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Locating Fish Farms with Analytic Hierarchy Process and Determining their Optimal Arrangement in the Gorgan Gulf

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ABSTRACT

Qualitative parameters such as temperature, nitrate, nitrite, ammonia, water depth, total alkalinity, water velocity, DO, pH and salinity are important for cultivation of various fish like marine carp which is a warm-water fish, salmon and trout that are cold-water fish, and beluga whose cultivation period is the whole year. Comparing the mean values of quality parameters mentioned in the Gorgan Gulf with an acceptable range of these parameters for cultivation the above-said fish in the previous report (Mohammadkhani, 2016), suggests that the Gorgan Gulf has the capability to develop these fish, and the vast body of water can be used for fish cultivation. But the qualitative parameters are not in an acceptable range in all parts of the Gulf and conditions of all parts of the Gulf are not favorable for fish cultivation. Therefore, in this report, performing locating operations on the Gorgan Gulf, fish cultivation capability is measured in different parts of the Gulf, and the appropriate areas of the Gulf are determined for fish cultivation; then, the appropriateness of this areas is identified and ranked to one another. Finally, the arrangement and spacing of fish farms (Pen Cultures) are determined for different species of fish in the Gulf.

Key words: Gorgan Gulf, Aquaculture, Analytic Hierarchy Process, Fish Farms.

INTRODUCTION

Gorgan Gulf, with an area over 400 square kilometers, is located in the southeast of the Caspian Sea and is considered the largest Gulf of the Caspian coast. The average length and width of the area are 40 and 10 km, respectively. The geographical coordinates of the Gulf are 53° 25’ to 54° 2’ E and 36° 46’ to 36° 54’ N. Part of the Gulf is located in Golestan province and the part is in the province of Mazandaran. In this report, performing locating operations on the Gorgan Gulf, fish cultivation capability is measured in different parts of the Gulf, and the appropriate areas of the Gulf are determined for fish cultivation; then, the appropriateness of this areas is identified and ranked to one another. Finally, the arrangement and spacing of fish farms (Pen Cultures) are determined for different species of fish in the Gulf.

MATERIALS AND METHODS

Analytic Hierarchy Process (AHP)

Given that the first presentation of the top priorities or options in plans, programs and different economic sectors dates back to more than five decades ago, during this period, the methods used have had evolutionary process, and have promoted from the calculation of qualitative factors towards the calculation of quantitative factors, and from individual opinions to group decisions (Qodsipour, 2000). Using Multi-Attribute Decision Making (MADM) methods is useful to select the best options, and different methods have been presented to prioritize the options in the form of MADM models (Vali Samani and Delavar 2010). AHP is one of the most comprehensive systems designed for MADM, because utilizing this technology, the problem can be made as hierarchical equations, and different qualitative and quantitative criteria can be considered in it. This process involves different options in decision making. AHP is established based on a pair-wise comparison, with the possibility of facilitating judgments and calculations. Furthermore, it shows the amount of consistency and inconsistency of the decision (Asgharpour, 1998). AHP method was developed by Thomas L. Saaty (1970s); then, many reforms took place on it.

AHP begins with identifying and prioritizing the elements of decision making. These elements include the objectives, criteria and possible options that are used in prioritizing. In this process, identification of elements and their relationships creates a hierarchical structure. The reason for being hierarchical is the summarization structure of decision-making elements at various levels. Therefore, the first step in AHP is to create a hierarchical structure of the issue under study which shows the objectives, criteria and options, as well as their relationship in this hierarchical structure (Saaty 1996). After the breakdown of the problem to a hierarchy, the elements of different levels will be compared in pairs, and matrix of pair-wise comparisons will be formed for every level of decision according to the criteria affecting in the upper level. Pair-wise comparisons are recorded in an n*n matrix (n is the number of effective criteria). AHP is a method that calculates the appropriate weight for each criterion depending on its role by pair-wise comparison. These weights show the relative importance of each criterion or characteristic (Saduq et al. 2010). For comparison of the criteria, 9-quantity scale of Saaty (Table 1) is used. After the formation of the comparison matrix by the eigenvectors method and approximate methods such as the arithmetic and geometric mean, the importance coefficients or the weights of the elements compared in pair-wise comparison matrix can be calculated. In the eigenvectors method, if the pair-wise comparison matrix is considered as A (Equation 1), and the determinant of the matrix (A-λI) is zero where λ is unknown and I is the unit matrix of n*n, eigenvalues of matrix A will be obtained. Eigenvector is obtained by placing the largest eigenvalue in equation (2) for λ. The eigenvectors obtained are the weights or importance coefficients $(w_1, w_2, \dots w_n)$.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad \text{(Equation 1)}$$

$$(A - \lambda I) \times (w_1, w_2, \dots w_n)^T = 0 \quad \text{(equation 2)}$$

Table 1: 9-quantity scale of Saaty for pair-wise comparison (Tavakoli et al. 2009)

