Biol. Mar. Medit. (2006), 13 (3) Parte Seconda: 112-123

M.T. Spedicato, P. Carbonara, P. Rinelli*, T. Silecchia, G. Lembo

COISPA Tecnologia & Ricerca, Stazione Sperimentale per lo Studio delle Risorse del Mare, Via dei Trulli, 18-20 - 70045 Bari (Torre a Mare), Italia.
spedicato@coispa.it
*IAMC-CNR, Sezione di Messina, Messina, Italia.

BIOLOGICAL REFERENCE POINTS BASED ON SPAWNING STOCK BIOMASS LEVELS: THE CASE OF RED MULLET (*MULLUS BARBATUS* L., 1758)

*REFERENCE POINTS DI TIPO BIOLOGICO BASATI SUI LIVELLI DI BIOMASSA DEI RIPRODUTTORI: IL CASO DELLA TRIGLIA DI FANGO (*MULLUS BARBATUS *L., 1758)*

Abstract

Biological reference points often reflect the combination of several components of stock dynamics (growth, recruitment and mortality) into a single index. In addition, the BRPs identify target and threshold levels to consider for a sustainable fishery (Precautionary BRP). Facing the problem of identification of suitable BRPs, two main aspects are often addressed in Mediterranean, i.e. testing the potential of indicators used in other geographical regions (e.g. ICES context) and evaluating BRPs that better incorporate the biological/technical specific characteristics of the area. The objective of this paper is to test BRPs based on the spawning stock biomass (SSB), using as case study the stock of red mullet of the central-southern Tyrrhenian Sea (GSA 10). Data (abundance indices and demographic structure of the population) are from the bottom trawl surveys GRUND and MEDITS carried out since 1994. Growth and total mortality, with associated variability, were estimated following the temporal evolution of the different cohorts, which were separated using a maximum likelihood estimator. Maturity and size at first capture were estimated as well, the latter from selectivity experiments conducted in the area. All these estimates were the input of a stochastic simulation model (biomass pool dynamic model) based on the Thompson & Bell approach. The condition of M. barbatus *(Osteichthyes, Perciformes) stock was thus modelled accounting for fluctuations in the growth parameters, recruitment and maturity. Safe levels occurred when the ratios SSB/SSBV and SSB/B were respectively ~20 and 70%, corresponding to B/R of 13-14 g and to an exploitation rate of ~0.5. Considering the multispecies-multigear characteristics of the Mediterranean fishery, suitable management options could be represented by the enforcement of the area and temporal closure.*

Key-words: *biological reference points, spawning stock biomass,* Mullus barbatus, *Tyrrhenian Sea, trawl survey.*

Introduction

Biological reference points (BRPs) often reflect the combination of several components of stock dynamics (growth, recruitment and mortality) into a single index.

In geographical regions where fisheries are managed following an adaptive strategy since long time (e.g. Atlantic Ocean, North Pacific, North Sea), the identification of pertinent BRPs relies upon the stock assessment models currently used to provide estimates of population abundance and to shed light on the underlying dynamics. Depending on the assessment and management techniques, BRPs can be expressed in terms of fishing mortality rate F, stock biomass B, spawning-stock biomass SSB, or other metrics of exploitation rate or stock abundance (e.g. Smith *et al.*, 1993; Restrepo *et al.*, 1999).

In the frame of the precautionary approach (e.g. FAO, 1995; FAO, 1999) the

need to distinguish between Target and Limit Reference Points has been well established, identifying threshold levels for a sustainable fishery (e.g. Smith *et al.*, 1993; Mace, 1994; Caddy and Mahon 1995; Prager *et al.*, 2003).

Recently, also interactions among different fish stocks as well as cross-relationships between these and the surrounding marine environment (i.e. ecosystem based approach to fishery management) represent a relevant challenge. This is, however, a very complex task as we need to understand the ecosystem well enough to predict with reasonable confidence the consequences of fishing removals on different stocks. Also, we need to consider competition between species (for food and habitat) and interactions between juvenile fish as well as predation by adults. In all of these aspects much work has been done (e.g. Pope, 1991; Sparre, 1991; Christensen and Pauly 1992; AA.VV., 2000; Walters *et al.*, 2000; Rochet and Trenkel, 2003), but further work is still required for understanding marine ecosystems and incorporating complex ecological/production assessments into quantitative management advice.

Considering the high degree of uncertainty inherent in fisheries research and the complexity of the whole system (e.g. Hilborn and Walters, 1992; Walters, 1998), holistic approaches accounting for stock dynamics, ecological, social and economic implications (e.g. Caddy, 1999, 2002; Garcia *et al.*, 1999; Pitcher, 1999) are recognised to be more robust and integrated techniques better for a multidisciplinary evaluation of fisheries sustainability.

Whatever is the method selected for providing management advice, diagnostics of the main targeted stocks is still relevant, at least as part of a more composite evaluation frame.

