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Spatial variability in strontium to calcium in the Caspian Sea: Recognition of starry sturgeon stocks from the pectoral fin spine chemistry

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ABSTRACT
One of the fundamental hypotheses in aquatic ecology deals with the recognition of fish stocks. The present study tested the spatial dynamics of starry sturgeon stocks across environmental gradients by spatial variability in strontium to calcium in the pectoral fin spine. Forty samples of starry sturgeon were collected from the north and south of the Caspian Sea. A quantitative method was used to examine stocks using digested pectoral fin spine, reflecting habitat characters of fish. Parts of pectoral fin spines from adult starry sturgeon were separated and analyzed using Inductively Coupled Plasma- Mass Spectrometry (ICP-MS). Comparisons of Sr/Ca ratios in digested spines of the fish from north and south of the Caspian Sea demonstrated that Sr/Ca varied in the region and this significance was reflected in the spine as well. Our results for starry sturgeon support the use of spine Sr/Ca as a proxy for ambient levels throughout their life-history, confident interpretation of life history from spine Sr/Ca chronologies, however likely require matching time series of ambient Sr/Ca in the water bodies of interest.

Keywords: Trace element, Caspian Sea, Sr/Ca, Habitat, Starry sturgeon.
Article type: Research Article.

INTRODUCTION
Quantifying stock characters is fundamental to separating populations in marine environments (Montefalcone *et al.* 2011). This information is often lacking in data-poor fisheries where there is a lack of basic life history broad study which supporting the role of habitat as a necessary factor for identifying populations (Fahrig 2001). Moreover, the efficiency with which habitat characters present in fish stock poorly understood due to the variability and complexity of dispersal among habitats (Fahrig 2001; Cheminée *et al.* 2017). Recent studies have indicated that calcified structures have the potential to store information on both the movement and environmental histories of fish (Campana 1999; Campana & Thorrold 2001). This probability can be influenced by feeding behaviors and ambient water characters such as salinity and temperature. The pectoral fin spine is a suitable calcified structure for studies life history traits without scarifying the fish and also it is applied for the determination of stock relationships of endangered fish (Guenette *et al.* 1992; Keenlyne *et al.* 1994; Bakhshalizadeh *et al.* 2011; Bakhshalizadeh *et al.* 2013b). Annual growth in the pectoral fin spine allows for Sr variation within spines to be added and influence spine chemistry. So, the knowledge of spatial variation of environment reconstruction from the spine is possible (Tzadik *et al.* 2017). The starry sturgeon, Acipenser stellatus, (Pallas 1771) supports major commercial fisheries in the Black, Azov, and Caspian Seas. The Caspian

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Sea, as the largest inland body of water in the world, stretches nearly 1,200 kilometers between latitudes 47.07'N and 36.33N and longitudes 45.43 E and 54.20E. The differences in salinity, temperature, and ecology were seen in these distances (Kostianoy & Kosarev 2005). The Northern Caspian has very fresh shallow water that, typically freezes in the winter and accounts for less than 1% of the total water volume with an average depth of only 5–6 meters but in contrast, the southern Caspian has the deepest brackish water and accounts for 66% of the total water volume (Bakhshalizadeh & Bani 2019). In the north and south Caspian Sea, a considerable portion of starry sturgeon life history occurs in estuarine and marine environments where they may encounter non-target fisheries. Moreover, the late onset of maturity, slow growth, and infrequent reproduction increases their vulnerability (Bakhshalizadeh *et al.* 2012). Furthermore, the value of their caviar causes intensive legal and illegal fisheries in the north and south waters of the Caspian Sea (Bakhshalizadeh *et al.* 2012; Bakhshalizadeh *et al.* 2017).

