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Determination of the probability of the occurrence of Iran life zones (an integration of binary logistic regression and geostatistics)

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Key words: Logistic regression, Life zones, Occurrence probability.

Abstract

The occurrence probability of the life zones of Iran including Hyrcanian humid forests, Zagros semiarid and humid forests, humid grasslands, semiarid scrub-grasslands, arid desert scrubs and arid deserts was determined using binary logistic regression. The environmental predictors in this study were elevation, mean annual precipitation, temperature, maximum and minimum temperature, relative humidity, and reference evapotranspiration. The occurrence of the life zones with the probability of 0-1, 0.2-1, 0.4-1, 0.6-1 and 0.8-1 was compared to the reference data using kappa coefficient and Z-statistic. Mean annual precipitation was the significant variable in determination of the presence probability of 5 out of 6 life zones followed by elevation and mean annual maximum temperature which were significant for predicting the occurrence probability of 4 life zones. The highest agreement between the predicted map and the reference map was related to the Hyrcanian humid forests and arid deserts. Continuously distributed life zones with no gap had the most accurate predicted presence, while the life zones which were discontinuously and sparsely distributed, had the lowest accurate predicted presence. The best agreement between the predicted data and the reference data for all the life zones was found for the occurrence probability of 0.2-1, and this range can be used as an efficient range of probability for comparing the predicted data and the reference data in vegetation and life zone modeling based on logistic regression.

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Introduction

Life zones are the main ecological unit of classification and they define conditions for ecosystem functioning (Lugo *et al.,* 1999). Life zones are usually delimited based on environmental variables such as precipitation, biotemperature, evapotranspiration and can be subdivided into associations according to more detailed climatic data, edaphic conditions, topography, etc (Holdridge, 1967). The study of occurrence and distribution of life zones is important in ecology and conservation biology for analyzing the relationships between the environmental variables and vegetation attributes such as distribution of species and communities, species composition, determining the potential of an area to support a particular species and high level of biodiversity, identifying the suitability of a given land use type as well as predicting the vegetation type and disturbance history in relation to the climate changes and management strategies during successional stages (Lugo *et al.,* 1999). A variety of quantitative world and regional models have been presented to relate the environmental variables to distribution of life zones (Holdrige, 1947; Box, 1981), plant species (e.g., Franklin, 1998; Guisan *et al.,* 1999), plant communities (e.g., Zimmermann and Kienast, 1999) and plant biodiversity (e.g., Wohlgemuth, 1998). One of the main aspects of these researches is improving the efficiency and accuracy of prediction using various environmental variables and statistical models. Logistic regression models have been efficiently used for predicting the distribution of vegetation species (Rijt *et al.,* 1996; Guisan, 1999; Aspinall, 2002; Calef *et al.,* 2005). Binary logistic regression uses maximum likelihood which maximizes the probability of classifying the observed data into the appropriate category given the regression coefficients. The probability can take any value between 0 and 1. Iran contains 6 main life zones including Hyrcanian humid forests, Zagros semiarid and humid forests, humid grasslands, semiarid scrub-grasslands (semiarid shrub-grasslands), arid desert scrubs (arid desert shrubs[1]) and arid deserts (Fig 2). A few studies have been done on the modeling of the presence and distribution of life zones using binary logistic regression. In logistic regression-based modeling, it is necessary to determine the range of probability in which the presence of a life zone is most accurately predicted. The objectives of this research were to evaluate the efficiency of logistic regression in determining the occurrence and distribution of the life zones of Iran, to determine the significant variables in prediction of the life zones distribution and to assess the accuracy of predicted occurrence of the life zones with the probability of 0-1, 0.2-1, 0.4-1, 0.6-1 and 0.8-1.

