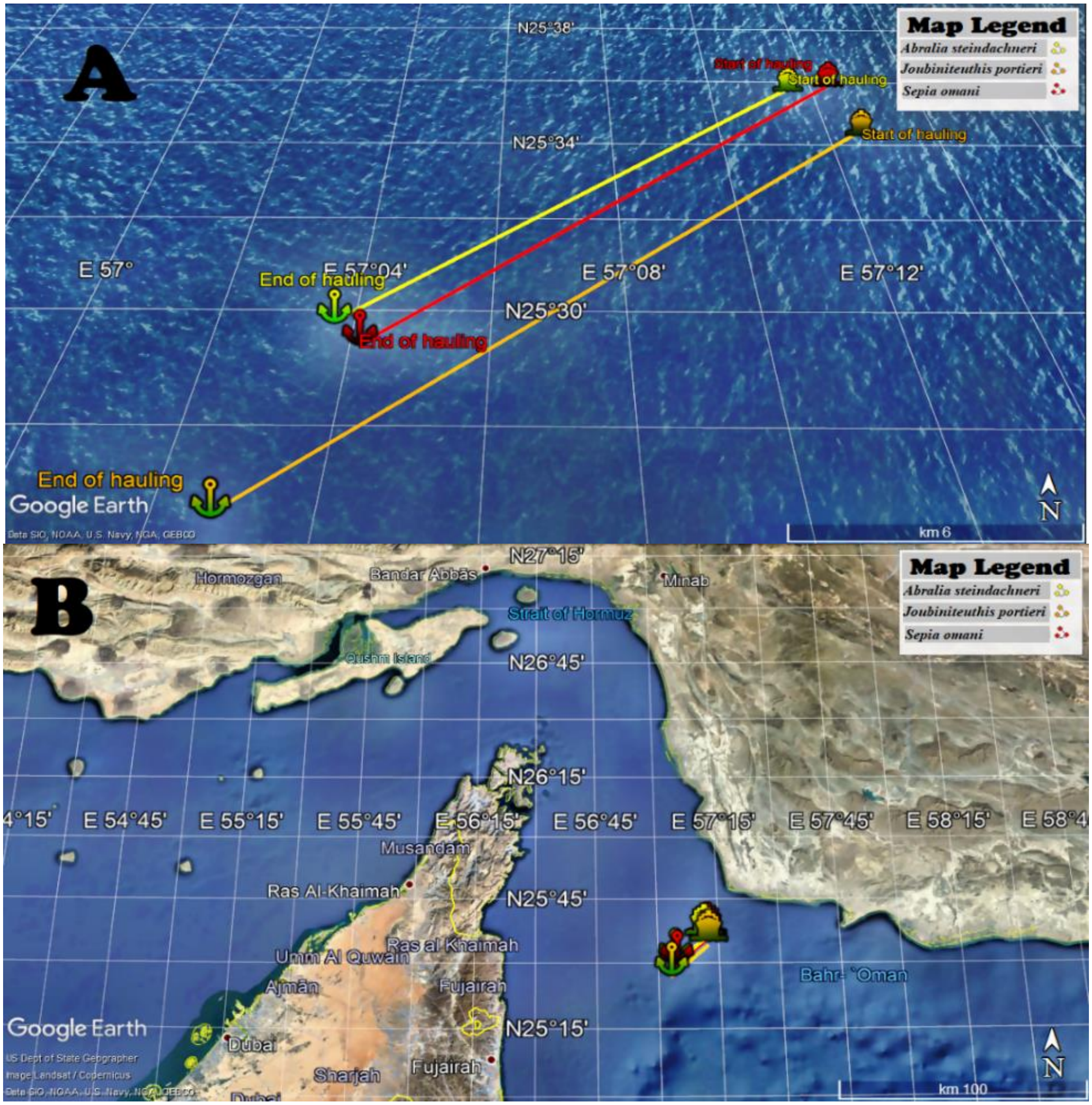

FIGURE 1. Geographical coordinates of studied area. A) hauling path for each species; B) study area in Iranian waters from north of the Gulf of Oman.

RESULTS

Abralia steindachneri Systematics: Phylum Mollusca Linnaeus, 1758; Class Cephalopoda Cuvier, 1795; Subclass Coleoidea Bather, 1888; Superorder Decapodiformes Young, Vecchione & Donovan, 1998; Order Oegopsida d'Orbigny, 1845; Family Enoploteuthidae Pfeffer, 1900; Genus Abralia Gray, 1849; Subgenus Abralia (Abralia) Gray, 1849; Species *Abralia (Abralia) steindachneri* Weindl, 1912.

Joubiniteuthis portieri or Joubin's squid Systematics: Phylum Mollusca Linnaeus, 1758; Class Cephalopoda Cuvier, 1795; Subclass Coleoidea Bather, 1888; Superorder Decapodiformes Young, Vecchione & Donovan, 1998; Order Oegopsida d'Orbigny, 1845; Family Joubiniteuthidae Naef, 1922; Genus Joubiniteuthis Berry, 1920; Species *Joubiniteuthis portieri* (Joubin, 1916).

Sepia omani or Oman cuttlefish Systematics: Phylum Mollusca Linnaeus, 1758; Class Cephalopoda Cuvier, 1795; Subclass Coleoidea Bather, 1888; Superorder Decapodiformes Young,

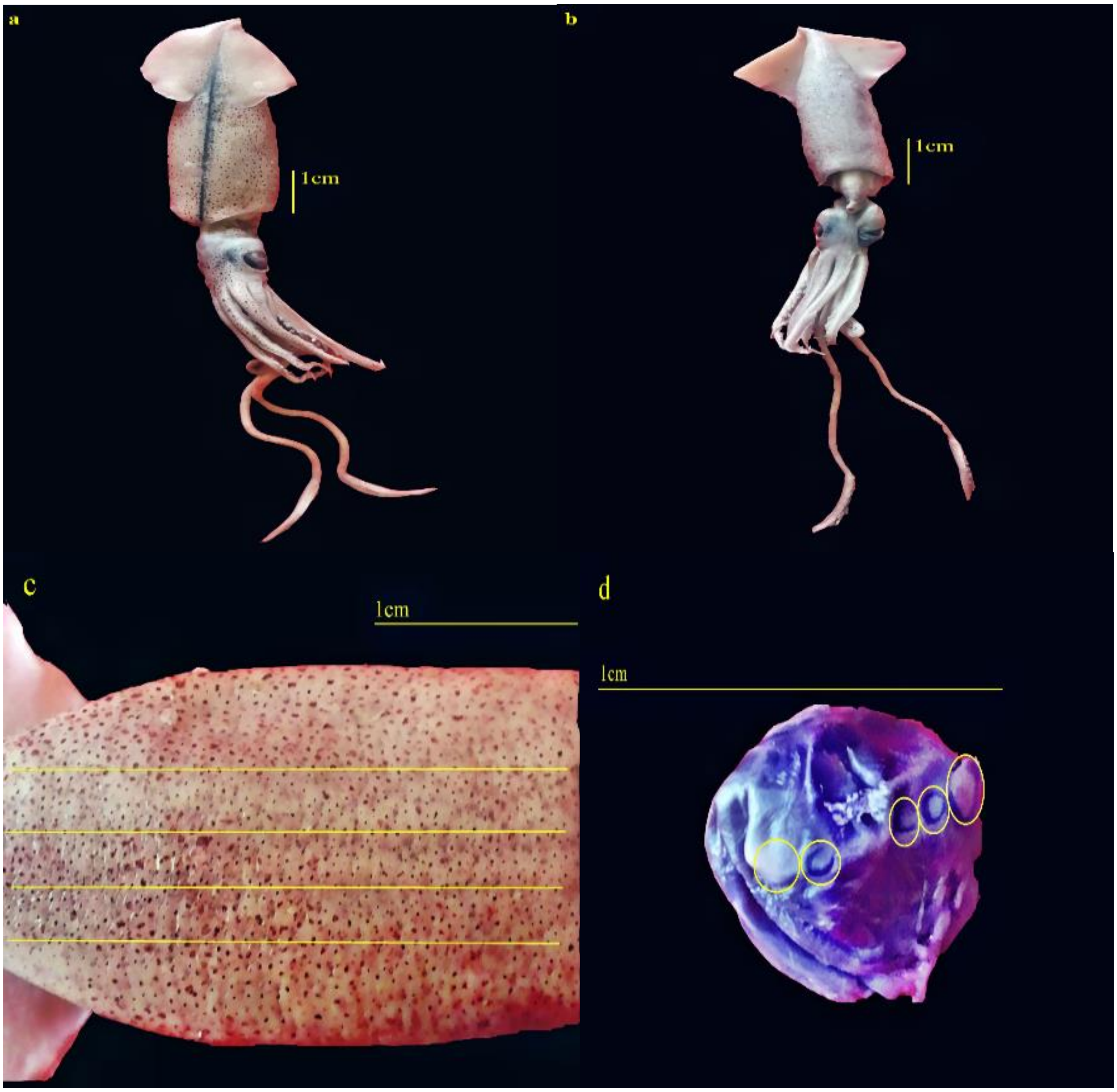

FIGURE 2. *Abralia steindachneri*: a) dorsal view; b) ventral view; c) integumental photophores from ventral view; d) eye photophores**.**

Vecchione & Donovan, 1998; Order Sepiida Zittel, 1895; Family Sepiidae Keferstein, 1866; Genus Sepia Linnaeus, 1758; Species *Sepia omani* Adam & Rees, 1966.

A. steindachneri (Fig. 2) diagnustic characters are: 1) six hooks on the ventral side of tentacle clubs, 2) four longitudinal stripes of integumental organs separated by photophore-less on the ventral mantle, and 3) five major complex organs on eyes including two large (terminal and opaque) organs also three intermediate (silvery) organs.

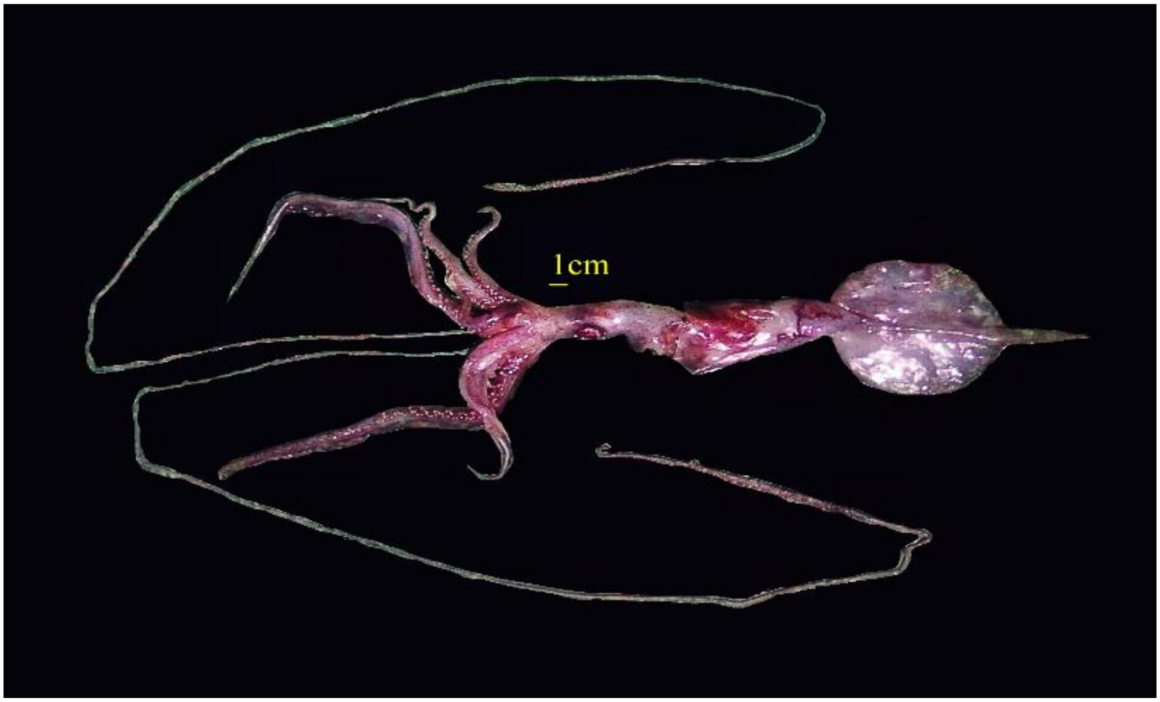

FIGURE 3. *Joubiniteuthis portieri*: dorsal view.

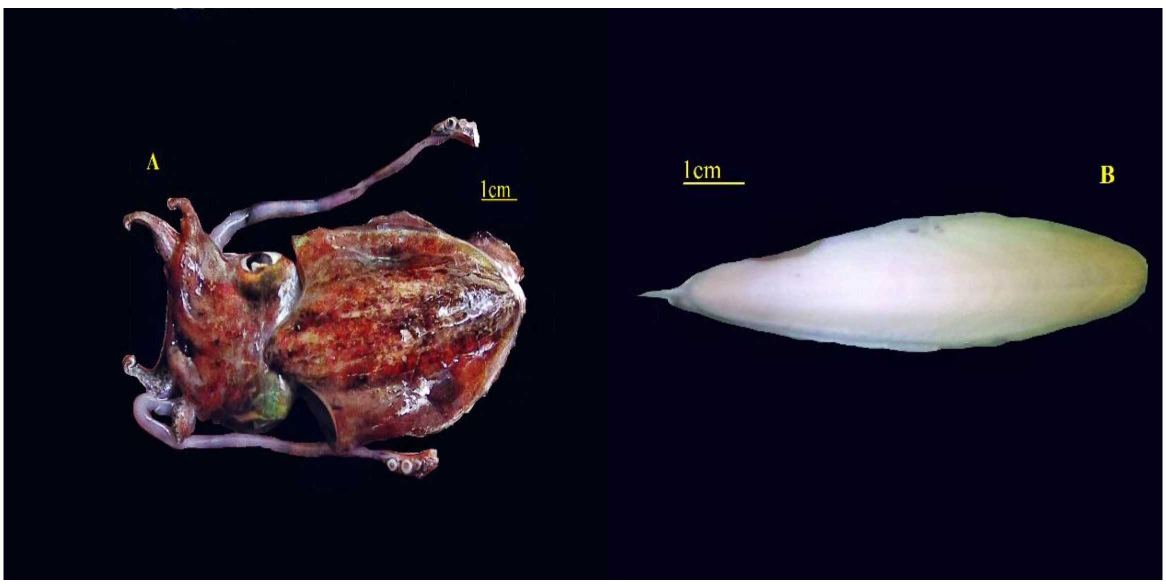

FIGURE 4. *Sepia omani*: A) dorsal view; B) dorsal view of cuttlebone.

J. portieri (Fig. 3) can be distinguished by: 1) a pair of extremely long and thin arms, 2) the thick and long tentacle (clubs), 3) narrow head, 4) long neck, 5) long tail, and 6) fins width and length are approximately equal

S. omani (Fig. 4) is recognizable with: 1) an oval mantle, 2) three suckers with different size in tentacle club, 3) light brown color, with dark brown transverse stripes in the dorsal mantle, and 4) Dorsal median rib, parallel sides, distinct lateral ribs, plus one long and pointed spine in the cuttlebone. The morphometric characteristics of the mentioned species are presented in Table 1. The extracted data from sea level, wind in the sea, moreover sea wave is given in Table 2.

TABLE 1. Morphometric characteristics of present specimens (Weights are in grams and lengths also rounds are in millimeters).

Species	Characters							
	Sex	Weight	Round*	Lengths				
				Mantle	Fin	Tentacle	Head	Arm
Abralia steindachneri	Female	10	34	43	17	78	15	36
Joubiniteuthis portieri	Female	50	70	165	64	788	44	135
Sepia omani	Male	80	112	83	72	175	28	31

*Round the body.

TABLE 2. Some sea level, wind in the sea, and sea wave characteristics (SST in degree centigrade, CHL-a in milligram per cubic meter, wind velocity in meter per second, wind direction in degree, wave direction in degree, and wave height in meter).

Species	Sea level		Wind		Sea wave	
	SST (M^a/A^b)	CHL-a (M/A)	velocity ($D^c \pm S.D^d$)	direction (D ± S.D)	height (D ± S.D)	direction (D ± S.D)
All species	16-32.50/16-32.50	0.8-9/0.09-3.4	-	-	-	-
Abralia steindachneri	-	-	3.44±1.79	248.7±115.59	0.43±0.17	151.71±77.05
Joubiniteuthis portiere	-	-	1.8±0.77	194±76.79	0.14±0.01	142.98±5.49
Sepia omani	-	-	5.01±1.07	125.66±11.20	0.38±0.11	318.40±6.10

[a] March since 2010 (limit); [b] April since 2010 (limit); [c] Daily average; [d] Standard Deviation

DISSCUSSION

The first record of *Abralia steindachneri* was in Shadwan Island in the Red Sea (Weindl, 1912). This species is quite large in comparison to the other congeners and has a mantle length of 50 mm. *A. steindachneri* is widely distributed in the Indo-West Pacific Ocean where it can be associated with shelf waters (Tsuchiya, 2018). Moreover, *A. steindachneri* is a mesopelagic species (Jereb & Roper, 2010). *Joubiniteuthis portieri* was reported for the first time from the Eeastern Central Atlantic Ocean (Joubin, 1916). The species is distributed in tropical, subtropical, and even temperate waters, especially in the Atlantic Ocean. *J. portieri* is a meso- to bathypelagic species (Jereb & Roper, 2010). The first observation of *Sepia omani* was in the South of the Gulf of Oman (Adam & Rees, 1966) and it is a neritic demersal species (Jereb & Roper, 2005). Other records of *S. omani* and *J. portieri* were from west of India (Sundaram, 2011) and east of Japan (Okutani & Kubota, 1972); respectively. While cuttlefish in Sundaram (2011) work is a *Sepia prashadi* sample (actually it is not *Sepia omani*).

Perhaps Melvill and Standen (1901) were one of the pioneers in terms of cephalopods studies in the Gulf of Oman that their study focused on the Mollusca of the Persian Gulf, Gulf of Oman and the Arabian Sea. Investigation of Rajabipour *et al.* (2001), after a century gap, was one of the recent and the most remarkable research in this case. They identified four species and one genus of squids in the Iranian waters of the Gulf of Oman (*Ancistrocheirus lesueurii, Liocranchia reinhardtii, Sthenoteuthis oualaniensis, Loligo duvaucelii, and Loligo sp*). According to the evidence provided by FAO (Jereb & Roper, 2005; Jereb & Roper, 2010; Jereb *et al.*, 2016), the species diversity of cephalopods in Iranian waters should be higher in the Gulf of Oman compared to the Persian Gulf. In this study, we have recorded three species *A. steindachneri*, *J. portieri*, and *S. omani* for the first time in Iran waters in the northwest Gulf of Oman. Hence, we believe that these findings would enhance our knowledge and understanding of the global distribution of these three species. Further studies are required to ventilate data on the likelihood of encountering more records in Iran. Probably, the paucity of cephalopods' records in Iran might be due to the lack of comprehensive samplings.

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RESEARCH ARTICLE **Open access**

New faunistic records of Chironomidae (Diptera: Insecta) from Iran

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Abstract
Ongoing investigation into Chironomidae specimens collected from the Sirwan River watershed in 2020 resulted in two new faunistic records for Iran, and new range extensions for the Palearctic region. Two species, *Paramerina divisa* (Walker, 1856) and *Xenochironomus xenolabis* (Kieffer, 1916) are diagnosed and reported for the first time from Iran. This contributes to establishing baseline data about the diversity and distribution of freshwater flora and fauna of this region.

Key words: *Chironomidae, Iran, faunistic records, Palearctic, Middle East, Kurdistan.*

INTRODUCTION

As part of an effort to acquire a baseline data on the diversity and distribution of the Kurdistan's freshwater flora and fauna, Mohammadi *et al*. (2020) provided a detail taxonomic diagnoses and description of specie of Chironomidae from Sirwan River watershed, the largest watershed in the province. Further investigation into materials obtained during this study indicated the presence of two other species which are new faunistic records for Iran and are considered range extension for the Palearctic. In this paper we provide a detail taxonomic diagnoses and description of *Paramerina divisa* (Walker, 1856) and *Xenochironomus xenolabis* (Kieffer, 1916) from Iran for the first time.

MATERIAL AND METHODS

A detailed description of Sirwan River watershed is provided by Mohammadi *et al*. (2020). A detailed description of the sampling procedure is provided by Mohammadi *et al*. (2020). The immature specimens were slide-mounted following the procedures outlined in Epler (2001) for immatures. Voucher specimens of chironomid species described and diagnosed in this study have been deposited in the Entomology Collection of the Royal Ontario Museum, Toronto, Ontario, Canada.

Images of the larval and pupal Chironomidae were produced using an OMAX A3550U Camera mounted on AMScope compound microscope. Morphological terminology, abbreviations, and measurements follow those used by Sæther (1980) for immature stages of Chironomidae.

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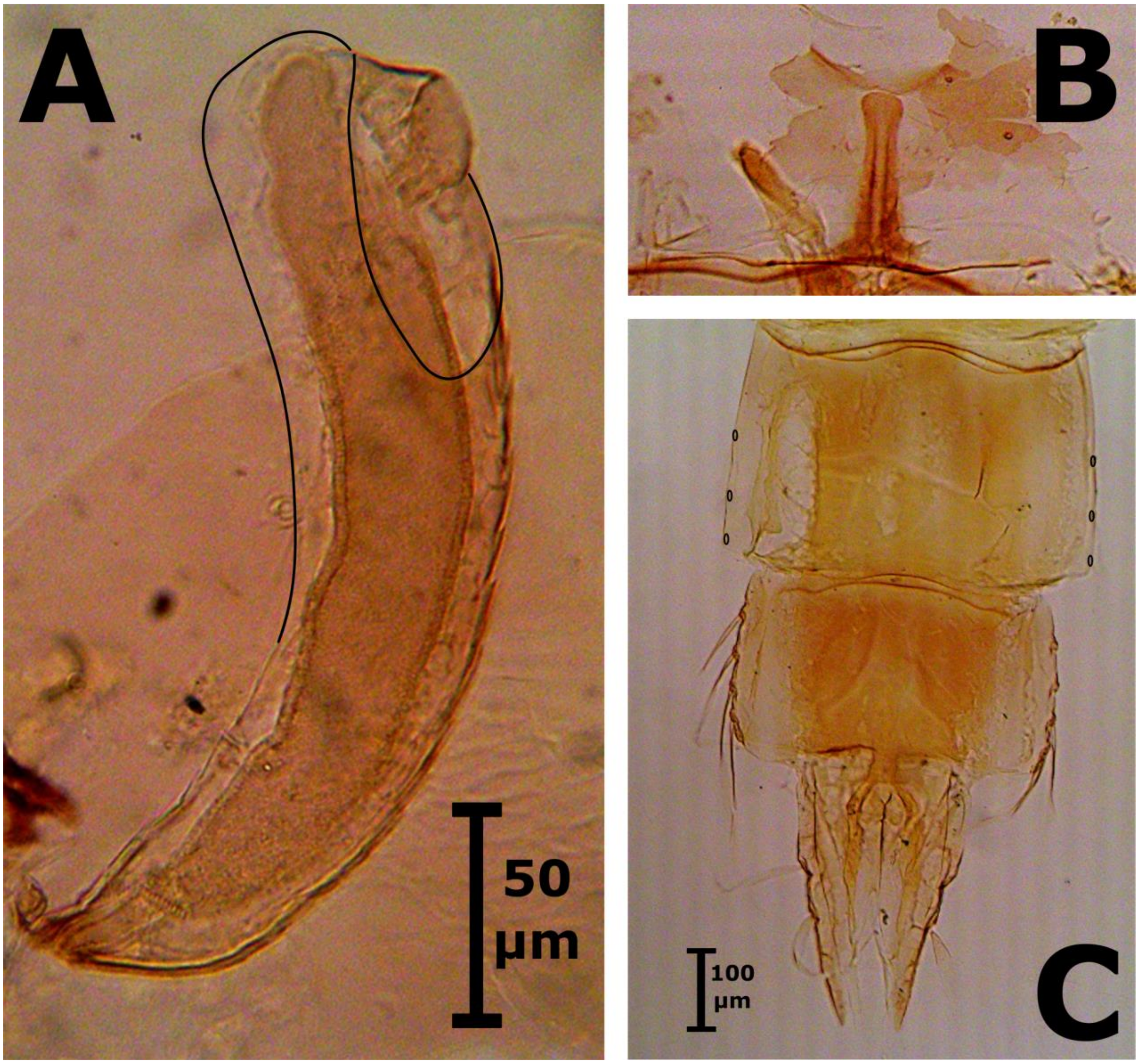

FIGURE 1. *Paramerina divisa* (Walker, 1856), A-C pupa. Thoracic horn (A); Tergite I scar (mark) (B); Tergites VII-IX (C).

The primary species geographical records were obtained from Ashe and O'Connor (2009) with additional records obtained from various taxonomic literature related to genera and species described in this study.

RESULTS

Faunistic records

The following species are recorded for the first time in Iran and are considered range extension for the Palearctic region: *Paramerina divisa* (Walker, 1856) and *Xenochironomus xenolabis* (Kieffer, 1916).

Review of the species

Subfamily Tanypodinae

***Paramerina divisa* (Walker, 1856)**

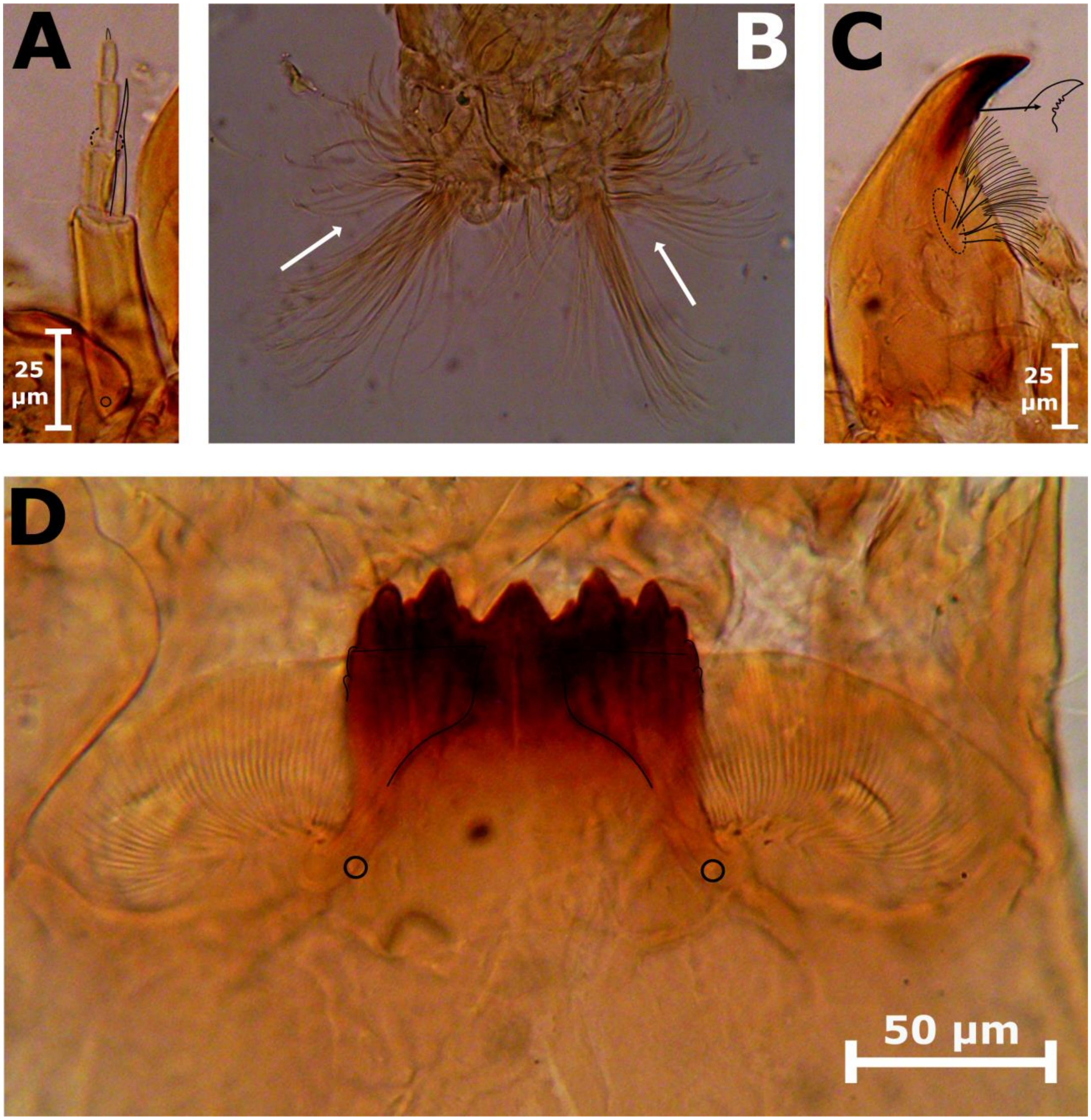

FIGURE 2. *Xenochironomus xenolabis* (Kieffer, 1916), A-D larva. Antenna (A); Labro-epipharyngeal region, arrow indicate the cluster of tick setae (B); Mandible (C); Mentum (D).

