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Technical measures without enforcement tools: is there any sense? A methodological approach for the estimation of passive net length in small scale fisheries

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Abstract

Passive nets are currently among the most important fishing gears largely used along the Mediterranean coasts by the small scale fisheries sector. The fishing effort exerted by this sector is strongly correlated with net dimensions. Therefore, the use of passive nets is worldwide managed by defining net length and net drop. The EC Reg. 1967/2006 reports that the length of bottom-set and drifting nets may be also defined considering their weight or volume; however, no practical suggestions for fisheries inspectors are yet available. Consequently, even if such technical measures are reasonable from a theoretical viewpoint, they are hardly suitable as a management tool, due to the difficulties in harbour control. The overall objective of this paper is to provide a quick methodological approach for the gross estimation of passive net length (by net type) on the basis of net volume. The final goal is to support fisheries managers with suitable advice for enforcement and control purposes. The results obtained are important for the management of the fishing effort exerted by small scale fisheries. The methodology developed in this study should be considered as a first attempt to tackle the tangled problem of net length estimation that can be easily applied in other fisheries and areas in order to improve the precision of the models developed herein.

Keywords: Net length estimation, passive nets, fisheries control, management measures, Mediterranean.

Introduction

Small-scale fishery (SSF) represents an important share of the fisheries sector in the European seas, and its considerable role has long been recognized (Guyader *et al*., 2013). Particularly in the Mediterranean basin, SSF is a major economic fishing activity in numbers of people employed, revenues and food supply (Farrugio *et al*., 1993; Sacchi, 2011; Lucchetti *et al*., 2014). Passive nets (gillnets, trammel nets, combined nets and small driftnets) are among the most important fishing gears largely used by SSF for the catch of a high variety of demersal, benthic and pelagic species. The fishing effort exerted by passive nets is strongly correlated with the length and the drop of nets, which are the most important technical measures currently used for the management of this fishery (GFCM, 2009). In this regard, the EC Regulation No. 1967/2006 concerning the management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, has defined the characteristics of bottom-set nets as follows:

- maximum drop: trammel net shall not exceed 4 m; bottom-set gillnet shall not exceed 10 m; combined bottom-set net shall not exceed 10 m
- maximum length of trammel net and bottom-set gillnet: 6000 m per vessel (4000 metres in case of a single fisherman, 5000 m for a second fisherman and another 1000 metres for a third one); maximum length of a combined bottom-set net shall not exceed 2500 m per vessel. By way of derogation, a bottom-set gillnet and a combined bottom-set net of maximum length of 500 m may have a maximum drop of 30 m.

Since 1 June 1992, the Council Regulation (EC) n° 345/92 (and subsequent regulations) has prohibited the use of driftnets longer than 2500 m (the European Commission has recently proposed a regulation that will prohibit fishing with driftnets in EU waters; EC, 2014).

Therefore, the control of fishing capacity in terms of net length and net drop is essential in order to guarantee the responsible exploitation of natural resources. The FAO Code of Conduct for Responsible Fisheries (1995) highlights that "*States should establish [...] effective mechanisms for fisheries monitoring, surveillance, control and enforcement to ensure compliance with their conservation and management measures [...]*". Unfortunately, although the previously described technical measures are reasonable from a theoretical viewpoint, their enforcement, and therefore efficacy, are not easy to verify. Thus, it is unfeasible for fisheries inspectors to have at least a rough estimate of net length during a field check, taking into account that the procedure for measuring in detail the net length usually requires several hours. The situation is even more complicated when passive nets are amassed or stowed on a fishing vessel's deck, on the dock of a port or placed in basket(s) or net container(s), a frequent practice in the Mediterranean. Therefore, the estimation of the passive net length by using the net volume could be the basis for effective fisheries controls; this is in accordance with the EC Reg. 1967/2006 which establishes that "*the length of bottom-set and drifting nets may be also defined based on its weight or volume*". However, no practical suggestions for fisheries inspectors are available at this time. What is the sense of setting technical measures without enforcement tools? This is a crucial problem that poses a threat to the effectiveness of the majority of management measures. The enforcement of net length provisions, as well as the monitoring and control of other measures - for instance, closed areas (such as Marine Protected Areas), individual catch quotas etc. - can be efficient only by fielding great effort in terms of human resources and tools (e.g. aircraft and patrol vessels). However, cost-effectiveness is a consideration that a manager should take into account when new management measures are established (Flewwelling *et al*., 2002; Raakjær Nielsen and Mathiesen, 2003). The lack of effective enforcement tools and activities will diminish the benefits of technical measures, especially in areas where illegal fishing practices are common and perceived as a normal activity and where usual education and conciliatory approaches are not effective.

