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A sampling strategy and methodology for assessment and monitoring of Mediterranean small-scale fisheries*

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SUMMARY: In order to reach a quantitative assessment of the Mediterranean small-scale fisheries, one of the main problems is to evaluate in space and time the elementary fishing efforts and yields of every component and their corresponding variations. These elements are essential for the evaluation of global production and fishing effort, the monitoring of which is of paramount interest for the study of the fisheries and exploited resource dynamics. This paper presents a methodology based on the statistical principles of so-called "stratified random sampling" which we have developed in an attempt to solve this problem. The collection of data is achieved in the field by a team of investigators which operates within a space-time stratification of the study area. The sampling strategy is based on two types of questions aimed to provide independent data series on effort and landings for each space-time stratum. The processing of the samples allows us to evaluate average yields and effort and their variance per stratum. Total catches and effort values are finally extrapolated after an appropriate weighting of these results.

Key words: Sampling, statistical assessment, small-scale fisheries, Mediterranean.

RESUMEN: ESTRATEGIA DE MUESTREO Y METODOLOGÍA PARA LA EVALUACIÓN Y EL SEGUIMIENTO DE LAS PESQUERÍAS MEDITERRÁNEAS DE ARTES MENORES. — Para realizar una evaluación cuantitativa de las pesquerías mediterráneas de artes menores, uno de los mayores problemas es la estimación espacio-temporal de los esfuerzos de pesca y rendimientos de cada componente elemental de las pesquerías y de las variaciones correspondientes. Estos elementos son esenciales para la evaluación de las producciones y de los esfuerzos globales que presentan un interés primordial para el estudio de la dinámica de las pesquerías y de los recursos explotados. Este documento presenta una metodología que hemos construido basándonos en los principios estadísticos del muestreo al azar estratificado. La colección de datos es realizada en el campo por un equipo de muestreadores que trabajan en una estratificación del dominio de estudio en el espacio y en el tiempo. La estrategia incluye dos tipos de muestreos que producen series de datos independientes sobre los esfuerzos y los desembarcos para cada estrato. El tratamiento de los datos permite la evaluación de rendimientos y esfuerzos medios y de las varianzas correspondientes en cada estrato. Las capturas y los esfuerzos globales para la pesquería completa son finalmente extrapolados después de una ponderación adecuada de estos resultados.

Palabras clave: Muestreo, evaluación estadística, pesca de artes menores, Mediterráneo.

INTRODUCTION

Mediterranean small-scale fishing is a very variable activity. Catches are highly multispecific and fishing intensities and strategies show very rapid fluctuations in space and time. Important variations of the number of active fishermen by area — sometimes in very short periods of time — is also a characteristic of the fishery.

At the moment, the various official national fisheries statistical systems cannot take into account the high variability of all the components in this sector. However a general concern in the Mediterranean countries is to reach a scientific understanding within the framework of coastal area management projects. In this context, a current way of approach starts from the idea that knowledge of many quantitative para-

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meters can be obtained through adapted sampling strategies which will allow statistically significant assessments (CHARBONNIER and CADDY, 1986; DURAND *et al.*, 1990).

This paper presents a methodology based on the statistical principles of "stratified random sampling", which we have developed in an effort to resolve some questions of Mediterranean small-scale fisheries monitoring.

TYPOLOGY AND PROBLEMATIC

The fisheries concerned operate near the coast (generally within 3 miles), with fleets of numerous small boats (rarely longer than 10 meters). They usually do daily trips and employ several different kinds of gear simultaneously, according season and area, and their catches contain a great number of species, which also vary from one season to another.

The fleets are very widespread, and the fishing grounds cover more or less the entire inshore area between the coastline and 5 to 10 miles (or more in some local cases). These grounds are generally very small areas in which a species or a group of species is exploited by a local or regional group of fishermen, using the same fishing technique during a certain period of the year. These units overlap a great deal, and constitute a complex patchwork due to the multispecificity of the resources, to their distribution patterns and seasonalities, and to the flexibility of boats.

