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# USE OF GEOGRAPHIC INFORMATION SYSTEM (GIS) TO SELECT FISH CAGE FARMING SITES IN SURMENE BAY, BLACK SEA

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## Abstract

Attempts to develop open sea fish farming projects in the Black Sea have often failed due to poor site selection. This problem can be solved by using the Geographic Information System (GIS) to collect, manipulate, query, display, and integrate various data sets. In this study, data sets were arranged together to analyze habitats and a site selection methodology was developed for the coastal region of Trabzon on the Surmene Bay. Data included temperature, salinity, and current velocity, collected during regular cruises of the KTU-R/V Denar-I research vessel. Shoreline data were digitized using regional maps and spatial relationships were examined using Boolean Algebra. Two interpolation methods (Kriging and Inverse Distance Weight) were used to form thematic maps and identify optimal sites for a rainbow trout cage farm. No significant differences were found between the results of the two methods. Temperature was the most influential factor determining the final site position.

## Introduction

Aquaculture has grown rapidly in recent years and is probably the fastest growing food industry in the world. However, this impressive growth has often been accompanied by significant failures that have caused aquaculture to be associated with high risk. In many cases, problems resulted not from a lack of technology but, rather, from a lack of understanding of the aquatic environment and the use of unreliable means for resource assessment (Ross et al., 1993). To deal with such problems, systematically planned and analyti-

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cally implemented habitat evaluation methods must accompany collection of data during the pre-planning assessment stage. Pre-planning assessment usually concentrates more on the habitat and less on the fish because physical features are more accessible and take less time to evaluate; the time and resources needed to assess fish communities rarely exist. A description of the combinations of habitat parameters that optimize growth and survival is required for site evaluation. Design engineers must take substrates, bathymetry, and the waves and water flow of the site into account. Hence, quantitative habitat information is necessary to evaluate development proposals and scientifically quantify the fish-habitat linkage (Minns and Nairn, 1999). Site selection is crucially important in any aquaculture operation because of the site's great influence on economic viability, capital outlay, running costs, rate of production, and mortality factors (Beveridge, 1987).

The Geographic Information System (GIS) is a computer program that integrates, processes, and analyzes different types of spatial data. Relationships between types of information can be examined by creating thematic maps. GIS is an important tool for environmental modeling and is often used as an integrating framework for spatial data analysis and modeling. GIS allows for increased speed and accuracy that enable decision makers to evaluate scenarios and make informed decisions. The superiority and power of GIS lies in its ability to combine or overlay themes, conduct spatial analysis, and perform queries within one layer or among objects in two or more layers. GIS is playing an increasingly important role in management and use of natural resources (Burrough, 1986).

GIS has been used to manage land-based data but, only recently, made its way to oceanographic applications (Lehmann and Lachavanne, 1997; Basu, 1998; Dai and Rocke, 2000). GIS is used to create spatial maps of habitats from oceanographic data, a fundamental requirement in establishing coastal management plans. Large-scale maps allow managers to visualize the spatial distribution of coastal habitats, aiding in the planning of marine protected areas and allowing the degree of habitat fragmentation to be monitored (Mumby and Harborne, 1999).

Habitats in aquatic ecosystems are not equally suitable for all life-stages of all fish species. The composition and productivity of fish assemblages ultimately depend on the suitability and supply of various habitat types (Minns and Bakelaar, 1999). Successful large-scale aquaculture requires the correct selection of grow-out sites. Until recently, site selection has largely been ignored, especially in the marine environment. GIS can make dynamic models of environmental parameters and, with its cartographic capabilities, has enormous potential in aquaculture and related studies (Manjarrez and Ross, 1995). Often, governmental agencies that issue aquaculture permits need spatial analysis of a proposed site to assess its potential environmental, economic, and social impacts. This need cannot be effectively addressed without GIS. Investors also require spatial information, especially at the site selection stage. GIS is a potentially powerful tool for such decision-makers.

GIS is already being used where infrastructure and trained personnel exist (Nath et al, 2000) and has been used to evaluate sites for shrimp aquaculture (Congleton et al., 1999) and grow-out of the hard clam (*Marcenaria* spp.; Arnold et al., 2000). GIS is especially important in countries that suffer from famine or natural disasters. Therefore, the Food and Agricultural Organization of United Nations (FAO) was involved in GIS related projects that assessed potential aquaculture areas for additional food supplies.

