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Use of MEDITS trawl survey data and commercial fleet information for the assessment of some Mediterranean demersal resources

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Abstract — An assessment of the state of the fisheries of hake, red mullet and Norway lobster was carried out by using trawl survey data from the MEDITS research programme. The assessment was performed by means of the application of a composite model utilising the total mortality rate Z as a direct index of fishing effort. The studied area covered the whole western Italian coast (Ligurian and Tyrrhenian seas) and the eastern coasts of Corsica. The area was divided into twelve sub-areas, considered to be of similar ecological characteristics with similar initial productivity but considered to experience different rates of exploitation. Available information on fishing fleets and their geographic distribution was used in creating sub-areas. For each one of these sub-areas, the total mortality rates and a mean catch per unit of effort were estimated. The estimation of Z was performed by analysing the size structure of the cumulated catch in each sub-area and for each year. Catch rates were estimated as the mean catch per one hour of tow. The positioning of the current values of Z for the different sub-areas relative to the Z at maximum biological production suggests that, in most of the sub-areas, hake is in general fully exploited and red mullet overexploited. In the case of Norway lobster, it was not possible to obtain a statistically acceptable result probably due to a lack of contrasting enough levels of fishing pressure among sub-areas. The results obtained for hake and red mullet are in good agreement with the available information on the consistency of the fleets operating in the different sub-areas.

Composite models / stock assessment / *Merluccius merluccius* / *Mullus barbatus* / *Nephrops norvegicus* / Mediterranean sea

Résumé — L'utilisation des données de campagnes de chalutage MEDITS et d'informations provenant de la flotte commerciale pour évaluer les ressources démersales en Méditerranée. Une estimation de l'état de la pêche du merlu, du rouget-barbet et de la langoustine est faite en utilisant les données de campagnes de chalutage des programmes de recherche MEDITS. L'estimation est faite au moyen d'un modèle composite en utilisant le taux de mortalité totale comme indice direct de l'effort de pêche. La surface étudiée couvre l'ensemble de la côte ouest italienne (mers Ligure et Tyrrhénienne) et les côtes est de la Corse. La surface est divisée en douze sous-secteurs, dont les caractéristiques écologiques sont considérées comme similaires avec une productivité initiale identique, mais considérés pour expérimenter différents taux d'exploitation. L'information disponible sur les flottes de pêche et leur répartition géographique est utilisée dans la création des sous-secteurs. Pour chacun d'entre eux, les taux de mortalité totale et une moyenne des prises par unité d'effort sont estimés. L'évaluation de Z est faite en analysant la structure par taille des captures cumulées dans chaque sous-secteur et chaque année. Les captures sont estimées en tant que captures moyennes par heure de chalutage. Les valeurs actuelles de Z pour les différents sous-secteurs, relatives au taux Z au maximum de production biologique, suggèrent que, dans la plupart des sous-secteurs, le merlu est en général entièrement exploité et le rouget surexploité. Dans le cas de la langoustine, il n'est pas possible d'obtenir un résultat statistiquement acceptable, probablement dû à un manque de niveaux de pression de pêche suffisamment contrastés entre les sous-secteurs. Les résultats obtenus pour le merlu et le rouget-barbet correspondent bien à l'information disponible sur l'importance des flottes opérant dans ces sous-secteurs.

Modèles composites / estimation des stocks / *Merluccius merluccius* / *Mullus barbatus* / *Nephrops norvegicus* / Méditerranée

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1. INTRODUCTION

Surplus production models can be used for the assessment of the state of a fishery. Hilborn and Walters [25] state that biomass dynamic models should be considered as "the simplest assessment methods to consider the net effects of recruitment, growth, and mortality when some measure of abundance is available". Traditional versions of these approaches, however, need long data series of catch and effort and a good knowledge of fishing effort partitioning. In order to obtain a good fit of the model, the available data need to be sufficiently 'contrasted' (catch rates corresponding to a wide range of fishing intensities, in ecologically similar areas with similar productivity). In Mediterranean demersal fisheries [8] many species are involved, many fishing strategies are used and therefore the collection of representative samples of the structure by size and data on total effort and amount of catch are very difficult and expensive. The lack of reliable long catch and effort time series makes it impossible in almost all the Mediterranean countries to use traditional approaches of this kind.

We have tried to demonstrate here that, for some species, a preliminary stock assessment mainly based on trawl survey data but integrated with commercial fleet data, constitutes a non-traditional but useful first approach based on simple surplus production models.

2. MATERIALS AND METHODS

2.1. Data sources

Data come from a wide area (*figure 1*) surveyed during the MEDITS cruises from 1994 to 1996, including the Ligurian and Tyrrhenian seas from the Italian/French border to western Sicily and the east coast of Corsica [10].

Cruises were always made in late spring and early summer, with hauls performed within the depth interval 10–800 m. The surveys being always carried out in the same period give a picture of the abundance indices that excludes the seasonal effects on CPUE that are likely to occur as noted in Fox and Starr [21].

The allocation of stations was random inside each of the five bathymetric strata. The design of the fishing gear as well as the materials used for their construction were the same in the whole study area. The three fishing vessels used were of similar gross tonnage and engine power, and all sampling procedures were executed following a common protocol. In each haul, the total catch in numbers and in weight was recorded separately by species. For the thirty most important species, all the individuals (or a representative sample in the case of very abundant catches) were measured and the stage of sexual maturity analysed.

