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The biology and stock assessment of *Merluccius merluccius* (L.) in the Adriatic Sea: an historical review by geographical sub-areas *

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The hake (Merluccius merluccius) *is one of the most heavily exploited main commercial species of the demersal fisheries of the Adriatic Sea coastal countries. This paper reviews critically the existing information on the population dynamics and stock assessment of hake. Despite the fact that most research indicates that exploitation of this species has been very high for prolonged period, fishery production has, apparently, not experienced a major crisis for a long time. Some of the possible reasons behind this contradiction, which should be taken into account for future research, are discussed.*

Key words: hake, Adriatic Sea, exploitation, historical review

INTRODUCTION

The hake is one of the most studied demersal species in the Adriatic Sea, partly owing to its substantial impact on fishery activities in the basin (due to its abundance and economic value). Annual hake landings in the Adriatic were estimated as ranging between 2000 and 6000 tons during the 1980s and 1990s according to statics of the General Fisheries Commission for the Mediterranean (GFCM). The species is the most abundant within the demersal group (representing more than 16% in the last fifty years, JUKIĆ *et al.*, 2001). In general, there was no well-defined trend in Italian landings and a positive trend in the eastern Adriatic where demersal fishery appeared to have developed quickly during the 1990s (MANNINI & MASSA, 2000). However, after the relatively high landing figures of 1993-1994, a marked drop was observed during the last four years for which data are available (Fig. 1).

Biological, ecological and distributional studies have been published in the last century since the 1950s. Basic information on the biology of species in the Adriatic was reported by MATTA (1954), GHIRARDELLI (1959), KARLOVAC, O. (1959) and ŽUPANOVIĆ (1961). Papers on biolo-

* This paper was originally conceived as a follow-up to the AdriaMed Working Groups on Shared Demersal and Small Pelagic Fishery Resources meeting held in Bari (February, 2001), where regional experts from Albania (FRI, Dürres; FD, Tirana), Croatia (IOF, Split), Italy (LBMB, Bari; IRPEM, Ancona; LMBF, Fano; ICRAM, Chioggia) and Slovenia (NIB, Ljubljana) agreed upon the suitability of producing such paper and requested the authors to prepare it.

gy and ecology were published between 1965 and 1976 (KARLOVAC, J., 1965; PICCINETTI & PICCINETTI MANFRIN, 1971a, 1971b; JUKIĆ, 1972; FROGLIA, 1973; JARDAS, 1976), and during the same years the first studies on population dynamics were available (ŽUPANOVIĆ, 1968; LEVI & GIANNETTI, 1972).

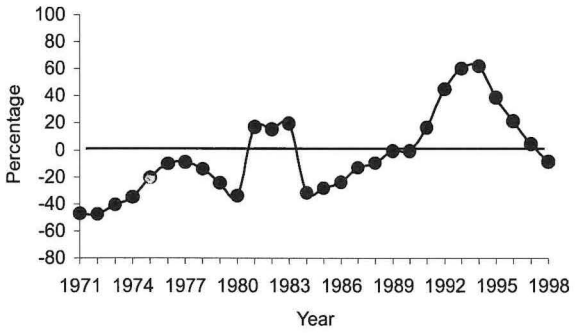

Fig. 1. Yield change relative to mean of the Adriatic Sea M. merluccius *(data source: GFCM)*

The 1980s were the years of population dynamics, stock assessment and resource-fishery interactions in the Adriatic. Various papers developed these subjects together with biological features (JUKIĆ & PICCINETTI, 1981, 1987a, 1987b; FLAMIGNI, 1984; JUKIĆ & ARNERI, 1984; BELLO *et al.*, 1986; GIOVANARDI *et al.*, 1986; ALEGRÍA HERNÁNDEZ *et al.*, 1982; ŽUPANOVIĆ & JARDAS, 1986, 1989; ALEGRÍA HERNÁNDEZ & JUKIĆ, 1988).

