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Management Hypotheses to Improve Yield-per-Recruit and Economic Returns in the Red Shrimp (*Aristaemorpha foliacea*) Fishery of Southern Sicily (Mediterranean Sea)

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Abstract

The giant red shrimp, *Aristaemorpha foliacea*, is a deep-water benthopelagic shrimp, distributed in the Mediterranean, Eastern Atlantic, Western and Central Pacific; in the Strait of Sicily, the annual landings exceed 1000 tons, worth over US$ 10 million. Two series of trawl experiments, carried out in 1985–87 and 1993 with different aims (trawl survey and selectivity study), produced two sets of data, which were used to reconstruct the length distribution of the landings and the life history of the stock (growth parameters, mortalities, size/age structure, etc.). Using the package ANALEN, and the estimated parameters, different short-term and long-term yield realizations are presented, both in terms of weight or value, when varying fishing mortality and/or mesh size (mesh size of reference, 40 mm stretched). Using the package VIT, the transitional evolution of the fishery, both in terms of biomass and of economic returns, is examined under three different management schemes: a sudden reduction of the fishing mortality of 15% or of 25%, and a reduction of 35% in seven years (5%/yr). In the transitional analyses, the older set shows a situation in which yields decrease and stay below the starting figure, following any reduction of the fishing mortality; examining the economic returns, after the initial decrease, the gross incomes stabilize more or less at the previous level. With the more recent set, in every studied management scheme, the yield bounces above the starting line already in the third year, with a stationary increase of 6-8%; the higher the fishing mortality reduction, the higher the final economic equilibrium, respectively approx. 5%, 10% and 15% above the initial value after four years. Applying a stochastic variability of even modest intensity to the recruitment produces ample fluctuations of yield. In conclusion, despite the uncertainty of the models, the results seem to show that the red shrimp fishery situation has worsened from 1985 to 1993, and suggest that a reduction of effort/fishing mortality is biologically sound, has almost no influence on catches and is economically advantageous (or, at the worst, neutral).

Key words: *Aristaeomorpha foliacea*, assessment, Central Mediterranean, fishery, giant red shrimp

Introduction

The giant red shrimp, *Aristaemorpha foliacea*, Risso 1827 is a deep-water benthopelagic shrimp, distributed in the Mediterranean, Eastern Atlantic, Western and Central Pacific (Bianchini and Ragonese, 1994). In the Strait of Sicily, the annual landings exceed 1000 tons, worth over US$ 10 million.

In recent years, the life history of the populations in Italian waters has been extensively studied (full list of references in Relini *et al.*, 1999). For the Sicilian stock, the biology (distribution, morphometry, maturity, mortality and growth) has been described (Ragonese *et al.*, 1997; Ragonese and Bianchini, 1995; Ragonese *et al.*, 1994), as well as some aspects (selectivity, enmeshing, technology, VPA, diel variation, by-catch) of the red shrimp fishery (Bianchini *et al.*, 1998a; Ragonese *et al.*, 2002; Ragonese *et al.*, 2001; Bianchini and Ragonese, 2001; Bianchini *et al.*, 1998b), but studies relevant to the management of this resource are still lacking.

This paper aims to provide a theoretical analysis of the evolution of the fishery and to evaluate short-term and long-term effects, on the biomass and on the value of the catch, resulting from possible management interventions. The evolution of the transitional period has also been examined.

Materials and Methods

The shrimps, *A. foliacea*, were collected during two periods, 1985–87 and 1993 from the Strait of Sicily, in study areas which are shown in Fig. 1.

In the first period, red shrimp length-frequency distributions (LFDs) were derived from 8 seasonal trawl surveys (codend with square mesh, 32 mm stretched) conducted from Spring 1985 to Winter 1987 (Levi *et al.*, 1998); 19 600 females were measured (carapace length, CL, mm). In the second period, LFDs were from a covered-codends (cover, square mesh of 28 mm stretched; codend, square mesh of 40 mm stretched) selectivity study carried out in the Strait of Sicily in 1993 (Bianchini, 1999); the total female catch (84 000 animals) was measured without subsampling. Both sets of data cover the period when the very young and small shrimps are present. It must be noted that the population reconstruction results should be taken cautiously, since both data sets used come from experimental hauls, and are therefore only an approximation of the population structure of the actual landings, and since the steady-state assumptions might not be fulfilled. Nevertheless, since in the red shrimp fishery of the Strait of Sicily captures and landings are almost coincident (there are no rejects, and selectivity is almost nil with the 40 mm mesh and below), the length structures obtained from these scientific campaigns could be substituted for commercial data without great imprecision. In respect of the overall landings, the subsampling ratio can also be estimated fairly reasonably, and indeed independent methods resulted in similar estimates.

