*Journal of the Marine Biological Association of the United Kingdom*, 2014, 94(3), 631–640. 
doi:10.1017/S0025315413001884

# Evidence of trawling impact on *Hoplostethus mediterraneus* in the central–eastern Mediterranean Sea

S. VITALE[1], S. RAGONESE[1], L. CANNIZZARO[2], F. FIORENTINO[1] AND S. MAZZOLA[1]

[1]Institute for Marine and Coastal Environment–National Research Council (IAMC-CNR), Mazara del Vallo, via L. Vaccara, 61, I-91026 Mazara del Vallo, Italy, [2]Institute for Marine and Coastal Environment–National Research Council (IAMC-CNR), Capo Granitola, via del Faro, 3, I-91021 Campobello di Mazara, Italy

*The silver roughy,* Hoplostethus mediterraneus *is a benthopelagic cosmopolitan fish regularly caught as by-catch of the deep-water crustacean trawl fishery (CTF) in the central–eastern Mediterranean. Monthly samples of silver roughy were sampled from the catches of four commercial trawlers in 2004. Each trawler operated in different fishing grounds (FGs), located off Northern Tunisia, South of Sicily, Malta Islands and in South Levant, for which different exploitation levels are reported. The overall length–frequency distribution (LFD) was constructed, and fishing impact indices (length as percentage of LFD, optimum and maximum length, percentage of mega-spawners and total mortality/von Bertalanffy curvature ratio) were calculated. In spite of an overall acceptable status (juveniles, matures and mega-spawners were present in the catch), sampling data revealed significant differences in LFD shape and status indices between FGs. Those FGs traditionally considered more exploited (Northern Tunisia and South of Sicily) showed a dominance of juveniles, a rarefaction of mega-spawners, a reduction in maximum and asymptotic length and a higher Z/K ratio. Considering the general homogeneity of Mediterranean deep-water habitats, the pelagic dispersal of eggs and the poor swimming capabilities of silver roughy, the present results indicated that deep-water trawling may induce a slow and subtle, although significant, erosion of the older, late maturing and slow growing component of the stocks in the Mediterranean (so-called longevity-overfishing).*

**Keywords:** silver roughy, deep-water trawling, length structure, stock status, longevity overfishing, Mediterranean Sea

Submitted 11 July 2013; accepted 11 December 2013; first published online 16 January 2014

## INTRODUCTION

There is increasing evidence that many fisheries are exploiting more and more deeper waters (Morato *et al.*, 2006), resulting in a reduced abundance, biomass and size-structure (Pauly *et al.*, 1998; Sadovy, 2001) of many deep-sea fish that cannot sustain high levels of exploitation, due to their characteristic slow growth, high longevity and low reproductive output (Clark, 2001).

The Mediterranean deep-water crustacean trawl fishery (CTF) is the main form of deep-water fishery (reaching depths of ~850 m) in the central–eastern Mediterranean; this fishery targets deep-water shrimps, although several fish species are caught regularly as by-catch, including silver roughy *Hoplostethus mediterraneus* (Cuvier, 1829; Pisces: Trachichthyidae), which is almost always discarded. This species is the main trachichthyid caught in the Mediterranean basin, with only sporadic records of its exotic relative *Gephyroberyx darwini* (Johnson, 1866), which was first recorded in Algerian waters (Dieuzeide, 1963).

*Hoplostethus mediterraneus* is a benthopelagic fish occurring on the middle slope in the eastern Mediterranean (Labropoulou & Papaconstantinou, 2000), the south-western Mediterranean (Moranta *et al.*, 1998) and the north-eastern Atlantic (Gordon & Duncan, 1987). Given its limited economic value, it has been subject to limited biological investigation. Available information concerns its horizontal distribution (Maurin, 1962, 1970), length- and depth–size distribution (Gordon & Duncan, 1987; Mytilineou *et al.*, 2001; Pais, 2001), feeding behaviour (Kerstan, 1989; Pais, 2002; Madurell & Cartes, 2005), reproductive cycle (Cau & Deiana, 1982; D'Onghia *et al.*, 1998) and age, growth and mortality (Kotlyar, 1980; D'Onghia *et al.*, 1998; Vitale *et al.*, 2004). The species shows heterogeneity in biological features at the population level.

Available abundance data for the species are characterized by a high variability. Many parts of the Mediterranean may not be optimal environments for *H. Mediterraneus* (Maurin, 1970). Furthermore, most Mediterranean bottom trawls operate in close contact with the sea bed (~1 m of vertical mouth opening), and such gears are not highly selective for silver roughy. Both commercial and experimental data highlight a wide variability in abundance indices, which range from usually a few g/h (Ligurian Sea; Di Natale *et al.*, 1995) up to quite large captures (over 40 kg/h in Greek waters; Madurell *et al.*, 2004). Similar results were obtained from the biomass indices collected during the MEDiterranean International Trawl Survey, (MEDITS) programme (Bertrand *et al.*, 2002) from 1994 to 2010 in the General Fisheries

**Corresponding author:**
S. Vitale
Email: sergio.vitale@cnr.it

Commission for the Mediterranean Geographical Sub Areas (GSAs) located in the central–eastern Mediterranean.

*Hoplostethus mediterraneus* tends to show a heterogeneous diffusion pattern, not only horizontally (even in close and very similar habitats; Maurin 1962), but also vertically (with larger fish occurring in deeper waters; D'Onghia *et al.*, 1998), presenting a dome-shaped distribution with preference between 500 m and 800 m depth (Cau & Deiana, 1982; Gordon & Duncan, 1987; Morales-Nin *et al.*, 2003; Follesa *et al.*, 2011).

Difficulties also exist with regard to the demographic parameters. Both length- and age-based methods are difficult to apply and properly interpret for the potential influence of density-dependent mechanisms that lead towards population stability (D'Onghia *et al.*, 1998). In spite of the almost discrete recruitment (D'Onghia *et al.*, 1998), length–frequency distributions (LFDs) can show a variable shape, from skewed to the left (i.e. with a prevalence of juveniles; Pais, 2001) to unimodal and centred (i.e. with poorly represented tails; Mytilineou *et al.*, 2001). Whichever the shape detected, there is evidence that the parental (i.e. the mature component) size-classes are composed of different overlapping and slower growing age-classes (D'Onghia *et al.*, 1998); that is, the LFD is affected by piling-up phenomenona (Pauly, 1984).

*Hoplostethus mediterraneus* otoliths are thick and difficult to interpret, even after sectioning (D'Onghia *et al.*, 1995, 1998; Vitale *et al.*, 2004), given the presence of multiple close checks of which some likely reflect ontological events, such as benthic and maturing checks (see Francis & Horn, 1997). Consequently, uncertainty affects the estimated von Bertalanffy growth parameters $K = 0.127\ y^{-1}$ (confidence limit: 0.104–0.149), as well as the asymptotic (total) length $L_\infty = 28.71$ cm (confidence limit: 26.73–30.69) (D'Onghia *et al.*, 1998). The maximum age in samples (11 yr; D'Onghia *et al.*, 1998) likely reflects problems in ageing or maybe fishing-induced effects, since the life span should be ~25 yr (D'Onghia *et al.*, 1998).