In the Mediterranean, where identification and implementation of BRPs is currently recommended by scientific and management Bodies (i.e. GFCM and European Commission), two main aspects are still faced: testing the potential of indicators used in other geographical regions (e.g. ICES context) and evaluating BRPs that better incorporate the biological/technical specific characteristics of the area. This is a difficult task because, given the complexity and diversity of Mediterranean fisheries, the available data are probably not sufficient for regular and trustworthy assessment of most species (Lleonart and Maynou, 2003).

The objective of this paper is to investigate on the dynamics of the red mullet stock in the central-southern Tyrrhenian Sea (geographical sub-area – GSA 10), assessing the level of reproductive capacity and its capability to maintain sustainable productivity, i.e. if year-classes produce sufficient spawning units so that successive generations replace, on average, each other. Hence BRPs based on the spawning stock biomass (SSB) have been tested.

The red mullet was selected as case-study given its economic importance and wide distribution along the Mediterranean coasts (e.g. Tserpes *et al.*, 2002). In Italy, for example, the production of red mullet in 2002 was 14,310 tons, accounting for 10.2% of fish production, excluding pelagic stocks (IREPA, 2003).

In addition, the specific features of the life history traits (discrete recruitment mode, early maturation) and of the fishing patterns (target species of trawlers) make this species a suitable subject to test BRPs.

Materials and methods

The data used in this paper (abundance indices and length structure of the red mullet population) mainly proceed from the GRUND (Relini, 2000) bottom trawl surveys integrated with those from MEDITS project (Bertrand *et al.*, 2002). Both trawl surveys were carried out along the Italian coats since 1994, respectively in autumn (September-October) and spring (May-June). Thus time series from 1994 to 2002 were employed in this analysis. Further details on the stratification scheme (stratified random sampling, each haul position randomly selected in small sub-areas) and sample allocation (proportional to the depth stratum areas) are in the aforementioned papers as well as in Greco *et al.*, 1998 and Spedicato *et al.*, 1998 with specific reference to the geographical sub-area (10-central-southern Tyrrhenian Sea). The total explored surface (from 10 to 800 m depth) is 20,255 km^2, while the continental shelf, where the red mullet is preferentially distributed, is extended for 7,362 km^2. Density in number and length frequency distributions were thus weighted accounting for this area and standardised to the square kilometre.

Given the discrete recruitment mode of the species occurring in late summer-early autumn, the reproduction season (May-June) and the timing of the surveys, data on both recruits (from GRUND) and adults (from MEDITS) were available.

A length-based pool dynamic model was built up to simulate the evolution of a red mullet population under current scenarios, according to the forward predictive Thompson & Bell forecast approach, following an analogous framework as in Sanders (1995).

The exponential decay of a fish population in absence (1) and presence (2) of fishing were the basic equations of the model:

$$\frac{dN}{dt} = -MN \qquad (1) \qquad\qquad \frac{dN}{dt} = -ZN \qquad (2)$$

integrated as follows:

$$N_{i+1} = N_i e^{-M_i * \Delta t_i}; \qquad\qquad N_{i+1} = N_i e^{-(F_i + M_i) * \Delta t_i}$$

where N_i indicates the population in number of individuals in Δt_i time interval, M_i, Z_i and F_i respectively the natural, total and fishing mortality in the same Δt_i. In the computing procedure all the variables were treated as vectors by size.

The input parameters and functions of the population model were: growth, according to the von Bertalanffy equation; initial length of recruitment to the fishery; total mortality *Z*; natural mortality *M* on the basis of empirical derivations (Beverton and Holt invariant with 1.6 coefficient was used); selection ogive (using a stretched legal mesh size of 40 mm); length-weight relationship; maturity ogive and an initial number of recruits with associated empirical $\log_e$-normal distribution, allowing a fluctuation range of ±20%.

The fishing mortality rate $F(L_i)$ for each time interval Δt was calculated inside the population model, using the input values of *Z* and *M* corrected by the probability of selection:

$$F_i = (Z_{input} - M_{input}) * S(\overline{L_i})$$

The input value of natural mortality *M* was partitioned over the length classes according to the formulation in Pope *et al.* (2000):

$$M(\overline{L_i}) = 4e^{C - 3\times 0,386 \ln(\overline{L_i})}$$

where the constant *C* is:

$$C = \ln \frac{ML_\infty}{B}$$

and *B* is a constant (Pope, in SAMED, 2002) calibrated so that the derived result (i.e. the survivals in the range of size classes between 20-80% of L_∞) is equivalent to that obtained through the application of a constant value for *M* (defined in input) for the whole size range.

Hence the total mortality Z_i for each time interval Δt_i was calculated as follows:

$$Z_i = F_i + M_i$$

Once the population in numbers (current stock and unfished or virgin stock) was reconstructed, the standing biomass and spawning stock biomass were obtained from the average numbers and weights for each length class as follows:

$$B = \sum N_i \times w_i; \qquad\qquad SSB = \sum N_i \times w_i \times S_i$$

where w_i is the weight and S_i is the proportion of mature fish.