The seasonal activity ratios of the regional fleets are very variable. They are related to the ecology of the different species, to meteorological conditions, periods of tourism, etc. The landing places are scattered all along the coasts, and a great part of the catch does not enter the classical infrastructures of bulk marketing (auctions, fish markets).

To reach a quantitative assessment of this kind of fishery, one of the main problems is to evaluate in space and time the elementary fishing effort and yield of each component and their corresponding variations. These elements will then permit an evaluation of the global production and effort, of which knowledge and monitoring are of paramount interest for the study of the fisheries and exploited resource dynamics.

BUILDING A SAMPLING STRATEGY

As has been shown by SNEDECOR and COCHRAN (1957) and GULLAND (1966) a stratified approach to population sampling can lead to improved precision compared to simple probabilist sampling.

Considering the general characteristics of the small scale Mediterranean fisheries, we have built our sampling strategy around this basic concept.

Data collection in the field is achieved by a team of investigators who operate within a space-time stratification of the study area.

The stratification

The stratification criterion is not necessarily a quantitative variable, but can be qualitative (SCHERRER 1983). Spatial stratification of an area is often realized considering the geographical constraints and the relative importance of the ports existing in the area. Such elements will result from appropriate "frame surveys" (CADDY and BAZIGOS, 1985). As an example, for the French coast of Languedoc-Roussillon these considerations led us to define 15 spatial strata, each including a single port or a group of 2 or 3 smaller ones (Fig. 1). These strata were then grouped into 5 superstrata, and each of them assigned to an investigator.

The distances between ports, the travelling times necessary to visit them, and the money allocated to the field operations are the main elements that govern time stratification. In the Languedoc-Roussillon example, these elements allowed us to plan on a weekly basis, for each investigator, three different port samplings of five-hours duration. Otherwise, at least two independent samples are necessary to calculate a variance for a single parameter. Taking this into account, and the number of ports to visit, led us to share the time in three-week time strata.

Within each space-time stratum, it is necessary to observe as strictly as possible the rules of simple random sampling (FRONTIER, 1983): every boat, every kind of gear, must have an equal probability to be included in the sample. In practice this kind of data should not result from the survey of some particular boats, but should be as near as possible a sample randomly drawn foom the fleet.

The collection of basic data

The sampling strategy we hereby propose is based on two types of inquiries, aimed at the production of independent data series, which concern essentially effort and landings for each space-time stratum.