No information is available concerning the stock identity of *H. mediterraneus* in the Mediterranean, but its life history traits (slow growth, high longevity, low natural mortality and the production of large, superficially buoyant eggs, i.e. more *K* oriented strategies), along with the almost steady deep-water habitats of the Mediterranean (Cartes *et al.*, 2004), may suggest a genetic homogeneity among the various populations (Maggio *et al.*, 2009). Such conjecture is also supported by the connectivity role of the overall hydrodynamic circulation of the Mediterranean Sea, characterized by a superficial flow (Modified Atlantic Water (MAW)), from the western to the eastern side and a counter-flow (Levantine Intermediate Water (LIW)) of more saline, deeper water from the eastern to the western basin (Millot *et al.*, 2006). In contrast, the typical poor swimming ability (Pakhorukov, 2008) and patchy occurrence (i.e. likely also reflecting a low catchability *sensu* Alverson, 1971) of *H. mediterraneus*, along with the high heterogeneous fishing effort applied to deep-water crustacean fisheries, might determine population differentiation at a local scale. Hence, different unit stocks *sensu* Gulland (1969, 1983) may be expected, since the low intermixing rates among contiguous stocks may be obscured by differences in fishing effort (Gulland, 1969; Ricker, 1975).

The present investigation provides a comparison of data on *H. mediterraneus* collected in fishing grounds subject to different histories and levels of exploitation, with the aim of investigating how local stocks respond to different fishing patterns, and to what extent measure bottom trawling may represent a threat to this long-living species.

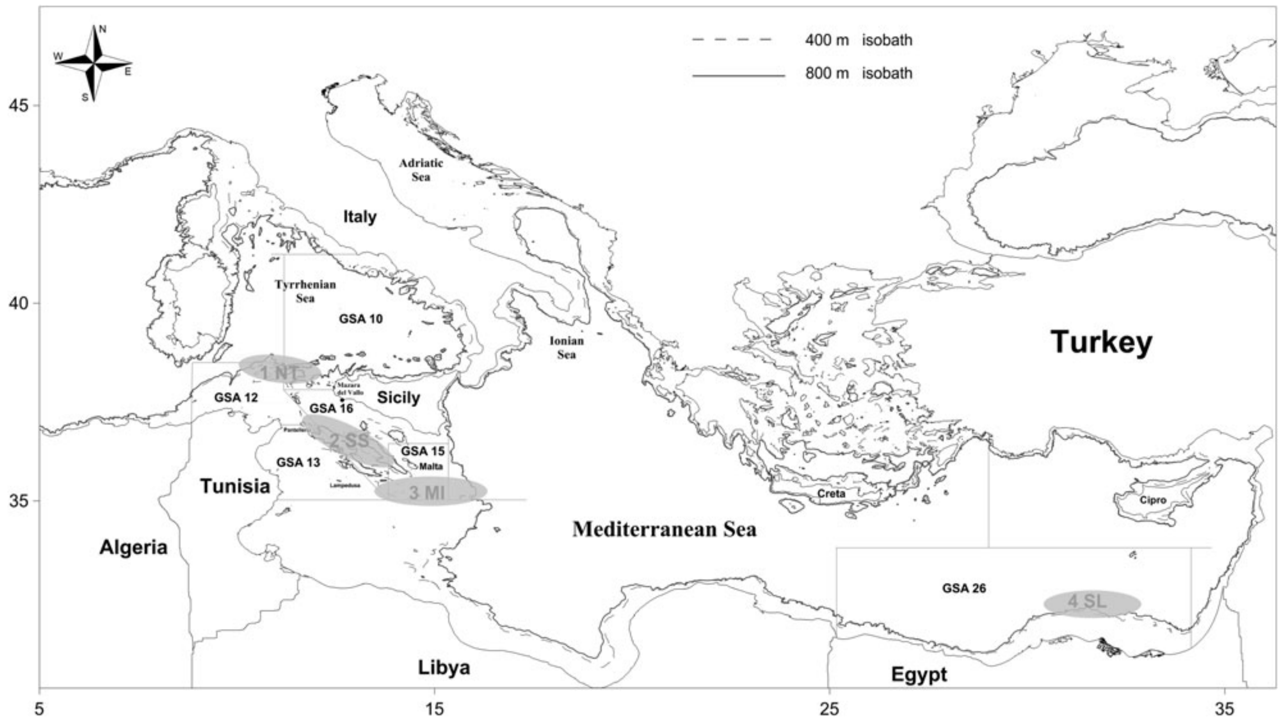


**Fig. 1.** The harbour of Mazara del Vallo and the four fishing grounds (Northern Tunisia, 1NT; South of Sicily, 2SS; Malta Island, 3MI; South Levant, 4SL) where commercial bottom trawlers collected samples of the silver roughy (*Hoplostethus mediterraneus*) in 2004. Present General Fisheries Commission for the Mediterranean delimitation (Geographical Sub-Area - GSA 10, 12, 13, 15, 16, 26) is superimposed.

## MATERIALS AND METHODS

A voluntary, 12-month self-sampling programme (Vølstad *et al.*, 2011) was implemented in 2004 to collect *H. mediterraneus* specimens from four commercial trawlers. Direct sampling by scientists was not cost-effective during commercial fishing operations, given the long voyages (up to 4 weeks) that characterize the offshore crustacean trawl fishery. These trawlers operated in the upper slope (500–850 m) of four deep-water shrimp fishing grounds (FGs) in the central–eastern Mediterranean Sea (Figure 1). In agreement with the captain, a member of each crew was carefully instructed in the Institute for Marine and Coastal Environment–National Research Council (IAMC-CNR), in order to standardize data collection among each sampling vessel. In particular, each trained fishermen extracted monthly and randomly samples of at least 100 specimens from the gross catches. During the investigation, a fishery biologist visited the crew to assess and ensure the quality of the self-reported data. At the end of the field sampling, a total of 4962 *H. mediterraneus* were recovered.

The four trawlers, belonging to the fleet of Mazara del Vallo (south-eastern Sicily), had gross tonnage ranging from 188 tsl to 191 tsl; all vessels used the same typical 'mazarese trawl net for deep shrimps' with the following main characteristics: headline, 74 m; groundline, 76 m; cod-end mesh size, 40 mm; length from the headline to the cod-end end, 35 m; and wings, 30 m.

**Table 1.** The three approaches and corresponding indices (referring to the gross catch length structure) employed for comparing fishing effects on silver roughy (*Hoplostethus mediterraneus*) stocks in the central–eastern Mediterranean Sea.

| | | | |
|---|---|---|---|
| **First approach** | | | |
| **Mean *L*** | **Mean total length** | **Continuous decrease** | |
| $L_{25\%}$ | Length at the twenty-fifth (L25%). The $L_{25}$ percentile characterizes juvenile fish | Juveniles increase or remain constant (according the stock-recruitment relationship) then decrease | Trenkel & Rochet, 2003 |
| $L_{75\%}$ | Lengths at the seventy-fifth (L75%). The $L_{75}$ percentile characterizes adult/mature fish | Continuous decrease | |
| $L_{95\%}$ | Lengths at the ninety-fifth (L95%). The $L_{95}$ percentiles characterizes larger/older fish | Quick and continuous decrease | |
| **Second approach** | | | |
| ***Z/K*** | *Z*, total instantaneous mortality rate; *K*, growth related coefficient of the von Bertalanffy growth function; which determines how fast the fish approaches its $L_\infty$ | Increase | Wetherall *et al.*, 1987 |
| $L_\infty$ | The mean length of very old (strictly: infinitely old) fish in the von Bertalanffy growth function | Quick decrease | von Bertalanffy, 1934; Ricker, 1975 |
| **Third approach** | | | |
| $L_m$ **'let them spawn once'** | The length at first sexual maturity. This index is used to compute the percentage of mature specimens ($\%L \geq L_m$) in the catch. Specimens with $L < L_m$ are referred as juveniles | Decrease | |
| $L_{opt}$ **'let them grow'** | The length at which the unexploited cohort reaches its maximum biomass. This index sets the upper limits of the optimum target (100% of the catch is composed of fish within Lm and $L_{opt} \pm 10\%$); i.e. no mega-spawners in the catch (see below) | Fast decrease | Froese, 2004; Froese *et al.*, 2008. |
| $L_{max}$ **'let the megaspawners live'** | The length of old, spawners fish in the catch, of size larger than $L_{opt} + 10\%$. References: 0% if a fishing strategy is implemented or 30–40% if no such strategy is in place (optima); <20% (alarming) | Quick decrease even at very low fishing activity | |

https://doi.org/10.1017/S0025315413001884 Published online by Cambridge University Press