Besides average standing biomass (*B*) and average spawning stock biomass (*SSB*), also the following quantities were outputs of the population model: the ratio between spawning stock biomass and unfished spawning stock biomass (*SSB/SSBV*), the length at which the cohort reaches its maximum biomass along its lifespan (*TLCr*) in the exploited population, and an average total mortality rate according to the Lleonart and Salat (1997) formula:

$$\overline{Z} = \frac{\sum_{i=1}^{n} Z_i \Delta t_i}{\sum_{i=1}^{n} \Delta t_i}$$

For each output standard deviation and coefficient of variation were computed.

All the main input parameters of the population model proceeded from data collected during GRUND and MEDITS surveys.

Growth and total mortality were estimated following the temporal evolution of the different cohorts. These were identified and separated using a maximum likelihood estimator (e.g. Fournier *et al.*, 1990; Yamakawa and Matsumiya, 1997), according to the procedure implemented in the SAMED project (2002). For the years 1998 and 1999 parameters were estimated using only information from MEDITS, while year 2002 parameters were approximated from a pseudo-cohort approach. The estimates of total mortality *Z* were performed considering that a full recruitment to the fishery was occurring at age 1. The variability of the curvature parameter *K* and of the asymptotic length L_∞ (approximated at ±2.5%) was incorporated in the population model, while the value of t_0 was fixed.

Recruitment indices were derived from the first components of the identified cohorts projected backward according to the estimated *Z* rates. In order to obtain a guess approximation of total recruitment, each index was extrapolated to the area most likely occupied by the recruits (shallower strata), assuming a survey catchability coefficient equal to 1.

Length at first maturity ($Lm_{50\%}$=135 mm; $Lm_{25\%}$-$Lm_{75\%}$=30 mm) and size at first capture ($L_{50\%}$=89 mm; $L_{25\%}$-$L_{75\%}$=18 mm) proceeded respectively from SAMED project (2002) and from selectivity experiments conducted in the area (Lembo *et al.*, 2002). Inside the population model, random variations (±5%) were also associated to the maturity parameters.

The exploitation rate *E* from trawl survey data was computed as follows:

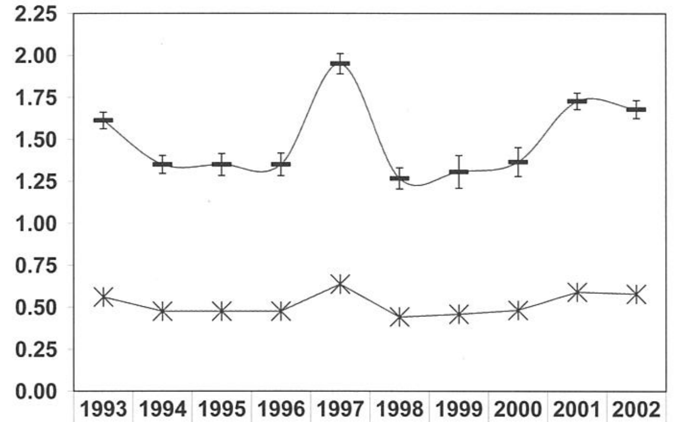
$$E = \frac{F}{Z} * (1 - e^{-Zt_\lambda})$$

where t_λ represents the exploitable life span of the species.

The status of *M. barbatus* stock was thus modelled, accounting for variability and uncertainty through fluctuations of the growth parameters, recruitment and maturity. Ten different scenarios, based on the detected changes of total mortality *Z* (Fig. 1) in the different identified cohorts from 1993 to 2002 were simulated. The relationships between BRPs and indicators derived from the model and from trawl-surveys were analysed by regressions, testing the correlation coefficients *r*.

Results

Total mortality of the cohorts from 1993 to 2002 are shown in Fig. 1. The average curvature parameter *K* was 0.445 (overall range: 0.38-0.51), while the asymptotic length L_∞ was from 268 to 282 mm and t_0 fixed at -0.2. The value of the natural mortality M_{input}, strictly correlated to *K*, was 0.71 and the error associated in partitioning M_{input} over the length classes was from 0.03 to 0.07%. The total mortality *Z* varied from 1.27 to 1.95 (overall range: 1.0-2.21) and changes of the exploitation rate *E* were from 0.44 to 0.64 (Fig. 1).