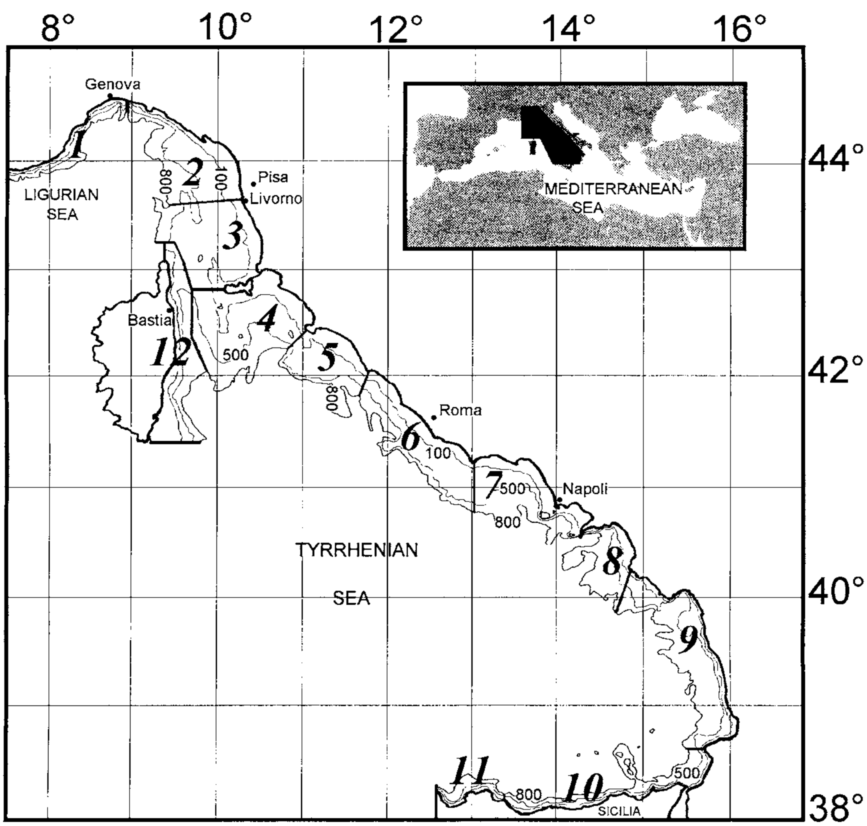


Figure 1. The study area (eastern Ligurian and Tyrrhenian seas) with the twelve proposed subdivisions.

Catch statistics and data from field surveys were collected in the main fishing harbours of the area by direct interviews or by filling in of log-books. These sources provided data on fishing effort and its repartition in space and time.

2.2. The model used

The Caddy and Csirke variant of surplus production modelling [12] was chosen using the instantaneous total mortality rate Z as a direct index of effort and catch per unit effort as an abundance index. This choice avoids the many problems related to the lack of availability of series of fishing effort and spatial partitioning of effort in the multispecies-multigear fisheries operating inside the study area. As proposed by Munro [31], and modified later by Caddy and Garcia [13] to incorporate both spatial and temporal information, the so-called 'composite models' use spatial information proceeding from several ecologically similar sub-areas exploited at different rates, which replace temporal series of catch and effort in conventional production modelling. A similar composite model approach was used in the western Mediterranean by Garcia [22] which allowed a general distinction between states of exploitation of sub-regions of the Spanish coast. With this approach, it is then possible to use the set of estimates to calculate the situation of each single sub-area relative to the total mortality rate, and in particular to calculate its position relative to the maximum biological production (Z_{MBP}). The maximum biological production includes both harvests by fishermen and losses due to natural mortality. This reference point corresponds to a slightly lower exploitation rate than the maximum sustainable yield (MSY), and is relatively stable and easy to calculate [17].

Initial productivity and its evolution under fishing pressure have to be assumed similar for all the considered sub-areas. The selected area covers the eastern Ligurian and the Tyrrhenian seas that belong to the western Mediterranean basin. The whole western Mediterranean is characterised by a relatively low productivity rate and high mean temperature and salinity [4, 8, 29, 30]. As regards the selected area, its productivity rate is lower than those that characterise other western Mediterranean areas such as the Gulf of Lyons and the Balearic Islands [14]. Data on catch rates and size composition were available for many other zones, such as the Sicilian channel and the Adriatic sea, but they were in any case excluded from the analysis owing to their quite different ecological characteristics. The chosen area can be considered homogeneous with regards the many oceanographic parameters. In the whole zone, the general circulation is neither strong enough nor sufficiently well oriented to favour upwelling [28]. No important coastal upwellings were described there and the contribution of nutrients, proceeding from land and from the Atlantic, is scarce. The area is characterised by the narrowness of its continental shelf and by the absence of important rivers that results in a reduced outflow of nutrients. Solar radiation, salinity and mean temperature are quite similar all along the area. Nutrient concentrations show only light differences along the studied area [26, 27].

The composite production approach assumes that each area exploited at a certain rate is at equilibrium with respect to the effort applied. This is probably the situation in the fisheries analysed here because in the last years they did not show important changes in total effort. Using complementary data proceeding from commercial catch assessment surveys on fishing fleet composition, spatial distribution of the fleets and level of fishing effort, this wide area was divided into twelve sub-areas, each one of them characterised by a certain level of fishing intensity. For each sub-area, and for a selected set of species (*Merluccius merluccius*, *Mullus barbatus*, *Nephrops norvegicus*), a mean catch rate (expressed in $kg \cdot h^{-1}$) and a total mortality rate Z were estimated. These three species were chosen because they were well represented in all the considered areas. For other species, even if represented in the catches, data on size structure in the catch were not available.

An appropriate method for estimating Z was chosen for each species, taking into account their biological characteristics (lifespan, growth and mortality rates, age of first capture, relative abundance, recruitment timing, etc.) as well as available data. For the estimation of the total mortality rates for each single species, the same technique and set of biological parameters were utilised in all the sub-areas.

