Remarks about the optimal harvest strategy for red shrimps (Aristeus antennatus, Risso 1816) on the basis of the Ligurian experience

Florentino F., Orsi Relini L., Zamboni A., Relini G.

in

Lleonart J. (ed.).
Dynamique des populations marines

Zaragoza : CIHEAM
Cahiers Options Méditerranéennes; n. 35

1998
pages 323-333

Remarks about the optimal harvest strategy for red shrimps (*Aristeus antennatus*, Risso 1816) on the basis of the Ligurian experience

F. Fiorentino, L. Orsi Relini, A. Zamboni and G. Relini
Laboratori di Biologia Marina ed Ecologia Animale, Istituto di Zoologia, Università di Genova, Via Balbi 5, 16126 Genoa, Italy

SUMMARY - Optimal harvest strategies for *Aristeus antennatus* stock(s) in the western Mediterranean are discussed in the light of the new ideas about the slow growth and high longevity of this species and the recently introduced "biological reference points". Unlike the main demersal resources in the Mediterranean, red shrimp fisheries exploit spawning shoals, endangering the sustainability of the stock. The collapse of red shrimp fisheries in the Central Eastern Ligurian Sea during the early eighties, and the decline of CPUE in the present fishing activity, which started in 1987, suggests that the current exploitation, close to the classical F_{max}, probably exceeds sustainability. Considering that the spawning stock/recruitment relationship for *Aristeus antennatus* is unknown, a more careful assessment should leave the F_{max} strategy in favour of the more conservative $F_{0.1}$ strategy.

Key words: *Aristeus antennatus,* Ligurian Sea, stock assessment, yield per recruit analysis, biological reference points, optimal harvesting strategy.

RESUME - *"Remarques sur une stratégie optimale d'exploitation pour la crevette rouge* (Aristeus antennatus, *Risso 1816) sur la base de l'expérience ligurienne". Les stratégies du niveau optimal d'exploitation pour les stocks de* Aristeus antennatus *dans la Méditerranée occidentale sont discutées à la lumière des nouvelles idées sur la lente croissance et sur la longévité élevée de cette espèce et des plus récents "points de référence biologique". Différemment des principales ressources démersales de la Méditerranée, la pêche de la crevette rouge exploite les agrégations des reproducteurs mettant en danger la subsistance des stocks. L'effondrement de la pêche de la crevette rouge dans la Mer Ligure Centre-Orientale au début des années 1980 et la diminution de CPUE dans la présente activité de pêche, commencée en 1987, conseille que l'exploitation courante, proche de la classique* F_{max}, *pourrait être loin de la subsistance. Considérant que la relation reproducteurs/recrues pour* Aristeus antennatus *est inconnue, une évaluation des stocks plus prudente devrait abandonner la stratégie de gestion* F_{max} *pour la crevette rouge en faveur de la plus conservatrice* $F_{0.1}$.

Mots-clés : Aristeus antennatus, *Mer Ligure, évaluation des stocks, analyse de la production par recrue, points de référence biologique, exploitation optimale.*

Introduction

In spite of a general overfishing of most of the demersal resources in the Mediterranean, some fishery biologists believe that the exploitation of *Aristeus antennatus* (Risso, 1816) stock(s) from the Western Mediterranean is quite close to the level of sustainable harvesting. This optimal exploitation should be related to the extremely broad distribution of the red shrimp on bathyal bottoms (Demestre and Martin, 1993; Bianchini and Ragonese, 1994; Sardà *et al.,* 1994; Ragonese and Bianchini, 1996).

Despite this optimistic scenario, some authors have reported very large fluctuations in catches of red shrimp along the Ligurian (Orsi Relini and Relini, 1985, 1994; Relini and Orsi Relini, 1987), French (Campillo, 1994) and Spanish coasts (Sardà, 1987; Tobar and Sardà, 1987; Oliver, 1993; Sardà and Cartes, 1994).

The main areas of red shrimp fisheries in the Ligurian Sea, shown in Fig. 1, are the canyons off Ventimiglia and San Remo, near the French border, the canyon off Punta S. Lorenzo, west of Imperia, the banks of "Vapore" and "Banco" between Imperia and Gallinara Island, the banks between Savona and Genoa, damaged by the sinking of the "Haven" in 1991 (Relini, 1994), the areas off the Portofino headland, called "Banchetto", "fuori le rame" and "di terra le rame", and finally the offshore fishing grounds north of Santa Lucia Bank.

