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Fishes of the Persis region of Iran: an updated checklist and ichthyogeography

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Abstract: This study provides a new and updated checklist of the freshwater fishes of the Persis region which drains to the Persian Gulf. The list is based on historical literature records and taxon occurrence data obtained from natural history collections and new fish collections. The confirmed freshwater fishes of the Persis region (sub-basin) comprise 44 species in 34 genera, 14 families, 11 orders and one class. The most diverse order is the Cypriniformes with 23 confirmed species (52.25%) followed by Cyprinodontiformes (6 species, 13.65%), Mugiliformes (4 species, 9.1%), Gobiiformes (3 species, 6.8%) and Perciformes with 2 species (4.55%). Acipenseriformes, Clupeiformes, Gonorynchiformes, Siluriformes, Salmoniformes and Synbranchiformes comprise only one species (2.25%). New species have been discovered, some subspecies have been elevated to species, some are being resurrected from synonymy and some taxonomic problems remain and are commented on briefly. Eleven endemic species (25%) in seven genera and four families and 10 exotic species (22.7%) in 8 genera and 3 families are listed here. The fish taxa were classified into different major groups based on the fish ichthyogeographical origin, ecoregion and ecological factors (tolerance to salt water and mode of life). The long history of connection and isolation from fresh and marine waters, multiple sources of species, uneven distribution of inflows and nutrient inputs, and the low to moderate ranges of salinity, different types of habitat (both fresh and brackish water habitats including rivers, lakes, lagoons, marshes, and marine environments), have all contributed to the high ichthyodiversity of the Persis region. It is proposed that the current isolated river systems of the Persis, Zohreh, Tigris and Kor River basins were interconnected during the Last Glacial Maximum of the Late Pleistocene (21,000–18,000 y. BP) and remained so until the sea-level rise of the Early Holocene (11,000 y. BP.). The predicted geographic distributions for the eight species of this region based on current bioclimatic variables revealed that a relatively large area of suitable climate for these native species in the Persis basin extend to western parts of Iran.

Keywords: Fish diversity, Biogeography, Ichthyogeography, Ecoregion, Endemic, Iran.

Introduction

The Iranian Plateau is located in the Palearctic region bordering the Oriental and African zones (Coad & Vilenkin 2004) with high biodiversity especially in freshwater fish of great importance (Esmaeili et al.

2010a, 2014a). The first extensive discussion of freshwater fishes within Iran with descriptions of new taxa dates back to the middle of the 19th century with the work of Johann Jakob Heckel (1843a, b; 1846-1849a-c). Subsequent studies have yielded

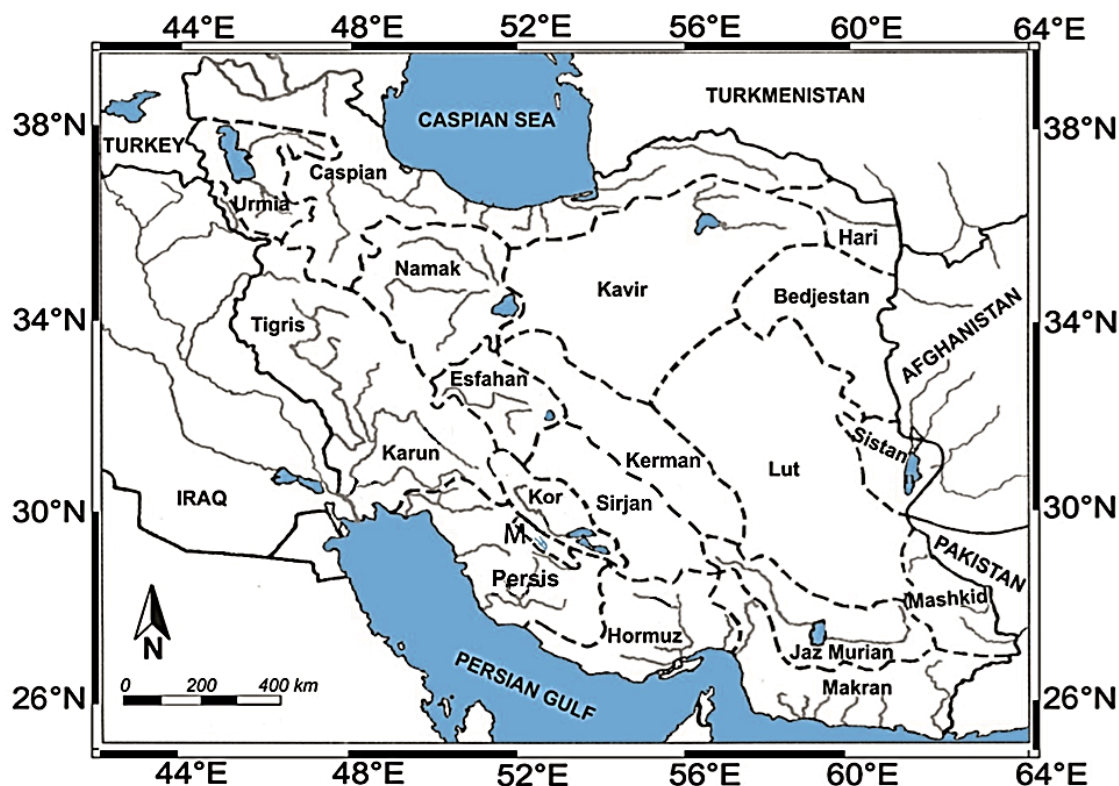


Fig.1. Map of Iran showing major drainage basins of Iran. M, Maharlo basin. Source of map: Coad (2014), modified.

dramatic increases in our knowledge of the biodiversity of Iranian freshwater fishes and accounts have been published by many authors in different countries describing fishes subsequently found in Iran. Early works of particular relevance to Iran include those by Graf Eugen Keyserling (1861, 1863), Filippo de Filippi (1863, 1864, 1865), Aleksandr Mikhailovich Nikol'skii (1897, 1899), and Lev Semenovich Berg (1949).

Coad (1995) listed 150 species in 25 families, 14 orders and 3 classes found in 19 drainage basins of Iran and considering the Persis region of the Persian Gulf basin (noted it as the Gulf basin) as the third rank of ichthyodiversity. Coad (1998) listed 155 species in 67 genera, 24 families, 15 orders and 3 classes found in 19 drainage basins of Iran. He reported the third rank of ichthyodiversity in the Persis region. The southern Caspian Sea, Tigris and Persis are large basins or regions (sub-basins) with diverse habitat and connection to a brackish or marine environment (Coad 1998) which provide such

high diversity (Esmaeili et al. 2014a, b). Esmaeili et al. (2010a) listed the freshwater fishes of Iran and confirmed that freshwater fishes of Iran comprise of 202 species in 104 genera, 28 families, 17 orders and 3 classes found in 19 different basins which is obviously higher than those listed by (Coad 1998). They also reported 23 species whose presence in the Iranian waters is needed confirmation by specimens.

Accordingly, it can be expected that endorheic and exorheic basins of Iran have a higher diversity of freshwater fish species i.e. approximately 222 species or more (see Esmaeili et al. 2014a) which is considerably higher than that given in the last checklist provided by Coad (1998) and Esmaeili et al. (2010a).

Based on Esmaeili et al. (2010a), the third rank of ichthyodiversity is observed in the Persis region which is a part of a highly diverse area of the Persian Gulf basin that drains to the Persian Gulf (Fig. 1). It comprises both fresh and brackish rivers, lakes, lagoons, marshes and marine environments and has



Fig.2. Map of Persian Gulf basin showing Tigris, Zohreh, Persis, Hormuz and Makran regions and its major river systems.

had a long history of connection and isolation from fresh and marine waters. Until 2010, 40 confirmed species belonging to 29 genera and 12 families were reported from the Persis region of Iran (Esmaeili et al. 2010a). Being a part of the Persian Gulf basin, the ichthyofauna of the Persis region has been of great importance for the modern biological researches. A wide range of articles are now being published on different aspects of the Iranian freshwater fishes including the Persis region. Hence, we provide an updated checklist including natives, endemics, exotics and transplanted species, ichthyogeography, threats and management of fishes from the Persis region.

