Iranian Iranian Journal of Fisheries Sciences 21(2) 372-386 2022
DOI: 10.22092/ijfs.2022.126294

Research Article

Relationship between shrimp catches per unit effort (CPUE) and satellite-based environmental parameters in Persian Gulf, Bushehr provincial waters

Aeinjamshid Kh.[1*]; Rabbaniha M.[2]; Fazelpoor Kh.[3]; Moradi G.[1]; Nasouri M.[4]

Received: September 2021 Accepted: January 2022

Abstract

In the present study relationship between shrimp catch per unit effort (CPUE) and satellite-based environmental parameters, chlorophyll-a (Chl-a) and sea surface temperature (SST), was investigated in 27 stations in Bushehr provincial waters in the geographical position from E 50˚ 44΄ and N 28˚ 59΄ to E 51˚ 40΄ and N 27˚ 33΄, in July 2017 and July 2018. SST and Chl-a data were extracted from +ETM Landsat 7 sensor and Modis Aqua (EOS PM) satellites images. Four research surveys were conducted using a traditional vessel to record local physico-chemical parameters of water and estimate shrimp catch per unit effort (CPUE) in studied stations.

The results of linear regression analysis and correlation coefficient showed a negative and strong relationship between SST- Chl-a overlap value and shrimp CPUE in waters of Bushehr province (r = -0.84), while weak negative and positive relationships were observed between SST and chlorophyll-a with shrimp CPUE with r = -0.34 and 0.03, respectively.

Keywords: Shrimp, Catch per unit effort, Environmental parameters, Satellite data, Bushehr, Persian Gulf

1-Shrimp Research Center, Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization, Bushehr, Iran.
2-Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization, Tehran, Iran.
3-Department Sistemasy Recursos Naturales, ETSI Montes, Forestalesy Medio Natural, Universidad Politécnica de Madrid, Madrid, Spain.
4-Department of Environment, Aras international campus, University of Tehran, Tehran, Iran.
[*]Corresponding author's Email: kh.aeinjamshid@areeo.ac.ir

Introduction

Persian Gulf waters' unique physical and biological conditions accommodate flourishing biodiversity. Productivity of Persian Gulf, which has supported fisheries for thousands of years, is seriously impacted due to environmental change, pollution and overfishing (Aein Jamshid *et al*., 2011).

Aquatics tend to aggregate in a particular environment for reproduction and feeding. Their ability to perform these functions is dependent on physical and chemical characteristics of the environment. Life of aquatic organisms is highly dependent on specific thermal conditions in aquatic environments; water temperatures above or below optimal thermal regimes can cause stress or even death. Changes in ecological water conditions affect the diversity and abundance of all living and non-living organisms in aquatic environments, such as plankton, fish and other organisms. Increasing water temperature increases salinity, decreases oxygen solubility in water, nutrition, and growth and even increases aquatic mortality (Brander, 2010; Drinkwater *et al*., 2010). In ocean waters, high chlorophyll concentrations are closely linked to high productivity (Deshpande *et al*., 2011).

First attempts on stock assessment of *Penaeus semisulcatus* in Bushehr waters was implemented in 1982 by Azimi (1985). Two projects were conducted on biology and population dynamics of *P. semisulcatus* by researchers of Persian Gulf Fisheries Research Center in Bushehr provincial waters in 1991 and 1992 (Ghasemi and Niamaimandi, 1994). In Bushehr provincial waters shrimp fishing is currently managed based on reducing daily catch per unit effort to prevent overfishing. Under this strategy, annual catch rate (catch per unit effort, CPUE) is used as an index of shrimp stock abundance to define opening and closure of shrimp fishing season (Niamaimandi *et al*., 2008). The shrimp fishing season in Bushehr provincial waters lasts approximately six to eight weeks each summer. The season is opened when 70% of the shrimp stock is greater than 12 cm TL, and subsequently closed when the CPUE index indicates that 20% of shrimp stock is remained. On average, this corresponds to approximately 40 kg/day (for large and small vessels). The results of Niamaimandi *et al.* (2007) investigation showed that *P. semisulcatus* shrimp were overexploited in Bushehr waters. Exploitation of *P. semisulcatus* in Bushehr waters is managed intending to protect spawners and juveniles in the stock for renewal.

Annual mean surface and bottom water temperatures in Iranian part of Persian Gulf are recorded as 26.8 and 23.3°C, respectively. The lowest water temperature was recorded in winter at 18°C, and its highest value was 34.2°C in summer. A decrease in temperature was observed from eastern to western parts of Persian Gulf (Aein Jamshid *et al*., 2011). The annual mean surface and bottom Chlorophyll in Persian Gulf were recorded as 0.44 and 0.55 mg/m3, respectively. The lowest and highest values of Chlorophyll were recorded as 0.1 and 1.6 mg/m3 in summer and

[DOR: 20.1001.1.15622916.2022.21.2.12.0]

autumn, respectively (Izadpanahi *et al*., 2005).

Remote sensing is a powerful tool for monitoring ocean conditions on a global scale and at high spatial and temporal resolution. In addition, satellite data are increasingly used to derive relevant ecosystem indicators (Polovina and Howell, 2005).

Earlier studies showed that satellite-derived fishery-aid data could reduce 25-50% in US commercial fisheries search time (Laurs *et al*., 1984). Satellite remote sensing is an essential technique in fishery research, management and harvesting because it provides synoptic ocean measurements for evaluating environmental influences on abundance and distribution of fish populations and allows ecological analyses at community and ecosystem scales (Stuart *et al*., 2011). The present work aimed to study the relationship between shrimp stocks with satellite-based ecological data of seawater in Persian Gulf to find a suitable way to optimize aquatic resources based on remote sensing.

