Iranian Journal of Fisheries Sciences
http:doi.org/ 10.22092/ijfs.2024.132469 2025, 24(2) 193-207

Research Article

Differentiation among the population of *Argyrops spinifer* in the Iranian waters of the Persian Gulf and Sea of Oman using Cytochrome Oxidase I (COI) gene

Valipour S.[1], Ghavam Mostafavi P.[1*], Shahhosseiny M.H.[2], Kaymaram F.[3]

1Department of Fisheries and Marine Science, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran
2Department of Microbiology, Islamic Azad University, Shahr-e-Ghods, Iran
3Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran
*Correspondence: mostafavi_pa@srbiau.ac.ir

Keywords

Haplotype diversity,
Genetic differentiation,
King Soldier bream,
mtDNA,
Cytochrome oxidase I

Article info

Received: July 2024
Accepted: September 2024
Published: March 2025

Abstract

Argyrops spinifer, commonly known as king soldier bream, is a species from the Sparidae family in the Persian Gulf and Oman Sea. This study was conducted to investigate the genetic diversity and demographic structure of the mentioned species based on the mitochondrial cytochrome c oxidase I gene. DNA was extracted using the ammonium acetate method from the caudal fin of 90 samples. The PCR reaction was performed using a pair of primers of the nucleotide sequences of the mitochondrial COI gene, and its PCR products were sequenced. Based on the results, the mean haplotype diversity was relatively high in Bandar Abbas (1.000), Chabahar (0.93), and moderate in Bushehr (0.533). The mean nucleotide diversity was also 0.194 in Bandar Abbas, 0.022 in Chabahar, and 0.0133 in Bushehr. Tajima's neutrality test and Fu's Fs index between the studied regions were -1.32 and -0.64, respectively ($p \leq 0.05$). The highest FST genetic distance was between the Chabahar and Bushehr populations (0.48). Also, the lowest genetic distance of 0.17 was observed between the Chabahar and Bandar Abbas populations. The results showed the presence of different populations of this genus in the Persian Gulf and Sea of Oman.

Introduction

There are more than 11 species of Sparidae in the Persian Gulf and Oman Sea. *Argyrops spinifer* belongs to the Sparidae family and is known as the king soldier bream in the southern part of Iran. *Argyrops spinifer* is distributed in the Persian Gulf and Oman Sea, as well as from the west to the east of the Indian Ocean and northern Australia (Orrell *et al*., 2002; Froese and Pauly, 2015). This species is a demersal species. The juveniles are found in shallow waters, while adults are found in deeper waters individually (Sommer *et al*., 1996; Randall *et al*., 1997; Al-Mamry *et al*., 2011). The body length reaches 70 cm but is 30 cm on average (Randall, 1995). This species is protogynous (Grandcourt *et al*. 2004) and feeds on benthic invertebrates and mainly mollusks, shrimps, crabs, and nektons (Fouda *et al*. 1998; Ghanbarzadeh *et al*., 2014). Sex reversal of this species is a common reproductive strategy in tropical coral islands (Grandcourt *et al*., 2004; Al Mamry *et al*., 2009). The COI gene in the mitochondrial genome is commonly used in species identification and biodiversity (Bingpeng *et al*., 2018). Geographical distribution, morphological differentiation, and genetic characteristics are the most basic needs for the conservation management of species. It should be noted that morphological indices are not a reliable method for distinguishing between potential populations (Aarbakke *et al*., 2011). Therefore, genetic markers are successfully used to link aquatic populations to the structure of their reserves (Van Herwerden *et al*., 2006). Sequencing the genome of living beings has become easier and error-free with the advancements in sequencing devices and specialized genetic studies software (Hedrick, 1999). Utilizing the genetics of aquatic populations is one of the ways to investigate the intraspecific diversity of aquatic organisms because the study of biodiversity and genetic structure of aquatic populations and also the systematic relationships of these organisms give a clear understanding of the structure of biological communities (Rezvani *et al*., 2006). Fish stocks are a crucial source of livelihood and nutrition, providing 156 million metric tons of food per year, representing some 17% of global animal protein consumed (Action, 2020).

The progressive decline in some species populations highlights the need to develop recovery plans it has long been understood that genetic data is important for planning species conservation (Simberloff, 1988).

Population genetic information plays an important role in conservation biology. Identifying genetic variation within and between populations can provide important information about the extent of interactions between local populations and allow assessment of the contribution of a metapopulation structure to regional persistence (Hanski, 1999).

Today, genetic diversity is used as an index for the ecological status of aquatic ecosystems. One of the ways to investigate the genetic structure of aquatic animals is the genetic study of populations and the identification of intraspecific changes and population structure using mitochondrial DNA molecular markers are two methods for examining the genetic makeup of aquatic animals. This is a crucial step towards the appropriate management and

exploitation of animal food sources (Pourkazemi *et al*., 2012). Population structure and genetic diversity of several fish species were studied using different molecular markers (Ghavam Mostafavi *et al*., 2007; Ghavam Mostavafi *et al*., 2011; Rahimi *et al*., 2016). Mitochondrial DNA (mtDNA) is being used more often to assess changes in genetic diversity compared to other methods (Johnson *et al*., 2018; Zhai *et al*., 2019; Righi *et al*., 2020). Studies on mitochondrial DNA can be used to reveal genetic similarities, phylogenetic classifications, and genetic differences between the populations of a species (Avise, 2004). Significant benefits of the DNA-based methods include their specificity, sensitivity, and speed (Civera, 2003; Rasmussen and Morrissey, 2008; Mazzeo and Siciliano, 2016). Nowadays, the classification and study of diversity in populations are conducted using DNA sequence differences. (COI) is a comparatively conservative gene with a moderate evolution rate. It is one of the most thoroughly studied mitochondrial genes and is suitable as a molecular marker (Sari *et al*., 2015). COI gene sequence variation has been used to study the population diversity and genetic structure of many fish species (Nneji *et al*., 2020; Sarropoulou *et al*., 2022). Molecular genetic studies have demonstrated that the relative paucity of morphological characteristics conceals a high genetic diversity (Shekhovtsov *et al*., 2014). Since *Argyrops spinifer* has an economic value, the study of its population genetics in the studied regions is a prerequisite for ecological and molecular biology activities for this fish (Mosafer *et al*., 2017). *Argyrops spinifer* is one of the most important species known in the waters of southern Iran that has been subjected to overfishing. Despite the economic importance of this species, there is no information about its population structure in the Persian Gulf and the Sea of Oman (Safari *et al*., 2019). Therefore, the present study was conducted to determine possible populations and identify the genetic diversity of *Argyrops spinifer* species in the Persian Gulf and Sea of Oman.