Therefore, understanding their population traits of starry sturgeon is critical for their conservation. Moreover, the identification of the starry sturgeon population which is listed as a threatened species by the International Union for Conservation of Nature (IUCN), through analyses of pectoral fin spines has an advantage in that it does not necessitate mutilation of the carcass, as is the case with otolith investigations (Bakhshalizadeh *et al.* 2013a; Bakhshalizadeh *et al.* 2015; Bakhshalizadeh & Bani 2018). Furthermore, the gene flow across the Caspian Sea causes problems for discriminating stocks by the usual genetic methods (Kotlik *et al.* 2008; Tabatabaei *et al.* 2020; Segherloo *et al.* 2021).

So, applying any method which brings the basic information about the stocks will be helpful for monitoring the history and anthropogenic factors base on geopolitics for their conservation and management. Therefore, the objective of our research was to estimate whether the Sr to Ca ratio of pectoral fin spine chemistry could provide information on population and geographic variation.

MATERIALS AND METHODS

Sampling and analysis of samples

A total of 40 adult starry sturgeon (*Acipenser stellatus*) were taken from a commercial catch of sturgeon for a restocking program in the north and south inshore waters of the Caspian Sea (Fig. 1). After biometry, sex determination was carried out using macroscopic examination of the fish gonad. Then, right pectoral fin spine were separated as a non-lethal method, cleaned with distilled water and dissolved with high purity HNO_3 (10 %) for subsequent analysis using Inductively Coupled Plasma- Mass Spectrometry (ICP-MS).

Statistical processing and data analysis

The homoscedasticity and normality of data were checked and transformed were necessary. To compare length and weight in individuals between sex and habitat, Two-Ways ANOVA were conducted. In the case of the interaction term, when significant ($p < 0.05$), the Tukey post-hoc test was conducted to compare each combination of sex and habitat, since the comparison of sex and habitat should not be done individually. Moreover, Sr/Ca ratio data were normalized as dividing by fish length to remove the influence of size (Azevedo *et al.* 2019). In addition, Two-Way ANOVA was applied to calculate the effect of sex and habitat on normalized data of Sr/Ca ratio in pectoral fin spines of the starry sturgeon. All statistical analyses were performed using SPSS 22.

RESULTS

The size of starry sturgeon from the north and south part of the Caspian Sea were depicted in Table 1. The interaction between sex and habitat was not significant for weight. However the weight of fish was significantly different between sex and habitat (0<0.05; Table 1). All the north starry sturgeon had higher weight compared to the south individuals and in both habitats, the weight of females was higher than that of males. Meanwhile, there was not any interaction between sex and habitat for length too and the length of individuals just differed between sex ($p<0.05$). In other words, females had higher fork length and body weight than males (Table 1).

The results revealed that the Sr/Ca ratio in pectoral fin spines of starry sturgeons were different between the north and south parts of the Caspian Sea. Moreover, the results showed an interaction between sex and habitat ($p<0.05$). The Sr/Ca ratio in females of the south part was statistically similar to males of the north (Fig. 2). The Sr/Ca ratio in males of the south was the highest, while the females in the north exhibited the lowest ratio of Sr/Ca in the pectoral fin spines (Fig. 2).