The four FGs exploited by trawlers from Mazara del Vallo only are: Northern Tunisia (1NT), characterized by a high level of exploitation since the 1970s; South Sicily (2SS), highly exploited since the 1980s; Malta Islands (3MI), with a minor level of exploitation due to the high occurrence of fish aggregation device moorings (*mazzare*); and South Levant (4SL), which represents a virgin bottom for CTF, because the fishery only started in 2004 (Garofalo *et al.*, 2007).

To reconstruct the different histories and levels of exploitation in each investigated FG, the following steps were performed: (1) estimation of the evolution of the offshore fishing capacity using historical references of the 1960s (Istituto Nazionale di Statistica, 1977; Centro Internazionale di Studi Giuridici, 1988) together with the data from the Mazara vessels registry and the European Union fleet structure (EU fishing fleet register, 2013) by decades from 1970 to 2010; and (2) assessment of the spatial-time distribution of the trawlers in each FG, through semi-structured interviews with the last 10 captains of the 1960s and 1970s (between 70 and 83 years old) as well as with 20 'younger' captains for the more recent periods.

Total length (TL, cm) was measured for each specimen and a length–frequency distribution (LFD) was constructed after five-class smoothing in order to reduce the sampling noise and better approximate equilibrium conditions for successive analysis (Rosenberg & Beddington, 1988). The LFD and the main indices (minimum, maximum and median values) were computed overall and by fishing ground; LFD comparison was performed according to non-parametric tests (Kruskal–Wallis and Kolmogorov–Smirnov). Moreover, to analyse the fishing effects due to the history of exploitation on *H. mediterraneus* populations in the central–eastern Mediterranean, the following three approaches were considered (Table 1).

The first approach considered the capacity of the indices (1) mean length and (2) lengths at the 25th ($L_{25\%}$), 75th ($L_{75\%}$) and 95th ($L_{95\%}$) percentile of the length distribution to provide information on fishery impacts (Trenkel & Rochet 2003; Rochet *et al.*, 2005).

The second approach was based on the estimation of the ratio $Z/K$ by the Powell–Wetherall plot (Wetherall *et al.*, 1987), as well as the asymptotic length ($L_\infty$) of the von Bertalanffy growth function (vBGF); where $Z$ is the total instantaneous mortality and $K$ and $L_\infty$ are the growth parameters of the vBGF. This method was implemented using the software Fisheries Management Science Programme (FMSP; Hoggarth *et al.*, 2006), with the aim of investigating the total mortality among the unit stocks. For long-lived species, the shape analysis of the LFD within the $Z/K$ ratio (from less than or around 1) and $L_\infty$ are expected to increase and decrease, respectively, along the intensification of the exploitation rate (Pauly, 1984).

The third approach required the estimation of three length indices: the length at maturity ($L_m$ 'Let them spawn'), the optimum length ($L_{opt}$ 'Let them grow') and the maximum length ($L_{max}$ 'Let the mega-spawners live') as suggested in Froese (2004). This author proposed a management scenario aimed at protecting juveniles and allowing the catch of only mature/large specimens (preferably avoiding the capture of the very old and large spawners, called 'mega-spawners'). In the present case, $L_m$ and $L_{opt}$ were computed according to the empirical equation of Froese & Binohlan (2000), while $L_{max}$ was estimated as proposed by Formacion *et al.* (1991). These three indices were superimposed on the LFDs with the aims of observing a possible fishing-induced change in the length structure of the population. At the same time, a comparison of the proportions of mature, optimum and mega-spawner lengths in the gross catch among FGs was carried out, as suggested by Froese (2004).

Having in mind the importance of determining the stock status in any fishery assessment (Pitcher, 1995), the estimated indices were used in a diagnostic system for a comparison between the four stocks. Consequently, the indices were standardized among the four investigated FGs, considering the values in the pristine FG 4SL as 'healthy'. The standardized indices of each approach were, hence, used as scores to quantify the overall degree of departure of the

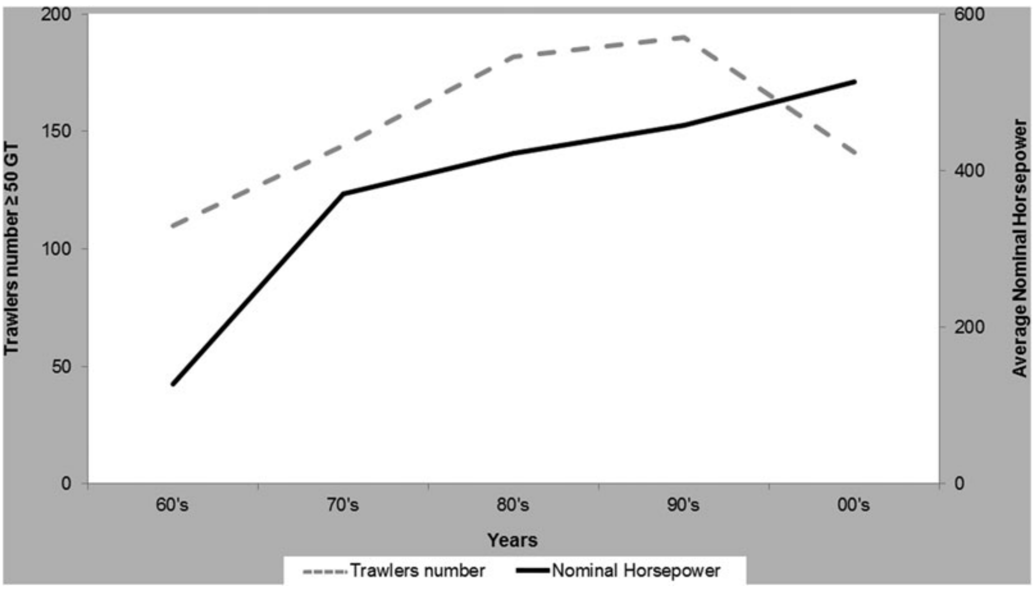


**Fig. 2.** Evolution by decades of the fishing capacity (number of trawlers, broken line; average nominal horsepower, solid line) of the Mazara del Vallo offshore trawlers between 1960 and 2010.

https://doi.org/10.1017/S0025315413001884 Published online by Cambridge University Press