Materials and methods

Study Area

The studied area includes 27 stations from Ra's-e-Shatt, near Bushehr city to Motaf area in Bushehr provincial water, in geographical positions from of E 50˚ 44´ and N 28˚ 59´ to E 51˚ 40´ and N 27˚ 33´, in July 2017 and July 2018 (Fig. 1 and Table 1).

Determination of shrimp CPUE

Four research surveys were conducted to calculate shrimp CPUE in July 2017 and July 2018. The first and second research cruises were carried out from 29/6/2017 to 2/7/2017and from 8/7/2017to 11/7/2017 sampling from the coast of Bushehr city to Motaf area in 27 stations. The third and fourth research cruises were carried out from 1/7/2018 to 3/7/2018 and 11/7/2018 to 13/7/2018 in the 27 studied stations (Fig. 1). Sampling was implemented using a traditional ship (bottom trawler with 24 m length and 360 horsepower engine). Before and after sampling with bottom trawl net, geographical position, depth, time, and direction were recorded at each station. A speed of 3 knots was maintained during sampling. Sub-samples were randomly collected from the total catch (5-10% of catch volume, about 5 Kg) to record biometric characteristics of shrimps, including total number, weight and length based on Roper *et al*. (1984) and Dore and Frimodt (1987). CPUE was calculated using equation no. 1 (Sparre and Venema, 1998):

Equation 1: $CPUE = Cw / t$

Where C_w is weight of shrimp catch (kg) and t is shrimp fishing time (hours).

Satellite data processing

Images of ETM+ sensor (Path 163, Row 40 and 41) of Landsat 7 satellite with a resolution band of 30 meter were used to extract sea surface temperature (SST) and chlorophyll (Chl-a) data.

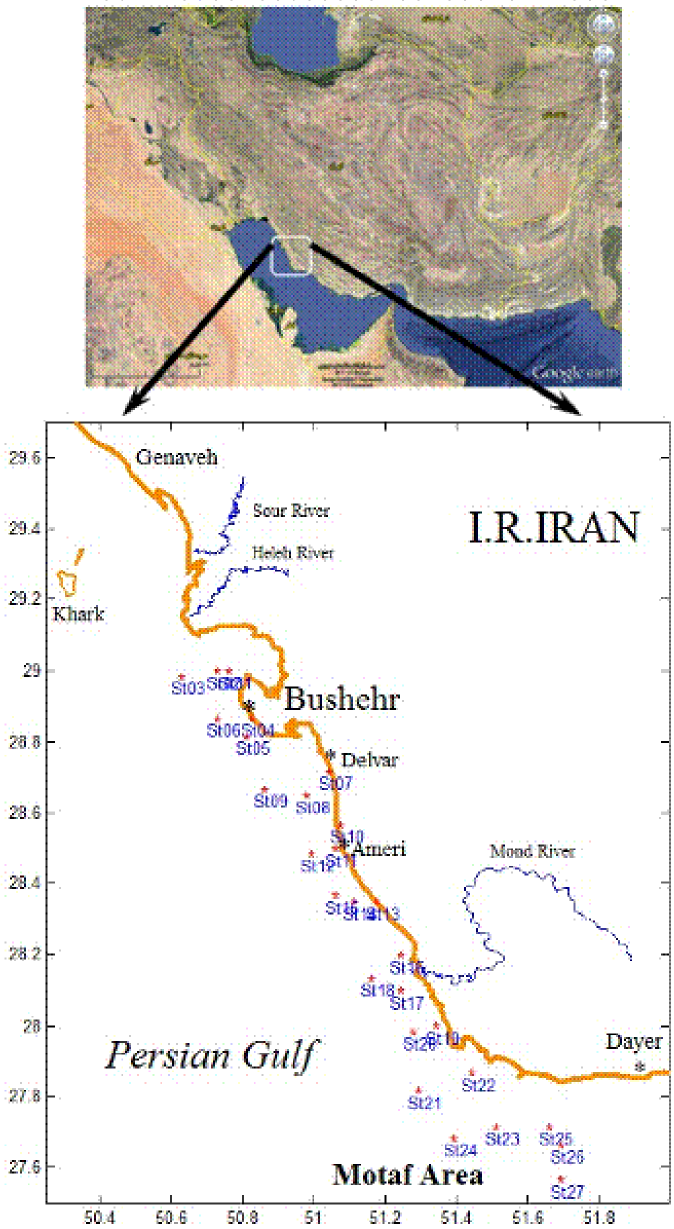

Figure 1: Map of the study area in Bushehr provincial waters, 2017-2018.

Table 1: Geographical position of the study area in Bushehr provincial waters, 2017-2018.