Score	Definition
1	Same preference
3	Slightly preferred
5	More preferred
7	Much more preferred
9	Quite preferred
2,4,6,8	Average preferred

The main condition for acceptance of pair-wise comparisons is the consistency of comparisons. For this purpose, consistency ratio (CR) is calculated for each matrix. Consistency ratio (CR) rate is a mechanism that shows the confidence of the priorities obtained so that if CR < 0.1, consistency of comparisons can be accepted, otherwise it is necessary to review the comparisons. The consistency ratio (CR) of each matrix is calculated according to the equation (3) (Tavakoli et al., 2009).

$$CR = \frac{CI}{RI} \quad \text{(equation 3)}$$

Where CI is the pair-wise comparison matrix consistency index which is estimated using the largest eigenvector (λmax) and then (n) by equation (4):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad \text{(equation 4)}$$

Parameter of RI (Random Index) is also extracted from Table (2). (Samani and Delavar, 2010).

In the absence of eigenvector method and using arithmetic mean method which is an approximate method, L with relation (5) is used instead of using the largest amount of eigenvector (λmax):

$$L = \frac{1}{n}\left[\sum_{i=1}^{n}\left(\frac{AW_i}{W_i}\right)\right]$$

(Relation 5)

AWi is a vector which is obtained from the multiplication of criteria pair-wise comparison matrix in the vector of Wi (weight vector or criteria importance coefficient).

After determining the criteria importance coefficients that are obtained by comparing criteria, and calculating the weight of options to any criteria obtained by pai-wise comparison of the options under the study criteria, we must calculate he final weight of the options obtained by total product of multiplication of weight of options to the criteria in the importance coefficient of criteria according to relation (6).

$$A_i = \sum_{j=1}^{m} a_{ij} \times w_j$$

(relation 6)

AI: Final weight of ith option

M: number of criteria

aji: weight of ith option to the jth criterion (Normalized weight)

wj: Importance coefficient of jth criterion (Normalized)

2.1 Research algorithm

Figure (1) shows the research algorithm to extract the maps of prioritization of Gulf for cultivation cold-water, warm-water and beluga fish (cultivation period: whole year). Each of the steps will be explained in the Research algorithm (Fig.1)

Table 2: Random Index (RI) values based on the matrix dimension (Bowen, 1993)

Dimension (n)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

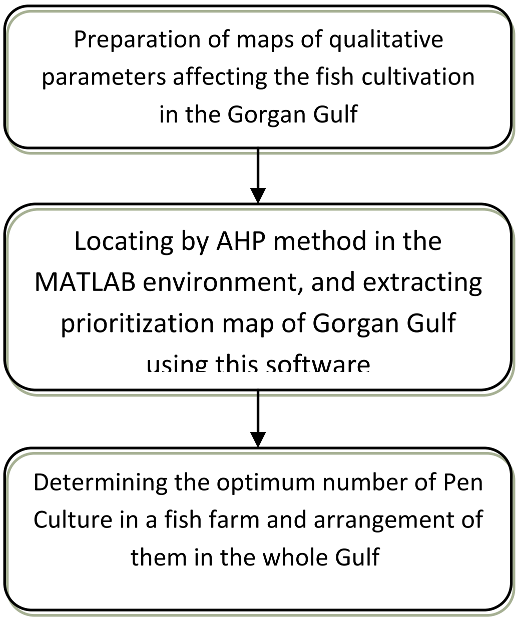

Fig. 1: Research algorithm

Locating by AHP method in MATLAB environment: AHP method was used to perform the locating operation on the Gorgan Gulf to rank the areas of the Gulf in terms of suitability for cultivation fish. This stage consists of four steps:

Step 1. Forming a hierarchical structure: for locating by AHP, the hierarchical structure of the problem must be examined first. This structure was established for the topic discussed that includes three levels of objectives, criteria and selection options. Figure (2) shows the formed hierarchical structure.