Methods

Sample collection

90 individuals were obtained from different fishing areas in the Persian Gulf and Oman Sea in February 2019 (Bandar Abbas 27° 10' 04"N, 56° 16' 09"E , Chabahar 25° 16' 02"N 60° 44' 34"E, and Bushehr 28° 49' 07"N 50° 54' 28"E). (Fig. 1). Thirty samples were collected simultaneously from each region.

Molecular analyses

The DNA of the samples was extracted by the ammonium acetate method (Saeidi *et al*. 2017). 50-100 mg of the caudal fin was isolated from the soft tissue of the samples and transferred to 1.5 ml tubes. The quantity and quality of DNA extracted was determined by spectrophotometry and 1% agarose gel electrophoresis respectively. PCR was performed from the COI region of the mitochondrial genome using the primers designed by Ward *et al*. (2005).

PCR was performed using 0.5 µL (50 ng) of genomic DNA, 0.3 µL of each forward and reverse primer with a concentration of 10 µL /pm, 1.5 units of *Taq* DNA Polymerase, 12.5 µL Master mix,

to reach a volume of 25 µL at 94°C for 5 min, with 30 cycles.

Figure 1 Sampling stations in the Persian Gulf and Oman Sea (Bandar Abbas, Bushehr and Chabahar). https://vajiramandravi.com/upsc-daily-current-affairs/prelims-pointers/Gulf-of-Oman-upsc/

Each cycle contained 30 seconds of denaturation at 94°C, 60 seconds of annealing at 63.2°C, 30 seconds of extension at 72°C and at the end of the reaction, 5 min of extension at 72°C. After the amplification reaction was completed, 5 µL of the sample was transferred on to 1.5% agarose gel to evaluate the quality of the gene fragments.

The band in question was 650 bp, the accuracy of which was established. PCR products were sent to BIONEER Company in South Korea for sequencing by Dideoxy Chain Termination based on the specific primer. The sequences were submitted to GenBank in NCBI (National Center for Biotechnology Information). All the accession numbers are shown in (Table 1).

Table 1: The sequences submitted in NCBI.

Accession number	OM158728	OM158729	OM158730	OM158731	OM158732	OM158733
Accession number	OM158734	OM158735	OM158736	OM158737	OM158738	OM158739
Accession number	OM158740	OM158741	OM158742	OM158743	OM158744	OM158745

Data analysis

Arlequin software, version 3.5 (Excoffier and Lischer, 2010), have been used for molecular analysis including obtaining the number of haplotypes, bases, and distances between and within the populations, as well as the assessment of the degree of genetic divergence using the F_{ST} index by DNA sp

v.5.0 (Librado and Rozas, 2009). Molecular data was aligned using BLAST (Basic Local Alignments Search Tool) and MEGA 7.0.2 Softwares (Kumar *et al*., 2016). The AMOVA test was used to calculate the F_{ST} by examining the structure of populations at different levels. DnaSP 5.0 software was used to determine haplotypic diversity and nucleotide diversity, to assess the expansion and distribution of the population history, two methods were used and including Tajima's test (D-test of Tajima, 1989) and Fu's Fs test (Fu, 1997). Population history expansion and distribution along with mismatch distribution resulting from the pair differences between the populations were calculated based on factors θ_0, θ_1 (θ before and after population growth) (Excoffier and Lischer, 2010) and τ (unit time of mutation rate) using Arlequin 3.5 and DnaSP 5.10.01 software (Rozas *et al*. 2003). The software Network V5.1 (Rohl, 2004) was used to plot haplotypes network based on the median-joining method (Bandelt *et al*., 1999).

Results

In this study, the quality and quantity of the PCR product were evaluated on 1.5% agarose gel and the resulting bands were observed in the range of 600-650 bp (Fig. 2). The numbers of haplotype in three different regions were 22. The haplotype diversity was relatively high in Bandar Abbas (1.000), Chabahar (0.93), and moderate in Bushehr (0.533). The nucleotide diversity was also 0.037 in Bandar Abbas, 0.005 in Chabahar, and 0.013 in Bushehr. (Table 2).

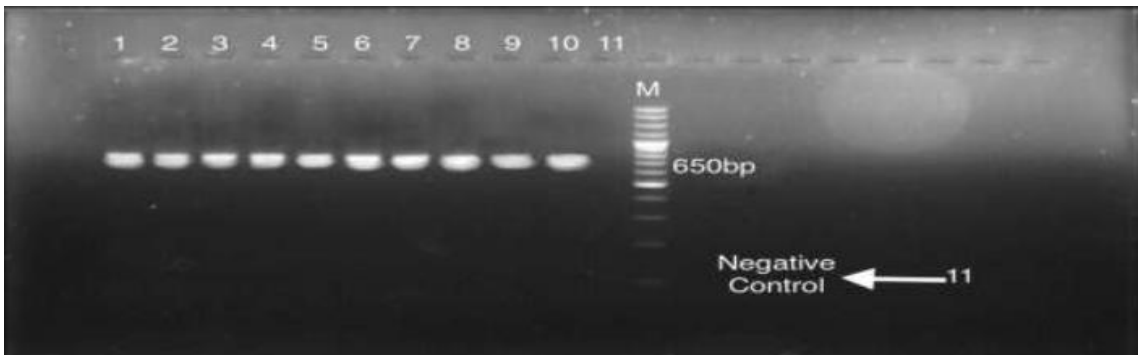

Figure 2: image of the PCR products on 1.5% Agarose gel.

