Mediterranean Marine Science

Vol 16, No 2 (2015)

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doi: [10.12681/mms.1087](https://doi.org/10.12681/mms.1087)

Supplementary Data

Multi-Criteria Decision Analysis as a tool to extract fishing footprints: application to small scale fisheries and implications for management in the context of the Maritime Spatial Planning Directive

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Mediterranean Marine Science, 2015, 16 (2), 294-304

S.1. Ranking and creation of spatial information

Bathymetry

The grading value given to each depth stratum is based on the preferences of fishers to exert higher fishing pressure in shallower waters (Table 2; Fig. 3A).

Distance from coast

Distance from coast is calculated in nautical miles and expressed as the minimum distance of each fishing rectangle's centroid to the nearest coastline (Fig. 3B). The distance from coast criterion mainly expresses the capacity of the coastal fishing fleet segments to carry out activities far from the coast (Table 2).

Sea Surface Chlorophyll (Chl-a)

Sea Surface Chlorophyll (Chl-a) (mg/m^3) seasonal pattern indicated that the study area can be generally considered mesotrophic with Patraikos Gulf and Messolonghi Lagoon showing the highest values (Fig. 3C). The estimation of this environmental criterion was based on the most recent four-year average concentration of Chl-a in the study area. Satellite imagery for years 2008 to 2011 has been used for this estimation and derived from the Ocean Color website (oceancolor.gsfc.nasa.gov), at a spatial resolution of 4 km. The ranking was based on the proposed eutrophication scale (Table S.1), which has been used to characterize the water quality in the eastern Mediterranean Sea (Karydis & Tsirtsis, 1996).

Table S.1. Eutrophiction scale of Chl-a concentration (Karydis & Tsirtsis, 1996)

0	Oligo-trophic Waters	0,084	Lower Meso-trophic Waters	0,359	Upper Meso-trophic Waters	0,793	Eutro-phic Waters

Since oligotrophic waters were not identified in the study area and eutrophic waters were limited to a small region (Mesollonghi Lagoon), an extra class (Medium Mesotrophic Waters) was added (Table 2). To this end, the 'Equal interval method' with three classes was applied with a minimum value of 0.084 and a maximum of 0.793.

Legislation for coastal fisheries

The ranking grades utilized were based on Greek and EU fisheries legislation containing a great number of conservation/management measures, broadly separated into two major categories: (i) those aiming to control fishing effort and (ii) those aiming to rationalize exploitation patterns. Generally, trawlers and purse-seiners are subject to more restrictions than coastal fisheries. (Vassilopoulou *et al*., 2012)

Year round no-take zones include area B of Lagana Gulf, Messolonghi lagoon, selected ports of Kefalonia Island, Itea and Galaxidi gulfs (Table 2; Fig. 3D).

Trawlers and Purse seiner fishing effort

According to Commission Regulation (EC) No 2244/2003 (EU, 2003), fishing vessels larger than 15 meters in total length, are obliged to be equipped with VMS, a satellite-based monitoring system, which at a regular two-hour time interval provides data to the fisheries authorities on the location, course and speed of vessels. VMS data, provided by the Hellenic Ministry of Maritime Affairs, Islands and Fisheries (October 2008 until May 2011), were used to estimate the fishing effort expressed in number of fishing days per gross tonnage (days at sea * GT) (Kavadas & Maina, 2012). In the study area, trawlers, purse seiners and coastal fishing vessels compete over the same resources, sharing the same marine regions. Average annual maps of fishing effort were derived for both fishing gears.

Trawlers

For trawlers, it was assumed that VMS readings of speed between 0 to 4 knots correspond to "fishing", while speeds greater than 4 knots correspond to "steaming"; vessel positions in or close to harbours were excluded. In general, trawlers operated in the north-western and eastern territories of Lefkada island, east of Kefalonia and Zakynthos islands, inside Patraikos Gulf and in the northern part of Korinthiakos Gulf. The highest values of fishing effort were identified around the Astakos region, the outer part of Patraikos Gulf and the western part of Korinthiakos Gulf.

The Trawler Fishing Effort (TFE) criterion was based on the intensity of trawler fishing effort. Ranking was based on four defined classes, under the assumption that coastal fishing pressure should be low when TFE is high (Table 2; Fig. 3E).

Purse seiners

VMS signals were also used to estimate fishing effort by purse seiners. VMS readings of speed close to zero corresponded to "fishing". Purse seiners mainly fished around Lefkada Island and the Astakos area, inside Patraikos Gulf and in the south-eastern part of Korinthiakos Gulf. The highest values occur around Astakos, in the southern part of Patraikos Gulf and part of the southern Korinthiakos Gulf.

The Purse seiner Fishing Effort (PFE) criterion was calculated in the same way as TFE above. Ranking was based on four defined classes, under the assumption that coastal fishing pressure should be low when PFE is high (Table 2; Fig. 3F).