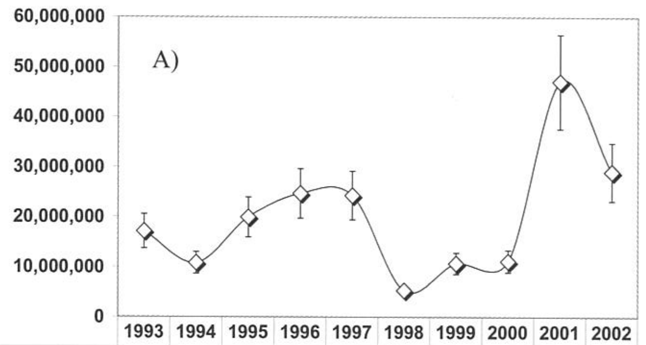
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
avg. Z (year)	1.61	1.35	1.35	1.35	1.95	1.27	1.31	1.37	1.73	1.68
E	0.56	0.48	0.48	0.48	0.64	0.44	0.46	0.48	0.59	0.58

Fig. 1 - Average total mortality (Z) with associated standard deviation and exploitation rate (E) estimated for the cohorts from 1993 to 2002 from trawl survey data.

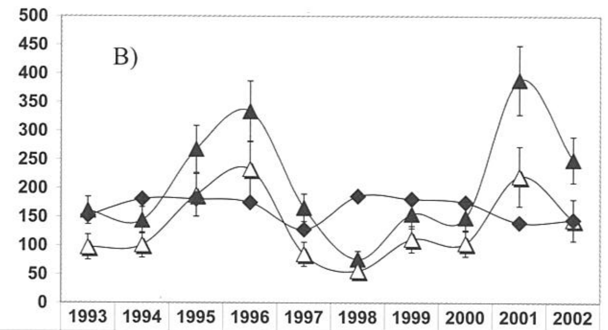
Mortalità totale (Z) con deviazione standard e tasso di sfruttamento (E) stimati per le coorti dal 1993 al 2002 sulla base di dati di trawl survey.

Very high fluctuations were observed in the recruitment (Fig. 2A) whose abundance was strictly correlated with the combination of two factors: the numerousness of the second modal component of the different cohorts, ranging from 139 to 1345 individuals/km², and the rate of total mortality acting on the cohort. The highest recruitment strength was thus observed in 2001 and the lowest in 1998 (Fig. 2A).

The following coefficients were obtained for the linearized length-weight relationship: intercept *a*=0.000011, slope *b*=3.025.



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
avg. R (number)	17,13	10,83	19,95	24,69	24,30	5,302	10,72	11,13	47,08	29,04



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
avg. B (t)	161	144	268	334	166	76	155	149	389	250
avg. SSB (t)	97	101	188	233	85	56	111	104	221	145
TLCr (mm)	152	181	181	175	128	186	181	175	140	145

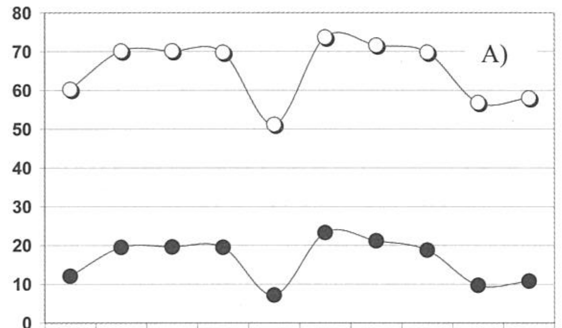
Fig. 2 - Average number of recruits (A) and outputs of the pool dynamic model (B) of the cohorts from 1993 to 2002. Standard deviations of average standing biomass (avg. B in tons) and average spawning standing biomass (avg. SSB in tons) are represented. The value of the size at which each cohort reaches its maximum biomass (TLCr in mm) is also reported.

Numero medio di reclute (A) e risultati del pool dynamic model (B) per le coorti dal 1993 al 2002. Sono indicate le deviazioni standard dello stock stazionario (avg. B in tonnellate) e dello stock stazionario di riproduttori (avg. SSB in tonnellate). E' inoltre riportato il valore (in mm) della taglia alla quale la coorte raggiunge il suo massimo in termini di biomassa (TLCr).

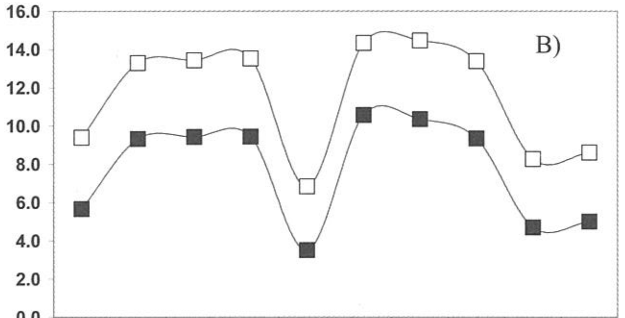
The model results showed the lowest values of the ratio *SSB/SSBV* (7.2%, Fig. 3A) and *TLCr* (128 mm; Fig. 2B) for the cohort of 1997, as consequence of the highest *Z*, as an index of exploitation. All the related parameters, such as the ratio of the spawning stock biomass/total biomass (*SSB/B*=51%; Fig. 3A), the biomass per recruit and the spawning stock biomass per recruit (*B*/*R*=6.8 g, and *SSB*/*R*=3.5 g; Fig. 3B) were the lowest, whereas the average total biomass (*B*=166 tons; Fig. 2B) was comparable to that of the other cohorts, as consequence of recruitment compensation (Fig. 2A). Regarding the exploitation indicators, a similar situation was observed for the cohort of 2001 (*SSB*/*SSBV*=10%; *SSB*/*B*=57%; *TLCr*=140 mm; *B*/*R*=8.3 g; *SSB*/*R*=4.7 g), although in this case the highest biomass occurred (*B*=389 tons) due to the recruitment strength.