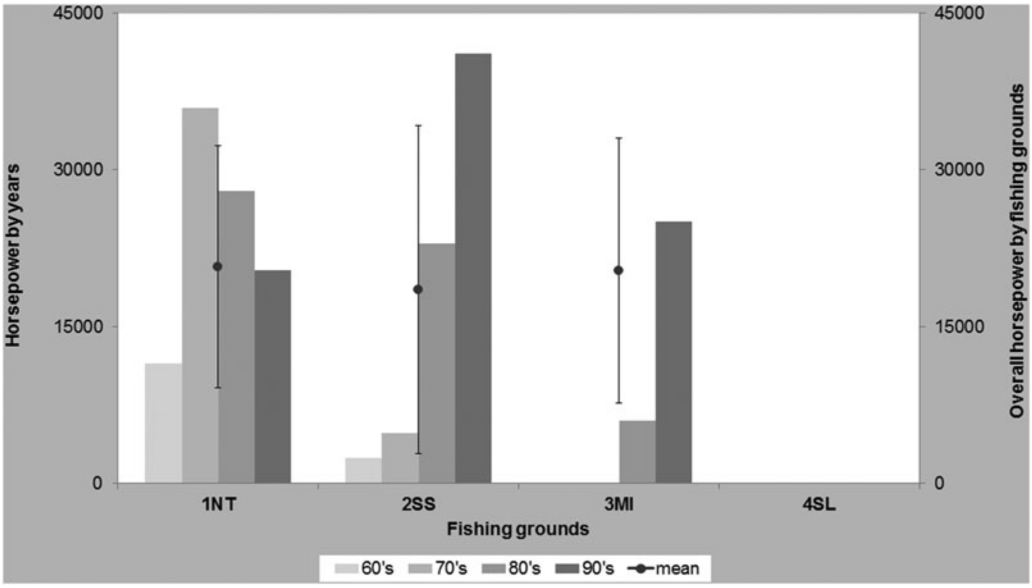


**Fig. 3.** Spatial–time distribution by decades of the fishing capacity (nominal horsepower) of the Mazara del Vallo offshore trawlers among the investigated fishing grounds (Northern Tunisia, 1NT; South of Sicily, 2SS; Malta Island, 3MI; South Levant, 4SL) between 1960 and 2000. Fishing activity in 4SL started in 2004. The overall mean and corresponding standard deviation by fishing grounds are superimposed.

other stocks from the condition in FG 4SL (with a score of 1). In particular, the mean of the scores of each approach was computed, with the aim of highlighting whether the expected response of the indices to exploitation is satisfied (see Table 1).

## RESULTS AND DISCUSSION

The evolution of the fishing capacity of the Mazara del Vallo trawler fleet, the most important in the central–eastern Mediterranean Sea, in the last 50 yr is shown in Figures 2 and 3. These indicate an increase in the number of trawlers from the 1960s until the end of the 1990s, with a reduction thereafter, although the mean horsepower has increased continuously, with a very rapid growth in the 1970s (Figure 2). The spatio-temporal distribution of the trawlers highlights the differences in fishing pressure among the FGs (Figure 3). During the late 1960s, about 110 trawlers exploited the offshore fishing grounds of the Strait of Sicily, the main fishing grounds for deep-water shrimps located off and around the Egadi Islands, off the northern coasts of Tunisia and along an ideal route connecting the bottoms off Cape Bon to Pantelleria and Linosa Islands (Scaccini *et al.*, 1970). During the 1970s and 1980s, the Mazara offshore trawler fleet increased in number, tonnage and power, and in the early 1990s reached the fishing grounds located off Lampedusa, Malta Islands and the Libyan coast, together

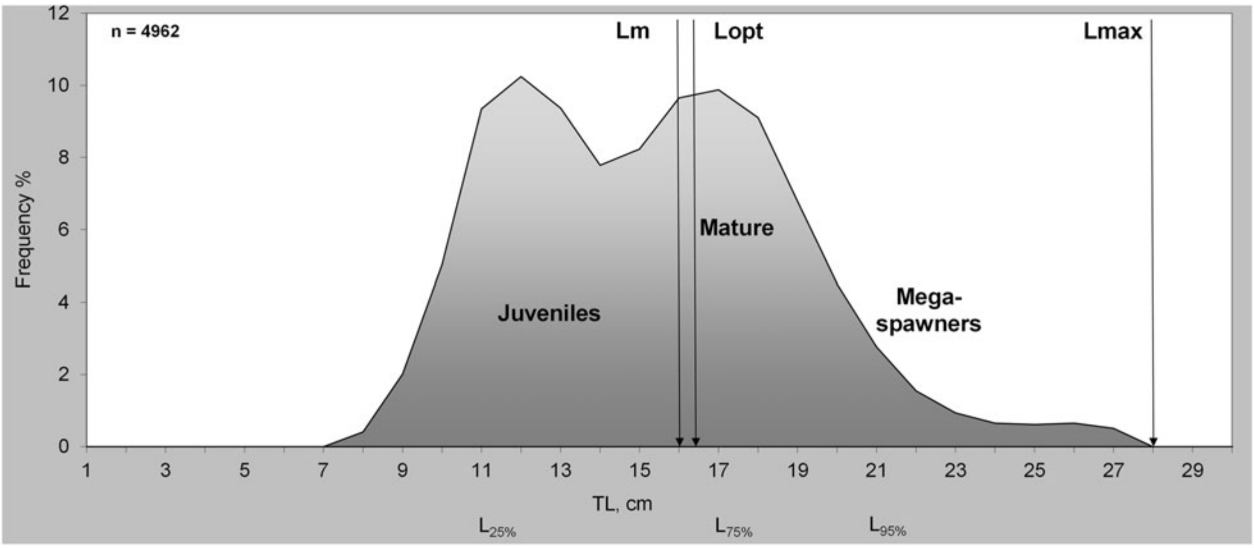


**Fig. 4.** Overall total length (TL) frequency distribution (cm) of silver roughy (*Hoplostethus mediterraneus*) sampled in the central–eastern Mediterranean Sea with the categories and part of the size indicators employed superimposed: length at sexual maturity, $L_m$ = 16.2 cm; optimum, $L_{opt}$ = 16.7 cm; maximum, $L_{max}$ = 28.0 cm; and percentiles ($L_{25\%}$ = 11.0 cm; $L_{75\%}$ = 17.0 cm; $L_{95\%}$ = 21.0 cm).

https://doi.org/10.1017/S0025315413001884 Published online by Cambridge University Press

