EFFECT OF CLIMATE CHANGE AND ANTHROPOGENIC PRESSURES ON THE EUROPEAN EEL *ANGUILLA ANGUILLA* FROM RAMSAR WETLAND ICHKEUL LAKE: PREDICTION FROM THE RANDOM FOREST MODEL

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Abstract – The present study aims to assess the trophic level of Ichkeul ecosystem and predict the effect of climate change and anthropogenic pressures on European eels.
Multimetric trophic index (TRIX) and Random Forest (RF) model were performed using a dataset consisting of 14 parameters for the period 2010-2020.
The observed TRIX values inside the lake show a non-uniform distribution and a variation between seasons reflecting poor water quality mainly in the river's discharges. While the RF model outcomes show that the most important predictors of eels landing appear to be water level, followed by turbidity and salinity. These results are consistent with the relationships found with the Pearson Correlation.
For comparison, the RF model yielded an R^2 of 58.4 % while the Multiple Regression Linear MLR yielded an R^2 of 40.3 %, confirming that the RF model is significantly better than the MLR and that the model predictions are statistically reliable. This study also demonstrated that the sustainable approach, which combines the two models, can be used in decision-making by civil authorities and other interested stakeholders.

1. Introduction

Coastal ecosystems are known for their wealth of biodiversity and biogeochemical processes and are among the richest environments in the worldwide [1]. Nowadays, these ecosystems are threatened by the fast growth of the human activities, which are the most impacting problems for ecosystem ecological quality [1]. Even though the Mediterranean ecosystems have been identified as some of the word's main biodiversity hotspots, these sites are no exception to the unfavourable biological biodiversity as they are in steep decline [2]. In North Africa, specifically, the Tunisian ecosystems are threatened by the deterioration of their water quality since the development of industry, touristic activities and agriculture [3].

Predicting the impact of climate change on ecosystems is complex due the interplay among different variables [4]. Thus, multiple models have been developed. In particular, the Random Forest (RF) model, which have recently gained popularity in marine ecology [5].

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In the present study, we develop the idea that the diadromous specie (European eel) is the most pertinent bio-indicator to assess the ecological state of the ecosystem. An exhaustive collection of data is used to build a predictive model of effect of climate change on coastal area, by coupling a RF model and a TRIX index. Our goals are as follows: (i) Characterize the seasonal contrasting state of the Ichkeul Lake (ii) Assess the trophic state of water body using the TRIX index and, (iii) Develop a predictive model to evaluate the most important factors influencing the presence of eels' species.

2. Materials and Methods

2.1. Study area

Ichkeul Lake is located in the northeast of Tunisia. It is surrounded by a temporary swamp and is bounded on the south by a mountain called Jebel Ichkeul (Fig.1). The hydrological regime of the lake is controlled by freshwater from precipitation and the watershed area (2600 km^2) and by marine water from Bizerte Lagoon. The lake is fed by six rivers that have been steadily cut off by dams since the 1990s [6].

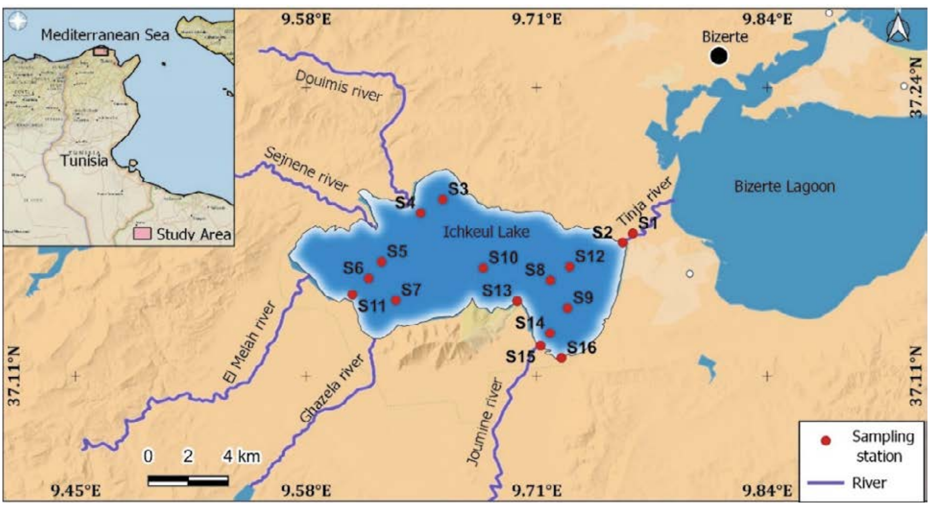

Figure 1 – Geographic localization of Ichkeul Lake and location of sampling stations.