Mariculture of rainbow trout *(Oncorhynchus mykiss* Walbaum) is the most intensive fish farming activity in the southeastern Black Sea region. Some projects, however, failed because of insufficient information in the feasibility phase of the project. Failure was often due to technical problems resulting from the incorrect choice of site in which to set cages in the dynamic conditions of the Black Sea. In this study, we used GIS to locate the most appropriate sites for rainbow trout cages in Surmene Bay in the southeastern Black Sea area of Turkey.

### Materials and Methods

*Study area.* The study site was Surmene Bay located in eastern Black Sea (Fig. 1). Spatial data were assembled, analyzed, and displayed using ArcInfo 8.0.2 and Arcview 3.2 GIS software. Assembly and analysis of information were confined to the rectangular area bounded by the GCS Int. 1924 coordinates 40.8749 N, 39.9996 E and 41.1662 N, 40.5004 E. The shores are predominantly covered by forests, with limited residential development. Fisheries are one of the most important sources of income in the area.

The seasonal variations of wind and fresh water discharge determine the coastal circulation (Kose et al., 2003). The coastal current reaches a maximum when the fresh water input is highest and winds are strong. Every year, 14,531 $km^3$ of fresh water runs into the Black Sea from rivers in this area. An important amount of sediment is transported to the sea by precipitation and river flows. The average total annual sediment load of eight regional rivers is estimated at 53.3 x $10^6$ tons per year (Eruz et al., 2000). The Solakli River, alone, transports 27,000-43,000 tons per year. The main coastal circulation is dominated by westerly winds, creating a northward anti-cyclonic rim current.

The air temperature reaches a maximum of 29°C in August and a minimum of 5°C in January-February. Mean salinity in the surface layer is about 18‰ and varies 17.5-18.5‰. The mean temperature of the surface layer is about 13°C, with a maximum 26°C in August and minimum 6-7°C in February. The water reaching a depth of 200-300 m can be divided into three layers: thermocline, seasonal thermocline, surface-mixing layer. The seasonal thermocline is found at a depth of 25-100 m. The changes in water mass depend on the season and area. There are more changes in the surface layer where the water interfaces with the atmosphere.

*Data collection and processing.* National region 6 maps (1:25,000) were obtained from governmental agencies and digitized by using Calcomp Digitizing Board III in an AutoCAD 2000 environment. Six basic GIS layers (sampling stations, sea, land, rivers, motorways, fishing ports) were formed and topologically
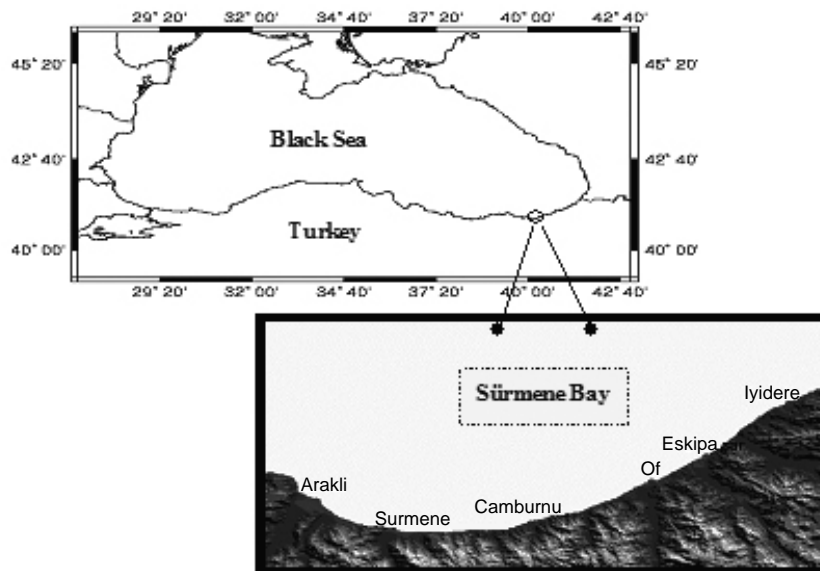


Fig. 1. Study area in southeastern Black Sea.

cleaned using ArcInfo 8.0.2 to represent sea, land, and sampling stations. The constructed layers were moved to Arcview 3.2 as shape files. The layers were fitted to the GCS International 1924 coordinate system. Sampling stations, in the form of point layers, were fixed using a Magellan 300 GPS receiver. Data sources were based on monthly surveys carried out in 1999-2002 at 38 stations (Fig. 2). Water samples were collected with an Aanderaa RCM-9 CTD data logger and processed using DRU 5059 software. Standard data tables were formed and converted to Data Base Format. The database contains basic oceanographic data such as salinity, temperature, and current velocity and direction. Although water samples were collected from the surface to a depth of 150 m, only the depth needed for a proposed submersible cage project (10-20 m) was processed.

