ISSN: 2594-0252

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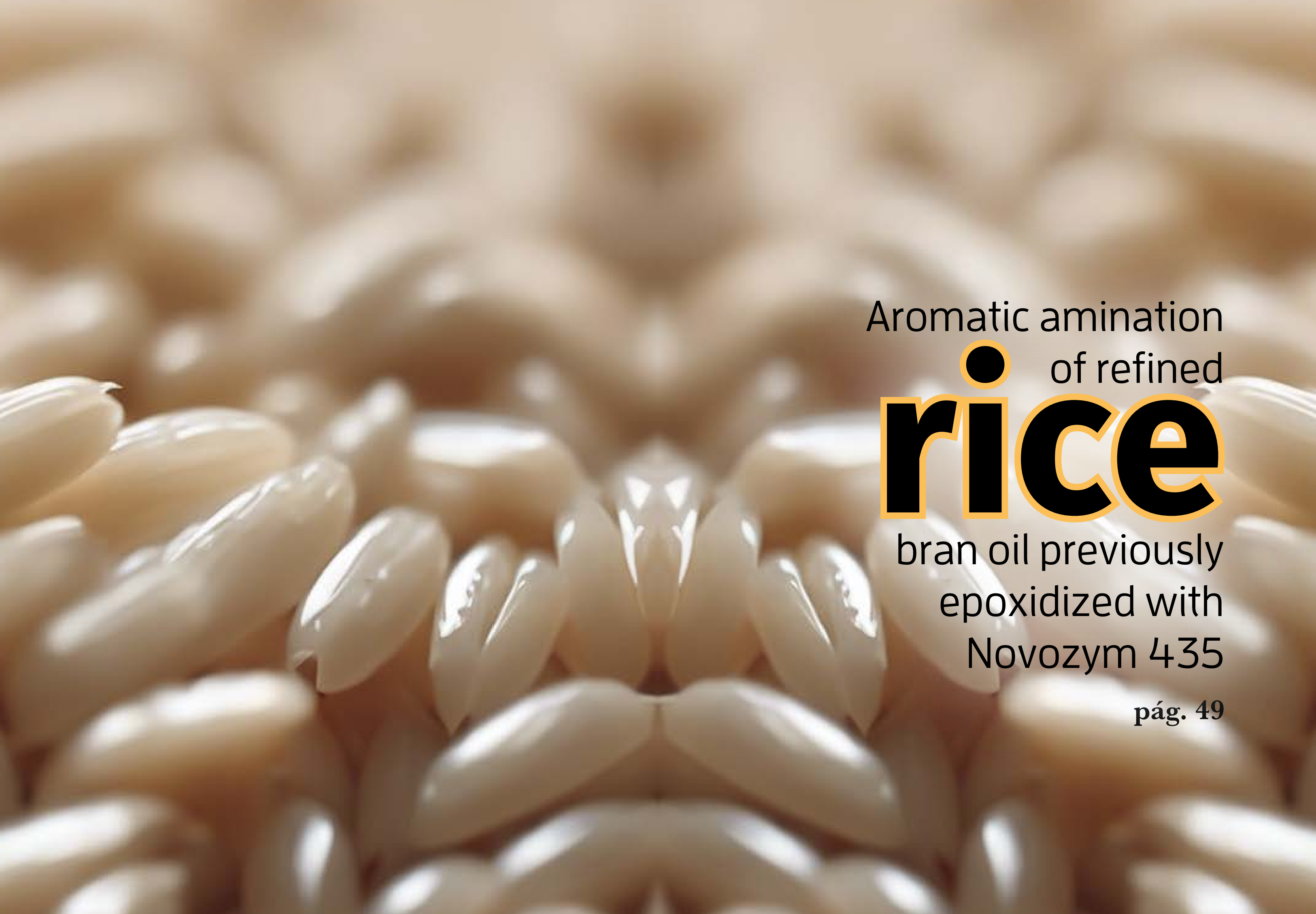

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Año 16 • Volumen 16 • Número 12 • diciembre, 2023

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Applied interpolation methodology with GIS used for artisanal fishing zoning in Bahía Magdalena, Mexico

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ABSTRACT

Objective: To limit the artisanal fishing zones in the mirror-still water of Bahía Magdalena, by means of interpolation.

