Elaboration of a fishing effort cartography protocol

BEN RAIS LASRAM FRIDA*, CRUZ FOLCH ANTONIO**

Jel classification: Q220, Q280

Abstract

The quantification of the fishing effort is one of the classical tools of fisheries' management.
In order to minimize the risks of conflict and over-exploitation, the General Fisheries Commission for the Mediterranean (GFCM) recommended a better consideration of the geographical distribution of the fishing effort.
According to this, the objective of this work is to set up a fishing effort cartography protocol based on a fishing activity database and on a mathematical distribution model validated by the new methods for gathering information about the fishing zones investigation and implemented on a geographic information system.
This pilot system, which offers a synoptic view of the spatial distribution of the fishing effort, is likely to provide fisheries' managers with better decision tools.

Keywords Geographic information system; cartography; fishing effort; modelling; fishing zones; validation

Résumé

L'un des outils classiques de la gestion de la pêche est la quantification de l'effort de pêche. Afin de minimiser les risques de conflits et de surexploitation, le Conseil Général de la Pêche en Méditerranée (CGPM) suggère une meilleure considération de l'aspect spatial de cet effort de pêche.
C'est dans cette optique que s'inscrit le présent travail à travers la proposition d'un protocole de cartographie de l'effort de pêche basé sur une base de donnée de l'activité de pêche et sur un modèle mathématique de distribution validé par de nouvelles méthodes de détermination des zones de pêche; et ceci étant réalisé par le biais d'un système d'information géographique.
Ce système pilote, permettant une vue synoptique de la distribution spatiale de l'effort de pêche, est susceptible de fournir aux responsables de la pêche de meilleurs outils de décision.

Mots cléfs: *Système d'information géographique; cartographie; effort de pêche; modélisation; zones de pêche; validation*

1. Introduction

One of the fisheries management main objectives is searching the most appropriate tools that ensure both the optimal yield of the fisheries and the conservation of the stocks. Indeed, the marine resources management has to satisfy a growing demand rate that guarantees the economic viability of the sector and avoids its over-exploitation.

Moreover, due to the extension of the national jurisdictions regarding the fishing activities, the responsibilities about the stocks management are entrusted to the coastal states that have to take control of the excessive fishing capacities and the fishing effort deployment.

These two quantities have a spatial dimension: the fishing effort allocation.

But, in spite of the multidimensional character of fisheries operations, the temporal aspect considerations have always dominated the spatial ones : the temporal data series have been largely used at the expense of the spatial dimension apprehension, thus, both for the coastal and the high sea fishing activities.

Some authors have proposed the fishing effort and the resource cartography as prior tasks of the fisheries management and have demonstrated their relevance on the general fishing context (Caddy and Garcia, 1986). In addition to the temporal characteristics classically used on the studies, it appears necessary to better consider the fishing effort spatial dimension.

So, the importance of the spatial dimension on the fisheries management is undeniable (Caddy and Garcia, 1986; Meaden and Do Chi, 1996; Taconnet and Bensh, 1998) and the use of the geographical information systems as a support tool has been started and demonstrated by the FAO and the GFCM (General Fisheries Commission for the Mediterranean).

The project FAO COPEMED, which consisted in the elaboration of the FAST tool in order to map the fishing effort and the resource, has inspired our work in proposing a methodology for the modelling of the fishing effort spatial distribution.

Our approach aims at setting up a fishing effort cartography protocol based on a fishing activity database and on a mathematical distribution model validated by the new methods of the fishing zones investigation and implemented on a geographical information system.

2. Cartography of the fishing effort

The elaboration of a fishing activity database is the base of the proposed approach : the information concerning the characteristics of the fishing boats, the fishing gears and the fishing operations (fisherman behaviour, ranges of action) are gathered by interviewing the fishermen and organised on a database.

* Institut National Agronomique de Tunisie. UR Ecosystèmes et Ressources Aquatiques.
** Departament de Recursos Marins Renovables, Institut de Ciències del Mar –CMIMA (CSIC), Barcelona, Spain.

Then, we allocate the fishing zones by combining this information and implementing the model managing the spatial distribution of the fishing effort. The new methods of the fishing zones investigation permit to validate the model outputs.

