Changes in spawning-stock structure and recruitment pattern of red mullet, Mullus barbatus, after a trawl ban in the Gulf of Castellammare (central Mediterranean Sea)


The increase in biomass of red mullet, Mullus barbatus, in the Gulf of Castellammare (northwestern Sicily, central Mediterranean) after a 14-year trawl ban, prompted us to compare the spawning-stock structure and the recruitment pattern before and after the closure. Datasets obtained from three experimental trawl surveys were available before the ban (April and September 1985; April–May 1986) and four post-ban (September and November 2004; March and May 2005). Spawning-stock biomass increased significantly after the ban. Moreover, females at depths >50 m in the post-ban period were larger than those collected before the ban at the same depth. The recruitment pattern of the population also changed. Notably, recruit numbers increased and recruitment occurs over a broader period. The increase in biomass after the trawl ban seems to be the result of a combination of different processes, mainly associated with the lowering of fishing mortality. A positive trend in sea surface temperature in the area may have played a role too.

Keywords: Mediterranean Sea, recruitment, red mullet, size structure, spawning-stock biomass, trawling ban.

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Introduction

Fishing mortality affects the abundance and the size and age structure of exploited fish populations, leading to changes in spawning-stock structure and recruitment (Beverton and Holt, 1957; Ricker, 1975; Rothschild, 1986; Cushing, 1988; Hilborn and Walters, 1992). Despite the number and the complexity of the processes involved, fisheries management has typically addressed issues concerned with maintaining the minimum spawning-stock biomass (SSB), believed necessary to ensure population persistence, and largely disregarded issues related to the age structure of the spawners (Mace and Sissewine, 1993; Mace, 1994; Myers et al., 1994). However, in the past decade, several studies on groundfish have described a significant increase in the survival of eggs and larvae with female age and size (Trippel et al., 1997; Marteinsdottir and Steinarsson, 1998; Vallin and Nissling, 2000; Berkeley et al., 2004a), suggesting that SSB alone may be a biased index of the reproductive potential of fish stocks, because it does not take account of the maternal effects on egg quality (Scott et al., 1999; Rochet, 2000; Secor, 2000; Murawski et al., 2001). Therefore, many authors have recognized that a spawning stock that contains a broad age composition and allows females to spawn repeatedly over several years is likely to give better renewal capabilities than an equivalent spawning biomass of recently matured fish (Rochet, 2000; Caddy and Seijo, 2002; Longhurst, 2002; Birkeland and Dayton, 2005; Fromentin, 2006).

Berkeley et al. (2004b) argue that spatially explicit management measures provide the best means of allowing sufficient female spawners to survive and to attain large size and old age. In particular, they suggest that a network of closed fishing areas distributed over the entire geographic range of a stock would be the most effective tool in maintaining spatial and temporal diversity of spawning.

In recent years, marine protected areas have been established in many parts of the world in a determined attempt to help over-exploited resources recover by reducing fishing mortality (Guénette et al., 1998; Lauck et al., 1998; Sumaila et al., 2000; Jaworski et al., 2006). The main benefits expected from total or partial fishery closures include habitat protection which may indirectly enhance survival, an increase in biomass, body size, spawning-stock size, age diversity, and the reproductive output of exploited species (Guénette and Pitcher, 1999; Gell and Roberts, 2002; Jones, 2002). A common way to demonstrate these benefits is to contrast data from a given area before and after protection, and/or data collected in protected and fished areas with similar habitat characteristics (Jaworski et al., 2006).

An opportunity to apply a before/after approach was provided by the Gulf of Castellammare fishery reserve (northwestern Sicily, central Mediterranean Sea), where an increase in the trawlable biomass of most demersal species was reported 4 years after trawling was banned (Pipitone et al., 2000) and was observed also in

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subsequent years (Pipitone et al., 2007). In particular, the biomass of red mullet, *Mullus barbatus*, a major target species for Mediterranean fisheries (Tserpes et al., 2002) recovered remarkably, with a mean 32-fold increase 4 years after the ban (Pipitone et al., 2000).