Some of the topics (both biology and stock assessment) continued to develop during the 1990s (ALEGRÍA HERNÁNDEZ & JUKIĆ, 1990, 1992; UNGARO *et al.*, 1993, 1996; UNGARO & MARANO, 1996; ARDIZZONE, 1998), and new papers based on time-series approach were published (PICCINETTI & PICCINETTI MANFRIN, 1994; MARANO *et al.*, 1994; MANFRIN *et al.*, 1998; MARANO *et al.*, 1994, 1998a, 1998b; UNGARO *et al.*, 1998). Information on the multi-gear exploitation of hake in the Adriatic was reported (DE ZIO *et al.*, 1998), and the proposal regarding of the importance of nursery areas was renewed (FRATTINI & PAOLINI, 1995). In the end of the 1990s, the distribution of hake was analysed by new mapping techniques (*i.e.* GIS), but only at national level (in Italian waters up to the international waters limit) (ARDIZZONE & CORSI, 1997; ARDIZZONE *et al.*, 1999).

Despite the large amount of information, published papers have a local outline (with a few exceptions) and refer to specific areas (northern, central or southern Adriatic) mostly within national borders or waters.

Recently, the GFCM promoted the definition and delimitation of Geographical Management Units (henceforth referred to as Geographical Sub-Areas or GSA, GFCM, 2001) within the Mediterranean. Two GSA for the Adriatic Sea were proposed during the 24th GFCM session (Alicante, 7-15 July 1999) and at the GFCM-SAC (Scientific Advisory Committee) Working Group on Management Units (Alicante, 23-25 January 2001). The first Adriatic GSA covers the whole extension of the northern and central Adriatic Sea, the second one the southern part (AdriaMed, 2001).

The main purpose of this paper is to review literature on the hake resources in the Adriatic GSAs.

REVIEW OF BIBLIOGRAPHIC DATA

This section includes some published results on biology (growth, reproduction, feeding), population dynamics, stock assessment of hake and time-series studies.

Geographical sub-area 17 (Northern and Central Adriatic)

Biological features

Growth: Reported growth parameters are: $L\infty = 85$ cm, $K = 0.12$ yr^{-1} (JUKIĆ & PICCINETTI, 1981; FLAMIGNI, 1984). Other papers also reported age per length values (Table 1, ŽUPANOVIĆ, 1968; JUKIĆ & PICCINETTI, 1981; FLAMIGNI, 1984). This information refers to both sexes, although

Table 1. M. merluccius*: age per length estimations in the Northern and Central Adriatic Sea*

Age (years)	1	2	3	4	5	6	7	8
TL (cm)	9-19	19-26	28-33	35-39	40	44	49	57

differential growth between sexes was reported in some papers (JARDAS, 1976).

Reproduction: Most papers report a long spawning period during the year (KARLOVAC, J., 1965; ŽUPANOVIĆ, 1968; JUKIĆ & PICCINETTI, 1981). Length at maturity was recorded at 20-30 cm (*TL*) and 26-33 cm (*TL*), for males and females respectively (ŽUPANOVIĆ, 1961, 1968; JUKIĆ & PICCINETTI, 1981).

Feeding: Hake feed mostly on fish (> 60% of prey items) and crustaceans (>15%). The percentage of preyed fish increases with hake length, while crustaceans are found mostly in the stomach of hakes smaller than 16 cm (KARLOVAC, O., 1959; ŽUPANOVIĆ, 1968; PICCINETTI & PICCINETTI MANFRIN, 1971a; JUKIĆ, 1972; FROGLIA, 1973; JARDAS, 1976).

Population dynamics, stock assessment and time-series studies

Most studies referred analysed catches from trawlers (landings and scientific surveys) (ŽUPANOVIĆ, 1968; JUKIĆ & PICCINETTI, 1981, 1987a, 1987b; FLAMIGNI, 1984; JUKIĆ & ARNERI, 1984; GIOVANARDI *et al.*, 1986; ALEGRÍA HERNÁNDEZ *et al.*, 1982; ŽUPANOVIĆ & JARDAS,1986, 1989; ALEGRÍA HERNÁNDEZ & JUKIĆ, 1988, 1990, 1992; ŽUPANOVIĆ & JARDAS, 1989; PICCINETTI & PICCINETTI MANFRIN, 1994; MANFRIN *et al.*, 1998). All the papers identified the depth 100-200 m as the area in which juveniles concentrate. Length distributions appeared to be quite similar over a thirty years period (see ŽUPANOVIĆ, 1968, and MANFRIN *et al.*, 1998), and most of the catches consisted of specimens of less than 20 cm *TL* (ŽUPANOVIĆ & JARDAS, 1986).