Concerning passive nets, several different technical parameters affect net volume (float dimensions, twine and rope material and diameter, etc.). However, it is not practical for inspection purposes to measure all these parameters. Therefore, this paper develops a methodological approach and four models for the estimation of the bottom-set nets (trammel, gillnets, combined bottom-set nets) and small-sized driftnets length on the basis of net volume, trying to design the most simple and straightforward approach to be applied in actual situations (gear inspections).

Materials and Methods

Data collection

The definition of reliable statistical models for the estimation of net length on the basis of net volume primarily implies the field measurement of all parameters that directly influence the volume of a net. To this goal, several different technical parameters of the passive nets that can affect the net volume were collected: net type, net drop, net length, vertical and horizontal hanging ratio, mesh length and mesh opening (of both internal and external panel in the case of trammel net), twine thickness, float dimensions, distance between floats, headrope and footrope diameter.

According to a standardized protocol (Lucchetti, 2012), data were collected by scientific operators through direct measurements on the nets, at landing points, directly on board of the vessels or in the warehouses, factories, depending on where the net to be measured was stored.

The EC Reg. 1967/2006 defines the net length as the length of the float line, while the drop as the sum of the height of the meshes (including knots) when wet and stretched perpendicular to the float line. The net length was defined by measuring the length of the float line with a tape measure, in compliance with the EC Reg. 1967/2006. The fully extended net drop (fictitious drop) was calculated by multiplying the mesh length for the number of meshes counted in a line from the floatline to the leadline. In the case of trammel net, the fully extended net drop corresponded to the height of the inner panels. The mesh opening was measured in compliance with the EC Reg. 517/2008 by applying a pre-selected force of 10 N to the electronic mesh gauge. The mesh length was taken by measuring, with a ruler, the total length of ten consecutive meshes (including the knots) and dividing this measure by ten.

The measurement of net volume raised some difficulties since passive nets can be stored in different ways. Two possible scenarios were considered for the net volume estimation, that is:

- nets placed in a container having well defined shape and dimensions;
- nets amassed or stowed on a fishing vessel's deck or on the dock of a port.

In the first case, the net volume was easily estimated by calculating the net stuffing percentage as described in Figure 1 ($(h-h_1)/h$). The net was first re-arranged by hand in order to avoid empty spaces in the basket. Then, the net stuffing percentage was measured by putting a lid over the net in the container and by measuring the distance between the lid and the upper edge of the basket. A 10 kg weight was used to provide a standard pressure in order to standardize the procedure. To obtain better results, the weight was uniformly distributed over the lid surface (Fig. 1) and the water contained in the netting was allowed to drain completely from the net container.

- In the case of nets amassed on the vessel or dock, two options were adopted for the net volume estimation:
- the net was re-arranged by hand on a known geometric shape (cylinder, dome, parallelepiped, etc.) owing to which the main dimensions could be easily measured.
- the net was placed in a container marked with