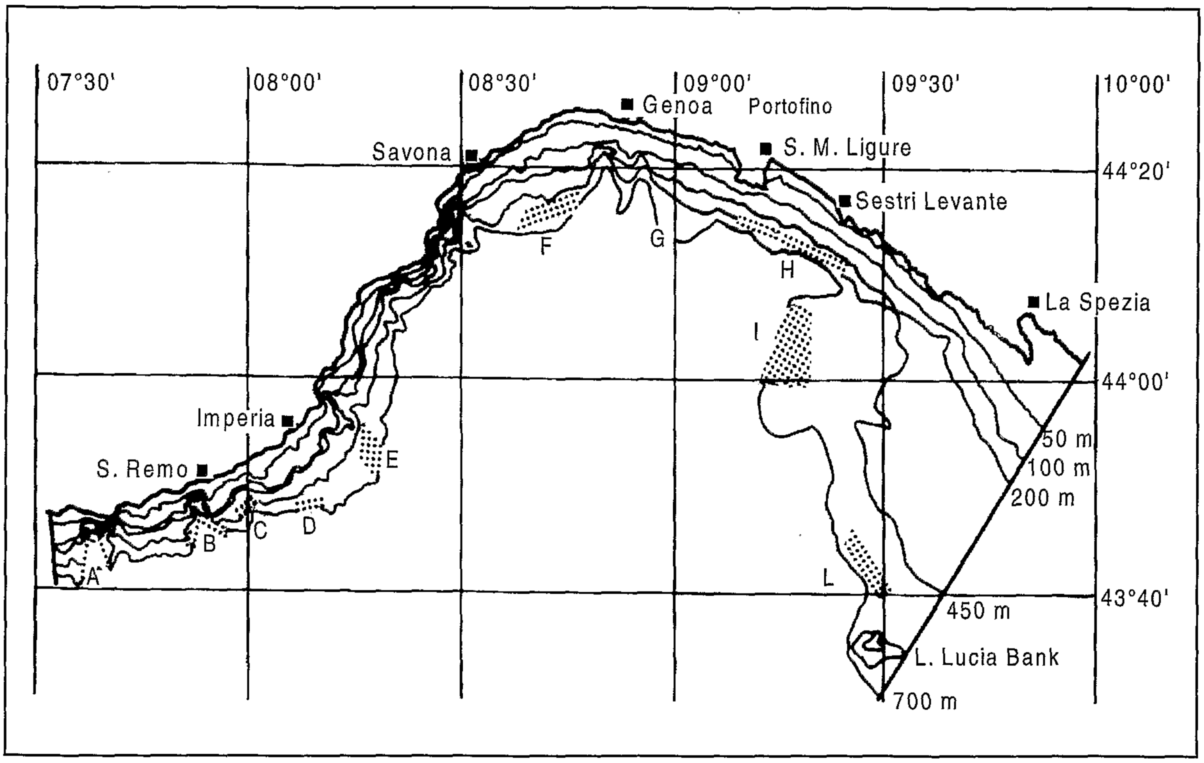

Fig. 1. Main *Aristeus antennatus* fishing grounds in the Ligurian Sea. A: Ventimiglia Canyon; B: San Remo Canyon; C: San Lorenzo Canyon; D: Vapore Bank; E: Banco Bank; F: Between Genoa and Savona Bank; G: Banchetto Bank; H: Di terra le rame Canyon; I: Di fuori le rame Bank; L: Banco Bank.

Orsi Relini and Relini (1985), Relini and Orsi Relini (1987) tried to reconstruct the history of red shrimp fishery in the Central Eastern Ligurian Sea on the basis of the literature, personal observations and fishermen's accounts. Fishermen began to exploit red shrimps on the epibathyal level during the thirties, catching between 100 and 200 kg per day per trawler. During this phase the resource was made up of *Aristeus antennatus* and *Aristaeomorpha foliacea* (Risso, 1827). After the second world war, during which fishing activities were suspended, catches increased to reach values as high as 1,000 kg per day per trawler. This stage of stock abundance came to an end approximately in 1955, when red shrimps became scarce on epibathyal bottoms and fisheries began to reach mesobathyal levels, mainly exploiting *A. antennatus*, with catches of 100 kg per day per trawler. From 1956 to 1980 *Aristaeomorpha* became rarer and rarer and the quantities of *Aristeus* progressively decreased until the fishery collapsed. In 1985 the first signs of a recovery were registered (Orsi Relini and Relini, 1986).

The possible causes of this decline in the catches of red shrimps in the Central-Eastern Ligurian Sea were discussed (Orsi Relini and Relini, 1985; Relini and Orsi Relini, 1987), although no sufficiently convincing hypothesis was found to explain why the fishery had come to an end. Together with overfishing the authors considered environmental decay, hydrology, recruitment failure due to predation and pathological factors.

During 1987 an uncommon recruitment of *A. antennatus* was observed on trawlable bottoms (Orsi Relini and Relini, 1988), which led to the beginning of an increased fishing activity both in terms of time and space (i.e., extention of trawled areas).

Since 1988 the *A. antennatus* stock has been exploited by 12-15 trawlers specialized in deep-sea fishing. The catches per unit of effort gained the highest levels in 1988 and then started to decline (Fiorentino *et al.*, 1995).

The aim of the present work is to present a Virtual Population Analysis (VPA) for the Ligurian catches and to discuss the most suitable biological reference points among those available to give a harvesting strategy for red shrimps stock(s), while considering the sustainability of the resource. The present analysis was influenced by the large fluctuations of the red shrimps in the Mediterranean, the reported decline in the Ligurian Sea, the more recent ideas on slow growth and high longevity of *A. antennatus* (Orsi Relini and Relini, 1996-1998; this volume) and the review on the biological reference points for management purposes, presented by Abella (1995) at the first DYNPOP meeting.

Materials and methods

Two series of data were collected: trawlers' landings at Santa Margherita Ligure and trawl surveys.