Diagnosis-Pupa: Thorax granular. Thoracic horn 277–281 (279) µm long with circular plastron plate, plastron plate about 1/3rd of the thoracic horn, atrium of thoracic horn thin-walled, joined with a short neck to the plastron plate, thoracic horn 4.3 x as long as wide (Fig. 1a). Tergite I with conspicuous scar (Fig. 1b). Tergite VII with 3 taeniae lateral setae, tergite VIII with 4 taeniae lateral setae, anal lobe 3 x as long as wide, anterior taeniae of anal lobe at 0.35 of lobe length (Fig. 1c).

Remarks: This species was described by Walker (1856) as *Chironomus divisus*. Adult male is described in key by Langton & Pinder (2007). The pupa is described by Langton & Visser (2003). The larva of this species is probably the *Paramerina* sp. described by Mohammadi *et al*. (2020) from the same watershed.

Mohammdi *et al*. (2020) noted at the time that their larva probably belongs to that of *Paramerina cingulata* (Walker, 1856).

Subfamily Chironominae

***Xenochironomus xenolabis* (Kieffer, 1916)**

Diagnosis-Larva: Total length 7.6–8.3 (8.0) mm. Antenna 5 segmented, segments sequentially decrease in size, blade reaches the base of the 4th segment, LO sitting opposite at the base of 2nd segment (Fig. 2A), AR 1.1. Labro-epipharyngeal region with two lobes, each with cluster of tick setae or brush (Fig. 2B), SI-SIII simple, SIV well-developed. Mandible with a broad and dark apical tooth and 3 small inner teeth, setae subdentalis simple, setae interna consist of 4 branches, each consist of a stalk with cluster of setae (Fig. 2C). Mentum dark, ventromental plates light golden, mentum with trifid median tooth and 7 pair of lateral teeth; 1st lateral teeth stand much higher than remaining teeth, 2nd lateral teeth sits much lower; ventromental plates 1.2–1.3x the width of mentum, Vmp L/W = 2; setae submenta sits just below the mentum aligned with last lateral teeth (Fig. 2D). Posterior parapods and procercus longer than wide. Anal tubules present.

Remarks: Species was described by Kieffer (1921) as *Chironomus xenolabis*. Adult male is described in key by Langton & Pinder (2007). The pupa is described by Langton & Visser (2003). Partial characteristics of adult male and pupa are also provided by Roback (1962). The larva is described by Roback (1962), and by Epler (2001).

DISCUSSION

Paramerina divisa is a widespread Palearctic species reported from the lotic habitats of many north to southern European countries. It has also been reported from Northern Africa, in the Middle East from Lebanon, and in the Oriental regions of Japan (Ashe & O'connor, 2009). *Xenochironomus xenolabis* inhabits stagnant and flowing waters where larvae make silken tubes and inhabit the outer layer of the freshwater sponges (Roback 1962). The species has a Neotropical and Holarctic distribution (Fusar *et al.* 2013, Langton & Visser, 2003). In the Palearctic, it is widespread in Europe, reported from Middle East and occurs as far east as the Korean Peninsula and Japan. The new faunistic records from Iran are also the first record for their corresponding genera in the country, and they further extend the range of these chironomids in the Palearctic region.

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RESEARCH ARTICLE Open access

New data on brittle stars (Echinodermata: Ophiuroidea) from the Persian Gulf and Oman Sea, Iran

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Abstract
Brittle stars are one of the most diverse classes of echinoderms distributed worldwide in marine habitats. In this study, brittle stars were sampled by hand from the intertidal zone of the Persian Gulf's western part to the Oman Sea, from locations accessible without the need of a boat or diving equipment. Sampling time was set in the first days of the lunar month or at least the time of lowest tide in each day. The specimens were first immobilized in freshwater, then fixed in neutralized buffered formalin, and finally preserved in 70% ethanol after one week of fixation. Of 22 sampling points, seven localities yielded intertidal brittle stars (*Macrophiothrix hirsuta cheneyi*, *Macrophiothrix elongata*, and *Ophiocoma scolopendrina*) during the sampling period (December 2017–March 2018). *Ophiocoma scolopendrina* is reported for the first time from Dayyer and Nayband in the Persian Gulf. We also re-evaluated recently reported data on ophiuroids from the studied area.

Key words: *intertidal, identification, Macrophiothrix, Ophiocoma, ophiuroid*

INTRODUCTION

The Persian Gulf is located between the Arabian Peninsula and Iran, extending from the Shatt al Arab delta to the Strait of Hormuz, connecting to the Indian Ocean via the Oman Sea, where both Persian Gulf and Oman Sea include different sandy, muddy and rocky habitats. Ophiuroidea, commonly named brittle stars, is one of the most diverse classes of the phylum Echinodermata (Stöhr et al., 2012), and in total, includes about 260 genera and 2,110 species (Stöhr et al., 2021). Generally, the marine habitats from the intertidal to hadal depths are inhabited by ophiuroids. They are living on the sea floor, on/inside other organisms, buried in mud, or hidden in/under rocks (Stöhr et al., 2012). In the Persian Gulf and Oman Sea, 20 genera and 38 species of brittle stars are known, probably five of them endemic to the region [compiled by Fatemi and Stöhr (2019)], and a recent study reported two additional records (*Ophionereis dubia* and *Ophiothrix savignyi*) for Abu Musa Island (Abdollahi et al., 2020), which cannot be evaluated due to the lack of images in the publication. Beigmoradi and Attaran-Fariman (2020) reported 11 species of ophiuroids from the Oman Sea, but a critical evaluation of the images and descriptions indicated that some specimens were misidentified.

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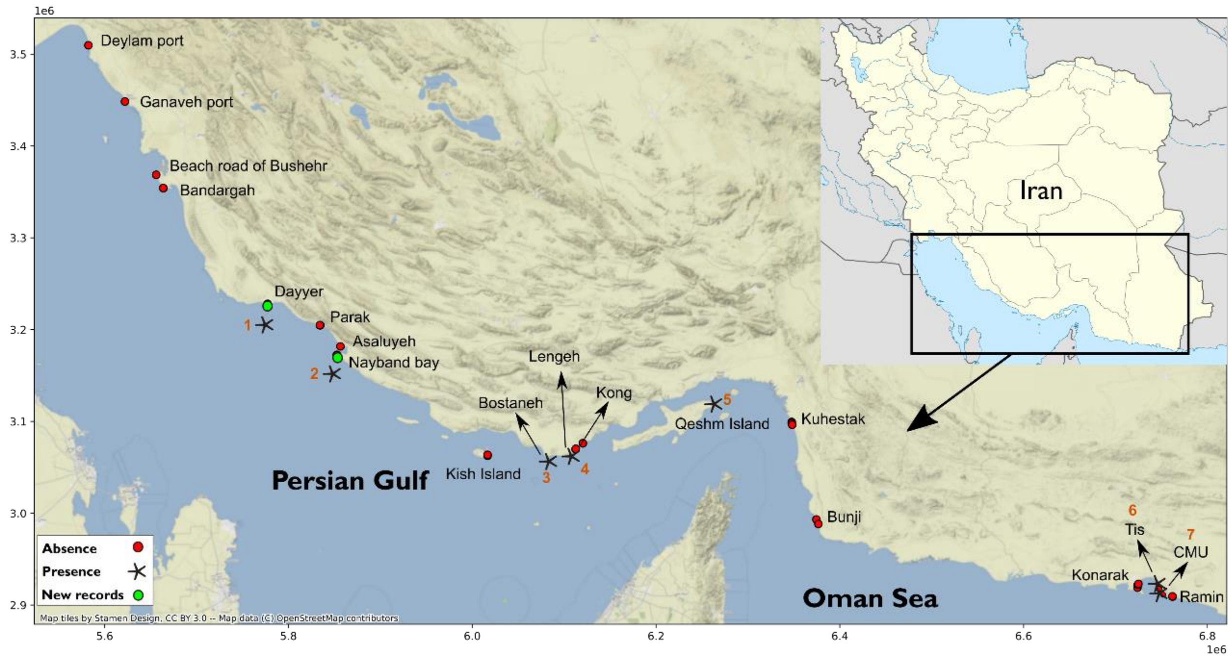

FIGURE 1. Sampling localities at the coast of the Persian Gulf and the Gulf of Oman. At localities marked by red circles no brittle stars were found, stars indicate the presence of brittle stars, and green circles mark new geographical records. At seven stations out of 22, the brittle stars were collected during the sampling time. The presence of *O. scolopendrina* from two stations is reported for the first time. Each locality includes several sampling points.

The majority of reported species from the Persian Gulf and Oman Sea occur in subtidal zones. However, little attention has been paid to their occurrence along the Iranian coast, especially in the intertidal zone. In this work, we examined the intertidal ophiuroid species along the Iranian coastline of the Persian Gulf to the Oman Sea, from habitats that were likely to be inhabited by specimens. We also aimed to update the latest data on ophiuroids of the Persian Gulf and Oman Sea, by examining the recently (after Fatemi and Stöhr, 2019) published papers from that area.

MATERIAL AND METHODS

Study area

We chose the stratified sampling method to classify the likely habitats for brittle stars according to the available data in Naderloo and Türkay (2017) and then sampled the specimens randomly from each location. Brittle stars were collected by hand from the intertidal areas of southern Iran, from locations accessible without the need of a boat or diving equipment. This research was carried out in two stages from December 16th, 2017 till March 25th, 2018. The first survey was primarily aimed to sample from the westernmost parts of the Persian Gulf to Bushehr (Fig. 1). The second one focused on the continuation of the initial sampling station (Parak) to Chabahar, a coastline of about 6000 km. The coasts of Khuzestan are muddy and are not a very likely habitat to find intertidal brittle stars, as these are usually seen in rocky and rocky-sandy habitats in Iranian waters (Fatemi and Stöhr, 2019). Deylam Port (sandy coast) was selected as the starting point of the survey, a habitat for which the presence/absence of brittle stars had not been reported yet.

The 50 sampling points along the Iranian coast of the Persian Gulf and Oman Sea were geographically divided into 22 sampling areas as follows: Deylam Port, Ganaveh Port, Beach Road of Bushehr, Bandargah, Halileh, Dayyer, Parak, Asaluyeh, Nayband Bay, Kish Island, Bostaneh Port, Lengeh Port, Kong, Qeshm Island, Kuhestak, Bunji, Konarak, Tis, the beach of Lipar Hotel, the beach of Chabahar Maritime and Marine University (CMU), Darya bozorg and Ramin Port. The main coordinates

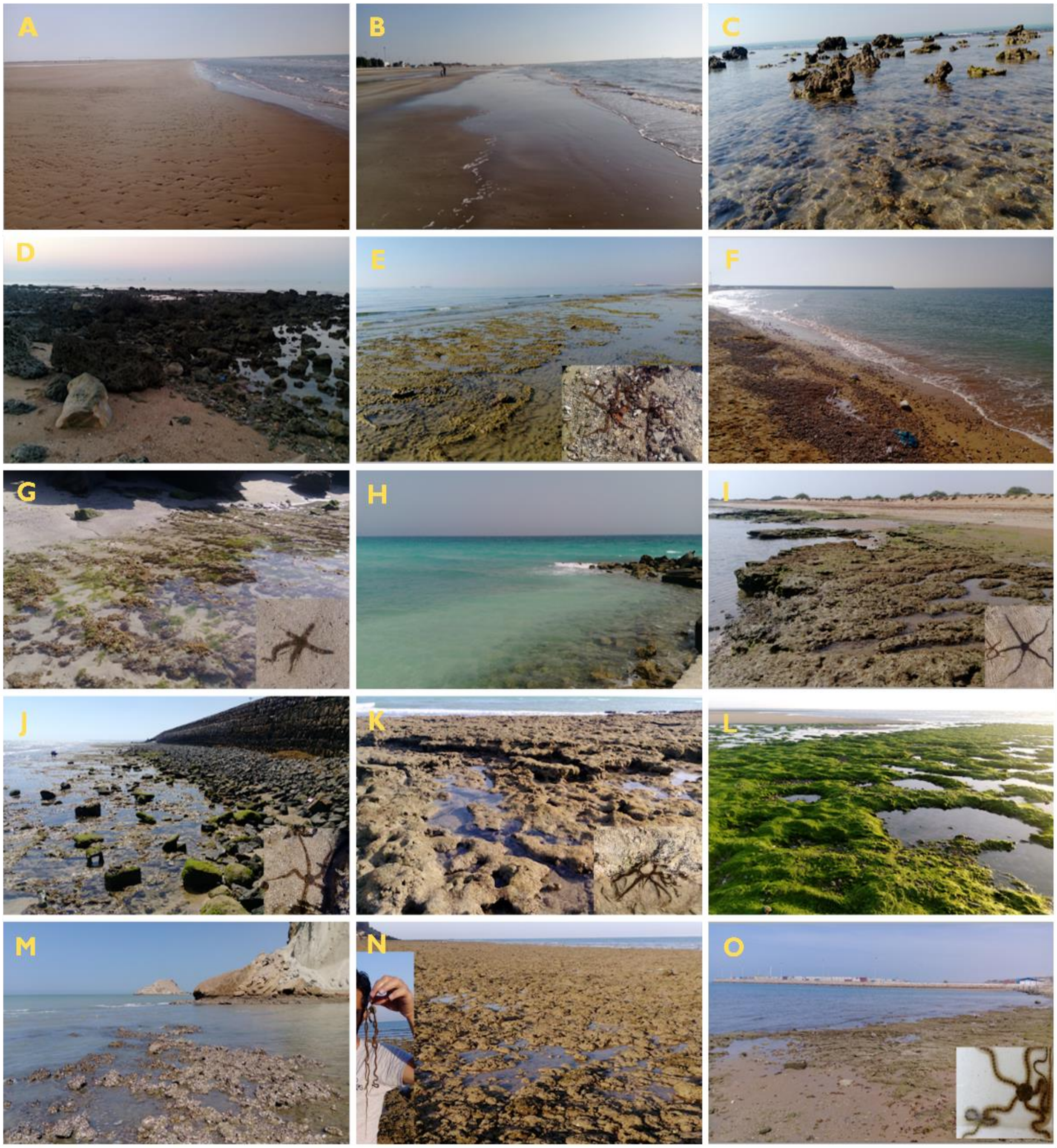

FIGURE 2. Various habitats at some of the sampling locations. A) Deylam Port, B) Ganaveh Port, C) Beach Road of Boushehr, D) Halileh, E) Dayyer, F) Parak, G) Nayband Bay, H) Kish Island, I) Bostaneh Port, J) Lengeh Port, K) Qeshm Island, I) Kuhestak, M) Bunji, N) Tis, and O) Chabahar university. The locations where brittle stars were found are marked by a photo of a specimen.

TABLE 1. The geographical coordinates of the sampling localities in the Persian Gulf and the Oman Sea.

Locality	Geographical coordinates	Habitat characteristics
Deylam Port	30.047, 50.146	Sandy
Ganaveh Port	29.570, 50.504	Sandy
Beach road of Bushehr	28.944, 50.879	Rocky cobble/dead corals
Bandargah	28.830, 50.879	Rocky/rock pool/Sandy
Halileh	28.831, 50.878	Rock pool/ cobble/Sandy
Dayyer	27.834, 51.898	Rock pool/dead corals/Sandy
Parak (4 sites)	27.648, 52.412	Sandy
Asaluyeh	27.465, 52.610	Sandy
Nayband Bay (4 sites)	27.390, 52.577	Rocky cliff/Sandy
Kish Island (4 sites)	26.517, 54.048	Rocky/rock pools
Bostaneh Port (3 sites)	26.502, 54.641	Rock pools/dead corals/Sandy
Lengeh Port (5 sites)	26.544, 54.879	Rocky cobble/dead corals/sandy
Kong (2 sites)	26.621, 54.979	Rocky/rock pools
Qeshm Island (2 sites)	26.929, 56.266	Rock pools/dead coral
Kuhestak (3 sites)	26.806, 57.021	Cobble/rock pools/Sandy
Bunji (2 sites)	25.953, 57.263	Dead corals/Sandy
Konarak (5 sites)	25.371, 60.403	Sandy
Tis (3 sites)	25.367, 60.609	Rocky/dead corals/Sandy
Lipar Hotel (2 sites)	25.321, 60.619	Rocky-Sandy
Chabahar University (CMU)	25.309, 60.625	Rocky/dead coral/Sandy
Darya bozorg	25.276, 60.665	Rocky/rock pools
Ramin Port (3 sites)	25.271, 60.744	Sandy

are listed in table 1 and the total sampling points were plotted using Geopandas and Stamen's Terrain map style (Fig. 1). The habitats of sampling stations and specimen numbers are illustrated in figures 2 and 3.

Data collection

Generally, the lowest tide is the best collecting time because it exposes the maximum area of the seafloor. The lowest tides usually occur during the early days of a lunar month. When the waters are receding, the intertidal flats are exposed and the animals can be collected before they have had a chance to hide. Therefore, sampling time was set in the first days of the lunar month or at least the time of lowest tide in each day. Sample size and habitat information (rocky, sandy, and sandy) were recorded. In total, 225 individuals were collected.

Morphological study

The specimens were first immobilized in freshwater, then fixed in neutralized buffered formalin, and finally preserved in 70% ethanol after one week of fixation (Batley and Simpson, 2016). Initial identification was performed based on the available identification keys (Gondim et al., 2013, Pomory, 2007, Goharimanesh et al., 2021). The samples were photographed with a digital camera attached to a stereomicroscope (model Olympus, SZH 10) located at the Faculty of Science, Ferdowsi University of Mashhad (FUM). Some of the specimens were later used for evolutionary morphological studies (Goharimanesh et al., 2020; Goharimanesh et al., in press).

RESULTS

The specimens (two genera) belonging to the two families Ophiotrichidae and Ophiocomidae were collected [for a detailed explanation of the family characters, see Goharimanesh et al. (2021)].

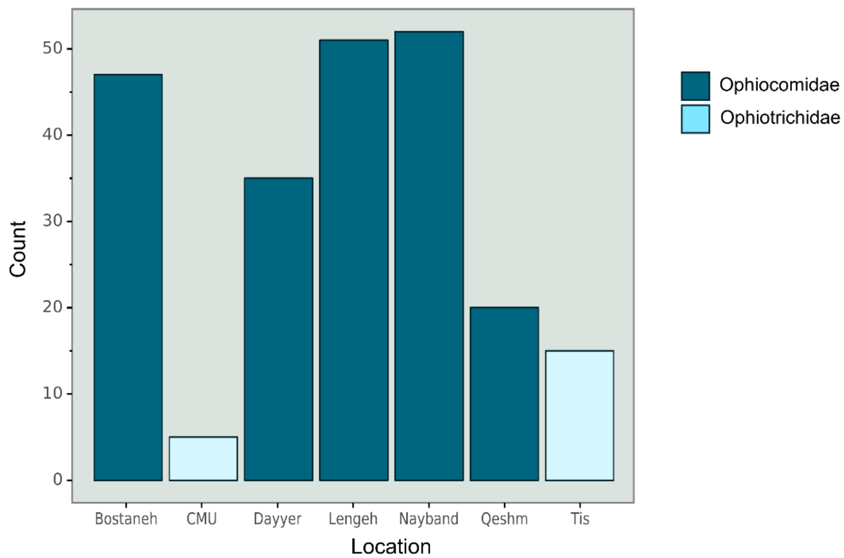

FIGURE 3. The number of collected specimens from each location.

The brittle stars were found in Dayyer, Nayband bay, Bostaneh port, Lengeh port, Qeshm Island, Tis, and CMU. Figure 3 shows the specimen number for each location. Intertidal brittle stars were only observed when the water was receding in rocky or rocky-sandy habitats and under rocks. Yet, they may have been missed in other rocky habitats such as Boushehr, Halileh, and Kish Island, due to their cryptic life-style, and hiding in crevices, or the sampling time may have been inappropriate.
The identified species, their occurrence, habitat, and diagnostic morphological characters are provided below.

Taxonomic account
Class Ophiuroidea Gray, 1840
Order Amphilepidida O'Hara, Hugall, Thuy, Stöhr & Martynov, 2017
Suborder Gnathophiurina Matsumoto, 1915
Superfamily Ophiactoidea Ljungman, 1867
Family Ophiotrichidae Ljungman, 1867

Genus *Macrophiothrix* H.L. Clark, 1938
***Macrophiothrix hirsuta cheneyi* (Lyman, 1861)**
Occurrence: Reported from the Persian Gulf and Oman Sea: Price, 1983, Khaleghi et al., 2015, Fariman and Beigmohammadi, 2016, Fatemi and Stöhr, 2019; Beigmoradi and Attaran-Fariman, 2020 and the present study from Tis and CMU (Fig. 2O).
Habitat in Oman Sea: Under rocks in rocky/sandy intertidal zone.
Diagnosis: Disc covered with short spines/stumps, more condensed or only seen between radial shields extending to ventral disc, disc, and arms without tubercles; dorsal and ventral color grey and dark blue or purple; dorsal arms with a longitudinal light line bordered by two dark blue stripes, ventral arms with wider median longitudinal stripe. Radial shields triangular covering two-thirds of the disc diameter. Oral shield much broader than long, covering less than one-third of interradius. Adoral shields separated. Several tooth papillae on the dental plate, but no lateral oral papillae on oral plate. Madreporite one, with one pore (Pourvali, 2015 and Goharimanesh et al., 2021).

***Macrophiothrix elongata* H.L. Clark, 1938**
Occurrence: Reported from the Persian Gulf and Oman Sea: Clark and Bowen, 1949, Price, 1981, Price, 1983, Khaleghi et al., 2017, Pourvali 2015, Fariman and Beigmohammadi, 2016, Beigmoradi and Attaran-Fariman, 2020 and by the present study from Tis (Fig. 2N) and CMU.
Habitat in Oman Sea: Under rocks in rocky/sandy intertidal area.
Diagnosis: *M. hirsuta cheneyi* and *M. elongata* are very similar in morphology and geographical distribution (Hoggett, 1990 and Clark, 1968), but the dorsal arm plates in *M. h. cheneyi* are rugose (Hoggett, 1990) and according to Clark (1968), *M. elongata* has much longer arms (about 20x disc diameter in *M. elongata*, and 10x in *M. h. cheneyi*).

Suborder Ophiodermatina Ljungman, 1867
Superfamily Ophiocomoidea Ljungman, 1867
Family Ophiocomidae Ljungman, 1867

Genus *Ophiocoma* l. Agassiz, 1836 sensu stricto O'Hara et al. 2019
***Ophiocoma scolopendrina* (Lamarck, 1816)**
Occurrence: Reported from the Persian Gulf and the Gulf of Oman: Mortensen, 1940, Fatemi et al. 2010, Pourvali 2015, Fatemi and Stöhr, 2019 and also the present study provides two new geographical records from Dayyer Port and Nayband Bay (Fig. 2, E, G, I, J, K, N, and O).
Habitat in Persian Gulf: Rocky and rocky-sandy intertidal area.
Diagnosis: Disc round or pentagonal. Dorsal disc fully covered by granules, covering the whole disc, including the radial shields. The disc colors range from light to dark brown, sometimes spotted patterns. Skin obscuring plates and scales. Ventral disc with granules, but less dense than on dorsal disc. Oral shields oval, shorter than wide. Adoral shields not meeting in front of the oral shield. Oral papillae five. Dorsal arm plates all fan-shaped, wider than long. Tentacle scales two, oval, arm spines alternatingly three and four (Fig. 4). Madreporite one, with one pore. Color in life variable, light and dark brown mottled, and changes in correlation with light intensity, but never completely black (Olbers et al., 2019, Goharimanesh et al., 2021). The specimens of Dayyer, Nayband and Qeshm were the darkest amongst the specimens collected (Fig. 5).