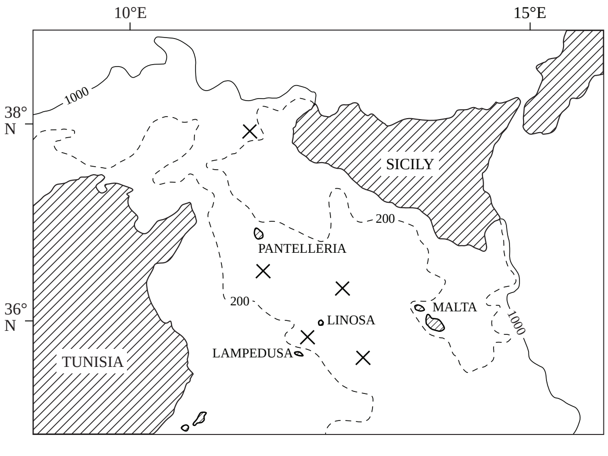

Fig. 1. The area of study, indicating the major fishing grounds.

Two programs, ANALEN (Chevaillier and Laurec, 1990) and VIT (Lleonart and Salat, 1992), were used for the analyses. These programs perform yield-per-recruit assessments (and virtual population reconstructions) starting from length-structured data. The programs use the pseudo-cohort approach and require equilibrium conditions; they are both flexible and can accommodate different categories of input, but each has its own limitations in the data structure. Besides the yield-per-recruit analysis, ANALEN can calculate short- and long-term variations of production after a modification of the exploitation regimen; VIT also allows a study of the transitional period, and a variable recruitment can be associated in the evolution of the scenarios.

The projections of future production have been studied using ANALEN, applying data from the new set (selectivity study) only. The virtual population vectors are the same as those examined in Bianchini and Ragonese (2001), while the input parameters were derived from Bianchini (1999), and are:

CL_{∞} = 70 mm (StD 4.9); K = 0.6/y (StD 0.018); M= 0.5; lower bound of last CL class = 62 mm; F_{term}= 0.5; a = 0.0013; b = 2.642; reference mesh = 40 mm, stretched; selection factor = 0.88; selection range = 5.7; $CL_{maturity\ 50\%}$ = 40 mm; range of $CL_{maturity}$ = 4 mm; price categories= 4 (for classes of lower weight of 27, 14, 6 and 3 g, respective values are approx. 15, 9, 5 and 3.50 Euro).

The VIT's transition analysis studies the evolution of a population when the mortality vector is modified (e.g. by a change in fishing effort) or the recruitment is not considered constant; in the first case, after a certain number of years, a new equilibrium is reached, and everything reverts to steady-state situation, while of course, in the second type of simulations, the population keeps fluctuating. The VIT's transition analysis is limited to data structured by age-classes, and the program itself has an option to produce age-structured data from length-structured inputs. A complete description of the VIT methodologies and of their theoretical foundations is reported in the application manual by Lleonart and Salat, 1997.

The transitional analyses were performed on both data sets (trawl surveys and selectivity study). The virtual population vectors and the input parameters are again the same, but VIT requires more information, i.e.: maturation, which starts at 26 mm CL and is general at 40 mm CL; a proportion factor, so as to reach a catch of 1 050 tons equal to 624 for the selectivity data, while the earlier data set requires a factor of 3 350.

In terms of the recruitment variability, there is not enough information to decide which stock-recruitment model, Beverton and Holt's or Ricker's, should be preferred; therefore, a mere stochastic variability has been applied to the "constant recruitment" situation. In the earlier surveys a variance of 1 has been applied to the log-normal distribution, thus resulting in a mode at 0.354 and a median at 0.707 of the mean, and upper and lower limits of the 95% confidence interval at 0.138 and 3.616; for the data from the selectivity study a variance of 0.5 has been applied, thus resulting in a mode at 0.544 and a median at 0.816 of the mean, and limits of the confidence interval at 0.234 and 2.844.

As a general rule, the price-per-unit of weight increases with shrimp size (Fig. 2). The Italian market considers four categories of red shrimp, arranged in the European way from "I" (the best one) to "IV" (small animals, not always over the minimum legal size). The prices vary in a bracket of ±25% according to demand but the averages considered here are 15, 9, 5, 3.50€/kg respectively for each category, roughly equivalent to 6.50, 3.50, 2.00, 1.50 US$/lb.

VIT does not allow for different "price categories", as is the case with the red shrimps. Nevertheless, since the assignment of a given shrimp to a specific "price stanza" is subject to considerable error (manual sorting), the price vector mimics a positive allometric potential curve ($b>3$). This length-value function, when replacing the length-weight regression, may be used to compute the economic return-per-recruit, in a way similar to the "standard" Y/R analysis, with the same input parameters. Considering the distribution of sizes in each price "stanza", value in Euro and carapace length in mm can be modeled by the regression $€ = 2.17 \times 10^{-7} \times CL^{3.708}$.