Design/methodology/approach: Social, economic and biological production data were collected through surveys from a sample of 56 artisanal fishing cooperatives. The data are integrated into a relational database with geospatial reference and geostatistically processed with interpolation methods using a geographic information system.

Results: Four zoning maps were established based on the interpolation of the variables target species, fishing effort, extraction volume and sale value.

Limitations on study/implications: The remoteness and difficult access to the study area.

Findings/conclusions: The methodology can be used at the national level to generate a delimitation of the priority zones for artisanal fishing in Mexico, contributing to decision making and management plans that can consider variables of the fisherman's social life.

Keywords: Artisanal fisheries, Krigging, Bahía Magdalena, Zoning.

Citation: Magadán-Revelo, L. D., Escalona-Maurice, M. J., Hernández-Álvarez, E. & Espinosa-Morales, J. C. (2023). Applied interpolation methodology with GIS used for artisanal fishing zoning in Bahía Magdalena, Mexico. *Agro Productividad*. https://doi.org/10.32854/agrop.v16i12.2667

Academic Editors: Jorge Cadena Iñiguez and Lucero del Mar Ruiz Posadas

Received: August 28, 2023.
Accepted: October 19, 2023.
Published on-line: January 12, 2024.

Agro Productividad, 16(12). December. 2023. pp: 109-118.

INTRODUCTION

Presently, artisanal fisheries represent between 30% and 40% of the global fishing production (Villegas, 2012), while for Mexico they represent 40% of the total fishing production in the country (Ramírez, 2011; Ojeda, 2012). Although the riverbank fishing activity has a fundamental role in the economic production of the country, there are no management plans, structured methodologies and proposals that integrate the factors that intervene in fishing and the analysis of the social subject into a systemic study (Beltrán & Magadán, 2010; Díaz *et al.*, 2013; Ojeda, 2012), in order to recognize the importance of action and transformation exerted on the fishing socio-environment.

The use of Geographic Information Systems (GIS) in the analysis of coastal environments is an area of opportunity in the organization and planning of the productive activity of artisanal fishing. Storing information databases with different variables of importance, the ease of spatial visualization, and the capacity to analyze the results statistically (Meaden & Do Chi, 1996) make GIS a tool of great use for the study of the marine environment in interrelation with the livelihood and production mode of coastal zones and, with this, to generate integral studies.

The development of methodologies for the evaluation of marine resources is necessary, integrating the use of remote sensors based on the potentialities of GIS and promoting the possibility for management and collection of necessary data (Mumbyab *et al.*, 1995). Technological resources must be priority, although it is necessary to recognize, select and incorporate the data that interact in the management of marine resources to the GIS (Pan, 2005), such as the existing relationship between the coast and the marine ecosystem, the interaction between different organizations, communities and social subjects, the establishment of a line of communication that provides understanding between scientific contributions and the livelihood of coastal communities, or the knowledge of the strengths and limitations of the natural medium. The description of a methodological protocol that incorporates local knowledge from the fishing communities (Close & Hall, 2006; De Freitas & Tagliani, 2009), and the economic, productive, biological and geographic factors to a GIS is nowadays a priority need that must be present in fishing management plans in Mexico.

The storage and analysis of the data under the different processes provided by the use of GIS allow obtaining specific and multivariate results that may be presented under different modalities, both cartographic (Silva *et al.*, 2010) and regionalization (Erisman *et al.*, 2011), according to the intention and need of the researcher or study at issue.

For the case of studies conducted in Mexico, there are approaches quite close to the development of integral proposals of data incorporation, as is the case of the Collaborative Science Program (*Programa de Ciencia Colaborativa*, PCC), which integrates local, scientific and common perception knowledge to elucidate the socioenvironmental context in which fisheries develop (Jiménez *et al.*, 2018), and others that make use of the multi-functionality of GIS as a tool for working with and analyzing relational databases.

The objective of this study is geographically zoning, through a methodology of geostatistical interpolation with the use of a GIS, the mirror-still waters known as the Bahía Magdalena lagoon complex (BMLC) using different management variables and handling of socioeconomic resources. The variables related are the impact of cooperative action on the environment, the target species, the geographic limits of the zone, and the economic aspects of sale value and extraction volume of marine resources.