Conversely, the safest condition was observed for the cohort of 1998 when the lowest total mortality was acting (*Z*=1.27). In this case, the highest ratio of *SSB*/*SSBV* (23%) and the maximum *TLCr* (186 mm) occurred, although the total biomass and the spawning stock biomass were the lowest (76 and 56 tons) in coincidence with the poorest recruitment.

For the other cohorts intermediate conditions were observed.



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
-○- SSB/B (%)	60	70	70	70	51	74	72	70	57	58
-●- SSB/SSBV (%)	12.1	19.5	19.6	19.5	7.2	23	21	19	10	11



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
-□- B/R (g)	9.4	13.3	13.4	13.5	6.8	14.3	14.5	13.4	8.3	8.6
-■- SSB/R (g)	5.7	9.3	9.4	9.4	3.5	10.6	10.4	9.3	4.7	5.0

Fig. 3 - Outputs of the pool dynamic model for the cohorts from 1993 to 2002: ratios between the current spawning stock biomass, the biomass (SSB/B in percentage) and the unfished spawning stock biomass (SSB/SSBV in percentage) (A); biomass per recruit (B/R in grams) and spawning stock biomass per recruit (SSB/R in grams) (B).

Risultati del pool dynamic model per le coorti dal 1993 al 2002: rapporti fra la biomassa dei riproduttori corrente, la biomassa totale (SSB/B, in percentuale) e la biomassa dei riproduttori non sfruttata (SSB/SSBV, in percentuale) (A); biomassa per recluta (B/R in grammi) e biomassa dei riproduttori per recluta (SSB/R in grammi) (B).

The analysis of the relationships between the different BRPs of the stock state derived from the model (*SSB*/*SSBV*, *SSB*/*B*, *B*/*R*) and directly from trawl survey results (*E*) (Fig. 4) highlights consistency in the model outputs and significant linear correlations ($p<0.05$) among the identified BRPs.

The information gathered by this analysis enabled to estimate potential thresholds for the different BRPs and indicators describing the status of the red mullet stock in the studied area. More safe levels occurred when the ratios *SSB*/*SSBV* and *SSB*/*B* were respectively ~20% and ~70%, corresponding to a *B*/*R* of 13-14 g and to an exploitation rate of ~0.5. Conversely, alarm situation could rise when *SSB*/*SSBV* and *SSB*/*B* are respectively lower than 15% and 60%, corresponding to a *B*/*R* less than ~10 g and to an exploitation rate higher than 0.55.

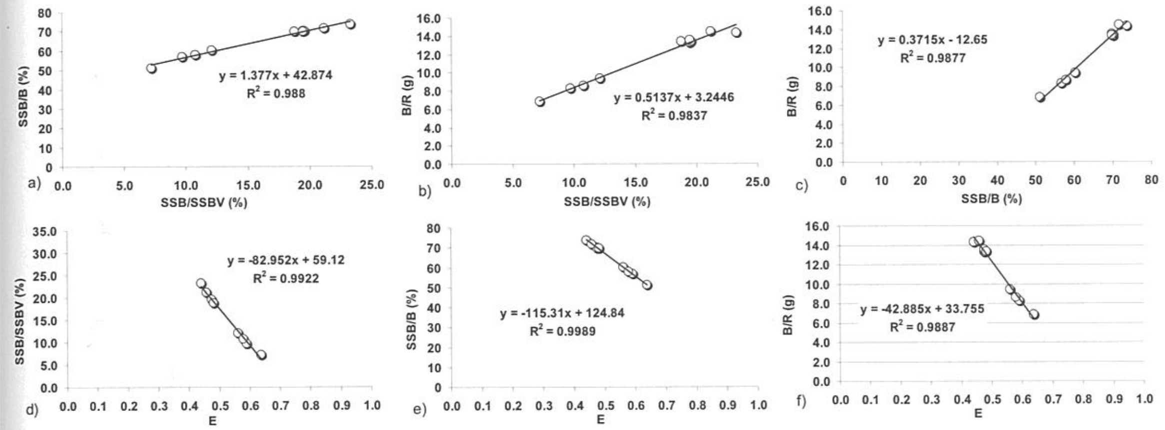


Fig. 4 - Relationships between the indicators and reference points derived from the trawl surveys (E) and the pool dynamic model.