The landings made by the Santa Margherita boats, which constitute 75% of the Central-Eastern Ligurian red shrimp fleet, has been monitored twice a month from 1987 up to today. Landings were recorded as boxes of red shrimps. The biomass values were obtained by multiplying each box or fractions of a box by 7 kg, which is the average weight of the full box. Since no part of red shrimp catches is discarded in Ligurian fishery, the landings can be directly used as measure of the catches.

Data on catches per unit of effort, together with the information on fishing effort, given by the fishermen, allowed us to estimate the yield of red shrimps in the Central-Eastern Ligurian Sea during 1991, 1992 and 1993. The estimated figures were 58, 62 and 47 tons respectively.

12 trawl surveys, carried out seasonally between 1991 and 1993 on bottoms fished by the commercial trawlers, provided approximately 4,100 specimens of *A. antennatus* females, which were measured in terms of 1 mm carapace length rounded down to the nearest mm. The length-frequency distributions, obtained in each seasonal survey of a given year, were added together, in order to gain length structures representative of the year. These collected length distributions were related to the total annual catches, derived from monitoring of landings, by using the ratio between weight of measured samples and weight of total catches.

A VPA was performed in the form of a Length Cohort Analysis (LCA) included in the VIT package designed by Lleonart and Salat (1992).

To gain the steady state assumed by the LCA method (Jones, 1981), the analysis was carried out on the average length structures of catches, obtained as mean figures over the three years.

As growth concerns two sets of parameters, recently proposed by Orsi Relini and Relini (1996-1998; this volume), were used (Table 1). The natural mortality rates were estimated by using the Taylor (1959) and Alagaraja (1984) methods. These authors calculate the rates giving the survivors equal to 5% and 1% of the initial effectives of a recruited cohort respectively, as a function of the longevity in an unexploited population. The maximum age for *A. antennatus* was estimated at 10 years (Orsi Relini and Relini, 1996; this volume).

To avoid errors due to the high variation in age of those shrimps whose length is close to L_∞, a plus group was introduced for those individuals from 56 mm LC size class onward. This threshold length, which is between 73 and 79% of L_∞, was chosen while also bearing in mind the suggestions of ICES (1991).

The outputs of LCA were used to estimate the spawning potential ratio (SPR) as the spawning biomass per recruit at a given level of fishing mortality (SSB/R), which is equal to the total biomass itself since red shrimp fishery exploits the spawning shoals, divided by the unfished spawning biomass per recruit (VSSB/R) (Goodyear, 1993).

Table 1. Biological parameters of *Aristeus antennatus* used for LCA

Parameters	Scenario 1	Scenario 2
L_∞	71.21	76.90
K	0.317	0.213
T_0	-0.047	-0.019
a	0.00354	0.00354
b	2.386	2.386
M	0.3-0.5	0.3-0.5
F_{term}	0.5	0.5
Plus group	56	56

As reference points to evaluate the optimal harvest strategy we consider both $F_{0.1}$, i.e., the fishing mortality rate at which the slope of the Y/R curve is 10% of its value for F equal 0, introduced by Gulland and Borema (1973) and F_{max}, i.e., the fishing mortality rate which gives the maximum yield per recruit for a given fishing strategy, which is currently used for red shrimps assessment in the Mediterranean.

Results

Figure 2 shows the decrease in the mean monthly catch per unit effort of the Santa Margherita fleet, in kg per trawler per day, from the beginning of the monitoring onward. Between 1988 and 1995 the CPUE was nearly halfed, going down from 35 kg to 18 kg per trawler per day.

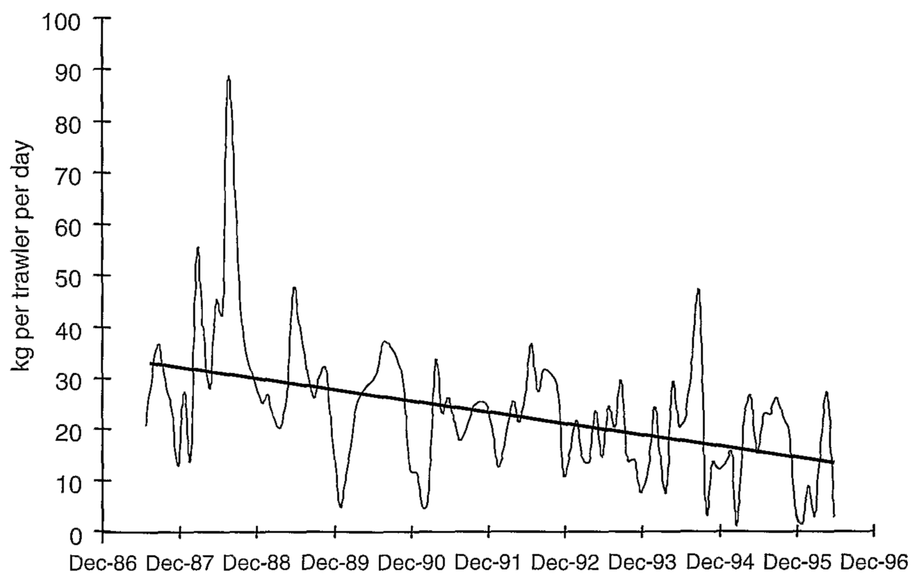

Fig. 2. Catch per unit effort (CPUE) of *Aristeus* of the Santa Margherita Ligure deep fishing fleet (each monthly figure represents the mean of two observations of landings) and general trend of catches.