Continuous wind forces rim current circulation and mixing. Therefore, water in the area is very well ventilated and water quality (alkalinity, dissolved oxygen, nitrates, nitrogen, total ammonia, etc.) is expected to meet aquaculture requirements. The area falls into the 1a water class according to the World Health Organization (Bakan and Buyukgungor, 2000), indicating no water quality constraints.

To prepare thematic maps of temperature, salinity, and current velocity fields, the Inverse Distance Weight (IDW) and Kriging methods were used to interpolate the values of field data on a grid with a 30 x 30 m mesh (x,y). The layer called "sea" was set as the boundary layer for the interpolation procedure and simple Boolean Algebra was applied for the selection. The IDW and Kriging methods were compared according to the final interpolated surface relevancy.

The principal of IDW interpolation is the assignment of a higher weight to data points that are closer to a particular value than to those that are farther away (Kitsiou and Karydis, 2000). The interpolated value $f(x,y)$ is calculated according to following formula:

[1]

$$f(x,y) = \left[ \sum_{i=1}^{N} w(d_i) z_i \right] / \left[ \sum_{i=1}^{N} w(d_i) \right]$$

where $w(d_i)$ is the weighted function, $d_i$ is the distance from value $(x,y)$, and $z_i$ is the data value at point $i$. The interpolated value $f(x,y)$ of any point in the dataset is bounded by the minimum and maximum $z_i$, as long as $w(d_i)>0$ to ensure that ridges or valleys are not erroneously included in the response surface. This weighting method is widely used because of its simplicity, calculating speed, programming ease, and credibility of interpolated surfaces for many types of data (Kitsiou and Karydis, 2000).

Kriging is a geostatistical method for point interpolation that presents the statistical surface as a regionalized variable, with a certain degree of continuity. The Kriging estimate is
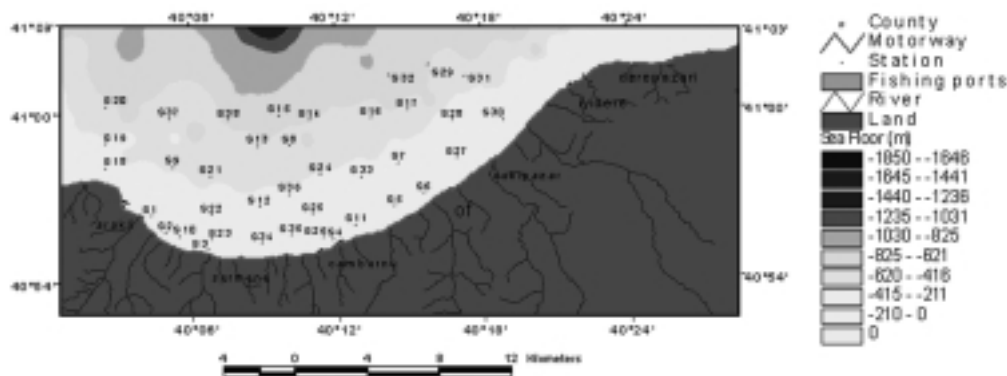


Fig. 2. Sampling stations in the study area.

known as the 'best linear unbiased estimate' (BLUE) because it is a linear combination of weighted sample values, with an expected error of zero and minimum variance. The main characteristic of Kriging is the generalized covariance *k(d)*. For a two-dimensional case

[2]

$$k(d) = \begin{cases} 1 + \dfrac{1}{c_1}\left(\dfrac{dc_0}{d_{max}}\right)^2 \ln\left(\dfrac{dc_0}{d_{max}}\right) & \text{if } d < d_{max} \\ 0 & \text{if } d > d_{max} \end{cases}$$

where $d_{max}$ is the maximum correlation distance considered, $c_0$ is the value at which the $k(d)$ function reaches its minimum (i.e., $c_1$). The interpolated value is then calculated using the statistical formula (Caruso and Quarta, 1998):

[3]

$$f(x, y) = a_1 + a_2 x + a_3 y + \sum_{j=i...N} b_j k(d_j)$$

where and $a_1$, $a_2$, $a_3$..., and $b_j$ are coefficients.