Maritime traffic activity

Since December 2004, the International Maritime Organization (IMO) requires that all vessels over 299 GT carry an AIS transponder on board, transmitting their position, speed and course, among some other information, such as the vessel's name, dimensions and trip details (www.marinetraffic.com)

In order to estimate the impact of maritime traffic on coastal fishing activity, we combined distance from coast with shipping lanes. Thus, the maritime traffic criterion is based on the assumption that shipping lanes that are closest to the coastline have the highest impact on coastal fisheries (Table 2; Fig. 3G).

No-take zones

Aquaculture farms, areas with bottom depths greater than 500m and no-take zones were excluded from the coastal suitability index due to the very low probability of a coastal vessel visiting these areas. Aquaculture farms were mainly found in the north-western part of the study area: north-western coastline of mainland Greece, around the island of Kefalonia, and along the northern coastline of Korinthiakos Gulf (Issaris *et al*., 2012). Areas with bottom depths greater than 500m are to be found in the central part of Korinthiakos Gulf and in the western part of the Ionian Sea (Fig. 3H).

S.2. Analytic Hierarchy Process and Weighted Linear Combination

The AHP is a multi-criteria decision-making approach which uses a multi-level hierarchical structure of criteria (Saaty, 1980). The pertinent data are derived by using a set of pair-wise comparisons. These comparisons are used to obtain the weights of importance for the decision criteria, and the relative performance measures for the alternatives (Saaty, 1980; Boroushaki & Malczewski, 2008). At the beginning, we constructed a matrix by comparing each criterion to all others, relative to its importance, on a scale of 1 to 9; 1 signified equal preference between two factors, while 9 that a particular factor was extremely favoured over another. For improving consistency, a weight estimate was calculated and used to derive a consistency ratio (CR) of the pair-wise comparisons.

The Sc was estimated using the Weighted Linear Combination (WLC) method (Drobne & Lisec, 2009). This is a widely utilized method for the calculation of final indices in multiple criteria problems. The mathematic formulation of the WLC method is:

$$S_c = \Sigma w_i x_i \times \Pi c_j$$

where: x_i – factor scores (spatial grid cells); w_i – weights assigned to each factor; c_j – constraints (or Boolean factors); Σ - sum of weighted factors; Π - product of constraints (1-suitable, 0-unsuitable). Classification in five classes (very low to very high) of S_c was based on Jenks Natural Brakes method (Jenks, 1967).

S.3. Fuzzy logic

S.3.1 Fuzzy membership

In Fuzzy set theory, a Fuzzy set is characterized by a membership function (FM). Fuzzy membership functions are used to standardize the original values of each criterion on a scale of 0 to 1. In the fuzzification process (Fuzzy membership), each standardized value that is nearer to unity represents the higher degree of membership in a fuzzy set (Zadeh, 1965; Burrough & McDonell, 1998; Malczewski, 2004). In this work, the spatial analyst toolbox was used to support the Fuzzy procedure (ESRI, 2011).

The *Fuzzy Linear transformation* function applies a linear function between the specified minimum and maximum values. The Zero value represents a grade below the minimum value of the original set. Linear transformations are commonly used in fuzzification of deterministic criteria (Fisher, 2000; Stelzenmuller *et al.,* 2010). Additionally, the *Fuzzy Large transformation* function is used when the larger input values are more likely to be a member of a set. The Large function uses a crossover point, assigned as a membership of 0.5. Values greater than the crossover point have a higher possibility of being a member of the set. The Large function also uses a spread parameter that defines the spread and the character of the transition zone (ESRI, 2011).

In our case, Linear and Large FM were applied to the optimal interpolation result of VAI_c. Four different scenarios for each FM transformation were applied. In particular, for Linear FM, four consecutive dilations (square roots of the FM) to the original function were used. For Large FM, the lowest value of the VAI_c data was defined as a crossover point in all scenarios. As a first scenario (S_0), no dilations were applied in Linear and Large FM. In the remaining 3 scenarios (S_1, S_2, S_3) sequential dilations were used. The correlation resulting from the aforementioned scenarios was estimated by Pearson's R correlation coefficients (Pearson, 1896), histograms and scatterplots fitted by Loess smoothers (Cleveland, 1981).

S.3.2 Fuzzy Overlay

Fuzzy logic explores the interaction of the possibility of a phenomenon belonging to multiple sets. In the fuzzy logic technique, combination is defined as a superclass of connectives that is used for fuzzy overlay (FO) (Jiang, 1996). In FO, there are specific techniques for investigating this relationship and quantifying the interaction. The combination approach used in this work was the Fuzzy Product or Fuzzy Algebraic product, as referred to in Zimmermann & Zysno (1980). The Fuzzy Product overlay type will, for each cell, multiply each of the fuzzy values for all the input criteria.