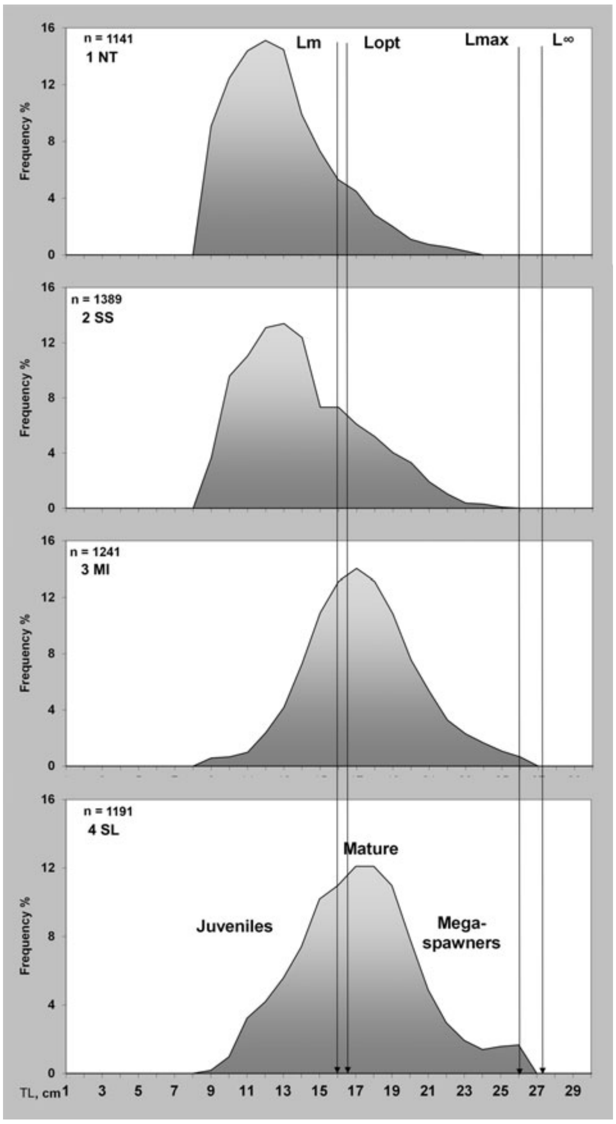


**Fig. 5.** Total length (TL) frequency distribution (in cm) of silver roughy (*Hoplostethus mediterraneus*) in the four fishing grounds investigated (Northern Tunisia, 1NT; South of Sicily, 2SS; Malta Island, 3MI; South Levant, 4SL). $L_\infty$ denotes the asymptotic length; for the other symbols see Figure 4.

with those on the eastern slope off Malta (Ragonese, 1995). The progressive decrease in catch rates of deep-water shrimp and the absence of deep trawling in the eastern Mediterranean have led to some boats fishing around Crete, Cyprus and off the Turkish and Egyptian coasts since 2004 (Garofalo *et al.*, 2007).

The overall LFD shape (Figure 4) was coherent with an almost discrete recruitment (first peak quite distinct), slow growth and piling-up effects (no further modes evident in the parental stock component). Assuming that the sampled catch accurately reflected the size structure of the stock, the occurrence of ~30% of specimens above the 'Let the mega-spawners live' indices ($L_{max}$) would suggest an optimum exploitation level (*sensu* Froese, 2004), notwithstanding that the large presence of juveniles clearly indicates a too precocious length at capture (i.e. growth overfishing problem). The judgment substantially changed when analysing both the LFDs shapes (Figure 5) and statistics separately for each FG (Table 2). LFD differences among the four FGs were significant (Kruskal–Wallis test, $H = -14889$, df $= 3$, $P < 0.0001$) among the median size and the overall LFD. The LFD pair-wise comparison revealed that the differences followed a western–eastern trend; in fact, no statistical differences (Kolmogorov–Smirnov test $P > 0.05$) were detected between 1NT and 2SS or between 3MI and 4SL.

Evaluating the indices estimated for each FG, an increasing trend of $L_{25\%}$, $L_{75\%}$ and $L_{95\%}$ and a decreasing trend of the *Z/K* ratio, in respect to a quite similar value of $L_\infty$ (Table 2), indicates signs of stress that may be due to fishing impacts. In particular, the aforementioned life-history traits of *H. mediterraneus*, as well as the estimated low rate of growth for 25 of the 30 species of the genus *Hoplostethus* (mean estimated $K = 0.15$, SD $= 0.06$, among all estimations available for the genus; Froese & Pauly, 2002) indicate a different fishing pressure among the FGs in agreement with their evolution of the exploitation in space and time. Similar considerations concern the increasing percentage of mature specimens, the specimens at optimum length and the mega-spawners in the catch from 1NT to 4SL. In particular, comparing the FGs 4SL and 1NT (Figure 5) the percentage of mature specimens, the specimens at optimum length and the mega-spawners in the catch are about seven times, four times and nine times higher in the former than in the latter (Figure 6).

Looking at the overall LFD, almost all indices used suggest an acceptable status of *H. mediterraneus* population in the central–eastern Mediterranean, whereas the analysis of the LFDs by FG showed potential signs of over-exploitation of the parental component in 1NT and 2SS. Similar conclusions can be highlighted by the diagnostic of the stock status reported in Table 3. The score obtained for each FG by approach showed a worsening trend from the 4SL to 1NT.

There is evidence that the demersal fish assemblage in the central–eastern Mediterranean has been characterized by a different history of exploitation, with decreasing levels of fishing pressure from the central to the eastern side of the basin (Gristina *et al.*, 2006). Although there are no quantitative data on the fishing effort, the evolution of the deep-water trawling fisheries of Mazara del Vallo from the 1960s to the first decade of this century (Scaccini *et al.*, 1970; Ragonese, 1995; Garofalo *et al.*, 2007) is consistent with the behaviour of the indices estimated in the present study. The evolution of deep-water trawling may be responsible for the fishing impact, that consists of a slow removal of the larger specimens, mainly in 1NT and 2SS, which have been affected by a longer and more intense exploitation. Although the shape of the detected length structures might be affected by sampling noise and bias (cf. Merrett & Haedrich, 1997) it is worth noting how, in a pristine or light exploitation condition, the LFDs in 3MI and 4SL resemble more the expected *K*-oriented shapes (i.e. $Z/K < 1$), whereas the LFDs in 1NT and 2SS look closer to an *r*-oriented shapes (i.e. $Z/K > 1$), (Pauly, 1984), in agreement with the different fishing patterns of the investigated fishing grounds.

The lower absolute presence of juveniles in the less exploited FGs is not in agreement with the discrete recruitment and the size-related depth segregation suggested by D'Onghia *et al.* (1998). In the present case, since the samples were gathered by trawlers operating in all months of the year and over the same depth range, a more suitable explanation could be that

**Table 2.** Silver roughy (*Hoplostethus mediterraneus*) length–frequency distribution (LFD) characteristics and indices calculated in the four fishing grounds investigated (Northern Tunisia, 1NT; South of Sicily, 2SS; Malta Island, 3MI; South Levant, 4SL) among the different approaches. Key: N, number; min, minimum; max, maximum; median and mean length (*L* total, cm) of the length frequency distribution; SD, standard deviation; CI, confidence intervals; SE, standard error. See Table 1 for details.

| Index/symbol | 1NT | 2SS | 3MI | 4SL |
|---|---|---|---|---|
| *LFD characteristics* | | | | |
| N. specimens | 1141 | 1389 | 1241 | 1191 |
| Minimum *L* | 8.0 | 8.0 | 7.0 | 11.0 |
| Maximum *L* (99%) | 20.0 | 21.0 | 24.0 | 27.0 |
| Median *L* | 11.0 | 12.5 | 16.0 | 16.5 |
| *First approach* | | | | |
| Mean *L* (SD) | 12.7 (2.6) | 13.9 (3.0) | 17.3 (3.0) | 17.6 (3.6) |
| $L_{25\%}$ | 10.0 | 11.0 | 15.0 | 14.5 |
| $L_{75\%}$ | 13.5 | 15.5 | 18.0 | 18.5 |
| $L_{95\%}$ | 17.0 | 19.0 | 22.0 | 25.5 |
| *Second approach* | | | | |
| *Z/K* | 3.6 | 2.8 | 2.1 | 1.3 |
| $L_\infty$ | 26.0 | 26.3 | 26.8 | 27.3 |
| *Third approach* | | | | |
| $L_{max}$, cm (95% CI) | | 26.0 (24.79–27.98) | | |
| $L_m$ from $L_\infty$, cm (SE range) | 15.6 (11.6–20.9) | 15.7 (11.7–21.1) | 16.0 (11.9–21.4) | 16.3 (12.1–21.8) |
| $L_{opt}$ from $L_\infty$, cm (SE range) | 15.9 (13.4–18.8) | 16.1 (13.6–19.0) | 16.4 (13.8–19.4) | 16.7 (14.1–19.7) |

the investigated stocks follow a dome-shaped Ricker's stock recruitment relationship, which foresees a recruitment lower in the unexploited than in the exploited condition (Ricker, 1975), or the reported tendency of juveniles of deep-water species to reduce their co-occurrence with adults in order to optimise energy utilization through balanced partitioning of available resources (Gage & Tyler, 1991; D'Onghia *et al.*, 1998); i.e. a reduction of adults might favour closeness of

