Spatial distribution of fishing effort: modellisation through deductive modelling

Fabio Corsi
Istituto Ecologia Applicata - Via L. Spallanzani, 32 00161 Roma Italia

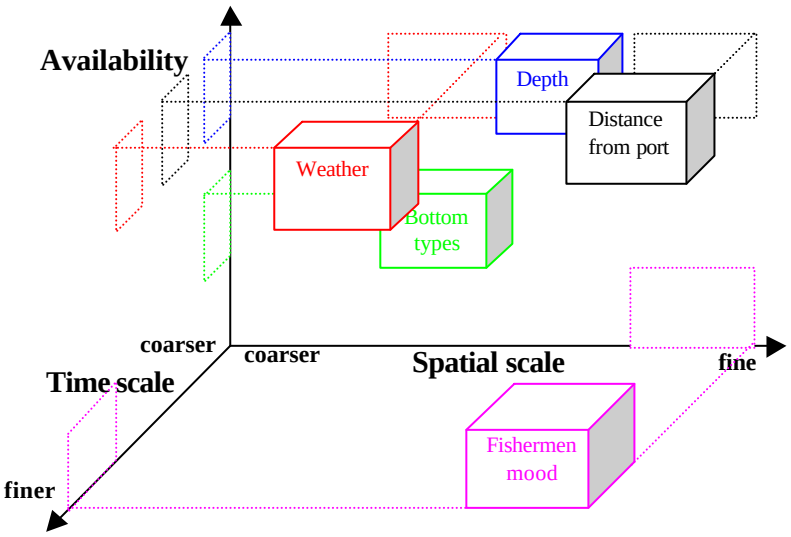
Introduction

Spatial distribution of fishing effort within fishing grounds is an important piece of information to assess the status of the fishery. Not only to address issues related to the exploitation of the resource applying traditional approaches developed within the field of fisheries biology; but also to address the growing concern which arises from the application of the IUCN threat criteria (IUCN, 1994) to fish populations.
Unfortunately there are no satisfactory direct means to investigate the behaviour of a fishing fleet. And although some investigation is being conducted on new ways of controlling the movements of the fishing fleet (e.g. GPS localisation, remote sensing, aerial surveys) most of these efforts are still at their early stages.
Recent proposals for a conceptual framework of GIS distribution models (e.g. Stoms *et al*., 1992; Norton and Possingham, 1993; Corsi *et al*., 1999) suggest that in situations of limited data availability a deductive modelling approach can provide interesting results, obviously within the constraints of the assumptions which underlay the model itself.

Thus the idea behind this application is to investigate the available data sets, how they correlate with fishing effort and the possible outcome of the modellisation of fishing effort distribution using the limited data available.

Methods

There are certainly many variables that can be correlated to fishing effort distribution; for instance those variables capable of describing the cost of reaching a certain fishing ground, the abundance of the resource to be fished, the behaviour of the fishermen, the condition of the sea. Considering a few of all the possible variables we can take into account sea bottom types, distance from the port, depth, weather.
According to the hierarchical hypothesis (O'Neill *et al*. 1986) that states that at any given scale there are particular environmental variables that drive the ecological processes and considering fishing effort as an ecological process that targets the fish population, each one of the variables becomes increasingly important to describe fishing effort distribution according to the spatial and temporal scale of the analysis.
For instance, both bottom type and depth provide evidence on the distribution of the fishing fleet in the temporal domain when analysed at a very coarse resolution. The two variables account essentially for the structural description of the fishing ground which indeed is rather static in time. On the other hand a detailed account of the fishing ground structure can provide fine resolution information in the spatial domain.
Similarly, distance from the port can be correlated to the economics of fishing activity and can provide insightful information when the analysis is conducted at finer detail compared to the previous variables both in the temporal and in the spatial domains



Weather can be correlated to an average resolution description of the accessibility to the resource in space, while the highly repetitive availability of data sets in the temporal domain makes it a variable of choice when conducting analyses at a very fine temporal scale. Finally to complete the list of variables given above, the hypothetical description of individual mood and attitude of fishermen on a daily basis would provide the final answer to the localisation of fishing effort both in time and space.

Figure 1 summarises this concept showing how these variables relate to fishing effort distribution both in the time scale and in the spatial scale. From the analysis of figure 1 it is possible to derive a general idea of the type and the extent of utilisation of a fishing effort distribution model that can be obtained from the different variables.

For a better understanding of the potential utilisation of the different variables within an effort distribution model, the present availability of each data set is also shown in the figure 1 on the vertical axis. Data availability is probably to major constrain in building adequate models in ecology (Corsi *et al*., 1999). For instance, for this study the available data set were depth and distance from the port. Figure 1 shows that with these data layer it is possible to define a rather fine spatial scale model at the cost of coarsening the temporal scale.