Table 2: DNA polymorphism and haploid and nucleotide diversity of the three regions (Bandar Abbas, Bushehr, and Chabahar).

	Number of sequences	Number of haplotypes	Haplotype diversity	Nucleotide diversity(Pi)	Average number of differences(K)
Bandar Abbas	30	10	1±0.04	0.194±0.01	18.86
Bushehr	30	4	0.53±0.18	0.0133±0.007	8.20
Chabahar	30	8	0.93±0.07	0.022±0.01	2.22

Based on the population history of *Argyrops spinifer* using the mismatch distribution test, which shows pairwise genetic differences between haplotypes. Also based on sudden expansion, population distribution was multimodal in Bandar Abbas, unimodal in Bushehr, and bimodal in Chabahar (Fig. 3).

The result of the median-joining network based on COI gene showed that the *Argyrops spinifer* samples from Bandar Abbas and Chabahar, were located at a short distance from each other with fewer mutations, the samples from Bushehr were located at a further distance with a higher number of mutations in compare to the two other regions. Also, Haplotype number 20 in Bushehr region with a frequency of 22 and haplotype number 11 in Chabahar with a frequency of nine were the most observed haplotypes in the study area. The other haplotypes with a frequency of three showed the least frequency in the study area (Fig. 4).

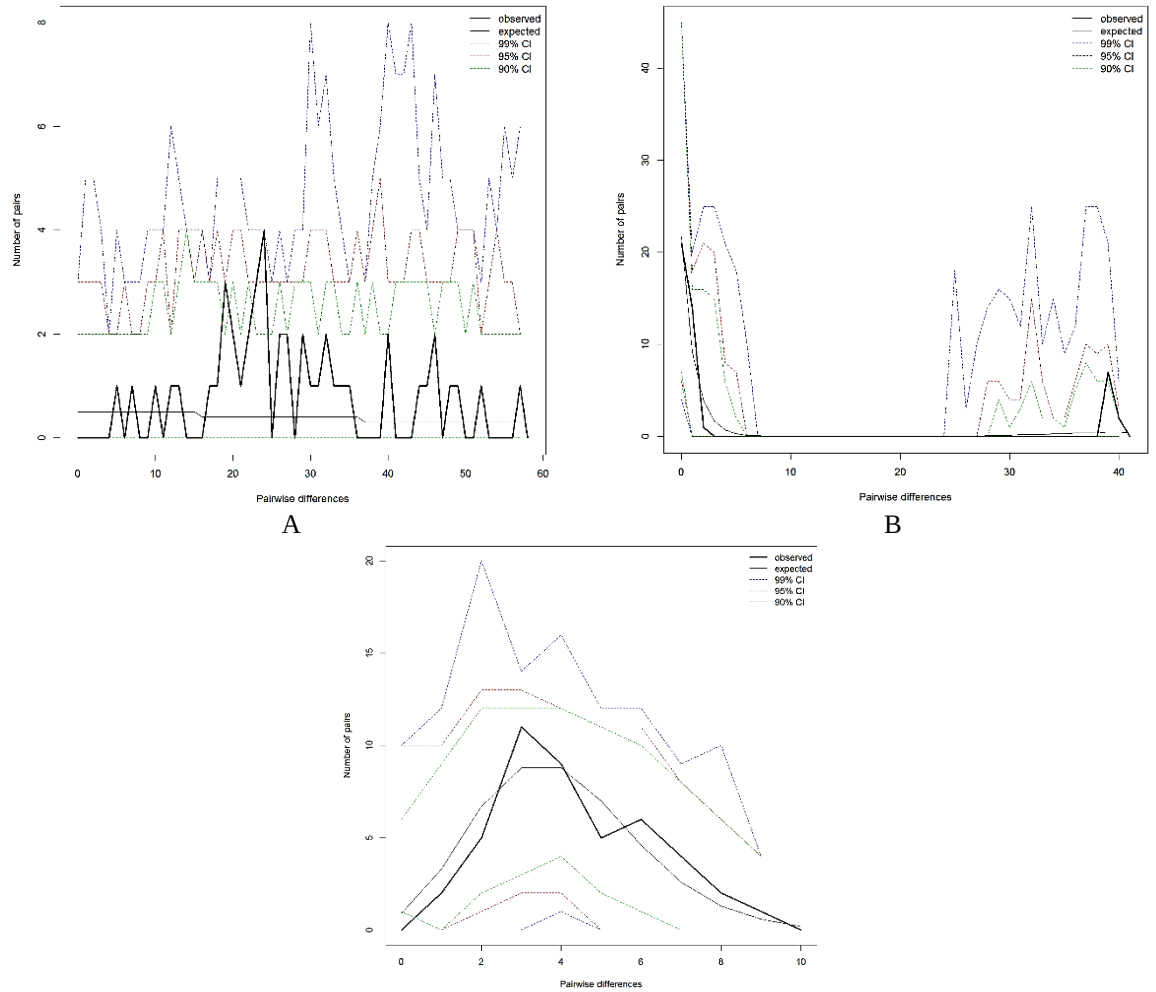

Figure 3: Mismatch distribution of *Argyrops spinifer* populations in studying area (A; Bandar Abbas, B; Bushehr and C:Chabahar).

The calculated value of the (Harpending *et al*., 1993) raggedness index (0.1) confirmed the similarity to the sudden expansion model (Table 3).