Material and methods

The data layers used for determining the probability of the presence of Iran life zones were digital elevation model (DEM), mean annual temperature (Tmean), mean annual maximum temperature (Tmax) mean annual minimum temperature (Tmin), mean annual precipitation (P), mean annual relative humidity (H) and mean annual reference evapotranspiration (ETo) (Fig 1). DEM, Tmean and P were created respectively using interpolating contour maps of elevation, mean annual temperature and precipitation of Iran produced by National Cartographic Center of Iran (NCCI). The data of 180 synoptic stations throughout Iran from 1955-2005 were applied to produce point layers of Tmax, Tmin, H and ETo. The point maps were interpolated by calculating variogram and kriging algorithm. Reference evapotranspiration was determined using Penman-Monteith equation (Allen *et al.,* 1998) based on the data of elevation, latitude, mean annual temperature, maximum and minimum temperature, relative humidity, wind speed and sunshine hours of the synoptic stations.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 U_2)}$$

[1]. The main scrub (shrub) species of the arid desert scrub life zone of Iran are *Artemisia, Astragalus, Tamarix, Haloxylon, Anabasis, Salsola, Calligonum, Acantholimon, Acanthophyllum, Cousinia* and *Zygophyllum.*

where ET_o : reference evapotranspiration [mm day^{-1}], R_n: net radiation at the crop surface [MJ m^{-2} day^{-1}], G: soil heat flux density [MJ m^{-2} day^{-1}], T :mean air temperature [°C], U_2: wind speed at 2 m height [m s^{-1}], e_s: saturation vapour pressure [kPa], e_a :actual vapour pressure [kPa], e_s - e_a: saturation vapour pressure deficit [kPa], Δ :slope vapour pressure curve [kPa °C^{-1}] and γ : psychrometric constant [kPa °C^{-1}].

To determine the presence probability of the life zones of Iran using logistic regression, all data layers and the reference life zone map of Iran (produced by NCCI) (Fig 2) were displayed together on one map window in ILWIS. 60 points were selected approximately uniformly on each life zone (a total of 360 points), and the elevation, mean, maximum, and minimum temperature, precipitation, humidity and reference evapotranspiration values for each point were registered. With binomial linear model, the inverse logistic transformation is (Guisan *et al.,* 1999)

$$P = \frac{\exp(a + b_1x_1 + b_2x_2 + ... + b_nx_n)}{1 + \exp(a + b_1x_1 + b_2x_2 + ... + b_nx_n)}$$

This equation gives a probability value from 0 to 1, where *p* is the probability of the occurrence of each object (life zone), exp is the base of natural logarithms, a is the constant of the equation, b is the coefficient of the predictor variables and x_1, x_2 ,.... x_n are the variables including E (elevation), Tmean, Tmax, Tmin, ETo, H and P. To predict the probability of the presence of each life zone (as dependant class), the life zone was coded as 1 and the other life zone classes as 0. Backward stepwise logistic regression method was used to identify the statistically significant predictors (P<0.05). The Wald chi-square was used to test the significance of individual predictors in each model. To determine the amount of variance explained by the predictors in each model, Nagelkerke's R square was calculated. The presence probability map of each life zone was then produced by the logistic regression models in ILWIS. The probability of the occurrence of each life zone was classified into 5 classes (0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8 and 0.8-1). The presence of each life zone type with the probability of 0-1, 0.2-1, 0.4-1, 0.6-1 and 0.8-1 was compared to the reference data to determine the accuracy of the predicted presence of the life zone with a specified probability class. Because 6 main life zones of Iran were studied in this research, the predicted maps were compared to the reference map following separating the other land covers (agricultural lands, dry farmlands, saltlands, wetlands, water and rock) from the maps. To obtain the accuracy of each model, Kappa coefficient was calculated to compare the predicted maps with the reference map. Kappa coefficient was calculated as:

$$Kappa = \frac{N\sum_{i=1}^{k} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}$$

where *r* is the number of rows in the matrix, x_{i+} and x_{+i} are the marginal totals of row *i* and column *i* respectively. *N* is the total number of observations and x_{ii} is the number of observations in row *i* and column *i*. Kappa statistic strength of agreement is classified as: <0 poor, 0-0.20 slight, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 substantial and 0.81-1 almost perfect (Landis and Koch, 1977). To test the significance of Kappa coefficient, Z statistics was calculated (Congalton and Green, 2008).