Relazioni fra indicatori stimati sui dati di trawl survey (E) e reference points stimati mediante l'applicazione di un pool dynamic model.

Conclusions

The most commonly applied stock assessment method to date is the Virtual Population Analysis (VPA) by which catch at age data and estimates of natural mortality are used to reconstruct cohorts, and consequently total numbers and biomass of fish at all ages over the period for which data are available (Hilborn and Walters, 1992).

In the Mediterranean, however the multispecific-multigear characteristics of most fisheries, the extremely dispersed landing sites, the small fraction of the catch that generally passes through organised fish markets (Lleonart and Maynou, 2003), make catch assessments in the area particularly difficult. In this situation VPA and similar techniques might provide biased estimates of the number at sea of younger ages due to undetected increases in mortality along the time, erroneous data of catches at age and of *F* or *M* estimates. Thus, most of the knowledge on the status of exploitation pattern of the demersal resources has been acquired by bottom trawl surveys, sampling the population at sea instead of the catches (Megrey, 1989). This approach also presents several limitations for the following main reasons: possible partial coverage of the area inhabited by the stock, high variability in the estimates, availability of the different fractions of the population to the trawl net, and timing of the survey which ultimately might imply incomplete sampling of all the population stages.

As regards the red mullet, however, the different age classes are similarly vulnerable to the trawl. In addition, in our case the timing of the surveys covered the occurrence of both recruits and spawners. Thus we assumed that the survey catches could be considered a proxy of the population at sea. Under this assumption, spawning stock biomass and exploitation rate were considered as BRPs and indicators of the fishing pressure on the stock.

Spawning-per-recruit measures are often used to estimate the impact of fishing (Parkes, 2000; Jennings *et al.*, 2001). Ideally, a spawning-per-recruit measure would keep track of per-recruit production of larvae or eggs (Jennings *et al.*, 2001). However, spawning stock biomass per recruit (*SSB/R*) is commonly used to estimate the reproductive output per recruit at different levels of fishing pressure.

Reference points that have gained prominence as proxies or independent measures of targets and limits are those based on fishing mortality at given levels of spawning stock ($F_{\%SPR}$). In particular, values in the range from $F_{20\%}$ to $F_{30\%}$ have frequently been used to characterize recruitment overfishing thresholds. The former was considered as a recruitment overfishing threshold for well-known stocks with at least average resilience, while the latter as a recruitment overfishing threshold for less well-known stocks or those believed to have low resilience (Gabriel and Mace, 1999).

Given the life history traits of the red mullet and the results from the population model, we estimated that safe levels occurred when the ratios *SSB/SSBV* and *SSB/B* were respectively higher than ~20% and 70%, corresponding to *B/R* of 13-14 g and to an exploitation rate *E* of ~0.5. Conversely, alarm situation could rise when *SSB/SSBV* and *SSB/B* are respectively lower than 15% and 60%, corresponding to a *B/R* less than ~10 g and to an exploitation rate higher than 0.55.

Die and Caddy (1997) suggested several simple reference points (e.g. Z*) that can be formulated as inequalities. These follow from the assumption that a precautionary reference point is one allowing the cohort a reasonable probability of spawning at least once before capture.

The consistency in the outputs from the model simulations and the significant correlations among the identified BRPs allow to point out that the ratio between spawning stock biomass and total biomass (*SSB/SSBV*, *SSB/B*) and exploitation rate *E* were suitable and simple indicators (Norris, 1991; Froese, 2004), for evaluating the state of the stock and ultimately suggesting management measures. The usefulness of BRPs like *SSB/B* and *E* rely also upon the fact that they can be defined using a rather comprehensible concepts such as: leave enough spawners to allow the stock to reproduce.

In the Mediterranean, where an adaptive management is not implemented, the BRPs based on the spawning stock biomass should not be viewed as levels for calibrating recommended TAC (Hilborn, 2003), but more as indicators to be monitored for adjusting management measures aimed at the reduction of mortality and protection of the recruits.

Caddy (1993) after categorising three main groups of demersal species (fish with large size at first maturity captured much before the first spawning, e.g. hake, angler fish, etc.; species such as red mullet or Norway lobster that require at least a stretched mesh size of 40 mm; small species such as shrimps, cephalopods, gobies, etc., which could be completely lost increasing mesh size from 40 mm) concluded that the increasing of the mesh size, even to 60-70 mm, could be not effective in protecting the spawners of the "large fish" making, conversely, unavailable the "small species". Thus, the effort should be reduced, and this measure should be complemented with the protection of young fish from exploitation and the protection of spawning stocks from the effects of extensive fishing.

Suitable management options for a sustainable fishery could be consequently represented by the enforcement of the areas and temporal closure, where and when the recruits are concentrated, i.e. shallower waters and summer season for the red mullet.

