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Research Article

Study of environmental and three kilka species regime shifts in the Caspian Sea

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Abstract

One of the major sources of impacts on marine resources comes from climate variability and regime shifts. In this context, the present study pinpoints the role of climatic and environmental parameters on the dynamic of kilka in the Caspian Sea. During the last decades, landings and stocks of the main pelagic species of kilka had been changed dramatically in the Caspian Sea. This study focuses on the last three decades of the climate regime and tries to explain the part of the changes in the recruitment (R) and spawning stock biomass (SSB) of three kilka species. Based on the statistical analysis of data series, it is found that regime changes in the global and regional environmental variables started in the mid-1995s, however, the shift of the late 1990s (1998) was more strong in the Caspian Sea. The study further reveals that the global climatic indices changes in the late 1990s are triggering the regional and local indices induced regime shifts in the late 1990s and 2000s. The study concludes that the changes in populations of fish species, especially for kilka, could be due to the regime shift.

Keywords: Climate changes, Shelf waters, Caspian Sea, Kilka stocks, Regime shift

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Introduction

During the last century, the ecosystem of the Caspian Sea has been under excessive pressure such as sea-level fluctuation (Ressen *et al*., 2007), pollution (Ivanov, 2000), and invasive species (Shiganova *et al.*, 2005; Zarbaliyeva *et al.*, 2016). During three recent decades, the new comb jelly invasion *Mnemiopsis leidyi* affected the composition of the Caspian Sea ecosystem, especially with respect to loss of biodiversity (Roohi *et al.* 2010; Pourang *et al.*, 2016). Also, this unique ecosystem has been encountered in several anthropogenic pressures such as overfishing, and illegal poaching of fish (Abdolmalaki and Psuty, 2007; Daskalov and Mamedov, 2007; Fazli *et al.*, 2007, 2013; Tavakoli *et al*., 2019).

Johnson and Welch (2009) defined that one of the main sources of marine resource impacts is climate variability and regime shifts. Marine aquatic resources may be affected by gradual and continuous variability or sudden and high perturbation. Regime shifts are described as abrupt climate alterations (deYoung *et al.*, 2008). It is revealed that regime shifts are critical to ecosystem-based management (Levin and Möllmann, 2015).

Regime shifts have been reported by several researchers in the North Sea (Alheit *et al.*, 2005), the Baltic Sea (Möllmann *et al*., 2009), Atlantic Sea (Alheit *et al.*, 2014; Cabrero *et al.*, 2018). The coupled ocean-atmosphere phenomenon called El Nino-Southern Oscillation (ENSO) has a significant bearing on drought and has global impacts. In the context of the Caspian Sea, it has been documented that the relationship between ENSO and sea level (Arpe *et al*., 2000) has also the utmost importance for exploring the probability of drought. In the case of the global marine ecosystem, Beyraghdar Kashkooli *et al.* (2017) documented that the benthopelagic stocks respond to climatic events and it seems that the Caspian Sea confronts the regime shift and they have emphasized the need for more investigations for further supporting evidences.

Three small pelagic fish species, including common kilka (*Clupenella caspia*, Svetovidov 1941), anchovy kilka (*C. engrauliformis*, Borodin 1904), and bigeye kilka (*C. grimmi*, Kessler 1877) distributed in the Caspian Sea . These species are an integral part of the food chain and ecological health indices in the Caspian basin (Karimzadeh *et al.*, 2010). The stenohaline species, anchovy, and bigeye kilka are endemic and concentered in the central and southern Caspian, while common kilka is Ponto-Caspian distributed in the Black , Caspian and Azov Seas (CABI, 2019). These species are the main food items for predators such as sturgeons and seals (Prikhod'ko, 1979). On the other hand, they are accounting about 80% of the total catch in the Caspian Sea (Daskalov and Mamedov, 2007).

Small pelagic fish species react quickly to climatic events (Alheit *et al*., 2014; Cabrero *et al.*, 2018). Therefore kilka as one of the pelagic fishes, are supposed to respond to these conditions.

Several previous studies revealed the effects of overfishing and the invasive species (*M. leidyi*) on kilka stocks in the Caspian Sea (Daskalov and Mamedov 2007; Fazli *et al.*, 2007; Karimzadeh *et al.*, 2010; Pourang *et al*., 2016). However, two kilka species (Anchovy and Bigeye) stocks dropped and entered into a negative period (Fazli *et al.*, 2020), which they have not yet recovered. Therefore, the present study aimed to reveal how climatic and environmental parameters affect the dynamic of three kilka species in the Caspian Sea. This study focuses on the last three decades of the unexpected regime shift and tries to explain the high changes in the recruitment and spawning stock biomass of these species.

Materials and methods

Study area

The Caspian Sea, the largest lake on the earth, is located in the north of Iran. This study focuses on the deeper southern region over the Iranian shelf waters of the Caspian Sea. There are three fishing harbors on the Iranian coast: two fishing harbors (Amir-abad and Babolsar) in Mazandaran province and Bandar-e Anzali harbor in Gilan province (Fig. 1). The kilka fishing takes place at depths 40 to 100 m by conical lift nets at night which are equipped with two underwater electric lamps. The capacity of fishing vessels is 15-100 tons (Fazli *et al*., 2007).