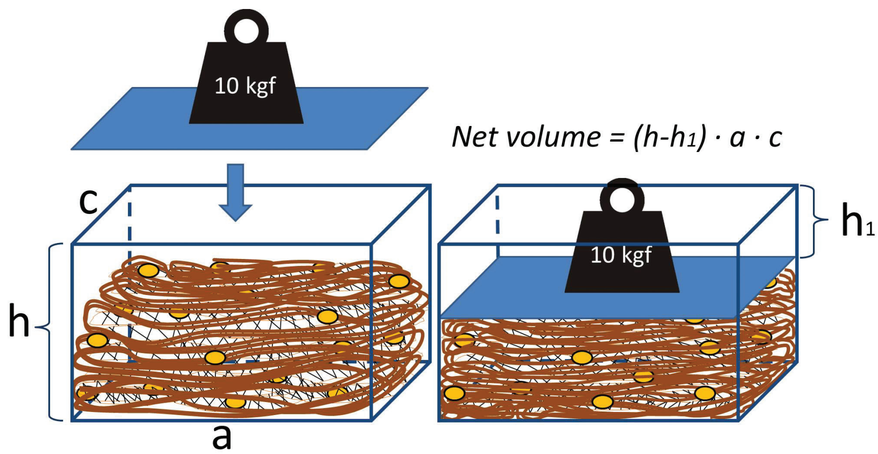

Fig. 1: Methodology applied for the computation of net stuffing percentage and net volume.

incremental volume readings (Fig. 2). This technique enables a quick and easy estimation of its volume by using the scaled readings.

Model applied

Passive nets were classified according to four categories: trammel nets, gillnets, combined bottom-set nets and driftnets. Such classification (equivalent to a statistical stratification) was in line with gear standards and at the same time provided a more meaningful data categorization from a statistical viewpoint.

From a theoretical viewpoint, the shape of a netting panel is determined by the process of hanging it on the rope frame (Friedman, 1986). By varying the vertical and horizontal hanging ratio, different shapes are obtained. The primary hanging ratio is defined as $E_1 = L/L_0$, where L is the hanging length of the netting or the mounted length of the main mounting rope and L_0 is the length of the same netting when fully extended. Likewise the secondary hanging ratio is defined as $E_2 = H/H_0$, where H is the hanging height of the netting and H_o is the fully extended height of netting. For a flat panel of netting, the relationship between the two hanging ratios is $E_1^2 + E_2^2 = 1$.

If M is the number of meshes along the length of a panel of netting, N is the number of meshes along its height, m_l is the extended mesh length (between the centers of opposite knots in the same mesh), the extended length and extended height of panel are calculated as $L_0 = m_l \cdot M$ and $H_0 = m_l \cdot N$

Considering the fictitious area $A_f = L_0 \cdot H_0$ and w the weight per square meter of fictitious area, the weight of the netting panel (P) is given by:

$$P=w\times L_0\times H_0=w\times\frac{L\times H}{E_1\times E_2} \quad (1)$$

Equation (1) can be re-written as:

$$L=\frac{P\;E_1\times E_2}{w\quad H} \quad (2)$$

Formula (2) can also be used to describe the relationship between volume V and length L by simply replacing weight P by ($V \times p$), where V is the volume of the net and p the weight per unit volume. Considering also that $H = E_2\times H_0$, formula (2) can be re-written as:

$L=p\times C_1\times C_2$ (3)

Where

$$C_1=\frac{E_1}{w} \qquad C_2=\frac{V}{H_0}$$

p is a parameter value that depends on the type of net category.

Formula (3) is the starting point for the statistical investigation of data collected.

Statistical approach

With the theoretical relationship firmly established by the alternative models expressed by formulae (1), (2) and (3), the study turned its attention to practical aspects concerning length estimation. From the operational viewpoint it should be rather evident that the simplified linear model (3), in which several predictor variables are combined into one, offers several advantages such as robustness, transparency in calculations and standard and widely understood statistical diagnostics. This model can be immediately recognized as a Simple Linear Regression case (SLR): $y=b\cdot x+\varepsilon$ (4)