The specific hydrology and the ecological importance of the lake have prompted its inclusion in multiple international conventions: UNESCO Biosphere Reserve, UNESCO World Heritage Element, Wetland of International Importance known as RAMSAR Convention, National Park of Tunisia and Important Wetland for Bird Conservation (ZICO) [7]. However, this wetland is an example of an impacted lake due to anthropogenic pressures such as damming of main rivers, agricultural intensification, and urbanization [7].

2.2. Data collection

The dataset used in the present study consists of 14 environmental variables at 16 sites for the period 2010-2020 (Fig.1). It was collected from different sources; from the DGPA (General Direction of Fisheries and Aquaculture, Tunisia), the platform of BASSIANA database, which is performed within the framework of the IMAS-Ichkeul project, through an extensive literature search and from a sampling campaign. The monitoring fieldwork was conducted in August 2020 and covered 10 sampling sites in the lake. The sampling points were selected at the mouths of the tributary rivers (S1 to S10).

Physico-chemical parameters were measured in the field by using a WTW multiparameter (Multi 340i). Surface water samples were analysed for chemical variables using an Auto-analyser [10], While the chlorophyll a (Chl a) concentrations were measured using the spectrophotometric method of [11] and following the procedure given by [12].

2.3. Data analysis

The derived dataset consists of 13 predictors and 1 response variable. To conform to the requirements of normality when using regression models, the target variable was transformed using the Box-Cox transformation [13].

The resulting dataset is derived from a variety of sources, that caused the insufficient information on some parameters. Overall, 30 % of the values were missing in the dataset. To avoid the adverse negative effect of any missing information, two solutions were conducted. Firstly, we removed the spatial information from the dataset (i.e., longitude and latitude columns) and average the rows of each feature that had the same date. Consequently, the proportion of missingness was decreased to 18 %. Secondly, we statistically imputed the 18 % of the missing values (NA) with a machine learning algorithm called 'missForest'[14]. This method is based on prediction and estimation from the non-missing value available from the original dataset [13]. The performance of this algorithm is assessed using the normalized root mean squared error NRMSE [14].

2.4. TRophic IndeX (TRIX)

TRIX index is a numeric expression that used to provide the degree of trophic status of coastal ecosystem, based on nutrient concentrations and productivity. TRIX index was originally tested in NW Adriatic Sea [15] and then applied to several coastal areas and seas, such as the Tyrrhenian Sea [16], the Greek coastal lagoon [17], Bizerte Lagoon [4], Ghar El Melh Lagoon [18] and Tunis Lagoon [3] . TRIX analytical expression is the following:

$$\mathrm{TRIX} = \mathrm{Log10}(\mathrm{DIN} * \mathrm{DIP} * |\mathrm{D\%O2}| * \mathrm{Chla})/\mathrm{b} \qquad (1)$$

where: DIN, DIP and Chla concentrations are expressed in µg/l, $|D\%O_2|$ represents the absolute percent deviation of DO from saturation (%), and the parameters a=1.5 and b=1.2. The value 0 corresponds to extreme oligotrophic conditions and the value 10 corresponds to extreme eutrophic conditions [16].

2.5. Random Forest model (RF)

The RF model is a statistical technique introduced by Breiman [19], and it is a popular algorithm that aims primarily to categorization by classification, then to obtain a consensus prediction by regression [19].

RF combine several decisions trees to achieve a reliable regression. In general, two-thirds of the data are used as a training data, while one-third is the out-of-bag OOB, used for testing set. An interest feature of RF is the use of OOB to evaluate the model and to estimate the OOB error [19]. The performance of the RF model was evaluated using the coefficient of determination (R^2).