DISCUSSION

In this study, three intertidal species of ophiuroid from the Persian Gulf and Oman Sea were identified. In addition to recent studies (Fatemi and Stöhr, 2019), the results of the present study confirmed the misidentification of *Ophiothrix savignyi* as *Macrophiothrix hirsuta cheneyi* published in Fariman and Beigmohammadi (2016). The disc in *O. savignyi* is covered by long spines, but the animals in their images lack these, and they have dorsal arm plates that are wider than long and look rugose, which fit the description of *M. hirsuta cheneyi*. Moreover, we discovered that a recent report by Beigmoradi and Attaran-Fariman (2020) misidentified several ophiuroid species from the Oman Sea. In their study, specimens identified as *Ophiothela tigris* and *Ophiothela* sp. are actually *Ophiothela venusta*. As mentioned in Clark and Rowe (1971), *O. tigris* is naked on the disc and arm, but the images presented by Beigmoradi and Attaran-Fariman (2020) showed a disc covered with granules. Also, the coloration did not fit that of *O. tigris*. The *Macrophiothrix* sp 1. and sp 2. are not two different species as mentioned in their study (Beigmoradi and Attaran-Fariman 2020), but the images show *M. hirsuta* instead. *Ophiothrix* sp. and *Ophiothrix savignyi*, presented on two figures with identical images but different captions, were also *M. hirsuta* as there are no spines on the dorsal arm plates and the arms are much shorter. *Macrophiothrix longipeda*, another species reported by Beigmoradi and Attaran-Fariman (2020) from the Gulf of Oman, was probably misidentified. According to Clark and Rowe (1971) and Martin et al. (2005), *M. longipeda* has radial shields covered by granules, and the coloration is spotted. It also has a disc diameter of up to 40 mm and arms that can be up to 80 cm long (Davie, 1998). Hence, *M. longipeda* may have been confused with *M. elongata* by Beigmoradi and Attaran-Fariman (2020), however, the images

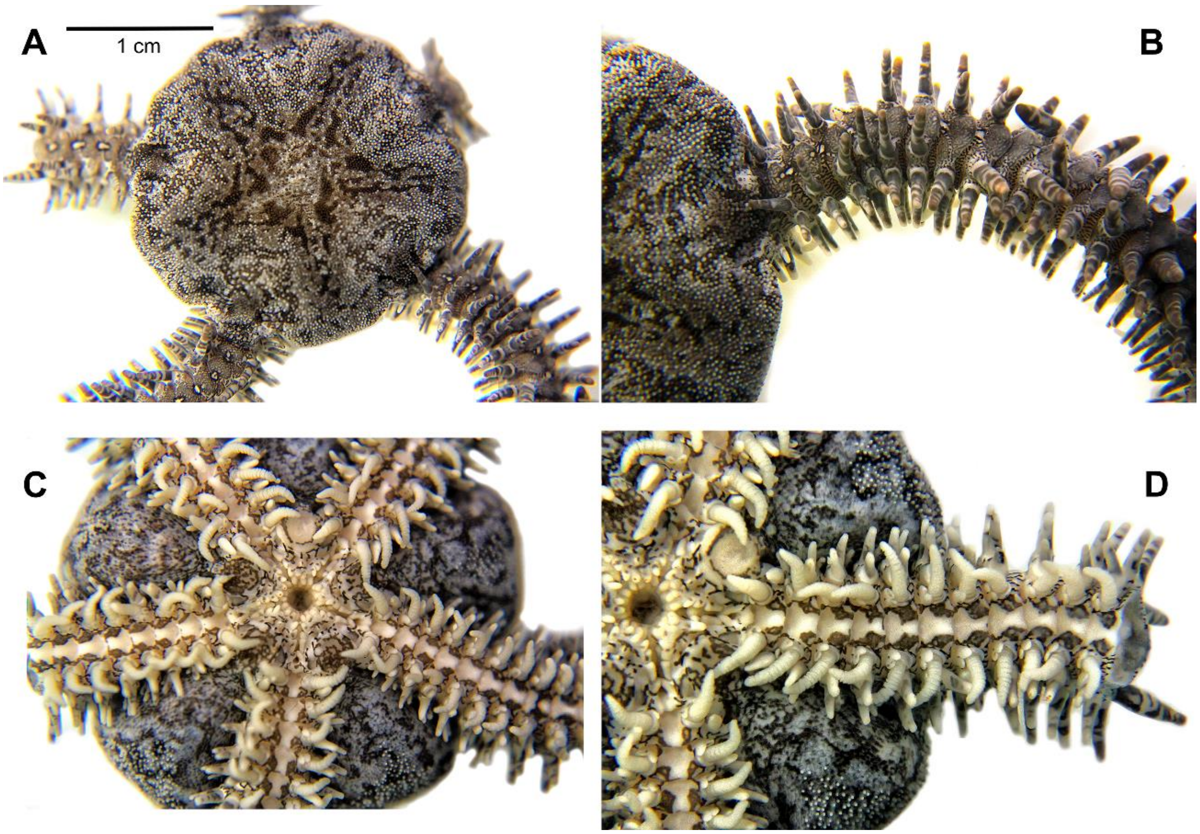

Figure 4. *Ophiocoma scolopendrina* dorsal (A & B) and ventral view (C & D), collected at Bostaneh.

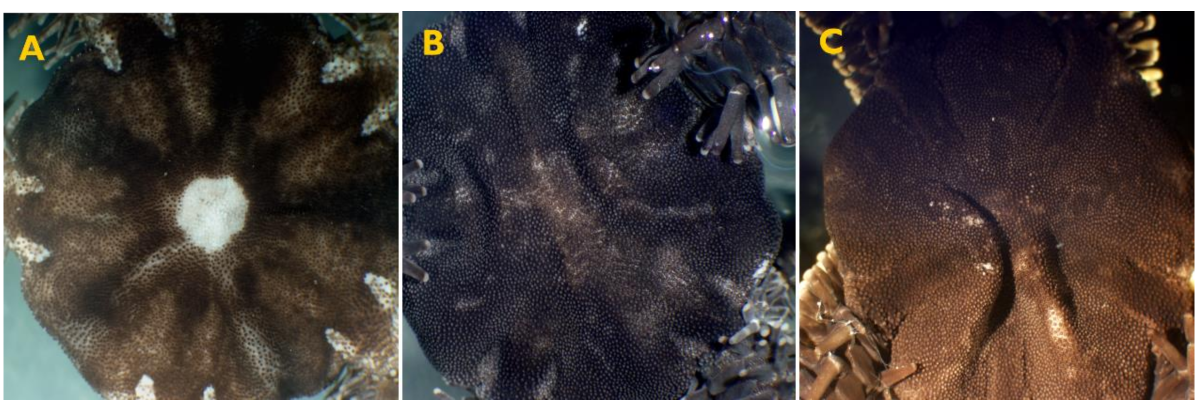

FIGURE 5. Dorsal disc color variation of *Ophiocoma scolopendrina* from A. Dayyer Port, B. Nayband Bay, and C. Qeshm Island.

are not clear enough to decide, as the arm length is the main difference between *M. elongata* and *M. hirsuta* (Clark, 1968). Currently, there are no records of *M. longipeda* in the Persian Gulf nor the Indian Ocean. As pointed out by Fatemi and Stöhr (2019), Attaran-Fariman and Beigmoradi (2016) misidentified *Amphipholis* and published the same erroneous record a second time (Beigmoradi and Attaran-Fariman, 2020). According to Clark and Rowe (1971), in *Amphiopholis* the outermost oral papillae are operculiform, and the oral papillae cover the oral slit. The images of Beigmoradi and Attaran-Fariman (2020) do not show such features. Instead, the figured disc lacks tubercles; three oral papillae arise from the oral plate, of which the outermost is not operculiform, and the oral papillae do not close the oral slit. These characters all fit the description of the genus *Amphiodia*. It also seems to have a single tentacle scale, a naked ventral disc, and the radial shield almost fully covered by scales (similar to *A. obtecta*). The pair of thorns on the radial shield, as mentioned in Clark and Rowe (1971) and shown in Stöhr et al. (2010) regarding *A. obtecta*, could not be detected on the published images (Attaran-Fariman and Beigmoradi, 2016; Beigmoradi and Attaran-Fariman, 2020), which makes identification to species level impossible. This re-evaluation implies that instead of 11 species reported by Beigmoradi and Attaran-Fariman (2020), there were only five species, and none of them were new records for the studied area.

New geographical records have been reported for *Ophionereis dubia* and *Ophiothrix savignyi* in Abu Musa Island (Abdollahi et al., 2020). However, the identification cannot be verified since the animals were neither figured nor described. *Ophiothrix savignyi* has been misidentified in previous studies (see Fatemi and Stöhr, 2019) and therefore, any records of this species should be treated with caution. In contrast, *Ophionereis dubia* has a characteristic and unique color pattern and should not be subject to confusion.

To conclude, apart from reporting the absence and presence of three intertidal species along the Iranian coast of the Persian Gulf and Oman Sea, two new geographical records are here reported for the species *O. scolopendrina* from Dayyer Port and Nayband Bay. Yet, they may have been missed in other rocky habitats such as Bushehr, Halileh, and Kish Island, due to their cryptic life-style, hiding under rocks or in crevices, or the sampling time may have been inappropriate. We suspect that the fluctuation of physical factors and stress exposure associated with tidal emersion (Knox, 2000) might affect diversity in the intertidal zone more than in the subtidal zone. This could explain the higher number of species of ophiuroid occurring in the subtidal rather than in the intertidal zone. Further studies on the subtidal zone along the studied areas are needed to understand these patterns.

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RESEARCH ARTICLE **Open access**

An Overview of Earthworm Biodiversity in Afghanistan with New Records for the Country (Clitellata: Megadrili)

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Abstract
In this paper a batch of earthworms from Afghanistan was studied and previous reports on the earthworm fauna of the country were evaluated. In the present study, earthworms were collected by digging and hand sorting, and fixed in 80% ethanol. Six species belonging to three families were identified. They are *Aporrectodea caliginosa*, *Ap. rosea*, *Eiseniella tetraedra*, *Drawida annandalei, Amynthas corticis*, and *Metaphire bahli*. Among them *A. corticis*, *Ap. caliginosa, D. annandalei*, and *M. bahli* are new records for the country. Nine species have previously been reported from Afghanistan of which two were collected in the current survey as well. Therefore, this study in Afghanistan increased the number of earthworm species registered for the country from 9 to 13 belonging to nine genera and three families. Out of the 13 species, 10 (*Ap. caliginosa*, *Ap. jassyensis*, *Ap. trapezoides*, *Ap. rosea*, *Bimastus parvus*, *Dendrobaena byblica*, *D. fedtschenkoi*, *Eisenia fetida*, *Eis. tetraedra*, and *Lumbricus rubellus*) belong to the Holarctic family Lumbricidae, two species (*M. bahli* and *A. corticis*) to the family Megascolecidae, and one species (*D. annandalei*) to Moniligastridae. Most of the species (10) are peregrine and only three of the lumbricid species in Afghanistan are regarded as autochthonous, *viz.*, *Ap. jassyensis*, *D. byblica*, and *D. fedtschenkoi*. The diversity and distribution of earthworms in Afghanistan is far from complete. To fill this gap in our knowledge on the earthworm fauna of the studied region more detailed investigations are needed to explore the earthworm fauna of this vast country.

Key words: *Aporrectodea caliginosa, Amynthas corticis, Drawida annandalei, Metaphire bahli, Lumbricidae, Megascolecidae, Moniligastridae.*

INTRODUCTION

Afghanistan is a landlocked and mountainous country in southern Central Asia. This country is bordered by Iran to the west; Turkmenistan, Uzbekistan, and Tajikistan to the north; China to the northeast; and Pakistan to the east and south. Physical geography in Afghanistan includes rugged mountains (northern three-quarters of the country) and desert plains. Despite having numerous rivers, large parts of the country are dry (Fisher, 2003; Gritzner & Shroder, 2007). Climatically, Afghanistan is similar to Iran and the Middle East (Barlow *et al.*, 2016).

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Very little research has been done on invertebrates in Afghanistan and the information that is available has not been combined. The most of biodiversity investigation was conducted prior to the outbreak of war in 1979. Thereafter, the deteriorating security situation has been made it difficult for researchers to safely survey the country and conduct research activities (UNEP, 2008; MoAIL, 2009; NBSAP, 2014). For this reason, hitherto, little is known about the biodiversity and distribution of earthworms in Afghanistan. The only available published resources are three old faunistic surveys which published by Omodeo (1959, 1962) and in Gates (1972), listing several taxa of earthworms from the country. The validity of the reported taxa and their presence in Afghanistan needs to be reassessed. Previous reported earthworms are all belonging to Lumbricidae, except for one unidentified Oligochaeta species (as “*Lumbriculus* sp.”) that belongs to the family Lumbriculidae.

In this study, we provide new earthworm records for the country and compare it with previous published data. Also, the validity of previously reported species is reassessed.

TABLE 1. List, geographic coordinates, and habitat types of sampling locations.

No. of Sampling Site	Locality Name	Latitude (N)	Longitude (E)	Habitat
1	Kapisa	34° 57' 55"	69° 38' 09"	Grassland
2	Heseh Dovom Kohestan	35° 02' 16"	69° 31' 24"	Woodland
3	Kishketan	34° 58' 59"	69° 36' 05"	Grassland
4	Golbahar	35° 07' 25"	69° 18' 23"	Grassland
5	Jamal Agheh	35° 01' 26"	69° 32' 19"	Grassland
6	Khom Zargar	35° 03' 03"	69° 29' 48"	Grassland
7	Rahman Khil	34° 59' 57"	69° 36' 12"	Grassland
8	Kohband	35° 00' 36"	69° 33' 54"	Grassland
9	Ghaleh Sahra	35° 05' 47"	69° 13' 15"	Grassland
10	Heseh Aval Kohestan	35° 03' 51"	69° 29' 59"	Woodland
11	Korreh Taz	34° 57' 26"	69° 40' 58"	Grassland

MATERIAL AND METHODS

Earthworms were collected by digging and hand sorting of 25×25×25 cm soil blocks collected at 11 stations of Kapisa Province, Afghanistan, in April 2018 (Table 1 and Figure 1). Three blocks were examined at each station so altogether we have analysed 33 samples. Collected specimens were anaesthetized in 15% and fixed in 80% ethanol, respectively. Anatomical observations were made by dissection the worms under a stereomicroscope. Specimens were housed in the Zoological Museum of Bu-Ali Sina University (ZMBASU) in Iran. Mature earthworms were identified according to Csuzdi and Zicsi (2003), Sims and Gerard (1999), and Perel (1979).

A similarity matrix was generated using Jaccard’s coefficient for earthworm fauna comparison between Afghanistan and neighbouring countries. Dendrogram of similarity was produced based on the Jaccard’s index using SPSS ver. 22 software.

RESULTS

During this study, altogether six peregrine earthworm species belonging to three families were recorded, namely, Lumbricidae (*Aporrectodea caliginosa* (Savigny, 1826), *Ap. rosea* (Savigny, 1826), and *Eiseniella tetraedra* (Savigny, 1826)); Moniligastridae (*Drawida annandalei* Stephenson, 1913); and Megascolecidae (*Amyntas corticis* Kinberg, 1867 and *Metaphire bahli* (Gates, 1945)). The different stations differed in species composition, being *A. corticis* and *M. bahli* the most frequent (found in four stations) and *Eis. tetraedra* and *D. annandalei* were the most uncommon, found in only one station (Table 2).

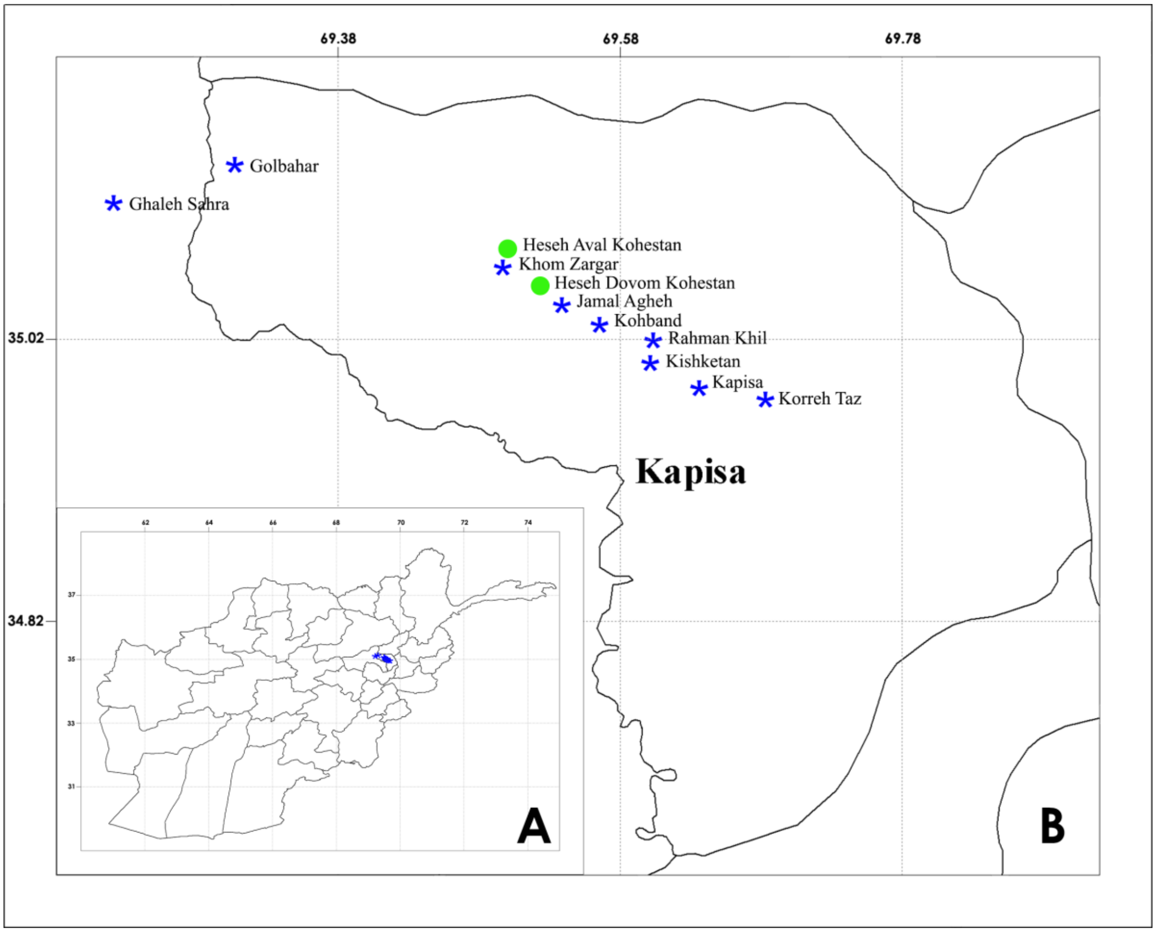

FIGURE 1. Map of sampling locations in studied area. **A.** Afghanistan. **B.** Kapisa Province. **Green Circles**. Woodlands. **Blue Stars**. Grasslands.

List of species
A) Lumbricidae Rafinesque-Schmaltz, 1815

A-1) *Aporrectodea caliginosa* (Savigny, 1826)
Material examined: (ZMBASU 22), [2 ex. Kapisa (34° 57' 55", 69° 38' 09")]; (ZMBASU 23), [2 ex. Golbahar (35° 07' 25", 69° 18' 23")]; (ZMBASU 24), [2 ex. Heseh Aval Kohestan (35° 03' 51", 69° 59' 29")].
Habitat: Grass-woodland.

A-2) *Aporrectodea rosea* (Savigny, 1826)
Allolobophora rosea f. acystis (Michaelsen, 1902): Omodeo 1959: 6.
Allolobophora rosea var.: Omodeo 1962: 6.
Eisenia rosea: Gates 1972: 104.
Material examined: (ZMBASU 25), [2 ex. Kapisa (34° 57' 55", 69° 38' 09")]; (ZMBASU 26), [1 ex. Rahman Khil (34° 59' 57", 69° 36' 12")]; (ZMBASU 27), [2 ex. Heseh Aval Kohestan (35° 03' 51", 69° 59' 29")].
Habitat: Grass-woodland.

A-3) *Eiseniella tetraedra* (Savigny, 1826)
Eiseniella tetraedra f. typica: Omodeo 1959: 8.
Eiseniella tetraedra: Omodeo 1962: 9, Gates 1972: 108.
Material examined: (ZMBASU 28), [3 ex. Kishketan (34° 58' 59", 69° 33' 54")].
Habitat: Stream.

B) Megascolecidae Rosa, 1891

B-1) *Amynthas corticis* (Kinberg, 1867)
Material examined: (ZMBASU 29), [1 ex. Khom Zargar (35° 03' 03", 69° 29' 48")]; (ZMBASU 30), [2 ex. Jamal Agheh (35° 01' 26'", 69° 32' 19")]; (ZMBASU 31), [2 ex. Kohband (35° 00' 36", 69° 33' 54"]; (ZMBASU 32), [1 ex. Korreh Taz (34° 57' 26", 69° 40' 58")].
Habitat: Grassland.

B-2) *Metaphire bahli* (Gates, 1945)
Material examined: (ZMBASU 33), [2 ex. Rahman Khil (34° 59' 57", 69° 36' 12")]; (ZMBASU 34), [1 ex. Jamal Agheh (35° 01' 26", 69° 32' 19")]; (ZMBASU 35), [2 ex. Heseh Dovom Kohestan (35° 02' 16", 69° 31' 24")]; (ZMBASU 36), [1 ex. Korreh Taz (34° 57' 26", 69° 40' 58")].
Habitat: Grass-woodland.

C) Moniligastridae Claus, 1880

C-1) *Drawida annandalei* Stephenson, 1913
Material examined: (ZMBASU 37), [5 ex. Ghaleh Sahra (35° 05' 47", 69° 13' 15")].
Habitat: Grassland.

DISCUSSION

Previously only two old documents were published about the earthworm fauna of Afghanistan, *viz.*, Omodeo (1959) and Omodeo (1962). Omodeo (1959) studied a batch of oligochaetes including 151 specimens and assigned them in 10 taxa. The specimens had been collected by Dr. K. Lindberg, at the Lund University, from 43 various localities in Afghanistan (Figure 2 and Table 2). Again, Dr. K. Lindberg sent Omodeo a second batch of oligochaetes, which he had collected from various localities in Afghanistan (Figure 2 and Table 2). Omodeo (1962) studied the specimens and identified them as nine different species, namely *Ap. caliginosa/trapezoides*, *Ap. jassyensis* (Michaelsen, 1891), *Ap. rosea*, *Bimastus parvus* (Eisen, 1874), *Dendrobaena byblica* (Rosa, 1893), *D. fedtschenkoi* (Michaelsen, 1900), *Eisenia foetida*, *Eis. tetraedra*, and *Lumbriculus* sp. Omodeo (1962) pointed out that the second collection has contained the same species as the first one, and they had had in roughly the same proportion; the only novelty had been the finding of *D. fedtschenkoi*.

Gates (1972) in his book on Burmese earthworms reported the occurrence of six species in Afghanistan, namely *Ap. rosea*, *Ap. trapezoides* (Duges, 1828), *B. parvus*, *E. fetida* (Savigny, 1826), *Eis. tetraedra*, and *Lumbricus rubellus* Hoffmeister, 1843; and doubtfully the presence of *D. octaedra* (Savigny, 1826) as well. He stated that the record of *Ap. trapezoides* is based on the study of his own specimens, but he did not mention anything about the other species.

In the present study, six species have been identified which four of them have not been previously reported from this region. *D. annandalei*, as one of the new records for this region, belongs to Moniligastridae. Earthworms of these family are native in the Oriental region (Gates, 1972; Jamieson, 1977; Blakemore *et al.*, 2014). Its natural range encompass south, southeast and east Asia, from peninsular India to Japan through Myanmar, China, extreme southern portion of Far East Russia, Korea,

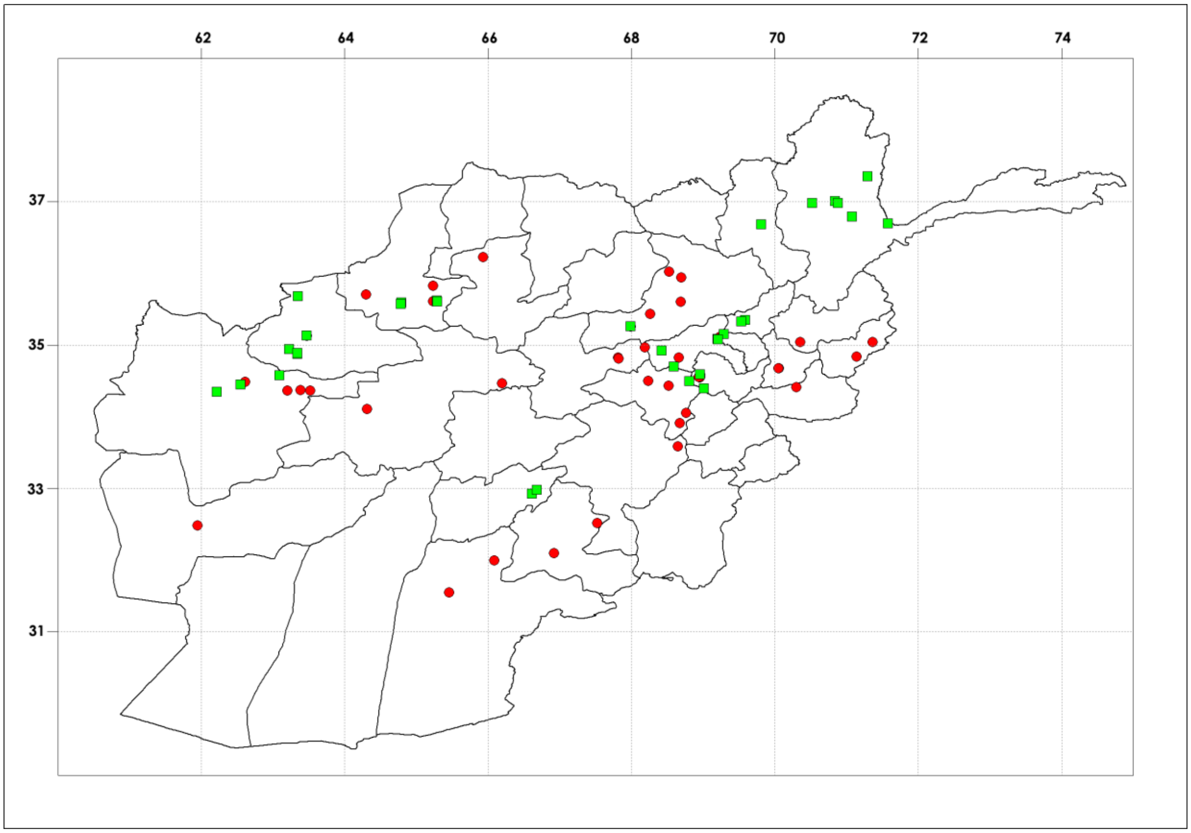

FIGURE 2. Sampling locations of earthworms in Afghanistan. **Red Circles.** First collection (Omodeo, 1959). Green **Squares.** Second collection (Omodeo, 1962).

the Philippines, Borneo, and Sumatra (Gates, 1972). *Drawida* is the most speciose moniligastrid genus that presumably colonized peninsular India after the collision of the Indian plate with Asia during Cenozoic period (Gates, 1972; Blakemore *et al.*, 2014). From the neighbouring countries Pakistan and China, two and 22 species of *Drawida* were reported respectively (Blakemore, 2006; Ghafoor *et al.*, 2008; Zhang & Sun, 2014). As a result, this species may have entered Afghanistan from the southeast or was introduced by man.

The two megascolecid species recorded in this study from Afghanistan (i.e. *A. corticis* and *M. bahli*) are both widely distributed peregrine worms (Blakemore, 2002). *M. bahli* is known mainly from Asia (Cambodia, Laos, Myanmar, Philippines, Sri Lanka, Thailand, and Vietnam) and Australia (Gates, 1945, 1972; Blakemore *et al.*, 2012; Nguyen *et al.*, 2016; Nguyen & Lam, 2017). Of the neighbouring countries, *A. corticis* and five species of *Metaphire* have been reported only from Pakistan (Sarwar *et al.*, 2006; Ghafoor *et al.*, 2008).

The lumbricid species in genera *Aporrectodea* and *Eiseniella* are of European origin (Wood & James, 1993). According to Mršić (1991) the genus *Dendrobaena* appeared on the Southern Aegean land masses, the genus *Eisenia* on the Asian plate, the genera *Aporrectodea* and *Lumbricus* in Western Europe, and the genus *Bimastos* in North America (Csuzdi & Zicsi, 2003). Several lumbricid species show anthropochore distribution, including *Ap. caliginosa*, *Ap. trapezoides*, *Ap. rosea*, *E. fetida*, *Eis. tetraedra*, *L. rubellus*, etc. (Csuzdi & Zicsi, 2003). Until now, only three of the reported lumbricid species in Afghanistan are regarded as autochthonous, *viz.*, *Ap. jassyensis*, *D. byblica*, and *D. fedtschenkoi* (Mısırlıoğlu *et al.*, 2008). *B. parvus*, native in North America, but now they are peregrine and introduced all over the world (Reynolds, 1977).

TABLE 2. Localities of the earthworm species studied by Omodeo (1959, 1962) and in present study.