The online “Catalog of Fishes” at the California Academy of Sciences (www.calacademy.org) provides summary taxonomic conclusions on the generic placement and species validity, references for these conclusions, and type localities for synonyms mentioned in the present list. The synonyms given are those recently used in Iran and do not include those dating from the early twentieth century and the nineteenth century (see Coad 1995, 2014; Esmaeili et al. 2010a, 2014a) for a fuller treatment of names.

Materials and Methods

Study area: This checklist has been compiled from the works listed in the references and also by examination of ichthyological collections in Iran (e.g., ZM-CBSU, Zoological Museum of Shiraz University, Collection of Biology Department, Shiraz; and those available in Coad (2015; CMNFI, Canadian Museum of Nature, Ottawa, Canada; BMNH, Natural History Museum, London, UK) and extensive field expeditions till 2014 from different river systems of the Persis region of Iran (Figs. 1, 2).

Persis region: The new classified drainage basins of Iran are shown in Fig. 1. The delimitation of these basins is somewhat arbitrary. Iran is a mountainous country and much of it is desert. There are thousands of small springs and streams with no present or recent connection to other water bodies. Practical considerations require a large scale. For a long time, the Iranian drainage basins have been divided into 19 major basins based on the fieldworks, maps, fish distributions, history of research, works on hydrography and areas deemed important for an understanding of zoogeography (see Esmaeili et al. 2010a, 2014a; Coad 2015). However, here after, we

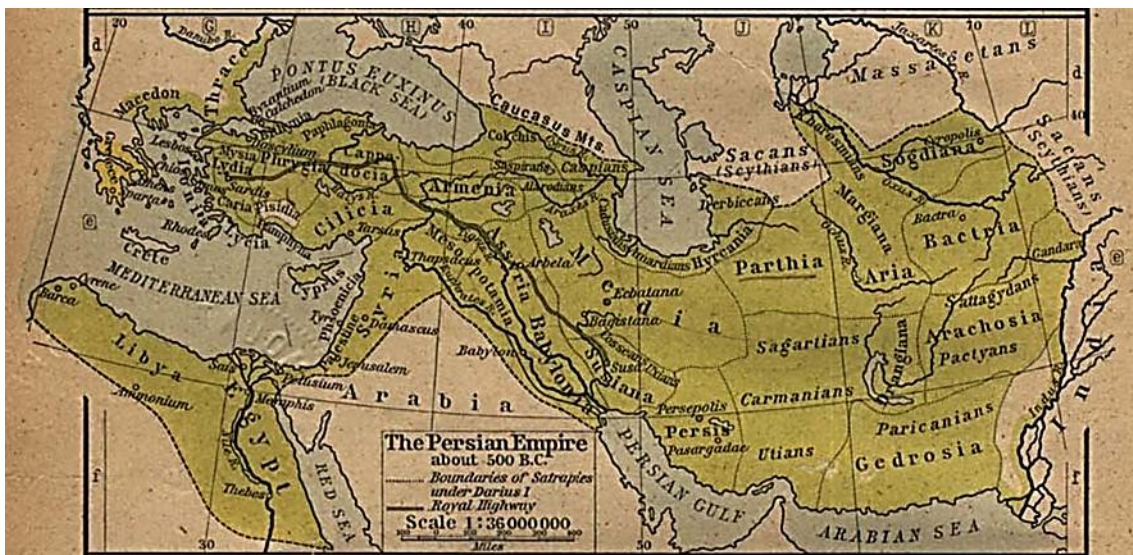


Fig.3. Old map showing Persian Gulf basin and location of the Persis region.

divide the Persian Gulf basin into 4 main or major regions (sub-basins) from west to east including the Tigris, Zohreh, Persis (previously known as Gulf basin) and Hormuz (Hormuzgan) regions which all drain to the Persian Gulf (see Figs. 1, 2).

Persis is an ancient name for the region (Fig. 3). This region comprises rivers which drain the southern Zagros Mountains to the head of the Persian Gulf, but which are not now tributaries of the Tigris River nor are they the salt streams of Hormuz. The major rivers are the Helleh (Shahpur or Shapur and Dalaki), which debouches into the Persian Gulf north of Bushehr ($28^{\circ}59'N$, $50^{\circ}50'E$) and the Mond or Qarah Aqaj (= the classical Sitakos), which, with its tributaries, drains much of Fars Province to the Persian Gulf south of Bushehr. Near Shiraz, it is known as the Qarah Aqaj or Kavar River. The Band-e Bahman, a weir or small dam on this river near Kavar, is probably pre-Islamic.

The Helleh River receives the Dalaki and Shapur River tributaries which drain the lower Zagros ranges west of Shiraz (Fig. 2). The area of this river drainage is estimated to be $20,300\text{km}^2$ and includes the Lake Famur or Parishan (Coad 2010). The delta of the Helleh River consists of brackish and freshwater marshes and lagoons with a maximum depth of 3.5 meter. It is the largest freshwater marsh system on the

Persian Gulf coast in southern Iran. The Lake Famur ($29^{\circ}31'N$, $51^{\circ}48'E$), near Kazeroun, is a particular feature of the Persian Gulf basin (Helleh), with an area of 42km^2 at about 820m above sea level. It is fed by about 80 fresh and brackish springs with a combined discharge of approximately 800 l sec^{-1} and supports fish populations near the springs (Coad 2015).

Fish taxa are classified according to their tolerance to salt water and mode of life to Fluvial, Anadromous, Semi-anadromous, Estuarine and Marine following (Naseka & Bogutskaya 2009).

In the present study, Species Distribution Modelling (SDM) was used to predict the climatically suitable habitats for the eight native species from Persis basin, including *Aphanius dispar*, *Aphanius pluristriatus*, *Luciobarbus barbatus*, *Arabibarbus grypus*, *Carasobarbus luteus*, *Capoeta saadii*, *Glyptothorax silviae* and *Mastacembelus mastacembelus*. To construct the model, 19 climatic variables including temperature and precipitation layers obtained from the WorldClim data set with 30-second spatial resolution (Hijmans et al. 2012) were combined to georeferenced occurrence locations for the species in Persis basin. A model was constructed using the maximum entropy algorithm implemented in MaxEnt 3.3.3 software.

At first, we ran the models with all climatic variables to diagnose the more informative variables. Environmental information from 500 randomly generated geographic points across the study area was extracted in order to establish a set of uncorrelated climatic layers. The more biologically informative variables (based on ecological requirements, a pairwise Pearson correlation matrix and variables with permutation importance or percent contribution up to 5% to construct the model recognized from an initial run with all layers) were retained in this step including seven variables with $R^2 < 0.90$ as follows; BIO3: isothermality, BIO6: min temperature of coldest month, Bio9: mean temperature of driest quarter, BIO13: precipitation of wettest month, Bio15: precipitation seasonality, Bio16: precipitation of wettest quarter and BIO17: precipitation of driest quarter.

The predictive model was evaluated by splitting localities into 75% training and 25% test data and 10 replicate runs were performed for each species. All Maxent runs were adjusted with a convergence threshold of $1.0E-5$ with 1000 iterations, application of a random seed, logistic probabilities and other settings were left at default levels. The models were tested using the AUC (area under the receiver operating curve) approach of Phillips et al. (2006) and mean value ≥ 0.7 as evidence that the model had sufficient discriminatory ability (Swets 1988). Resulting ASCII files imported into DIVA-GIS (available at <http://www.diva-gis.org/>) to visualize the models.

Results

The confirmed freshwater fishes of the Persis region comprise 44 species in 34 genera, 14 families, 11 orders and one class. The most diverse order is the Cypriniformes with 23 confirmed species (52.25%) followed by Cyprinodontiformes (6 species, 13.65%), Mugiliformes (4 species, 9.1%), Gobiiformes (3 species, 6.8%) and Perciformes with 2 species (4.55%). Acipenseriformes, Clupeiformes, Gonorynchiformes, Siluriformes, Salmoniformes

and Synbranchiformes each has only one species (2.25 %). New species are expected to be discovered, the taxonomic status of some species has been changed and some subspecies have full species rank, some are being resurrected from synonymy, some taxonomic problems remain and are commented on briefly. Eleven endemic species (25%) in four families and ten exotic species (22.7%) in three families are listed here.