$$z = \frac{k}{\sqrt{\text{var}(k)}}$$

The value of z > 1.96 (α =0.05) indicates that the classification is significantly better than a random result.

$$\text{var}(k) = \frac{1}{N}\left[\frac{\theta_1(1-\theta_1)}{(1-\theta_2)^2} + \frac{2(1-\theta_1)(2\theta_1\theta_2 - \theta_3)}{(1-\theta_2)^3} + \frac{(1-\theta_1)^2(\theta_4 - 4\theta_2^2)}{(1-\theta_2)^4}\right]$$

where $\theta_1 = 1/N\sum_{i=1}^{C} x_{ii}$,

$$\theta_2 = 1/N^2\sum_{i=1}^{C} x_{i+} + x_{+i} \text{ ,}$$

$$\theta_3 = 1/N^2\sum_{i=1}^{C} x_{ii}(x_{i+} + x_{+i}) \text{ ,}$$

$$\theta_4 = 1/N^3 \sum_{i=1}^{C}\sum_{j=1}^{C} x_{ij}(x_{j+} + x_{+i})^2$$

Results

Logistic regression models

All of the six logistic regression models created for determining the occurrence probability of the main life zones of Iran had significant chi square values (P= 0.000) (table 1). The predicted map of the presence probability of each life zone produced by the logistic regression models is shown in fig. 3.

Table 1. The logistic regression results using seven environmental variables including elevation (E), mean annual precipitation (P), temperature (Tmean), maximum temperature (Tmax), Minimum temperature (Tmin), reference evapotranspiration (ETo) and humidity (H). B: the coefficient of the logistic regression, Wald statistic test, Omnibus Chi Square, Nagelkerke R square and significant level. The equation (*P*) for determining the occurrence probability of each life zone is presented.

Life zone	Variable	B	Wald	Sig.	Chi square	Sig.	Nagelkerke R square
Hyrcanian humid forests					203.5	0.000	0.941
	ETo	-7.129	4.6	0.032			
	Tmax	1.331	4.26	0.039			
	E	-0.005	8.77	0.003			
	P	0.018	9.31	0.002			
	Constant	-13.651	3.99	0.046			
P=[exp (-13.651-7.129ETo+1.331Tmax-0.005E+0.018P)]/[1+exp(-13.651-7.129ETo+1.331 Tmax -0.005 E+0.018P)]							
Arid Deserts					167.54	0.000	0.81
	E	-0.004	12.34	0.000			
	P	-0.055	18.15	0.000			
	Constant	9.045	19.49	0.000			
P=[exp(9.045-0.004E- 0.055P)]/[[1+exp (9.045-0.004E- 0.055P)]							
Arid desert Scrubs					200.6	0.000	0.603
	Tmax	0.349	36.63	0.000			
	H	0.092	9.79	0.002			
	E	0.001	10.73	0.001			
	P	-0.013	31.7	0.000			
	Constant	-11.936	25.02	0.000			
P=[exp(-11.936+0.349Tmax+0.092H+0.001E-0.013P)]/[1+exp(-11.936+0.349Tmax+0.092H+ 0.001 E-0.013 P)]							
Humid grasslands					113.2	0.000	0.437
	Tmax	-0.19	9.1	0.003			
	Tmean	-0.312	35.09	0.000			
	Constant	5.341	19.73	0.000			
P=[exp(5.341-0.19Tmax-0.312Tmean)]/[1+ exp(5.341-0.19Tmax-0.312Tmean)]							
Zagros semiarid and humid forests					94.3	0.000	0.348
	ETo	-2.221	22.22	0.000			
	Tmax	0.906	34.9	0.000			
	Tmin	-0.572	28.57	0.000			
	E	0.001	12.93	0.000			
	P	0.003	21.33	0.000			
	Tmean	0.118	3.9	0.048			
	Constant	-12.839	51.16	0.000			
P=[exp(-12.839-2.221ETo +0.906Tmax-0.572Tmin+0.001E+0.003P +0.118Tmean)]/[1+ exp(-12.839-2.221 ETo +0.906Tmax-0.572Tmin+0.001E+0.003P+0.118Tmean)]							
Semiarid scrub-grasslands					65.07	0.000	0.233
	ETo	-0.399	4.31	0.038			
	P	-0.004	22.6	0.000			
	Tmean	-0.197	25.83	0.000			
	Constant	4.232	21.34	0.000			
P=[exp(4.232-0.399ETo-0.004P-0.197Tmean)]/[1+exp(4.232-0.399ETo-0.004P-0.197 Tmean)]							