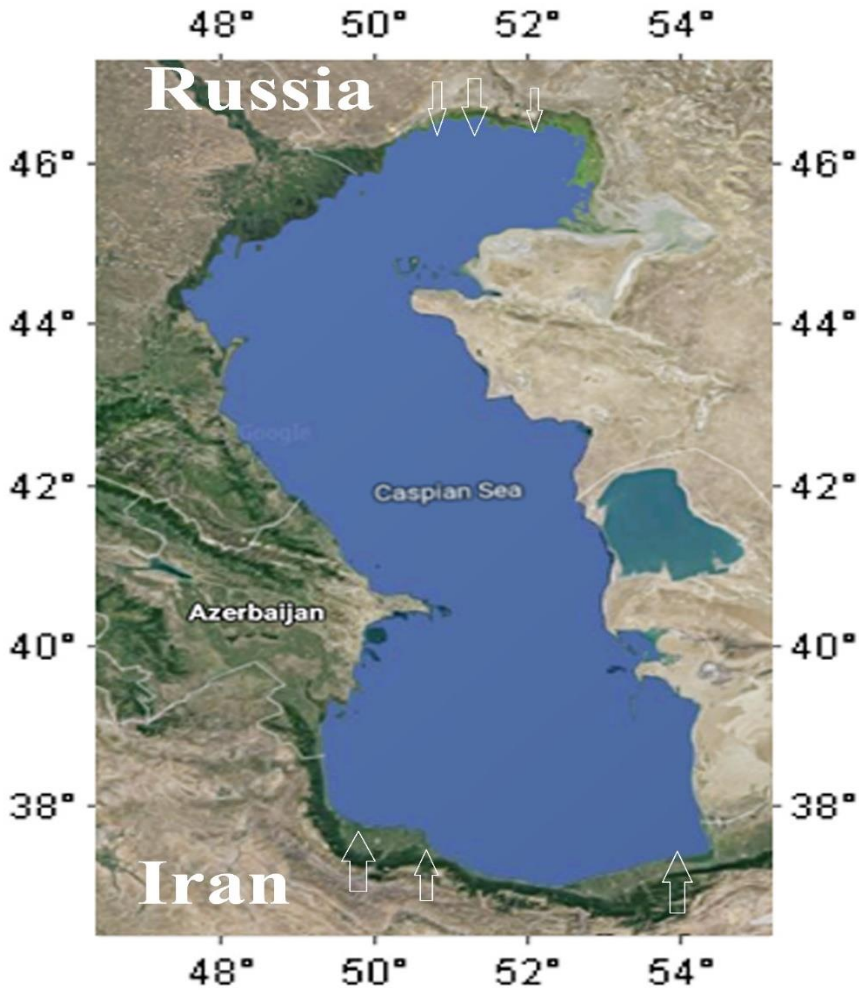

Fig. 1. Maps indicating different sampling points in the Caspain Sea. sampling points are indicated with arrows in the north and south parts of the Caspian Sea.

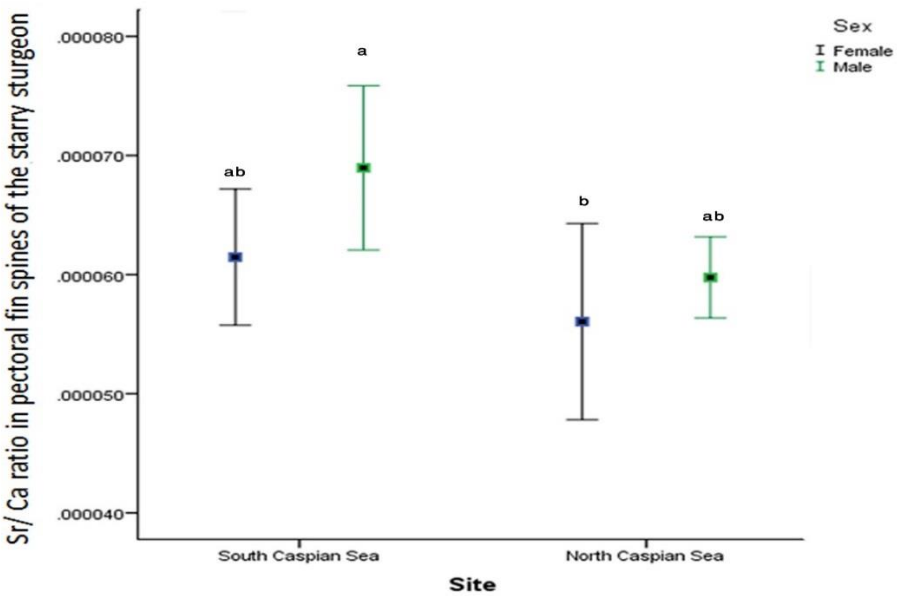

Fig. 2. Comparision of Sr/ Ca ratio of pectoral fin spines in the starry sturgeon between sex and habitat. Different letters indicate statistical differences ($\alpha = 0.05$). Two-Way ANOVA indicates an interaction between sex and habitat ($p<0.05$).