Station	Area	Depth (m)	Latitude		Longitude	
			deg	min	deg	min
1	Ra's-e-Shatt 1	8.56	28	59	50	44
2	Ra's-e-Shatt 2	15.75	28	59	50	42
3	Ra's-e-Shatt 3	29.82	28	58	50	36
4	Halileh 1	8.51	28	51	50	48
5	Halileh 2	19.66	28	48	50	47

Table 1 (continued):

Station	Area	Depth (m)	Latitude		Longitude	
			deg	min	deg	min
6	Halileh 3	30.46	28	51	50	42
7	Bashi 1	4.93	28	42	51	1
8	Bashi 2	15.18	28	38	50	57
9	Bashi 3	27.03	28	39	50	50
10	Rostami 1	8.67	28	33	51	3
11	Rostami 2	16.23	28	29	51	2
12	Rostami 3	27.29	28	28	50	58
13	Kelat 1	10.05	28	20	51	9
14	Kelat 2	20.12	28	20	51	5
15	Kelat 3	27.7	28	21	51	2
16	Mond River 1	10.93	28	11	51	13
17	Mond River 2	15.92	28	5	51	13
18	Mond River 3	24.36	28	7	51	8
19	Ra's-e-Khan 1	7.53	27	59	51	19
20	Ra's-e-Khan 2	19.85	27	58	51	15
21	Ra's-e-Khan 3	24.7	27	48	51	16
22	Nakhiloo 1	8.61	27	51	51	25
23	Nakhiloo 2	19.29	27	42	51	29
24	Nakhiloo 3	27.54	27	40	51	22
25	Motaf 1	8.6	27	42	51	38
26	Motaf 2	11.74	27	39	51	40
27	Motaf 3	22.29	27	33	51	40

Landsat 7 satellite images were obtained from Earth Explorer at: https://earthexplorer.usgs.gov. Global algorithms for SST and Chlorophyll were extracted and calibrated for waters of Bushehr Province. The model used to calculate SST was MCSST, which is more accurate due to zenith angles of the satellite and atmospheric correction. MCSST was calculated based on equation no. 2 (Iron, 2012):

Equation 2: Modis_SST = C1 + C2 * T31 + C3 * T3132 + C4 * (sec (ϴ) - 1) * T3132

Where T31 is brightness temperature of band 31, T3132, brightness temperature difference of band 31 and 32 and ϴ is zenith angle of the satellite. C1, C2, C3 and C4 are coefficients for MODIS bands 31 and 32 SST global algorithm.

The satellite zenith was extracted from the satellite image's initial data, and its value was calculated for all image pixels.

OCEAN SEVEN 316 CTD device used for recording ground-based physico-chemical parameters including, temperature (°C), salinity (ppt), conductivity (ms/cm), dissolved Oxygen, pH and chlorophyll-a to calibrate satellite data at studied stations. The data were recalculated to assess accuracy of the proposed algorithm using satellite images in July 2017.

Surface chlorophyll was calculated based on equation no. 3.

Equation 3: Chl-a = (0.0979 * Exp (2.5926 * B2 / B1))

Where B1 and B2 are band numbers.

Relationship between shrimp CPUE and physico-chemical data

Pearson's correlation and ANOVA tests were used to determine the relationship between shrimp CPUE and physico-chemical parameters. Also fuzzy overlay of studied parameters was calculated. Fuzzy overlay analysis is based on set theory, where permit entities to be partial members of different, overlapping attribute classes. This model is used to identify the areas which satisfy a particular ecological condition (Baidya *et al*., 2014). SST and chlorophyll-a data overlap was performed using ArcGIS 10.2 software in Spatial Analysis section, → Fuzzy Overlay, → using MSSmall method. For fuzzy data process, the data were changed from discrete to continuous data. After data normalization, the coefficient of overlap was considered between 0 and 1. Zero data overlap indicated a higher value, and 1 indicated absence or a low value.

Data processing and statistical analysis were done by SPSS 21, Excel 2010 and ArcGIS 10.2 soft wares.

Results

Shrimp CPUE

Summary results of calculated shrimp CPUE data of four research cruises, conducted in July 2017 and July 2018, are shown in Figure 2 and Table 4.

Average shrimp catch per unit effort (CPUE) in first and second cruises in July 2017 were 9.2 and 11.6 kg/h, respectively. The highest amount of shrimp was observed around Mond river estuary, and the lowest amount was observed in the coastal area with a depth less than 10 meters in July 2017. During third and fourth cruises in July 2018, average shrimp CPUE were 9.4 and 5.7 kg/h, respectively. The highest shrimp was captured in Ra's-e-Khan, around Mond river estuary and Nakhiloo areas. The lowest amount of shrimps was observed in Halileh and Bashi areas in July 2018.

Physico-chemical data

Summary results of ground-based physico-chemical data in the studied area in July 2017 are presented in Table 2. Sea surface temperature and chlorophyll-a of seawater in the studied area, extracted from satellite image, were compared with ground-based physico-chemical data, recorded by CTD in research cruises. The results showed a positive strong relationship between ground-based and satellite-based surface water temperature in the studied area (r=+0.84) (Table 2). Also, a positive strong relationship existed between ground-based and satellite-based chlorophyll-a in the studied area (r=+0.75). Averages SST in the studied area in July 2017 and July 2018 were 31.46°C and 31.34°C, respectively (Table 3).

