

Original Article

Spatial and temporal variabilities in abundance and size structure of Caspian sand smelt, *Atherina caspia* (Pisces: Atherinidae) in a coastal plain estuary of the southeast Caspian Sea, Iran

Khadijeh Maramaei, Rahman Patimar*, Hojjatallah Jafaryan, Hadi Raeesi, Seyyedeh Ainaz Shirangi, Seyyed Mostafa Aghilinezhad

Department of Fisheries, Gonbad Kavous University, Gonbad Kavous, Iran.

Abstract: To investigate seasonal and habitat trends in the community structure of *Atherina caspia*, a total of 14791 specimens caught in four habitats from the eastern part of Gorgan Bay (southeast Caspian Sea) were examined to test variability in intrapopulation and inter-habitat abundance. Fish in four coastal habitats, including a sea-coast habitat (SC), a strait-zone habitat (SZ), a bay-zone habitat (BZ), and an old canal of Khozeini habitat (CZ). The largest specimen was observed in the SZ, with a total length of 135 mm, and the heaviest was in the BZ, weighing 14.20 g. The relative abundance of the fish was the highest in CZ (33.4%) and the lowest in BZ (14.75%). All habitats except KZ showed the highest abundance of this fish in summer, while KZ had the highest abundance of this species in spring. A comparison of fish size showed significant differences between habitats. Although females were dominant in all habitats, the intensity of female dominance varied across habitats. Analysis of age composition revealed inter-population and in-habitat variability. Age 1+ was dominant in SC and KZ habitats, whereas age 2+ dominated in SZ and BZ habitats. The results suggest that *A. caspia* populations may largely differ among habitats, indicating high interpopulation variability that may contribute to its dominance across habitats in the southern Caspian Sea.

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Introduction

Gorgan Bay is a typical coastal shallow wetland with approximately 80% < 2 m deep (Kiabi et al., 1999) located on the southeastern coast of the Caspian Sea. The Bay receives most of its water from the Caspian Sea, and the remainder drains into the bay from its southern watersheds. Gorgan Bay is an ecologically important region within the Miankaleh Peninsula complex. The general circulation of the bay is weak; therefore, it is subject to a wide variety of environmental stressors, most importantly eutrophication (Maleki et al., 2020, 2022). The bay area around the junction with the Caspian Sea shows marked ecological heterogeneity, which can have a notable influence on local taxa. Generally, the distribution and abundance of a certain taxon across this area are spatially and temporally variable, primarily from the taxon's response to its

environment, and related to heterogeneity in the habitat.

Several studies have described the biological attributes of *Atherina caspia* in the southern Caspian Sea (Ghorbanalidoost et al., 2004; Patimar et al., 2009; Zahedi and Rahimibashar, 2015; Taghavi et al., 2017; Harak-Ata et al., 2019). According to these studies, this species is one of the dominant fish in shallow habitats of the southern Caspian Sea. However, no attempts have been made to compare the spatiotemporal variability in its distribution and abundance, and it is often unclear how this species' distribution and population structure vary across habitats. In shallow wetland ecosystems, such as Gorgan Bay, spatial and temporal variations in a given species are mainly driven by habitat factors. Thus, investigation of the distribution, abundance, and population structure of this species in the

*Correspondence: Rahman Patimar
E-mail: rpatimar@yahoo.com

heterogeneous area of the Gorgan Bay allows estimation of its habitat preference, underscores the bay's vitally important habitats for recovery, and predicts the recruitment of this species in the southern Caspian waters. Alternatively, the distribution pattern of the fish may explain its spatial and temporal habitat segregation in the adjacent coastal waters of the Caspian Sea, allowing us to use the species as an indicator of future interactions between ecosystem changes and species assemblage.

