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THE DEEP-WATER RED SHRIMP, *ARISTAEOMORPHA FOLIACEA*, OF THE SICILIAN CHANNEL: BIOLOGY AND EXPLOITATION

Marco Bianchini

A dissertation submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

1999

Program Authorized to Offer Degree: School of Fisheries

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Abstract

The deep-water red shrimp, *Aristaeomorpha foliacea*, of the Sicilian Channel: biology and exploitation

Marco Bianchini

Chairperson of the Supervisory Committee:
professor Vincent F. Gallucci
School of Fisheries

A research has been carried out the red shrimp, *Aristaeomorpha foliacea*, resources of the Strait of Sicily (Mediterranean Sea); the study was aimed at assessing the natural history of the local population, at evaluating the specific fishery, and at proposing management interventions. The experiment was based on seasonal trawl surveys and on two selectivity surveys, employing the covered cod-end method. Various methods have been used to estimate the growth parameters (MULTIFAN, MIX, etc.), as well as the mortality coefficients: morphology and reproduction have been studied too. Specific fishery aspects have been addressed, among which yields, diel differences, selectivity, engagement pattern, quali-quantitative composition of the by-catch. The virtual population has been reconstructed, and the subsequent yield-per-recruit analysis has been accomplished on with different methodologies (incomplete beta function, Thompson & Bell, VIT, ANALEN); sensitivity analyses, transitional profiles, variable recruitment and yield scenarios have been performed. The economic yield-per-recruit analysis has been carried out following the same approaches. Fishermen's interviews, exam of logbooks and other instruments produced an overview of the human factors ruling the fishery. The Y/R estimates suggest a situation of light overfishing; in economic terms, lowering F to the level of the $F_{0.1}$ strategy will even produce a substantial increase in the present economic Y/R. Gains in the Y/R could not be obtained without changing the age of first capture. *A. foliacea* in the Sicilian Channel is caught before reaching the maximum reproductive potential; moreover, undersize animals are worthless in economic terms. Raising and enforcing the legal mesh size could control this growth overfishing; in fact, the present legal mesh (20 mm, side) makes no biological or economical sense. The introduction of a 28 mm mesh cod-end would result in the escapement of almost exclusively the juveniles; since these small shrimps are valued sensibly less than large specimens, only a small loss in the immediate economic return should be expected, followed by long-term gains for the shrimp population, the fishermen and the environment.

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DEDICATION

The author wishes to dedicate this dissertation to Bibi, Isabelle, Lilla, Chiadu and Pielle.

INTRODUCTION

Generalities

Worldwide, prawns and shrimps are amongst the most sought-after fishery resources (Neal and Maris, 1985), since they command high prices in the richer markets, viz. Europe, Japan and the United States. For this reason in the last decades, the degree of exploitation has increased dramatically worldwide. Most of the stocks are considered fully exploited, with little opportunity of increasing the total catch (Gulland and Rothschild, 1984). A possible exception is represented by the deep-water shrimps, already an important group from the point of view of fisheries and of marine biology around the world, but whose potential might still be underestimated. In fact, while their life cycles have been studied in many instances, their spatio-temporal patterns are still not well understood, even though a large amount of information has accumulated in the last two decades.

The deep-water giant red shrimp (Fig. 01), *Aristaeomorpha foliacea* (Risso, 1827), is of great economic interest, actual or potential, over all its wide area of distribution (Holthuis, 1980; Dore and Frimodt, 1987). *Aristaeomorpha foliacea* occurs in the Mediterranean, Central Atlantic, South Africa and in the Indo-Pacific ocean. It shows a preference for muddy bottoms, with aggregations mainly in submarine trenches and canyons along the continental slope from 150 m to 1850 m with a peak in abundance between 300 m and 700 m (Grey *et al.*, 1983; Holthuis, 1987; Dietrich, 1987; Pérez Farfante, 1988; Bianchini and Ragonese, 1994). The giant red shrimp belongs to the family Aristeidae, which includes other important species such as the blue-and-red (*Aristeus antennatus* Risso, 1816) and the scarlet shrimps (*Plesiopenaeus edwardsianus* Johnson, 1868) (Holthuis, 1987). *Aristaeomorpha foliacea* and *Aristeus antennatus* are often caught together in the Strait of Sicily (Central Mediterranean Sea), where the giant red shrimp outnumbers the blue-and-red shrimp (the ratio of captures of the two species

in the area is of 13:1; Ragonese, 1995), whereas the opposite occurs in the Western Mediterranean (Sardà, 1988; Cau, 1992; Bianchini and Ragonese, 1994).

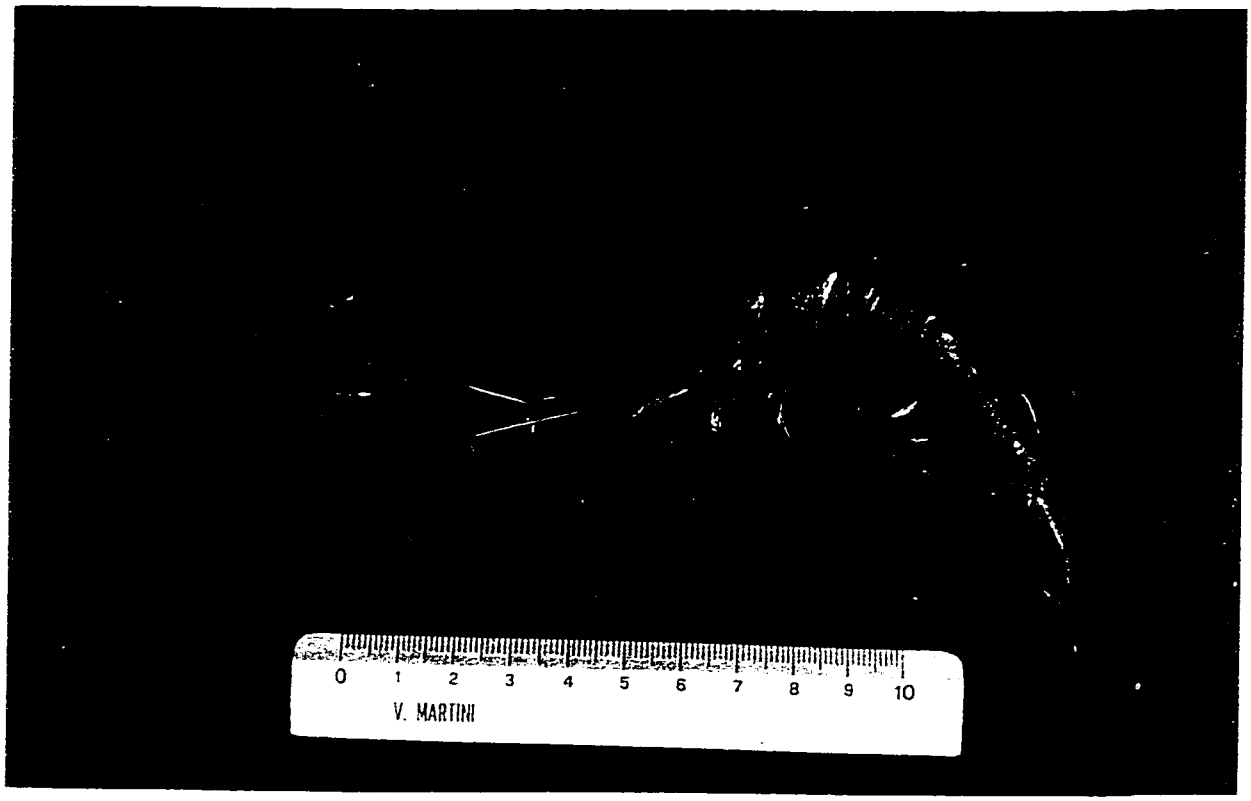


Fig. 01 - The deep-water giant red shrimp *Aristaeomorpha foliacea* (adult female).

Since the giant red shrimp is a valuable species for local and offshore fleets which trawl the mesobathyal level of the Strait of Sicily, where landings are estimated to be above 1000 tons per year and worth about 15 million $ US, there is a growing interest in this resource, resulting in increased knowledge about its distribution, biology and life history (Ragonese *et al.*, 1994; Ragonese and Bianchini, 1995); nevertheless, only scanty data exist on the population dynamics, productive potential and exploitation. *Aristaeomorpha foliacea* represents, together with the other red shrimp *Aristeus antennatus* (Demestre, 1990) and the Norway lobster, *Nephrops norvegicus* (Bianchini

et al., 1998a), the target for the Sicilian demersal trawl fisheries operating between 200 and 800 m, i.e. over the continental slope (Orsi Relini and Relini, 1985; Sardà, 1988; Ragonese, 1989; Ragonese and Bianchini, 1992), where the "potential" fishing area encompasses around 25,000 km^2. Over 100 trawlers, the majority from the Mazara harbour, target the red shrimp resources from time to time. The fishing boats are medium-to-large in size (up to 1000 HP) and stay out for 2-3 weeks at a time. The red shrimp fishery could be considered monospecific (Sardà, 1988; Demestre, 1990), since the by-catch is reduced and mainly composed of trash fish such as small sharks, ratfish, etc.

Biological aspects

Morphometry

The oblique dorsal carapace length (CL) is the current standard measurement to measure red shrimps. In the past, body measures other than the carapace length were used, e.g., "total body length" (Azouz, 1972), "ocular length" (Arena and Li Greci, 1973) and "curvilinear total length" (Balestra *et al.*, 1975). The relationships between the carapace length *vs.* total and ocular length and body weight are analyzed to allow comparisons with other populations and make data collected in the past comparable with today standard measures.

Among the many published morphometric relationships the most interesting feature, since it shakes the validity of ordinary Y/R analyses following the Beverton and Holt's formulation, is the (negative) allometric relationship ($b << 3$) between weight and carapace length that resulted from all of the studied populations of *Aristaeomorpha foliacea*, and the appearance of a more than proportional increment in height than length in the carapace of *Aristaeomorpha foliacea* (Balestra *et al.*, 1975b) (whereas the reverse happens in *Aristeus antennatus*; Balestra *et al.*, 1975a). Another point arising from morphometric studies is the spline in the gradient of many body characteristics that males show when reaching maturity.

Growth

As is generally the case for crustaceans, growth in red shrimps is accomplished mainly by a continuous alternating of ecdysis (molt) and anaecdysis (intermolt) cycles which separate the different stages or "instars" (Hartnoll, 1985). The molt occurs rapidly (Sardà, 1986) and is not truly a discontinuity in the life cycle of the shrimp (Pessano, 1960). The flexibility of the exoskeleton in such not-hard-armored animals allows for moderate growth ("stretching") during the intermolt period (Garcia, 1985; Caddy, 1987). Individual ages cannot be directly estimated in shrimps; rearing (Sardà, 1986) or tagging (marking) and release experiments are very difficult to carry on with red shrimps.

Data to assess growth in shrimps, i.e. increment at molt and frequency of molting (Hartnoll, 1985; Caddy, 1987) are lacking for *Aristaeomorpha foliacea*. Some estimates are available for *Aristeus antennatus*, based on microscopic observation of the integumentary setae of the pleopods of the last segments (Sardà and Demestre, 1985; 1987): the intermolt period lasts about 46 days and the molt frequency varies with size, passing from 3-4 events per year in juveniles to 1-2 molts (before and/or after spawning; Demestre, 1995) per year in older animals, and are not necessarily linked to growth. In *Aristeus antennatus* there is lack of molt synchronism (Demestre, 1990), with specimens molting almost continuously all year round with a peak during the spawning season.

At the moment, length frequency distribution (LFD) analysis represents the only suitable method to study the dynamics of red shrimp populations. Generally, two main approaches are used: a direct analysis of the LFDs, using non-parametric (e.g. ELEFAN; Pauly *et al.*, 1984)) or parametric (such as MIX or MULTIFAN; Mac Donald and Pitcher, 1979; Fournier *et al.*, 1991; Baelde, 1994) programs or indirectly, by a preliminary resolution of the LFD in its normal components and successive linkage of the modes (i.e. modal progression analysis). All these methods explicitly assume a direct relationship between individual age and length, and implicitly a lack of synchronism in molting. The main problems in using LFDs are the representativeness of the samples and the degree of overlap between the different components (the so-called "piling-up"), that makes deconvolution difficult.

Despite the discontinuities in the growth process (Dall *et al.*, 1990), continuous asymptotic models are considered a reasonable approximation for shrimp growth (Pauly *et al.*, 1984; Garcia, 1985). The most common way to represent length-age relationships in shrimps is the model of von Bertalanffy (Moffitt and Polovina, 1987). More complicated growth curves could be used (for example, the log-log or Gompertz's); however, such complicated curves are seldom justified (Mac Donald, 1987) because the gain in the goodness of fit does not compensate for the increased complexity. In fact, a two- or three-piece broken line can sometimes model red shrimp growth, especially in the case of males.

Mortality

Different methods have been used to estimate the instantaneous coefficients of mortality (Z) in red shrimps, always in accord with the negative exponential model. Generally, the methods are the same as those classically used for fish (Sparre *et al.*, 1989), that require samples representative of the true proportions from different cohorts (year-class strength). In the case of discrete recruitment and assuming stable populations, like that of the Mediterranean red shrimps (Ragonese and Bianchini, 1992; Ragonese *et al.*, 1994), Heincke's formulation could allow a reasonable estimation of total mortality (Garcia and Le Reste, 1981).

Concerning the part of the total mortality ascribable to "natural factors" (M), the situation becomes more critical (Vetter, 1988); in shrimps, particularly, molting further complicates the analysis since it is likely that natural mortality might be correlated with the frequency of molting (Caddy, 1987). Moreover, the assumption of independence of M in respect to F has been questioned (Cobb and Caddy, 1989). Estimates of M derived from virgin populations lead to optimistic values of the exploitation ratio (E= F/Z); in contrast, using data from an exploited population, underestimates of M and overestimates of the E ratio could occur (Longhurst and Pauly, 1987). In peneid shrimps, the estimates of M fall in a wide interval (0.5-26 per year!) but values above 3-4 (i.e., a survival rate of less than 5% per year) are evidently inconsistent for the deep-water shrimps. A reasonable

range could be 0.5-2.0/year (Caddy, 1987). In fact, available estimates for red shrimps suggest a range for M of 0.4-1.0 per year.

Sex and reproduction

Even a superficial study of the biology of *Aristaeomorpha foliacea* requires knowledge of the morphology, structure and function of the reproductive system (Levi and Vacchi, 1988). The relationship between size (as a proxy of age) and reproductive events, such as mating and sexual maturity, is of great importance to understand the dynamics of a stock (Welch and Foucher, 1988). Moreover, sexual maturation in crustaceans could be linked with substantial modifications in growth and mortality patterns (Kurata, 1962). The size corresponding to the "maximum reproductive potential" (Rikhter and Efanov, 1976) is a parameter frequently used to characterize the reproductive aspects (Trippel and Harvey, 1991), given the ease by which it can be related to other demographic parameters such as growth and mortality rates (Rikhter and Efanov, 1976) or longevity (Gunderson and Dygert, 1988). These considerations, together with the present tendency for an overall integration of the growth, mortality and reproductive aspects (Schnute and Richards, 1990) of a population explain the recent scientific interest in size-at-maturity studies, and in particular the focus on the analysis of variability and the reliability of the estimates (Welch and Foucher, 1988; Trippel and Harvey, 1991).

As is generally the case for crustaceans (Adiyodi, 1985; Hartnoll, 1985), mating in *Aristaeomorpha foliacea* is believed to occur between a mature male and a soft (postmolt), advanced (but still not fully mature) female. Even though this is the rule for penaeoid shrimps that have closed thelyca (Bauer, 1991), further proof is needed for it to be accepted for species like *Aristaeomorpha foliacea*, which have open thelyca (Orsi Relini and Relini, 1979). In fact, data from the Sicilian Channel (Ragonese and Bianchini, 1994) indicate a 100% presence of spermatophores in females above a certain size, regardless of tegument condition or season. Multiple mating can be observed in a small fraction (<10%) of the females (Orsi Relini and Relini, 1979; Demestre, 1995).

An empirical scale of macroscopic maturity (Levi and Vacchi, 1989) has been

developed, on the basis that sexual maturation in *Aristaeomorpha foliacea* females changes with color of the ovary, as it accumulates black caroproteins during the maturation process. In the case of *Aristaeomorpha foliacea*, the first stage should be split in two substages ("virginal", unmated; and "adult recovering" or "precocious juvenile", mated) according to the presence of the spermatophores on thelycum (Ragonese and Bianchini, 1994). In *Aristaeomorpha foliacea* females of the Sicilian Channel (Ragonese *et al.*, 1994) the two criteria, presence of spermatophore and maturation stage, were combined to determine the size of "maximum potential", resulting in a carapace length of 40 mm. Mature females were observed almost only in summer. The 100% of ovaric mature animals was never reached, even in the largest size classes.

A shortened rostrum (Sardà and Demestre, 1989; Demestre, 1990), a fused petasma and the presence of emi-spermatophores inside the terminal ampullae are the macroscopic characters used to assess the maturity condition in males. In contrast with what was previously believed (Bas, 1965), the shortening of the rostrum occurs quite abruptly (Cau *et al.*, 1982; Demestre, 1990; Demestre and Sardà, 1992; Ragonese *et al.*, 1994), at a size of about 30-33 mm CL for *Aristaeomorpha foliacea*.

Demography

The biological aspects just examined have general interest relative to the natural history of shrimps, but they are also useful for reconstruction of the population-at-large. The assessment can be synthetic, providing "global" stock parameters such as standing biomass and yearly production, or more or less analytical, providing responses by classes (age, size, etc.), that are thereafter summed up. Moreover, the answers could be solutions of elegant algorithms, as it is the case for the VPA or length cohort analysis (Lleonart and Salat, 1992), or strictly computational, as in Thompson and Bell's spreadsheet (Sanders, 1995).

Since biological parameters are in general obtained as an approximation of the true values, and are used repeatedly in the models, an out-of-range estimate can propagate and produce havoc in the assessment. A sensitivity analysis, either analytical (Laurec and Mesnil, 1987) or by stochastic simulation (Ragonese and Bianchini, 1992), should be

carried out (Majkowski *et al.*, 1987), especially when dealing with unconsolidated situations (e.g. with crustaceans, where model assumptions made on fish do not always hold; Conan, 1991).

Of course, any production-oriented report presents figures that can be considered an assessment of the stock under study. Nevertheless a truly scientific approach to the stock assessment of deep-water shrimp populations is rare (Baelde, 1994).

Fisheries aspects

Fishery

The peculiar life cycle pattern of red shrimps (Garcia, 1985), with the fact that unit value increases markedly with individual size (Cobb and Caddy, 1989), are likely to produce in the shrimp resource a condition of "economic growth overfishing". That is, the total weight and total gross value of the shrimp catch is reduced by a precocious recruitment to the gear, with the inclusion of too many juveniles each with reduced economic value. In fact, a general characteristic of shrimp trawl fisheries is the very fine mesh-size employed, that rarely exceeds 50 mm (Vendeville, 1990).

Exploitation of young under-sized prawns is considered a poor utilization of the resource from an "ethical" point of view (Valdemarsen, 1988), since small meshes lead to large amounts of protein being caught as by-catch, most of which, by then dead, is discarded (Sheridan *et al.*, 1984; Andrew and Pepperell, 1992). The Mediterranean fisheries of deep-water shrimps do not present great problems of mixed-stock management, since they are almost monospecific. Another negative implication of catching juveniles consists of the high proportion of recently-molted animals, and the consequent higher probability of bacterial spoilage since the integument is not firm enough (Neal and Maris, 1985). This is because molt frequency in shrimps decreases with age and size (Hartnoll, 1982; 1985).

Care should be taken in assessing production, since some differences in yield and length structure of both species of red and violet shrimp depend upon the different zones trawled in the Sicilian Channel. These differences are usually recognized both by

fishermen and scientists, and geographical variability is generally reported for these species also in the scientific literature.

Selectivity

Attention has been focused since the 70s on studying and improving the selectivity of the gear used for shrimp fisheries (Anon., 1973; Anon., 1988; Vendeville, 1990). There is a general agreement about the advantages of increasing the mesh size in shrimp fisheries (Lhomme and Garcia, 1984) in order to take only sizes with commercial value and to reduce the by-catch. From a biological point of view, this should allow the animals to reach the size at onset of maturity. The implicit assumption is that undersize shrimp are able to pass safely through the mesh (MacMullen, 1981). Nevertheless, the body shapes and features (many appendages and spines) and behaviour with respect to vulnerability (escape reaction) and to cod-end selectivity (passive filtering; Valdemarsen, 1988) complicate shrimp selectivity studies, which have been considered haphazard (Gulland, 1972).

The covered-codend method represents the most common choice in selectivity studies, basically for its technical simplicity (it has no special technical requirement) and because this method corresponds to the critical requirements inherent to sampling of binomial data. Other methods (such as alternate hauls, paired hauls, trouser gear, etc.) could be adopted, but the analysis of data require some statistical modifications (Pope *et al.*, 1975; MacLennan, 1992; Millar and Walsh, 1992).

The implication in fishery dynamics of an appropriate estimation of L50% has been widely described in the fisheries literature as being related to the optimal theoretical utilization of a resource along with the rate of fishing mortality both in a single (Beverton and Holt, 1957) and multispecies (Sainsbury, 1984) bottom trawl contest. For trawl gear, size-specific selectivity follows a typical asymptotic pattern in which the proportion of retained animals increases along an S-shaped curve with size (i.e. the selection curve is a non decreasing function of length), up to a limit above which all specimens entering the cod-ends are retained ($p = 1$). Before the availability of software on personal computers,

the parameters of the selection curve have been usually estimated after linearization. The most common transformations were the "logit", i.e. assuming a cumulative logistic distribution (and multiplicative relationships in the error terms), and the "probit" transformation, which is based on the standard normal cumulative distribution (Pope *et al.*, 1975; Welch and Foucher, 1988; Schnute and Richards, 1990), the latter being very similar to the former.

Escapement

Usually, selectivity curves in fishery science are obtained from the catch-at-length distributions, total length (TL) for fish or carapace length (CL) for shrimps. In theory, the girth perimeter or cross-section surface measurements should be more suitable for assessing selectivity patterns (Anonymous, 1993), because they are better correlated to the enmeshing probability which, ultimately, depends largely on the shape of the body. In fact, the girth and the surface approaches are sometimes used on fish (Pauly, 1984; Ragonese and Bertolino, 1994), but not on shrimps.

The underlying mechanisms of the processes that determine the escapement ability of shrimps from the cod-end of bottom trawl are still poorly understood. However, it is well known that, contrary to fish, shrimps are not motivated to escape through the mesh (passive filtering; Valdemarsen, 1989) and the selectivity experiences have indicated that red shrimp specimens pass the mesh backward in a folded-up position, i.e. with the tail pressed on the ventral side of the body, likely in order to protect the rostrum.

Adult males, above 31 mm CL, of *Aristaeomorpha foliacea* present a much shorter rostrum than females and juveniles, and should thus be presumed to escape more easily than females of the same size through the mesh. In fact, the hypothesis that this process might have any influence on the selectivity pattern is the basic reason for the common splitting of the samples in two components: adult males vs. adult females and juveniles (males and females).

Differences in daylight and night fishing

In the Sicilian Channel, as in other places, fishermen do not target the red shrimps at night if alternative fishing bottoms, such as banks or epibathyal grounds, are nearby. According to the Sicilian fishermen, a night haul yields a smaller catch than during daylight, but more large shrimps are caught in proportion to daylight hauls.

A similar phenomenon has been studied for *Aristeus antennatus* (Relini and Orsi Relini, 1986; Tobar and Sardà, 1992; Cartes *et al.*, 1993), and is often qualitatively reported in the literature for *Aristaeomorpha foliacea*; for the latter, it has been confirmed statistically, limited to the reduction in catches, for the population of the Australian slope (Rainer, 1992).

By-catch and anthropic waste

The by-catch in shrimp fisheries is a worldwide concern. It is considered an undesirable effect to be reduced, even when the by-catch itself is valuable. This important problem has been recently reviewed by Andrew and Pepperell (1992). Most available information, however, concerns coastal shrimp fisheries, especially those in the tropics. Any estimation of the by-catch/shrimp ratio is very difficult both as a consequence of natural, human (different fishing typology) and geographical variability and of the general problems in getting accurate long-lasting statistics on the by-catch species (IDRC, 1982; Saila, 1983; Gulland and Rothschild, 1984; Harris and Poiner, 1990; Andrew and Pepperell, 1992). The most frequently used conventional approximations for total *vs.* commercial catch are the 5:1 and 10:1 ratios in temperate-subtropical regions and tropical regions respectively. According to Sheridan *et al.* (1984) the shrimp/by-catch percentage is very variable, falling in the range 0.1-72%, but rarely do shrimps represent more than 10% of the catch. In the specific case of the red shrimps in the Mediterranean Sea, the fishery can be generally considered as monospecific, because none of the other economically important species is caught at the same time in such a quantity as to represent a sought-after species for fishermen.

Each year, millions of anthropic items are wasted on the sea bottoms (Dixon and

Dixon, 1981). Most originate from industrial activity, but a large amount of plastics and other more or less persistent debris arise from ship-generated litter dumping. The Sicilian Channel is affected by this phenomenon (Arena and Li Greci, 1973; Arena, 1985; Ragonese *et al.*, 1994) as a consequence of the discards by fishermen at sea and by merchant ships which criss-cross the area. River outfall is modest, and coastal dumping is limited to untreated sewage waters and scrap materials, since industrial activity in the area is underdeveloped.

Productivity

The resilience of a stock to continuous exploitation is a measure of its productivity. Only a part of the production can be taken on a sustainable basis. The yield-per-recruit analyses are commonly used tools to assess the relative "useful production" of an exploited stock. Different approaches can be utilized, but Beverton and Holt's model is probably the most widely applied. In the case of shrimps, several assumptions in the Beverton and Holt's formulation are not met, and the results of the analysis should be interpreted with caution. The von Bertalanffy growth function and the isometric (b= 3) weight-length relationship are two of the key assumptions of the model (a third one is the knife-edge selectivity): while the first one is in general accepted, even in "dubious" cases (splines in the growth, growth "stanzas", etc.), a substantial departure from isometry voids the Beverton and Holt's integration and requires the use of an incomplete beta function in the yield-per-recruit analysis (Paulik and Gales, 1964).

The yield-per-recruit estimates obtained after the reconstruction of the virtual population (*sensu* Megrey, 1989) require commercial statistics that are seldom collected in the Sicilian Channel (Labanchi *et al.*, 1998); moreover, the life history of the red shrimp does conform to the theoretical assumptions only loosely.

Similar commercial data are needed to implement the Thompson and Bell (1934) approach, that proceeds in an opposite direction to virtual population analysis (Sanders, 1995). However, this inelegant approach is flexible enough to allow for non-standard behaviour to be taken into consideration.

Steady state *vs.* non-steady state

Many terms are used, with slightly different meanings, to indicate a strong constraint in dealing with the traditional stock assessment models: the fishery must be at equilibrium, i.e. in a given set of environmental conditions and exploitation level, the population parameters - and the growth parameter too (Beverton and Holt, 1957) - stabilize around a peculiar value. In a stationary situation, the outcomes may be almost unpredictable (Walters, 1987), following a stochastic process, but the probability function of the variation around a given relationship is constant (the actual realization is drawn from a known distribution).

When the initial conditions are changed, a system reacts and reaches a new steady state, characteristic of the new conditions: this passage is not instantaneous, and a transitional analysis is required during this time lapse (Lleonart and Salat, 1992). A system that returns in the previous equilibrium when the perturbation is removed is a stable system (Hilborn and Walters, 1992); the trajectory back to the previous state may be linear, or with dumped oscillations around the equilibrium. In an unstable system, some elements are permanently changed, and very large or "oriented" fluctuations may lead even to annihilation of the system. A system may be locally stable, but when the perturbation exceed a certain threshold, it become unstable (Hilborn and Walters, 1992): it may subsequently reach a new local steady state, start a cycle, or behave chaotically.

Unluckily, rarely are times series (in the fisheries domain, at least) long enough to permit a test of the stationarity (both of mean and variance) hypotheses (Walters, 1987). Moreover, global stability and equilibrium conditions are theoretical concepts, that almost never occur in real life; in fact, few ecological process are long-term steady state (Gallucci *et al.*, 1996). This situation leads to the warning "never use equilibrium methods" (Hilborn and Walters, 1992; page 305) in estimation procedures, since the risk of overestimating surplus production (and optimum effort) with actually declining stocks is deemed high. On the other hand, "experiences from stochastic modeling and the analysis of transients .... clearly demonstrates the importance of steady state solutions" (Gallucci *et al.*,

1996; page 11). The equilibrium assumptions are an oversimplification of the natural conditions, but they do work in some cases, at least when dealing with short- and medium-term issues. Incidentally, since the length cohort analysis is most dependent on the steady state (and on the von Bertalanffy's growth model) assumptions, its results should be taken with more caution that those derived from age cohort analysis (Gallucci *et al.*, 1996).

Management aspects

The starting point for the management of a fishery is knowledge of what is already going on; personal experience, interviews with the fishermen, examination of log-books, as well as the reciprocal trust between parties. These are essential for the assessment of the present situation. In any case, the sustained exploitation of a marine living population usually requires some fishery management tools (Neal and Maris, 1985).

Production

Among the management tools, the regulation of cod-end mesh size is one of the most appealing (Armstrong *et al.*, 1990) and easily obtainable. Minimum size measures are established more to prevent growth overfishing than recruitment overfishing since shrimp stocks are usually quite resilient to increases in fishing effort, mainly as a consequence of their high fecundity (Neal and Maris, 1985) and poorly defined stock-recruitment relationships (Gulland and Rothschild, 1984; Garcia, 1983). The relationship between size (as a proxy of age) and reproductive events, such as mating and sexual maturity, is of great importance to understand the dynamics of a stock. The size corresponding to the "maximum reproductive potential" is a parameter frequently used to characterize the reproductive aspects, given its easiness to be related to other demographic parameters such as growth and mortality rates or longevity. The size at the onset of maturity (SOM) is generally used by fishery scientists as an "empirical" reference point to suggest an appropriate minimum legal size for retention and landing (Cobb and Caddy, 1989), since individual age cannot be determined directly in shrimps and prawns.

Economics

Evidence tends to suggest that consistent increases in mesh size could be introduced in shrimp fisheries without appreciable immediate economic loss (and likely with a future gain). For example, for the peneid fishery in Senegal, Lhomme and Garcia (1984) found that the mesh opening (stretched) could have been increased from 37 mm to 62 mm without appreciable short-term loss in the economic return for the fishery. This is due to the fact that it is not the total biomass landed that counts in economic terms, but it is the number of large shrimps present in the catch that brings the best price.

Environment

Given that bottom trawl nets are the most commonly used gear in shrimp and prawn fisheries (Neal and Maris, 1985), specific design (such as the introduction of excluder devices) and changes in mesh size and type (for example, squared vs. diamond mesh) represent the main management instruments aimed at reducing the retention of small and lower-priced animals and at achieving a separation of the catch from unwanted species. Specific technological designs are often unpopular due to handling complexity and lower efficiency (Neal and Maris, 1985) and cannot be implemented without the factual cooperation of fishermen (Isaksen *et al.*, 1992). Modification of the mesh type and/or size in the cod-ends appears more attractive for the relative conceptual and experimental simplicity, as well for the easy enforcement. In the red shrimp fishery, a larger mesh size will be beneficial, even if the sieved-out animals are dead, since their biomass would be left on oligotrophic deep-water grounds.

Biological knowledge

Only the minimal overview of the biological characteristics of *Aristaeomorpha foliacea* (Fig. 02) is reported here: a fuller list, together with the necessary bibliographical references, follows in Appendix A.

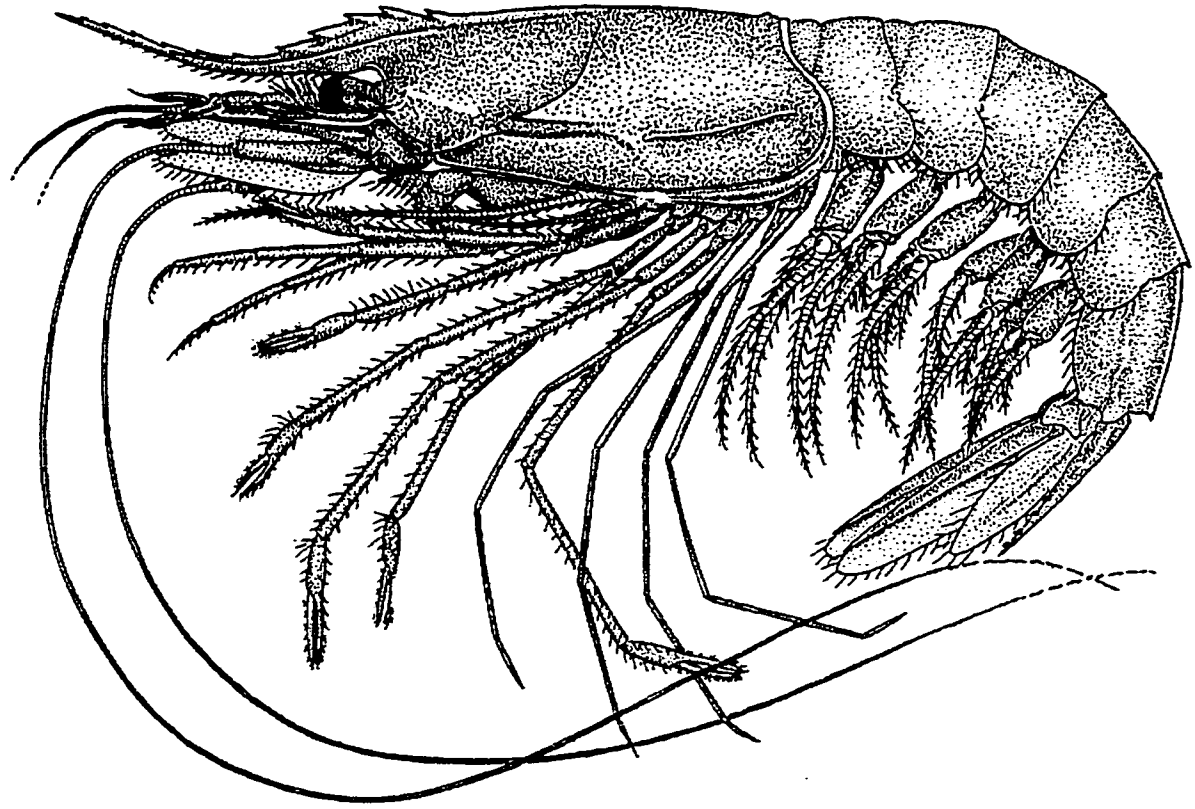


Fig. 02 - Drawing of the red shrimp *Aristaeomorpha foliacea* (adult female).

Taxonomy, identity and morphology

Aristaeomorpha foliacea is a marine crustacean belonging to the Aristeidae family, which is distinguished from the other three members of the superfamily Penaeoidea (Decapoda Natantia, suborder Dendrobranchiata) for the lack of a postorbital spine, the presence of a well developed "prosartema" in the first antennular segment, the

occurrence of an *appendix interna* at the base of the endopod of males and for the upper (dorsal) antennular flagellum, markedly shorter than the other, and inserted near the base of the 3rd article of antennular peduncle. The family includes three genera of commercially important shrimps (*Aristaeomorpha*, *Aristeus* and *Plesiopenaeus*), all large-size shrimps that occur in deep water off the continental shelf.

The systematic location of *Aristaeomorpha foliacea* can be described as: Phylum Arthropoda; Class Malacostraca; Subclass Eumalacostraca; Superorder Eucarida; Order Decapoda; Suborder Dendrobranchiata; Superfamily Penaeoidea; Family Aristeidae; Genus *Aristaeomorpha*.

The basic specific distinctive features can be summarized as follows: body setose; rostrum either long or short (adult males) bearing at least 4-6 rather stout teeth; grooves and crests on carapace rather well developed. Color is wine-red, with darker-violet reflections on upper side of the carapace (in ready-to-spawn females the dorsal portion assumes a dark coloration). Research to discriminate sub-stocks on the basis of chromosomic (2n= 74÷78) characters has not been implemented yet.

Synonymy and common names

Aristaeomorpha foliacea is distinctly recognized from its few congeners, and is unanimously considered a valid species. Formerly reported with the name of *Penaeus foliacea*, several different scientific names have been used since the original description, but none is still in use. Even though some doubts persist among systematic scientists, the Indo-Pacific specimens caught off Madagascar, Mozambique, Australia and New Zealand are all ascribed to the species *Aristaeomorpha foliacea*.

Besides the FAO names Giant red shrimp, Gambon rouge, Langostino moruno, the most common vernacular names for *Aristaeomorpha foliacea* are:
Kam'rn (Algeria), Red prawn (Australia), Rote Garnele (Germany), Garida (Greece), Ariston adom (Israel), Gambero rosso (Italy), Tsunonagachihiro ebi (Japan), Crevette royale (Morocco), Royal red prawn (New Zealand), Gamba roja (Spain), Gambri ahmar (Tunisia), Spanish red shrimp (USA), Langostino rojo (Venezuela), Kozika crvena (Yugoslavia).

Sexual and reproductive characteristics

Adult red shrimp *Aristaeomorpha foliacea* shows sexual dimorphism both in cladistic and meristic characters, but it is less evident than that of the companion species *Aristeus antennatus*. Although a high variability can be observed in single hauls and between different periods and areas, *Aristaeomorpha foliacea* females tend to be slightly more abundant than males in trawl catches, but the overall sex-ratio (m/m+f) approaches the expected 50% value. Females seems to be more abundant in the upper and middle levels whilst males seem to be more abundant going deeper. Considering the size classes, the sex-ratio decreases, more or less linearly, from about the 50% value (in juveniles) to 0% above 40-44 mm, i.e. the largest animals are only female.

Male external genitalia consist of an *appendix masculina* and a "copulatory" structure, the petasma. The petasma is morphologically complex but it can be considered completely open, appearing as flattened plates with the ventral *costae* not turned ventrally. The petasma is involved in handling and transferring the spermatophore. It likely acts by pushing the twin emi-spermatophores to the thelycum of the female; the spermatophore shows a complex structure, not substantially different from those of other peneids (nevertheless, it is a taxonomic feature).

Female external genitalia consist of the thelycum, situated on the ventral side of the two last thoracic segments; the thelycum is formed by the modification of the sternite of the same thoracic segments between which the thelycum is placed. Thelyca display spines and setae which are more developed in adult shrimps. They are different from those of other peneids, confirming the taxonomic relevance of these structures. Females lack seminal receptacles and their thelycum is considered relatively simple ("open thelycum"). Mating in *Aristaeomorpha foliacea* is believed to occur between a mature male and a soft (post molt) advanced (but not fully mature) female; however, this is a rule only for shrimps with closed thelyca. Multiple mating (up to two or three spermatophores on a thelycum) is observed in a small fraction (< 10%) of females.

The ovary structure in *Aristaeomorpha foliacea* reflects the general reproductive

system of peneid females; three regions, cephalic (paragastric), thoracic (lateral) and abdominal (caudal) are generally recognized but their development during the maturation process occurs simultaneously. The number of ova ranges between 100,000-250,000; the fecundity-size scatterplots are generally fitted by a power, negative allometric ($b < 3$) relationship, with high dispersion. *Aristaeomorpha foliacea* has a substantially lower fecundity than *Aristeus antennatus*.

The gonadic development and spawning of adult females of red shrimps takes place over several months usually starting in spring and lasting to early fall but the peak of sexual activity and spawning generally occurs in summertime. The maturation differences could be mainly a consequence of natural inter-year variability, with some exceptions (such as the Australian population of *Aristaeomorpha foliacea*, where mature females were found all year round). The maturation of the ovary seems to be a rapid process over one or two months; a rapid emptying of the ovary is suggested. The presence of "cortical granules" in the ovocytes is a clear index of completed maturity. Observing the change in the color of the ovary as they accumulate caroproteins during the maturation process macroscopically monitors sexual maturation in female red shrimps. The minimum mating and spawning size is variable but females are occasionally able to mature at a very small size (< 30 mm CL). The size at massive maturation or the size at the onset of sexual maturation (SOM) is however higher, generally about 35-40 mm CL.

A shortened rostrum (a process which occurs mainly in summer), a fused petasma and the presence of emispermatophore inside the terminal ampullae are the macroscopic characters used to assess the maturity condition in males. The shortening of the rostrum occurs quite abruptly. Above the 30-33 mm CL, all males are mature and apparently always ready to mate, at least morphologically. In *Aristaeomorpha foliacea* of the Sicilian Channel, between 28 and 31 mm CL more than 50% of males show positive indices of maturity and above 32-33 mm CL all males can be considered as mature specimens. In Australian populations, however, slightly lower values for the petasma fusion (18 mm), sperm development (20 mm) and shortening of the rostrum (30 mm) have been found.

Larval distribution

Females of red shrimps release their eggs directly into the sea. Eggs hatch as nauplius. Some morphological differences exist between the nauplii of the two red shrimp species. A demersal laying is possible, due to the absence of nauplii at the surface layers of the water. Larvae and post-larvae distribution patterns are to a large extent still unknown in deep-water shrimps. *Ad hoc* collections of Aristeids larvae have had been carried on in 1995 producing 15 larval stages for *Aristaeomorpha foliacea*, around the Balearic Islands, in September. Larvae are passively transported by the currents and it is likely that poor hydrological conditions could affect occurrence and abundance of post-larvae. Such an effect has been advocated to explain the fluctuation in the abundance of the stocks of red shrimps.

Movements

Aristaeomorpha foliacea moves on wide horizontal and vertical displacements. Searching for food was considered the main explanation for the diel vertical movements, whereas adaptation to hydrological change of water masses and different phototropic reactions have been proposed for the horizontal, seasonal ones. These movements, however, cannot be considered true migration or due to reproductive or feeding exigencies, none of which has been reported for the species. *Aristaeomorpha foliacea* tends to concentrate in shoals during mating and spawning, becoming more available to the gear. They are also more aggregated at the bottom and more available (or vulnerable) to the trawl during daylight (or full moon) and thereafter tend to disperse (or concentrate) up in the water column during the night. Red shrimps are not strictly benthic animals since they normally inhabit the water layer close to the bottom.

The different *facies* of the bathyal mud are largely correlated with the firmness and compactness of the substrata. Consequently, a key-role of the substratum in explaining the occurrence of red shrimps has been repeatedly assumed, with the tautological support from the available data because trawls, the elective gears to capture these animals, only operate on suitable muddy bottoms. Direct and indirect observations

indicate that the physical habitat of *Aristaeomorpha foliacea* might be more structured and complex than previously believed. The species tends to aggregate within the trenches and canyons, apparently showing specific preferences. The main role of substratum in controlling the distribution patterns of the two species of Mediterranean red shrimps was raised when their respective occurrences in the catches were analyzed relative to different geographical locations. It was evident that, at least in the Mediterranean Sea, red shrimps were caught in a different reciprocal proportions (one species prevalent on the other or both species being almost equally represented) according to the characteristics of the water instead of the bottoms. In fact, the two species seem to show subtle preference for different temperatures (close to 12.8°C for *Aristeus antennatus* and 13.5°C for *Aristaeomorpha foliacea*) and salinity. Some evidence tends to indicate that the dissolved oxygen concentration is one of the factor influencing both occurrence and abundance of red shrimp, but this cannot be the case for the Mediterranean Sea, where the O_2 concentration is high throughout, even if it decreases with depth. Light irradiance and penetration into the sea could also play an important role influencing both distribution and catchability patterns in red shrimps.

Even if a unifying hypothesis is lacking, the present level of knowledge suggests that *Aristaeomorpha foliacea* is a eurybathic species which shows an opportunistic behaviour with respect to environmental factors such as salinity, light, oxygen, and nature of bottoms. The companion species *Aristeus antennatus* seems more linked to the substratum than *Aristaeomorpha foliacea*, at least on the basis of frequency of benthic prey. It is likely that these species are able to expand their area of distribution by colonizing (or recolonizing) different zones when food and general condition are favorable.

General distribution

Aristaeomorpha foliacea is a widespread species with an area of distribution larger than that of *Aristeus antennatus*. *Aristaeomorpha foliacea* is found in the Mediterranean Sea (now rare in the Adriatic Sea), Eastern Atlantic (off Morocco and

South West Sahara and Portugal), South Africa, NorthWestern Atlantic (from Venezuela and Gulf of Mexico to North Carolina), Indian Ocean and Western Pacific, including Japan, Australia and New Zealand. *Aristaeomorpha foliacea* populations in the Mediterranean Sea are considered immigrants from the subtropical Atlantic.

Red shrimps are characteristic species of the assemblage recognized for the bathyal mud bottoms in the Mediterranean; they usually inhabit deep and cold waters, from the edge of continental shelf (about 200-300 m), to the upper and middle level of the continental slope and, maybe, down to the low level of the slope (till 2,200 m). Sometimes *Aristaeomorpha foliacea* is found less deep, around 150 m. Depths in the range 500-800 m, the upper level of the mesobathyal "horizon", represent the preferential bathymetric range. Red shrimps species represent a characteristic component of the bathyal *facies* of the macrofauna of soft-compact mud, originally colonized by the gorgonian *Isidella elongata* (forming the so-called "*Isidella* bottoms"), once making wide and dense beds or "prairies" over the muddy bottoms. These are now depressed as a consequence of the intensive trawling (the drastic depauperation of the beds of *Isidella*, however, did not seem to have direct influence on the red shrimps).

Although some degree of geographical variation can be detected, it is evident that *Aristaeomorpha foliacea* presents seasonal (but not true "migratory") and diel movements, resulting in variable distribution patterns. Inter-year variations are conspicuous too: as an example, along the Northern coasts of Sicily *Aristeus antennatus* is presently the dominant species, while *Aristaeomorpha foliacea* was the preeminent species (7:1) in the '70s.

Geographical distribution and abundance in the Mediterranean

In the French Mediterranean, *Aristaeomorpha foliacea* and *Aristeus antennatus* were inconsistently exploited by the fishermen of the Gulf of Lions during the '60s. It is interesting to note that, since 1984, *Aristaeomorpha foliacea* seems to have disappeared from the fishing grounds of the Gulf of Lions. Around the east coast of Corsica, *Aristaeomorpha foliacea* was, and still is, always dominant over *Aristeus antennatus*.

In the Ligurian Sea, catches of the two species of red shrimps were documented from the period 1930-1940 at depths of 400-500 m, on the same bottoms. The landings of both species were almost nil in the '70s and early '80s. After the 1987 boom of *Aristeus antennatus*, *Aristaeomorpha foliacea* reappeared in the commercial catch too, but in insignificant relative abundance (3%).

Viareggio and Leghorn bottom trawling fleets exert a very low fishing pressure on red shrimps. The resources of both species are scarce and only a small number of specimens were caught in the experimental trawl surveys, always deeper than 550 m. Sizes are small too: the largest *Aristaeomorpha foliacea* female was 57 mm CL and the biggest male 39 mm CL. Mature females of both species are present during the summer. In the Southern Tuscany archipelago, the vertical distribution of *Aristaeomorpha foliacea* ranges in a bathymetric interval between 430-650 m (the maximum sampling depth). More abundant catches are observed at depths greater than 500 m, up to 5 kg/h. The observed size range is comprised between 14-44 mm CL for males and between 15-66 mm CL for females. Histological analyses suggest that the largest females had at least two successive breeding episodes. Recruitment occurs during spring.

Along the Latium coast, in the three main fishing zones (Civitavecchia, Fiumicino, Terracina) *Aristaeomorpha foliacea* is present during spring on bottoms between 300-450 m, therafter having a progressive bathymetric migration to 600-650 m. The female length frequency distributions allow a von Bertalanffy's curve defined by the parameters: $CL_\infty = 73.19$ mm; K/year= 0.62; $t_0 = 0.19$ yr. The sex-ratio is close to 1:1 until 450 m; beyond this depth it changes greatly in different areas, suggesting a differentiated distribution for the two sexes. The analysis of the frequencies of pre-ovulatory females suggests a reproductive season between the middle of May and September, with a maximum occurring in July and August. The relative abundance of the two species of red shrimp is nearly 70%-30%, respectively for *Aristaeomorpha foliacea* and *Aristeus antennatus*.

In Campania (Southern Tyrrhenian), the mean size increases according to the depth: the most abundant catches are observed in the deepest stratum and the highest

relative density is in the two sub-areas of Salerno Gulf and Cape Bonifati. The autumn catches are generally more abundant than in the other seasons. The growth parameters were estimated as $CL_\infty = 70.9$ mm and K/year= 0.47. In the fisheries between Capo Suvero (Western Calabria) and Palermo (Northern Sicily), the red shrimp catch per boat per day is generally very low, from 10 kg/d/boat to 20 kg/d/boat (both species of red shrimps pooled). In the most profitable fishery, West of Milazzo, the total landings went down regularly from 72 t in 1985 to 35 t in 1993. From surveys, it appears that the proportion of *Aristeus antennatus* and *Aristaeomorpha foliacea* varies according to year, season and location, but altogether the two species are quite even in abundance, with a small general prevalence of *Aristaeomorpha foliacea*. The relative dominance is reverted in the less productive Calabrian side. Strangely enough, probably because the fishermen exploit different fishing grounds than those randomly selected for the experimental trawl surveys, commercial landings are in favor of *Aristeus antennatus*, in a ratio of 2:1, both in Western Calabria and in Northern Sicily.

Around Sardinia, during the summer the largest quantity of *Aristaeomorpha foliacea* is caught in daylight at the deepest grounds (650-740 m), but the greatest number of large-size animals is recorded in the hauls just after sunset between 550-600 m, i.e. the same hauls which during the day produced a lot of small-size shrimps. In winter, the depth distributions and diel cycles resemble that of summer, but the largest concentration of middle-sized individuals is found higher, between 550-600 m. Winter produces smaller catches and sometimes small quantities (1-2 kg/h) of *Aristaeomorpha foliacea* are found even in the transition zone. *Aristaeomorpha foliacea* populations make, at least where the slope is very steep and broken by gaps, vertical movements related only to hydrological phenomena. In Sardinia the vertical migration has been verified for both species. The diel cycle of vertical displacement (in the water body) is definitely of smaller scale than the seasonal migration (in the order of 150-200 m, along the slope) and is probably linked to search for prey.

In Tunisian waters, over the Sentinelle bank the relative abundance is nearly 80%-20%, at La Galite 50%-50% and between Morocco and Algeria nearly 0-100%,

respectively for *Aristaeomorpha foliacea* and *Aristeus antennatus*. Between the Sisters' Rock and the Skerki Channel, the catch varies from 8 kg/h to 25 kg/h of very large *Aristaeomorpha foliacea*; in the Pantelleria Channel, *Aristaeomorpha foliacea* is found consistently only below 600 m, with catches around 10-15 kg/h. On the Algerian coast, *Aristaeomorpha foliacea* is captured almost exclusively in the Annaba region; experimental observations show a limited bathymetric difference between day and night. Females reach a size of 67 mm CL.

In the Italian Ionian Sea, two zones exist where fishing on *Aristeus antennatus* and *Aristaeomorpha foliacea* is carried out: one in the north between Taranto and Gallipoli (Western Apulian coast) and the other, a wider zone, in the south between Cariati and Capo Spartivento (Eastern Calabrian coast). Across the Ionian Sea there are other grounds deeper than 400 m, where red shrimps are not caught. The maximum carapace length is 72 mm in *Aristaeomorpha foliacea* females, and males are sometimes very large (51 mm CL). Very small individuals are observed in almost every survey, with restricted periods of recruitment for *Aristaeomorpha foliacea* (while being rather continuous for *Aristeus antennatus*). Mature females were observed in size classes larger than 34 mm CL in *Aristaeomorpha foliacea*; in autumn, spermatophores were observed only on females larger than 40 mm CL. The VBGF parameters for females of *Aristaeomorpha foliacea* has been estimated as CL_{∞}= 74.18 mm with K/year= 0.503. In Apulia, *Aristeus antennatus* is the main target species and is more abundant than *Aristaeomorpha foliacea*; the proportion in numbers is about 13.5%-86.5%. In Eastern Sicily, *Aristaeomorpha foliacea* is the less common and less abundant of the two species, the average catch being very low, at a maximum of 0.66 kg/h. Specimens are caught at depths of 145-680 m. The depth range along the Eastern coast of Sicily seems broader than usually reported, probably due to the steepness of the bottom and to the presence of submarine canyons, which are likely to facilitate the vertical displacements of benthopelagic species.

In Greece, *Aristaeomorpha foliacea* has been reported from the Aegean Sea in general and from the North Euboikos Gulf. The species has also been reported all around

Crete. Historical data report the shrimp in southwestern Turkey at 1242 m and off Egypt at 725 m. *Aristaeomorpha foliacea* is also reported from Larnaca Bay in Cyprus. In Israel, *Aristaeomorpha foliacea* is characterized as commercial and reported in the same localities and depths as *Aristeus antennatus*. The species is found along the Mediterranean coast of Israel deeper than 300 m: nevertheless, it is fished in the Haifa area throughout the year in the 70-80 m depth range on the edge of a submarine canyon, where it is caught only in the middle of the night from 22:00 to 03:00. The annual catch is around 20 tons. During winter and spring (December-April) the catch is greater (5-30 kg/h) than between May and November.

Geographical distribution and abundance in the Sicilian Channel

In the fisheries of the Sicilian Channel, the "potential" fishing area encompasses around 25,000 km^2. Those grounds are furrowed by many non-trawlable canyons. The bottom temperature is stable in time all over the area, at around 13.5°C. The giant red shrimp is distributed in a wide depth range (300-1000 m) but shows a marked preference for (or a higher vulnerability to trawling on) muddy bottoms located between 500 m and 750 m; larger catches are reported to occur especially where narrow depressions or canyons notch the sea-bed. The lower bathymetric limit for this species is probably deeper than 1000 m.

The bathymetric maps suggest two main distribution zones for this species in the Sicilian Channel ("West" and "East" side of the Strait of Sicily). Between them there is a narrow passage with sufficient depth (200-400 m) to allow adult shrimps to move from one side to the other. In addition, the East zone could be further divided into a "Far-South" and a "South-East" zone, partially separated by two deep elongate depressions, each deeper than 1000 m, known as "Pantelleria trough" and "Malta trough". In fact, the regional distribution of *Aristaeomorpha foliacea* presents three or four areas of greater importance, interspersed with 20% "dry" hauls. At a smaller scale, densities seem of the "contagious" type, e.g. hypergeometric, with patches of higher concentration.

Differences in the productive parameters between West and East shrimps have been noted, but it has been difficult to support a hypothesis of "more than one stock" because of

the limited time series of comparable data. Therefore, the area of the Central Mediterranean Sea between the Sicilian and North-African coasts (the Sicilian Channel *sensu lato*) is considered a "Unitary Management Area" (UMA) for demersal resources.

The giant red shrimp probably migrates vertically (they are almost exclusively trawled during daylight hours), and seem not to be limited to a specific type of soft bottom. For example, they are often captured along with the burrowing Norway lobster (*Nephrops norvegicus*). However, the giant red shrimp supposedly prefers the temperature of the so-called "Eastern water" (13.5°C), an intermediate stratum of warm and salty water which originates in the Eastern Mediterranean Sea and flows towards the Strait of Gibraltar.

In the Sicilian Channel, the recruitment to the gear is discrete, limited at the spring and summer months, at around 25 mm CL, i.e. at an age of 9 months. Reproduction happens in the summer months, with smaller episodes in the spring too. The female "maximum reproductive potential" is at 39.7 mm CL (range 28-62 mm CL), corresponding at an age of 18 months. Males are mature when CL reaches 31 mm, the size at which the rostrum shortens. Mature animals are found all over the distribution area, without significant correlation in space or depth. In contrast, unmated females are more frequent above 600 m. There is a positive linear correlation between depth and shrimp size. The yields and sex-ratio data show no specific pattern and a high level of "variability". According to local fishermen, who fish with small (and illegal) cod-end mesh sizes (less than 18 mm, side), large catches of juveniles occur in winter at least over the Westernmost sea beds, but the available records do not permit verification. At present, the catch per hour in experimental surveys is around 3 kg/h, with peaks at 9 kg/h. It is worth noting that the literature shows a decreasing trend: 25 kg/h in the early '60s, 8 kg/h in 1972, 5 kg/h ten years ago.

Biology of the companion species *Aristeus antennatus* in the Sicilian Channel

The ratio of captures of the two species in the area is of 13:1 in favor of *Aristaeomorpha foliacea*, and the annual landings of *Aristeus antennatus* are in the order of 100 tons only. The regional distribution of *Aristeus antennatus* shows two areas of

concentration, 25 nm West of Marettimo (a rugged bottom area, where the ratio with *Aristaeomorpha foliacea* reaches 50:50) and 25 nm East of Pantelleria, interspersed with 60% of "dry" and 15% of "rare presence" hauls: at smaller scale, densities are even more "patchy". The vertical distribution, from experimental surveys, ranges from depths of 500 m up to at least 820 m; that means that the upper limit is 100 m below that of *Aristaeomorpha foliacea*. At present, the catch per hour in experimental positive hauls is around 0.3 ±0.7 kg/h, with peaks at 4.2 kg/h (12 ±27 animals/h, max 163 animals/h).

In *Aristeus antennatus* the sex-ratio in the catch is 6.25:1 in favor of the females; the males are much smaller (max carapace length 43 mm, mean below 30 mm CL) than the females (CL_{max}= 66 mm). The length-frequency distributions of females show 2-4 components. The growth of the females of *Aristeus antennatus* is modeled by a von Bertalanffy's function, but also by a discontinuous linear empirical model. The parameters of the von Bertalanffy growth curve are estimated as CL_{∞}= 71 mm and K/year= 0.51. Estimates of the female total mortality (Z/year) vary from 0.5-0.75 (Heincke's method) to 0.70 (Hoenig's method). The recruitment to the gear is discrete, limited to the summer months; the size of full capturability is at a CL of 36 mm (Ragonese *et al.*, 1994b).

No correlation has been demonstrated between the presence of *Aristeus antennatus* and that of *Aristaeomorpha foliacea*, maybe as a consequence of its extreme patchiness.

Food, feeding behaviour and trophic relationships

From stomach contents analysis, *Aristaeomorpha foliacea* appears to behave as carnivorous and opportunistic animals, ingesting heterogeneous food items, from foraminifera to fish and crustaceans (including other decapods), even plant material. Red shrimps have also detritivorous habits, and are partially scavengers. *Aristaeomorpha foliacea* is a more active predator than *Aristeus antennatus*, feeding on benthopelagic decapods such as *Plesionika martia*, *Pasiphaea* sp. and *Meganyctiphanes norvegica*, preying upon these species mainly during the daylight (when they approach the bottom),

and moving mid-water during the night. In contrast, *Aristeus antennatus* is an opportunistic random feeder, less active and slower in the movements than *Aristaeomorpha foliacea*. From the frequency of benthic preys in the stomach, *Aristeus antennatus* is more linked to the bottom where it is able to dig, searching for bivalves, macruran burrowing crustacean, etc.

Aristaeomorpha foliacea taken in the Sicilian Channel show an average of 12% with empty stomachs. The highest percentage of empty stomachs (19%) is recorded in spring, the lowest (7%) in winter. The general trend shows that decapod crustaceans are always the most frequent prey (50%≤ *F*≤ 65%), followed by bony fishes (39%≤ *F*≤ 54%), unidentified crustaceans (19%≤ *F*≤ 52%) and cephalopods (14%≤ *F*≤ 23%). In particular, small *Pasiphaea sivado* are the most frequent item identified among decapods (up to *F*= 13% in summer), and macrurids among fishes (up to *F*= 16% in spring). Foraminifera occur in 16% (summer) to 68% (winter) of stomachs, always in very small amounts. The only prey items showing a strong seasonal occurrence are diphyid siphonophores (*F*= 41% in spring) and benthic gastropods (*F*= 24% in autumn). The comparison among small (<40 mm CL) and large (≥40 mm CL) *Aristaeomorpha foliacea* shows that decapods and fishes are always the highest percent occurrence in both groups. In contrast, cephalopods were eaten in greater amounts by large specimens, as well as shrimps and siphonophores, while small specimens more frequently consumed benthic molluscs and, with a few exceptions, foraminifera.

Aristaeomorpha foliacea seems to be an active hunter, whose diet is composed prevalently by motile and relatively large-sized species. The high percent occurrence of shrimps and cephalopods in the stomach contents supports this hypothesis. The fish remains (generally vertebrae, eye lenses and scales) frequently found in the stomachs also suggest scavenging habits, as is usually thought of decapods feeding on fishes. Macrurids (*Nezumia* spp. and *Coelorhinchus coelorhynchus*) are indeed one of the main components of fishing discards in the area, and the role of by-catch discarded by trawlers in the diet of both shallow and deep-water decapods has already been highlighted. Siphonophores of family Diphyidae are consumed by *Aristaeomorpha foliacea* mainly in spring, when an

abundance peak of these organisms commonly occurs in the Western Mediterranean plankton. This suggests that the red shrimp is also able to exploit resources available in great amounts in a restricted period of the year.

The giant red shrimp appears to be a high level consumer in the food web of the upper middle slope; it seems to be an "holozoic" predator, a rather opportunistic carnivorous feeder exploiting a wide range of resources, mainly of pelagic or benthopelagic origin, while benthic preys seem to play a minor role in its diet. The remarkable occurrence of such prey items like siphonophores and *Pasiphaea sivado*, which undergo marked upward migrations at night, suggests a trophic link with the meso- and infrapelagic environment, which is an important feature of the ecology of the benthic boundary layer.