This recovery is analysed further here, because it is unlikely attributable to a simple increase in the biomass-per-recruit expected from a lower harvest rate. One can hypothesize that an increase in recruitment took place through improvements in the spawning-stock size and structure (biomass and size/age composition). According to the literature, the red mullet is a batch-spawner (Menini et al., 2001), reproducing from April to July or later (Voliani, 1999), when the bulk of the spawning stock is 1 year old [total length (TL) range: 120–150 mm for females, and 110–135 for males]. Fish recruit to inshore sandy substrata from late summer to early autumn after a pelagic post-larval phase, then gradually disperse towards greater depth (Voliani, 1999).

Our main objective here is to assess whether and how the biomass and the size structure of the spawning stock and the recruitment pattern of red mullet in the Gulf of Castellammare have changed after trawling was banned.

**Material and methods**

**Study area and fisheries**

The Gulf of Castellammare (~400 km²) lies in northwestern Sicily, Mediterranean Sea (Figure 1). Most of the seabed of the gulf is muddy or sandy mud, so making it a suitable habitat for red mullet. The gulf hosted an important demersal fishery in the past, but in 1990 the use of trawlnets and all other bottom-towed gears was banned over an area of ~200 km², covering the whole continental shelf and part of the upper slope (Regional Act no. 25/1990). The closed area was established to resolve conflicts between trawlers and artisanal fishers (small boats <12 m overall length and 10 grt deploying gillnets, trammel-nets, longlines, and traps), as well as to recover depleted demersal stocks (Pipitone et al., 2000).

Recent information (Crescimanno and De Stefano, 2003) reports 77 artisanal vessels based inside the gulf and fishing in the no-trawl area, whereas before the ban, 175 artisanal vessels and 15 trawlers operated totally or partially inside the gulf. Since the ban, four trawlers have left the fishery totally, and the others have moved outside the protected area to seek red shrimp in deeper water.

**Data**

Datasets obtained from experimental trawl surveys (Pipitone et al., 2000) were available to compare catch rates and the population structure of the fishery reserve in the pre- and post-ban periods. The results of three surveys from before the ban were available (April and September 1985; April–May 1986; Source: Italian National Programme for the Assessment of Demersal Resources funded by the Italian Ministry of the Merchant Navy), and four post-ban (September and November 2004; March and May 2005; Source: Study no. 63/2004 funded by the Italian Ministry of University and Research). However, we stress that the surveys were not designed with the present comparison in mind and that consequently there are both similarities and some differences in survey technique between the two periods.

All surveys were of a stratified random sampling design, based on three depth strata: A (10–50 m), B (51–100 m), and C (101–200 m), with the number of hauls proportional to the surface of each stratum (Pipitone et al., 2000; Figure 1). The pre-ban surveys were all made with FV “La Cara Madre” (34.86 grt, 110 hp), which completed 11 × 60-min trawls on each survey. The post-ban surveys were made with FV “Giaguaro” (40.1 grt, 160 hp), which carried out 24 × 30-min trawls during each survey. All surveys were carried out at the same towing speed (2.5 knots) and using similar traditional Italian otter trawls (low vertical opening) with a mesh size of 18 and 20 mm (pre- and post-ban, respectively) in the codend, allowing catches of small fish (Table 1). As the differences in the main factors affecting the catch of the two vessels (engine power, headline, and bridle) do not produce different fishing power (Auteri et al., 1990), a simple standardization based on the net wingspread was applied to the pre-ban catches to make them comparable with post-ban catches (D’Anna and Badalamenti, 1995).

Red mullet, either the whole catch or representative subsamples (1/2 or 2/3), were weighed to the nearest gramme and measured (TL) to the 0.5-cm below. Fish from the post-ban surveys were sexed, and maturity was allocated according to the 5-stage scale of Holden and Raft (1974). Otoliths were extracted for age determination.