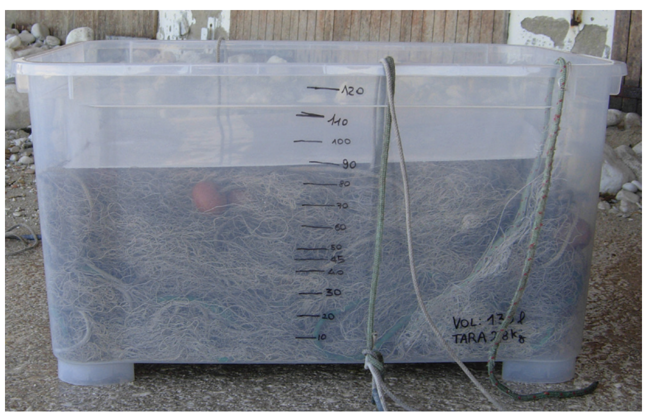

Fig. 2: Graduated container used for the evaluation of the net volume.

where:

y denotes the response variable (estimated net length);

x denotes the predictor variable (combined variables of models 1 and 2);

b is the regression coefficient;

ε represents measurement error as well as any variation unexplained by linear model (4).

To minimize ε and achieve an optimal goodness of fit, the Least Squares algorithm was adopted throughout the study, the goodness of fit being measured by the Coefficient of Determination R^2.

A major concern was the possibility of two or more datasets (each correctly describing length-volume relationships of different nets) being mixed together and thus resulting unacceptable indicators of goodness of fit for the combined data. In other words, prior to applying SLR to a dataset, it was essential to ensure that the latter was not relating to different gears that should have been stratified.

With this aspect in mind, a special routine was developed based on Microsoft EXCEL™ (outliers.xlsm). For each type of net the outliers.xlsm routine was applied to the original dataset with the purpose of identifying possible "outliers" in the samples, the removal of which could further improve correlation (R^2 and coefficient b). Here the term "outliers" refers not only to statistical noise but eventually also to points that can themselves describe linearly "hidden" length-volume relationships pertaining to different gears.

The outliers.xlsm routine was prepared specifically to support the SLR approach by means of a practical and easy-to-use tool for the identification of outliers. The specific objective of the process is to split an original SLR set into two datasets in such a manner that the compound coefficient of determination will be optimal. Each run of the routine consists of the following computational steps:

1. Running an SLR for the original dataset and computing the respective coefficient (b) and R^2. It is assumed that the original dataset contains n pairs (Li , Xi), i = 1,2,…,N.
2. Outlier pairs (*Lk*, *Xk*) are successively taken off the original dataset 1 and added to a new dataset 2 on a trial basis. The criterion for a point to be taken out is that with its removal the compound coefficient of determination is optimized. This compound expression is computed involving the coefficients of determination R_1 and R_2 resulting from the same linear regression when applied to datasets 1 and 2 respectively. This is described by:

$$\frac{mR_1^2 + nR_2^2}{m+n} - R^2 = MAX \quad (5)$$

Where m and n are the number of data points in data set 1 and 2, respectively.

3. The iteration process ends when there is no pair (*Lk*, *Xk*) satisfying equation (5).

The results of the program are provided in two worksheets named Group 1 and Group 2. Unless there is a clear linear pattern among the successively excluded points, the second group contains outliers with very low R^2.

It should also be noted that the above process can be repeated by the simple means of copying Group 1 onto the original dataset and re-running the routine. In this manner the progressive improvement of the R^2 and the number of points in the SLR dataset are fully controlled by the user.

Results

Detailed technical data from 175 individual nets belonging to the 4 types were collected from 41 Mediterranean mooring places, representing 11 different FAO-GFCM Geographical Sub Areas (GSAs) and 5 countries (Spain, France, Italy, Albania, Greece; Fig. 3). On the basis of the data collected, the models were developed according to each passive net type (trammel, gillnet, combined bottom-set net, and small size driftnet).