Biological data

Kilkas landings data were taken from Iran Fisheries Organization (IFO) (http://www.shilat.com). The most important population component *i.e*. recruitment (R), and spawning stock biomass (SSB) of three kilka species were estimated by Stock Assessment Department in the Caspian Sea Ecology Research Center (CSERC) throughout 1994-2018 (Janbaz, 2020; Fazli *et al*., 2020). The biomass at age was estimated by using the biomass cohort analysis method (Zhang and Sullivan, 1988). Recruitments were calculated by dividing the biomass of age 1 by the average weight of this age. SSB of three species was estimated from the biomass multiplying the maturity index at each age (Fazli, 2007).

Environmental data

In this study, seventeen environmental variables on global, regional, and local spatial scales from 1991 to 2018 were obtained and used (Table 1). Global variables, with large-scale influence, were the East Atlantic pattern (EA), West Pacific pattern (WP), East Pacific-North Pacific pattern (EPNP), Pacific-North American pattern (PNA), East Atlantic-West Russian pattern (EA-WE), Southern Oscillation Index (SOI), North Tropical Atlantic index (NTA), Pacific decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO) and Arctic Oscillation (AO).

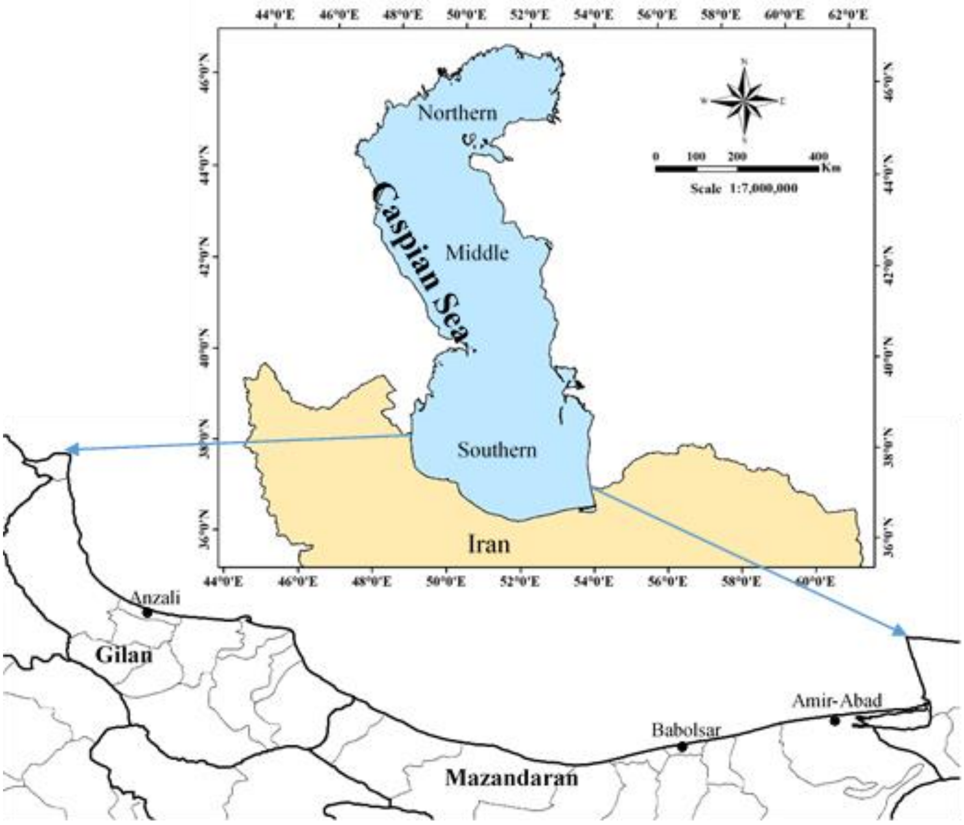

Figure 1: Map of the study area in the southern Caspian Sea.

Table 1: Summary of the environmental variables and sources of data.

Scale	Variable		Source of data
Global	EA	East Atlantic pattern	https://catalog.data.gov
	WP	West Pacific pattern	
	EP-NP	East Pacific-North Pacific pattern	
	PNA	Pacific-North American pattern	
	EA-WR	East Atlantic-West Russian	
	SOI	Southern Oscillation Index	https://cpc.ncep.noaa.gov/data/indices/soi
	NTA	North Tropical Atlantic index	https://esrl.noaa.gov/psd/forecasts/sstlim
	AO	Arctic Oscillation	https://ftp.cpc.ncep.noaa.gov
	PDO	Pacific Decadal Osciallation	http://jisao.washington.edu/pdo
	AMO	Atlantic Multidecadal Oscillation	https://esrl.noaa.gov/psd/data/timeseries/AMO
Regional	SST	Sea surface temperature	https://neo.sci.gsfc.nasa.gov
	SSL	Sea surface level	Caspian Sea National Research Center
Local*	DS	Duration of sunshine	Meteorological Organization of Mazandaran
	AT	Air temperature	
	EV	Evaporation	
	PR	Precipitation	
	RD	Rainy days	

*In Babolsar station

Two regional environmental variables- sea surface temperature (SST) and sea surface level (SSL) were investigated to assess the potential impact on the fish

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species dynamics in the Caspian Sea. Monthly averaged regional satellite-based environmental variable, i.e. SST with resolution 1˚×1˚ from NOAA website (https://neo.sci.gsfc.nasa.gov) is used to calculate the annual average of the southern part of the Caspian Sea (Fig. 1). Also, monthly sea surface level (SSL) was obtained from the Caspian Sea National Research Center (CSNRC), which is used as input data (Table 1).