First collection (Omodeo 1959)			**Second collection (Omodeo 1962)**		
Name of location	**Species***	**No. of species**	**Name of location**	**Species***	**No. of species**
Tchehel Tan Cave	Apr	1	Tang Lalander	Apc	1
Tchehel Tan	Apc	1	Diaouz	Apc, Apr	2
Haouz-Mahiyan	Eit	1	Paghman	Apc, Bp	2
Tchidjan	Apc	1	Pol Matak	Apc	1
Chahr Golghola	Bp	1	Pol Matak	Apc	1
Bamian	Apc, Eit, Bp	3	Mazaneh	Apj, Apc, Apr, Eit, Dbb	5
Diwal Kol	Apc	1	Bamvardar Aoudak	Lsp, Apc, Apr	3
Salar	Apc, Apr	2	Navalitch	Apc	1
Ziyaret Khvadjeh Safa	Lsp, Apc, Apr, Eit	4	Till Païn	Apc, Eit	2
Paghman	Apj, Apc	2	Kou Najak	Lsp, Dbb	2
Chah Qatar	Apc, Apr, Eit, Dbb	4	Sar-haouz	Apr	1
Douazdah Emam	Apj	1	Chercher	Eit, Dbf	2
Soltanpour	Apr	1	Oal'eh Darreh Zang	Ef, Apc, Apr, Eit, Dbf	5
Pialeh Cave	Apr	1	Oal'eh Darreh Zang	Ef	1
Kouh-Chigui	Apr	1	Masdjed Tchoubi	Apr, Eit	2
Sri Tighi Cave	Apr	1	Herat	Apc	1
Djalala	Apr	1	Karokh Cave	Apr, Dbb	2
Samotch	Apr	1	Darreh Boum	Ef, Apc	1
Sang-Tanab	Apr	1	Between Qal'a-i-Nau and Qaddis	Apc	1
Pul-i-Khomri	Apc, Alsp	1	Qaddis	Apc, Eit, Dbb	3
Sorkh Kotal	Apc	1	Qaddis: Tchehel Dokhteran	Lsp	1
Goti	Apj	1	Ghoroutou	Lsp	1
Zir Chibar	Apc	1	Tirgaran	Apc	1
Doab-i-Mekhzarin	Alsp	1	Faizabad	Apc	1
Jebel os-Siradj	Lsp	1	Shiva Kul Lake	Eit	1
Pol-Matak	Dbb	1	Gazestan	Apc, Apr, Dbb	3
Qaisar	Lgsp	1	Ichkachem	Bp	1
Darreh-Beltchiragh	Apc, Apr	2	Baharak	Eit, Dbb	2
Kham Zindan Cave	Lgsp	1	Baharak	Apc	1
Sar-i-Pul	Apc	1	Orozgan	Apc, Apr	2
Darreh-Boum	Apr, Eit	2	Sabz Tchachmeh	Apc	1
Qal'eh Dahan-Tchakka	Eit, Lgsp	2	Doab-i-Mekhzarin	Apc	1
Qal'a-Shaharak	Apc	1	**Present study**		
Khvadjeh Tchicht	Apc	1	Kapisa	Apc, Apr	2
Between Tchicht and Soumi	Apc	1	Heseh Dovom Kohestan	Meba	1
Obeh	Apr, Eit	2	Kishketan	Eit	1
Karokh Cave	Lgsp	1	Golbahar	Apc	1
Kalat-i-Ghilzai	Ef, Apc	2	Jamal Agheh	Amco, Meba	2
Sirouas	Alsp	1	Khom Zargar	Amco	1
Pandjvai	Apc, Apr	2	Rahman Khil	Apr, Meba	2
Chahr Safa	Dbb	1	Kohband	Amco	1
Kelidan Cave	Eit	1	Ghaleh Sahra	Dra	1
Kouh-Mostoufi	Apc	1	Heseh Aval Kohestan	Apc, Apr	2
			Korreh Taz	Amco, Meba	2

***Abbreviations:** Alsp: *Allolobophora* sp.; Amco: *A. corticis*; Apc: *Ap. caliginosa*; Apj: *Ap. jassyensis*; Apr: *Ap. rosea*; Bp: *B. parvus*; Dbb: *D. byblica*; Dbf: *D. fedtschenkoi*; Dra: *D. annandalei*; Ef: *E. fetida*; Eit: *Eis. tetraedra*; Lgsp: *Lumbricidarum* gen. sp.; Lsp: *Lumbriculus* sp. (microdrili); Meba: *M. bahli*.

TABLE 3. Jaccard's similarity coefficient matrix for earthworm fauna comparison between Afghanistan and neighbouring countries.

Country	Tajikistan	Turkmenistan	Iran	Uzbekistan	Pakistan
Tajikistan					
Turkmenistan	0.375				
Iran	0.385	0.231			
Uzbekistan	0.480	0.222	0.382		
Pakistan	0.056	0.063	0.067	0.043	
Afghanistan	0.444	0.375	0.286	0.276	0.118

Omodeo (1959) regarded the Afghanistan earthworm fauna as Holarctic because the autochthonous taxa like *Ap. jassyensis* and *D. byblica* are from the family Lumbricidae and no native taxa were found from the neighbouring oriental region. By identifying two species of Megascolecidae and one species of Moniligastridae does not change this position because perhaps all the three species were introduced by human activity.

In short, according to our present and previous literature records, 13 species, nine genera, and three families of earthworms are known to be present in Afghanistan. This number is much lower than the 18 species recorded for the much smaller Jordan, which is also a desert area (Pavlíček & Csuzdi, 2006).

According to current data (Tables 3 and 4), the earthworm fauna of Afghanistan most closely resembles Iran, Tajikistan, and Uzbekistan in terms of number of shared species (8 shared species); Turkmenistan and Tajikistan in respect of percentage of shared species, 66.67% and 61.54%, respectively; and it is most similar to Tajikistan with regard to Jaccard's similarity coefficient (0.444).

TABLE 4. Earthworm species in Afghanistan and adjacent countries.

	Uzbekistan	**Tajikistan**	**Iran**	**Turkmenistan**	**Pakistan**	**Afghanistan**
Species*	Apc, Apj, Apr, Apt, Bp, Br, Dbb, Dboc, Dbv, Ef, En, Eit, Oc, Ol, Pa, Pc, Pf, Pg, Pk, Pmi, Po, Ps, Pta, Pu	Apc, Apj, Apr, Apt, Bp, Dbb, Dbv, Ef, Eit, Oc, Pk, Pme, Pta	Apc, Apj, Apl, Apr, Apt, Bp, Br, Dbb, Dbh, Dboc, Dbor, Dbp, Dbs, Dbv, Ea, Ef, Em, Eo, Eit, Mid, Mip, Ol, Pk	Apj, Apr, Apt, Ef, Eit, Lr, Pk, Pp, Ptu	Amb, Amca, Amco, Amg, Ami, Aml, Ammi, Ammo, Amo, Ams, Apc, Apl, Dim, Drn, Drp, Ef, Lr, Mea, Mebi, Mec, Meh, Mep, Ob, Pot, Ti	Amco, Apc, Apj, Apr, Apt, Bp, Dbb, Dbf, Dra, Ef, Eit, Lr, Meba
No. of Species (NSS)(PSS)	24 (8) (33.33)	13 (8) (61.54)	23 (8) (34.78)	9 (6) (66.67)	25 (4) (16)	13
References	Omodeo (1959); Rakhmatullaev *et al.* (2010); Asirovic (2011).	Omodeo (1959); Asirovic (2011).	Farhadi *et al.* (2013); Szederjesi *et al.* (2014); Latif *et al.* (2017); Latif *et al.* (2018).	Gates (1972); Asirovic (2011).	Sarwar *et al.* (2006); Ghafoor *et al.* (2008).	Omodeo (1959, 1962); Gates (1972); Present study.

***Abbreviations:** Amb: *A. bournei* (Rosa, 1890); Amca: *A. carinensis* (Rosa, 1890); Amco: *A. corticis*; Amg: *A. gracilis* (Kinberg, 1867); Ami: *A. indicus* (Horst, 1885); Aml: *A. lignicolus* (Stephenson, 1914); Ammi: *A. minimus* (Horst, 1893); Ammo: *A. morrisi* (Beddard, 1892); Amo: *A. osmastoni* (Michaelsen, 1907); Ams: *A. suctorius* (Michaelsen, 1907); Apc: *Ap. caliginosa*; Apj: *Ap. jassyensis*; Apl: *Ap. longa* (Ude, 1885); Apr: *Ap. rosea*; Apt: *Ap. trapezoides*; Bp: *B. parvus*; Br: *B. rubidus* (Savigny, 1826); Dbb: *D. byblica*; Dbf: *D. fedtschenkoi*; Dbh: *D. hortensis* (Michaelsen, 1890); Dboc: *D. octaedra*; Dbor: *D. orientalis* (Cernosvitov, 1940); Dbp: *D. pentheri* (Rosa, 1905); Dbs: *D. semitica* (Rosa, 1893); Dbv: *D. veneta* (Rosa, 1886); Dim: *Dichogaster modiglianii* (Rosa, 1896); Dra: *D. annandalei*; Drn: *D. nepalensis* Michaelsen, 1907; Drp: *D. pellucida* (Bourne, 1894); Ea: *E. andrei* Bouche, 1972; Ef: *E. fetida*; Em: *E. malekae* Szederjesi, Latif and Csuzdi, 2014; En: *E. nordenskioldi* (Eisen, 1879); Eo: *E. omranii* Latif, Malek and Csuzdi, 2017; Eit: *Eis. tetraedra*; Lr: *L. rubellus*; Mea: *M. anomala* (Michaelsen, 1907); Meba: *M. bahli*; Mebi: *M. birmanica* (Rosa, 1888); Mec: *M. californica* (Kinberg, 1866); Meh: *M. houlleti* (Perrier, 1872); Mep: *M. posthuma* (Vaillant, 1868); Mid: *Microscolex dubius* (Fletcher, 1887); Mip: *M. phosphoreus* (Duges, 1837); Ob: *Octochaetona beatrix* (Beddard, 1902); Oc: *Octolasion cyaneum* (Savigny, 1826); Ol: *O. lacteum* Orley, 1885; Pa: *Perelia arnoldiana* (Perel, 1971); Pc: *P. chlorocephala* (Perel, 1977); Pf: *P. ferganae* (Malevic, 1949); Pg: *P. graciosa* (Perel, 1977); Pk: *P. kaznakovi* (Michaelsen, 1910); Pme: *P. media* (Perel, 1977); Pmi: *P. microtheca* (Perel, 1977); Po: *P. ophiomorpha* (Perel, 1977); Pp: *P. persiana* (Michaelsen, 1900); Ps: *P. stenosoma* (Perel, 1977); Pta: *P. taschkentensis* (Michaelsen, 1900); Ptu: *P. turcmenica* (Malevic, 1941); Pu: *P. umbrophila* (Perel, 1977); Pot: *Polypheretima taprobanae* (Beddard, 1892); Ti: *Typhoeus incommodus* Beddard, 1901; NSS: Number of Similar Species with Afghanistan; PSS: Percent of Similar Species with Afghanistan.

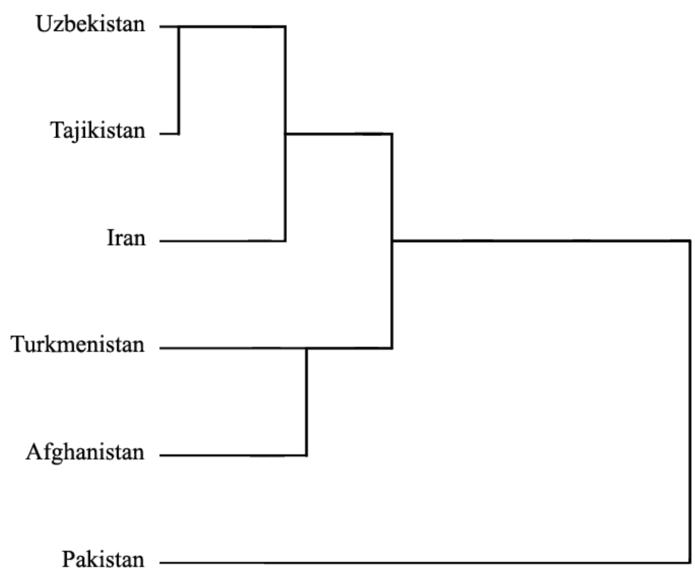

FIGURE 3. Jaccard's similarity dendrogram for earthworm fauna comparison between Afghanistan and neighbouring countries.

Jaccard's similarity coefficient matrix shows the most similarity of earthworm fauna between Afghanistan and its two northern neighbouring countries, *viz.*, Tajikistan and Turkmenistan (Table 3). This similarity is due to the sharing of Holarctic lumbricid species (Table 4). Afghanistan and Tajikistan share a roughly 1,300 km border, which has the largest shared border after the border with Pakistan. The existence of water resources on the common border of Afghanistan and Tajikistan is perhaps one of the reasons for providing the same conditions. The least Jaccard's similarity coefficient occurs between Afghanistan and Pakistan, in despite of shared existence of the families Moniligastridae and Megascolecidae (Figure 3).

According to Omodeo (1959) the fauna of the former Soviet republics Kyrgyzstan, Tajikistan, Uzbekistan, and Turkmenistan is practically identical to that of Afghanistan. Existing differences will likely diminish or disappear when the fauna survey of these regions will be completed.

Our knowledge about the diversity and distribution of earthworms in Afghanistan and its neighbouring countries is far from complete, since we still have limited data concerning the different parts of Afghanistan and some neighbours of this country. To fill this gap in our knowledge on the earthworm fauna of the studied region more detailed investigations are needed to explore the earthworm fauna of this vast country.

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RESEARCH ARTICLE **Open access**

BDI: A tool for management and conservation of Iran's biodiversity

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Abstract
Biodiversity is one of the key components of environmental sustainability and its conservation is very important. To conserve biodiversity, both its management and measurement management are necessary. Biodiversity measurement means some quantitative value that can be ascribed to the various measurements so these values can be compared. With its geographic and climatic variety, Iran has a valuable biodiversity, which includes about 1130, 25000, and 8000 species of vertebrates, invertebrates and flora, respectively. Due to the large amount of data (occurrence points) and complexity of calculations, utilizing computer programs is essential. We here present BDI v. 1.0.0 (BioDiversity of Iran), a user-friendly software utility which facilitates the biodiversity management and conservation by documenting the data and calculating the most commonly used biodiversity indices and then spatially visualizes the results on a map. While we acknowledge the other computer programs in this field, this software has a high spatial precision and resolution and is able to read and create both graphical and digital data formats. BDI is highly efficient in biodiversity evaluation and conservation priorities of protected areas.

Key words: *BDI, Software, Biodiversity indices, Iran.*

INTRODUCTION

Biodiversity is one of the key components of environmental sustainability, and achieving higher biodiversity can enhance the temporal stability of all ecosystem properties (Vackar *et al.* 2012; Wang & Loreau 2016). The term biodiversity (biological diversity) was first used by Lovejoy (1980) and describes the number of species. In fact, biodiversity represents the complexity of life on Earth, and has four dimensions: phenotypic, genotypic, taxonomic, and ecologic. Biodiversity can be measured within taxa (e.g., genetic diversity), across taxa (e.g., species diversity, which includes important conceptual components: richness, evenness, dominance, and rarity), or across ecosystems (e.g., landscape diversity) (Swingland 2001; Wilsey *et al.* 2005).

To conserve biodiversity, both its management and measurement management are necessary. Biodiversity measurement means some quantitative value that can be ascribed to the various measurements so these values can be compared (Swingland 2001). Three spatial scales for measuring biodiversity are alpha (diversity within a community or ecosystem), beta (diversity between communities or ecosystems), and gamma (overall diversity within a geographical area) (Whittaker 1972). To measure the different components of biodiversity, a great variety of indices were proposed (Morris *et al.* 2014). An efficient way to calculate biodiversity indices is using computer programs. In other words, to better

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identify and conserve biodiversity, utilizing modern and efficient tools such as computer programs is essential (Casanoves *et al.* 2011).

Iran, with a terrestrial surface area of 1,648,195 km^2 (equivalent to the combined surface areas of Spain, Germany, France, and the United Kingdom), is the seventeenth largest country in the world (Jowkar *et al.* 2016). Because of its geographic and climatic variety, Iran has valuable biodiversity and is one of the most important countries in the Middle East in biodiversity conservation. The ecosystems of Iran contain approximately 1130, 25000, and 8000 species of vertebrates, invertebrates and flora, respectively (Farashi & Shariati 2017; Department of Environment of Iran 2015).

Although there are several different computer programs such as Biodiverse (Laffan *et al.* 2010), EcoMeth (Kenny & Krebs 2001), WorldMap (Williams 2000), EstimateS (Colwell & Elsensohn 2014), and BIODIV (Baev & Penev 1995) in this field, the creation of a particular spatial visualization program with high precision and resolution and the ability to read and create both graphical and digital data formats were necessary. This has motivated the development of a rapid, convenient, and reliable computer program for management of Iran's biodiversity.

MATERIAL AND METHODS

The program: BDI v. 1.0.0 (BioDiversity of Iran)

Here introduced is BDI, a user-friendly software utility to facilitate two aims: 1) spatial visualization of taxa distribution with high precision and resolution and 2) facilitation of the calculation process and interpretation of the most commonly used biodiversity indices (alpha indices) by reading the data on the map based on the taxonomic relationships.

To achieve the above objectives, the provincial border map of Iran was first prepared and divided into 4,480 square units (quadrates) with dimensions of about 25 * 25 kilometers. These georeferenced square units are the basis of the geographic visualization of taxa distribution and indices calculation.

BDI is written in C# and is available to download from http://appliedzoology.um.ac.ir free of charge. It can run under 32-bit or 64-bit MS Windows, with Microsoft Net Framework v. 4 or later, which is pre-installed in MS Windows 8 and higher. The program has been successfully tested in MS Windows 7, 8, and 10. To execute this program, the BDI zip file needs only to be decompressed and readily installed in the proper path.

Environment

The BDI software has a friendly environment. It is customizable for display in both the Persian and English languages. By logging into the application, the first window, "Biodiversity of Iran", contains four options: "File", "Help", and "Language". In the "File" menu, by selecting "New project", "Open", or "Samples", a window entitled "BDI" will be displayed (Fig. 1). This window includes two main parts: On the left side, there will be Iran's map as well as three menus and on the right side, a panel with several tabs.

Importing data

The principle category for all calculations in the program is "species", and the taxonomic status of taxa will be considered. Whenever some species are selected by the user to calculate an index, the software will automatically select all species within that category. Hence, before inputting the taxa abundance and occurrence point data, the taxonomic status of each taxon must be defined (located on tree) for the software in the path: "File" > "Taxa management" (Fig. 2).

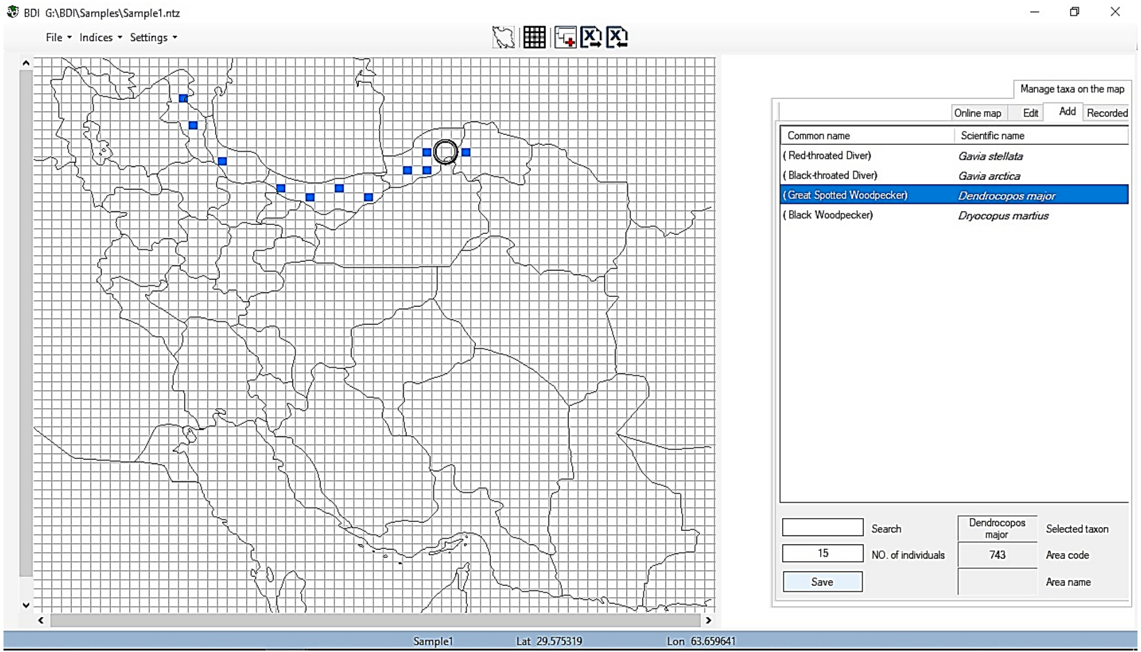

FIGURE 1. "BDI" window, the most usable window in the program.

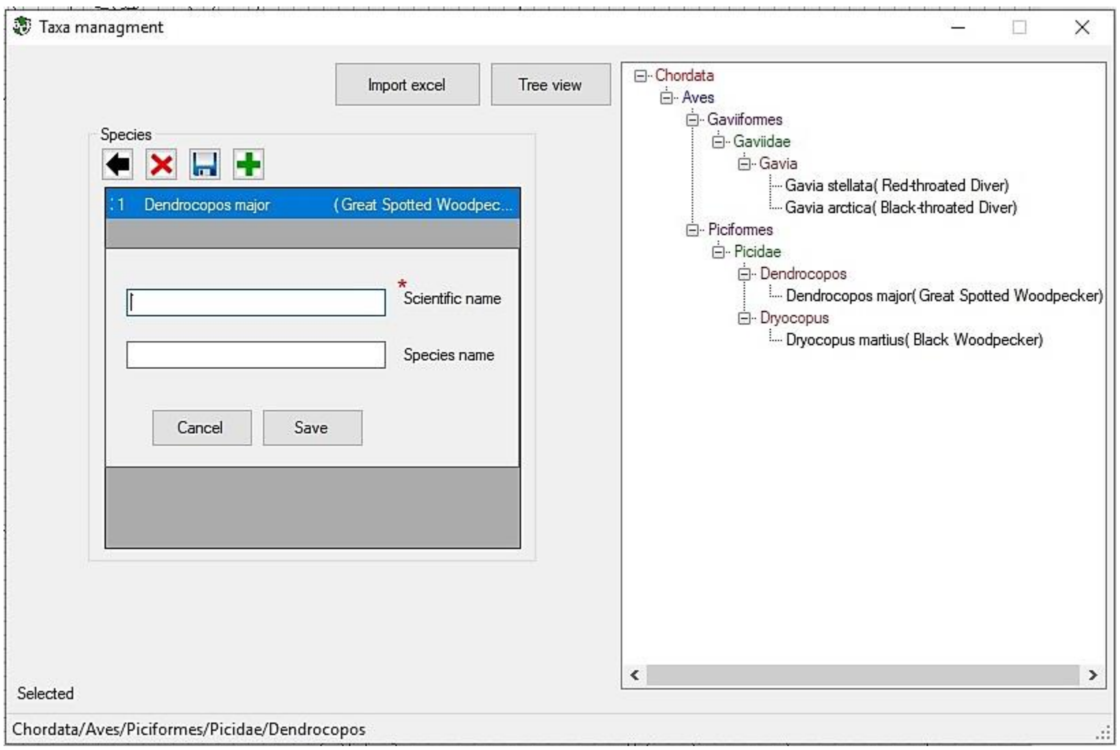

FIGURE 2. The "Taxa management" window contains two parts: taxa entry (on the left) and tree panel (on the right).

There are two ways to insert taxa on the map:

a) When occurrence point data are available in MS Excel format, it is possible to import data by clicking "File" > "Import Excel".
b) Whenever the data are not available in Excel format, manually select the species name from the "Add" panel and then add it to the quadrates on the left side (Fig. 1).
   Data correction is available in the "Edit" panel whenever the saved taxa must be changed.

RESULTS

Calculating the biodiversity indices

The BDI software can calculate 16 biodiversity indices within three concepts of biodiversity, Species Richness, Heterogeneity, and Evenness (Table 1) (Krebs 1999). The user should select only the taxa names from the "Recorded" panel and then click on the relevant index accessible in the "Indices" menu. Only quadrates containing at least two species will be calculated. The results will be displayed in two formats: a) table (except Jackknife and Bootstrap) and b) map (except Jackknife, Rarefaction, and Bootstrap) (Fig. 3). An example input file which contains four bird species distributed in northern Iran is provided to calculate more indices in the software package in the path: "File" > "Samples" > "Sample 1".

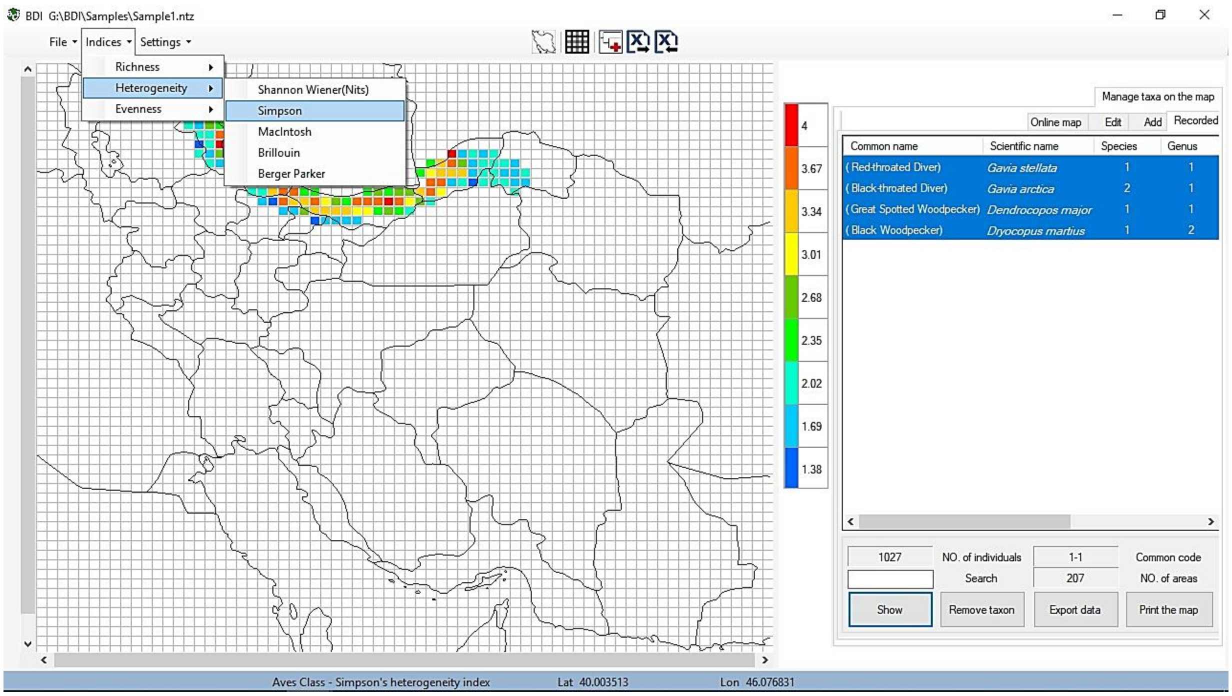

FIGURE 3. Final visualized result (Simpson's heterogeneity index).