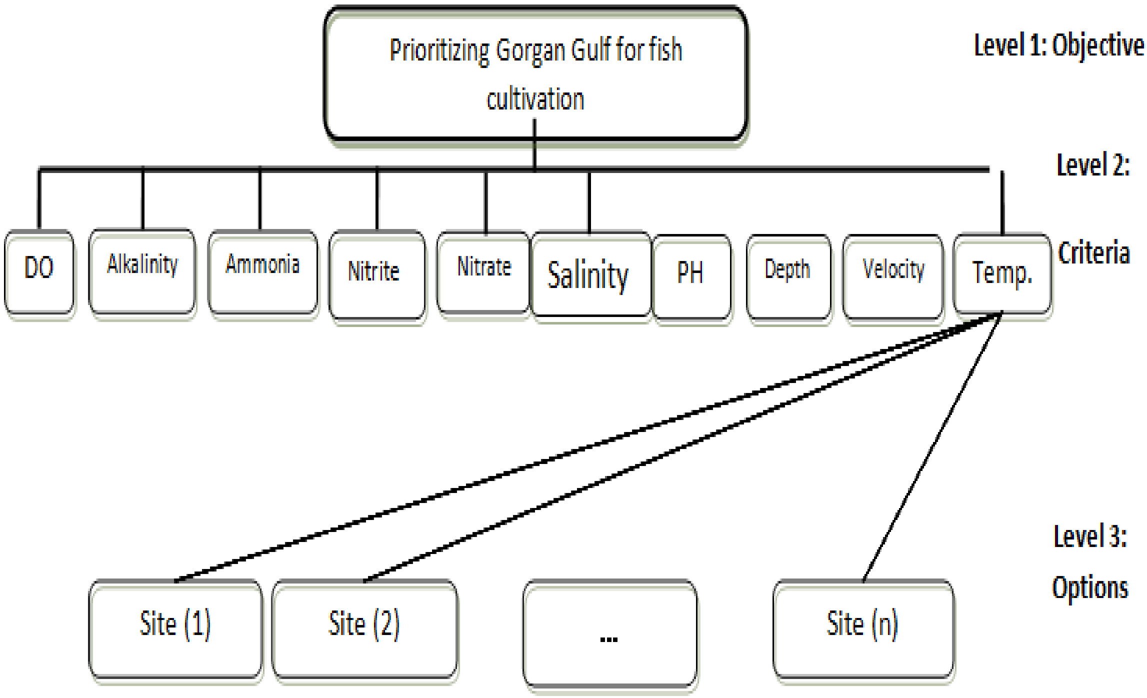

Fig. 2. hierarchical structure of prioritization of different areas of the Gorgan Gulf for fish cultivation.

In this structure, the criteria are the same ten parameters whose spatial distribution map has been prepared with 22-meter pixels for the first and second six months, and the whole year. Options (fish cultivation sites) are equal to maps the total number of pixels (701*2541); a number of these pixels will be removed at the beginning of the locating operation according to the acceptable range of these parameters for different species of farmed fish in three different cultivation periods.

Step 2. Calculating the importance coefficient of the criteria: In AHP method, for calculating the importance (weight) coefficients of criteria, the criteria are compared in pairs and recorded in a n*n matrix. Here, given that we have ten criteria, this matrix is 10*10. The comparison matrix is shown in Table (3). The relative importance of various parameters for the growth and survival of fish is ranked from 1 to 7. This segmentation is done based on the experience of fishery professionals. Entries of the main diameter of this matrix will be 1 because of the lack of priority of each criterion on its own. In the formation of comparison matrix, it should be noted that preference of criterion a on the criterion m is b, the preference of criterion b on a will be 1/m.

Then eigenvector method was used to calculate the criteria importance coefficient; if the pair-wise matrix of the criteria in Table 3 is considered as Matrix A, the importance coefficients or weights are calculated according to relations 1 and 2. The importance coefficients are shown in Table 3 (weight column). These coefficients that are normalized by dividing by the total sum of the coefficients are shown in the last column of Table (3). This column of Table 3 which is a matrix of 10 × 1 is the same matrix of Wj in relation 6.

The consistency ratio (CR) of this comparison matrix is approximately zero showing the consistency of comparisons. This ratio was calculated using equation (3).