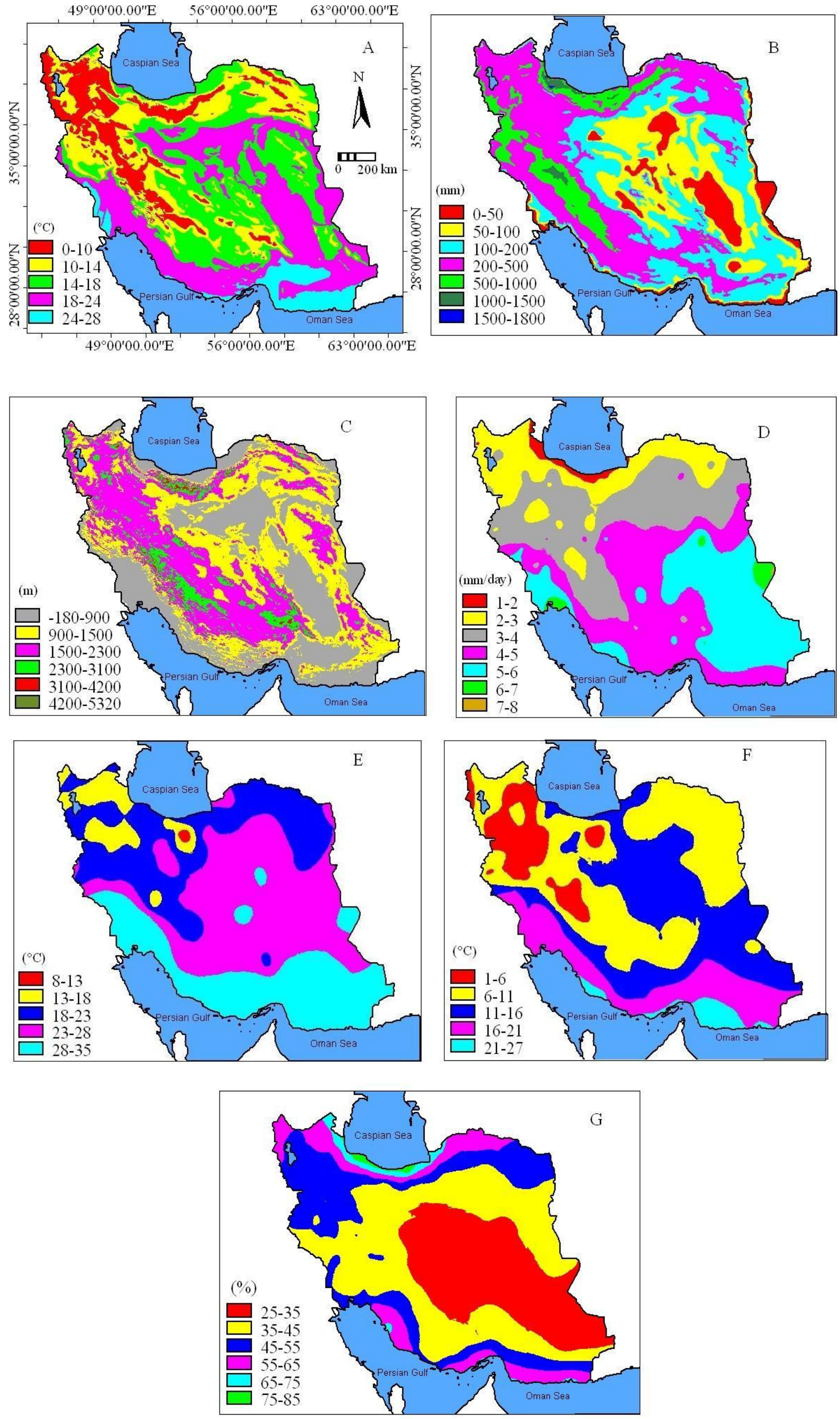

Fig. 1. A) Mean annual temperature, B) mean annual precipitation, C) digital elevation model, D) mean annual reference evapotranspiration, E) mean annual maximum temperature, F) mean annual minimum temperature and G) mean annual relative humidity map of Iran based on the data of 1955-2005.

Mean annual precipitation was the significant variable in determination of the presence probability of 5 life zones followed by E, Tmax, Tmean, ETo, H and Tmin variables which were significant for identifying the presence probability of 4, 4, 3, 3, 1 and 1 life zones respectively (table 1). P, E, ETo and Tmax were significant predictors ($P < 0.05$) in determining the probability of the occurrence of the Hyrcanian humid forests using Wald test. Nagelkeke's R square of 0.94 indicated a strong relationship between the prediction and the predictors for this life zone. E and P ($P = 0.000$) made a significant contribution to prediction of the occurrence probability of arid deserts. Nagelkeke's R square (0.81) showed a strong relationship between the prediction and the variables. Tmax, H, E and P ($P<0.01$) contributed significantly to the prediction of the presence probability of arid desert scrub life zone. A reasonable relationship between the prediction and the predictors was found for this life zone (Nagelkeke's R square of 0.6). Tmax and Tmean had a significant influence ($P < 0.01$) for humid grassland life zone. The Nagelkeke's R square (0.44) was moderate. For the Zagros semiarid and humid forests, the most number of variables (6 out of 7) including ETo, Tmax, Tmin, E, P, and Tmean were significant ($P < 0.05$), however Nagelkeke's R square of 0.35 did not indicate a strong relationship between prediction and the predictors. ETo, P and Tmean were significant predictors ($P < 0.05$) in predicting the presence probability of semiarid scrub-grassland life zone. The weakest relationship between the prediction and the predictors was found for this life zone (Nagelkeke's R square = 0.23) in compared to the other life zones.

The accuracy of predicted occurrence