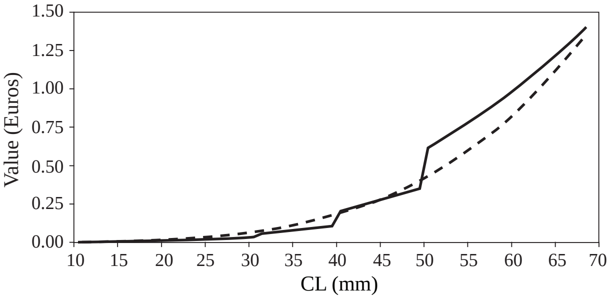

Fig. 2. Approximate individual value of red shrimps, by size (Italian market; value in Euro; size in mm of CL): solid line = price categories; dashed line = price function.

The selectivity data require a weighing factor of 772 (a multiplier of the sample capture, used to reach a total value for the catch of 13 million Euro), while the earlier surveys require a proportion factor of 1570.

Besides the standard approach, i.e. the "stanza" prices, the price function has also been used with the ANALEN model.

Results

Yield scenarios

The estimates of the variations (%) in the short- and long-term productions per recruit, varying fishing mortality and/or mesh size, obtained by the ANALEN program from the selectivity study data, are reported in Table 1 and Table 2, respectively. Figures represent the percent variation assuming the present situation as standard (F = 100% of starting F; mesh = 40 mm stretched).

It is apparent that an increase in the mesh size from 40 mm to 48 mm, or even to 56 mm, produces only a marginal loss in the short-term, which is rapidly offset by the gain in the long-term. This trend is even more evident when the mesh increase is accompanied by a reduction of the fishing mortality.

Transitional period (earlier surveys)

The VIT program, using the virtual population reconstruction from the earlier surveys, permits one to examine the transitional behaviour of the fishery, when passing from the old steady-state to the new equilibrium (Fig. 3).

A sudden reduction of the fishing mortality of 15% (line a) produces in the first year a drop of 10%

TABLE 1. Variations in the short-term productions (%, weight per recruit) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; starting situation (Strait of Sicily) underlined.

	F multipliers									
Mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
64	-53.47	-44.17	-34.86	-25.56	-16.25	-6.95	2.36	11.67	20.97	30.28
56	-51.92	-42.30	-32.68	-23.07	-13.45	-3.83	5.78	15.40	25.02	34.63
48	-50.75	-40.90	-31.05	-21.20	-11.35	-1.50	8.35	18.20	28.05	37.90
40	-50.00	-40.00	-30.00	-20.00	-10.00	0.00	10.00	20.00	30.00	40.00
32	-49.68	-39.62	-29.56	-19.49	-9.43	0.63	10.69	20.76	30.82	40.88

TABLE 2. Variations in the long-term productions (%, weight per recruit) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; starting situation (Strait of Sicily) underlined.

	F multipliers									
Mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
64	5.16	8.37	9.98	10.59	10.57	10.15	9.48	8.66	7.74	6.78
56	3.67	6.44	7.64	7.88	7.51	6.76	5.79	4.69	3.52	2.31
48	1.90	4.22	5.00	4.85	4.12	3.05	1.78	0.39	-1.05	-2.50
40	0.39	2.35	2.80	2.34	1.33	0.00	-1.51	-3.12	-4.76	-6.41
32	-0.46	1.29	1.56	0.94	-0.22	-1.70	-3.34	-5.07	-6.82	-8.57

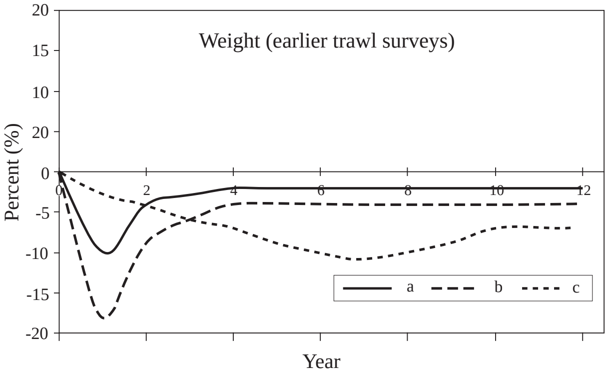

Fig. 3. Transitional status of the *Aristaeomorpha foliacea* fishery with different management interventions (reduction of the fishing mortality: a = 15% sudden; b = 25% sudden; c = 35% in 7 years); percent yield (weight per recruit) variations, analysis from 1985–87 data.

in the yield-per-recruit; in the second year, the yield recovers 6%, and it is stable in the fourth year at 98% of the initial value. The increase in biomass of the standing stock (SS) is 4% in the first year, 8% in the second, and stabilizes in the fourth year at 10% above the starting value. For the spawning stock biomass (SSB), the respective increases are 5%, 11% and 15%. A sudden reduction of the fishing mortality of 25% (line b) produces in the first year a drop of 18% in the yield-per-recruit; in the second year, the yield recovers 10%, and it is stable in the fourth year at 96% of the initial value. The increase in SS is 7% in the first year, 17% in the second, and stabilizes in the fourth year 19% above the starting value. For the SSB, the respective increases are 9%, 20% and 26%.