Table 3: criteria pair-wise comparison matrix and importance coefficient of various parameters

Comparing criteria under locating target	**Temp.**	**Nitrate**	**Nitrite**	**Ammonia**	**Velocity**	**Depth**	**DO**	**Ph**	**Alkalinity**	**Salinity**	**weight**	**Normalized weight**
Temp.	1	2	2	2	3	3	4	5	6	7	0.686332	0.2547
Nitrate	1.2	1	1	1	3.2	3.2	2	5.2	3	7.2	0.343166	0.1273
Nitrite	1.2	1	1	1	3.2	3.2	2	5.2	3	7.2	0.343166	0.1273
Ammonia	1.2	1	1	1	3.2	3.2	2	5.2	3	7.2	0.343166	0.1273
Velocity	1.3	2.3	2.3	2.3	1	1	4.3	5.3	2	7.3	0.228777	0.0849
Depth	1.3	2.3	2.3	2.3	1	1	4.3	5.3	2	7.3	0.171583	0.0849
DO	1.4	2.4	2.4	2.4	3.4	¾	1	5.4	6.4	7.4	0.137266	0.0637
pH	1.5	2.5	2.5	2.5	3.5	3.5	4.5	1	6.5	7.5	0.114389	0.0509
Alkalinity	1.6	2.6	2.6	2.6	3.6	3.6	4.6	5.6	1	7.6	0.098047	0.0424
Salinity	1.7	2.7	2.7	2.7	3.7	3.7	4.7	5.7	6.7	1	0.228777	0.0364
Total weight											2.694671082	1.0

Step 3. Calculation of the options importance coefficient: to calculate the options importance coefficient, all candidate options (pixels having the appropriate conditions) were compared by ten different criteria. The number of pair-wise comparison matrixes formed is equal to the number of criteria. Consider that the number of options is S, a pair-wise comparison matrix of S × S is created for each of the 10 criteria. The entries of this matrix is calculated based on 9-quantity Saaty scale with the difference that instead of integers, based on a linear relationship, the numbers 1 to 9 (or vice versa:1.9 to 1) was assigned to each option. For example, consider that for the pH criterion, range suitable for the growth of warm-water fish is 6 to 9, and its optimum level is 7 (the previous report , Mohammadkhani, 2016). According to Table 1, score of 9 is considered for pH=7, and score of 1 is considered for pH=6 and 9. Then linear relationships will be established between the scores of 9 and pHs of 1 and 7, and also scores of 9 and 1 and 6 and pHs of 7 and 9. These linear relationships are as y=8*pH-47 and y=-4*pH+37, respectively. Suppose that two areas in the Gulf that are 100th and 200th options of S have pHs of 6.5 and 8.5, respectively. The values of these two areas are obtained 5 and 3 according to the linear relationships above. Then, in the pair-wise comparison matrix having the dimensions of S*S, the value of pair-wise comparison matrix is equal to 5.3 in the entry of 100th line and 200th column. And the entry of 200th lien and 100th column is 3.5. Entries of the main diameter of the matrix above are 1 because it indicates the pair-wise comparison of each option with itself. Each entry of the S*S pair-wise comparison matrix will be calculated for the Ph in this way. Similarly, pair-wise comparison matrix of options will be calculated for the other nine criteria. After obtaining the mean of each line, each of the pair-wise comparison matrixes of S*S is obtained as an S*1 vector. Then, the numbers of the S*1 matrix will be normalized, the obtained values indicate the superiority of different options to each other for the criteria. This operation is performed for 10 different criteria and thus, 10 matrixes of S*1 is obtained. If the 10 matrixes are combined together,

a matrix of S*10 will be created. This matrix is the matrix aij in equation 6.

Step 4. Calculating the final weight of options and extracting maps of prioritization of the appropriate areas: now, having Wj matrix which is a 10*1 matrix (calculated in the previous step) and aij matrix which is a S*10 matrix, we can extract the matrix Ai (S*1) which represents the final weight of each option or the priority of fish cultivation options in the Gulf using Relation 6.

All the above operations were performed in Matlab 7.10 software environment. Finally, maps of Gorgan Gulf prioritization for three periods of fish cultivation were extracted using this software, and the areas of the Gulf that were suitable for fish cultivation, were ranked.

The programs written in MATLAB environment for locating operation using AHP method are provided in Appendix One.

The optimum number and arrangement of Pen Cultures in a fish farm in the whole Gulf: Fish farms should be located at a distance so that in the event of pollution in one farm in a moment, it does not spread to its neighboring farms and they are not infected. The studies showed that the optimum distance is 100 meters (How to calculate the distance using Mike 21 software is extensively expressed in the previous report), and if farms are placed at this distance from each other, they will have no effect on each other. Another issue that can be raised is the suitable number of Pen Cultures in a farm. The number of suitable areas for fish cultivation obtained by locating operations must be converted to a number of farms placed in 100 meters distance from each other. Since the arrangement of Pen Culture on farms is usually in double rows that are separated by a corridor, in the environment of Matlab7.10 software, using the prioritization maps of the Gulf, and considering distances of 100 meters in horizontal and vertical directions, as well as the number of pairs of Pen Culture in fish cultivation in each farm, appropriate number of Pen Cultures of fish cultivation on a farm was determined. Writing a program in Matlab7.10 software environment, arrangement map of fish farms were with different Pen Cultures was extracted.