The most diverse family is the Cyprinidae with 20 species (45.45%) followed by Cyprinodontidae and Mugilidae each with 4 species (9.1%), Gobiidae and Nemacheilidae each with three species (6.8%), and Poeciliidae with two species (4.55%). Acipenseridae, Clupeidae, Chanidae, Sisoridae, Salmonidae, Mastacembelidae, Percidae, and Sparidae each with only one species (2.25%). The Persis region comprises 7 endemic species (15.9% of the total Persis region ichthyofauna) in two families: Cyprinidae (4, 9.1%) and Nemacheilidae (3, 6.8%).

Ten exotic species in three families are listed from the Persis region (Table 1). Cyprinidae with seven exotic species (70% of the total exotic species in the Persis region) is ranked first followed by the Poeciliidae (two species, 20%), and Salmonidae with one exotic species (10%) (Table 1). Some exotic species have been established, such as *Pseudorasbora parva* and *Gambusia holbrooki* (Table 1). Some alien species such as *Hypophthalmichthys nobilis*, *H. molitrix*, and *Ctenopharyngodon idella* are questionably established but are abundant in the basin due to stocking by the Department of Fisheries. Live photos of some native and exotic fishes and their habitats in the Persis region are provided (Figs. 4-19).

We expect more species to be described as new, resurrected from synonymy, recorded for the first time from the Persis region, or recorded as established introductions. Hence, the fish fauna could soon exceed those recorded in this checklist. The listing includes selected taxonomic comments including synonyms where these have been used in recent literature. Older synonyms can be found in Coad (1995). The type localities are given for all

listed species from Persis basin.

Checklist

* = endemic to Iran, ** = exotic. Unconfirmed species are those mentioned in the literature but without confirmatory specimens in a museum. They are included in the total in the checklist.

Class Actinopterygii

Order Acipenseriformes (1 family, 1 genus and 1 species)

Family Acipenseridae (1 genus and 1 species)

Genus *Huso* Brandt and Ratzeburg, 1833

Huso huso (Linnaeus, 1758)

Comment: Translocated from the Caspian Sea basin to the Haftbarm wetland by the Fisheries Department.

Order Clupeiformes (1 family, 1 genus and 1 species)

Family Clupeidae (1 genus and 1 species)

Genus *Tenulosa* Fowler, 1934

Tenulosa ilisha (Hamilton, 1822)

Order Gonorynchiformes (1 family, 1 genus and 1 species)

Family Chanidae (1 genus and 1 species)

Genus *Chanos* Lacepède, 1803

Chanos chanos (Forsskål, 1775)

Order Cypriniformes (2 families, 17 genera and 23 species)

Family Cyprinidae (15 genera and 20 species)

Genus *Acanthobrama* Heckel, 1843

Acanthobrama persidis (Coad, 1981)* (Figs. 4, 5).



Fig.4. *Acanthobrama persidis*, an endemic cyprinid fish, from upstream of Helleh River.

Comment: Perea et al. (2010) place this species (*Petroleuciscus persidis*) in *Acanthobrama* on the basis of molecular evidence which contradicts morphology. Further study is needed.



Fig.5. Natural habitat of *Acanthobrama persidis* in upstream of Helleh River.

Genus *Alburnus* Rafinesque, 1820

Several members of this genus in Iran require revision.

Alburnus mossulensis Heckel, 1843

Type locality: Tigris River near Mosul, Iraq.

Comment: A wide-ranging species with several available names usually placed in synonymy but possibly valid including *Alburnus capito* Heckel, 1843 from Kurdistan and *Alburnus iblis* Heckel, 1849 (Persepolis area and the waters of the Araxes [=Kor], Iran), *Alburnus schejtan* Heckel, 1849 (Araxes [= Kor] River at Persepolis, Iran), *Alburnus caudimacula* Heckel, 1849 (Kara Agatsch River and near the village of Gerè, Iran) and *Alburnus megacephalus* Heckel, 1849 (Araxes [= Kor] River, Fars, Iran). The work by Heckel, in which the descriptions of the three latter species (and many others below) are given, is dated 1846–1849 and copies we have seen do not have any dating internally, so, we use the later date. The online CAS Catalog of Fishes refers to a Fowler & Steinitz (1956) manuscript and uses the date 1847.

Genus *Arabibarbus* Borkenhagen, 2014

Arabibarbus grypus (Heckel, 1843)

Comment: *Labeobarbus kotschy* Heckel, 1843 is a synonym.

Genus *Barilius* Hamilton, 1822

Barilius mesopotamicus Berg, 1932

Genus *Capoeta* Valenciennes, 1842

Several members of this genus require revision.

Capoeta mandica Bianco and Bănărescu, 1982 *
(Figs. 6, 7).



Fig.6. *Capoeta mandica*, an endemic cyprinid fish from upstream of Mond River.



Fig.7. Natural habitat of *Capoeta mandica* in upstream of Mond River.

Type locality: Mond River (incorrectly called Mand by Bianco & Bănărescu, (1982)), near Dasht-e Arzhan (correct name is Dasht-e Arjan), Persis region, Iran.

Comment: Ozuluğ & Freyhof (2008) consider *Capoeta barroisi mandica* Bianco and Bănărescu, 1982 to be a valid species.

Capoeta saadii (Heckel, 1849)*

Type locality: Pulwar River (Sivand), Kor River basin, near Persepolis, ruins northeast of Shiraz, Iran.

Comment: Under revision (Alwan et al., 2014).

Scaphiodon saadii was described from Persepolis, Pulwar River (Sivand), Kor River basin, ruins northeast of Shiraz, Iran. The following taxa named from Iran have been regarded as synonyms:

Scaphiodon amir Heckel, 1849, *Scaphiodon niger* Heckel, 1849, *Scaphiodon chebisiensis* Keyserling, 1861, *Scaphiodon rostratus* Keyserling, 1861 and *Capoeta capoeta intermedia* Bianco and Bănărescu, 1982 (non *Capoeta intermedia* Temminck and Schlegel, 1846 = *Acheilognathus lanceolata* (Temminck and Schlegel, 1846). *Capoeta damascina* (Valenciennes, 1842) was earlier considered by many authors as one of the most common freshwater fish species found throughout the Levant, Mesopotamia, Turkey and Iran. However, it seems that *C. damascina* is restricted to the Damascus basin, Syria (Alwan et al. 2014).

Genus *Carasobarbus* Karaman, 1971

Taxonomic revision of the genus *Carasobarbus* Karaman, 1971 is given by Borkenhagen & Krupp (2013).

Carasobarbus luteus (Heckel, 1843)

Comment: *Systomus albus* var. *alpina* Heckel, 1849 (from Rūdkhāneh-ye Qarah Āghāj near Shīrāz = Qarah Āghāj River, Mond, Persis region, [29°31'3"N, 52°15'0"E] and also from Daryācheh-ye Parīshān = Parishan wetland [29°31'7"N, 51°47'47"E]) and *Barbus parieschanica* Wossughi, Khoshzahmat and Etemadfar, 1982 from Parishan wetland, Helleh River basin, Iran are synonyms (see Borkenhagen & Krupp 2013).

Genus *Carassius* Jaroocki, 1822

Comment: The author of the genus follows Bogutskaya & Naseka (2004).

Carassius auratus (Linnaeus, 1758) ** – introduced to several Iranian basins.

Carassius gibelio (Bloch, 1782) ** – probably mirrors distribution of *C. auratus*.

Comment: Kottelat & Freyhof (2007); Bogutskaya et al. (2008, with question); Esmaeili et al. (2010a); Kalous et al. (2012) considered it as distinct species.

Genus *Ctenopharyngodon* Steindachner, 1866

Ctenopharyngodon idella (Valenciennes, 1844) **

Genus *Cyprinion* Heckel, 1843

Comment: *Scaphiodon* Heckel, 1843 has been used for *Cyprinion* and *Capoeta* species in Southwest Asia.

Cyprinion macrostomum Heckel, 1843

Comments: Originally spelt *macrostomus* but correctly *macrostomum* (Berg, 1949). Presence of *Cyprinion macrostomum* in the Persis region should be confirmed.

Cyprinion tenuiradius Heckel, 1849 * (Figs. 8, 9).



Fig.8. *Cyprinion tenuiradius*, an endemic cyprinid fish from upstream of Mond River.



Fig.9. Natural habitat of *Cyprinion tenuiradius* in upstream of Mond River.