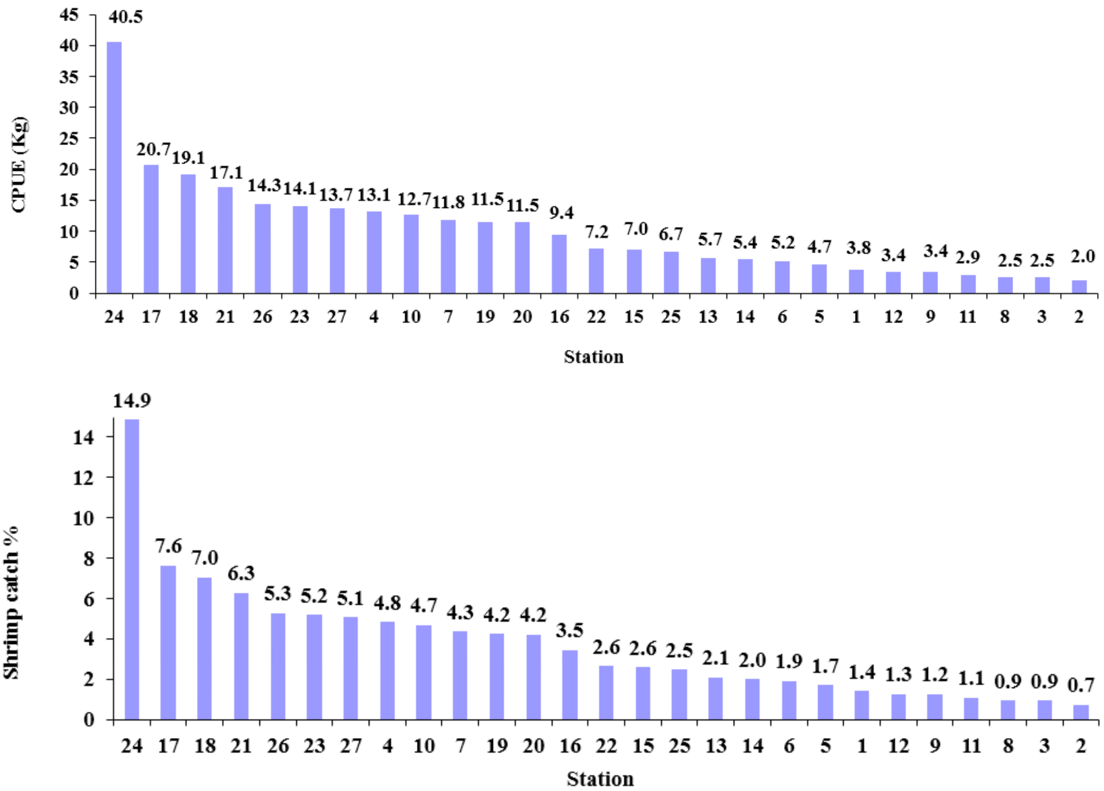

Figure 2: Average shrimp CPUE (top) and percentage of shrimp catch (bottom) in studied stations in waters of Bushehr province, July 2017 and July 2018.

Table 2: Average physico-chemical parameters in sea surface and bottom layers of waters of Bushehr province, recorded using CTD device in July 2017.

	Water Temp (°C)	Conductivity (ms/cm)	Salinity (ppt)	DO (mg/L)	pH	Chl-a (µg/ L)
Surface Layer	31.24	65.00	38.55	7.29	8.30	0.35
Bottom Layer	29.74	63.64	38.81	7.48	8.29	0.99
Average	30.22	63.93	38.63	7.52	8.30	0.77

Table 3: The correlation coefficients of ground-based and satellite-based data in waters of Bushehr province, July 2017.

	Sat SST	Sat Chl-a	CTD Temp	CTD Chl-a
Sat SST	1.00			
Sat Chl-a	-0.39	1.00		
CTD Temp	0.84	-0.31	1.00	
CTD Chl-a	-0.36	0.75	-0.35	1.00

The minimum SST was 30.00°C at Ra's-e- Khan-1 station (St 19) in July 2018, and its maximum value reached 32.47°C at Ra's-e-Shatt-3 station (St 03) in July 2018. Averages Chlorophyll-a in the studied area in July 2017 and July 2018 were 0.35 µg/ L and 0.63 µg/ L, respectively (Table 4). The minimum Chlorophyll-a was 0.31 µg/ L at Motaf -2 station (St 26) in July 2017, and its maximum value reached 1.02 µg/ L at Mond River-2 station (St 17) in July 2018. Averages SST-Chl overlap values in the studied area in July 2017 and July 2018 were 0.62 and 0.50, respectively (Table 4). Minimum SST-Chl overlap value was 0.07 at Nakhiloo-1 station (St 22) in July 2018, and its maximum value reached 1.00 at Ra's-e-Shatt 2, Helileh-1, Helileh-3, Rostami-1, Kelat-3 and Mond River-1 stations (St 02, 04, 06, 10, 15 and 16) in July 2017 (Figs. 3 and 4).

Table 4: Average chlorophyll-a and sea surface temperature extracted from ETM+ sensor images of Landsat 7 satellite, calculated by corrected algorithm for the studied area, SST-Chl Overlap and CPUE data in waters of Bushehr province, July 2017 and July 2018.

Parameter	Year	2017	2018
SST (°C)	Average	31.46	31.34
	Min	30.58	30.00
	Max	32.9	32.47
Chl-a (µg/ L)	Average	0.35	0.63
	Min	0.31	0.49
	Max	0.9	1.02
SST-Chl overlap	Average	0.62	0.50
	Min	0.15	0.07
	Max	1.00	0.90
CPUE (g)	Average	7394	7823
	Min	430	260
	Max	40000	27260

Relationship between shrimp CPUE and physico-chemical data

Results of ANOVA and statistical analysis of studied data are collected in Tables 5, 6 and Figure 5. Correlation coefficient of SST with shrimp CPUE value was -0.34, and correlation coefficient of chlorophyll-a with shrimp CPUE value was 0.03. These two parameters showed a weak relationship with shrimp CPUE, but correlation coefficient of SST-Chl overlap with shrimp CPUE value was significant (r=-0.84). ANOVA results showed that relationship between SST-Chl overlap and shrimp CPUE with a level of 6.84E-07 (p<0.05) was significant. These results indicated a linear correlation between these parameters (Table 6).

