Iranian Journal of Fisheries Sciences 17(1) 74-94 2018
DOI: 10.22092/IJFS.2018.115586

Essential fish habitats (EFH) of small pelagic fishes in the north of the Persian Gulf and Oman Sea, Iran

Salarpouri A.[1]; Kamrani E.[1*]; Kaymaram F.[2]; Mahdavi Najafabadi R.[3]

Received: October 2015 Accepted: March 2016

Abstract

Small pelagic fishes particularly anchovy (Encrasicholina punctifer) and sardine (Sardinella sindensis) have an important role to support the Iranian fisheries and are distributed along the coastal waters of the Persian Gulf and Oman Sea. Using a logbook on small pelagic fisheries, a GIS-based environmental modeling approach was applied to investigate the presence and abundance of anchovy and sardine in relation to environmental variables. Redundancy analysis (RDA) was applied to provide a preliminary view of the relationships between fish presence/absence and environmental variables. Generalized Additive Models (GAMs) indicated the presence/absence of fish was related to distance from the nearest coast, depth, sea surface Chlorophyll-a, and SST. Results of the EFH showed that sardine is concentrated in specific areas of more favorable conditions, such as north of the Persian Gulf and all areas of the northwest of the Oman Sea. However, EFH of anchovy showed a more widespread distribution, occupying most of the north-west of the Oman Sea coastal waters, south of Qeshm Island in the Strait of Hormoz as well as the Parsian district in the north of the Persian Gulf. In this study, it seems that the anchovy showed the probability of presence in the areas with more distance from the coastal waters. However, the EFH probability presences of sardine were predicted for near coastal water and obviously, shallower waters. Due to the development of small pelagic fisheries, it is highly recommended to investigate anchovy and sardine fishing possibility in areas with high EFH prediction probability.

Keywords: Small pelagic fishes, Essential fish habitat, Marine environment, Persian Gulf, Oman Sea.

1-Fisheries Department, Faculty of Marine Science and Technology, Hormozgan University, Bandar Abbas, Iran. P.O. Box; 3955
2-Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research Education and Extension Organization (AREEO), P.O. Box: 14965/149. Tehran, Iran.
3-Department of Natural Resources Engineering, Hormozgan University, Bandar Abbas, Iran.
*Corresponding author's Email: ehsan.kamrani@hormozgan.ac.ir

Introduction

Small pelagic fish species belonging to the family Clupeidae (including sardine and anchovy) thrive in the productive pelagic waters of upwelling ecosystems and have long supported large fisheries systems around the world (Schwartzlose *et al*., 1999). Management of small pelagic fisheries is confounded by large variability in population size (Cushing, 1971; Blaxter and Hunter, 1982). Anchovies and sardines are also ecologically important, because their large biomass is a link in coastal food-webs, transferring the energy in plankton and small organisms to larger fishes, seabirds and marine mammals (Ganias, 2014). Populations of sardines and anchovies support the marine ecosystem of the Persian Gulf and Oman Sea as food for other fishes. In addition, they play a very important role in the livelihood and sustainable employment for indigenous people in the Iranian coastal areas (Salarpouri *et al*., 2012; Dehghani *et al.***,** 2016). Total catch of small pelagic fishes rose to 57 thousand tonnes (65% anchovies and 35% sardines) in 2014, and they make up 25 percent of the total landed fishes in Hormozgan province, Iran (Alizade and Oliaei, 2015). A variety of species of small pelagic fishes are present in the Persian Gulf and Oman Sea waters, but the most commercially exploited species are Sind sardinella (*Sardinella sindensis*), Gold strip sardinella (*Sardinella gibbosa*), White sardine (*Sardinella albella*), Indian oil sardine (*Sardinella longiceps*), Rainbow sardine (*Dussumieria acuta*), Gulf herring (*Herklotsichthys lossei*), Buccaneer anchovy (*Encrasicholina punctifer*) and Indian anchovy (*Stolepherus puncitfer*) (FAO, 1981; Owfi, 1991; Owfi, 1994, Iran, 1998). The fishing season of small pelagic fishes on the Iranian side of the Persian Gulf and Oman Sea starts from early autumn to late spring, the peak of fishing being reported in winter (Alizade and Oliaei, 2015; Dehghani *et al.*, 2015).

Spatial heterogeneity of the coastal pelagic environment, and the high mobility of small pelagic fish, generally, leads their distribution to be concentrated within areas which they find most favorable (Masse *et al*., 1996; Freon *et al*., 2005). The identification of Essential Fish Habitats (EFH), i.e. areas or volumes of water and bottom substrates that provide the most favorable habitats for fish populations to spawn, feed and mature throughout their life cycle, is important for the conservation of biodiversity and sustainable fisheries management. The sustainability of fish populations and their associated fisheries could be conserved by limiting anthropogenic stressors in such habitats (Valavanis *et al*., 2008). EFH analysis should be able to identify those areas within the distribution of a species that contribute most to sustain the long-term viability of a population (Valavanis *et al.*, 2008). Studies of habitat requirements of exploited marine fish have been driven both by the need to support management actions and the increasing availability and accessibility of suitable tools. By using the Sea surface parameters, Geographic Information Systems (GIS) and powerful statistical modelling tools such as generalized additive models (GAM), which allow modelling of non-linear relationships, and multivariate analysis such as redundancy analysis (RDA) relationships between species and environmental variables, through the development of the ''R'' programming language were explored (Guisan and Zimmerman, 2000; Pierce *et al.,* 2001; Pierce *et al*., 2002; Valavanis *et al*., 2004; Zuur *et al*., 2007;Valavanis *et al*., 2008).

A detailed knowledge of species' distribution in relation to their environment is essential for understanding many aspects of their ecology, as well as for effective conservation, management and assessment of possible impacts from anthropogenic activities (Lindenmayer *et al*., 1991; Beerling *et al.,* 1995; Schulze and Kunz, 1995; Austin *et al*., 1996). Associations between high concentrations of plankton and fish have been observed with *C. harengus* in the northern North Sea (Maravelias, 1999) and anchovy (*Engraulis mordax*) in the eastern Pacific (Robinson, 2004). Agenbag *et al*. (2003) estimated environmental preferences of South African pelagic fish species using catch size and remote sensing data. The relationship between sea surface temperature and presence / or abundance of a number of species including herring (*Clupea harengus*) in the northern North Sea (Maravelias and Reid, 1995); anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) off the coast of Chile (Castillo *et al.*, 1996); and sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*) in the northern Aegean Sea (Giannoulaki *et al*., 2005) was studied. Bellido *et al*. (2008) identified the essential fish habitat for small pelagic fishes in the Spanish Mediterranean waters. Valavanis *et al*. (2004) used the GIS - environmental approach to identify short-finned squid (*Illex coindetti*) in the eastern Mediterranean Sea. Koubbi *et al*. (2006) reported an application on habitat modeling for flatfish larvae in the eastern English Channel. An alternative approach was taken by Friedlander *et al.* (2007) and Le Pape *et al*. (2007), the community assemblage and interactions between species and substrate in order to identify essential fish habitats examined by Friedlander *et al.* (2007) and Le Pape *et al*. (2007). This study aims to use a GIS and statistical modeling-based approach to investigate relationships between small pelagic fishes (sardine and anchovy) and environmental conditions in the Persian Gulf and Oman Sea coastal waters. A further aim is to extend this approach to identify EFH and its spatial variability in sardine and anchovy.