3. Results

3.1. Parameter's properties

Concerning the meteorological parameters, the mean annual precipitation was 59.28 mm for the period 2010-2020. In dry period, 9.42 % of the rainfall occurred and 90.57 % in wet period (Table.1). While the mean wind intensity was approximately 6.01 m s^{-1} and 5.22 m s^{-1} in dry and wet period, respectively, and the dominant wind was originating the north-western side.

Table 1 – Summary of environmental parameters in Ichkeul Lake for the period 2010-2020

Parameter	Abbreviation and Unit	Dry period			Wet period		
		Min	Max	Mean	Min	Max	Mean
Season	Se	Summer and Spring			Winter and Autumn		
Precipitation	P (mm)	0.00	73.91	15.96	0.00	249.93	82.61
Wind Intensity	W (m.s-1)	3.64	8.90	6.01	2.41	8.82	5.22
Temperature	T (°C)	12.76	28.60	21.11	10.00	62.76	15.39
Water Level	WL (cm)	3.00	113.00	44.29	3.00	156.00	67.44
Salinity	S (psu)	11.30	71.00	44.68	3.43	59.59	21.42
Dissolved Oxygen	DO (mg. l-1)	4.20	11.00	7.29	3.20	14.00	7.13
Turbidity	Tur (NTU)	10.14	34.20	18.90	12.10	46.00	27.34
Dissolved Inorganic Nitrogen	DIN (µM)	6.21	73.51	22.05	11.01	56.60	29.46
Total Nitrogen	TN (µM)	16.70	32.58	22.66	18.69	22.84	20.97
Dissolved Inorganic Phosphorus	DIP (µM)	0.11	7.62	2.08	0.25	2.57	1.06
Total Phosphorus	TP (µM)	3.56	36.42	12.80	4.29	13.03	7.60
Chlorophyl a	Chl.a ($\mu g \cdot l^{-1}$)	1.24	9.80	6.80	1.21	9.14	3.36
Eels landing	Eels (tons)	0.02	11.80	1.84	0.07	45.00	9.34

Regarding the physico-chemical parameters, the water level was between 44.29 cm in dry season and 67.44 cm in wet season. Whilst the average annual water temperature was 21.11 °C with a maximum of 28.60 °C and a minimum of 12.76 °C. The salinity level was likely to be homogenously distributed with a mean of 44.68 psu and 21.42 psu in dry and wet seasons, respectively. Mean annual dissolved oxygen levels were approximately 7 mg l^{-1}, and mean turbidity was varied between 18.90 NTU and 27.34 NTU.

The chemical parameters also exhibit a seasonal trend and they showed two episodes during a year: high level in wet period and low concentrations in dry period. Overall, the chemical parameters in the lake were mainly high in the estuaries of rivers.

The chlorophyll-a concentration, that approximate the phytoplankton biomass, was ranged between 6.80 µg l^{-1} and 3.36 µg l^{-1}, while the highest quantity of European eels hidden in the lake was during the period between November and March, with a peak in December (45 tons).

3.2. Statistical analysis

The MissForest algorithm was used in the present study to deal with missing values, and it gave an NRMSE of 0.22 indicating a sufficiently good performance. The Pearson correlation result (Fig.2) showed that eel landing was positively correlated with water level (r=0.73) and turbidity (r=0.61), and negatively correlated with S (r=- 0.44).

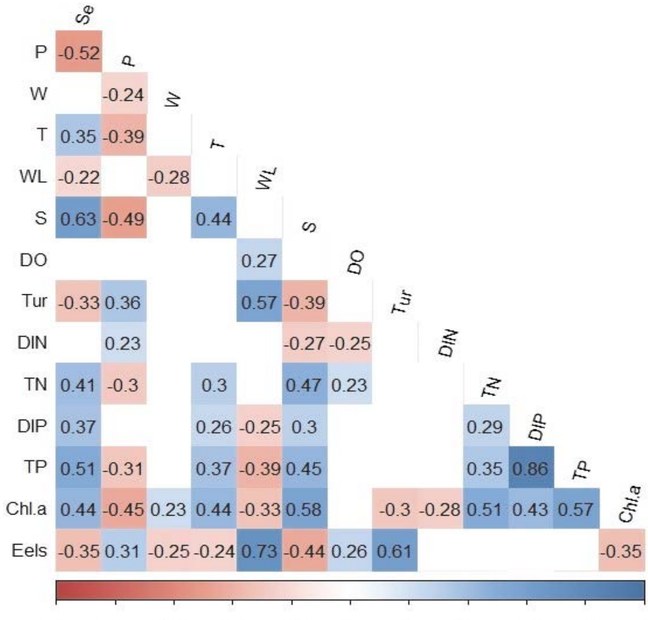

Figure 2 – Lower triangular correlation matrix of the predictors and Eels landing in Ichkeul Lake.