[DOR: 20.1001.1.15622916.2022.21.2.12.0]

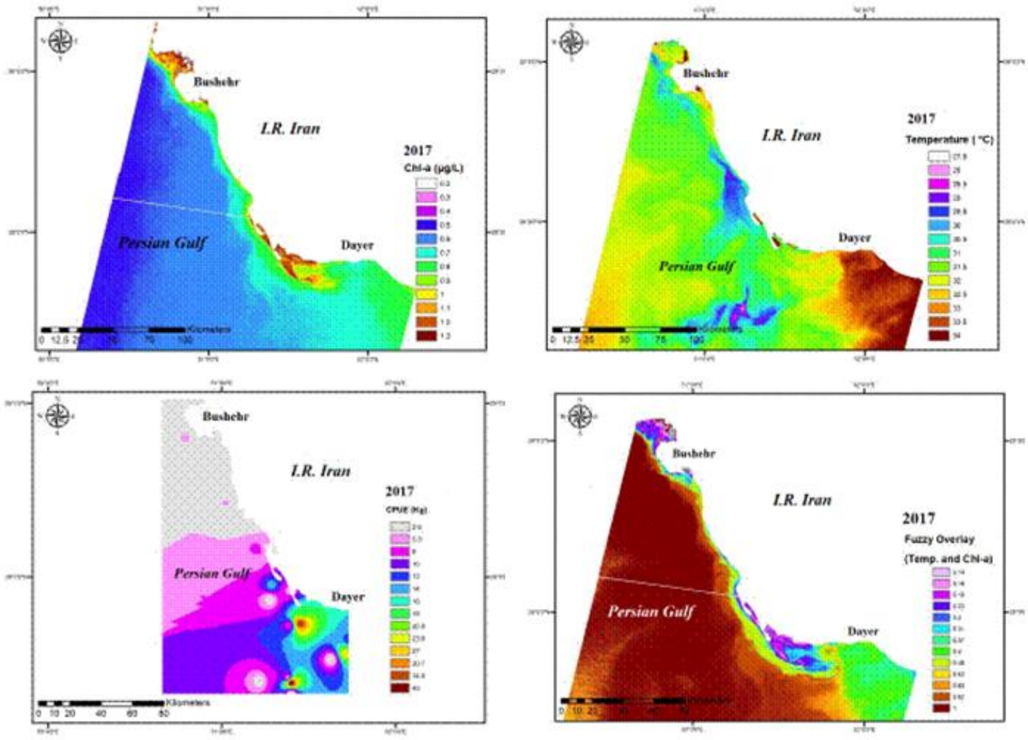

Figure 3: Chlorophyll-a (top-left) and sea surface temperature (top-right) maps, extracted from ETM+ sensor images of Landsat 7 satellite, CPUE distribution (bottom-left) and SST-Chl overlap (bottom-right) in waters of Bushehr province, July 2017.

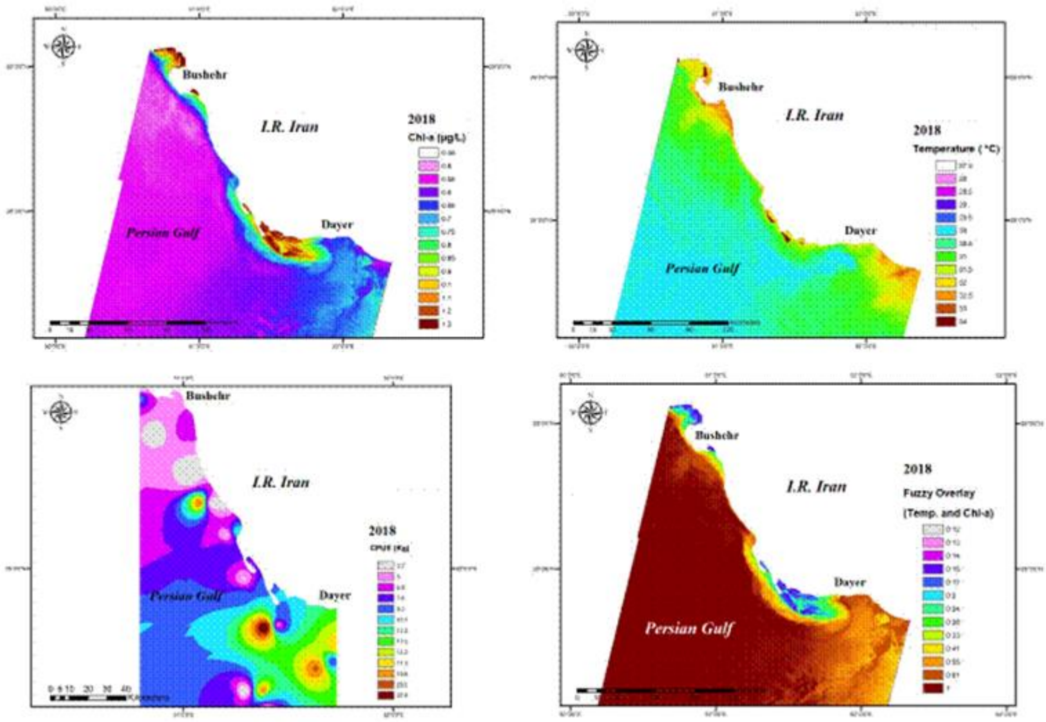

Figure 4: Chlorophyll-a (top-left) and sea surface temperature (top-right) maps, extracted from ETM+ sensor images of Landsat 7 satellite, CPUE distribution (bottom-left) and SST-Chl overlap (bottom-right) in waters of Bushehr province, July 2018.

Table 5: Correlation coefficients of chlorophyll-a, SST, SST-Chl overlap and shrimp CPUE in waters of Bushehr province, July 2017 and 2018.