Material and methods

Study area

The study area comprises the northern Persian Gulf and Oman Sea coastal waters of Iran (Fig. 1). The Persian Gulf and Oman Sea waters are environmentally unique with an unusual faunal assemblage (Carpenter *et al*., 1997). The Persian Gulf is a semi-closed water body connected to the Oman Sea through the Strait of Hormoz (Reynolds, 1993). The study area includes the following separate zones including zone1) north-west of Oman Sea, this region has a historical background with small pelagic fishes, zone 2) Central zone located near the Strait of Hormoz, small pelagic fisheries in this area were well developed in recent years, zone 3) north of the Persian Gulf zone covers the less developed fishing grounds. The boundary defined in this study encompasses the coastal environment from the coastline to -50 m isobaths (FAO, 1981).

Data sampling

Catch data were obtained from the fishing logbook fishing annual or yearbook, carried out by Iranian fisheries organization, from the October 2014 to March 2015. Small pelagic fisheries data are recorded specially, on a daily basis by fishermen in the area. Logbook data were selected from reliable fishermen, who reported the shooting position with GPS data. The index of fish abundance, catch per unit effort (CPUE) was calculated as tone/shooting from logbook data. Monthly average environmental data were collected from Internet-based sources and scientific documents and then processed into files suitable for use in a GIS (Table 1). Environmental data collections were planned for 112 stations in 28 transect (covers -10, -20, -30 and -50 meter depths), and fisheries logbook data were collected for 330 shooting from small pelagic fishery logbook data (see Fig. 1). GIS layers of fish logbook records were combined with environmental grids of 3 nautical miles (nm^2) to extract the environmental values associated with each location of the fish logbook record. Each grid cell was assigned a value for SST, SSS, Chlo-a, PAR, water depth, sea ground slope, and distance from the nearest coast using ARC GIS 10 software.

Redundancy analysis (RDA)

Multivariate analysis was applied in order to reveal plausible relationships between species and environmental variables. Correlation analysis and RDA were applied to the fishery and environmental data. RDA is a constrained ordination method which represents the relationships between two matrices: one dependent matrix of response variables (i.e. the species variables) and the other independent matrix of explanatory variables (i.e. the environmental variables). The ordination seeks the combination of explanatory variables that best explain the variation of the response variables. Also using Monte Carlo permutation tests, and determines the statistical significance of the effects of each of the suite of explanatory variables (Zuur *et al.,* 2007; Bellido *et al.,* 2008; Valavanis *et al.*, 2008; Borcard *et al.*, 2011). RDA graphic results were presented in the form of a correlation biplot, showing the response and explanatory variables on the same diagram.

Table 1: Sources and descriptions of environmental data used in the GIS, in the north of the Persian Gulf and Oman Sea fishing grounds (2014-2015).

Variable	Units	Source	Sensor/Model	Description
Sea surface temperature (SST)	°C		MODIS	
Sea surface Chlorophyll-a concentration (Chlo-a)	(mg/m^3)	NASA (2015)	MODIS	Oceancolor WEB, GSFC/ NASA, USA, http://oceancolor.gsfc.nasa.gov
Photosynthetically active radiation(PAR)	(E/m^2/d)		MODIS	
Sea surface salinity (SSS)	psu	Ebrahimi *et al.* (2012), Behzadi *et al.* (2013)	CTD, Salinimeter	data collated from sampling cruises
Wind Speed (WS)	(m/sec)	Neku Amal Kermani (2015)	Anemometer	data recorded every 3 hours, collected from 10 coastal and marine metrological stations
Wind direction (WD)	(o from N)		Wind vane	
Bathymetry (depth)	m	NCC (2002)	Paper-based map	created depth points and isobaths shape files using Arc GIS 10
Distance from the nearest coast	nm			
Sea ground slope	%	NCC (2002)	Creating from DEM raster data	sea ground slope created from depth points and isobaths using Arc GIS 10

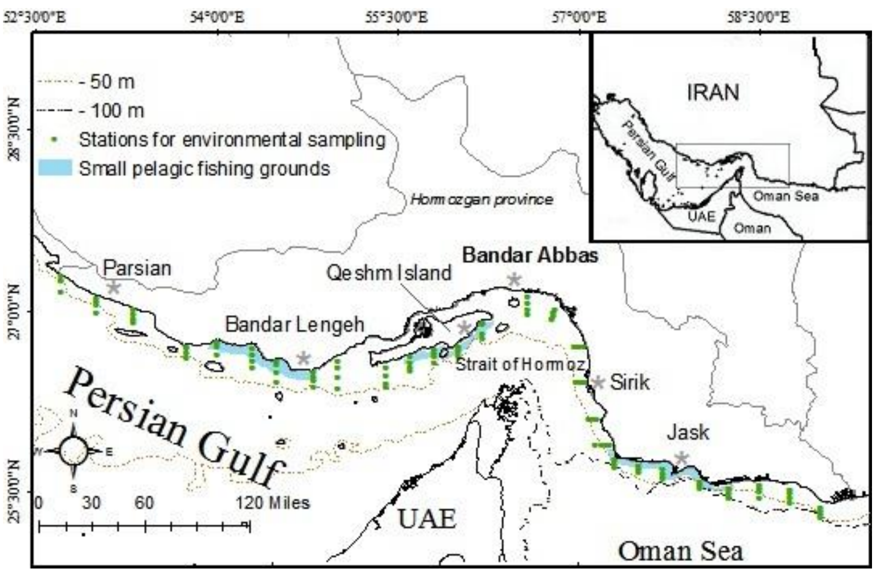

Figure 1: Study area, including the small pelagic fishing grounds, northwest of Oman Sea (Zone 1), Strait of Hormoz area (Zone 2) and north of the Persian Gulf (Zone 3).

The length and angles in the RDA correlation biplot reflect correlations between response and environmental variables, and between response and environmental variables themselves.

Since a limitation of this technique is that effects are assumed to be linear, most of the explanatory variables were log-transformed (Bellido *et al.,* 2008).

Generalized additive models (GAM)

The multivariate analysis results were also utilized as an exploratory analysis prior to GAM modeling (Bellido *et al.,* 2008; Valavanis *et al*., 2008; Clark, 2013). Generalized additive model (GAM) is a generalized linear model in which the linear predictor depends linearly on unknown smooth functions of some predictor variables, and interest focuses on inference about these smooth functions. GAMs were originally developed to blend properties of generalized linear models with additive models (Hastie and Tibshirani, 1990). The static used to select the best models was the Akaike Information Criterion (AIC) (Chambers and Hastie, 1997). The AIC is a measure of the relative quality of statistical models for a given set of data. Given a collection of models for the data, AIC estimates the quality of each model, relative to each of the other models (Aho *et al.,* 2014). For the final model, the probabilities of presence of sardine and anchovy occurrence were calculated for all grid cells in the study area by substituting the intercept value and the coefficients for each of the variables into the following equation: Probability of presence = $e^{g(x)}$ where g(x) is the regression equation from the GAM (Drexler and Ainsworth, 2013). Statistical analysis was applied by R software using "Vegan package" for RDA, and "GAM package" for generalized additive models (GAMs).

EFH maps

The values of probability of presence (in range of 0 to 1) were calculated for each station from the GAM model. The probability for each grid square was calculated and mapped to represent the EFH distribution during the study period. Probability presence data were processed into files suitable for use in GIS as a data layer (Valavanis *et al*., 2008). EFH maps were created from probability presence data layer, using Arc GIS explanatory spatial analysis tools based on Inverse Distance Weighted (IDW) interpolation technique. Maps were produced to visualize the distribution of fish and, after fitting of models, the probabilistic predictions of EFH for sardine and anchovy throughout the study area (Valavanis *et al.*, 2004; Valavanis *et al.*, 2008; Knudby *et al*., 2010)

Results

The average CPUE of anchovy and sardine was estimated 1.13 and 1.03 tone/shooting, respectively. High CPUE of anchovy was found in the north of the Persian Gulf (Zone 3), but the highest abundance of anchovy was recorded in the Strait of Hormoz (Zone 2), and in small quantities in the north-west of the Oman Sea (Zone 1).