*Site selection procedure for cage aquaculture.* There are three categories of criteria in site selection. The first concerns physicochemical conditions (temperature, salinity, oxygen, currents, pollution, algal blooms, water exchange) that determine whether a species can thrive in an environment. The second comprises factors (weather, shelter, depth, substrates) that determine whether a cage system can be successful. The third comprises business elements (legal aspects, access, proximity to hatcheries or other company components, government regulations, security, social and market considerations). It is difficult to find and combine all these data. In this study, we used only temperature, currents, salinity, and proximity data to evaluate the suitability of sites for a submersible salmonid cage system similar to that of Ross et al. (1993) at a depth of 10-20 m (to reduce atmospheric climatologic effects such as wind and waves).

Rainbow trout was selected because of its suitability to Black Sea climatic conditions. Except for salinity, spatial analyses were carried out by taking optimum values into account (Ross et al., 1993). Data were collected monthly in spring through fall of 1999-2002.

Boolean query instructions were applied to every layer in "Grid or Vector" format. The final query "If 10≤temperature≤15 and salinity≤19‰ and if 10≤current velocity≤50" was used to identify suitable sites and create a final thematic map of the bay.

**Results and Discussion**

The thematic maps illustrating suitable sites are shown in Figs. 3-10. No significant differences were found between the Kriging and IDW methods. The boundary layer selected for interpolation was proportionally greater than the sampling area, possibly causing some interpolation errors but such errors do
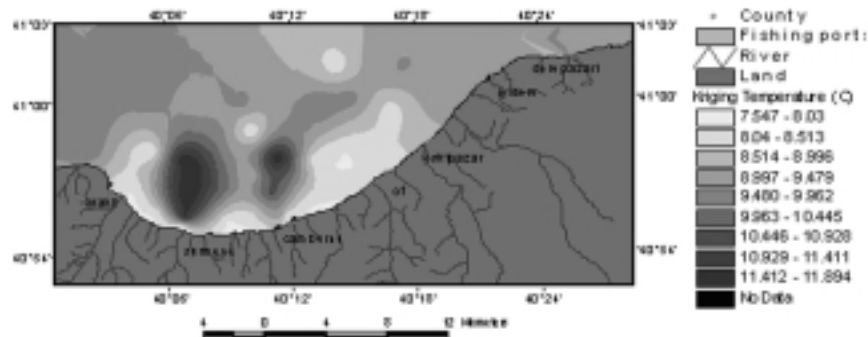


Fig. 3. Kriging interpolation of temperature distribution (°C), average of spring and fall measurements in 1999 and 2002.
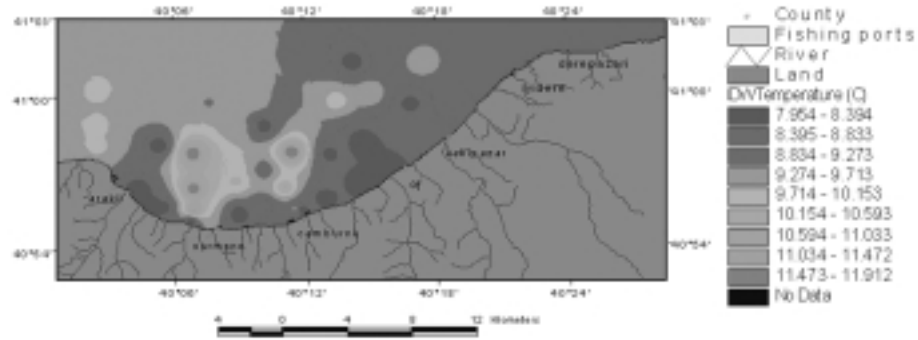
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Fig. 4. IDW interpolation of temperature distribution (°C), average of spring and fall measurements in 1999 and 2002.
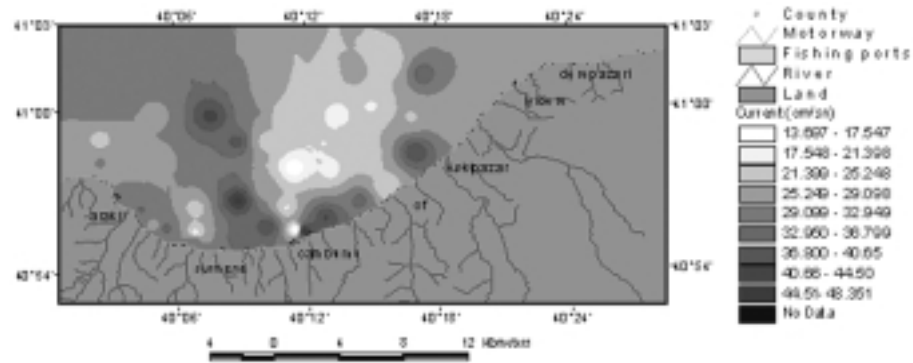