Local indices were obtained from the Meteorological Organization of Mazandaran (MOM) from 1991 to 2018 (Table 1). These indices were measured in Babolsar meteorological station is relevant to the main kilka landing, which includes the duration of sunshine (DS), air temperature (AT), evaporation (EV), Precipitation (PR), rainy days (RD).

Statistical analysis

As described by Cabrero *et al.* (2018), principal components analysis (PCA) also called empirical orthogonal functions (EOF) is performed on environmental (Table 1) and biological data (landings, recruitment and spawning stock biomass of three kilka species) to identify the principal modes of variability. PCAs have been used for examples in dimensionality reduction and pattern extraction. The principal components of data, , which are given by PCA are orthogonal to each other. It means that every principal component will show a unique pattern and they have zero correlation in-between them. This orthogonal basis is derived by computation of the eigenvectors of a spatially weighted anomaly covariance matrix, and the corresponding eigenvalues give a measure of the percent variance explained by each pattern. Thus, EOFs of a space-time physical process (suppose to be represented by an environmental or biological variable) can represent mutually orthogonal space patterns. The data variance is concentrated, with the first pattern being responsible for the largest part of the variance, similarly the second for the largest part of the remaining variance, and so on. In nutshell, the PCA aims to find a new set of variables that capture most of the observed variance from the data through the linear combination of the original variables. In this viewpoint, PCA analysis was carried out to detect the biological changes and subsequently to elucidate their coupling with the environmental parameters

The Rodionov (2004) methodology is used to detect the regime shifts, based on a sequential t-test analysis on the time series data. The simplified Excel software program by NOAA was used to calculate the rigme shift index, RSI (https://www.beringclimate.noaa.gov/regimes). The cut-off length was set in 6 years, the significance level was set at 0.05, and the Huber parameter was set as 1. To elude autocorrelation and an increase in the number of incorrect regime shifts, prewhitening was executed before starting the regime shift identification. Red noise was built with the first-order autoregressive model

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(AR)1 and the coefficients were calculated by the ordinary least square method (OLS).

Results

Environmental data series

Three dominant modes explain the environmental variabilities, which account for 56.1% of the total variance. Loadings of the three PCs are presented in Table 2.

Table 2: Contribution of each variable to the principal components in the Caspian Sea.

Loadings Environmental variables	Principal components		
	1	**2**	**3**
EA	-0.2	-0.3	0.2
WP	0.1	0.1	-0.2
EPNP	0.2	-0.2	0.0
PNA	-0.1	-0.2	-0.4
EAWR	0.3	0.1	0.0
SOI	-0.2	0.2	0.0
NTA	-0.3	-0.2	-0.3
PDO	0.1	-0.4	-0.1
AMO	-0.3	-0.1	-0.2
AO	0.2	0.1	0.4
SST	-0.3	0.0	0.0
SSL	0.1	0.2	-0.4
B*_DS	-0.3	0.0	-0.1
B*_AT	-0.3	-0.1	0.1
B*_EV	0.2	0.0	0.2
B*_PR	0.2	0.0	0.1
B*_RD	0.2	-0.2	0.3
SST_April	-0.2	0.2	0.2
B*_AT April	-0.2	0.3	0.1
B*_DSApril	0.0	0.3	-0.3
B*_ PR April	0.1	-0.3	-0.3
B*_RD April	0.1	-0.4	0.1

*Babolsar meteorological station

The first mode (PC1) comprised 32.2% of the total variance, which was affected by East Atlantic - West Russian (EA-WR), North Tropical Atlantic Index (NTA), Atlantic Multidecadal Oscillation (AMO), meteorological variables like Sea Surface Temperature (SST), Duration of Sunshine (DS), and Air Temperature (AT) (Fig. 2a). PC2 (13.9%) seems to be influenced by East Atlantic pattern (EA), Pacific Decadal Oscillation (PDO), AT of April, DS of April, Precipitation (PR) of April, and Rainy Days (RD)of April (Fig. 2b). PC3 (10%) looks to be associated with Pacific-North American Pattern (PNA), North Tropical Atlantic Index (NTA), Arctic Oscillation (AO), and environmental variable Sea Surface Level (SSL), RD, DS , and PR of April (Fig. 2c).

Based on the regime shift analysis and the three modes of environmental parameters, four regime shifts were detected: 1995-98, 2002, 2011, and 2015 (Fig. 3a). The 1995-98 regime shift index is strong and seems to have an influence only on the PC1 of environmental variance. The 2002 regime shift index has an influence on the B_EV. The 2011 regime shift depicts the strongest index value and affects the SSL. The shifts identified close to the end of the series have to be dealt with caution, hence it is not considered.

Additionally, all environmental variables used in the PCA analysis were analyzed individually to determine which ones contribute each year. It shows that most of the regime shifts gather around the years 1995-98, 2002, and 2010s. (Fig. 3b).

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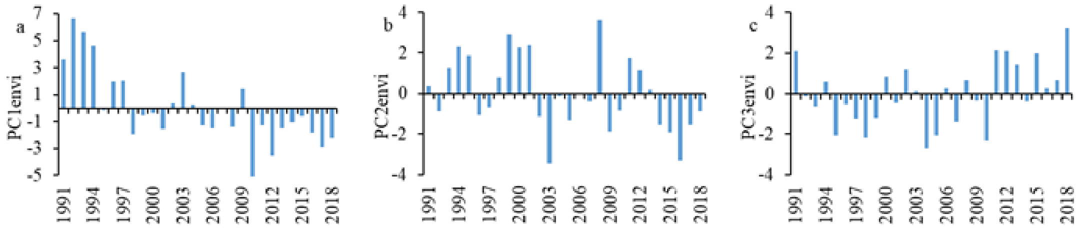

Figure 2: Environmental principal component time series.