Kappa value and related Z-statistic were calculated for obtaining the accuracy of the predicted presence of Iran life zones with the presence probability of 0.8-1, 0.6-1, 0.4-1, 0.2-1 and 0-1. The highest agreement between the predicted occurrence of the life zones and the reference data was found for the Hyrcanian humid forests with a substantial agreement (κ =0.67), followed by arid deserts with a moderate agreement (κ = 0.55), and humid grasslands (κ = 0.33), arid desert scrubs (κ =0.26), Zagros semiarid and humid forests (κ =0.26) and semiarid scrub-grasslands (κ =0.21) with a fair agreement (table 3). The occurrence of the Hyrcanian humid forests with the probability of 0.8-1, 0.6-1, 0.4-1 and 0.2-1 had a substantial agreement with the reference data (κ =0.64 – 0.67). The kappa values of close to 0 and the negative kappa values indicated a poor agreement and disagreement between the reference data and the occurrence of all the life zones with the probability of 0-1. There was a moderate agreement between the predicted presence of arid deserts with the probability of 0.8-1, 0.6-1, 0.4-1 and 0.2-1 and the reference data (κ =0.49 – 0.55). The kappa values of 0.12-0.19 for arid desert scrubs with the occurrence probability of 0.8-1, 0.6-1 and 0.4-1 indicated a slight agreement, but the kappa value of 0.26 for the occurrence probability of 0.2-1 indicated a fair agreement between the presence probability of this life zone and the reference data. The kappa values of close to 0 for semiarid scrub-grasslands with the presence probability of 0.8-1 and 0.6-1 showed a poor agreement, but the kappa value of 0.18 and 0.21 for the presence probability of 0.4-1 and 0.2-1 showed a slight and fair agreement respectively for this life zone. A slight agreement was found between the reference data and the presence of humid grasslands with the probability of 0.8-1, but a fair agreement was found on this life zone with the probability of 0.6-1, 0.4-1 and 0.2-1 (κ =0.22 – 0.33). The Kappa values for the Zagros semiarid and humid forests gave the same results as for humid grasslands (, κ =0.17, a slight agreement for the presence probability of 0.8-1, and a fair agreement for the presence probability of 0.6-1, 0.4-1 and 0.2-1, κ =0.21 – 0.26)