Fig. 5. IDW interpolation of current velocity (cm/s), average of spring and fall measurements in 1999 and 2002.
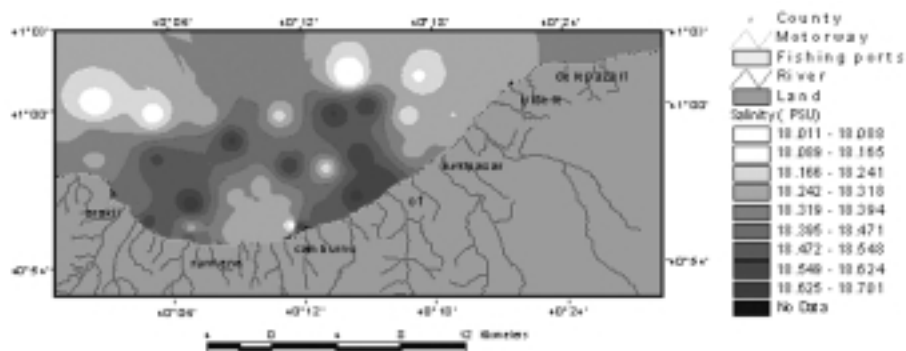


Fig. 6. IDW interpolation of salinity distribution (PSU), average of spring and fall measurements in 1999 and 2002.
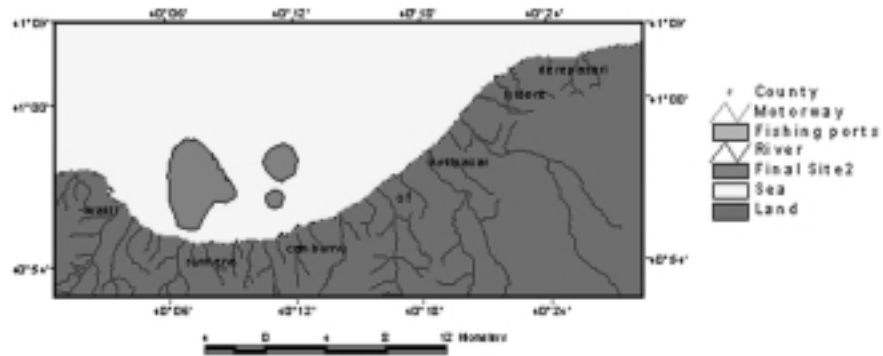
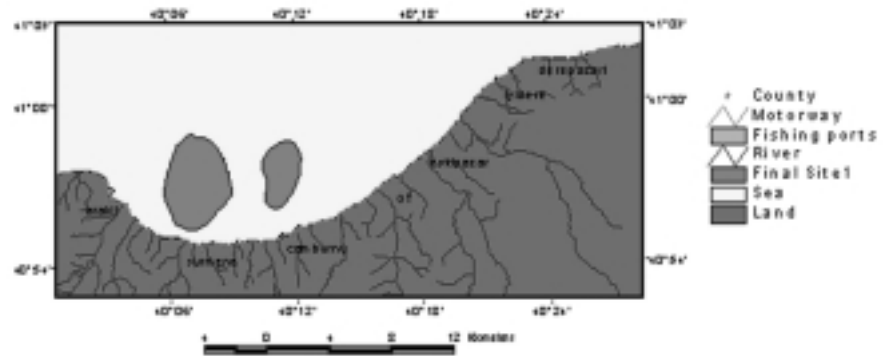Fig. 7. Optimal sites according to IDW method.