Genetic diversity indices and neutrality tests (Fu's FS index and Tajima's D) were -1.32 and -0.64 between the regions, respectively, both of which are negative and not statistically significant ($p \geq 0.05$).

Genetic diversity differences were calculated based on population hierarchy, three populations, and three regions based on the AMOVA test. The highest percentage of differences between the populations was 61.15% and the lowest percentage of genetic differences between members of the species was 38.85% (Table 4).

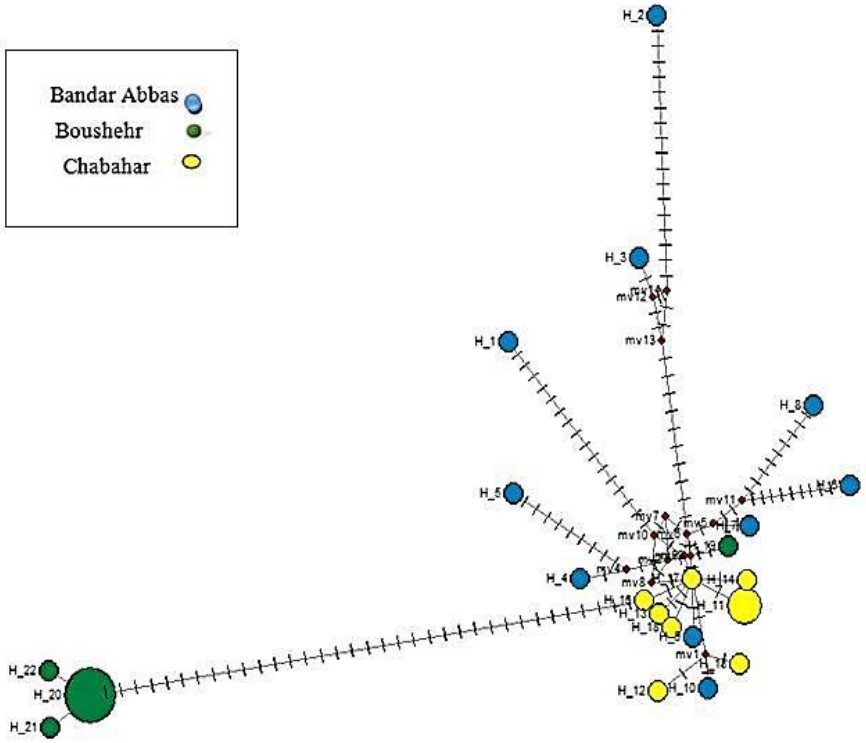

Figure 4: Median-joining haplotype network (Network 10.2.0.0 software) based COI mtDNA of *A.spinifer* sampled from 3 studied regions. Each pie represents a haplotype and its size reflects the frequency of samples. Distances between pies correspond to a number of mutations (*m*) between the haplotypes.

Table 3: COI mismatch distribution test in *Argyrops spinifer*.

Region	Tajima's D		Fu's FS		Mismatch distribution			Goodness-of-fit tests			
	P	D	P	FS	τ	θ_1	θ_0	P	Ragg*	P	SSD
Bandar Abbas	0.3	-0.54	0.09	-1.92	15.46	98.024	4.77	0.46	0.01	0.57	0.02
Bushehr	0.0	-2.10	0.97	4.64	0.62	6837.21	0.035	1.00	0.11	0.00	0.03
Chabahar	0.01	-1.32	0.00	-4.65	2.5	3414.97	0	0.08	0.18	0.07	0.05
Mean	0.11	-1.32	0.35	-0.64	6.19	3450.07	1.60	0.51	0.12	0.21	0.03

*Ragg: Harpending raggedness index, SSD = the sum of the squared deviations. θ_0, θ_1 (θ before and after the population growth), τ (unit time of mutation rate).

Table 4: The AMOVA results for *Argyrops spinifer* populations in the three regions.

Origin of variance	df	SS	Total variance	Percentage of diversity
Among the populations	2	227.03	10.67	61.15
Within the populations	27	183.10	6.78	38.85
Total	29	410.13	17.45	

The F_{ST} index was also used to measure genetic differentiation. The inter-population (intergroup) distance of *Argyrops spinifer* in the three studied regions was measured using DnaSP5.10.01 software. The highest inter-population distance was between Bushehr and Chabahar (0.48) and the lowest inter-population distance was between Chabahar and Bandar Abbas (0.151) (Table 5).

Table 5 Comparing F_{ST} in different *Argyrops spinifer* populations (Kimura 2- Parameter model).

Sampling area	Bandar Abbas	Bushehr	Chabahar
Bandar Abbas	---	0.11	---
Bushehr	---	---	0.48*
Chabahar	0.151*	---	---

*: Significant (p<0.05)

Discussion

The haplotype is a good index of the extent of genetic diversity among populations. The haplotype diversity level can vary from 0 (all population members have similar haplotypes) to 1 (all population members have different haplotypes) (Abiom *et al*., 2005). Bushehr had four haplotypes, while Bandar Abbas had the most haplotypes (10), indicating extremely high genetic diversity in the current study. In Bandar Abbas, 1, 0.53±0.18 in Bushehr, and 0.93±0.07 in Chabahar, the haplotype diversity was measured. In Bandar Abbas, 0.194 in Bushehr, 0.0133 and 0.022 in Chabahar, there existed nucleotide diversity. Additionally, the average number of differences was 2.22 in Chabahar, 8.20 in Bushehr, and 18.86 in Bandar Abbas. There are several reasons for this finding, Bandar Abbas and Chabahar regions are the habitat of different populations of this species, increasing of the indices can indicate high genetic dynamism and a more suitable population structure of this region compared to Bushehr due to more opportunities for natural reproduction, optimal utilization of the fishery resources of the region, and the non-destroyed natural habitat. It is not easy to give biological significance to the mentioned parameters. These findings can indicate the environmental stresses existing in this region. It is worth noting that genetic diversityis greater in species living in unstable and stressful environments compared to the same species living in stable environments; however, during short evolutionary periods (spanning several generations), a species' genetic diversity will be reduced if it is exposed to pollution for a prolonged time, is under fishing pressure within a certain age range, its natural habitat is destroyed, or its spawning