3.3. TRIX derivation

The calculated seasonal averages of the TRIX index inside the lake are shown in Fig 3. Overall, the index values show a non-uniform distribution and a variation between seasons. Indeed, in dry period, the water quality was poor, and the highest values (between 4 and 6) were recorded in the eastern side of the lake close to Tinja, Tine and Joumine rivers, while the eutrophication level in the west side was relatively medium. As opposite, in wet period, the high values (from 4 to 5) were recorded in the north region where the Douimiss river take place, while in the eastern sector, the eutrophication level was between 3.5 and 4.

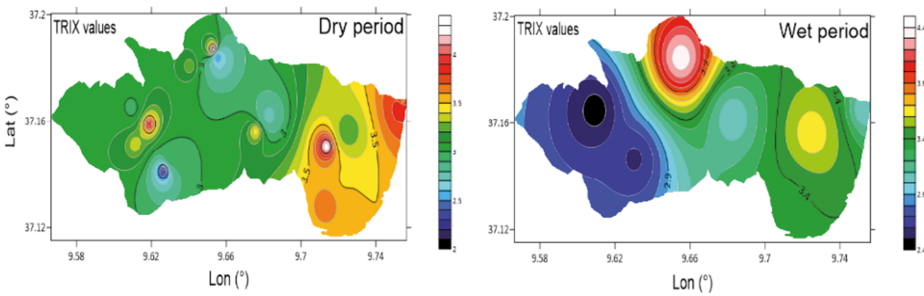

Figure 3 – Distribution of TRIX values in Ichkeul Lake for the period 1995-2020.

3.4. Random Forest RF deviation

The RF model was implemented in R [20], and it resulted in an R^2 equal to 58.4 %. The automatic evaluation of the model using the test set is similar to cross-validation.

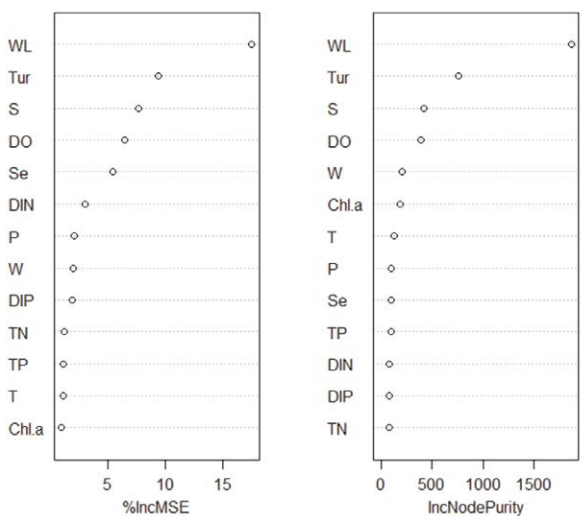

Figure 4 – Predictor's importance ranking for the RF model for the period 1995-2020.