Figure 3 illustrates the variation in the number of females smaller than 38 mm CL caught in the Eastern Central Ligurian Sea during the autumn trawl surveys carried out every year between 1990 and 1995. The reference size 38 mm CL was chosen bearing in mind that the 1987 recruits had this modal size (see also Relini Orsi e Relini, this volume). The fraction of young individuals in the stock seems to have decreased between 1991 and 1995.

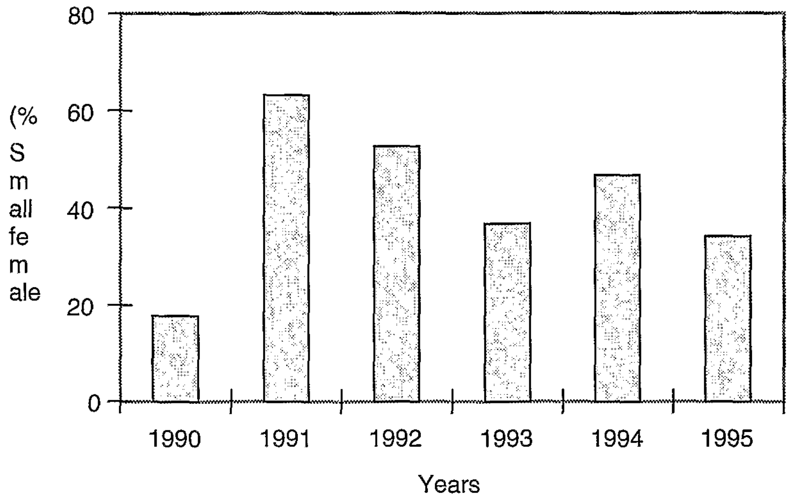

Fig. 3. Variation of fraction of females smaller than 38 mm CL in sample collected during the autumn trawl surveys, carried out in the Ligurian Sea from 1990 to 1995.

Figure 4 shows the annual length structures derived from the trawl surveys from 1991 to 1993 which were used for LCA. It is possible to note the decrease in the youngest fraction over the same period.

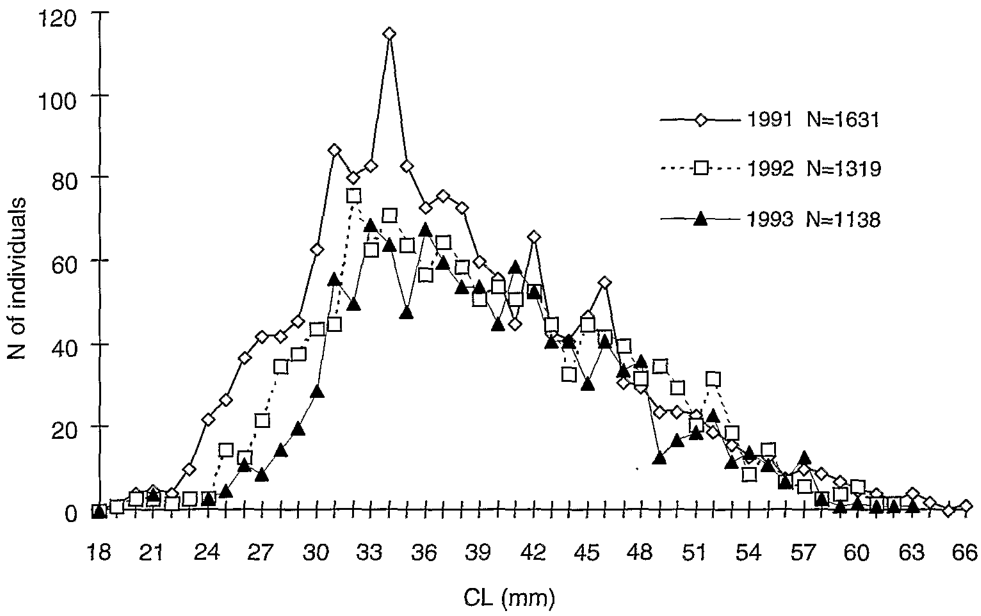

Fig. 4. Length structure of *Aristeus antennatus* females in three consecutive years (each profile represents the sum of four seasonal surveys carried out on the eastern fishing ground).

In Tables 2 and 3 the main results of LCA and yield per recruit analysis are given.

Figure 5 shows the variation of yield per recruit as a function of a multiplicative factor of current fishing mortality rate (F_c). According to the two growth parameters used in the analysis, if we assume M=0.3, F_c ranges from 0.28 to 0.40. Similarly, if we assume M=0.5, F_c ranges from 0.19 to 0.29 (Table 2-3).