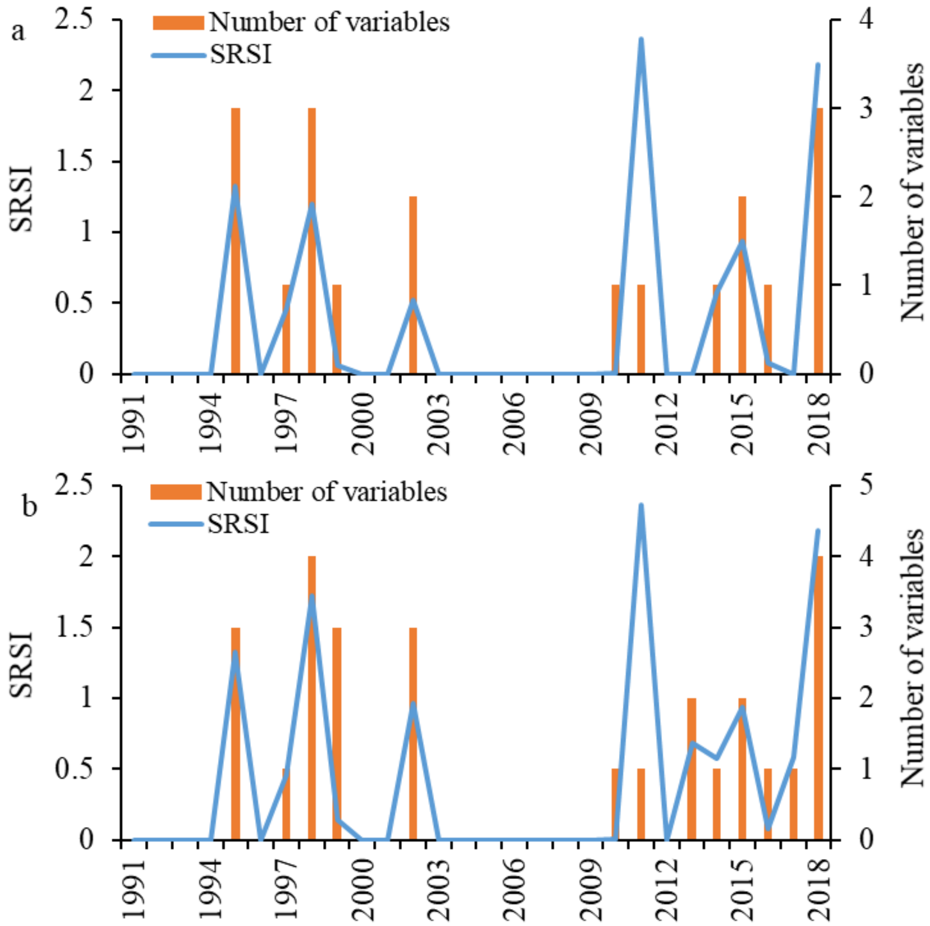

Figure 3: The number of variables that show a regime shift in a particular year (bars) and a sum of regime shift indices (solid line), (a) in environmental principal components (PCs), (b) in each one of the environmental variables joints to the environmental PCs.

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Fisheries variability and regime shifts

Regime shifts conducted to catch three pelagic species of kilka (Fig. 4) pinpoints that only one regime shift was detected for anchovy and bigeye kilka in the year 2001. In contrast, related to common kilka, there were three positive regime shifts in the years 1999, 2004, and 2009.

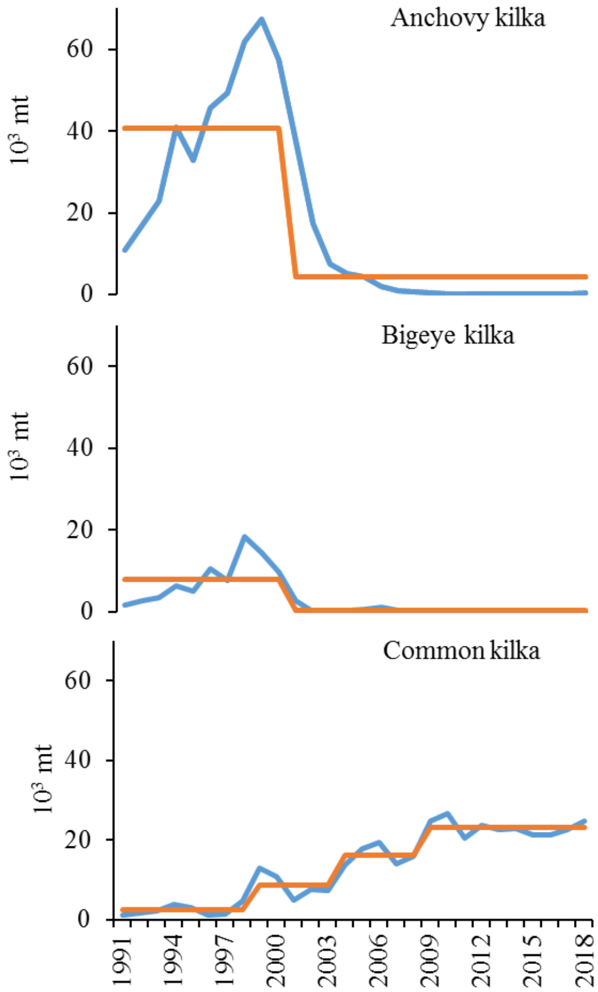

Figure 4: Landings regime shifts of three kilka species in the southern Caspian Sea.