If the analysis of the diet seems straightforward, the issue of what species prey on red shrimps is more confused. Many species, commonly associated in the catch and considered as companion species, represent potential predators of red shrimp. Shrimps are generally considered an attractive prey for fish but many studies show that this observation cannot be generalized especially for the deep-water red shrimps. For example, analysis of hake stomachs from the same area revealed that fish and euphasids, not decapod crustaceans, represent the bulk of the prey. In fact, various studies tend to demonstrate that these deep-water shrimps have no systemic predator (but man), at least during their adult phase of life. In contrast, an active predation is supposed on the pelagic (juvenile) stage of life. On the other side, many companion species of red shrimps are competitors for food (preying upon Decapoda Natantia or on the same benthic prey).

Area features

The characteristics of the area of study are just outlined: a more complete description, together with the necessary bibliographical references, follows as Appendix B.

Hydrography and hydrology

The body of water between the Southern Coast of Sicily and the Northern coasts of Africa represents the transition between the Western and Eastern basins of the Mediterranean Sea. The Strait of Sicily, an area of 111.000 km^2, is a relatively shallow area with a complex bottom orography. The 1,000 m isobath is surpassed only in the central area where there are 3-4 depressions which work as decantation basins. These depressions are situated close to one another in a southeastern direction forming a sort of deep valley splitting the area in two sectors, which has been defined as South-East and Far-South zones. The valley communicates with the Western and Eastern Mediterranean Sea by a narrow sill, North-West of Pantelleria island 400-500 m deep, and a wider channel, South-East of Malta 500-600 m deep, respectively. The average depth is estimated at about 352 m; half of the area falls inside the 0-200 m isobaths, while the depth range for red shrimps (400-800 m) can be estimated at about 28% of the area.

Morphologically, the Strait of Sicily belongs to the continental shelf and slope but other morphologic sub-units of the slope are usually identified: basins, seamounts (guyots) and "banks". Along the Southern coasts of Sicily, the shelf is wider in front of Mazara (Adventure bank) and Capo Passero (Malta bank); in Tunisia, the shelf is wide in the southeastern sector. The slope shape is extremely irregular, incised by many canyons, trenches and steep declives, intervalled by sub-horizontal and more accessible (trawlable) traits. The seamounts are generally of small size, sub-conic in shape and of volcanic origin; two of them emerge to form the Pantelleria and Linosa islands. Banks are typical morphologic units in the Strait of Sicily: their tops raise above the 200 m isobath and show a sub-flattened surface with signs of abrasion; in fact they have been exposed to the surface repeatedly during the glaciations in the Quaternary period.

Basically, the hydrology of the area resembles that of the Mediterranean Sea at large; it can be defined a "negative" or "concentration" sea, i.e. a sea with a negative hydrological balance. Through the sills in the Strait of Sicily, the outflowing Atlantic water changes in salinity from 37.0 ppt (parts per thousand) to 37.3 ppt whereas the incoming subsurface water changes from 38.8 to 38.7 ppt. The Levantine water

influences mainly the depth range between 150-200 m and 1,000-1,200 m or less (200-600 m) and is more saline (38.8 ppt); the bulk of these bodies of water follows the same path but in opposite directions, diverging only at the two extremities. According to a recent model, the deep-water circulation seems to become well discriminated from that of the surface at about 500-600 m, producing a layer of almost still water at about 400 m; below the former level, the water is quite homogeneous and the exchange occurs mainly by vertical mixing.

In the Strait of Sicily, the Atlantic water extends its influence down to 150-200 m where it meets and partially mixes with the Levantine water; its surface temperature varies according the seasons (about 15°C and more than 22°C in winter and summer respectively) and its saline content is about 37.5 ppt; flowing towards the Eastern basin waters become cooler and more saline. The Levantine water is about 14.2°C and 38.7 ppt when reaching the Strait of Sicily, where its influence extends down to 600-800 m. Bathythermograms evidences a general situation of homeothermy (13-14°C), with the exclusion of the surface layers.

Trophic conditions

The biological productivity of the Mediterranean Sea is known to be among the lowest in the world, due to the relatively low concentration of biologically important chemical nutrients (biogenic elements) such as N, P and C, except perhaps in the vicinity of large rivers. Primary production varies according to the complex hydrology already evidenced, ranging from about 80-90 g C/m²/year in the Western Mediterranean to 6-20 g C/m²/year in the Eastern basin. The nitracline is located below the phosphatocline; phosphorous represents the most important limit for the Mediterranean plankton. The chlorophyll biomass is generally low in the euphotic layer and its maximum concentration is found at about 65-80 m and 80-120 m in the Western and Eastern side respectively.

In the Strait of Sicily, the huge amount of solar energy received (on average 650-765 kj/cm^2/year), the strong current pattern, and the virtual lack of river runoffs and limited rainfall have a negative impact on plankton populations (thus, the off-shore

waters of the Strait of Sicily are very clean and transparent). In fact, satellite data reveals that the Strait of Sicily is an area of moderate phytoplankton crops. In contrast, the same conditions allow benthic vegetation to flourish.

Bionomy

Different studies on the benthic communities in the Strait of Sicily show the dominance of rheophilic species, and with an Atlantic affinity. Bottoms between 50 m and 200 m are all ascribed to the "circalittoral" layer, mainly characterized by kind and quantity of light penetration, that determines the biological aspects; the next, deeper level, generally associated with the continental slope and the deep steeps around the banks, is the "bathyal" layer. Considering the bathymetrics that are or could be trawled, this last bionomic layer can be split in two bands, "epi-bathyal" and "meso-bathyal", with 450 m depth being the separation.

The Mediterranean shows a peculiar biocoenotic series, the "coralligenous bottoms" of the hard substrates of the circalittoral layer. Another circalittoral biocoenosis of the hard bottoms is that of the "off-shore rocks". The biocoenosis of the "coastal deposits" belongs to the soft bottoms. In the Strait of Sicily, the hard bottoms of the bathyal layer are characterized by many huge "buildings" produced by madrepores generally forming scattered clumps, that gives rise to the "white coral assemblages" biocoenosis, locally known as "cannelleri" (namely "organ pipes": those strong, stony corms make extended surfaces of the grounds between 300 m and 450 m dangerous for fishing, or even untrawlable altogether.

The epi-bathyal layer extends between 200-250 m and 400-450 m, whose bottoms are generally muddy, with a consistent fraction of fine sand; their biocoenoses are poorer and less varied than those of the mesolittoral. The most typical biological indicator species is the sea pen *Funiculina quadrangularis*, even if it is now quite rare especially on the trawlable grounds. The occurrence of such a species is closely related to the abundance of the food supply; in a few places the brachiopod *Terebratula vitrea* is dominant, but always associated with *Funiculina quadrangularis*. Among the crustaceans

of this layer, the pink shrimp *Parapenaeus longirostris* is the most commercially interesting. The Norway lobster, *Nephrops norvegicus*, is caught here too, as well as other smaller shrimps, such as *Solenocera membranacea* and the Atlantic shrimps *Plesionika martia, Plesionika heterocarpus, Plesionika antigai.*

The bottoms below 400-450 m belong to the meso-bathyal layer; they are muddy, with a large proportion of compacted, oxidized, yellow sediments, and smaller surfaces of reducing, gray mud. The characteristic *facies* of this bionomic stratum is that at *Isidella elongata* (Gorgonacea), that is associated with the red shrimps *Aristaeomorpha foliacea* and, depending on the zones, *Aristeus antennatus*. Parts of the same facies are the brachiopod *Terebratula vitrea* and the echinoderm *Brisingella coronata*. Besides the red shrimps, other crustaceans, some of which with pelagic life, are: *Sergestes robustus, Sergestes arcticus, Sergestes corniculum, Pasiphaea multidentata, Pontocaris lacazei, Polycheles typhlops*, and more shrimps; a few spiny lobsters *Palinurus mauritanicus* are also caught here. The cephalopods are not abundant, but anyway represented by *Pteroctopus tetracirrhus, Scaeurgus unicirrhus* and *Neorossia caroli, Rossia macrosoma, Todaropsis eblanae, Todarodes sagittatus, Illex coindetii*. Fishes are the most abundant component of the meso-bathyal, with a dominance of cartilaginous fish such as the dogfish *Galeus melastomus* and the rabbit fish *Chimaera monstrosa*; also frequent at those depths is *Centrophorus uyato*. Bony fishes are strongly represented by the rat-tail fishes, the snake eel, many myctophids and some commercial species.

In the Northern part of the Sicilian Channel, the mesobathyal layer shows some typical and exclusive species, such as the sponges *Pheronema grayi* and *Poecillastra compressa*, the cnidaria *Lophogorgia sarmentosa, Madrepora oculata, Lophelia prolifera, Dendrophyllia cornigera, Calliactis parasitica* and *Amphianthus dohrni*, the crab *Anamanthia rissoana*, the gastropods *Natica millepunctata, Lunatia fusca, Buccinum humphreysianum* and *Fusinus rostratus*, the cephalopods *Bathypolypus sponsalis, Heteroteuthis dispar, Alloteuthis media, Abralia veranyi, Histioteuthis reversa, Chiroteuthis veranyi* and *Octopoteuthis sicula.*

MATERIALS AND METHODS

Area

The area of study belongs to the central basin of the Mediterranean Sea (FAO fishing zone 37.4), known as Strait of Sicily or Sicilian Channel. Four groups of islands are present: the Egadi Islands in the northern tip, Pantelleria and the Pelagie Islands (Linosa and Lampedusa) in the middle, and the Maltese Archipelago at the south-eastern limit. The study area is characterized by the rugged nature of the bottoms and strong hydrodynamism; the Sicilian Channel represents an area of transition between the Western and Eastern Basins of the Mediterranean from the point of view of biogeography; still, it is more similar to the Atlantic province.

Table 01 - Depth range fished (mean depth, m) by zone and sampling season.

ZONE	DEPTH RANGE (m) SPRING	SUMMER
MA	553 - 651	-
NW	635 - 651	602 - 633
NE	577 - 704	621 - 697
SE	572 - 678	586 - 683

The Sicilian Channel could be considered for the demersal resources as part of an ample "Unitary management area" whose limits are the coastal lines of Sicily and Northern Africa, and the bathymetric of 1,000 m that separates the unit from the Ionian trench (at East) and the Western basin (at West). There are four major red shrimp fishing zones in the Sicilian Channel inside the area routinely covered by the Fishery Institute

ITPP/CNR of Mazara (Levi, 1990) (Fig. 03 and Table 01), designated as: 1) Marettimo (West of the Egadi Islands, "MA"); 2) West of Linosa (or Channel of Pantelleria, "NW"); 3) Scirocco of Linosa (South-East of Linosa, "SE"); 4) Grecale of Linosa (North-East of Linosa, "NE").

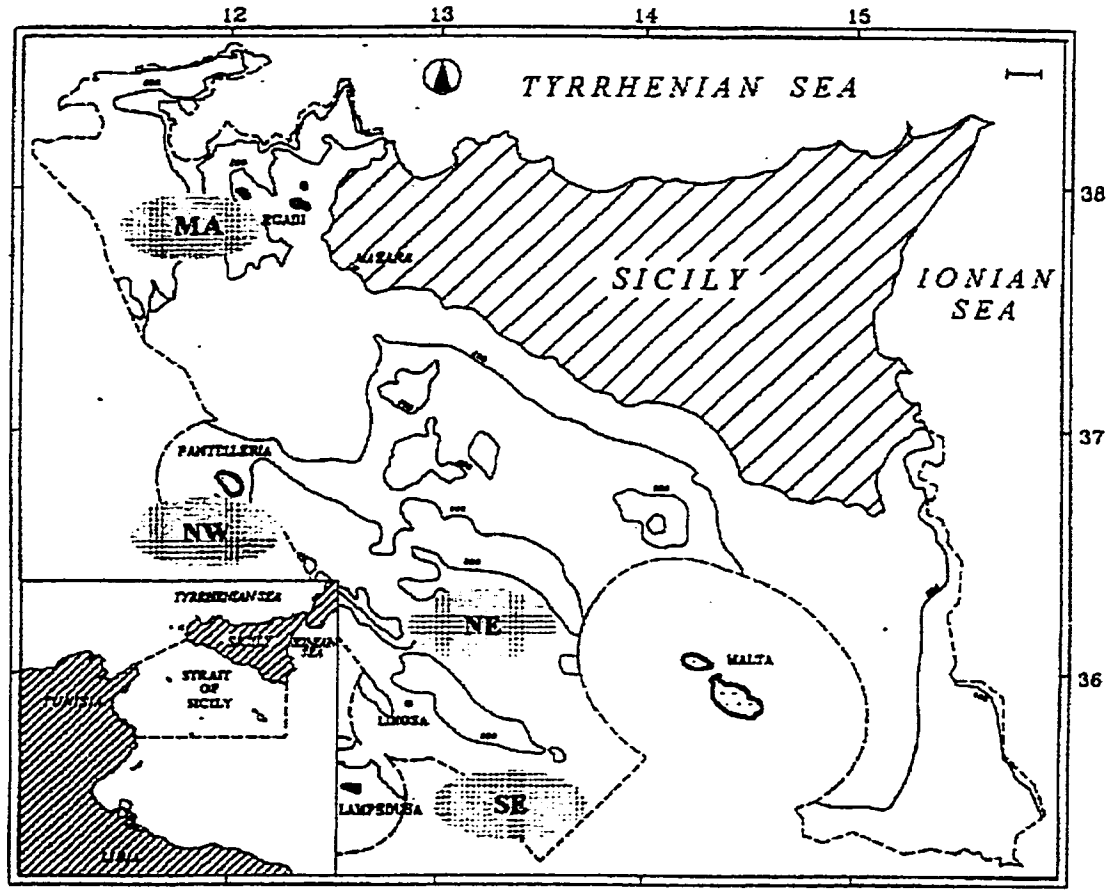


Fig. 03 - Study area and zones explored during the red shrimps selectivity study (MA: Marettimo; NW, NE and SE: northwest, northeast and southeast of Linosa).

Vessel and gear

Vessel

The stern trawler "Sant'Anna" (Fig. 04), built of steel in 1981, has been employed; it has a GRT of 198 tonnes, a length of 32.2 m and a width of 7.2 m, a draught of 3.2 m, and is powered by a diesel engine MAK 6M331AK of 1,012 HP. The fishing winch has two drums, holding 3,000 m of steel cable each. The boat is equipped (Table 02) with radar, satellite loran (GPS), video plotter, three echosounders, automatic pilot, radio, transmitter and radio phone; moreover, it has two deep-freeze cells (up to -40°C) and two storage bunkers (up to -25°C).



Fig. 04 - The fishing vessel "Sant'Anna" (GRT 198 tonnes, 1012 HP), routinely used for the experimental surveys in the Sicilian Channel.

Table 02 - Characteristics and apparels of the fishing boat "Sant'Anna".

VESSEL NAME	M/P S. Anna
YEAR BUILT	1981
SHIPYARD	Arturo Stabile - Trapani - Italy
GROSS REGISTERED TONNAGE	197.6
LENGTH OVERALL (m)	32.3
BREADTH (m)	7.2
DRAUGHT (m)	3.2
MAKE OF ENGINE	MAK, Diesel, model 6M331AK
SHAFT HORSE POWER (HP)	1012
YEAR BUILT	1980
GAS TANK (t)	55
MAXIMUM AHEAD SERVICE SPEED (knots)	12
DONKEY ENGINE	n° 2 VM of 27 HP and 100 HP
GENERATOR	n° 2 of 12 kW each
COMPRESSOR	n° 3 of 3.300 frigories/h
ICE MAKER	1 of 1 t /24 h
FREEZER CELL	n° 2 (-40°C)
FISH-HOLD	n° 2 (-25°C)
BEAKER (t)	27
VIDEO PLOTTER	Furuno GD-170
COLOR ECHO-SOUNDER	Furuno FCV-201
ECHO-SOUNDER	n° 2 Furuno
LORAN SATELLITE	Furuno Navigator GPS-50
LORAN	Furuno LC-70
RADAR	Furuno FR-711
AUTOMATIC PILOT	Skipper Pilot AP 103
RADIO VHS	Furuno
TRANSCEIVER	Skanti TRP 6000

Trawl net

A trawl net of the commercial type, called "di fondale" has been used (Fig. 05). The net (Fig. 06) is made of nylon and polyammide and is divided (Table 03) in the following sectors (from mouth to cod-end):

- 2 wings ("chiarazze"), each divided in a top and a bottom part, made up of the front (11 m, 45 mm mesh) and the back (16 m, 28 mm mesh);

- 4 triangular cuts ("scaglietti") of which: two lateral (1.3 m, 28 mm mesh) which hold the base of each wing, another on top ("scaglietto di summo") (8.6 m, 28 mm mesh; 180 meshes at the beginning and 20 at the end) and one on the bottom ("scaglietto di chiummu") (14.5 m, 45 mm; 130 meshes at the beginning and 25 at the end);
- the ceiling ("cielo") divided in two preprinted parts (10 m, 22 mm mesh; 15 m, 18 mm mesh);
- the floor ("sottano") made of three parts (11.1 m, 28 mm mesh; 14 m, 24 mm mesh; 5.1 m, 20 mm mesh);
- the cod-end ("pozzale") (5 m, usually of 14-18 mm mesh size in the case of shrimp fisheries and between 16-45 mm in the present study).

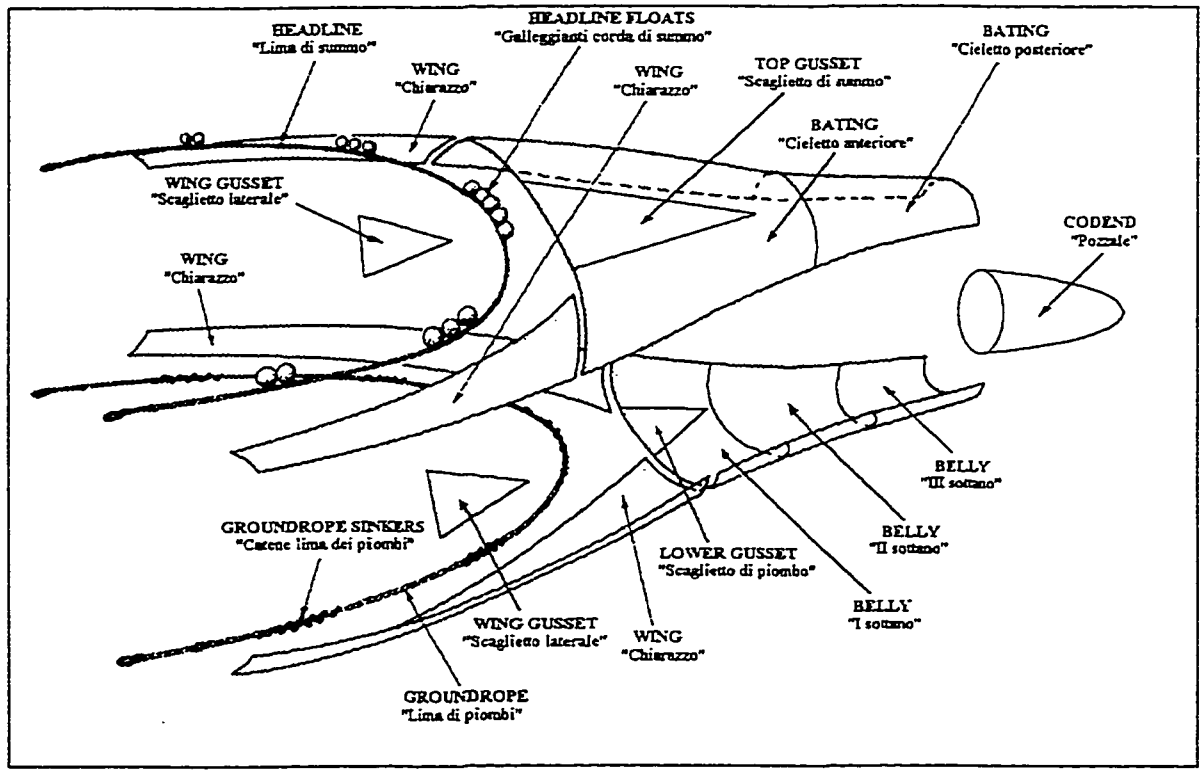


Fig. 05 - Schematic representation of the deep-water bottom trawl-net used in the Sicilian red shrimp fishery.

The net mouth (Table 04) is limited on the top by a rope ("lima di summo"), of a total length of 66 m (29 m for each wing and 8 m for the "scaglietto di summo"), whose

floating is due to 82 plastic fishing balls (11 cm diameter and 200 g weight) and at the bottom by another rope ("lima di chiummu") of 67 m of length (29 m for each wing and 4.5 m for the "scaglietto di fondo"), weighed with 16 pieces of chain of 1.5 kg each for the wings and one 4-kg piece for the "scaglietto"). A metal device ("forchetta") is used to link the two parts of the wings (through two ropes of 30 m, called "curette") and the lines ("calamenti"). The lines are made of five twines of steel covered with polyammide, intertwined for 231 m, with a total diameter of 34 mm. The lines are connected to the steel otter boards (oval shape of 2.3x1.1 m, weighing 400 kg each). The otter boards (Fig. 07) are finally attached to the boat by a steel cable of 14.5 mm in diameter.

Table 03 - Net components and measures.

NETTING	ITALIAN NAME	LENGTH (m)	MESH n°	MESH SIDE (mm)
Codend	Pozzale (Sacco)	5.00	Variable	Variable
Cover	Controsacco	10.00	420	14
Bating	Cieletto posteriore	15.00	760 (end)	18
	Cieletto anteriore	10.00	1260 (beginning)	22
Wing	Chiarazzo posteriore	16.00	600	28
Flying wing	Chiarazzo anteriore	11.25	240	45
Belly	III Sottano	5.10	70	20
	II Sottano	14.00	160	24
	I Sottano	11.10	160	28
Top gusset	Scaglietto di summo	8.60	180 (beginning)/20 (end)	28
Lower gusset	Scaglietto di piombo	14.50	130 (beginning)/25 (end)	45
Wing gusset	Scaglietto laterale	1.30	-	28

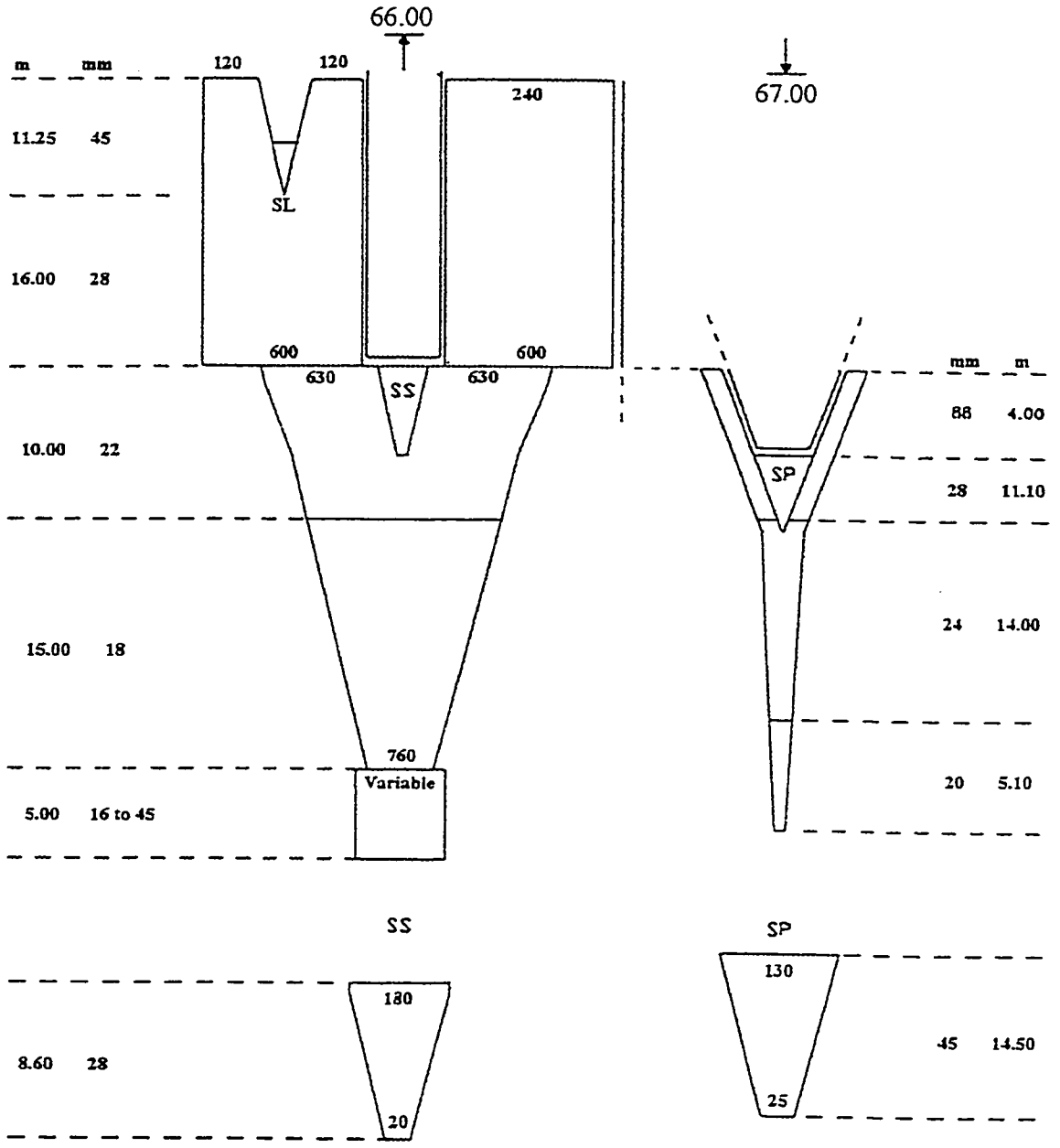


Fig. 06 - Plan of the trawl net used.

The net is locally called "with 4 sides" because the wings are divided into two sectors. In reality, it is a 2-side net (Garner, 1977). Its structure favors the horizontal opening against the vertical height (estimated around 70-100 cm) (Sarà, 1969; Arena, 1985), similarly to the typical "Italian" nets (Fiorentini and Cosimi, 1981). Considering the useful opening (about 25 m) and the vessel speed (5 km/h), the area swept can be estimated at 10 ha/h.

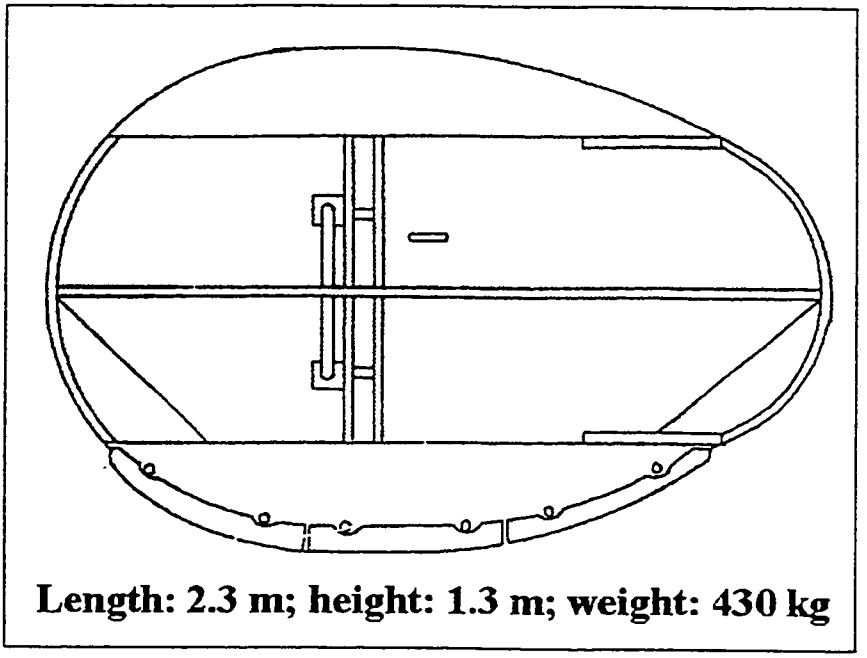


Fig. 07 - The otter boards employed.

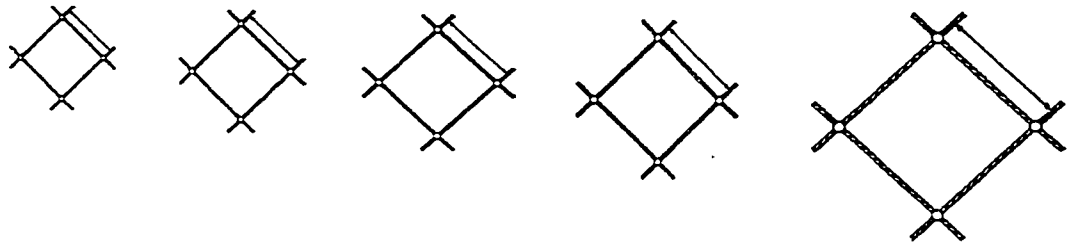
Table 04 - Characteristics of the gear accessories.

English name	Italian name	length (m)	Ø (mm)	material	total n.	weight (kg @)
Setting	Ponte di summo	-	8	Polyamide	-	-
"	Ponte di piombi	-	14	"	-	-
Cover float	Galleggiante al cover	-	113	Polystyrene	14	0.25
Headline float	Galleggiante di summo	-	110	"	82	"
Trawl warp	Cavo d'acciaio	3100	14.5	Steel	2	-
Otter board	Divergente	2.3	1300	Plate	2	430
Pennant	Curetta centrale	2.2	22 up, 34 blw	Plastic lined steel	1	-
Backstrop	Curetta laterale	0.9	-	"	2	-
Bridle	Calamento	230	34	Polyamide lined steel	2	-
Dan leno triangle	Forchetta	-		Steel	2	-
Headline	Lima di summo	66	22	Double plastic plait	1	-
Groundrope	Lima di piombi	67	38	"	1	-
Central sinker	Catena petto piombo	3	-	Steel	1	4
Groundrope sinker	Catena lima piombi	-	-	"	16	1.5

Cod-ends

In the earlier trawl surveys, the cod-end had 18 mm mesh, and no cover.

During the trawl gear selectivity experiment, different cod-ends were used, each made with cast, non-knotted mesh of 16, 20, 24, 28 or 45 mm of nominal side (Fig. 08); each cod-end resembles a cylinder of about 5 m length, with frontal mesh numbers of 380, 260, 210, 180 e 150 respectively (Table 05).



16 mm 20 mm 24 mm 28 mm 45 mm

Fig. 08 - The different meshes that have been used in the selectivity study: measures refer to the side of the mesh (actual size 2/3 of real one).

Table 05 - Cod-ends and cover specifications during the selectivity study (the second cod-end is the standard one, used also in the earlier trawl surveys). Mean mesh sizes following UNI rule n° 8783 (1985), ± standard deviation.

COD END	GEAR	MESH	OPENING	MEAN	MESH SIDE (mm)			MESH LENGTH (mm)		
	CODE	COUNT	MESH n°	LENGTH (m)	NOMINAL	MEAN (UNI)	S.D.	NOMINAL	MEAN (UNI)	S.D.
Cover	/14	210/72	420	10.00	14	14.4	0.26	28	28.6	0.25
1st cod end	16/14	210/18	380	4.95	16	16.1	0.04	32	32.2	0.09
2nd cod end	20/14	210/18	260	4.80	20	20.2	0.11	40	40.5	0.22
3rd cod end	24/14	210/18	210	4.75	24	24.0	0.07	48	48.1	0.15
4th cod end	28/14	210/18	181	4.85	28	28.0	0.29	56	56.0	0.58
5th cod end	45/14	210/24	150	4.85	45	48.6	0.46	90	97.2	0.92

In the selectivity experiment, each cod-end was covered with a single type of cover: 14 mm mesh, about 10 m long, larger than the cod-end and with frontal mesh number of 420 (Fig. 09). The cover twine is stronger than the cod-end (in fact, a chafer has been used as protection when fishing without cover); three series of plastic balls were connected with the top of the cover to prevent it from collapsing.

Each configuration of cod-end/cover (GC) was kept if possible only for one day and in any case for no more than two consecutive days. At the end of the day the meshes were measured on the wet cod-end (UNI rule n° 8783; 1985).

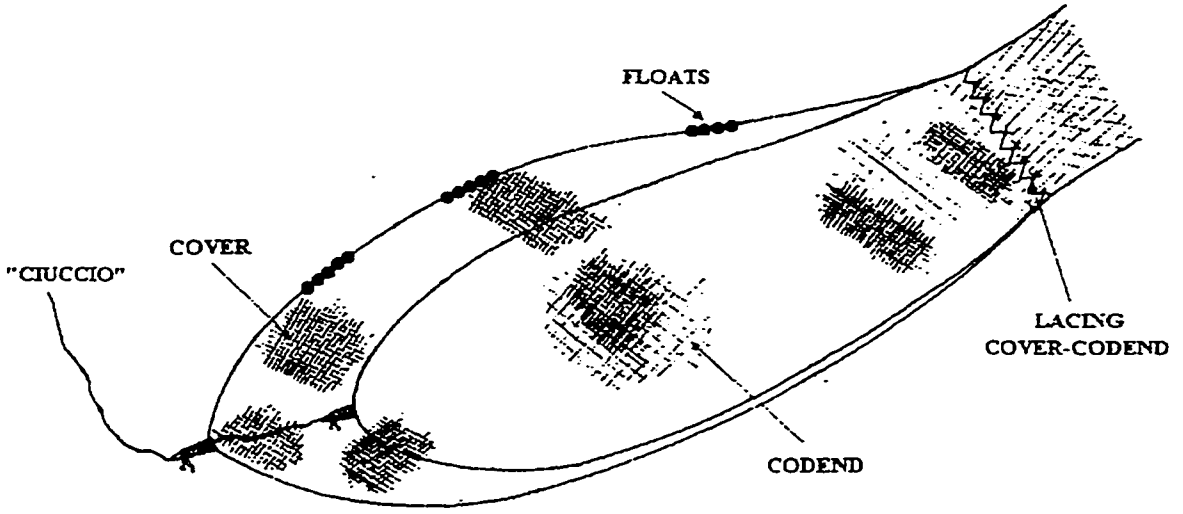


Fig. 09 - Experimental technique for the selectivity study: a small-mesh (14 mm side) cover is placed around the cod-end (of various larger mesh).

Experimental design

Two different sets of experiments were used in this study: eight earlier general trawl surveys, and a two-survey *ad hoc* selectivity study.

In the earlier surveys, data were derived from eight seasonal random stratified experimental trawl surveys carried out by the Institute of Fisheries (ITPP-CNR) of Mazara between spring 1985 and winter 1987, as part of an Italian-wide fisheries

assessment. Hauls were limited to one-hour in daylight, i.e. during the period of maximum availability of these shrimps (Sardà, 1988) which are presumed to swim in the water column during the night (Lagardère, 1972). The length of each haul was about 5000 m (1 h at 2.8 knots, in a "random" direction). Each sampling period lasted for 15-20 days according to meteorological conditions (see Levi, 1991, for a description of the general program). Since no information is available for the structure of the landings of red shrimps from the Sicilian Channel, the seasonal surveys were pooled to simulate the commercial catch curve required for the yield-per-recruit approach.

The experimental design for the selectivity study represents a compromise between the need to emulate commercial fishing activities and the need to expand the area explored; the aim was to obtain as large as possible a picture of the length frequency distributions (LFDs). Commercial fishing hauls last 4 hours on the bottom, plus setting (15 min) and hauling (45 min) time. The fishermen believe that with the 4-hour haul the catch is maximized, without risk of spoiling it. In contrast, the selectivity experimental hauls were 3-hour long to obtain a larger number of samples. Commercially, once the fishermen find an area considered good, the haul is repeated in the same identical location in a back and forth motion as long as the yields are subjectively considered satisfying. In the selectivity study the fishing spots were rotated to spread and distribute the coverage. The fishing areas were chosen because they were known to be good for shrimp fishing inside the zones of the earlier surveys. Moreover, following the captain's advice, the hauls were chosen to minimize the risk of malfunctioning, for example caused by the presence of "cannizzati" (stones used to anchor a sort of FAD), "denti di cane" and "cannelleri" (namely "dog teeth" and "organ pipes", grasps of biological origin), heavy mud (that fills the net and clogs the otter boards), etc. Also, the two selectivity surveys were pooled to simulate a commercial catch curve.

The distribution of the valid hauls ("control", i.e. without cover, and "night" excluded), which were on bottoms between 500 m and 750 m depth (the bathymetric range for the specific populations is 400-800 m; Ragonese, 1989) is shown in Table 06, divided by area and cod-end type.

Table 06 - Number of valid hauls by gear configuration (GC), season and zone (control and night hauls excluded) during the selectivity study.

GEAR CODE	ZONE NW	NE	SE	MARETTIMO	TOTAL
SPRING SAMPLE					
16/14	-	-	1	1	2
20/14	-	8	4	3	15
24/14	1	2	5	-	8
28/14	4	8	-	-	12
45/14	1	2	-	-	3
TOTAL	6	20	10	4	40
SUMMER SAMPLE					
16/14	-	4	-	-	4
20/14	-	4	8	-	12
24/14	4	2	8	-	14
28/14	5	-	11	-	16
45/14	4	-	4	-	8
TOTAL	13	10	31	-	54

During the selectivity experiment a few night hauls (by convention those started at or after 7 p.m.) were done to check for any macroscopic difference in yields, length frequency distributions or selection behaviour between daylight and night catches. Twelve night hauls were conducted, seven and five in the spring and in the summer respectively, unevenly distributed among the different GCs.

Table 07 - Descriptive statistics of the total catch (in number and weight) of *Aristaeomorpha foliacea* during the selectivity study, by zone and season.

ZONE	MA	N W		N E		S E		Combined		
SEASON	Spring	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer	Combined
No. of hauls (3h each)	4	6	13	19	15	10	35	39	63	102
NUMBER	1551	3804	8898	26994	18991	28846	88181	61195	116070	177265
Min	134	381	322	483	562	1147	325	134	322	134
Max	658	1031	1384	2217	3063	4897	4063	4897	4063	4897
Mean	387.8	634.0	684.5	1420.7	1266.1	2884.6	2519.5	1569.1	1842.4	1737.9
s.d.	215.4	220.6	345.1	442.1	722.2	1217.6	1013.31	1097.8	1150.8	1133.2
WEIGHT	46.9	109.01	274.1	561.01	447.3	415.3	1479.4	1132.1	2200.8	3332.8
Min	3.3	9.6	12.2	10.4	15.5	21.8	4.8	3.3	4.8	3.3
Max	20.8	33.9	31.2	44.8	61.8	58.0	63.8	58.0	63.8	63.8
Mean	11.7	18.2	21.1	29.5	29.8	41.5	42.3	29.0	34.9	32.7
s.d.	7.2	8.8	73	10.1	12.1	11.4	14.6	13.6	15.4	14.9

Table 08 - Descriptive statistics of the total catch (in number and weight) of *Aristeus antennatus* during the selectivity study, by zone and season.

ZONE	MA	N W		N E		S E		Combined		
SEASON	Spring	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer	Combined
No. of hauls (3h each)	4	4	13	17	13	7	31	32	57	89
NUMBER	1108	638	1391	2086	875	48	299	3880	2565	6445
Min	114	43	6	1	2	1	2	1	2	1
Max	630	338	291	243	225	24	76	630	291	630
Mean	277.0	159.5	107.0	122.7	67.3	6.9	9.6	121.3	45.0	72.4
s.d.	239.9	125.8	93.6	80.6	77.7	8.6	14.4	129.4	70.6	102.1
WEIGHT	28.6	15.1	26.1	46.1	12.6	1.2	3.8	90.9	42.4	133.3
Min	2.8	1.0	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Max	16.7	9.3	6.6	5.9	3.5	0.6	1.5	16.7	6.6	16.7
Mean	7.1	3.8	2.0	2.7	1.0	0.2	0.1	2.8	0.7	1.5
s. d.	6.4	3.7	1.9	1.7.	1.4	0.2	0.3	3.4	1.5	2.6

Biological material

The total catch of *Aristaeomorpha foliacea* in the eight earlier surveys was 463 kg, corresponding to 19,400 animals, coming from 164 valid hauls, of which 132 were positive for red shrimps. The LFDs of the females by season are presented in Fig. 10.

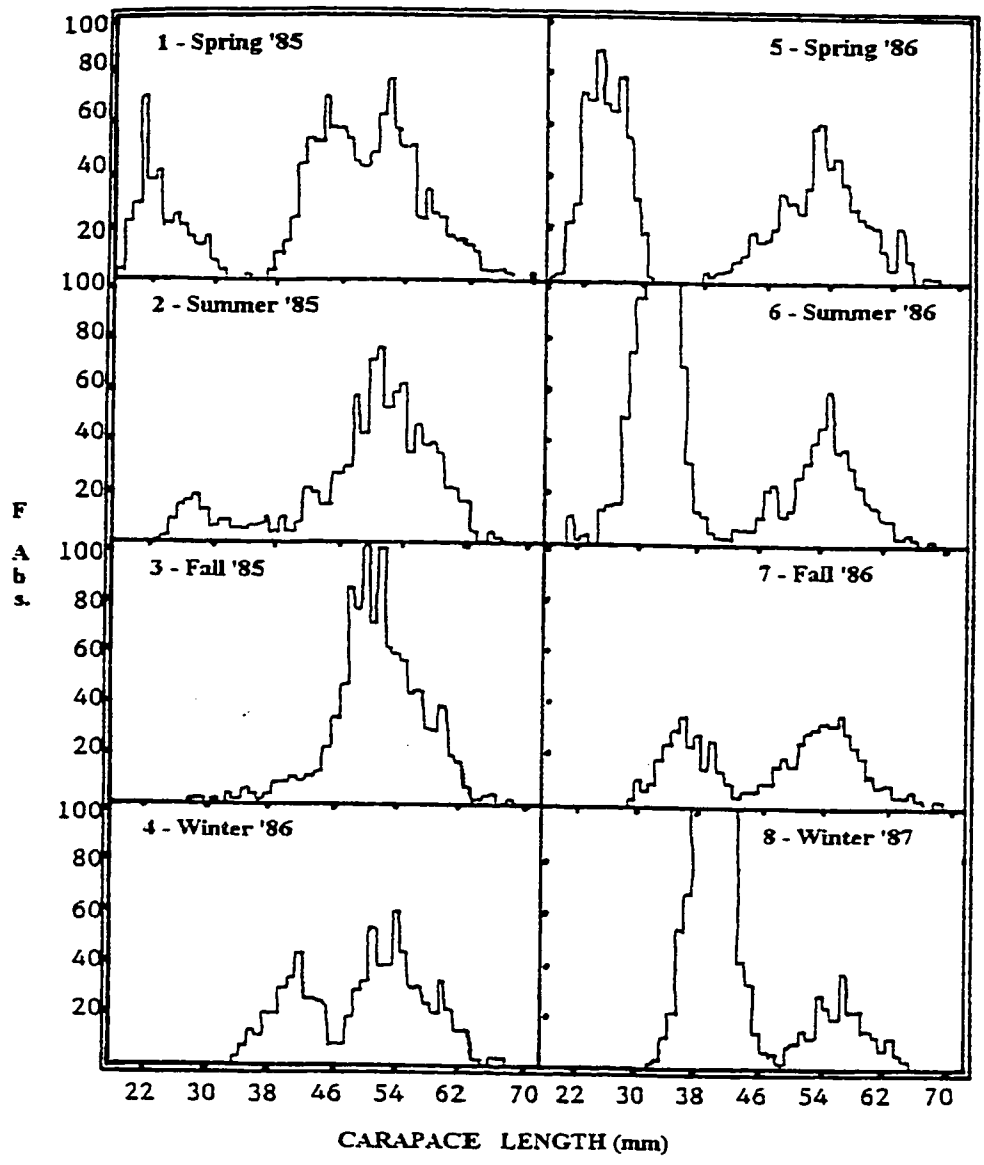


Fig. 10 - Length-frequency distribution of *Aristaeomorpha foliacea* females during the earlier trawl surveys, by season.

The two surveys of the selection study produced 177,300 *Aristaeomorpha foliacea*, corresponding to 3333 kg, coming from 102 3-hour valid hauls. Complete analyses were performed on a subsample of 162,850 shrimps (only those from the 79 hauls carried out in the zones NE and SE). The descriptive statistics of the catch are reported in Table 07. For a better picture of the red shrimps fishery in the Sicilian Channel, the descriptive statistics for the catches of the companion species, the violet shrimp *Aristeus antennatus*, are also reported in Table 08.

The sample size for the study of body engagement was 635 specimens, 394 females and 241 males. The sample was balanced among the useful CL classes.

Measures

Total body weight (BW) was recorded (at 0.1 g) using an analytical balance.

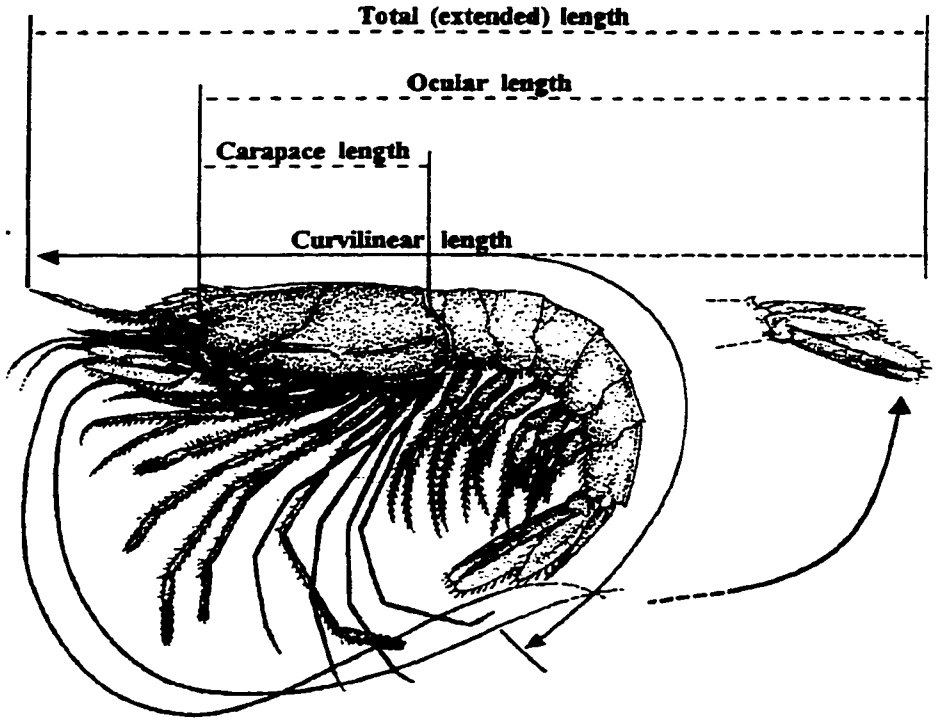


Fig. 11 - Body measures used in shrimps.

The "oblique" carapace length (hereafter CL) was considered the standard measure (Farmer, 1986; Dall *et al.*, 1990). It was taken with a watch caliper, from the orbital sinus to the posterior hind edge of the carapace (Mayrat, 1964) with a tolerance of 1 mm (rounded down). For morphometric analyses, the specimen was placed on its back over a flat metallic "ichthyometer" and gently stretched. The "total length" (hereafter TL), from the tip of the rostrum to the edge of the telson, and the "body length", according to Farmer (1986), hereby defined as "ocular length" (OL), from the posterior margin of the orbit to the tip of the telson, were measured (Fig. 11).

Procedures

In the field

In the earlier trawl surveys, a log-book was kept for the haul conditions, and target species of fish and cephalopods were ordinarily frozen for further analysis in the laboratory. Whenever possible, the shrimps were measured on board recording the oblique length of the carapace as well as the sex (Fig. 12); if it was not possible to operate on board (time between hauls was in general short), the shrimps were frozen and brought at the laboratory for further treatment.

In the selectivity study, field data were collected in four pre-arranged forms, concerning:

- the haul specifications (time, position, sea conditions, gear type, team, notes, etc.);
- the catch (weight and number of target species and of selected by-catch in the cod-end and in the cover, anthropic waste, notes, etc.);
- the length (carapace length, mm; only for two red shrimps species);
- the stomach analysis of potential large predators with basic measurements.

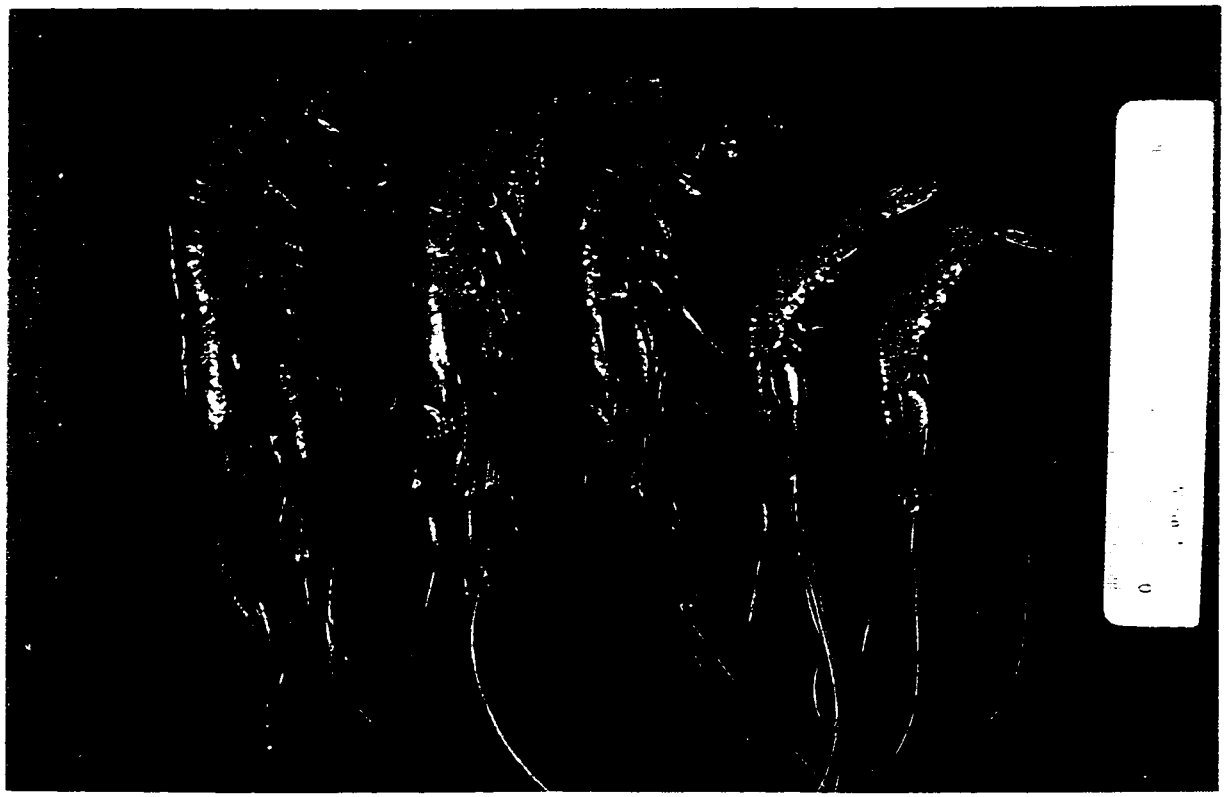


Fig. 12 - Sexual and maturation differences in the red shrimp *Aristaeomorpha foliacea*: large adult female, adult female, adult male, juvenile female, juvenile male.

Aristaeomorpha foliacea shrimps were preliminarily sorted in two components, a) females, plus juveniles males and b) adult (i.e. with short rostrum) males, keeping separated the catch in the cod-end and in the cover. Weighing, counting and measuring was performed on board on fresh material. The red shrimp catch was always measured without sub-sampling, i.e. all the shrimps, regardless of sex, were individually measured. The proportion of juvenile males was thereafter estimated on a subsample, and their number moved from component a) to component b).

Haul No.: 94 **Gear configuration:** 24/14 **Average depth:** 620 m **Zone:** SE

TAXON		IN		OUT		TOT (IN+OUT)		SEL.RATIO (OUT/TOT)	
		No.	kg	No.	kg	No.	kg	No.	kg
CRUSTACEAN									
Aristaeomorpha foliacea	aM	999	15.95	-	-	999	15.95	0	0
	jM + F	1915	31.7	72	0.4	1987	32.1	0.036	0.012
	Sex comb.	2914	47.65	72	0.4	2986	48.05	0.024	0.008
Aristeus antennatus	M	-	-	-	-	-	-	-	-
	F	4	-	-	-	4	-	0	-
	Sex comb.	4	-	-	-	4	-	0	0
Nephrops norvegicus		10	0.45	-	-	10	0.45	0	0
Parapenaeus longirostris		89	0.65	6	0.1	95	0.75	0.063	0.133
Other crustaceans		-	1.15	-	1.25	-	2.4	-	0.521
SHARKS AND SKATES									
Chimaera monstrosa		-	-	-	-	-	-	-	-
Etmopterus spinax		1	0.11	-	-	1	0.1	0	0
Galeus melastomus		3	0.15	-	-	3	0.15	0	0
Raja sp.		-	-	-	-	-	-	-	-
Other sharks and skates		-	-	-	-	-	-	-	-
BONY FISH									
Conger conger		-	-	1	0.05	1	0.05	1	1
Helicolenus dactylopterus		8	0.35	-	-	8	0.35	0	0
Lepidorhombus boscii		2	0.1	-	-	2	0.1	0	0
Merluccius merluccius		42	1.1	32	0.3	74	1.4	0.432	0.214
Micromesistius poutassou		10	0.9	2	0.2	12	1.1	0.166	0.181
Mullus surmuletus		1	0.05	-	-	1	0.05	0	0
Phycis blennoides		7	0.45	-	-	7	0.45	0	0
Other bony fish		-	1.75	-	0.6	-	2.35	-	0.255
CEPHALOPODS									
Todarodes sagittatus		-	-	-	-	-	-	-	-
Other cephalopods		-	-	-	-	-	-	-	-

Fig. 13 - Example of a synoptic form for catch recording.

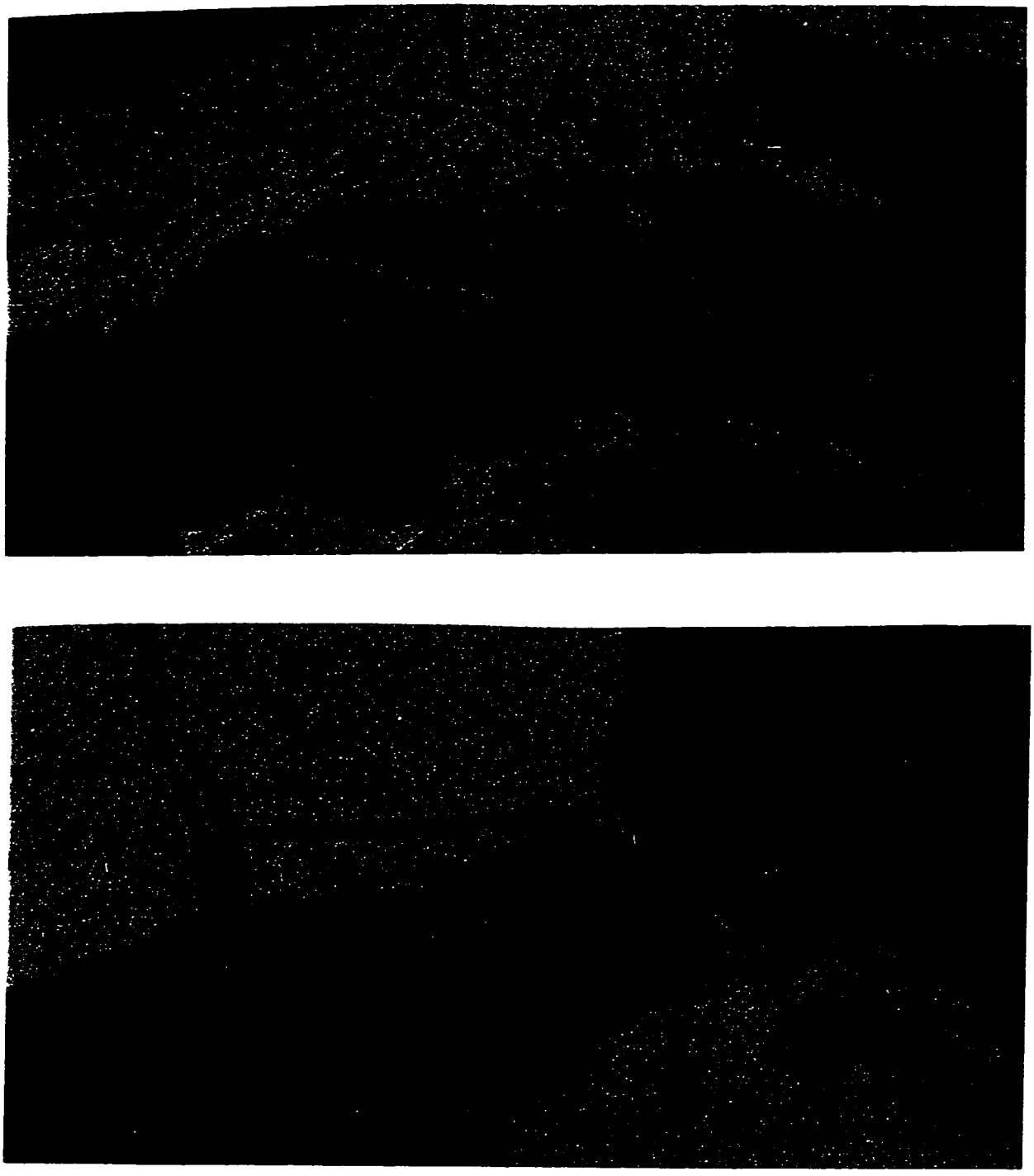


Fig. 14 - The "IN" and "OUT" components of the catch (haul n. 9, gear configuration 20/14).

Selected by-catch species, such as *Aristeus antennatus* (blue-and-red shrimp), *Nephrops norvegicus* (Norway lobster), *Merluccius merluccius* (Mediterranean hake), *Galeus melastomus* (green-eye shark) and *Todarodes sagittatus* (flying squid) were always sorted, counted and weighed. Other taxa were separated as "other crustaceans", "other bony fishes", "other skates and sharks" and "other cephalopods"; of these mixed categories, only the global weight was routinely recorded. A non-random sub-sampling of the mixed categories was carried out in order to identify the species and organize a (not exhaustive) faunistic list of the by-catch. Catch sub-samplings were analyzed for a systematic identification to the lowest possible taxon. Dubious species were preserved for specialistic identification. The results of the macroscopic analysis of the stomachs of the expected red shrimp predators were recorded, as well as their body length and weight, in each haul.

An *ad hoc* program was used as soon as possible to organize data gathered on board in a synoptic form (Fig. 13). The total catch and the selection ratios, both considering number and weight, were computed automatically by the *ad hoc* program. A picture was taken of every haul, divided in the IN and OUT component (Fig. 14).

In the laboratory

On-board and in-lab measurements were compared by taking multiple sub-samples of fresh shrimps until the whole size range (20-40 mm and 20-70 mm, carapace length, for males and females respectively) was represented and bringing them to the lab in refrigerated condition. To "balance" the sample, an upper limit of 10-15 specimens for each length class (1 mm) and sex was set (i.e., a length-stratified sample). In the laboratory, the specimens, already sorted by sex, were soaked in tap water, measured and weighed. Water was drained from the surface and the gill-chambers by allowing the samples to rest upon a plastic sieve. Specimens were then placed individually in a plastic bag, labeled, deep-frozen (-30°C) overnight, and stored at -18°C for two weeks (the usual period of both experimental surveys and commercial off-shore trawl operations). The shrimps were then defrosted (overnight at room temperature) and

measured again. Thawed *vs.* fresh measures were compared using both parametric ("paired t") and non-parametric ("sign" for lengths and "Wilcoxon" for weights) tests, to detect any difference between fresh and thawed conditions. Thereafter, only the fresh measures were used for further investigations.

Depending of the use, the weight of the animals was obtained by direct measurement on an analytical scale, or was estimated from length-weight regressions or from *ad hoc* length-weight conversion keys (Table 09).

Table 09 - Actual average body weight by sex and CL class, in *Aristaeomorpha foliacea* (modified from Bianchini *et al.*, 1998b). (sample balanced to 10 specimens per class and sex)

CL (mm)	**19**	**20**	**21**	**22**	**23**	..	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**
males (g)	3.0	3.4	4.0	4.5	5.2		13.3	14.5	15.9	17.2	18.7	20.2	21.8	23.5	25.3	27.1	29.1
females (g)	3.1	3.5	4.1	4.6	5.1		12.3	13.3	14.4	15.6	16.8	18.0	19.4	20.7	22.2	23.7	25.2

Different body measurements were also taken for comparison with the "historical" records, namely the total length (TL) and the ocular length (OL) on a sample of 394 females and 241 males.

For the study on theoretical escapement, other measures than the standard carapace length, namely maximum width (MW) and height (MH) of the folded body (Fig. 15), were also measured in the lab, using another sample of red shrimps (157 males, CL range 18-41 mm; 293 females, CL range 16-67 mm) from the commercial catch.