Parameter	SST	Chl-a	SST-Chl overlap	CPUE
SST	1			
Chl-a	0.16	1		
SST-Chl overlap	0.07	-0.39	1	
CPUE	-0.34	0.03	-0.84	1

Table 6: ANOVA results of SST-Chl overlap and shrimp CPUE in waters of Bushehr province, July 2017 and 2018.

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8.26E+08	1	8.26E+08	31.92096	6.84E-07	4.026631
Within Groups	1.35E+09	52	25878595			
Total	2.17E+09	53				

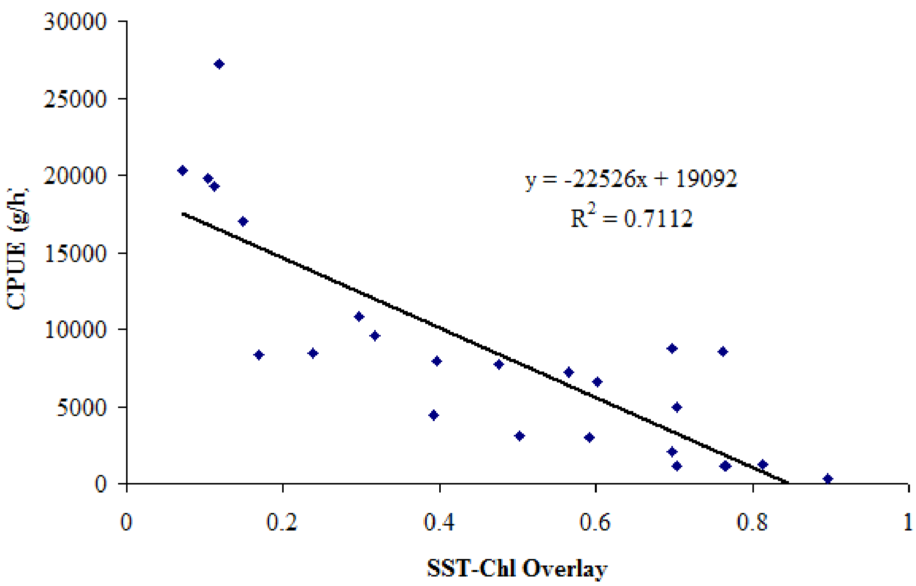

Figure 5: Linear regression between SST-Chl overlap and shrimp CPUE in waters of Bushehr Province, July 2017 and July 2018.

Discussion

Growth, reproduction and survival of aquatics are related to environmental water condition. The most important environmental parameters affecting aquatic organisms are temperature, nutrients, and salinity of water resources. Every aquatic species needs optimal and unique ecological condition for its maximum growth. Growth of aquatics decreases at temperatures above or below optimum temperature, which is specific for each aquatic species. Change in seawater ecological condition affect diversity and abundance of all living organisms in aquatic environment, such as plankton, fish and other organisms. Increasing water temperature and decreasing amount of nutrients reduce abundance of phytoplankton as primary producers and thus lead to reduced growth rate, adaptation, spawning efficiency, migration and ultimately increased aquatic mortality (Lehodey, 2001; Brander, 2010; Drinkwater *et al.*, 2010). Optimum temperature for shrimp growth depends on its age, from 28 to 30 degrees Celsius (Kumlu *et al.*, 2000).

The results of linear regression analysis and correlation coefficient showed a negative strong relationship between SST-Chl overlap value and shrimp CPUE in waters of Bushehr province (r=-0.84) (Tables 5 and 6 and Fig. 5), while weak negative and positive relationships were observed between SST and chlorophyll-a with shrimp CPUE, r=-0.34 and 0.03, respectively (Table 5). A strong negative correlation between SST-Chl overlap and shrimp CPUE revealed that value of CPUE in studied stations increases with decrease in SST-Chl overlap value. As previously described in Materials and Methods section, lower overlap of SST-Chl indicates a higher value of SST and Chl, and higher overlap of SST-Chl indicates absence or a low value of SST and Chl. So, in stations in which SST and Chl values were more, shrimp CPUE was more.

The lowest value of SST-Chl overlap was at Nakhiloo-1 (St 22), Rostami-1 (St 10), Motaf-1 (St 25), Ra's-e-Khan-1 and 2 (St 19 and 20) and Mond River-3 and 2 (St 18 and 17) stations. These results are consistent with results of "Green tiger shrimp stock assessment and determination of shrimp season in Bushehr province waters" research projects conducted from 2002 to 2016. Based on these projects results, more than 60% of shrimps are captured in Nakhilo (St 23 and 24), Mond River (St 17 and 18), Ra's-e-Khan (St 21), Motaf (St 26 and 27) and Rostami (St 10) stations (Khorshidian, 2007; Moradi, 2011; Moradi *et al.*, 2016). A negative relationship between SST and shrimp CPUE revealed that the value of CPUE in studied stations decreased with increasing SST.

Santamaría *et al.* (2011) studied the effect of climate variability on shrimp fishery in upper Gulf of California, and west coast of southern Baja California using artisanal and industrial catches of blue shrimp (*Penaeus stylirostris*) and brown shrimp (*Penaeus californiensis*). Catch data were compared with Southern Oscillation Index (SOI) and remotely sensed environmental parameters, including sea surface temperature, chlorophyll-a, coloured dissolved organic matter, and particulate organic carbon (Rrs412 and Rrs490). Overall, temperature was the best environmental indicator of commercial shrimp catches. Catches of blue shrimp varied directly and brown shrimp indirectly with SOI in their dominant areas, suggesting that El Nino conditions influence the two species differently.