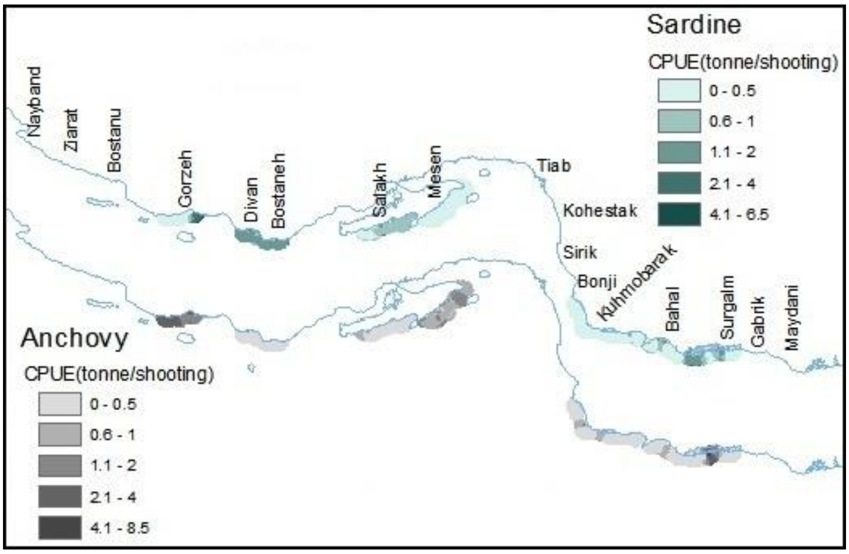

Figure 2: CPUE index distribution were mapped for sardine (above) and anchovy (below) in the north of the Persian Gulf and Oman Sea small pelagic fishing grounds (2014-2015).

Table 2: Species–environment RDA correlations and Monte Carlo tests of significance of canonical axes, in the north of the Persian Gulf and Oman Sea small pelagic fishing grounds (2014-2015).

	1st Axis	2nd Axis	3rd Axis	4th Axis
Eigenvalues	0.297	0.100	0.035	0.001
Species–environment correlations	0.66	0.39	0.35	0.13
Cumulative percentage variance of species data	40	78	92	100
Cumulative percentage variance of species–environment relation	67	95	99	100
	Sum of all Eigenvalues 1.8			
	Sum of all canonical Eigenvalues 0.43			
Monte Carlo test of significance (1000 permutations)			F-ratio	*p*-value
First canonical axis	Eigenvalue= 0.297		196.93	0.001
All canonical axes	Trace = 0.43		33.78	0.001

The patterns of distribution and abundance of sardine CPUE were rather similar to those of anchovy, although sardine appeared to be in high concentrations from north of the Persian Gulf, and partly in the Strait of Hormoz and north-west of the Oman Sea (Fig. 2). *P*-values from Monte Carlo tests show the significance of the RDA ordination method both for the first canonical axis and all canonical axes (Table 2). The first axis comprised up to 76% of the cumulative variance of species-environment relationships, reaching up to the 100% in the fourth axis. The first axis accounted for a species–environment correlation of 0.58, whilst the second, third and fourth axes accounted for 0.33, 0.24 and 0.11, respectively (Table 2). Anchovy and sardine occurrence were influenced by both the first and secondary canonical axis. Distance from the nearest coast, Latitude, and depth appeared to be the most important variables on the first canonical axis. Wind direction, wind speed, PAR, Chl-a, SST, and SSS are the most important variables on the second canonical axis (Fig. 3). Distance, Chl-a, SSS, and SST showed a positive effect on anchovy and sardine occurrence. Depth, wind direction, wind speed, slope, and PAR had an important negative effect on anchovy and sardine occurrence variables. Latitude and longitude are considered secondary variables, as their effect can be hidden in other environmental variables.

Finally, distance from the nearest coast, depth, SST, and Chlorophyll-a concentration (Chlo-a) were selected for GAM models as they showed considerable variability throughout the study area and were believed to be easier to interpret biologically than some other variables available. The use of GAM allows non-linear relationships between response and explanatory variables. Binomial GAMs were developed for sardine and anchovy, local occurrence (presence=1 and absence = 0) was modeled against environmental variables for all zones combined. GAMs were also developed for individual zones. The constructed models, from all zones combined, were then used to predict the probability of sardine and anchovy presence at the resolution of the environmental grids, i.e. 3 nm^2.

The model for presence/absence of anchovy, for all zones combined, explained 29.1% of the deviance (Table 3). Separate models for each zone explained 30, 44.7 and 47.8% of the deviance for north-west of the Oman Sea, Strait of Hormoz and north of the Persian Gulf, respectively. For sardine, the presence/absence model explained 31.8% of the deviance for all zones combined. For separate-zone models the deviance explained was 30.8, 42.2 and 50.1% for north-west of the Oman Sea, Strait of Hormoz and north of the Persian Gulf zones, respectively (Table 3). All models included effects of distance, depth, SST, and chlorophyll, except the model for anchovy in the north-west of Oman Sea, which did not include SST, and north of the Persian Gulf zone which did not include depth, and for sardine in the north-west of Oman Sea which did not include chlorophyll. Some common trends in these results were apparent. With the exception of the north-west of Oman Sea for sardine, models for individual zones explained a greater proportion of the deviance than models for all zones combined.

Relationships between fish presence/absence and environmental variables were somewhat similar for both species (see Fig. 4 for anchovy and Fig. 5 for sardine). In all models, distance from the nearest coast was highly significant and the most important variable, except in the Strait of Hormoz zone model for anchovy and the north of the Persian Gulf zone model for sardine that was substituted with Chl-a and depth variables, respectively.

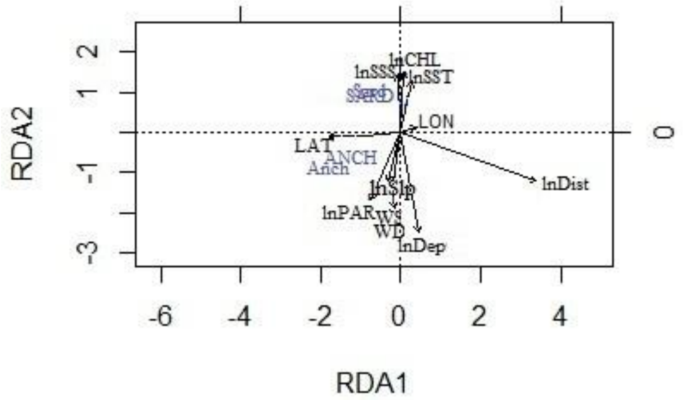

Figure 3: RDA correlation biplot. Species variables are Anch: Anchovy CPUE; Sard: Sardine CPUE. ANCH: Presence/Absence of Anchovy; SARD: Presence/Absence of Sardine; Environmental variables are LAT: Latitude; LON: Longitude; PAR: Photosynthetically Active Radiation (Natural Log); SST: Sea Surface Temperature (Natural Log); CHL: Sea surface Chlorophyll-a concentration (Natural Log); SSS: Sea Surface Salinity (Natural Log); WD: Wind Direction; WS: Wind Speed; Dep: Depth (or Bathymetry) (Natural Log); Dist: Distance from nearest coast (Natural Log); Slp: Sea ground slope (Natural Log) from north of the Persian Gulf and Oman Sea small pelagic fishing grounds (2014-2015).

Table 3: Anchovy and sardine presence/absence GAM results, shows the best model for each zone. Variables are ordered according to their importance in the model, based on results from classification trees. The order runs from left (most important) to right (least important), north of the Persian Gulf and Oman Sea small pelagic fishing grounds (2014-2015).