2.3. An attempt to reduce noise in the data

The MEDITS fishing gear is characterised by a very small meshed cod-end (20-mm stretched mesh size) and this explains for almost all species the net predominance of age 0+ individuals in the catch. The estimation of the true mean size in the catch and mean catch rates for each zone is therefore difficult to obtain. This is because certain size classes may be concentrated in separated areas of relatively reduced extension and hence with reduced probability of sampling. This problem is particularly critical for hake because juveniles are densely concentrated in relatively small nursery areas. In order to avoid increasing noise in the overall estimate as a result of this phenomenon, the catch rates and size structure by area were calculated after the removal of age group 0+ individuals. The separation of modal distributions (each representing a cohort) from the size distributions of the catch were performed using the methods of Bhattacharya [9] and NORMSEP [24].

2.4. Estimating the instantaneous total mortality (Z)

For *Merluccius merluccius*, the instantaneous total mortality rate (Z) was first estimated by comparing the survivors between 1+ and 2+ ages assuming similar recruitment strength for the two successive cohorts. The separation of normal components with an acceptable accuracy was, however, not always possible. This occurred, for instance, for the underexploited sub-area 12 (Corsica) considered very important in the analysis. For this reason, the Beverton and Holt estimator [11] based on the mean size in the catch was an alternative method. This latter method allowed us to estimate Z for all sub-areas (excluding sub-area 10 for which the equation did not give a reasonable value). In order to use the Beverton and Holt estimator, excluding age 0+ individuals implies the need to define a new knife-edged 'fully exploited' size (L'). The new value for L', obtained by analysing the left-hand portion of the new size distributions without age 0+ gave a knife-edge selection of 13 cm. For the utilisation of this method, we made the assumption of equilibrium in each area. Anyhow, when the two alternative approaches were available, similar results were obtained for each sub-area relative to the estimation of the Z_{MBP}. The von Bertalanffy growth parameters given in Farrugio [19] of $L_\infty = 85$ cm, $K = 0.163 \cdot \text{year}^{-1}$ and $t_o = -0.044$ were used as input in the Beverton and Holt equation. Without distinguishing by sex, this set of parameters describes quite well the growth performance for the former years of life of the hake.

The two methods described above provide rough estimates of Z. In the first case, we are exclusively calculating the total mortality rate from age 1+ to age 2+. Lower values of Z found for the older individuals of hake are expected to be due to the observed reduction in vulnerability with increase in individual size found by Abella et al. [1]. Moreover, a higher natural mortality rate of juveniles leads us to expect higher values of Z for the first year of life. The second method will tend to overestimate Z because the mean size that we introduce in the Beverton and Holt equation is necessarily an underestimate of the true mean size considering the above-mentioned changes in vulnerability by size. In consequence, both estimates have to be considered only as indexes of the real Z that we assume proportional to fishing effort. Despite the problems just mentioned, it is possible that the error term is roughly the same for each sub-area, making comparisons among them possible.

For the estimation of the red mullet juvenile mortality rates, data of the Italian trawl-surveys performed during the same time interval (1994–1995) but in different periods of the year were alternatively utilised. Z was calculated as the natural logarithm of the survival rate between the numbers at sea (for the 1994 cohort) present in autumn (after recruitment) and in the successive spring 1995 surveys. Z estimates were expressed on an annual base. In the case of *M. barbatus*, MEDITS data did not allow us to obtain estimates of Z suitable for this kind of analysis. This is mainly due to the period of the year when these surveys were carried out (end of spring), which coincides with the spawning period. At this time, the species biomass is at its minimum because the stock is already drastically reduced by the massive fishing pressure on the densely concentrated recruits that every year during autumn and winter occurs near shore [43]. On the other hand, the current year's cohort has still not been recruited to the fishable stock and the demographic structure of the catch is dominated by the survivals of the last year's cohort, which are practically 1 year old, plus a reduced number of older individuals. Using MEDITS data we are only able to analyse the decline in numbers that occurred between 1- and 2-year-old individuals. This mortality rate, however, is not useful for the purposes of this study. In fact, fishing pressure exerted on this phase of the species life history is not responsible for the massive biomass reduction that occurred earlier. For each sub-area, the catch rates were calculated by averaging the estimates obtained in the MEDITS 1994–1996 surveys considering the resulting values representative of the local steady-state situations. Some sub-areas were excluded from the analysis because the catch data or the samples of size frequencies from the surveys were too scanty and did not allow us to obtain sound estimates of Z or of catch rates. In the case of sub-area 11, a correct separation of cohorts by means of statistical procedures proved impossible. In any case, we can assume that in this sub-area, the stock is practically unfished. This is mainly because, over a major portion of the specified zone (Gulf of Castellamare, sub-area 11), a total fishing ban for trawling has been established for the whole depth range in which the species lives (0–200 m). All the fishing vessels proceeding from the ports located inside this sub-area operate offshore or exploit fishing grounds positioned inside neighbouring sub-areas. In consequence, we have assumed for this sub-area Z = M and utilised an estimate of the natural mortality rate M as an alternative for Z. A value of 1.1 was adopted. It represents a mean value from those obtained through the most frequently utilised empirical equations for the estimation of the natural mortality rate proposed by Pauly [32], Rikhter and Efanov [38] and Alagaraja [3], which considers the close relationship of M with several biological characteristics of the species (growth rates, lifespan, etc.).

The use of the length-converted catch curve (LCCC) for the estimation of Z was considered suitable in the case of *Nephrops norvegicus*. This is because the species' catch is always composed of several fully vulnerable year classes. For *Nephrops*, the assumption of both M and F as constant for all the age classes over the age at first capture was considered reasonable. The analyses were made separately by sex considering the noticeable differences in size at age in the case of adult individuals. For some areas, the samples were constituted by few individuals, therefore with size distributions poorly representative. The corresponding length frequencies were considered unsuitable for an accurate estimation of Z and hence the mentioned areas were excluded from the analysis.