Abundance and biomass indices by haul were computed and expressed in terms of number and weight per 30-min haul. Experience gained from Mediterranean trawl surveys has shown that biomass indices of red mullet have been higher when estimated from 60-min hauls than from 30-min hauls (Fiorentini et al., 1996). Therefore, our selection represents a conservative approach in evaluating the positive effects of the trawling ban. Abundance by size was further normalized to 20 hauls per survey to allow direct comparison of length frequency distributions (LFDs).

**Data analysis**

SSB indices by haul in the post-ban spring survey of May 2005 were obtained directly by summing the weights of mature (stage 4) females. This approach could not be used for the pre-ban spring surveys (April 1985 and April/May 1986), because no data on sex and maturity were available for that period. SSB indices by haul in the pre-ban surveys were therefore reconstructed based on the following three-step procedure: (i) the number of females by size class was isolated from the sex-combined pre-ban LFDs, using a sex ratio vector (number of females/number of fish sexed) computed with data collected from 1994 to 1999 in northern Sicily, with trawling effort and a selectivity pattern similar to the pre-ban scenario of the Gulf of Castellammare (source: SAMED, 2002; Figure 2a); (ii) the number of mature females by size class was computed using four maturity ogives obtained from the same Geographical Subarea (GSA 10 – southern Tyrrhenian, as established by the General Fishery Commission of the Mediterranean, GFCM; ogive 1, 1994–1996; ogive 2, 1997–1999; ogive 3, 2000–2002; ogive 4, 2003–2004; Figure 2b; M. T. Spedicato, pers. comm.); (iii) abundance indices of mature females by size class were transformed to SSB indices by haul using a length/weight relationship computed with pre-ban data. Four pre-ban SSB indices were computed, using each maturity ogive separately, but for further analysis we selected the ogive that gave the most optimistic view of the pre-ban situation (i.e. the 1997–1999 ogive, which produced the highest SSB index).
The equation used is the classical

\[ \text{Mat}(L) = \frac{1}{1 + e^{-r(L-L_{50\%})}} \]

where \( r \) is the ogive slope \((-1.30 \pm 0.20)\), and \( L_{50\%} \) (10.3 \( \pm \) 0.41) is the TL (cm) at which 50\% of females are mature.

The differences between pre- and post-ban indices of SSB between depth strata were compared by one-way ANOVA, with

Table 1. Main characteristics of the traditional otter trawl gears used in the pre- (La Cara Madre) and post-ban (Giaguaro) surveys.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>La Cara Madre</th>
<th>Giaguaro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Otter board (m²)</td>
<td>1.04</td>
<td>1.68</td>
</tr>
<tr>
<td>Headline (m)</td>
<td>32</td>
<td>31.3</td>
</tr>
<tr>
<td>Bridle (m)</td>
<td>152</td>
<td>162</td>
</tr>
<tr>
<td>Groundrope (m)</td>
<td>44</td>
<td>41</td>
</tr>
<tr>
<td>Floats (number)</td>
<td>60</td>
<td>43</td>
</tr>
<tr>
<td>Float diameter (mm)</td>
<td>n/a</td>
<td>110</td>
</tr>
<tr>
<td>Lead weight (kg)</td>
<td>40</td>
<td>24</td>
</tr>
<tr>
<td>Mesh opening at codend (stretched mesh size, mm)</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Mesh opening at wings (stretched mesh size, mm)</td>
<td>50</td>
<td>58</td>
</tr>
<tr>
<td>Mean wingspread (m)</td>
<td>10 (estimated)</td>
<td>11.9 (measured)</td>
</tr>
<tr>
<td>Mean vertical opening (m)</td>
<td>n/a</td>
<td>0.77</td>
</tr>
</tbody>
</table>

n/a, not available.