MATERIALS AND METHODS

The working units are the riverbank or artisanal fisheries of the BMLC, which are characterized by making use of small vessels and implementing artisanal fishing arts at a distance from the coast no greater than 12 nautical miles; these fisheries generate 2,502 direct jobs in the surrounding area (Ojeda & Ramírez, 2012). The main legal form in which the fishermen are associated to perform this activity is the Cooperative Fishing Production Society (*Sociedad Cooperativa de Producción Pesquera*, SCPP) which includes more than 90% of the population that has the legal possibility of gaining access to the extraction of the fishing resource (CONAPESCA, 2012; Villegas, 2012).

A database was created as a census of a representative sample of the artisanal fishing cooperatives. The sample size was obtained through the application of a formula to estimate the proportion of a known population universe of cooperative organizations (Rojas, 1995; Hernández *et al.*, 2010).

$$n = \frac{N * Z^2 * p * q}{d^2 * (N-1) + Z^2 * p * q}$$

From a population of 132 SCPP a random sampling with a total of 56 registered organizations was applied. The data that were collected are of social, organizational character, of impact on work, means of production and commercialization.

The data are integrated into a relational database with geographic references. The database used the ArcView 3.2 software of ESRI and a series of fields are established with specific characteristics to store the information gathered from each segment that makes up the research.

The structure of metadata with which the base study was constructed follows the technical norm recommended by the National Institute of Statistics and Geography based on ISO 19115:2003, where the minimal dispositions for the elaboration of metadata from the geographic data of national interest are established (INEGI, 2015); it is composed not only of the base structure of organization and conformation, but rather uses the resource of geographic location and characterization (Barbosa, 2013).

To generate the results expressed in this study, three vector layers were interrelated: 1) fishing zones, 2) cooperatives, and 3) fishing permits, which were approached under the structure of relational table in a *Dbase* (.dbf) format and linked directly to a geospatial visualizer in *shapefile* (.shp) format, having as a basis a raster *Rapideye* image of the geographic zone with *Enhanced Compression Wavelet* (ECW) format, a resolution of 2.5 meters pixel and color composition of three bands. Each vector layer has the following specific characteristics of information and composition:

1) Fishing zones: The layer has a polygon structure with a trace scale of 1:25,000 and a projection of the geoid WGS84. This vector layer delimits the fishing areas because of their geographic condition and marine characteristics; the polygon area represents 8,030.09 Km^2 of the surface and is divided into three differentiated zones: Pacific coast with 7,203.49 Km^2, estuary and Canals with 151.96 Km^2, and coastal lagoon with 674.64 Km^2.
2) Cooperatives: Layer made up by geographic points on land obtained through GPS geo-referencing with an error range plus/less 3 m. The layer offers the information of identity with regards to the organization of each SCPP, shows 56 fiscal addresses

of SCPPs, and incorporates quantitative and qualitative data of each organization gathering socioeconomic data, environments and livelihood of riverside fishermen.

3) Fishing permits: The layer is composed by vector points in the sea proposed by the fishermen themselves through the use of a participatory methodology where the fisherman, through observation of the satellite photograph and the use of GIS, pointed out and recorded the main fishing points that he approaches to perform his task; it also records verification points collected by joining fishing trips for each of the species registered (shrimp, crab, squid, marine scale, pen shell; *generosa*, *roñosa* and *chocolata* clams; octopus and shark), and data such as the volume permitted and quota granted for each SCPP registered as well as official data present in the permit.

The three vector layers serve as a basis of information so that cartographic results can be presented through the interpolation method, to delimit the fishing area according to four criteria of interest: 1) target species, 2) extraction in kilograms, 3) sale value, and 4) fishing effort.

Kriging interpolation method

The kriging interpolation method is a geostatistical technique (Bosque 1997) (Bosque 1997) that serves to interpolate data and/or create maps, which allows predicting the values of a series of cells (Villatoro *et al.*, 2008; Londoño *et al.*, 2010) from focalized values, assuming that the spatial distribution of the points follows a correlation (García *et al.*, 2010; Murillo *et al.*, 2012; Paredes *et al.*, 2013), "*the advantage they have against other interpolation models lies in including the behavior of the variable in space" (Quiroz 2011: 20) "it is based on the hypothesis that the spatial variations of the variable are statistically homogeneous throughout a surface*" (Ruiz *et al.* 2010: 111).

For the case of coastal zones and mirror-still waters, the cartography of fishing resources is a priority and is part of the objectives of management, emphasizing the spatial aspect of the information based on the capacities of the interpolation models (Ruiz *et al.* 2010).