DISSCUSSION

BDI is a software tool developed to document the georeferenced biological specimen and survey data, as well as to analyze the spatial patterns of a broad array of biodiversity indices (species richness, heterogeneity, evenness, and taxonomic range restriction) using a great database. Presenting an alternative approach to the other computer programs in this field, this software has a high spatial precision and resolution and is able to read and create both MS Excel and graphical formats. Although calculating biodiversity indices of the whole of Iran is theoretically feasible using BDI, much time is needed to gather input data (even for a genus). Consequently, as the first step, this software is very efficient in biodiversity evaluation and conservation priorities of the smaller ecosystems, like protected areas. As the next step, this software would be able to find the areas with high scores as the new protected area candidates.

Future plans

Since distribution of taxa is not restricted by artificial boundaries, many Iran's taxa (e.g., birds) shared their distribution with the adjacent countries. Hence, we intend to expand its geographic range to Iran and the neighboring countries, in addition to increasing the performance in indices calculation (e.g., beta indices) in the next versions. Moreover, designing a web-based version and creating a national database by biologists to share with other researchers would be the final goal and a strong motivational factor to use this software.

TABLE 1. The accessible indices in BDI.

Concept	**Index**	**Formula**	**Reference**
Species Richness	Menhinick	$D_{Mn} = \frac{S}{\sqrt{N}}$	Whittaker, 1977 Menhinick, 1964
	Margalef	$D_{Mg} = \frac{S-1}{\ln N}$	Clifford & Stephenson, 1975 Hawksworth, 1995
	Jackknife	$\hat{S} = s + \left(\frac{n-1}{n}\right) k$	Heltshe & Forrester, 1983
	Rarefaction	$E(\hat{S}_n) = \sum_{i=1}^{s} \left[1 - \frac{\binom{N-Ni}{n}}{\binom{N}{n}}\right]$	Simberloff, 1972
	Bootstrap	$B(\hat{S}) = S + \sum (1 - P_i)^n$	Smith & van Belle, 1984
Heterogeneity	Shannon-Wiener	$\mathrm{H}' = -\sum_{i=1}^{s} P_i \ln P_i$	Shannon & Weaver, 1949 Magurran, 1988
	Simpson (Yule)	$\frac{1}{D} = \frac{1}{\sum_{i=1}^{s} {P_i}^2}$	Simpson, 1949 Hawksworth, 1995
	McIntosh	$D = \frac{N - \sqrt{\sum_{i=1}^{s} {n_i}^2}}{N - \sqrt{N}}$	McIntosh, 1967
	Brillouin	$H_B = \frac{\ln \mathrm{N}! - \sum \ln n_i !}{N}$	Margalef, 1958
	Berger-Parker	$\frac{1}{d} = \frac{1}{\frac{N_{max}}{N}}$	Berger & Parker, 1970
Evenness	Shannon	$E = \frac{H'}{\ln S}$	Shannon & Weaver, 1949 Magurran, 1988
	Simpson	$E_{\frac{1}{D}} = \frac{\frac{1}{D}}{S}$	Simpson, 1949 Hawksworth, 1995
	McIntosh	$E = \frac{N - \sqrt{\sum_{i=1}^{s} {n_i}^2}}{N - \frac{N}{\sqrt{S}}}$	Magurran, 1998
	Brillouin	$E = \frac{HB}{HB_{max}}$	Margalef, 1958
	Camargo	$E' = 1 - \left(\sum_{i=1}^{s} \sum_{j=i+1}^{s} \left[\frac{\lvert P_i - P_j \rvert}{S}\right]\right)$	Camargo, 1993
	Smith and Wilson	$E_{var} = 1 - \left(\frac{2}{\pi}\right)\left[\arctan\left\{\frac{\sum_{i=1}^{s}\left(\log(n_i) - \frac{\sum_{j=1}^{s}\log(n_j)}{S}\right)^2}{S}\right\}\right]$	Smith & Wilson, 1996

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RESEARCH ARTICLE **Open access**

Range Extension and Sexual dimorphism in *Asaccus nasrullahi* Werner, 2006 (Sauria: Phyllodactylidae), from western Iran

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Abstract
The Leaf-toed Geckos of genus *Asaccus* are distributed in Turkey, Syria, Iraq, and Iran of the Middle-East characterizing by a unique characteristic of cloacal sacs and postanal bones absence. The genus *Asaccus* includes 19 species with at least 10 species in Iran distributing along the Zagros Mountains. Sexual size dimorphism (SSD) is a body size difference between males and females of the same species, being a widespread phenomenon in reptiles. We collected additional specimens of *Asaccus nasrullahi* (Phyllodactylidae) from four new localities in Ilam and Khuzestan Provinces, western Iran. In this study, 110 adult specimens of this lizard were examined (for nine metric and four meristic characters). The analyses of morphological data revealed that the males are significantly larger than the females in eight metric characters including forelimb to hind limb length (FHL), length of forelimb (LFL), length of hind limb (LHL), head height (HH), head length (HL), head width (HW), rostrum to anus length (RAL), and tail length (TL). There is no significant difference in the rate of tail shedding between the sexes. The range of this species is extended beyond type locality in Lorestan Province into adjacent areas in Ilam and Khuzestan Provinces.

Key words: *Leaf-toed gecko, Asaccus nasrullahi, Ilam Province, Khuzestan Province, SSD*.

INTRODUCTION

The genus *Asaccus* Dixon and Anderson, 1973 (formerly included in *Phyllodactylus* Gray, 1828) is distributed in Turkey, Syria, Iraq, and Iran encompass 19 species (Uetz & Hošek, 2020) with at least 10 species in Iran distributing along the Zagros Range including *Asaccus andersoni*, *A. elisae*, *A. granularis*, *A. griseonotus*, *A. iranicus*, *A. kermanshahensis*, *Asaccus kurdistanensis*, *A. nasrullahi*, *A. tangestanensis*, and *A. zagrosica* (Nasrabadi *et al.*, 2017).

Werner (2006), based on the re-identification of a single specimen (ZMUC 3447; Zoological Museum, University of Copenhagen), which had been identified by Schmidt (1955) as *Ptyodactylus hasselquisti,* described a new species of *Asaccus*, *A. nasrullahi*. As an endemic species in some parts of the Zagros mountains in Iran, few studies have been done on this species. To our knowledge, only one study has done on the morphological and ecological aspects of this species (Torki *et al.*, 2010).

Comparative studies of sexual dimorphism should generally encompass body size as a potential determinant (Fairbairn *et al.*, 2007). The evolutionary result of selection acting differently

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on body size and other morphological traits of males and females is referred to as sexual size dimorphism (Andersson, 1994). During this study, the distribution range of *A. nasrullahi* is expanded and sexual dimorphism pattern is evaluated.

MATERIAL AND METHODS

Field study

We examined 110 adult specimens (51 males and 59 females) of *A. nasrullahi* during numerous fieldworks from June to August 2012. The specimens were collected by hand, both in day and night, on rocky substrates of the Zagros Mountains in the following localities: locality 1 or Sarab-e-Dareshahr (33° 05' N, 47° 20' E, 820 m a.s.l.), locality 2 or Bahram-e-Chobin strait (33º 05' N, 47° 27' E, 690 m a.s.l.) and locality 3 or Sheykh Makan (33° 05' N, 47° 23' E, 709 m a.s.l.), in Darr-e-Shahar township, Ilam Province.

These three localities are all along the Kabir-Kooh range and the distance from first (Sarab-e-Dareshahr) to last locality (Bahram-e-Chobin) is 10.8 Km in a northwest-southeast direction. Specimens collected from these three localities were used in statistical analyses. Some specimens were also collected in rocky areas of the Shevi or Tale-Zang Waterfall (32° 47' N, 48° 49' E, 872 m asl) in Dezful township, Khuzestan Province. These specimens were not used in statistical analyses, but identified as *A. nasrullahi* and used in the map of range extension.

Examined characters

A total of 13 morphometric characters (nine metrics and four meristics) were recorded. The metric characters comprise RAL (rostrum to anus length, according to Werner (1971)), HW (head width; in its widest part), HL (head length; from the tip of rostrum to the anterior border of ear, according to Goren & Werner (1993)), HH (head height; at the level of eyes), LFL (length of forelimb; in an extended position from axilla to tip of the longest finger), LHL (length of hind limb; in an extended position from groin to tip of the longest toe), FHL (forelimb to hind limb length; from axilla to groin), TL (tail length; from posterior margin of the anus to tip of tail, in just original tails) and AW (anus width). The meristic characters include BT (the number of tubercle rows on dorsum), CT (number of crossbars on the dorsal side of tail), IL (number of infralabials), and SL (number of supralabials) (Fathinia *et al.*, 2011).

The metric characters were measured by a digital caliper to the nearest 0.01 mm accuracy. The meristic ones were recorded using a stereomicroscope. To determine the sex of specimens, we noticed the presence or absence of two swellings at the base of the tail just behind the anus. The swellings accommodate hemipenes in males (Fig. 1). Some specimens were fixed and deposited in Razi University Zoological Museum (RUZM) as vouchers and the remaining specimens were released into their natural habitat after measuring the specifications. Each location was surveyed just once to avoid repeated catching of the same specimens.

Statistical analyses

Both univariate and multivariate analyses were done on the dataset. The Shapiro-Wilk test was employed to determine the normality of variables. Before conducting statistical analyses, our data were divided into four datasets: datasets 1 to 3 conform to localities 1 to 3 and dataset 4 coincides with datasets 1 to 3 combined. Each of these four datasets was analyzed separately for sexual dimorphism. Independent sample t-test as well as Mann-Whitney U test was used for univariate analysis of normally and non-normally distributed characters, respectively. To determine the sexual dimorphism of *A. nasrullahi* at the multivariate level, we used Principal Component Analysis (PCA: correlation matrix). TL and CT were not included in the PCA analysis because a total number of 75 individuals had missed values (i.e. regenerated tails). The Chi-square test was used to determine if the rate of broken tails is significant between males and females. All the statistical analyses were done using SPSS 16.

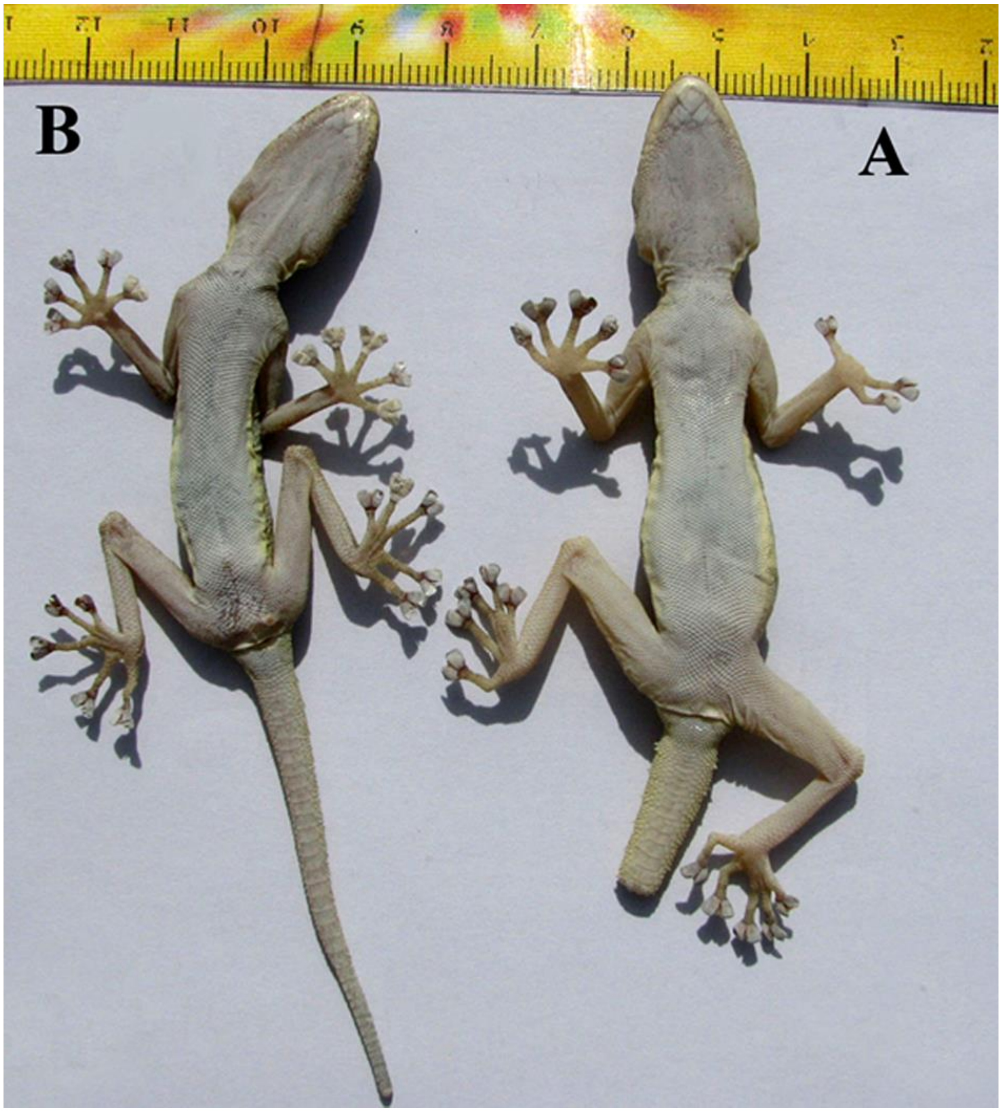

FIGURE 1. Ventral view of adult male (A) and female (B) specimens of *Asaccus nasrullahi*.

RESULTS

New localities for *Asaccus nasrullahi* are reported in Ilam (Darr-e-Shahr township) and Khuzestan (Dezful township) Province. These new localities extend the range of *Asaccus nasrullahi* beyond previous records of this species in Lorestan Province (Tang-e-Gavshomar and Shahbazan regions) (Fig. 2). A total of 13 morphological characters (nine metrics and four meristics) were included in this study. Univariate analyses using Mann-Whitney U-test and Independent-sample t-test were done for each locality and pooled data. These results show that there is no significant difference in characters between two sexes in dataset 1 (Locality 1; Sarab-e-Dareshahr) ($P > 0.05$; Table 1).

The population in dataset 2 (Locality 2, Bahram-e-Choobin) showed a significant male-biased difference between the two sexes only in the character FHL ($P = 0.028$; Table 2). In contrast, the population in dataset 3 (Locality 3, Sheikh-Makan) showed significant male-biased differences in four characters HW, LFL, RAL, and TL ($P < 0.05$; Table 3). The results of univariate analyses for dataset 4 (localities 1 to 3) showed male-biased significant differences between sexes in eight out of 13 characters FHL, LFL, LHL, HH, HL, HW, RAL, and TL ($p \leq 0.05$). All meristic characters are not significantly different between the sexes ($P > 0.05$) (Table 4).

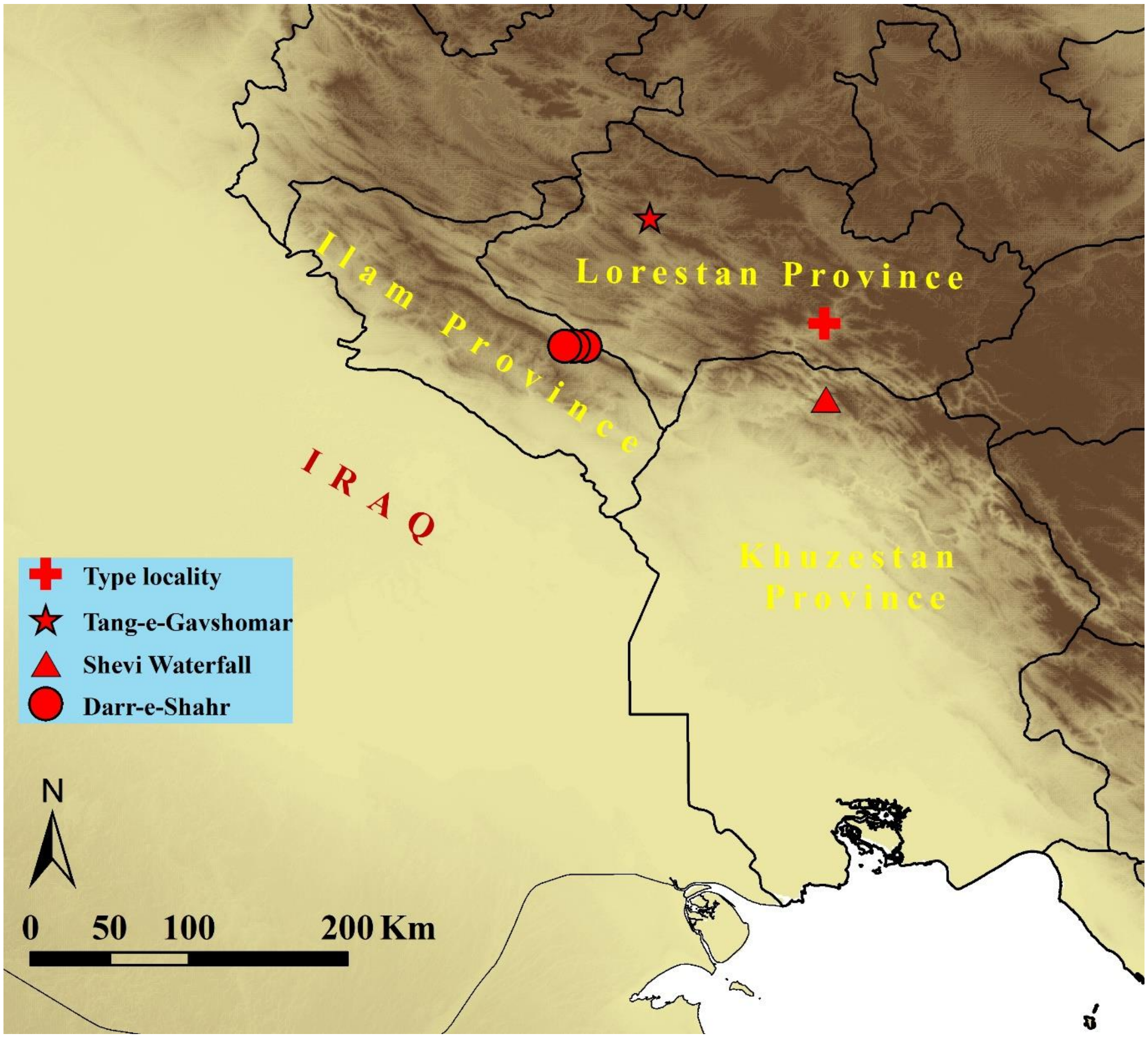

FIGURE 2. A map shows the previous and new localities of *Asaccus nasrullahi* in western Iran. Previous records; green Plus sign, holotype locality in Shahbazan region and green star, Tang-e-Gavshomar region. New localities; green triangle, Shevi Waterfall and green circles, Sarab-e-Darreshahr (left), Sheikh-Makan (middle), and Bahram-e-Choobin (right) along the Kabirkooh range in Ilam province.

A total number of 75 individuals (35 males and 40 females) have broken tails. The result of the chi-square test (X^2 = 0.009, P = 0.926) shows that the rate of broken tails does not show a significant difference between the sexes. Principal Component Analysis (PCA) was carried out on the significantly different characters between sexes in dataset 4. The character TL was excluded from this analysis because of having missed values.

The results of this analysis show that the first four axes collectively represent 95.18% of the total variation (Table 5). Of this, 82.3 is explained by PC1, with all characters (i.e., FHL, LFL, LHL, HH, HL, HW, RAL) mainly responsible for the observed variation, and 5.28% is explained by PC2, in which FHL and HH have the highest values. This analysis shows that the PC1 is chiefly responsible for the separation of males and females of *Asaccus nasrullahi* (Fig. 3).

TABLE 1. The results of univariate analysis using the Mann-Whitney U and Independent Sample t-test on the standardized metric and meristic characters of *Asaccus nasrullahi* in locality 1 (Sarab-e-Darreshahr). Abbreviations: SD, standard deviation; D. of d., the direction of difference; Sexes, 1 = male and 2 = female; T-test, Independent Sample t-test; U-test, Mann-Whitney U. All measurements in millimeter.

Character		Sex	No.	Mean±SD	*P-value*	Test used	D. of d.
Meristics	BT	1	17	7.45±0.79	0.949	T-test	F = M
		2	35	7.43±0.9			
	CT	1	6	13±0.89	1.000	U-test	F = M
		2	13	12.85±1.21			
	IL	1	17	7.88±0.70	0.882	U-test	F = M
		2	35	7.86±0.73			
	SL	1	17	11.18±0.95	0.728	U-test	F = M
		2	35	11.23±0.97			
Metrics	AW	1	17	6.89±0.65	0.707	T-test	F = M
		2	35	6.98±0.82			
	FHL	1	17	30.17±3.45	0.920	T-test	F = M
		2	35	30.27±3.39			
	LFL	1	17	29.28±2.07	0.447	T-test	F = M
		2	35	28.82±2.07			
	LHL	1	17	38.9±3.01	0.208	U-test	F = M
		2	35	37.88±2.51			
	HH	1	17	7.08±0.63	0.294	T-test	F = M
		2	35	6.91±0.51			
	HL	1	17	16.85±1.31	0.243	T-test	F = M
		2	35	16.43±1.16			
	HW	1	17	13.35±1.21	0.064	T-test	F = M
		2	35	12.77±0.94			
	RAL	1	17	65.93±5.06	0.344	T-test	F = M
		2	35	64.41±5.51			
	TL	1	6	78.02±6.57	0.051	T-test	F = M
		2	13	71.54±6.10			

DISCUSSION

Asaccus nasrullahi presented marked sexual dimorphism in general body size and several body parts, with males being significantly larger than females in eight out of 13 studied characters. Our results show that there is considerable variation in sexual dimorphism among different populations of *A. nasrullahi*. For instance, in dataset 1 (Sarab-e-Dareshahr) there is no difference between the sexes. In dataset 2 (Bahram-e-Choobin) males are larger than females in only one character while in dataset 3 (Sheikh-Makan) males are larger than females in four metric characters. But the pooled data show that males are larger than females in eight metric characters. These incongruences in SSD results among subsets and pooled datasets may be the result of insufficient sampling in the three sampled locations.

TABLE 2. The results of univariate analysis of *Asaccus nasrullahi* in locality 2 (Bahram-e-Choobin). Abbreviations as in Table 1. Abbreviations: SD, standard deviation; D. of d., the direction of difference; Sexes, 1 = male and 2 = female; T-test, Independent Sample t-test; U-test, Mann-Whitney U. All measurements in millimeter.

Character		Sex	No.	Mean±SD	*P-value*	Used test	D. of. D.
Meristics	BT	1	8	7.71±0.87	0.111	T-test	M = F
		2	13	7.17±0.62			
	CT	1	3	13.33±0.58	0.116	T-test	M = F
		2	3	12±1.00			
	IL	1	8	7.88±0.64	0.224	U-test	M = F
		2	13	8.15±0.38			
	SL	1	8	11.75±0.71	0.736	T-test	M = F
		2	13	11.62±0.96			
Metrics	AW	1	8	6.92±0.69	0.596	T-test	M = F
		2	13	6.76±0.63			
	FHL	1	8	31.95±2.99	**0.028**	T-test	M > F
		2	13	28.61±3.21			
	LFL	1	8	29.35±2.78	0.757	T-test	M = F
		2	13	28.89±3.53			
	LHL	1	8	39.22±3.43	0.302	T-test	M = F
		2	13	37.82±2.62			
	HH	1	8	7.24±0.83	0.293	T-test	M = F
		2	13	6.9±0.62			
	HL	1	8	16.96±1.39	0.176	T-test	M = F
		2	13	16.17±1.14			
	HW	1	8	13.11±1.31	0.128	T-test	M = F
		2	13	12.39±0.79			
	RAL	1	8	65.81±6.17	0.281	T-test	M = F
		2	13	62.77±6.07			
	TL	1	3	69.03±1.52	0.52	T-test	M = F
		2	3	70.56±3.46			

Many taxa show geographic variation in SSD with moderate differences in proportional sizes between the sexes (Harvey & Ralls, 1985; Schwaner & Sarre, 1988). But, at least in one case (*Morelia spilota*), proportional sizes between the sexes show dramatic differences among different populations. Different causes have been proposed to explain such variations in SSD. For example, selective pressures on male body size may vary among different localities, resulting in geographic variation in SSD among distinct populations of the same species (Shine & Fitzgerald, 1995). Another explanation for this phenomenon is the genetic control of SSD in different populations (Pearson *et al.*, 2002).

TABLE 3. The results of univariate analysis of *Asaccus nasrullahi* in locality 3 (Sheikh-Makan). Abbreviations as in Table 1. Abbreviations: SD, standard deviation; D. of d., the direction of difference; Sexes, 1 = male and 2 = female; T-test, Independent Sample t-test; U-test, Mann-Whitney U. All measurements in millimeter.

Character		Sex	No.	Mean±SD	*P-value*	Used test	D. of. D.
Meristics	BT	1.0	26.0	7.52±0.56	0.176	T-test	M = F
		2.0	11.0	7.8±0.55			
	CT	1.0	6.00	12.67±1.21	0.395	U-test	M = F
		2.0	3.00	12±0.00			
	IL	1.0	26.0	8.27±0.53	0.646	U-test	M = F
		2.0	11.0	8.36±0.50			
	SL	1.0	26.0	11.88±0.95	0.054	U-test	M = F
		2.0	11.0	11.27±0.65			
Metrics	AW	1.0	26.0	7.03±0.39	0.055	T-test	M = F
		2.0	11.0	7.36±0.61			
	FHL	1.0	26.0	31.75±1.65	0.13	T-test	M = F
		2.0	11.0	30.48±2.40			
	LFL	1.0	26.0	30.46±1.38	**0.001**	T-test	M > F
		2.0	11.0	28.52±1.37			
	LHL	1.0	26.0	40.17±1.38	0.061	T-test	M = F
		2.0	11.0	38.33±2.38			
	HH	1.0	26.0	7.34±0.64	0.056	T-test	M = F
		2.0	11.0	6.9±0.58			
	HL	1.0	26.0	17.14±0.65	0.084	T-test	M = F
		2.0	11.0	16.65±1.00			
	HW	1.0	26.0	13.68±0.63	**0.006**	T-test	M > F
		2.0	11.0	12.99±0.70			
	RAL	1.0	26.0	68.86±2.46	**0.027**	T-test	M > F
		2.0	11.0	65.22±4.54			
	TL	1.0	7.00	77.92±3.54	0.157	T-test	M = F
		2.0	3.00	67.95±8.05			

Several hypotheses have been proposed to explain the intraspecific variation in SSD including 1) fecundity selection in which females have larger body size than males (Andersson, 1994; Sandercock, 2001; Rastegar Pouyani *et al.*, 2015), 2) niche partitioning through which males and females are different in the size of some parts of the body (such as head size) to use different niche dimensions (Smith & Nickel, 2002), 3) Sexual selection acting on either sex may select for SSD (Raihani *et al.*, 2006). These selection processes may be reinforced via female choice (Thornhill & Alcock, 1983; Choe & Crespi, 1997).

TABLE 4. The results of univariate analysis of *Asaccus nasrullahi* in all three localities. Abbreviations as in Table 1. Abbreviations: SD, standard deviation; D. of d., the direction of difference; Sexes, 1 = male and 2 = female; T-test, Independent Sample t-test; U-test, Mann-Whitney U. All measurements in millimeter.