Li and Clarke (2005) studied the relationship between sea surface temperature and brown shrimp (*Penaeus aztecus*) population in Gulf of Mexico during 1987–2000. Their results showed that annual number and weight of brown shrimp per trawl were positively correlated with annual sea surface temperature (SST) averaged over the continental shelves. Correlations of monthly anomalous SST by calendar month with the annual shrimp data were highest in April and May. Past work suggested a possible reason for this: juvenile brown shrimp, which mainly develop from post-larvae in coastal estuaries in April and May, grow faster in warmer waters and are more likely to escape predators. Since juvenile shrimp population is a good predictor of adult shelf shrimp population, and since estuarine and shelf SST are closely linked, it is reasonable that April and May shelf SST be positively correlated with the number and weight of brown shrimp per trawl.

Aein Jamshid (2016) studied the relationship between shrimp landing and fish capture with air temperature and precipitation in ports of Deylam, Bushehr and Dayaer in Bushehr province from 2004 to 2011. He reported a strong negative relationship between shrimp landing with average air temperature during rainy months (November to April) in Bushehr province. Based on these results, shrimp capture decreased with increasing air temperature in Bushehr province. Due to increasing sea surface temperature and hot conditions of 2010 El-Nino, total shrimp landing in Bushehr province was declined from 1431 tons in 2009 to 847 tons in 2010. No significant relationship was observed between precipitation and shrimp landing. A moderate negative correlation was also observed between fish capture with an average annual air temperature in Bushehr province. The precipitation had a moderate positive relationship with fish capture in Bushehr province. The results of the current work were consistent with findings of this study.

Results of Mondal *et al*. (2021) investigation on habitat suitability modelling for feeding ground of juvenile albacore in southern Indian Ocean (SIO) showed a high correlation (R2=0.8276) between temperature and ocean chlorophyll with CPUE for albacore habitat in SIO.

SST, Chlorophyll, rainfall, salinity, yearly degree cooling month (DCM) and surface currents all significantly influenced marine fisheries along Kerala coast. Lower SST, high salinity and rainfall promote fisheries of small and large pelagic groups like scads. Along with negative relationship between SST and fishery, the analyses also showed a positive relationship with yearly DCM, indicating that coastal waters' warming negatively impacts fisheries along Kerala coast (Punya *et al*., 2021).

Based on the results of the current study, there was a strong and positive relationship between inverse fuzzy overlay of sea surface temperature (SST) and Chlorophyll- a with shrimp CPUE in the studied stations in Bushehr provincial waters in 2017 and 2018. By integrating satellite data of SST and Chlorophyll and providing a distribution map of this parameter, it is possible to guide fishermen to shrimp aggregation areas.

Shrimp stocks are managed by determining the opening-closure time for allowed shrimp fishing season. By guiding the fishermen to shrimp aggregation areas, it is possible to catch the shrimps in the shortest time and reduce the impact of shrimp trawling on seabed and the marine environment. It also could lead to reduced shrimp searching time, reduced cost of fishing, saving fuel consumption, and ultimately improving socio-economic condition of fishermen.

Acknowledgment
This work was funded by Iran National Science Foundation (INSF 94001730). The researchers are very thankful for this support.

References:

Aein Jamshid, K., 2016. Effects of drought on aquatic stocks in Bushehr province. *Iranian Journal of Marine Science and Technology*, 20(**77**), 44-50.

Aein Jamshid, K., Owfi, F., Nikouyan, A. R., Mortazavi, M. S., Sanjani, S. and Rabaniha, M., 2011. Effects of war on the ecological condition of the Persian Gulf (Iranian Parts). *Journal of the Persian Gulf*, 2(**4**), 41-50.

Azimi, A., 1985. *Final report on shrimp resources survey project in Bushehr coast of the Persian Gulf.* Persian Gulf Fisheries Research Center, Bushehr, Iran, 56 P. Research report in Persian.

Baidya, P., Chutia, D., Sudhakar, S., Goswami, C., Goswami, J., Saikhom, V., Singh, P.S. and Sarma, K.K., 2014. Effectiveness of fuzzy overlay function for multi-criteria spatial modeling—A case study on preparation of land resources map for Mawsynram Block of East Khasi Hills district of Meghalaya, India. *Journal of Geographic Information System*, 6(**6**), 605-612. https://doi.org/10.4236/jgis.2014.66050.

Brander, K., 2010. Impacts of climate change on fisheries. *Journal of Marine Systems*, 79(3-4), 389-402. https://doi.org/10.1016/j.jmarsys.2008.12.015.

Deshpande, S.P., Radhakrishnan, K.V. and Gopalakrishna Bhat, U., 2011. Direct and indirect validation of potential fishing zone advisory off the coast of Uttara Kannada, Karnataka. *Journal of Indian Society Remote Sensing.*, 39(**4**), 547–554. https://doi.org/10.1007/s12524-0104-4.

Dore, I. and Frimodt, C., 1987. *An illustrated guide to shrimp of the world.* Osprey Publishing, Oxford, UK, 229 P.

Drinkwater, K.F., Beaugrand, G., Kaeriyama, M., Kim, S., Ottersen, G., Perry, R.I., Pörtner, H.O., Polovina, J.J. and Takasuka, A., 2010. On the processes linking climate to ecosystem changes. *Journal of Marine Systems*, 79(**3-4**), 374-388. https://doi.org/10.1016/j.jmarsys.2008.12.014.

Ghasemi, S. and Niamaimandi, N., 1994. *Biological parameters of Penaeus semisulcatus at different depths of the Persian Gulf, Iranian waters.* Iranian Fisheries Research

Organization, Tehran, Iran, final research report in Persian.