places are restricted. Also, overfishing of adult fish and failure to replace them in several generations causes only a small number to be able to reproduce, as a result of which the fish are born from a few breeders, which again reduces the genetic diversity (Welch *et al*., 2009). Bargelloni *et al*. (2003) examined the phylogeny of five species of Sparidae across the Atlantic-Mediterranean and reported the number of haplotypes for *Pagrus pagrus*, *Lithognathus mormyrus*, *Dentex dentex*, *Pagellus bogaraveo*, and *Spondyliosoma cantharus* as 32, 23, 23 12 and 41, and their haplotypic diversity as 0.92, 0.90, 0.67, 0.56, and 0.98, respectively. Accordingly, the mentioned parameters are consistent with the data obtained from this study.

The most F_{ST} genetic distance was between the Chabahar and Bushehr populations (0.48). Also, the lowest genetic distance of 0.17 was observed between the Chabahar and Bandar Abbas populations. The results showed the presence of different populations of this genus in the Persian Gulf and Sea of Oman.

There are two primary measures of the amount of genetic variation in a population at a locus: heterozygosity and the number of alleles. Allelic richness (number of alleles) is a measure of genetic diversity indicative of a population's long-term potential for adaptability and persistence. It is used less commonly than heterozygosity as a genetic diversity measure, partially because it is more mathematically difficult to take into account the stochastic process of genetic drift for allelic richness (Greenbaum *et al*., 2014). In general, the mean number of haplotype per locus for saltwater fish is 20 (DeWoody and Avise, 2000). In this study, the number of haplotype observed at different loci was 22, which is slightly higher than the number of haplotype in saltwater fish. Varying numbers of haplotype have been reported in the Sparidae family. In general, the population of *Argyrops spinifer* in the Persian Gulf shows a relatively moderate and desirable number of haplotype in different loci compared to other regions and species of the same genus. The number of haplotype in Bushehr was lower, which could be due to the Persian Gulf being an enclosed sea, the low migration of the populations of this species in the Persian Gulf, and the limited gene exchange with other populations. This lower number could also indicate the effects of fishing pressure in these areas (Lind *et al*., 2008).

The MJ-haplotype network showed that the star-like topology was not formed in the study area, suggesting that these populations have not experienced recent population expansion and showing long-term stability (Mila *et al*., 2000; Xue *et al*., 2014). Both neutrality tests (Tajima's D and Fu's Fs) for the studied sequences resulted in -1.32 and -0.64, respectively, indicating the expansion of *Argyrops spinifer* in the three studied regions. The high haplotypic and nucleotide diversity could probably be due to this population expansion (after a period in which the effective population size was low) (Hewitt, 1996; Carstens and Knowles, 2007). This finding is consistent with the results of these tests in this study. In their study of *Dentex dentex* and *Lithognathus mormyrus*, Bargelloni *et al*. (2003), reported Tajima's D test results as -0.72 and -0.99, respectively.

The Fst index describes the differentiation of populations at different levels of genetic structure. An Fst value of 0-0.05 shows low genetic differentiation, 0.05-0.15 shows high differentiation, and >0.25 shows very high differentiation (Balloux *et al*., 2002). Accordingly, the genetic difference between the populations of Chabahar and Bushehr was 0.48, which indicates a high genetic difference, and the lowest value of 0.15 was obtained between the populations of Chabahar and Bandar Abbas, which is quite justifiable due to the lack of gene flow between the studied regions. An Fst>0.05 indicates that gene flow is limited among the populations and does not allow some populations to be subdivided (Hoolihan *et al*., 2006). In a study by Ghasemi *et al*. (2019), Fst levels were 0.01-0.4 among different Sparidae populations, which suggests a high differentiation between the populations. In another study by Ghasemi *et al*. (2019) on *Sparidentex hasta*, the reason for the high differentiation was the low migration of populations of this species between the distribution regions, which is consistent with the biology of this species, which has a slow swimming speed and show vertical migrations. In a study of *Acanthopagrus latus* populations, Syazini *et al*. (2015) identified high genetic differentiation between populations due to extensive migration although only at short distances. In a study of *Sparus aurata* populations in waters around Italy, Franchini *et al.* (2012), also reported geographical distance as the reason for the high genetic differentiation between these populations. Water currents in the Persian Gulf are very slow, and as a result, they have less impact on the movement of fish larvae and juveniles than in other places, such as the waters of western Japan and Korea or monsoon currents in the China Sea and the Taiwan Sea. As a result, it is expected that there be distinct populations of this species in the Persian Gulf, as the populations of the studied regions are highly differentiated. Although sea currents play a major role in Sparidae populations, geographical distance is also a determining factor. Therefore, the results of the AMOVA test in this study based on the Fst index showed high genetic diversity among the populations (61.15) and relatively high genetic differences within the populations (38.85). The test results reported by Morgan *et al*. (2018) for *Chrysophrys auratus* on the east coast of Australia was 76.3.