The von Bertalanffy growth parameters used were those proposed in Abella and Righini [2]. It is well known that the total mortality rate estimations are

NORWAY LOBSTER

Year	Subarea	MALES Z	MALES CPUE	FEMALES Z	FEMALES CPUE
1994	2	0.67	0.77	0.94	0.77
1995	2	1	0.87	0.9	0.87
1996	2	0.81	1.71	1	1.71
1994	3	0.89	1.49	1.15	1.49
1995	3	0.63	0.99	0.94	0.99
1996	3	0.97	0.24	1.07	3.24
1994	4	1.34	0.9	1.44	0.9
1995	4	1.13	1.08	1.22	1.08
1996	4	1.23	1.11	1.49	1.11
1994	5	0.66	0.27	1.25	0.27
1995	5	0.67	0.68	1.15	0.68
1996	5	0.66	0.91	1.13	0.91
1994	6	0.8	0.7	1.12	0.7
1995	6	0.97	1.25	1.4	1.25
1996	6	0.69	1.1	1.41	1.1
1994	7	1.16	0.37	0.6	0.37
1995	7	1.11	0.58	1.87	0.58
1996	7	1.09	0.28	1.42	0.28
1994	12	0.66	4.11	0.99	4.11
1995	12	0.46	2.18	0.73	2.18
1996	12	0.61	4.55	1.02	4.55

RED MULLET

Z	Average catch rates 1994-96 for each subarea: 1	2	3	5	7	9	11
5,00	3.2						
5,62		0.8					
3,38			4.3				
4,97				0.7			
6,56					0.37		
2,96						2.13	
1,10							10.6

HAKE

Year	Subarea	Z	CPUE
1994	1	1.09	1.66
1995	1	0.93	3.1
1996	1	1.24	2.06
1994	2	1.12	2.17
1995	2	0.96	2.43
1996	2	1.32	1.77
1994	3	2.13	2.43
1995	3	1.62	2.69
1996	3	1.79	2.33
1994	4	2.12	1.89
1995	4	2.7	
1996	4		2.72
1994	5	2	1.54
1995	5	1.17	3.21
1996	5	1.69	1.56
1994	6	1.7	1.09
1995	6	1.21	1.56
1996	6	1.82	1
1994	7	2.9	1.07
1995	7	2.36	1.51
1996	7	2.14	0.52
1994	8	2.69	1.54
1995	8	1.81	2.51
1996	8	2.12	0.95
1994	9	2.9	1.33
1995	9	1.93	1.59
1996	9	3.29	0.93
1994	11	0.81	3.85
1995	11	0.9	0.05
1996	11	1.08	0.89
1994	12	1.88	2.55
1995	12	0.67	3.37
1996	12	1.04	1.34

Figure 2. Used data on total mortality rates Z and CPUE for Norway lobster (*Nephrops norvegicus*), hake (*Merluccius merluccius*) and red mullet (*Mullus barbatus*).

sensitive to the input values of growth parameters but even if very slow growth rates are hypothesised (as in the model proposed by Sardà and Lleonart [39], the resulting estimates of Z do not differ too much (they are only 10–20 % lower). *Figure 2* shows the pairs of Z and catch rates used in the analysis for each sub-area and species.

2.5. Estimation of catch rates

The catch rates for each species were estimated and expressed as the mean catch in kg per hour. Only the hauls performed inside a defined depth range, considered characteristic for a given species, obviously the same for all the sub-areas, were used. In order to avoid the unnecessary extension of the external limits of the depth range due to the presence of isolated individuals, a minimum number of individuals by tow was fixed. The estimation of this number was made by means of several trials by observing the resulting number of null catches that had to be included as a consequence of each different choice. The final choice was four individuals because over this threshold the number of null catches did not show any observable reduction. The same threshold was considered suitable for the three studied species.

2.6. Fitting the model

The pairing of catch rates and Z estimates from trawl surveys allowed us to estimate, for each species, the so-called maximum biological production (MBP) under the hypothesis of the linear model of Schaefer and the exponential model of Fox. In the case of hake and Norway lobster, the pairs of Z and catch per unit effort (CPUE) estimates proceeding from all 3 years (1994–1996) were used for the fitting of a unique model. For red mullet, as explained above, only one estimate of Z was available for each sub-area relative to the studied period. These estimates were correlated with the corresponding catch per hour obtained by averaging the mean catch rates available for the 3 years. The parameters of the Caddy and Csirke model, U_∞ and b', were estimated for each of the mentioned species and models by linear regression analysis allowing the construction of the MBP curves. Successively, for the three species, the Z values estimated for each sub-area were compared to the corresponding value of Z_{MBP}.

2.7. Validation of results

Independent information on fishing fleets for each sub-area was used for a preliminary validation of the

Table I. Main statistics of the linear regressions assuming Schaefer and Fox models for hake and red mullet.