With regard to abundance, JUKIĆ & ARNERI (1983) reported a maximum CPUE (kg trawling hour^{-1}) of 6 kg h^{-1} during the years 1948-49, and around 3 kg h^{-1} in 1982. JUKIĆ & PICCINETTI (1981) reported 6 kg h^{-1} during 1972-73 and similar value was also found during the 1990s (MANFRIN *et al.*, 1998). A maximum production (MSY) of 3000-4000 tons year^{-1} was estimated for the basin during the years 1972-73 (JUKIĆ & PICCINETTI, 1981).

Natural mortality estimates mostly ranged between 0.2 and 0.3 yr^{-1}, while total mortality (*Z*) referenced values, calculated by means of catch curve and HEINCKE methods, were higher than 0.8 yr^{-1} in most assessments (ŽUPANOVIĆ, 1968; JUKIć & PICCINETTI, 1981, 1987a, 1987b; FLAMIGNI, 1984; GIOVANARDI *et al.*, 1986; ALEGRÍA HERNÁNDEZ & JUKIĆ, 1990, 1992). Global models noted that hake has been overexploitation since the 1960s (LEVI & GIANNETTI, 1972; ALEGRÍA HERNÁNDEZ *et al.*, 1982).

Recent time-series studies carried out in the western part of the GSA 17 (PICCINETTI & PICCINETTI MANFRIN, 1994; MANFRIN *et al.*, 1998) showed an increasing trend in surveyed catch rates from 1985 to 1995 and a decreasing trend during the last two years (Fig. 2), but small quantitative variations with respect to previously published data. In all surveys the catches consisted of specimens less than 20 cm *TL*. Length distributions were quite stable throughout the investigated period (Fig. 3).

Geographical sub-area18 (Southern Adriatic)

Biological features

Growth: Growth has been reported for females ($L\infty$ = 82.6 cm, K = 0.13 yr^{-1}) and for

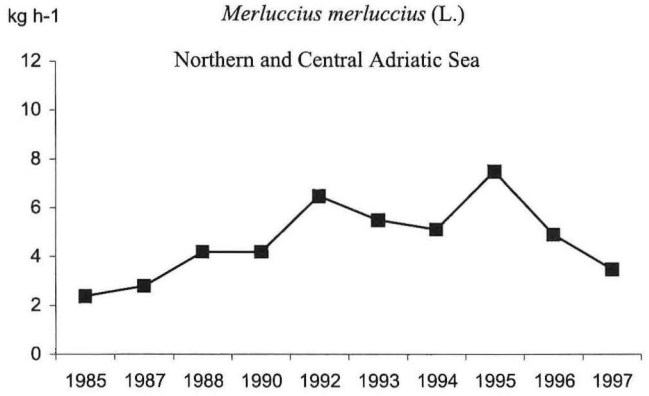

Fig. 2. Catch rates (kg h^{-1}) per year from trawl surveys 1985-1997 in the Northern and Central Adriatic Sea (data from MANFRIN et al., 1998)