The fish studied was previously identified as *A. boyeri* Risso, 1810, in the Caspian Sea and was also found in European waters. But this species is systematically distinct from *A. boyeri* and is considered a valid species for the Caspian Sea as *A. caspia* (Eagderi et al., 2022); therefore, data on its habitat preferences and ecological aspects are lacking. The life stages of a species have distinct ecological requirements (Nasri et al., 2018). Within such species, aspects of habitat preference may be significant, varying on both temporal and spatial scales under different environmental influences. One generality that has emerged from the ecological view is that temporal and spatial distribution patterns are the main drivers of ecological events in life history. Accordingly, persistent differences in fish abundance can cause spatial patterns in population abundance. Knowledge of spatio-temporal changes in species abundance and occurrence would greatly enlighten our understanding of the relationship between fish and habitats in the region and would help test the hypotheses that the extent and magnitude of their distribution and abundance vary spatially and seasonally among sites within the bay. We hypothesized that habitats modify the population structure of this species in the Gorgan Bay. In particular, the objective of the present study is to evaluate the spatial and temporal trends in the community structure of *A. caspia* across different habitats in a coastal wetland of the southern Caspian Sea. Finally, we predicted that habitat changes would be driven by fish abundance trends, informing ecological impact assessments of frequent anthropogenic events in the area.

Materials and Methods

We sampled fish in four coastal habitat types in April 2019 and March 2020, including a sea-coast habitat (SC), strait-zone habitat (SZ), bay-zone habitat (BZ), and an old canal of Khozeini habitat (CZ). These habitats were located in the north-eastern part of the Gorgan Bay in the southeastern Caspian Sea. The SC habitat consisted of bare sand sediment and had less vegetation. Its environmental parameters are the same as the sea environment; therefore, it can be considered representative of the sea habitat. The SZ habitat was dominated by widgeon grass (*Ruppia maritima*). This habitat is a connecting zone between the Caspian Sea and the Gorgan Bay, and its current regime classifies it as an estuarine zone. The BZ habitat mainly consisted of clay sediment, with less sand sediment and less aquatic plant cover. This sampling point was representative of the bay ecosystem, whereas the KZ habitat consisted mainly of clay and silt, with less sand and high aquatic plant cover.

Specimens were sampled using a small beach seine (30 m in length, 2 m in depth, 3 mm mesh size) for each habitat. Seining was conducted three times and was assumed to provide sufficient replicates to sample the fish community in a representative manner, given the size of the habitats. Atherinid specimens were identified and counted among the fish. The biometric data, including total length and total weight, were recorded for all specimens. For the analysis, four traits were used for the fish: individual abundance, size (total length and weight), male-to-female ratio, and individual age.

Relative abundance of considered groups was analyzed using the chi-square test, including relative total and seasonal abundance of individuals, male-female abundance, and age abundance. These relative abundances were tested among habitats (inter-habitat), seasons (inter-seasons), and populations (inter-population). Mean size (total length and weight) was checked among habitats (in-habitat) and among populations (inter-population) using ANOVA. All analyses were performed using SPSS 20, and the figures were drawn in Excel.

Results

To perform population abundance analysis with high accuracy, a total of 14791 specimens of Caspian atherina were collected from their habitats and analyzed. The largest specimen had a total length (mm) of 126 mm in SC habitat, of 135 mm in SZ habitat, of 127 mm in BZ habitat, and of 123 mm in KZ habitat, indicating that the longest specimen observed was in SZ habitat, while the heaviest one was caught in BZ habitat. The maximum observed weight was 10.66 g in SC habitat, 11.05 g in SZ habitat, and 9.06 g in KZ habitat. All the largest specimens were female ones (Fig. 1).

Frequency density distribution (relative abundance) showed that most of the atherinids (33.4%) were found on the CZ habitat and only a small percentage (14.75%) was found on the BZ habitat (Fig. 2). Statistical analysis revealed a significant difference in abundance of the fish among habitats (χ^2 -test, $P < 0.05$).

Analysis of seasonal abundance of the species showed that not only is there a considerable difference in seasonal abundance among the habitats, but there are also significant differences in population abundance within each habitat between seasons (Fig. 3). The species showed the highest abundance in CZ,