	Schaefer model	Fox model (linear transformed)
Merluccius merluccius		
Number of observations	32	32
Intercept a	3.8926	1.3838
Standard deviation of intercept	0.5376	0.2158
Confidence interval of intercept	2.7958 to 4.9837	0.9436 to 1.8241
Slope b	– 0.9895	– 0.4299
Standard deviation of slope	0.2912	0.1169
Confidence interval of slope	– 1.5835 to – 0.3954	– 0.6684 to – 0.1915
Correlation coefficient	0.5272	0.5575
Confidence interval of correlation coeff.	– 0.7399 to – 0.2187	– 0.7587 to – 0.2592
Significance test *t*	3.3982	3.6785
Mullus barbatus		
Number of observations	7	7
Intercept a	10.1423	2.9658
Standard deviation of intercept	1.9771	0.6065
Confidence interval of intercept	5.0611 to 15.2235	1.4072 to 4.5244
Slope b	– 1.6581	– 0.5609
Standard deviation of slope	0.4333	0.1329
Confidence interval of slope	– 2.7717 to – 0.5444	– 0.9025 to – 0.2193
Correlation coefficient	0.865	0.884
Confidence interval of correlation coeff.	– 0.9799 to – 0.3223	– 0.9827 to – 0.3901
Significance test *t*	4.2291	4.6221

consistency of the obtained mortality indices and catch rates. The analysis was performed by regressing fishing intensity against the corresponding estimates of Z and CPUE proceeding from the surveys. Fishing intensity, for each sub-area, is defined here as effort directed to a given species (expressed as number of fishing trips) divided by the surface in km^2 over which the species is distributed inside the specific sub-area. It was observed that fishing trip duration and mean fishing power of the fishing fleets operating inside the different sub-areas are very similar. Based on the available information, we can assume that during the last few years, the situation did not change and an equilibrium status with respect to the applied effort is likely to occur in each defined sub-zone.

An ANOVA, with multiple classification criteria, was performed in order to analyse the effects of the two independent variables (areas and years) on the Z estimates. The main goal of the analysis was to exclude the hypothesis of statistically significant differences among the estimates of Z obtained for the three different years. The rejection of the hypothesis should provide support for the equilibrium assumption.

3. RESULTS

Figure 2 shows the estimates of Z and CPUE for each species (*Nephrops*, etc., and sub-area. *Figures 3, 4, 5* show the results of the application of the composite model obtained for the three species analysed and the fitting of data assuming the Schaefer and the Fox models. In the case of hake (*figure 3*), the obtained correlation coefficients were low irrespective of the model chosen *(table I*) but the estimated values of *t* have shown that the correlations were always statistically significant at $\alpha = 0.01$. For most sub-areas, the observed pairs of direct indices of effort ('Z') and catch rates are concentrated close to the value of Z corresponding to the maximum biological production (Z_{MBP}). The obtained values of Z_{MBP} assuming the Schaefer and the Fox model were similar: 1.96 for the first and 2.4 for the second. This suggests that, irrespective of the model chosen, the hake can in general be considered fully but not overexploited in the area. Only for sub-areas 7 and 9 did the estimated values of Z generally exceed the Z_{MBP} value, irrespective of the model chosen, and for all the years, while four other sub-areas [1, 2, 11, 12] are positioned well

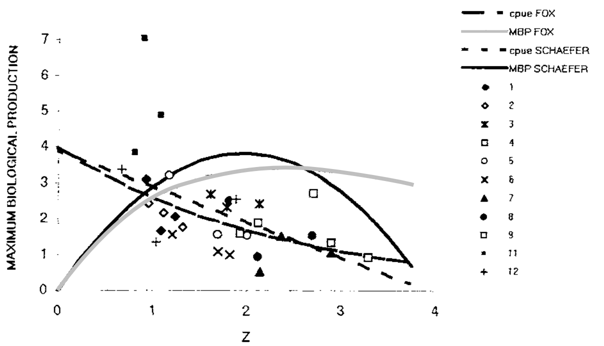


Figure 3. *Merluccius merluccius* distribution of total mortality couples of estimates of Z and CPUE ($kg \cdot h^{-1}$) for hake. Each point corresponds to one sub-area and year. The analysis covers the period 1994–1996. The regression lines obtained assuming both a Schaefer and a Fox model as well as the two biological production curves derived from these models are also represented.

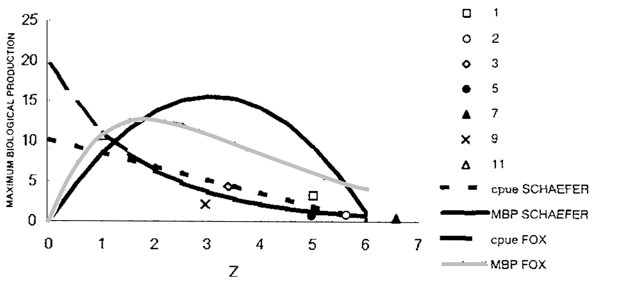
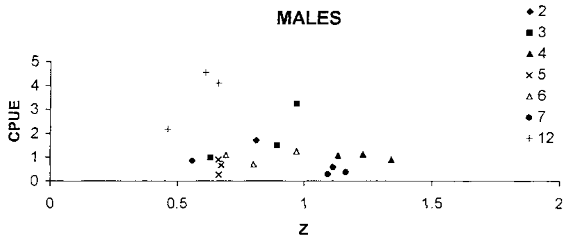


Figure 4. *Mullus barbatus* distribution of couples of estimates of Z and CPUE (kg·h^{-1}) for red mullet obtained in each sub-area. Each point is considered here as a mean value for the period 1994–1996. The regression lines, obtained assuming both a Schaefer and a Fox model as well as the two biological production curves derived from these models are also represented.

under the Z_{MBP} reference point. The points for the 3 analysed years corresponding to each area are generally positioned fairly close. This makes the results more plausible and supports the steady-state assumption made earlier for both abundance and fishing pressure in the period of analysis. The evaluation of the significance of variations of the Z estimates among years and areas by means of an analysis of variance is shown in *table II*. The results support the equilibrium assumption because they show that the inter-annual variation of the estimates of Z is not statistically significant. On the other hand, the inter-zone variation is highly significant.