Table 2. Kappa coefficient and related Z- statistic for the presence of Iran life zones with the probability of 0-1, 0.2-1, 0.4-1, 0.6-1 and 0.8-1.

	occurrence probability of the life zone				
	0-1	**0.2-1**	**0.4-1**	**0.6-1**	**0.8-1**
Life Zone					
Hyrcanian humid forests					
Kappa	0.0001	0.642	0.645	0.668	0.673
Z	5.8**	268**	260.3**	264.8**	258.3**
Arid Deserts					
Kappa	-0.086	0.486	0.535	0.546	0.516
Z	-224.75	554.7**	581.5**	567.4**	502**
Humid grasslands					
Kappa	-0.0004	0.3	0.33	0.22	0.07
Z	-12	183.7**	143.7**	91.2**	40.8**
Arid desert scrubs					
Kappa	-0.0054	0.262	0.193	0.138	0.117
Z	-33.8	306**	214.3**	169.5**	207**
Zagros semiarid and humid forests					
Kappa	0.0001	0.212	0.255	0.256	0.168
Z	3**	200.1**	167.3**	135.9**	85.2**
Semiarid scrub- grasslands					
Kappa	0.001	0.201	0.183	0.0093	0.0002
Z	29.7**	232.4**	158**	23.1**	2.8**