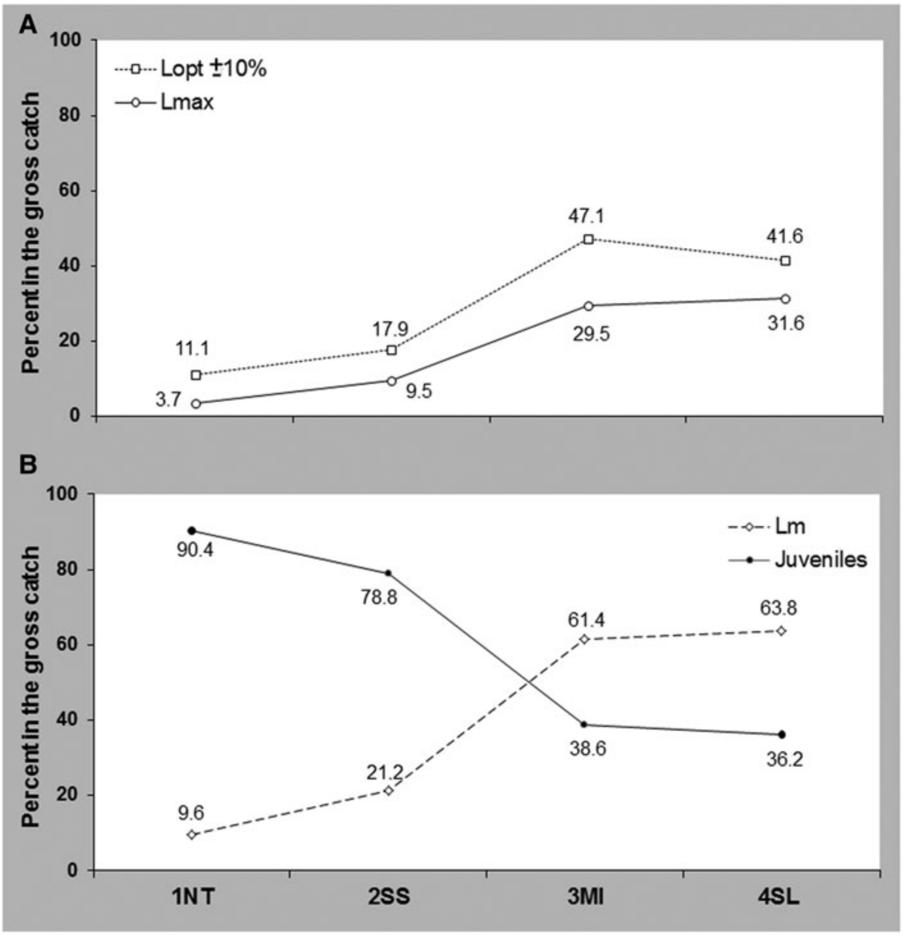


**Fig. 6.** Silver roughy (*Hoplostethus mediterraneus*) percentages in the gross catch $L_{opt}$ ± 10%, $L_{max}$ (A), juveniles and $L_m$ (B), in the four fishing grounds investigated (Northern Tunisia, 1NT; South of Sicily, 2SS; Malta Island, 3MI; South Levant, 4SL).

https://doi.org/10.1017/S0025315413001884 Published online by Cambridge University Press

**Table 3.** Comparison of the stock status among the four investigated fishing grounds (Northern Tunisia, 1NT; South of Sicily, 2SS; Malta Island, 3MI; South Levant, 4SL) for silver roughy (*Hoplostethus mediterraneus*). The indices by approach (Table 2) were standardized (ratio) using the value of the FG 4SL as baseline ('healthy condition'), and then employed as a score: the higher the distance of the mean scores from 1, the worst the condition of the given fishing ground. Key: GM, geometric mean of the scores, see Table 1 for details of the indices/symbols.

| | 1NT | 2SS | 3MI | 4SL |
|---|---|---|---|---|
| ***First approach*** | | | | |
| Mean ***L*** | 0.72 | 0.79 | 0.98 | 1 |
| ***L*** at 25° percentile | 0.69 | 0.76 | 1.03 | 1 |
| 75° percentile | 0.73 | 0.84 | 0.97 | 1 |
| 95° percentile | 0.67 | 0.75 | 0.86 | 1 |
| GM | 0.70 | 0.78 | 0.96 | 1 |
| ***Second approach*** | | | | |
| $Z/K$ | 0.36 | 0.46 | 0.62 | 1 |
| $L_{\infty}$ | 0.95 | 0.96 | 0.98 | 1 |
| GM | 0.66 | 0.71 | 0.80 | 1 |
| ***Third approach*** | | | | |
| $L_{max}$ | 0.74 | 0.82 | 0.93 | 1 |
| $L_m$ | 0.96 | 0.96 | 0.98 | 1 |
| $L_{opt}$ | 0.95 | 0.96 | 0.98 | 1 |
| GM | 0.88 | 0.91 | 0.97 | 1 |

juveniles to the bottom. Other factors such as a differential recruitment strength, a very critical consideration for long-living deep-water fish (Leaman & Beamish, 1984; Cailliet *et al.*, 2001; Ragonese, 2004), might have determined the observed differences in LFD that, in any case, cannot be recognized over a single year of observation.

Notwithstanding the lack of long-term observations, especially on recruitment, the present results support the idea that the parental component of the *H. mediterraneus* stock in the central–eastern Mediterranean may have been affected by trawling, even assuming a low catchability (*sensu* Alverson, 1971) in a commercial tow. Deep-water fishing activity may progressively shift the LFD towards younger fish (that do not have the same productivity per unit biomass as older fish; Beamish *et al.*, 2006), as well as reducing the number of adults and, hence, losing their heterozygous traits (Smith *et al.*, 1991).

Consequently, although the exploited stocks of *H. mediterraneus* in the Mediterranean seem able at present to maintain an effective parental stock and recruitment levels sufficient to sustain the present standing stock (i.e. stocks show compensative mechanisms), the gradual loss of genetic components might determine, according to Beamish *et al.* (2006) a longevity overfishing (such as in 1NT and 2SS), with unforeseeable long-term consequences.

## CONCLUSION

The comparison of four silver roughly stocks by three different approaches has highlighted clear signs of overfishing in those fishing grounds characterized by a long history of a high level of exploitation. Consequently, to maintain the health of silver roughly and other slow growing fish caught in deep water shrimp fisheries, it is crucial to avoid exerting high fishing pressure for long periods on the fishing grounds. This clearly places in question, together with control of fishing effort, the adoption of specific technical measures to improve sustainability of deep water trawling, such as enforcing 50 mm diamond stretched mesh in the cod-end or establishing limited trawl lanes where the fishery is allowed (Dimeck *et al.*, 2012). This might contribute to ensuring the health of the silver roughly stock, as well as of other deep-sea species that are believed to be sustainable at low rates of exploitation. A final comment concerns the present deep limit of 1000 m for trawling established by the European Union (Council Regulation–EC–No 51/2006), which seems not precautionary, at least for the silver roughly stocks investigated in the present work.