In the case of red mullet (*figure 4*), only seven areas were included in the final analysis. The fittings with the two models were quite good and the resulting correlations were statistically significant at $\alpha = 0.01$. In any case, the choice of the Schaefer or the Fox model is decisive for the estimation of the optimal total mortality rate (Z_{MBP}) of the species. The values for Z_{MBP} derived from these two models were 3.04 and 1.78, respectively. Nevertheless, for almost all the sub-areas, data show, irrespective of the assumed model, that mortality rates generally exceed the estimated Z_{MBP}. Two areas (3 and 9) can be considered fully exploited according to the results obtained with the Schaefer model but they have to be considered overexploited if the Fox model is chosen. Area 11 is decisively underexploited irrespective of the model chosen. This latter sub-area roughly corresponds to the area in which trawling has been forbidden in recent years at the depth range 0–200 m.



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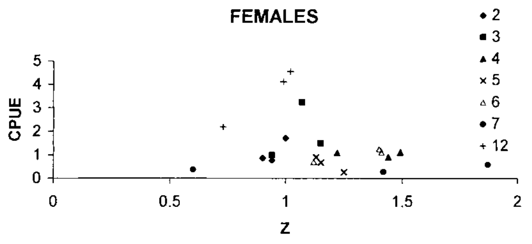

b

Figure 5. Distribution of couples of Z and CPUE (kg.h^{-1}) for *Nephrops norvegicus* estimated for the different sub-areas and years. The analysis covers the period 1994–1996.

Due to the lack of a statistically significant model for *Nephrops norvegicus* (*figure 5a, b*), it was impossible to either estimate Z_{MBP} or make comments regarding the adequacy of the current exploitation rates in the different sub-areas. For this species, there were no observable differences among the estimated Z values, suggesting either small differences in fishing effort between zones or limited availability of this species to the gear used. For almost all the areas, only a small portion of the fleets has *Nephrops* as a target species. We can make only a special reference to the contrasting results obtained for two sub-areas: Corsica (sub-area 12), represented in the figure by three crosses all in the upper left corner of the graph suggesting an underharvesting situation and the estimates relative to sub-area 4 (south of Elba island) represented by dark triangles in the right and lower part of the graph which might suggest overfishing. It is important to remark that in the latter sub-area the most important fishing fleet targeting *N. norvegicus* and red shrimps operates, landing mainly in Porto Santo Stefano.

Table II. Results of the ANOVA applied to estimates of total mortality of hake in order to evaluate the significance of the interannual and interzone variations.

	Variation	Degrees of freedom	Mean of squares	*F*	*F*0.95	*F*0.99	Significance of the differences
Zones	11.693	10	1.169	4.869	2.35	3.37	significant
Years	1.158	2	0.579	2.410	3.49	5.85	not significant
Residual	4.803	20	0.240				
Total	17.654	32					

Table III. Estimated number of mean annual fishing trips for the period 1994–1996 targeting the three different species and measure of surface of fishing grounds (in km^2) for each sub-area.

	Hake		Red mullet		N. lobster	
Sub-area	Fishing trips	Fishing area (km^2)	Fishing trips	Fishing area (km^2)	Fishing trips	Fishing area (km^2)
1						
2	12 600	7 440	14 000	3 360	3 640	4 800
3	7 280	5 206	5 600	4 462	560	992
4	14 560	7 364			7 840	6 049
5	6 440	4 471				
6	10 920	6 972				
7	21 280	6 640	14 280	2 656	7 000	3 984
8	8 400	2 988	5 600	2 500		
9	15 960	5 976	8 400	3 320		
10	8 960	4 980				
11			0	996		
12					560	1 992

For the three species, good correlation was in general obtained among the fishing intensity indexes estimated using statistics of commercial fleets and corresponding Z (*tables III, IV*; *figure 6*). A linear model was used for the fitting of data. The model suggests (as expected) that the two variables are related by a linear regression with positive slope. On the other hand, a decreasing curve was expected, and in fact observed, for the regressions between fishing intensity and CPUE. In this case, both a linear and an exponential model were tested. For *Merluccius merluccius*, the decline in CPUE with the increase in fishing intensity is less clear suggesting that the precision of the catch rate estimates is the main factor responsible for the relatively low correlation coefficients obtained. In the case of red mullet and Norway lobster, all the correlations between fishing intensity and CPUE, irrespective of the chosen model, are significant at an $\alpha = 0.01$ level.

4. DISCUSSION

The comparison of the above-described results from the surveys with the information on commercial fleet distribution and relative fishing intensity gives very acceptable results. If compared to the corresponding estimates of fishing intensity, the estimates of Z and catch rates (for each area and species and for the 3 years of available data) show strong coherence. The fishing intensity exerted in each sub-area is directly correlated to the corresponding Z and is inversely correlated with the index of abundance (catch·h^{-1}). These results are encouraging because they constitute some sort of validation of the approach considering that the data used proceed from independent sources. Another aspect that will probably need more attention in the near future relates to other potential uses of this kind of data. For instance, the intercept with the ordinates obtained by regressing fishing intensity against Z provides an independent estimate of natural mortality (the total instantaneous mortality rate at zero fishing effort). The obtained intercept values for the three species derived from the linear model look reasonable and are very similar to the values of M

Table IV. Main statistics of the regressions of fishing intensity versus Z and CPUE assuming a linear and an exponential model.