Comment: Karaman (1971) assigns this taxon as a subspecies of *Cyprinion macrostomum* and Bianco & Banareescu (1982) suggest it may be a subspecies in a polytypic species. Berg (1949) records it from the Tigris River where it may be sympatric with *C. macrostomum*. He considers it to be close to that species, perhaps its southeastern subspecies. Howes (1982) considers *C. tenuiradius* to be a variant of *C. macrostomum*.

Genus *Cyprinus* Linnaeus, 1758

Cyprinus carpio Linnaeus, 1758 **

Comment: Native populations in the Caspian Sea basin; also introduced there and elsewhere in Iran.

Genus *Garra* Hamilton, 1822

Comments: Under revision with possible new taxa. Phylogenetic relationships of this taxon in the Middle East is under revision by Hashemzadeh et al. (2014, submitted article).

Garra rufa (Heckel, 1843) (Figs. 10, 11).



Fig.10. *Garra rufa*, a native cyprinid fish in Persis sub-basin.



Fig.11. Qanat, an old water system acting as refuge for more than 5000 years in Iran for several fish species including *Garra rufa*.

Comments: *Discognathus crenulatus* Heckel, 1849 and *Garra rufa gymnothorax* Berg, 1949 are considered here as synonyms. The taxon in Iran has been referred to as *G. r. obtusa* Heckel, 1843.

Genus *Hypophthalmichthys* Bleeker, 1859

Hypophthalmichthys molitrix (Valenciennes, 1844)

**

Hypophthalmichthys nobilis (Richardson, 1844) **

Genus *Luciobarbus* Heckel, 1843

Luciobarbus barbulus (Heckel, 1847)

Luciobarbus pectoralis (Heckel, 1843)

Comments: This species might not be found in Iran

as its main distribution range is Orontes River system in Turkey and Syria, Mediterranean watersheds of Turkey. The Orontes is the only perennial river in Western Asia that flows north from Lebanon to Syria and Turkey and drains west into the Mediterranean Sea.

Genus *Mesopotamichthys* Karaman, 1971

Mesopotamichthys sharpeyi (Günther, 1874)

Genus *Pseudorasbora* Bleeker, 1859

Pseudorasbora parva (Temminck and Schlegel, 1846) **

Type locality: *Leuciscus parvus* Temminck and Schlegel, 1846 was originally described from Japan.

Family Nemacheilidae (2 genera and 3 species)

Comments: Formerly included in the family Cobitidae or the family was named Balitoridae (see Tang et al. 2006; Kottelat & Freyhof 2007; Freyhof et al. 2011; Esmaeili et al. 2014b). Iranian species were placed in the genera *Nemacheilus*, *Adiposia*, *Barbatula*, *Orthrias* and *Schistura* in earlier literature.

Genus *Oxynoemacheilus* Bănărescu and Nalbant, 1967

Comment: Further study is needed.

Oxynoemacheilus persa (Heckel, 1847) *

Comments: *Oxynoemacheilus farsicus* (Nalbant & Bianco, 1998) was frequently reported from Namak Lake, Kor River and Persis basins. It named for Fars Province, collected from the "River Kor near Persepolis" in Fars Province. According to Freyhof et al. (2011), it is a synonym.

Genus *Paraschistura* Prokofiev, 2009

Comment: Further study is needed.

Nemacheilid loaches of the genus *Paraschistura* are a group of poorly known species from the Tigris drainage in Turkey east throughout Iran and Pakistan to the Indus River and the Hari, Murghab and Helmand endorheic basins in Afghanistan, Iran, Pakistan and Turkmenistan (Kottelat 2012) and thus the revision on this taxon is needed.

Paraschistura nielsenii (Nalbant & Bianco, 1998) * (Figs. 12, 13).

Comment: Report of *Paraschistura bampurensis* (Nikol'skii, 1900) from this basin might be a mistake.



Fig.12. *Paraschistura nielsenii* an endemic loach from upstream of Helleh River.



Fig.13. Natural habitat of *Paraschistura nielsenii* in upstream of Shapur River.

Bănărescu & Nalbant (1966) report this species from Shapur, 12km north of Kazerun and from Shah Bazan on a tributary of the Ab-i-Diz, and "probably most of Iran". This seemed inherently unlikely as the type locality is in Baluchestan and the material was later described as a new species, *P. nielsenii* q. v.

Paraschistura sp.*

It has been proposed to be distinct species by Freyhof et al. (2015) based on molecular data.

Order Siluriformes (1 family, 1 genus and 1 species)

Family Sisoridae (1 genus and 1 species)

Genus *Glyptothorax* Blyth, 1860

The Middle Eastern members of this genus are in need of revision.

Glyptothorax silviae Coad, 1981 *

Type locality: "Khuzestan, stream 3 km south of Bagh-e Malek, tributary to Rud-e Zard or Ab-e Ala in the drainage of the Jarrahi River, 31°29'N, 49°54'30"E". Now is also found in the Persis sub basin.

Order Salmoniformes (1 family, 1 genus and 1 species)

Family Salmonidae (1 genus and 1 species)

Genus *Oncorhynchus* Suckley, 1861

Oncorhynchus mykiss (Walbaum, 1792) **

Order Mugiliformes (1 family, 3 genera and 4 species)

Family Mugilidae (3 genera and 4 species)

Genus *Chelon* Rose, 1793

Comment: The type species of the genus *Liza* is *Mugil capito* Cuvier, 1829 (currently *L. Ramada* (Risso, 1827)). The phylogenetic results imply that *L. ramada* be placed under genus *Chelon*, which in turn implies that *Liza* is a junior synonym of *Chelon*. (see Durand et al. 2012a, b). Further study is needed. *Chelon abu* (Heckel, 1843)

Comments: *Liza abu* (Heckel, 1843) is a synonym. *Mugil pseudotelestes* Pietschmann, 1912 and *Mugil hishni* Misra, 1943 are synonyms. The subspecies *Mugil abu zarudnyi* Berg, 1949 from Iran is of a doubtful validity. Still under *Liza* in the Catalog of Fishes (see also Durand et al. 2012a, b).

Chelon subviridis (Valenciennes, 1836)

Comments: Synonyms are *Mugil dussumieri* Valenciennes in Cuvier and Valenciennes, 1836 and *Mugil jerdoni* Day, 1876.

Genus *Ellochelon* Whitley, 1930

Ellochelon vaigiensis (Quoy and Gaimard, 1825)

Genus *Mugil* Linnaeus, 1758

Mugil cephalus Linnaeus, 1758

Order Cyprinodontiformes (2 families, 3 genera and 6 species)

Family Cyprinodontidae (1 genus and 4 species)

Genus *Aphanius* Nardo, 1827

Comments: Various isolated populations may prove to be distinct species. Formerly placed in the genera *Lebias* Goldfuss, 1820 or *Cyprinodon* Lacepède, 1809.

Aphanius dispar (Rüppell, 1829)

Aphanius pluristriatus (Jenkins, 1910)*- Figs. 14 & 15.

*Aphanius shirini**- Gholami, Esmacili, Erpenbeck and Reichenbacher, 2014



Fig.14. Male and female specimens of *A. pluristriatus*, a threatened and endemic fish species restricted to the Persis sub-basin.



Fig.15. Water extraction from a pool near type locality of *Aphanius pluristriatus* (water extraction is identified as one of the greatest threats to the freshwater fish of Persis sub-basin).

Comment: Probably translocated to the Persis region. *Aphanius sophiae* (Heckel, 1849)*

Comments: It has been recorded from Kor River basin and Persis region (Helleh River basin) (see Gholami et al. 2014). *Lebias punctatus* Heckel, 1849 and *Lebias crystalloodon* Heckel, 1849 are synonyms.

Family Poeciliidae (2 genera and 2 species)

Genus *Gambusia* Poey, 1854

Gambusia holbrooki Girard, 1859 ** (Fig. 16).



Fig.16. Male and female specimens of *Gambusia holbrooki*, a non-native introduced species to Persis sub-basin.

Genus *Xiphophorus* Heckel, 1848

Xiphophorus hellerii Heckel, 1848 ** (Fig. 17).



Fig.17. Male and female specimens of *Xiphophorus hellerii*, a non-native introduced species to Persis sub-basin.