Then, the maps were transferred to the GIS environment of ILWIS software for further analysis. After that, the curve of the used Gulf area against the different numbers of Pen Cultures was drawn for three different cultivation periods (the first six months (warm-water fish), the second six months (cold-water fish) and during the year (Beluga)). Using these curves, the appropriate number Pen Cultures of fish cultivation on each farm was determined for three cultivation periods; this number is corresponding to the most used area of the Gulf or the maximum level of fish cultivation.

RESULTS AND DISCUSSION

In this study, AHP is used in locating operation on the Gorgan Gulf to prioritize the appropriate areas for fish cultivation. Temperature, nitrate, nitrite, ammonia, water depth, total alkalinity, water velocity, DO, pH and salinity, are the quality parameters affecting the fish cultivation in the Gulf which are used in locating operations. Locating operations on the Gorgan Gulf were performed for three cultivation periods including the first and second six months, and the whole year. These periods are according to cultivation periods of warm-water fish (marine carp), cold-water fish (salmon, trout) and beluga. All operations were performed in the environment of Matlab 7.10, and the maps of spatial distribution of the areas suitable for fish cultivation ranked in Gorgan Gulf were extracted for three periods of cultivation using this software and AHP method. Then, the extracted maps were transferred to the environment of GIS in ILWIS software and were displayed in this environment (Figures 3 to 5).

In these figures, when the ranks are closer, those areas are more suitable for fish cultivation.

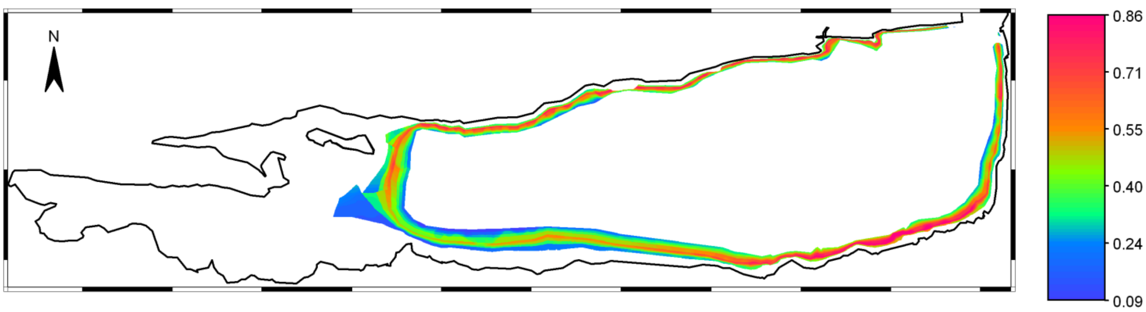

Fig. 3: Map of Gorgan Gulf suitable areas for warm-water fish cultivation and ranking the appropriate areas (cultivation period: the first six months of the year).

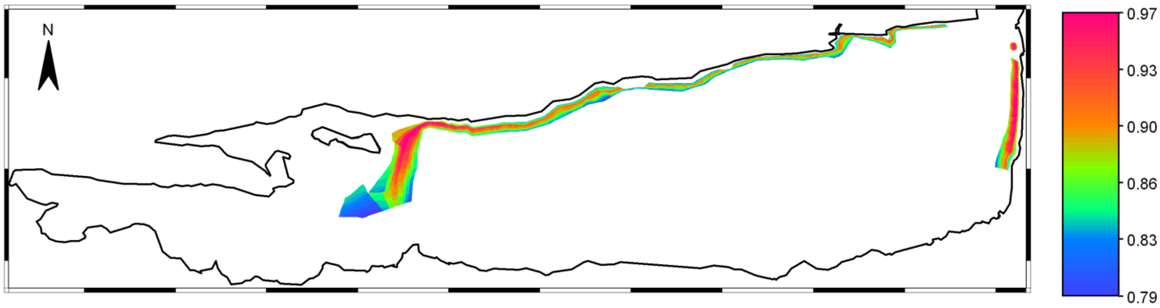

Fig. 4: Map of Gorgan Gulf suitable areas for cold-water fish cultivation and ranking the appropriate areas (cultivation period: the second six months of the year)