Regime shift methodology was also executed to the recruitment (R) time series of three species of kilka. In the case of anchovy kilka, one regime shift in both absolute recruitment (R) and SSB was found in 2000. Related to bigeye kilka, one regime shift in recruitment (R) and SSB was detected in 1998 and 2000, respectively. In contrast, related to common kilka, a positive regime shift in both absolute recruitment (R) and SSB was found in 2003. The second positive regime in SSB was observed in 2008 (Fig. 5).

Relationship between environmental series and biological data of kilkas

During the last three decades, anchovy and bigeye kilka landings, recruitment (R), and SSB data series depict only one

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negative regime (Figs. 4 and 5). The first shift occurred in recruitment (R) of bigeye kilka in the year-1998. The next shift was observed in recruitment (R) and SSB of both species in the year2000. Then, a great negative shift happened in the landings of both species in 2001. In contrast, common kilka landings, recruitment (R), and SSB data series signify a great positive shift in 2003. Most of the environmental variables show a regime shift around the year of 1998 bigeye kilka recruitments shifts. These variables are related to East Atlantic Pattern (EA), East Pacific North Pacific Pattern (EP-NP), SOI (Southern Oscillation Index; shows the effect of El Nino or La Nina), PDO, SST, SST of April, AT of April, and DS (Fig. 6). The most important regional and local variables with the highest influence are SST, SST of April, and AT of April.

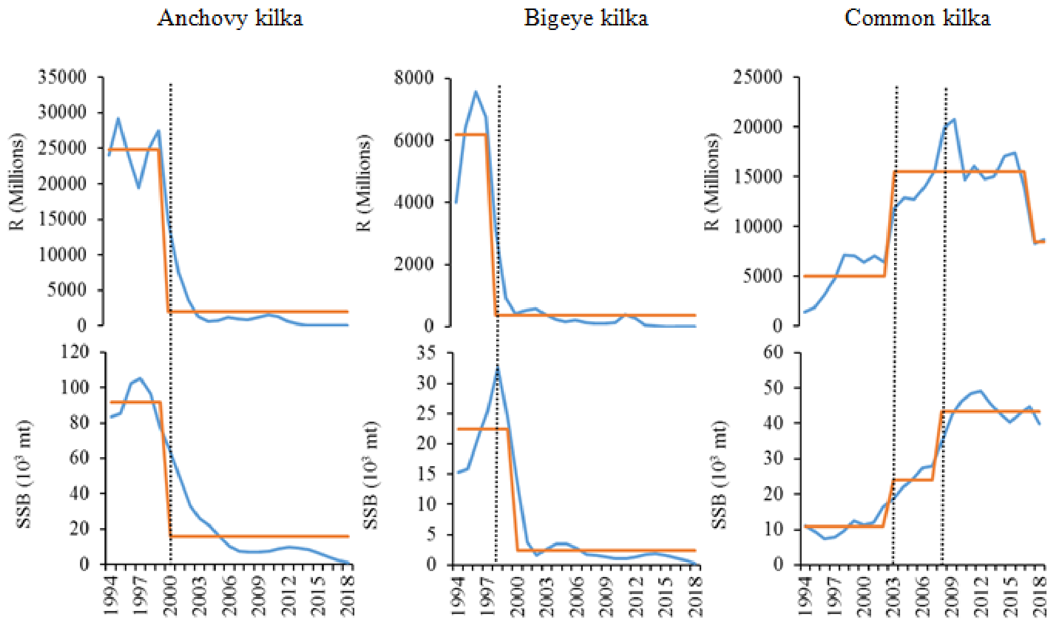

Figure 5: Recruitment (R) and spawning stock biomass (SSB) regime shifts of three species of kilka in the Caspian Sea. Dotted lines mark the environmental regime shifts.

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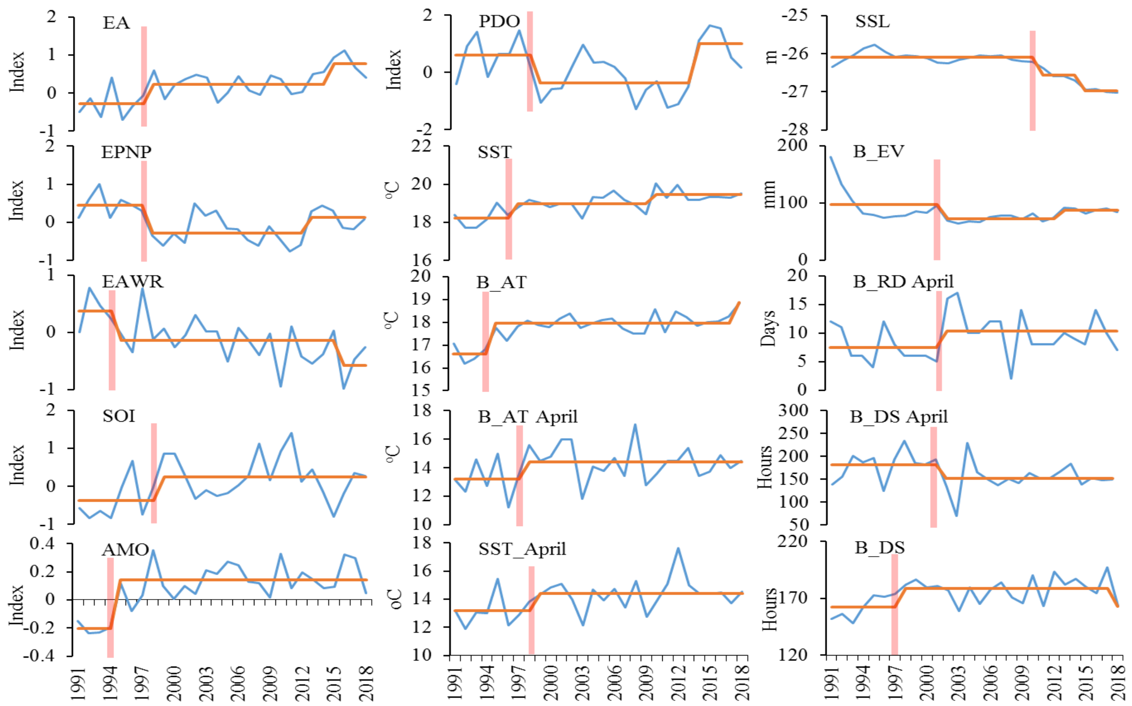