2.1. Allocation of the potential fishing zones

In order to determine the activity zones of a given fleet, we proceed – as proposed by Bensch and *al.* (2000)- by the intersection of what we call "geo-entities". A geo-entity is a set of rules, activities, practices and physical characteristics defining the spatial extent of a fishery:

The legislation is the legally authorised zone for fishing. It excludes the military areas, the protected areas, the fixed fisheries, the navigation areas, the areas situated above the allowed isobaths and all the other areas governed by general or specific clauses. On the GIS, this geo-entity is represented by polygons.

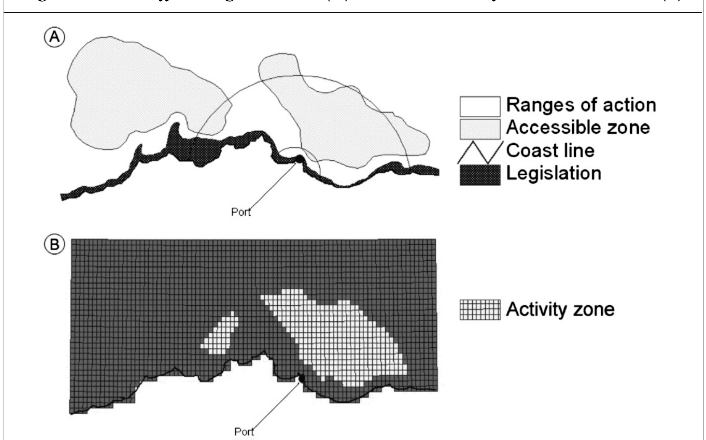
The accessible area is the area compatible with the fishing gear. For a pelagic fleet, it depends only on the gears dimensions (the height of the water column has to be sufficient to permit the gear manoeuvre) and for a benthic fleet, it principally depends on the ground nature (rocky, sandy …). This geo-entity is also represented by polygons on the GIS.

The range of action: each fishing boat operates between a minimum range of action fixed either by the legislation or by a fisherman self-imposed limit by the, and a maximum range of action over which the fisherman doesn't work. On the GIS, these ranges are represented by semi-circles as buffers around the port.

The potential activity area: this geo-entity is generated by the intersection of the geo-entities "legislation", "accessible area" and "range of action" and represents the potential fishing area for each fishing boat of the studied fleet, which means the area likely to be frequented.

The intersection is executed for each fishing boat on a grid with a unit cell size defined according to the whished spatial resolution. This routine is executed by a program that permits to generate automatically the activity areas (Figure 1).

Figure 1. *The different geo-entities (A) and the result of their intersection (B)*



In the attribute table of the geo-entity "potential activity area", the score 1 is affected to the cells where a fishing activity is exerted and the score 0 is affected to the cells where this fishing activity is absent.

2.2. Fishing effort spatial distribution modelling

In order to analyse the fishing effort spatial distribution, we have to introduce a model layer on the GIS. It means that we have to formulate a model describing the fishing effort spatial distribution and to implement it on the GIS in order to visualize the geographical allocation by generating maps.

It is obvious that a limiting factor conditioning the distribution of the fishing establishment that could be spread from a giving port exists : the distance.

Caddy (1999) carries that, according to the conventional theory of geography, the nature of the "fishing field" is a "friction of distance". The limiting factor constituted by the distance is due to:

- the travel time duration: going further away from the harbor decreases the effective fishing time.
- the cost: going further away from the harbor increases the fuel cost and the risk to come back too late to benefit from the best market prices.

On the basis of the grid used to generate the potential activity area, we may say that the fishing effort for a boat k on a cell i f_i^k, is modelled by:

$$f_i^k = f^k . W_i^k / A_i$$

Where:

- f_i^k is the fishing effort for a boat k on a cell i
- f^k is the fishing effort unit for the boat k determined whether by the classical methods or by the multivariate analysis
- A_i is the area of the cell i
- W_i^k(d) is the friction of distance factor, managed by a truncated normal distribution function (Aitchison and Brown, 1981) (Figure 2) using the minimum and the maximum ranges of action et and the distance separating the cell i considered from the port of the boat k studied: the fishing effort is null under an inferior limit represented by the minimal range of action , then it increases rapidly to reach a maximum, and decreases to become null over a superior limit corresponding to the maximal range of action.