	Fishing intensity versus Z	Fishing intensity versus CPUE	
Merluccius merluccius	Linear model	Linear model	Exponential model (linearised)
Number of observations	25	25	25
Intercept a	0.808	3.178	2.586
Slope b	0.5553	– 0.7461	– 0.2110
Correlation coefficient r	0.6632	– 0.4544	– 0.2012
Significance test *t*	4.25	2.45	0.99
Significance 0.05	1.71	1.71	1.71
Significance 0.01	2.50	2.50	2.50
Mullus barbatus			
Number of observations	6	6	6
Intercept a	1.659	9.133	10.71
Slope b	0.7917	– 1.8956	– 0.6681
Correlation coefficient r	0.9142	– 0.8859	– 0.9978
Significance test *t*	4.51	3.82	30.10
Significance 0.05	2.13	2.13	2.13
Significance 0.01	3.75	3.75	3.75
Nephrops norvegicus			
Number of observations	15	15	15
Intercept a	0.747	4.466	5.772
Slope b	0.3988	– 0.3269	– 1.817
Correlation coefficient r	0.5176	0.7406	0.8276
Significance test *t*	2.1811	3.9739	5.31596
Significance 0.05	1.77	1.77	1.77
Significance 0.01	2.65	2.65	2.65

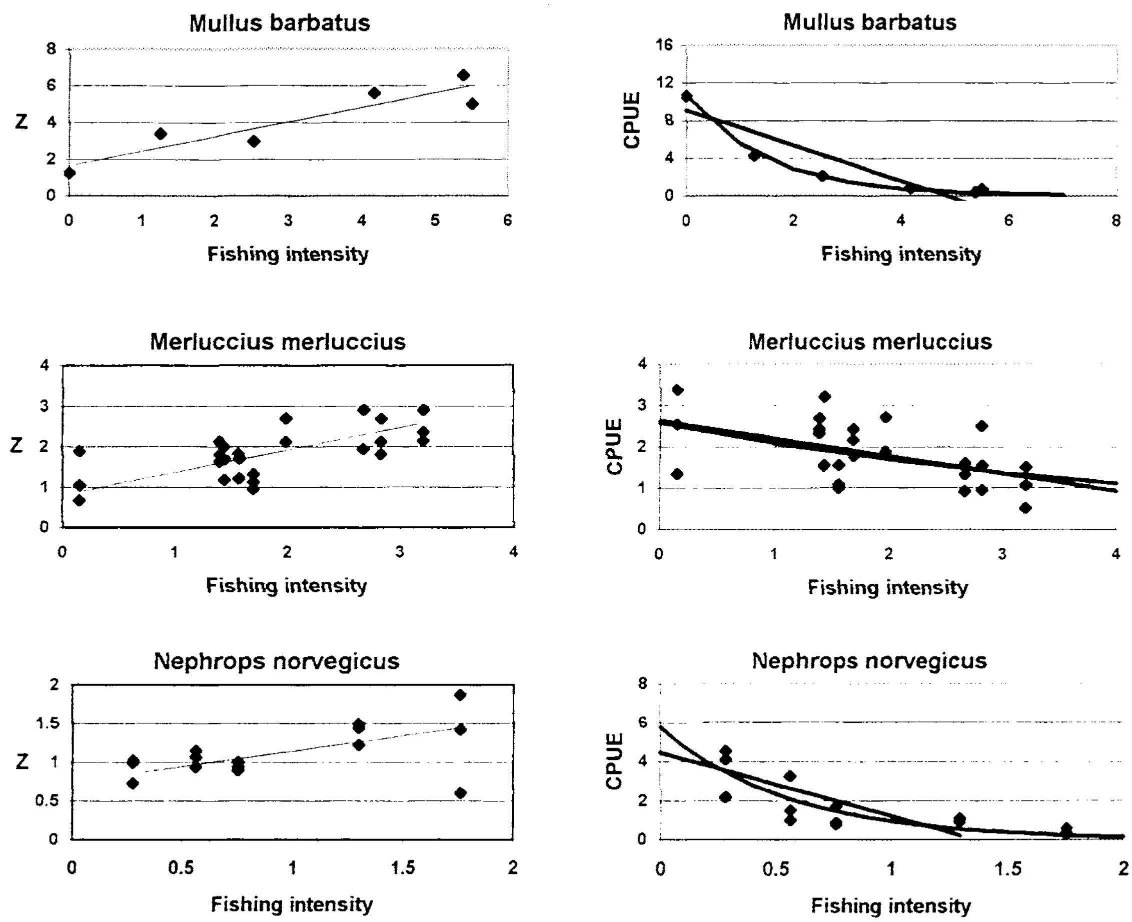

Figure 6. Relationship among fishing intensity indices (expressed as number of annual fishing trips per square kilometre) and corresponding values of Z and CPUE for hake, red mullet and Norway lobster. In the case of hake and Norway lobster, the estimates of Z and CPUE derive from MEDITS data. For red mullet, they derive from a combined analysis of data from MEDITS and from the Italian Research Programme of trawl surveys performed during the same period.

obtained with empirical equations or by means of the estimation of Z in virgin areas relative to individuals of the considered age intervals. More attention should be paid to this aspect because there is an urgent need in the Mediterranean for this kind of information! A more detailed analysis of fishery fleets and more exact estimations of the repartition of effort in each area are, however, necessary and this would further refine the approaches described here.

The results of the application of the composite model for hake suggest a better situation for the studied resources in the eastern Ligurian and Tyrrhenian seas than that generally provided by conventional approaches such as simple assessments based on the exploitation rate, yield-per-recruit analyses, virtual population analyses, etc.) *(table V)*. Sometimes, the latter approaches led to unreliable assessments, largely due to an erroneous determination of the current exploitation rate for a given resource. Results are also compatible with the stationariness of biomass indices for the last 10 years derived from trawl surveys [36] and estimated with the swept-area method [5].

The use of the length-converted catch curve (LCCC) is not suitable for the estimation of Z in red mullet because the main assumptions for a correct application of this technique are not met [32]. The same considerations are also valid for hake. The assumption of constant natural mortality in fine-meshed fisheries such as that operating in the Mediterranean, overestimates the expected increase in yield per recruit that should follow a reduction of F [17] and can also produce very pessimistic assessments of the state of a fishery if conventional VPA approaches are utilised [1].