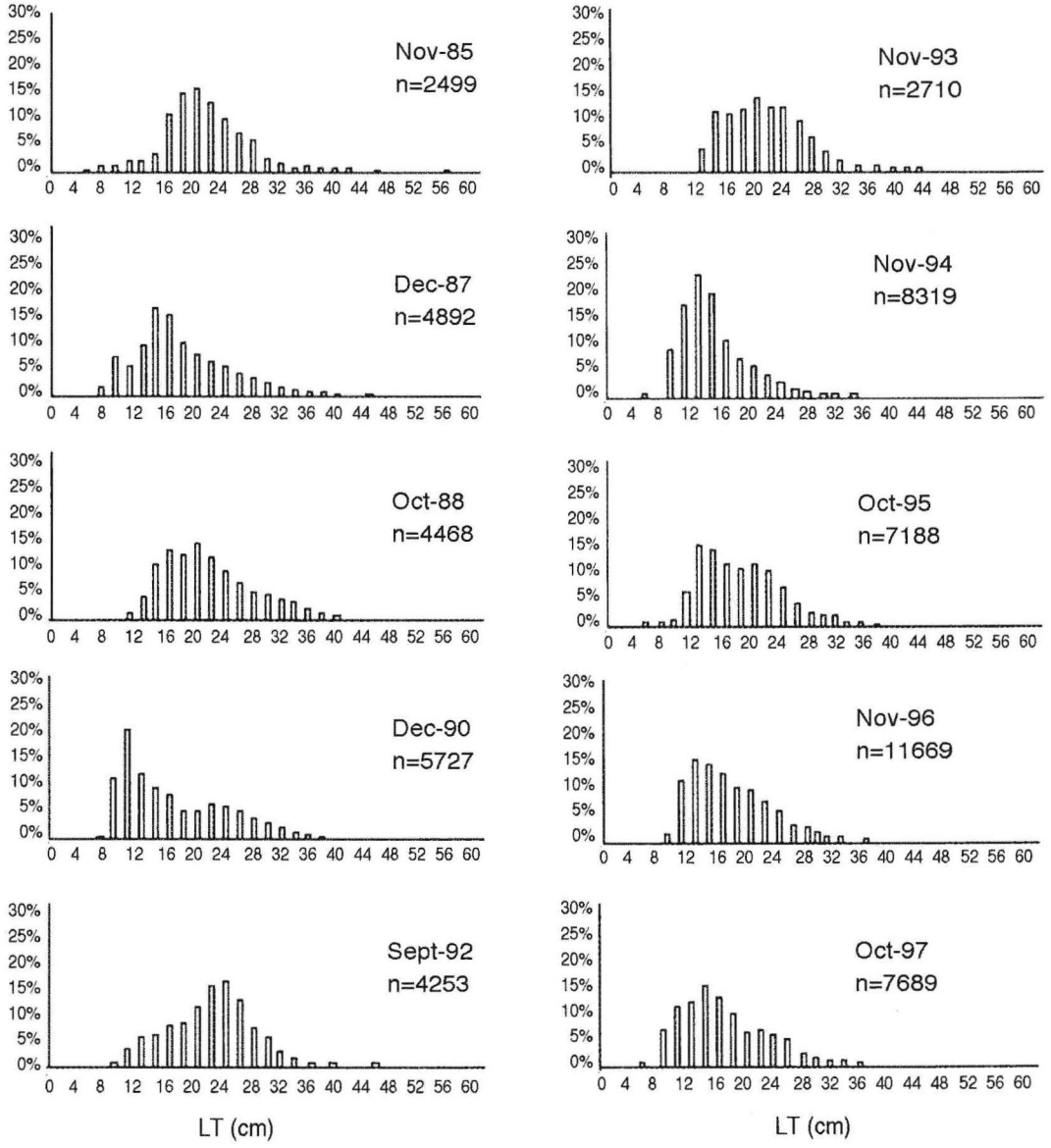

Fig. 3. Length-frequency distributions per year of M. merluccius *from seasonal (Autumn) trawl-surveys 1985-1997 in the Northern and Central Adriatic Sea (modified from MANFRIN et al., 1998)*