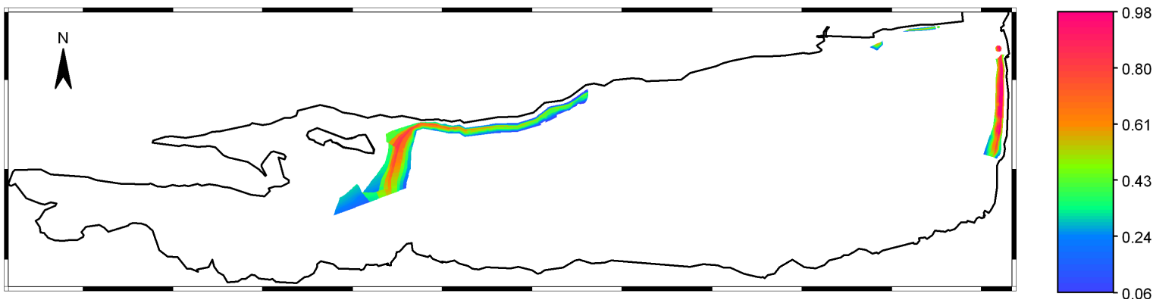

Fig. 5: Map of Gorgan Gulf suitable areas for beluga fish cultivation and ranking the appropriate areas (cultivation period: the whole year)

Then, to find the appropriate number of Pen Cultures of fish cultivation in each fish farm, Gulf prioritization maps were used to determine the total area of suitable areas for fish cultivation for the number of different Pen Cultures in each farm. Drawing the changes of the Gulf area used against the number of Pen Cultures of a farm (Figures 6 to 8), the appropriate number of Pen Cultures of fish cultivation on a farm that is corresponding to the largest area, was determined. Figures 6 to 8 shows that the optimal number of Pen Cultures of fish cultivation on a farm for warm-water and cold-water fish and beluga were: 18 (two 9-item rows), 18 (two 9-item rows) and 20 (two 10-item rows) of Pen Culture. According to the optimum Pen Cultures of fish cultivation on a farm for warm-water and cold-water fish, and beluga, cultivation area is 9.225 square kilometer (1060 farms with 18 Pen Cultures), 3.833 square kilometer (440 farms with 18 Pen Cultures), and 2.673 square kilometer (276 farms with 20 Pen Cultures).

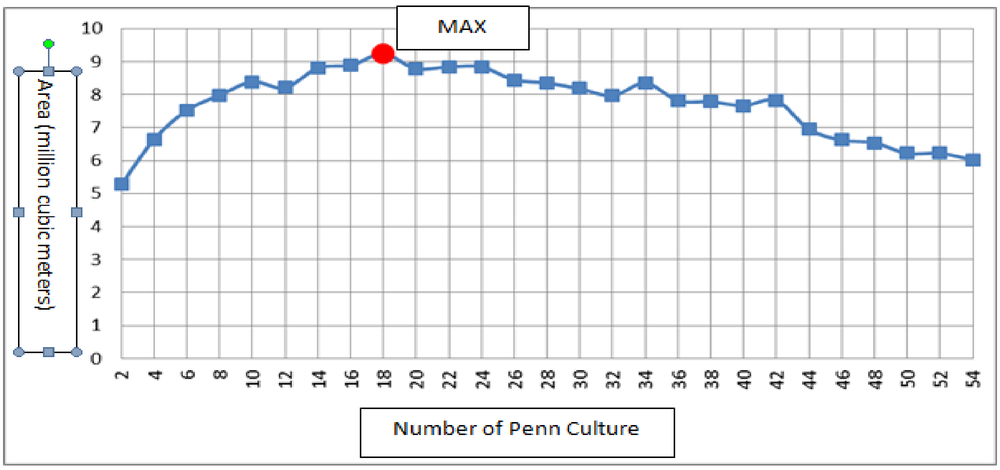

Fig. 6: The variation curve of Gorgan Gulf area used against the number of Pen Cultures in a fish farm (cultivation period: the first six months of the year)