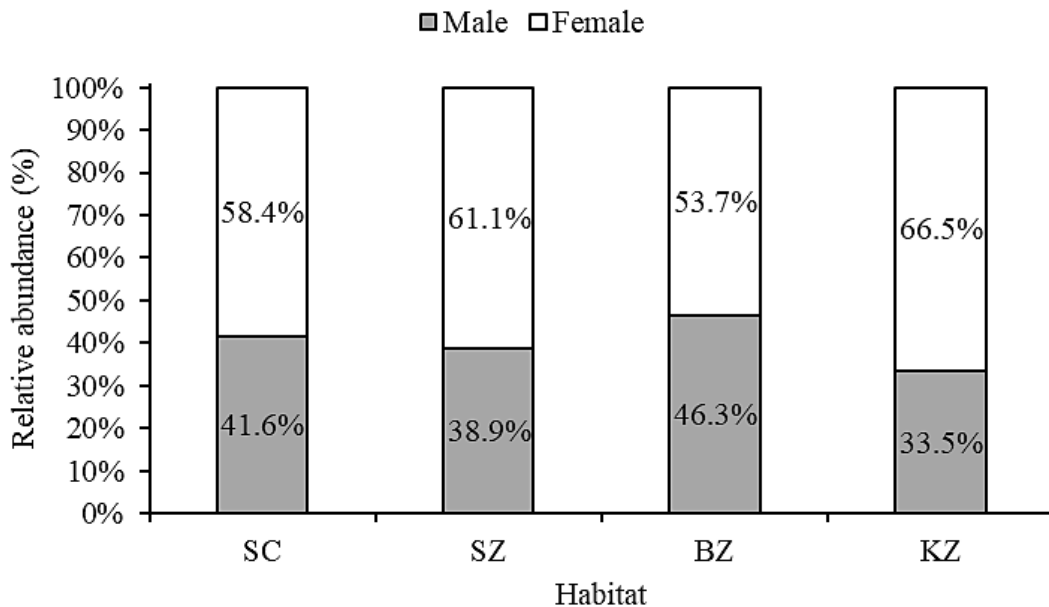


Figure 1. Mean size (length and weight) of *Atherina caspia* in the Gorgan Bay habitats- SE Caspian Sea.

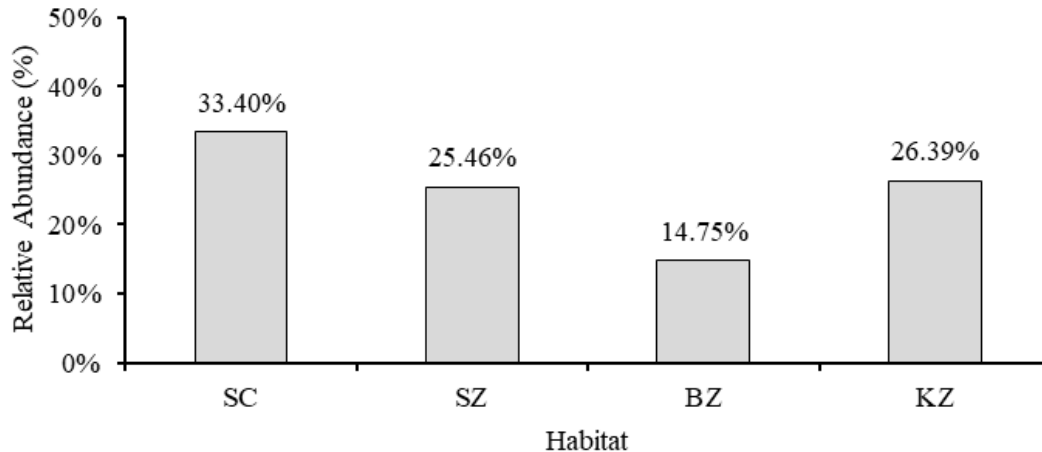


Figure 2. Distribution of the densities (relative abundance as %) of *Atherina caspia* in the Gorgan Bay habitats- SE Caspian Sea.