**: significant at 0.05 probability level.

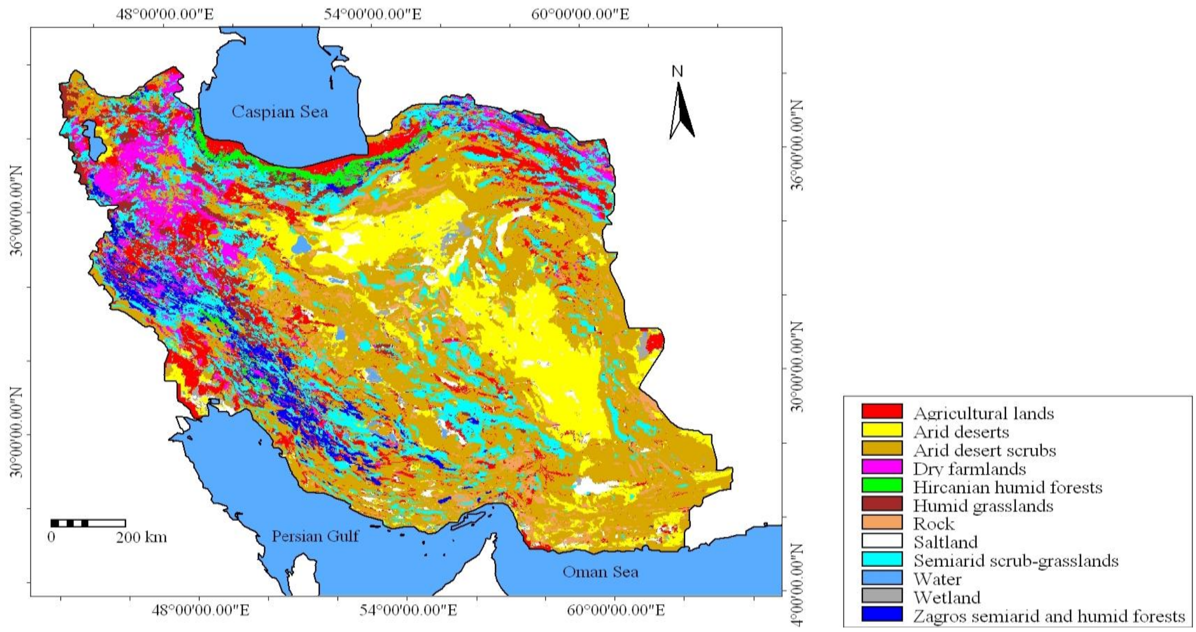

Fig. 2. The reference land cover map of Iran in which the life zones including Hyrcanian humid forests, Zagros semiarid and humid forests, humid grasslands, semiarid scrub-grasslands (semiarid shrub-grasslands), arid desert scrubs (arid desert shrubs) and arid deserts are shown together with the other land covers (agricultural lands, dry farmlands, water, saltlands, wetlands and rock)