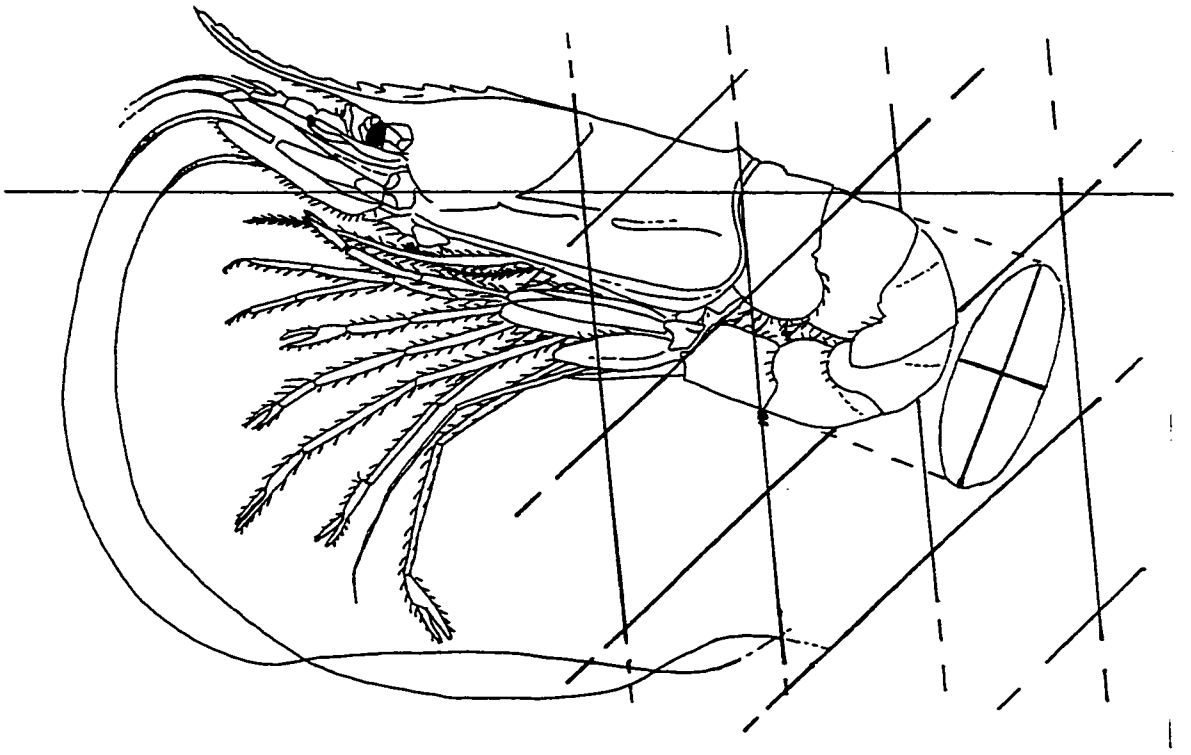


Fig. 15 - The folded position that red shrimps assume in escaping from the net.

Morphometry

The carapace length *vs.* total length or ocular length relationships were investigated, since a simple linear regression resulted unsuited, a linearized allometric (natural logs) was used. The same model was used for the length-weight relationships.

Least square estimates of parameters were based on the predictive or Type I linear regression model (Sokal and Rohlf, 1981). The t-test was used to test the hypothesis of isometry (b= 1 or b= 3, for length and weight relationships respectively). The occurrence of discontinuities ("disharmonies" or "splines") in the relationship was examined using a piece-wise linear regression model (Neter *et al.*, 1985, modified by Wilkinson, 1987). The standard assumptions of the regression models were evaluated using scatterplots of variables, Studentized residuals *vs.* estimates, normality plot of residuals, and by

performing a Kolmogorov-Smirnov test on standardized residuals ("Lilliefors test"; in Wilkinson, 1987). A "runs test" was used to check the lack of randomness in residuals, i.e., the absence of pattern (Draper and Smith, 1981). The presence of influential observations was detected by analyzing the Cook's statistic (Neter *et al.*, 1985). The Furnival's index (Furnival, 1961) was used to make possible the comparison of the goodness-of-fit among other models. Least squares estimates (AM or type I regression) were preferred to the standard major axis estimates (GM), in view of a predictive use (Jolicoeur, 1975; Sprent and Dolby, 1980; Sardà *et al.*, 1995).

After having chosen the model, the historical available measures different from the standard carapace length were converted by inverse prediction. The conversion allowed to compare the historical length frequency distributions with the present ones. Data coming from fishing grounds at SW-Egadi were examined in detail. Estimated regression coefficients were also qualitatively compared with the weight-length estimates available from other conspecific populations.

Growth

The Bhattacharya's method (MPA), as implemented by Gayanilo *et al.* (1994), was used for a preliminary discrimination of the Gaussian components; the selection points have been chosen subjectively, not taking in consideration the suggestion of Pauly and Caddy (1985). The Bhattacharya's (1967) method for deconvoluting a LFD in its normal components is based on the fact that the logarithm of a Gaussian distribution has a concave quadratic shape and its derivative is a negative-slope linear. A scatterplot of the first differences of the logarithms of a LFD with multiple modes (real components) therefore shows a series of negative linear regression lines (Titterington *et al.*, 1985).

The evolution in time of the mean lengths ("modal progression"), estimated for "representative components" (in general, components with a frequency greater than 10 and a separation index greater than 2) was qualitatively analyzed. Since the seasonal LFDs exhibit considerable variability over the years, two methods were applied to

dampen the differences: first, LFDs were combined by like-seasons (i.e. Summer 1985 plus Summer 1986, and so on), and second they were smoothed over 3-points (running average). An age was assigned to each Gaussian component on the basis of the survey season, and of previous information on the reproductive pattern (Ragonese, 1989).

The relationship between CL and age has been modeled with the Brody-von Bertalanffy equation, either in its special (C= 0; Ricker, 1979) or seasonal form (Somers in Sparre *et al.*, 1989). It is important to note that the two curves are only homologous, not equal or similar: that means that they produce estimates of "different" CL_∞ and K and therefore a strict comparison of the parameters is impossible. Different growth models, such as the quadratic, potential, linear as well as the Gompertz's model (Ricker, 1979), were also considered. The procedure NONLIN of SYSTAT (Wilkinson, 1992) was used to estimate the growth parameters. The ratio of the number of shrimps and the standard deviation of the component was used as a weighing coefficient.

Different models (normal, log-normal, gamma distributions) for the components were evaluated with the program MIX (MacDonald and Green, 1985). The deconvolution of the LFDs by Gaussian components was preferred. The estimated "representative modes" were integrated, or "stretched" (Caddy, 1986), on the assumption of a "steady-state" condition. The modal progression analysis was performed with the internal option of MIX and by a weighed non-linear fitting (least square methods, with Quasi-Newton and Simplex minimization algorithms; SYSTAT, 1992) of the VBGF. The mean values of asymptotic length and curvature parameter (a.k.a. the Brody growth coefficient, following Ricker, 1975), derived by bootstrapping (Efron, 1981) of ELEFAN (Gayanilo *et al.*, 1989) results, represented the seed-values for the non-linear regression. The reciprocal of the standard error of each estimated modal length was used as weighing factor. Supposed absolute ages (year) were assigned according to the available information on the reproductive biology of the population, i.e., a single spawning peak in summer (Azouz, 1972). Three months (i.e., 0.25 year) were assumed as the time interval between surveys. Goodness-of-fit of the data with different birth date was evaluated using the mean square error (MSE) of the model and the residuals pattern.

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Function values (and number of parameters) for systematic search 4 Page

# Age Classes	Initial estimates of von Bertalanffy K ----> 0.350	0.425	0.500	0.575	0.650	0.725	0.800	0.87
3	1713.65	1748.55	1769.80	1770.34	1771.92	1780.76	1768.09	1742.7
	(9)	(9)	(9)	(9)	(9)	(9)	(9)	(9
4	1712.48	1752.78	1792.37	1830.78	1846.80	1832.03	1818.31	1803.2
	(11)	(11)	(11)	(11)	(11)	(11)	(11)	(11
5	1706.83	1748.34	1789.47	1831.60	1870.25	1897.23	1865.08	1828.8
	(13)	(13)	(13)	(13)	(13)	(13)	(13)	(13
6	1798.53	1744.92	1785.03	1829.18	1868.96	1923.11	1906.51	1844.3
	(15)	(15)	(15)	(15)	(15)	(15)	(15)	(15
7	1852.80	1741.76	1780.21	1825.36	1866.93	1923.11	1922.20	1853.0
	(17)	(17)	(17)	(17)	(17)	(17)	(17)	(17

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Probability level for Chi squared test on increasing age classes Page

# Age Classes	Initial estimates of von Bertalanffy K ----> 0.350	0.425	0.500	0.575	0.650	0.725	0.800	0.87
3								
4					100.00			
5						100.00		
6						100.00		
7						0.25		

Fig. 16 - An example of the preliminary output from the MULTIFAN program.
Top: the "age-K" grid; bottom: the χ^2 test on increasing age classes.

The female length-frequency distributions from the selectivity study, cumulative and/or by area, were also analyzed in detail using MULTIFAN (Fournier *et al.*, 1990; 1991). The male length-frequency distributions from the selectivity study were only broadly analyzed. MULTIFAN is a program that simultaneously processes a temporal series of LFDs. First, MULTIFAN calculates likelihood estimators on a grid of K and age values (Fig. 16). On an array of fixed K values, the program fits models with increasing number of age cohorts, and tests whether the subsequent increments in the maximum-likelihood estimators are significant. MULTIFAN model implies that the LFDs are made of normally-distributed age components ("modes"), that the actual growth follows the von Bertalanffy curve and that the residuals are well-behaved. Then, the case that corresponds to one of these estimators is chosen, on the basis of its value but also of "expert" information. Previous biological knowledge and ancillary information, such as

the range of K values, constraints on mean length and proportions, number of cohorts, recruitment behaviour must be used to "frame" the subsequent analysis and improve the biological meaning of the output. The program then calculates the von Bertalanffy's parameter L_{∞}, as well as the proportions-at-age in each sample and the mean length of the cohorts (Fig. 17).

```
Fit: AC
Objective function value = 1846.80298; total penalty = 0.00676
Maximum gradient component = 0.00009
Number of non-empty length intervals: 104; Number of estimated parameters: 11
Approximate number of degrees of freedom: 93

Number of age classes: 4
Parameter Estimates:
   von Bertalanffy K = 0.650 (1/year); L infinity =  59.8
   First Length = 20.759; Last Length =  54.231; Brody rho  =   0.522 (1/year)
   Estimated age of the first age class =  0.66 years.
   Mean length at age in month 1:
     20.64  39.35  49.12  54.21
   Standard Deviations of length at age in month 1:
      2.55   2.55   2.55   2.55
   Average Standard Deviation =  2.545; ratio of first to last S.D.=  1.000
   Seasonal Growth Amplitude =   0.103; Seasonal Growth Phase =   0.538
```

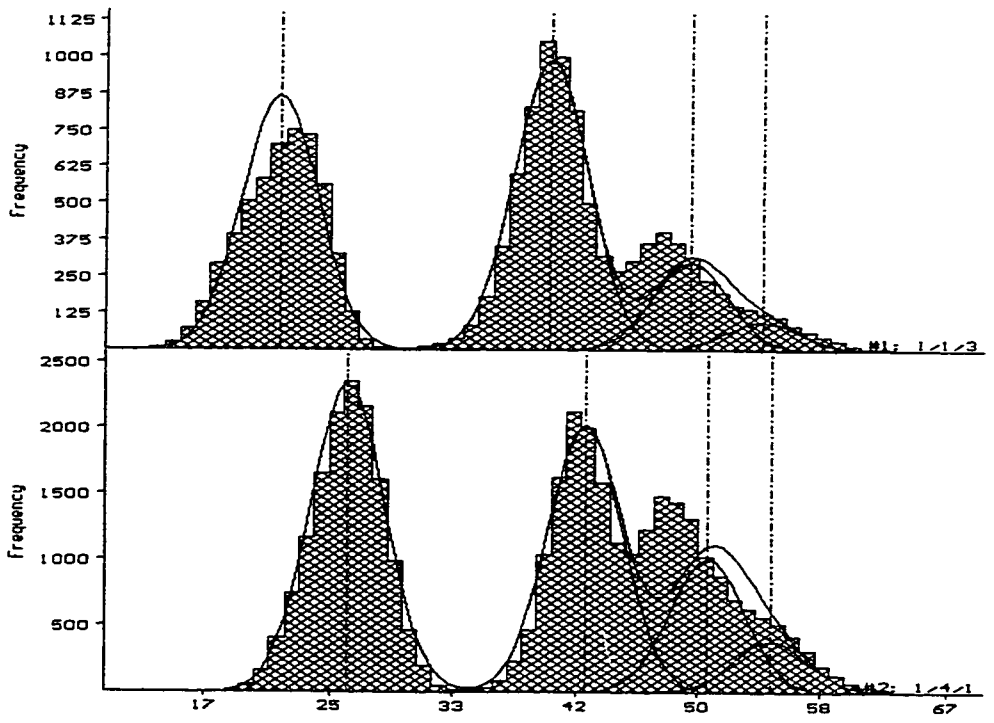


Fig. 17 - An example of the analysis output from the MULTIFAN program. Top: the parameters assessment; bottom: the resulting modal components.

The basic MULTIFAN model becomes more complex as additional parameters might be incorporated in the algorithm, introducing a possible size selectivity in the first cohort, and/or a seasonality in the VBGF, and/or a length-dependent trend in the standard deviations. Finally, the last step integrates the preliminary results and allows for "definitive" estimates with variable K. The analysis is completed with standard deviations of the estimates and correlation coefficients of the parameters.

The phi prime $\varphi' = \log_{10}K + 2\log_{10}L_\infty$ of Munro and Pauly (1983) and the omega $\omega = K * L_\infty$ parameter of Gallucci and Quinn (1979) have also been computed, for broad comparison of the overall growth performances of other populations.

Mortality

Total mortality rates (Z/year) was estimated by sex with the classical approach of the regression on the "right side" of the converted catch curve (Fig. 18). The total mortality was estimated also with the Heincke's method Z= -ln(1 -proportional strength of first cohort) (Garcia and Le Reste, 1981), which is based on the hypothesis of demographic stationarity (Ebert, 1981), on the LFDs derived from the earlier trawl surveys combined by like-seasons and on the two selectivity surveys. The Beverton and Holt's method (1956), based on length moments, whose formulation is $Z = K * (CL_\infty - CL_{mean})/(CL_\infty - CL_{fully\ recruited})$, has been utilized as an alternative approach. It was implemented in the earlier trawl surveys on overall pooled data to reduce the bias associated with the discrete recruitment (Ralston, 1989). Estimates of total mortality were also computed with MULTIFAN. The longevity ($T_{0.01}$) estimation for the exploited stock was computed using the Taylor's approximation (Taylor, 1958).

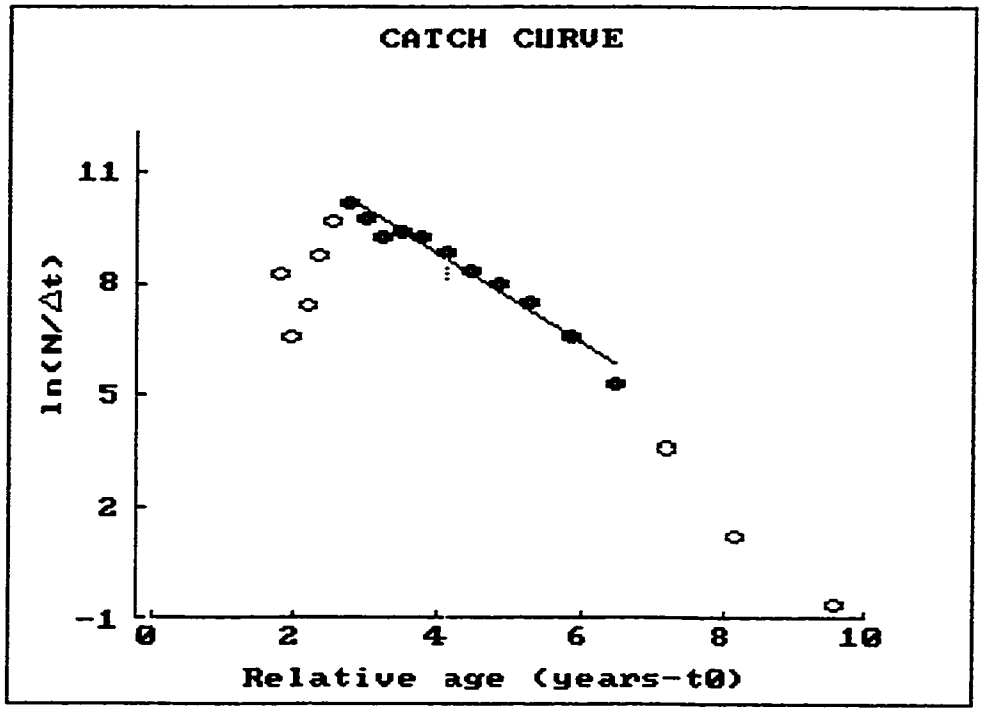


Fig. 18 - An example of the total mortality (Z) estimation using the intercept of the regression of the catch curve. Data: large *Aristaeomorpha foliacea* females, from NE Linosa, spring and summer surveys pooled and smoothed; intercept= -1.19.

A point value for the natural mortality of the females has been estimated with the Rikhter and Efanov's empirical equation (Garcia and Le Reste, 1981) using 18 months as a value for T_{m50} (Ragonese *et al.*, 1992). Another empirical point estimate of M was obtained with the Hoenig's formulation (Hoenig, 1987). A series of natural mortality values (M/year) was derived along with the empirical method of Alagaraya (Sparre *et al.*, 1989), based on longevity estimates for unexploited stocks, i.e. $M_h = -(\log_e 0.01)/T_{max}$, where T_{max} refers to the age at which about 1% of one cohort would have survived in absence of a fishery. The approach of Munro (1984) was used to estimate the natural mortality from selectivity, based on the younger classes that are not fully recruited to the commercial gear, following the formulation $Z_{i,i+1} = M + F^* p_{i,i+1}$, where M is the intercept of the regression, F the slope and $p_{i,i+1}$ refers to the probability of capture of the experimental mesh between adjacent classes i and i+1. Using data from the selectivity

study, an estimate of M was tentatively derived from the size classes that were not recruited to the gear in spring, and that had grown to be still only marginally recruited in the summer survey; in fact, those classes should show a reduction in strength due solely to the effects of the natural mortality operating for the time elapsed between the two surveys. Estimates of the fishing mortality by year classes were computed within the VIT program (Lleonart and Salat, 1992).

Sex and reproduction

Sex was determined macroscopically, looking for the presence of the thelycum or the petasma, respectively for females and males; on larger animals, the rostrum shape was used as an alternative method (Fig. 19).

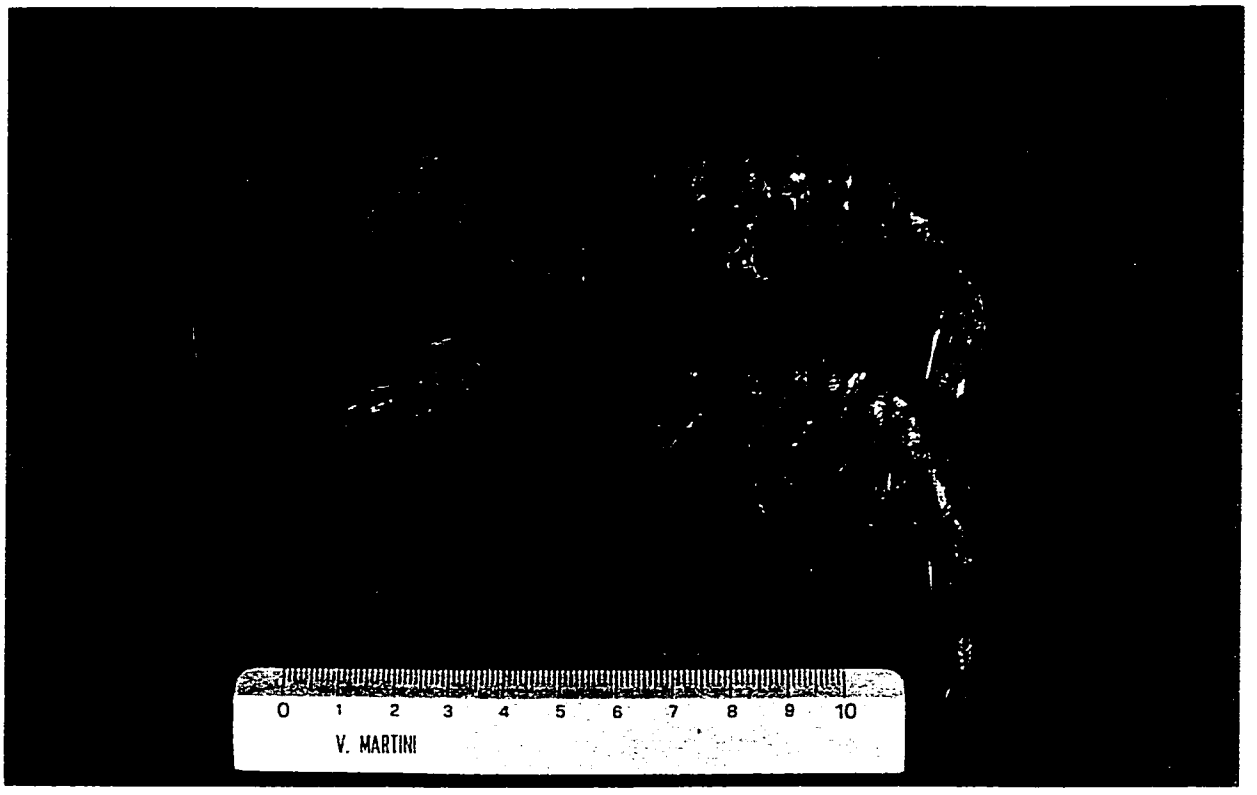


Fig. 19 - Sexual dimorphism in adult *Aristaeomorpha foliacea*: males (bottom) show a shorter rostrum than females (top), adult male, juvenile female, juvenile male.

Only data from the earlier trawl surveys were used to assess maturity features. The degree of female gonadic maturity was evaluated using an empirical 4-stage scale (Levi and Vacchi, 1988); gonads were examined after opening the carapace, to eliminate the possible effect of residual coloring (Relini Orsi and Relini, 1979). The presence of spermatophores was checked by visual exam of the thelycum. Length frequency distributions (LFDs) by sex and survey were produced for the overall distribution area. Stages III (almost ready) and IV (ready to spawn) were combined to estimate the percentage of mature animals in each size class. The logistic model was chosen for the description of the gonadic condition and of the presence/absence of spermatophores. Contrary to the common use, where the asymptote is fixed at 1 by default, the possibility of a lower asymptote was also evaluated (Restrepo and Watson, 1991).

The integral form of the curve was employed:

$$p_i = \frac{p_{max}}{[1 + \exp^{-a*(CL_i - b)}]}$$

where "p_i" is the proportion of mature animals in the i^{th} class, "p_{max}" is the asymptote, "a" is a constant (the "steepness" parameter), "b" is the length corresponding to 50% of p_{max} (the "location" parameter), and CL_i is the i^{th} carapace length class considered.

The parameters of the logistic were estimated without linearization using the procedure NONLIN of SYSTAT (1992). Given the binomial distribution of the events (mature/non mature; with/without spermatophores), a maximum likelihood criterion (Welch and Foucher, 1988) was used in the loss function of the program. In particular, the negative of the $\log_e$ ML was minimized, i.e.:

$$\text{loss} = -\{\text{Mature}*[\log_e(\text{estimate})] + (\text{Total} - \text{Mature})*[\log_e(1 - \text{estimate})]\}$$

where "Total" and "Mature" represent the sample size and the number of mature females in the i^{th} size class respectively. The square root of the frequency in each class was employed as weighting coefficient. Only the last $p_i = 0$ and the first $p_i = 1$ value in each tail

(of course, except those included between $0< p_i< 1$ proportions) were retained in the computations. Different seed values in two minimization algorithms (Quasi-Newton and SIMPLEX) were used. The goodness-of-fit was evaluated on the basis of the mean square errors and on the analysis of the residuals.

The size of maximum reproductive potential has been conventionally defined here as the size corresponding to the intersection of the gonadic maturity curve (stages III and IV) and the mating complementary curve (i.e. absence of spermatophores), during the maximum reproductive activity of the stock (summer months).

The male maturity was related to rostrum dimension (long= immature; short= adult) (Sardà and Demestre, 1989), degree of fusion of the petasma (Holthuis, 1987) and presence of spermatic masses in the terminal *ampullae* (Relini Orsi and Relini, 1979; Tunesi, 1987). The pattern of the above processes with increasing size (CL) was derived over 4 combined seasons (Spring '86; Summer '86; Autumn '86 and Winter '87) from the earlier trawl surveys.

Differences in daylight and night fishing

The total catch (IN+OUT, sex combined), for a standard haul (3 hours), in weight (Y; kg) and number (C), together with the mean individual weight (MW; g), was qualitatively analyzed by comparing the night haul(s) with the most analogous (i.e., same day, gear configuration, zone) daylight haul(s). Particularly, the night/daylight ratio of the catch was computed; when at least two hauls were available, mean values and corresponding standard deviation were estimated and compared. All the night hauls were compared with the homologous daylight hauls, except the 102^{nd}.

To test the significance of the differences between daylight and night hauls, paired t-tests were used to compare the hourly yield (in weight) and catch (in number), and the average weight; the differences in mean weight were analyzed also with a non-parametric Wilkinson's sign test. The length frequency distributions from daylight and night hauls

were converted to cumulative percentages and tested with the Kolmogorov-Smirnov method.

Selectivity

In fishery science, the catchability is defined as the probability of an individual to be caught by the fishing gear (Laurec and Le Guen, 1981), that results from interacting factors such as accessibility, vulnerability and efficiency. The term "selectivity", in its broad sense, includes those part of vulnerability directly related to the fishing gear and it is usually split in two main categories (Nedelec *et al.*, 1979): a) "species" selectivity, i.e. the ability to catch one species rather than another; and b) "size" selectivity, i.e. the ability of the gear to retain only certain sizes or the power of a fishing unit to retain an individual of one species according to its size (Briggs, 1986). Since different terminology for selectivity parameters and other reference points is often encountered in literature, essential definitions are reported in the glossary.

Based on the binomial nature of the events, considered as independent from each other (i.e., a single animal is, or is not, retained, resulting as p= 1 or p= 0 respectively, independently from the other animals), the selectivity has been generally modeled by a logistic (symmetric or antisymmetric) curve (ogive) in which the "size of capture" (l_c) is conventionally defined as the size corresponding to 50% of the asymptote. This represents an objective method to define a parameter, since the determination of the coordinates of the inflection point corresponding to l_c is univocal. Other curves, always asymptotic but more flexible to account for asymmetry (often detected in natural populations), such as the log-log or Gompertz's curve, the Richards' or the Weibull's curves, were also tested as alternative choices (Pope *et al.*, 1975; Saila *et al.*, 1988; Millar, 1991; Millar and Walsh, 1992). Most of the curves used in describing the selectivity patterns have been developed originally to model the growth of living beings, often on the basis of biological interpretation (Ricker, 1979). In selectivity studies, however, models are applied more empirically as a reasonable way to describe a complex

natural phenomenon ("fitting" approach).

Different integrated forms of the logistic exist but the basic parameters are obviously linked (Sparre *et al.*, 1989). In this study, the form which immediately gives the size at 50% was preferred (Saila *et al.*, 1988; Chevaillier and Laurec, 1990) as the basic tools for analysis of data:

$$P_i = P_{max}/(1-\exp(-A(X_i - X_{50\%}))),$$

where P_{max} is the asymptote (usually, $P_{max}=1$), Xi is the length class, A is a parameter which indicates the steepness of the curve (the "slope" parameter) and $X_{50\%}$ denotes the length at 50% of retention (the "location" parameter).

The Gompertz's model was chosen as the alternative model to the logistic in the following form:

$$P_i = (P_{max})*\exp(-A*\exp(-B*X_i))$$

where $P_{max}= 1$, in this specific case.

Both of the above models include an inflection point, but it is differently located, at $0.5*P_{max}$ and $0.36*P_{max}$ in the logistic and Gompertz's curves respectively. Sometimes this situation does not adequately fit the observed retained proportions. Sardà *et al.* (1993), for example, working on the selection scatter-plots of Norway lobsters, obtained a better result by fitting a curve with no inflection point. Many other exponential or power models might be tested in order to give a reasonable fitting of the observed data, but both the determination of the "size of capture" (l_c) and the interpretation of results become difficult. Since the logistic curve is of almost universal use, and generally yields a good approximation of the data even in cases where some asymmetry exists, it was chosen as the preferential model when comparing its performance with that of the Gompertz's curve.

In this study the following general computational criteria were applied:

a) Size classes with a total frequency (IN+OUT catch) of less than two specimens were not considered.

b) Only the first of both extreme values ($P_i= 0$ and $P_i= 1$), not included between $0< P_i< 1$

values, was maintained in the computations.

c) Preliminary estimates were derived by a weighed linear least-square regression where the square root of the sample size (IN+OUT) of each length class represented the weighing factor. It is known that the variance of the observed proportions is inversely related to the sample size when data are derived from the binomial distribution.

d) The preliminary estimates were used as seed values in the maximum likelihood estimation of the parameters (Welch and Foucher, 1988; McCullagh and Nelder, 1989; Fryer, 1991). ML estimates were found by minimizing the negative of the log-likelihood function derived from a binomial distribution with independent observed proportions. In the language of the statistical package employed in this study (SYSTAT, 1992), this function can be expressed as follows:

$$\text{loss} = -\text{sum}\ (\log L) = -\text{sum}\ [R_i * \log(P_i) + (N_i - R_i) * \log(1 - P_i)]$$

where R_i, N_i and P_i denote the number of retained shrimp (IN), the total number of caught animals (IN+OUT) and the retained proportion in each length class (i) respectively.

e) The robustness of the estimates were checked by varying seed-values, convergence criterion (the tolerance) and minimization algorithm (Quasi-Newton and Simplex).

f) The asymptotic standard error (ASE) of the estimates along with the correlation matrix of the parameters were also computed.

g) The estimated curves were plotted over the observed proportions, distinguishing the used (or usable) points from the not used (or not usable) ones.

Data were pooled by combining sexes (after testing for significant differences) and hauls. This implies the assumption that the selectivity pattern is the same for each haul besides sampling variability, i.e. the selectivity curves vary randomly from haul to haul about a mean selectivity curve. This is the basic assumption in most selection studies (see Fryer, 1991, and Millar, 1993, for the limits of such assumption for comparison purposes). In this study, the independence between the selection factors (SF) and mesh sizes was tested by analysis of the coefficients of correlation (Spearman and Pearson) and

by linear regression analysis (Sokal and Rohlf, 1981), when sufficient data were available.

The optimal length at first capture (l_c*) has been estimated approximately according to some empirical relationships (Sainsbury, 1984) such as that by Jones (1976): $0.4\ L_\infty < l_c^* < 0.7\ L_\infty$; and that by Sinoda *et al.* (1979): $l_c^* = 0.59\ L_\infty$.

"Control hauls" (gear configurations without cover)

Two hauls without cover (hereby defined as XX/00) were foreseen for each gear configuration to get an idea of an eventual masking effect (although unlikely, according to the first trials with the 45/14 gear configuration) or any other macroscopic negative influence of the cover on the performance of the gear (Pope *et al.*, 1975; see Ferro and Stewart, 1990, for the statistical problems). Adverse weather conditions allowed the realization of such control hauls only in summer. On the overall, ten "control" hauls were done, eight of which were considered to be valid; two hauls, one with the 24/00 and the other with the 45/00 gear configuration, were invalidated. The capture of red shrimps, both in terms of number and yield (kg), of the control hauls were qualitatively compared with the retained (IN) catches of the experimental ("normal", i.e. those with XX/14 GC) hauls for the summer. Ranges were compared considering both the most homologous hauls and all summer hauls pooled.

Rostrum effect and body engagement pattern on the selectivity by sex

To assess any effect of sex on selectivity (Fig. 20), the retained proportions of adult males and females were compared in each overlapping length class, in each valid haul and gear configuration. A cut-off length of 31 mm CL was chosen because the latter resulted to be the length above which almost 100% of males have short rostrum. Consequently, lengths below 31 mm CL were not considered.

The "IN" and "OUT" catch for adult males and females of the same length were compared after having combined the hauls for each gear configuration. The overall retained proportions (IN/IN+OUT) were computed. The Z test (Sokal and Rohlf, 1981)

was employed to assess the significance of the departure from the expected null hypothesis ("proportions retained of adult males and females of corresponding carapace length are the same") or H_0: $p_m = p_f = p$.

Maximum width (MW) and height (MH) of the folded body were used to compute a surface index (EA) on the assumption of an elliptic approximation of the cross-section of the folded shrimp, according to the formula π*MW*MH/4. The sample was balanced, with the aim of obtaining 10 specimens per sex in each length class, and the log-linear regressions of height, width and surface *vs.* carapace length were estimated. Since the size range is larger in females than males (maximum CL: males= 45 mm, females= 70 mm), a non-parametric one-way ranking comparison (Mann-Whitney U-test) has been performed for each measurement parameter and CL class (Wilkinson, 1987). For the body engagement study, the length/weight relationships (males: $W = 0.0006\ CL^{2.873}$; females: $W = 0.0013\ CL^{2.642}$) obtained on the same population (Ragonese *et al.*, 1997) were used.

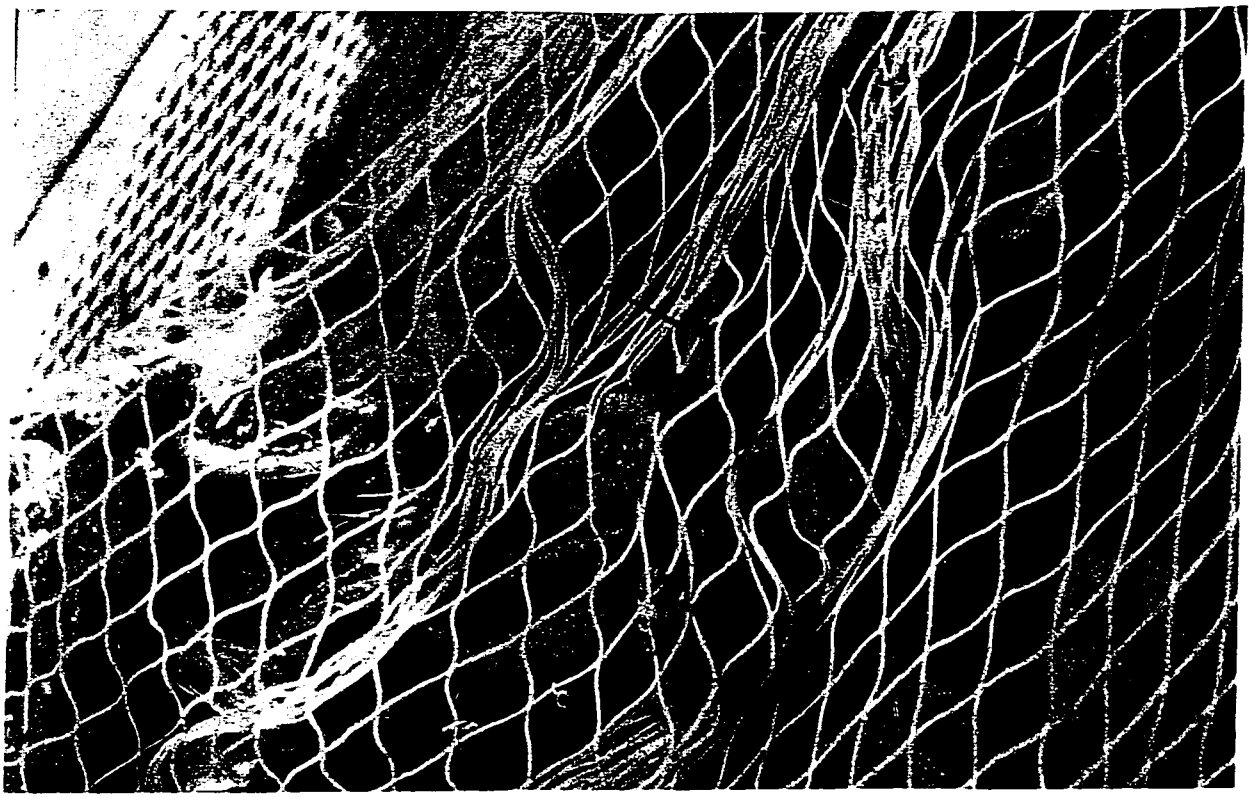


Fig. 20 - Red shrimps *Aristaeomorpha foliacea* escaping from the net.

Virtual population

The virtual population (*sensu* Megrey, 1989) can be reconstructed by means of the standard VPA (as in Gulland, 1965) or thru the cohort analysis (as in Jones, 1982); the first generally used for data structured in age-classes, the second for data both in age- or length-classes. Both approaches are implemented in the package VIT (Lleonart and Salat, 1992). The standard VPA requires the survival and capture equations plus an estimate of the terminal fishing mortality: first, the population strength at the beginning of the last class is computed; then the F_{t-1} from iterating

$$C_i = (F_i/Z_i)\ N_{i+1}\ (e^{Z_i \Delta t_i} - 1)$$

is used to compute the strength of the next-to-the-last class; this backward process is repeated until the first class is reached. The cohort analysis utilizes Pope's (1972) pseudo-cohort equation

$$N_i = N_{i+1}\ e^{M_i \Delta t_i} + C_i e^{M/2 * \Delta t_i}$$

to analytically calculate the strength of the previous class. A complete description of the VIT methodologies and of their theoretical foundations is reported in Lleonart and Salat, 1992.

For the virtual population reconstruction, female shrimps from the selectivity study were arranged by one-mm carapace length classes, without the use of a plus-class. The input parameters were $L_\infty = 70$ mm, $K = 0.6$ y, $t_0 = 0$, $a = 0.0013$, $b = 2.642$, $M = 0.5$, $F_{term} = 0.5$, proportion factor= 624 (as to reach a catch of 1050 tons), maturation starting at 26 mm CL and always mature at 39 mm CL. In the analysis by ages, the terminal fishing mortality is adjusted to $F_{term} = 0.04$, and so is the maturation which is almost nil at age 1, 94% at age 2, and always present from age 3 on, until the last class (age 8) is reached. In the virtual population reconstruction from the earlier trawl surveys, the following input differences are present: proportion factor= 3350; maturation starting at 28 mm CL and

always mature at 40 mm CL; with age-structured data, the terminal fishing mortality is adjusted to F_{term}= 0.125, and so is the maturation which is nil at age 1, 2/3 at age 2, and always present from age 3 on, until the last class (age 6) is reached. It must be noted that the virtual population reconstruction output results should be taken with precaution, since both data set 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.

Yield-per-recruit analysis

The yield-per-recruit could be estimated just by dividing the catch in weight by the number of recruits calculated thru the virtual population reconstruction. In fact, the Y/R is used mainly to simulate what shall happen when the effort changes, and therefore a more complex approach is required. The problem with the classical yield-per-recruit analysis arises from the steady-state assumptions, that are rarely satisfied in general, and even less when dealing with the recruitment processes.

The simplest way to estimate the yield-per-recruit follows from the computationally-long Thompson and Bell's (1934) yield analysis, as implemented for PC by Sanders (1995), modifying the input parameters until some check points (e.g. the actual catch) are met, and repeating it in different scenario conditions. The Thompson and Bell's analysis proceeds in the opposite direction of the VPA, and is very flexible to the introduction of ancillary information that could be used to break any continuous behaviour of modeling curves. Since the preparation of a Thompson and Bell's analysis is highly subjective, a list of the main equations and parameters used in the Excel spreadsheet is reported in Table 10; these basic inputs were subsequently fine-tuned to integrate ancillary and expert information.

Table 10 - List of the basic parameters used for the computation of the yield-per-recruit values using the Thompson and Bell's approach, for *Aristaeomorpha foliacea*.

Contemporary fishing effort	X_1 = 100,000 fishing hours
Effort multiplier	$e_1 = 1$
Catchability coefficient	$q_1 = 5.x10^{-6}$
Natural mortality coefficient	M = 0.5 /yr
No. of recruits at zero length	$R = 140 \times 10^6$
Asymptotic length - juvenile + males shrimp	L_∞ = 60.0 mm CL
Curvature coef. - juvenile + males shrimp	K= 0.65 /yr
Asymptotic length - mature female shrimp	L_∞ = 70.0 mm CL
Curvature coef. - mature female shrimp	K = 0.35 /yr
Length/weight constants (when W in g and L in mm)	a = 0.0013
	b = 2.64
Gear as fraction of unit (20 mm mesh size)	$n_2 = 1$
Probability of capture	v_1, v_2....= spreadsheet

$t = (1/K).\ln((L_\infty - L_1)/(L_\infty - L_2))$

$F_1 = t.q_1.e_1.X_1.u$

$M' = t.M$

$N_2 = N_1.\exp(-(F_1+F_2+M'))$

$N' = (N_1-N_2)/(F1+F_2+M')$

$Cn_1' = F_1.N'$

$D' = M'.N'$

$w' = (1/(L_2-L_1)).(a/(b+1)).(L_2^{(b+1)}-L_1^{(b+1)})$

$Cw_1' = w'.Cn_1'$

$Cn_1 = \text{sum}(Cn_1')$

$D = \text{sum}(D')$

$Cw_1 = \text{sum}(Cw_1')$

$w_1 = Cw_1/Cn_1$

$(Cw/X)_1 = Cw_1/X_1$

$Cw_4 = \text{sum}(Cw_2')$ for lengths >35 mm CL

$B = Cw_4/(q_2.e_2.X_2)$

The classical integrated formulation of the yield-per-recruit of Beverton and Holt (1957) can be written as

$$\frac{Y}{R} = F * \exp[-M*(t_c - t_r)] * W_\infty * \left[\frac{1}{Z} - \frac{3S}{Z+K} + \frac{3S^2}{Z+2*K} - \frac{S^3}{Z+3*K}\right]$$

where $S = e^{-K*(t_c - t_0)}$.

A semplified formulation (1964) refers to the "relative" yield-per-recruit Y/R':

$$\frac{Y'}{R} = EU^{M/K}\left\{1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)}\right\}$$

where $U = 1 - (L_c/L_\infty)$, $m = (1 - E)/(M/K) = (K/Z)$ and $E = F/Z$.

In both cases t_c (and L_c) is the age (and length) of full recruitment to the gear, and selectivity is considered knife-edged (but a different selectivity can be implemented, such as in the FiSAT procedure); moreover, the animals should be long-living (ideally $t_\lambda \rightarrow \infty$). What is even of greater importance is the fact that the above integrations do require that the growth follows the von Bertalanffy curve, and that the length-weight relationship is isometric (b= 3).

Since the length-weight relationships for *Aristaeomorpha foliacea* in the studied area indicate a strong negative allometry (b< 3), the incomplete beta function was used to compute Beverton and Holt's yield-per-recruit curves (Paulik and Gales, 1964). The yield-per-recruit formulation according to the incomplete beta function can be written:

$$Y/R = F/K \; W_\infty \; e^{-Z(t_c - t_0)} \; \beta_{x,x1}(u,v)$$

where F and Z represent the instantaneous fishing and total mortality,

K is the curvature parameter of the VBGF,

W_∞ is the asymptotic weight,

t_c is the mean age at first capture,

t_0 is the location parameter of the VBGF model,

$\beta_{x,x_l}(u,v)=\int_{x}^{x_l} t^{u-1}\ (1-t)^{v-1}\ dt$ is the incomplete beta function,

u and v being its parameters, i.e., u= Z/K

v, the estimated allometric coefficient plus one (specific case v= 3.6),

and the integration limits:

$x = e^{-K(t_c-t_0)}$ and $x_l= e^{-K(t_\lambda-t_0)}$ (with t_λ= maximum age of contribution to the fishery).

The Wilimovsky and Wicklund's (1963) tables and the integration tools of the BlackBox program (1996) were used to compute discrete Y/R' values for different levels of F and t_c (Table 11). The rationale for using the beta function is explained in Appendix C.

Table 11 - List of the parameters used for the computation of the yield-per-recruit values using the incomplete beta function, for *Aristaeomorpha foliacea* females.

PARAMETERS			COMMENTS
CL_∞	mm	70	Estimated asymptotic length
K	y^{-1}	0.6	curvature parameter of the VBGF
t_0	y	0	VBGF location parameter (line passes thru origin)
t_c	y	1	Mean age at first capture
Z	y^{-1}	0.95	Estimated total mortality rate
M_l	y^{-1}	0.5	Natural mortality rate
F_l	y^{-1}	0.45	Fishing mortality rate
t_{max}	y	8	Theoretical life span
t_λ	y	6	Maximum age of actual contribution to the fishery
b		2.64	Allometric coefficient
W_∞	g	80	Estimated asymptotic weight according to the length-weight relationship from literature

The VIT package (Lleonart and Salat, 1992) implements the following expression, where ϕ represents the factor that multiplies the effort (or, better, its proxy in the form of an increase or decrease of the fishing mortality):

$$Y/R_{(\phi)} = 1/N_i \sum_{i=1}^{n} C_i w_i \overline{\phi} = 1/N_i \sum_{i=1}^{n} N_i w_i F_i \overline{\phi}.$$

Of course, the option of the procedure that has been used recalculates the mean weight vector each time ϕ changes. The VIT procedure calculates the mean weight from a non-linear function, thus w is not the average of the weights in the i^{th} class nor the weight of the mean size of the i^{th} age-class. The VIT procedure for computing the Y/R is not based on the classical Beverton and Holt's integration, and should therefore be insensitive to allometric ($b \neq 3$) growth.

The ANALEN program (Chevaillier and Laurec, 1990) performs yield-per-recruit assessments (and virtual population reconstructions) starting from length-structured data; the program uses the pseudo-cohort approach (Jones, 1983) and requires equilibrium conditions. The solution by iteration of the survival and catch equations, giving the F_i, is obtained using the Newton algorithm (VIT utilizes the Simpson method). Besides the yield-per-recruit analysis, the program can calculate short- and long-term productions after a modification of the exploitation regimen, but not the transitional period. ANALEN is flexible and can accommodate different categories of input: besides the standard sexual maturity by class, it can take into consideration different gear, variable price categories, selectivity parameters (from a logistic model). The program permits computation of the rejects too, but this option is useless in the red shrimp situation of the Mediterranean, since everything is landed and commercialized. ANALEN cannot be run if the data includes lengths greater than L_∞; moreover, to avoid large errors in the estimates, it is suggested that all animals with lengths near L_∞, say over 80% of it, should be grouped in a plus-class (Table 12).

Table 12 - List of the input parameters used for running ANALEN, for *Aristaeomorpha foliacea* females.

1 general module		
K	0.6	StD 0.018
L_∞	70	StD 4.9
M	0.5	
lower bound of last CL class	62	
smoothing	yes, 3 points	
2 cohort analysis module		
F_{term}	0.5	
recruits	20000	
3 Y/R module		
a	0.0013	
b	2.642	
price categories	4	
prices	*lower weight*	*value*
	27.5	30
	14	18
	6	10
	3	7
mesh	20	
selection factor	0.88	
selection range	5.7	
F assays	11	
intervals	equal	
% first F	0.5	
% increment	0.1	
number of gear	5	
smaller mesh	16	
mesh increment	4	
4 fecund biomass module		
$CL_{maturity\ 50\%}$	40	
range of $CL_{maturity}$	4	

To take into account all the above variables, the algorithms used by ANALEN are quite complex, but they reduce to the following basic equation

$$Y = \sum N_i * (\text{marketed}_i/\text{hauled and dead}_i) * F_i/Z_i * (1-\exp(-Z_i\ \delta t^i)) * W_i * \text{value}_i$$

where the summation is extended above the i^{th} class corresponding to L_∞ (i.e., the plus-group is separated again in its original classes); moreover, in the case of the Sicilian red shrimp fishery, the whole catch is landed, thus (marketed/hauled)= 1.

Transitional period

The 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 (i.e., in the case of VIT, it is stochastic under a log-normal distribution); 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 kind of simulations the population keeps fluctuating (besides, both Beverton-Holt's and Ricker's stock-recruitment models can be implemented). 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. For the selectivity data a variance= 0.5 has been applied to the log-normal distribution, thus resulting in a mode at 0.544 and a median at 0.816 of the mean, and upper and lower limits of the 95% confidence interval at 0.234 and 2.844 respectively. For the data from the earlier trawl surveys a variance= 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 respectively.

Sensitivity

Given the iterative approach to the Y/R, the VIT package performs a sensitivity analysis of the parameters using scenario simulations in which the parameter(s) under examination is/are actually replaced by the plus- or minus-variant one(s) (Table 13). One

limitation of the program is that in the case of multiple parameters their percent variations must be the same, thus not allowing for previous knowledge of their real range to be incorporated in the sensitivity analysis.

Table 13 - Variations of input for the empirical sensitivity analysis of VIT, for *Aristaeomorpha foliacea* females.

	C.V.%	variations					
L_∞	7	0.05	0.10	0.15	0.20	0.25	
K	< 3	0.02	0.04	0.06	0.08	0.10	0.50
T_0	-						
a	< 2	0.02	0.04	0.06			
b	0.5	0.005	0.010	0.015	0.020	0.025	
a$	2.9	0.03	0.06	0.09			
b$	1.7	0.01	0.02	0.03	0.04	0.05	
M	-	0.10	0.20	0.30	0.40	0.50	
F_{term}	-	0.10	0.20	0.30			
$L_\infty * K$	-	0.10	0.20	0.30			
$M * F_{term}$	-	0.10	0.20	0.30			

In contrast, the ANALEN approach to the sensitivity analysis is totally analytical, based on the delta method, i.e. a Taylor's series polynomial development. This allows inference not only on the parameters errors but on their bias too. For practical purposes, the Taylor's approximation is in general limited to the second degree. The development of the first order is a straight line, tangent on the curve; the second order development is a parabola (always tangent) whose curvature makes it fit better: the ratio of first/second order developments is a measure of the quality of the approximation. The analysis of multiple parameters can be performed with percentages of variation due to errors different

for each of them; there is no possible sensitivity analysis for the parameter b of the length-weight regression. This approach to sensitivity, although more rigorous than the VIT empirical approach, should be employed only for small errors around the "true" value, since the Taylor's approximation that has only local value; for this reason, it does show trends more than actual parameters errors. In fact, if the objective is to study large variations of the parameters, the development of a function in a Taylor's series is not a sufficient approximation and it is suggested to redo the complete analysis with the new values, around which an analytical sensitivity analysis could be again performed.

In this study, the analytical sensitivity analysis of ANALEN has been applied only on the Y/R output, using data both from the selectivity study and from the earlier trawl surveys, while the sensitivity on input parameters N and F has been studied empirically on the selectivity study data with the help of VIT program.

Economic virtual population

For the "economic" virtual population reconstruction, female shrimps were arranged into one-mm carapace length classes, without the use of a plus-class. The input parameters were L_∞= 70 mm, K= 0.6 y, t_0= 0, a= 0.00042, b= 3.708, M= 0.5, F_{term}= 0.5, proportion factor= 772 (a multiplier of the sample capture, used to reach a total value of the catch of 25 billion Italian liras), maturation starting at 26 mm CL and always mature at 30 mm CL. In the analysis by ages, the terminal fishing mortality is adjusted to F_{term}= 0.04, as well as the maturation that is almost nil at age 1, 94% at age 2, and always from age 3 on, until the last class (age 8) is reached. In the "economic" virtual population reconstruction from the earlier trawl surveys, the following input differences are present: proportion factor= 1570; maturation starting at 28 mm CL and always mature at 40 mm CL; with age-structured data, the terminal fishing mortality is adjusted to F_{term}= 0.125, as well as the maturation that is nil at age 1, 2/3 at age 2, and always from age 3 on, until the last class (age 6) is reached. It must be noted again that the irrtual population output results should be taken with precaution, since both data set 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.

Economic yield-per-recruit analysis

The economic yield-per-recruit could be estimated just by dividing the total value of the catch, i.e. 25 billion liras, by the number of recruits calculated thru the virtual population reconstruction. In fact, the economic Y/R is used mainly to simulate what shall happen when the effort changes, and therefore a more complex approach is required. The problem with the economic yield-per-recruit analysis arises from the steady-state assumptions, that are rarely satisfied in general, and even less when dealing with the recruitment processes.

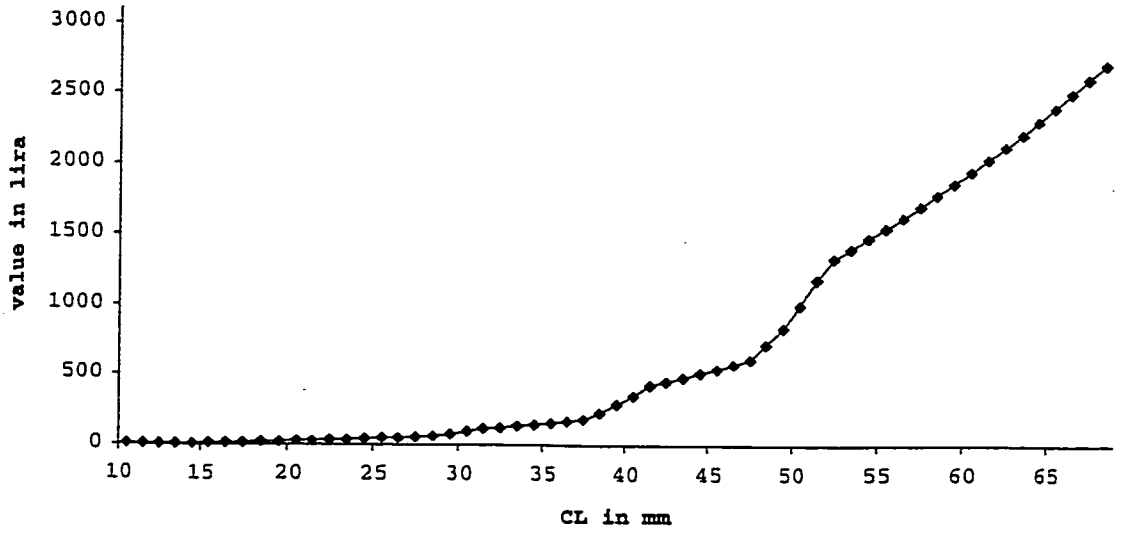


Fig. 21 - Approximate individual value of red shrimps, by size (values in Italian lira; sizes in mm of CL).

As a general rule, the price per unit of weight increases with shrimp size (Fig. 21). 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 varies in a bracket of ±25% according to demand but the averages here considered are 30000, 18000, 10000, 7000 lira/kg respectively for each category, roughly equivalent to 8.00, 4.50, 2.50, 2.00 US$/lb.

The simplest way is to use the Thompson and Bell's (1934) yield analysis, as implemented for the PC by Sanders (1995), modifying the input parameters until some check points (e.g. the actual total value of the fishery) are satisfied, and repeat the analysis in different scenario conditions. The Thompson and Bell's approach is well suited for the red shrimp situation, since it only requires an empirical vector of prices to be added to the spreadsheet.

The classical Beverton and Holt's (1957) Y/R 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), the incomplete beta function could be used to compute economic yield-per-recruit, in a way similar to the "standard" Y/R analysis, with the same input parameters and $\$_\infty$ being the asymptotic price, derived from the market.

A similar approach, the use of parameters obtained by a price-length relationship, may be applied to the VIT procedure for computing the economic Y/R. Considering the distribution of sizes in each price "stanza", value in lira and carapace length in mm can be modeled by the regression $\$= 0.00042 * CL^{3.708}$.

Skippers' log-books and interviews

Written records (of different sorts) coming from various fishing vessels that operated during the last 25 years in the Sicilian Channel grounds were consulted, and the resulting material checked through personal interviews of Mazara skippers and fishermen, and integrated with data from nautical charts; a few foreign sources were consulted too.

(upper left corner) **LAT 36° 10' N - LONG 12° 20' E**				
depth (fathoms)	240	**type of substrate**		mud
"afferrature" (n & kind)		1 ("denti di cane")		
prevalent fishery		trawling - drifting longlines		
amount of hauls	2 (30%)	**direction**	SW, SE	
intensity of hauling				
	Winter	x	Spring	6
	Summer	6	Fall	6
target organisms				
	Winter	x		
	Spring	"slope" assemblage		
	Summer	"slope" assemblage		
	Fall	"slope" assemblage		
evolution in time		worsening		
notes				

Fig. 22 - Example of the information reported in each pixel of the Sicilian red shrimp fishery map.

The information on the different fisheries are reported in general for the whole Sicilian Channel, but the trawl fishery around the Pelagie Islands has been examined in greater detail. The area around the Pelagie Islands has been divided in 64 pixels, each a 10' by 10' "square"; the characteristics of 40 of them, the most suited for the red shrimp fishery, have been mapped too. For each pixel, identified by the latitude and longitude of its upper left corner, the following data have been collected (Fig. 22):

- The depth range (in fathoms, with broad approximation) of the trawlable grounds (it does not have to be the range of a specific haul).
- The type of substrate of the trawlable grounds, as found in the nets.

- The number and kind of "afferrature", fishing impediments, that could be of physical (boulders, trenches, etc.), biological ("denti di cane", "organ pipes", etc.) or human (wrecks, ammunitions, etc.) origin; the reported number of "afferrature" may have a double meaning: the area is (or has been) heavily fished, thus producing many records of impediments, or the area is not worth fishing, given the risk of damaging the gear.
- The prevalent type(s) of fishery, i.e.: trawling. drifting longlines, bottom (light) longlining, seining with FADs (i.e. presence of "mazzare" on the grounds), fishing pots (only one instance):
- The number of trawling paths, and the percentage of the trawlable area in the pixel. This number expresses the degree of difficulty of the trawling (skippers have to sweep in a limited area, making such and such turn, etc.), how valuable is the fishing activity (it is worth going there, even if it requires a lot of ability and attention), etc. The percentage may be, and generally is, independent from the number of hauls: e.g. 100% and few hauls means an easy zone, where you may freely diverge from a unique path, while 10% and 10 hauls means that if the skipper does not strictly adhere to the specific path, he will spoil the haul (low catch, damage to gear, stranding on foreign grounds, etc.).
- The very broad estimate of the prevalent direction of the hauls: some hauls require that, in addition, fishermen follow a versus (i.e. SE to NW, not NW to SE). If that pixel needs an adjoined map, it is underlined here.
- The intensity of hauling has been assessed by season, on the base of a "grade" (0 to 10 scale), that integrates objective abundance of preys, market values, market demands, spatial proximity, time since last fished and other "feeling" parameters in one figure, valid for the average Mazarese trawl fishermen (but not necessarily for others) and for that grid as a part of the whole Sicilian Channel; as an example, an "8" means a good ground, where it is worth trying a few hauls, and where many boats would therefore congregate, a "6" a ground of lower potential, but probably without competing vessels, a "5" the outsider grounds, where betting is a high risk (and thus potentially very rewarding), or a take-it-easy campaign (maybe it is close to a harbour); there are no

grades below "5", since fishermen should be crazy to fish in a bad-for-sure haul; a "x" indicate that the ground is rarely fished in that particular season.

- The target organisms, by season, given as "commercial assemblages" plus characteristic organisms (if any); targets of longlining are on a yearly basis.
- The evolution in time of the fishing grounds, as appreciated by the captains.
- Notes on common names of the fishing grounds, trawlability, bottom configuration, presence of cables, etc.

Statistical tools

Different statistical tools, both parametric and non-parametric, were used to test hypotheses or to compare results. Besides peculiar cases, the formulations followed Zar (1974), Camussi *et al.* (1986) and Chieppa *et al.* (1994) for the general part, Sokal and Rohlf (1981) for the biometry and Neter *et al.* (1985) for the regressions. Fishery-specific approaches followed Ricker (1975a). In general, statistics were performed following the methodologies implemented in the package SYSTAT (1992) or using the "EXCEL for Windows, ver. 5.0" (1993) spreadsheet for *ad hoc* applications. Specific programs (FiSAT: Gayanilo *et al.*, 1994; MIX: MacDonald and Green, 1985; MULTIFAN: Fournier *et al*, 1990; VIT: Lleonart and Salat, 1992; ANALEN: Chevaillier and Laurec, 1990) had their internal statistical procedures (errors, MLE, χ^2, correlations, etc.) and the results were analyzed accordingly to the specific needs. When needed, the mathematical tools of the program BlackBox (1996) were used for calculus computations.

Linear regressions of the AM (arithmetic mean) or GM (geometric mean) type were produced depending on the envisaged use (Ricker, 1975a). Least squares estimates (AM or type I regression) were preferred to the standard major axis estimates (GM) in case of predictive uses (Jolicoeur, 1975; Sprent and Dolby, 1980; Sardà *et al.*, 1995). Non-linear data were linearized before the regression analysis, or non-linear regression techniques were utilized. The parameters of the selectivity logistics were always estimated without linearization, even if a linearization with the Cox (1970) or the arcsin

transformation (Trippel and Harvey, 1991) was possible. The convergence of the loss function (i.e. the negative of the objective function) of the procedure NONLIN of SYSTAT (1992) was obtained by Simplex or Quasi-Newton minimization algorithms (incidentally, ANALEN uses Newton's, and VIT Simpson's method). The asymptotic standard error (ASE) were computed for the non-linear regressions. The standard assumptions of the regression models (the so-called Gauss-Markov's conditions, i.e., independence and normality/lognormality of residuals, homogeneity of variance, etc.) were evaluated using scatterplots of variables, Studentized residuals *vs.* estimates, normality plot of residuals, and by performing the "Lilliefors test" (a modified Kolmogorov-Smirnov test on Studentized residuals). When necessary, the presence of influential observations was detected by analyzing the Cook's statistic (Neter *et al.*, 1985). The variability of the MIX growth parameters was assessed by bootstrap (Efron, 1981). The robustness of the estimates of the selectivity parameters was checked by varying seed-values, convergence criterion (i.e., tolerance) and minimization algorithm.