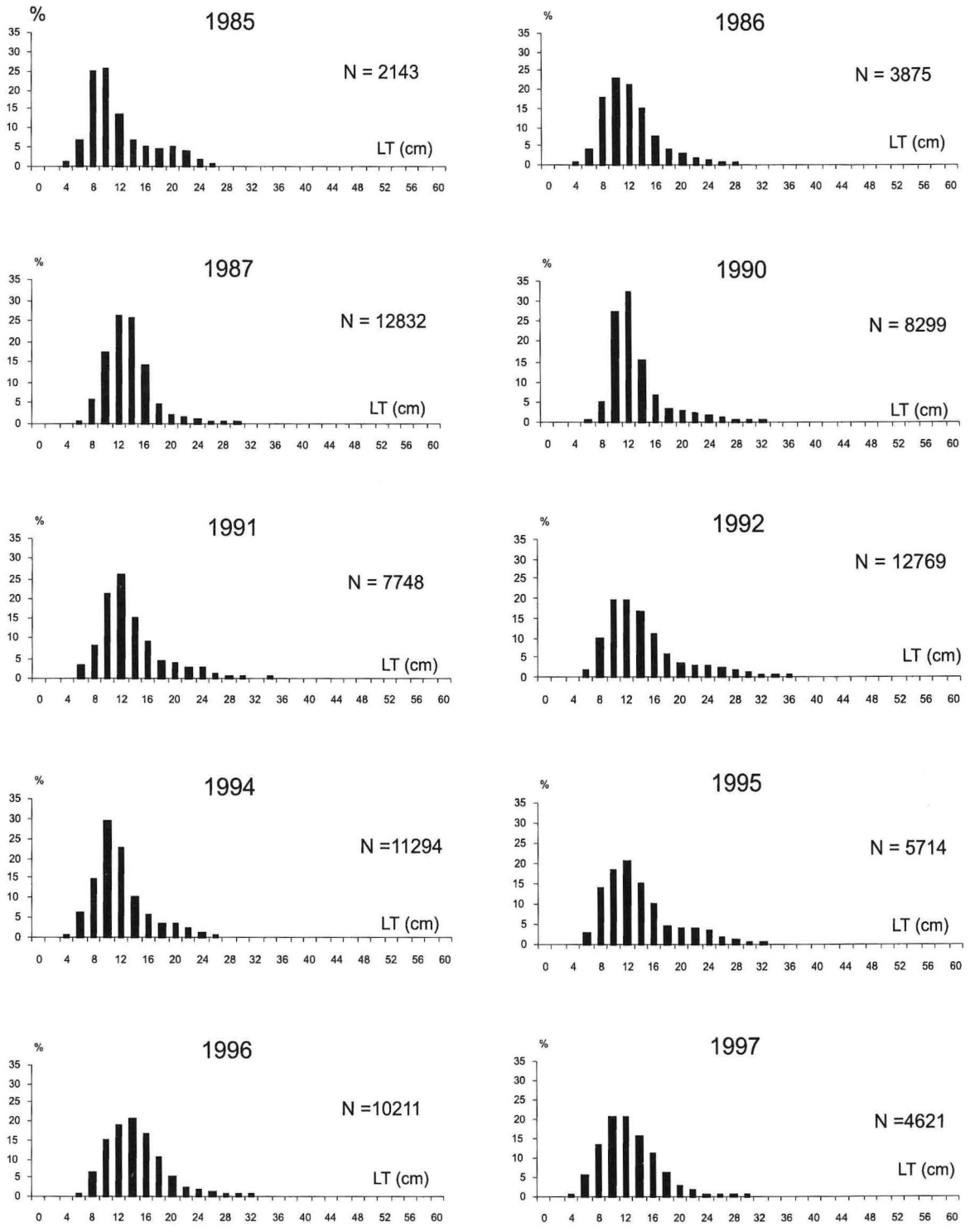

Fig. 4. Length-frequency distributions of M. merluccius *from seasonal (autumn) trawl surveys 1985-1997 in the southern Adriatic Sea (data from MARANO* et al., *1998a)*

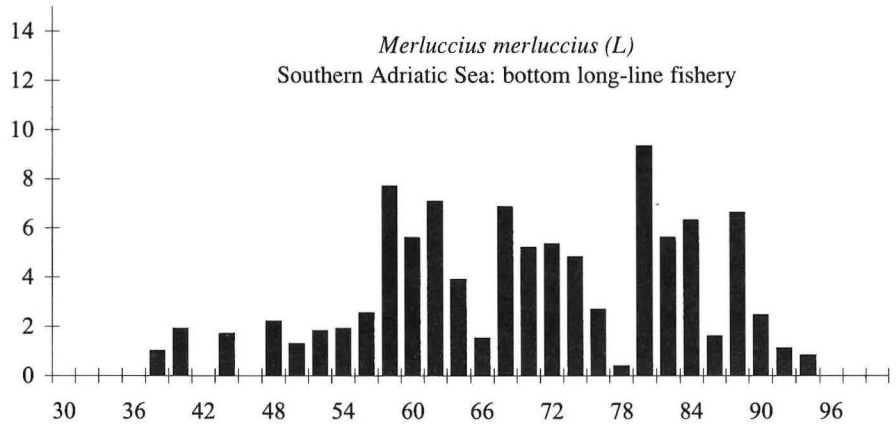

Fig. 5. Length-frequency distributions of M. merluccius *from bottom long-line fishery in the southern Adriatic Sea (modified from DE ZIO* et al., *1998)*

both sexes, combined ($L\infty = 75.7$ cm, $K = 0.15$ yr^{-1}). Differential growth between the sexes has been noted (UNGARO *et al.*, 1993; UNGARO & MARANO, 1996).

Reproduction: Hake have a long spawning period, with peaks during the summer and winter (UNGARO *et al.*, 1993). Length at maturity was

25-30 cm *TL* (lower for males, higher for females; UNGARO *et al.*, 1993).