Fishing-effort

Within a given stratum, this parameter should be

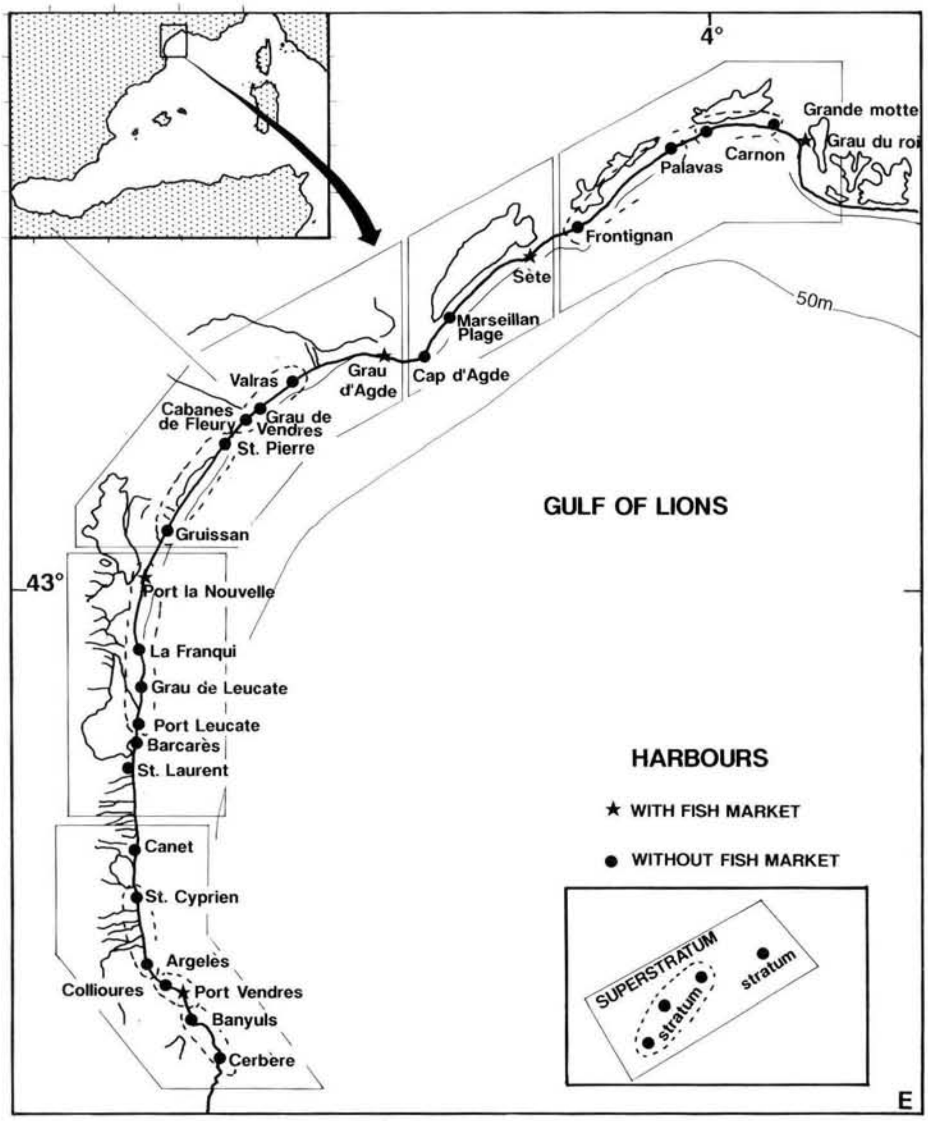

FIG. 1. — Geographic situation and stratification of the Gulf of Lions.

determined from the number of active boats and of fishing days for each kind of gear or group of gear used in the stratum.

A model form for the collection of this kind of data in the Mediterranean area should include the following items:

a) station code and sampling data,
b) identification number of the investigator,
c) start and end sampling times,
d) for each boat observed: registration number, full name, gears, crew, time departure and time return.

This "effort sampling form" will permit an observer standing on a given day on a strategic point (extremity of a wharf or port entry for example) to establish an exhaustive record of the boats leaving or coming back during this day. This is an essential data because it allows to define the ratio of active fishing units in the fleet.

The descriptors of the observed boats can be their registration number or their name (or both), and their crew number.

The fishing activity is described by the types of gear on board and the times of departure or return to the port.

Landings

Within the same space-time stratum, the landings should be sampled in weight and value by species, gear and boat. Notice that these samples will not necessarily be acquired the same day as fishing effort of the fleet is sampled. In practice these two operations are generally very difficult to realize simultaneously. The model form for landings sampling should include the same three first items (a, b, c) as the previous one, followed by several types of descriptors.

The descriptors of the fishing effort linked to the landing samples concern the types, quantities and fishing times of each gear, the crew numbers and the trip durations. The spatial distribution of effort is described by the location of the fishing grounds (when known).

The economic descriptors are the types of commercialization of the fish.

The catches are detailed by gear, species and eventually by commercial categories accompanied by the corresponding weights and prices (considered as rough primary economic descriptors).

Each of the two basic sampling forms presents several encoding fields, so that an appropriate computerization of the information will be possible before further processing.

The extrapolating term of reference

In order to extrapolate the total yields and effort from the above-mentioned samples, such a strategy should also include an exhaustive knowledge of the total number of boats existing in the whole area. This can be defined as the "potential fishing fleet", which is generally obviously different from the observed "active fishing fleet". Such information can be obtained by compiling administrative files or by a series of field counts. It will then give us a possibility to estimate the "weight" of each stratum, in order to permit a consistent updating of the total sample.