Conclusions

Based on the present findings, the COI gene is a suitable marker for identifying the species in the Persian Gulf and the Sea of Oman. The higher molecular diversity indices in Bandar Abbas demonstrating the higher genetic dynamics and more appropriate population structure of this region. The most genetic distance was observed between the populations of Chabahar and Bushehr and the lowest genetic distance between the populations of Chabahar and Bandar Abbas which is quite justifiable due to the lack of gene flow between these regions. *Argyrops spinifer* has a favorable and high genetic diversity. There are different populations of this species in the Persian Gulf and the Sea of Oman, and the main factors differentiating the populations include slow swimming, vertical migration, geographical distance,

and the sea currents from the Strait of Hormuz toward the north of the Persian Gulf, which should be considered for the management of the Stock of this economically and ecologically important species.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Aarbakke, O.N.S., Bucklin, A., Halsband, C. and Norrbin, F., 2011. Discovery of *Pseudocalanus moultoni* in Northeast Atlantic waters based on mitochondrial COI sequence variation. *Journal of Plankton Research*, 33(**10**), 1487-1495. DOI: 10.1093/plankt/fbr057

Aboim, M.A., Menezes, G.M., Schlitt, T., and Rogers, A.D., 2005. Genetic structure and history of populations of the deep-sea fish *Helicolenus dactylopterus* (Delaroche, 1809) inferred from mtDNA sequence analysis. *Molecular Ecology*, 14(**5**), 1343-1354. DOI: 10.1111/j.1365-294X.2005.02518.x

Action, S.I., 2020. World fisheries and aquaculture. *Food and Agriculture Organization*, 244 P.

Al-Mamry, J., Meriem, S.B., McCarthy, I.D. and Richardson, C.A., 2011. Fishing pattern and interactions of fleet components in the *Argyrops spinifer* (Actinopterygii: Perciformes: Sparidae) fisheries of the Arabian Sea, Oman. *Acta Ichthyologica et Piscatoria*, 41(**1**), 55-62. DOI: 10.3750/AIP2011.41.1.08

Al-Mamry, J., Meriem, S.B., McCarthy, I.D. and Richardson, C.A., 2009. Biology of the kingsoldier bream (*Argyrops spinifer*, Forsskål 1775; Sparidae), from the Arabian Sea, Oman. *Journal of Applied Ichthiology*, 25(5) 559-564. DOI: 10.1111/j.1439-0426.2009.01260.x

Avise, J.C., 2004. Molecular Markers, Natural History, and Evolution (Second Edition). Sinauer, Sunderland, MA. 684 P.

Balloux, F. and Lugon-Moulin, N., 2002. The estimation of population differentiation with microsatellite markers. *Molecular Ecology*, 11(**2**), 155-165. DOI: 10.1046/j.0962-1083.2001.01436.x

Bandelt, H.J., Forster, P. and Röhl, A., 1999. Median-joining networks for inferring intraspecific phylogenies. *Molecular Biology and Evolution*, 16(**1**), 37-48.

Bargelloni, L., Alarcon, J.A., Alvarez, M.C., Penzo, E., Magoulas, A., Reis, C. and Patarnello, T., 2003. Discord in the family Sparidae (Teleostei): divergent phylogeographical patterns across the Atlantic–Mediterranean divide. *Journal of Evolutionary Biology*, 16(**6**), 1149-1158. DOI: 10.1046/j.1420-9101.2003.00620.x

Bingpeng, X., Heshan, L., Zhilan, Z., Chunguang, W., Yanguo, W. and Jianjun, W., 2018. DNA barcoding for identification of fish species in the Taiwan Strait. *PloS one*, 13(**6**), e0198109. DOI: 10.1371/journal.pone.0198109.

Carstens, B.C. and Knowles, L.L., 2007. Shifting distributions and speciation: species divergence during rapid climate change. *Molecular Ecology*, 16(**3**), 619-

627. DOI: 10.1111/j.1365-294X.2006.03167.x

Civera, T., 2003. Species identification and safety of fish products. *Veterinary research communications*, 27(**1**), 481-489. DOI: 10.1023/B:VERC.0000014205.87859.ab

DeWoody, J.A. and Avise, J.C., 2000. Microsatellite variation in marine, freshwater and anadromous fishes compared with other animals. *Journal of fish biology*, 56(**3**), 461-473. DOI: 10.1111/j.10958649.2000.tb00748.x

Excoffier, L. and Lischer, H.E., 2010. Arlequin suite ver 3.5: A new series of programs to perform population genetics analyses under Linux and Windows. *Molecular Ecology Resources*, 10(**3**), 564-567. DOI: 10.1111/j.17550998.2010.02847.x

Fouda, M.M., Hermosa Jr, G.V. and Al-Harthi, S.M., 1998. Status of fish biodiversity in the Sultanate of Oman. *Italian Journal of Zoology*, 65(**S1**), 521-525.

Franchini, P., Sola, L., Crosetti, D., Milana, V. and Rossi, A.R., 2012. Low levels of population genetic structure in the gilthead sea bream, *Sparus aurata*, along the coast of Italy. ICES *Journal of Marine Science*, 69(1), 41-50. DOI: 10.1093/icesjms/fsr175

Froese, R. and Pauly, D., 2015. FishBase. World Wide Web electronic publication. www.fishbase.org.

Fu, Y.X., 1997. Statistical tests of neutrality of mutations against population growth, hitchhiking and background selection. *Genetics*, 147(**2**), 915-925. DOI: 10.1093/genetics/147.2.915

Ghanbarzadeh, M., Soofiani, N.M., Keivany, Y. and Taghavi-Motlagh, S.A., 2014. Use of otolith length and weight in age estimations of the kingsoldier bream, *Argyrops spinifer*, in the Persian Gulf. *Iranian Journal of Ichthyology*, 1(**1**), 1-6. DOI: 10.22034/iji.v1i1.1

Ghasemi, A., Mohamadi, M. and Fakhri, A., 2019. Population genetic structure of yellow seabream (*Acanthopagrus latus*) in North Costal of Persain Gulf. *Journal of Applied Ichthyological Research*, 7(**2**), 29-44.

Ghavam Mostafavi, P. Shahnavaz, S., Noroozi, M., Fatemi, S.M.R., Shahhosseiny, M. and Mahvari, A., 2011. Population genetic of two Islands in the northern part of the Persian Gulf using microsatellite markers. *International Journal of Marine Science and Engineering*, 1, 69-73.