A reduction of the fishing mortality of 35% over 7 years (line c), with a constant annual reduction of 5%, produces a smoother transition: 7 years of small drops in the yield-per-recruit, up to the lowest 89%, and a partial recovery for 3 years, reaching a stable situation at 93% of the initial value in the 10th year. Every year during the transition there is an increase in SS that levels off at 130% in 10 years; the SSB is also always increasing, up to 140% of the starting value.

Applying a stochastic variability to the "constant recruitment" situation, over a period of 15 years, with a sudden drop in the fishing mortality of 15%, the yield-per-recruit is expected to stay between 90% and 110% of the starting level (91% and 111% of the new target level), but with ample possible fluctuations (95% confidence intervals with borders as low as 23% and as high as 330% of the starting value). With a sudden drop in the fishing mortality of 25%, the yield is expected to stay between 82% and 102% of the starting level (85% and 106% of the new target level), but with ample fluctuations (95% confidence intervals with borders as low as 24% and as high as 269% of the starting value). With a gradual drop in the fishing mortality of 35% in 7 years, the yield is expected to stay between 85% and 96% of the starting level (92% and 104% of the new target level), again with substantial fluctuations (95% confidence intervals with borders as low as 23% and as high as 266% of the starting value).

Transitional period (selectivity study)

Again, the virtual population reconstruction from the selectivity study can be used to examine the transitional behaviour of the fishery (Fig. 4).

A sudden reduction of the fishing mortality of 15% (line a) produces in the first year a drop of 8% in the yield-per-recruit; in the second year the yield is already 101% of the starting value, and it is stable in the fourth year at 104% of the initial value. The increase in SS is 7% in the first year, 12% in the second, and stabilizes in the fourth year at 14% above the starting value. For the SSB, the respective increases are 8%, 15% and 18%. A sudden reduction of the fishing mortality of 25% (line b) produces in the first year a drop of 14% in the yield-per-recruit; in the second year, the yield is back to a full 100%, and stabilizes in the fourth year at 106% of the initial value. The increase in SS is 11% in the first year, 22% in the second, and stabilizes in the fourth year 26% above the starting value. For the SSB, the respective increases are 13%, 27% and 32%.

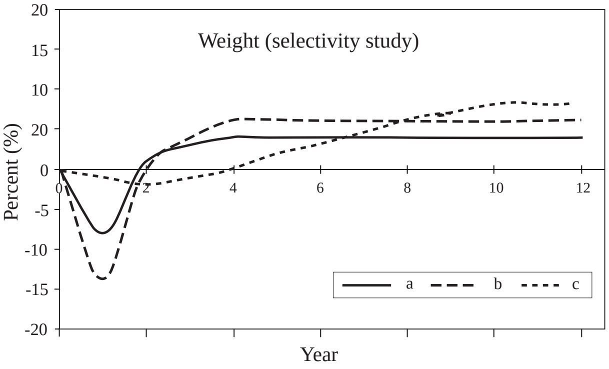

Fig. 4. Transitional status of the *Aristaeomorpha foliacea* fishery with different management interventions (reduction of the fishing mortality: a = 15% sudden; b = 25% sudden; c = 35% in 7 years); percent yield (weight per recruit) variations, analysis from 1993 data.

A reduction of the fishing mortality of 35% over 7 years (line c), with a constant annual reduction of 5%, produces of course a smoother transition: 2 years of small drops in the yield-per-recruit, up to the lowest 98%, a partial recovery for another 2 years, increasing up a stable situation of 108% of the initial value in the tenth year. Every year during the transition there is an increase in SS that levels off at 141% in 9 years; the SSB is also always increasing, up to 152% of the starting value.

Considering a stochastic variability in recruitment, over a period of 15 years, with a sudden drop in the fishing mortality of 15%, the yield-per-recruit is expected to stay between 92% and 112% of the starting level (89% and 108% of the new target level), but with ample possible fluctuations (95% confidence intervals with borders as low as 38% and as high as 242% of the starting value). With a sudden drop in the fishing mortality of 25%, the yield is expected to stay between 86% and 114% of the starting level (81% and 101% of the new target level), but with ample fluctuations (95% confidence intervals with borders as low as 40% and as high as 244% of the starting value). With a gradual drop in the fishing mortality of 35% in 7 years, the yield is expected to stay between 96% and 116% of the starting level (89% and 107% of the new target level), again with substantial fluctuations (95% confidence intervals with borders as low as 37% and as high as 246% of the starting value).