## ACKNOWLEDGEMENTS

We thank the captains (Pasquale Giacalone, Maurizio Giacalone, Antonino Genovese, Antonino Adamo) and all the crews of the commercial trawlers for their valuable collaboration in collecting the monthly samples. A special thanks and recognition is extended to all captains and colleagues who contributed to the extensive work during the semi-structured interviews. We are grateful to Dr Jim Ellis of the Centre for Environment, Fisheries & Aquaculture Science, Lowestoft, UK for his genuine interest in this paper.

## REFERENCES

**Alverson D.L.** (1971) *Manual of methods for fisheries resource survey and appraisal. FAO Fishery Technical Paper 102*. Rome: FAO, 80 pp.

**Beamish R.J., McFarlane G.A. and Benson A.** (2006) Longevity overfishing. *Progress in Oceanography* 68, 289–302.

**Bertrand J.A., Gil de Sola L., Papaconstantinou C., Relini G. and Souplet A.** (2002) The general specifications of the MEDITS survey. *Scientia Marina* 66, 9–17.

**Cailliet G.M., Andrews A.H., Burton E.J., Watters D.L., Kline D.E. and Ferry-Graham L.A.** (2001) Age determination and validation studies of marine fishes: do deep-dwellers live longer? *Experimental Gerontology* 36, 739–764.

**Cartes J.E., Maynou F., Sardà F., Company J. B., Lloris D. and Tudela S.** (2004) The Mediterranean deep-sea ecosystems: an overview of their diversity, structure, functioning and anthropogenic impacts. In *The Mediterranean deep-sea ecosystems: an overview of their diversity, structure, functioning and anthropogenic impacts with a proposal for their conservation*. Malaga/Rome: IUCN/WWF, pp. 9–38.

**Cau A. and Deiana A.M.** (1982) Contributo alla conoscenza della biologia di *Hoplostethus medirerraneus* (Valenciennes, 1829) (Osteitti, Bericiformi). *Bollettino della Società sarda di scienze naturali* 21, 185–192.

**Centro Internazionale di Studi Giuridici** (1988) *La disciplina della pesca in acque territoriali*. Napoli: Edizione Scientifiche Italiane, 322 pp.

**Clark M.** (2001) Are deepwater fisheries sustainable? The example of Orange roughy *Hoplostethus atlanticus*) in New Zealand. *Fisheries Research* 51, 123–135.

**Di Natale A.** (1995) Survey of red shrimp fishing in the western Italian basins. *Final Report, Project MED 92/005 (European Union, D.G. XIV), Volumes I + II*, 773 pp.

**Dieuzeide R.** (1963) Sur la presénce et Méditerranée de *Gephyroberyx darwini* (Johnson). *Recueil des Travaux de la Station Marine d'Endoume* 28, 113–116.

**Dimech M., Kaiser M.J., Ragonese S. and Schembri P.J.** (2012) Ecosystem effects of fishing on the continental slope in the Central Mediterranean Sea. *Marine Ecology Progress Series* 449, 41–54.

**D'Onghia G., Matarrese A., Tursi A., Sion L. and Panza M.** (1995) Aspetti della biologia di *Hoplostethus medirerraneus* (Pisces, Osteichthyes) nel Mar Ionio: riproduzione e accrescimento. *Biolologia Marina Mediterranea* 2, 251–255.

**D'Onghia G., Tursi A., Marano C.A. and Basanisi M.** (1998) Life history traits of *Hoplostethus mediterraneus* (Pisces: Beryciformes) from the north-western Ionian Sea (Mediterranean Sea). *Journal of the Marine Biological Association of the United Kingdom* 78, 321–339.

**EU fishing fleet register** (2013) Available at: http://ec.europa.eu/fisheries/fleet/index.cfm (accessed 21 December 2013).

**Follesa M.C., Porcu C., Cabiddu S., Mulas A., Deiana A.M. and Cau A.** (2011) Deep-water fish assemblages in the central–western Mediterranean (south Sardinian deep-waters). *Journal of Applied Ichthyology* 27, 129–135.

**Formacion S.P., Rongo J.M. and Sambilay V.C.** (1991) Extreme value theory applied to the statistical distribution of the largest lengths of fish. *Asian Fisheries Science* 4, 123–135.

**Francis R.I.C.C. and Horn P.L.** (1997) Transition zone in otoliths of Orange roughy (*Hoplostethus atlanticus*) and its relationship to the onset of maturity. *Marine Biology* 129, 681–687.

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

**Froese R. and Binohlan C.** (2000) Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. *Journal of Fish Biology* 56, 758–773.

**Froese R. and Pauly D.** (2002) *FishBase*. Available at: www.fishbase.org (accessed 21 December 2013).

**Froese R., Stern-Pirlot A., Winker H. and Gascuel D.** (2008) Size matters: how single-species management can contribute to ecosystem-based fisheries management. *Fisheries Research* 92, 231–241.

**Gage J.D. and Tyler P.A.** (1991) Deep-sea biology: a natural history of organisms at the deep-sea floor. *Journal of the Marine Biological Association of the United Kingdom* 71, 747–748.

**Garofalo G., Giusto G.B., Cusumano S., Ingrande G., Sinacori G., Gristina M. and Fiorentino F.** (2007) Sulla cattura per unità di sforzo della pesca a gamberi rossi sui fondi batiali del mediterraneo orientale. *Biologia Marina Mediterranea* 14, 250–251.

**Gordon J.D.M. and Duncan J.A.R.** (1987) Aspects of the biology of *Hoplostethus atlanticus* and *H. mediterraneus* (Pisces: Berycomorphi) from the slopes of the Rockall Trough and the Porcupine Sea Bight (north-eastern Atlantic). *Journal of the Marine Biological Association of the United Kingdom* 67, 119–133.

**Gristina M., Bahri T., Fiorentino F. and Garofalo G.** (2006) Comparison of demersal fish assemblages in three areas of the Strait of Sicily under different trawling pressures. *Fisheries Research* 81, 60–71.

**Gulland J.A.** (1969) Manual of methods for fish stock assessment, Part 1: Fish population analysis. *FAO Manuals in Fisheries Science, No. 4*. Rome: FAO, 154 pp.

**Gulland J.A.** (1983) Fish stock assessment. A manual of basic methods. *FAO/Wiley Series on Food and Agriculture, No. 1*. Rome: FAO/Wiley, 233 pp.

**Hoggarth D.D., Abeyasekera S., Arthur R.I., Beddington J.R., Burn R.W., Halls A.S., Kirkwood G.P., McAllister M., Medley P., Mees C.C., Parkes G.B., Pilling G.M., Wakeford R.C. and Welcomme R.L.** (2006) Stock assessment for fishery management—a framework guide to the stock assessment tools of the Fisheries Management Science Programme (FMSP). *FAO Fisheries Technical Paper 487* Rome: FAO, 261 pp.

**Kerstan S.L.** (1989) The food of silver roughy (*Hoplostethus mediterraneus*, Beryciformes, Trachichthyidae) from New Zealand waters. *Meeresforschung* 32, 241–247.

**Kotlyar A.N.** (1980) Age and growth speed of the bigheads, *Hoplostethus atlanticus* and *H. mediterraneus* Cuvier (Trachichthyidae, Beryciformes). In Shirshon P.V. (ed.) *Fishes of the open ocean*. Moscow: Institute of Oceanography, pp. 68–88.