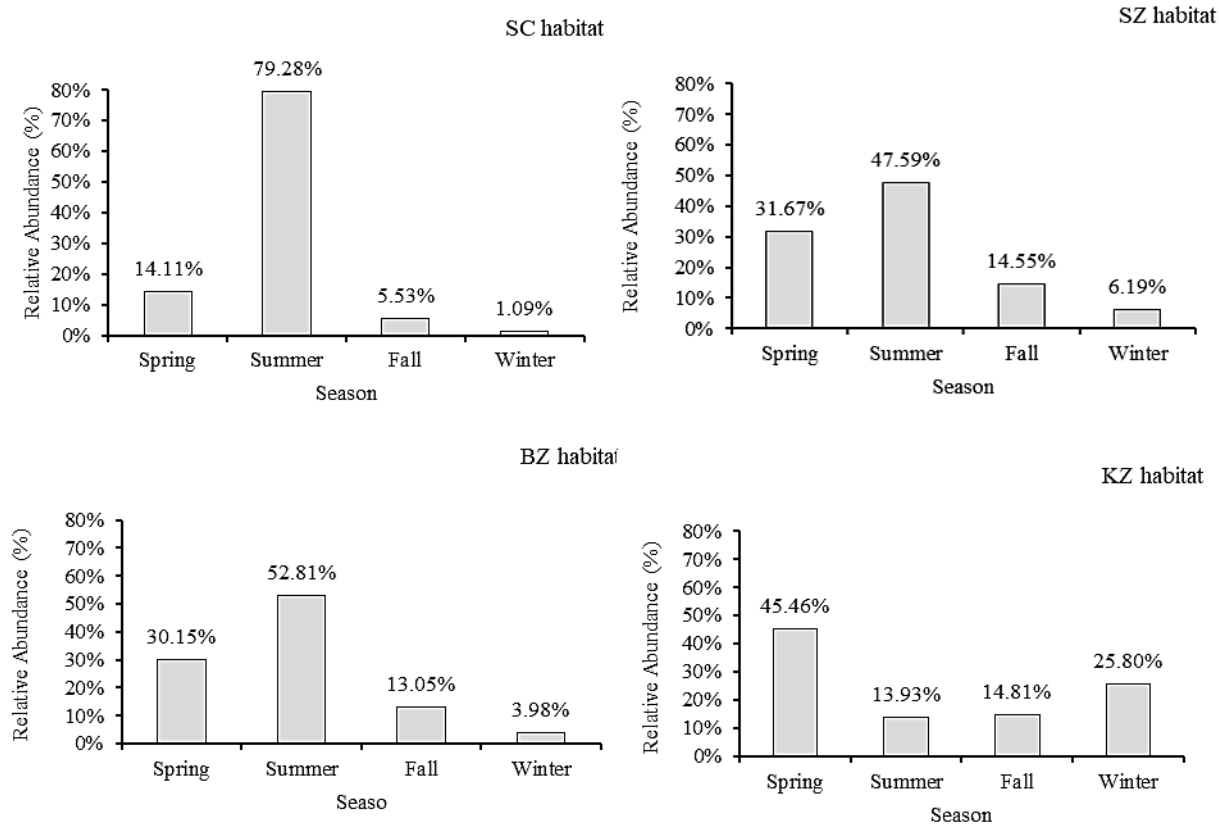


Figure 3. Monthly distribution of the densities (relative abundance as %) of *Atherina caspia* in the Gorgan Bay habitats- SE Caspian Sea.

SZ, and BZ habitats during summer, and the KZ habitat had the highest abundance in the spring season. Both inter-season-habitat and in-habitat-season abundance of the fish were significant (χ^2 -test, $P < 0.05$).

Comparison of size (including length and weight) showed that the fish size is a significant variable among habitats. The SZ habitat had longer and heavier individuals, whereas the SC habitat had smaller individuals in both length and weight ($P < 0.05$) (Fig. 4).

Sex ratios differed among habitats (χ^2 test, $P < 0.05$), with female dominance in all habitats. Although females were dominant across all areas, the intensity of female dominance varied among habitats; the relative abundance of females was highest in the KZ habitat and lowest in the BZ habitat.

Analysis of age composition revealed inter-population and in-habitat variability (χ^2 -test, $P < 0.05$). Age 1+ was dominant in SC and KZ habitats, while age 2+ dominated the population in SZ and BZ habitats (Fig. 5).

Discussions

In the literature, there are various reports on the biological parameters of this species from the southern Caspian (Ghorbanalidoost et al., 2003; Patimar et al., 2009; Amri-Sahebi et al., 2015; Zahedi and Rahimibashar, 2015; Taghavi et al., 2017; Harak-Atta et al., 2019; Houshmand et al., 2020). None of the studies, however, investigated temporal and spatial fluctuations in species' abundance as a measure of population density. However, because there is no information on methods for estimating the population abundance of this fish in the southern Caspian Sea, assessments of *A. caspia* abundance across different habitats in shallow coastal waters typically rely on counts of individuals captured during sampling. This information is essential for the development of population models. Coupling the population's parameters with the spatiotemporal abundance of the species will contribute to the effective management of local biodiversity and habitats.