To complete the data set used for this analysis, along with the GIS vector layer of the bathymetry, the GIS vector layer of the locations of the 10 fishing ports in the study area, the GIS vector layer with the limits of the fishing grounds pertaining to each port, and the total effort of each of the 10 ports expressed in gross tonnage were also available.

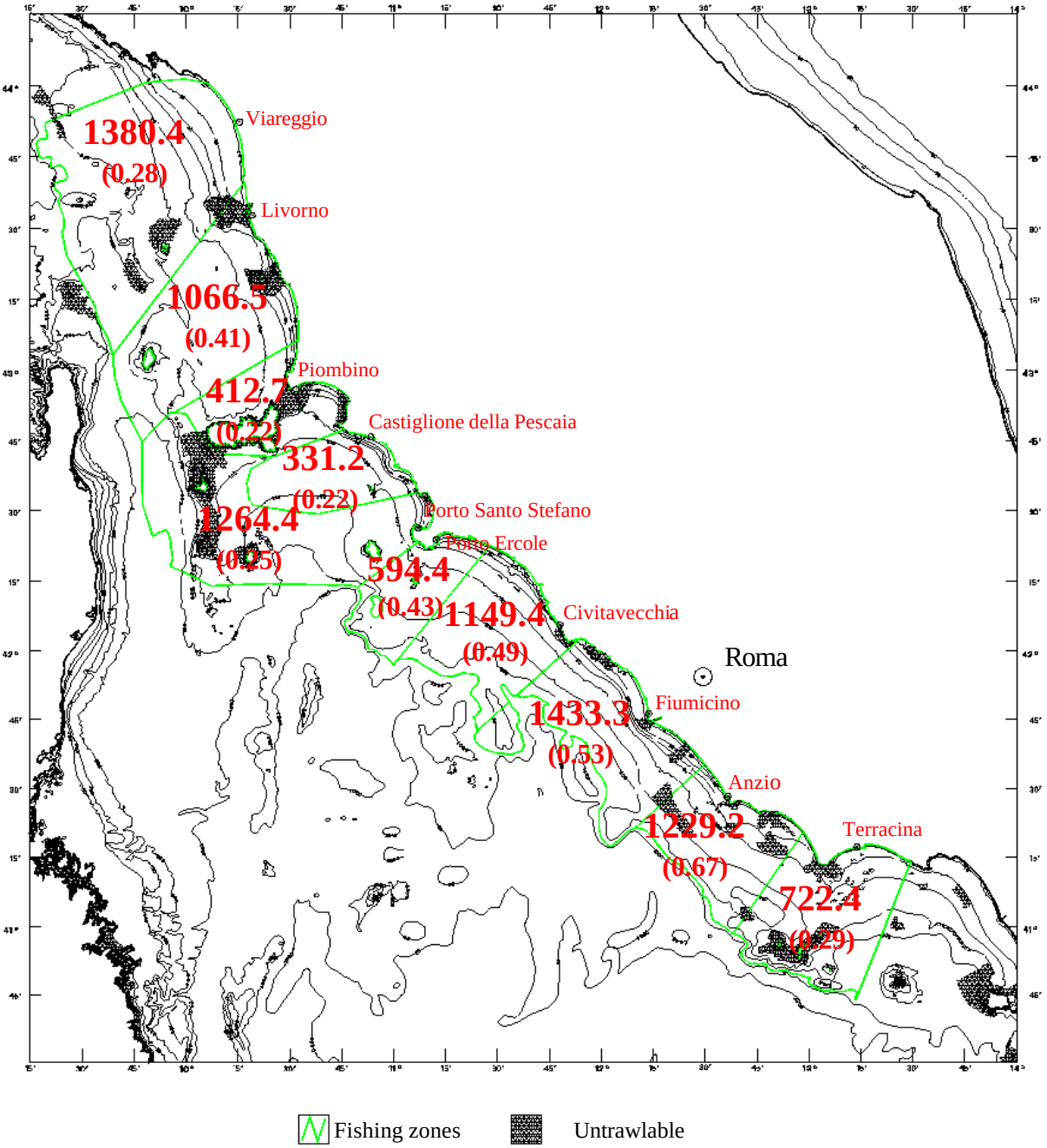
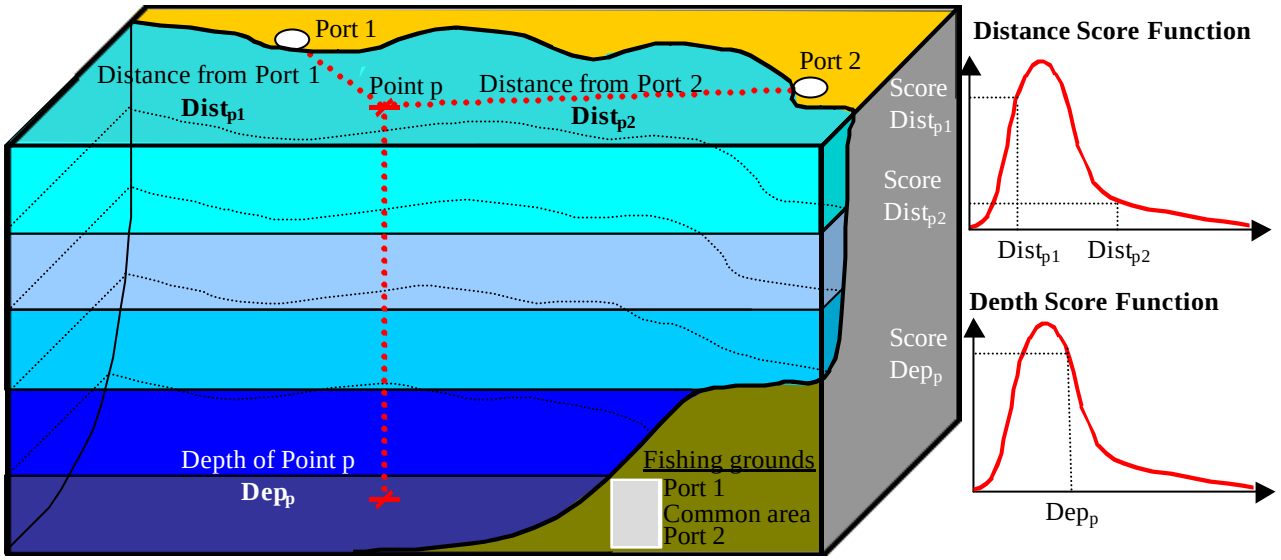