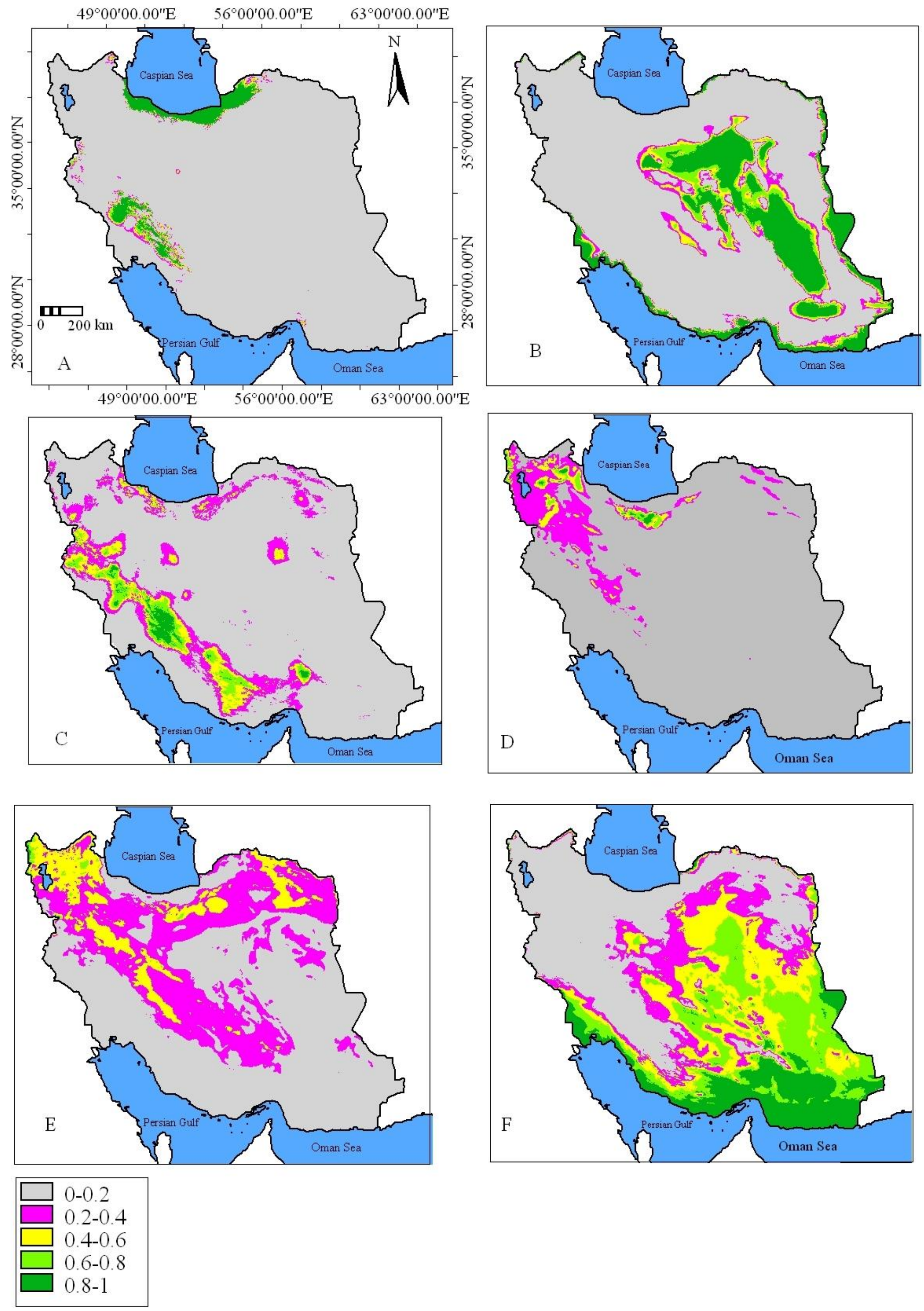

Fig. 3. The predicted map of the occurrence probability of A) Hyrcanian humid forests, B) arid deserts, C) Zagros semiarid and humid forests, D) humid grasslands, E) semiarid scrub-grasslands and F) arid desert scrubs produced by logistic regression models. The occurrence probability is classified into 5 classes (0-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1)

Discussion

The probability of the presence of main life zones of Iran was determined using seven environmental factors based on binary logistic regression. The efficiency of logistic regression has been proved in detecting vegetation-environment relations (Aspinall, 2002; Calef *et al.,* 2005). Mean annual precipitation was the most important factor for determining the occurrence of the life zones, since it was significant for determining the occurrence of 5 out of 6 life zones followed by elevation and mean annual maximum temperature which were significant for predicting the presence of 4 life zones. The effect of elevation on temperature and precipitation induces a compression of the typical meridional climatic gradients, causing changes in life zones (Diaz *et al.,* 2006). Chakraborty *et al.* (2013) stated that the changes in temperature and precipitation cause changes on the area cover and distribution of life zones. The presence of the Hyrcanian humid forests and arid deserts was most accurately predicted by logistic models. A substantial and moderate agreement was found between the reference data and the presence probability of the Hyrcanian humid forests and arid deserts respectively, while there was a fair agreement on the other life zones (arid desert scrubs, semiarid scrub-grasslands, humid grasslands and Zagros semiarid and humid forests). This may be due to three reasons: 1) The Hyrcanian humid forests are dense forests of Iran and both the Hyrcanian humid forests and arid deserts are continuously distributed as there is almost no gap within each of these life zones. The other life zones are discontinuously and sparsely distributed throughout Iran. Because of discontinuity and island-like form of these life zones, the collected data could not show the exact distribution of the life zones, although the extension of these life zones was efficiently predicted. 2) The occurrence probability of the life zones may be accurately predicted, but the human effects, management strategies and environmental disturbances during successional stages have changed the actual status of the life zones to the current status. This is obvious for the north and northwest parts of Iran where the vast area of humid grasslands and semiarid scrub-grasslands has been changed into agricultural lands and dry farmlands. 3) More detailed data such as soil properties are needed to accurately determine the distribution of the life zones. The occurrence probability of 0.2-1 for all the life zones had the best agreement with the reference data. Although the highest kappa value on the Hyrcanian humid forests was related to the presence probability of 0.8-1, the same strength of agreement (substantial agreement) was found for the presence probability of 0.8-1 and 0.2-1. The same result was found for arid deserts, as the occurrence probability of 0.2-1 had the same strength of agreement with the occurrence probability of 0.8-1. Both the highest kappa value and the strength of agreement on arid desert scrub and semiarid scrub-grassland life zones were related to the occurrence probability of 0.2-1. For the humid grasslands and the Zagros semiarid and humid forests, the highest kappa value was found for the presence probability of 0.4-1 and 0.6-1 respectively, but the strength of agreement (fair agreement) for these two presence probability was the same as for the presence probability of 0.2-1. The findings of this research indicate the efficiency of binary logistic regression in predicting the occurrence and distribution of life zones. The probability of 0.2-1 can be considered as the most efficient range of probability for predicting life zones occurrence and distribution using logistic regression.

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