The quantitative information in the present work provides insight into inter-population variability in

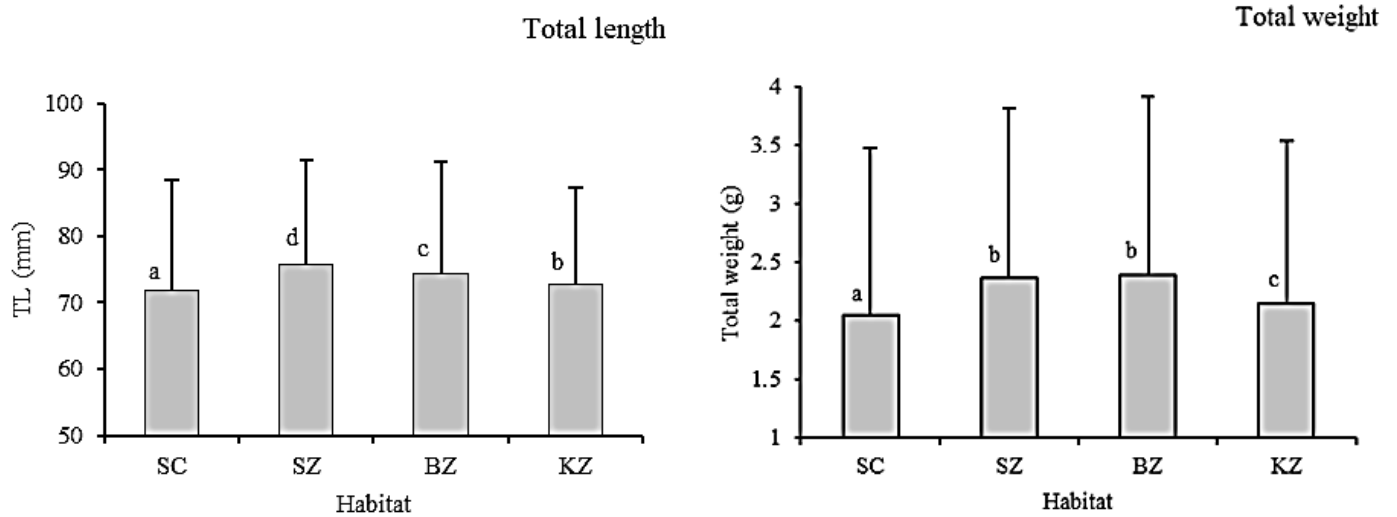


Figure 4. Mean size (length and weight) of *Atherina caspia* in the Gorgan Bay habitats- SE Caspian Sea.

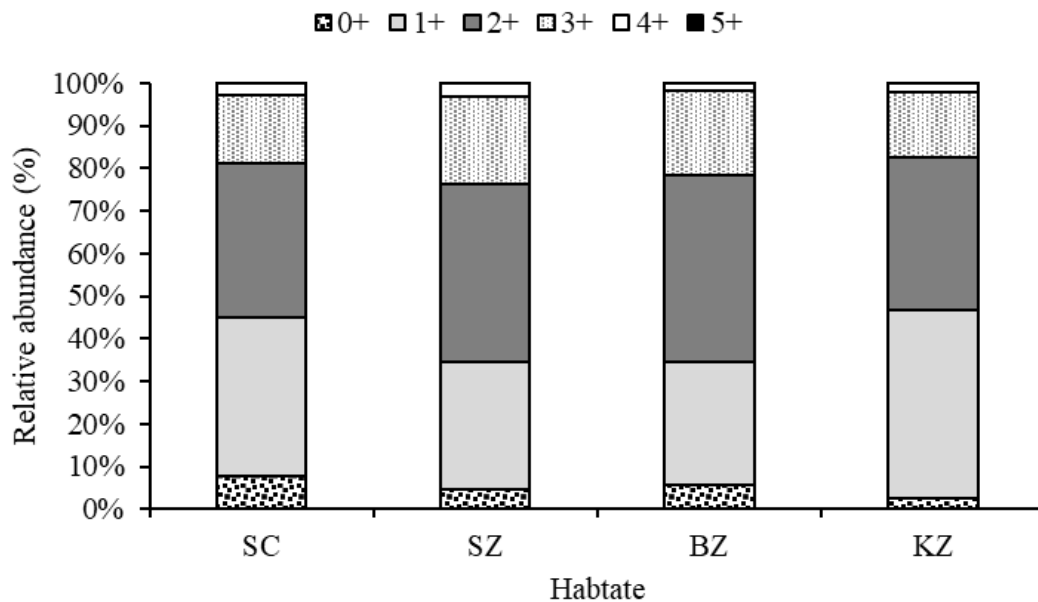


Figure 5. Age composition of *Atherina caspia* in the Gorgan Bay habitats- SE Caspian Sea.