$$W_i^k(d) = S^k . \left(d - r_{\min}^k\right) / r_{\min}^k . \left(r_{\max}^k - d\right) / r_{\max}^k . e^{-\left(r_{\max}^k - d / r_{\max}^k\right)}$$

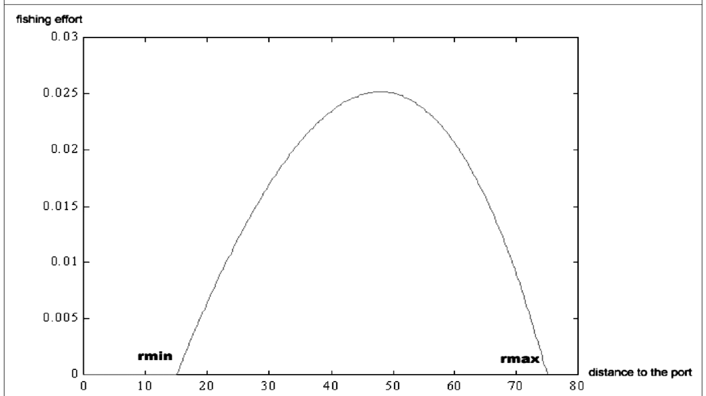
Where:

- d is the distance separating the cell i, where the boat k operates, from the port
- r^k_{min} is the minimum range of action of the boat k
- r^k_{max} is the maximum range of action of the boat k
- S^k is a factor chosen to ensure the normalization of the function, as:

$$\int_{rk_{min}}^{r^k_{max}} W_i^k(d)\,dd = 1$$

Then, we arrange in a first table the fishing effort units for each boat, the minimum and maximum ranges of action. In a second table, we arrange the distances separating each cell of the grid from the port of each fishing boat.

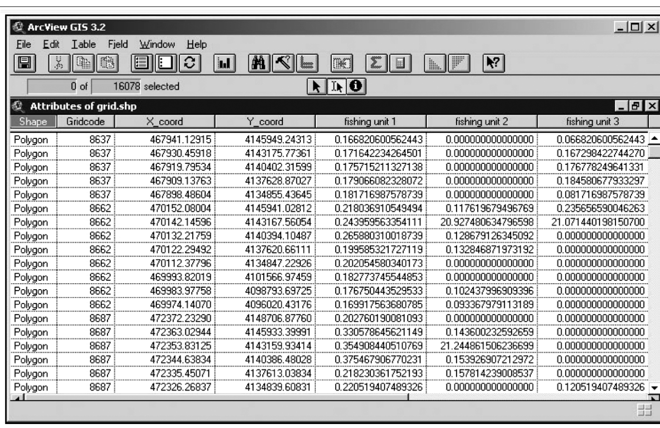
Figure 2. *Shape of the friction of distance function*



Next, it is the question of writing a program allowing to execute the routine calculating according to the distribution model.

The multiplication of the matrix so obtained by the score matrix (0 and 1) resulting from the intersection of the geo-entities leads to the generation of a final matrix whose rows are represented by the cells and the columns by the boats : the cells where the fishing activity is absent are affected by the value 0 and the others are affected by the value of the corresponding effort (Figure 3).

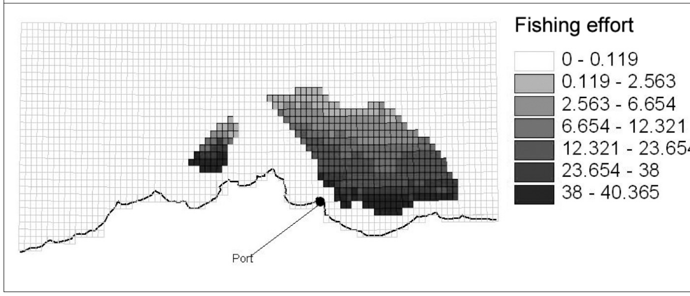
Figure 3. *Example of an attribute table leading to the generation of fishing effort distribution maps*