Species	Zone	n	Variables (*p*-value)	Deviance explained (%)
Anchovy	All	1002	Distance(0.001), SST(0.001), Chl-a(0.003), Depth(0.006)	29.1
	Zone 1	289	Distance(0.001), Depth(0.001), Chl-a(0.002)	30
	Zone 2	401	Cho-a(0.001), Distance(0.001), Depth (0.001) , SST(0.006)	44.7
	Zone 3	312	Distance(0.001), SST(0.001), Chl-a(0.002)	47.8
Sardine	All	1002	Distance(0.001), Depth(0.001), Chl-a(0.001), SST(0.001)	31.8
	Zone 1	289	Distance(0.001), Depth(0.001), SST(0.005)	30.8
	Zone 2	401	Distance(0.001), Depth(0.001), Chl-a(0.001) , SST(0.001)	42.2
	Zone 3	312	Depth(0.001), Chl-a(0.002), Distance(0.012), SST(0.034)	50.1

The relationship between fish presence/absence and distance from the nearest coast was generally negative, with a strong negative effect at a distance of approximately 2.7 miles (1 on the natural log scale, Figs. 4a and 5a). Depth was generally the second important explanatory variable and its effect was generally negative in all models with a moderately negative effect at depths of approximately 50 m (3.8 on natural log scale, Figs. 4b and 5b), depth was the most effective variable in the north of the Persian Gulf zone model for sardine, and the little effect for anchovy model in Strait of Hormoz zone and intangible effect for the anchovy model in the north of the Persian Gulf.

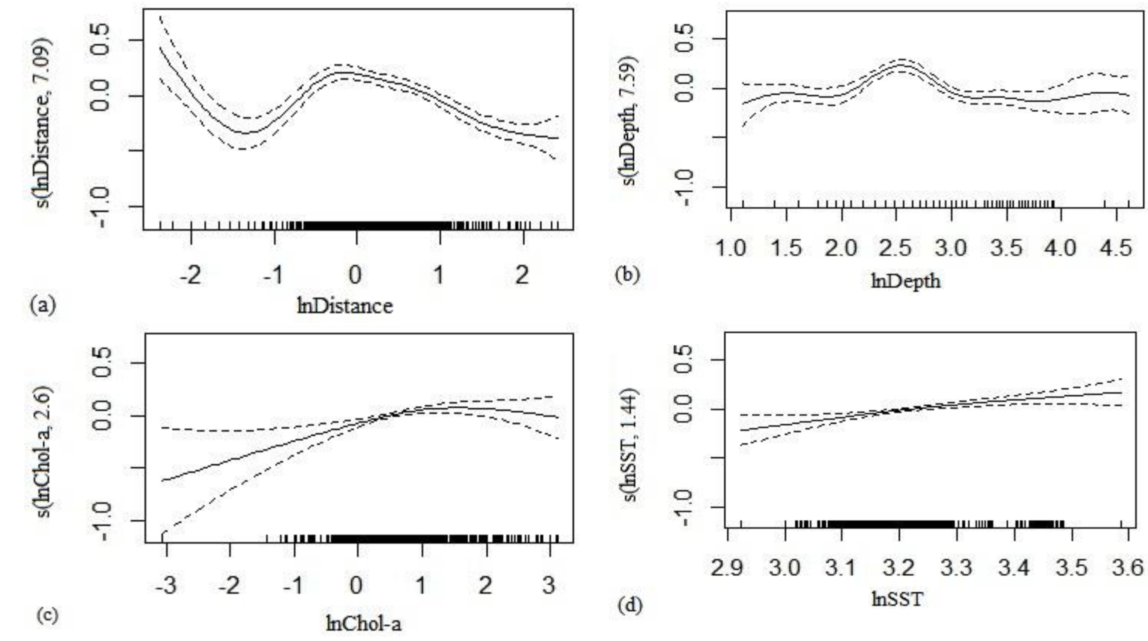

Figure 4: GAM plots for anchovy presence/absence (all zones combined) showing the effect of every environmental variable on fish presence. a): distance(natural log). b) depth (natural log). c): Chlo-a (natural log). d): SST (natural log), north of the Persian Gulf and Oman Sea small pelagic fishing grounds (2014-2015).

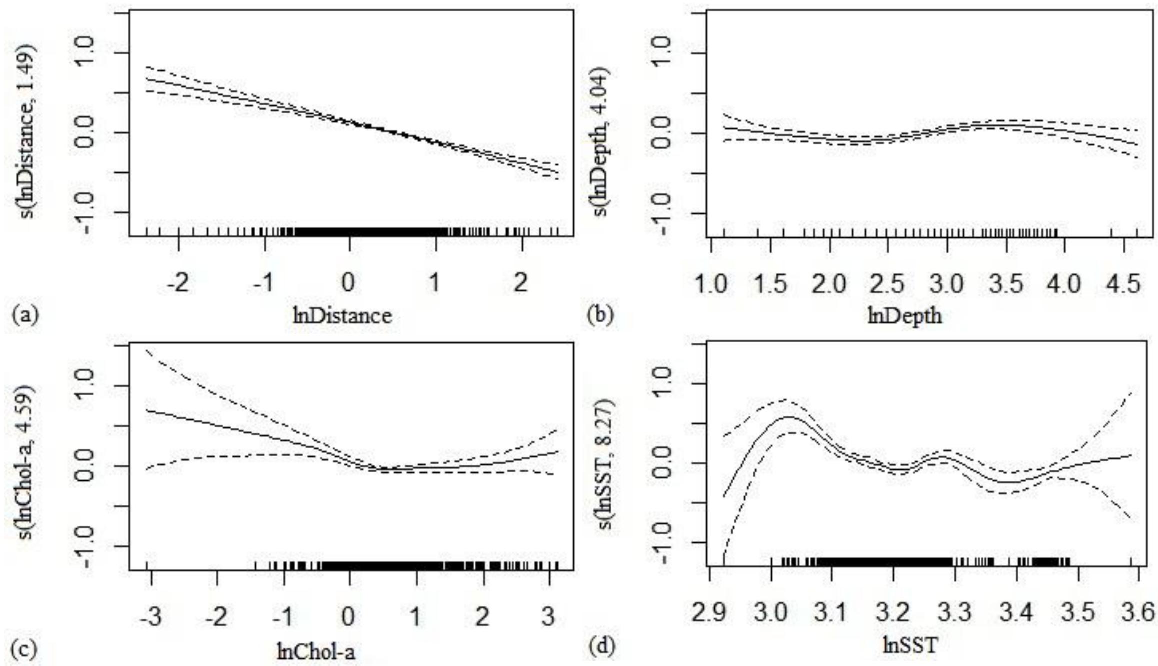

Figure 5: GAM plots for sardine presence/absence (all zones combined) showing the effect of every environmental variable on fish presence. a): distance (natural log). b) depth (natural log). c): Chlo-a (natural log). d): SST (natural log), north of the Persian Gulf and Oman Sea small pelagic fishing grounds (2014-2015).

Generally, depth is directly related to the distance from the coast, so that depth increases with increasing distance. Chl-a is generally the third important explanatory variable and its effect was significant for all models.

The relationship between fish presence/absence and Chl-a is generally weakly positive, Chlo-a was the second effective variable for the anchovy model and third effective variable for sardine model. Chl-a had a limited effect on anchovy and sardine presence/absence in range of approximately 0.5 to 2.7 mg m^{-3} (1.6 and 2.7 on a natural log scale, Figs. 4c and 5c). SST was generally the least important explanatory variable. A slight peak of positive influence on sardine presence was apparent between approximately 22 and 33^{o}C (3.1 and 3.5 on a natural log scale, see Fig. 4d). However, it seems that SST had less effect on anchovy presence (Fig. 5d).