DATA PROCESSING METHODOLOGY

We will use the following abbreviations:

— Indices

- k = spatial superstratum
- i = spatial stratum (varying from 1 to M)
- j = time stratum (varying from 1 to P)
- h = a given day in a stratum (varying from 1 to L or l)
- q = an observation for a given day (varying from 1 to Q)

— Variables

- U = catch per unit effort
- E = fishing effort
- C = catch
- N = potential effort (boats)
- n = number of boats sampled
- L = total number of days of a given stratum
- l = number of days sampled in a given strata
- X = total n.° of fishing days in a given strata ($0 > X < L$)
- M = total number of spatial strata
- P = total number of time strata
- Q = total number of observation within a given day

— Symbols

- $\bar{}$ = true average
- $\hat{}$ = estimator

We have constructed the following formulae using the general statistical concepts and definitions presented by SNEDECOR and COCHRAN (1957).

Evaluation of fishing effort

The unit of effort

The data on fishing effort collected in the field allow the use of the very precise unit of the boat/day/man. However we think the most suitable unit to use generally in this kind of approach is boat/day. So the value of the daily effort will be the number of active boats that day. This is the basic elementary piece of information contained in our field effort sampling file, and we have chosen it for subsequent theoretical developments.

Variance of effort

The best estimate of this parameter will result from the relation between the average effort and the corresponding variance, which can be obtained by establishing their regression parameters from all strata in which at least two activity samples exist.

Depending on the result of this regression, it will be possible to apply a uniform variability to all the strata, or to apply to them the same variation coefficient, or to estimate individual stratum variations using the equation of the average/variance relationship.

Knowing the potential number of active boats within a stratum, two different situations can be met:

If the data base contains several activity samples by stratum (i,j), the average effort in a space-time stratum will be:

$$\bar{E}_{ij\cdot} = \sum_{h=1}^{L} \frac{E_{ijh}}{L} \quad (1)$$

Which can be estimated by:

$$\hat{\bar{E}}_{ij\cdot} = \sum_{h=1}^{l} \frac{E_{ijh}}{l} \tag{2}$$

and the associated variance of this average effort will be:

$$Var\,(\bar{E}_{ij\cdot}) = \left(1-\frac{l}{L}\right) \frac{\sum_{h=1}^{L} (E_{ijh}-\bar{E}_{ij\cdot})^2}{l(L-1)} \tag{3}$$

whose corresponding estimate is:

$$\widehat{Var}\,(\hat{\bar{E}}_{ij\cdot}) = \left(1-\frac{l}{L}\right) \frac{\sum_{h=1}^{l} (E_{ijh}-\hat{\bar{E}}_{ij\cdot})^2}{l(l-1)} \tag{4}$$

with $L > l > 1$ and in which $(1\text{-}l/L)$ is the value of the correction factor for finite populations.

This factor is null (and no correction has to be done) if $l = L$ (i.e. if the stratum has been sampled every day).

On the other hand, to make this calculation, at least one day has to be sampled in the stratum; if not, the value of $1 - 0/L$ cannot be calculated.

So, the correction factor is always positive, and the smaller its value, the greater the number of days sampled in the stratum (and vice-versa).

However, if the data base contains only a single activity sample by stratum, no variance can be calculated and the above method cannot be applied. In that case a solution should be sought by grouping several strata in time, in space, or in both space and time as follows:

Space-and-time grouping consists in adding the strata in space and the super-strata in time. As the effective and potential effort vary from strata to strata we will now have recourse, following COCHRAN (1977), to an "average activity ratio" calculated for two adjacent time strata belonging to the same superstratum k. This average ratio will be used to estimate the average daily effort in each stratum.

We think that this concept of average activity ratio is very important because it will allow us to avoid overemphasizing the largest ports in the sampling.

The ratio estimator resulting from this kind of approach is:

$$\hat{R} = \frac{\sum_{i=1}^{M} \sum_{j=1}^{P} E_{kij}}{\sum_{i=1}^{M} \sum_{j=1}^{P} N_{kij}} \tag{5}$$

and its variance will be:

$$Var\,(\hat{R}) = \left(1-\frac{l}{L}\right) \frac{\sum_{i=1}^{M} \sum_{j=1}^{P} (E_{kij}-\hat{R}\,N_{kij})^2}{2M\,\bar{N}\,k^2\,(2M-1)} \tag{6}$$

At that time, for a given stratum, a value of the average daily fishing effort will be expressed by:

$$\hat{\bar{E}}_{kij} = \hat{R}\,N_{kij} \tag{7}$$

for which we have the following variance estimator:

$$Var\,(\hat{\bar{E}}_{kij}) = N_{kij}^2\, Var(\hat{R}) \tag{8}$$

Two adjacent strata can also be simply grouped in time. Estimations of the effort and its variations will then be obtained using formulae num. (2) and (4).