The t-test was used to test the hypothesis of isometry in the length-weight relationships and to compare thawed *vs.* fresh measures. To test daylight and night hauls differences, paired t-tests were used to compare the hourly yield (in weight) and catch (in number), and the average weight. The Z test (Sokal and Rohlf, 1981) was employed in the study of sex-related differences in selectivity, to assess the significance of the departure from the expected null hypothesis ("proportions retained of adult males and females of corresponding carapace length are the same") or H_0: $p_m = p_f = p$. The statistics have been computed following the formula $Z = (p_m - p_f) / \mathrm{sqr}\,(p*q/N_m + p*q/N_f)$ (Camussi *et al.*, 1986), where the denominator corresponds to the square root of the variance of the difference of the mean, p is the overall (males plus females) retained proportion, q is its complement (q= 1-p) and N is the sample sizes. The independence between the selection factors and mesh sizes was tested by analysis of the coefficients of correlation (of Spearman and of Pearson). The correlation between depth and size was tested with the Spearman's coefficients.

Non-parametric tests were used when the parametric constraints were not met, or as back-up conservative tests. Runs tests were used to check the lack of randomness in residuals, i.e. the absence of pattern (Draper and Smith, 1981). The "sign" (for lengths) and Wilcoxon (for weights) tests were employed to detect any difference between fresh and thawed conditions. The differences in mean weight between daylight and night catches were analyzed with the Wilkinson's sign test. In a few cases, the length frequency distributions were converted to cumulative percentages and tested with the Kolmogorov-Smirnov's method. In the study of escapement, since the size range is larger in females than in males, a one-way ranking comparison, the Mann-Whitney U-test, has been performed for each measurement parameter and CL class (Wilkinson, 1987).

Two indices for comparison of the overall growth performances of various populations were computed: the phi prime $\varphi' = \log_{10}K + 2\log_{10}L_\infty$ of Munro and Pauly (1983) and the omega $\omega = K*L_\infty$ parameter of Gallucci and Quinn (1979). The Furnival's index (Furnival, 1961), used to make possible the comparison of the goodness-of-fit among regression models. The Furnival's index (herein denoted as "I") is a modified maximum likelihood estimator useful for comparing the fit of equations after transformation of the original variables; in this case: $I = [\exp(\text{mean } \log Y_i)] * SEE$; where SEE denotes the standard error of the estimate (i.e., the square root of the mean square error). Of course, the lower the index the better the model fit.

Sensitivity of the Y/R results to errors and variability in the input parameters was studied by scenario simulations (with VIT results) and by analytical development (Taylor's series in the ANALEN program).

RESULTS

BIOLOGY

Population structure

The length frequency distributions of the catch are reported on Fig. 23 and Fig. 24, respectively for the females in the data set from the 1987-88 trawl surveys and from the selectivity experiments of 1994, and on Fig. 25 for the males from the selectivity study.

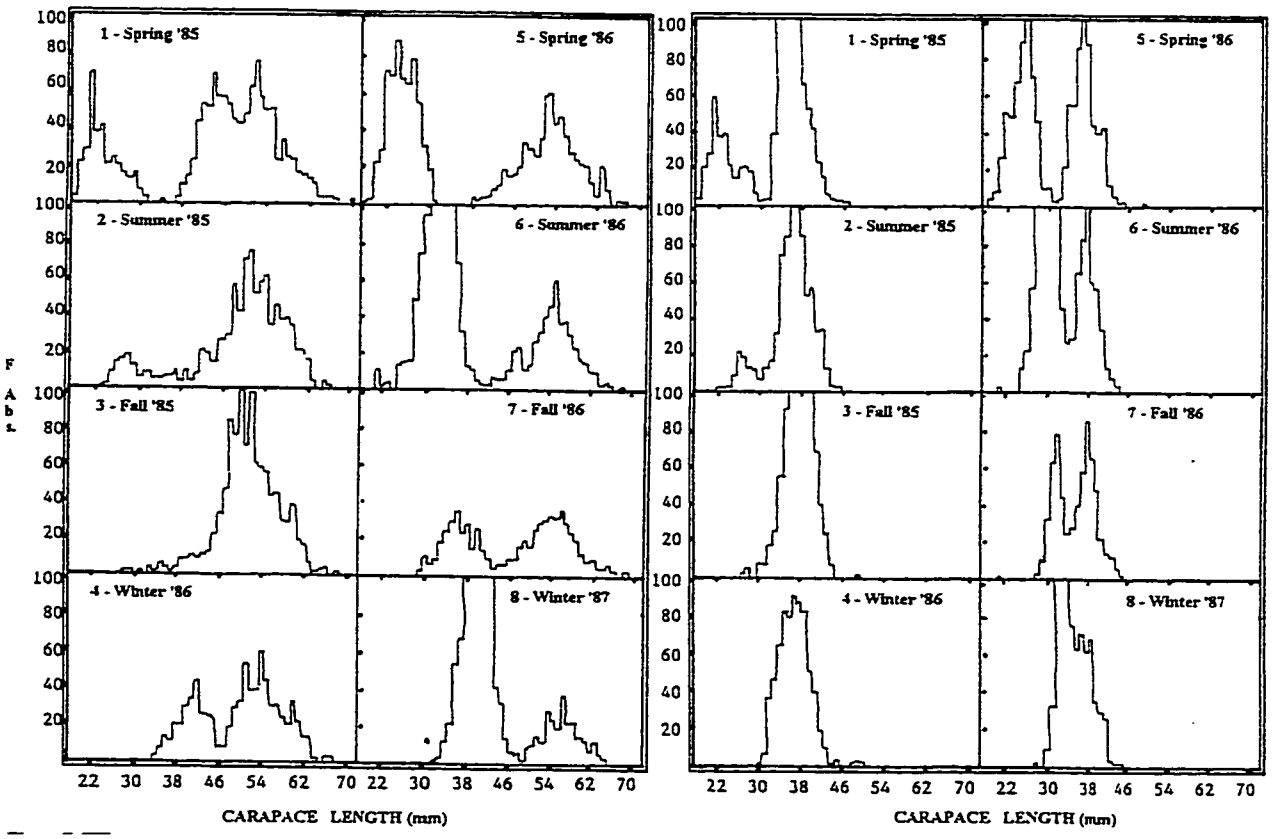


Fig. 23 - Length frequency distributions of the catch of *Aristaeomorpha foliacea* (left: females; right: males) from the earlier trawl surveys.

The earlier trawl surveys showed that the surveyed female population is made of two major components: the first, the recruits, appears in the springtime with one or two modes (in this last case, of different strengths and substantially overlapping). The recruits are completely separated from the second component, which shows two to three representative modes. Despite the large variability it is possible to distinguish a basic seasonal scheme where the recruit component quickly progresses up to the second, until merging in the following spring, when a new recruitment pulse appears. The last mode shows a long tail on the left reflecting the presence of at least one more overlapped mode of very old and larger-size females.

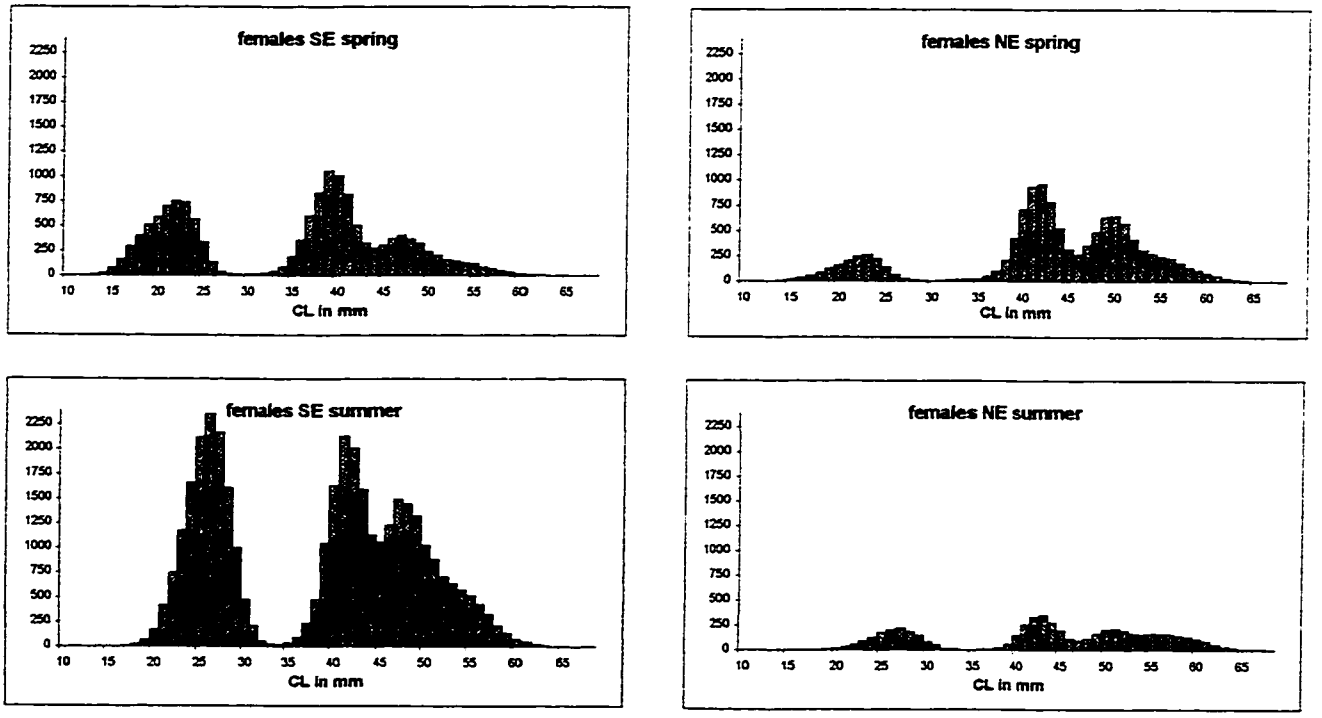


Fig. 24 - Length frequency distributions of the catch of *Aristaeomorpha foliacea* females from the selectivity study.

The smallest and largest red shrimps captured during the selectivity study were respectively 12 mm CL and 69 mm CL for the females and 13 mm CL and 46 mm CL for the males. Since the cover sac did retain even smaller crustaceans, it may be considered that the smallest size of red shrimp is representative of the true minimum size, at least for the trawled grounds and the explored period of time. From knowledge of the commercial catch, it seems that also the largest size present in the sample is representative of the true population of the Sicilian Channel.

Although the degree of separation of the normal components is good in almost all the seasonal cases of the earlier trawl surveys, a univocal approach is not possible using the Bhattacharya's approach, especially for the second component (adults) where the modal classes do overlap. The recruit class is nearly perfectly identified, with an average length at around 25 mm, which corresponds to less than one year of age, presumably 9 months.

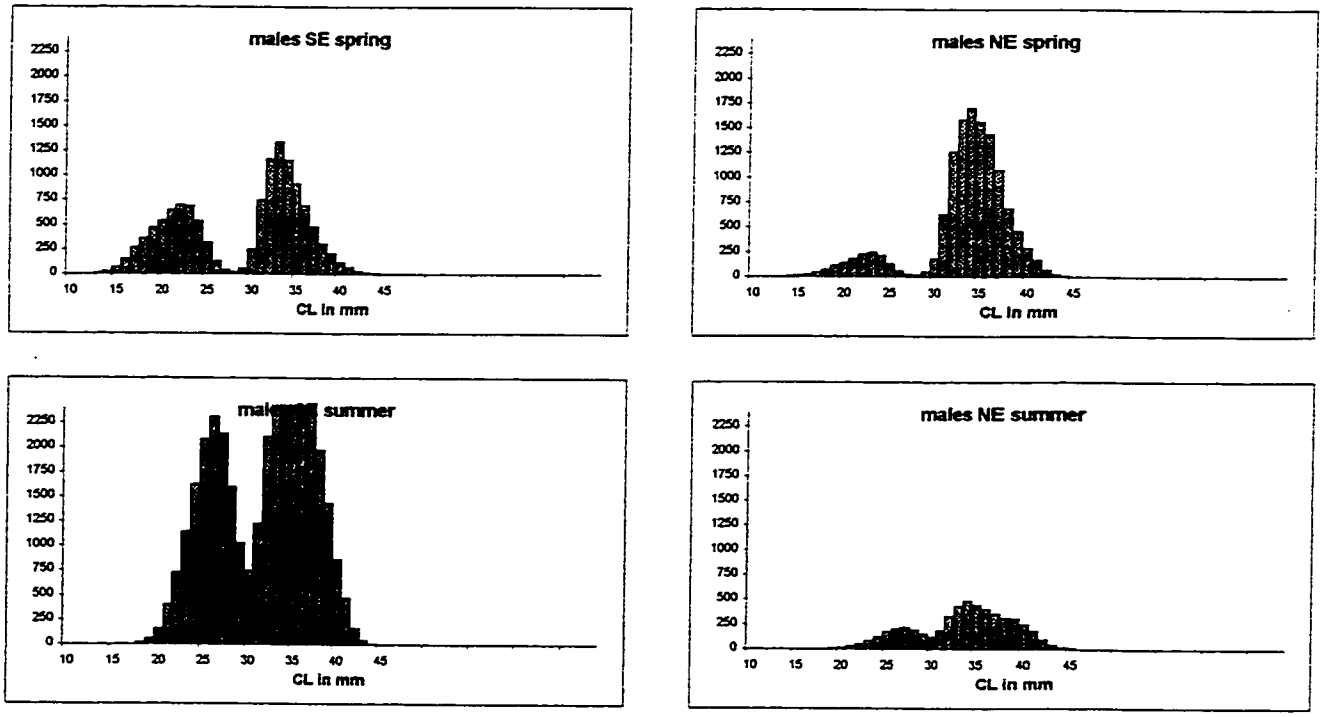


Fig. 25 - Length frequency distributions of the catch of *Aristaeomorpha foliacea* males from the selectivity study.

Besides the different length range (males are smaller), the size structure of males in the earlier trawl surveys and its evolution broadly resemble that of the females. From a qualitative analysis of the LFDs, especially in the spring, the overlap in sizes between the adult component of females and males results very small. The male adult component cannot be easily separated into classes, even if 2-3 modes are sketched. The presence of two modes for the first major component tends to confirm the hypothesis of a double recruitment pulse for the males too

The shrimp sizes do segregate by depth, as shown by the Spearman's correlation coefficients between depth of trawling and 3-class sizes (small < 35 mm CL, medium 35-50 mm CL, large <50 mm CL) on the earlier trawl surveys (Table 14).

Table 14 - Spearman's correlation coefficients between depth of trawling and size (small < 35 mm CL, medium 35-50 mm CL, large <50 mm CL) for *Aristaeomorpha foliacea* females, by zones.

Area	n	r (small)	r (medium)	r (large)	critical value α= 0.05
NW	28	-0.458	-0.545	0.493	0.375
FS	54	-0.629	-0.667	-0.058	0.268
SE	49	-0.603	-0.447	0.207	0.282

Morphometry

Thawed measurements (Table 15) for all the variables considered (CL, TL, OL and BW) are systematically lower than the fresh ones in both sexes; the differences are significant according to t-test and non-parametric tests. With respect to linear measures, total and ocular lengths were more affected than carapace length by the defrosting

process, whereas the body weight was the most altered. Non-parametric tests lead to the same conclusion supporting their parametric counterparts. Considering the regression approach (thawed = b*fresh), the average length decrement was, however, quite low (ca. 1%) whereas the average loss in body weight was about 5%.

Table 15 - Descriptive statistics of fresh and thawed values of different body measures of *Aristaeomorpha foliacea*, by sex (modified from Ragonese *et al.*, 1997).

FEMALES

	Carapace length (mm)		**Total length (mm)**		**Ocular length (mm)**		**Body weight (g)**	
	fresh	thawed	fresh	thawed	fresh	thawed	fresh	thawed
N	394	394	349	338	393	385	394	390
min	20	19	95	99	74	74	3.2	2.6
max	65	65	259	254	205	199	79.0	74.4
mean	37.9	37.8	164.2	165.3	129.8	129.9	22.8	21.5
s.d.	11.19	11.20	36.82	35.70	32.44	31.42	16.39	15.36

MALES

	Carapace length (mm)		**Total length (mm)**		**Ocular length (mm)**		**Body weight (g)**	
	fresh	thawed	fresh	thawed	fresh	thawed	fresh	thawed
N	241	241	215	209	241	236	241	241
min	20	20	97	95	72	73	3.1	2.5
max	43	43	174	169	160	155	28.6	26.8
mean	29.9	29.8	132.9	132.4	111.2	111.2	12.2	11.5
s.d.	6.06	6.02	15.65	15.73	21.45	21.46	6.50	6.36

Results by sex of the morphometric analyses are reported in Table 16 which shows the output of the regressions, as well some of the elements useful to interpret the "goodness" of the estimates: coefficients of determination, Furnival's index of fit (I), screening of the residuals plots, test of normality, number of suspected values and

extreme Cook's statistics. In all analyses, removal of data of extreme Cook's values never significantly improved the results; therefore, the data sets were always kept at their original size. Total length (TL) is the most critical measurement since many shrimps had a damaged rostrum. In the fresh samples, the number with missing TL was 11.7% and 10.8% in females and males, respectively.

Table 16 - Summary of the regressions for *Aristaeomorpha foliacea* females and males (long- and short-rostred). Legend: N: sample size; a: first parameter in the allometric model; b: slope coefficient of the model; s.e.: standard error of the corresponding coefficients; r^2: coefficient of determination; I: Furnival's index of fit; Residuals N-test and R-test: shape of the normal and the residuals plots; Cook's values: number of suspected elements and number of "outliers" (with comparison values) (modified from Ragonese *et al.*, 1997).

	N	a	s.e.(a)	b	s.e.(b)	r^2	I	Residuals normal.	Residuals randomn.	Cook's values suspect	Cook's values high
FEMALES											
total *vs.* carapace length											
	349	2.376	0.022	0.755	0.006	0.978	5.4	departure	no trend	3	0
ocular *vs.* carapace length											
	393	1.839	0.013	0.834	0.003	0.992	2.9	departure	no trend	3	0
weight *vs.* carapace length											
	394	-6.647	0.043	2.642	0.012	0.992	1.2	ok	no trend	0	0
MALES											
total *vs.* carapace length											
long-rostrum	104	2.500	0.071	0.719	0.022	0.912	3.9				
short-rostrum	111	1.786	0.102	0.890	0.029	0.898	3.4	ok	bad	3	1 (0.8 *vs.* <0.4)
ocular *vs.* carapace length											
	241	1.525	0.026	0.938	0.008	0.984	2.7	ok	2 clusters	2	0
weight *vs.* carapace length											
	241	-7.368	0.065	2.873	0.019	0.989	0.6	ok	no trend	0	0

As a general rule, the situation for the females is quite straightforward with a unique, continuous regression line since juveniles and adults do not show any abrupt change in their morphology. The residual plots do not show evident trends, but the departure from normality of the data distributions is sometimes bothersome even if the tests used are deemed robust. A change in slope seems to occurs above the 45-50 mm CL sizes in the BW *vs.* CL relationship, but attempts to fit a piece-wise regression were unsuccessful (Fig. 26). Results indicate log-linearity, a significant negative allometry ($b << 3$), and a strong improvement in Furnival's index in respect to both the length-length relationships.

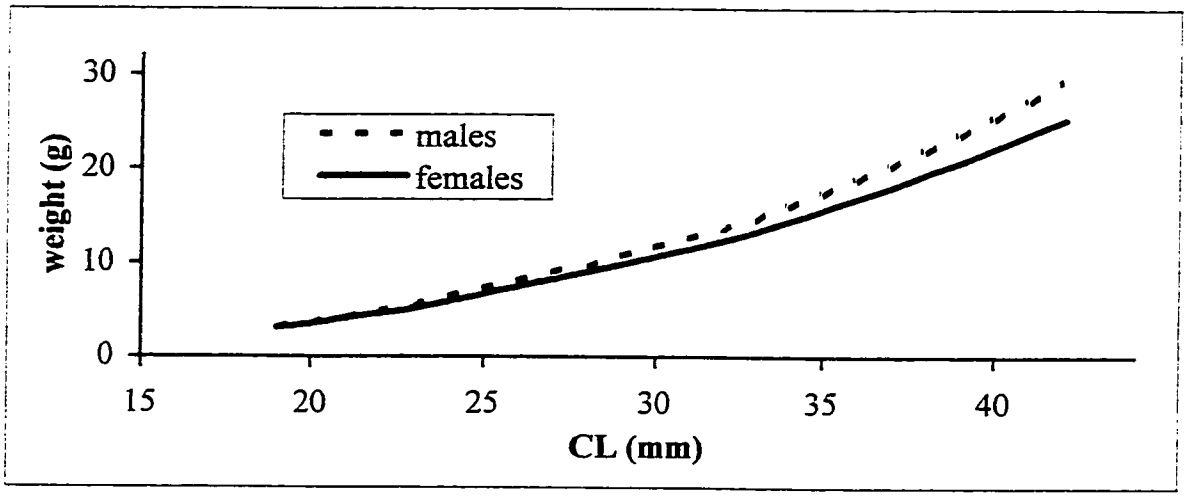


Fig. 26 - Scatterplot of body weight (BW, in g) *vs.* carapace length (CL, in mm) in *Aristaeomorpha foliacea*, by sex.

The morphometric analysis of males is more complex since there is an evident discontinuity in their body measurements as a consequence of the dimorphism of the rostrum in juveniles and adults. In fact, the residuals do not behave well and show clustering patterns. A splice is evident at CL <27 mm for the BW *vs.* CL. The relationship is still negatively allometric but the slope value is higher than that estimated for females (i.e., for the same length class males weigh more than females).

The conversion coefficients from Table 16 allowed the conversion of historical non-standard measures (TL; OL) in standard (CL) length frequency distributions comparable with recent data.

Growth parameters

The analyses of the LFDs produced different results depending both on the method and on the simultaneous use of ancillary information from literature and "expert" knowledge. A detailed report of the analyzing process is attached in Appendix D.

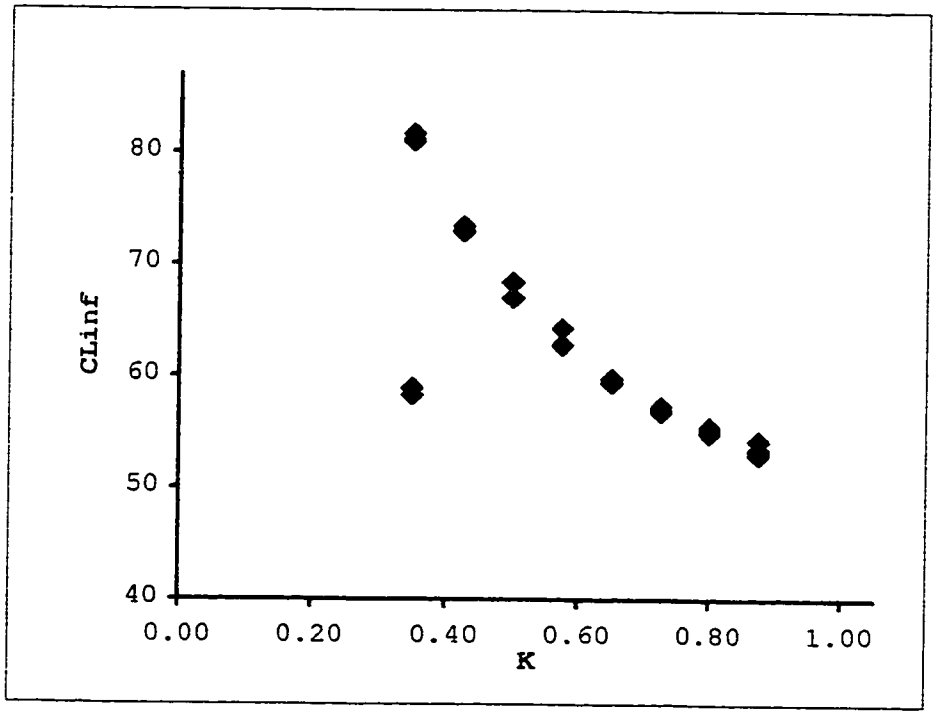


Fig. 27 - Relationship between von Bertalanffy's parameters CL_∞ (mm) and K (K/y) in *Aristaeomorpha foliacea* (example from Multifan first search grid, data from Linosa SE).

It can be anticipated that this step, the determination of the VBGF parameters, is the most sensitive of the whole red shrimp fishery analysis. In fact, no method allows for an objective determination of the L_∞. K is highly negatively correlated to this "subjective"

L_∞ (Fig. 27). Sometimes t_0 is not even considered in the resolving algorithms. Moreover, the constraints of subsequent assessment procedures often require that input values possess specified characteristics that the estimated parameters do not have (e.g. that L_∞ used as input must be at least 10% greater that L_{max}).

Results from ELEFAN

The non-parametric procedure of ELEFAN produces quick-and-dirty results, but unfortunately lacks the "rigor" for a scientific study, and is rather just a fitting tool. The analysis of the earlier trawl surveys data produced two sets of parameters of similar "strength" corresponding to a "slow" and a "fast" hypothesis (Ragonese and Bianchini, 1995). The bootstrap procedure utilized on the similar shrimp *Aristeus antennatus* to obtain a range of variation for the growth parameters (Ragonese and Bianchini, 1991) has not been performed on *Aristaeomorpha foliacea*.

Results from the Bhattacharya's separation

The results of the deconvolution of the LFDs from the earlier eight trawl surveys rearranged by pooling homologous seasons are reported in Table 17. While the females are easily separated in "age" groups, the male LFD resolution is statistically significant (i.e., produces a valid chi-square, with at least 10 d.o.f.) only in spring and summer.

The Bhattacharya's method is highly subjective and requires trading among different imprecisions; the indexes that are provided, i.e. standard deviation of the means, correlation, χ^2 are indeed only indicative. Even the modal progression analysis that is performed after the separation of the modes by the Bhattacharya's method can produce multiple results. The highest risk of subjectivity resides in the earlier decision of the number of "age" classes to be deconvoluted. Moreover, the pooling of the data is not always reasonable since there is a risk of making the modes not separable, especially in animals that reproduce and grow like shrimps.

Table 17 - Bhattacharya's method applied to *Aristaeomorpha foliacea* LFDs from the earlier trawl surveys (the black dot • indicates modes not well discriminated) (from Ragonese *et al.*, 1994e).

	group	age (months)	mean CL (mm)	s.d.	N	separ. index		chi-square	d.o.f.
FEMALES									
	1	9	24.8	3.62	912				
Spring	2	21	44.9	3.42	640	5.7			
'85+'86	3	33	53.6	3.53	847	2.5			
	4	45	61.3	2.99	153	2.4			
								22.3	16
	1	12	32.9	3.45	1198				
Summer	2	24	50.0	4.56	632	4.3			
'85+'86	3	36	55.1	3.52	524	1.3	•		
	4	48	60.4	3.12	150	1.6	•		
								22.2	13
	1	15	37.3	3.94	284				
Autumn	2	27	51.6	3.81	1034	3.7			
'85+'86	3	39	59.0	3.81	276	2.0			
								5.4	13
	1	18	40.6	3.15	1191				
Winter	2	30	55.1	4.88	732	3.6			
'86+'87	3	42	61.9	1.98	36	2.0			
								13.7	11
MALES									
	1	6	23.1	2.37	513				
	2	9	26.9	1.56	308	1.9	•		
Spring	3	21	34.8	1.55	753	5.1			
'85+'86	4	33	38.0	1.50	644	2.1			
	5	45	41.4	1.33	130	2.4			
	6	57	45.3	0.77	6	3.7	•		
								10.8	14
	1	9	22.1	1.42	6		•		
Summer	2	12	30.7	2.34	1239	4.6			
'85+'86	3	24	37.5	1.64	796	3.4			
	4	36	40.1	1.66	247	2.1			
								16.3	13
	1	15	32.5	1.78	352				
Autumn	2	27	37.4	1.72	794	2.8			
'85+'86	3	39	40.7	1.57	403	2.0			
	4	51	43.9	0.90	28	2.6			
							•	3.3	8
	1	18	33.9	1.58	1034				
Winter	2	30	38.4	1.79	668	2.7			
'86+'87	3	42	42.0	1.35	107	2.2			
	4	54	49.5	1.19	6	6.0	•		
							•	5.5	8

The SE Spring females from the selectivity study were analyzed with an "automatic", macroscopic approach and five "age" groups were easily separated (Fig. 28). A more subjective analysis, aimed at maximizing the visual fitting, suggested a 6-group subdivision (mainly deriving from a split of the first assemblage, that should be reunited for the growth analysis), even if the first and last separation indices were low. The SE Summer data set was thereafter analyzed and this LFD appeared quite difficult to interpret, even at the simplest visual glance. Four "age" groups were separated with the "automatic" approach but the total χ^2 was meaningless; three "reasoned" analyses were therefore tried and each of them produced five groups.

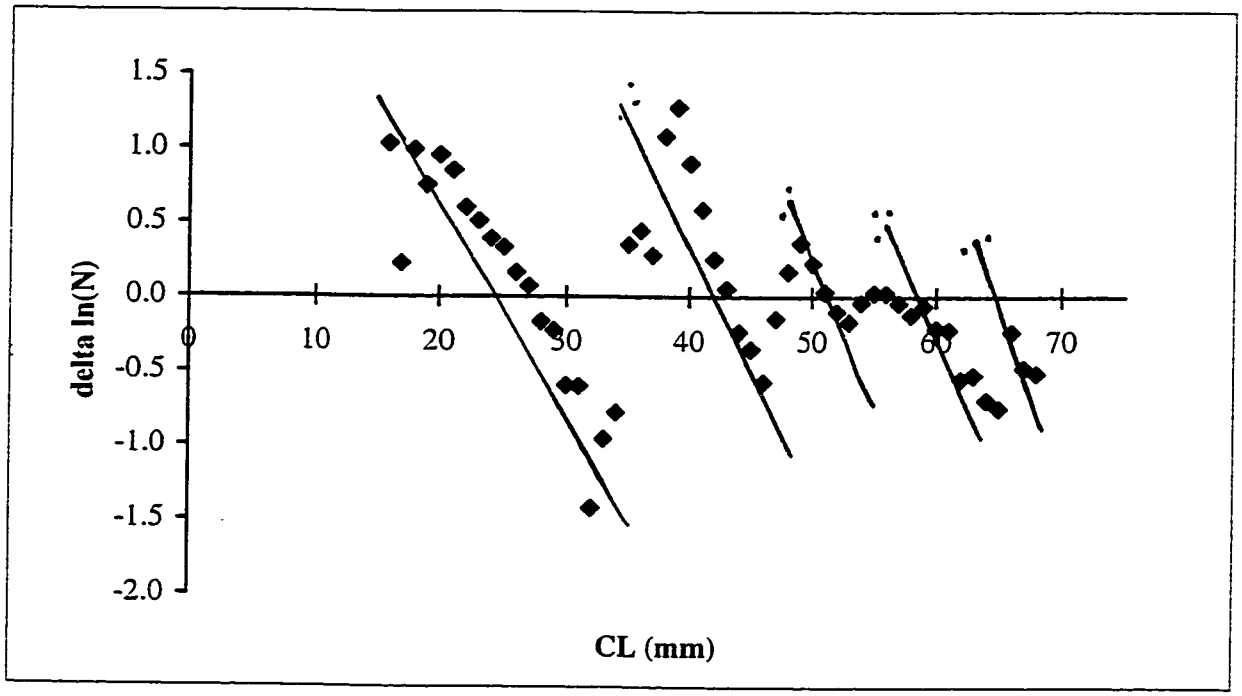


Fig. 28 - Bhattacharya's deconvolution of *Aristaeomorpha foliacea* LFDs from the selectivity study, SE of Linosa in the spring.

Four "age" groups were separated with the "automatic" approach in the NE Spring females from the selectivity study. Another analysis, as "objective" as possible but tuned with small corrections by the inclusion of marginal points, did not improve the results. A more subjective analysis proposed a 6-group subdivision, but the last separation index was low and the second "age" group was probably an artifact. Even when eliminating the last component to revert to the 5-group hypothesis, the second "age" group remained spurious. The NE Summer data set was thereafter analyzed and four "age" groups were separated by the "automatic" approach. Another, more subjective analysis produced four separated groups again. To assess the sensitivity of the method to the sample size, one of the data sets (NE, both spring and summer) was multiplied by a factor of 0.1 and by a factor of 10, and treated in "automatic". While the results were almost identical, such was not the case for the significance of the χ^2 (original data set: χ^2= 298, 15 d.o.f.; reduced set, χ^2= 28.7, 10 d.o.f.; enlarged set: over χ^2> 999).

The detailed results of the modal separation by area and season from the selectivity study, i.e. the mean size of each group, its standard deviation, the population of each group, the separation indexes and the total χ^2 are reported in Appendix D.

The results from the Bhattacharya's separation of the LFDs from the earlier trawl surveys were used to estimate the VBGF parameters with the FiSAT internal procedure and with the Systat NONLIN procedure (Fig. 29). Both procedures converge rapidly and independently of (reasonable) seed values to similar results; NONLIN estimates are associated with measures of variability. The standard error for the third parameter (t_0= 0.17, close to 0 in any case) is 13.2 (which is very high) suggesting that a two-parameter VBGF is probably the best choice (CL_∞= 65.5 mm, s.e.= 1.24; K/year= 0.669, s.e.= 0.0257). The estimate of CL_∞ is lower than the maximum CL observed in this specific stock (CL_{max}= 70 mm) which is nevertheless consistent with a mean square fitting algorithm and biologically, in that only a minimal fraction (4%) of the measured sample is larger than 60 mm. Among the fitting curves (VBGF, linear, potential, Gompertz's) that were tried, the VBGF had the lowest MSE, besides being the

most commonly employed. No further analysis was performed on the Bhattacharya's separation results from the selectivity study.

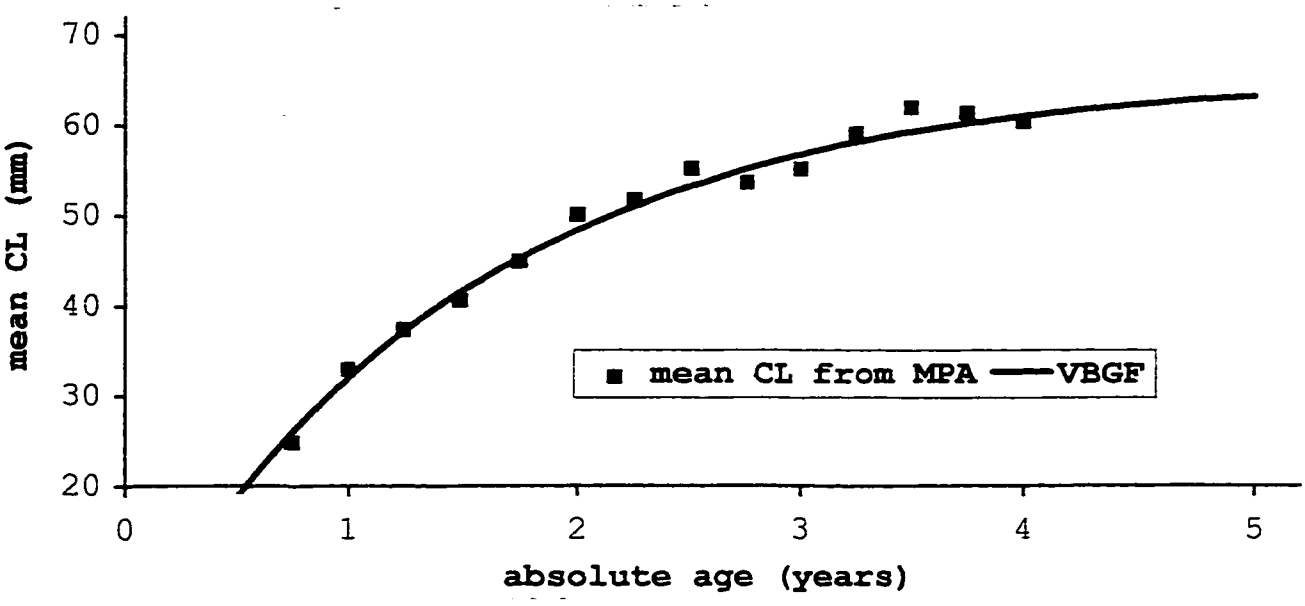


Fig. 29 - The VBGF resulting from the modal progression analysis of *Aristaeomorpha foliacea* females (modified from Ragonese *et al.*, 1994e).

Results from the MIX deconvolution

The results obtained by the Bhattacharya's deconvolution were used as seeds for the MIX procedure, which represents a more "objective" approach. In fact, MIX allows for a greater flexibility in deciding how to separate the "age" classes of a LFD. Still, it has several of the same problems of the Bhattacharya's method.

A summary of the most probable growth parameters resulting from the deconvolution of the LFD using the MIX procedure is presented in Table 18. The detailed actual results, i.e. the mean size of each group, the standard deviation, the relative percentage of each group, their associated standard errors and the total χ^2 are reported in Appendix D.

The four sets (SE Spring, SE Summer, NE Spring, NE Summer) of female data from the selection study were analyzed with the "normal" option on the two distinct assumptions of four or five "ages". The option allowing use of log-normal and gamma distributions did not significantly influence the final outputs. A tentative trial with a reduced number of classes, by doubling the length interval to 2 mm, did not improve the results.

Table 18 - The VBGF parameters resulting from the MIX deconvolution of LFDs of *Aristaeomorpha foliacea* females, by zone and putative month of hatching.

Zone	birth date	CL_∞ ±MSE	K ±MSE	s.e.
South-East	August	58.0 ±0.96	0.62 ±0.025	0.58
South-East	September	56.6 ±0.85	0.70 ±0.025	0.57
South-East	October	55.3 ±0.96	0.79 ±0.035	0.93)
North-East	August	62.2 ±1.34	0.60 ±0.035	0.99
North-East	September	60.6 ±1.20	0.67 ±0.035	1.00
North-East	October	59.1 ±1.26	0.75 ±0.050	1.42)
Pooled	August	60.1 ±1.35	0.61 ±0.035	2.15
Pooled	September	58.6 ±1.20	0.68 ±0.035	2.15
Pooled	October	57.2 ±1.14	0.77 ±0.035	2.48

The incorporated search for the von Bertalanffy's parameters did not produce reasonable results; therefore a non-linear regression was preferred. The possible coefficients were CL_∞, K and t_0, but since the latter was always imprecisely estimated (asymptotic s.e. of $t_0 \approx t_0$ itself) it was dropped altogether. Since the hatching time is unknown, the supposed birth date for the recruits was tentatively set at the previous-year's August, September or October. From the behaviour of the mean standard error of the regressions, September has been chosen as presumptive birth date supporting the decision to keep the two zones separated (Fig. 30).

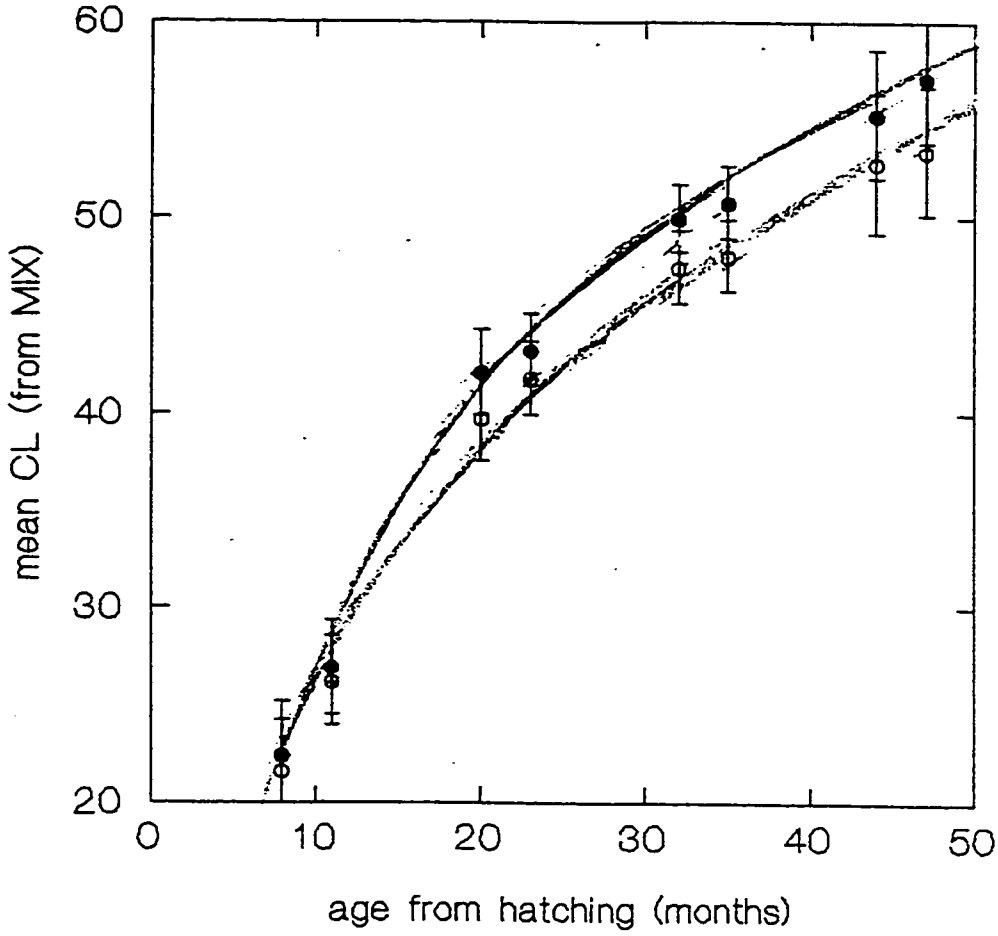


Fig. 30 - The VBGFs resulting from the MIX deconvolution of LFDs of *Aristaeomorpha foliacea* females from the two zones NE (black dots) and SE (white dots), considering September as the putative month of hatching.

Results from the MULTIFAN procedure

Only a summary of the most probable population structure resulting from MULTIFAN is presented here. The detailed actual results, i.e. the proportions of each modal class by sample, the mean size of each group in the first sample, the youngest absolute age, the standard deviation of the model and of the estimates, some correlations and the Maximum Likelihood Estimators and their significant increments (in terms of χ^2) are reported in Appendix D.

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timates of L_inf (and K) for systematic search 0

Age	Initial estimates of von Bertalanffy K ---->					
asses	0.350	0.425	0.500	0.575	0.650	0.725
3	81.2	73.4	68.4	64.3	59.5	57.3
	0.35	0.43	0.50	0.57	0.65	0.73
4	81.0	73.0	67.0	62.8	59.8	57.3
	0.35	0.43	0.50	0.57	0.65	0.73
5	81.7	72.9	67.0	62.7	59.5	57.0
	0.35	0.43	0.50	0.57	0.65	0.73
6	58.9	73.0	67.0	62.7	59.5	56.8
	0.35	0.43	0.50	0.57	0.65	0.73
7	58.3	73.0	67.0	62.7	59.4	56.8
	0.35	0.43	0.50	0.57	0.65	0.73

Fig. 31 - Example of MULTIFAN output in the "systematic search" of CL_∞ estimates of *Aristaeomorpha foliacea* females.

Females

On all the valid females of South-East, the first search with Multifan, that implied a simple systematic search on the age-K grid (Fig. 31), produced the best MLE at K= 0.8 with "age" 7, and sub-optimal MLEs at K= 0.65 with "age" 4, at K= 0.725 with "age" 5 and with "age" 6. Having opted for a "life span" of five classes that represents a compromise of the biological knowledge and the best MLEs, with K= 0.725 the resulting CL_∞ was 57.0 mm, quite short for the available biological knowledge of the area

(> 64 mm). The difficulty in accepting these Multifan estimates resides in the "absence" of the fourth class, the principal problem being that zero recruitment in the previous years does not appear reasonable from past commercial landings and from knowledge of the fishery. This was even worse with longer life spans. Conversely, renouncing to maximize the overall MLE, thus opting for a relatively short "life span" of four classes, with K= 0.65 the corresponding CL_∞ was improved at 59.8 mm. The third peak of the LFDs has not been "absorbed" well. To overcome this problem, the fitting curves were constrained with fixed proportions and/or boundaries but, even if the eye was satisfied, the analytical elements worsened.

The second search with Multifan allowing StD to vary produced the best MLEs again in the K= 0.8-"age" 7 position and at K= 0.725 with "age" 5. Having opted again, for the same reasons as above, for a "life span" of four classes, the resulting CL_∞ was 59.8 mm. The introduction of an additional parameter to be estimated (StD) is not justified by improved results with the four "ages" hypothesis; conversely, even though slightly improved, the outcomes for other "ages" remain biologically unsatisfying.

The following step, that implied the varying of two "seasonal" parameters, growth amplitude and growth phase, changed the position of the best MLEs to the K= 0.725 column, with significant improvements up to six "ages". Having opted again, since the problem of the "ghost class" did persist, for a "life span" of four classes, the corresponding CL_∞ was always 59.8 mm. The seasonal growth amplitude was 0.10, and its phase 0.54; the introduction of two additional parameters to be estimated (SGA and SGP) is not justified by improved results.

The next possibility of single fluctuation, that implying the bias in the first class due to capture processes, almost mimicked the initial search, suggesting only a negligible bias.

The last and most important possibility offered by the Multifan procedure, the one allowing the estimation of K, produced "flat" MLEs contours, meaning that the maximum for each "age" was spread over a range of K values, about 0.2 wide. Still, Multifan suggested K= 0.635 for "age" 4, K= 0.731 for "age" 5 and K=0.772 for "age" 7; the

maximum improvement remained between "ages" 3 and 4. Since the previous problems could not be overcome, and having therefore opted again for a "life span" of four classes, the resulting proportions and average CL are reported in Table 19. For these results K moved to 0.635, and the corresponding CL_∞ changed to 60.3 mm, an apparently reasonable estimate. It should be remembered that, with or without improvements, it is always deemed necessary to conclude the estimation procedure by letting K vary (Fig. 32).

Table 19 - Relative proportions by age of *Aristaeomorpha foliacea* females seasonal samples in zone SE, and mean lengths from the first survey (complete data set from the selectivity study).

"age"	1	2	3	4
Spring sample	0.39	0.44	0.14	0.04
Summer sample	0.41	0.35	0.18	0.06
mean length of Spring sample	20.6	39.3	49.2	54.4

The Multifan procedure permits "multiple" fluctuations, that are almost always with K varying and another parameter. None of these "multiple" estimations has improved the "single" fluctuation output enough to justify the introduction of a new parameter to be estimated, since the gain in the MLE is marginal. The search allowing the estimation of all the parameters in the above starting age-K grid did produce the very best MLE of the whole process; that is probably not a real maximum of the objective function, since the Hessian matrix is not definite.

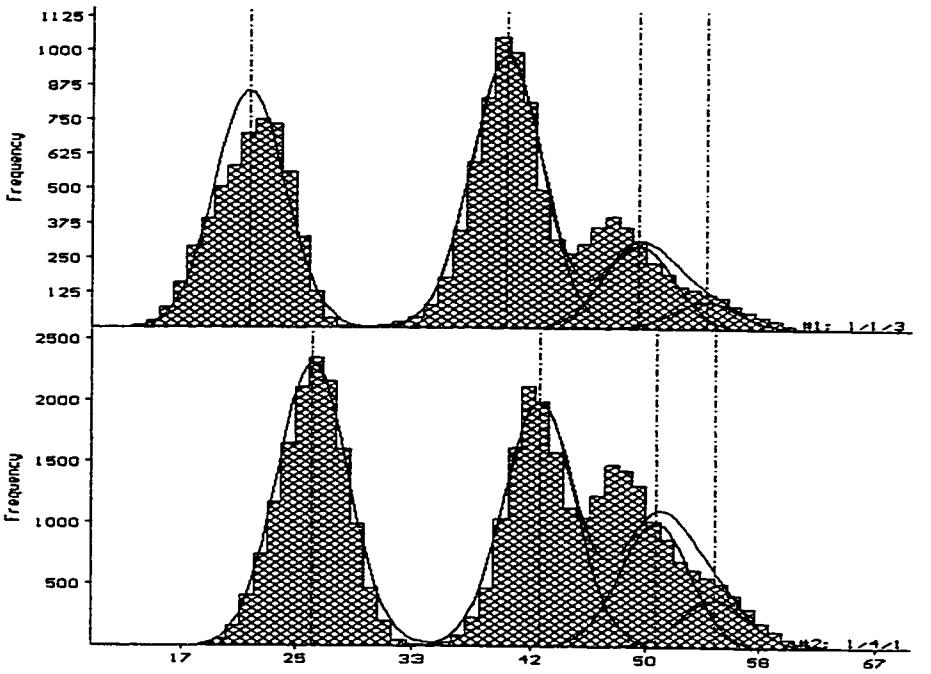


Fig. 32 - Example of MULTIFAN deconvolution (*Aristaeomorpha foliacea* females, zone SE, from selectivity study).

In the event that the red shrimps present a splice in the growth curve, the South-East data set has been modified by removal of the data in the first mode, thus reducing it to large specimens only; this modified data set has been treated on the basis of the previous results, allowing the fluctuation of K in a 3-5/0.200-0.625 age-K grid (the "ages" 3, 4, 5 thus presented by Multifan are in fact equivalent to "true" ages 3+1, 4+1 and 5+1), and analyzing in more detail "age" 4+1 in the area that produces about CL_∞= 70. The resulting proportions and average CL are reported in Table 20. For these results, K moved to 0.308, and the corresponding CL_∞ changed to 69.6 mm, a quite reasonable estimate.

Table 20 - Relative proportions by age of *Aristaeomorpha foliacea* females seasonal samples in zone SE, and mean lengths from the first survey (reduced "large only" data set from the selectivity study).

"age"	1	2	3	4	5
Spring sample	--	0.65	0.25	0.08	0.02
Summer sample	--	0.52	0.33	0.12	0.02
mean length of Spring sample	--	39.4	47.4	53.2	57.6

The simple systematic search of Multifan on all the valid females of NorthEast produced the best MLE at K= 0.725 with "age" 7, and sub-optimal MLEs at K= 0.575 with "age" 4, at K= 0.650 with "age" 5 and with "age" 6. The K values for the NorthEast area shifted one step down compared to those for the SouthEast zone. Having opted for a "life span" of five classes, which represents a compromise of biological knowledge and the best MLEs, with K= 0.650 the resulting CL_∞ was 61.1 mm, somewhat shorter than what is known from the available biological knowledge for the area (> 64 mm). For sake of comparison with the South-East area, the "life span" of four classes has been analyzed too; its CL_∞ was 65.3 mm, more consistent with the available biological knowledge for the area (> 64 mm). Notwithstanding the reasonable CL_∞ and the consistency of the "life span" with that of the SouthEast, the fitting of the latter is quite unsatisfactory, particularly around the third peak. It should be noted the better estimate of CL_∞, and the lower "performance" of NE *vs.* SE data is understandable given the smaller database (only 5400 *vs.* 36700 animals in the second seasonal survey). The major problem with these Multifan estimates is the large "inversion" of the final proportions, i.e. the relative greater strength of the last "age" group.

The second search with Multifan, allowing StD to vary, produced again the best MLEs in the K= 0.725-"age" 7 position, and sub-optimal MLEs at K= 0.575 with "age" 4 and at K= 0.650 with "age" 5 or "age" 6. Nevertheless, the maximum improvements happened between "ages" 4 and 5, and the corresponding MLE was almost optimal. Having opted again for a "life span" of five classes, with K= 0.650 the CL_∞ was 61.1 mm.

In the Multifan following step, varying growth amplitude and growth phase, notwithstanding the better fit, the introduction of two additional parameters to be estimated is not justified by improved results. Also the introduction of the additional bias parameters in the model is not justified.

Table 21 - Relative proportions by age of *Aristaeomorpha foliacea* females seasonal samples in zone NE, and mean lengths from the first survey (complete data set from the selectivity study).

"age"	1	2	3	4	5
Spring sample	0.13	0.44	0.33	0.04	0.06
Summer sample	0.25	0.35	0.22	0.01	0.17
mean length of Spring sample	21.2	40.3	50.2	55.4	58.0

The last and most important possibility offered by the Multifan procedure, the one allowing the estimation of K, produced "flat" MLEs contours, meaning that the maximum for each "age" was spread over a range of K values, about 0.25 wide. Still, Multifan suggested K= 0.591 for "age" 4, K= 0.658 for "age" 5, and K= 0.800 for "age" 6; the maximum improvement remained between "ages" 3 and 4, with still a very large improvement between "ages" 4 and 5. Using the usual "life span" of five classes, the resulting proportions and average CL are reported in Table 21. For these results, K moved to 0.658, and the corresponding CL_∞ changed to 60.9 mm. As already said, it should be

remembered that, with or without improvements, it is always deemed necessary to conclude the estimation procedure by letting K vary (Fig. 33).

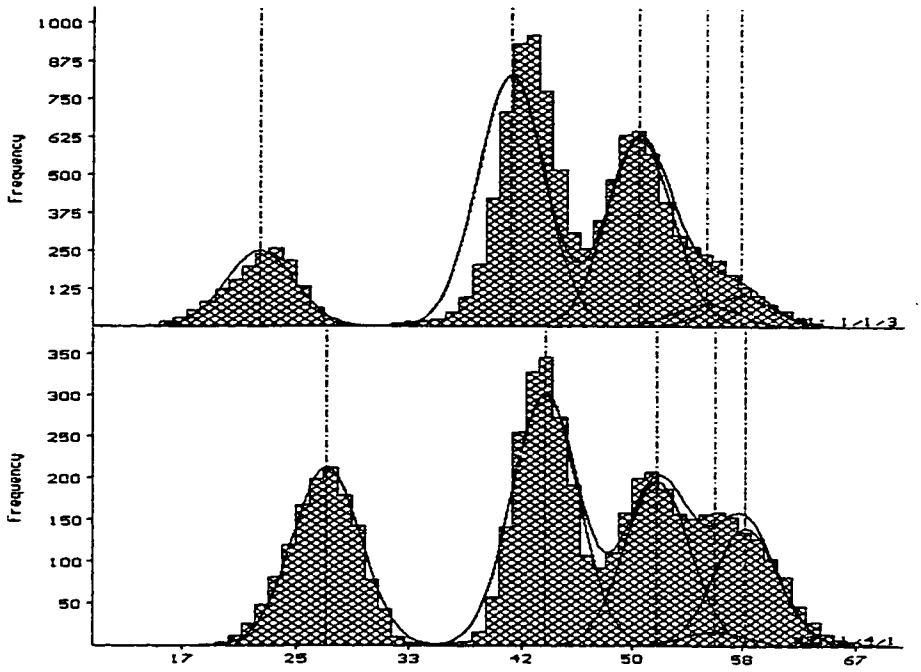


Fig. 33 - Example of MULTIFAN deconvolution (*Aristaeomorpha foliacea* females, zone NE, from selectivity study).

The Multifan procedure permits "multiple" fluctuations, that are almost always with K varying and another parameter. Of such types, the first "multiple", the one allowing the estimation of K and StD, produced very similar "best" MLEs in a large K range. The most suited final approach is to test for the "life span" of four classes (for comparison with the SouthEast shrimps), of five classes (for consistency and because of the ancillary biological information) and of six classes (given the higher MLE). Following the option for a "life span" of four classes, K moved to 0.56, and the corresponding CL_∞ was 64.9 mm. Following the option for a "life span" of five classes, K moved to 0.66, and the corresponding CL_∞ was 60.9 mm. In contrast, following the option for a "life span" of six classes, K moved to 0.68, and the corresponding CL_∞ lowered to 60.0 mm.

Of all other "multiple" fluctuations, none has improved the "single" fluctuation output enough to justify the introduction of a new parameter to be estimated. The search

allowing the estimation of all the parameters in the same starting age-K grid did produce the best MLE of the whole process, but is probably not a real maximum of the objective function, since the Hessian matrix is not definite. The above trials clearly show the shortcomings of a program such as Multifan, in which the "mathematical" increases do not correspond to biologically-sound estimates: in fact, e.g. the empty "age" classes are a sure artifact, and the decrease of the CL_∞ is another misfit.

As with the SouthEast females, also the NorthEast data set has been modified by removal of the data in the first mode, thus reducing it to large specimens only; this modified data set has been treated on the basis of the previous results, allowing the fluctuation of K in a 3-5/0.200-0.625 age-K grid (the Multifan "ages" 3, 4, 5 are in fact equivalent to the "true" ages 3+1, 4+1 and 5+1), and analyzing in more detail "age" 4+1 in the area that produces about $CL_\infty = 70$. The resulting proportions and average CL are reported in Table 22. For these results, K moved to 0.325 and the corresponding CL_∞ changed to 70.8 mm, a very reasonable estimate.

Table 22 - Relative proportions by age of *Aristaeomorpha foliacea* females seasonal samples in zone NE, and mean lengths from the first survey (reduced "large only" data set from the selectivity study).

"age"	1	2	3	4	5
Spring sample	--	0.50	0.35	0.12	0.03
Summer sample	--	0.46	0.27	0.18	0.10
mean length of Spring sample	--	41.6	49.7	55.6	59.8

Males

For the males, given their lesser importance in the fishery, the Multifan procedure has been "shortened", following the estimation steps in a more "automatic" fashion. Therefore, only the terminal estimates, with varying K, are reported.

Males from SouthEast, were assigned a "life span" of three classes, and K was 1.08, and the corresponding CL_∞ 40.1 mm, a reasonable estimate (Fig. 34). Males from NorthEast, were assigned a "life span" of three classes, and K was 1.08, and the corresponding CL_∞ 40.6 mm. Note that K is identical for the SouthEast and NorthEast males.

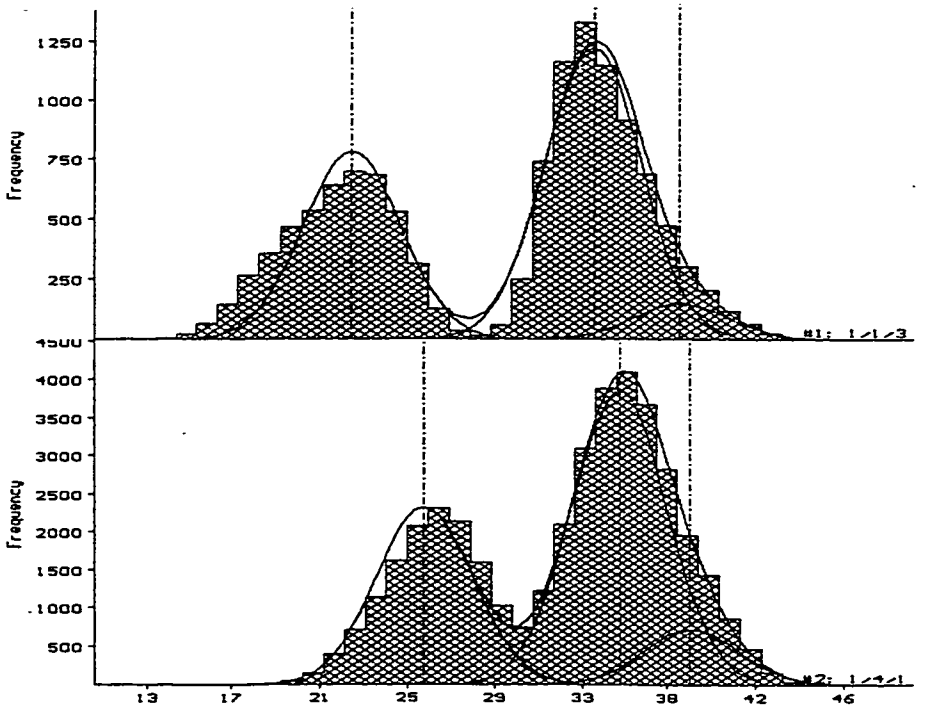


Fig. 34 - Example of MULTIFAN deconvolution (*Aristaeomorpha foliacea* males, zone SE, from selectivity study).

Multifan behaviour

It has been deemed necessary to explore the behaviour of Multifan when working on a data set of smaller dimension; with this in mind, the data set of NorthEast females has been reduced to 1/5 of the original size.

The first search for reduced NorthEast, that implied a simple systematic search, produced the best MLEs in the K= 0.725 column. A "life span" of five classes should be selected for comparative purposes anyhow and it even had "best" MLE. The resulting CL_∞ was 60.8 mm, just a little shorter than that obtained with the complete data set (61.1 mm). One of the problem with the analysis of the complete data set, the "inversion" of the final proportions, seems reduced. Skipping for sake of simplicity the trials on reduced NorthEast with oscillating StD, seasonality or bias, the last possibility offered by the Multifan procedure, the one allowing the estimation of K, produced the best MLEs in the both the K= 0.650 and K= 0.725 columns. With the usual "life span" of five classes, K moved to 0.714, and the corresponding CL_∞ to 60.4 mm (they were K= 0.66 and CL_∞=60.9 with the original data). On reduced NorthEast, allowing the simultaneous estimation of K and StD, Multifan produced very similar "best" MLEs in the K range 0.6-08. This time, the approach has been to test for both "life span" of five classes (for consistency) and "life span" of seven classes (given the higher MLE). Following the option for a "life span" of five classes, K moved to 0.713, and the corresponding CL_∞ was 60.4 mm (they were K= 0.66 and CL_∞=60.9 with the original data). In contrast, following the option for a "life span" of seven classes, K moved to 0.757, and the corresponding CL_∞ lowered to 59.0 mm. Even the simple systematic search on the reduced data set for SouthEast produced the best MLEs in the K= 0.725 column. This time, having opted just for comparison for a "life span" of five classes, the resulting CL_∞ remained at 57.0 mm.