The areas of higher probabilities for EFH of anchovy were located in the vicinity of the Strait of Hormoz zone especially south of Qeshm Island and somewhat in the north of the Persian Gulf zone (Fig. 6). Another coastal area of high EFH was the Parsian district; this was particularly true for the north-west of Oman Sea zone which showed a continuous moderate probability of anchovy presence (Fig. 6).The probability of anchovy EFH predicted presence probability well distributed all around north of the Persian Gulf and Oman Sea coastal areas. High probabilities of sardine presence were less extensive than those of anchovy. The coastal area from south of Qeshm Island in the Strait of Hormoz zone and partly from the north of the Persian Gulf zone showed a relatively moderate probability of sardine presence. Coastal areas of the north-west of Oman Sea zone showed an almost continuous moderate probability of sardine presence (Fig. 7). Unsurprisingly, the areas of highest predictions of anchovy and sardine were almost the same as the areas of higher anchovy and sardine CPUE index identified in Fig. 2. Interestingly, there are some areas such as Parsian district coastal waters, in the north of the Persian Gulf zone, as well as in the western part of Jask area in the north-west of Oman Sea zone, identified for EFH presence probability, while no catch was reported for anchovy and sardine in the period of the study. This was true for both species, while anchovy showed stronger extended EFH presence probability than the sardine.

Discussion

The study showed that anchovy and sardine were distributed throughout the north of the Persian Gulf and Oman Sea waters. Several areas were identified where fish could be found in high concentrations. In addition to the well-known small pelagic fishing grounds in the north-west of the Oman Sea, EFH maps of presence probability of the Strait of Hormoz and the north of the Persian Gulf showed that the Strait of Hormoz has high EFH presence probability of fish, and moderate probability of fish presence was found in the adjacent coastal waters of the north-west of Oman Sea zone (see Fig. 6 for anchovy and Fig. 7 for sardine).

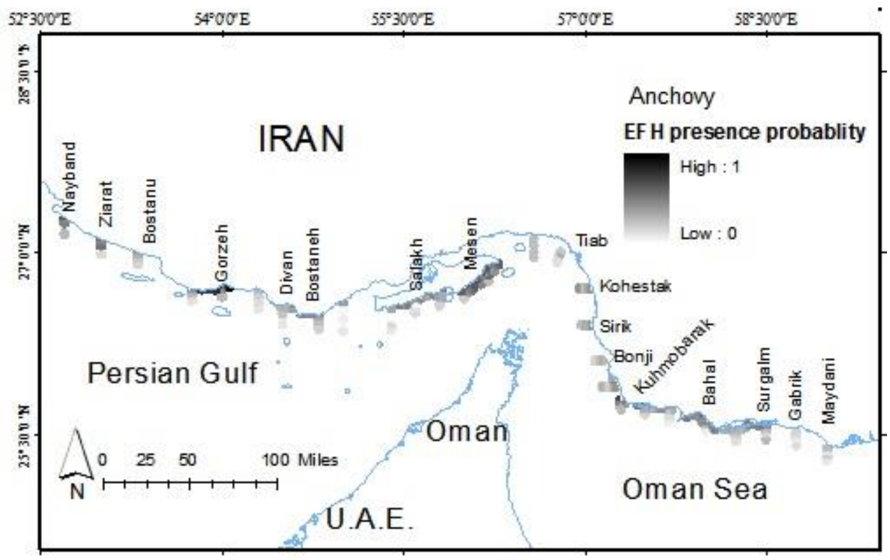

Figure 6: EFH maps showing the predicted probability of presence of anchovy in north of the Persian Gulf and Oman Sea small pelagic fishing grounds (2014-2015).

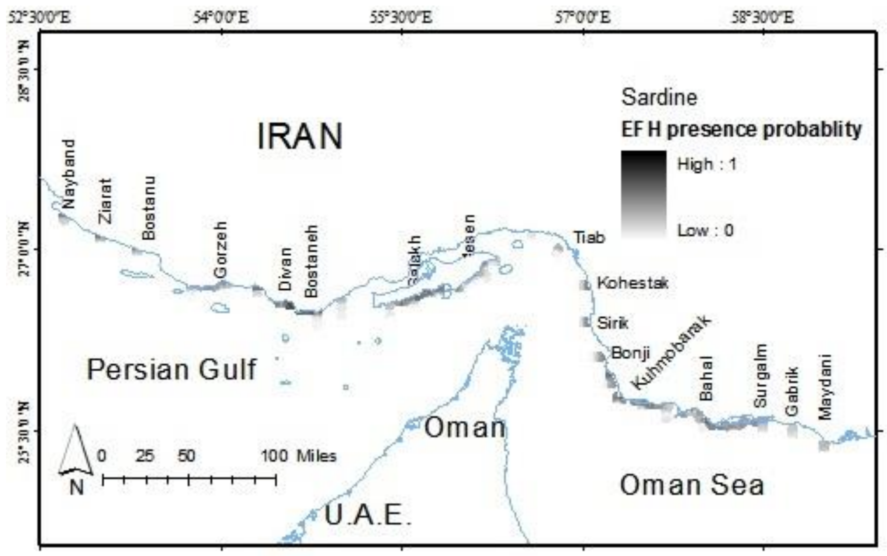

Figure 7: EFH maps showing the predicted probability of presence of sardine in north of the Persian Gulf and Oman Sea small pelagic fishing grounds (2014-2015).

Previous studies have documented the perfect concentrations of small pelagic fishes from the adjacent waters of Qeshm Island to Bandar Lengeh area continuing to the coastal waters of Bushehr Province (FAO, 1981). Van Zailinge *et al*. (1993) declared suitable density and concentration of small pelagic fishes from the northern coastal waters of the Persian Gulf. Acoustic surveys showed that the mean density of small pelagic fishes was estimated at 28.15 tonnes nm^{-2} in the Persian Gulf and Oman Sea (FAO, 1981). The maximum sustainable yields (MSY) for small pelagic fishes were estimated as 120 and

154 thousand tonnes for sardine and anchovy, respectively from the northern waters of the Persian Gulf, and the optimistic MSY for northern waters of Oman Sea was estimated as 13-44 thousand tonnes (Van Zailinge *et al*., 1993).

Results showed that presence/absence of small pelagic fishes has a strong relationship with distances lower than 2.7 miles from the coast. This range of distance generally covers the depth of -50 m isobaths, which is the range of possible depth for small pelagic fisheries operations. The other geological variable was the sea ground slope, however, slope was not used in the model but it seems that the effect of slope can be hidden in distance and depth variables. The marine environment of the Persian Gulf is characterized by environmental extremes due to its location and bathymetry (Chao *et al*., 1992; Kampf and Sadrinasab, 2006). The Indian Ocean Surface Waters (IOSW) normally flow into the Persian Gulf from the open ocean along the northern side of the Strait of Hormoz and continues northward along the Iranian coast, but this current appeared banked against Oman (south) side of the channel (Reynolds, 1993; Swift and Bower, 2003). Surface waters flow into the Persian Gulf in the northern part of the Strait of Hormoz as a wedge of less saline water that penetrate deep into the Persian Gulf along the Iranian coast (Brewer and Dyrssen, 1985; Reynolds 1993), increasing in salinity and exiting at depths through the Strait of Hormoz (Kampf and Sadrinasab, 2006). Both multivariate analysis and GAMs showed a significant positive relationship between the distribution and abundance of fish and Chlorophyll, which are relatively strong. The distribution of chlorophyll suggested higher levels of nutrient enrichment in shallower waters and close to the coastline. This suggests that Chlorophyll and fish are directly related so that higher Chlorophyll is an indicator of conditions favoring fish. Chlorophyll is a measure of the standing stock of phytoplankton in surface waters; therefore higher concentrations are likely to be associated with productive feeding grounds for planktivorous fishes such as small pelagic fishes (Bellido *et al*., 2008). It is likely that fishes select these areas due to the higher concentrations of food associated with these productive waters. Sardine schools distributions have a direct relation with temperature profiles, planktonic distribution and marine currents (Tameishi *et al*., 1996). Relationships between fish and SST were typically weaker and less significant than those with Chlorophyll. SST is likely to be less direct in its relationship with fish than Chlorophyll, especially for sardine presence. Cooler SST can be indicative of nutrient enrichment processes such as wind mixing, upwelling and river-runoff, which are associated with favorable conditions for fish. Thus enrichment events indicated by high Chlorophyll and low SST may be more associated with fish after sufficient time has passed for both zooplankton abundance to rise, and fish to locate the area (Bellido *et al*., 2008).