The base vector delimitation was taken from the "fishing zone" layer, highlighting the differences in areas, and the quantitative information that the layers of cooperatives and fishing permits offer was interpolated on it, to obtain as a result the specialized cartography that shows: 1) the spatiality of the target species, 2) the extraction volume, 3) the value obtained from the sale, and 4) the number of fishing efforts. The layers were interrelated by the closest neighboring process that links the site to be estimated and the data used in the valuation (Emery, 2008); thus, the model offers as a result the projective parameters where the resulting zoning delimits the areas of interest.

The mapping, analysis of geo-referencing data, and interpolation model used a projection system in format of degrees, minutes and seconds with the geoid and WGS84 datum, maximum 25° 19' 12" and minimum 24° 18' 36" latitude North and maximum 112° 47' 24" and minimum 111° 50' 60" longitude West.

The values obtained from the interpolation were reclassified in function of their specificity or quantified range in order to obtain the cartography with differentiated polygons that promote their zoning.

RESULTS AND DISCUSSION

Zoning by target species permitted

The resulting data offer as result the great diversity found in the riverside zone, where three extractive zones can be differentiated punctually with perfectly represented characteristics and impact of target species:

1) The adjacent estuary zone shows a clear impact of the target species crab and mullet.
2) The bay zone shows a diversity of fisheries devoted to the extraction of clams such as *roñosa*, *catarina*, *chocolata* and *generosa*, as well as extraction of shrimp, pen shell, and different species of marine scale, we can affirm that the greatest diversity of target species is extracted mainly from bay waters.
3) The Pacific coast zone provides the habitat for fisheries of shark, marine scale, squid and octopus.

Figure 1 shows that the zoning can be represented based on the target species, where the estuary area is habitat for populations of crustaceans and "minor" marine scale species, and on which the action of trappers has a much higher influence.

The bay area is habitat of bivalve species (species that settle in the seabed) and which thanks to the conditions of bathymetry, salinity and organic matter find the place ideal for their reproduction; this is the place of action of harvesting divers.

In addition to this, the Pacific coast area has target species that carry out migratory processes, so their fishing is seasonal; this zone is the place of action of a much reduced group of fishermen.

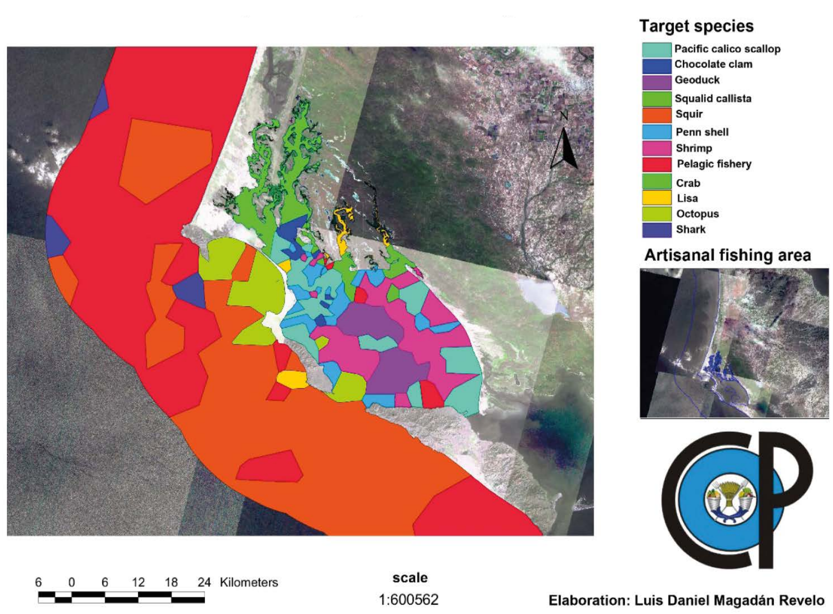

Figure 1. Target species.

Zoning by extraction in kilograms

In this interpolation exercise, the amount of extraction in kilograms found in the study area can be observed (Figure 2), which shows that in estuary zones and part of the Pacific coast is where most of the extraction takes place, which represents an area mostly dominated by a range of extraction between 8,001 and 30,000 kg, presenting small zones that denote areas that reach extraction volumes of up to 99,000 kg of product obtained by cooperative.

Similarly, we can observe that within the bay zone, the average extraction of kilograms of product by SCPP is 1,000 to 8,000 Kg, which represents the smallest value range in terms of extraction.