A. caspia. A species' abundance is not inherent but is related to habitat- and population-specific characteristics, and is primarily affected by ecological conditions in those areas. However, the aim of this study was not to investigate the effects of ecological factors on this species' populations. In this context, the results provided both a detailed and a general view of the species' abundance across different habitats, which could be interpreted as variability in habitat preference of *A. caspia*. Totally, these findings are important for the species' demographic parameters.

Atherina caspia dominated the fish community of the Gorgan Bay (Maramaei, 2024) and the Gomishan

Wetland - SE Caspian Sea (Patimar et al., 2009). Generally, the size structure and abundance of a species with a wide distribution, such as *A. Caspia* in the Caspian Sea, varied through time and space, as observed in the populations of *A. boyeri* in a small non-tidal Mediterranean lagoon (Maci and Basset, 2010). *Atherina caspia* generally has a long spawning season, starting in March and extending until mid-summer (Patimar et al., 2009). Therefore, based on the observations, it was possible to suggest that the high abundance of this species in the study area during spring and summer could be related to its spawning migration to coastal areas in the SE Caspian Sea.

Additionally, in warmer months (spring and summer), the higher abundance of fish in these habitats may be related to greater food availability. Thus, the low number of individuals collected in the fall and winter suggests that this species leaves coastal areas after the spawning period and migrates to deeper waters. On the other hand, the cold season in the Gorgan Bay is less severe than in the northern Caspian, with temperatures rarely falling below 10°C, allowing a significant portion of the population to remain in shallow habitats. Based on our results, environmental parameters were not directly determined or related to fish abundance; rather, the results were based on individual abundance in each habitat. Using this procedure, we identified distinct abundance modes across habitats and estimated that *A. caspia* exhibits diverse population densities across areas. These results imply that different habitats in the shallow coastal areas make significant contributions to the species' population dynamics.

The abundance of *A. caspia* must vary among seasons within a single habitat, as the fish is likely affected by seasonal changes. This has been attributed to species responses to different ecological conditions (Patimar et al., 2009). However, clear differences in mean and maximum individual sizes were found among populations within habitats. Thus, the prediction of small-scale abundance patterns can be confirmed for *A. caspia* in the southern Caspian Sea. In fact, remarkable differences in abundance characterize populations of *A. caspia* inhabiting habitats that are relatively close to one another, suggesting that habitat features (such as abiotic or biotic conditions) determine population size and density more than ecosystem location does across ecoregional gradients (Mouludi-Saleh et al., 2020).

The results revealed differences in sex ratios among the four habitats, confirming the importance of small-scale structures and processes in driving reproductive movements in *A. caspia* populations. These observations suggest that a large proportion of females prefer to settle and spawn in the studied habitats, which offer more favorable conditions.

All this variability could be explained as a response

by the population to habitat-selective pressures and the “niche filtering” process (Zobel, 1997; Mouillot et al., 2007; Maci and Basset, 2010). However, these results underscore the need for further research into how ecological parameters drive population density in key areas (such as wetlands and estuaries) of the southern Caspian Sea. Future research should aim to better understand how variability in habitat ecological conditions may affect the species' abundance, reproduction, mortality, and feeding within coastal habitats. Based on the pattern of *A. caspia* abundance described here, we inferred population abundance processes in specific directions. The abundance patterns were consistent with the area's habitat type.

A general conclusion from our analysis is that differences in fish abundance among habitats can be considered a functional parameter for *A. caspia* populations. Additionally, the strait zone (SZ habitat: estuarine type) is the species' preferred habitat in the area. These results reinforce the need for a good knowledge of the habitats so as to better understand the complex habitat/species interactions influencing recruitment of Caspian fish populations

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