Character		Sex	No.	Mean±SD	*P-value*	Used test	D. of. D.
Meristics	BT	1.0	51.0	7.53±0.96	0.554	T-test	M = F
		2.0	59.0	7.44±0.81			
	CT	1.0	15.0	12.93±0.96	0.385	U-test	M = F
		2.0	19.0	12.58±1.12			
	IL	1.0	51.0	8.08±0.63	0.622	U-test	M = F
		2.0	59.0	8.02±0.66			
	SL	1.0	51.0	11.63±0.96	0.123	U-test	M = F
		2.0	59.0	11.32±0.92			
Metrics	AW	1.0	51.0	6.97±0.53	0.783	T-test	M = F
		2.0	59.0	7.00±0.76			
	FHL	1.0	51.0	31.26±2.65	**0.023**	T-test	M > F
		2.0	59.0	29.94±3.22			
	LFL	1.0	51.0	29.89±1.93	**0.002**	U-test	M > F
		2.0	59.0	28.78±2.33			
	LHL	1.0	51.0	39.6±2.42	**0.000**	U-test	M > F
		2.0	59.0	37.95±2.55			
	HH	1.0	51.0	7.24±0.66	**0.004**	T-test	M > F
		2.0	59.0	6.9±0.54			
	HL	1.0	51.0	17.01±1.02	**0.004**	T-test	M > F
		2.0	59.0	16.41±1.12			
	HW	1.0	51.0	13.48±0.98	**0.000**	T-test	M > F
		2.0	59.0	12.73±0.88			
	RAL	1.0	51.0	67.4±4.34	**0.001**	T-test	M > F
		2.0	59.0	64.2±5.45			
	TL	1.0	16.0	76.29±5.72	**0.009**	T-test	M > F
		2.0	19.0	70.82±5.92			

Competition between males may favor large body size in species in which males compete intensely for females (Mitani *et al.*, 1996; Dunn *et al.*, 2001; Lindenfors *et al.*, 2003; Raihani *et al.*, 2006). In this case, larger males are more likely to survive or mate with females (Clutton-Brock & Harvey, 1977; Anderson & Vitt, 1990). The positive correlation between combat success and body size has been studied and proved in lizards (Olsson, 1992; Zucker & Murray, 1996). However, the phenomenon of male combat suggests sexual selection for larger male size, predicting a phylogenetic correlation between male-biased SSD and male aggressive behavior. Thus, sexual selection for large males will not occur unless success in combat also translates into greater reproductive success (Cox *et al.*, 2003; Kratochvíl & Frynta, 2006). The "rostrum to anus length" (RAL) and forelimb to hind limb length (FHL) in males of *A. nasrullahi* are greater than those in females. These two male-biased characters (RAL and FHL) can be explained by the sexual selection theory, stating combat among males occur for females.

TABLE 5. Loadings from a principal component analysis of seven significant metric characters of *Asaccus nasrullahi*. Variables loading strongly on each principal component are shown in bold.

Variables	**PC1**	**PC2**	**PC3**	**PC4**
FHL	**0.853**	**-0.358**	**0.368**	0.060
LFL	**0.885**	-0.129	**-0.304**	**0.288**
LHL	**0.920**	0.049	-0.108	0.030
HH	**0.842**	**0.468**	0.218	0.131
HL	**0.965**	0.020	-0.048	-0.078
HW	**0.916**	0.018	-0.111	**-0.336**
RAL	**0.963**	-0.057	0.020	-0.063
Eigenvalues	5.763	0.370	0.302	0.228
% of Variance	82.322	5.285	4.317	3.257
Cumulative%	82.322	87.607	91.925	95.182

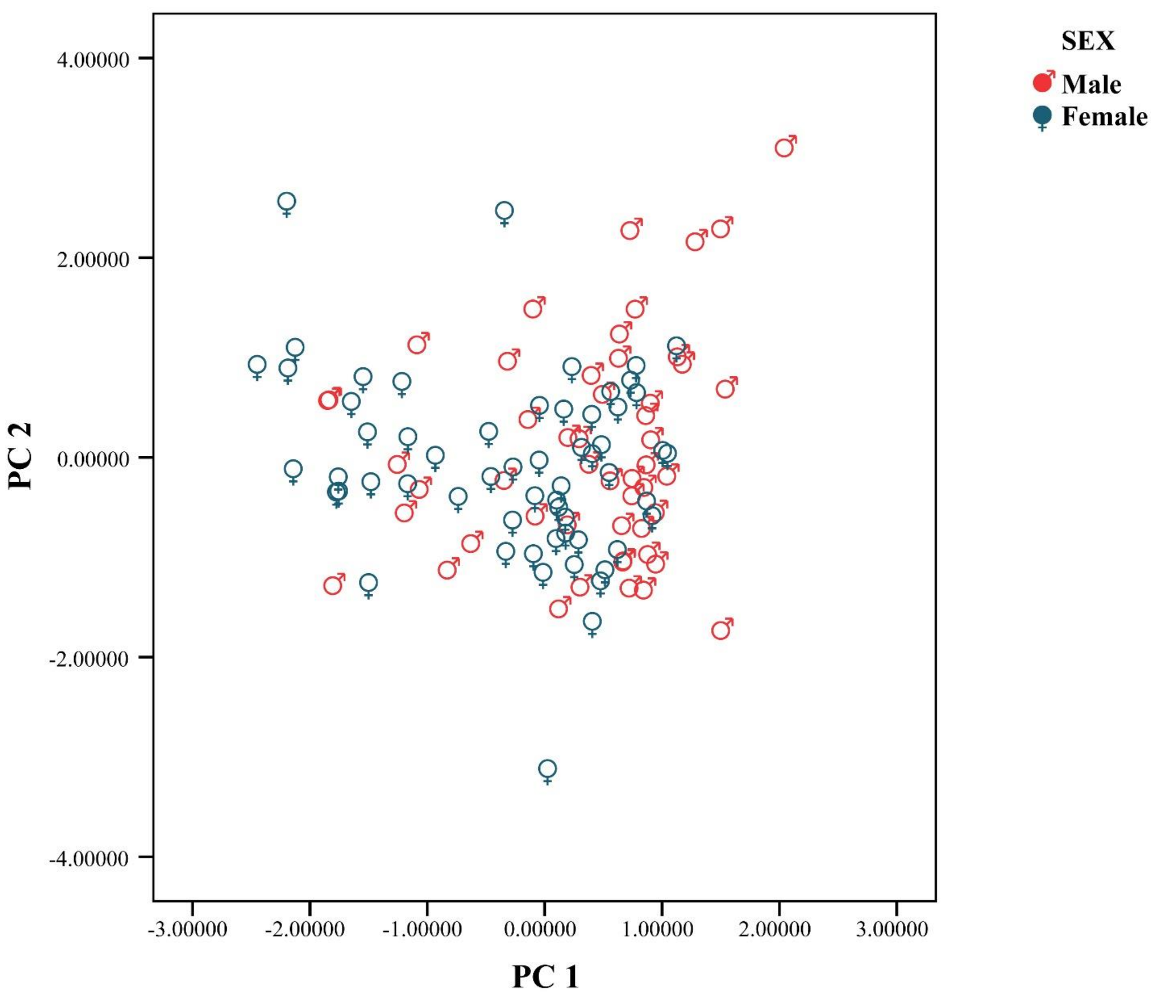

FIGURE 3. Ordination of the individual males and females of *Asaccus nasrullahi* on the first two principal components, showing poor separation.

In the current study, the significant male-biased differences in head dimensions (i.e. HL, HH, and HW) between sexes of *A. nasrullahi* were proved. Many studies have shown male-biased differences in the size of head dimensions in a variety of lizards (Barbadillo *et al.*, 1995; Hews, 1996; Smith *et al.*, 1997; Smith & Nickel, 2002; Verrastro, 2004; Fathinia *et al.*, 2011; Karamiani *et al*., 2013). Head size is a character that can support the niche divergence hypothesis in other vertebrates (Selander, 1972; Shine, 1989). There is a direct relation between head size and bite force which may have a direct effect on dominance. These traits (head dimensions) may have been evolved under both sexual and natural selections (Huyghe *et al.*, 2005). These ideas may explain the presence of larger heads in males of *A. nasrullahi*.

The values of LFL and LHL in males of *A. nasrullahi* are significantly greater than those in females. Males can take advantage of having long limbs by increasing maximum sprint speed, allowing them to catch prey, escape predators (Calsbeek & Smith, 2003), chase females for mating (Fathinia *et al.*, 2011), and defense territory (Peterson & Husak, 2006) more effectively. A combination of these causes may explain male-biased differences in the limbs of *A. nasrullahi*.

Shedding a portion or most of the tail followed by regeneration is an ability that one can see in a majority of lizards. Tail shedding can take place as the result of a predator attack or intraspecific conflicts. This behavior allows a lizard to have an efficient escape (Cott, 1957). As the main purposes of this research were investigating sexual dimorphism and distribution of *Asaccus nasrullahi*, additional studies are needed to shed light on the causes and consequences of tail shedding in this gecko. In summary, a combination of three different causes may have driven the SSD in *A. nasrullahi*: sexual selection, niche divergence, and natural selection.

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RESEARCH ARTICLE **Open access**

New data on the terrestrial isopod fauna of Iran (Isopoda: Oniscidea) with the first description of the male of *Schizidium golovatchi* Schmalfuss, 1988

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Abstract
In the present study, seven species of terrestrial isopods are reported from Iran for the first time. These include *Platyarthrus schoblii* Budde-Lund, 1885; *Trichorhina tomentosa* (Budde-Lund, 1893); *Armadillo alievi* Schmalfuss, 1990; *A. officinalis* Duméril, 1816; *Armadillidium azerbaidzhanum* Schmalfuss, 1990, *A. nasatum* Budde-Lund, 1885 and *Schizidium golovatchi* Schmalfuss, 1988. The male of the latter species is described for the first time and its diagnostic characters are illustrated. Sampling localities for the species are presented on a map.

Key words: *Oniscidea; new record; terrestrial isopods; Iran.*

INTRODUCTION

In the recent years, the number of contributions on the terrestrial isopod fauna of Iran has been dramatically increased. Currently, 46 species are reported from Iran (Kashani 2018, Bakhshi & Sadeghi 2019), but even some higher taxa expected to be present in the country have not been recorded yet.

In the present study, seven species of terrestrial isopods were reported from Iran for the first time: *Platyarthrus schoblii* Budde-Lund, 1885 and *Trichorhina tomentosa* (Budde-Lund, 1893) of the family Platyarthridae; *Armadillo alievi* Schmalfuss, 1990 and *A. officinalis* Duméril, 1816 members of the new recorded family Armadillidae; *Armadillidium azerbaidzhanum* Schmalfuss, 1990, *A. nasatum* Budde-Lund, 1885 and *Schizidium golovatchi* Schmalfuss, 1988 of the family Armadillidiidae. The aim of the present study is therefore, to introduce seven more species to the terrestrial isopod fauna of Iran and illustrate and describe the male characteristics of *Schizidium golovatchi* for the first time.

MATERIAL AND METHODS

The specimens of the present study were collected in a range of localities in Iran (Fig 1). The specimens were collected by hand and preserved in 96% ethanol. The species were identified based on comparison with the original descriptions and confirmed by Dr. H. Schmalfuss (Stuttgart) or Dr. S. Taiti (Florence). Detailed synonymies and distributional data are provided in Schmalfuss (2003). The specimens are deposited in the Iranian Research Institute of Plant Protection (IRIPP). Some more specimens are kept in the personal collection of the author (PCGMK).

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FIGURE 1. Map of Iran; indicating the sampling localities of *Platyarthrus schoblii* (▲), *Trichorhina tomentosa* (▼), *Armadillo alievi* (■), *A. officinalis* (✳), *Armadillidium azerbaidzhanum* (⭘), *A. nasatum* (◘) and *Schizidium golovatchi* (●). Ar: Ardabil; E. A: Eastern Azarbaijan; Gi: Guilan; Hm: Hamedan; K.B: Kohgilouyeh-Boyerahmad; Ke: Kermanshah; Kh: Khouzestan; Ku: Kurdestan; Mz: Mazandaran; Qm: Qom; Qz: Qazvin; W.A: Western Azarbaijan; Zn; Zanjan.

RESULTS

Taxonomy

Family Platyarthridae Budde-Lund, 1913

Platyarthrus schoblii Budde-Lund, 1885

Material examined: ***Qom***, Qanavat, 5.4.2012, leg. G.M. Kashani, one female (IRIPP Iso-1062); same data as before, two females (PCGMK 1590); ***Qazvin***, 10 Km S Abgarm, 35° 42' N, 49° 14' E, elev. 1660 m, 12.9.2013, leg. G.M. Kashani & B. Eshaghi, det. S. Taiti, one female (IRIPP Iso-1063); same data as before, four females (PCGMK 1709); Nikouiyeh, Charandagh village, 36° 07' N, 49° 28' E, elev. 1660 m, 4.6.2014, leg. G.M. Kashani & B. Eshaghi, two females (IRIPP Iso-1064); same data as before, one male, two females (PCGMK 1765); ***Zanjan,*** 3 Km E Ab-bar, 07.03.2014, one female (PCGMK 1726); Mazandaran, 60 Km S Amol, 36° 03' N, 52° 15' E, elev. 1000 m, 11.9.2014, leg. G.M. Kashani, one female (PCGMK 1850); 4 Km N Sari, 36° 41' N, 53° 03' E, elev. −30 m, 31.7.2014, leg. G.M. Kashani, two females (IRIPP Iso-1065); same data as before, two females (PCGMK 1991); ***Guilan***, Lahijan, 37° 12' N, 50° 01' E, 18.8.2014, leg. G.M. Kashani & S. Hamidnia, two females (IRIPP Iso-1066); same data as before, five females (PCGMK 1833); Anzali Port, 22.5.2015, leg. A. Abedini, two males, thirty females (PCGMK 2081); ***Khuzestan***, Baghmalek, 31° 31' N, 49° 52' E, elev. 650m, 20.6.2016, leg. G.M.

Kashani, four females (PCGMK 2352); ***Eastern Azarbaijan***, Ahar, Naghdooz village, 38° 23' N, 49° 21' E, elev. 1040m, 27.6.2016, leg. G.M. Kashani, one female (PCGMK 2416); Ahar, 38° 27' N, 47° 05' E, elev. 1300m, 27.6.2016, leg. G.M. Kashani, one female (PCGMK 2420); 4 Km E Ahar, 38° 27' N, 47° 08' E, elev. 1300m, 27.7.2019, leg. G.M. Kashani, G. Morovati, seven females (PCGMK 2830);
Comments: Recently, Bakhshi & Sadeghi (2019) identified *Platyarthrus hoffmannseggii* Brandt, 1833 in southern Iran. *Platyarthrus schoblii* is the second species of the genus *Platyarthrus* reported from Iran. This species has been possibly introduced to Iran by human activities (Dr. Stefano Taiti, personal communications). This myrmecophilous species was found inside of the ant nests or in the soil, often in the gardens and parks. Due to its small size and its lifestyle ("creeper", according to the eco-morphological classification proposed by Schmalfuss (1984)), much more distribution can be expected for the species. Identification of the species was made based on the illustrations and description presented in Vandel (1946: p.218; Figs. 64–66) and confirmed by Dr. Taiti.
Distribution: Macaronesian Islands; Mediterranean region and the Black Sea coasts; Iran.

Trichorhina tomentosa **(Budde-Lund, 1893)**
Alloniscus tomentosus Budde-Lund, 1893
Material examined: ***Zanjan***, Mahneshan, 22.5.2011, leg. R. Sayadi, det. S. Taiti, five females (IRIPP Iso-1067); same data as before, twelve females (PCGMK 1564); same data as before, 29.4.2012, twenty females (PCGMK 1537).
Comments: This species was found in huge numbers only in one locality in a farm. All evaluated specimens were female, almost all bearing marsupium. A detailed description and illustrations of the species were presented in Schmidt (2003: p.63; Figs. 87–93). The identification of the species was made by Dr. Taiti.
Distribution: Tropical America; introduced to greenhouses worldwide.

Family Armadillidae Budde-Lund, 1899
Armadillo alievi Schmalfuss, 1990
Material examined: ***Western Azarbaijan*,** Poldasht, 39° 18' N, 45° 04' E, 8.11.2004, leg. A. Kazemi, det. H. Schmalfuss, one female (IRIPP Iso-1068); same data as before, one male, three females (PCGMK 1144); Poldasht to Makoo, Yulagoldi, 39° 17' N, 44° 42' E, 19.6.2008, leg. G.M. Kashani, one female (PCGMK 1248); ***Eastern Azarbaijan*;** Tabriz to Marand, Soofian, 38° 15' N, 46° 01' E, 19.6.2008, leg. G.M. Kashani, det. H. Schmalfuss, one male (PCGMK 1245).
Comments: This species was found in Northwestern Iran (Fig. 1) which is in continuity with the reported distribution of the species in Azerbaijan (Schmalfuss 1990). The identification of the species was made according to the original description and illustrations presented by Schmalfuss (1990: p.8, Figs. 12–15; 1996: p.20, Figs. 38–41) and confirmed by him.
Distribution: Azerbaijan; NW Iran.

Armadillo officinalis Duméril, 1816
Figure 2F
Material examined: ***Hamadan***, Nahavand, Qaleh-Qobad village, 34° 06' N, 48° 25' E, 11.09.2016, leg. G.M. Kashani, A. Abedini, M. Dadashi, twelve males and nine females (PCGMK 2557); ***Kurdestan*,** Bijar, 35° 50' N, 47° 36' E, 14.09.2016, leg. G.M. Kashani, A. Abedini, M. Dadashi, three males and eight females (PCGMK 2596); Sanandaj, leg. A. Abedini, one male (PCGMK 2631).
Comments: This species was found in western Iran. Schmalfuss (1996, 2003) questioned the presence of this species in Mesopotamia (Iraq) reported by Omer-Cooper (1923). The occurrence of *A. officinalis* in western Iran would indicate the accuracy of Omer-Cooper's recognition. The identification of the species was made according to the description and illustrations presented by Schmalfuss (1996: p.4, Figs. 1–22).
Distribution: Mediterranean and western Black Sea coasts; Iraq; W Iran.

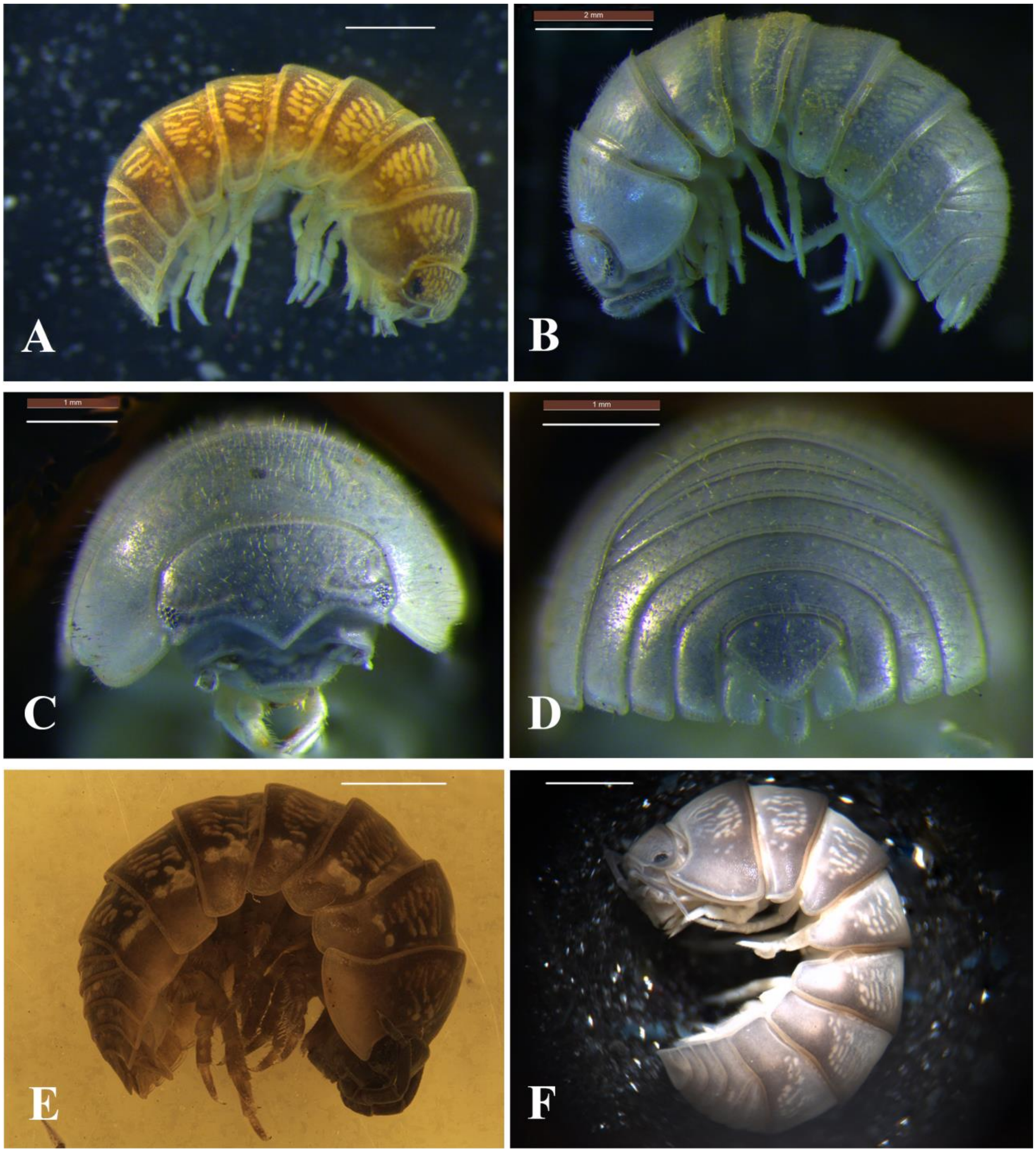

FIGURE 2. A-D, *Schizidium golovatchi*; E, *Armadillidium azerbaidzhanum*; F, *Armadillo officinalis*. A, B, habitus, lateral view; C, head, dorsal view; D, pleon, dorsal view; E, habitus, lateral view; F, habitus, dorsal view. Scale = A-B, E-F, 2 mm; C-D, 1 mm.

FIGURE 3. *Schizidium golovatchi*, male. A, pereopod I; B, pereopod VII, rostral view; C, pereopod VII ischium, caudal view; D, pleopod endopodite I; E, pleopod exopodite I; F, pleopod exopodite IV; G, pleopod exopodite V. Scales: A-C, 0.2 mm; D-G, 0.1 mm.

Family Armadillidiidae Brandt, 1833

***Armadillidium azerbaidzhanum* Schmalfuss, 1990**

Figure 2E

Material examined: ***Ardabil***, Meshkin-Shahr to Pars-Abad, Ziveh, 39° 09' N, 47° 37' E, elev. 480 m, 17.6.2008, leg. G. M. Kashani, det. H. Schmalfuss, two males, two females (IRIPP Iso-1069); same data as before, eight males, thirteen females (PCGMK 1233); Neer, Koorabbasloo village, 37° 57' N, 48° 03' E, elev. 1740 m, 17.4.2019, leg. F. Heydarnezhad, one male, two females (PCGMK 2729); 30 Km S Germi, 39° 00' N, 47° 54' E, elev. 920 m, 17.4.2019, leg. F. Heydarnezhad, one male, one female (PCGMK 2751); Khalkhal, Hashtjin, 37° 15' N, 48° 25' E, elev. 740 m, 1.4.2019, leg. F. Heydarnezhad,

one male, one female (PCGMK 2763); ***Eastern Azarbaijan***, Asheghloo, Tatar-e-Olia village, 39° 04' N, 46° 47' E, elev. 300 m, 28.7.2016, leg. G.M. Kashani, A. Abedini, M. Dadashi, four males, eight females (PCGMK 2450); Asheghloo, to Siahroud, 38° 54' N, 46° 36' E, elev. 360 m, 28.7.2016, leg. G.M. Kashani, A. Abedini, M. Dadashi, two males, two females (PCGMK 2453).
Comments: This species is distributed in Northwestern Iran. The identification of the species was made based on the comparison with the original description and illustrations presented by Schmalfuss (1990: p.5, Figs. 6–7, 9–11) and confirmed by him.
Distribution: Eastern Caucasus region; NW Iran.

***Armadillidium nasatum* Budde-Lund, 1885**
Material examined. ***Zanjan*,** Tarom**,** 37° 04' N, 48° 50' E, elev. 500 m, 7.4.2016, leg. G. M. Kashani, one male (PCGMK 2263); Qeydar, 20.4.2017, leg. G. L. Karami, two males, one female (PCGMK 2492); ***Kohgilouyeh-Boyerahmad***, Yasouj, 30˚40'N, 51˚34.8'E, elev. 2000m, 20.7.2015, leg. G. M. Kashani, one male, three females (PCGMK 2212); ***Guilan***, Amlash, Rahimabad, 37˚02'N, 50˚19'E, elev. 20 m, 14.09.2014, leg. G. M. Kashani, two males, one female (PCGMK 1900); Rasht, 01.07.2017, leg. M. Pourlatifi, two males, one female (PCGMK 2627).
Comments: Schmalfuss (2003) considered the autochthonous distribution of *A. nasatum* in Western Europe which introduced to many other parts of the world by human activities. Scattered distribution of this species in Iran (Fig. 1) indicates the potential existence of the species in a broad range. Identification of the species was made according to Vandel (1962: p.787, Figs. 380) and confirmed by Dr. Schmalfuss.
Distribution: Western Europe, introduced to many other countries.

***Schizidium golovatchi* Schmalfuss, 1988**
Figures 2A-D
Material examined: ***Kurdestan***, Baneh, 36˚08'N, 54˚40'E, alt. 1435, 2.10.2008, leg. G. M. Kashani, four females (PCGMK 1354); ***Western Azarbaijan***, Sardasht to Mirabad, 36˚23'N, 45˚23'E, elev. 1390, 2.10.2008, leg. G. M. Kashani, one male and eight females (PCGMK 1358); ***Eastern Azarbaijan*,** Aghkand, Karow village, 37˚24'N, 48˚08'E, 25.7.2016, leg. G. M. Kashani, seven females (PCGMK 2388); same data as before, 19. 4.2017, leg. A. Abedini, six males, seven males (PCGMK 2619); 25 Km S Marand, 38˚18'N, 45˚56'E, 25.7.2019, leg. G. M. Kashani, G. Morovati, one female (PCGMK 2812); 45 Km S Miyaneh, 37˚20'N, 47˚46'E, 19.4.2017, leg. A. Abedini, three males, seven females (PCGMK 2620); ***Qazvin***, Takestan, Changooreh village, 36˚13'N, 49˚28'E, 4.6.2014, leg. B. Eshaghi, one female (PCGMK 1766); Takestan, Nikouiyeh, 36˚16'N, 49˚31'E, 4.6.2014, leg. B. Eshaghi, one female (PCGMK 1773); ***Kermanshah***, Tazeh-abad to Javanroud, 34˚44'N, 46˚15'E, elev. 1330m, 13.8.2018, leg. G. M. Kashani, one female (PCGMK 2687); Paveh, Ghouriqaleh village, 34˚53'N, 46˚30'E, elev. 1650m, 14.8.2018, leg. G. M. Kashani, one female (PCGMK 2693); ***Zanjan***, Mahneshan, Behestan village, 36˚39'N, 47˚44'E, elev. 1290m, 10.3.2016, leg. G. M. Kashani, three females (PCGMK 2255); Nikpey to Mahneshan, 36˚43'N, 47˚50'E, elev. 1980m, 5.5.2016, leg. G. M. Kashani, one male, one female (PCGMK 2274); Armaghankhaneh, Mari village, 36˚59'N, 48˚28'E, 11.5.2014, leg. G. M. Kashani, nineteen males, nine females (PCGMK 1758); Zanjan, Gavazang district, 36˚44'N, 48˚31'E, elev. 2130m, 15.4.2016, leg. A. Abedini, two males, one female (PCGMK 2250); 17 Km S Chavarzagh, 7.3.2014, leg. G. M. Kashani, one male, three females (PCGMK 1721).