In our analysis multispecies and multigears factors were not considered. Although the limitations inherent a single species approach, the state of the red mullet stock could be viewed as a part of a more composite frame of BRPs and indicators such as the traffic light approach (Caddy, 1999, 2002). In addition, evaluation regarding inshore fish like red mullet might be also indicative of the fishing pressure exerted on the continental shelf, where this species represents one of the most important fishery target.

References

AA.VV. (2000) - *Fishing down the Mediterranean food web*? Ciesm Workshop series, **12**: 99 pp.

BERTRAND J.A., GIL DE SOLA L., PAPACONSTANTINOU C., RELINI G., SOUPLET A. (2002) - The general specifications of the MEDITS surveys. In: Abelló P., Bertrand J.A., Gil de Sola L., Papaconstantinou C., Relini G. and Souplet A. (eds), *Mediterranean Marine Demersal Resources: the MEDITS International Trawl Survey* (1994-1999). *Sci. Mar.*, **66** (Suppl. 2): 9-17.

CADDY J.F. (1993) - Some future perspectives for assessment management of Mediterranean fisheries. *Sci. Mar.*, **57** (2-3): 121-130.

CADDY J.F. (1999) - Deciding on Precautionary Management Measures for a Stock Based on a Suite of Limit Reference Points (LRPs) as a Basis for a Multi-LRP Harvest Law. *NAFO Sci. Coun. Studies*, **32**: 55-68.

CADDY J.F. (2002) - Limit reference points, traffic lights, and holistic approaches to fisheries management with minimal stock assessment input. *Fish. Res.*, **56**: 133-137.

CADDY J.F., MAHON R. (1995) - Reference points for fisheries management. *FAO Fish. Tech. Pap.*, **347**: 83 pp.

CHRISTENSEN V, PAULY D. (1992) - ECOPATH II-a software for balancing steady-state models and calculating network characteristics. *Ecol. Modelling*, **61**: 169-85.

DIE D.J., CADDY J.F. (1997) - Sustainable yield indicators from biomass: are there appropriate reference points for use in tropical fisheries? *Fish. Res.*, **32**: 69-79.

FAO (1995) - Precautionary approach to fisheries. Part 1: Guidelines on the precautionary approach to capture fisheries and species introductions. *FAO Fish. Tech. Pap.*, **350** (Part 1): 52 pp.

FAO (1999) - *Indicators for sustainable development of marine capture fisheries*. FAO Technical Guidelines for Responsible Fisheries, 8. FAO, Rome: 68 pp.

FOURNIER D.A., SIBERT J.R., MAJKOWSI J., HAMPTON J. (1990) - MULTIFAN a likelihood-based method for estiating growth parameters and age composition for multiple length frequency data sets ilustrated using data for southern bluefin tuna *(Thunnus maccoyii)*. *Can. J. Fish. Aquat. Sci.*, **47**: 301-317.

FROESE R. (2004) - Keep it simple: three indicators to deal with overfishing. *Fish and Fisheries*, **5**: 86-91.