The main advantage of such methods as composite production modelling is that only a reduced amount of data is needed for its application. The required information is quite simple and the variant proposed by

Table V. Main results of previous assessments made in different areas of the Tyrrhenian and Ligurian seas with alternative approaches for hake and red mullet.

Authors	Area	Model	Reference points	Assessment
Merluccius merluccius				
Fiorentino et al. [20]	1 + 2	Thompson and Bell Y/R with variable M at size	Fmax	overexploited
Abella et al. [1]	2 + 3	Y/R. eggs/R and VPA with variable M at size	Fmax, SSB%	fully exploited
Reale et al. [34]	4	VPA + Y/R	Fmax	highly overexploited
Ardizzone and Cau [6]; Ardizzone [7]	5 + 6	Y/R + composite model	F0.1	overexploited
Spedicato and Lembo [42]	7 + 8	length-converted catch curve + exploitation rate	E	overexploited
Greco [23]	9 + 10 + 11	length-converted catch curve + exploitation rate	E	overexploited
	12			no assessment
Mullus barbatus				
Relini et al. [35]	1 + 2	Y/R	Fmax	fully exploited
Voliani et al. [43]	2 + 3	Y/R with variable M at size	Fmax + SSB%	fully exploited
Demestre et al. [16]	4	VPA + Y/R	Fmax	overexploited
Ardizzone [7]	5 + 6	Y/R	F0.1	overexploited
Spedicato and Lembo [42]	7 + 8	length-converted catch curve + exploitation rate	E	overexploited
Greco [23]	9 + 10 + 11	length-converted catch curve + exploitation rate	E	overexploited
	12			no assessment

Caddy and Garcia [13] to the Munro approach [31] which incorporates both temporal and spatial data, allow one to use this approach even in situations where a few years of data are available (a fairly common situation in many Mediterranean areas).

Finally, we present some considerations regarding Z_{MBP} as a useful reference point. In selecting a target reference point, it is necessary to be sure that it is a guarantee of the sustainability of a fishery fishing at any level of effort up to this rate, taking into account likely errors in our estimate of the state of the stock. Caddy and Csirke [12] suggested that the utilisation of the Z_{MBP} as a target allows managers to avoid serious consequences for the fishery “due to ecological perturbations”, since F at maximum biological production is lower than the F at maximum sustainable yield. [40, 41]. For stocks subject to density-independent fluctuations, yield becomes increasingly variable as fishing mortality increases, and confirms that environmentally caused instability in recruitment in conjunction with errors in estimation of parameters of the yield models means that in practice the long-term maximum average yield (MAY) should be maintained at a level below that providing the MSY. Doubleday [18] also noted that where recruitment fluctuates, a fishing strategy that produces catches attaining the MSY each year could lead to the collapse of the stock.

The level of effort for a fishery operating at the maximum biological production point, where total production from the stock (predators + fishery) is maximised, should be a more safe reference point [15, 17]. Economic considerations also suggest that the optimal economic return from a fishery is obtained at levels of effort lower than the ones corresponding to the MSY level; hence, we may consider that in the absence of an economic analysis, a fishery targeted at MBP better approximates than MSY to such a sustainable situation.

5. CONCLUSION

The methodology applied here allowed us to carry out an assessment of the state of the fisheries of hake and red mullet on the western Italian coasts and eastern Corsica. The approach failed in the case of the *Nephrops norvegicus* stock probably due to the lack of sufficient contrasting values of Z among the different sub-areas and to the relatively high variability in the catch per unit of effort for this species. For Norway lobster, in the last few years, the observed increases in catch rates for both commercial and scientific surveys suggest an increase in *Nephrops* biomass for at least the northern portion of the studied area [37]. Even if the assessment with this approach was not possible for *Nephrops*, the narrow range of estimates of Z are quite close to the value of total mortality obtained for Corsica, an area that is supposed to be underharvested for this species, leading to the preliminary conclusion that the species may be very lightly exploited in almost all this area.

In most of the analysed fishing grounds, the total mortality rates estimated for *Mullus barbatus* were higher than those corresponding to maximum biological production (MBP), suggesting for several subareas that overharvesting situations apply. In some sub-areas, the stock biomass has drastically declined owing to fishing, but observed stability in standing stock biomass during the last few years suggests that stock self-renewal can still be guaranteed. It is necessary to note that the particular situation of sub-area 11 is currently characterised by extremely high catch rates. These catch rates were very low before the imposition of a complete and permanent fishing ban in 1990. The recent extraordinary increase in biomass that followed the imposition of this management action is described in Pipitone et al. [33]. This experience is very important because it is one of the few examples of a drastic reduction of effort in the Mediterranean and has to be considered very useful for a better understanding of the biological mechanisms of reaction of stock to changes in fishing pressure (for instance the poorly documented question of ‘reversibility’ implicit in management actions aimed at stock rebuilding).

Merluccius merluccius seems in general fully exploited and in some sub-areas overexploited. The fishing mortality of hake is mainly due to trawling and is exerted mainly on juveniles. The current fishing intensity looks sustainable because in general in the last few years no negative trends in biomass have been observed. A sustained increase in the use of trammel and gill nets aimed at hake has been observed practically everywhere during the last few years. This change in the fishing pattern should have future consequences for the stock but so far the model described here is unable to evaluate the future consequences of such changes.

This paper attempts to demonstrate that information proceeding from direct methods such as trawl surveys can also be utilised for goals other than the traditional ones of biological data collection, estimation of abundance indexes for analysis of temporal trends, evaluation of recruitment, etc. It is evident that the assessments presented here have to be considered preliminary, and it is possible that for some sub-areas, errors in the estimation of mortality rates or in the index of abundance have led to inaccurate assessments of the real state of exploitation. Notwithstanding this, the authors believe that the approach is probably more robust and more suitable for the Mediterranean fisheries than others frequently used in the past in the area.

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