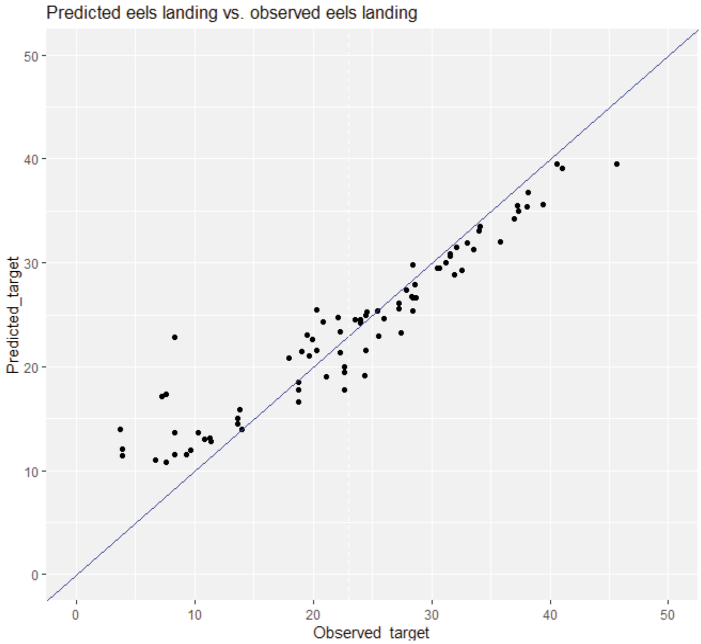

Figure 5 – Scatter plot of the observed and the predicted eels landing.

The most important predictors contributing to the estimation of eel biomass are water level, followed by turbidity and salinity (Fig.4). Figure 5 showed that the observed eel landing was correctly predicted. In addition, the MLR gave an R^2 of 47.4 % which is lower than the RF model.

4. Discussion

The data analysis suggested that the Ichkeul ecosystem is characterized by a seasonal variation of its environmental factors and that the values of these factors are generally recorded in Mediterranean ecosystems [4], [18]. Yet, the present study also revealed that the above-mentioned parameters experienced exceptional values within the lake, such as the increase in salinity (70 psu in dry period) and the decrease in water level (30 cm in dry season). This is presumably related to several anthropogenic stressors and climate change. Indeed, the construction of six dams on the main rivers flowing into the lake, low precipitation and high evaporation have reduced the water level of the lake. Furthermore, under the pressure of climate change, the water level has been drastically reduced, resulting in a very high salinity and a lower water depth.

These stressors have also led to an increase in the eutrophication level in the lake, as evidenced by the low concentration of dissolved oxygen and the significant nutrient budget. On an annual basis and according to the TRIX index results, the lake can be considered a mesotrophic ecosystem with good to poor water quality. The high eutrophication on the eastern and northern sides is mainly due to rural settlements without sewage treatment systems and extensive agricultural activity [21].

Climatic conditions and human activities have equally affected the marine resources of the lake. In fact, results obtained from the RF model and Pearson correlation indicated that the most important variables for eels landing were water level, following by turbidity and salinity. In fact, water level and turbidity promote eel migration and facilitate the foraging process [22]. Furthermore, salinity plays a key factor in the cycle life of European eels [22]. In decreasing the order of importance of predictors, the other descriptors were dissolved oxygen, season, and nutrients. In agreement with several studies.

Climatic and anthropogenic pressures have disturbed eel's growth by causing habitat alteration, niche width, and non-food availability[22]. The presence and the trophic strategies of this species reflect the quality of the water body. In fact, the eels enlarged its trophic niche under eutrophic conditions and become omnivore predator and shift from pelagic (fish) to benthic (invertebrates) prey, which demonstrated in Ichkeul Lake by the study of [23]. Thus, this confirmed the high eutrophic conditions in the lake.

The present research is the first to investigate the relation between abiotic variables and ichthyological resources in Ichkeul wetland using the machine learning algorithms. The dependence between environmental parameters and chlorophyll-a concentration was studied in Bizerte Lagoon [4], Ghar E Melh Lagoon [18]. The fitted RF model in Ichkeul Lake (present study) was similar to that found in Ghar El Melh L (R^2= 0.64), yet it was better than in Bizerte Lagoon (R^2= 0.45). This is presumably due to the type of dataset used, the hydrological process of each ecosystem and the different impacts that threaten.

5. Conclusion

Being a biosphere reserve and a RAMSAR site, Lake Ichkeul does not allow the use of biomanipulation measures to control eutrophication, and therefore the best procedures to control localized anoxia and eutrophication would be improved management of water flows and organic waste from the towns and villages bordering the lake. The sustainable approach, which combines the RF model and the TRIX index, could be useful to assess the evolution of trophic status and improve our understanding of the effects of anthropogenic pressures and climate change on the biological status of these ecosystems. It can be used in decision making by civil authorities and other interested stakeholders.

6. Acknowledgment

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