Figure 2 shows the study area, located in the North and Central Tyrrhenian Sea, with the location of the ten ports, the limits of the fishing grounds and the gross tonnage pertaining to each one. Gross tonnage per square kilometre is also shown in parenthesis

Based on the above data sets the deductive model was built according to the advise of a fishery expert with for the study area. The expert was asked to define to percentage use of space according to distance and depth, each one of the percentage use of space tables were then fitted with a continuous function which serves as a smoothing tool for the threshold defined by the expert. These function were then used to assign a score to each cell in the study area. The scores were finally used to weight partition the total effort of the fishing ports whose fishing area included the individual point. Figure 3 summarises the process of assigning a portion of the total effort to a point generic point p that falls within the fishing grounds of two distinct ports. To this extent, points fished by more than one fishing fleet sum up all effort contributions from each one of the different fleets.



$$effort_p = effortPort_1 * \frac{WDist * ScoreDist_{p1} + WDep * ScoreDep_p}{WDist * \sum_{i=1}^{N_1} ScoreDist_{1i} + WDep * \sum_{i=1}^{N_1} ScoreDep_i} + effortPort_2 * \frac{WDist * ScoreDist_{p2} + WDep * ScoreDep_p}{WDist * \sum_{i=1}^{N_1} ScoreDist_{12} + WDep * \sum_{i=1}^{N_1} ScoreDep_i} \quad [1]$$

Equation 1 is the formalisation of the process described in figure 3. To generalise the equation a weighting factor was introduced in the formula both for the distance (Wdist) and for the depth (Wdep) variable. For a correct application of the formula the weights must sum to 1.

For this specific application not having any evidence of a different contribution to fishing effort allocation of the two variables, each one was given a weight of 0.5.