Feeding: Hake feed mostly on fish and crustaceans (>80% of prey items); the percentage of fish increases with the length of the hake, while crustaceans are found mostly in the stomachs of hake smaller than 15 cm (UNGARO *et al.*, 1993).

Population dynamics, stock assessment and time-series studies

Most studies refer to analyses of catches from trawlers (mostly scientific surveys; BELLO *et al.*, 1986; UNGARO *et al.*, 1993, 1996, 1998; MARANO *et al.*, 1994, 1998a, 1998b; UNGARO & MARANO, 1996). CPUE values ranged from 1.4 to 9.9 kg h^{-1} during 1985-1997 (MARANO *et al.*,

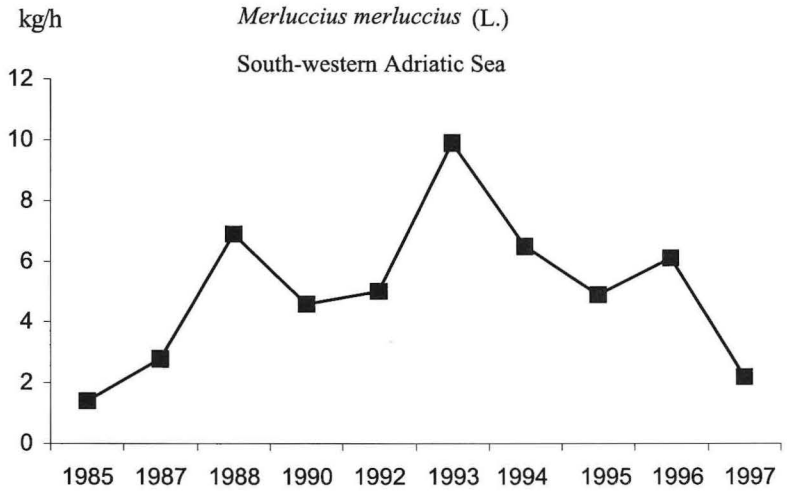

Fig. 6. Catch rates (kg h^{-1}) per year from seasonal trawl surveys 1985-1997 in the southern Adriatic Sea (data from MARANO et al., *1998a*

1998a). Mortality was similar (M =0.3 yr^{-1} and Z =1-1.7 yr^{-1}; UNGARO *et al.*, 1993) to mortality in GSA17. The exploitation rate was high, according to the THOMPSON & BELL model (UNGARO & MARANO, 1996). The catches consisted mostly of specimens under 20 cm *TL*, as in GSA17, and the length distribution remained quite stable throughout the entire examined period (Fig. 4).

DE ZIO *et al.* (1998) reported the size structure of the catch from the bottom long-line fishery (Fig. 5), noting how it differed from trawl survey catches (Figs. 3, 4).

Recent time-series studies of the western part of GSA18 (MARANO *et al.*, 1994, 1998a) showed an increasing trend in survey catch rates from 1985 to 1993 and a decreasing trend from 1994 to 1997 (Fig. 6). According to both regression analysis (MARANO *et al.*, 1998b) and ARIMA models (UNGARO *et al.*, 1998), no significant trend was found.

DISCUSSION AND CONCLUSIONS

The "scientific heritage" of fifty years of fishery research in the Adriatic Sea is probably one of the most important in the Mediterranean area. This review of bibliographic references and published data on hake in the Adriatic highlights the following.

1) Juveniles represented more than 90% of the catch in two surveys carried out at an interval of fifty years (90% in the HVAR 1948 survey and 97% in the MEDITS 1998 survey). The length distributions in both surveys generally overlapped at premature lengths (up to 30 cm; Fig. 7). At least two cohorts (at 8-10 and 16-18 cm) were distinguished in both surveys, while adult lengths were more abundant in the HVAR survey samples.

This is probably due to exploitation and the relative efficiency of the gear used in the survey. Large hake escaped the MEDITS trawl net (1998 survey), probably because of the large mesh used in the belly sections, as reported by DREMIÈRE *et al.* (1999). Age classes 0+ and 1+ seem to have supported the Adriatic trawl fishery since the Second World War period. Interestingly, as long ago as the 18th century, MOLLER pointed out the high occurrence of juvenile hake in trawl catches (MOLLER, 1775, in ŽUPANOVIĆ & JARDAS, 1986).