Shape	Gridcode	X_coord	Y_coord	fishing unit 1	fishing unit 2	fishing unit 3
Polygon	8637	467941.12915	4145949.24313	0.166820600562443	0.000000000000000	0.066820600562443
Polygon	8637	467930.45918	4143175.77361	0.171642234264501	0.000000000000000	0.167298422744270
Polygon	8637	467919.79534	4140402.31599	0.175715211327138	0.000000000000000	0.176778249641331
Polygon	8637	467909.13763	4137628.87027	0.179066082328072	0.000000000000000	0.184580677933297
Polygon	8637	467898.48604	4134855.43645	0.181716987578739	0.000000000000000	0.081716987578739
Polygon	8662	470152.08004	4145941.02812	0.218036910549494	0.117619679496769	0.235656590046263
Polygon	8662	470142.14596	4143167.56054	0.243959563354111	20.927480634796598	21.071440198150700
Polygon	8662	470132.21759	4140394.10487	0.265880310018739	0.128679126345092	0.000000000000000
Polygon	8662	470122.29492	4137620.66111	0.199585321727119	0.132846871973192	0.000000000000000
Polygon	8662	470112.37796	4134847.22926	0.202054580340173	0.000000000000000	0.000000000000000
Polygon	8662	469993.82019	4101566.97459	0.182773745544853	0.000000000000000	0.000000000000000
Polygon	8662	469983.97758	4098793.69725	0.176750443529533	0.102437996909396	0.000000000000000
Polygon	8662	469974.14070	4096020.43176	0.169917563680785	0.093367979113189	0.000000000000000
Polygon	8687	472372.23290	4148706.87760	0.202760190081093	0.000000000000000	0.000000000000000
Polygon	8687	472363.02944	4145933.39991	0.330578645621149	0.143600232592659	0.000000000000000
Polygon	8687	472353.83125	4143159.93414	0.354908440510769	21.244861506236699	0.000000000000000
Polygon	8687	472344.63834	4140386.48028	0.375467906770231	0.153926907212972	0.000000000000000
Polygon	8687	472335.45071	4137613.03834	0.218230361752193	0.157814239008537	0.000000000000000
Polygon	8687	472326.26837	4134839.60831	0.220519407489326	0.000000000000000	0.120519407489326

The implementation of such a matrix on the GIS leads to the generation of maps in order to visualize the potential spatial distribution of the fishing effort in the studied zone (Figure 4).

Figure 4. *Example of a map of the potential spatial distribution of the fishing effort*



2.3. Validation of the fishing effort

Once the model has been tested, it has to be validated with real georeferenced field data. The basic pattern to do is to obtain a new raster covering the same area used for modelling but with real numbers of fishing effort. It will be very easy then to perform simple cell-by-cell comparison and generate a new raster showing the difference between the model and the real world. In other words, cells occupying the same location but belonging to different rasters can be evaluated together to find statistical differences. Statistical methods applied depend on possibilities of every GIS analysis software.

The main information necessary to achieve this goal is the real fleet distribution and the real effort.

Fleet distribution can be obtained from different methods, described in details in the next session. First of all, it is necessary to create a grid vectorial map similar to base map used prior in modelling tasks, using the same bidimensional grid size and number. Information about spatial distribution of fishing fleet will be digitized (if necessary) and stored as georeferenced elements as vectorial points. Merging both vectors, we will obtain a spatial matrix in which there will be the spatial distribution of the fishing fleet in marks per cell.

Total fishing effort (fishing hours, CPUE, etc) can be obtained from the bibliography, administrative data or daily Auction data. This total effort can be then redistributed in spatial matrix created in a previous step calculating the value for each grid cell by the formula:

$$Cell\ value = Effort \times \frac{Number\ marks\ in\ cell}{\sum Number\ marks}$$

This georeferenced effort values grid is used to perform an intensity map or DEM (Digital Elevation Model) by Geographic Information System and to create a new raster of same size, extents and cell size.

The final step consists in matching grids obtained from modelling and from validation procedure and performing a single raster subtract operation to obtain a new georeferenced entity that shows differences between the model and the real world.

3. Methods of obtaining information about fishing zones

There are various techniques available to obtain information about fishing zones in direct field observations or remote estimation of spatial distribution. Note that these methods are not only useful for getting information from fishing zones; they are also used as direct fishing effort estimation tools. A suitable method will depend on distribution pattern and size of fishing fleet.