**Istituto Nazionale di Statistica** (1977) *Annuario statistico della zootecnia, pesca e caccia*. Rome: Istat

**Labropoulou M. and Papaconstantinou C.** (2000) Community structure of deep-sea demersal fish in the North Aegean Sea (northeastern Mediterranean). *Hydrobiolgia* 440, 281–296.

**Leaman B.M. and Beamish R.J.** (1984) Ecological and management implications of longevity in some northeast pacific groundfishes. *International North Pacific Fisheries Commission Bulletin* 42, 85–230.

**Madurell T., Cartes J.E. and Labropoulou M.** (2004) Changes in the structure of fish assemblages in a bathyal site of the Ionian Sea (eastern Mediterranean). *Fisheries Research* 66, 245–260.

**Madurell T. and Cartes J.E.** (2005) Temporal changes in feeding habits and daily rations of *Hoplostethus mediterraneus* in the bathyal Ionian Sea (eastern Mediterranean). *Marine Biology* 146, 951–962.

**Maggio T., Lo Brutto S., Cannas R., Deiana A.M. and Arculeo M.** (2009) Environmental features of deep-sea habitats linked to the genetic population structure of a crustacean species in the Mediterranean Sea. *Marine Ecology* 30, 354–365.

**Maurin C.** (1962) Etude des fonds chalutables de la Méditerranée occidentale (Ecologie et Peche). Résultats des campagnes des navires océanographiques 'Président-Théodore-Tissier' 1957 et 1960 et 'Thalassa' 1960 et 1961. *Revue des Travaux de l'Institut des Pêches Maritimes* 26, 163–218.

**Maurin C.** (1970) Quelques aspects de la faune ichthyologique Méditerranée. *Journées Ichthyologiques* 7, 27–38.

**Merrett N.R. and Haedrich R.** (1997) *Deep-sea demersal fish and fisheries*. London: Chapman and Hall, Fish and Fisheries Series, 287 pp.

**Millot C., Candela J., Fuda J.L. and Tber Y.** (2006) Large warming and salinification of the Mediterranean outflow due to changes in its composition. *Deep-Sea Research I* 53, 656–666.

**Morales-Nin B., Maynou F., Sardà F., Cartes J., Moranta J., Massutì E., Company J., Rotllant G., Bozzano A. and Stefanescu C.** (2003) Size influence in Zonation Patterns in fishes and crustaceans from deep-water communities of the western Mediterranean. *Journal of Northwest Atlantic Fishery Science* 31, 413–430.

**Moranta J., Stefanescu C., Massutì E., Morales-Nin B. and Lloris D.** (1998) Fish community structure and depth-related trends on the continental slope of the Balearic Islands (Algerian basin, western Mediterranean). *Marine Ecology Progress Series* 171, 247–259.

**Morato T., Watson R., Pitcher T.J. and Pauly D.** (2006) Fishing down the deep. *Fish and Fisheries* 7, 24–34.

**Mytilineou C.H., Maiorano S., Kavadas S., D'Onghia G., Kapiris K. and Capezzuto F.** (2001) Size structure comparison in some demersal species between two areas of different fishing impact in the deep water of eastern–central Mediterranean (Ionian Sea). In NAFO SCR (eds) *Proceeding of the Deep-sea Fisheries Symposium, 12–14 September Cuba. Deep-Sea Fisheries Symposium*. NAFO SCR, Doc. 01/125, pp. 1–7.

**Pais C.** (2001) Aspects of the biology of *Hoplostethus mediterraneus* from the south coast of Portugal. *Journal of the Marine Biological Association of the United Kingdom* 81, 711–712.

**Pais C.** (2002) Diet of a deep-sea fish, *Hoplostethus mediterraneus*. *Journal of the Marine Biological Association of the United Kingdom* 82, 351–352.

**Pakhorukov N.P.** (2008) Visual observations of fish from seamounts of the Southern Azores region (the Atlantic Ocean). *Journal of Ichthyology* 48, 114–123.

**Pauly D.** (1984) Fish population dynamics in tropical waters: a manual for use with programmable calculators. In *ICLARM Studies and Reviews 8*. Penang: ICLARM, 325 pp.

**Pauly D., Christensen C., Dalsgaard J., Froese R. and Torres F. Jr** (1998) Fishing down the food webs. *Science* 279, 860–863.

**Pitcher T.J.** (1995) The impact of pelagic fish behaviour on fisheries. *Scientia Marina* 59, 295–306.

**Ragonese S.** (1995) Geographical distribution of *Aristaeomorpha foliacea* (Crustacea-Aristeidae) in the Sicilian Channel (Mediterranean Sea). *ICES Journal of Marine Science* 199, 183–188.

**Ragonese S.** (2004) Growth and senescence interaction in fish: the state of art. *Biologia Marina Mediterranea* 11, 91–106.

**Ricker W.E.** (1975) Computation and interpretation of biological statistics of fish population. *Bulletin of the Fisheries Research Board of Canada 191*. Ottawa: Fisheries and Marine Service, 382 pp.

**Rochet M.J., Trenkel V.M., Bellail R., Coppin F., Le Pape O., Mahé J.C., Morin A., Poulard J.C., Schlaich I., Souplet A., Vérin Y. and Bertrand J.A.** (2005) Combining indicator trends to assess ongoing changes in exploited fish communities: diagnostic of communities off the coasts of France. *ICES Journal of Marine Science* 62, 1647–1664.

**Rosenberg A.A. and Beddington J.R.** (1988) Length-based methods of fish stock assessment. In Gulland J.A. (ed.) *Fish population dynamics*. 2nd edition. New York: Wiley, pp. 83–103.

**Sadovy Y.** (2001) The threat of fishing to highly fecund fishes. *Journal of Fish Biology* 59, 90–108.

**Scaccini A., Piccinetti C. and Sarà R.** (1970) Stato attuale della pesca in acque profonde nei mari italiani. *Bollettino di pesca, di piscicoltura di idrobiologia* 1, 5–36.

**Smith P.J., Francis R.I.C.C. and McVeagh M.** (1991) Loss of genetic diversity due to fishing pressure. *Fisheries Research* 10, 309–316.

**Trenkel V. and Rochet M.J.** (2003) Performance of indicators derived from abundance estimates for detecting the impact of fishing on a fish community. *Canadian Journal of Fisheries and Aquatic Sciences* 60, 67–85.

**Vitale S., Cannizzaro L., Bono G., Beltrano A.M., Ingrassia M. and Milazzo A.** (2004) Age determination of Silver roughty *Hoplostethus mediterraneus* (C., 1829) (Pisces; Trachichthyidae) in the Strait of Sicily. *Biologia Marina Mediterranea* 11, 661–665.

**Vølstad J.H., Korsbrekke K., Nedreaas K.H., Nilsen M., Nilsson G.N., Pennington M., Subbey S. and Wienerroither R.** (2011) Probability-based surveying using self-sampling to estimate catch and effort in Norway's coastal tourist fishery. *ICES Journal of Marine Science* 68, 1785–1791.

and

**Wetherall J.A., Polovina J.J. and Ralston S.** (1987) Estimating growth and mortality in steady-state fish stocks from length-frequency data. In Pauly D. and Morgan G.R. (eds) *Length based methods in fisheries research*. Manila: International Center for Living Aquatic Resources Management, pp. 53–74.

**Correspondence should be addressed to:**
S. Vitale
via Luigi Vaccara, 61, I-91026 Mazara del Vallo, TP, Italy
email: sergio.vitale@cnr.it