Order Synbranchiformes (1 family, 1 genus and 1 species)

Family Mastacembelidae (1 genus and 1 species)

Genus *Mastacembelus* Scopoli, 1777

Mastacembelus mastacembelus (Banks & Solander,



Fig.18. Mesopotamian spiny eel, *Mastacembelus mastacembelus*, a native fish from Helleh River.

1794) (Fig. 18).

Comment: *Rhynchobdella halepensis* Bloch and Schneider, 1801 is a synonym. *Mastacembelus aleppensis* Günther, 1861 is an unjustified emendation of *halepensis*.

Order Perciformes (2 families, 2 genera and 2 species)

Family Percidae (1 genus and 1 species)

Genus *Sander* Oken, 1817

Sander lucioperca (Linnaeus, 1758)

Comment: Translocated to the Persis sub_basin.

Family Sparidae (1 genus and 1 species)

Genus *Acanthopagrus* Peters, 1855

Acanthopagrus arabicus Iwatsuki, 2013- Fig. 19.



Fig.19. *Acanthopagrus arabicus*, a native sparid fish found in Persian Gulf basin.

Order Gobiiformes (1 family, 3 genera and 3 species)

Family Gobiidae (3 genera and 3 species)

Comment: Systematic position of this family is under revision.

Genus *Periophthalmus* Bloch and Schneider, 1801

Periophthalmus waltoni Koumans, 1955

Comment: The Memoirs of the Indian Museum for 1938-1942 were published in 1955 (this is the date on the title page).

Genus *Boleophthalmus* Valenciennes, 1837

Boleophthalmus dussumieri Valenciennes, 1837

Genus *Scartelaos* Swainson, 1839

Scartelaos tenuis (Day, 1876)

Comment: Originally described as *Boleophthalmus tenuis* Day, 1876 from Estuaries of Karachi, Sind, Pakistan. It is found on mud flats with *Boleophthalmus dussumieri* and *Periophthalmus waltoni* in Helleh estuary.

Discussion

Biogeographic history: A central aim of research in modern historical biogeography is to understand the distributions of species and ecosystems in light of historical processes that shape landscape evolution (Cox & Moore 2005; Lomolino et al. 2010). This effort has made rapid progress over the past decade in the study of freshwater fishes. Freshwater fishes are more or less confined to drainage systems and cannot disperse without connections of the freshwater systems. They provide a relatively conservative system for examining zoogeographical patterns. These features make them one of the most zoogeographically important groups of animals (Berra 2007). Changes in river systems and evolution of the fishes might affect on heterogeneity in the geographic distribution of the strict freshwater fishes (Watanabe 1998). In other words, zoogeographic patterns form strong evidence of evolution (Berra 2007). However, anthropogenic effects have played a significant role in changing distribution pattern of freshwater fishes, especially in the past few decades (Esmaeili et al. 2010b, 2012, 2014c-e), which can be well understood in the case of some of the freshwater fish species distributed in different endorheic and exorheic basins of Iran.

Iran occupies a significant portion of the Middle East, in terms of land and water area and in terms of zoogeography. The freshwater fish fauna of Iran stands out from its neighboring counterparts in terms of species richness and level of endemism (see Esmaeili et al. 2010a, 2014a-c; Coad 2015). Geographical isolation, together with the climatic conditions and watershed fragmentation experienced by the Iranian plateau over geological time, has led

to differentiation of the freshwater ichthyofauna into several independent and isolated populations promoting speciation.

A) Fish origin: Iran contains elements of both Ethiopian and Oriental ichthyofauna, although it is predominantly a part of the Palearctic Realm (Coad 1985). This zoogeographical situation, coupled with the past geological history, vicariance events and recent anthropogenic effects have played a significant role on the ichthyodiversity of Iran in different endorheic and exorheic drainage systems including the Persis region. Southern Iran is the main route for movement of animals, especially fish, between the Oriental and Ethiopian biogeographical regions; therefore the southern ichthyofauna of Iran, especially the Persis region, is a combination of the Oriental, Ethiopian and western Palearctic ichthyofauna due to its geographic situation. The origin and distribution of fish taxa in the Persis region could be attributed to several events e.g. drainage captures, marine penetrations, exotic introductions and also endemism. The fish origins are:

I) Ethiopian (African): The Ethiopian region, also called the Afrotropical Region, is one of the major land areas of the world defined on the basis of its characteristic animal life. The Persis region has received some genera (e.g., *Carasobarbus*) from this region.

II) Palearctic: The Palearctic or Palaearctic is one of the Earth's eight ecozones. This region is the largest ecozone on Earth. It includes the regions of Europe, Asia (north of the Himalayan foothills), northern Africa, and the northern and central regions of the Arabian Peninsula. There are few west Palaearctic fish elements (e.g., *Capoeta saadii*, *Luciobarbus barbatus* and *Alburnus mossulensis*) in the Persis region.

III) Oriental: Some genera, for example, *Glyptothorax* (Sisoridae), *Mastacembelus* (Mastacembelidae), *Garra* (Cyprinidae) and *Cyprinion* (Cyprinidae) that are found in the Persis region belong to the Oriental Realm.

B) Attributed events

I) Drianage captures: River capture (also called stream capture or stream piracy) is a geomorphological process by which the flow of part of a stream or river drainage basin is diverted into that of a neighbouring basin. River capture may arise from the influence of several geomorphological processes, including tectonic uplift or tilting, damming by the actions of glaciers or landslides, denudation of watershed margins by erosion, or avulsion of watershed margins by sediment accumulation in fans and estuaries (see Roxo et al. 2014).

Much of Iran is an active zone of orogeny and drainage or headwater captures are common (Oberlander 1965; Coad 1987). A number of basins have headwaters which arise close together on a high plain of the Zagros Mountains (e.g. the Persis, Hormuz, Esfahan and Tigris basins) and transfer of fish species may be expected over time. The Anatolia and pluvial conditions in the past would have facilitated fish dispersal (see Coad 1987; Coad 1996).

A significant proportion of the families and genera in the Tigris-Euphrates and Persis regions are found in the Ponto-Caspian basin (the Black-Caspian Sea basin). Such widespread, northern cyprinid genera as *Alburnoides*, *Alburnus*, *Leusciscus*, *Barbus*, *Chondrostoma*, *Luciobarbus* and *Squalius* reach their southern limit in the Tigris-Euphrates basin (and neighboring Iranian basins) suggesting that they reached the Tigris-Euphrates basin from the north (see Coad 1996; Esmaeili et al. 2014a). Headwaters of a number of the Tigris-Euphrates rivers interdigitate with the upper reaches of the Black-Caspian Seas basin, e.g. the Aras River of the Caspian Sea and the Kizilirmak of the Black Sea with the Euphrates near Erzurum and Silvas, respectively; the Qezel Owzan (a tributary of Safidrud) of the Caspian Sea with the Tigris tributaries (Coad 1996).

II) Pleistocene connectivity: The Persis region borders the Tigris and Zohreh regions from the west and northwest, the Kor River and Lake Maharlu basins from the north and Hormuz basin from the east. It is in connection with the Persian Gulf with the

high degree of salinity in the south to southwest direction (Fig. 2).

The Persis and Tigris regions are characterised by a wide variety of niches, which are inhabited by a diverse freshwater fish fauna consisting of about 32 primary and eight secondary freshwater species in the Persis systems, and some 62 primary and eight secondary freshwater species in the Tigris Basin (Esmaeili et al. 2010b). The endorheic Kor River basin is markedly smaller in extent than the exorheic basins (Fig. 1a) and may represent a centre of freshwater fish speciation in southern Iran, because it harbours about 9 primary and 2 secondary species, seven of which are endemics (Esmaeili et al. 2007, 2010b; Teimori et al. 2010; Coad 2015; Gholami et al. 2013; Gholami et al. 2014).