The importance of the SST on primary production and the life cycle of anchovy and sardine are well known. So it seems SST directly affects the production process in the marine environment and is particularly important in the feeding and reproduction strategy of pelagic fishes. The results indicate that three main areas of fish distribution can be described, following an east-west axis. The first area with high abundance and occurrence of sardine and anchovy was adjacent to the Jask area coastal waters, in the vicinity of the north-west of the Oman Sea zone. This area is characterized by an important input from oceanic currents, and high frequency of mangrove creeks. This area is influenced by local upwelling of the Gulf of Jask and has high concentrations of nutrients (Reynolds, 1993; Ebrahimi *et al*., 2012).

The adjacent coastal waters in the south of Qeshm Island support 70 % of the total small pelagic fishes (Alizadeh and Oliaei, 2015). The waters of the western region of Qeshm Island extending to Bandar Lengeh region are supported by mangrove productive flow and have the highest concentration of chlorophyll in the area (Reynolds, 1993; Ebrahimi *et al*., 2005, 2006). Local upwelling was identified from the west point of Qeshm Island (Reynolds, 1993). Water exchange with the Oman Sea dominates the circulation of the southern Persian Gulf. An important, secondary current in the Persian Gulf is a coastal, reverse circulation along the Iranian coast (Reynolds, 1993). The productivity of these areas and nutrient enrichment result in phytoplankton, and then zooplankton growth providing feeding grounds for fish. The north of the Persian Gulf generally covers the deepwater areas, as the depth increases immediately with distance from the beach, in these areas depth was a technical problem for purse seine operation. Year-round northwesterly winds, known as the Shamal, are believed to create a southeastward coastal upwelling jet along the Iranian coast between 28^{o} –29^{o} N, but observational evidence thereof is sparse (Sadrinassab and Poorkiani, 2011).

EFH maps showed the predicted probability of anchovy and sardine presence. Predictions were made according to the environmental conditions at a specific time, based on modeled relationships between environmental conditions and fish presence over 6 months of the survey data. The pattern of predictions can be considered a measure of the quality of EFH. Higher predicted the probability of occurrence clearly indicate better quality habitat, in terms of the environmental variables considered in the model on which the predictions are based. The EFH maps act as a tool for identifying areas where environmental conditions are favorable or less favorable for fish to occur.

Results showed the EFH of sardine to be concentrated in specific areas of more favorable conditions. However, EFH of anchovy showed a more widespread distribution; occupying most of the study area (see Figs. 6 and 7). In this study, it seems that the anchovy has probability presence whispered to the areas with more distance from the coastal waters. However, the EFH probability presences of sardine were predicted for near coastal waters and obviously, shallower waters. Sardine and anchovies are short lived and fast growing and are characterized by marked fluctuations in their stock size because of their high dependence on highly variable, environmentally-driven, annual recruitment pulses (Barange *et al*., 2009). Acoustic surveys in the Persian Gulf showed that the sardine mainly lives in shallow waters less than -30 m in depth and anchovy lives in waters less than -40 m in depth (FAO, 1981). Anchovy populations have more range of distribution from -5 to -60 m in depth (Myers, 1991; Supongpan *et al*., 2000). They were distributed from the bottom to the surface during the day, in high and narrow dense schools (FAO, 1981). The relative ease with which they are caught by purse seiners, owing to their schooling behavior, combined with the enormous biomasses reached by some populations, has made them important economically (Cole and Glade, 1998). In particular, the sardines and anchovies appear to be a major forage source for tuna and mackerel fishes, occupying a significant ecological role in the Persian Gulf and Oman Sea, where sardines contributed to 15 to 60 percent of the stomach contents of longtail tuna (Shawghi, 1992; Darvishi *et al*., 2003; Kaymaram *et al.*, 2013) and 45 percent of the stomach content of Spanish king mackerel (Darvishi, 2008). The anchovies are the main food source for yellowfin tuna, longtail tuna, Kawa Kawa and large hairtail, occupying a significant ecological role in the region (Darvishi *et al*., 1993, Kamali *et al.*, 2003; Daghooghi *et al*., 2010).

Takasuka *et al*. (2007) proposed a simple ‘‘optimal growth temperature” hypothesis, in which anchovy and sardine regime shifts are caused by differential optimal temperatures for growth during the early life stages. It is generally agreed that habitat selection in marine fish is based on the ‘‘ideal free distribution” (Fretwell and Lucas, 1970), according to which habitat choice is based on suitability and geared towards maximizing individual fitness. For some authors habitat suitability is density-dependent, leading to the prediction that the geographical area occupied by a population expands as population size increases and contracts as it declines (Paloheimo and Dickie, 1964; MacCall, 1990; Bertrand *et al*., 2004).

Predictions for EFH mapping are only as accurate as the models they are based on. The use of different environmental variables at different temporal resolutions should be investigated, with a view to explaining a greater proportion of the deviance in fish distribution and abundance. Another logical step forward is to produce predictions of abundance in addition to presence. However, this task is reliant upon finding sufficiently strong relationships between environmental conditions and fish abundance. The quality of survey data used in this study is not readily available for many areas which support similar assemblages of fish. The spatial transferability of models developed in this study should be tested to see if models based on fish in the waters of this study area can predict the distribution of fish in other areas. Environment and topography play an important role in directing local distribution and variability of these essential fish habitats. However, the underlying relationships between oceanographic conditions and fish require further investigation. Due to the development of small pelagic fisheries, it is highly recommended to investigate anchovy and sardine fishing possibility in areas with high EFH prediction probability in the western areas of the Persian Gulf zone, and some eastern areas of the Oman Sea zone. However, in order to increase the accuracy and scope of EFH prediction probability for small pelagic fishes, implementation of a comprehensive acoustic survey in small pelagic fishing season and fishing grounds is highly recommended for all Iranian coastal waters.

Acknowledgments

The authors are grateful to Dr. M.S. Mortazawi, head of the Persian Gulf and Oman Sea Ecological Institute, for cooperation and facilities. We appreciate A. Nekoamal from Hormozgan meteorological organization for providing the metrological data. We thank Ms. E. Dehghani for valuable tips in GIS. Special thanks are also extended to the P. Mohebbi, the head of Hormozgan Fisheries Organization, and his colleagues M. Barani, E. Alizadeh, A. Golshani, Q. Farkhondeh, S. Ghafouri, R. Darvishi for planning, collecting and providing the fisheries data and logbooks. A special acknowledgment goes to the local fishermen for their devotional cooperation.

References

Agenbag, J.J., Richardson, A.J., Demarcq, H., Freon, P., Weeks, S. and Shillington, F.A., 2003. Estimating environmental preferences of South African pelagic fish species using catch size and remote sensing data. *Progress in Oceanography*, 59, 275–300.

Aho K., Derryberry D. and Peterson T., 2014. Model selection for ecologists: the worldviews of AIC and BIC. *Ecology*, 95(**3**), 631-636.

Alizade E. and Oliaei M., 2015. Report of fisheries statistics of Hormozgan province, Iran (the year 2014). Hormozgan Province Fisheries Organization Office (In Persian). 88P.