Figure 6: Global, regional, and local environmental time-series data regime shifts. Most of the environmental time series showing regime shifts around 1998.

Discussion

Based on extensive data series analysis, it is found that regime changes in the global and regional environmental variables started in the mid-1990s, although the shift of the late 1990s (1998) was more strong in the Caspian Sea. Similar results were reported in the southern Caspian Sea by using “shiftogram” method (Beyraghdar Kashkooli *et al*., 2017). They pointed out regime changes in the global environment variables from the late 1980s to the 1990s and regime changes in SST from 1991 to 2000, which confirms the results of the present study. Also, environmental conditions related to the regime shift of the mid-1990s were the core of sardine landings regime shift in the Iberian Atlantic shelf waters (Cabrero *et al*., 2018).

Serykh and Kostianoy (2020) explained the increase of AT from the late 1990s was related to the weakening of the North Atlantic influence on the Caspian region, coinciding with the decline in the sea level of the Caspian Sea. Changes in environmental parameters can affect any stage of life history. In the Caspian Sea, the fisheries regime shift fit with the 1998 environmental regime shift, which is well reflected all fisheries components and variations. The global environmental changes (Fig. 6) could be one of the key-factors for the wide range of changes in the Caspian ecosystem (Beyraghdar Kashkooli *et al*., 2017), especially on three small pelagic fish species of kilka.

EA and SOI patterns entered a positive phase on a large scale, and EPNP and PDO patterns changed negatively in

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1998. Positive EA is related directly to average surface temperature in Europe and indirectly to average precipitation across southern Europe (http://www.cpc.noaa.gov). According to Cabrero *et al.* (2018), EA and North Atlantic Oscillation (NAO is related to warmer and wetter winter in Southern Europe) could be a reason for the increase of water temperature. In the case of the Caspian Sea, Arpe *et al*. (2000) investigated the relation between SSL and NAO changes and concluded that the NAO influences the precipitation of the Volga region. In contrast, Beyraghdar Kashkooli *et al*. (2017) pointed out that the NAO regime shift is weak and a major influence of the Siberian High (SH) is triggering the SST regime shift in the Caspian Sea. In general, it suggested that the global climatic indices changes in the late 1990s are starting the regional (SST) and local indices (AT, RD, EV, and DS; Fig. 6) regime shift in the late 1990s and 2000s.

On the regional scale, the SST exhibited a strong positive regime shift in 1997. The increase in SST was influenced in the recruitment (R) regime shift of bigeye and anchovy kilka in 1998 and 2000, respectively. These changes could be explained as follows. These two species are concentrated in the central and southern Caspian Sea, it resists salinity and temperature changes (Prikhod'ko, 1979; Whitehead, 1985). On the other hand , the SSL of the Caspian Sea had an increasing trend during 1977-95 which caused a negative correlation between SSL and landings of kilka (Fazli *et al*., 2017). Bigeye and anchovy kilka catch comprise about 95% of the total kilka catch.

It seems that the environmental conditions/variables, especially SST and SSL, were the main reasons to explain the shifts in two species of kilka from the late 1990s to the 2000s. In contrast, common kilka is a euryhaline and eurythermal species, distributed in the whole of the sea in depths less than 100 m (Kottelat and Freyhof, 2007; Coad, 2017), had a different type of response. The rising SSL was an advantage to expand the suitable habitat for these species (Mamedov, 2006). Consequently, in the new condition during the late 1990s and 2000s, a negative regime shift in both absolute recruitment (R) and SSB was found for anchovy and bigeye kilka, and a positive regime shift for common kilka.

The positive correlation between recruitment (R) of anchovy and bigeye and SSL is surprising in 1994-2018. This phenomenon could be explained as follows. Seyedvalizadeh *et al.* (2020) tried to explain the role of SSL changes on the vertical water exchange at the inter-annual time scale. They pointed out that when SSL started falling in the 1970s, deeper water ventilation occurred and vertical circulation penetrates deeper and faster which expands oxygen and nutrient in the water column, it further provides more bio-productivity in the Caspian Sea. In contrast, they found, the last SSL fall (since 1995) had a different impact which reflecting as

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hypoxia due to global warming. They suggested that the new condition would lead to low bio-productivity and diversity in the south of the sea, which confirms the decreasing trend of two deeper pelagic species (anchovy and bigeye kilka) recruitments.