It must be kept in mind that in the space-and-time procedure, the use of a ratio estimator leads to a biased estimate, while it is unbiased in the case of the simple-time grouping situation.

According to the case, the variance of the average daily estimate of fishing effort calculated for a superstratum k during a given period of time will therefore be:

$$\sum_{i=1}^{M} \sum_{j=1}^{P} \frac{N_{kij}^2\, Var\,(\hat{R})}{4M^2} \tag{9}$$

$$\sum_{i=1}^{M} \frac{Var\,(\hat{\bar{E}}_{ki\cdot})}{M^2} \tag{10}$$

with

$$\hat{\bar{E}}_{ki\cdot} = \sum_{h=1}^{l} \frac{E_{kih}}{l} \tag{11}$$

and

$$Var\,(\hat{\bar{E}}_{ki\cdot}) = \left(1-\frac{l}{L}\right) \sum_{h=1}^{l} \frac{(E_{kih}-\hat{\bar{E}}_{ki\cdot})^2}{l(L-1)} \tag{12}$$

The smallest of these (9) and (10) will indicate the method which gives the best accuracy, while their ratio will indicate the relative efficiency of each of the two cases.

It should be noted that each one of the two results can be obtained for the same price. In the field of fishing effort sampling strategies, the best approach will therefore be the method which gives the least variance.

Evaluation of yields

A simple way to obtain an evaluation of the yields is to calculate the average daily yield for a stratum, which is a simple average of catches per unit of effort (CPUE). This procedure is different from the value that would be obtained from a simultaneous sampling of effort and catches, which will lead to an evaluation of individual effort-weighted CPUE, a more classical approach in population dynamics.

Concerning this point, we recall that we have adopted independent samplings of catches and effort to give greater flexibility to the field operations. However, this choice prohibits the use of the classic "sub-sampling" technique, which requires a pairing of observations on effort and yield.

So, for a given period, yield is calculated as the average of the averages of the daily yields during the period. It has to be kept in mind that generally the estimated yields coming out from inquiries on a fishery cannot be considered as pertaining to a finite population. In other words the value that can be obtained for a given stratum is always an estimator of a real value which is out of reach.

At this stage, one may think of using an average weighted by the number of observations during a sampling day. But this method assumes implicitly a theoretical yield which is invariant in a given space-and-time stratum. Such a hypothesis hardly seems plausible in the case of fishing, since it is well-known that yields fluctuate with effort.

This is why we suggest the use of non-weighted averages, except in some specific cases. Applying this principle we can then establish the following formulae (valid for a single stratum or for the whole area studied):

Non-weighted estimation

Yield:

$$\bar{U}_{ij} = \frac{\sum_{h=1}^{l_{ij}} \bar{U}_{ijh}}{l_{ij}} \quad \text{with } \bar{U}_{ijh} = \frac{\sum_{q=1}^{n_{ijh}} U_{ijhq}}{n_{ijh}} \tag{13}$$

Variance of the yield:

$$\widehat{Var}\,(\bar{U}_{ij} = \frac{\sum_{h=1}^{l_{ij}} (\bar{U}_{ijh} - \bar{U}_{ij})^2}{l_{ij}(l_{ij}-1)} \tag{14}$$

Weighted estimation

Yield:

$$\bar{U}_{ij} = \frac{\sum_{h=1}^{l_{ij}} n_{ijh}\, \bar{U}_{ijh}}{\sum_{h=1}^{l_{ij}} n_{ijh}} \tag{15}$$

Variance of the yield:

$$\widehat{Var}\,(U_{ij} = \frac{\sum_{h=1}^{l_{ij}} n_{ijh}\,(\bar{U}_{ijh} - \bar{U}_{ij})^2}{(l_{ij}-1)\sum_{h=1}^{l_{ij}} n_{ijh}} \tag{16}$$

Evaluation of Catch

Starting from the average daily effort and yield, the daily average catch for each stratum and its associated variance can easily be calculated using formulae (1) and (2).