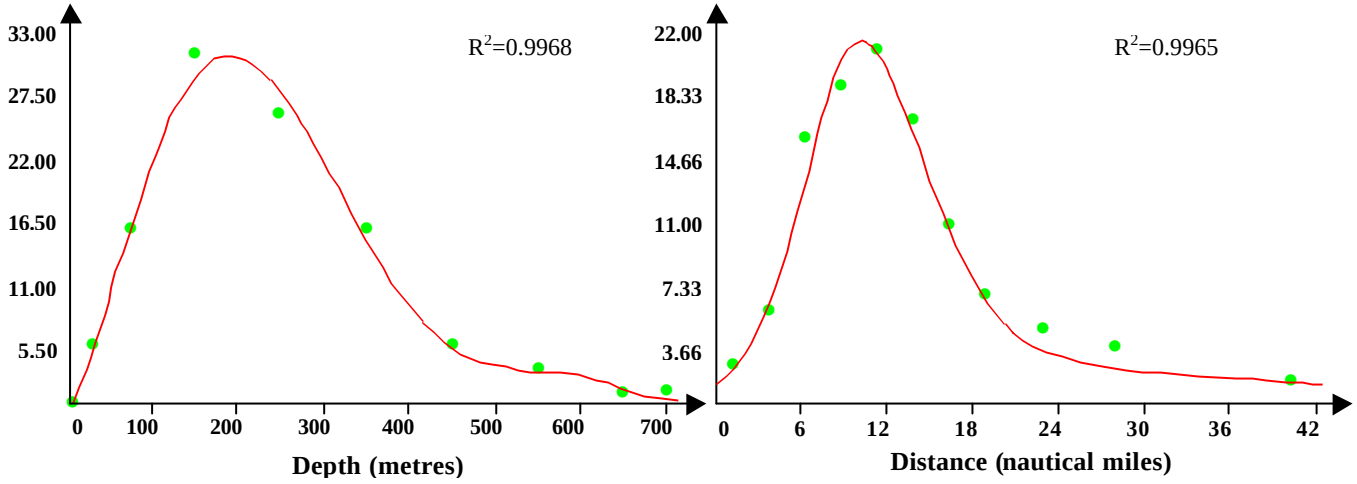
Results

The fishery expert identified the intervals shown in tab 1 and 2, respectively for distance from the port and depth. In the same table also the percentage use of space assigned by the expert to each class is shown. The tables reflect the fact that fishing effort is concentrated, averaging over a time span of at least a few years, at distances within a day cruise from the port (very seldom boats do not return in harbour at night), and at depths of about 200 metres (which is e few 10ths of metres less than the average length of the net cables used by the average fishing boat in the area).

Distance (nautical miles)	Use score
2.5	2
5	5
7.5	15
10	18
12.5	20
15	16
17.5	10
20	6
25	4
30	3
>30	1

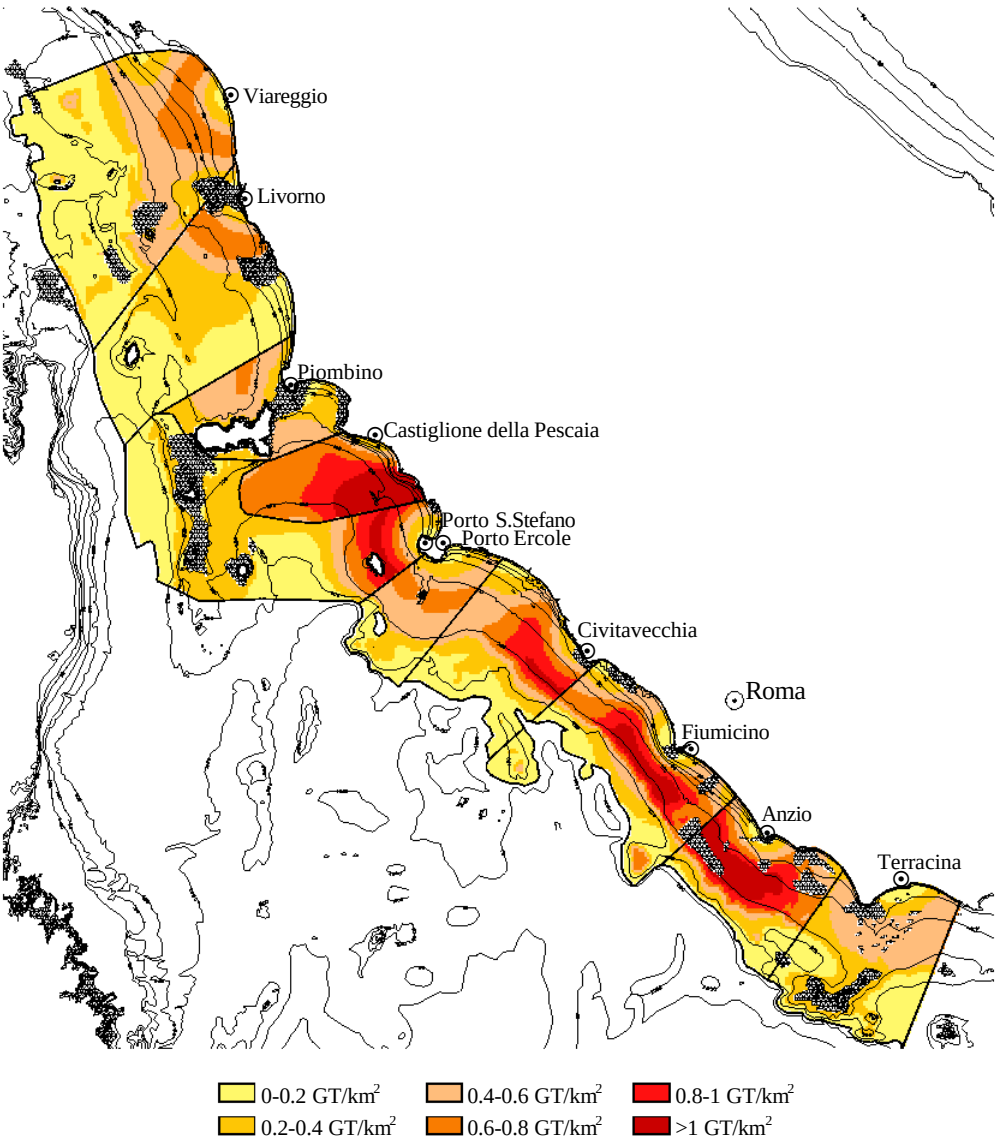
Depth (metres)	Use score
10	0
50	5
100	15
200	30
300	25
400	15
500	5
600	3
700	1
>700	1