The comparison of the two sets of analyses shows only slightly different results. Altogether, even in the simple, "deterministic" search, the size of the data set did not produce results sufficiently different to warrant further study.

The valid females of the two fishing zones, SouthEast and NorthEast, were pooled to examine the behaviour of the estimates, even if it appears from a visual analysis of the fitting curves in the everything-fixed search, that combining the zones is not appropriate.

Limiting the discussion to only the variable-K estimates, the best MLEs were in the columns from K= 0.65 to K= 0.85, and the maximums (all equal) laid at "age" 6.

Even these fittings were never good; for consistency, only the usual "life spans" of four and five classes are considered. For the 4-classes results, K moved to 0.69, and the corresponding CL_∞ to 60.0 mm. For the 5-classes results, K moved to 0.727, and the corresponding CL_∞ to 58.4 mm.

It has been deemed necessary to explore the behaviour of Multifan when the location of the age-K grid varies. With this in mind, the data set of SouthEast males was employed on three grids, keeping everything else constant: a) age classes 3, 4 and 5, K from 0.2 to 1.2, by 0.2 increments (the one against which the others were compared); b) age classes 3, 4 and 5, K from 0.8 to 1.2, by 0.2 increments; and c) age classes from 2 to 6, K from 0.2 to 0.8, by 0.1 increments (K out of "true" boundaries). The "true" results for SouthEast males are supposed to be: K= 1.08, CL_∞= 40.6 mm, StD of the mean length in Spring sample= 2.55.

In the simple search, the preliminary estimates of CL_∞s varied by only 0.3 mm. Nevertheless, proceeding toward the more "complicated" Multifan estimates, such as those with varying K, the situation worsen. Even if the proportions of the age vectors are close to each other for a) and b), the results may be misleading, for example in assessing mortality. Something similar happens for the parameters. In fact:

- for the "true" results, the StD of the mean length in Spring sample was estimated at 2.51, K was 1.08, and the corresponding CL_∞ 40.1 mm;
- for the "other" results, the StD of the mean length in Spring sample was estimated at 2.30, K was 0.99, and the corresponding CL_∞ 40.7 mm.

The confidence limits of the mean length in Spring sample and of CL_∞ for the two sets of values do overlap, and they do not for the values of K.

Looking at an "out of range" location, the MLEs of point "age 4 - K= 0.6" in the simple search show a difference of almost 3% between a) and c); this difference produced a preliminary estimate of CL_∞= 39.3 for c) against the corresponding CL_∞= 40.6 for a), a (too) large difference for the same starting seed values. In any event, the ancillary biological information require subjective decisions on which "best" MLE to consider,

often with differences greater than 5% from what suggested by Multifan. It must be emphasized that these trials were expressly performed "out of tune" with the regular procedure, to simulate extreme situations. Overall, the three sets of analyses do show different results in "corresponding" situations, usually slightly divergent but significantly in the case of poor seed values. The most "risky" aspect is the fact that the variability associated with the different estimates is fairly small, an optimistic and misleading result.

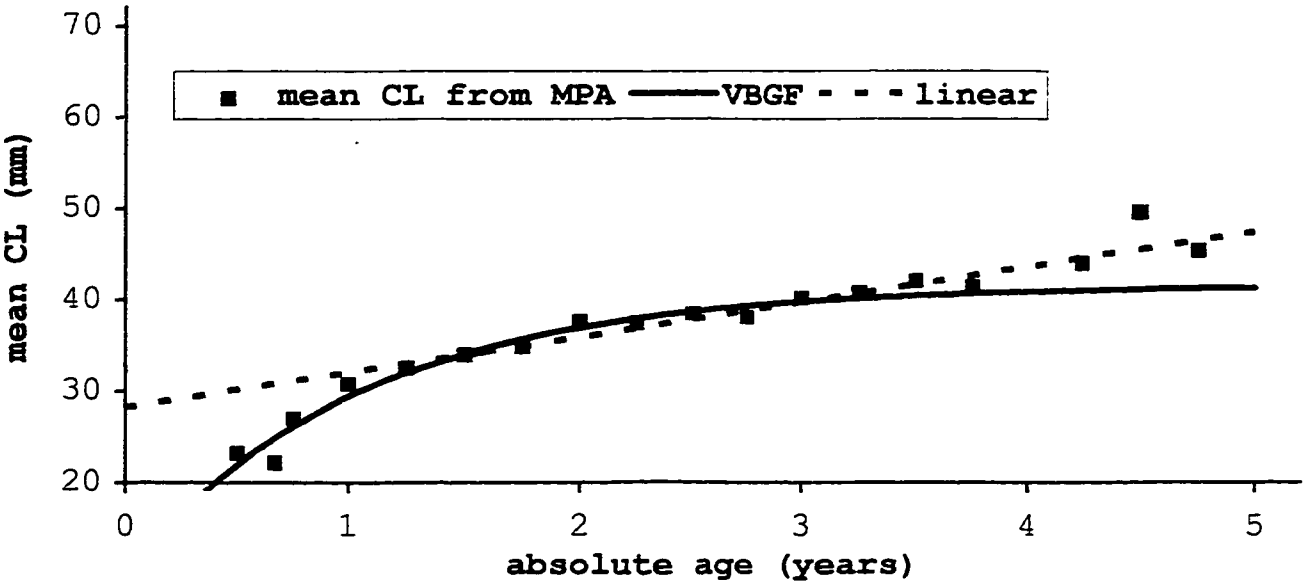


Fig. 35 - The linear regression and the VBGF resulting from the modal progression analysis of *Aristaeomorpha foliacea* males (modified from Ragonese *et al.*, 1994e).

All the above results are related to a VBGF model which, for the reasons already described, is both considered physiologically sound and utilized without much concern in much of the literature. Still, at least for the males, an apparent linear relation exists for CL_{mean} *vs.* age; above the length of sexual maturity (around CL= 31 mm; Cau *et al.*, 1982; Ragonese, 1989) this linearity is very clear. As a consequence, the curvilinear models are poor descriptors of male growth (Fig. 35). The VBGF is the "least inadequate" among the essayed curves (VBGF, linear, potential, Gompertz's) but the residual plots are in general

unacceptable and the t_0 estimate imprecise. On the other hand, a straight line, with the exclusion of the 0-group (9 months of age), results in a very good fit (CL_{mean}= 28.17 + 3.84* age in years; r^2= 0.946; MSE = 0.84), with robust estimates insensitive to weighing.

The von Bertalanffy's growth parameters obtained with the different methods employed are reported on Table 23 divided by sex.

Table 23 - Summary of the VBGF parameters estimated with different data sets of *Aristaeomorpha foliacea*.

females (non-lin, MIX)	CL_t= 65.5 *(1 -e$^{-0.669 *(t)}$)	MSE = 1.32
females (Multifan, SE, 4y)	CL_t= 60.3 *(1 -e$^{-0.635 *(t)}$)	
females (SE, large)	CL_t= 69.6 *(1 -e$^{-0.308 *(t)}$)	
females (Multifan, NE, 5y)	CL_t= 60.9 *(1 -e$^{-0.658 *(t)}$)	
females (Multifan, NE, 4y)	CL_t= 64.9 *(1 -e$^{-0.559 *(t)}$)	
females (trawl surveys)	CL_t= 61.1 *(1 -e$^{-0.779 *(t)}$)	
males (non-lin, MIX)	CL_t= 41.5 *(1 -e$^{-0.96 *(t +0.28)}$)	MSE = 1.07
males (Multifan)	CL_t= 40.6 *(1 -e$^{-1.08 *(t)}$)	

The overall index of performance is $\varphi' = 1.74$ and $\varphi' = 3.46$ for K expressed in weeks and years respectively; incidentally, the Munro's φ' (phi') for *Aristeus antennatus* and *Aristaeomorpha foliacea* derived from the literature falls in the range 1.4-3.8/year worldwide. The ω (Gallucci and Quinn, 1979), depending on the different scenarios, ranges from 25-45 (large females-males), and has never before been applied to shrimps.

Mortality

Females

On the earlier trawl surveys data, the ratio of recruits to total population is 0.357, 0.478, 0.178 and 0.608 for spring, summer, fall and winter, respectively. Heincke's mortality estimate based on the Summer surveys (Z/year= 0.651) is the most suited, because the juveniles are fully recruited to the area and to the gear (CL_{mean}= 33 mm); it is lower than the value (Z/year= 0.786) obtained from the method of moments (CL'= 40 mm, CL_{mean}= 51.7 mm) and of the growth parameters (CL_{∞}= 65.5 mm, K/year= 0.669). The longevity computed with Taylor's approximation based on the above VBGF parameters and on a $T_{0.01}$ is around 7 years, quite a high value. With the Alagaraya's method assuming a longevity range from 6 to 8 years, it is possible to estimate a natural mortality of 0.92, 0.77 and 0.58 for age 6, 7 and 8 respectively. On the other hand, the estimate of M/year from the reproductive pattern is around 0.7.

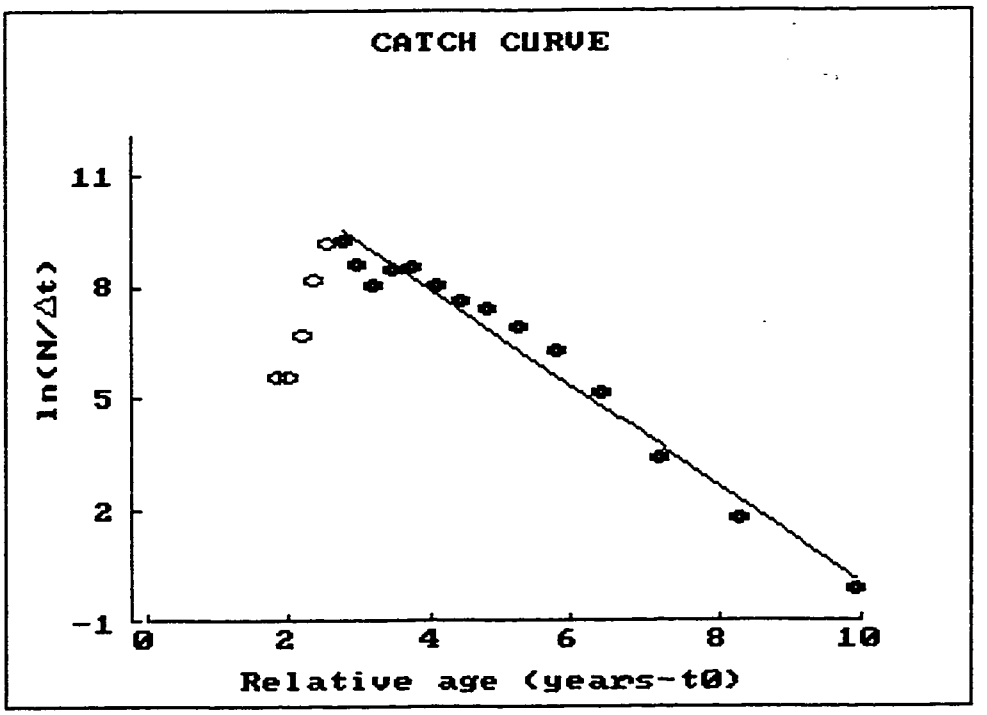


Fig. 36 - Total mortality (Z) of *Aristaeomorpha foliacea* females (large specimens only) estimated with the catch-curve method.

Examining the selectivity study data, Heincke's estimates of the annual Z were 0.49 and 0.53 in the SE red shrimps, respectively for spring and summer. The same estimates for the NE animals were unrealistically low (0.14 and 0.24). The estimates from the logarithmic regression on adults (Fig. 36) were 0.86 in SE (both in spring and in summer, s.e.= 0.051 and s.e.= 0.169 respectively) and 0.99 in NE (only spring could be used; s.e.= 0.172).

The instantaneous annual total mortality rate (Z) for the SE shrimps was computed on the preferred search method (varying K) of Multifan. When both seasonal samples were used, Z/year resulted 0.71. When only the summer sample was used, i.e. considering that the first component was not fully recruited in the spring, Z/year dropped to 0.63. The instantaneous annual total mortality rate was computed on the SE "large specimens only" data set utilizing both seasonal samples (all large shrimps are always fully recruited) resulting in a Z/year of 0.97.

The total mortality Z/year from Multifan was computed for the NE shrimps too. This time, the summer sample gave an unrealistic 0.38. The instantaneous annual total mortality rate was computed also on the NE "large specimens only" data set, resulting in a Z/year of 0.73.

On the reduced data set, mortality estimates were again produced: in NE with variable K, having opted for a "life span" of five classes, and a selectivity of 0.22 for the first "age" (and 1.00 thereafter), the resulting Z (annual basis) was 0.68. Changing the "life span" to six classes and the selectivity to 0.23 for the first "age", the annual Z resulted 0.67. With the "life span" of seven classes, and the selectivity to 0.25 for the first "age", the annual Z remained at 0.67. Besides a general agreement with the results from the full sample, it appears that trials with different "life span" produced similar mortality estimates.

The reconstruction of the population performed by the VIT program results in a global fishing mortality of 0.46 with age-structured data, and F= 0.55 in length-structured data. The fishing mortalities by age are: F_1= 0.22; F_2= 0.82; F_3= 1.9; F_4= 2.3; F_5= 1.1,

F_{term}= 0.3. The Thompson and Bell's computation puts the total annual number of deaths for the Sicilian Channel stock at 210 million (considering pre-recruits too).

Since data on not-recruited sizes are available in both the surveys from the selectivity study, the natural mortality could be estimated directly. Nevertheless, the number of animals that belong to this group is so scanty that no useful assessment was obtained. The Munro's technique, to estimate M/year on the basis of partially recruited sizes, failed to converge.

Given that this stock is intensely exploited (Z is substantially larger than M), notwithstanding that the shape of the pooled LFD from the earlier trawl surveys suggests a "type K" configuration with Z/K< 1 (Barry and Tegner, 1990), the coupled estimates of annual Z= 0.95 and M= 0.5 appear to be the most probable, also in view of what was already reported or assumed in the literature for other "temperate" shrimps (Pauly *et al.*, 1984; Yahiaoui *et al.*, 1986; Moffitt and Polovina, 1987; Sardà, 1988; Demestre, 1990; Ragonese and Bianchini, 1991; D'Onghia *et al.*, 1998). The exploitation ratio (E= F/Z) is 0.47, a reasonable estimate given that exploitation of this species begins at an early age.

Males

Utilizing the earlier trawl surveys data, results for male mortality are analogous to those obtained for the females. The ratio of recruits to total population is 0.349, 0.543, 0.223 and 0.569 for spring, summer, fall and winter, respectively. The most useful for Heincke's estimate of mortality is again that of summer, which yields Z/year= 0.783. The shape of the pooled LFD from the earlier trawl surveys suggests again a type "k" configuration but the estimates of M from Alagaraya's method would be reasonable only under the hypothesis of a longer life, of the same order as that of the females. It is worth noting that the observed CL_{max} of 50 mm corresponds to an age of 5-6 years, when the linear model is used.

The total mortality of males from selectivity study differ from the female mortality estimates. Heincke's estimates of annual Z were 0.46 and 0.40 in the SE male red shrimps, respectively for spring and summer. The same estimates for the NE animals

were unrealistically low (Z/year= 0.12 and 0.29). The estimates by logarithmic regression on adults (the regressions are statistically very weak) were Z/year= 0.37 (spring) and Z/year= 0.50 (summer) in SE and Z/year= 0.48 and Z/year= 1.00 in NE.

Sexual parameters and reproduction

Of the 18,582 individuals from the earlier trawl surveys that were sexed, 9,842 (53%) were females. The sex-ratio from the selectivity study was similar. It is worth noting that the above sex-ratio is not that of the population but that of the catch. The variability of sex-ratio by haul is high, but data pooled by survey, area or other *super partes* criteria show a general agreement with such proportion. A qualitative analysis of data from the early trawl surveys shows that males and females in the catch were not segregated in different bathymetric ranges (means of 8 values ± standard deviation: upper stratum 300-500 m, sex-ratio 0.515 ±0.0396; lower stratum 500-700 m, sex-ratio 0.484 ±0.0370). Since females grow larger than males, males dominate in the smaller size classes, and only females are present in the larger sizes (Fig. 37).

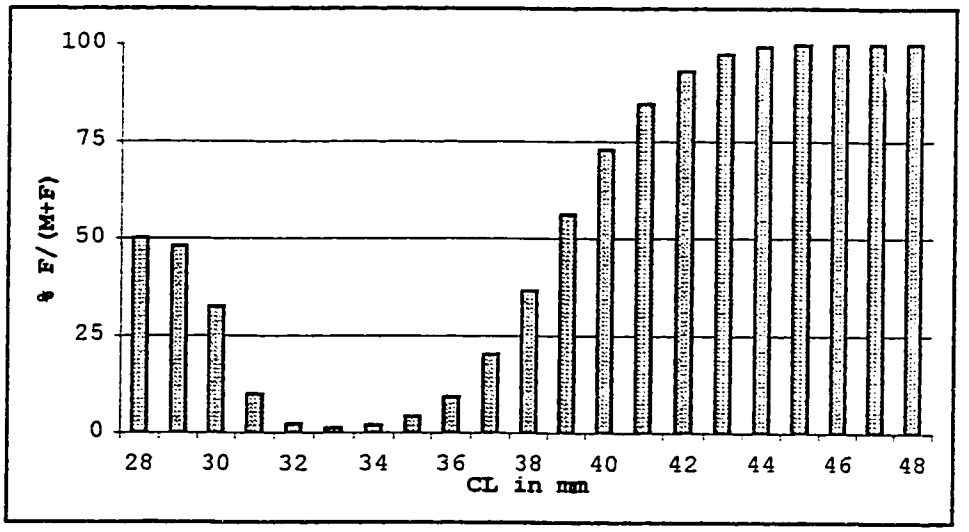


Fig. 37 - Sex-ratio (F/tot) by size (CL, mm) of *Aristaeomorpha foliacea* from zone SE (data from the selectivity study).

Only data from the earlier trawl surveys were analyzed for stages of reproductive maturation (Ragonese and Bianchini, 1995). Females, both mature and immature, were captured all over the explored area, and across the vertical distribution range. Females in stages III or IV show a large variability in length, which ranges from 28 to 62 mm CL (Fig. 38). There is a consistent overlap in the length frequency distributions per maturation stage, in such a way to eliminate any clear separation of maturation by size.

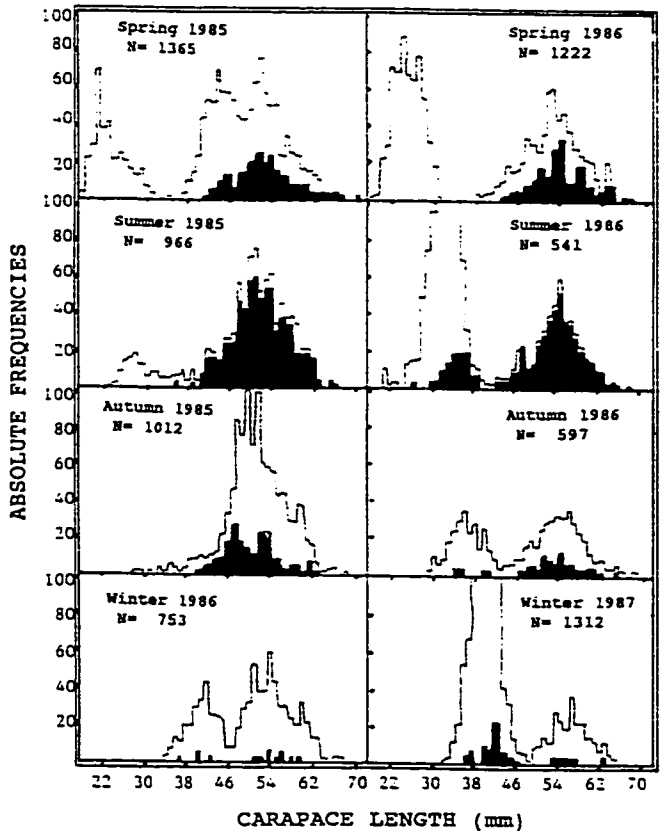


Fig. 38 - Observed degree of maturation of females of *Aristaeomorpha foliacea*, by survey; dark area for stages III+IV (from Ragonese and Bianchini, 1995).

In general, the spermatophore starts to appear in the 30 mm class and all females above 40 mm have it (Fig. 39). Females without spermatophore were all in the first stage; the recruits were unmated (and immature). Mating starts in summer for the larger young

animals, but most of the cohort acquires the spermatophore during the winter. In general all adult females had a spermatophore: the few mature females without spermatophore had probably lost it by accident (Relini Orsi and Relini, 1979). Unlike the pattern of maturation stages, unmated females tended to concentrate in the upper part of the bathymetric range (400-600 m), while mated individuals were more evenly distributed.

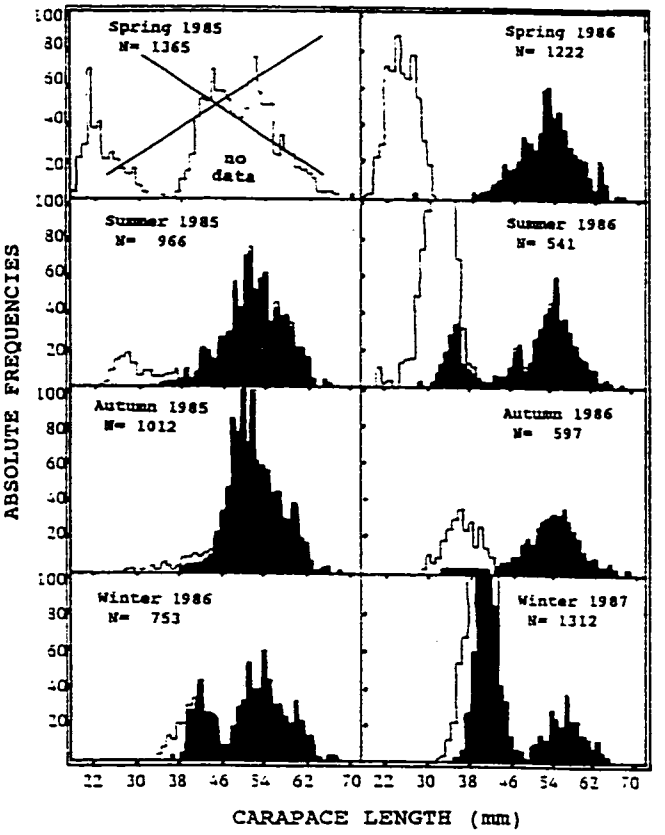


Fig. 39 - Observed presence/absence of spermatophores of females of *Aristaeomorpha foliacea*, by survey; dark area for presence (spermatophores were not checked during the first survey) (from Ragonese and Bianchini, 1995).

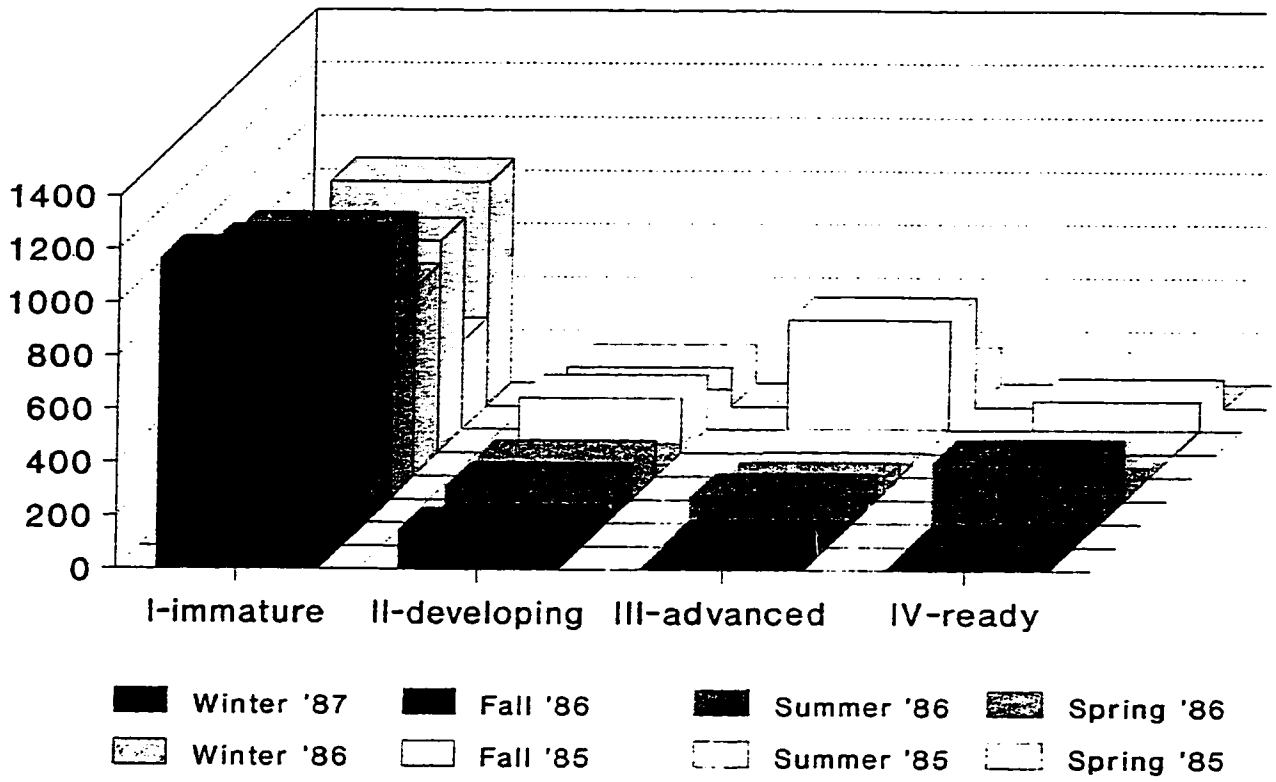


Fig. 40 - Frequency of different maturation stages of *Aristaeomorpha foliacea* females by season (data from earlier trawl surveys) (from Ragonese and Bianchini, 1995).

The reproductive season starts in spring and peaks in summer (Table 24); 89% of the ready-to-spawn females were captured during the summer surveys, where they represent 12-15% of the catch (Fig. 40). Simply speaking, recruits in spring are all immature; a few, the larger ones, may reproduce during the summer but most start their gonadic development in the winter, to reach their full reproductive stage in the second summer. The proportion of mature females in each size class was always lower than 100%, including during the reproductive peak.

Table 24 - Percentage of females of *Aristaeomorpha foliacea*, by survey and a) maturity stage and b) presence/absence of spermatophore.

	1985				1986				
	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Total
a) STAGE									
I	74.4	36.1	78.8	94.8	81.2	68.8	86.6	88.8	75.6
II	13.1	7.0	20.5	4.5	11.0	9.2	11.6	11.2	11.2
III	12.5	45.0	0.5	0.7	4.5	6.7	1.8	0.0	8.7
IV	0.0	11.9	0.2	0.0	3.3	15.3	0.0	0.0	4.5
b) SPERMATOPHORE									
presence	-	88.3	96.1	92.6	50.7	39.7	62.5	67.0	67.6

Advanced maturation (stages III+IV) and the presence of spermatophores by CL size are well fitted by logistic models (Table 25). The summer surveys appear to be most suited to understand the reproductive aspects, where the parameters of the logistic curves were:

$\alpha = 0.6533 \pm 0.023$; $\beta = 0.4668 \pm 0.1642$; $\gamma = 41.80 \pm 0.6010$; MSE= 0.0097 and

$\alpha = 1$; $\beta = 0.5858 \pm 0.0581$; $\gamma = 36.69 \pm 0.1994$; MSE= 0.0091.

The combination of the two models has been used (Ragonese *et al.*, 1992) to establish a size of "maximum reproductive potential" of 39.7 mm (Fig. 41), which corresponds to an age of about 18 months, an age older and a size larger than those reported as size-at-maturity for the species (Cau *et al.*, 1987).

Table 25 - Parameters estimates (summer only, data from the earlier trawl surveys) for a) maturity (stages III+IV) and b) presence of spermatophore $P= \alpha/[1-e^{-\beta*(CL-\gamma)}]$ in *Aristaeomorpha foliacea* (from Ragonese and Bianchini, 1995).

	α	β	γ	MSE
a) STAGES III+IV				
Summer 1985	0.66	0.43	41.1	0.021
Summer 1985 weighed	0.66	1.04	42.1	0.009
Summer 1986	0.61	3.62	43.2	0.014
Summer 1986 weighed	0.65	0.35	43.1	0.009
Summer 85+86	0.64	0.59	42.1	0.018
Summer 85+86 weighed	0.65	0.47	41.8	0.010
b) PRESENCE OF SPERMATOPHORE				
Summer 1985	1	1.97	32.9	0.007
Summer 1985 weighed	1	1.77	32.9	0.003
Summer 1986	1	0.58	36.8	0.014
Summer 1986 weighed	1	0.59	36.8	0.005
Summer 85+86	1	0.45	34.8	0.023
Summer 85+86 weighed	1	0.59	36.7	0.009

Males complete their maturity in a restricted size range (30-33 mm CL). The biometric analysis showed that the transition between long and short rostrum happens in the 31 mm class (Ragonese, 1990). Since a TL-CL plot of *Aristaeomorpha foliacea* males suggested other discontinuities (besides the rostrum shortening process) in the range 25-28 mm CL, the percentage of males (seasons combined) with short-rostrum, males with welded-petasma and males with spermatophore pads in the *ampullae* were plotted against carapace length (Fig. 42). The graph indicates that the shortening of the rostrum follows the storage of spermatophores and the welding of petasma. For the rostrum, the change from long to short condition occurs between 29 and 33 mm CL (primarily in 31-32 mm range); for the petasma and *ampullae* characters, the transition is more gradual. Above 33-35 mm CL, all males are apparently "fully mature".

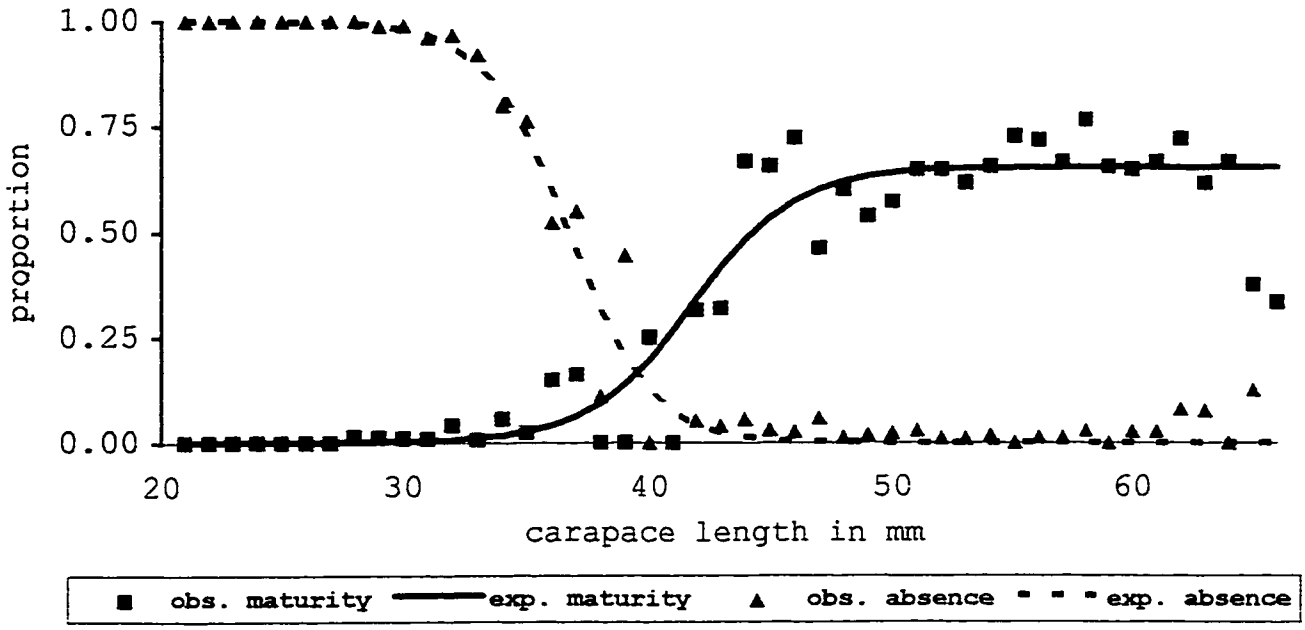


Fig. 41 - Reproductive potential of *Aristaeomorpha foliacea* females by two criteria, maturity stage and presence of spermatophore (data from earlier trawl surveys) (modified from Ragonese and Bianchini, 1995).

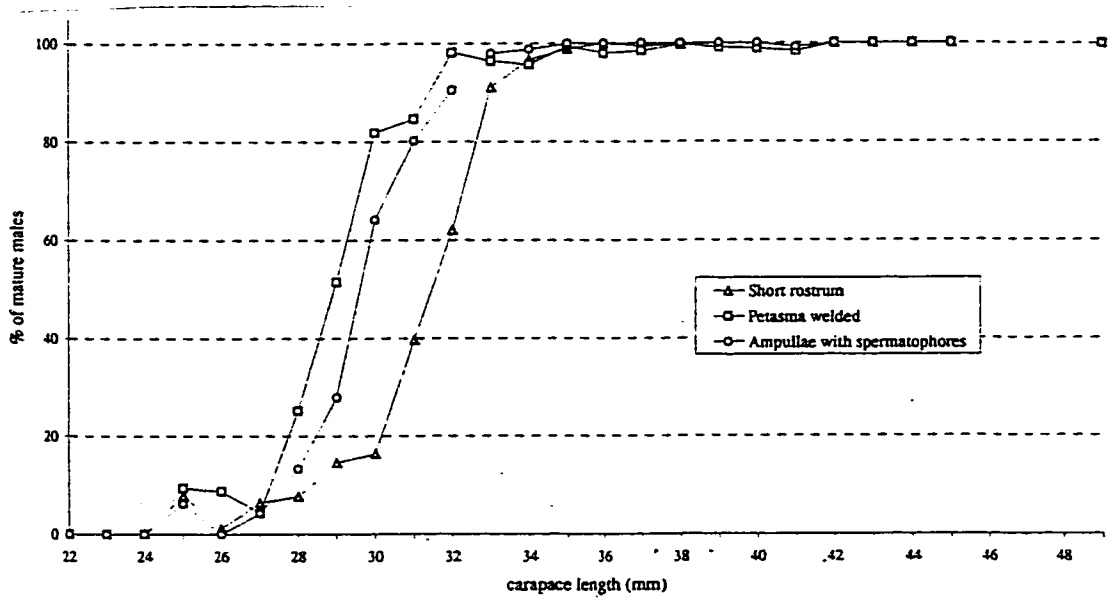


Fig. 42 - Reproductive potential of *Aristaeomorpha foliacea* males by three criteria, rostrum shape, welded petasma and presence of spermatophores (data from earlier trawl surveys) (modified from Ragonese *et al.*, 1997).

Recruitment

Macroscopically, two main groups can always be observed in red shrimp LFDs; the recruits of the year (juvenile males and females) and the adults (males and females), survivors from the recruitment events of previous years. The first group is unimodal (sometimes a double pulse can be observed) and well defined (till the autumn). Despite the large variability (especially the much smaller recruitment in the first year of the earlier trawl surveys) it is possible to distinguish a basic seasonal scheme where the first component quickly progresses up to the second, until the merging in the following spring, when a new recruitment pulse appears.

Table 26 - Percentage of landings of *Aristaeomorpha foliacea* of the IV commercial category (i.e., recruits), by season (years 1991-94).

	Spring		Summer		Fall		Winter	
	%	St.D.	%	St.D.	%	St.D.	%	St.D.
1991	30		21		28		21	
1992	24		23		18		35	
1993	19		33		23		25	
1994	22		15		20		43	
mean	24	±3.9	23	±6.6	22	±3.8	31	±11.5

Notwithstanding the aleas in the recruitment strength, data from the commercial catch (landings of category IV, i.e. small individuals) show that a consistent recruitment (Table 26) was always present in previous years, at least in the last decade. The virtual population reconstruction done with the ANALEN program estimates the number of

exploitable recruits (those surviving at 12 mm CL) at 120-130 million for the Sicilian Channel when using the earlier trawl surveys data, and at 75-80 million with the selectivity study data. The rough bottom configuration creates non-fishable havens, thus part of the actual recruitment never becomes available to the gear.

FISHERY

Yields

The red shrimp *Aristaeomorpha foliacea* was caught over the whole surveyed area during the selectivity experiment (the sampling design was targeting red shrimps). The yield was a total catch of 177,265 specimens (3,333 kg) from 102 valid hauls. The highest catch was observed in the SE zone and during summer. Considering the seasons combined, the mean catch per standard haul (3 hours) was 1,738 specimens (i.e., 579 shrimp/h) or 33 kg (i.e., 11 kg/h); this corresponds to almost 2000 shrimp/km^2, or 110 kg/km^2. It is worth noting that the literature reports 25 kg/h in the early '60s. There was high variability within the same zone and season, both for the red shrimp and for the associated species. Even a qualitative analysis of data shows consistent differences among geographical areas especially in the catch composition (for example, juveniles were poorly or not represented in the MA and NW zones).

In the earlier eight trawl surveys the total catch of *Aristaeomorpha foliacea* was 463 kg (corresponding to 19,400 animals) from 164 valid hauls of which 132 were positive for red shrimps (the sampling design was random stratified). The catch per hour in the earlier trawl surveys was around 3 kg/h with peaks at 9 kg/h. A qualitative analysis of data from the early trawl surveys shows that the catch in weight was greater in the lower levels (500-700 m) but not statistically (mean catch in kg/h ± standard deviation, n= 8: upper stratum 300-500 m, Y/h= 2.25 ±0.727; lower stratum, Y/h= 3.31 ±1.099). The catch in number showed an opposite but still not significant trend, suggesting the animals were bigger at greater depths (upper stratum, catch in number= 123.1 ±69.33; lower stratum, n= 110.1 ±37.06).

No correlation has been demonstrated between the presence of *Aristeus antennatus* and that of *Aristaeomorpha foliacea* (Table 27), perhaps as a consequence of the extreme patchiness of the former. Incidentally, the catch per hour in the hauls positive for *Aristeus antennatus* was around 0.3 ±0.7 kg/h, with peaks at 4.2 kg/h (12 ±27 animals/h, max 163 animals/h).

Table 27 - Association between red shrimps (*Aristaeomorpha foliacea* and *Aristeus antennatus*) captures, from earlier trawl surveys (amount of hauls limited to potentially productive ones) (modified from Ragonese and Bianchini, 1992).

		Aristaeomorpha				
	class	**0**	**1**	**2**	**3**	**4**	**tot**
A							
r	**0**	30	4	13	21	28	96
i	**1**	0	4	3	12	10	29
s	**2**	0	0	1	10	9	20
t	**3**	0	0	0	11	6	17
e	**4**	0	0	0	0	1	1
u							
s	**tot**	30	8	17	54	54	163

Frequency classes of capture:

0 = no capture in the haul
1 = 1 - 5 specimens
2 = 6 - 25 specimens
3 = 26 - 125 specimens
4 = > 125 specimens

Differences in daylight and night fishing

The hourly capture (Table 28) was very variable among the hauls but in all cases (with the exception of the violet shrimp in hauls 50 *vs.* 51) the daylight catch of shrimps, both in weight (Fig. 43) and number (Fig. 44), was consistently higher than the night catch. In *Aristaeomorpha foliacea*, the overall mean differences were 219 *vs.* 488 animals (ratio 0.45) and 5.2 kg/h *vs.* 9.7 kg/h (ratio 0.53), for night and daylight respectively, and the probability of both t-tests was less than 0.001 (Table 29).

Table 28 - Hourly captures in weight and number, and mean individual weight of *Aristaeomorpha foliacea* and *Aristeus antennatus*; by night and daylight hauls (noted by their progressive number), and their ratio (modified from Bianchini *et al.*, 1998c).

			yield			catch			mean weight		
			night	day	N/D	night	day	N/D	night	day	N/D
haul Night/Day	season	zone	kg/h	kg/h	%	n/h	n/h	%	g	g	%
Aristaeomorpha foliacea											
59 *vs* 60	Spring	Marettimo	1.5	3.8	39	53	117	45	27.8	32.5	86
102 *vs* 101	Summer	SE Linosa	8.9	10.5	85	516	627	82	17.3	16.8	103
79 *vs* 75,76,77,78	Summer	NE Linosa	2.3	8.9	26	73	385	19	31.4	23.2	135
13 *vs* 12,14	Spring	SE Linosa	11.6	17.4	67	464	1155	40	25.1	15.1	166
26 *vs* 24	Spring	NE Linosa	2.5	3.5	72	89	326	27	28.1	10.6	264
50 *vs* 51	Spring	NW Linosa	3.7	6.1	60	103	186	55	36.0	32.9	109
97 *vs* 96	Summer	SE Linosa	9.1	13.7	66	449	743	60	20.2	18.4	110
40,45 *vs* 42,43	Spring	NE Linosa	2.8	12.9	22	124	493	25	22.9	26.2	88
88 *vs* 84,85,86,87	Summer	SE Linosa	7.1	8.6	83	295	526	56	24.2	16.3	148
35 *vs* 36,37	Spring	NE Linosa	5.8	13.0	44	214	567	38	27.0	23.0	117
70 *vs* 71,72,73,74	Summer	NE Linosa	1.5	7.9	19	34	237	15	42.7	33.2	129
mean			5.2	9.7	53	219	488	45	23.5	19.8	119
Aristeus antennatus											
59 *vs* 60	Spring	Marettimo	1.1	1.8	58	44	74	59	24.2	24.7	98
50 *vs* 51	Spring	NW Linosa	0.9	0.8	122	46	46	101	20.1	16.8	120
40 *vs* 42,43	Spring	NE Linosa	0.4	1.7	25	19	72	26	23.2	24.0	97
35 *vs* 36,37	Spring	NE Linosa	0.6	1.5	41	34	70	48	18.6	21.8	85
70 *vs* 71,72,73,74	Summer	NE Linosa	0.4	1.3	32	19	71	27	21.1	17.8	118
mean			0.7	1.4	49	32	67	49	21.4	21.4	100

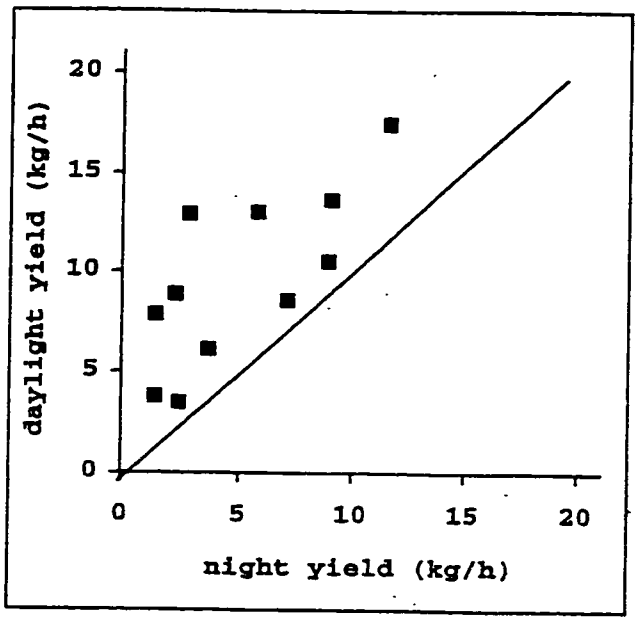


Fig. 43 - Yield (kg/h) of daylight and night hauls for *Aristaeomorpha foliacea* (data from selectivity study) (modified from Bianchini *et al.*, 1998c).

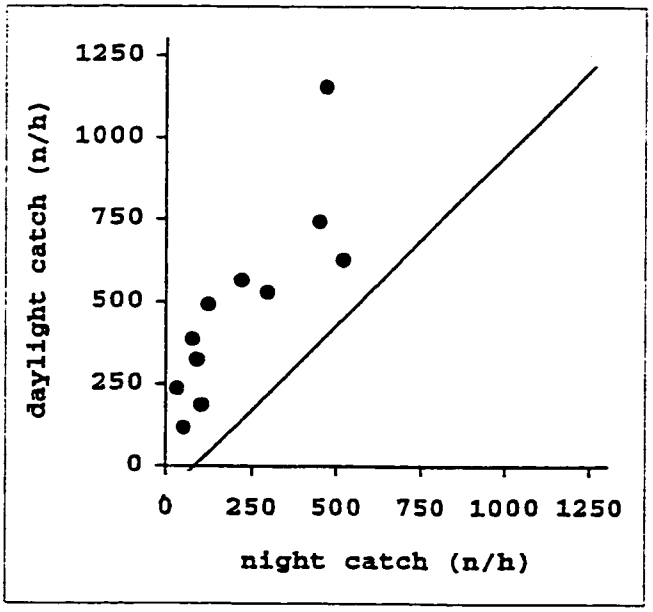


Fig. 44 - Yield (specimen/h) of daylight and night hauls for *Aristaeomorpha foliacea* (data from selectivity study) (modified from Bianchini *et al.*, 1998c).

Table 29 – Statistical test for the differences in daylight/night results of *Aristaeomorpha foliacea*.

parameter	**test**	**value**	**P**
yield in kg	t	5.04	0.0005
catch in n	t	5.08	0.0005
individual weight in g	t	-.56	0.0285
individual weight in g	sign	9/2	0.065

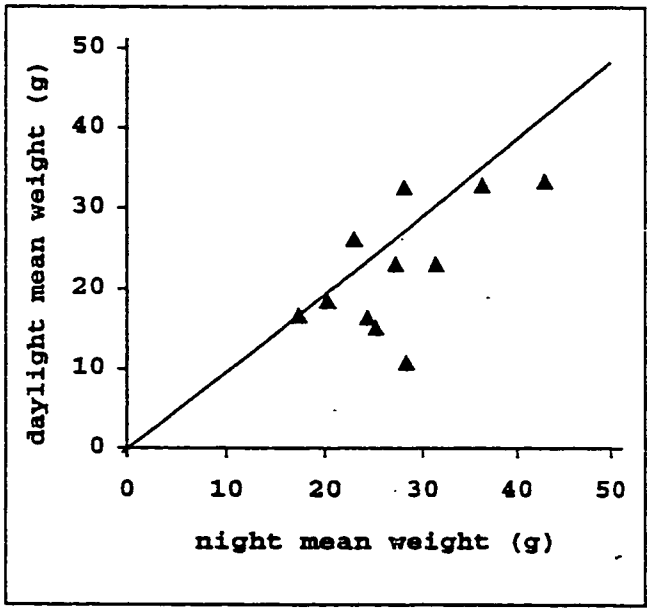


Fig. 45 - Mean weight (g) of *Aristaeomorpha foliacea* catches during daylight and night hauls (data from selectivity study) (modified from Bianchini *et al.*, 1998c).

An opposite trend was present in the mean individual weights, but not as strong (Fig. 45); still, an overall mean weight of 23.5 g in the night catch corresponded 19.8 g in

daylight (ratio 1.19) with a probability for the t-test lower than 0.03 (the non-parametric sign test was only marginally significant, at 0.06).

The comparison of the carapace length frequency distributions also showed dramatic differences: in all the 11 sets the differences were statistically significant (Table 30) with the night catch always trailing the daylight catch. Notwithstanding the smoothing due to the pooling, this behaviour was still visible in the combined data set (Fig. 46). Incidentally, for violet shrimp the night trawls yielded half the weight and number achieved in daylight hauls but did not show differences in size.

Table 30 - Kolmogorov-Smirnov test on the night/daylight carapace length frequency distribution of *Aristaeomorpha foliacea* (modified from Bianchini *et al.*, 1998c).

	catch		K & S statistics		5% critical	
haul N/D	night	daylight	D	D'	value	signif.
59 *vs* 60	136	336	0.0846	0.1454	0.1381	*
102 *vs* 101	1305	1817	0.1371	0.1861	0.0493	*
79 *vs* 75,76,77,78	200	1049	0.3047	0.3187	0.1048	*
13 *vs* 12,14	1285	3238	0.3028	0.3507	0.0448	*
26 *vs* 24	235	873	0.5261	0.6112	0.0998	*
50 *vs* 51	302	526	0.1434	0.2196	0.0981	*
97 *vs* 96	1317	2078	0.0519	0.0865	0.0478	*
40,45 *vs* 42,43	333	1326	0.1291	0.0818	0.0832	*
88 *vs* 84,85,86,87	844	1537	0.2897	0.3429	0.0582	*
35 *vs* 36,37	605	1555	0.1221	0.1491	0.0651	*
70 *vs* 71,72,73,74	102	655	0.2115	0.2261	0.1446	*
tot	583	1340	0.1055	0.1587	0.0674	*

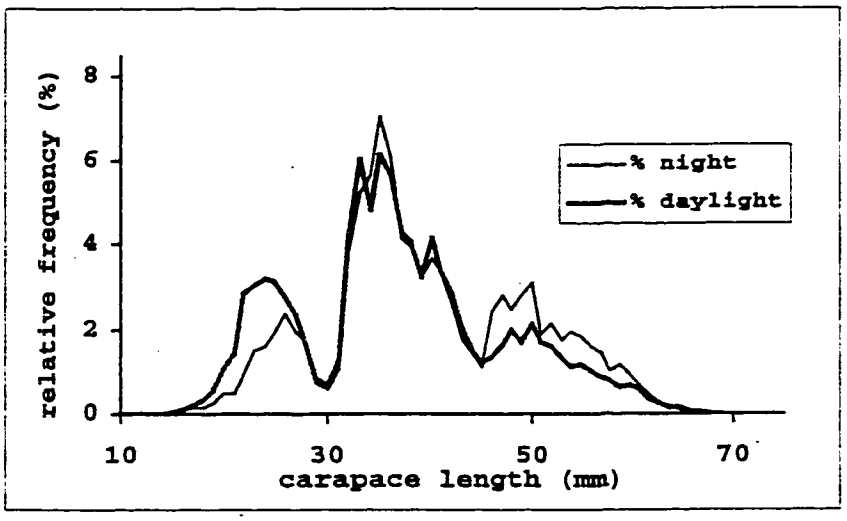


Fig. 46 - LFDs (CL, mm) of *Aristaeomorpha foliacea* catches during daylight and night hauls (data from selectivity study) (modified from Bianchini *et al.*, 1998c).

Selectivity

Interzone variability

The scarcity of juveniles and the presence of large-size red shrimps (CL> 60 mm) in both Marettimo and NW zones was evident whereas the recruitment occurred almost exclusively in the other two surveyed zones, SE and NE. Incidentally, juveniles (19-32 mm, CL) of violet shrimp have been caught in the NW zone, too. The small amount of red shrimp recruits in the Marettimo and NW zones remains an object of speculation.

The zone differences in the population structure has determined a large variability in the selection ratios, e.g. the mean of the selection ratios for *Aristaeomorpha foliacea* observed in summer ranged from 0.2% (NW) to 5.3 % (NE) with the 24/14 gear configuration. The qualitative comparison of the retained proportion *vs.* size class by gear configuration and zone lead to the conclusion that even if a zone-effect does actually occur, it is a consequence of sampling variability and does not reflect differences in the

selectivity processes of the different sub-populations. The retention in the summer red shrimp data appears to be systematically lower in the 45/14 and 24/14 gear configurations of NE than of the SE zone; in both cases, however, the differences reflect the different length structures and sample sizes observed in those zones.

Selection ogives and parameter estimation

Only the graphics corresponding to the data concerning the seasons combined (Fig. 47, 50, 53, 54, 55) are presented, while the parameter estimates are presented both as seasonal tables (Table 31 and Table 32) and as seasons combined table (Table 33). Estimated ogives were superimposed on the original scatter plots (placed below the corresponding LFDs). The logistic and the Gompertz's models adequately fit the observed data, at least when enough points ($N > 30$) and number of specimens in the length classes (n_i) are available, resulting in differences in the mean square errors (MSE= LOSS/N-2) almost always less than 1%. The Gompertz's model usually approaches the points corresponding to the smallest length classes better and its estimates are more correlated ($r > 0.9$) than those corresponding to the logistic ($r < 0.6$). Nevertheless, since the first classes are generally poorly represented numerically, the "best" graphical fitting does not necessarily correspond to the best maximum likelihood fitting, in which the number of specimens in each length class plays a very important role, as shown by the asymptotic standard errors of the estimates reported in the synoptic tables. The logistic model has generally been preferred, except when departure from symmetry is radical. Examples of the IN and OUT capture with small-size (Fig. 48 and Fig. 49) or medium-size (Fig. 51 and Fig. 52) meshes are pictorially presented too.

Table 31 - Selectivity estimates for *Aristaeomorpha foliacea* from the spring survey. GC: gear configuration; N: sample size (CL classes used); Chosen: model preferred. Logistic model: $\rho = 1/(1 + \exp(-\alpha*(X - \beta)))$; Gompertz's model: $\rho' = \exp(-\alpha'*\exp(-\beta'*X))$; where ρ and X denote the retained proportion and the carapace length (CL; mm) respectively. CL50%: size at 50% of retention; range: CL75%-25%; overall rate (%): out/(in+out); factor: CL50%/mesh side. s.e. denotes the asymptotic standard error of the estimated coefficients α, β.

		MODEL						CHOSEN			SELECTION	
		logistic			Gompertz							
GC	N	α	β	CL50%	α'	β'	CL50%	type	CL50%	range	rate (%)	factor
16/14		-	-	-	-	-	-	-	-	-	0.30	-
20/14	34	0.393	17.77	17.8	348.0	0.348	17.8	logistic	17.8	5.6	5.24	0.89
s.e.		0.0117	0.125		64.88	0.0092						
24/14	40	0.407	20.38	20.4	456.0	0.322	20.1	logistic	20.4	5.4	16.44	0.85
s.e.		0.0101	0.073		62.68	0.0067						
28/14	46	0.163	24.68	24.7	20.8	0.139	24.5	Gompertz	24.5	6.4	15.67	0.87
s.e.		0.0039	0.259		1.89	0.0029						
45/14	44	0.052	56.43	56.4	4.5	0.033	56.5	-	-	-	69.03	-
s.e.		0.0042	1.380		0.49	0.0027						

Table 32 - Selectivity estimates for *Aristaeomorpha foliacea* from the summer survey. GC: gear configuration; N: sample size (CL classes used); Chosen: model preferred. Logistic model: $\rho = 1/(1 + \exp(-\alpha*(X - \beta)))$; Gompertz's model: $\rho' = \exp(-\alpha'*\exp(-\beta'*X))$; where ρ and X denote the retained proportion and the carapace length (CL; mm) respectively. CL50%: size at 50% of retention; range: CL75%-25%; overall rate (%): out/(in+out); factor: CL50%/mesh side. s.e. denotes the asymptotic standard error of the estimated coefficients α, β.

		MODEL						CHOSEN			SELECTION	
		logistic			Gompertz							
GC	N	α	β	CL50%	α'	β'	CL50%	type	CL50%	range	rate (%)	factor
16/14		-	-	-	-	-	-	-	-	-	0.00	-
20/14	27	0.362	16.72	16.7	306.0	0.350	17.4	logistic	16.7	6.0	1.59	0.83
s.e.		0.0178	0.415		125.92	0.0167						
24/14	36	0.313	18.78	18.8	197.4	0.293	19.3	logistic	18.8	7.0	4.01	0.78
s.e.		0.0096	0.228		42.58	0.0085						
28/14	36	0.184	22.59	22.6	31.2	0.166	22.9	Gompertz	22.9	9.5	16.16	0.82
s.e.		0.0034	0.152		2.59	0.0029						
45/14	50	0.051	51.54	51.5	3.8	0.033	51.1	-	-	-	67.45	-
s.e.		0.0019	0.624		0.17	0.0012						

Table 33 - Selectivity estimates for *Aristaeomorpha foliacea* from the pooled selectivity surveys. GC: gear configuration; N: sample size (CL classes used); Chosen: model preferred. Logistic model: $\rho = 1/(1 + \exp(-\alpha*(X - \beta)))$; Gompertz's model: $\rho' = \exp(-\alpha'*\exp(-\beta'*X))$; where ρ and X denote the retained proportion and the carapace length (CL; mm) respectively. CL50%: size at 50% of retention; range: CL75%-25%; overall rate (%): out/(in+out); factor: CL50%/mesh side. s.e. denotes the asymptotic standard error of the estimated coefficients α, β.

		MODEL						CHOSEN			SELECTION	
		logistic			Gompertz							
GC	N	α	β	CL50%	α'	β'	CL50%	type	CL50%	range	rate (%)	factor
16/14	6	-	-	-	-	-	-	-	-	-	0.09	-
20/14	34	0.399	17.68	17.7	426.0	0.360	17.8	logistic	17.7	5.5	3.33	0.88
s.e.		0.0085	0.117		63.00	0.0069						
24/14	40	0.379	20.14	20.1	442.2	0.323	20.0	logistic	20.1	5.8	8.60	0.84
s.e.		0.0061	0.071		43.90	0.0045						
28/14	46	0.170	22.81	22.8	23.2	0.152	23.1	Gompertz	23.1	10.5	16.00	0.82
s.e.		0.0025	0.137		1.39	0.0021						
45/14	50	0.050	53.09	53.1	3.8	0.032	52.9	-	-	-	67.80	-
s.e.		0.0017	0.592		0.15	0.0010						

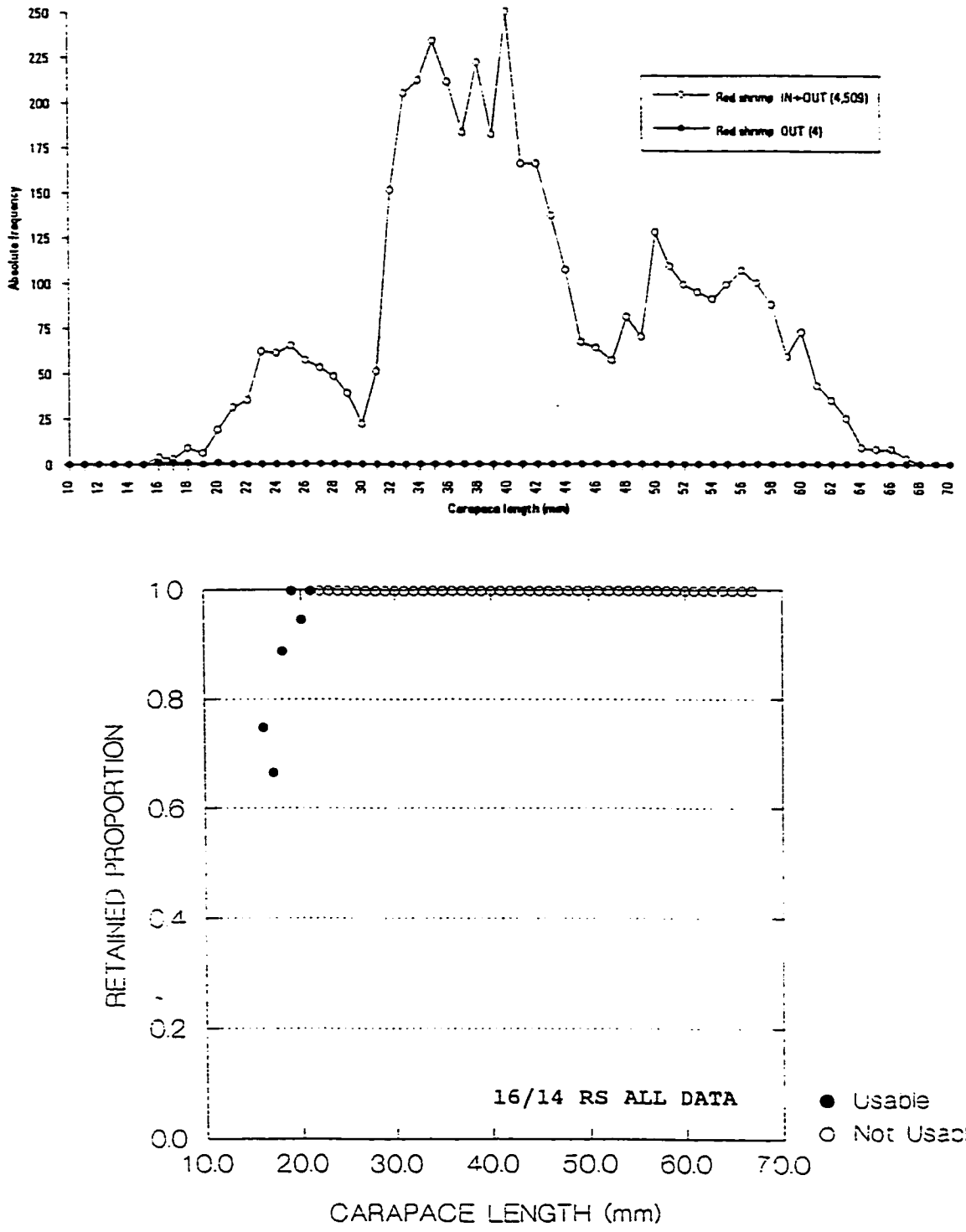


Fig. 47 - Selectivity of the gear configuration 16/14 for *Aristaeomorpha foliacea* (seasons combined), and corresponding selection curves.