2) There was no clear trend in abundance indices from the catches (kg h^{-1}, data from trawl surveys), although they fluctuated throughout the reported time periods. Reported nominal landing data mostly agreed with this pattern (MANNINI & MASSA, 2000).

3) Exploitation indices, such as Z, F and E, were high for the last thirty years. Both global and analytical stock assessment models produced similar results.

For most years, there was a discrepancy between the high estimated exploitation and the fish yield. Some possible reasons could be as follows:

- the length of captured stock is strongly related to the trawl gear. In the Adriatic, the authorised stretched mesh size at the cod end of commercial trawl nets ranged between 30 and 40 mm since the 1950s. Therefore, the length of fish in the first catch (50%) was around 10-12 cm (much smaller than the length at sexual maturity) and juveniles were the main component of the commercial catch (N. UNGARO, pers. observation). The catchability of large specimens with a trawl net is low, while other kinds of gear (*e.g.*, bottom long-line) collect mostly large specimens. Therefore, the size structure of most catches is not representative of the entire hake population.

- most growth estimates are probably biased due to the sampling procedure and subsequent data are unlikely to fully represent the population at sea.

- mortality estimates are probably biased. Natural mortality values are affected by estimation methods to which the effect of "constant M assumption" should be added. This may be particularly relevant for juveniles. Z values from

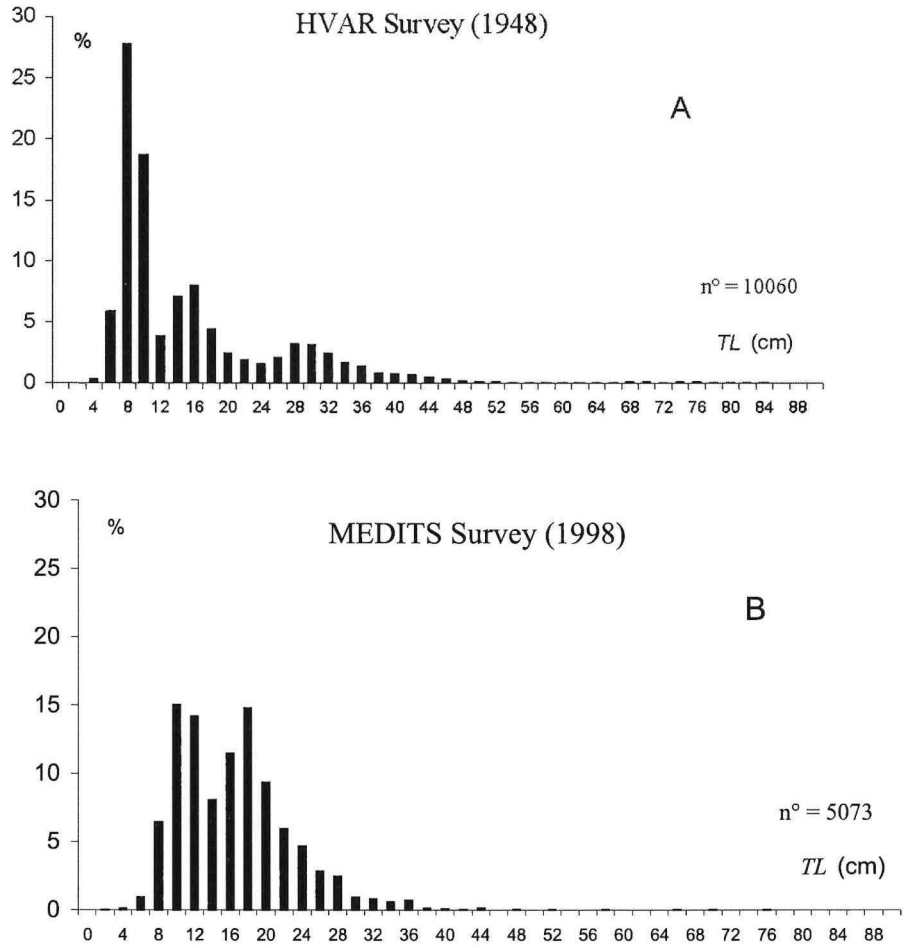

Fig. 7. Length distributions of M. merluccius *from two trawl surveys carried out at a fifty year interval in the same season (spring-summer) in the same area of the Adriatic (A = HVAR Survey, 1948; B = MEDITS Survey, 1998)*

length-converted catch curves were overestimated because of the analysed length distributions. Consequently, the resulting F is overestimated since $F = Z\text{-}M$.