Table 2. Main results of Length Cohort Analysis and Yield per Recruit Analysis. Growth parameters according to Scenario 1

Scenario 1	F_C		$F_{0.1}$		F_{max}	
	M=0.3	M=0.5	M=0.3	M=0.5	M=0.3	M=0.5
Y/R	13.8	8.9	12.9	8.5	13.8	no maximum
SSB/R	23.7	19.9	45.9	22.4	27.8	-
F	0.40	0.29	0.18	0.24	0.33	-

Table 3. Main results of Length Cohort Analysis and Yield per Recruit Analysis. Growth parameters according to Scenario 2

Scenario 2	F_C		$F_{0.1}$		F_{max}	
	M=0.3	M=0.5	M=0.3	M=0.5	M=0.3	M=0.5
Y/R	11.7	6.6	10.7	6.6	11.7	no maximum
SSB/R	26.7	21.1	44.5	21.2	26.7	-
F	0.28	0.19	0.13	0.19	0.28	-

Considering as reference point the "classical" F_{max} and assuming M=0.3, the red shrimp stock appears to be quite close to the optimal harvesting level with the first growth scenario, while a condition of light overfishing is detected if the second growth scenario is adopted. On the contrary a clear overfishing is identified if the $F_{0.1}$ is chosen as the desiderable harvest strategy for the fishery, by using both growth parameters.

If we assume M=0.5, the yield curves has not any maximum, for both the growth parameters, showing that F_{max} is not a suitable strategy for this stock.

If the $F_{0.1}$ strategy is accepted as the optimal one, the stock is lightly overfished with the first growth parameters while an optimal harvesting is detected with the second growth ones.

According to the different simulations the current spawning potential ratio ranges between 18 and 23% with M=0.3, and between 37 and 47%, with M=0.5. If the stock is exploited on the F_{max}. strategy, the ratio ranges between 21 and 23%, depending on the different biological parameters used; this figure rises to approximately 36-47% if the $F_{0.1}$ strategy is applied (Table 4).

Discussion

The available stock(s) assessments of *A. antennatus* in the Western Mediterranean, are reported in Table 5.

The oldest assessment, carried out by Cirugeda-Delgado and Garcí-Mamolar (1976) and based on the production models of Schaefer (1954, 1957) and Fox (1970), concerns the fishery of *A. antennatus* in the Balearic area from 1959 to 1974. The optimal effort level, identified as that giving the Maximum Sustainable Yield and ranging between 2,000 (Fox model) and 2,800 (Schaefer model) units of standard effort, was exceed in 1962 (Fox model) or in 1966 (Schaefer model), showing a state of clear overexploitation.

More recently, Demestre and Lleonart (1993) gave an assessment of *A. antennatus* fishery off Catalonia and Valencia between 1984 and 1989. They made LCA and the yield per recruit analysis, using the programs implemented in the VIT package. The authors considered as biological reference point the "classical" F_{max} and concluded that stocks were exploited at a level close to the optimum.

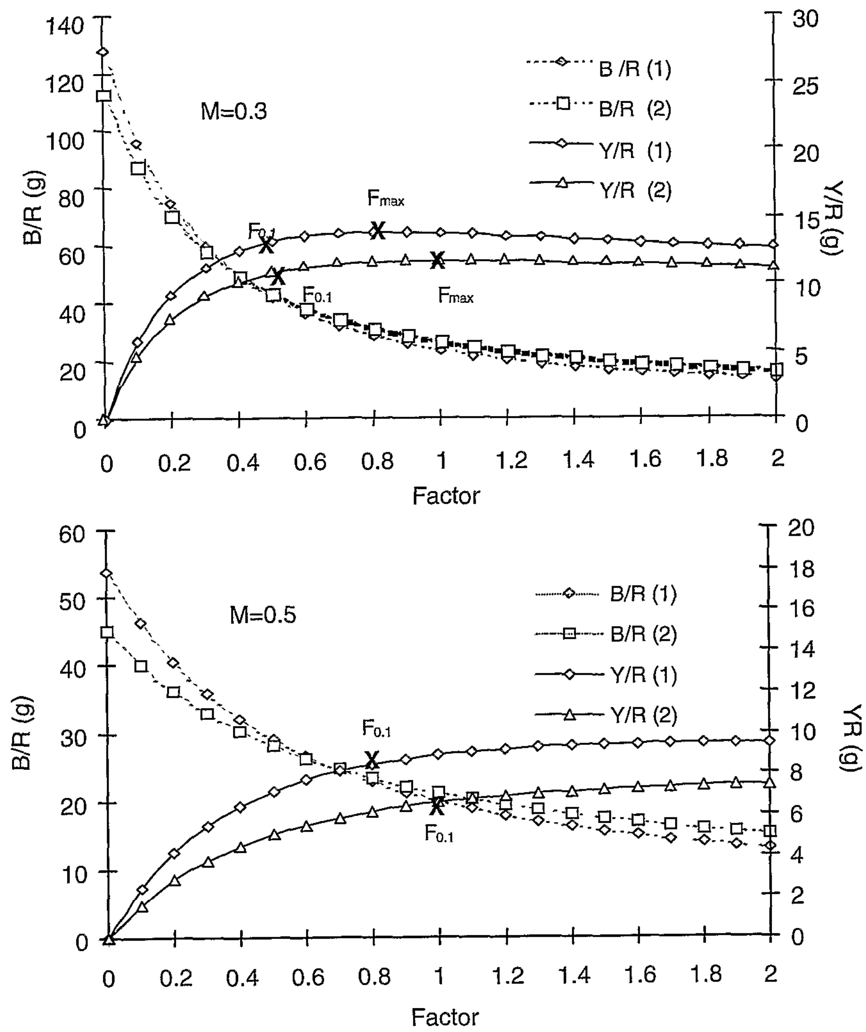

Fig. 5. Biomass per recruit (left) and yield per recruit (right) curves of *Aristeus antennatus* females in the Ligurian Sea, derived with different scenarios of growth (1 and 2) and natural mortality (M=0.3-0.5). The multiplicative factor of current F (factor=1) corresponding to $F_{0.1}$ and F_{max} are shown.