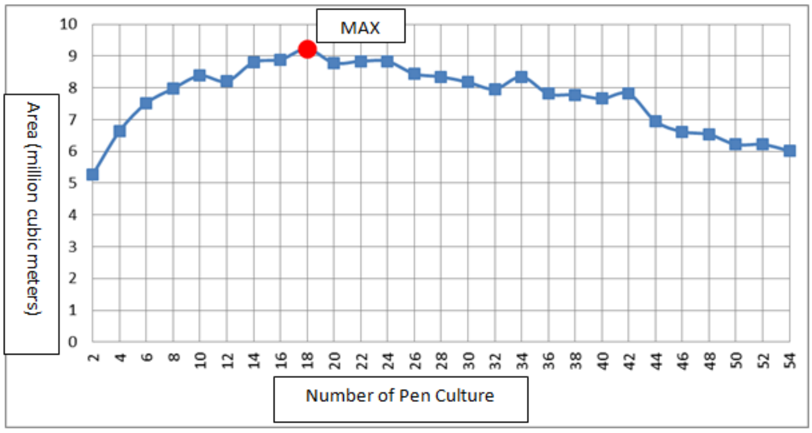

Fig. 7: The variation curve of Gorgan Gulf area used against the number of cages in a fish farm (cultivation period: the second six months of the year)

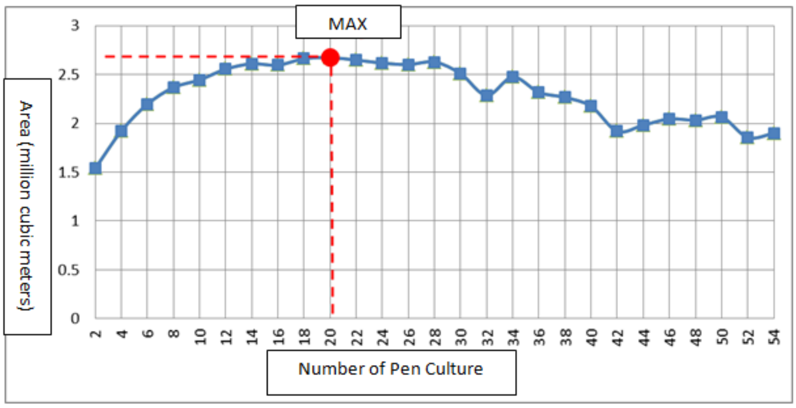

Fig. 8: The variation curve of Gorgan Gulf area used against the number of cages in a fish farm (cultivation period: the whole year)

Finally, distribution map of fish farms (with the appropriate number of calculated Pen Cultures of fish cultivation) in the Gorgan Gulf was extracted using a program written in the Matlab 7.10 software and was displaced in the environment of GIS in ILWIS software. (Figures 9 to 11).

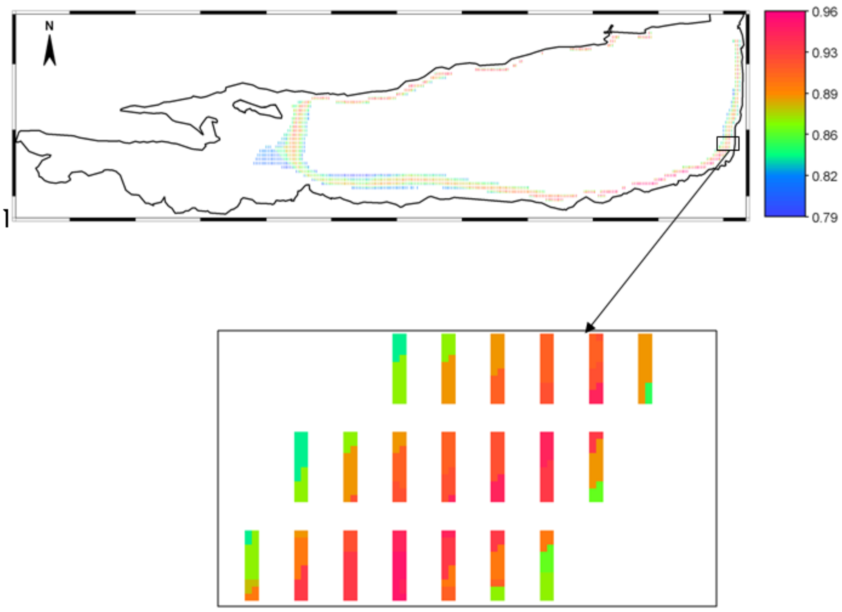

Fig. 9: Distribution of warm-water fish farms in Gorgan Gulf, with 18 Pen Cultures in each field with magnification of a small part of the distribution and the shape of the farms (cultivation period: the first six months of the year)