Ghavam Mostafavi, P., Fatemi, S.M.R., Shahhosseiny, M.H., Hoegh-Guldberg, O. and Loh, W.K.W., 2007. Predominance of clade D Symbiodinium in shallow-water reef-building corals off Kish and Larak Islands (Persian Gulf, Iran). *Marine Biology*, 153, 25-34. DOI: 10.1007/s00227-007-0796-8

Grandcourt, E.M., Al Abdessalaam, T.Z., Francis, F. and Al Shamsi, A.T., 2004. Biology and stock assessment of the Sparids, *Acanthopagrus bifasciatus* and *Argyrops spinifer* (Forsskål, 1775), in the Southern Arabian Gulf. *Fisheries research*, 69(**1**), 7-20. DOI: 10.1016/j.fishres.2004.04.006

Greenbaum, G., Templeton, A.R., Zarmi, Y. and Bar-David, S., 2014. Allelic richness following population founding events–a stochastic modeling framework incorporating gene flow and genetic drift. *PloS one*, 9(**12**), p.e115203. DOI: 10.1371/journal.pone.0115203

Hanski, I., 1999. Metapopulation ecology. Oxford University Press.

Harpending, H.C., Sherry, S.T., Rogers, A.R. and Stoneking, M., 1993. The genetic structure of ancient human populations. *Current Anthropology*, 34(**4**), 483-496.

Hedrick, P.W., 1999. Perspective: highly variable loci and their interpretation in evolution and conservation. *Evolution*, 53(**2**), 313-318. DOI: 10.2307/2640768

Hewitt, G.M., 1996. Some genetic consequences of ice ages, and their role in divergence and speciation. *Biological Journal of the Linnean Society*, 58(**3**), 247-276. DOI: 10.1006/bijl.1996.0035

Hoolihan, J.P., Anandh, P. and van Herwerden, L., 2006. Mitochondrial DNA analyses of narrow-barred Spanish mackerel (*Scomberomorus commerson*) suggest a single genetic stock in the ROPME sea area (Arabian Gulf, Gulf of Oman, and Arabian Sea). *ICES Journal of Marine science*, 63(**6**), 1066-1074. DOI: 10.1016/j.icesjms.2006.03.012

Johnson, B.M., Kemp, B.M. and Thorgaard, G.H., 2018. Increased mitochondrial DNA diversity in ancient Columbia River basin chinook salmon *Oncorhynchus tshawytscha*. *PLoS One*, 13(**1**), p.e0190059. DOI: 10.1371/journal.pone.0190059

Kumar, S., Stecher, G. and Tamura, K., 2016. MEGA7: molecular evolutionary genetics analysis version 7.0 for bigger datasets. *Molecular biology and evolution*, 33(**7**), 1870-1874. DOI: 10.1093/molbev/msw054

Librado, P. and Rozas, J., 2009. DnaSP v5: a software for comprehensive analysis of DNA polymorphism data. *Bioinformatics*, 25(**11**), 1451-1452.

Lind, P.A., Eriksson, C.P. and Wilhelmsen, K.C., 2008. The role of aldehyde dehydrogenase-1 (ALDH1A1) polymorphisms in harmful alcohol consumption in a Finnish population. *Human genomics*, 3, 1-12. DOI: 10.1186/1479-7364-3-1-24

Mazzeo, M.F. and Siciliano, R.A., 2016. Proteomics for the authentication of fish species. *Journal of proteomics*, 147, 119-124.

Mila, B., Girman, D.J., Kimura, M. and Smith, T.B., 2000. Genetic evidence for the effect of a postglacial population expansion on the phylogeography of a North American songbird. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 267(**1447**), 1033-1040. DOI: 10.1098/rspb.2000.1107.

Morgan, J.A., Sumpton, W.D., Jones, A.T., Campbell, A.B., Stewart, J., Hamer, P. and Ovenden, J.R., 2018. Assessment of genetic structure among Australian east coast populations of snapper Chrysophrys auratus (Sparidae). *Marine and Freshwater Research*, 70(**7**), 964-976. DOI: 10.1071/MF18146

Mosafer M, Rezvani Gilkolaei S, Ghavam Mostafavi P., 2017. Population Genetic Studies of *Atrobucca Nibe* (Jordan and Thompson, 1911) Using D-Loop Sequencing in the Northwest Coasts of the Oman Sea. *Journal of Aquaculture Development*, 11(**2**), 91-103.

Nneji, L.M., Adeola, A.C., Mustapha, M.K., Oladipo, S.O., Djagoun, C.A., Nneji, I.C., Adedeji, B.E., Olatunde, O., Ayoola, A.O., Okeyoyin, A.O. and Ikhimiukor, O.O., 2020. DNA barcoding silver butter catfish (*Schilbe intermedius*) reveals patterns of mitochondrial genetic diversity across african river systems. *Scientific reports*, 10(**1**), 7097. DOI: 10.1038/s41598-020-63837-4

Orrell, T.M., Carpenter, K.E., Musick, J.A. and Graves, J.E., 2002. Phylogenetic and biogeographic analysis of the Sparidae (Perciformes: Percoidei) from cytochrome b sequences. *Copeia*, 2002(**3**), 618-631. DOI: 10.1643/0045-8511

Pourkazemi, M., Khoshkholgh, M., Nazari, S., and Pormehr, L., 2012. Genetic relationships among collections of the Persian sturgeon, *Acipenser persicus*, in the south Caspian Sea detected by mitochondrial DNA Restriction fragment length polymorphisms. *Caspian Journal of Environmental Sciences*, 10, 215-226.

Rahimi, P., Rezvani Gilkolaie, S., Ghavam Mostafavi, P., Jamili, S. and Rahnema, M., 2016. Population genetic structure of the white sardine, Sardinella albella, in the Persian Gulf and Sea of Oman by analysis of mitochondrial control region. *Iranian Journal of Fisheries Sciences*, 15(**3**), 995-1008.