Economic return scenarios

The estimates of the economic variations (%) in the short and long-term productions, varying fishing mortality and/or mesh size, obtained from the selectivity study data, with the classical approach of price "stanzas", are reported in Tables 3 and 4, respectively. It is apparent that an increase in the mesh size from 40 mm to 48 mm, or even to 56 mm, produces only marginal losses in the short term, which are offset by the gain in the long-term. This trend is even more evident when the mesh increase is accompanied by a reduction of the fishing mortality.

The estimates of the economic variations (%) in the short- and long-term productions, varying fishing mortality and/or mesh size, obtained from the selectivity study data, with the *ad hoc* approach of a continuous price function, are reported in Tables 5 and 6, respectively. Once again an increase in the mesh size from 20 mm to 24 mm, or even to 28 mm, produces only marginal losses in the short term, which are offset by the gain in the long term.

TABLE 3. Variations in the economic short-term productions (%, value per recruit by price category) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; starting situation (Strait of Sicily) underlined.

	F multipliers									
Mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
64	-51.63	-41.96	-32.29	-22.61	-12.94	-3.27	6.41	16.08	25.75	35.42
56	-50.75	-40.90	-31.05	-21.20	-11.35	-1.50	8.35	18.20	28.05	37.90
48	-50.25	-40.30	-30.35	-20.41	-10.46	-0.51	9.44	19.39	29.34	39.29
40	-50.00	-40.00	-30.00	-20.00	-10.00	0.00	10.00	20.00	30.00	40.00
32	-49.92	-39.90	-29.89	-19.87	-9.85	0.16	10.18	20.20	30.21	40.23

TABLE 4. Variations in the economic long-term productions (%, value per recruit by price category) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; starting situation (Strait of Sicily) underlined.

	F multipliers									
Mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
64	15.78	18.07	18.55	17.90	16.57	14.81	12.82	10.71	8.54	6.36
56	13.14	14.80	14.69	13.51	11.70	9.51	7.12	4.64	2.14	-0.34
48	10.33	11.38	10.71	9.02	6.75	4.15	1.39	-1.43	-4.23	-6.99
40	8.10	8.67	7.58	5.52	2.90	0.00	-3.03	-6.09	-9.11	-12.07
32	6.91	7.24	5.93	3.67	0.88	-2.18	-5.35	-8.53	-11.66	-14.71

TABLE 5. Variations in the economic short-term productions (%, value per recruit by continuous price function) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; starting situation (Strait of Sicily) underlined.

	F multipliers									
Mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
64	-52.14	-42.57	-32.99	-23.42	-13.85	-4.27	5.30	14.87	24.44	34.02
56	-51.06	-41.27	-31.48	-21.70	-11.91	-2.12	7.67	17.45	27.24	37.03
48	-50.38	-40.46	-30.54	-20.61	-10.69	-0.76	9.16	19.08	29.01	38.93
40	-50.00	-40.00	-30.00	-20.00	-10.00	0.00	10.00	20.00	30.00	40.00
32	-49.86	-39.83	-29.80	-19.77	-9.74	0.29	10.32	20.35	30.37	40.40

TABLE 6. Variations in the economic long-term productions (%, value per recruit by continuous price function) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; starting situation (Strait of Sicily) underlined.

	F multipliers									
Mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
64	17.14	18.60	18.40	17.23	15.52	13.54	11.44	9.30	7.20	5.15
56	14.67	15.57	14.86	13.23	11.12	8.78	6.34	3.91	1.52	-0.78
48	12.03	12.37	11.15	9.08	6.57	3.86	1.10	-1.63	-4.28	-6.84
40	9.89	9.80	8.20	5.79	2.98	0.00	-3.00	-5.96	-8.81	-11.55
32	8.75	8.43	6.63	4.04	1.07	-2.05	-5.18	-8.25	-11.20	-14.03

It can be seen that the difference in the two approaches, "stanzas" or continuous function, are minimal, therefore allowing the innovative use of the price regression. In fact, not only are the qualitative aspects the same, but even the quantitative figures are almost identical, with differences in the order of 1% or less.

Economic transitional period (earlier surveys)

The VIT program, using the virtual population reconstruction from the earlier surveys, permits the examination of the transitional economic behaviour of the fishery, when passing from the old steady-state to the new equilibrium (Fig. 5).