Description of male: Maximum length: 10 mm.
Coloration: pale to dark brown with the usual pale muscle spots (Fig. 2A). Body convex, able to roll up into a ball. Tergites with long upright setation. Head with interrupted frontal ridge and a further parallel interrupted ridge starting from behind eyes (Fig. 2C). Schisma with inner lobe somewhat shorter than outer one (Fig. 2B). Telson short, triangular with broadly rounded apex and straight sides, not reaching body outline formed by pleonites and uropod exopodites (Fig. 2D).
Pereopods I-VII merus and carpus with a brush of pointed setae on ventral margin (Fig. 3A, B). Pereopod VII basipodite not laterally enlarged, ischium distally with bulbous ridge on frontal side, with concave

ventral margin equipped with pointed setae; merus and carpus short and stout, with a spare brush of setae on ventral margin (Fig. 3B, C).
Pleopod I endopodite (Fig. 3D) with distal part bent outward and pointed apex bearing a row of fine setae on inner margin; exopodite (Fig. 3E) with well-developed rounded hind lobe equipped with a row of pointed setae. Pleopods IV-V exopodites as in Figs 3 F-G.

Comments: Schmalfuss (1988) identified *Schizidium golovatchi* based on two female specimens from southern Armenia. Though the male features are usually exploited in the identification of terrestrial isopods, the presence of an interrupted ridge starting from behind the eyes was considered as distinguishing character of the species (Schmalfuss 1988). Here, the male characteristics were presented for the first time based on the specimens from Iran. Along with the features proposed by Schmalfuss (1988), *Schizidium golovatchi* is easily distinguished by the male pereopod VII ischium with a distinct projection in distal part and deeply convex ventral margin. This species has a broad distribution in west and northwestern Iran (Fig. 1), where it is a common species. The identification of the species was verified by Dr. Schmalfuss, either.
Distribution: S Armenia and W Iran.

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RESEARCH ARTICLE Open access

Landmark-based geometric analysis of body shape variation and meristic plasticity among populations of *Alburnoides idignensis* from Tigris River Drainage, Persian Gulf Basin, Iran

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Abstract
To compare body shape variations and meristic plasticity among four populations of *Alburnoides idignensis* fish from Aab-barik, Aab-Sardeh, Darband and Sarab-e Kayvareh rivers in Tigris River Drainage, Persian Gulf Basin of Iran. Geometric morphometric method was used to compare shape data extracted by recording 15 landmark points on 2-D pictures of 94 specimens collected from the rivers by electrofishing and a seine net. The principal component analysis, Canonical Variate analysis and MANOVA analysis were used to examine shape differences among the populations. Eight meristic traits including number of lateral line scales (LL), scales above and below LL to ventral fin, pre-dorsal scales, dorsal, anal, pectoral and pelvic branched rays were counted under a stereomicroscope and mean number of the data were compared by Kruskal–Wallis and ANOVA in SPSS software. Significant differences were found among the four populations in all meristic traits but the number of LL scales and in their body shape, separating them from each other. Results revealed that the studied populations have some differences in meristic characters and in the shape and size of the head, body, caudal peduncle and ventral and anal fin position.

Key words: *Cyprinidae, Leuciscidae, river systems, Cypriniformes*

INTRODUCTION

Comparisons of anatomical traits of organisms have long been considered as the central component of biology Adams et al. (2004). The morphological accounts and descriptions of organisms turned out to be the basis for underpinning the understanding of life and classification of organisms Adams et al. (2004). Many geographical barriers to gene flow exist for fishes and, therefore, most species and populations have the opportunity to show natural variations (Marcil et al. 2006; Banimasani et al. 2018). Adaptive radiation has been defined as the process of extremely rapid species formation coupled with ecological, morphological, and behavioral diversity (Schluter, 2000). Moreover, phenotypic plasticity in morphometric traits may often be adaptive, reflecting the effects of anthropogenic impacts or prey-predator processes in

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the ecological niches of a population (Robinson & Parsons, 2000; Jalili et al. 2015; Ghorbani-Ranjbari & Keivany 2018a,b)

The “morphometrics” is a generally used word for the statistical analysis of a large number of distances, angles, or ratios. “Geometric morphometrics” deals directly with coordinates of anatomical landmarks, either in two or three dimensions, rather than with traditional distances or angles. Landmark points are loci that have names as well as Cartesian coordinates (Bookstein, 1991). Thus, we examined some populations of *Alburnoides idignensis* using this newer technique.

The genus *Alburnoides* De Filippi, 1863 with over 30 valid species has a distribution ranging from Europe to Asia Minor and Central Asia (Bogutskaya & Coad, 2009; Coad & Bogutskaya, 2009; Coad & Bogutskaya, 2012; Mousavi-Sabet et al. 2015; Mousavi-Sabet et al. 2015). Recently, 12 species are considered to occur in Iranian freshwaters (keivany et al. 2016; Esmaeili et al. 2017; Esmaeili et al. 2018), although Eagderi et al. 2013 synonymized some of these species. The species in the genus *Alburnoides* is distinguished by having a combination of morphological characters such as different fin ray counts and molecular traits (Jouladeh Roudbar et al. 2015; 2016). Differences in habitat and feeding ecology of the species can change body shape traits. Herein, we used some meristic traits and the geometric morphometrics approach [9] to explore body shape variations among four populations of *Alburnoides idignensis* Bogutskaya & Coad, 2009, collected from the Tigris River Drainage, Persian Gulf Basin in Iran.

MATERIAL AND METHODS

Geometric morphometric

A total of 94 specimens from four populations of *Alburnoides idignensis*, caught by electrofishing and a seine net, from Aab-barik at 48º15'34"E, 34º56'44"N, Aab-Sardeh at 48º39'24"E, 33º46'06"N, Darband at 49°15'59"E, 33°26'24"N and Sarab-e Kayvareh at 48º43'22"E, 33º48'59"N in Tigris River Drainage, Persian Gulf Basin during 2008-2009 and preserved at IUT museum, were measured (Table 1).

Each specimen was photographed on left side by a digital camera (13 megapixel) at the same light exposure condition. The digital photographs were then processed using tpsDig 2.10 software for landmark acquisition. Some 18 Landmarks (Fig. 1) were identified by conventional rules on biological homology basis (spatial congruence, ontogenetic and phylogenetic) (Bookstein, 1991). The landmarks were digitised then their position was related to systems of coordinates (the x and y coordinates) which were useful for transformation. Each set of co-ordinates were submitted separately to a generalized procrustes analysis (GPA) available in the tpsRelw software1.45. This procedure translated, rotated and scaled the original configurations in order to achieve the best superimposition of all shapes. The size of each specimen is represented by the "centroid size", a measure that is able to estimate the size in all directions in a body better than is possible by using univariate measures such as maximum length. The TpsSmall 1.20. software was used to assess the correlation between Procrustes and Kendall tangent space distances to ensure that the amount of shape variation in a data set is small enough to allow statistical analyses to be performed in the linear tangent space, approximating the Kendall shape space, which is non-linear (Hammer, 2001; Rohlf, 2003; 2007).

The software was used to introduce shape variables into a Principal Component Analysis (PCA), and to visualize the warping associated with the various principal components (PCs). These components represent relative warps in the context of a TPS (thin-plate spline) approach (Bookstein, 1991). Finally, Principal Component Analysis, Canonical Variate Analysis and Cluster Analysis were conducted using PAST software (Eagderi et al. 2019).

Meristic characters

Eight meristic traits including number of lateral line scales (LL), scales above and below LL to ventral fin, pre-dorsal scales, dorsal, anal, pectoral and pelvic branched rays were counted under a stereomicroscope and after a normality test, the mean number of the non-normal data were compared by Kruskal–Wallis and the mean number of the normal data by ANOVA in SPSS software.

TABLE 1. Mean±SD, Kruskal–Wallis and ANOVA results for the meristic characters in *A. idignensis* populations.

	Meristic traits	Aab-Barik	Aab-Sardeh	Darband	Sarab-e Kayvareh	*p*
1	Lateral line scales (LL)	42.00±2.87	44.44±4.16	42.70±2.26	42.84±3.02	0.06
2	Scales above LL	08.12±0.72	08.79±0.60	07.58±0.77	08.50±0.93	0.00
3	Scales bellow LL to ventral fin	04.95±0.45	05.03±0.88	04.52±0.49	05.34±0.87	0.01
4	Pre-dorsal scales	17.95±2.44	22.34±2.39	20.29±2.65	22.07±1.79	0.00
5	Anal branched rays	11.25±0.66	11.27±0.58	11.11±0.58	10.65±0.67	0.00
6	Dorsal branched rays	08.08±0.49	07.93±0.25	07.64±0.47	07.88±0.31	0.01
7	Pectoral branched rays	14.04±0.73	13.27±0.94	13.05±0.99	13.57±0.56	0.00
8	Pelvic branched rays	06.87±0.33	06.93±0.25	06.47±0.49	06.61±0.68	0.00

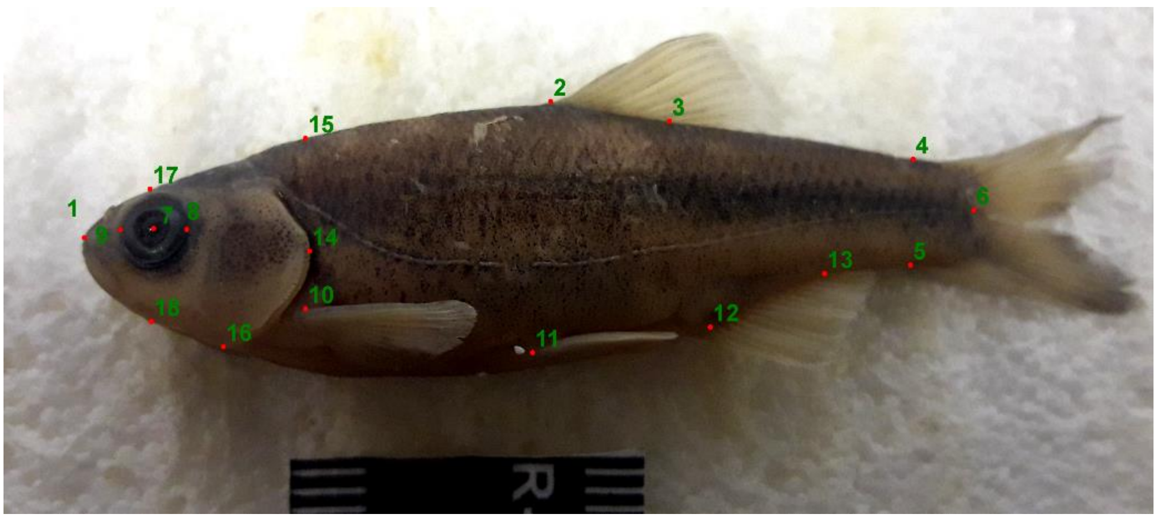

FIGURE 1. The location of the landmarks used for geometric morphometric analysis of *A. idignensis* populations in Tigris River Drainage, Persian Gulf Basin.

RESULTS

Geometric morphometric

Our results of principle component analysis (PCA) with landmark-points data showed that the three first PCs accounted for 64.19 % of variances (35.175, 18.01 and 12.8 % for PC1, PC2 and PC3, respectively, Fig. 2). The scree plot is used to determine the number of factors to retain in principal components to keep in a principal component analysis (PCA). Investigations of deformation grids along the CV1 and CV2 showed that the populations along PC1 (positive side) have smaller head, lower snout length, shorter base of anal fin, higher body height and longer of caudal peduncle. The populations along PC2 (positive side) have lower body height, pelvic and anal fins in anterior position and longer caudal peduncle length. Figure 5 shows the results of cluster analysis of the landmark-points data of *A. idignensis* populations and shows that Aab-Sardeh, Darband and Aab-Barik populations are in the same group and Sarab-e Keyvareh is in another group.

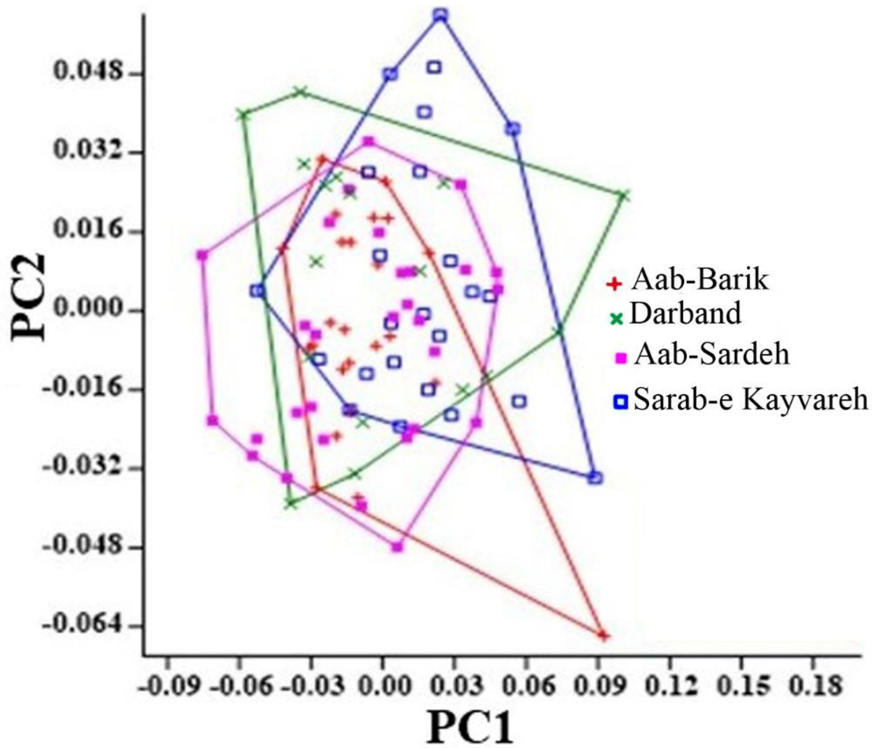

FIGURE 2. Principal Component Analysis (PCA) of *A. idignensis* populations in Tigris River.

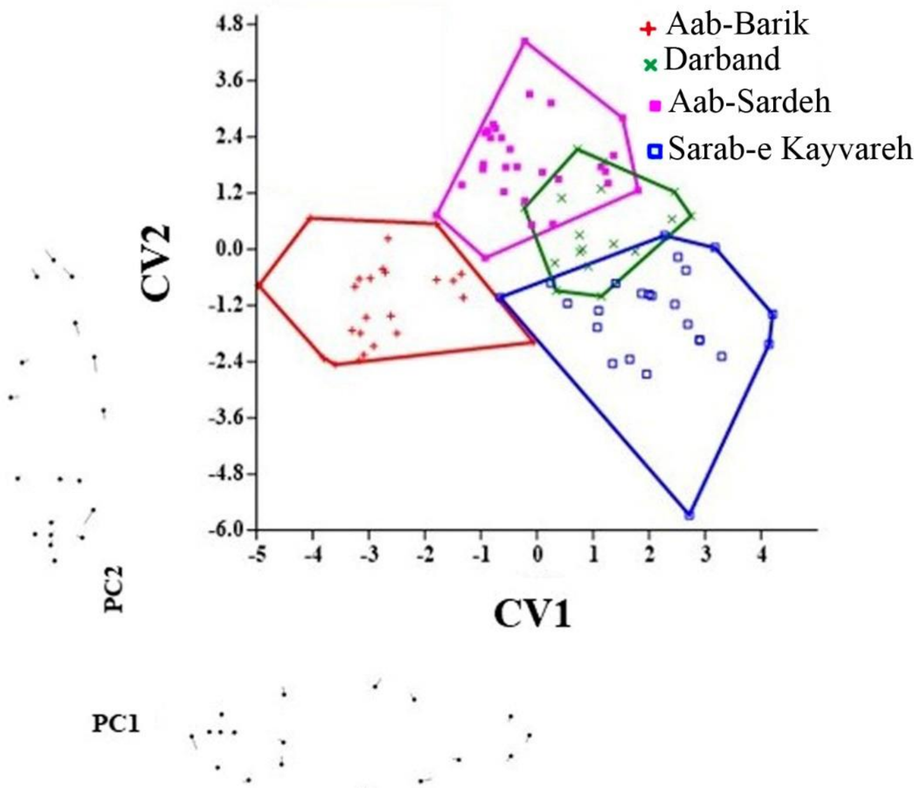

FIGURE 3. Canonical Variance Analysis (CVA) of *A. idignensis* populations in Tigris River Drainage, Persian Gulf Basin and TPS-deformation grid along the CV1 and CV2.

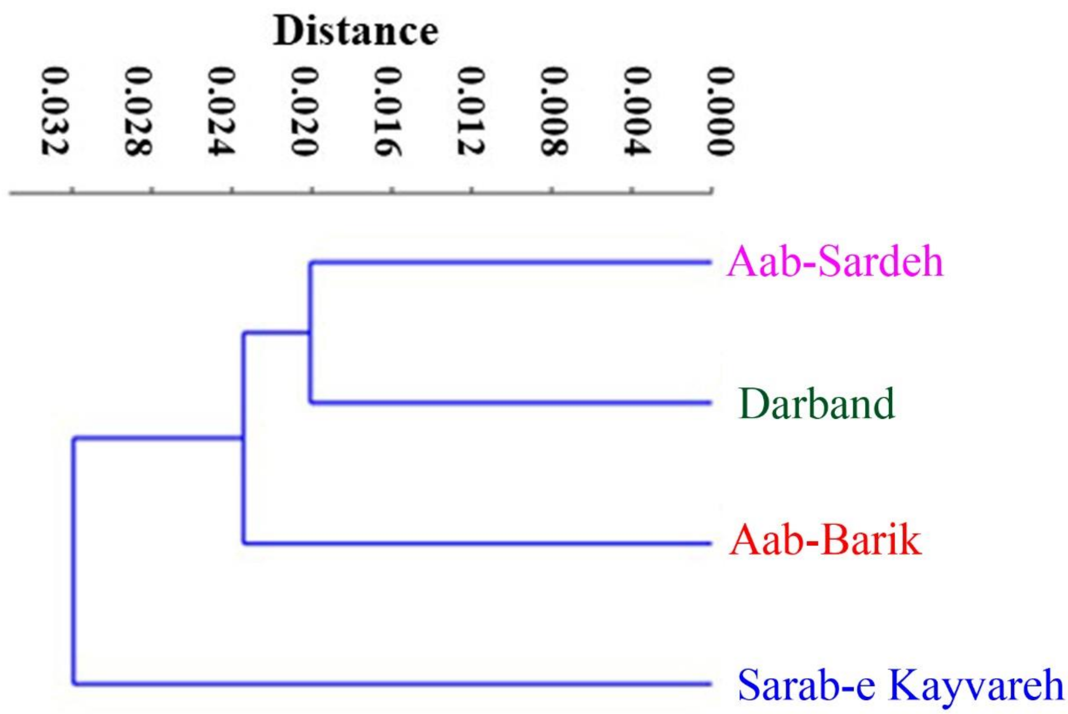

FIGURE 4. Cluster analyses of *A. idignensis* populations in Tigris River Drainage, Persian Gulf Basin.

Meristic characters

Based on normality test, all meristic characters were nonparametric except lateral line scales (LL) and pre-dorsal scales, so they were analysed with Kruskal–Wallis and ANOVA, respectively (Table 2) and showed that studied populations were different in all meristic character ($p<0.05$) except in the LL scales.

DISCUSSION

The four studied populations were different in most meristic traits (7 out of 8) and body shape. Aab-Sardeh, Darband and Aab-Barik populations are in the same group and Sarab-e Keyvareh is in another group. In a study on *Alburnoides eichwaldii*, it was indicated that the body shape of fish populations inhabiting different habitats and rivers are different and these differences show the habitat-specific separation in the studied populations (Eagderi et al. 2013; Rohlf, 2010; Mouludi-Saleh e al. 2017; 2018; Tajik & Keivany; 2018). Moreover, results of PCA and CVA in the morphometric characteristics of Tajan, Babolrud and Aras rivers, somewhat separated from each other. The meristic characteristics of *Alburnoides eichwaldii* were very close together and there was high degree of overlap in their characteristics. In some northern rivers *Alburnoides eichwaldii* showed Intra-population variations in their morphology while morphometric and relative morphometric characters were not useful for separating the two populations and sexes. However, the meristic characters could relatively separate these two populations (Haghighy, 2015).

Jouladeh Roudbar et al. showed that *A. idignensis* cannot be distinguished from other three studied species because the species overlapped in morphometric and meristic traits (Jouladeh Roudbar et al. 2015; 2016). These shape changes are probably related to differences in habitat and feeding habits among the populations (Keivany & Arab, 2017). The onset of adaptive radiation often requires two conditions to be met, the formation of a new habitat or a dramatic change of an already existing habitat and the owning of a key innovation, such as, a set of traits allowing for rapid adaptation towards new niches (Sturmbauer, 1998; Yoder, 2010). Generally, morphological changes seen in the rivers may be the result of phenotypic plasticity, local adaptation, ecological character displacement, genetic divergence or the interaction of any of these factors (Nicieza, 1995). In the species level, morphological differences among the species are often discussed as genetic divergent as results of competition and ecological preferences, so that different species exploiting different resources (Ehlinger & Wilson, 1988; Dynes et al. 1999). However, differences among-population are often considered to be the result of acclimation to local environmental conditions (Mittelbach et al. 1992). As a result, and in a general concept, variation in morphology resulted from environmental effects on phenotypic characters or by counteracting genetic differences between populations (Marcil et al. 2006).

Evaluation and explanation of the phenotypic plasticity among isolated population as well as the pattern of these variations has always been a great and difficult subject for evolutionary biologist. It is particularly true in the case of geographically widely distributed species. In nature, water flow and temperature vary considerably along streams and are very important in influencing the structure and morphological traits of fish communities. Even within streams, the range of temperature can be different from one part of the stream to the next. This variation in conditions eventually results in the adaptation of different populations to a given range of temperatures and water flow conditions [38,39]. Body depth showed differences among the individuals of three populations. Variation in body depth could affect the overall fusiform shape of the fish; therefore, it may change the hydrodynamic power and swimming ability of the fish [40] and can be considered as eco-morphological variation [41]. For example, we observed a lower caudal peduncle length in the populations that is probably caused by a high-water flow in Darband and a moderate flow in Aab-Sardeh and Sarab-e Keyvareh in Lorestan province. Aab-Barik with a low water flow is in Hamedan province. Moreover, Langerhans and Reznick (Langerhans, 2008). hypothesized that increasing water flow regimes may lead to increases in fin areas.

The relationship between morphology and ecology in fishes has long been known, and a few studies have applied multivariate morphometric methods to investigate ecomorphological patterns in multi-species fish communities (Douglas, 1992). Variation and differences in body shapes are important if lead to adaptations to environmental conditions and increases survival rates in aquatic habitats. Such adaptations are related to the need for compatibility with hydrodynamic forces to saving energy during biological behaviours (Nacua et al. 2010). The main reason for the separation of these populations in different rivers is probably due to the geographical separation of these populations which often leads to a decrease in the gene flow between them (Hellberg, 1994). In other words, genetic and body shape differences among populations increases with geographical barriers or isolation (Zamani-Faradonbe et al. 2015). Differences in the body forms of populations from different habitats and even in different species of same habitat, indicate the differences in the type of acclimation of fish to the type of habitat (like pools or riffles) (Tabatabaei et al. 2014). Differences in head shape and position of the mouth probably is related to feeding behaviours (Langerhans et al. 2003). Also, morphological variability and evolutionary proses of body shape of various populations of fish indicate that the habitat conditions along with the geographical separation are the key factors that change the phenotypic characters of the fish inhabiting that area. Different distribution of some populations in canonical discriminant analysis graph might be based on the habitat characters; geographical distance and isolation mechanisms (Cicek et al. 2016).

The phenotypic variability of the populations of a species in various environments is a phenomenon that results from the effects of environmental factors on this generation and previous generations in terms of adaptation and speciation. So these differences in body shapes among populations of *A. idignensis* probably reflects differences in environmental conditions and genetic variation. Since the purpose of this study was to compare the body shape of different populations of *A. idignensis* inhabiting different rivers, the results showed that studied populations differed in meristic characters and in the shape and size of head, body, caudal peduncle and ventral and anal fin position. Further studies are needed to provide a better genetic relationship in these populations.

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RESEARCH ARTICLE **Open access**

Avian diversity of Fars province (Southwestern Iran) with note on the zoogeographical composition

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Abstract
Rich avifauna of Fars province, SW Iran, is a stem from high diversity of habitat and climate beside its geographical position as a crossroad between Palearctic, Oriental, and Afrotropical realms. It shares the greatest number of bird species with the Palearctic region, however two other faunal realms, including Oriental and Afrotropical have a pronounced influence on its avifauna. It seems its bird fauna to be more in common with the Oriental elements than Afrotropical ones; the question addressed in this study. In addition, the province is located east of the Western Palearctic and close to the Eastern Palearctic border. I explored how much its bird elements have in common with the Eastern Palearctic. It is important because in some cases, western and eastern bird elements may come together with a narrow or wide hybrid zone. Based on my expeditions in recent years and pervious published literature, I present the comprehensive annotated checklist including 371 bird species in 197 genera, 68 families and 23 orders. At least 88 species are resident, 193 species are breeding, 33 species are rare and 21 species are vagrant. Based on the international conservation criteria, five species fall under the EN, nine under the VU, 16 under the NT of IUCN and 62 species fall under the appendices of CITES, including eight species in appendix I and 54 in appendix II. Results show that the Fars province shares the greatest number of bird species with the Palearctic region (364). The province lies within the West Palearctic faunal region and as expected, its bird fauna shares a greater number of species with the western Palaearctic than its eastern (346 versus 314). Our results also showed that the two other adjacent faunal regions including Oriental and Afrotropical have influence on its avifauna, and the province shares a greater number of species with the Oriental than to Afrotropical.

Key words: *Bird fauna, Conservation, Distribution, Zoogeography, Taxonomy, Iran.*

INTRODUCTION

The knowledge of Iranian avifauna traces back to second half of 19th and entire 20th centuries that was almost dotted with pioneering contributions of western researchers (e.g. Blanford, 1876; Schalow, 1876; Witherby, 1903; Beldi, 1918; Capito, 1931; Trott, 1947; Vaurie & Koelz, 1949; Koelz, 1950; Marien, 1950a, 1950b, 1951a, 1951b; Vaurie 1949a, 1949b, 1950a, 1950b, 1951a, 1951b, 1951c; Passburg, 1959; Diesselhorst, 1962; Erard & Etchécopar, 1970; Scott *et al*., 1975). On the other hand, the first two decades of the current century are more characterized by the studies of Iranian researchers, ornithologists and birdwatchers, which led to the publication of some books, many journal articles and dissertations (e.g. Tohidifar & Kaboli, 2012; Yousefi *et al*., 2015*;* Aliabadian *et al*., 2016*;* Haghani *et al*.,

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2016; Kaboli *et al*., 2016; Gholamhosseini *et al*., 2017; Kayvanfar *et al*., 2017; Khaleghizadeh *et al*., 2015, 2017; Alaie Kakhki *et al*., 2018).