Randall, J.E., 1995. Coastal fishes of Oman. University of Hawaii Press, Honolulu, Hawaii. 439 P.

Randall, J.E., Allen, G.R. and Steene, R.C., 1997. Fishes of the great barrier reef and coral sea. University of Hawaii Press.

Rasmussen, R.S. and Morrissey, M.T., 2008. DNA-based methods for the identification of commercial fish and seafood species. *Comprehensive Reviews in Food Science and Food Safety*, 7(**3**), 280-295.

Rezvani, S., Eimanifar, A., Aghili, R. and Laloei, F., 2006. PCR–RFLP analysis of mitochondrial DNA for identification of *Rutilus rutilus caspicus* populations on the southern coast of the Caspian Sea, Iran. *Journal of the Marine Biological Association of the United Kingdom*, 86(**6**),. 1463-1467.

Righi, T., Splendiani, A., Fioravanti, T., Casoni, E., Gioacchini, G., Carnevali, O. and Caputo Barucchi, V., 2020. Loss of mitochondrial genetic diversity in overexploited mediterranean swordfish (*Xiphias gladius*, 1759) population. *Diversity*, 12(**5**), 170. DOI: 10.3390/d12050170

Rozas, J., Sanchez-DelBarrio, J.C., Messeguer, X. and Rozas, R., 2003. DnaSP, DNA polymorphism analyses by the coalescent and other methods. *Bioinformatics* 19, 2496–2497. DOI: 10.1093/bioinformatics/btg359

Röhl, A., 2004. Network: a program package for calculating phylogenetic networks, version 4.1. 0.9. *Fluxus Technology Ltd., Hamburg.*

Saeidi, Z., Rezvani Gilkolaei, S. and Soltani, M., 2017. Population genetic structure studies of *Liza aurata* based on mtDNA control region sequences analyses in the southern coasts of the Caspian Sea. *Iranian Journal of Fisheries Sciences*, 17(**4**), 1341-1348. DOI: 10.22092/IJFS.2018.114743

Safari, R., Qasemi, S. A., Rezvani Gilkalaee, S., Qafari, H., 2019. Population structure of *Holothuria leucospilota* in the north of Persian Gulf and Oman Sea using DNA sequencing method. *Journal of Aquaculture Sciences*, 7(**12**), 42-51.

Sari, A., Duran, M., Sen, A. and Bardakci, F., 2015. Investigation of Chironomidae (Diptera) relationships using mitochondrial COI gene. *Biochemical Systematics and Ecology*, 59, 229-238. DOI: 10.1006/mpev.2001.0898

Sarropoulou, X., Tsaparis, D., Tsagarakis, K., Badouvas, N. and

Tsigenopoulos, C.S., 2022. Different patterns of population structure and genetic diversity of three mesopelagic fishes in the Greek Seas. *Mediterranean Marine Science*, 23(**3**), 536-545. DOI:10.12681/mms.28567.

Shekhovtsov, S.V., Golovanova, E.V. and Peltek, S.E., 2014. Genetic diversity of the earthworm *Octolasion tyrtaeum* (Lumbricidae, Annelida). *Pedobiologia*, 57(**4-6**), 245-250. DOI: 10.1016/j.pedobi.2014.09.002

Simberloff, D. 1988. The contribution of population and community biology to conservation science. *Annual Review of Ecology and Systematics*, 19, 473–511.

Sommer, C., Schneider, W. and Poutiers, J.M., 1996. FAO species identification field guide for fishery purposes: *The Living Marine Resources of Somalia*, FAO, *Rome.* 383 P.

Syazni, K.A., Tomano, S., Ueno, K., Ohara, K. and Umino, T., 2015. Genetic structure of yellowfin black seabream *Acanthopagrus latus* in western Japan based on microsatellite and mtDNA marker analyses. *Aquaculture Science*, 63(**1**), 17-27. DOI: 10.11233/aquaculturesci.63.17

Tajima, F. 1989. Statistical method for testing the neutral mutation hypothesis by DNA polymorphism. *Genetics*, 123(3), 585-95. DOI: 10.1093/genetics/123.3.585.

van Herwerden, L., Choat, J.H., Dudgeon, C.L., Carlos, G., Newman, S.J., Frisch, A. and Van Oppen, M., 2006. Contrasting patterns of genetic structure in two species of the coral trout Plectropomus (Serranidae) from east and west Australia: introgressive hybridisation or ancestral polymorphisms. *Molecular Phylogenetics and Evolution*, 41(**2**), 420-435. DOI: 10.1016/j.ympev.2006.04.024

Ward, R.D., Zemlak, T.S., Innes, B.H., Last, P.R. and Hebert, P.D., 2005. DNA barcoding Australia's fish species. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(**1462**), 1847-1857. DOI: 10.1098/rstb.2005.1716

Welch, D.J., Buckworth, R.C., Ovenden, J.R., Newman, S.J., Broderick, D., Lester, R.J.G., Ballagh, A.C., Stapley, J., Charters, R.A. and Gribble, N.A., 2009. Determination of management units for grey mackerel fisheries in northern Australia. 158 P.

Xue, D.X., Wang, H.Y., Zhang, T. and Liu, J.X., 2014. Population genetic structure and demographic history of Atrina pectinata based on mitochondrial DNA and microsatellite markers. *PloS one*, 9(**5**), p.e95436. DOI: 10.1371/journal.pone.0095436

Zhai, D.D., Li, W.J., Liu, H.Z., Cao, W.X. and Gao, X., 2019. Genetic diversity and temporal changes of an endemic cyprinid fish species, *Anchery*throculter *nigrocauda*, from the upper reaches of Yangtze River. *Zoological research*, 40(**5**), 427. DOI: 10.24272/j.issn.2095-8137.2019.027