3.1. Fishermen Interviews

One of the most used methods is direct fishermen interviews combined with onboard GPS positioning of hauls. This is quite useful in case of small artisanal fleets formed by small, medium-sized vessels that return every day to their home harbour. Taking into account that we will be forced to georeference this data, we will have to prepare a grid map similar to base map used prior in modelling tasks, using the same bidimensional grid size and number and ask fishermen to mark cells where they usually go fishing. These interviews should be done several times with different fishermen and in different times of the year in case we are attempting to take a well represented image of yearly vessel distribution. The ideal way is to interview the crews from all vessels implied, but this can be very difficult in case of huge fleet sizes or wide geographical extents.

Interview results have then to be digitized into georeferenced elements (marks per cell) in order to obtain the geographic distribution of fishing effort.

3.2. Overflight (Aerial Surveillance)

Airborne surveys can be very useful in order to obtain geographic position of fishing vessels and their spatial distribution. On plane, it is possible to travel long distances in a short time, to identify vessels accurately and to take vessel position with a single GPS. The results obtained show a global vision of the spatial distribution of the fishing fleet.

The main disadvantage of this technique is the huge costs, due to pilot rental and fuel spending. Unless the local Government takes periodically this kind of data as a part of its MCS (Monitoring Control and Surveillance) of fishing vessels, overflight surveys imply a lot of economic efforts for investigators.

3.3. Radar

3.3.1. Onboard Radar

Radar technology has been designed for detecting objects in a wide spread of distances and accuracy. The smallest fishing vessel carries a radar device onboard that can be used as a tool for detecting and mapping the entire fishing fleet. This can be done during ordinary onboard sampling cruises, registering position of other boats working in the area. From the radar screen of sampled fishing vessel, observed marks are translated into papers issued with a pattern similar to electronic display. By tracking geographic position of sampling vessel on every different sample, written marks can be digitized and georeferenced at the lab. This method can be improved by the use of tracking technology that comes with most of modern onboard radar devices, like Radar-ARPA (Automatic Radar Plotting Aids) by directly plotting on paper or on electronic georeferenced format.

3.3.2. Land-based Radar

Another technique consists in a land-based radar on a fixed coastal station. In this case, the survey is restrained to radar device range, but the planning and time spent on sea sampling cruises are avoided. A land-based station allows remote controlling of radar device and instant download of acquired data via internet at a very low cost (it can be done with simple computer equipment).

3.4. Remote Sensing

3.4.1. VMS (Vessel Monitoring System)

The use of Vessel Monitoring Systems (VMS) to automatically plot the positions of fishing vessels has been adopted in several countries. The on-board vessel equipment uses modern satellite communication systems that have an inbuilt global positioning system (GPS) (FAO, 1998).

Countries which have already implemented VMS systems for selected categories of fishing vessel are Australia, New Zealand, USA, South Africa, Japan and Canada. The European Community has required most of its fishing vessels over 24 metres in overall length to be included in a VMS programme since the beginning of 2005.

Complete VMS data can be extremely useful for validation methods. In fact, it is the most accurate approach that can be made without direct intervention of investigators. Row georeferenced data can be downloaded, classified and mostly analyzed immediately. But this technology has a great disadvantage: its cost. It is necessary that the local Government, responsible of study zone, makes an important effort to homogenize and upgrade fishing fleet with this system. Nowadays, only developed countries have implemented VMS and for big trawler fleets that work on very huge areas in order to control fishing activity of foreign vessels in their territorial waters (e.g. North Sea). Besides, obtaining such data is not easy because of bureaucratic barriers. In case of small coastal fleets, VMS is not widely implemented in all vessels in developed countries and there is a lack of control of implementation by fishermen, who usually ignore on board VMS device.

3.4.2. Satellite Surveillance

Remote sensing has increased its importance during the past years. Necessity for obtaining information at global scale has led to develop a large amount of services related to obtention of images from the earth surface using a wide range of sensors. In spite of such technology that has been typically the preserve of military intelligence agencies, satellite imagery has become more accessible and is used now for a variety of commercial and governmental purposes. Applications on estimation of fishing effort and MCS are evident. Vessel position and distribution can be detected and stored with different techniques.

One type is that based on high definition optical/infrared devices (e.g. Quickbird, Ikonos, Spot, Landsat), that can obtain coloured orthorectified images in visual band with a resolution up to 0.6 meters (Volpe, 2003). The use of this data as a validation method to quantify, identify and locate fishing vessels depends highly on the area to be surveyed, due to costs of this kind of high resolution images, based on scanned area. This is also a decision basically dependant on cost-benefit terms.