Starting from the formula (3), for investigating the dependence referred to any statistical relationship between

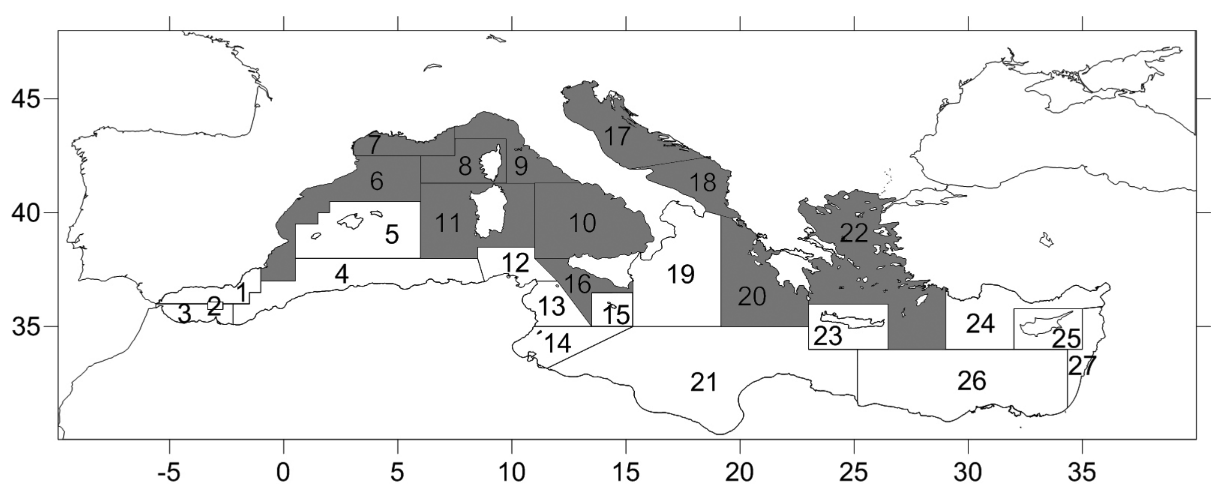

Fig. 3: FAO GFCM Geographical Sub Areas (GSAs) investigated during the study.

Table 1. Summary of regression coefficient (*b*) and ANOVA results. Mean, Lower and upper limits of confidence reported; s.e.: standard error; dof: degrees of freedom.

	Regression Coefficient (*b*)				ANOVA			
	Mean	Lower 95%	Upper 95%	s.e.	R^2	F statistic	dof	Significance
Gillnet	7010	6506	7514	95.5	0.967	811.999	29	1.10022E-21
Trammel net	5788	5520	6056	63.2	0.976	1888.142	48	5.33831E-39
Driftnet	17258	15856	18660	163.2	0.989	775.623	10	2.98243E-09
Combined net	9286	8360	10212	77.3	0.985	534.277	9	7.19453E-08

C_1, C_2, and L, the correlation matrix is shown:

	C_1	C_2	L
C_1	1		
C_2	-0.101	1	
L	-0.075	0.886	1

C2 emerged as the best suitable parameter for the final simple linear regression model for each type of nets:

$$L = b \cdot C_2$$

where:

L denotes the response variable;

C_2 denotes the predictor variable;

b is the regression coefficient;

Gillnets

A total of 45 measurements were carried out.

In Figure 4 and Table 1, the gillnet linear regression model and lower limit of confidence (95%) are illustrated. The best model ($R^2 = 0.967$) explaining the relation between the net length (L) and the coefficient C_2 produced a slope coefficient (b) equal to 7010. Therefore, the model for the estimation of the net length on the basis of the net volume and net drop is:

$L = 7010\ (V/H_0)$ (6)

Where: $L\ [m]$ net length

$V\ [m^3]$ net volume

$H_0\ [m]$ net height (number of mesh per mesh opening)

A major consideration was the risk of obtaining type I error (false positives) regarding predicted net lengths, i.e. over-estimated lengths, while in actual terms the inspected net is within the regulation limits. To reduce such risk, the least probable regression coefficient was utilized, using the lower confidence limit (*b*-) computed by the SLR, instead of the most probable one (that shown in the SLR results as b).

Thus, the model to be used is:

$L = 6506\ (V/H_0)$ (7)

The equation (7) should be considered as an intended under-estimation of the net length in order to reduce the risk of type I error (false positives), flashing out a regular net due to statistical errors.

The value of 6506 was truncated to 6500 for simplicity. This simplified model is proposed as precautionary for estimating net length. The same model was applied both to gillnets and small driftnets, since these two types of nets have similar technical characteristics.