The differences between pre- and post-ban indices of SSB between depth strata were compared by one-way ANOVA, with
a significance level ($p$) of 0.05. Cochran’s $C$-test was performed to check for homogeneity of variance (Underwood, 1997) after log($x + 1$) data transformation. Pre-ban spring surveys were combined to increase the number of hauls available for analysis. The median length of mature females in each stratum before and after the ban was compared between spring surveys with the Kruskal–Wallis non-parametric ANOVA, with a significance level set at $p < 0.05$. A non-parametric test was chosen because the variance was not homogenous before or after data transformation.

The size structure of the red mullet population before and after the ban was analysed to derive the recruitment pattern. The LFDs (sexes combined) from each survey were split into modal components using Bhattacharya’s method (Bhattacharya, 1967), as implemented in the FiSAT package (Gayanilo et al., 1996). To back-calculate the date of birth of juveniles for each post-ban survey, the sagittae of $\sim$25 fish belonging to the first modal length class in each LFD ($n = 98$) were used for daily micro-increment analysis, according to Santana et al. (2006).

**Results**

There was a significant increase in SSB after the ban, over the whole area: stratum A ($F_{1,10} = 30.857$, $p = 0.00002$); stratum B ($F_{1,15} = 15.221$, $p = 0.00142$); and stratum C ($F_{1,14} = 10.315$, $p = 0.00627$; Figure 3).

Comparison of median lengths by stratum before and after the trawl ban revealed a significant difference between strata B and C because of an increase in the number of large fish (Figure 4; Kruskal–Wallis test: $H = 10.08$, $p = 0.0015$ in stratum B; $H = 12.829$, $p = 0.0003$ in stratum C).

**Size structure of the population, and the recruitment pattern**

The pre-ban LFDs appear to have been unimodal in the reproductive season (April 1985; April–May 1986), although two adult components can be identified (Figure 5a). The first component (mean TL $\sim$130 mm) dominated in terms of abundance (Table 2). Recruits (mean TL 83 mm) were present only in September, and for that survey, the LFD was again virtually unimodal, but with a long tail on the right side (Figure 5a; Table 2).

**Discussion and conclusions**

Following the ban on trawling, there was a notable change in the abundance and structure of the red mullet stock in the Gulf of Castellammare. Although our sampling design lacked spatial controls and the differences calculated refer only to the periods before and after the trawling ban, we believe that the increase in biomass we recorded should be attributed mainly to the effect of protection afforded to the stock with the ban on trawling. Indeed, one clear effect of the ban on red mullet biomass in the gulf has been demonstrated by Badalamenti et al. (in press), who adopted a BACI (before-after-control-impact; Green, 1979) approach to support a cause–effect relationship between protection and biomass increase that corroborates our findings on SSB. According to Badalamenti et al. (in press), there were no differences between pre-ban data in the Gulf of Castellammare and in a fished control area and between pre- and post-ban data in the control area. Significant differences were found instead between the two areas after the ban and between pre- and post-ban data in the no-trawl area.
The changes we found in the spawning stock were both quantitative and qualitative. Indeed, there was a significant increase in SSB in the whole area and in fish size at depths between 50 and 200 m, after the closure. We do acknowledge that the use of data from adjacent trawled areas to reconstruct the pre-ban spawning-stock structure is a weak point in our analysis. Nevertheless the indices of SSB we obtained using different maturity ogives produced similar values, indicating limited dependence on the ogives we used.

Beside SSB, the size structure and the recruitment pattern of the red mullet population have changed. Recruitment, in particular, has increased, and it has spread over a longer period. Before the
Mediterranean stocks of red mullet (Levi et al., 1997; Voliani, 1999; Tserpes et al., 2002), is slower than that of first-time spawners (Trippel, 1995). In addition, laboratory studies on batch-spawners have shown that the duration of batch spawning by second-time spawners is nearly twice as long as that of first-time spawners (Trippel, 1995). Finally, larvae derived from the eggs of older females are larger, grow faster, and tend to survive better than the larvae derived from younger spawners (Marteinsdottir and Steinarsdottir, 1998; Vallin and Nissling, 2000; Berkeley et al., 2004a), and this can have major implications for recruitment success.