In conclusion, several studies revealed that the stocks of three pelagic fish species (kilka) change due to two parallel events, overfishing and the new invader species (*M. leidyi*) in the Caspian Sea, since the 2000s (Daskalov and Mamedov, 2007; Fazli *et al.,* 2020; Pourang *et al.*, 2016). Although, the abundance of comb jelly declined to the lowest level in the 2010s (Roohi *et al*., 2021), and the spring fishing season closed due to the reproduction season of kilka, but the stocks of two main kilka species (anchovy and big eye kilka) are still close to the lowest level and could not be recovered in the last decade (Fazli *et al*., 2020). Therefore, based on recent studies (Beyraghdar Kashkooli *et al.*, 2017), another main reason for the changes in populations of fish species especially for two main species of kilka could be the regime shift. It also can be attributed to the positive SST regime shift and stenothermal species, the stocks of these species have not been recovered in the 2010s.

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References

Abdolmalaki, S. and Psuty, I., 2007. The effects of stock enhancement of pikeperch *Sander lucioperca*) in Iranian coastal waters of the Caspian Sea. *The ICES Journal of Marine Science,* 64, 973-980. DOI:10.1093/icesjms/fsm062

Alheit, J., Möllmann, C., Dutz, J., Kornilovs, G., Loewe, P., Mohrholz, V. and Wasmund, N. 2005. Synchronous ecological regime shifts in the central Baltic and the North Sea in the late 1980s. *The ICES Journal of Marine Science,* 62, 1205–1215. DOI:10.1016/j.icesjms.2005.04.024

Alheit, J., Licandro, P., Coombs, S., Garcia, A., Giráldez, A., Santamaría MTG, Slotte, A. and Tsikliras, AC., 2014. Atlantic Multidecadal Oscillation (AMO) modulates dynamics of small pelagic fishes and ecosystem regime shifts in the eastern North and Central Atlantic. *The Journal of Marine Systems*, 133, 88–102. DOI:10.1016/j.jmarsys.2014.02.005

Arpe, K., Bengtsson, L., Golitsyn, G., Mokhov, I., Semenov, V. and Sporyshev, P.V., 2000.Connection between Caspian Sea level variability and ENSO. *Geophysical Research Letters*, 27, 2693-2696. DOI:10.1029/1999GL002374

Beyraghdar Kashkooli, O., Gröger, J. and Núñez-Riboni, I., 2017.

Qualitative assessment of climate-driven ecological shifts in the Caspian Sea. PLoS ONE, 12, 5, e0176892

CABI, 2019. Fallopia japonica In: Invasive Species Compendium CAB International, Wallingford, UK

Cabrero, Á., González-Nuevo, G., Gago, J. and Cabanas, J.M., 2018. Study of sardine (*Sardinapilchardus*) regime shifts in the Iberian Atlantic shelf waters. *Fisheries Oceanography*, 28(**3**), 305-316. DOI:10.1111/fog.12410

Coad, B.W., 2017. Review of the Herrings of Iran (Family Clupeidae). *International Journal of Aquatic Biology*, 5(**3**), 128-192

Daskalov, G.M. and Mamedov, E.V., 2007. Integrated fisheries assessment and possible causes for the collapse of anchovy kilka in the Caspian Sea. *The ICES Journal of Marine Science*, 64, 503-511. DOI:10.1093/icesjms/fsl047

deYoung, B., Barange, M., Beaugrand, G., Harris, R., Perry, R.I., Scheffer, M. and Werner, F., 2008. Regime shifts in marine ecosystems: Detection, prediction and management. *Trends in Ecology and Evolution*, 23, 402 – 409. DOI:10.1016/j.tree.2008.03.008

Fazli, H., 2007. Population dynamics and stock assessment of kilka (genus:Clupeonella) in Iranian waters of the Caspian Sea. PhD thesis, Pukyong National University. 145P.

Fazli, H., Zhang, C.I., Hay, D.E.- Lee, C.W., Janbaz, A.A. and Borani, M.S., 2007. Population ecological parameters and biomass of anchovy kilka *Clupeonella engrauliformis* in the Caspian Sea. *Fisheries Science,* 73, 285-294. DOI:10.1111/j.1444-2906.2007.01334.x

Fazli, H., Daryanabard, G.R., Abdolmaleki, S., Bandani ,G.A., 2013. Stock assessment and management implications of golden grey mullet (*Liza aurata* Risso, 1810) in Iranian waters of the Caspian Sea. *Journal of Applied Ichthyology*, 29, 431–436. DOI:101111/jai.12003

Fazli, H., Ghanghermeh, A.A., Shahifar, R., 2017. Analysis of landings and environmental variables time series from the Caspian Sea. *Environmental Resources Research*, 5(**1**), 1-11. DOI:10.22069/IJERR.2017.12124.1180

Fazli, H., Janbaz, A.A. and Khedmati, K., 2020. Risk of stock extinction in two species of kilkas (*Clupeonella engrauliformis* and *C grimmi*) from the Caspian Sea. *Iranian Journal of Ichthyology*, 7(**1**), 92-100. DOI:10.22034/iji.v7i1.371

Ivanov, V.P., 2000. Biological Resources of the Caspian Sea KaspNIRKh, Astrakhan. 96 P.

Janbaz, A.A., 2020. Investigation of some biological properties and stock assessment of Kilka fishes On the Iranian coastal of the Caspian Sea. Iranian Fisheries Research Organization (IFRO). 48 P.