A sudden reduction of the fishing mortality of 15% (line a) produces in the first year a drop of 10% in the economic return-per-recruit; in the second year, the economic return recovers 7%, and it is stable in the fourth year back at the initial economic value. A sudden reduction of the fishing mortality of 25% (line b) produces in the first year a drop of 17% in the economic return-per-recruit; in the second year, the economic return recovers 11%, and it is stable in the fourth year at 99% of the initial economic value. A reduction of the fishing mortality of 35% over 7 years (line c), with a constant annual reduction of 5%, produces of course a smoother transition: 7 years of small drops in the economic return-per-recruit, up to the lowest 91%, and a partial recovery for three years, reaching a stable situation at 97% of the initial economic value in the tenth year.

Having applied a stochastic variability in recruitment, over a period of 15 years, with a sudden drop in the fishing mortality of 15%, the economic return-per-recruit is expected to stay between 88% and 113% of the starting (and new target) level, but with ample possible fluctuations (95% confidence intervals with borders as low as 20% and as high as 313% of the starting economic value). With a sudden drop in the fishing mortality of 25%, the economic return is expected to stay between 83% and 111% of the starting level (84% and 113% of the new target level), but with ample fluctuations (95% confidence intervals with borders as low as 20% and as high as 309% of the starting economic value). With a gradual drop in the fishing mortality of 35% in 7 years, the economic return is expected to stay between 88% and 99% of the starting level (91% and 102% of the new target level), again with substantial fluctuations (95% confidence intervals with borders as low as 21% and as high as 291% of the starting economic value).

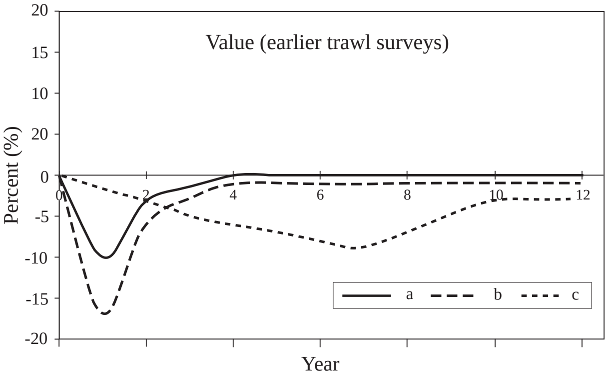

Fig. 5. Transitional economics of the *Aristaeomorpha foliacea* fishery with different management interventions (reduction of the fishing mortality: a = 15% sudden; b = 25% sudden; c = 35% in 7 years); percent economic return (value per recruit) variations, analysis from 1985–87 data.

Economic transitional period (selectivity study)

The virtual population reconstruction from the selectivity study also permits an examination of the transitional economic behaviour of the fishery (Fig. 6).

Examining the transitional behaviour of the fishery, a sudden reduction of the fishing mortality of 15% (line a) produces in the first year a drop of 7% in the economic return-per-recruit; in the second year, the economic return surpasses the initial value at 103%, and it is stable in the fourth year at 107%. A sudden reduction of the fishing mortality of 25% (line b) produces in the first year a drop of 13% in the economic return-per-recruit; in the second year, the economic return again surpasses the initial value at 103%, and it is stable in the fourth year at 111% of the initial economic value. A reduction of the fishing mortality of 35% over 7 years (line c), with a constant annual reduction of 5%, produces of course a smoother transition: two years of small drops in the economic return-per-recruit, up to the lowest 97%, and a complete recovery at three years, reaching a stable situation of 115% of the initial economic value in the tenth year.

With a stochastically variable recruitment, over a period of 15 years, with a sudden drop in the fishing mortality of 15%, the economic return-per-recruit is expected to stay between 92% and 113% of the starting level (87% and 108% of the new target level), but with ample possible fluctuations (95% confidence intervals with borders as low as 37% and as high as 248% of the starting economic value). With a sudden

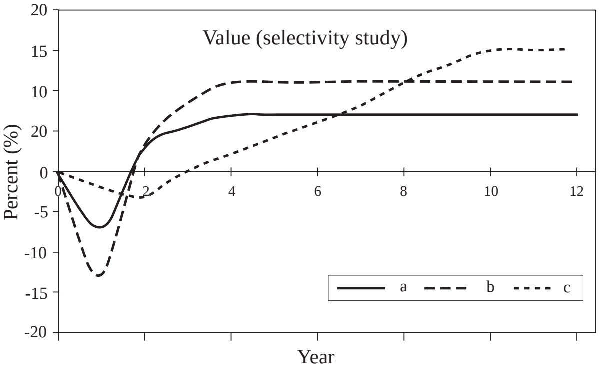

Fig. 6. Transitional economics of the *Aristaeomorpha foliacea* fishery with different management interventions (reduction of the fishing mortality: a = 15% sudden; b = 25% sudden; c = 35% in 7 years); percent economic return (value per recruit) variations, analysis from 1993 data.

drop in the fishing mortality of 25%, the economic return is expected to stay between 87% and 114% of the starting level (84% and 113% of the new target level), but with ample fluctuations (95% confidence intervals with borders as low as 41% and as high as 251% of the starting economic value). With a gradual drop in the fishing mortality of 35% in 7 years, the economic return is expected to stay between 93% and 121% of the starting level (91% and 102% of the new target level), again with substantial fluctuations (95% confidence intervals with borders as low as 41% and as high as 291% of the starting economic value).