Pleistocene connectivity among now isolated drainages in southern and southwestern Iran has already been discussed by Esmaeili et al. (2014e). They used *Aphanius* taxa, including Mond tooth-carp, *A. pluristriatus* (the Persis region), Mesopotamian tooth-carp, *A. mesopotamicus* (the Tigris River basin) and Kor tooth-carp, *A. sophiae* (the Kor River basin) as a model to describe Pleistocene connectivity of these isolated drainages systems. According to them and other related studies (see also Esmaeili et al. 2012; Gholami et al. 2014), the splitting off of *A. sophiae* is clearly related to the formation of the endorheic Kor River basin in the Late Pleistocene or Early Holocene (Gholami et al. 2014), and that those related forms (e.g., *A. sophiae*, *A. pluristriatus* and *A. mesopotamicus*) represent the products of a very young diversification, originating probably about 11,700 to 4000 years ago (Early to Middle Holocene) (Esmaeili et al. 2014d). In addition, *A. pluristriatus* is most likely to be a relict of the ancient *Aphanius* population in the Pleistocene Paleo-Kor River, which at that time drained from the High Zagros Mountains into the Persian Gulf (Esmaeili et al. 2012). It is obvious from the young divergence ages for *A. sophiae*, *A. pluristriatus*, and *A. mesopotamicus* that the drainages of the present Persis, Tigris and Kor River basin systems must have

Table 1. Exotic and transplanted (T) fishes of the Persis region. E= established.

Order	Family	Species	Status
Cypriniformes	Cyprinidae	<i>Carassius auratus</i>	E
		<i>Carassius gibelio</i>	E
		<i>Ctenopharyngodon idella</i>	
		<i>Cyprinus carpio</i>	E
		<i>Hypophthalmichthys molitrix</i>	
		<i>Hypophthalmichthys nobilis</i>	
		<i>Pseudorasbora parva</i>	E
Cyprinodontiformes	Cyprinodontidae	<i>Aphanius shirini</i>	T,E
		<i>Gambusia holbrooki</i>	E
	Poeciliidae	<i>Xiphophorus hellerii</i>	E
Salmoniformes	Salmonidae	<i>Oncorhynchus mykiss</i>	
Acipenseriformes	Acipenseridae	<i>Huso huso</i>	T
Perciformes	Percidae	<i>Sander lucioperca</i>	T,E?

been interconnected up until the Late Pleistocene.

In the following, we provide a qualitative comparison of the similarities between the piscine faunas of the related basins and discuss a potential scenario for their past connectivity.

Notably, in spite of clear differences in terms of area, topography and connectivity, the rivers and streams in the Persis, Tigris, Zohreh and Kor drainage systems share several fish species in common (Esmaili et al. 2010a; Teimori et al. 2010; Coad 2015). Thus, *Alburnus mossulensis*, *Capoeta saadii*, *Carasobarbus luteus*, *Garra rufa* (all cyprinids), *Mastacembelus mastacembelus* (Mastacembelidae) and *Chelon abu* (Mugilidae) are present in all four drainage basins. In addition, the Persis, Zohreh and Tigris River region systems share *Arabibarbus grypus*, *Mesopotamichthys sharpeyi*, *Luciobarbus barbulus*, *Barilius mesopotamicus*, *Glyptothorax silviae* and *Aphanius dispar*, while *Acanthobrama persidis* is present both in the Persis and Kor River basins, and *Capoeta aculeata* occurs in the Tigris, Zohreh and Kor River basins. In addition, Tigris and Zohreh regions harbour some fishes (e.g., *Carasobarbus sublimus* and *Carasobarbus kosswigi*) not found in the Persis and Kor River basins. *Cyprinion macrostomum*, *Capoeta aculeata* and *A. mesopotamicus* from the Tigris region have been replaced by *C. tenuiradius*, *Capoeta mandica* and *A. pluristriatus* in the Persis region. *Alburnoides*

idignensis, *Chondrostoma regium*, *Cobitis avicennae*, *Paracobitis molavii*, *Oxy-noemacheilus kiabii* and *A. mesopotamicus* from the Tigris River basin have been replaced by *Alburnoides qanati*, *Chondrostoma orientale*, *Cobitis linea*, *Paracobitis persa*, *Oxy-noemacheilus tongiorgii* and *Aphanius sophiae* in the Kor River basin, respectively, showing disconnection of these drainage systems promoting allopatric speciation.

Most species mentioned in the checklist (and see Table 2) are primary freshwater species and their distribution in currently isolated drainage basins cannot be explained by migration via the coastal waters of the Persian Gulf. The present-day biogeography of these freshwater species indicates instead that the Persis, Zohreh, Tigris and Kor basin systems must have been connected to each other in the recent past. A plausible scenario suggests that these drainage systems formed a single network during the Last Glacial Maximum of the Late Pleistocene (21,000-18,000 y. BP). At that time, the floor of the Persian Gulf was exposed due to the global fall in sea level, and it is therefore not unlikely that the Tigris and Euphrates (Tigris), Zohreh, Mond, Helleh (Persis), Kol (Hormuz), and also the Kor River (ancient exorheic Kor Basin) extended onto what is now the floor of the Persian Gulf (Fig. 20), where they came together (see Sarnthein 1972; Lambeck 1996; Teller et al. 2000; Teimori et al.

Table 2. List of fish taxa of the Persis region in different ecological group. A: Anadromous; E: Estuarine, F: Fluvial, M: Marine, SA: Semi-anadromous.

Family	Species	Ecological group	Family	Species	Ecological group
Acipenseridae	<i>Huso huso</i>	A	Cyprinidae	<i>Pseudorasbora parva</i>	F
Clupeidae	<i>Tenualosa ilisha</i>	F-A	Nemacheilidae	<i>Oxyoemacheilus persa</i>	F
Chanidae	<i>Chanos chanos</i>	M-E		<i>Paraschistura nielsenii</i>	F
Cyprinidae	<i>Acanthobrama persidis</i>	F		<i>Paraschistura</i> sp.	F
	<i>Alburnus mossulensis</i>	F	Sisoridae	<i>Glyptothorax silviae</i>	F
	<i>Arabibarbus grypus</i>	F	Salmonidae	<i>Oncorhynchus mykiss</i>	F
	<i>Barilius mesopotamicus</i>	F	Mugilidae	<i>Chelon abu</i>	F-E (occasionally)
	<i>Capoeta mandica</i>	F		<i>Chelon subviridis</i>	E
	<i>Capoeta saadii</i>	F		<i>Ellochelon vaigiensis</i>	E
	<i>Carasobarbus luteus</i>	F		<i>Mugil cephalus</i>	M-E
	<i>Carassius auratus</i>	F	Cyprinodontidae	<i>Aphanius dispar</i>	F-E
	<i>Carassius gibelio</i>	F		<i>Aphanius pluristriatus</i>	F
	<i>Ctenopharyngodon idella</i>	F		<i>Aphanius shirini</i>	F
	<i>Cyprinion macrostomum</i>	F		<i>Aphanius sophiae</i>	F
	<i>Cyprinion tenuiradius</i>	F	Poeciliidae	<i>Gambusia holbrooki</i>	F
	<i>Cyprinus carpio</i>	F-SA		<i>Xiphophorus hellerii</i>	F
	<i>Garra rufa</i>	F	Mastacembelidae	<i>Mastacembelus mastacembelus</i>	F
	<i>Hypophthalmichthys molitrix</i>	F	Percidae	<i>Sander lucioperca</i>	F-SA
	<i>Hypophthalmichthys nobilis</i>	F	Sparidae	<i>Acanthopagrus arabicus</i>	M-E
	<i>Luciobarbus barbulus</i>	F	Gobiidae	<i>Periophthalmus waltoni</i>	E-F
	<i>Luciobarbus pectoralis</i>	F		<i>Boleophthalmus dussumieri</i>	E-F
	<i>Mesopotamichthys sharpeyi</i>	F		<i>Scartelaos tenuis</i>	M-E

2012). This postulated interconnection, which may have lasted until the Holocene sea-level rise at around 11,000 y. BP, offers a persuasive explanation for the similarities observed between the fish faunas in drainage systems that are now wholly isolated from each other.

III) Marine penetrations: The distribution of certain families and species in southern Iran are the results of marine migrations by freshwaters which are known to have a wide tolerance of salinities (Coad 1987). These marine penetrators into rivers of the Persis region include *Chelon subviridis* and *Ellochelon vaigiensis* (Mugilidae), *Tenualosa ilisha* (Clupeidae), *Chanos chanos* (Chanidae), *Aphanius dispar* (Cyprinodontidae), *Acanthopagrus arabicus*

(Sparidae), *Periophthalmus waltoni*, *Boleophthalmus dussumieri* and *Scartelaos tenuis* (Gobiidae).