Austin, G.E., Thomas, C.J., Houston, D.C. and Thompson, D.B.A., 1996. Predicting the spatial distribution of buzzard Buteo buteo nesting areas using a geographical information system and remote sensing. *Journal of Applied Ecology*, 33, 1541–1550.

Barange, M., Coetzee, J., Takasuka, A., Hill, K., Gutierrez, M., Oozeki, Y. and Agostini, V. 2009. Habitat expansion and contraction in anchovy and sardine populations. *Progress in Oceanography*, 83(**1**), 251-260.

Beerling, D.J., Huntley, B. and Bailey, J.P., 1995. Climate and the distribution of *Fallopia japonica*: Use of an introduced species to test the predictive capacity of response surfaces. *Journal of Vegetation Science*, 6, 269–282.

Bellido, J.M., Brown, A.M., Valavanis, V.D., Giráldez, A., Pierce, G.J., Iglesias, M. and Palialexis, A., 2008. Identifying essential fish habitat for small pelagic species in Spanish Mediterranean waters. *Hydrobiologia*, 612(**1**), 171-184.

Bertrand, A., Segura, M., Gutiérrez, M. and Vásquez, L., 2004. From small-scale habitat loopholes to decadal cycles: a habitat-based hypothesis explaining fluctuation in pelagic fish populations off Peru. *Fish and Fisheries*, 5, 296–316.

Blaxter, J.H.S. and Hunter, J.R., 1982. The biology of the clupeoid fishes. *Advances in Marine Biology*, 20, 1–223.

Borcard, D., Gillet, F. and Legendre, P., 2011. Numerical ecology with R. Springer Science and Business Media. 301P.

Brewer, P.G. and Dyrssen, D., 1985. Chemical oceanography of the Persian Gulf. *Progress in Oceanography*, 14, 41-55.

Carpenter, K.E., Krupp, F., Jones, D.A. and Zajonz, U., 1997. Living marine resources of Kuwait, eastern Saudi Arabia, Bahrain, Qatar, and UAE. FAO species identification field guide for fishery purposes, 1-293. Rome, Italy: FAO Publication.

Castillo, J., Barbieri, M.A. and Gonzalez, A., 1996. Relationships between sea surface temperature, salinity, and pelagic fish distribution off northern Chile. *ICES Journal of Marine Science*, 53, 139–146.

Chambers, J.M. and Hastie, T.J., 1997. Statistical models in S. Chapman and Hall, New York. 608P.

Chao, S.Y., Kao, T.W. and Al-Hajri, K.R., 1992. A numerical investigation of circulation in the Persian Gulf. *Journal of Geophysical Research*, 97(**11**), 219-236.

Clark, M., 2013. Generalized additive models: getting started with additive models in R. Center for Social Research, University of Notre Dame and Available at http://www3. nd. edu/mclark19/learn/GAMS. pdf.

Cole, J. and McGlade J., 1998. Clupeoid population variability, the environment and satellite imagery in coastal upwelling systems. *Reviews in Fish Biology and Fisheries*, 8(**4**), 445-471.

Cushing, D.H., 1971. The dependence of recruitment on parent stock in different groups of fishes. *Journal du Conseil/ Conseil Permanent International pour l'Exploration de la Mer*, 33, 340–362.

Daghooghi B., Salarpouri, A., Darvishi, M., Momeni, M., Seraji, F. and Safaei, M., 2010. Investigation on the feeding of sardines and major tuna fishes in the west of Oman Sea (Jask area). 117P.

Darvishi, M., Behzadi S. and Salarpouri A., 1993. Spawning, fecundity, and feeding of longtail tuna (*Thunnus tonggol*) in the Persian Gulf and Oman Sea (Hormozgan Province). *Pajouhesh and Sazandegi*, 59, 70-75.

Darvishi, M., Behzadi, S., and Salarpouri, A., 2003. Spawning, fecundity, and feeding of longtail tuna (*Thunnus tonggol*) in the Persian Gulf and Oman Sea (Hormozgan Province). *Journal of Pajouhesh and Sazandegi*, 59, 70-75.

Darvishi, M., 2008. Biology and assessment of Spanish king mackerel *(Scomberomorus commerson)* in Hurmuzgan Province. MSc, Islamic Azad University, Bandar Abbas, Iran.

Dehghani, M., Kamrani, E., Salarpouri, A. and Kamali E., 2015. Age and growth of Sind sardine (*Sardinella sindensis*) using otolith from Qeshm Island (Persian Gulf). *Iranian Journal of Fisheries Science*, 14(**1**), 217-231.

Dehghani, M., Kamrani, E., Salarpouri, A. and Sharifian, S., 2016. Otolith dimensions (length, width), otolith weight and fish length of *Sardinella sindensis* (Day, 1878), as an index for environmental studies, Persian Gulf, Iran. Marine Biodiversity Records, 9(**1**), 44.

Drexler, M. and Ainsworth, C.H., 2013. Generalized additive models used to predict species abundance in the Gulf of Mexico: an ecosystem modeling tool. *PloS one*, 8(**5**), e64458.

Ebrahimi, M., Mortazawi, M.S., Ejlali, K., Aghajari, N., Khodadadi Jokar, K., Akbarzadeh, G., Saraji, F. and Aghajari, S., 2005. Hydrological and hydrobiology studies on the Persian Gulf in Hormozgan, south of Iran. Iranian Fisheries Research Organization. 130P.

Ebrahimi, M., Mohebbi, L., Saraji, F., Eslami, F., Salimzadeh, M., Ejlali, K. and Aghajary, N., 2006. Hydrological and hydrobiological monitoring in the northeastern part of the Persian Gulf and Strait of Hormoz (Hormozgan Province water). Iranian Fisheries Research Organization (in Persian). 109P.

Ebrahimi, M., Khodadadi Jokar, K. and Azini, M., 2012. Study on Physicochemical properties of the Iranian waters in the Oman Sea. Iranian Fisheries Research Organization (in Persian). 100P.

FAO, 1981. Pelagic resources of the (Persian) Gulf and the Gulf of Oman. Regional Fishery Survey and Development project.144P.

Freon, P., Cury, P., Shannon, L. and Roy, C., 2005. Sustainable exploitation of small pelagic fish stocks challenged by environmental and ecosystem changes a review. *Bulletin of Marine Science,* 76, 385–462.

Fretwell, S.D. and Lucas, H.L., 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. *Acta Biotheoretica*, 19, 16–36.

Friedlander, A.M., Brown, E.K. and Monaco, M.E., 2007. Coupling ecology and GIS to evaluate the efficacy of marine protected areas in Hawaii. *Ecological Applications*, 17(**3**), 715-730.

Ganias, K., 2014. Biology and ecology of sardines and anchovies. CRC Press. 382P.

Giannoulaki, M., Machias, A., Somarakis, S. and Tsimenides, N., 2005. The spatial distribution of anchovy and sardine in the northern Aegean Sea in relation to hydrographic regimes. *Belgian Journal of Zoology*, 135, 151–156.

Guisan, A. and Zimmermann, N.E., 2000. Predictive habitat distribution models in ecology. *Ecological Modelling*, 135,147–186.

Hastie T.J. and Tibshirani R.J., 1990. Generalized additive models. CRC Press. 352P.

Iran, M., 1998. Report on small pelagic (sardine) fisheries statistics in south Iranian coastal waters (fishing season 1997-1998). Iranian Fisheries Research Institute- Bandar Abbas center (in Persian). 44P.

Kamali E., Dehghani, R., Behzadi, S., Salarpouri, A., Darvishi, M. and Valinassab, T., 2003. Study on stock condition of cutlassfishes in Hormozgan waters. Iranian Fisheries Research Organization. 75P

Kämpf, J. and Sadrinasab, M., 2006. The circulation of the Persian Gulf: a numerical study. *Ocean Science*, 2(**1**), 27-41.