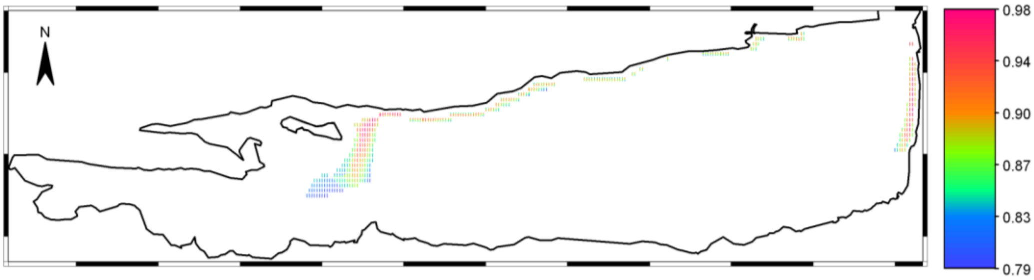

Fig. 10: Distribution of warm-water fish farms in Gorgan Gulf, with 18 Pen Cultures in each field (cultivation period: the second six months of the year)

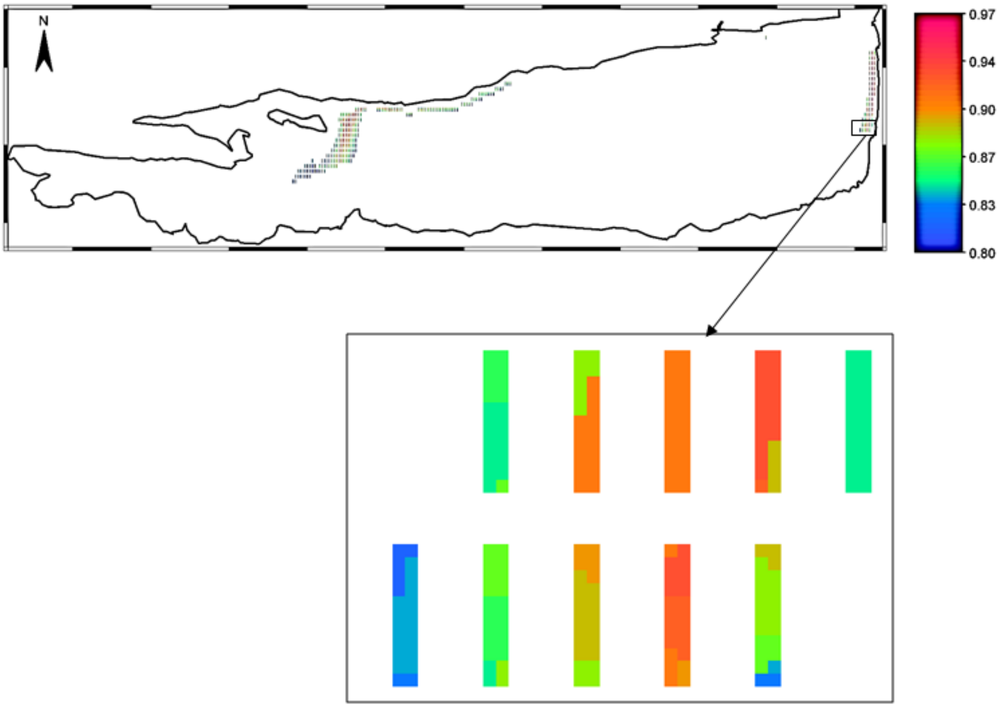

Fig. 11: Distribution of beluga farms in Gorgan Gulf, with 20 Pen Cultures in each field with magnification of a small part of the distribution and the shape of the farms (cultivation period: the whole year)

CONCLUSION

Locating operation of the appropriate areas of warm-water and cold-water fish and beluga in the Gorgan Gulf was done using AHP, and the suitable cultivation areas were identified and ranked. AHP method showcased excellent results in the locating operations.

Then, the optimum number of pen cultures in a farm was calculated by maximizing the area of suitable cultivation areas, and considering the confidence distance of about 100 meters. The results show the number of 18, 18 and 20 pen cultures on each farm for the warm-water and cold-water fish and beluga, respectively.

Taking into account the confidence distance of 100 meters and optimum number of pen culture, the arrangement of warm-water and cold-water fish and beluga fishes farms in the Gorgan Gulf, and the map of farms of different species in the Gulf was determined in the GIS environment.

According to the arrangement determined, the appropriate area for warm-water and cold-water fish, and beluga cultivation is 9.225 square kilometer (1060 farms with 18 Pen Cultures), 3.833 square kilometer (440 farms with 18 Pen Cultures), and 2.673 square kilometer (276 farms with 20 Pen Cultures).

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