In the northeastern area of the bay, a strip can be seen that denotes an average extraction of 8,001-30,000 Kg which, compared to the areas with the distribution map per target species, shows that in the zone described there is extraction of estuary shrimp.

Small, focalized points close to the coast can be seen within the same zone of the bay, where there are extractions that exceed 75,000 kilograms, and in these small areas with huge extraction there is fishing of roñosa clam which is found in a phase of incorporation to the labor market of the SCPP.

Zoning by sale value

In economic issues, it can be stated that the main areas of extraction are located primarily within the bay area, where sale values between 1,001 to 7,500 thousand pesos MX are obtained (Figure 3).

Strictly speaking, fisheries of generosa clam and shrimp are the ones that generate higher yields, since the proportion of volume extracted is lower compared to other fisheries; however, the incomes obtained from the extraction of these products are highly profitable due to their high sale value.

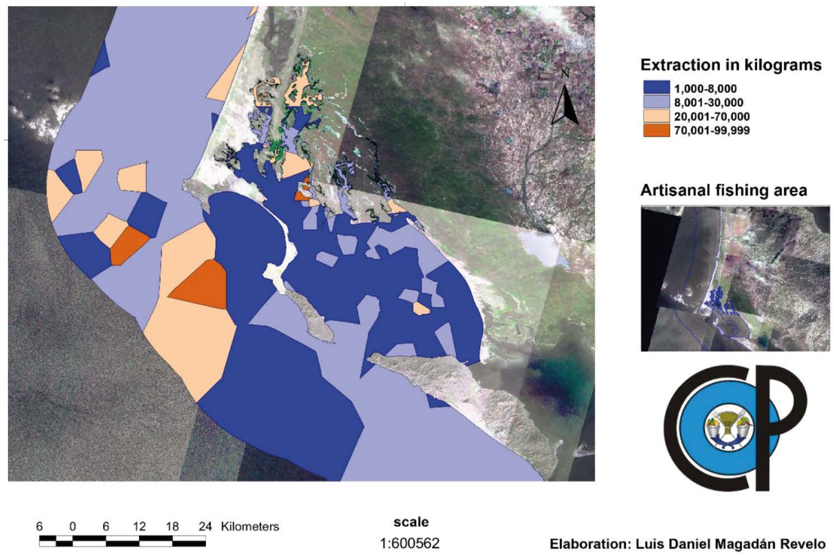

Figure 2. Extraction in kilograms.

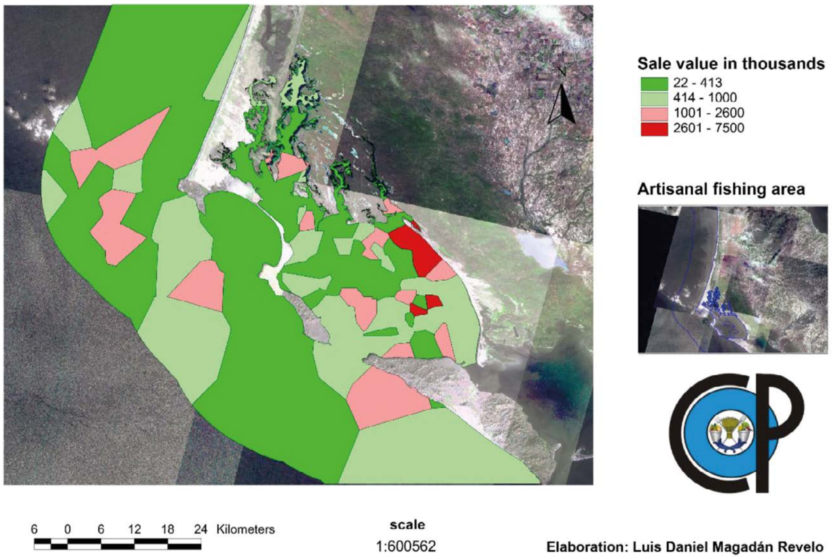

Figure 3. Sale value.

The contrary case can be seen in neighboring estuaries and the Pacific coast, since the proportion of product is much higher than that extracted from the bay zone, since it reports lower sale values. We can affirm that fisheries of crab, marine scale, squid and octopus manifest a directly proportional relation between the extraction volume and the value obtained from the sale of the product.