GABRIEL W.L., MACE P.M. (1999) - A Review of Biological Reference Points in the Context of the Precautionary Approach. In: Restrepo V.R. (ed), *Proceedings of the 5th NMFS National stock assessment workshop: providing scientific advice to implement the precautionary approach under the Magnuson-Stevens Fishery Conservation and Management Act*. NOAA Tech. Memo. NMFS-F/SPO-40: 34-45.
GARCIA S.M., STAPLES D.J., CHESSON J. (1999) - The FAO Guidelines for the development and use of indicators for sustainable development of marine capture fisheries and an Australian example of their application. *ICES CM 1999/P*: 5 pp.
GRECO S., RINELLI P., GIORDANO D., PERDICHIZZI F. (1998) – Valutazione delle risorse demersali da Capo Suvero a san Vito lo Capo (Tirreno Meridionale). *Biol. Mar. Medit.*, **5** (3): 74-84.
JENNINGS S., KAISER M.J., REYNOLDS J.D. (2001) - *Marine Fisheries ecology*. Blackwell Science, Oxford: 417 pp.
HILBORN R. (2003) - The state of the art in stock assessment: where we are and where we are going. In: Ulltang, Ø and G. Blom (eds), *Fish stock assessments and predictions: Integrating relevant knowledge*. *Sci. Mar.*, **67** (Suppl. 1): 15-20.
HILBORN R., WALTERS C.J. (1992) *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall, New York: 570 pp.
IREPA (2003) - *Osservatorio economico sulle strutture produttive della pesca marittima in Italia 2001-2002*. Franco Angeli s.r.l. Milano, Italy, IREPA Ricerche: 343 pp.
LEMBO G., CARBONARA P., SILECCHIA T., SPEDICATO M.T. (2002) – *Prove di pesca a strascico con rete a doppio sacco per la valutazione della selettività dell'attrezzo e della qualità del prodotto*. I quaderni scientifici della Lega Pesca, Roma: 1-47.
LLEONART L., MAYNOU F. (2003) - Fish stock assessments in the Mediterranean: State of the art. In: Ulltang, Ø and G. Blom (eds), *Fish stock assessments and predictions: Integrating relevant knowledge*. *Sci. Mar.*, **67** (Suppl. 1): 37-49.
LLEONART J., SALAT J. (1997) - *VIT: Software for fishery analysis. User's manual*. FAO Computerised Information Series. Fisheries, **11**: 107 pp.
MACE P.M. (1994) - Relationships between common biological reference points used as threshold and targets of fisheries management strategies. *Can. J. Fish. Aquat. Sci.*, **51**: 110-122.
MEGREY B.A. (1989) - Review and comparison of age-structured stock assessment models from theoretical and applied points of view. *American Fisheries Society Symposium*, **6**: 8-48.
NORRIS J.G. (1991) - Further perspectives on Yield per Recruit Analysis and Biological Reference Points. *Can. J. Fish. Aquat. Sci.*, **48**: 2533-2542.
PARKES G. (2000) - *Understanding SPR and its use in U.S. fishery management*. Center for marine conservation, Washington D.C.: 62 pp.
PITCHER T.J. (1999) - Rapfish, a rapid appraisal technique for fisheries, and its application to the Code of Conduct for Responsible Fisheries. *FAO Fish. Circ.*, **947**: 47 pp.
POPE J.G. (1991) - The ICES Multispecies Assessment working Group: evolution, insights and future problems. *ICES Mar Sci. Symp.*, **193**: 22-33.
POPE J.G., MACDONALD D.S., DAAN N., REYNOLDS J.D., JENNINGS S. (2000) - Gauging the impact of fishing mortality on non-target species. *ICES J. Mar. Sci.*, **57**: 689-696.
PRAGER M.H., PORCH C.ED., SHERTZER K.M., CADDY J.F. (2003) - Targets and limits for management of fisheries: a simple probability-based approach. *N. J. Fish. Man.*, **23**: 349-361.
RELINI G. (2000) – La ricerca sulla pesca: le risorse demersali. *Biol. Mar. Medit.*, **7** (4): 13-45.
RESTREPO V.R., THOMPSON G.G., MACE P.M., GABRIEL W.L., LOW L.L., MACCALL A.D., METHOT R.D., POWERS J.E., TAYLOR B.L., WADE P.R., WITZIG J.F. (1999) - Technical guidance on the use of precautionary approaches to implementing national standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Tech. Memo. NMFS-F/SPO-31: 54 p.
ROCHET M.J., TRENKEL V.M. (2003) - Which community indicators can measure the impact of fishing: a review and proposals. *Can. J. Fish. Aquat. Sci*, **60**: 86-99.
SAMED (2002) - *Stock Assessment in the Mediterranean*. Final Report EU Project n° 99/047.
SANDERS M.J. (1995) - Introduction to Thompson and Bell Yield analysis using EXELl spreadsheets. *FAO Fish. Circ.*, **895**: 21 pp.

SMITH S.J., HUNT J.J., RIVARD D. (1993) - *Risk evaluation and biological reference point for fisheries management*. Canadian Special Publication of Fisheries and Aquatic Sciences, **120**: 442 pp.
SPARRE P. (1991) - Introduction to multispecies virtual population analysis. *ICES Mar. Sci. Symp.*, **193**: 12-21.
SPEDICATO M.T., LEMBO G., CARBONARA P., SILECCHIA T. (1998) – Valutazione delle risorse demersali dal Fiume Garigliano a Capo Suvero. *Biol. Mar. Medit.*, **5** (3): 64-73.
TSERPES G., FIORENTINO F., LEVI D., CAU A., MURENU M., ZAMBONI A., PAPACONSTANTINOU C. (2002) - Distribution of *Mullus barbatus* and *M. surmuletus* (Osteichthyes: Perciformes) in the Mediterranean continental shelf: implications for management. In: Abelló P., Bertrand J. A., Gil de Sola L., Papaconstantinou C., Relini G., Souplet A. (eds), *Mediterranean Marine Demersal Resources: the MEDITS International Trawl Survey (1994-1999)*. *Sci. Mar.*, **66** (Suppl. 2): 39-54.
WALTERS C.J. (1998) - Designing fisheries management systems that do not depend on accurate stock assessment. In: Pitcher T. J., Hart P.J.B. & Pauly D. (eds), *Reinventing Fisheries Management*. Chapman & Hall, London: 279-288.
WALTERS C., PAULY D., CHRISTENSEN V., KITCHELL J.F. (2000) - Representing Density Dependent Consequences of Life History Strategies in Aquatic Ecosystems: EcoSim II. Ecosystems, **3**: 70-83.
YAMAKAWA T., MATSUMIYA Y. (1997) - Simultaneous analysis of multiple length frequency data sets when the growth rates fluctuate between years. *Fisheries Science*, **63** (5): 708-714.

The data reported in this paper were collected within research projects funded by the Italian Ministry of Agriculture Policy and the European Commission.