IV) Exotics: Exotics comprise ten fish species in three families (Table 1) introducing to the Persis region for different purpose. *Cyprinus carpio*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *H. nobilis*, *Carassius auratus*, *C. gibelio*, *Pseudorasbora parva* (all Cyprinidae), *Gambusia holbrooki*, *Xiphophorus hellerii* (Poeciliidae) and *Oncorhynchus mykiss* (Salmonidae) are exotic species in the Persis region. *Sander lucioperca* (Percidae), *Huso huso* (Acipenseridae) and *Aphanius shirini* (Cyprinodontidae) have been translocated to this region. Diversity, environmental impacts and management of alien and invasive freshwater fish

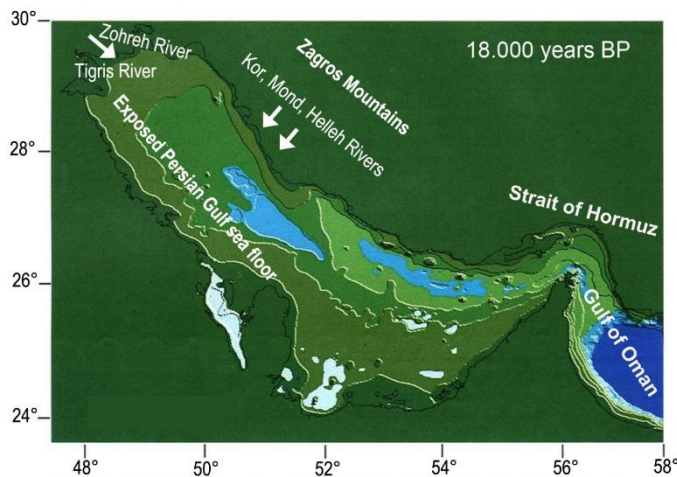


Fig.20. Exposed sea floor of the Persian Gulf Sea during the Last Glacial Maximum of the Late Pleistocene at 18,000 years BP, with possible freshwater areas in depressions (marked in blue); elevations above sea level are indicated with different greenish colours at 20, 50, 100 and 150m (modified from Lambeck, 1996 and Esmaili et al. 2014e). Arrows indicate river runoff from the Zagros Mountains.

species in Iran have been discussed by Esmaili et al. (2014c).

V) Endemics: There is a degree of local endemism in the Persis region. Here, endemic taxa include those fishes which are restricted to the Persis region of Iran and there is no record of them in other neighboring basins and countries. These are: *Cyprinion tenuiradius*, *Capoeta mandica* (Cyprinidae), *Paraschistura nielsenii* (Nemacheilidae) and *Aphanius pluristriatus* (Cyprinodontidae). These endemic fishes probably reflect a history of transgressions, isolation and speciation (see also Pleistocene connectivity).

In general, a long history of the connection and isolation from fresh and marine waters, multiple sources of species, uneven distribution of inflows and nutrient inputs, and low to moderate salinity, different habitat types (both fresh and brackish habitats, rivers, lakes, lagoons, marshes and marine environments) all have contributed to the high ichthyodiversity found in the Persis region. The use of molecular markers will provide additional data on the molecular ichthyogeography of fish taxa in the Persis and related basins.

B) Other grouping of the Persis region fishes: The fish taxa listed from the Persis region might be classified to the following major groups based on ecoregions and ecological parameters:

a) Ecoregion grouping: A map depicting the global biogeographical regionalisation of Earth's freshwater systems was published (Abell et al. 2008). This map of freshwater ecoregions is based on the distributions and compositions of freshwater fish species and incorporates major ecological and evolutionary patterns. In this new classification, the Persis region lies in the Upper Tigris and Euphrates (Temperate Floodplain Rivers and Wetlands). This ecoregion includes essentially the upper sections of the Tigris and Euphrates Rivers and their tributaries, with adjacent drainages in Iran that flow into the northern Persian Gulf and other neighboring internal basins, and the Quwaiq River basin in Syria. It is bounded by the Orontes, Southern Anatolia, and Lower Tigris and Euphrates ecoregions to the west; northern Anatolia and Western Transcaucasia ecoregions to the north; Lake Van, Lake Orumiyeh (Urmia), Caspian Sea Highlands, Namak, Esfahan, and Kavir and Lut Deserts to the east; and Persian and Northern Hormuz Drainages to the south. This ecoregion encompasses the upper sections of the Tigris and Euphrates Rivers, with tributaries including the Murat, Great Zab, Little Zab and Diyala rivers. The ecoregion also includes the Karun, Zohreh, Mond, Helleh and Kor rivers in Iran. The southern Iranian parts of this basin have large salt lakes, fed by fresh springs and rivers. Lake Zaribar in Iran is a deep, freshwater upland lake, which is comparatively rare in the Middle East. Nearly a third of about 70 fish species in the ecoregion are endemic, most of which occur in the genera *Garra* (Cyprinidae), *Cobitis* (Cobitidae), *Oxyneomacheilus*, *Paracobitis*, *Paraschistura*, *Turcinoemacheilus* (Nemacheilidae), *Glyptothorax* (Sisoridae) and *Aphanius* (Cyprinodontidae) (see Golzarianpour et al. 2013; Esmaili et al. 2014b; Freyhof et al. 2014).

Some fish taxa classified in this category which found in the Persis region are: *Alburnus mossulensis*,

Barilius mesopotamicus, *Cyprinion tenuiradius*, *Capoeta mandica*, *Capoeta saadii* (Cyprinidae), *Oxynoemacheilus persa*, *Paraschistura nielsenii* (Nemacheilidae), *Glyptothorax silviae* (Sisoridae), *Aphanius pluristriatus* (Cyprinodontidae) and *Mastacembelus mastacembelus* (Mastacembelidae).

b) Ecological grouping: We followed the classification introduced by Kessler (1877) and also Naseka and Bogutskaya (2009) which is based on criteria of physical habitats and the presence/absence of migrations between them. However some fish taxa may be classified in more than one category.

I) Fluvial: fluvial, 'of various waters' ["raznovodnyye"] species are those which rarely met in the Sea occurring only in deltas and freshened coastal shallows. Freshwater and fluvial species belong to several families (Cyprinidae, Cyprinodontidae, Mastacembelidae, Mugilidae, Nemacheilidae, Poeciliidae, Sisoridae, and Salmonidae. Examples are: *Capoeta mandica*, *Aphanius shirini*, *Mastacembelus mastacembelus*, *Chelon abu*, *Oxynoemacheilus persa*, *Xiphophorus hellerii*, *Glyptothorax silviae* and *Oncorhynchus mykiss*. As indicated in Table 2, most of the fluvial freshwater species belong to the family Cyprinidae followed by Nemacheilidae which are primary division families sensu Myers (1938, 1951) (i.e. those families whose members are strictly intolerant of salt water, both currently and historically). Mugilidae and Gobiidae are secondary division families (i.e. those families which are supposed to be of marine origin but contain members that now live in fresh water, see Naseka & Bogutskaya (2009)).

II) Anadromous: Anadromous species comprise those taxa that spawn in rivers, often much farther upstream than semi-anadromous fishes, and forage all over the Sea under-taking long-distance migrations (Naseka & Bogutskaya 2009). However, as indicated in Table 2 and list of taxa the only purely anadromous fish of the Persis region (*Huso huso*) was translocated from the Caspian Sea basin to the Persis region for aquaculture. Example is: *Tenualosa ilisha* (fluv) (see Table 2).



Fig.21. Habitat modification threatens endemic tooth-carp, *Aphanius pluristriatus* in the Persis sub-basin.

III) Semi-anadromous: Semi-anadromous fishes keep spawning in fresh water (limnetic waters, 0.5 ppt and less) but forage in oligohaline water (around 0.5–5 ppt). Examples are: exotic fish, *Cyprinus carpio* (fluv & semi anadr) (Cyprinidae) and translocated *Sander lucioperca* (fluv & semi anadr) (Percidae) (Table 2).

IV) Estuarine: Species that are classified as 'estuarine' mostly inhabiting deltaic areas and adjacent coastal shallows, some of them being distributed also in lower reaches of rivers and/or open marine habitats. Most species belong to the families Gobiidae and Mugilidae. This group contains those species which can be classified as vicarious sensu Meyers, i.e. strictly or preferably freshwater or oligohaline species of primarily marine families. Examples are: *Chelon subviridis*, *Ellochelon vaigiensis*, *Chelon abu* (fluvial & occasionally estuarine), *Mugil cephalus* (marine & estuarine), *Chanos chanos* (marine & estuarine), *Aphanius dispar* (fluvial & estuarine), *Acanthopagrus arabicus* (marine & estuarine), *Periophthalmus waltoni* (estuarine & fluvial), *Boleophthalmus dussumieri* (estuarine & fluvial) and *Scartelaos tenuis* (marine & estuarine) (Table 2).