Trammel nets

A total of 81 different trammel nets were measured. Regression parameters and ANOVA results are summarized in Table 1. The best formula for estimating the net length based on the best regression model ($R^2 = 0.976$) was:

$L = 5788\ (V/H_0)$ (8)

For control and inspection purposes, a more conservative approach was chosen (refer to the cautious approach described earlier), therefore the lower limit of the *b* coefficient of the trammel net model (8) was selected (Fig. 4):

$L = 5520\ (V/H_0)$ (9)

The truncated value of *b* at 5500 is proposed as a conservative conversion factor for estimating the net length on the basis of net drop and net volume, although a *b* value close to 6000 could produce a better estimation in most cases.

Driftnets

Most of the measured nets were represented by currently illegal driftnets (according to the provisions of EC Reg. 1239/1998) confiscated by Italian fishery inspectors. The nets measured were highly heterogeneous, therefore these results should be considered with care. The exploratory investigation with outliers.xlsm program enabled to identify outliers which, when removed from the original dataset, produced an improvement to R^2 and a significantly different coefficient *b*.

The best model ($R^2 = 0.989$) for the estimation of the net length on the basis of net drop and net volume was (Fig. 4):

$L = 17258\ (V/H_0)$ (10)

Considering the lower limit of confidence, the *b* value in equation (10) was set to 15856 and the final model became:

$L = 15856\ (V/H_0)$ (11)

Therefore, for a more conservative approach, the net length can be estimated by multiplying the ratio V/H_0 with 15856. However, in most cases, a *b* value equal to 17258 provides a more reliable net length estimation.

Combined nets

This type of net is not very common among the fisheries investigated, therefore only a reduced number of

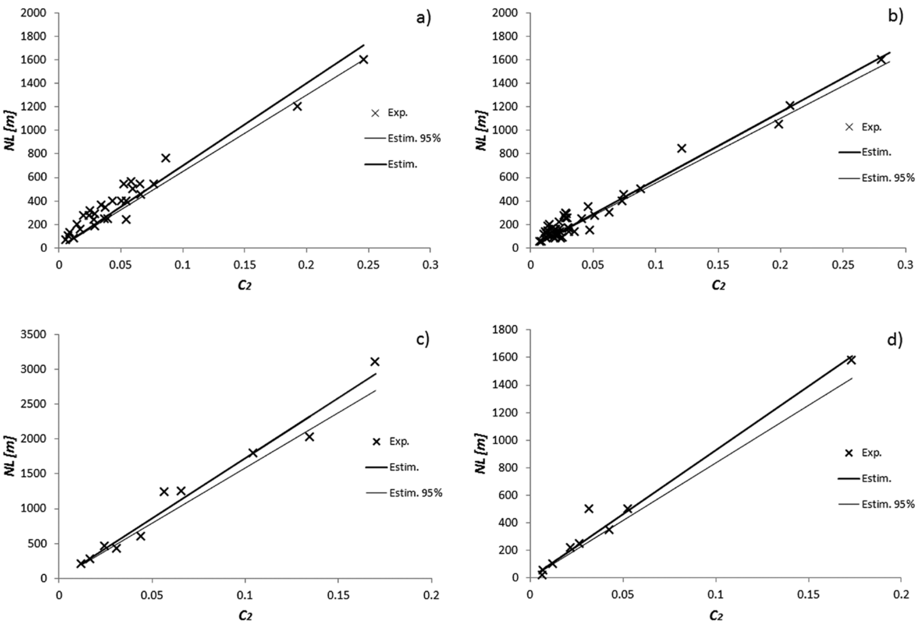

Fig. 4: Linear regression model and lower limit of confidence (95%) of the investigated net types. a) Gillnets; b) Trammel nets; c) Driftnets; d) Combined nets; NL: Net length; Exp.: experimental data; Estim.: estimated model; Estim. 95%: lower confidence limit of the model (95%).

nets was available for the purposes of this study. The best model (R^2 =0.985) explaining the relation between net length and V/H_0 was (Fig. 4):

$L = 9286\ (V/H_0)$ (12)

The lower confidence limit of model 12 was used in the end as a more conservative approach for the estimation of the net length:

$L = 8360\ (V/H_0)$ (13)

This model is considered more suitable for inspection purposes since it is more conservative and the risk of overestimating the net is low. However a *b* value equal to 9286 usually provided a better estimation of the net length for the majority of nets.