It is likely that the changes recorded in the abundance and length/age structure of the spawning stock have led to an increase in the spatial and temporal dispersion of eggs and larvae, which in turn have produced a large reproductive reservoir and resulted in an extension of the recruitment period (Hutchings and Myers, 1993; Marteinsdottir et al., 2000). Further, the increased abundance of large spawners has probably improved larval and
there is some doubt that the micro-increments on the otoliths otolith readings supporting the plausibility of batch-spawning, in the female red mullet we examined. Despite the results of provide conclusive evidence of multiple spawning within a year temporal expansion of recruitment. A prolonged reproductive spawners, an increase in the abundance of large spawners, and a an increase in SSB, a broadening of the size composition of female trawling ban can be explained by a combination of different, exploring the contribution of temperature to the trend observed. Unfortunately, a lack of control areas (i.e. fished areas) in our sampling prevented us further complementary to the positive effect of the greater protection afforded to the stock with the trawling ban. We are grateful to Mauro Sinopoli, Massimiliano Giacalone, Giuseppe Di Stefano, and Angela Granzotto for their help during post-ban surveys, to Silvano Riggio and Mario Arculeo for making the pre-ban data available to us, and to Maria Teresa Spedicato for the maturity ogives. We also acknowledge two anonymous referees for their constructive comments on an earlier version of the manuscript. Finally, we thank John Pope and Marie-Joëlle Rochet for their time in reading and commenting on an earlier version of the manuscript.

In conclusion, the increase in red mullet biomass after the In addition to the change in fishing pressure after the trawling ban, environmental factors could have potentially favoured the red mullet in the Gulf of Castellammare. Levi et al. (2003) showed that the recruitment of red mullet in the Strait of Sicily (central Mediterranean) was positively influenced by warmer-than-average sea surface temperature (SST) during the prerecruitment phase. The same authors demonstrated that adding temperature anomalies to their model allowed them to explain \( \approx 80\% \) of the total variance in recruitment, whereas just \( 60\% \) was accounted for when only SSB was considered. More recently, Maravelias et al. (2007) reported that red mullet abundance in the Aegean Sea (eastern Mediterranean) was consistently higher in areas with warmer water near the seabed.

In the Gulf of Castellammare, SST during the prerecruitment phase June–August has increased significantly \( \left( r_{\text{pearson}} = 0.491; n = 20; p < 0.05 \right) \) between 1985 and 2004 (Figure 6). Hence, one could conclude that temperature has had a positive influence on the SSB of red mullet in the Gulf of Castellammare, perhaps supplementary to the positive effect of the greater protection afforded to the stock with the trawling ban. Unfortunately, a lack of control areas (i.e. fished areas) in our sampling prevented us further exploring the contribution of temperature to the trend observed.

In conclusion, the increase in red mullet biomass after the trawling ban can be explained by a combination of different, likely related, processes that include a decrease in fishing mortality, an increase in SSB, a broadening of the size composition of female spawners, an increase in the abundance of large spawners, and a temporal expansion of recruitment. A prolonged reproductive season would be consistent with our results, but we cannot provide conclusive evidence of multiple spawning within a year in the female red mullet we examined. Despite the results of otolith readings supporting the plausibility of batch-spawning, there is some doubt that the micro-increments on the otoliths are produced daily. Recent research suggests that the age of recruits may be underestimated for increments deposited at a rate of fewer than 1 per day, as a consequence of varying seasonal environmental conditions and food availability (Folkvord et al., 2000; Neuman et al., 2001). In the current case, though, we believe the changed recruitment pattern is the result of a complex of spatio-temporal issues that have impacted the stock.

**References**


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