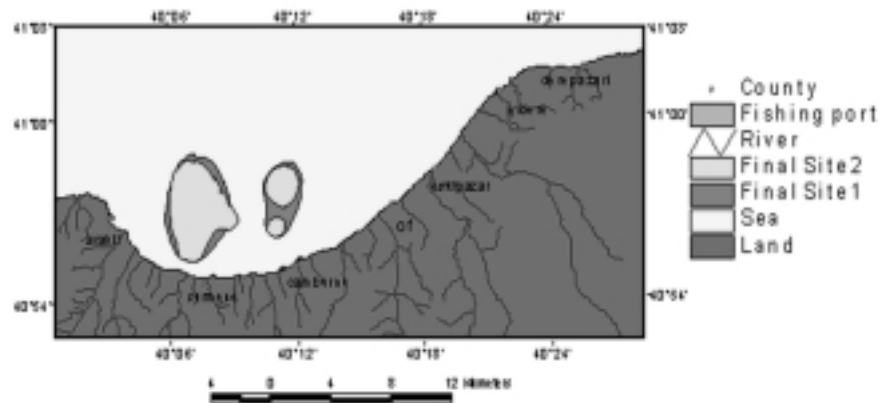Fig. 8. Optimal sites according to Kriging method.



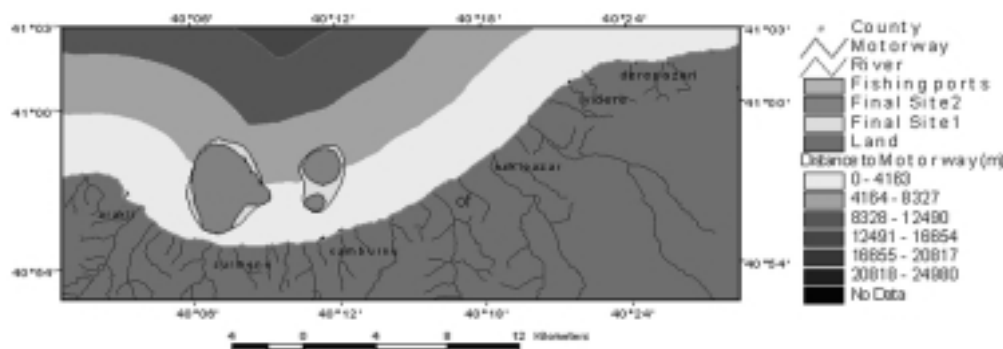Fig. 9. Overlay position of final site 1 (Kriging) and final site 2 (IDW).

Fig. 10. Final map of site proximity to motorways (markets), intersected with maps of salinity, current velocity, and temperature (IDW and Kriging), indicates areas suitable to commercial fish farming at 10-20 m depth in Surmene Bay.

not limit or alter the applied methods and are beyond the scope of this study. These errors could be investigated by improving the quality of the samplings by direct field analysis.

Salinity can change the amount of energy available for growth of fishes by altering the energetic cost of ionic and osmotic regulation. Rainbow trout has the highest growth rate in 15-18‰ salinity, slower growth in lower salinities, and the lowest growth rate in fresh water. However, the relationship between salinity and growth is complex and not readily predictable (Altinok and Grizzle, 2001). Optimum salinity for rainbow trout, adapted to Black Sea conditions, is 17.5-18.5‰. Comparison of the IDW distributions of current velocity (Fig. 5) and salinity (Fig. 6) with Fig. 10 shows that both had almost no effect on identifying suitable areas, possibly because of the small study area. Comparison of the Kriging (Fig. 3) and IDW (Fig. 4) distributions with the final map (Fig. 10) shows that temperature was the factor that most influenced site selection during the study. Indeed, temperature is the main limiting factor for rainbow trout culture in this region while salinity levels seemed quite suitable for rainbow trout culture (Sahin et al., 1999).

Overlaying the most suitable sites (Fig. 9) according to the IDW (Fig. 7) and Kriging (Fig. 8) methods shows there is no great difference between the methods. The total sampling area was about 210 km². The sites suitable to commercial cage fish farming were 16.48 km² and 23.46 km², calculated by IDW and Kriging interpolations, respectively, approximately 10% of the total area. The difference between the two methods was 6.99 km², insignificant in terms of site selection. Depth had no effect on the final site and climatologic factors were mostly eliminated in the submersed cages. Proximity to motorways is crucial for any marine farming site because of the market factor. In terms of market needs, the final sites were suitable and close to the major cities of Trabzon and Rize provinces.

In conclusion, rainbow trout can be successfully cultured on the southern coast of the Black Sea from September to June in the Black Sea but must then be transferred to fresh water because of limiting environmental factors, especially high temperatures.

The availability and abundance of data are the most important issues in terms of GIS. The GIS approach to site selection has the potential to give useful results. The reliability of the results depends, however, on the source data. Once obtained, digitized data become a valuable and permanent resource that requires only periodic maintenance in addition to satellite imagery and aerial photography. Current velocity, salinity and temperature data require field investigation and acceptance of the assumptions and limitations of the interpolation technique.

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