As for all sampling strategies based on the stratification of the field of study, the average daily catch for the whole area will be the sum of the variances of the corresponding estimates, weighted by $(1 - l_{ij}/L_{ij})$, a correcting term for a finite population bearing the variance of the effort.

TOTAL CATCH AND EFFORT ESTIMATES

An estimate of the daily average catch by stratum ($\hat{\bar{C}}kij$) can be obtained simply by calculating the product of the average daily yield ($\bar{U}kij$) by the average daily estimated fishing effort ($\hat{\bar{E}}_{kij}$):

$$\hat{\bar{C}}_{kij} = \bar{U}_{kij}\,\hat{\bar{E}}_{kij} \tag{17}$$

in which

$$\bar{U}_{kij} = \frac{\sum_{h=1}^{l_{kij}} \bar{U}_{kijh}}{l_{kij}} \tag{18}$$

with

$$\bar{U}_{kijh} = \frac{\sum_{q=1}^{n_{kijh}} U_{kijhq}}{l_{kijh}} \tag{19}$$

The average total catch by superstratum can then be obtained by multiplying the estimated average daily catch by the corresponding total number of fishing days (i.e. $C_{kij} \cdot X_{kij}$).

The value of X_{kij} is found by direct counting or by using the calendar of meteorological characteristics within the analyzed stratum (X = number of days when sea conditions permit the boats to go fishing).

We recall that the previous formula results from a strategy which enables us to ensure the independence of the observations on the two series of variables. So the variance of the average daily catch will be estimated by:

$$\widehat{Var}\,(\bar{C}_{kij}) = \widehat{Var}\,(\bar{U}_{kij})\,\widehat{Var}\,(\bar{E}_{kij}) + \\ + \widehat{Var}\,(\bar{U}_{kij})\,(\bar{E}^2_{kij}) + \widehat{Var}\,(\bar{E}_{kij})\,\bar{U}^2_{kij} \qquad (20)$$

Nevertheless, this kind of strategy is manpower consuming, and it is quite obvious that the human and financial resources necessary to achieve large scale random sampling plans routinely is not always available. However the cost of the information can be reduced by setting up more limited plans, including just the sampling of a few major species and fleets at a limited number of sites (CHARBONNIER and CADDY, 1986). Another cheaper approach to monitor small-scale fisheries evolution involves multiannual application of the sampling strategy (DURAND *et al.*, 1990). This procedure allows periodic updating of the essential parameters and checking of the chronological consistency — or variability — of the fisheries. In both cases it is possible to optimize the relation between price and precision of information, since our method is an estimator of efforts and catches evaluations and their associated variances, for a known total cost.

DISCUSSION

From a progressive adjustment after several years of field application, we think the methodology presented here can be applied to the majority of small-scale Mediterranean fisheries.

This methodology was used for the first time on the Languedoc-Roussillon coast (FARRUGIO and LE CORRE, 1984). It was extended until 1990 to several others French Mediterranean coastal areas and lagoons, in which are several artisanal fleets interact (FARRUGIO and LE CORRE, 1991). After some minor adjustments, it has also been tested in Morocco (LAHNIN *et al.*, 1991) and more recently in Tunisia (Zoghlami, pers.comm.). These applications show that it is possible to obtain a regular flow of precise information about small scale fisheries activities in these areas. We consider that this kind of approach offers two main advantages.

On the one hand, most of the required data can be collected directly in the field by the samplers, whithout any trouble for the fishermen (filling forms, answering questions...), which is a cause of failure of many inquiry based studies.

On the other hand, the handling of the information does not require sophisticated computer hardware. Sample files are easy to complie by means of standard commercial data-base softwares suitable for personal computers. BASIC programmes to process such files using formulas 3 to 14 as algorithms already exist (FARRUGIO and LE CORRE, 1984-1985), but the data can also be processed by means of standard statistical packages.

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