Table 4. Spawning potential ratio (SPR) in function of different growth and mortalities

Growth	M	VSSB/R	SPR_{Fc}	$SPR_{F0.1}$	SPR_{Fmax}
Scenario 1	0.3	128.1	18.5	35.8	21.7
	0.5	53.8	37	41.6	-
Scenario 2	0.3	113.5	23.5	39.2	23.5
	0.5	45.1	46.8	47	-

Spedicato *et al.* (1995), made an assessment of the Central-Southern Tyrrhenian *A. antennatus* stock, using the classical model of Beverton and Holt (1957), applied to data collected during trawl surveys in 1992-93. These authors reported in stock assessment both the $F_{0.1}$ and the F_{max} values, but considered only F_{max} in evaluating the harvest state of the stock. According to this biological reference point the stock resulted to be in an early stages of growth overfishing.

Table 5. *Aristeus antennatus* stocks assessment in the western Mediterranean. The analytical models concern with females only

Author	Area	Model	Current F or f	Optimal F or f	Reference point	Evaluation
Cirugeda Delgado *et al.*, 1976	Baleares	Fox	4,000	2,000	f_{MSY}	Overfishing
		Schaefer		2,800	f_{MSY}	
Demestre and Lleonart, 1993	Catalonia	LCA plus Y/R analysis	1.2[a]	1.2	F_{max}	Optimal harvesting
	Valencia		1.1[a]	1.1	F_{max}	
Spedicato *et al.*, 1995	Southern Tyrrhenian Sea	Classical Beverton and Holt	1.3[b]	1.3	F_{max}	Initial Overfishing
				0.6	$F_{0.1}$	
Ragonese and Bianchini, 1996	Strait of Sicily	Modified Beverton and Holt	0.3[c]	1.1	F_{max}	Underexploitation
			0.6[d]	0.6	F_{max}	Exploitation close to the maximum
This study	Ligurian Sea	LCA plus Y/R analysis	0.40[e]	0.33	F_{max}	Light overfishing
				0.18	$F_{0.1}$	High overfishing
			0.28[f]	0.28 0.13	F_{max} $F_{0.1}$	Optimal harvesting High overfishing
			0.29[g]	no maximum 0.24	 $F_{0.1}$	 Light overfishing
			0.19[h]	no maximum 0.19	 $F_{0.1}$	 Optimal harvesting

a: Mean values of several pseudocohorts with M=0.5; b: M=0.65 and age at first capture (t_c) of 0.98 year; c: M=0.5 and t_c=1 year; d: M=0.8 and t_c=1 year; e: Scenario 1 and M=0.3; f: Scenario 2 and M=0.3; g: Scenario 1 and M=0.5; h: Scenario 2 and M=0.5

Ragonese and Bianchini (1996), assessed the *A. antennatus* stock of the Strait of Sicily by using data gathered during 1986-87 trawl surveys and applying the Beverton and Holt model as modified by Paulik and Gales (1964) for allometry in growth. The authors inferred that, if one takes M=0.8 and F_{max} as a reference point, the stock is underexploited, while if one takes M=0.5, the harvesting is close to the maximum yield and gains in production per recruit could not be obtained without changing the age of first capture.

Looking at the results of the Ligurian stock assessment, the F_{max} strategy gives an optimal harvesting for M=0.3 and regardless of growth scenarios. For M=0.5 the yield per recruit curves do not show any maximum and therefore the F_{max} cannot be used. Considering as reference point $F_{0.1}$ and M=0.3 an high overfishing is detected in both growth scenarios. For M=0.5 a light overfishing is recognized when growth parameters accord to scenario 1, while an optimal harvesting is reached when growth occurs as in scenario 2.

In our opinion M=0.3 should be the most realistic estimate of natural mortality rate for *A. antennatus*. This suggestion is based to the fact that M=0.3 is a "well accepted" estimate for *Nephrops norvegicus,* which shows a lifespan similar to the red shrimp (Brander and Bennet, 1989; ICES, 1997). When M is equal 0.3 and regardless growth patterns used, the current fishing mortality rate in *A. antennatus* of the Ligurian Sea is close to F_{max}. Although the F_{max} value is reached CPUEs and recruitment level are decreasing. These features are warning signals that the F_{max} strategy produces recruitment overfishing and depletion of the red shrimp stock.

This conclusion does not agree with the opinion of most fishery biologists, who believe that the current effort on red shrimps is close to the optimal one, in contrast with the large part of Mediterranean demersal resources (see Table 5). We think that their optimistic evaluation does not fully consider the historical collapses of the red shrimp populations occurred in some areas of the Western Mediterranean. Such evaluation is also influenced by "high rate" population parameters (both growth and natural mortality) and by an uncritical use of F_{max} as target reference point for fishery management.

On the basis of the new life history interpretation and considering the history of the fisheries in the Ligurian Sea from the thirties up to date, we do not exclude the possibility that the current exploitation of *A. antennatus* in the Mediterranean, which is in general close to F_{max}, exceeds sustainaibility.