- the application of the mentioned parameters in global and analytical models such as the BEVERTON & HOLT or THOMPSON & BELL models could give misleading information.

The Adriatic trawl fishery mostly targeted the juvenile fraction of the hake population. Nevertheless, no major crises are reported to have affected the hake fishery during the last fifty years. Possible reasons could be the low vulnerability of large spawners to the trawl fishery (*i.e.*, the "refugium concept" hypothesised by CADDY, 1993) or that the hake population compensated for the decrease of other predators (JUKIĆ *et al.*, 2001). Most important is the question, how sustainable is the fishing pressure on juveniles?

Nominal fishery statistics such as landing data are generally thought to be of low reliability and accuracy. Nevertheless, they can reflect major patterns over time (GRAINGER & GARCIA, 1996; FIORENTINI *et al.*, 1997). One of the most important known changes in the eastern Adriatic fishery has been the development of

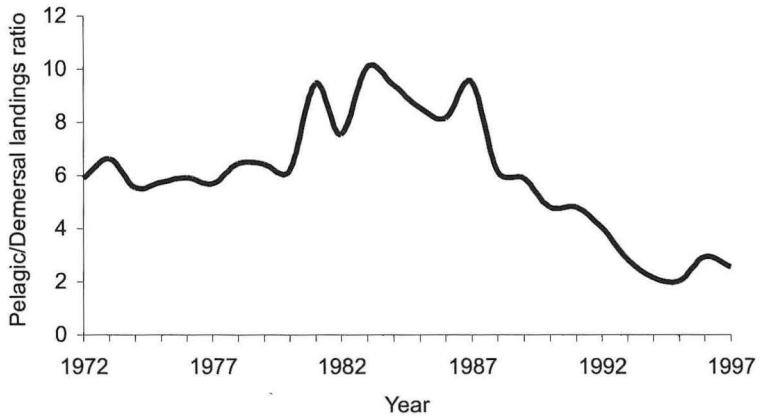

Fig. 8. Ratio between landings from pelagic and demersal capture fisheries in the eastern Adriatic Sea (adapted by MANNINI & MASSA, 2000). Data for 1972 to 1991 are from Albania and Yugoslavia and for 1992 onwards from Albania, Croatia, Federal Republic of Yugoslavia, and Slovenia

the demersal trawl fishery and the regression of the small pelagic fishery since the early 1990s (CADDY & OLIVER, 1996; MANNINI & MASSA, 2000; Fig. 8).

This has contributed to, if not determined, initially increased landings followed by a marked decline, which is continuing. The growth of the trawl fishery should be considered crucial to understanding the current sustainability of the hake fishery in the Adriatic Sea. It seems that the stock had been fished at a sustainable level until recently, but it may be unable to sustain higher exploitation rates.

Key fishery resources, such as the hake stock, can be appraised and many questions can be answered by using different stock assessment approaches (ABELLA *et al.*, 1997) and by studying recruitment from, *e.g.*, trawl surveys that focus on nursery and spawning areas of the Adriatic (*e.g.*, Jabuka Pit) and other gears (*i.e.*, bottom long-line). Comparison and integration of data from fishery-independent sources (such as trawl surveys) and fishery-dependent sources (such as commercial catches and efforts) would greatly contribute to the information available for stock assessment purposes. The importance of appropriately taking into account all available information when assessing fishery resources is widely accepted.

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Biologija i procjena stoka (stock) oslića (*Merluccius merluccius*) (L.) u Jadranskom moru: povijesni pregled podataka prema zemljopisnim područjima

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SAŽETAK

Oslić (*Merluccius merluccius*) je jedna od najviše eksploatiranih komercijalnih vrsta u pridnenom ribolovu zemalja Jadranskog mora. Cilj ovog rada je dati kritički osvrt na postojeće podatke o populacijskoj dinamici i procjenama stoka. Prikupljeni podaci, uprkos činjenici da ukazuju na vrlo visoku razinu eksploatacije vrste u dužem periodu, ulov dugoročno gledano ipak ne pokazuje neke veće krize. Neki od mogućih razloga ovih proturječnosti, a koje treba uzeti u obzir u budućim istraživanjima, su izneseni u ovom radu.

Ključne riječi: oslić, Jadransko more, eksploatacija, povijesni pregled