Kaymaram, F., Darvishi, M., Behzadi, S. and Ghasemi, S., 2013. Population daynamic parameters of *Thunnus tonggol* (Bleeker, 1851) in the Persian Gulf and Oman Sea. *Iranian Jouanal of Fisheries Scinces*, 12(**4**), 855-863.

Knudby, A., Brenning, A. and LeDrew, E., 2010. New approaches to modeling fish–habitat relationships. *Ecological Modelling*, 221(**3**), 503-511.

Koubbi, P., Loots, C., Cotonnec, G., Harlay, X., Grioche, A., Vaz, S. and Carpentier, A., 2006. Spatial patterns and GIS habitat modeling of *Solea solea*, *Pleuronectes flesus* and *Limanda limanda* fish larvae in the eastern English Channel during the spring. *Scientia Marina*, 70S2, 147-157.

Le Pape, O., Baulier, L., Cloarec, A., Martin, J., Le Loc'h, F. and Désaunay, Y., 2007. Habitat suitability for juvenile common sole (*Solea solea*, L.) in the Bay of Biscay (France): A quantitative description using indicators based on epibenthic fauna. *Journal of Sea Research*, 57(**2**), 126-136.

Lindenmayer, D.B., Nix, H.A., McMahon, J.P., Hutchinson, M.F. and Tanton, M.T., 1991. The conservation of Leadbeater’s possum, *Gymnobelideus leadbeateri* (McCoy): A case study of the use of bioclimatic modeling. *Journal of Biogeography*, 8, 371–383.

MacCall, A.D., 1990. Dynamic geography of marine fish populations. University of Washington Press, Seattle, 153P.

Maravelias, C.D. and Reid, D.G., 1995. Relationship between herring (*Clupea harengus* L.) distribution and sea surface salinity and temperature in the northern North Sea. *Scientia Marina*, 59, 427–438.

Maravelias, C.D., 1999. Habitat selection and clustering of a pelagic fish: effects of topography and bathymetry on species dynamics. *Canadian Journal of Fisheries and Aquatic Sciences*, 56, 437–450.

Masse, J., Koutsikopoulos, C. and Patty, W., 1996. The structure and spatial distribution of pelagic fish schools in multispecies clusters: an acoustic study. *ICES Journal of Marine Science*, 53, 155–160.

Myers, R.F., 1991. Micronesian reef fishes. Second Ed. Coral Graphics, Barrigada, Guam. 298P.

NASA, 2015. Goddard Space Flight Center, Ocean Biology Distributed Active Archive Center; (2014): Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Ocean Color Data, NASA OB.DAAC, Greenbelt, MD, USA. http://doi.org/10.5067/ORBVIEW-2/SEAWIFS_OC. 2014.0. Maintained by NASA Ocean Biology Distributed Active Archive Center (OB.DAAC), Goddard Space Flight Center, Greenbelt MD.

NCC, 2002. Map of the Persian Gulf and Oman Sea, Digitized from Indian Chart No. 20 and plotted at the Hydrographic Department, Islamic Republic of Iran.

Neku Amal Kermai, M., 2015. Daily data source on Meteorology of Hormozgan Province. Hormozgan meteorological organization, Department of Research. Available at http://www.hormozganmet.ir/ (in Persian).

Owfi, F., 1991. Report on sardine fishes from the Persian Gulf and Oman Sea. Iranian Fisheries Research Institute- Bushehr Center (in Persian). 7P.

Owfi, F., 1994. A survey on biology and stocks of sardine fishes from the Persian Gulf. Iranian Fisheries Research Institute- Bushehr Center (in Persian). 47P.

Paloheimo, J.E. and M Dickie, L., 1964. Abundance and fishing success. Rapports et proces-verbaux des réunions du Conseil International pour l’Exploration de la Mer, 155P.

Pierce, G.J., Wang, J., Zheng, X., Bellido, J.M., Boyle, P.R., Robin, J.P. and Denis, V., 2001. The cephalopod fishery GIS for the northeast Atlantic: development and application. *International Journal of Geographical Information Science*, 15, 763–784.

Pierce, G.J., Wang, J. and Valavanis, V., 2002. Application of GIS to cephalopod fisheries: workshop report. *Bulletin of Marine Science*, 71, 35–46.

Reynolds, R.M., 1993. Physical oceanography of the Gulf, Strait of Hormoz, and the Gulf of Oman—results from the Mt Mitchell expedition. *Marine Pollution Bulletin*, 27, 35-59.

Robinson, C.J., 2004. Responses of the northern anchovy to the dynamics of the pelagic environment: identification of fish behaviors that may leave the population under risk of overexploitation. *Journal of Fish Biology*, 64, 1072–1087.

Sadrinasab, M. and Poorkiani, K., 2011. A three-dimensional numerical modeling of contaminant dispersion from Arvand Rood River into the Persian Gulf. *Journal of the Persian Gulf*, 2(**4**), 19-26.

Salarpouri, A., Behzadi, S., Darvishi, M., Momeni, M., Shojaei, M., Daghooghi, B. and Sobhani, A., 2012. Stock assessment of sardine and anchovy in Hormozgan Province with emphasize on fisheries. Iranian Fisheries Research Organization (IFRO). 117P.

Schulze, R.E. and Kunz, R.P., 1995. Potential shifts in optimum growth areas of selected commercial tree species and subtropical crops in southern Africa due to global warming. *Journal of Biogeography*, 22, 679-688.

Schwartzlose, R.A., Alheit, J., Bakun, A., Baumgartner, T.R., Cloete, R.J., Crawford, M. and Zuzunaga, J.Z., 1999. Worldwide large-scale fluctuations of sardine and anchovy populations. *South African Journal of Marine Science*, 21(**1**), 289-347.

Shawghi, H., 1992. Survey on tuna biology. Offshore Fisheries Research Center, Chabahar. 80P.

Supongpan, M., Chamchang, C., Boongerd, S. and Laowapong, A., 2000. Technical report on the anchovy fisheries in the Gulf of Thailand. FAO/FISHCODE Project GCP/INT/648/NOR: Field report F-6 Suppl. (En).Rome, FAO, 105P.

Swift, S.A. and Bower, A.S., 2003. Formation and circulation of dense water in the Persian/Arabian Gulf. *Journal of Geophysical Research: Oceans (*1978-2012), 108(**C1**), 1-4.

Takasuka, A., Oozeki, Y., Kubota, H. and Lluch-Cota, S.E., 2007. Contrasting spawning temperature optima: why are anchovy and sardine regime shifts synchronous across the North Pacific? *Progress in Oceanography*, 77, 225–232.

Tameishi, H., Shinomiya, H., Aoki, I. and Sugimoto, T., 1996. Understanding Japanese sardine migrations using acoustic and other aids. *ICES Journal of Marine Science*, 53(**2**), 167-172.

Valavanis, V.D., Georgakarakos, S., Kapantagakis, A., Palialexis, A. and Katara, I., 2004. A GIS environmental modelling approach to essential fish habitat designation. *Ecological Modelling*, 178, 417–427.

Valavanis, V.D., Pierce, G.J., Zuur, A.F., Palialexis, A., Saveliev, A., Katara, I. and Wang, J., 2008. Modelling of essential fish habitat based on remote sensing, spatial analysis and GIS. *Hydrobiologia*, 612(**1**), 5-20.

Van Zailinge, N.P., Owfi, F., Ghasemi, S., Khorshidian, K. and Niamaimandi, N., 1993. Resources of small pelagics in Iranian waters, a review. FAO/ UNDP Fisheries Development Project Ira/83/013, 370P.

Zuur, A.F., Ieno, E.N. and Smith, G.M., 2007. Analyzing ecological data. Springer Series, Statistics for Biology and Health, New York: 700P.