V) Marine: Strictly 'marine' or almost marine (mostly inhabiting the open sea, benthic or pelagic waters) form a small group of species from the

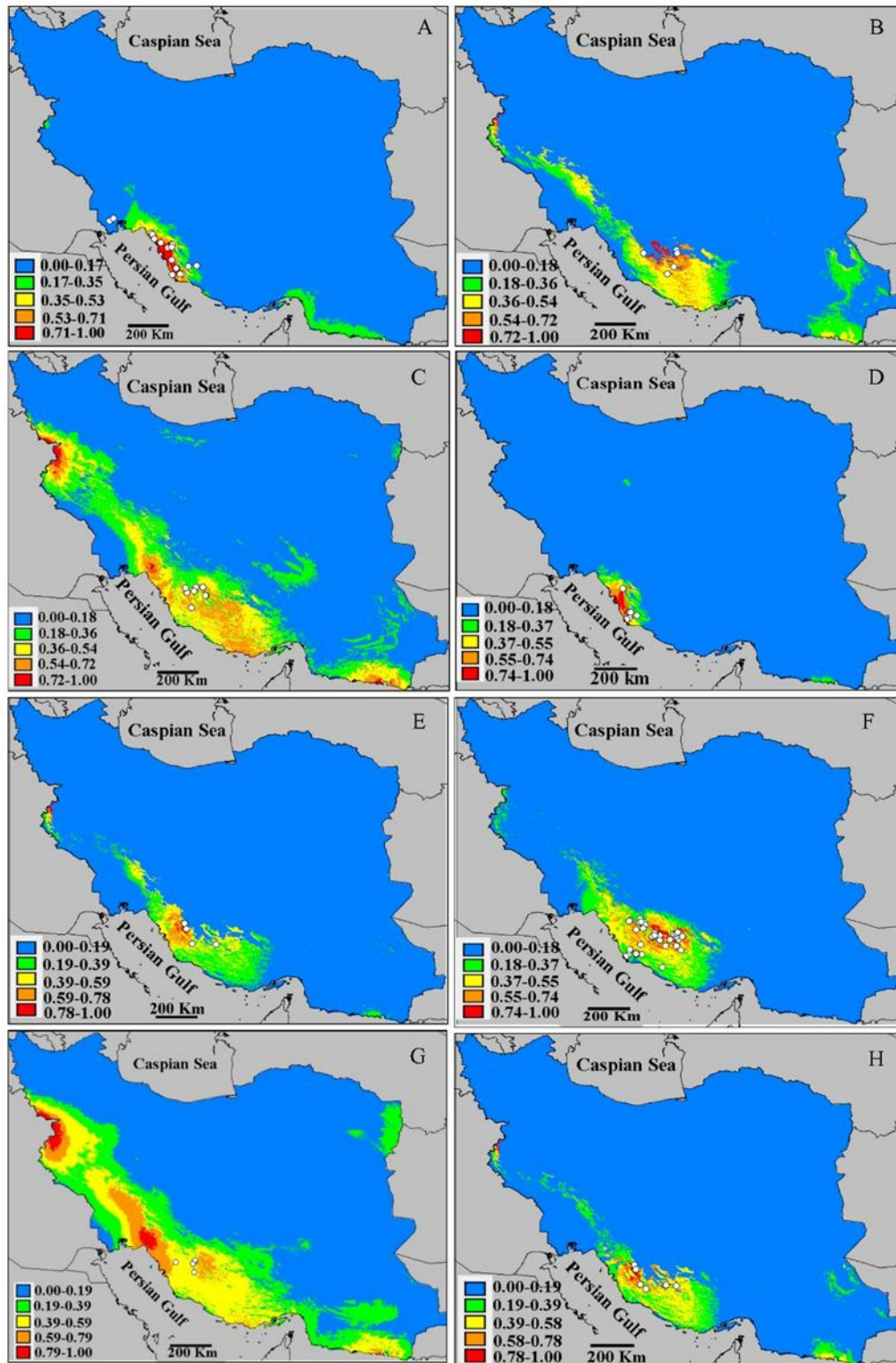


Fig.22. Potential distribution of A: *Aphanius dispar*, B: *Aphanius pluristriatus*, C: *Luciobarbus barbulus*, D: *Arabibarbus grypus*, E: *Carasobarbus luteus*, F: *Capoeta saadii*, G: *Glyptothorax silviae* and H: *Mastacembelus mastacembelus* in Iran based on occurrence points in Persis basin using SDM in Maxent. Red colors indicate higher habitat suitability for each species. Hollow circles indicate distribution points.

families of Chanidae, Mugilidae, Sparidae and Gobiidae. Examples are: *Chanos chanos* (marine &

estuarine), *Mugil cephalus* (marine & estuarine), *Acanthopagrus arabicus* (marine & estuarine), and

Scartelaos tenuis (marine & estuarine) (Table 2).

Threats: Similar to threats observed in other countries, habitat modification (Fig. 21), pollution, water extraction (Fig. 14), eutrophication resulting from urban sewage and agricultural runoff, dam construction (which limits sediment and nutrient flow downstream to deltas), drainage for irrigation and drinking water, introduction of exotic aquatic species (Figs. 16, 17), droughts, human population growth and illegal fishing are the main threats to fish diversity in the Persis region (see Esmaeili et al. 2014c). Other major threats to future fish survival include intrinsic factors such as restricted range and limited dispersal, and increasing number of invasive species from the aquarium industry (Fig. 17).

A number of sites have been identified as regionally important for endemism and as centres of threatened species. The main sites being the upper reaches of the Shapur River (Helleh) and Mond River harboring *Paraschistura nielsenii* and *Aphanius pluristriatus* (see Keivany & Esmaeili 2014). Despite the presence of two protected areas in the Persis region (Mond and Helleh protected area), however these are not harbouring many endemic species.

Conservation and management: River basins are complex, open systems with ill-defined boundaries. They fulfil many important functions ranging from the supply of water to households and agriculture to the provision of transport routes. They also provide habitat for many different species which in turn provide a valuable resource to people through activities such as fishing and recreation (Smith & Darwall 2006). It is essential that there is sufficient water of the right quality in the right place at the right time. To guarantee the continued social, environmental and economic services provided by freshwater systems, these systems must be adequately protected and sensitively developed (Smith & Darwall 2006).

Iran is one of the arid regions of the world on basis of various definitions of climatic conditions, vegetation types or potential for food production. Due to their high ecological value, monitoring of arid

regions is necessary and priority should be given to conservation and management of freshwater ecosystems located in these area. To protect critical services such as flood control and valuable economic and livelihood benefits, all users of freshwater including biodiversity need to be taken into consideration when managing water resources.

Finally, it is suggested that maps of conservation hot spots to be drawn based on a combination of characters (e.g., fish diversity, population density, ecological requirements, threats), and risk level of incurring losses to local-global biodiversity (e.g., number of critically endangered species). Moreover, the potential distribution of many species especially key or/and endangered species regarding zoogeographical point of view and conservation management strategies can be modelled in future.

Species Distribution Modelling (SDM): The predicted geographic distributions for the eight species based on current bioclimatic variables are visualized in Figure 12. The AUC value for all species supported the discriminative power of the model. The models showed a relatively large area of suitable climate for these native species in Persis basin extended to western parts of Iran. Estimate of relative contribution of the climatic factors to the Maxent model showed that for the distribution of the *A. pluristriatus*, *A. dispar*, *C. luteus* and *M. mastacembelus* Bio6 (min temperature of coldest month), for *A. grypus* Bio 3 (isothermality), for *C. saadii* Bio 15 (precipitation seasonality) and for *L. barbatus* Bio 16 (precipitation of wettest quarter) were the most important variables with more contribution for construct the model (Fig. 22).

The information collated and presented here should be readily available for policy makers and environmental planners in a format that can easily be employed for integration within the development planning process.

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