Generally speaking, the broad retention of the LFD will depend on the season and gear configuration as clearly indicated by the variability in the selection ratios as evidenced by the differences in the mean values and the corresponding standard deviation. For the red shrimp, by combining the data from the different localities, the following results were obtained:

GC 16/14; Total hauls = 6 (2 in spring and 4 in summer).

Spring - 1,343 specimens were caught, of which only 4 (of 16, 17, 18 and 20 mm CL) were able to escape, resulting in a very low selection ratio (0.30%). The length range was 16-67 mm but length classes below 21 mm and above 58 mm were poorly represented (n< 20). The scanty usable points (6) made model fitting unfeasible. In spring, this GC was practically non-selective.

Summer - 3,166 specimens were caught and fully retained (SR= 0%). The length range was 17-67 mm but length classes below 23 mm and above 62 mm were poorly represented (n< 30). In summer this GC resulted to be non-selective.

Combined - The total catch is 4,509 shrimp with only 4 specimens escaped thus reducing the global SR to 0.09%. The minimum retained proportion is 0.67 and only 6 data could have been used, but fitting was unfeasible. The conclusion is that the 16/14 gear is non-selective for red shrimp (Fig. 47).

GC 20/14; Total hauls = 27 (15 in spring and 12 in summer).

Spring - 23,120 specimens were caught, of which 1,211 were able to escape resulting in a selection ratio of 5.24%. The length range was 12-66 mm and only the extreme length classes at both tails were poorly represented (n< 30). The retained proportion increased quickly with size and both models fit the data quite well giving the same CL50%, 17.8 mm, and a selection factor of 0.89.

Summer - 25,464 specimens were caught, of which only 405 escaped, thus reducing the SR (1.59%). The length range was 18-67 mm and almost all sizes were well represented. The lack of retained proportion below the 0.5 limit, determined different, less precise estimates; according to the logistic model, the CL50% (16.7 mm) and, consequently, the SF (0.83) are slightly lower than spring estimates (Fig. 48 and Fig. 49).



Fig. 48 - A typical "IN" component of the catch with small mesh (haul 113, gear configuration 20/14, summer survey) in the red shrimps fishery.

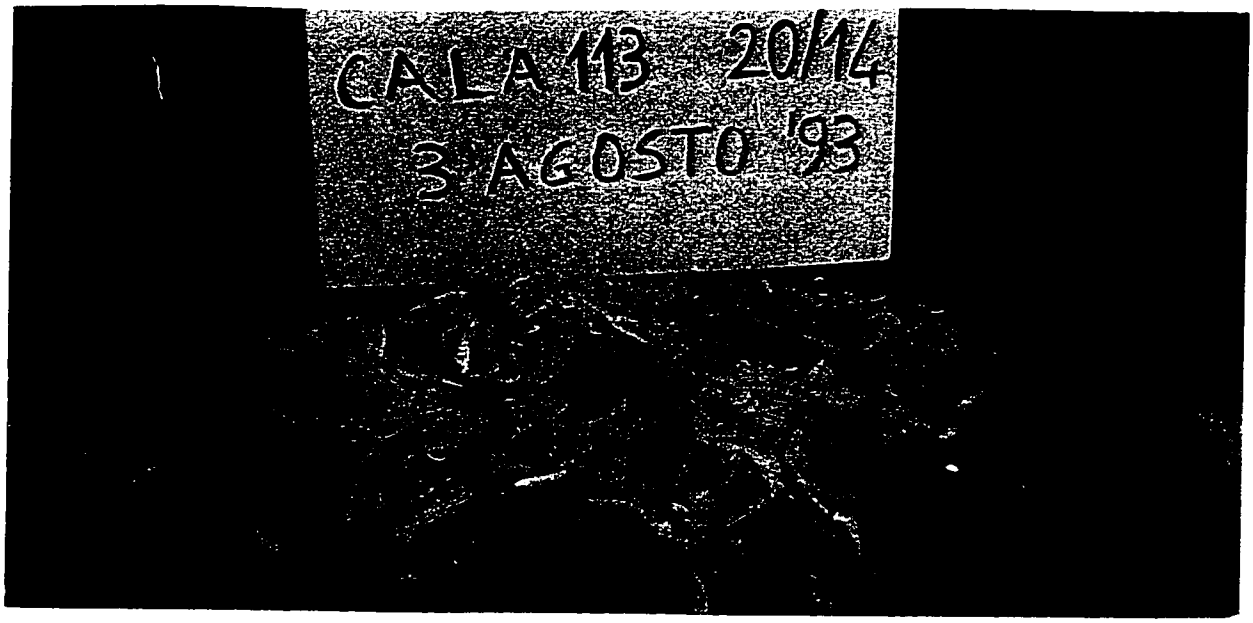
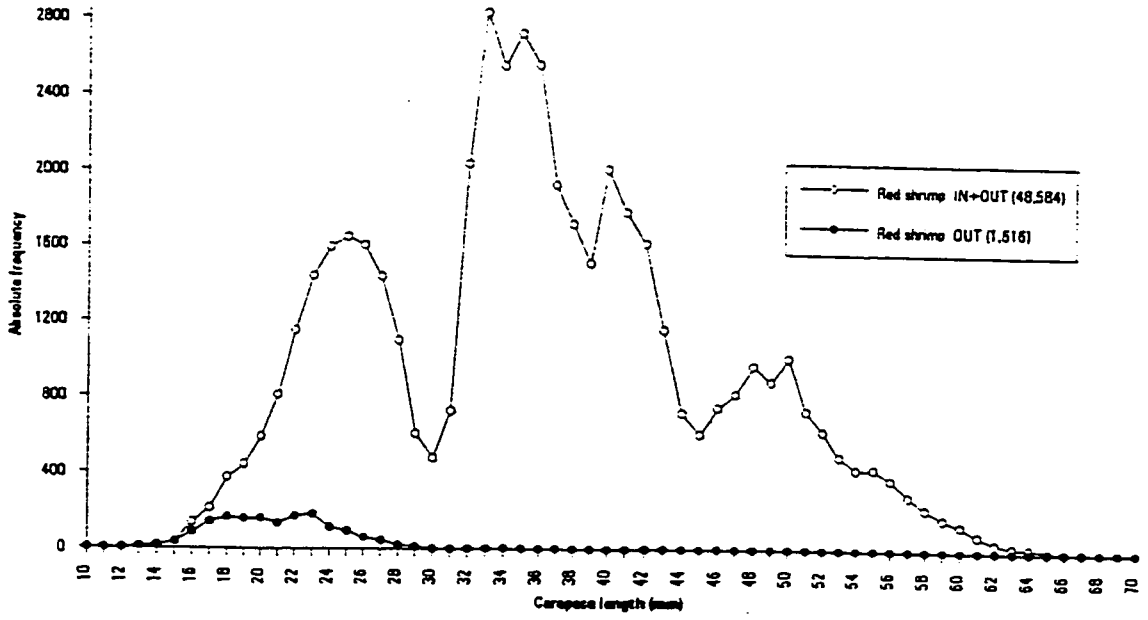


Fig. 49 - A typical "OUT" component of the catch with small mesh (haul 113, gear configuration 20/14, summer survey) in the red shrimps fishery.



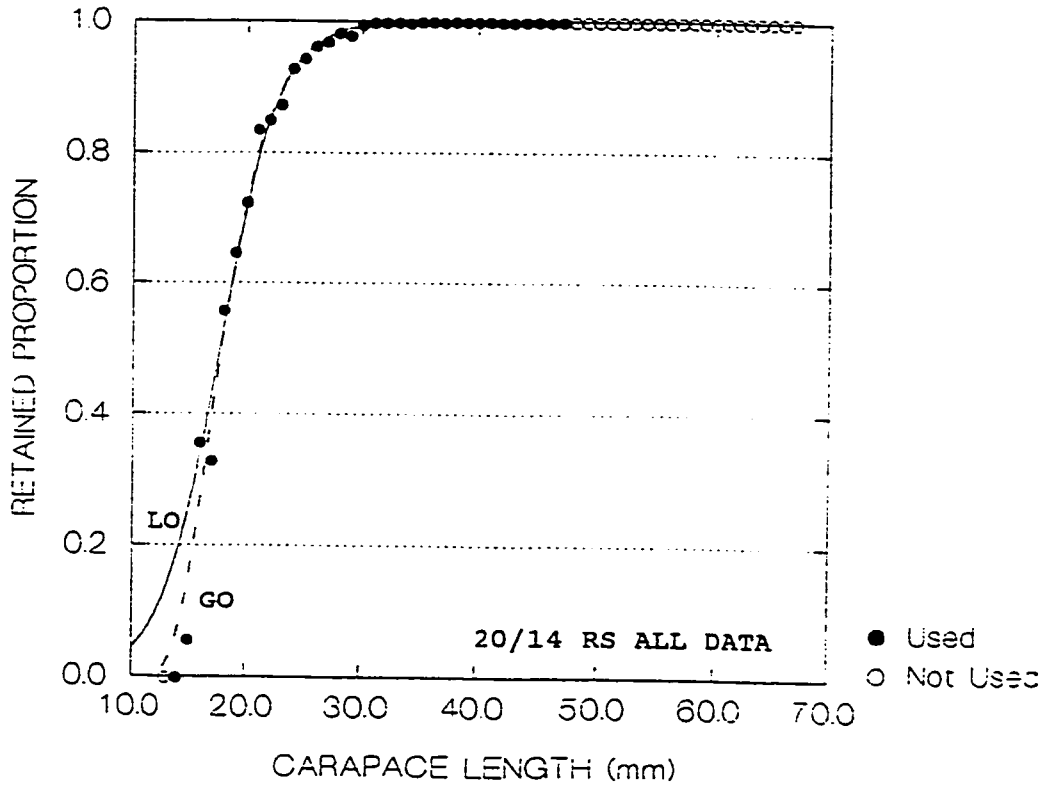


Fig. 50 - Selectivity of the gear configuration 20/14 for *Aristaeomorpha foliacea* (seasons combined), and corresponding selection curves.



Fig. 51 - A typical "IN" component of the catch with larger mesh (haul 108, gear configuration 24/14, summer survey) in the red shrimps fishery.



Fig. 52 - A typical "OUT" component of the catch with larger mesh (haul 108, gear configuration 24/14, summer survey) in the red shrimps fishery.

Combined - The total catch is 48,584 shrimps of which 1,616 escaped resulting in a total SR of 3.3%. Both scatter plot and estimation are slightly improved but the estimated coefficient and SF are practically unchanged with respect to the spring situation (Fig. 50).

GC 24/14, Total hauls = 24 (8 in spring and 14 in summer).

Spring - 16,334 specimens were caught, of which 2,686 were able to escape resulting in a selection ratio of 16.44%. The length range was 13-65 mm and almost all the length classes were well represented. The retained proportions approached quite well a sigmoidal model and both models yielded the same conclusion, i.e. a CL50% of about 20 mm. According to the logistic estimate (20.4), a SF of 0.85 did result.

Summer - 27,790 specimens were caught, of which 1,119 were able to escape (SR= 4.01%); the drastic reduction of the SR is a consequence of the growth of the first component (Fig 51 and Fig. 52). The length range was 16-68 mm and almost all length classes were well represented, except the 3 at the extreme tails of the LFD. Even if the modal progression reduced the scatterplot to the half side above the 50% of retention, the sigmoid was chosen as the best between the 2 models. According to the logistic, a CL50% of 18.8 mm was derived with a corresponding SF of 0.78.

Combined - The total catch is 44,224 shrimps, of which 3,805 are able to escape with a SR of 8.6%. The scatterplot shows a slight improvement. A certain degree of asymmetry is appreciable, but since the first 4 used points correspond to length classes quite poorly represented, the logistic is still preferred; the CL 50% was 20.1 mm (*vs.* 20 mm of the Gompertz's curve) with a SF of 0.84 (Fig. 53).

GC 28/14; Total hauls = 27 (11 in spring and 16 in summer)

Spring - 11,730 specimens were caught, of which 1,838 were able to escape resulting in a selection ratio of 15.7%. The length range was 14-66 mm and almost all the length classes were well represented. The retained proportions did not fully

correspond to the sigmoidal model; the inflection point seems to occur quite precociously and the plot went up almost straight before approaching the asymptote. Nevertheless, both models yielded similar and quite satisfactory conclusions as a consequence of the low weights. The Gompertz's estimates were however preferred given the high departure from the symmetry. The estimates were 24.5 mm and 0.87 for CL50% and SF respectively.

Summer - 25,549 specimens were caught, of which 4,128 were able to escape (SR= 16.16%); the slight increase in the SR observed in this case (contrarily to the previous ones) is a consequence of the fact that the growth in carapace length of recruits, between the two seasons, did not compensate anymore the increase in the mesh size. The length range was 16-68 mm and almost all length classes were well represented, except the few at the extreme tails of the LFD. Available points resulted to be well distributed along the length range but the asymmetry was very pronounced. For this reason, and although the discrepancy between the logistic and observed data is more apparent than real (the first classes were poorly represented) the Gompertz's model was preferred; the resulting CL50% was 22.9 mm (close to the logistic value: 22.6) for a SF of 0.82.

Combined - The total catch is 37,279 shrimps, of which 5,966 were able to escape with a SR of 16.00%; it is worth to note that in this case this value does not change with the sampling season. The asymmetry of the points distribution becomes more accentuated even though considering the (relatively) scanty numeric consistency of the first classes. Both logistic and Gompertz's give similar results, but again the latter model is preferred, to take into account the asymmetric condition. The resulting CL50% is 23.1 mm with a SF of 0.82 (Fig. 54).

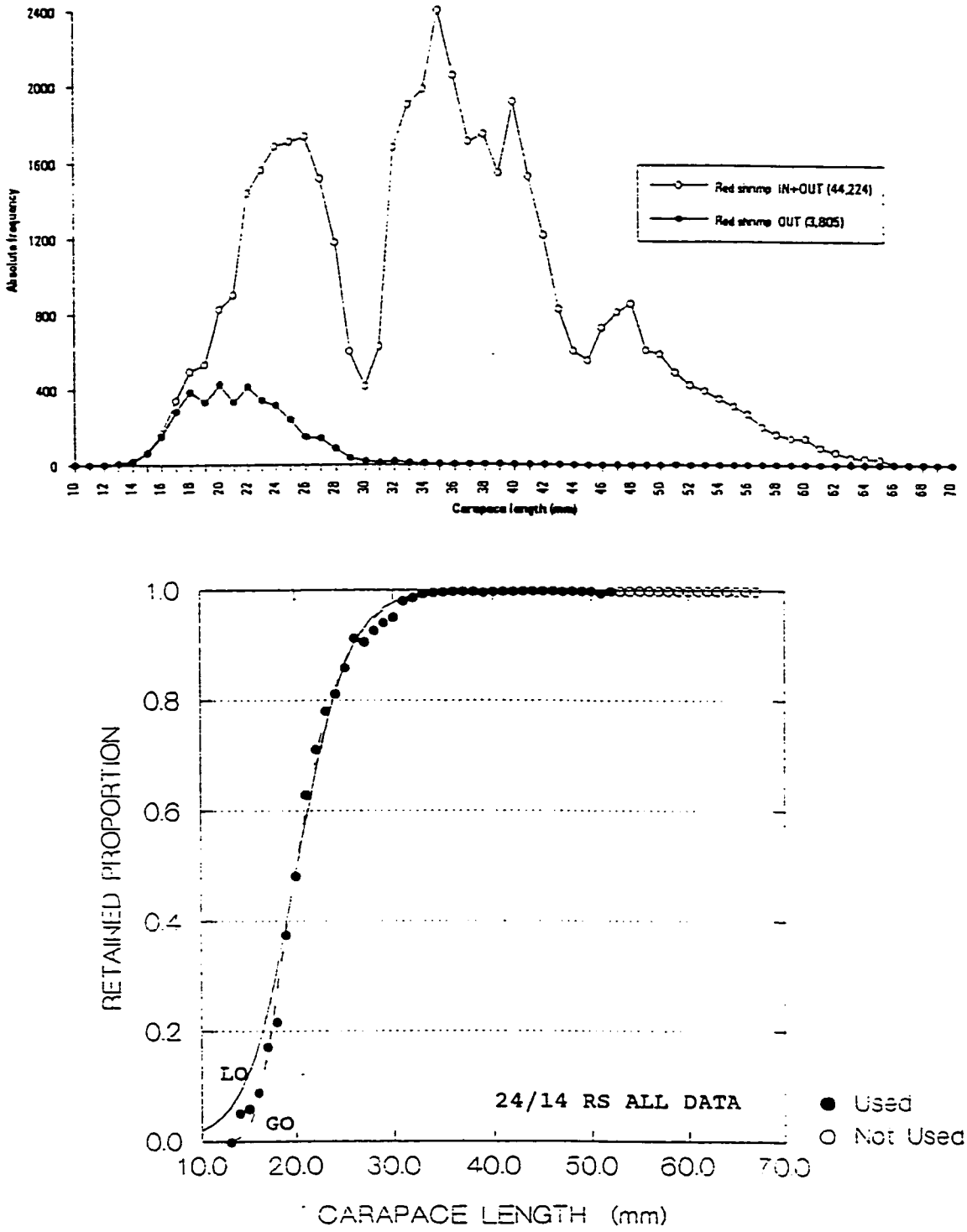


Fig. 53 - Selectivity of the gear configuration 24/14 for *Aristaeomorpha foliacea* (seasons combined), and corresponding selection curves.

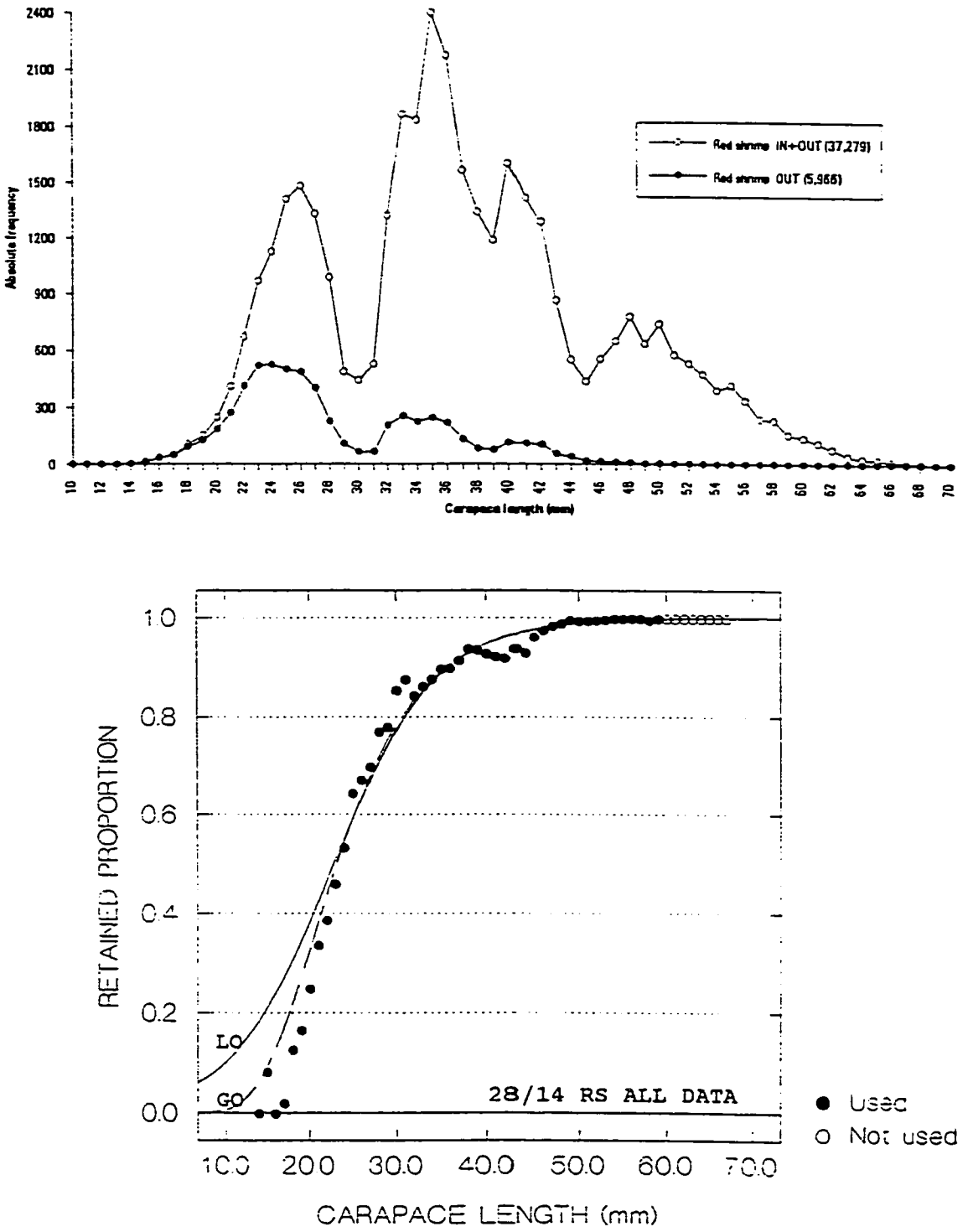


Fig. 54 - Selectivity of the gear configuration 28/14 for *Aristaeomorpha foliacea* (seasons combined), and corresponding selection curves.

GC 45/14; Total hauls = 11 (3 in spring and 8 in summer).

Spring - 3,746 specimens were caught, of which 12,586 were able to escape resulting in a selection ratio above the 50% (SR= 69.03%). The length range was 17-66 mm but length classes below 32 mm and above 58 were poorly represented. The retained proportions increased with size but the variability was large and the pattern did not correspond to a sigmoidal model, or at least was not well definable according to it; neither an asymptote nor an inflection point was evident. Nevertheless, both models were able to fit to some degree the observed data yielding similar results, for example a CL50% of about 56 mm. The imprecision of the estimates and the "huge" selection range made these results only indicative.

Summer - 13,434 specimens were caught, of which 9,062 were able to escape (SR= 67.45%). The length range was 18-67 mm and almost all length classes were well represented except the few at the extreme tails of the LFD. Available points resulted to be better distributed than in the spring sample but still not along a well-defined sigmoidal curve; in fact, a power or polynomial (parabolic) model could have been more suitable but not useful for the aim of the present study. Both models fitted the data to some degree, resulting in a lower CL50% (about 51 mm) and a slight improvement in the precision of the estimates. No model was chosen, given the above considerations.

Combined - The total catch is 17,180 shrimps, of which 11,648 were able to escape with a SR of 67.8%. The approximation of the points to a power model becomes more evident but it must be noted that the first length classes are very poorly represented. Again, both logistic and Gompertz's give similar results but this time a higher degree of precision corresponds to the estimates derived by the latter model. No model was chosen, given the above considerations (Fig. 55).

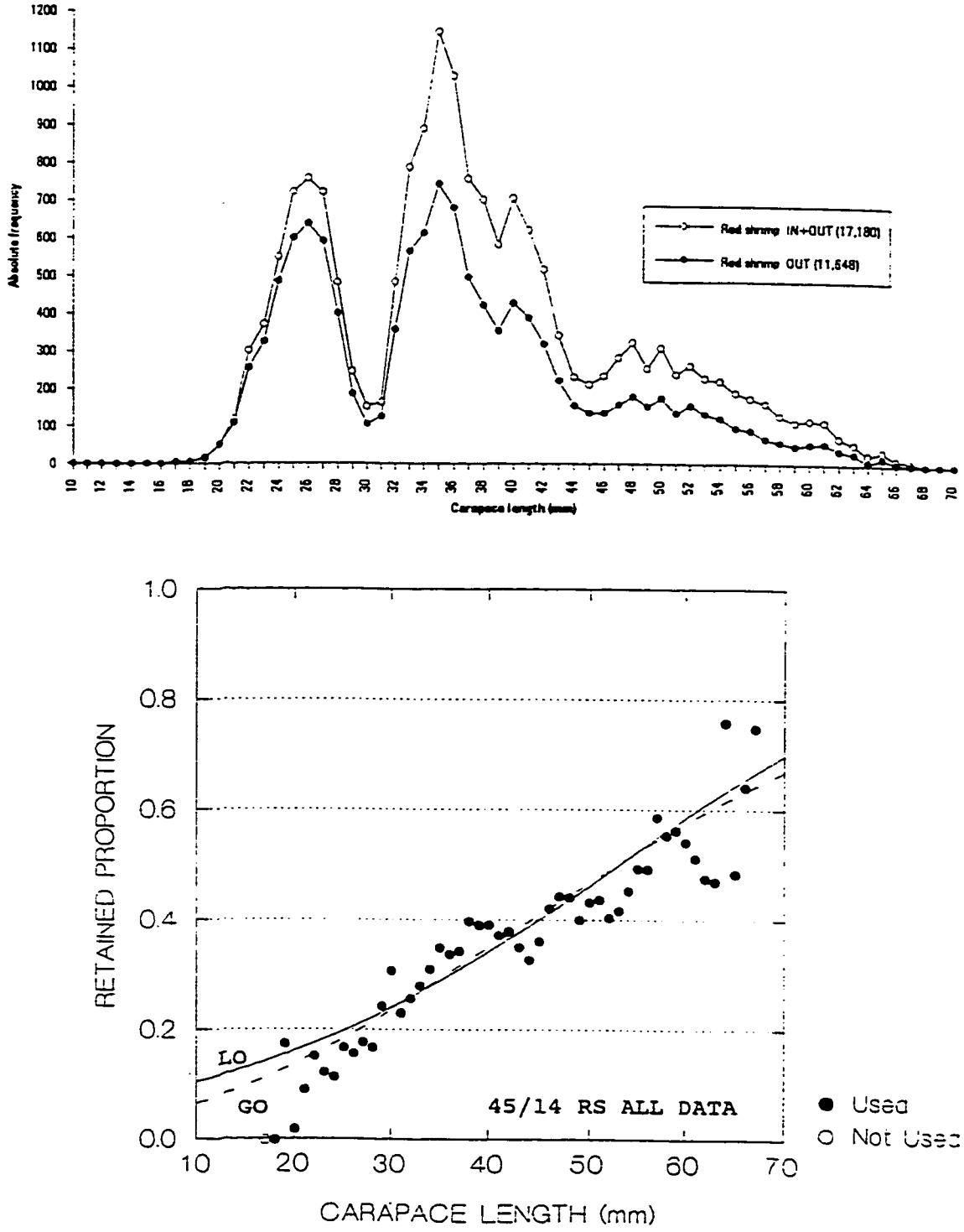


Fig. 55 - Selectivity of the gear configuration 45/14 for *Aristaeomorpha foliacea* (seasons combined), and corresponding selection curves.

Length at 50% of retention and selection factors *vs.* mesh size

The different carapace lengths at 50% of retention were plotted against the different mesh sizes for each season and for seasons combined (Fig. 56). Estimates derived by spring samples were higher than those derived in summer whilst it is worth noting the correspondence of the combined estimates with the spring ones for the 20/14 and for the 24/14 GCs; that behaviour was not observed for the 28/14 GC. This pattern results from the combined effects of the recruitment peak in spring (higher values) and from the under-compensation of the growth in CL *vs.* the increase in mesh size when the 28/14 GC was in use. From the graph it is evident that the combined data are more linearly correlated than each single season data ($r = 0.998$ *vs.* $r = 0.992$ and 0.983 for spring and summer estimates respectively). The attempt to fit a linear model with a non-zero intercept led to the non-rejection of the hypothesis "constant= 0" ($p >> 0.05$). Consequently the regression lines were recalculated with the constraint that they must pass through the origin (models without a constant). The slope of these lines gave the best overall estimate of the selection factor, resulting 0.870 (standard error= 0.011), 0.810 (s.e.= 0.014), and 0.843 (s.e.= 0.017) for spring, summer and combined data respectively. Even though the limited number of data warrants some cautions, the assumption of direct proportionality seems to be confirmed.

The individual selection factor *vs.* mesh side plot is presented in Fig. 57; while the spring and summer values show no appreciable trend, some negative linearity seems to characterize the combined data. According to Spearman's rank correlation test ($r_{sp} = -1$) the selection factors for the combined seasons are correlated with the mesh size whereas for the single seasons they are not ($r_{sp} = -0.5$). The negative correlation means that the curves become more flattened as the mesh increases. In fact, contrary to the theoretical expectation, the extrapolation of the effective results (e.g., calculating the selection factor of an hypothetical 22 mm mesh starting from the actual 20 mm or the actual 24 mm mesh) produced different estimations. Linear regressions, however, resulted to be not significant ($p = 0.67$, 0.88 and 0.121 for spring, summer and seasons combined

respectively); according to this approach, also the hypothesis of independence should be accepted.

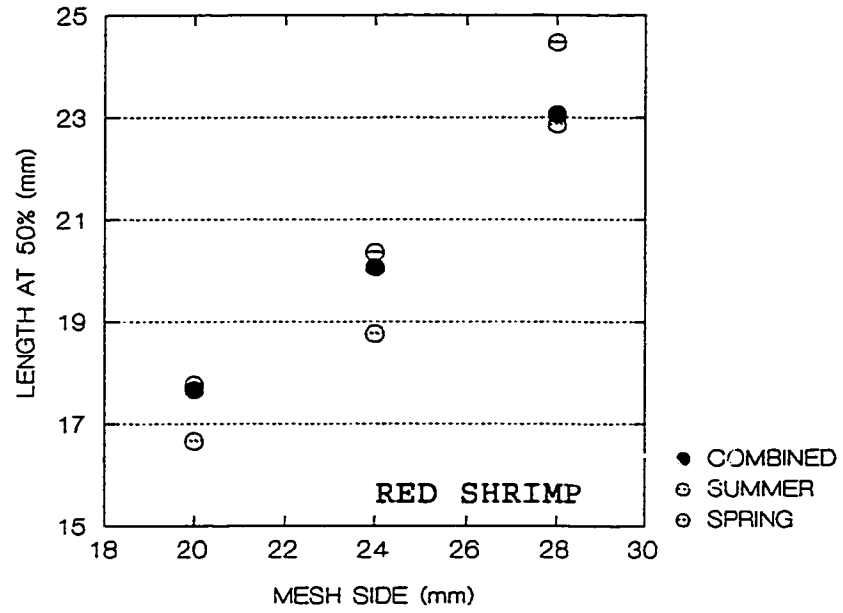


Fig. 56 - Length at 50% of retention *vs.* mesh side for red shrimps.

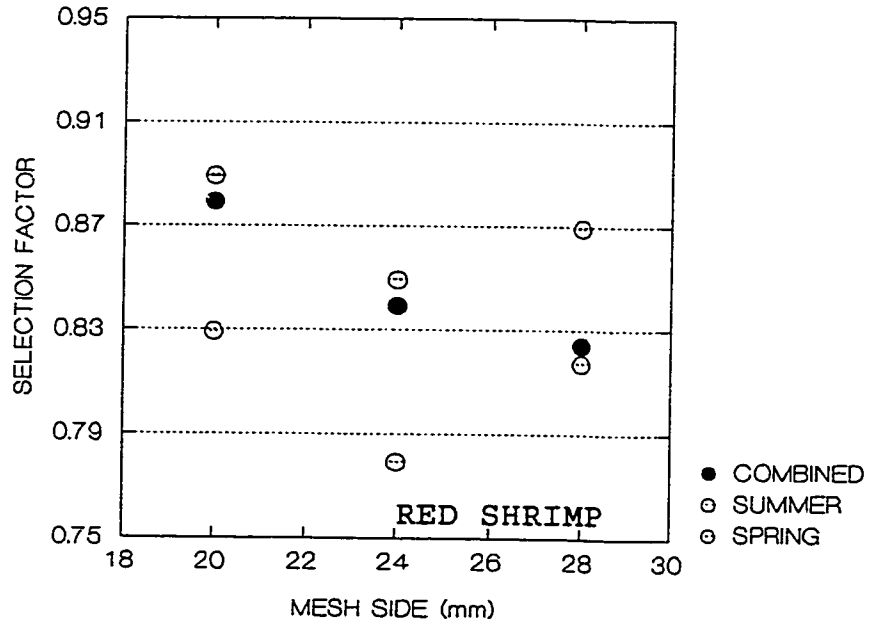


Fig. 57 - Selection factor *vs.* mesh side for red shrimps.

According to the empirical formulations and the life cycle parameters available for red and violet shrimps, the optimal size of first capture (Sinoda *et al.*, 1979), together with its range (Jones, 1976), is 38.6 mm or $26.2 < l_c^* < 45.8$ (for the violet shrimp: 42.0 mm or $28.4 < l_c^* < 49.7$).

"Control hauls"

The catch of the control hauls (gear configurations without cover) is comparable with those of experimental hauls within the 16/00 and 24/00 gear configurations, whereas a lower catch in number and weight was observed for the 28/00 and 45/00 GC. The difference, however, is substantial only for the 45/00 GC if data corresponding to all the summer hauls are compared.

Effect of sex on selectivity

An exploratory analysis of the data by gear configuration gave the following results where the numerator denotes the animals in the OUT component while the denominator indicates the whole sample (i.e., IN+OUT):

- 20/14 GC: very few length classes and specimens can be compared. It must be noted that above 30 mm CL practically all specimens were retained. Only 2/330 males escaped in the 8th haul whilst all females were retained (0/10) in the length range 32-33 mm CL. Similar results were observed in the 28th haul: 2/165 males *vs.* 0/3 females. In the 78th haul all males of 43 mm CL were retained (0/3) while 1/27 female was found in the OUT component. Finally in the 32nd haul all large males resulted to be in the IN component (0/2) whilst 1/49 female was able to escape from the cod-end.
- 24/14 GC: more cases were comparable. In the 12th haul, females, ranging from 31 to 33 mm CL, were all retained (0/26) ($p = 1$) whilst 7/872 males were found in the OUT component resulting in a retained proportion of 0.992. In the 14th and 15th hauls, between 32 and 35 mm CL, 15 females were caught and retained (0/15) where 8/559 males resulted in the OUT component ($p = 0.986$). In the 16th haul, between 32 and 36 mm CL, no female escaped (0/41) whereas 6/410 males were found in the OUT

component (p= 0.985). In the 93rd haul, 1/98 male of 37 mm CL was able to escape (p= 0.99) *vs.* 0/3 females which were retained. In the 95th haul all females (2 of 32 mm and 1 of 35 mm CL) were retained (0/3) *vs.* 3/288 males escaping (p= 0.99). In the last three hauls (107th, 125th and 126th) for which a comparison was possible, for the length class 32 mm, all females were retained (0/7) whereas 5/223 males (p= 0.978) were able to escape.

For the above two gear configurations, it seems that females are almost always retained whereas some males are able to escape. However, the very small number of female samples in these length classes, in respect to those of males, makes the retained proportions for females poor estimates of the true population parameters. Furthermore, almost all specimens above the 32-36 mm CL range were retained with the above configurations, whatever the sex.

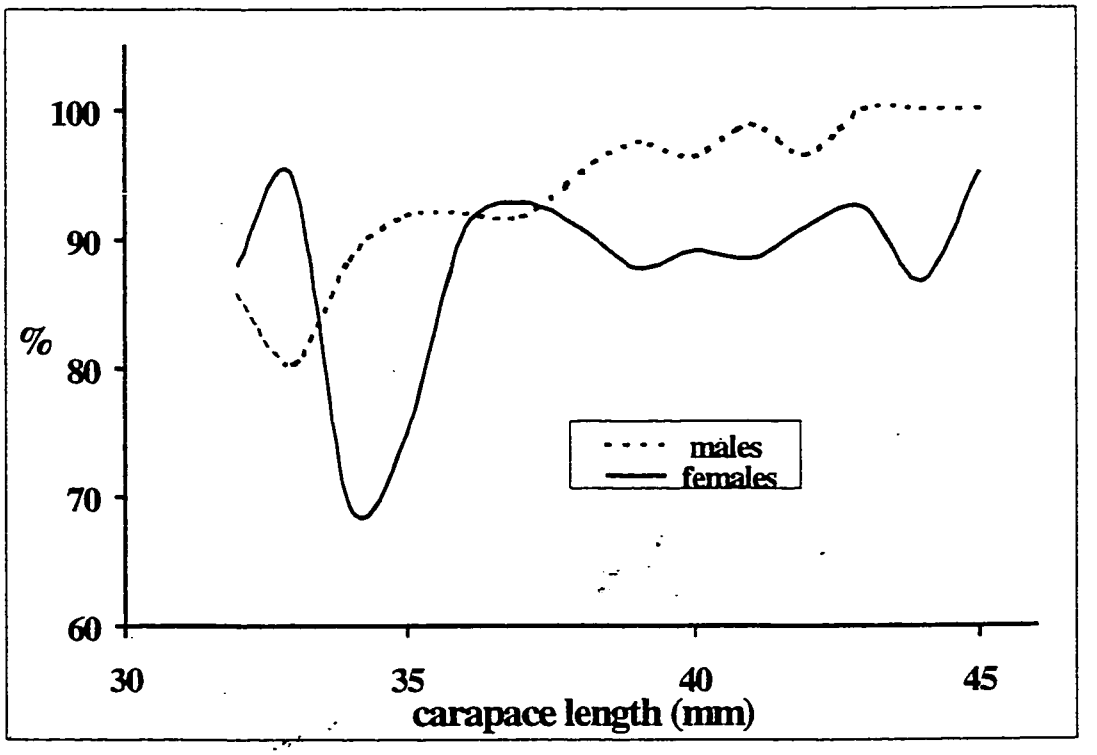


Fig. 58 - Overall trend of the proportions retained with the 28 mm mesh, by size (CL, mm), for *Aristaeomorpha foliacea* (modified from Bianchini *et al.*, 1998b).

More data were available for the two largest configurations, 28/14 and 45/14, and for these GCs a general comparison and testing was attempted. The trend for the 28/14 GC is shown in Fig. 58. The IN and OUT catch for adult males and females of the same length were compared after having combined the hauls for each gear configuration. The overall retained proportions (IN/IN+OUT) were computed and are reported in Fig. 59. The results of the Z test employed to assess the statistical significance of the departure from the expected null hypothesis ("the retained proportion is independent from the rostrum length") are reported in Table 34. Generally, lengths of males and females do not overlap very much and consequently in some cases the sample size could be too small and the result of each test might be taken as indicative only. The most useful gear configuration (28/14 GC) showed statistically significant differences in eight size classes (vs. six classes) and retained proportions of 91.8% and 89.6% for males (6838 animals) and females (3455 animals) respectively. The Z test for the 28/14 GC was highly significant (Z= 3.391).

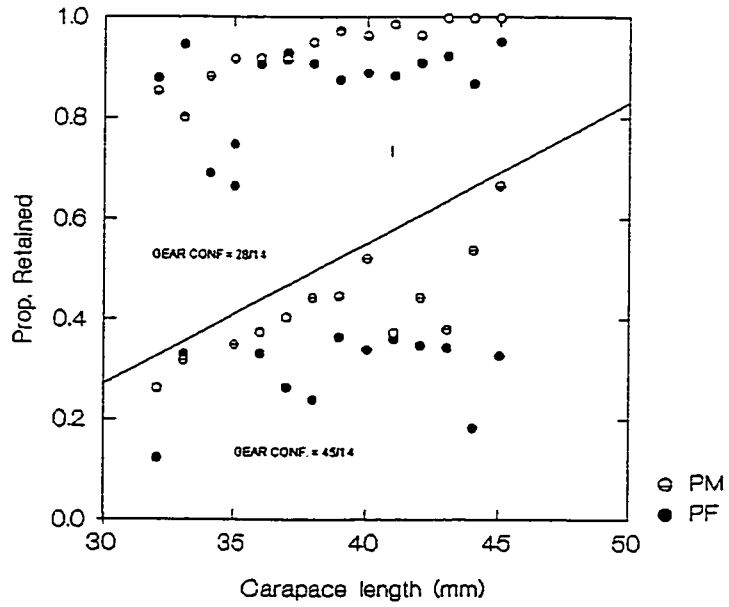


Fig. 59 - Retained proportion *vs.* size by sex (M: males; F: females) and gear configuration, for *Aristaeomorpha foliacea*.

Table 34 - Statistical comparison (Z test) of retained proportions (p) of males and females with the same carapace length (but different rostrum length). *= significant ($p< 0.05$); **= highly significant ($p< 0.01$) (modified from Bianchini *et al.*, 1998b).

		MALES				FEMALES					
GEAR	CL (mm)	IN	OUT	TOT	P	IN	OUT	TOT	P	Z	H_0
28/14	32	606	103	709	0.85	22	3	25	0.88	-0.357	
28/14	33	389	96	485	0.80	18	1	19	0.95	-1.575	
28/14	34	306	40	346	0.88	9	4	13	0.69	2.068	*
28/14	35	926	82	1008	0.92	15	5	20	0.75	2.689	**
28/14	36	1013	88	1101	0.92	40	4	44	0.91	0.264	
28/14	37	796	72	868	0.92	91	7	98	0.93	-0.416	
28/14	38	696	36	732	0.95	159	16	175	0.91	2.105	*
28/14	39	534	14	548	0.97	308	43	351	0.88	5.799	**
28/14	40	501	19	520	0.96	680	83	763	0.89	4.777	**
28/14	41	254	3	257	0.99	673	87	760	0.89	4.989	**
28/14	42	165	6	171	0.97	701	69	770	0.91	2.368	*
28/14	43	72	0	72	1.00	235	19	254	0.92	2.406	*
28/14	44	15	0	15	1.00	105	16	121	0.87	1.490	
28/14	45	6	0	6	1.00	40	2	42	0.95	0.546	
45/14	32	46	127	173	0.26	1	7	8	0.13	0.882	
45/14	33	99	211	310	0.32	1	2	3	0.33	-0.046	
45/14	35	156	288	444	0.35	4	2	6	0.67	-1.600	
45/14	36	272	450	722	0.38	4	8	12	0.33	0.304	
45/14	37	197	287	484	0.41	8	22	30	0.27	1.520	
45/14	38	202	252	454	0.45	16	50	66	0.24	3.137	**
45/14	39	130	160	290	0.45	48	83	131	0.37	1.571	
45/14	40	125	113	238	0.52	118	226	344	0.34	4.366	**
45/14	41	64	106	170	0.38	134	236	370	0.36	0.276	
45/14	42	67	83	150	0.45	134	249	383	0.35	2.055	*
45/14	43	18	29	47	0.38	81	153	234	0.35	0.477	
45/14	44	7	6	13	0.54	8	35	43	0.18	2.535	*
45/14	45	2	1	3	0.67	7	14	21	0.33	1.128	

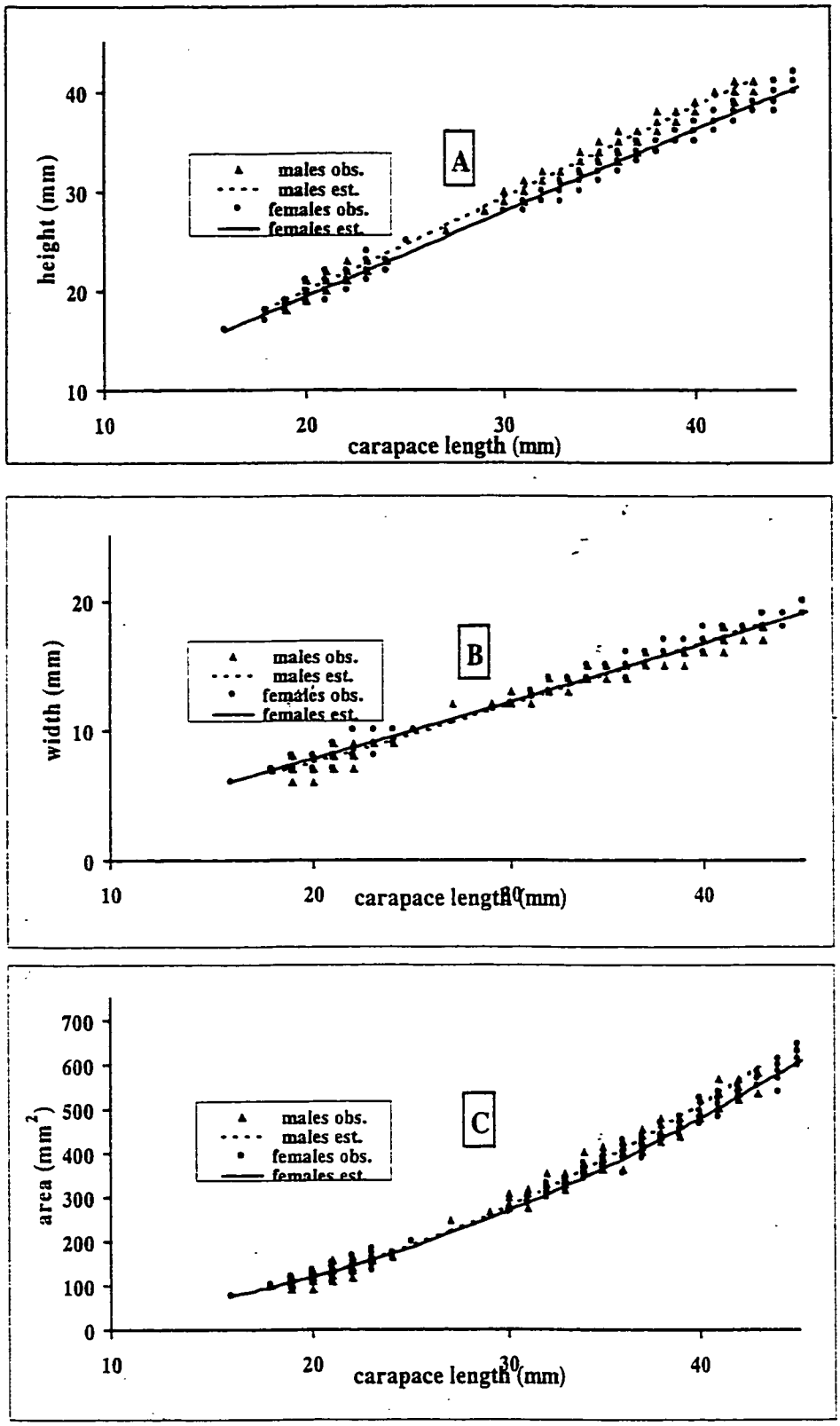


Fig. 60 - Height, width and area of elliptical section of folded body *vs.* carapace length, in *Aristaeomorpha foliacea* (from Bianchini *et al.*, 1998b).

Body engagement pattern

The scatterplots and the regression lines of males and females for the folded body height (Fig. 60A), width (Fig. 60B) and elliptic area (Fig. 60C) *vs.* the carapace length suggest that males are substantially higher than females, while the latter are slightly wider than males; this results in a mildly larger cross-section of males *vs.* females. Table 35 reports the parameters of the regression lines drawn in Fig. 60.

Table 35 - Estimated log-linear regression coefficients (± standard error) of folded measures *vs.* carapace length, in *Aristaeomorpha foliacea* (157 males and 293 females). $M_{folded} = a*CL^b$. a= intercept; b= slope; r^2= coefficient of determination; SEE= standard error of estimate (modified from Bianchini *et al.*, 1998b).

	a	±s.e.	b	±s.e.	r^2	SEE
FEMALES						
body height *vs.* carapace length	0.270	0.0148	0.900	0.0041	0.994	0.0240
body width *vs.* carapace length	-1.257	0.0269	1.105	0.0074	0.987	0.0438
ellipse area *vs.* carapace length	-1.228	0.0324	2.005	0.0089	0.994	0.0526
MALES						
body height *vs.* carapace length	0.169	0.0251	0.944	0.0073	0.991	0.0231
body width *vs.* carapace length	-1.472	0.0585	1.164	0.0170	0.968	0.0538
ellipse area *vs.* carapace length	-1.544	0.0682	2.108	0.0198	0.986	0.0627

This general impression is verified class by class with the Mann-Whitney results shown in Table 36. Males dominate 15 times on 16 events in the folded body height, and 12 times this prevalence is highly significant; conversely, females are wider in 87.5% of the cases, but only 5 times in a significant manner. Finally, examining the elliptic area, males are dominant again (13/16 occasions), but only once significantly.

Table 36 - Probability of ranking values independent of sex (Mann-Whitney U-test), with indication of the sex of prevalence, in *Aristaeomorpha foliacea*; classes with less than 4 measurements per sex were excluded (sample balanced to 10 specimens per class and sex). H_0: the folded measure is independent from sex. *= significant ($P< 0.05$); **= highly significant ($P< 0.01$) (modified from Bianchini *et al.*, 1998b).

Carapace Length mm	**Body Height** P ≤		**Height prevailing sex**	**Body Width** P ≤		**Width prevailing sex**	**Ellipse Area** P ≤		**Area prevailing sex**
19	0.28		M	0.53		F	0.85		F
20	0.12		M	0.04	*	F	0.28		F
21	0.01	**	M	0.69		F	0.29		M
22	0.05	*	M	0.69		M	0.23		M
23	0.95		F	0.71		M	0.75		M
....									
32	0.01	**	M	0.19		F	0.24		M
33	0.01	**	M	0.15		F	0.22		M
34	0.01	**	M	0.17		F	0.08		M
35	0.01	**	M	0.06		F	0.20		M
36	0.01	**	M	0.09		F	0.62		M
37	0.01	**	M	0.17		F	0.27		M
38	0.01	**	M	0.02	*	F	0.14		M
39	0.01	**	M	0.04	*	F	0.89		F
40	0.01	**	M	0.05	*	F	0.21		M
41	0.01	**	M	0.38		F	0.03	*	M
42	0.01	**	M	0.01	**	F	0.82		M

Quantitative and qualitative composition of the by-catch

The compilation of a (non exhaustive) systematic list only represents a marginal by-product, given the special targets of the study; 132 taxa were identified, 25, 26, 20 and 61 for crustaceans, cephalopods, cartilaginous and bony fish, respectively. As the general situation in shrimp fisheries, the by-catch was composed mostly by fish (Table 37), in quantities well above non-target crustaceans and cephalopods. Considering the data based on the 102 daylight hauls, the mean catch in weight was 67 kg/3 hours of which 49% were red shrimps, about 1% violet shrimp, 26% bony fishes, 16% cartilaginous fishes and 7% other crustaceans. The mean catch in number was 2,597 specimens of which 67% were red shrimps, 2% violet shrimps, 14% bony fish, 14% other crustaceans and 2% cartilaginous fishes (cephalopods gave only a marginal contribution). Among the "big" fish, the most common captures were the sharks *Galeus melastomus* and *Etmopterus spinax* (always discarded), and hake, greater fork beard and silver scabbard fish. Pandalids (locally called "gobbetti", i.e. "little hunchbacks") and *Pasiphea* sp. represent the largest fraction of the crustaceans by-catch, with the rest composed of Norway lobsters *Nephrops norvegicus* and white shrimps *Parapenaeus longirostris*.

A consistent part of the by-catch is made of potentially commercial species; that notwithstanding, in long-haul fishing vessels, almost everything but shrimps is thrown overboard or used for internal consumption. The composition of the "useful" catch from the earlier trawl surveys is shown in Fig. 61. It should be noted that the proportion of red shrimps is lower than during the selectivity study because the design of the surveys was random stratified, and not specifically targeted to the red shrimp grounds.

Table 37 - Taxonomic list of the fish by-catch in the Sicilian red shrimp fishery (bold: "commercial" fish; underline: common species).

Class CHONDRICHTHYES

FAMILY HEXANCHIDAE
Heptranchias perlo
Hexanchus griseus

FAMILY SQUALIDAE
Centrophorus granulosus
Centrophorus uyato
Dalatias licha
Etmopterus spinax
Squalus acanthias
Squalus blainvillei

FAMILY OXYNOTIDAE
Oxynotus centrina

FAMILY SCYLIORHINIDAE
Galeus melastomus
Scyliorhinus canicula

FAMILY TRIAKIDAE
Mustelus asterias

FAMILY RAJIDAE
Raja alba
Raja clavata
Raja fullonica
Raja melitensis
Raja oxyrinchus

FAMILY TORPEDINIDAE
Torpedo marmorata
Torpedo nobiliana

FAMILY CHIMAERAE
Chimaera monstrosa

Class OSTEICHTHYES

FAMILY ALEPOCEPHALIDAE
Alepocephalus rostratus

FAMILY APOGONIDAE
Epigonus constanciae
Epigonus denticulatus

FAMILY ARGENTINIDAE
Argentina sphyraena

FAMILY BRAMIDAE
Brama brama

FAMILY CALLIONYMIDAE
Synchiropus phaeton

FAMILY CAPROIDAE
Capros aper

FAMILY CARANGIDAE
Trachurus trachurus

FAMILY CENTROLOPHIDAE
Centrolophus niger

FAMILY CHAULIODONTIDAE
Chauliodus sloani

FAMILY CHLOROPHTHALMIDAE
Chlorophthalmus agassizi
Bathypterois mediterraneus

FAMILY CONGRIDAE
Conger conger

FAMILY CYNOGLOSSIDAE
Symphurus ligulatus
Symphurus nigrescens

FAMILY EVERMANELLIDAE
Evermanella balbo

FAMILY GADIDAE
Gadiculus argenteus argenteus
Gaidropsarus megalokynodon
Micromesistius poutassou
Molva dipterygia macrophthalma
Molva molva
Phycis blennoides

FAMILY LABRIDAE
Acantholabrus palloni

FAMILY LOPHIIDAE
Lophius budegassa
Lophius piscatorius

FAMILY MACROURIDAE
Coelorinchus coelorincus
Hymenocephalus italicus
Nezumia sclerorhynchus

FAMILY MERLUCCIIDAE
Merluccius merluccius

FAMILY MORIDAE
Gadella maraldi
Mora moro

FAMILY MULLIDAE
Mullus barbatus
Mullus surmuletus

FAMILY MYCTOPHIDAE
Ceratoscopelus maderensis
Diaphus metopoclampus
Diaphus rafinesquei
Lampanyctus crocodilus
Lobianchia dofleini
Myctophum punctatum
Notoscopelus elongatus

FAMILY NETTASTOMATIDAE
Nettastoma melanurum

FAMILY NOMEIDAE
Cubiceps gracilis

FAMILY NOTACANTHIDAE
Notacanthus bonapartei

FAMILY PARALEPIDIDAE
Lestidiops jayakari
Sudis hyalina

FAMILY PERISTEDIIDAE
Peristedion cataphractum

FAMILY SCOMBRIDAE
Scomber scombrus

FAMILY SCOPHTHALMIDAE
Lepidorhombus boscii

FAMILY SCORPAENIDAE
Helicolenus dactylopterus
Scorpaena elongata
Scorpaena scrofa

FAMILY SERRANIDAE
Polyprion americanus

FAMILY SOLEIDAE
Bathysolea profundicola

FAMILY SPARIDAE
Boops boops
Pagellus bogaraveo

FAMILY STERNOPTYCHIDAE
Argyropelecus hemigymnus

FAMILY STOMIIDAE
Stomias boa

FAMILY SYNAPHOBRANCHIDAE
Dysomma brevirostre

FAMILY TRACHICHTHYIDAE
Hoplostethus mediterraneus

FAMILY TRICHIURIDAE
Lepidopus caudatus

FAMILY TRIGLIDAE
Lepidotrigla cavillone

in **bold**, somehow "commercial" species, underlined, species common in the catch

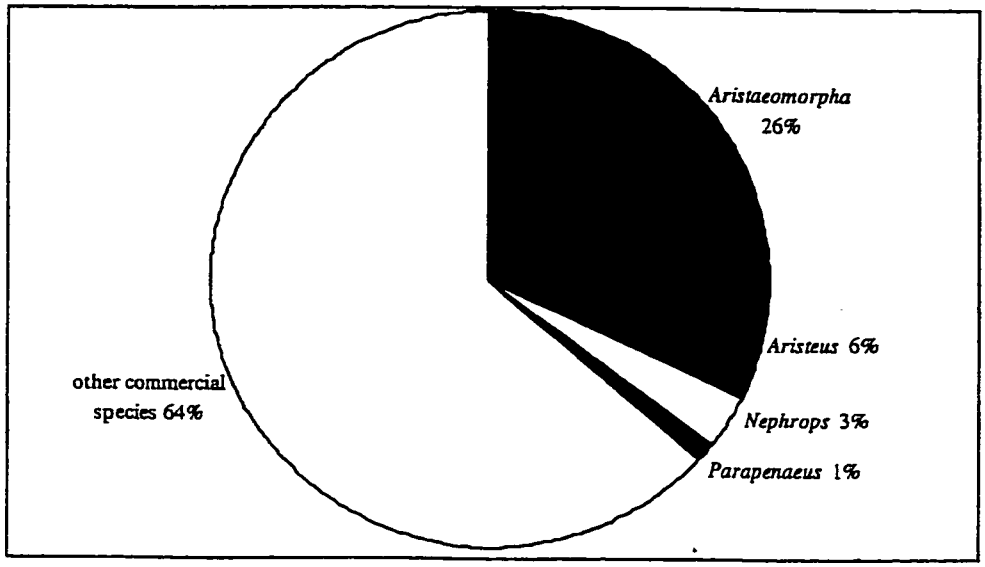


Fig. 61 - Proportion of the commercial catch by groups of species in Sicilian deep-water red shrimp fishery.

Herewith, some brief results from the selectivity study surveys, spring and summer (102 3-hour hauls), are reported.

Aristeus antennatus - The violet shrimp was caught slightly less frequently (91% of the valid hauls) than the red shrimp, but in very low quantity; the overall catch was 6,445 specimens and 133 kg. This species was practically absent in the SE zone whereas the highest abundance was observed in the Marettimo zone (as expected). The catch was lower in summer than spring. Considering the seasons combined, the mean catch in number was 72 specimens (i.e., 24 specimen/h) and the mean catch in weight was about 1.5 g (i.e., 0.5 kg/h).

Parapenaeus longirostris - This shrimp was caught throughout the surveyed area yielding a total catch of 7,471 specimens and 79 kg. It was more abundant in the NW zone and in spring. Overall the mean catch per standard haul was 92 specimens and 1 kg. Mean catch was lower by night: 35 specimens and 0.4 kg.

Nephrops norvegicus – Norway lobsters was caught throughout the surveyed area yielding a total catch of 4,693 specimens and 123 kg. It was more common in the

NE zone and in spring. Overall the mean catch per standard haul was 48 specimens and 1.3 kg. Mean catch was lower by night: 5 specimens and 0.1 kg.

Galeus melastomus - This shark was caught throughout the surveyed area and in 97% of the samples, yielding a total catch of 2,680 specimens and 454 kg. The catch was higher in spring than summer. Overall, the mean catch per standard haul was 27 specimens and 6 kg. Mean catch was almost the same by daylight or by night.

Etmopterus spinax - This shark was caught throughout the surveyed area and in 97% of the samples, yielding a total catch of 2,928 specimens and 266 kg. On average the captures were higher in spring than summer but differences among the zones were not consistent. Overall the mean catch per standard haul was 31 specimens and 2.8 kg. By night the mean catch was lower: 11 specimens and 1.1 kg.

Chimaera monstrosa - This cartilaginous species was caught throughout the surveyed area but in less than 50% of samples, yielding a total catch of 388 specimens and 19 kg. It is worth noting that large animals occurred in the Marettimo grounds. Overall the mean catch per standard haul was 9 specimens and 0.4 kg.

Raja sp. - These skates were caught only in about 30% of samples and always as few animals of good size. In fact, the mean catch in weight was 2.7 kg/haul even with a low mean catch in number (1.4 specimens/haul).

Conger conger - This anguillid fish was caught throughout the surveyed area and in 77% of samples, yielding a total catch of 256 specimens and 78 kg. The catch in number was higher in spring than summer whereas no consistent difference among the zones was observed. The mean catch was very low (3 specimens and 1 kg per haul) and close to the night values.

Helicolenus dactylopterus - This rockfish was caught throughout the surveyed area and in 77% of samples, yielding a total catch of 841 specimens and 61 kg. The highest catch was observed in spring and in the SE zone. Overall the mean catch per standard haul was 11 specimens and 0.8 kg. The night values were lower: 2 specimens and 0.2 kg (per haul). It is worth noting the small average size of the animals: about 63 g.

Lepidorhombus boscii - This flatfish has been caught mainly in the NE and SE zone and never in the Marettimo zone, yielding a total catch of 333 specimens and 18 kg. On the overall the mean catch per standard haul was 6 specimens and 0.3 kg. By night values were lower: 3 specimens and 0.1 kg per haul.

Merluccius merluccius – Hake was caught throughout the surveyed area and in 74% of the samples, yielding a total catch of 3,511 specimens and 201 kg. It was more abundant in the SE zone whilst no difference among the other zones was evident. Overall the mean catch per standard haul was 46 specimens and 2.6 kg. Both frequency and numeric abundance of this species were strongly reduced by night (less than 50% of samples and 2 specimens) but the mean weight was higher (1.8 kg/haul).

Micromesistius poutassou – This gadid fish was caught throughout the surveyed area and in 83% of samples, yielding a total catch of 845 specimens and 91 kg. This fish resulted to be more abundant in the SE zone. Overall the mean catch per standard haul was 10 specimens and 1.1 kg. The catch was lower by night (3 specimens and 0.4 kg).

Mullus surmuletus - This fish species was mainly caught in the SE zone (never in the MA zone) and in 50% of samples, yielding a total catch of 322 animals and 23 kg. Overall the mean catch per standard haul was 6 specimens and 0.4 kg.

Phycis blennoides - This fish was caught throughout the surveyed area and in all samples, yielding a total catch of 2,974 specimens and 358 kg. The catch was higher in spring than summer. Overall the mean catch per standard haul was 29 specimens and 3.5 kg. For this species the night catch in weight was higher (2.3 kg) whereas that in number was lower (15 specimens) than the daylight values.