Given that the direct harvest of spawning aggregations increases the risk of fish stock sustainability (Olver *et al.,* 1995), a prudential approach in *A. antennatus* assessment is desiderable. Hence F_{max} should be considered as a limit reference point (i.e., a dangerous level of fishing mortality where the risk of stock collapse is high), while the more conservative $F_{0.1}$ should be regarded as a target reference point (i.e., an optimal fishing rate) (García, 1994; Caddy and Mahon, 1995). The reference point $F_{0.1}$, when age at maturity and age at recruitment coincide, is close to the fishing rate giving a spawning biomass per recruit at sea equal to 35-40% of the unfished one (see Table 4). This spawning potential ratio is recommended to avoid the "collapse" of the stocks when the parental biomass-recruitment relationship is unknown (Clark, 1991; Mace, 1994).

References

Abella, A. (1995). Use of single-species reproduction-based reference points for the Mediterranean demersal fisheries management. In: Report on the first meeting of the CIESM working group DYNPOP, Tunis, Tunisia, 10-14 September 1994, *Cah. Options Méditerr.,* 10: 85-102.

Alagaraja, K. (1984). Simple methods for estimation of parameters for assessing exploited fish stocks. *Indian J. Fish.,* 31: 177-208.

Beverton, R.J.H. and Holt, S.J. (1957). On the dynamics of the exploited fish populations. *Fish. Invest. Minist. Agric. Fish. Food. G.B.,* (2 Sea Fish) 19: 533.

Bianchini, M.L. and Ragonese, S. (eds) (1994). Life cycles and fisheries of the deep-water shrimps *Aristaeomorpha foliacea* and *Aristeus antennatus.* In: *Proceedings of the International Workshop held in the Istituto di Tecnologia della Pesca e del Pescato (ITPP-CNR),* Mazara del Vallo, Italy, 28-30 April 1994, NTR-ITPP Special Publications, 3: 88.

Brander, K.M. and Bennet, D.B. (1989). Norway lobsters in the Irish Sea: Modelling one component of a multispecies resource. In: *Marine Invertebrate Fisheries. Their assessment and management.* Caddy, J.F. (ed.). J. Wiley and Sons, NY, USA, pp. 183-204.

Caddy, J.F. and Mahon, R. (1995). *Reference points for fishery management.* FAO Fisheries Technical Paper, 347, Rome, FAO, p. 83.

Campillo, A. (1994). Bioecology of *Aristeus antennatus* in the French Mediterranean. In: *Proceedings of the International Workshop held in the Istituto di Tecnologia della Pesca e del Pescato (ITPP-CNR),* Bianchini, M.L. and Ragonese, S. (eds). Mazara del Vallo, Italy, 28-30 April 1994, NTR-ITPP Special Publications, 3: 25-26.

Cirugeda-Delgado, M.E. and García-Mamolar, J.M. (1976). Aplicación de los modelos de producción de Schaefer y Fox a tres pesquerías del Mediterráneo Español. *Bol. Inst. Espa. Oceanogr.,* 217: 26.

Clark, W.G. (1991). Groundfish exploitation rates based on life history parameters. *Can. J. Fisheries Aquat. Sci.,* 48: 734-750.

Demestre, M. and Lleonart, J. (1993). Population dynamics of *Aristeus antennatus* (Decapoda: Dendrobranchiata) in the northwestern Mediterranean. *Sci. Mar.,* 57(2-3): 183-189.

Demestre, M. and Martin, P. (1993). Optimum exploitation of a demersal resource in the western Mediterranean: the fishery of the deep-water shrimp *Aristeus antennatus* (Risso, 1816). *Sci. Mar.,* 57(2-3): 175-182.

Fiorentino, F., Massi, D., Zamboni, A. and Relini, G. (1995). Rendimenti dello strascico batiale del Mar Ligure centro-orientale in una serie pluriennale di osservazioni. *Biol. Mar. Medit.,* 2(2): 191-197.

Fox, W.W. (1970). An exponential yield model for optimizing exploited fish populations. *Trans. Am. Fish. Soc.,* 99: 80-88.

García, S.M. (1994). The precautionary approach to fisheries with reference to straddling fish stocks and highly migratory fish stock. *FAO Fish. Circ.* 871, p. 76.

Goodyear, C.P. (1993). Spawning stock biomass per recruit in fisheries management: Foundation and current use. In: *Risk Evaluation and Biological Reference Points for Fisheries Management.* Smith, S.J., Hunt, J.J. and Rivard, D. (eds). Canadian Special Publication on Fisheries and Aquatic Sciences, p. 120.

Gulland, J.A. and Borema, L.K. (1973). Scientific advice on catch levels. *Fish. Bull.,* 71(2): 325-335.

ICES (1991). *Guidance to the assessment working groups from ACFM and the Secretariat.* September 1991, p. 14 (mimeo).

ICES (1997). *Report of the Working Group on Nephrops stocks.* Part 1 and 2. ICES CM 1997/Assess. 9 (mimeo).

Jones, R. (1981). *The use of length composition data in fish stock assessment (with notes on VPA and Cohort Analysis).* FAO Fisheries Circular 734, p. 46.