Johnson, J.E. and Welch, D.J., 2009. Marine fisheries management in a changing climate: a review of vulnerability and future options. *Reviews in Fisheries Science*, 18, 106-124. DOI:10.1080/10641260903434557

Karimzadeh, G., Gabrielyan, B. and Fazli, H., 2010. Population dynamics and biological characteristics of kilka species (Pisces: Clupeidae) in the southeastern coast of the Caspian Sea *Iranian Journal of Fisheries Science*, 9(**3**), 422-433

Kottelat, M. andFreyhof, J., 2007. Handbook of European Freshwater Fishes Publications Kottelat, Cornol, Switzerland

Levin, P.S. and Möllmann, C., 2015. Marine ecosystem regime shifts: challenges and opportunities for ecosystem-based management. *Philosophical Transactions of the Royal Society B*, 370:20130275. DOI:10.1098/rstb.2013.0275

Mamedov, E.V., 2006. The biology and abundance of kilka (*Clupeonella* spp) along the coast of Azerbaijan, Caspian Sea. *ICES Journal of Marine Science*, 63(**9**), 1665-1673. DOI:10.1016/j.icesjms.2006.07.005

Möllmann, C., Diekmann, R., Müller-Karulis, B., Kornilovs, G. Plikshs, M. and Axe, P., 2009. Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: A discontinuous regime shift in the Central Baltic Sea Global Change. *Biology*, 15, 1377-1393 DOI:10.1111/j.1365-2486.2008.01814.x

Möllmann, C., Folke, C. and Edwards, M.. Conversi A. 2015. Marine regime shifts around the globe: theory, drivers and impacts. *Philosophical Transactions of the Royal Society BBiological Sciences*, 370. DOI:10.1098/rstb.2013.0260

Pourang, N., Eslami, F., Nasrollahzadeh Saravi, H. and Fazli, H., 2016. Strong biopollution in the southern Caspian Sea: the comb jelly *Mnemiopsisleidyi* case study. *Biological Invasions*, 18(**8**), 2403-2414. DOI:10.1007/s10530-016-1171-9

Prikhod'ko, B.I., 1979. Ecological features of the Caspian kilka (genus *Clupeonella*). *Journal of ichthyology*, 19(**5**), 27-37

Ressen, H., Lougheed, B., Aerts, J., De Moel, H., Ward, P. and Kwadijk, J.C.J., 2007. Simulating long-term Caspian Sea level changes: the impact of Holocene and future climate conditions. *Earth and Planetary Science Letters*, 261, 685-693. DOI:10.1016/j.epsl.2007.07.037

Rodionov, S.N., 2004. A sequential algorithm for testing climate regime shifts Geophysical Research Letters, 31, L09204. DOI:10.1029/2004GL019448

Roohi, A., Kideys, A.E., Sajjadi, A., Hashemian, A., Pourgholam, R., Fazli, H., Khanari, A.G. and Eker-Develi, E., 2010. Changes in biodiversity of phytoplankton, zooplankton, fishes and macrobenthos in the Southern

Caspian Sea after the invasion of the ctenophore *Mnemiopsisleidyi*. *Biological Invasions*, 12, 2343-2361. DOI:10.1007/s10530-009-9648-4.

Roohi, A., Kideys, A.E., Naderi Jolodar, M., Afraei Bandpei1, M., Mokarami Rostami, A. 2021. Long-term changes in gelatinous zooplankton, mesozooplankton and kilka fish in the Southern Caspian Sea: Environmental controls and trophic webs interactions. *Journal of Oceanography and Marine Science*. (in press).

Serykh, I. V. and Kostianoy, A. G., 2020. The Links of Climate Change in the Caspian Sea to the Atlantic and Pacific Oceans. *Russian Meteorology and Hydrology*, 45(**6**). 430–437.

Seyed Valizadeh, M., Alizadeh Ketek Lahijani, H. and Siadatmousavi, S.M., 2020. South Caspian vertical circulation during rapid sea level rise and fall. *Caspian Journal of Environmental Sciences*, 19, 19-29

Shiganova, T.A., Musaeva, E.I., Pautova, L.A. and Bulgakova, Yu.V., 2005. The Problem of Invaders in the Caspian Sea in the Context of the Findings of New Zoo- and Phytoplankton Speciesfrom the Black Sea. *Biology Bulletin*, 32(**1**), 65–74. DOI:10.1007/s10525-005-0011-8

Tavakoli, M., Fazli, H., Moghim, M., Khoshghalb, M.R, Valinasab, T. and Abdolmaleki, S., 2019. Population ecological parameters and stock assessment of Russian sturgeon *Acipensergueldenstaedti* Brandt Ratzeburg, 1833 in the Southern Caspian Sea. *Journal of Applied Ichthyology*, 35(**1**), 378-386. DOI:10.1111/jai.13730

Whitehead, P.J.P., 1985. FAO Species Catalogue Volume 7 Clupeoid fishes of the world (suborder Clupeioidei) An annotated and illustrated catalogue of the herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings FAO. *Fish Syno*, 125(**7/1**), 1-303.

Zarbaliyevab, T.S., Akhundovb, M.M., Kasimova, A.M., Nadirovb, S.N., Hyseynovab, G.G., 2016. The Influence of Invasive Species on the Caspian Sea Aboriginal Fauna in the Coastal Waters of Azerbaijan. *Russian Journal of Biological Invasions*, 7(**3**), 227–236. DOI:10.1134/S2075111716030139

Zhang, C.I. and Sullivan, P.J. ,1988. Biomass-based cohort analysis that incorporates growth. *Transactions of the American Fisheries Society*, 117, 180-189. DOI:10.1577/1548-8659(1988)117<0180:BBCATI>2.3.CO;2