Discussion and Conclusions

The management of passive nets fisheries is worldwide applied by limiting the gear dimensions (mesh size, net length and net drop; FAO, 1997; EC Reg. 1967/2006; Scovazzi and Samier, 2012). However, the net length can be considered as a reasonable management measure only from a theoretical viewpoint. In fact, the direct measurement of the whole net with a measuring tape is hardly suitable for inspection purposes, although this is the more accurate way to measure the net length on a fishing wharf. Owing to this weakness, the enforcement of net length provisions has largely remained unapplied and the small scale fishing sector operating with passive nets is practically unregulated. This study was carried out bearing all these constraints in mind and with the goal to develop simple and reliable tools (by means of methodologies and application models) for the estimation of the net length on the basis of net volume, as required by the EC Reg. 1967/2006.

The investigations carried out in this study enabled to conclude that in the Mediterranean Sea a wide range of passive nets is commonly used, each one with different technical specifications (twine diameter, headrope and groundrope diameter, float dimensions etc.) capable of affecting net length and volume. Therefore, it was decided to focus the model development on the basis of a few basic parameters that could be measured effectively during inspections. The alternative approach of setting-up sophisticated models which, in addition to dimensions, would include many other technical net aspects (such as materials, float dimensions, etc.), was generally considered unrealistic. Thus, it was considered as a good approach to first classify passive nets in four main types (gillnet, trammel net, combined net and driftnet) and then devise a unique model to apply to each net type using appropriate parameters deriving from actual length and volume field measurements. In particular, the final model used for estimating the net length consisted in encompassing the direct field measurements of the three most important parameters only: mesh opening, net drop and net volume.

The results obtained from this study provide management bodies with possible advice for enforcement and control purposes. The numeric formulas developed herein can be considered as a tool for providing fishery inspectors with a kind of "conversion factor" which can be used for the first estimation of the net length starting from few parameters. The differences obtained for the coefficient C_2 in the trammel net and gillnet can be explained as follows: gillnets and trammel nets are often made of similar netting twine and have similar net drop; however, the trammel net is composed of three netting panels instead of one; therefore, when comparing a trammel net and a gillnet with the same specifications (net volume and net drop), the trammel net will have a shorter length. For this reason, the coefficient C_2 computed for the gillnet is greater than the same coefficient obtained for the trammel net.

A more conservative approach for inspection purposes was proposed so as not to overestimate the net length since this is a risk which may cause disputes with fishermen. Therefore, a lower limit of confidence was suggested for each model, although the use of the upper limit produced more reliable estimates in most cases. By using these models during inspections, the netting length estimated should be a lower value than the true one, with less than 5% of error.

On the basis of these findings, it is possible to suggest the following steps for inspection procedures:

- the inspector should first estimate and/or measure the net volume;
- the inspector should measure mesh size pursuant to the EC Reg. 517/2008;
- the inspector should count the vertical number of meshes;
- the inspectors should estimate the overall length by simply applying the empirical formula

According to our statistical analysis, this procedure seems to be practical enough and of acceptable accuracy and capable of providing a reasonable estimate of net length from an inspector's viewpoint. Finally, if the net length estimated exceeds or moves closer to the legal limit, the inspector should measure the net length directly.

However, the model and methodologies developed in this study should be considered as a first attempt to tackle the tangled problem of net length estimation. Despite the large amount of net measured, collection of further data is recommended in order to increase the reliability of the models. In any case, the results obtained are essential for the management of the fishing effort exerted by small scale fisheries, and the methodology developed herein can be easily applied in other fisheries and areas.

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