Iron, J. 2012. Landsat 7 science data user's handbook, in, Report 430- 15-01-003-0. National Aeronautics and Space Administration [online]. Available from: http://landsathandbook. gsfc. nasa. gov/[Accessed 6 July 2012], 2011.

Izadpanahi, Gh., Aein Jamshid, K., Mohsenizadeh, F., Omidi, S., Haghshenas, A., Asadi Samani, N., Mohammad Nejad, J., Hossein Khezri, P. and Rabaniha M., 2005. *Hydrology and hydrobiological study of the Persian Gulf in the Bushehr region.* Iranian Fisheries Research Organization, Tehran, Iran, final research report, in Persian.

Khorshidian, K., Moradi, G., Khodadadi, R., Shabani, M.J., Mobarrezi, A. and Keshtkar, E., 2007. *Monitoring of green tiger prawn stock in Bushehr province.* Iranian Fisheries Research Organization, Shrimp Research Center, Bushehr, Iran, final research report, in Persian.

Kumlu, M., Eroldogan, O.T. and Aktas, M., 2000. Effects of temperature and salinity on larval growth, survival and development of *Penaeus semisulcatus*. *Aquaculture*, 188(**1-2**), 167-173. https://doi.org/10.1016/s0044-8486(00)00330-6.

Laurs, R.M., Fiedler, P.C. and Montgomery, D.R., 1984. Albacore tuna catch distributions relative to environmental features observed from satellite. *Deep Sea Research Part A. Oceanographic Research Papers*, 31(**9**), 1085-1099. https://doi.org/10.1016/0198-0149(84)90014-1.

Lehodey, P., 2001. The pelagic ecosystem of the tropical Pacific Ocean: dynamic spatial modelling and biological consequences of ENSO. *Progress in Oceanography*, 49(**1-4**), 439-468. https://doi.org/10.1016/s0079-6611(01)00035-0.

Li, J. and Clarke A.J., 2005. Sea surface temperature and the brown shrimp (*Farfantepenaeus aztecus*) population on the Alabama, Mississippi, Louisiana and Texas continental shelves. *Estuarine Coastal and Shelf Science*, 64(**2**), 261-266. https://doi.org/10.1016/j.ecss.2005.02.019.

Mondal, S., Vayghan, A.H., Lee, M.A., Wang, Y.C. and Semedi, B., 2021. Habitat suitability modeling for the feeding ground of immature albacore in the southern Indian Ocean using satellite-derived sea surface temperature and chlorophyll data. *Remote Sensing*, 13(**14**), 2669. https://doi.org/10.3390/rs13142669.

Moradi, G., 2011. *Study and determination of exploitation pattern of water shrimp reserves in Bushehr province.* Shrimp Research Center, Bushehr, Iran, final research report, in Persian.

Moradi, G., Shabani, M.J., Mobarzi, A. and Esmaili, A., 2016. *Determining the opening of closure of green tiger shrimp season in Bushehr* *province.* Iranian Fisheries Science Research Institute, Shrimp Research Center, Bushehr, Iran, final research report, in Persian.

Niamaimandi, N., Arshad, A.B., Daud, S.K., Saed, R.C. and Kiabi, B., 2007. Population dynamic of green tiger prawn, *Penaeus semisulcatus* (De Haan) in Bushehr coastal waters, Persian Gulf. *Fisheries Research*, 86(**2-3**), 105–112. https://doi.org/10.1016/j.fishres.2007.05.007.

Niamaimandi, N., Arshad, A.B., Daud, S.K., Saed, R.C. and Kiabi, B., 2008. Reproductive biology of the green tiger prawn (*Penaeus semisulcatus*) in coastal waters of Bushehr, Persian Gulf. *ICES Journal of Marine Science*, 65(9), 1593–1599. https://doi.org/10.1093/icesjms/fsn172.

Polovina, J.J. and Howell, E.A., 2005. Ecosystem indicators derived from satellite remotely sensed oceanographic data for the North Pacific. *ICES Journal of Marine Science*, 62(**3**), 319–327. https://doi.org/10.1093/j.icesjms.2004.07.031.

Punya, P., Kripa, V., Padua, S., Mohamed, K.S. and Nameer, P.O., 2021. Impact of environmental changes on the fishery of motorized and non-motorized sub-sectors of the upwelling zone of Kerala, southeastern Arabian Sea. *Estuarine Coastal and Shelf Science*, 250, 107144. https://doi.org/10.1016/j.ecss.2020.107144.

Roper, C.F.E., Sweeney, M.J. and Nauen C.E., 1984. *FAO species calalogue. Volume 3. Cephalopods of the world.* FAO Fisheries Synopsis, 125(**3**), 277 P. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Santamaría-Del-Angel, A.E., Millán-Nuñez, R., González-Silvera S., Callejas-Jiménez, J.M., Cajal, M.R. and Galindo, B.M.S., 2011. The response of shrimp fisheries to climate variability off Baja California, México. *ICES Journal of Marine Science*, 68, 766–772. https://doi.org/10.1093/icesjms/fsq186.

Sparre, P. and Venema, S.C., 1998. *Introduction to tropical fish stock assessment. Part 1. Manual.* FAO Fisheries Technical Paper No. 306.1, Rev. 2, 407 P. Food and Agriculture Organization of the United Nations, Rome, Italy.

Stuart, V., Platt, T. and Sathyendranath, S., 2011. The future of fisheries science in management: a remote-sensing perspective. *ICES Journal of Marine Science*, 68(**4**), 644-650. https://doi.org/10.1093/icesjms/fsq200.