Zoning by fishing effort

The fishing effort refers to the number of barges or vessels allowed for the extraction of target species (Figure 4). It shows the number of barges there are by cooperative in

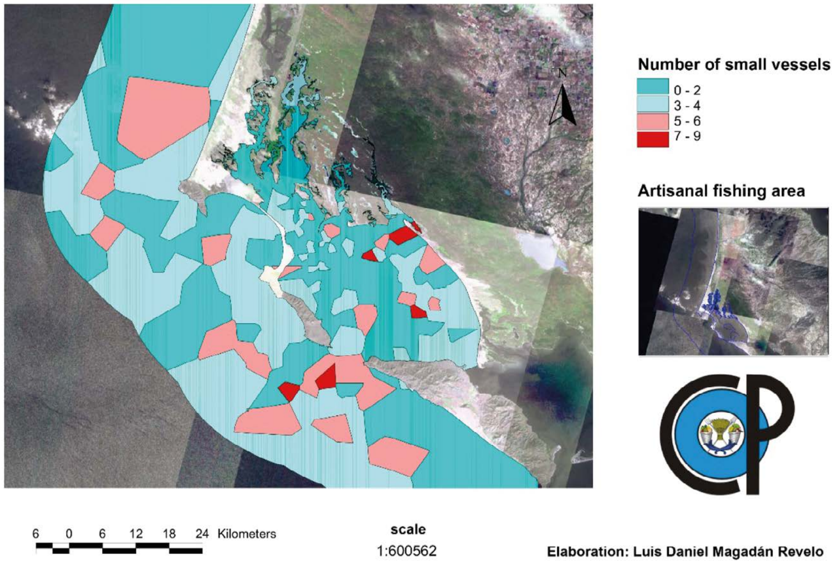

Figure 4. Number of small-scale fishing vessels.

the three different fishing zones (estuary, bay and coast). As can be observed, taking into consideration that the average number of vessels from each cooperative is 4 barges, the zones with the highest number of fishing efforts are located in the Pacific coast, since this is where a greater fishing area is concentrated, with possibilities of 3 to 9 permitted vessels; since this is the zone of migratory species, the institutions in charge of fishing codes offer a higher number of extraction permits.

There is a strip within the bay that shows a number of 3 to 6 barges per cooperative, so it can be inferred that the target species to which this fishing effort is directed is that of estuary shrimp.

On the other hand, a fishing effort of 1 to 2 barges permitted per SCPP can be seen in most of the bay zone and this corresponds to the sedentary nature of the target species that are extracted there, which mostly belong to the group of bivalves.

Meanwhile, in the estuary area we find again a fishing effort of 1 to 2 barges, where the work that is performed does not need greater vessel infrastructure because since it is a zone of crab and minor marine scale, fishing arts such as *chinchorro* and traps are used, which work for prolonged periods of time, allowing 1 to 2 vessels to carry out the work required there.

CONCLUSIONS

The socioeconomic activity of artisanal fishing actively impacts the marine ecosystem but it is important to analyze that the productive-commercial transit of the products obtained is a direct and indirect financial source for a large number of social stakeholders, and this is why in face of management and zoning plans for marine areas, there should be an analysis of the socioeconomic aspects of artisanal fishermen. This interest is a central piece of the study by Rodríguez *et al.* (2015) who describe the need to zone these aspects in order to generate a general action plan jointly, which could have special emphasis in the zoning of the areas of interest presented here.

Applying the interpolation method for the definition and characterization of areas in function of some significant variables or criteria makes it possible to obtain cartographic products of huge interest, not only for the characterization of fishing zones but also for the management, monitoring and planning of actions that can be centered in local needs that can be linked with state and federal initiatives, and thus facilitate the management of marine ecosystems involving the local population in decision making.

The resulting maps from the interpolation process through *kriging* offer the visualization of the working zone in the BMLC, based on socioeconomic perspectives that together with biogeographic data, contribute greatly to the clarification of priority attention areas, future decision making, and for management plans to consider the variables of the fisherman's social life.

This working methodology can be used at the national level and thus generate a delimitation of priority zones of artisanal fishing in Mexico. The reach of future works must consider the universe of SCPPs settled in the localities that are studied, as long as there are the necessary monetary and human resources.

The communication channel of this cartography can be more efficient when it is linked to a web cartographic visor that allows access and free use of the information for people interested in this thematic axis.

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