Todarodes sagittatus - This squid was caught throughout the surveyed area and in 63% of samples but always as few animals; it yielded a total catch of 240 specimens and 65 kg. Overall the mean catch per standard haul was 4 specimens and 1 kg.

Other crustaceans - Usually small-size animals with practically no economic value. Overall, the mean catch per standard haul was 248 specimens and 3.1 kg.

Other sharks and skates - Generally, few but moderate- to large-size animals were caught in each haul. Overall the mean catch per standard haul was 13 specimens and 5.3 kg.

Other bony fish - A wide variety (over 50 species) of small-size animals were included in this category. Overall the mean catch per standard haul was 279 specimens and 9.2 kg.

Other cephalopods - Seldom more than a few small-size bobtail squids and octopuses were caught over deep-bottoms. Overall, the mean catch per standard haul was only 5 specimens and 0.4 kg.

The selection ratio was low (or nil) for the large fish independently of the gear configuration with the only exception of *Conger conger* which showed a high ability to escape through the different cod-ends. Herewith, mean SR (expressed as percentage) derived from the combined data are presented both for the catch in number and weight (in brackets) for the most interesting species (Table 38).

Aristeus antennatus - The difference in recruitment time between red and violet shrimp produced a slightly different behaviour in their respective selectivity estimates by season. Generally speaking, the broad retention fraction of the LFD thus depend on red shrimp species, season and gear configuration as clearly indicated by the variability in the selection ratios. For the violet shrimp the following results were obtained (selection ratios in number and in yield):

- Spring

a) juveniles were poorly represented;

b) with the 16/14 GC, the retention was complete; few specimens could escape with a selection ratio in number (SR n) of 0.2%;

c) with the 20/14 GC, everything was retained but a few isolated specimens, even though the estimated mean selection ratio (SR n; 6%) was quite high; the scarcity of the samples gave an unacceptable level of precision (sd= 14.4%);

d) with the 24/14 GC, a few juveniles were able to escape; the mean selection ratio (SR n; 1.5%) was lower than the previous value;

e) with the 28/14 GC, large-size females (CL> 46 mm) were fully retained, a slight fraction of adult (medium size females and males) were able to escape while the fraction of juveniles sieved out of the cod-end increased; the mean selection ratio was 26% (SR n) and 9% (SR y), but still very imprecise;

f) with the 45/14 GC, the OUT becomes higher than the IN component, but still a few juveniles were retained; the mean selection ratio was 72% (SR n) and 68% (SR y);

- Summer

a) the juvenile component became evident, showing a CL range of 20-30 mm, with two peaks;

b) with the 16/14 GC, everything was retained;

c) with the 20/14 GC, everything was still retained;

d) with the 24/14 GC, adults were totally retained whilst a large quantity of juveniles of the smallest classes (CL< 20 mm) was sieved out and collected in the cover; the mean selection ratio was 10% (SR n) and 2% (SR y);

e) with the 28/14 GC, only the largest females (CL> 49 mm) were retained whereas a large fraction of juveniles and a small amount of adult males and females were able to escape from the cod-end; the mean selection ratio was 21% (SR n) and 11% (SR y);

f) with the 45/14 GC, the fraction that escaped was higher than that retained and practically no juvenile was hauled. The mean selection ratio was 72% (SR n) and 68% (SR y).

Parapenaeus longirostris - Few small animals were able to escape from the 16/14 GC (SR n 0.5%); the SR n % for the other GCs were 2 (SR y 1%), 9 (SR y 9%), 32 (SR y 26%) and 80 (SR y 79%). For this species the loss in number is more or less equivalent to the loss in weight.

Nephrops norvegicus - No animal was able to escape from the 16/14 GC; the SR n % for the other GCs were 1 (SR y 0.3%), 6 (SR y 3%), 19 (SR y 14%) and 80 (SR y 62%). The loss in number for this species is higher than the loss in weight indicating that some selection occurs.

Galeus melastomus - The retention was complete with the 16/14 GC and few small-size animals were able to escape from the 20/14 GC (SR n 0.6%); the mean SR n % for the other GCs were 13 (SR y 2%), 16 (SR y 8%) and 87 (SR y 89%).

Etmopterus spinax - No animal escaped from the 16/14 GC; the SR n % for the other GCs were 3 (SR y 2%), 2 (SR y 0.8%), 17 (SR y 14%), and 89 (SR y 89%).

Conger conger - This powerful anguillid fish was able to escape even from the 16/14 GC resulting SR n % of 4 (SR y 2%); the SR n % for the other GCs were 32 (13), 68 (58), 75 (71) and 99 (80).

Helicolenus dactylopterus - No animal escaped from the 16/14 GC and only a few (SR n 0.4%) were found in the cover bag of the 20/14 GC; the SR n % for the other GCs were 1 (SR y 0%), 13 (SR y 6%) and 87 (SR y 91%).

Lepidorhombus boscii - No animal escaped from both 16/14 and 20/14 GCs; the SR n % for the other GCs were 0.3 (SR y 0%), 5 (SR y 0.4) and 62 (SR y 35%). The GCs below the 28/14 are practically non-selective for this flatfish.

Merluccius merluccius - No animal escaped from the 16/14 GC but a consistent fraction, SR n 16% (SR y 8%), was found in the cover bag of the 20/14 GC; the SR n % for the other GCs were 22 (SR y 8%), 37 (SR y 15) and 81 (SR y 68%). It is worth noting that the 28/14 GC allows on average the escapement of one third of hakes with a minimal loss in weight, suggesting that the most part of the commercial, large-size fish are retained.

Phycis blennoides - Less than 5% (SR y 1%) of the catch was lost with the 16/14, 20/14 and 24/14 GCs; the SR n % for the other 2 GCs were 20 (SR y 10%) and 82 (SR y 75%).

Todarodes sagittatus - The retention was complete with the 16/14, 20/14 and 24/14 GCs and even with the largest GC (45/14) the loss was low: SR n 8% (SR y 5%). The

body shape and the presence of the long tentacles together with the absence of juveniles in the catch are the basic explanations of the low escaping ability of this oceanic squid.

Concerning the mixed categories ("other"), the mean selection ratios (in weight; season combined) indicated that:

a) no loss occurred for sharks and skates, with the exception of the 45/14 GC (SR n 28%);
b) no loss occurred for cephalopods with the 16/14 and 20/14 GCs; a mean loss in number of about 6%, 12% and 29% resulted for the 24/14, 28/14 and 45/14 GCs;
c) the loss of crustaceans is minimal with the 16/14 GC (SR n 0.9%) and increases with GC: 14%, 33%, 46% and 74% with the 20/14, 24/14, 28/14 and 45/14 GC;
d) profuse loss occurred for the bony fish: 14%, 17%, 36% 53% and 89% in number with the 16/14, 20/14, 24/14, 28/14 and 45/14 GCs respectively.

Table 38 - By-catch of the most important fish species in the Sicilian red shrimp fishery and selection ratios by mesh side (mm).

	freq.	higher in		catch		selection ratio (in n)					selection ratio (in kg)				
	%	season	d/n	n	kg	16	20	24	28	45	16	20	24	28	45
Galeus melastomus	97	spring		2680	454	0	1	13	16	87	0	0	2	8	89
Etmopterus spinax	97	spring	day	2928	266	0	2	3	17	89	0	2	1	14	89
Chimaera monstrosa	50			388	19										
Raja sp.	30														
Conger conger	77	spring		256	78	4	32	68	75	99	2	13	58	71	80
Hel. dactylopterus	77	spring	day	841	61	0	0	1	13	87	0	0	0	6	91
Lepidorh. boscii			day	333	18	0	0	0	5	62	0	0	0	0	35
Merl. merluccius	74		day	3511	201	0	16	22	37	81	0	8	8	15	68
Microm. poutassou	83		day	845	91										
Mullus surmuletus	50			322	23										
Phycis blennoides	100		night?	2974	358	5	20	82	100	100	1	10	75	100	100
Other bony fishes				279	9						14	17	36	53	89

Anthropic waste

On the 132 hauls carried out in this study, only 14 resulted "clean", i.e. a percentage of about 10%. Rubbish was always found in the cod-end, sometimes in large quantities; a maximum of 80 items were counted and a maximum of about 400 liters of waste volume was estimated in individual hauls (Fig. 62). Drink cans, plastic "shoppers" and glass bottles were the most frequent items of anthropic origin, having being found in 98, 83 and 45 hauls. Iron tanks, shoes, pelagic drift net and longline buoy signalers were other common objects. Other items such as plastic tanks, iron drums and synthetic lure occurred a few times, as well as lines and anchorage stones of the "cannizzati" (7 times). Tires, pieces or boxes of wood, plastic debris, tissue, pieces of metal and bricks were gathered sporadically. Furthermore, unusual objects were found once: a gas tank, a wheel rim, a coffee machine, a carpet and a shovel.

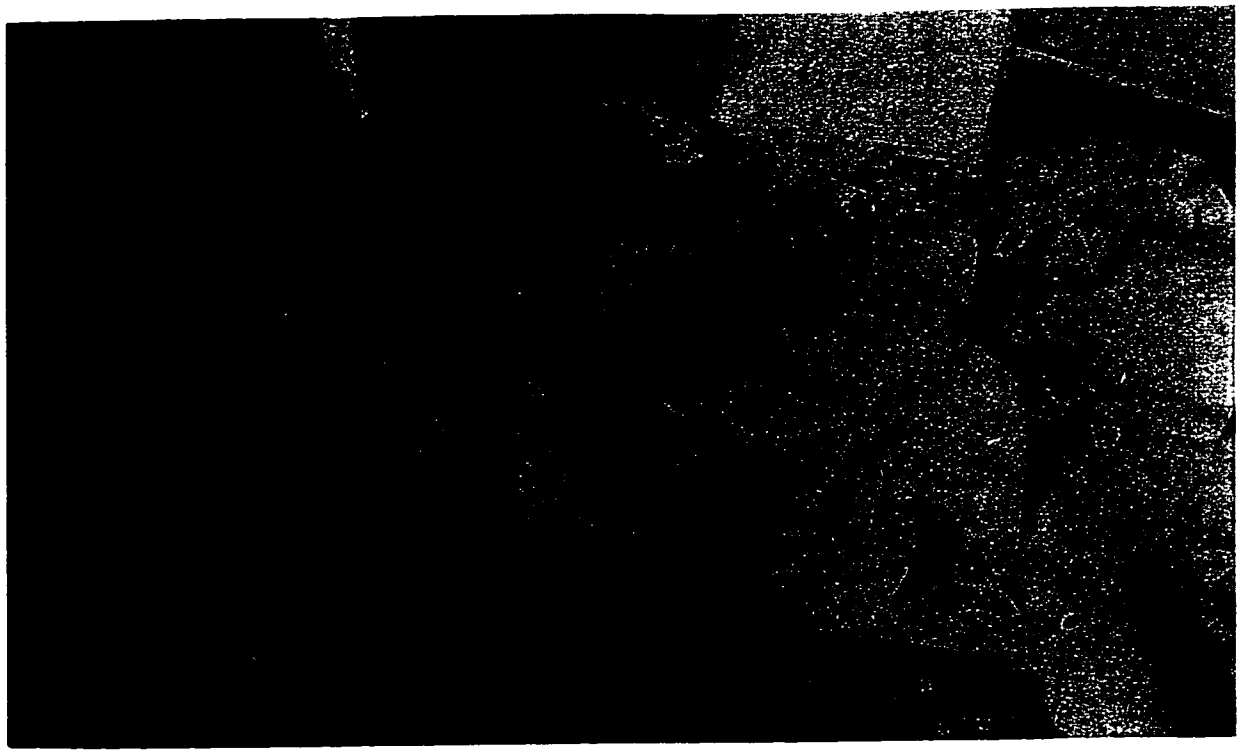


Fig. 62 - Anthropic waste in the Sicilian red shrimp fishery (note the "cannizzati" stones).

Predation upon red shrimps

Almost all the stomachs of potential red shrimp predators were found empty but the problem of stomach eversion (as a consequence of the quick depressurization, especially in hake) made it very difficult to derive any conclusion. Only in very few cases did red shrimps occur: particularly, whole (i.e. recently ingested) red shrimps were identified only in *Conger conger* and *Lophius* sp., whereas pieces (i.e., past ingested) of red shrimps were identified in few hakes (Table 39). Matter-of-factly, cephalopods and fish (whole or in pieces) represent the most common items found in the examined stomachs.

Table 39 - Number of stomachs checked, percentage empty or extroverted, maximum fish weight, shrimp remnants in the fish by-catch of the Sicilian red shrimp fishery.

Species	controlled n	empty %	max weight g	shrimp content
Centrolophus niger	10	0	5200	
Centrophorus sp.	35	85	5000	
Chimaera monstrosa	5	60	1200	
Conger conger	13	70	9000	*A. antennatus* x1
Dalatias licha	11	64	3500	shrimp x1
Galeus melastomus	3	67	500	
Heptranchias perlo	3	33	2800	
Hexanchus griseus	2	0	11600	
Lepidopus caudatus	5	60	1400	
Lophius budegassa	7	43	20600	*A. foliacea* x1
Lophius piscatorius	6	50	18000	*A. foliacea* x2
Merluccius merluccius	126	83	2050	*A. foliacea* x4
Micromesistius poutassou	1	0	500	
Molva dipterygia macrophthalma	3	100	2000	
Molva molva	1	100	1400	
Phycis blennoides	11	100	1600	
Raja clavata	2	100	3300	
Raja oxyrinchus	16	56	5500	shrimps x2
Squalus acanthias	5	80	3500	
Squalus blainvillei	2	50	2000	
Torpedo nobiliana	1	100	18400	

Virtual population

Selectivity study

After conversion to age-structured data, the analysis from the selectivity study produced 8 age classes and resulted in a mean age of the catch of 1.30 y and a mean CL of 34.4 mm. The classes that contribute the most to the catch are those of age 1 and age 2. Using the non-restructured data (57 shrimp length classes: min 12 mm CL, max 68 mm), all values are 10-15% higher that those obtained with age classes, thus a mean age of the catch of 1.49 y and a mean CL of 39.1 mm, while the classes that are contributing the most to the catch are those between 40 and 55 mm CL.

The virtual population calculated from age-restructured data (Table 40) has a mean age of 0.8 y, and a mean CL of 23.6 mm, while the classes most represented (in weight) are those of age 1 and age 2 (521 tons and 198 tons, respectively); the average weight of the virtual population is 944 tons. The critical age is 1.0 y for the actual stock (corresponding to a critical length of 31.6 mm), and 2.54 y for the virgin stock (critical length 54.8 mm). On a total biomass balance of D= 1375 tons, the input is totally assigned to growth, while the output is 34.3% for the natural deaths, and 65.7% for the catch; the turnover is 145.6%. There is almost no difference in the two options, standard or pseudo-cohort analysis, since the two sets of results disagree for less than 0.5%, at least with the present data.

Table 40 - "Age" structure in number and weight (percentages) of the virtual population of *Aristaeomorpha foliacea*; data from the selectivity study.

age class	0	1	2	3	4	5	6
mean number (%)	69.0	26.1	4.7	0.3	0.1	0.0	0.0
mean weight (%)	20.8	54.6	20.8	2.4	0.3	0.1	0.0

In contrast, the virtual population reconstruction performed on the shrimp length classes has a mean age of 1.02 y, a mean CL of 30.0 mm and mean fishing mortality of F= 0.46, while the classes most represented (in weight) are those between 31 and 49 mm CL; the average weight of the virtual population is 1066 tons. The critical age is 1.36 y for the actual stock (corresponding to a critical length of 39.0 mm), while it remains at 2.54 y for the virgin stock (critical length 54.8 mm). On a total biomass balance (D) of 1583 tons, the input is split 1:20 between recruitment and growth, while the output is 1/3 for the natural deaths, and 2/3 for the catch. The turnover is 148.5%.

A few compact elements of the VPA from the selectivity study, useful for comparisons in time or space, are presented in Table 41.

Table 41 - "Compact" results of the virtual population analysis of *Aristaeomorpha foliacea*; data from the selectivity study, classified by CL size or restructured by age. R/B_{mean}, ratio of recruits to mean standing biomass; B_{max}/B_{mean}, ratio of biomass of the critical class to mean standing biomass; D/B_{mean}, turnover, i.e. ratio of annual biomass balance to mean standing biomass; B_{max}/D, ratio of biomass of the critical class to annual biomass balance.

	R/B_{mean}	B_{max}/B_{mean}	D/B_{mean}	B_{max}/D
from age (%)	0	54.1	145.6	37.2
from length (%)	7.0	69.7	148.5	46.9

Earlier trawl surveys

After conversion to age-structured data, the analysis from the earlier trawl surveys produced 6 age classes and resulted in a mean age of the catch of 1.81 y and a mean CL of 42.8 mm. The classes that are contributing the most to the catch are those of age 1 and age 2. Using the non-restructured data (49 shrimp length classes: min 18 mm CL, max 66 mm), all values are just a little 5% higher that those obtained with age classes, thus a mean age of the catch of 1.89 y and a mean CL of 44.9 mm, while the classes that are contributing the most to the catch are those between 50 and 61 mm CL (remember that the catch was adjusted to about 1000 tons).

The virtual population calculated from age-restructured data has a mean age of 1.0 y, and a mean CL of 27.5 mm, while the class most represented (in weight) is that of 2 years; the average weight of the virtual population is 1584 tons. The critical age is 2.0 y for the actual stock (corresponding to a critical length of 48.9 mm), and 2.54 y for the virgin stock (critical length 54.8 mm). On a total biomass balance of D= 1747 tons, the input is totally assigned to growth, while the output is 45.4% for the natural deaths, and 54.6% for the catch; the turnover is 110.2%.

In contrast, the virtual population reconstruction performed on the shrimp length classes from the earlier trawl surveys has a mean age of 1.36 y, a mean CL of 36.5 mm and a mean fishing mortality of F= 0.78, while the classes most represented (in weight) are those between 34 and 54 mm CL; the average weight of the virtual population is 1568 tons. The critical age is 1.72 y for the actual stock (corresponding to a critical length of 45.0 mm), and 2.54 y for the virgin stock (critical length 54.8 mm). On a total biomass balance of 1785 tons, the input is split 1:9 between recruitment and growth, while the output is 43.9% for the natural deaths, and 56.1% for the catch. The turnover is 113.8%.

A few compact elements of the VPA from the earlier trawl surveys, useful for comparisons in time or space, are presented in Table 42.

Table 42 - "Compact" results of the virtual population analysis of *Aristaeomorpha foliacea*; data the earlier trawl surveys, classified by CL size or restructured by age. R/B_{mean}, ratio of recruits to mean standing biomass; B_{max}/B_{mean}, ratio of biomass of the critical class to mean standing biomass; D/B_{mean}, turnover, i.e. ratio of annual biomass balance to mean standing biomass; B_{max}/D, ratio of biomass of the critical class to annual biomass balance.

	R/B_{mean}	B_{max}/B_{mean}	D/B_{mean}	B_{max}/D
from age (%)	0	46.8	110.2	42.4
from length (%)	11.4	49.4	113.8	43.4

Yield-per-recruit analysis

The four different approaches that have been used produce, even on the same set of data, qualitatively different scenarios, i.e. the present level of exploitation appears situated on the right or left side of the maximum yield-per-recruit value. On the other hand, the quantitative estimates are of course different among the various approaches, but not far from each other, since the response surfaces are quite flat at the summit.

The biological yield-per-recruit' (Y/R') results obtained applying the incomplete beta function show that the response surface is flat around the maximum (Fig. 63). At the present level of exploitation, the yield-per-recruit' is 11.7, about 10% lower than the maximum (12.9 at F= 1); raising t_c by three months from the present one year does not produce a sensible increase (+0.3) in the yield-per-recruit' at F= 0.5, but the maximum reaches 14.0 at F=1.4. As already said, the yield-per-recruit' should not be estimated with the classical Beverton and Holt's integration, since the red shrimp growth is strongly

allometric (b<< 3); in fact, these "wrong" estimates have been computed anyhow, and do actually differ substantially from the values obtained when applying the incomplete beta function.

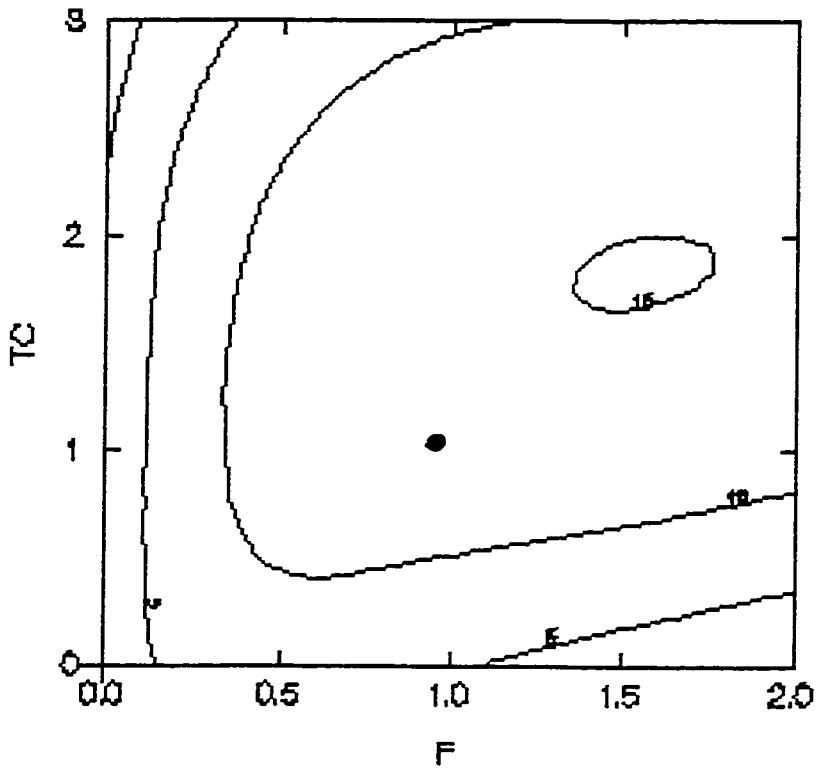


Fig. 63 – Isopleths of the biological yield-per-recruit' *vs.* age at first capture (t_c, in year) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea* (M= 0.5), using the incomplete beta function. The black dot denotes the current level of exploitation according to the growth and mortality estimates.

Selectivity study data

The biological yield-per recruit of the present exploitation regimen (20 mm mesh) resulting from the Thompson and Bell's approach is 7.8 g/recruit, and the maximum (7.9 g/recruit) is situated at F= 0.6 (35% more than present F), but the response surface is

very flat around the maximum (the isopleth of 7.8-7.9 g/recruit encompasses F from 0.45 to 0.90).

The biological yield-per-recruit (g/recruit) in different exploitation scenarios, varying fishing mortality and/or mesh size, is reported in Table 43. The isopleth surface is presented in Fig. 64.

Table 43 - Biological yield-per-recruit (g) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; data from the selectivity study (Thompson and Bell's analysis). Present situation underlined; the maximum Y/R is reported together with the percent fishing mortality increase needed to obtain it.

	mesh (mm)			
F multiplier	16	20	24	28
0.50	6.0	6.3	6.4	6.4
0.75	6.7	7.3	7.4	7.5
1.00	7.0	<u>7.8</u>	7.9	8.1
1.25	6.9	7.9	8.2	8.4
1.50	6.7	7.9	8.2	8.6
max Y/R (F increase)	7.0 (+5%)	7.9 (+35%)	8.2 (+45%)	8.6 (+70%)

The present level of exploitation (fishing mortality multiplier 1.00, i.e. F= 0.45; mesh size 20 mm) seems to be of slight underfishing, but an increase of the fishing mortality should not be sought after in this scenario, since it is almost at its maximum. In fact, an increase of less than 2% in the yield-per-recruit would require a disproportionate increase of 35% in the fishing mortality, with an unacceptable rise in the risks and all the negative consequences on the environment. On the other hand, an increase in mesh size

would raise the yield-per-recruit with the present level of F; in this scenario, an increase of fishing mortality could in theory be targeted or, better, the margin can be used as a risk buffer.

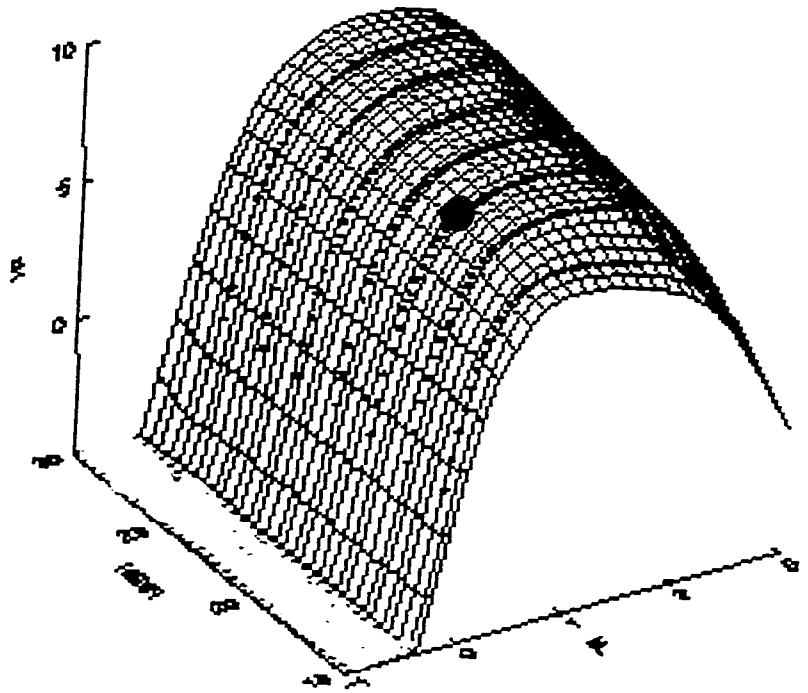


Fig. 64 – Surface response of the biological yield-per-recruit *vs.* fishing mortality variation (F/year multiplier) and/or mesh size (mm) for *Aristaeomorpha foliacea*, using the Thompson and Bell's analysis. The black dot denotes the current level of exploitation according to the growth and mortality estimates.

The biological yield-per-recruit (age classes) from the selectivity study obtained with the VIT program is represented in Table 44. The slope of the yield-per-recruit curve at the origin is 77.99, and the virgin biomass is 5305 tons.

Table 44 - Biological yield-per-recruit (g), standing biomass-per-recruit (g) and spawning stock standing biomass-per-recruit (g) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the selectivity study, restructured by age (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the yield-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	Y/R	biomass/R	Spawning stock biomass/R
F_0	0	0.00	67.79	64.78
$F_{0.1}$	0.32	12.76	28.38	25.50
F_{max}	0.58	13.62	19.49	16.70
F_{actual}	1.00	12.94	13.14	10.49
F_{double}	2.00	10.83	7.63	5.29

The data from the selectivity study restructured by age show that the present fishing mortality is situated on the right hand of the yield-per-recruit curve, well over the fishing mortality that produces the maximum yield-per-recruit (13.6 g/R), and that the standing biomass-per-recruit is presently about 20% of the virgin stock biomass-per-recruit.

The biological yield-per-recruit (length classes) from the selectivity study obtained with the VIT program is represented in Table 45. The slope of the yield-per-recruit curve at the origin is 98.26, and the virgin biomass is 5501 tons.

Table 45 - Biological yield-per-recruit (g), standing biomass-per-recruit (g) and spawning stock standing biomass-per-recruit (g) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the selectivity study, classified by CL size (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the yield-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	Y/R	biomass/R	Spawning stock biomass/R
F_0	0	0.00	60.06	59.92
$F_{0.1}$	0.33	10.45	24.22	21.35
F_{max}	0.55	11.04	17.21	14.50
F_{actual}	1.00	10.22	10.69	8.24
F_{double}	2.00	7.96	5.64	3.67

In the analysis of the selectivity study data set, the comparison between the values obtained with data structured by size or age-restructured data shows that the estimates are somehow different, but the general picture remains almost the same. Again, the present fishing mortality (0.45) exceeds the optimal value (about 0.25), and the present spawning

stock biomass-per-recruit is less than 15% of the spawning biomass-per-recruit of the virgin stock.

The surface response and the corresponding isopleths of the biological yield-per-recruit (length classes) from the selectivity study obtained with the ANALEN program are represented in Fig. 65 and Fig. 66, respectively; the current level of exploitation is also noted.

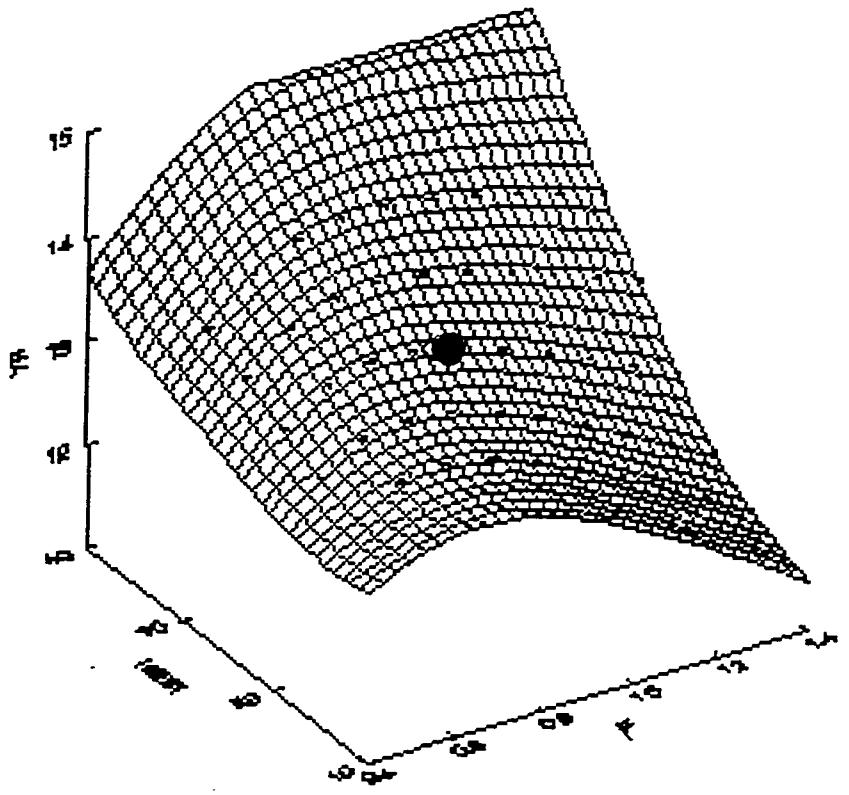


Fig. 65 - Surface response of the biological yield-per-recruit (g) *vs.* mesh size (mm) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea*; data from the selectivity study (from ANALEN). The black dot denotes the current level of exploitation according to the growth and mortality estimates.

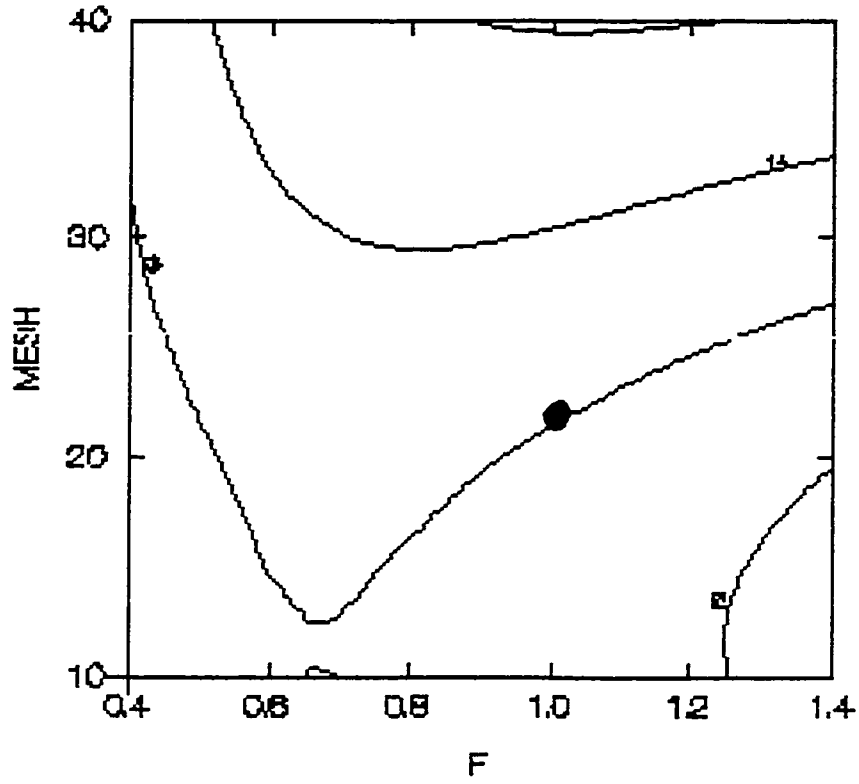


Fig. 66 - Isopleths of the biological yield-per-recruit (g) *vs.* mesh size (mm) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea*; data from the selectivity study (from ANALEN). The black dot denotes the current level of exploitation according to the growth and mortality estimates.

In summary, the yield-per-recruit estimated by the VIT program (both from age- and length-structured data) from the selectivity study data (as well as the graphs from the ANALEN program) suggests a situation of overfishing with a yield-per-recruit value near the maximum, but on the right side of the curve. A drastic reduction of F, from the present 0.45 to about 0.15 will bring the level of exploitation to the safer level of the $F_{0.1}$ strategy without consistent changes in the yield-per-recruit. In the meantime, the standing biomass per recruit should more than double.

The variations in spawning biomass-per-recruit (%) due to changes in mesh size and/or fishing mortality obtained with the ANALEN program from the selectivity study data are reported in Table 46. It appears that an increase in mesh size from 20 mm to 28 mm is almost equivalent to a reduction of 10% in the fishing mortality (viz. effort). Even if they are presented in a different way, the estimates are consistent with those obtained with the VIT program, notwithstanding the different approach.

Table 46 - Variations in spawning biomass-per-recruit (%) in different exploitation scenarios, varying fishing mortality and/or mesh size; data from the selectivity study (from ANALEN). Present situation underlined.

	F multipliers									
mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
32	94.63	73.47	56.02	41.43	29.05	18.44	9.24	1.18	-5.92	-12.23
28	88.39	66.86	49.15	34.37	21.87	11.17	1.92	-6.16	-13.26	-19.55
24	82.79	60.93	43.00	28.06	15.46	4.70	-4.58	-12.66	-19.74	-26.00
20	78.64	56.55	38.47	23.44	10.78	0.00	-9.28	-17.34	-24.39	-30.61
16	76.52	54.34	36.18	21.11	8.44	-2.35	-11.62	-19.66	-26.69	-32.88

Earlier trawl surveys data

The biological yield-per-recruit (age classes) from the earlier trawl surveys obtained with the VIT program is represented in Table 47. The slope of the yield-per-recruit curve at the origin is 39.52, and the virgin biomass is 4508 tons.

Table 47 - Biological yield-per-recruit (g), standing biomass-per-recruit (g) and spawning stock standing biomass-per-recruit (g) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the earlier trawl surveys, restructured by age (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the yield-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	Y/R	biomass/R	Spawning stock biomass/R
F_0	0	0.00	63.87	57.81
$F_{0.1}$	0.64	14.14	30.43	24.72
F_{actual}	1.00	15.11	23.68	18.15
F_{max}	1.17	15.18	21.44	15.99
F_{double}	2.00	14.51	14.88	9.80

The data from the earlier trawl surveys restructured by age show that the present fishing mortality is situated on the left hand of the yield-per-recruit curve, that the value of the present yield-per-recruit is almost at its maximum, and that the present standing biomass-per-recruit is above the 35% of the virgin stock biomass.

The biological yield-per-recruit (length classes; from the earlier trawl surveys) obtained with the VIT program is represented in Table 48. The slope of the yield-per-recruit curve at the origin is 54.85, and the virgin biomass is 4228 tons.

Table 48 - Biological yield-per-recruit (g), standing biomass-per-recruit (g) and spawning stock standing biomass-per-recruit (g) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the earlier trawl surveys, classifed by CL size (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the yield-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	Y/R	biomass/R	Spawning stock biomass/R
F_0	0	0.00	54.10	47.85
$F_{0.1}$	0.70	10.90	23.60	18.00
F_{actual}	1.00	11.48	19.05	13.72
F_{max}	1.18	15.54	17.06	11.88
F_{double}	2.00	10.97	11.75	10.97

The surface response and the corresponding isopleths of the biological yield-per-recruit (length classes; from the earlier trawl surveys) from the selectivity study obtained with the ANALEN program are represented in Fig. 67 and Fig. 68, respectively; the current level of exploitation is also noted.

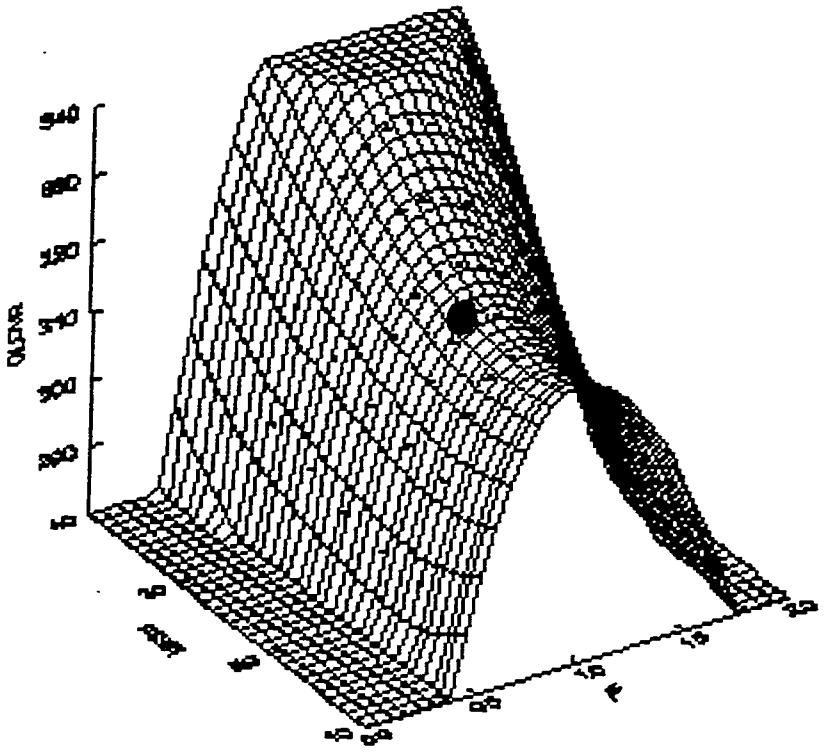


Fig. 67 - Surface response of the biological yield-per-recruit (g) *vs.* mesh size (mm) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea*; data from the earlier trawl surveys (from ANALEN). The black dot denotes the current level of exploitation according to the growth and mortality estimates.

In summary, also from the earlier trawl surveys, the overall picture is again the same in the analysis performed with size- or age-structured data. The yield-per-recruit estimated by the VIT program from the earlier trawl surveys data suggests a situation of slight underfishing, with a yield-per-recruit value near the maximum in the age-structured set, and only 75% of the maximum in the length-structured set (ANALEN shows a situation of almost "optimal" exploitation). In the apparent situation of slight underfishing, the pursuit of the safer $F_{0.1}$ strategy would cause a decrease of the present yield-per-recruit, however of little value,given the flatness of the summit.

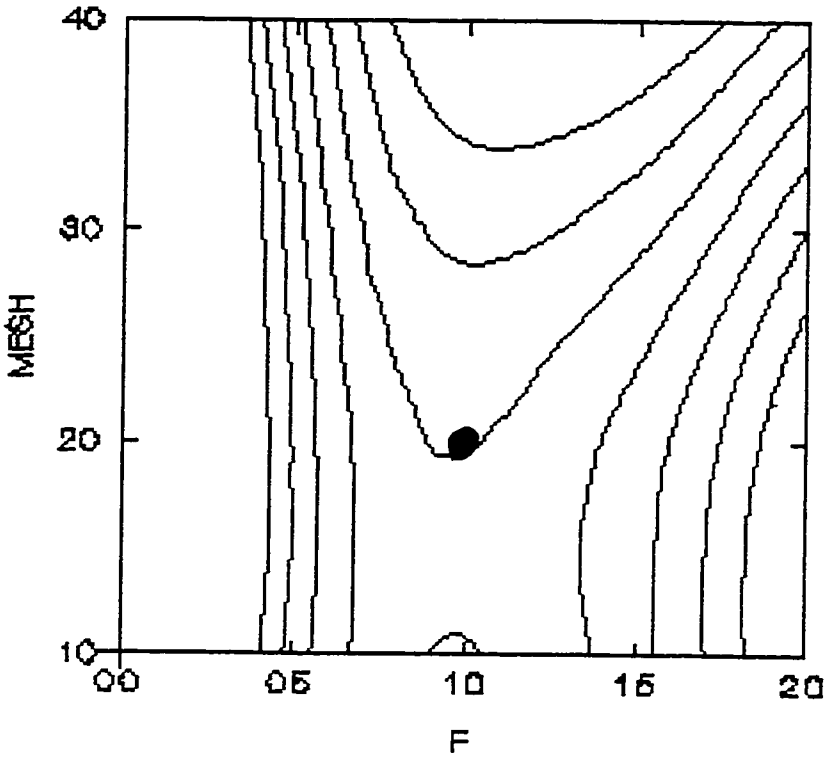


Fig. 68 - Isopleths of the biological yield-per-recruit (g) *vs.* mesh size (mm) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea*; data from the earlier trawl surveys (from ANALEN). The black dot denotes the current level of exploitation according to the growth and mortality estimates.

For the sake of double-checking, the yield-per-recruit analysis was performed also on the full data set coming from the earlier trawl surveys (52 length classes; min 18 mm CL, max 69 mm), that produces an 8-year classes discrimination. The slope of the yield-per-recruit curve at the origin is 85.93, and the virgin biomass is 4792 tons. This resulted in a slightly different yield-per-recruit curve, whose salient points are presented in Table 49. To summarize the differences, the fishing factor for the $F_{0.1}$ strategy is almost

50% lower, and F_{max} switches from above to below F_{actual} (i.e. the shrimp resources seem to pass from slightly underfished to lightly overfished).

Table 49 - Biological yield-per-recruit (g), standing biomass-per-recruit (g) and spawning stock standing biomass-per-recruit (g) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the earlier trawl surveys, restructured by age, considering the three CL classes above CL_∞ (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the yield-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	Y/R	biomass/R	Spawning stock biomass/R
F_0	0	0.00	75.9	70.04
$F_{0.1}$	0.43	14.57	35.19	29.54
F_{max}	0.90	15.87	23.43	18.01
F_{actual}	1.00	15.85	21.96	16.60
F_{double}	2.00	14.63	13.86	8.96

Sensitivity

The sensitivity analysis performed using the VIT program on biomass (both from selectivity and from earlier trawl surveys data) shows that the yield-per-recruit results are influenced very strongly by the exponent parameter of the weight-length relationship: an error of 10% produces a 3-fold variation in the output, i.e. when b= 2.4 or b= 2.9 (10%

below and above the "true" b= 2.64), the yield-per-recruit passes from 5.4 at 42.6 (being the "true" value 15.1). In fact, an error of such a magnitude is not common in the estimation of the parameter: nevertheless, just a 3% error in the input (b= 2.56 and b= 2.72, respectively) moves the yield-per-recruit to 11.7 or 19.6, i.e. an error in the output of about 30%; even a 1% mis-estimate (almost the order of magnitude of rounding) creates a 10% difference in the yield-per-recruit.

Table 50 - Sensitivity analysis of the yield-per-recruit estimates (VIT empirical approach): sign of the variation in outputs in relation to positive input errors. *Aristaeomorpha foliacea* females from the selectivity study. CL_∞ and K, VBGF parameters; a and b, parameters of the length-weight regression; M and $F_{terminal}$, natural mortality and fishing mortality of the last group.

	Y/R	biomass/R	spawning stock biomass/R
CL_∞	+	-	-
K	+	-	-
a	+	+	+
b	+	+	+
M	-	-	-
$F_{terminal}$	+	-	-

An error on CL_∞ carries less effect: a reduction of 10%, i.e. from 70 mm to 63 mm CL (an increase has not been considered, since 70 mm is already above CL_{max}), produces a 20% reduction in the yield-per-recruit. Incorrect estimates of K cause an almost proportional change on the yield-per-recruit output. A similar behaviour is shown by the parameter "a", the intercept of the weight-length curve. A variation of M causes almost

proportional changes too, but of opposite sign than with "a" and K. Finally, as expected, the yield-per-recruit is almost insensitive to errors in $F_{terminal}$: a 30% input error produces a restricted range of values of 14.9-15.2. The sensitivity analysis performed on age-restructured data closely resembles qualitatively that of length-restructured data. Nevertheless, the influence of biased inputs is somehow greater for the growth parameters CL_∞ and K, and for the mortality M (about a 30-40% increase). Broadly speaking, the sign of the variation in the outputs in relation to positive input errors is reported in Table 50.

In ANALEN the sensitivity is studied analytically as the tendency of the curve (in fact, its Taylor's expansion) when the fishing mortality varies 1%. Table 51 reports the sensitivity coefficients, i.e. the numerical parts of the polynomial expansion, of the different parameters in the situation from the selectivity study, and the percent variation of the coefficient in a new ($F_{new}= F_{actual}+1\%$) exploitation regimen (note the opposite values of K and M in the first order development). In the selectivity study scenario the yield-per-recruit decrease 1.45%, showing a trend that suggests the stock is (heavily) overfished (but even with small errors in the input parameters, the coefficient of variation of the decrease is many-fold).

Table 52 reports the sensitivity coefficients of the different parameters in the earlier trawl surveys situation, and the percent of variation of the coefficient in a new ($F_{new}= F_{actual}+1\%$) exploitation regimen. In the scenario from the earlier trawl surveys, the overall yield-per-recruit estimate increases 1.11%, a trend suggesting a slightly underfished stock.

Table 51 - Sensitivity analysis of the yield-per-recruit estimates (ANALEN analytical approach): parameter of the Taylor's expansion of the first and second order, and percent variation when $F_{new}= 1.01*F_{old}$. *Aristaeomorpha foliacea* females from the selectivity study. CL_∞ and K, VBGF parameters; M and E, natural mortality and exploitation rate.

	I order	I variation %	II order	II variation %
CL_∞	1.61	-0.10	-3.87	0.42
K	0.71	-0.03	-0.52	-0.02
M	-0.71	-0.03	0.19	0.00
E	0.21	0.01	-0.03	-0.01
$K*CL_\infty$	-0.85	-0.08		
K*M	0.33	0.00		

Table 52 - Sensitivity analysis of the yield-per-recruit estimates (ANALEN analytical approach): parameter of the Taylor's expansion of the first and second order, and percent variation when $F_{new}= 1.01*F_{old}$. *Aristaeomorpha foliacea* females from the earlier trawl surveys. CL_∞ and K, VBGF parameters; M and E, natural mortality and exploitation rate.

	I order	I variation %	II order	II variation %
CL_∞	2.67	-1.77	-7.79	8.47
K	0.90	-0.36	-0.58	0.30
M	-0.90	0.36	0.32	-0.06
E	0.14	-0.33	-0.17	0.24
$K*CL_\infty$	-0.88	1.13		
K*M	0.26	-0.01		

Transitional period (selectivity study)

The VIT program, using the virtual population reconstruction performed on age-structured data from the selectivity study, permits one to examine the transitional behaviour of the fishery, when passing from the old steady-state to the new equilibrium (Fig. 69).

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, yield-per-recruit is already 101% of the starting value, and it is stable in the fourth year at 104% of the initial yield-per-recruit. The increase in biomass of the standing stock is 7% in the first year, 12% in the second, and stabilizes in the fourth year 14% above the starting value. For the spawning stock biomass, 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, yield-per-recruit is back a full 100%, and it is stable in the fourth year at 106% of the initial Y/R. The increase in biomass of the standing stock is 11% in the first year, 22% in the second, and stabilizes in the fourth year 26% above the starting value. For the spawning stock biomass, the respective increases are 13%, 27% and 32%.

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 yield-per-recruit in the tenth year. Every year during the transition there is an increase in biomass of the standing stock that levels off at 141% in 9 years; the spawning stock biomass is also always increasing, up to 152% of the starting value.

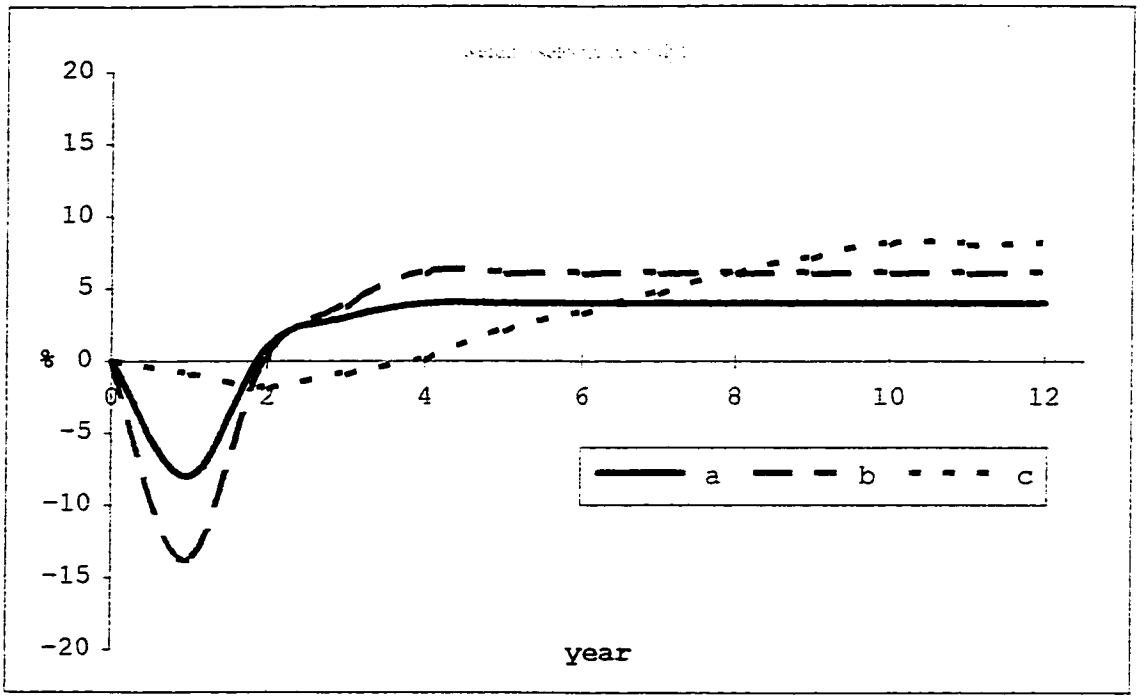


Fig. 69 - Transitional status of the *Aristaeomorpha foliacea* fishery with different management interventions (reduction of the fishing mortality: a= 15% sudden; b= 25% sudden; c= 35% in 7 years). Percent yield (weight) variations, analysis from the selectivity study.

There is not enough information as to decide which stock-recruitment model, Beverton and Holt's (1957) or Ricker's (1954), should be preferred. Therefore, just stochastic variability (log-normal distribution, variance= 0.5) can been applied to the "constant recruitment" situation on the data from the selectivity study. 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 yield-per-recruit). With a sudden drop in the fishing mortality of 25%, the yield-per-recruit 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 yield-per-recruit). With a gradual drop in the fishing mortality of 35% in

7 years, the yield-per-recruit 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 yield-per-recruit).

Transitional period (earlier trawl surveys)

Also the virtual population reconstruction performed on age restructured data from the earlier trawl surveys permits examination of the transitional behaviour of the fishery (Fig. 70). A sudden reduction of the fishing mortality of 15% (line a) produces in the first year a drop of 10% in the yield-per-recruit; in the second year, yield-per-recruit recovers 6%, and it is stable in the fourth year at 98% of the initial yield-per-recruit. The increase in biomass of the standing stock is 4% in the first year, 8% in the second, and stabilizes in the fourth year 10% above the starting value. For the spawning stock biomass, 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, yield-per-recruit recovers 10%, and it is stable in the fourth year at 96% of the initial yield-per-recruit. The increase in biomass of the standing stock is 7% in the first year, 17% in the second, and stabilizes in the fourth year 19% above the starting value. For the spawning stock biomass, 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 of course 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 yield-per-recruit in the tenth year. Every year during the transition there is an increase in biomass of the standing stock that levels off at 130% in 10 years; the spawning stock biomass is also always increasing, up to 140% of the starting value.

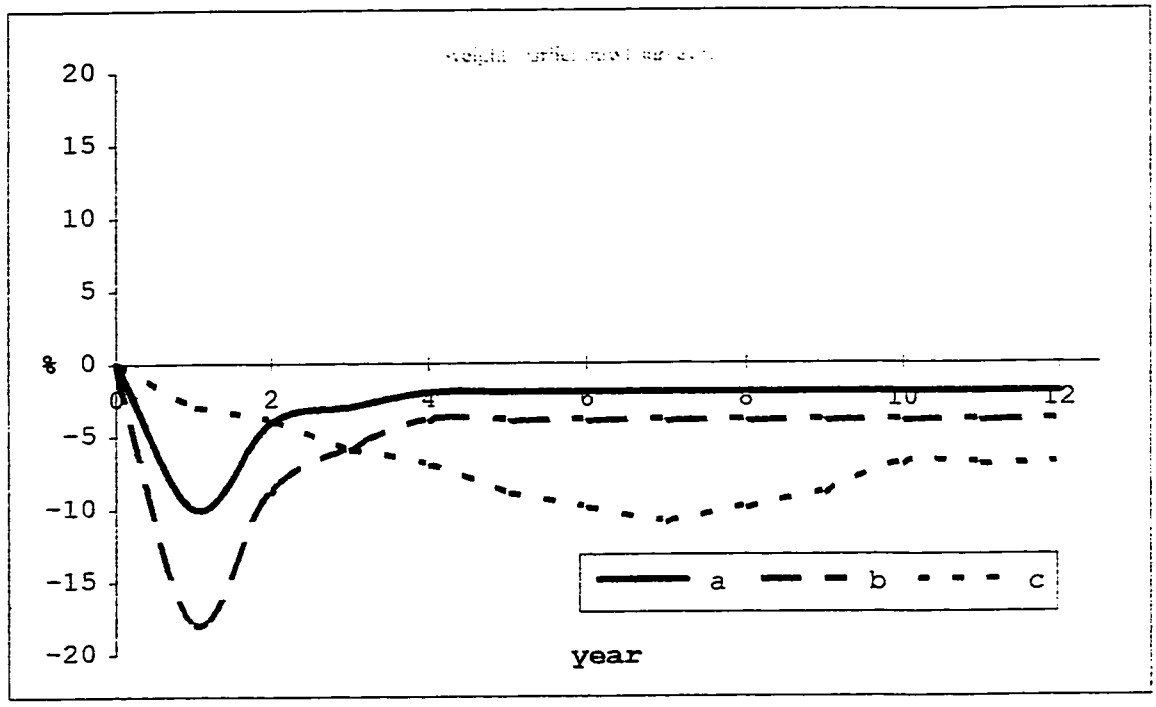


Fig. 70 - Transitional status of the *Aristaeomorpha foliacea* fishery with different management interventions (reduction of the fishing mortality: a= 15% sudden; b= 25% sudden; c= 35% in 7 years). Percent yield (weight) variations, analysis from the earlier trawl surveys.

A stochastic variability (log-normal distribution, variance= 1) has been applied to a "constant recruitment" situation also on the data from the earlier trawl surveys. 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 yield-per-recruit). With a sudden drop in the fishing mortality of 25%, the yield-per-recruit 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 yield-per-recruit). With a gradual drop in the fishing mortality of 35% in 7 years, the yield-per-recruit 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 yield-per-recruit).

Yield scenarios

The hourly yield (kg/h) that results in different exploitation scenarios using the Thompson and Bell's approach, varying fishing mortality and/or mesh size, is reported in Table 53.

Table 53 - Hourly yield (kg/h) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; data from the selectivity study (Thompson and Bell's analysis). Present situation underlined; the yield at maximum Y/R is reported too.

	mesh (mm)			
F multiplier	16	20	24	28
0.50	16.8	17.7	17.8	17.8
0.75	12.6	13.7	13.9	14.0
1.00	9.7	<u>10.9</u>	11.1	11.3
1.25	7.7	8.9	9.1	9.4
1.50	6.3	7.4	7.6	8.0
at max Y/R	9.3	8.2	7.9	7.1

The hourly catch in weight does not appear to be strongly influenced by the changes in mesh size; nevertheless, given the apparent situation of underfishing, the hourly yield at maximum yield-per-recruit is lower than the present value.

Table 54 - Variations in the short-term productions (%) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size (from ANALEN). Yields were expressed in weight; present situation underlined.

	F multipliers									
mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
32	-53.47	-44.17	-34.86	-25.56	-16.25	-6.95	2.36	11.67	20.97	30.28
28	-51.92	-42.30	-32.68	-23.07	-13.45	-3.83	5.78	15.40	25.02	34.63
24	-50.75	-40.90	-31.05	-21.20	-11.35	-1.50	8.35	18.20	28.05	37.90
20	-50.00	-40.00	-30.00	-20.00	-10.00	0.00	10.00	20.00	30.00	40.00
16	-49.68	-39.62	-29.56	-19.49	-9.43	0.63	10.69	20.76	30.82	40.88

Table 55 - Variations in the long-term productions (%) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size (from ANALEN). Yields were expressed in weight; present situation underlined.

	F multipliers									
mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
32	5.16	8.37	9.98	10.59	10.57	10.15	9.48	8.66	7.74	6.78
28	3.67	6.44	7.64	7.88	7.51	6.76	5.79	4.69	3.52	2.31
24	1.90	4.22	5.00	4.85	4.12	3.05	1.78	0.39	-1.05	-2.50
20	0.39	2.35	2.80	2.34	1.33	0.00	-1.51	-3.12	-4.76	-6.41
16	-0.46	1.29	1.56	0.94	-0.22	-1.70	-3.34	-5.07	-6.82	-8.57

The estimates of the variations (%) in the short- and long-term productions, varying fishing mortality and/or mesh size, obtained by the ANALEN program from the selectivity study data, are reported in Table 54 and Table 55, respectively.

It is apparent that an increase in the mesh size from 20 mm to 24 mm, or even to 28 mm, produces only a marginal loss in the short term, that is offset by the gain in the long term.

MANAGEMENT

Exploitation and fisheries

The deep-water red shrimps began to constitute the target of artisanal and semi-industrial trawl fishing since the '30s in the Ligurian Sea and Balearic Sea, where the first trawlers fishing the epibathyal depths arrived to catch 10-200 kg/day and in some periods the captures went up to 1,000 kg/day/boat. Nowadays, thousand of tons of red shrimps are likely landed along all the Mediterranean coasts; indeed, the Mediterranean red shrimps fisheries can be considered monospecific.

The *Aristaeomorpha foliacea* and *Aristeus antennatus* fisheries in the Mediterranean Sea are often distinct even if a degree of overlapping exists: the main *Aristaeomorpha foliacea* fisheries are located in the Strait of Sicily and in Southern Sardinia, whereas *Aristeus antennatus* occurs in the Western basin and in the Ionian Sea, according to a sort of West-East and North-South gradients in the reciprocal dominance.

The species are commercialized fresh (iced) or, more frequently, frozen. Fast sorting and quick storage is essential to prevent the development of blackening, off-flavors (i.e., iodoform smell) and microbial spoilage. The "black-spot" (or melanosis) is an unaesthetic (but not harmful to consumers) blackening of the head and the tail in shrimps, just a few hours after having been caught. Icing or chilling alone do not prevent this phenomenon, but the problem is now solved, since the introduction of a solution of a reducing salt (usually sodium metabisulphite, at 1.5-2.5 % in seawater). Furthermore, the red prawns smell iodoform if not stored accurately and this phenomenon is more pronounced in some populations (even just after capture).

The "fresh" shrimp catch of the short-range trawlers includes the whole range of sizes (practically no discards), sorted in four categories: small (juveniles, often mixed with other species like *Parapenaeus longirostris*), "3rd" (small specimens, mainly males), "2nd" (large males and small/medium females) and "1st" (large females). The shrimps are boxed (about 8 kg/box) and stored in a cool place, usually without ice, and landed after a few hours.

The composition of the frozen landings depends on the quality of the catch: in the first days of campaign, fishermen start freezing all four commercial groups; if the catch is good, in order to free space in the storage compartments for the highest categories, the smallest are discarded at sea, even if already frozen; sometimes, to reduce their volume, the juveniles are beheaded. The value of the fresh catch is highly variable, depending mainly on seasonal demand; the price of the frozen red shrimps is more stable (Table 56).

Table 56 - Commercial categories, characteristics and landing prices for *Aristaeomorpha foliacea* from the Sicilian Channel.

Category	CL (mm)	weight (g)	n/kg	value (Lire @)	price (Euro/kg)
IV	10-29	0.5-10	800-100	4-75	3-4
III	30-39	11-20	100-50	75-300	4-6
II	40-49	21-40	50-25	300-800	8-10
I	50-69	41-99	25-10	800-3000	12-18

Incidentally, *Aristaeomorpha foliacea* is not or very scantily commercialized in the Western Atlantic and in New Zealand, where its potentiality has been put in evidence since the '50s. In Australia only a small fishery has been developed off-shore the Western coasts; yet experimental surveys have indicated large potentiality of *Aristaeomorpha foliacea* and other Aristeid species throughout the whole Australian continent slope. Marketing, handling and logistic problems have prevented these fisheries to grow; effectively the only true specific fisheries are those of the Mediterranean Sea.