Discussion

The yield-per-recruit estimates and the virtual population reconstructions have been applied in the population assessment of the companion species *Aristeus antennatus* (Demestre and Lleonart, 1993; García and Esteban, 1999); these analyses, however, require commercial statistics that are seldom collected in the Strait of Sicily. All these estimates are obviously based on the equilibrium assumption, although the life history of the red shrimp does conform to the theoretical assumptions only loosely. The equilibrium assumptions are an oversimplification of the natural conditions, but they could be supposed at least when dealing with short- and medium-term issues.

In the *A. foliacea* fishery, as in the case of *A. antennatus*, the shape of all the yield-per-recruit curves suggests a rapid increase of yield-per-recruit for small increments of *F*, and thereafter the curves flatten out, without any evidence of a clear maximum.

Yield scenarios

Using the ANALEN program on the selectivity study data, translated to the absolute values (Table 7), it is apparent that a reasonable increase in the mesh size (from 40 mm to 48 mm) produces only negligible short-term losses, while a net gain is achieved in the long run. This effect is even more marked when changing to the larger mesh (56 mm); this is the case of both the catch and of its value.

The different approaches to the economic return, i.e. the classical "price stanzas" and the *ad hoc* continuous price function, produce similar estimates, therefore allowing the innovative use of the price function in the ANALEN procedure.

The two modalities of analysis, even using the same data sets, produce qualitatively different scenarios, i.e. the level of exploitation appears situated on the right or left side of the maximum yield-per-recruit value, the results have demonstrated that an increase in the mesh size employed to catch red shrimp in the Strait of Sicily is feasible without any appreciable loss in the yield from the fishery. On the contrary, an increment in the capture level could be expected even in the short-term, assuming that the shrimps survive the escapement through the mesh without suffering a higher mortality rate. In fact, similar results have already been observed in the companion species *A. antennatus* in the same area (Ragonese and Bianchini, 1996).

The estimates from the earlier data suggest a situation of slight underfishing. On the contrary, the estimates from the newer set suggest a situation of overfishing, with a yield-per-recruit value near the maximum, the fishing mortality situated on the right-hand side of the curve, over the fishing mortality corresponding to the maximum yield-per-recruit, and the standing biomass representing only a small fraction of the virgin stock biomass. A drastic reduction of F will bring the exploitation to a safer level without consistent changes in the yield; in the meantime, the standing biomass should increase.

Transitional period

Examining the transitional behaviour of the fishery, when passing from the old steady-state to the new equilibrium, the earlier and the newer data sets produce different results, when examining both the biological yields or the economic returns (Table 8).

TABLE 7. Long-term economic productions (gross return, in million Euro) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; starting situation (Strait of Sicily) underlined.

	F multipliers					
Mesh	0.70	0.80	0.90	1.00	1.10	1.20
56	14.92	14.70	14.43	14.13	13.81	13.50
48	14.43	14.16	13.84	13.50	13.13	12.77
40	14.05	13.74	13.37	13.00	12.60	12.21

TABLE 8. Transitional results for *Aristaeomorpha foliacea* in three scenarios of fishing mortality reduction, with various data sets.

F reduction	15% (sudden)	25% (sudden)	35% (smooth)
	1985–87 data		
% biological short-term drop	-10	-18	≈-11 at year 7
% biological long-term loss	-2	-4	-7
% long-term standing stock increase	10	19	30
% economic short-term drop	-10	-17	≈-9 at year 7
% economic long-term loss	0	-1	-3
	1993 data		
% biological short-term drop	-8	-14	≈-2 at year 2
% biological long-term gain	4	6	8
% long-term standing stock increase	14	26	41
% economic short-term drop	-7	-13	≈-3 at year 2
% economic long-term gain	7	11	15

The earlier surveys data show that after the drop that follows the reduction of the fishing mortality, the yield never fully recovers and stabilizes at a lower level after a few years. In percentages, the short-term drop is in the order of two thirds of the fishing mortality reduction, and the long-term loss in the order of about one fourth of the *F* reduction. Of course, the standing biomass increases steadily, up to a percentage value that is almost two thirds the *F* reduction.

On the contrary, the selectivity study data show that after the drop that follows the reduction of the fishing mortality, the yield recovers almost immediately and stabilizes at a higher level in 3–4 years after the interference has been removed. In percentages, the short-term drop is in the order of half of the fishing mortality reduction, and the long-term gain in the order of about one fourth of the *F* reduction. In the meantime, the standing biomass increases steadily, up to a percentage value that is almost equal to the *F* reduction.