Table1. Descriptive length and weight compositions of the starry sturgeon genders in the north and south parts of the Caspian Sea.

Habitat	Size	Sex	Mean ± S.E	Min	Max
South Caspian Sea	FL (cm)	Female	145± 4.71	122	167
		Male	125.50± 2.92	116	141
	W (kg)	Female	7.10± 0.57	5	10
		Male	4.95± 0.38	4	7
North Caspian Sea	FL (cm)	Female	143.86± 4.71	130	160
		Male	128.54± 1.79	119	140
	W (kg)	Female	7.71± 0.40	6.40	8.90
		Male	6.21± 0.21	5	7.60

DISCUSSION

Our results show that habitat influences the Sr/Ca ratio in pectoral fin spines between the north and south parts of the Caspian Sea. Individuals from the north exhibited the lower Sr/Ca ratio in pectoral fin spines in comparison with those from the south part of the sea which coincided with the habitat condition in north and south parts. A useful criterion in dealing with habitat is salinity which affect retention, physiology and distribution of fish and plays an important role in the absorption of many elements (Albert 2007; Pouil *et al.* 2018; Shirai *et al.* 2018). A positive relationship was reported between calcified structures of Sr and salinity (Secor *et al.* 1998; Tran *et al.* 2019; Morrissey *et al.* 2020) which displays dominant influences of salinity over temperature on Sr/Ca ratio in the calcified structures (Secor *et al.* 1995; Secor & Rooker 2000). The harmony of the results with ambient water conditions in the north and south of the Caspian Sea seems to be derived from the huge fresh water inflows from the Volga and Ural rivers leading to the low salinity <8 practical salinity unit (PSU) in the north part, while elevating to 12.6–13.5 PSU in the middle and south parts (Alizadeh 2004). In addition, a deep south basins in comparison with the north part with shallow water (Alizadeh 2004; Kostianoy & Kosarev 2005) also leads to the low variation of temperature in south part beside low latitudes, tending to a higher average of surface temperature in the south than in the north (Ginzburg *et al.* 2005). This may be affected by the strontium to calcium distributions which suggest that calcified structure of strontium bands is related to environmental variations in salinity (Raoult *et al.* 2016). Moreover, Sr/Ca is a well determined geochemical marker in calcified structures of the sturgeon fish to reconstruct migration history (Arai *et al.* 2002; Allen *et al.* 2009; Allen *et al.* 2018). It also plays a key role in discriminating among sites (Smith *et al.* 2016). Factors affecting Sr deposition rate in calcified structures includ genetic, growth, diet, and reproductive stage (Campana & Thorrold 2001; Raoult *et al.* 2016; Sweeney *et al.* 2020), although the influences of these factors have not been checked about the temperature and salinity effects on these structures (Secor & Rooker 2000). The predominance of females of largest size is consistent with life history of a probably longer life span with previous authors in the whole Caspian Sea (Bakhshalizadeh *et al.* 2012; Bakhshalizadeh *et al.* 2017). The Sr/Ca ratio in pectoral fin spines of males were larger than that of females in both parts of the sea. The North Caspian Sea females tended to reside in the low salinity throughout their lives, whereas males exhibited similar rates of increased salty inhabiting which is similar to those reported from the Hudson River populations (Secor *et al.* 1998). Izzo *et al.* (2016) reported about 2% influences of sex on the separating regions by analyzing calcified structures chemically. However, the small sample size of adults hindered the power of identification stocks based on size or sex. The influence of habitat on the stock dynamics of fish due to limitations of tagging, catch curve analysis and hydro acoustic methods were not well exhibited. However our method provides a clean scale of detection between demographic and spatial dynamics.

CONCLUSION

The results presented here demonstrate that Sr/Ca ratio as a natural marker provides a very good index in the pectoral fin spine of adult starry sturgeon for separating the habitat without any harming these valuable rare species.

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