Synthetic Aperture Radar (SAR) is the other main types of satellite imagery. Satellites with SAR capabilities include ERS and JERS series, ENVISAT and RADARSAT. SAR is less affected by cloud cover and darkness than other type of satellites and its resolution is enough to detect vessels subject to VMS (Kourti et *al*., 2001).

This type of satellite has been proved useful in monitoring commercial fishing grounds in order to detect illegal fishing activities. With wide swath SAR, large ocean areas can be monitored by frequent revisit schedules, thus allowing detected ships to be observed and identified by patrols that are vectored on these targets from cuing derived from the SAR information (Montgomery, 2000). Radar's capability to detect oil spills, bathymetric features in shallow waters and ships has led to systematic use of SAR images in operational surveillance (Johannessen, 2000; Olsen and Wahl, 2000)

4. Conclusion

The fishing sector, a complex system where the fishermen, the administration, the politics and the research interact, is at the centre of the fishing managers' concerns. Indeed, since the Code of Conduct for Responsible Fisheries has come into force, the member countries of the FAO agreed to implement decision tools in order to assure the durable exploitation of the aquatic living resources which are highly threatened nowadays. One of these decision tools is the monitoring and the control of the fishing effort.

By coupling a fishing activity database and a mathematical distribution model validated by some recent methods of obtaining information about fishing zones, we propose in this work a fishing effort cartography protocol that belongs to the actual tendency of including the spatial dimension of the fishing effort in the decision measures.

Thus, the availability of a synoptic view of the fishing effort distribution makes the implementation of the decision measures easier.

Besides, it is possible to simulate different scenarios of the fleet increase in order to anticipate the risks of overexploitation by overlapping the fishing effort and the resource distribution maps.

References

AITCHISON, J., BROWN, J.A.C.,1981. The Lognormal Distribution. Cambridge University Press. ISBN:0 521 04011 6. 87-99.

BENSCH A., CAROCCI F., CORSI F., DRAPEAU L., LE CORRE G., MORALES J., 2000. SFEM : conceptual and methodological document. Workshop I, 11-14/04/2000. Montpellier. Spatial modelling of fishing effort. 47 p.

CADDY J.F., 1999. Spatial modelling in GIS fisheries applications. SFEM : conceptual and methodological document. Workshop I, 11-14/04/2000. Montpellier. Spatial modelling of fishing effort. 23 p.

CADDY F., GARCIA S., 1986. Fisheries thematic mapping : a prerequisite for intelligent management and development of fisheries. Océanographie tropicale. 21 (1). 31-52.

MEADEN G., DO CHI T., 1996. Geographical information systems. Applications to marine fisheries. FAO Fisheries Technical Paper (356). 335 p.

TACONET M., BENSCH A.,1998. Une revue régionale de l'utilisation des Systèmes d'Information Géographique comme outil d'aide à la décision en gestion des pêches. FAO COPEMED. Project GCP/REM/057/SPA. Towards the use of Geographic Information System as a decision. 7 p.

FAO., 1998. *Fishing operations. 1. Vessel monitoring systems.*Fisheries Dep., Rome (Italy) Fishing Technology Seri.

JOHANNESSEN J. A., 2000. *Coastal observing systems: The role of synthetic aperture radar.* Johns Hopkins APL Technical Digest. 21(1). 41-48.

KOURT N., SHEPHERD I., SCHWARTZ G., PAVLAKIS P., 2001. *Integrating space-borne SAR imagery into operational systems for fisheries monitoring*. Canadian Journal of Remote Sensing/Journal Canadien de Télédetection. 27(4). 291-305.

MONTGOMERY D. R., 2000. *International fisheries enforcement management using wide swath SAR.* Johns Hopkins APL Technical Digest. 21(1). 141-147.

OLSEN R. B., WAHL T., 2000. *The role of wide swath SAR in high-latitude coastal management*. Johns Hopkins APL Technical Digest. 21(1). 136-140.

VOLPE F., 2003. *Mapping information from space with Quickbird satellite data*. In Digital Earth 2003 Conference–Brno (Chez Republic).