Lleonart, J. and Salat, J. (1992). VIT. Programa de análisis de pesquerías. *Inf. Tec. Sci. Mar.,* 168-169: 116.

Mace, P.M. (1994). Relationships between common biological reference points used as threshold and targets of fisheries management strategies. *Can. J. Fisheries Aquat. Sci.,* 51: 110-122.

Oliver, P. (1993). Analysis of fluctuations observed in the trawl fleet landings of the Balearic Islands. *Sci. Mar.,* 57(2-3): 219-227.

Olver, C.H., Shuter, B.J. and Minns, C.K. (1995). Toward a definition of conservation principles for fisheries management. *Can. J. Fisheries Aquat. Sci.,* 52: 1584-1594.

Orsi Relini, L. and Relini, G. (1985). The red shrimps fishery in the Ligurian Sea: Mismanagement or not? *FAO Fish. Rep.,* 336: 99-106.

Orsi Relini, L. and Relini, G. (1986). Displacements of *Aristeus antennatus* deduced from the structure of the fished stock in the Portofino area (Eastern Ligurian Riviera). *Rapp. P. V. Reun. CIESM,* 30(2): 12.

Orsi Relini, L. and Relini, G. (1988). An uncommon recruitment of *Aristeus antennatus* (Risso) (Crustacea: Aristeidae) in the Gulf of Genoa. *Rapp. Comm. int. Mer Medit.,* 31(2): 24.

Orsi Relini, L. and Relini, G. (1994). Biological characteristics of *Aristeus antennatus* as highlighted by long-term observations in the Ligurian Sea. In: *Proceedings of the International Workshop held in the Istituto di Tecnologia della Pesca e del Pescato (ITPP-CNR),* Bianchini, M.L. and Ragonese, S. (eds). Mazara del Vallo, Italy, 28-30 April 1994, NTR-ITPP Special Publications, 3: 27-28.

Orsi Relini, L. and Relini, G. (1996). Report on the second meeting of the CIESM working group DYNPOP, Genoa, Italy, 2-6 October 1996, *Cah. Options Méditerr.* (submitted).

Orsi Relini, L. and Relini, G. (1996-1998). Seventeen instars of reproductive life in *Aristeus antennatus.* A new interpretation of life span and growth. In: *Colloquium Crustacea Decapoda Mediterranea, "La Specola",* Florence 12-15 September 1996, Abstract Vol., pp. 69-70, (Text accepted for proceeding in Journal of Natural History).

Paulik, C.J. and Gales, L.E. (1964). Allometric growth and the Beverton and Holt yield equation. *Trans. Am. Fish. Soc.,* 93: 369-381.

Ragonese, S. and Bianchini, M.L. (1996). Growth, mortality and yield per recruit of the deep-water shrimp *Aristeus antennatus* (Crustacea-Aristeidae) of the Strait of Sicily (Mediterranean Sea). *Fish. Res.,* 26: 125-137.

Relini, G. (1994). Gli ecosistemi e le risorse biologiche del Mar Ligure dopo il disastro della Haven. *Biol. Mar. Medit.,* 1(1): 3-42.

Relini, G. and Orsi Relini, L. (1987). The decline of the red shrimps stocks in the Gulf of Genoa. *Inv. Pesq.*, 51(1): 245-260.

Sardà, F. (1987). Progresos realizados en el conocimiento de la biología pesquera de la gamba, *Aristeus antennatus* (Risso, 1816). Ensayo de evaluación de bancos en el Mediterráneo Occidental. *FAO Rapp. Pêches,* 395: 76-83.

Sardà, F. and Cartes, J.E. (1994). Status of the qualitative aspects in *Aristeus antennatus* fisheries in the north western Mediterranean. In: *Proceedings of the International Workshop held in the Istituto di Tecnologia della Pesca e del Pescato (ITPP-CNR),* Bianchini, M.L. and Ragonese, S. (eds). Mazara del Vallo, Italy, 28-30 April 1994, NTR-ITPP Special Publications, 3: 23-24.

Sardà, F., Cartes, J.E. and Norbis, W. (1994). Spatio-temporal structure of the deep-water shrimp *Aristeus antennatus* (Decapoda: Aristeidae) in deep-water population in the western Mediterranean. *Fish. Bull.,* 92: 599-607.

Schaefer, M. (1954). Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bull. int. Am. Trop. Tuna Comm.,* 1(2): 27-56.

Schaefer, M. (1957). A study of the dynamics of the fishery for yellowfish tuna in the eastern Tropical Pacific Ocean. *Bull. int. Am. Trop. Tuna Comm.,* 2: 247-268.

Spedicato, M.T., Greco, S., Lembo, G., Perdichizzi, F. and Carbonara, P. (1995). Prime valutazioni sulla struttura dello stock di *Aristeus antennatus* (Risso, 1816) nel Tirreno Centro-Meridionale. *Biol. Mar. Medit.,* 2(2): 239-244.

Taylor, C.C. (1959). Temperature and growth - The Pacific Razor Clam. *J. Cons. CIEM,* 25: 93-101.

Tobar, R. and Sardà, F. (1987). Análisis de la evolución de las captura de gamba rosada *Aristeus antennatus* (Risso, 1816), en los últimos decenios en Cataluña. *Inf. Tec. Inst. Invest. Pesq.*, 142: 20.