Blanford (1876) presented 383 species in his book, then world-famous ornithologist N.A. Zarudny conducted four prominent expeditions during 1896 until 1904 to eastern, central, and western parts of Iran and in 1911 listed a complete list including 714 species and subspecies for Iranian birds (Roselaar & Aliabadian, 2007; Aliabadian *et al*., 2012). In the 1960s, S.H. Jervis Read listed 430 species (Jervis Read, 1958) and then Scott *et al.* (1975) listed 491 bird species for the country. Later, Scott & Adhami (2006) listed 514 species of birds believed to occur in Iran, and currently, complete checklist of bird species of Iran includes about 556 species (Khaleghizadeh, 2020).

In southwestern Iran, Fars Province is the fourth largest province of the country. The vertebrate diversity of Fars is reflected in several published checklists (freshwater fishes: Esmaeili & Teimori, 2017, herpetofauna: Gholamifard *et al*., 2012, and mammals: Zarei *et al*., 2019), but no pervious comprehensive checklist has yet been published on the bird fauna of this part of Iran except for some wetlands (e.g. Banan, 2008; Rahimi *et al*., 2009; Amininasab & Radmanesh, 2010; Tabiee, 2010; Tabiee *et al*., 2014) or some local areas (e.g. Zareian *et al*., 2012; Yousefi *et al*., 2015) and, an online simple checklist (including 367 species) according to the data collected by the Iran Bird Records Committee (IBRC 2020; http://iranbirdrecords.ir/, see Joolaee *et al*., 2020).

A wide range of geographical and physiographic conditions, coupled with climatologically diverse environments and geographical position as an ornithological crossroads between East Palearctic, West Palearctic, Oriental and Afrotropical regions (Fig. 1), have provided a great diversity of species especially birds in this part of the country (Esmaeili & Teimori, 2017; Gholamifard *et al*., 2012; Zarei *et al*., 2019). In this paper, I'm going to provide the comprehensive updated checklist of Fars avifauna and show its zoogeographical composition.

Fars province is located in the southwestern Iran in the Palearctic region and shares the greatest number of bird species with the Palearctic region. However, two other faunal realms have a pronounced influence on its avifauna: the Oriental realm in the southeast, and the Afrotropical in the southwest. It seems its bird fauna to be more in common with the Oriental elements than Afrotropical ones, the question addressed in this study. In addition, the province is located east of the Western Palearctic and close to the Eastern Palearctic border. I explored how much its elements have in common with the Eastern Palearctic. It is important because in some cases, western and eastern bird forms may come together with a narrow or wide hybrid zone.

MATERIAL AND METHODS

Study Area

Fars Province lies between 27° and 31°N and 50° and 55°E in southern Iran and its total area is about 122,608 km² (7.4% of total area of Iran). The map of study area which has been created using Global Mapper 18 (Global Mapper Software LLC, Olathe, Kansas) and Surfer 11 (Golden Software, LLC) is given in Figure 2. The elevation of Fars ranges from 450 m in the south to about 3,943 m in the north, with a mean of 1,491 m. Fars possess three national parks (Bamou, Bakhtegan and Qatruiyeh), one wildlife refuge (Bakhtegan), seven protected areas (Arzhan and Parishan, Mianjangal, Hormod, Bahram-e Goor, Moleh Galeh, Tang-e Bostanak and Margoon, as well as minor parts of the two other protected areas, Dena and Tarom) and 17 non-hunting areas (Fig. 2).

Data collection

The data presented in this checklist comes from the previous (see the selected bibliography) and recently published books and journal articles (especially Roselaar & Aliabadian, 2009; Mansoori, 2013; Kaboli *et al*., 2016; Khaleghizadeh *et al*., 2011, 2017), data collected by the Iran Bird Records Committee (IBRC 2020; http://iranbirdrecords.ir/, e.g. Joolaee *et al*., 2020), unpublished reports from the Iranian DoE (Department of Environment) and my field expeditions in Fars province during recent years. Therefore, this checklist is a combination of historic and recent data. Birds were identified in the field based on the

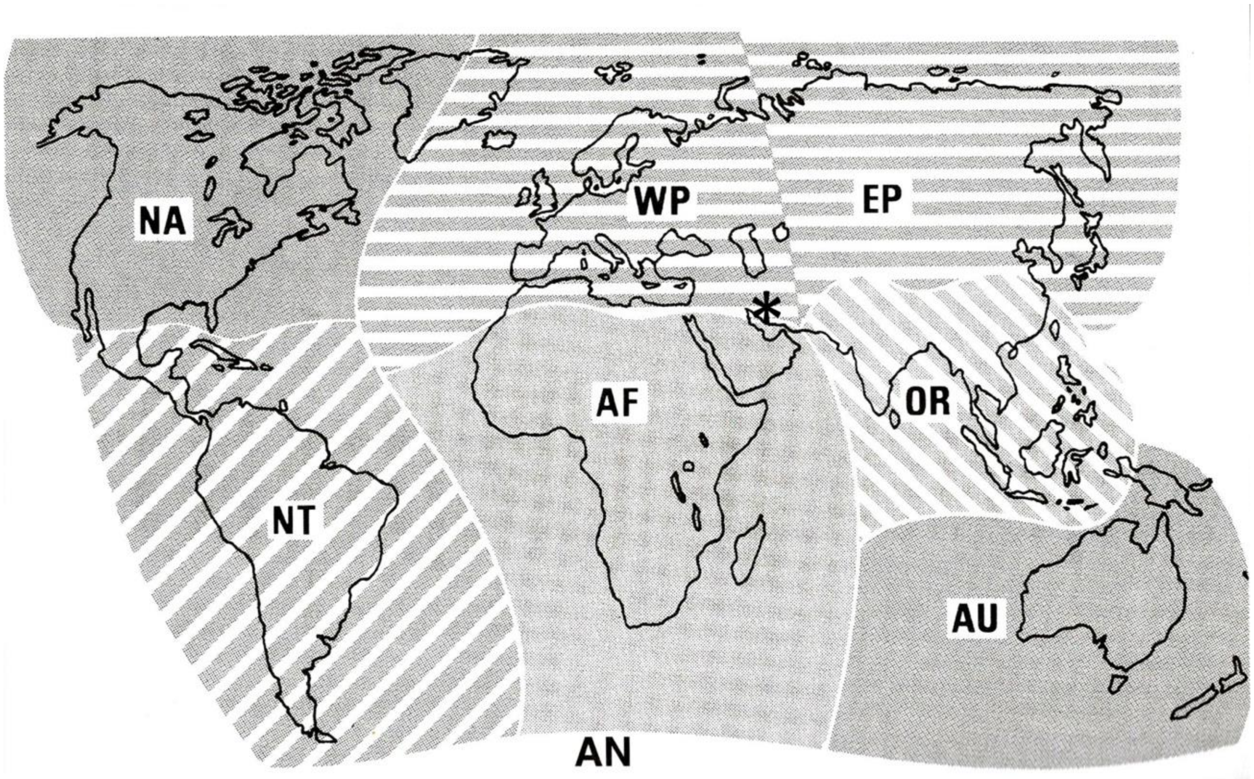

FIGURE 1. Map of global terrestrial zoogeographic regions showing the position of Fars province (southwestern Iran). AU (Australian), OR (Oriental or Indomalayan), EP (East Palearctic), WP (West Palearctic), AF (Afrotropical), NA (Nearctic), NT (Neotropical). (After Madjnoonian et al., 2005). * Indicated the Fars province position.

morphological characteristics using various field guides (e.g. Porter *et al*., 2004; Svensson *et al*., 2009; Mansoori, 2013). They were observed through a Vanguard 10x50 Spirit ED Binocular. Photographs were taken using a Canon EOS 760D camera equipped with a Sigma 150-600 mm lens. Taxonomy of IOC World Bird List (v 9.1) was followed.

Status of occurrence for Fars province

Status includes individuals or various populations existing in different parts of the province as residents, summer visitors, winter visitors, passage migrants, or vagrants that extracted from Kaboli *et al.* (2016) and Khaleghizadeh *et al.* (2017), as well as based on my field observations. The status of occurrence of each species in the province is showed by the following abbreviations on the species list:

Resident (R): Bird that remains in a specific area all year round and breed there. Summer visitor and breeding (S): Bird that arrives in spring, remains throughout the breeding season, and leave the region in autumn. Summering non-breeder status is denoted by a 's' letter. Winter visitor (W): Bird that arrives in autumn, remains throughout the winter, and leave the region in spring. Passage migrant (P): Bird that passes over the region in spring or autumn during its migration between breeding grounds in the north and wintering grounds in the south. Vagrant (V): Bird that is recorded outside its regular distribution range and is wanderer in the region.

Rare species

Rare species for Iran extracted from Khaleghizadeh *et al.* (2011), Scott (2008), Roselaar & Roselaar (2009) and Iran Bird Records Committee (IRBC).

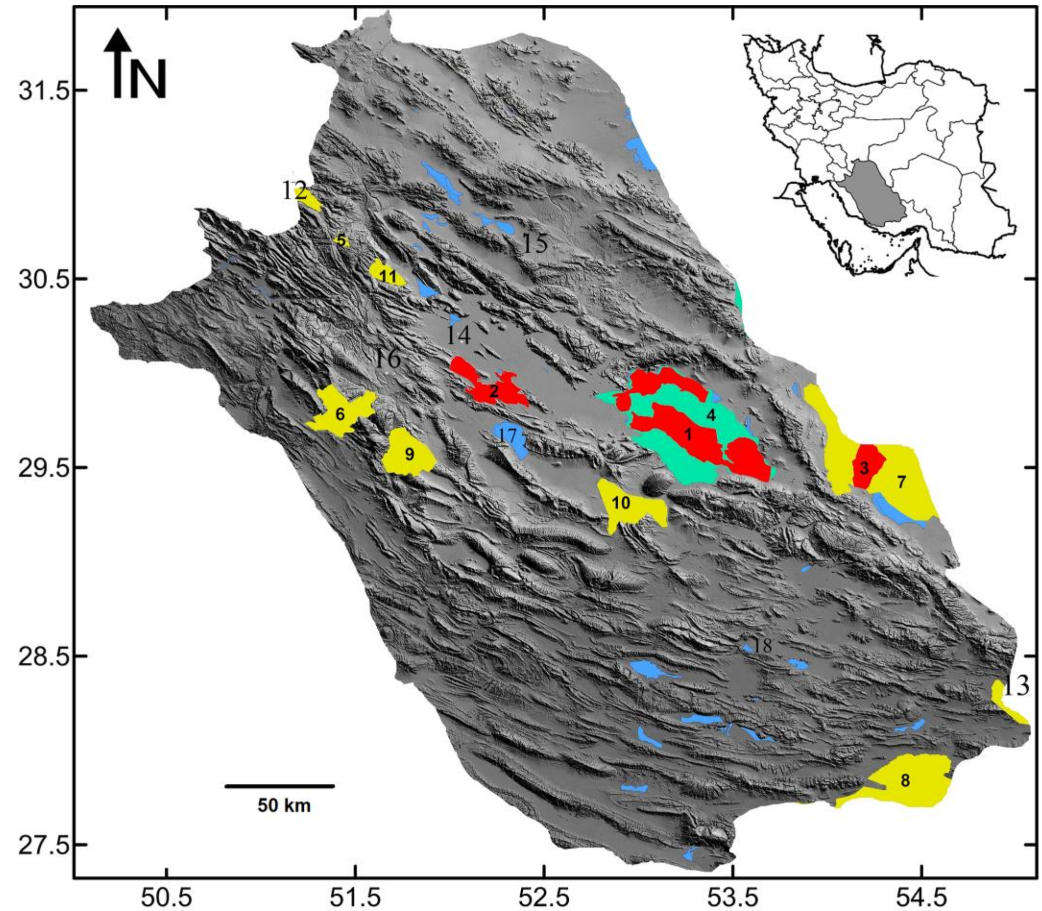

Figure 2. Map of Fars Province, southern Iran showing the area and distribution of protected and Important Bird Areas (IBAs). 1, Bakhtegan National Park; 2, Bamou National Park; 3, Qatruiyeh National Park; 4, Bakhtegan Wildlife Refuge; 5, Margoon Protected Area; 6, Arzhan and Parishan Protected Area; 7, Bahram-e Goor Protected Area; 8, Hermood Protected Area; 9, Moleh Galeh Protected Area; 10, Mianjangal Protected Area; 11, Tang-e Bostanak Protected Area; 12, Dena Protected Area; 13, Tarom Protected Area; 14, Dorudsan Dam; 15, Kaftar Lake; 16, Haft Barm; 17, Lake Maharlu; 18, Harm Lake.

Conservation status

To determine the conservation status of bird species, the IUCN Red list of Threatened Species version 3.1 was used: critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), data deficient (DD) or least concern (LC).

To determine levels of protection from over-exploitation within international trade, appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) were used. The national level of conservation (defined and implemented by the Iranian Department of the Environment: DOE) for each species is presented as endangered (End.), protected (Prot.), unprotected (no letter) and pest species (Pest).

Zoogeographical composition

At first, the distribution (both breeding and non-breeding range) of each bird species in different zoogeographical regions was extracted from Madjnoonian *et al* (2005), and Del Hoyo (2019) was followed for some species that not listed in that. Also, we updated the distribution of all species according to Del Hoyo (2019). Then, the numbers of species that Fars province share with each zoogeographical region was calculated. For this, I inserted all species in the left column of a spreadsheet and each zoogeographical region in the following columns and occurrence of each species in each zoogeographical region showed by (1). Sum of cells of each column was calculated.

Symbols used for global distribution: AU (Australian), OR (Oriental or Indomalayan), EP (East Palearctic), WP (West Palearctic), AF (Afrotropical), NA (Nearctic), NT (Neotropical).

RESULTS

Diversity

The Fars Province has a rich and diverse avifauna that comprises 371 species in 197 genera, 68 families and 23 orders. Maximum bird species were recorded from the Order belonging to Passeriformes (173 species, 46.63% of the avifauna) and Charadriiformes (55 species, 14.82%). In term of families, Muscicapidae were the most diverse family present with 31 species (8.35% of avifauna) and Accipitridae with 30 species (8.08% of avifauna). Twenty families have only one species each. At least 88 species are resident, 193 species are breeding and 33 species are rare.

Annotated species list

An annotated list of bird species including classification, scientific name, authority, common name, global distribution in the zoogeographical regions, status of occurrence for Fars Province and conservation status (IUCN, CITES, national) is provided (see electronic supplementary material; dx.doi.org/10.6084/m9.figshare.16571280). Species observed by the author are marked with an asterisk in front of the scientific name of each species.

Conservation status

Among the reported species, 341 species (91.91%) are LC, nine VU (2.42%), five EN (1.34%), and 16 species (4.31%) are NT in the IUCN Red List of Threatened Species. Eight species (2.15%) are listed in the Appendix I, and 54 species (14.55%) in Appendix II of CITES. In addition, 15 species (4.04%) are endangered, 72 species (19.40%) are protected and eight species (2.15%) are pest based on the rules and regularities/laws of the Iranian DOE.

6 out of 33 rare species reported from Fars province are birds of prey. In the IUCN category; 2 out of 9 species considered as VU, 4 out of 5 species considered as EN and 3 out of 16 species considered as NT are birds of prey. According to appendices of CITES; 4 out of 8 species listed in appendix I and 46 out of 54 species listed in appendix II are birds of prey. Also, according to the category of DOE, 9 out of 15 species considered as EN and 41 out of 72 species considered as protected are predatory.

Zoogeographical composition

In total, the Fras avifauna shares 364 species with the Palearctic region (345 with the West Palearctic and 313 with the East Palearctic), 240 with the Oriental, 213 with the Afrotropical, 43 with the Nearctic, 34 with the Australian and 26 with the Neotropical. As expected, the Fras shares the greatest number of bird species with the Palearctic (the closest region) and the fewest with the Neotropical (the most remote region), although the distribution of some species reaches Central America, not South America. Despite the general Palearctic nature of the avifauna of southwestern Iran, the significance of this area as a crossroad between three biogeographical regions, the Palearctic, the Oriental and the Afrotropical is apparent and southwestern Iran shares many bird species with the Oriental and Afrotropical. Also, the province lies within the West Palearctic faunal region (eastern margin) and as expected, its bird fauna shares a greater number of species with the western Palaearctic (n=345) than its eastern (n=313). When the total species are considered, the province shares a greater number of species with the Oriental (n=240) than to Afrotropical (n=213).

DISCUSSION

The purpose of this study was to gather previously published data, and data obtained from field observations to present a general view of the Fars avifauna (southwestern Iran) and its zoogeographical composition. I conclude that the avifauna of Fars is highly rich (comprise 371 species in 197 genera, 68 families and 23 orders) and taxonomically diverse when compared to the country's total bird fauna (371 versus about 556 species; 66.72%) and to those of its neighbouring provinces in southern Iran such as Isfahan (280 species), Yazd (226 species), Kerman (308 species), Bushehr (327 species), and Kohgiluyeh and Boyer-Ahmad (234 species) (IBRC 2020).

Joolaee *et al*, 2020 was followed for including Common rosefinch *Carpodacus erythrinusas* and Twite *Linaria flavirostris* in the checklist, however more confirmation is needed. Some records in published literature and online sources have been made only based on the external morphological features, which in some cases (e.g. complex genera) needs to be confirmed using molecular markers. Five species are included in the current checklist which are not listed by Joolaee *et al* (2020) as following.

Rough-legged Buzzard *Buteo lagopus* is a scarce and irregular winter visitor to south Caspian region; also recorded in Khorasan-e Razavi, Tehran and Fars provinces (Khaleghizadeh *et al*., 2017). One specimen was recorded on 31 October 1997 at Persepolis, Fars (Darreh-Shoori *et al*., 2001).

Lanner Falcon *Falco biarmicus* is a scarce resident in north-western Iran, especially in basin of Urumiyeh Lake (Kaboli *et al*., 2016). It has also been recorded in Hormozgan and Esfahan during the period 2011-2015 (see Khaleghizadeh *et al*., 2017). Three specimens were recorded from Kaftar Lake, Kamjan Lake, Sivand dam (Fars) in Jan. 2009 by Joolaee *et al* (2009).

European Pied Flycatcher *Ficedula hypoleuca* is a scarce passage migrant in west and north Iran, occasionally east to Fars. It has been observed/collected in Neyriz on 29 March 1940 (Roselaar, *unpubl.* in Khaleghizadeh *et al*., 2011), but not apparently reported from Fars after that.

Red-headed Bunting *Emberiza bruniceps* is a summer visitor in northern, northeastern and eastern of Iran**.** Black-headed and Red-headed Buntings are closely related passerine species that were reported to meet in a hybrid zone southeast of the Caspian Sea, Iran, over 70 years ago (Gholamhosseini *et al*., 2017). One vagrant specimen has observed near Shiraz at spring 2017 by the author. During winter, the two Bunting species flock together on their wintering grounds and when the two species migrate to breeding grounds, it's maybe some specimens of one species migrate with another mistakenly.

Pygmy Cormorant *Microcarbo pygmaeus* is a locally fairly common breeding bird in Guilan and possibly also Khuzestan; locally abundant winter visitor to south Caspian region and uncommon winter visitor to wetlands of Khuzestan. This species was recorded from Parishan Lake (Fars) by Joolaee *et al* (2009).

Lanius excubitor complex is an example of a taxonomically contentious group. *Lanius pallidirostris* is split from *Lanius excubitor* by some authors but not by HBW, Clements, nor H&M4. Restore to status as ssp of *excubitor* pending full resolution of this complex. According to IOC, *L. excubitor* has 12 subspecies including *L. e. excubitor*, *L. e. aucheri*, *L. e. lahtora*, *L.e. pallidirostris*. Monophyletic Southern Grey Shrike *L. meridionalis* is split from Great Grey Shrike based on mtDNA (Olsson *et al*., 2010).

One major reason for this high species diversity is the large area of the province, as with approximately 122,608 km² (7.4% of total area of Iran), it is the fourth largest province of the country that covered the most of southwestern part of Iran. However, a closer look at the issue will show that the biodiversity in Fars has an ecological background (Esmaeili & Teimori, 2017; Zarei *et al*., 2019). It possesses three main terrestrial ecoregions, (i) the central Persian desert basins in the north and northeast, (ii) Zagros Mts. forest steppe extended from northwest to the southeast, and (iii) Nubo-Sindian desert and semi-desert ecoregion in the south (Olson *et al*., 2001), as well as numerous aquatic ecoregions including lakes and rivers. The wide range of geographical and physiographic conditions, coupled with climatologically diverse environments in this province, have provided enormous diversity in this part of Iran (Gholamifard *et al*., 2012; Esmaeili *et al*., 2017; Esmaeili & Teimori, 2017; Zarei *et al*., 2019). Fars also has ten Important Bird Areas (IBAs, Dorudsan dam, Kaftar Lake, Haft Barm, Bakhtegan Lake, Tashk Lake and Kamjan marshes, Bamou National Park, Maharlu Lake, Harm Lake, Hormod Protected Area, Bahram-e Goor, Arjan and Parishan Protected Area; total area 1,176,832 ha) (Evans, 1994; BirdLife International, 2019) (Fig. 2). These natural and man-made IBAs, both act as breeding, wintering and staging grounds and can provide suitable habitats for many bird species, especially many waders and waterbirds. Finally, another main reason for the high species diversity in Fars is its specific zoogeographic position. Zoographically, Iran is an interesting country, as much of its area is located in the West Palearctic and the birds of Iran are predominantly Palearctic, but specially in southern parts are affected by the Oriental and Afrotropical elements (Madjnoonian *et al*., 2005; Roselaar, 2006; Coad, 2017). The Palearctic region shares 39% of its species and 97% of its families with the Oriental region and 12% of its species and 88% of its families with the Afrotropical region (Newton 2003) and same pattern also observed in southwestern Iran in Fars province and the province shares the greatest number of bird species with the Palearctic region and then with the Oriental. Thus, the avian diversity of Fars is such that it can be considered predominantly Palearctic, with some Oriental and Afrotropical species. Some oriental bird elements, e.g. Pheasant-tailed jacana and Afrotropical elements, e.g. Namaqua Dove are just wandering in Fars province.

Despite all conservation efforts, the world's biodiversity is in declining (Balnford *et al*., 2003; Jenkins *et al*., 2003). Owing to negative effects of human activities on the environment, many taxonomic groups are declining in both their population size and geographic ranges (Duraiappah, 2005). The bird fauna in the world is facing several main common threats mainly due to anthropogenic activities/human-induced disturbances. Considering internationally protected bird species, five species from this checklist are EN in the IUCN Red Data List, which most are birds of prey (4 from 5*;* 80%) including *Aquila nipalensis, Haliaeetus leucoryphus, Neophron percnopterus* and *Falco cherrug* and also four species in the appendix I of CITES are birds of prey (4 of 8; 50%) including *Aquila heliaca, Haliaeetus albicilla, Falco pelegrinoides and Falco peregrinus*. Many of the birds of prey have a scatter distribution and protected areas protect only small part of their populations. This checklist also presented 33 bird species for the Fras province that have already been considered as rare species for Iran and these records are important for conservation planning. Although, some forms of legal protection have already been instituted, along with education of local people by the Iranian DOE, nongovernmental organizations (NGOs), and media initiatives; I think that habitat monitoring is urgent for investigating the population status of birds, especially birds of prey. Moreover, gaining basic information about genetic diversity is highly recommended.

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Short communication **Open access**

On the occurrence of *Stylocheilus longicauda* (Quoy & Gaimard, 1825) (Heterobranchia, Aplysiidae) in the Persian Gulf

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Stylocheilus longicauda (Quoy & Gaimard, 1825), a member of long-tailed sea hares (the genera *Stylocheilus* Gould, 1852 and *Bursatella* Blainville, 1817), is a pelagic species that almost associated with drifting algae. Its distribution range is limited to the pantropical region (Chinnadurai *et al*., 2014; Gosliner, Valdez, & Behrens, 2018). It is clearly distinguished from the other species of this genus by having blue spots that circled by red organ bands and also by the lack of longitudinal lines (Yonow, 2008; Chinnadurai *et al*., 2014; Gosliner, Valdez, & Behrens, 2018). Based on the occurrence of the members of this genus in the adjacent waters (Yonow, 2012; Chinnadurai *et al*., 2014), we except the presence of some congeners in the Persian Gulf, a subtropical region with suitable conditions and habitats for the sea hares (Naderloo, 2017). In previous study, Rezaei *et al*. (2016) reported *S. striatus* (Quoy & Gaimard, 1832) from the Persian Gulf.

During a fieldwork on investigation of nudibranch diversity in the Persian Gulf on November 2019, a single specimen of a sea hare was collected near shore of Hadkan port (28°17'14.3"N 51°01'15.5"E) in Bushehr Province. The specimen was found on the green algal filament, attached to a cage structure (aquaculture facilities) in the depth of 1.5 m. After photography of fresh animal, the specimen was preserved in the 96% ethanol.

Based on the following morphological charactres, the specimen was identified as *S. longicauda*: body elongate, bright yellow and slightly translocate; body soft and smooth; with several bright blue spots on the mantle, which surrounded by orang red rings; bearing several branched papillae in different size on body surface; presence of a slightly long tail; rhinophores and oral tentacles are tubular, same color pattern as the body color; body (4 cm) long and slender; pale yellow foot without blue spots (fig. 1).

Figure 1. Live specimen of *S. longicauda* from the Persian Gulf. Sclae: 1 cm.

Stylocheilus striatus was reported by Rezai *et al*. (2016) from the Persian Gulf, without any morphological descriptions and illustrations. Therefore, due to confusion on distinguishing between *S. longicauda* and *S. striatus*, and, also because of loosing captured specimen in this study, we were not able to make sure that these two were different or same species. Yonow (2012) reported *S. longicauda* from the Muscat of Oman. Considering having longtidunal lines on the body, it has been misidentified and it is *S. striatus* which is now considered as the benthic form of the *Stylochielus*,

Stylocheilus longicauda has a circumtropical distribution which has reported from Kenya and Zanzibar (Bebbington, 1974), India (Apte, 2013; Chinnadurai *et al*., 2014), and Red Sea (Yonow, 2008). It always has been found floating on the algae (Bazzicalupo *et al*., 2020).

Anyway, during this study, *S. longicauda* is reported for the first time from the Persian Gulf. More studies are recommended to examine taxonomic status of the long-tailed sea hares in this region.

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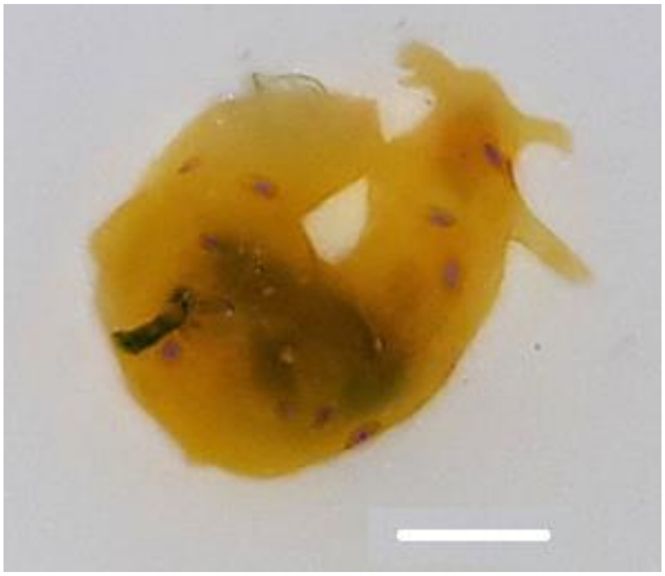

FIGURE 1. Live specimen of *S. longicauda* from the Persian Gulf.

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