The smoothing process produced the polynomial functions shown in fig 4. These functions were chosen from a set of different polynomial functions which were fitted to the original data of tables 1 and 2 based on their performance (maximum R^2). Thus their coefficient do not imply any specific parameter which can describe a functional relationship between either one of the variables and fishing effort allocation.



The functions were then used to assign to each 1x1 km cell in the study area a score to apply equation [1]. Finally, using equation [1], the total catch of each fishing port was spatially partitioned to produce the map shown in fig. 5.

Areas of higher fishing effort are shown on the map where two fishing fleet overlap (fishing grounds in front of Castiglione della Pescaia, which overlaps completely on the fishing ground of Porto S.Stefano) and in zones in which the exploitable surface is smaller due to a steeper continental slope (e.g. the fisheries of Fiumicino, Anzio and Civitavecchia which have fleets similar to those of Viareggio and Livorno but appear to be exploiting their grounds more intensively.
A few artefacts of the modelling procedure are evidenced by abrupt changes in fishing intensity especially in areas which show higher efforts (e.g. at the southern boarder between the fishing grounds of Castiglione delle Pescaia and Porto S.Stefano and at the northern one between



Fiumicino and Anzio). Another possible artefact can be seen in the area of Porto S.Stefano and Porto Ercole where the shape of the coast line projects outwards with the promontory of Argentario. Here the more irregular shape of the coast creates a less realistic distribution of the fishing effort with range bands excessively influenced by the distance parameter.

Discussion

Although simplistic to may extents, the approach described in this paper shows god accordance with the expected distribution of fishing effort in the study area. At least this is the result of a review of the final map which was carried out by an independent group of experts during the meeting "Assessment of demersal resources by direct methods in the Mediterranean and adjacent seas" which was held in Pisa on the 18-21 March 1998. The group of experts participating to the meeting found that the map could give an adequate representation of the effort distribution within the constraints of the assumptions that underlay the model.

Once more it is important here to underline the assumptions which underlay this model, as the assumptions also define its utilisation limits.

The spatial resolution of the model has been increased at the cost of reducing that of the temporal scale. The resulting spatial model should then be seen, in any given place of the study area, as the representation of the average fishing intensity over a broad time scale. According to the observed statistical trend of the fishing fleet gross tonnage and engine power, it seems reasonable to that this time scale should not be less than 3 years.

There are many possible enhancement that can be foreseen for this type of model, and which were not introduced here to maintain a simple presentation of the methodology.

For instance only one expert was asked to partition the use of space according to the available variables, whereas a pool of experts can be brought together, for instance in a facilitated meeting, to produce more accurate estimates of the percentage use of space. Similarly in the application presented in this paper a single table of scores of use of space was produced for each one of the variables. However there is no limit in the number of tables and segments that can be included in the model once they are identified by the experts. The segments can represent different behaviour of the fishing fleet which operates in a certain area based on, for instance, different traditions, different seasons, different average boat dimension etc. On the other hand different segments could represent different fishing gears thus allowing to investigate the total fishing effort which operates on a given fishing ground. Any possible blend of tables can by merged to produce a more realistic allocation of the fishing effort.

The point is that there is a great wealth of information that is sitting out there in the brain of fishermen and scientists. Having very limited tools to produce independent estimates of fishing effort distribution, it seams reasonable to try to formalise the available knowledge into a framework which enables to incorporate it in the management process.

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