S.4. Implementation and evaluation of interpolation methods

The evaluation of the optimal spatial grid VAIc was based on a cross validation procedure to distinguish between Ordinary Kriging (OK) and Inverse Distance Weighted (IDW) interpolation methods. OK is a geostatistical approach for modelling. Instead of weighting nearby data points by some power of their inverted distance, OK relies on the spatial correlation structure of the data to determine the weighting values. This is a more rigorous approach to modelling, as correlation between data points determines the estimated value at an unsampled point (Matheron, 1963).

In addition, the IDW method is based on the assumption that the interpolating surface should be influenced most by the nearby points and less by the more distant points. The interpolating surface is a weighted average of the scatter points and the weight assigned to each scatter point diminishes as the distance from the interpolation point to the scatter point increases (Shepard, 1968).

The optimal interpolation result, corresponding to each method, was estimated by the lowest value of Root Mean Square Error (RMSE). In the sequel, a comparison of the optimal results of two methods was applied. Several plots (Quantile-Quantile-plots, QQplot) and RMSE were used to validate the results.

S.5. Implementation of the spatial clustering process

The Global Moran's I statistic measures spatial autocorrelation and is based on a variable's locations and attributes (Moran, 1950). It was used for assessing the overall pattern and trend of FPc and finally for the evaluation of the most appropriate scale to be used in Local Moran's I test. The Local Morans' I test (Anselin, 1995), detects local spatial autocorrelation and it can be used to identify local clusters or spatial outliers as well as to reveal the areas of high fishing pressure from coastal fisheries.

References

Boroushaki, S., Malczewski, J., 2008. Implementing an Extension of the Analytical Hierarchy Process Using Ordered Weighted Averaging Operators with Fuzzy Quantifiers in ArcGIS. *Computers & Geosciences*, 34 (4), 399-410.

Burrough P.A, McDonnell A., 1998. *Principles of geographical information systems*. Oxford University Press, New York, 510 pp.

Cleveland, W. S., 1981. LOWESS: A program for smoothing scatterplots by robust locally weighted regression. *The American Statistician,* 35 (1), 54.

Drobne, S., Lisec, A., 2009. A Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging. *Informatica*, 33, 459-474.

ESRI, 2011. ArcGIS Desktop: Release 10. CA: Environmental Systems Research Institute. Redlands

EU, 2003. Commission Regulation 2244/2003/EC of the European Parliament of the Council Regulation of 18 December 2003 laying down detailed provisions regarding satellite-based Vessel Monitoring Systems. Official Journal of the EU L 333, 17-27.

Fisher, P., 2000. *Fuzzy modelling.* Taylor & Francis, London, 459 pp.

Jenks, GF., 1967. The Data Model Concept in Statistical Mapping, *International Yearbook of Cartography,* 7, 186-190.

Jiang, J., 1996. *Fuzzy Overlay Analysis and Visualization in Geographic Information Systems.* PhD Thesis. University of Utrecht, Netherlands, 167 pp.

Karydis, M., Tsirtsis, G., 1996. Ecological indices: a biometric approach for assessing eutrophication levels in the marine environment. *The Science of the Total Environment*, 186, 209-219.

Kavadas S., Maina I., 2012. Methodology of analysis of Vessel Monitoring System data: Estimation of fishing effort for the fleet of open sea fishery, p. 165. 10th *Panhellenic Symposium of Oceanography & Fisheries, Athens, 7-11 May.* HCMR, Athens.

Malczewski J., 1999. *GIS and multicriteria decision analysis*. Wiley & Sons, New York, 393.pp.

Matheron, G., 1963. Principles of Geostatistics, *Economic Geology*, 58, 1246-1266.

Pearson K., 1896. Mathematical contributions to the theory of evolution. III. Regression, heredity, and panmixia. *Philosophical Transactions of the Royal Society,* 187, 253–318.

Saaty TL., 1980. *The analytical hierarchy process: planning, priority setting, resource allocation*. McGraw-Hill, New York, 309 pp.

Shepard, D., 1968. A two-dimensional interpolation function for irregularly-spaced data. 517-5, *Proceedings 23rd National Conference ACM*.

Stelzenmüller, V., Lee, J., Rogers, S.I., 2010. Quantifying cumulative impacts of human pressures on the marine environment: A geospatial modelling framework. *Marine Ecology Progress Series*, 398, 19-32.

Vassilopoulou, V., Anagnostou, C., Damalas, D., Drakopoulou, V., Giakoumi, S., et al., 2012. *Application of the MESMA Framework. Case Study: Inner Ionian Archipelago & adjacent gulfs*. MESMA report, 81 pp + Annex.

Zadeh, L.A., 1965. Fuzzy sets. *Inform. And Control*, 8, 338-353.

Zimmermann H. J., Zysno P., 1980. *Fuzzy Set Theory and Its Application*," Kluwer-Nijhoff Publishing, Boston, Dordrecht, Lancaster, 363 pp.