From the data of the selectivity study, the economic return suggests a situation of overfishing, with a value away from the maximum on the right side of the curve; a drastic reduction of *F* (to less than one third) will bring the exploitation to a safer level, say the level of the $F_{0.1}$ strategy, and produce, at the same time, substantial gains over the starting economic return. Conversely, the data from the earlier surveys show that the fishing mortality was almost at its maximum. Even in this case, the pursuit of the safer $F_{0.1}$ strategy would have caused only a modest decrease of the economic return, while the fishing mortality will have been reduced by one third.

During the transitional period, the newer set shows that after the initial drop that follows the reduction of the fishing mortality, the yield recovers almost immediately and stabilizes at a higher level in 3–4 years. On the other hand, the earlier data show that after the drop that follows the reduction of the fishing mortality, the yield never fully recovers and stabilizes at a slightly lower level in a few years.

Stochastic recruitment

There is not enough information to decide which stock-recruitment model, Beverton and Holt's or Ricker's, should be preferred. Therefore, just a stochastic variability of modest intensity has been applied to the "constant recruitment" situation. On average, the yield-per-recruit, over a period of 15 years, stays in acceptable limits that are around 10–15% of those expected in a steady-state, deterministic situation of a fishing mortality reduction in the range of 15–35%, applied in a sudden or smoothed manner. The same "reasonable" behaviour is shown by the economic return. Nevertheless, ample fluctuations are possible, since the 95% confidence intervals have borders as low as 40% or as high as 290% of the corresponding deterministic realizations. Therefore, the actual outcomes of the fishery, even in a stationary situation, are almost unpredictable (Walters, 1987); a "bad" year following by chance any management intervention, e.g. the increase in the legal mesh size, risks being mis-interpreted by the fishermen as the "ominous effect" of the new regulations.

Conclusions

Taking as reference the F_{max} point, the level of exploitation for the red shrimp resources in the Strait of Sicily appears close to the optimal harvest strategy, but very near the maximum or on the right hand of the curve; when considering for example the safer strategy of $F_{0.1}$, it could be implemented with minimal losses, or even with productive gains.

The results of the present study, coupled with more general biological observations on the fisheries in the Strait of Sicily, contribute to strengthen the feeling that, while the shrimp resources are probably not yet exceedingly exploited, some sort of growth overfishing may be present and that the fishing activities are not operating in accordance to an optimal profile; in fact, a similar pattern (growth overfishing and worsened temporal trend) has already been demonstrated, thanks to the discovery of virgin populations, for the Mediterranean deep-water red shrimps (Politou *et al.*, 2000).

The life cycle of red shrimps and the fact that unit value increases markedly with individual size are likely to produce a condition of "economic growth overfishing", i.e. the total weight and total gross value of the shrimp catch is reduced by a premature recruitment to the gear, with the inclusion of too many juveniles of almost no economic value; in fact, the present legal mesh (40 mm, stretched) is barely selective. Changes in mesh size and type (e.g. squared *vs* diamond mesh) represent the main management tools aimed at reducing the retention of small and lower-priced animals and at achieving a separation of the catch from unwanted species. Modification of the mesh type and/or size in the cod-ends appears attractive for the conceptual simplicity and easy enforcement. Therefore, it is advantageous to increase the mesh size in shrimp fisheries, in order to take only sizes with commercial value and to reduce the by-catch. Moreover, from a biological point of view, this should allow a greater number of animals to reach the size at onset of maturity.

In the Sicilian red shrimp fishery, a reduction of the fishing pressure is in theory required in any event:

- if the overexploitation scenario is the right one, in order to bring the fishing mortality back on the left hand of the yield-per-recruit curve;
- in case the situation is one of maximum biological exploitation, in order to pursuit safer strategies such as the $F_{0.1}$, with minimal loss in the yield;
- from the economic point of view, a reduction of the fishing pressure is again required in any event, since it should permit to both pursue safer exploitation strategies and increase the economic returns;
- under any scenario, even a small delay in the age at first capture would be biologically beneficial, without any economic harm, even short-term.

In conclusion, the adoption of a mesh side of 56 mm in the codend employed for red shrimp fisheries is strongly recommended because only positive effects, although not drastic, can be expected. The red shrimp fishery will benefit by the proposed management measures directly, through the increased value of the catch, the fact that the exploitation regimen becomes less risky for the resource, the reduced costs of towing a “lighter” gear, the lower labour cost of sorting the commercial catch; and indirectly, through the reduction of the by-catch and the improved environmental conditions. In fact, even if escapees from the trawl are dead, their biomass would be left on the oligotrophic deep-water grounds. Nevertheless, the regulation of mesh size could be only a subsidiary device for fisheries management, which should be used together with other management options (for example, a temporary closure in spring).

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