Economic virtual population

Selectivity study

The virtual population calculated from age-restructured data from the selectivity study has an average value of 19.5 billion liras. On a total value balance of D= 31.3 billion liras, the input is totally assigned to growth, while the output is 31.3% for the natural deaths, and 68.7% for the catch; the turnover is 160.0%. In contrast, the average value of the virtual population is 22.0 billion liras when calculated for length-structured data. The critical age for value is 1.41 y for the actual stock (corresponding to a critical length of 40.0 mm), and 2.54 y for the virgin stock (critical length 54.8 mm). On a total value balance of D= 36.0 billion liras, the input is split 1:99 between recruitment and growth, while the output is 30.5% for the natural deaths, and 69.5% for the catch. The turnover is 163.9%. A few compact elements of the economic VPA from the selectivity study, useful for comparisons, are presented in Table 57.

Table 57 - "Compact" results of the economic virtual population analysis of *Aristaeomorpha foliacea*; data from the selectivity study, classified by CL size or restructured by age. $R/\$_{mean}$, ratio of recruits to mean standing value; $\$_{max}/\$_{mean}$, ratio of value of the critical class to mean standing value; $\$D/\$_{mean}$, turnover, i.e. ratio of annual value balance to mean standing value; $\$_{max}/\$D$, ratio of value of the critical class to annual value balance.

	$R/\$_{mean}$	$\$_{max}/\$_{mean}$	$\$D/\$_{mean}$	$\$_{max}/\$D$
value (age)	0	56.2	160.0	35.1
value (length)	1.9	68.4	163.9	41.8

Earlier trawl surveys

The virtual population calculated from age-restructured data obtained from the earlier trawl surveys has an average value of 34.9 billion liras. On a total value balance of D= 41.3 billion liras, the input is totally assigned to growth, while the output is 42.2% for the natural deaths, and 57.8% for the catch; the turnover is 118.5%. In contrast, the average value of the virtual population is 34.6 billion liras when calculated for length-structured data. The critical age for value is 1.93 y for the actual stock (corresponding to a critical length of 48.0 mm), and 2.54 y for the virgin stock (critical length 54.8 mm). On a total value balance of D= 42.3 billion liras, the input is split 1:24 between recruitment and growth, while the output is 40.9% for the natural deaths, and 59.1% for the catch. The turnover is 122.3%. A few compact elements of the economic VPA from the earlier trawl surveys, useful for comparisons, are presented in Table 58.

Table 58 - "Compact" results of the economic virtual population analysis of *Aristaeomorpha foliacea*; data from the earlier trawl surveys, classified by CL size or restructured by age. $R/\$_{mean}$, ratio of recruits to mean standing value; $\$_{max}/\$_{mean}$, ratio of value of the critical class to mean standing value; $\$D/\$_{mean}$, turnover, i.e. ratio of annual value balance to mean standing value; $\$_{max}/\$D$, ratio of value of the critical class to annual value balance.

	$R/\$_{mean}$	$\$_{max}/\$_{mean}$	$\$D/\$_{mean}$	$\$_{max}/\$D$
value (age)	0	50.6	118.5	42.7
value (length)	4.2	51.2	122.3	41.9

Economic yield-per-recruit analysis

The four different approaches that have been used produce qualitatively similar scenarios, i.e. the present level of economic exploitation appears situated always on the right hand of the yield-per-recruit curve, as well as self-consistent quantitative estimates.

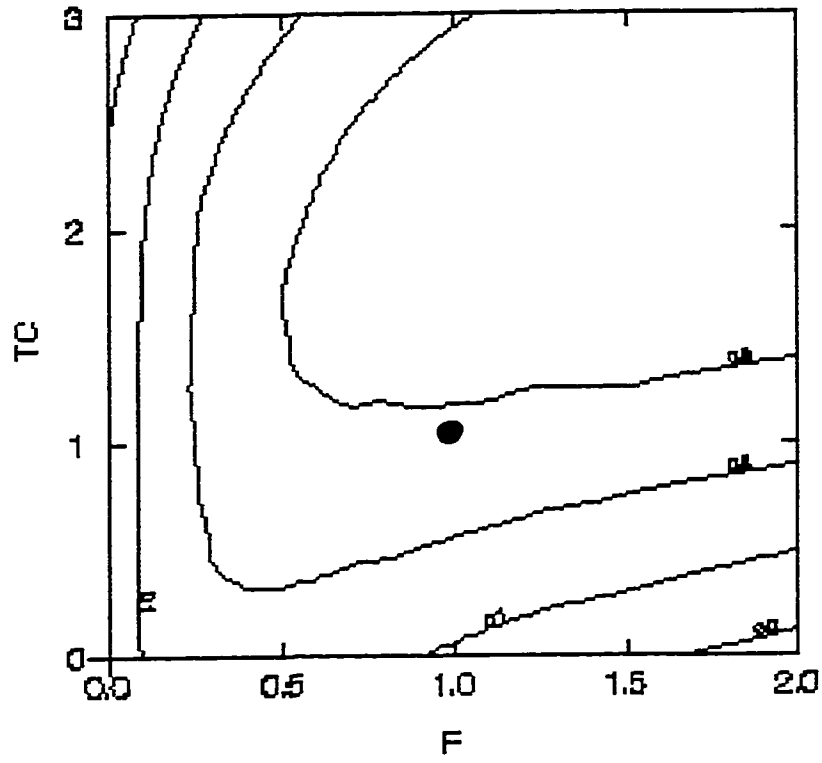


Fig. 71 – Isopleths of the economic yield-per-recruit' *vs.* age at first capture (t_c, in year) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea* (M= 0.5), using the incomplete beta function. The black dot denotes the current level of exploitation according to the growth and mortality estimates.

The economic yield-per-recruit' ($Y/R') results obtained applying the incomplete beta function show that the response surface is flat around the maximum (Fig. 71). At the present level of exploitation, the economic yield-per-recruit' is 0.25, about 4% lower than the maximum (0.26 at F= 1); raising t_c by three months from the present one year does

produce a modest increase (+0.02) in the economic yield-per-recruit' at F= 0.5, and the maximum reaches 0.29 at F=1.0. As already said, the classical Beverton and Holt's approach does not permit estimation of an economic yield-per-recruit in cases where unit prices depend on size (as it is with shrimps). In fact, the present innovative approach with the beta function, which uses a price function as if it were a growth function, seems to behave well when applied to red shrimps, but needs further testing in different situations.

Selectivity study data

The economic yield-per recruit of the present exploitation regimen (20 mm mesh) resulting from the Thompson and Bell's approach is 176.5 Lit/recruit, and the maximum (176.6 Lit/recruit) is situated at 5% less than present F; the response surface is flat around the maximum (the isopleth above 170 Lit/recruit encompasses F from 0.35 to 0.60).

Table 59 - Economic yield-per-recruit (Italian liras, Lit.) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size; data from the selectivity study (Thompson and Bell's analysis). Present situation underlined; the maximum $Y/R is reported together with the percent fishing mortality increase needed to obtain it.

	mesh (mm)			
F multiplier	16	20	24	28
0.50	146	156	159	162
0.75	157	173	178	185
1.00	155	<u>177</u>	182	193
1.25	146	173	180	194
1.50	136	166	174	190
max $Y/R (F increase)	157 (-20%)	177 (-5%)	182 (+0%)	194 (+15%)

The economic yield-per-recruit (Lit/recruit) in different exploitation scenarios, varying fishing mortality and/or mesh size (Thompson and Bell's approach), is reported in Table 59. The isopleth surface is presented in Fig. 72. The level of exploitation (fishing mortality multiplier 1.00, i.e. F= 0.45; mesh size 20 mm) is near the maximum for the present scenario. An increase in mesh size would slightly raise the economic yield-per-recruit keeping the present level of F, and produce an almost "optimal" exploitation without an increase of fishing mortality.

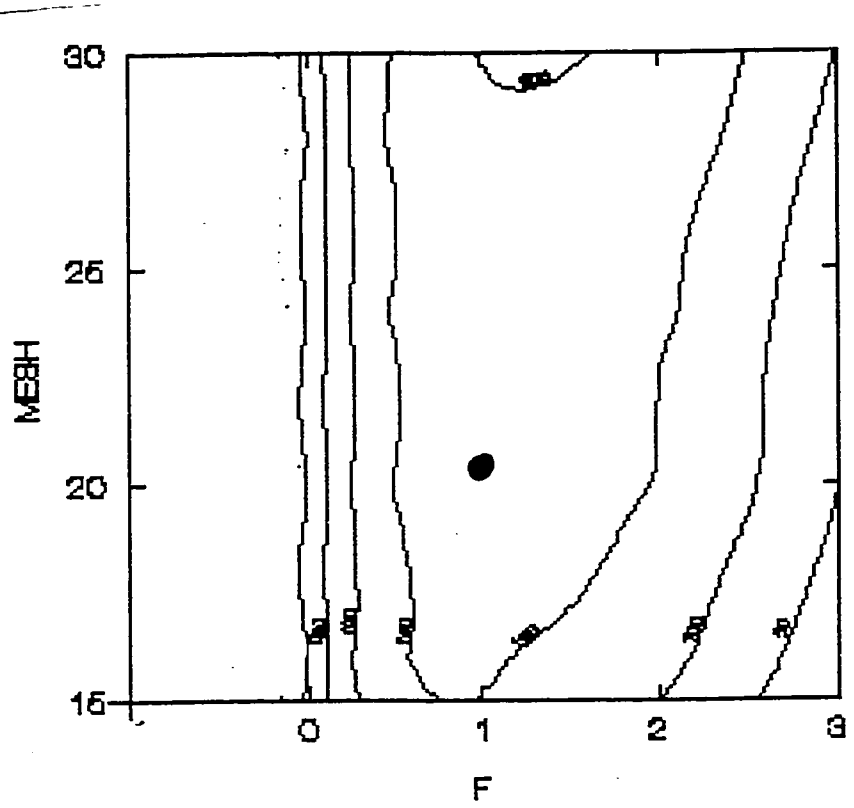


Fig. 72 – Isopleths of the economic yield-per-recruit *vs.* fishing mortality variation (F/year multiplier) and/or mesh size (mm) for *Aristaeomorpha foliacea* (M= 0.5), using the Thompson and Bell's analysis. The black dot denotes the current level of exploitation according to the growth and mortality estimates.

The economic yield-per-recruit (age classes, from the selectivity study) obtained with the VIT program is represented in Table 60. The slope of the economic yield-per-recruit curve at the origin is 1878, and the virgin value is 155.6 billion liras.

Table 60 - Economic yield-per-recruit (Italian liras, Lit.), standing value-per-recruit (Lit.) and spawning stock standing value-per-recruit (Lit.) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the selectivity study, restructured by age (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the $Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the value-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	$ Y/R	standing value/R	Spawning stock value
F_0	0	0	159.7	156.6
$F_{0.1}$	0.28	275	62.7	59.8
F_{max}	0.45	289	44.5	41.6
F_{actual}	1.00	249	21.9	19.2
F_{double}	2.00	184	11.2	8.9

The data from the selectivity study restructured by age show that the present fishing mortality is situated on the right hand of the economic yield-per-recruit curve, well over the fishing mortality that produces the maximum economic yield-per-recruit (289 Lit/R), and that even the safer $F_{0.1}$ strategy shall provide better economic results; the standing value-per-recruit is presently less than 15% of the virgin stock value-per-recruit.

The economic yield-per-recruit (length classes) obtained with the VIT program is represented in Table 61. The slope of the economic yield-per-recruit curve at the origin is 2374, and the virgin value is 160.1 billion liras.

Table 61 - Economic yield-per-recruit (Italian liras, Lit.), standing value-per-recruit (Lit.) and spawning stock standing value-per-recruit (Lit.) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the selectivity study, classified by CL size (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the $Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the value-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	$ Y/R	standing value/R	Spawning stock value
F_0	0	0	142.5	138.9
$F_{0.1}$	0.29	226	54.0	50.7
F_{max}	0.44	235	30.4	36.3
F_{actual}	1.00	197	17.9	15.2
F_{double}	2.00	134	8.2	6.2

In the analysis of the selectivity study data set, the comparison between the economic values obtained with data structured by size or the age-restructured data shows that the estimates are somehow different, but the general picture remains almost the same.

Again, the present fishing mortality (0.45) is past the optimal one (about 0.20), and the present spawning stock value-per-recruit is only 12% of the spawning value-per-recruit of the virgin stock.

The surface response and the corresponding isopleths of the economic yield-per-recruit (length classes) from the selectivity study obtained with the ANALEN program are represented in Fig. 73 and Fig. 74, respectively.

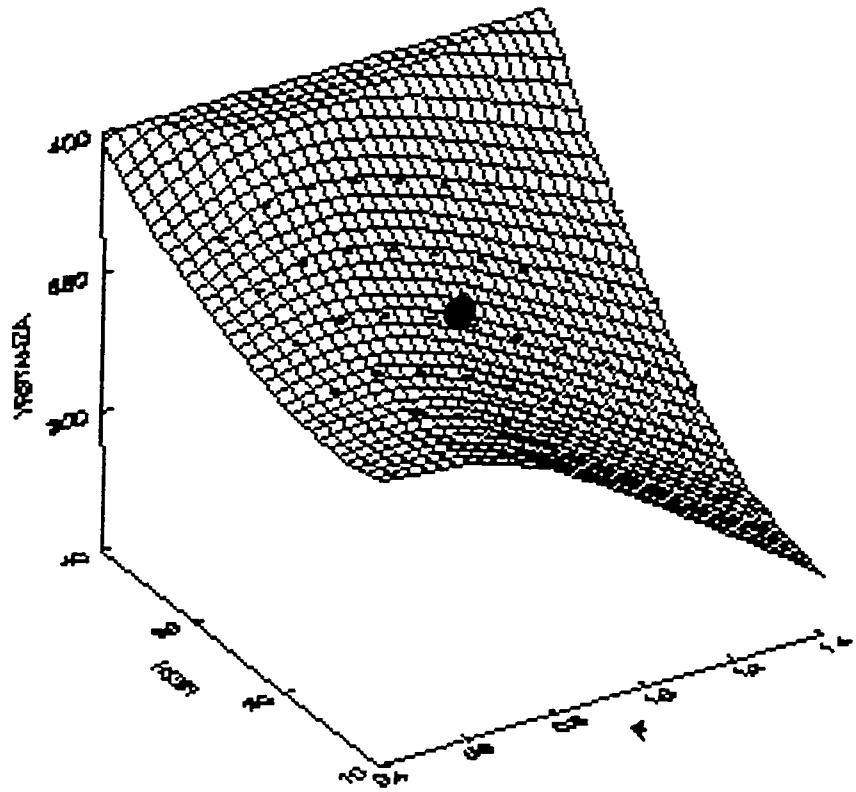


Fig. 73 – Surface response of the economic yield-per-recruit (Italian liras, Lit.) *vs.* mesh size (mm) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea*; data from the selectivity study (from ANALEN). The black dot denotes the current level of exploitation according to the growth and mortality estimates.

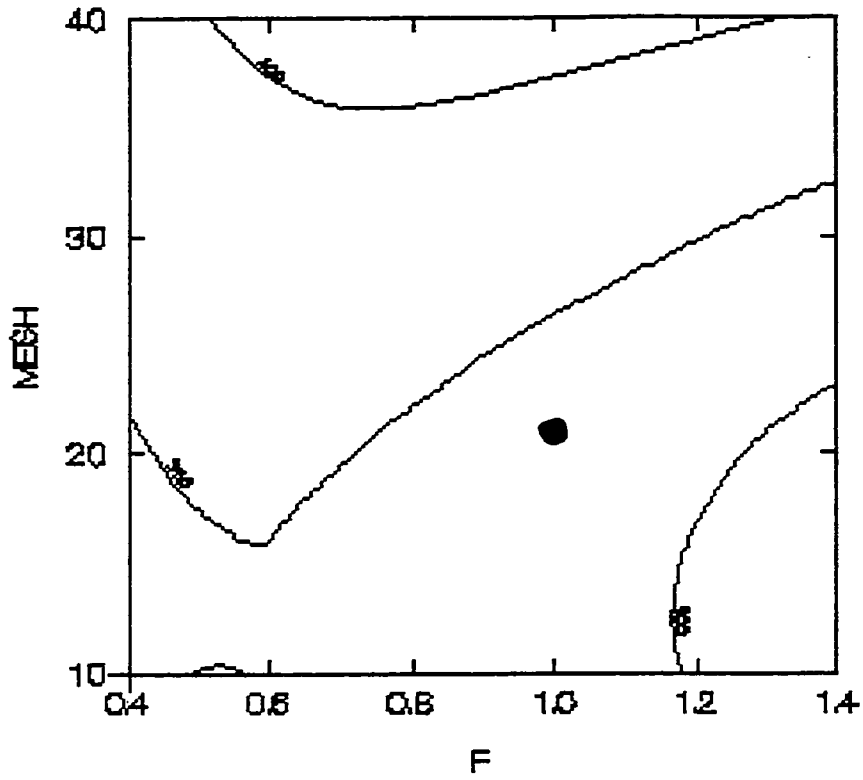


Fig. 74 - Isopleths of the economic yield-per-recruit (Italian liras, Lit.) *vs.* mesh size (mm) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea*; data from the selectivity study (from ANALEN). The black dot denotes the current level of exploitation according to the growth and mortality estimates.

In summary, the economic yield-per-recruit estimated by the VIT program (both from age- and length-structured data) from the selectivity study data (as well as the graphs from ANALEN) suggests a situation of overfishing, with an economic yield-per-recruit value distant from the maximum on the right side of the curve; a drastic reduction of F, from the present 0.45 to about 0.10-0.15 will bring the level of exploitation to the safer level of the $F_{0.1}$ strategy with even a substantial increase in the economic yield-per-recruit. In the meantime, the standing value-per-recruit should more than triple.

Earlier trawl surveys data

The economic yield-per-recruit (age classes, from the earlier trawl surveys) obtained with the VIT program is represented in Table 62. The slope of the economic yield-per-recruit curve at the origin is 948, and the virgin value is 131.7 billion liras.

Table 62 - Economic yield-per-recruit (Italian liras, Lit.), standing value-per-recruit (Lit.) and spawning stock standing value-per-recruit (Lit.) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the earlier trawl surveys, restructured by age (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the $Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the value-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	$ Y/R	standing value/R	Spawning stock value
F_0	0	0	144.8	137.2
$F_{0.1}$	0.56	306	65.7	58.5
F_{max}	0.90	323	48.2	41.2
F_{actual}	1.00	322	44.6	37.7
F_{double}	2.00	281	25.3	19.0

The data from the earlier trawl surveys restructured by age show that the present fishing mortality is situated on the right hand of the economic yield-per-recruit curve, that the value of the present economic yield-per-recruit is almost at its maximum, and that the present standing value-per-recruit is above the 30% of the virgin stock value.

The economic yield-per-recruit (length classes) obtained with the VIT program from earlier trawl surveys data is represented in Table 63. The slope of the economic yield-per-recruit curve at the origin is 1321, and the virgin value is 112.5 billion liras.

Table 63 - Economic yield-per-recruit (Italian liras, Lit.), standing value-per-recruit (Lit.) and spawning stock standing value-per-recruit (Lit.) of *Aristaeomorpha foliacea* in different exploitation scenarios; data from the earlier trawl surveys, classified by CL size (from VIT). F_0, no fishing mortality; $F_{0.1}$, the fishing mortality at which the slope of the $Y/R curve is 10% of the slope at F_0; F_{max}, the fishing mortality at which the value-per-recruit is maximized; F_{actual}, the present fishing mortality; F_{double}, twice the present fishing mortality. Factor, the multiplier of the present fishing mortality.

	factor	$ Y/R	standing value/R	Spawning stock value
F_0	0	0	124.7	115.7
$F_{0.1}$	0.61	235	51.3	43.4
F_{max}	0.94	246	37.6	30.2
F_{actual}	1.00	245	35.7	28.5
F_{double}	2.00	214	19.6	13.6

The surface response and the corresponding isopleths of the economic yield-per-recruit (length classes) from the earlier trawl surveys obtained with the ANALEN program are represented in Fig. 75 and Fig. 76, respectively.

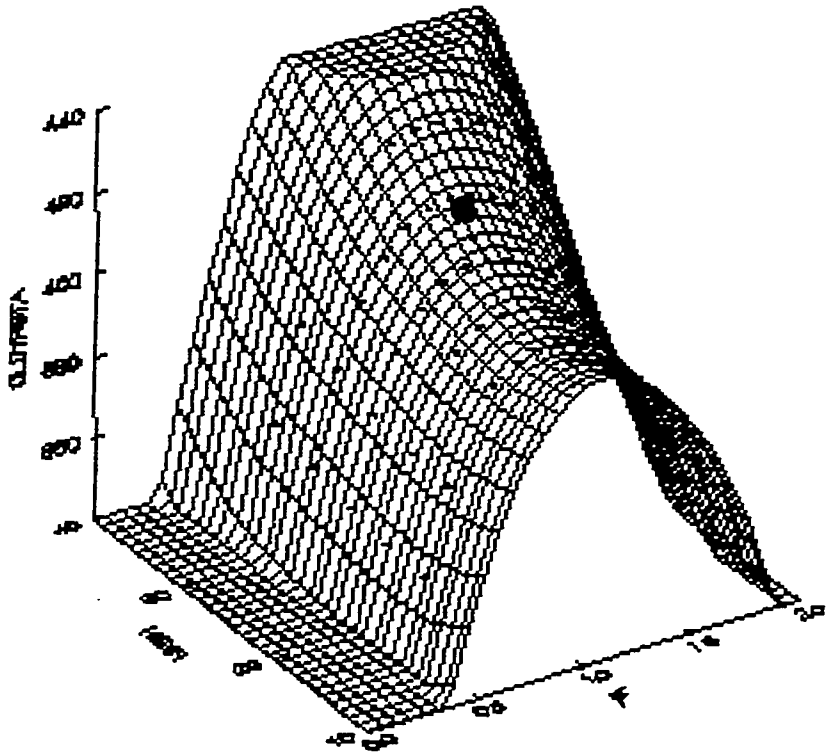


Fig. 75 – Surface response of the economic yield-per-recruit (Italian liras, Lit.) *vs.* mesh size (mm) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea*; data from the earlier trawl surveys (from ANALEN). The black dot denotes the current level of exploitation according to the growth and mortality estimates.

In summary, taking from the earlier trawl surveys, the overall picture remains again the same when the analysis is performed with size- or age-structured data, regardless of the VIT or ANALEN program. The economic yield-per-recruit estimated by the VIT program from the earlier trawl surveys data suggests a situation of almost "optimal" fishing, with a economic yield-per-recruit value near the maximum in both the age- and the length-structured set (but on the right side of the curve). The pursuit of the safer $F_{0.1}$ strategy, with an F more than 1/3 lower than the present F= 0.45, would cause a modest decrease of the economic yield-per-recruit (less than 5%).

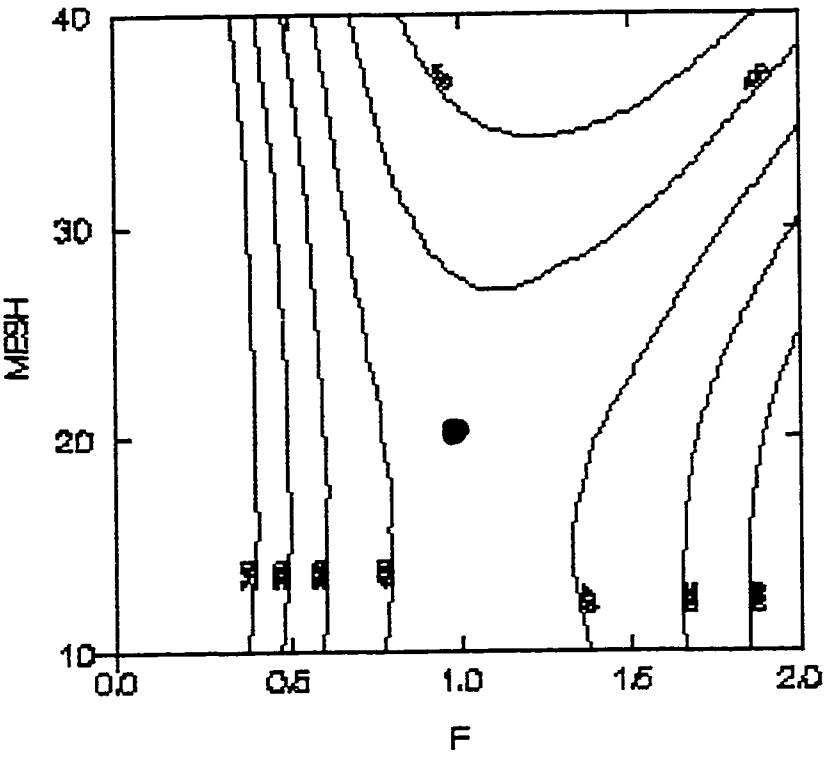


Fig. 76 - Isopleths of the economic yield-per-recruit (Italian liras, Lit.) *vs.* mesh size (mm) and fishing mortality variation (F/year multiplier), for *Aristaeomorpha foliacea*; data from the earlier trawl surveys (from ANALEN). The black dot denotes the current level of exploitation according to the growth and mortality estimates.

Sensitivity

The sensitivity analysis performed using the VIT program on weights (both from the selection study and the earlier trawl surveys) shows that the economic yield-per-recruit results are influenced very strongly by the exponent parameter of the value-length relationship: an error of 3% produces a 40-50% variation in the output, i.e. when b= 3.6 or b= 3.8 (3% below and above the "true" b= 3.71), the economic yield-per-recruit passes from 207 to 500 (the "true" value being 322); even a 1% mis-estimates creates a 15% difference in the economic yield-per-recruit. An error on CL_∞ carries less effect: a reduction of 10%, i.e. from 70 mm to 63 mm CL (an increase

has not been considered, since 70 mm is already above CL_{max}), produces a 15% reduction in the economic yield-per-recruit. The sensitivity of the economic yield-per-recruit on the parameters K, a, M and $F_{terminal}$ is comparable to that of the biological Y/R.

Transitional period (selectivity study)

The VIT program, using the virtual population reconstruction performed on age-structured data from the selectivity study, permits the examination of the transitional economic behaviour of the fishery, when passing from the old steady-state to the new equilibrium (Fig. 77).

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 yield-per-recruit; in the second year, economic yield-per-recruit surpasses the initial value at 103%, and it is stable in the fourth year at 107%. The increase in value of the standing stock is 8% in the first year, 15% in the second, and stabilizes in the fourth year 18% above the starting value. For the spawning stock value, the respective increases are 9%, 17% and 20%. A sudden reduction of the fishing mortality of 25% (line b) produces in the first year a drop of 13% in the economic yield-per-recruit; in the second year, economic yield-per-recruit again surpasses the initial value at 103%, and it is stable in the fourth year at 111% of the initial economic yield-per-recruit. The increase in value of the standing stock is 13% in the first year, 27% in the second, and stabilizes in the fifth year 34% above the starting value. For the spawning stock value, the respective increases are 15%, 32% and 39%.

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 yield-per-recruit, up to the lowest 97%, and a complete recovery at three years, reaching a stable situation of 115% of the initial economic yield-per-recruit in the tenth year. Every year during the transition there is an increase in value of the standing stock that levels off at 154% in 10 years; the spawning stock value is also always increasing, up to 161% of the starting value.

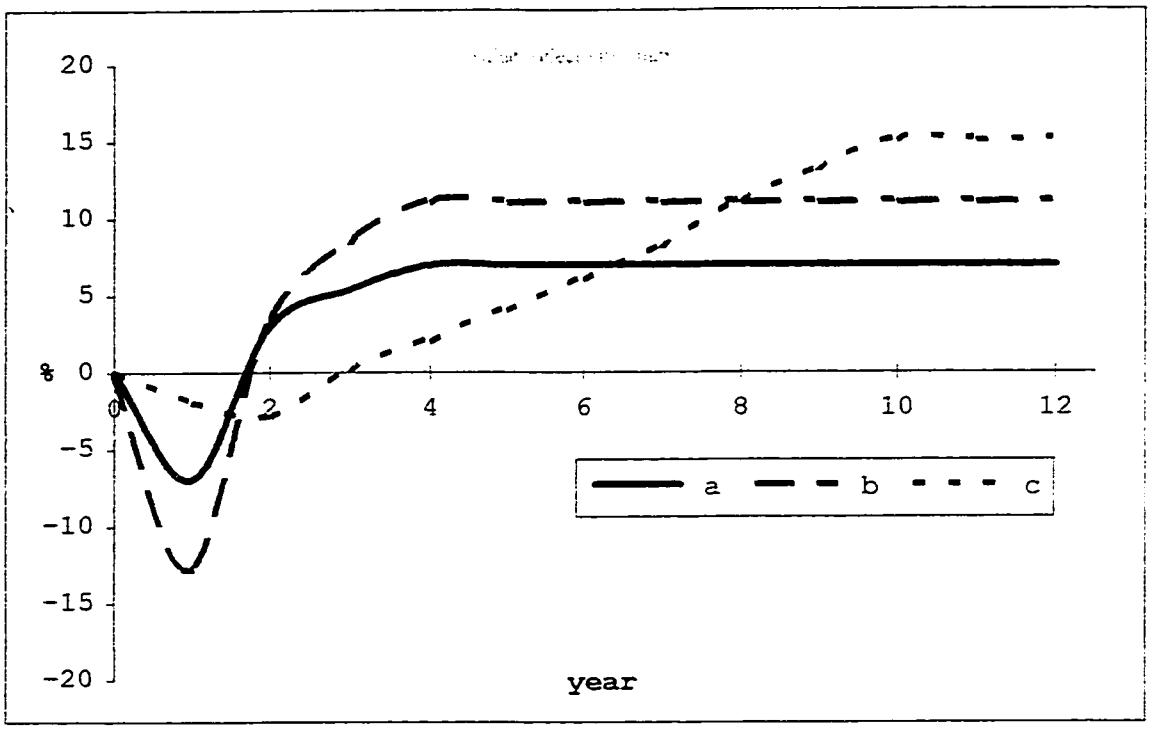


Fig. 77 - Transitional economics of the *Aristaeomorpha foliacea* fishery with different management interventions (reduction of the fishing mortality: a= 15% sudden; b= 25% sudden; c= 35% in 7 years). Percent economic yield variations, analysis from the selectivity study.

Stochastic variability (log-normal distribution, variance= 0.5) has been applied to a "constant recruitment" situation for the selectivity data. Over a period of 15 years, with a sudden drop in the fishing mortality of 15%, the economic yield-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 yield-per-recruit). With a sudden drop in the fishing mortality of 25%, the economic yield-per-recruit 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 yield-per-recruit). With a gradual drop in the fishing mortality of 35% in 7 years, the economic yield-per-recruit 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 yield-per-recruit).

Transitional period (earlier trawl surveys)

Also the virtual population reconstruction performed on age restructured data from the earlier trawl surveys permits examination of the transitional economic behaviour of the fishery (Fig. 78). A sudden reduction of the fishing mortality of 15% (line a) produces in the first year a drop of 10% in the economic yield-per-recruit; in the second year, economic yield-per-recruit recovers 7%, and it is stable in the fourth year back at the initial economic yield-per-recruit. The increase in value of the standing stock is 5% in the first year, 10% in the second, and stabilizes in the fourth year 14% above the starting value. For the spawning stock value, the respective increases are 5%, 12% and 16%. A sudden reduction of the fishing mortality of 25% (line b) produces in the first year a drop of 17% in the economic yield-per-recruit; in the second year, economic yield-per-recruit recovers 11%, and it is stable in the fourth year at 99% of the initial economic yield-per-recruit. The increase in value of the standing stock is 8% in the first year, 18% in the second, and stabilizes in the fifth year 25% above the starting value. For the spawning stock value, the respective increases are 9%, 22% and 30%.

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 yield-per-recruit, up to the lowest 91%, and a partial recovery for three years, reaching a stable situation at 97% of the initial economic yield-per-recruit in the tenth year. Every year during the transition there is an increase in value in the standing stock that levels off at 138% in 10 years; the spawning stock value is also always increasing, up to 148% of the starting value.

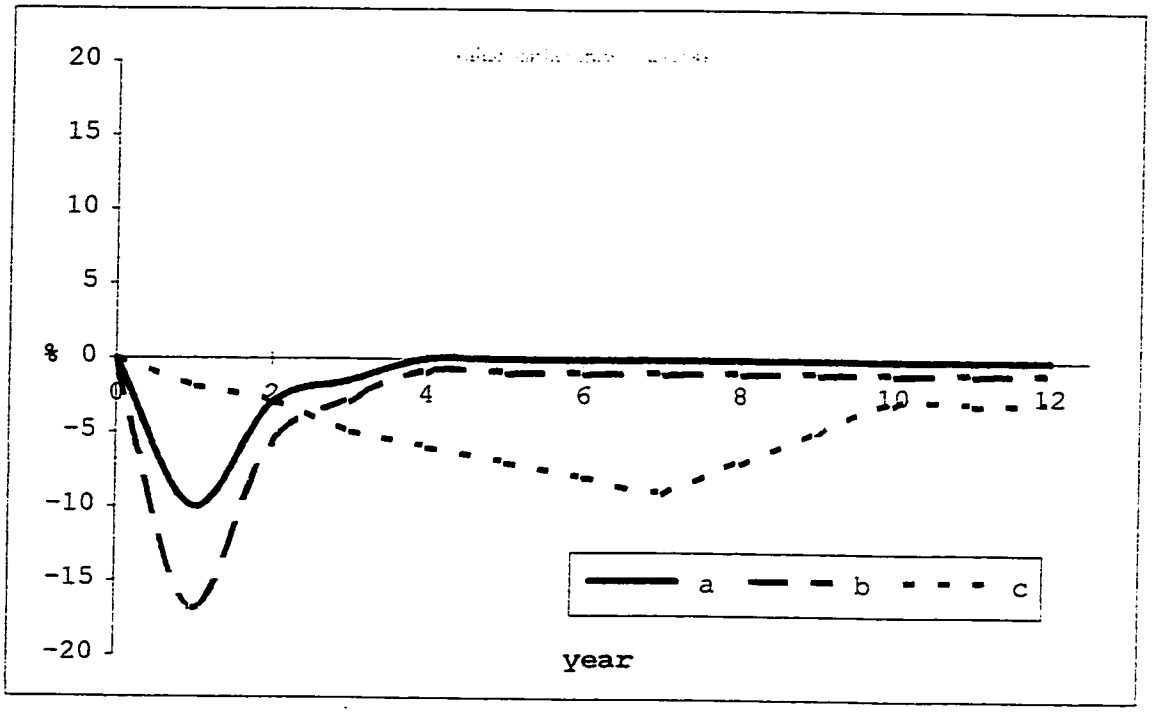


Fig. 78 - Transitional economics of the *Aristaeomorpha foliacea* fishery with different management interventions (reduction of the fishing mortality: a= 15% sudden; b= 25% sudden; c= 35% in 7 years). Percent economic yield variations, analysis from the earlier trawl surveys.

Stochastic variability (log-normal distribution, variance= 1) has been applied to a "constant recruitment" situation also in the data set coming from the earlier trawl surveys. Over a period of 15 years, with a sudden drop in the fishing mortality of 15%, the economic yield-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 yield-per-recruit). With a sudden drop in the fishing mortality of 25%, the economic yield-per-recruit 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 yield-per-recruit). With a gradual drop in the fishing mortality of 35% in 7 years, the economic yield-per-recruit 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 yield-per-recruit).

Economic yield scenarios

The estimates of the economic variations (%) in the short- and long-term productions, varying fishing mortality and/or mesh size, obtained by the ANALEN program from the selectivity study data, with the classical approach of price "stanzas", are reported in Table 64 and Table 65, respectively.

Table 64 - Variations in the economic short-term productions (%) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size (from ANALEN). Yields were expressed in value (by categories); present situation underlined.

	F multipliers									
mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
32	-51.63	-41.96	-32.29	-22.61	-12.94	-3.27	6.41	16.08	25.75	35.42
28	-50.75	-40.90	-31.05	-21.20	-11.35	-1.50	8.35	18.20	28.05	37.90
24	-50.25	-40.30	-30.35	-20.41	-10.46	-0.51	9.44	19.39	29.34	39.29
20	-50.00	-40.00	-30.00	-20.00	-10.00	0.00	10.00	20.00	30.00	40.00
16	-49.92	-39.90	-29.89	-19.87	-9.85	0.16	10.18	20.20	30.21	40.23

Table 65 - Variations in the economic long-term productions (%) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size (from ANALEN). Yields were expressed in value (by categories); present situation underlined.

	F multipliers									
mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
32	15.78	18.07	18.55	17.90	16.57	14.81	12.82	10.71	8.54	6.36
28	13.14	14.80	14.69	13.51	11.70	9.51	7.12	4.64	2.14	-0.34
24	10.33	11.38	10.71	9.02	6.75	4.15	1.39	-1.43	-4.23	-6.99
20	8.10	8.67	7.58	5.52	2.90	0.00	-3.03	-6.09	-9.11	-12.07
16	6.91	7.24	5.93	3.67	0.88	-2.18	-5.35	-8.53	-11.66	-14.71

It is apparent that 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, that are offset by the gain in the long term.

The estimates of the economic variations (%) in the short- and long-term productions, varying fishing mortality and/or mesh size, obtained by the ANALEN program from the selectivity study data, with the *ad hoc* approach of a continuous price function, are reported in Table 66 and Table 67, respectively. It can be seen that the difference in the two approaches are minimal, therefore allowing the innovative use of the price function in the ANALEN procedure.

Table 66 - Variations in the economic short-term productions (%) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size (from ANALEN). Yields were expressed in value (continuous curve); present situation underlined.

	F multipliers									
mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
32	-52.14	-42.57	-32.99	-23.42	-13.85	-4.27	5.30	14.87	24.44	34.02
28	-51.06	-41.27	-31.48	-21.70	-11.91	-2.12	7.67	17.45	27.24	37.03
24	-50.38	-40.46	-30.54	-20.61	-10.69	-0.76	9.16	19.08	29.01	38.93
20	-50.00	-40.00	-30.00	-20.00	-10.00	0.00	10.00	20.00	30.00	40.00
16	-49.86	-39.83	-29.80	-19.77	-9.74	0.29	10.32	20.35	30.37	40.40

Table 67 - Variations in the economic long-term productions (%) of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size (from ANALEN). Yields were expressed in value (continuous curve); present situation underlined.

	F multipliers									
mesh	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40
32	17.14	18.60	18.40	17.23	15.52	13.54	11.44	9.30	7.20	5.15
28	14.67	15.57	14.86	13.23	11.12	8.78	6.34	3.91	1.52	-0.78
24	12.03	12.37	11.15	9.08	6.57	3.86	1.10	-1.63	-4.28	-6.84
20	9.89	9.80	8.20	5.79	2.98	0.00	-3.00	-5.96	-8.81	-11.55
16	8.75	8.43	6.63	4.04	1.07	-2.05	-5.18	-8.25	-11.20	-14.03

Catch variability and fishing effects

The inter-annual variability in yields, indeed a normal characteristic of all fisheries, appears particularly pronounced for at least some "stocks" of red shrimps. Beside the famous change in *Aristeus antennatus* and *Aristaeomorpha foliacea* stocks of the Ligurian Sea, such apparent sudden collapses or absence of one species or the other or both the red shrimps resources in specific areas have been reported many times and for many different places.

Declines in the catch rates (catch per unit of effort, "cpue") have been often described for such fisheries even if no clear relationship seems to exists between yield and fishing effort. Many scientists and all the fishermen think that the fishing activity has a positive effect on yields at least at the beginning of the exploitation and in a wide range of fishing effort. In the Sicilian Channel, catches of red shrimps at the beginning of such fisheries (1960) were reported at about 30 kg/h, with peaks up to 90 kg/h; after 20 years of exploitation the figures are between 2-11 kg/h, suggesting some fishing effect; only in the fishing grounds around the Egadi archipelagos, where trawling is limited by the rugged nature of the bottoms, the yields are still comparable.

Fishing is generally carried out continuously but seasonality can occur as a consequence of bad weather or the prevalence of other main targets. For the Mediterranean, the first trials are carried out in late winter and early spring; thereafter, as the resources are detected and the yields considered to be remunerative, the main season starts with diversion of fishing effort from circalittoral and epibathyal bottoms. The fishing season ends practically at the beginning of autumn, even though some units keep on fishing till winter. As a consequence, the peak of fishing season coincides with the peak of maturity and breeding activity and most likely with the moment in which the shoaling is maximum. In general, skippers adapt the fishing depth intuitively according the movement of the main shoals, changing from 450-600 m in winter to 750-800 m in summer.

Due to the ridiculous mesh sizes commonly employed by Mediterranean trawlers, the exploited size range is quite wide (15-70 mm, CL) and symptoms of growth overfishing are evident, a bad strategy considering that the economic value of juveniles is quite lower than that of the adult component.

Fishing fleet, gear and equipment

Gear

The otter trawl is almost universally used as elective gear in red shrimps fisheries; attempts to use traps were unsuccessful, but mid-water trawls have been employed for *Aristaeomorpha foliacea* at the edge of the shelf and the use of such pelagic nets should be encouraged. The type of net changes from area to area but single-rigged nets are generally employed in deep-water; in Australia, a triple rigged net is sometimes used.

GROSS TONNAGE		25	40	59	66	89	192	198	198
LENGTH OVERALL (m)		18	22	26	22	27	31	32	32
SHAFT HORSE POWER		400	190	470	530	600	550	101	101
GEAR TYPE		italian	italian	italian	volantina	volantina	italian	italian	volantina
BRIDLE	LENGTH (m)	200	124	165	200	18	264	226	230
	DIAMETER (mm)	34	38	32	28	24	20	32	34
TRAWL WARP	DIAMETER (mm)	12	12	12	13	13	14	14	15
OTTER BOARD	TYPE	WOOD	WOOD	WOOD	WOOD	STEEL	STEEL	WOOD	STEEL
	WEIGHT (kg)	130	90	180	220	140	150	350	430
OTTER BOARD DISTANCE (m)		80-120	70-	65-150	86-	79-100	77-147	118-	?
HEADLINE	LENGTH (m)	42	35	43	48	44	46	50	66
GROUNDROPE	LENGTH (m)	53	43	53	55	53	60	69	67
LEAD OR CHAIN WEIGHT (kg)		45	17	30	38	75	30	24	24
NET OPENING	VERTICAL (m)	0.7	0.9	0.7 - 0.9	0.8 -	0.5 -	0.6 - 0.9	0.6 -	?
	HORIZONTAL (m)	15-20	12-	13-23	11-	12-	13-22	21-30	?

Fig. 79 - Typical trawl net configuration for a range of different size trawlers in the Sicilian Channel.

Fig. 79 shows the great variability of gear characteristics for a small sample of different boats (ranging from 25 to 200 tons, 18 to 32 m, 190 to 1000 HP) operating in the Sicilian Channel: note that the second boat is a very old, underpowered vessel.

The headline range from 12-15 m to 27-30 m and the height is generally lower than 1.5 m and much lower (<1 m) in the Italian fisheries. The foot-ropes are usually rigged with chain hung in bights but rubber discs and spacer bobbins assembly could improve the performance of the gear by reducing the amount of debris.

Mesh size in the cod-ends is the prime factor in determining selection by the net, and protecting the juveniles is intuitively beneficial for the red shrimp; nevertheless, the mesh size in use are generally very small (around 40 mm mesh, stretched).

A description and a rough design of a "Mazarese" net plan, the most common in the area, has been already enclosed. One of the most common modifications is the "volantina", where the wings present a cut of swallow-tail shape. A few boats, 10-15%, employ a "French" trawl net, i.e. with a higher mouth opening (everything else is similar). The general description of the local gear should only be considered as indicative. In fact, it is impossible to standardize a design, since many nets are cut and made locally according to the characteristics of the boat and the personal "taste" of the skipper, who moreover adjusts chains, bridles, etc. at sea, making each net a unique artifact; that is also true for other kind of gear, especially those of the small-scale fisheries.

The wooden otter boards are still in use in 50% of the boats; the other half has switched to lighter, more modern steel-plate boards (sometimes cambered); an example of their characteristics is also included. In Fig. 79, a line presents the spreading of the otter boards as actually measured underwater (Fiorentini *et al.*, 1994); consider also that it takes about 15 minutes for the net to come to a stable configuration in 500-700 m bottoms. It is worth noting that in the deepest hauls, with a lot of cable out, it seems that its own weight produces a collapse of the spreading devices, thus reducing the area swept and otter boards distance.

Size, horsepower and number of boats

The Sicilian Channel grounds are exploited by the fishing fleets of 10 Southern Sicilian harbors (of course with different degrees and ratios): Mazara, Sciacca (that harbors consistent trawling fleets), Porto Empedocle and Licata (the closest to the study area), Trapani and Marsala (their fishermen are now mainly converted to drifting gear, such as longlines), Gela, Scoglitti, Pozzallo, Porto Palo (the last four are present only marginally in the study area). A few boats come from other Italian regions and provinces (Bari, Cagliari, Messina, etc.), while the foreign fleets present in the Sicilian Channel do not operate by deep-bottom trawling. Only a few fishing vessels exploit the red shrimp grounds all year around; usually fishers change their targets according to the seasons and availability of other resources, mainly red mullets or pink shrimps.

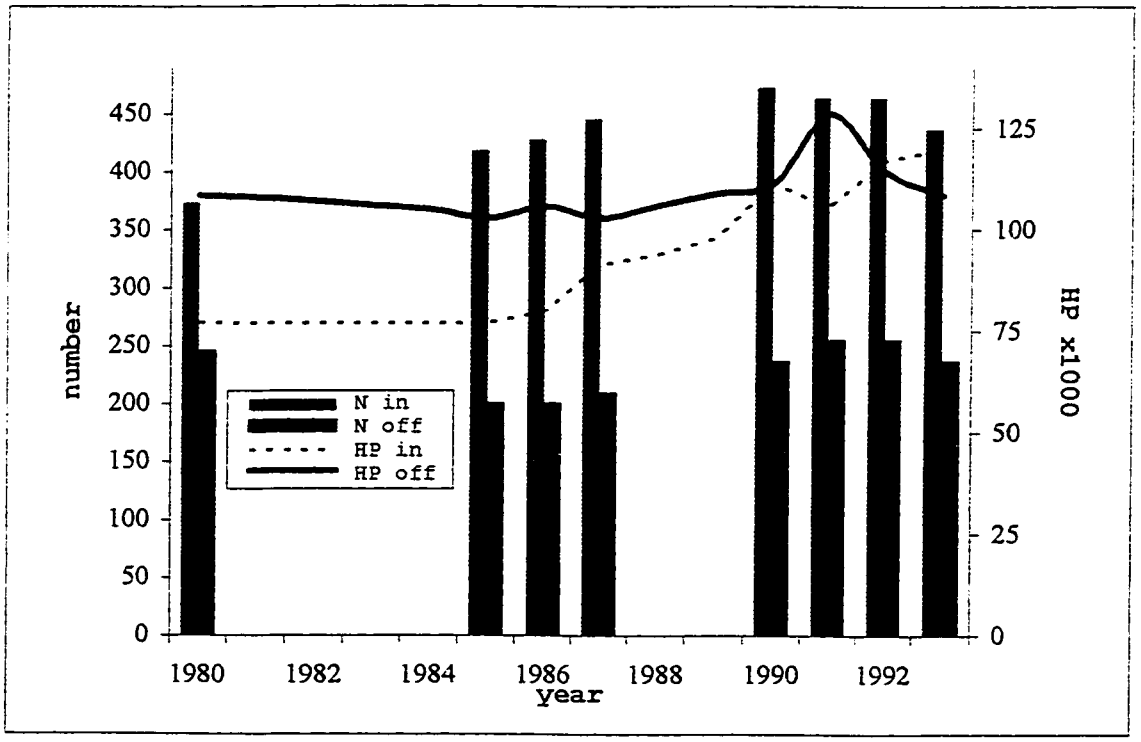


Fig. 80 - Evolution of number, total tonnage and total power of trawlers (coastal and open-sea) of the fleets of the entire 10 Southern Sicilian harbors.

Fig. 80 (elaboration from Andreoli *et al.*, 1995) reports the evolution (1980-1993) of the fleets of the entire 10 Southern Sicilian harbors combined, i.e. number, total

tonnage and total power of trawlers (coastal and open-sea). The total number of boat-days per year is around 100,000 (all kind of fishing boats combined).

Mazara is the largest fishing harbor of the region (70-80% of the total fishing crafts), and the composition of its fleet should be considered representative of the whole Sicilian Channel situation. 361 boats are registered as fishing crafts in the Mazara harbor; they could be subdivided in the following groups:

- 118 boats under 125 HP, mainly geared for trammel netting and/or bottom longlining, with or without ice boxes;
- 43 boats up to 250 HP, with average length 21 m, 52 tons, 191 HP, 33 years of age, mainly of the "polyvalent" type, or for coastal trawling, with ice boxes;
- 109 boats up to 500 HP, with average length 28 m, 117 tons, 365 HP, 27 years of age, mainly coastal or deep-sea trawling, with refrigerators or freezers;
- 76 boats up to 1100 HP, with average length 32 m, 186 tons, 746 HP, 36 years of age (but the oldest are near decommissioning), for deep-sea trawling, with deep-freezing devices;
- 15 boats over 1100 HP, with average length 39 m, 349 tons, 1331 HP, 11 years of age, for oceanic fishing, that do not operate in the Channel.

Fishing techniques

The method of fishing of the off-shore Sicilian fishermen is as follow:

- they reach the area where they want to fish (1-2 day trip);
- they start fishing following the path of a single, known haul;
- they keep going back and forth on the same haul, just varying it by a few meters (if the bottom configuration allows it);
- this activity goes on as long as the captain considers the haul to be remunerative;
- as a rule the catch increases after a few passes, stays flat for a while, and declines fairly rapidly;

- a boat could exploit the same haul for a few days, and stay in the same area for the whole length of the trip, or move to 3-4 different "grounds";
- there is no shared information during the haul, and fishermen even use "codes" when speaking with their relatives on shore or the boat owner (or the occasional sharing is based on personal relationships);
- conversely, everybody knows the characteristics, both physical and biological, of the grounds, and the most renowned hauls even have a common name.

Names of the fishing zones are representative not only of geographical position or quality/quantity of the catch, but of special "characteristics" known to the predatory Sicilian fishermen: "Touch and go", since Tunisian patrol vessels will catch you if you stay there; "The bike", because you have to push on your pedals to escape the Coast Guard; "Night only", because they can not identify you while illegally fishing; etc.

As a common rule, large vessels stay at sea for 2.5-3 weeks, freeze their captures (almost only shrimps, with only a few first-quality fishes), sometimes upgrading the catch (throwing outboard previously packed, second-quality shrimps, to make room for better ones), fish continuously in 4-hour hauls (plus setting and hauling). Given the low "night" catchability of red shrimps, if a bank is around they will fish over it during the night.

Medium-size boats go for 1-2 days trips, keep their catch on ice, sell fresh (getting good prices even for second-quality fish); they do fish over banks regularly, not only at night. Particularly in the summer period, many use Lampedusa as their temporary port of call. A few boats of the medium-size category double their stay at sea to 4-5 days, but the fish, always kept on ice, looses some of its value.

As can be seen from the maps, contouring is not a requirement, and a single haul may end 50 fathoms and more above the initial depth (fishermen tend to go "up"). Given the roughness of the bottom and the number of impediments, the path is sometimes very articulated (sharp and frequent turns around obstacles), and requires ability and attention.

The most common trawling speed is around 2.5-2.8 knots while targeting shrimps, a little more over the banks. On "di fondale" bottoms, fishermen would prefer to go for

four hours (more would spoil the catch), but many times the bottom conformation does not allow for such a length: there are known hauls of less than one hour.

More than on astronomical seasons, the fishing activities are based, with great inter-annual and personal variability, on:

- "Winter", i.e. 4 months from late November till early March;
- early "Spring", 2 months from the end of "Winter" till early May;
- "Summer" for the following 4.5 months;
- late "Fall", which lasts 6 weeks;

the last three "seasons" may be combined in a "good weather" period (that is the reason why many pixels show the same "grade" in these three seasons).

Mainly the 45-day ban and the severity of the sea conditions regulate the distribution of effort among seasons; moreover, fishermen tend to fix and maintain their boat during the winter. For sake of security, areas far away from a protecting harbor are neglected in the stormy season (gales are quite strong in the Sicilian Channel). Somehow somewhere sometime, all the area that is fishable (i.e. above the 800 m depth) is swept in any season, of course with different intensities.

In many instances, differences in the catch composition are due more to changes in availability than to changing fishing grounds. The shrimp fisheries are carried out all year long on both pink and red shrimps, but the majority of the larger vessels go for pink shrimp in the winter season, and for the red shrimps in spring (juveniles) and summer. The medium-size trawlers stay on "slope" grounds, where the target is the pink shrimp. Large and medium-size boats are more prone to exploit the banks in the winter season. For the Pelagie area, this kind of information is reported in detail on the "grid pixels". Summarizing, it appears that, on a total of 45 trawlable pixels, 25 pixels are not fished in winter, and 8 pixels are not fished in autumn. Trawling over banks is present 16 times during the winter period; of these, winter (and fall) is the preferred season in 11 cases.

There are not general "open" and "close" seasons, besides what is explained hereafter. In the Sicilian Channel, the fishing ban is 45 days per year in the "non-Winter" season (Levi, 1991); this limitation applies to Sicily-registered boats, while vessels from

other administrative regions must comply for the entire ban period (e.g. for the trawlers it is a total of five months). While on stop, (Sicilian) crew and owner receive a paltry "salary" from the regional administration (for a while, this situation created a movement toward registering in Sicilian ports).

The by-laws of the ban are a matter of guessing, since the administration changes rules almost every year (as an example, a few years ago non-Sicilian boats could fish without restriction). Recently, the ban was differentiated among fisheries; in fact:

- the trawlers split the 45-day period in two parts: 20 days during February-March, 25 days between August-October;
- the "polyvalent" boats must prioritize one fishing method, and stop accordingly.

It should be said that bans are more fishermen- than fish-oriented: in fact, the forbidden periods sometimes correspond to those when exploitation is already minimal (because of bad weather): although illegal, many fishermen employ the ban period to improve the efficiency of their boat.

Trawling grounds

From the point of view of the trawl fisheries, there are three main "assemblages":

- "Bank", on shallow bottoms, 25-100 m, whose characteristic catch is made of the ubiquitous Mediterranean hake (*Merluccius merluccius*) and striped red mullet (*Mullus surmuletus*), red mullet (*Mullus barbatus*), pandora (*Pagellus erythrinus*), red scorpionfish (*Scorpaena scrofa*), cuttlefish (*Sepia officinalis*), octopus (*Octopus vulgaris*), musky octopus (*Eledone moschata*);
- "Slope", on medium-depth bottoms, 100-400 m, whose characteristic catch is made of the ubiquitous Mediterranean hake (*Merluccius merluccius*) and striped red mullet (*Mullus surmuletus*), red mullet (*Mullus barbatus*), rockfish (*Helicolenus dactylopterus*), catshark (*Scyliorhinus canicula*), pink shrimp (*Parapenaeus longirostris*), Norway lobster (*Nephrops norvegicus*);
- "Depth", on deep bottoms, 400-800 m, whose characteristic catch is made of the ubiquitous Mediterranean hake (*Merluccius merluccius*, large sizes) and striped red

mullet (*Mullus surmuletus*), rockfish (*Helicolenus dactylopterus*), Norway lobster (*Nephrops norvegicus*), red shrimp (*Aristaeomorpha foliacea*) and the more rare violet shrimp (*Aristeus antennatus*).

After a few "cleaning" passages to remove bony fish and sharks, a few hauls (on deep bottoms) become almost monospecific, with only red shrimps. This procedure must be repeated at the beginning of every year.

Even if it presents different grounds requiring different fishing crafts, the study area can be considered, from the point of view of the fishing fleet, as a quite homogeneous sub-sector of the whole Sicilian Channel fisheries. A detailed survey has been conducted on the fishing grounds in a radius of 30 miles around the Pelagie Islands (Fig. 81). The present overall trawlability of the Pelagie area is about 30% (Table 68). As a matter of fact, of the 64 pixels that compose the fishing area around the Pelagie Islands, 19 are almost non-trawlable, 36 show an actual trawling activity over at least 15% of their surface, 28 are fished with drifting longlines, 3 are exploited by bottom longlining, 7 present FADs fisheries, and pots are used in only one. Speaking of the "quality" of the trawlable grounds (as the trawl fishermen feel it, on a 10-point scale), 5% of the pixels were graded "5", 36% received a "6", 42% got a "7", and 17% scored a "8" (Table 69).

Fishing intensity

The Italian fleet is considered to work an average of 220 days per year, due to bad weather, technical stops, holidays (in general, crews do not work on shifts, and their members take breaks or vacations at the same time). The fishing ban subtracts another effective 30 days (out of 45 nominal). The total effort is allocated to each area with a relative ratio that depends on the "estimated value" of the hauls, which takes into account objective abundance of preys, market values, market demands, spatial proximity, time since last fished, and other "feeling" parameters of the fishermen (the "grade" assigned to each grid is valid for the Mazarese fishermen, but not necessarily for others, and for that pixel as a part of the whole Sicilian Channel).

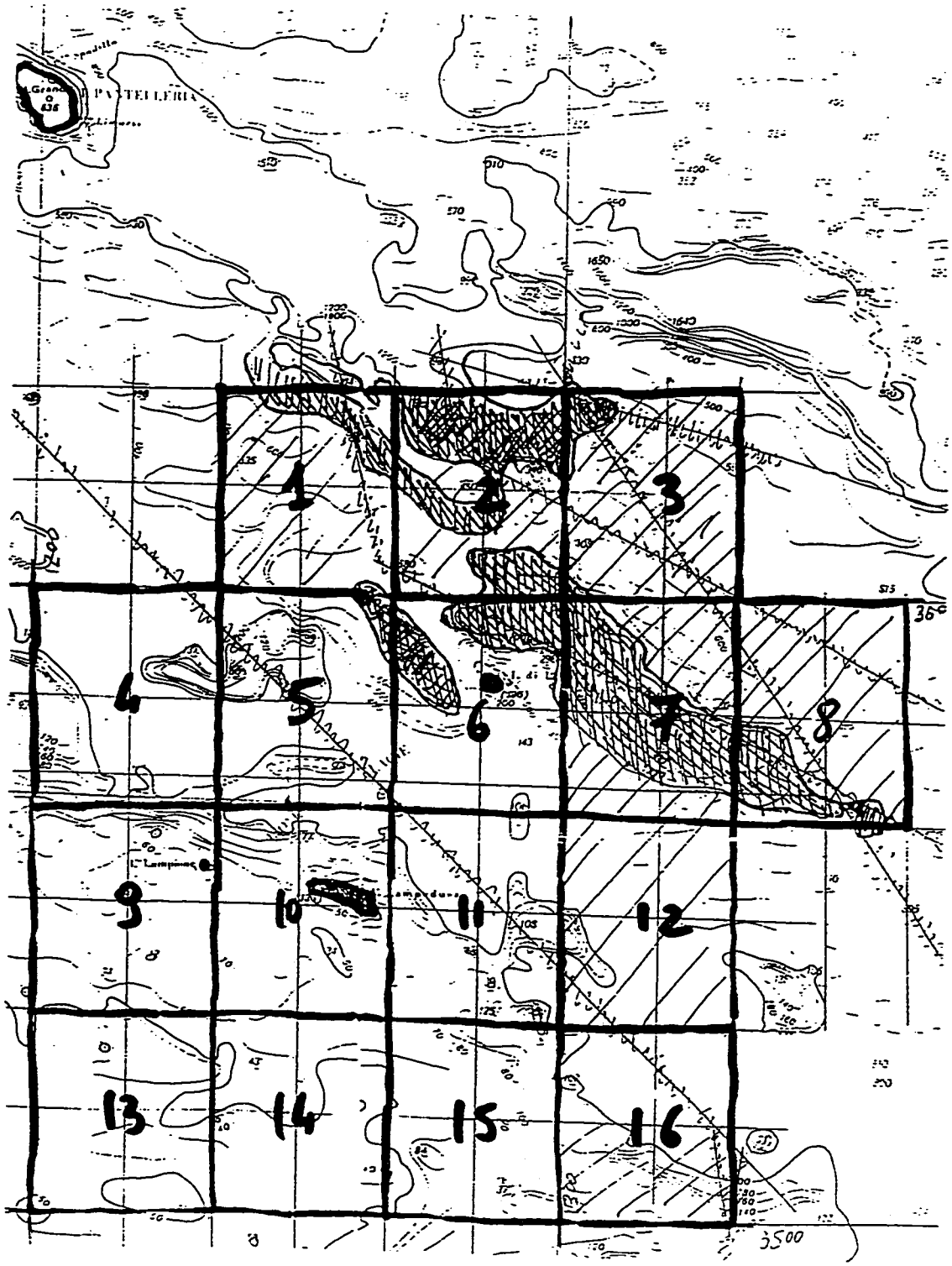


Fig. 81 - The 16x4 pixels that compose the fishing area around the Pelagie Islands.

Table 68 - Percentage of trawlable surface in the different pixels around the Pelagie islands (boxed) in the red shrimp, *Aristaeomorpha foliacea*, fishery. The geographical reference is the latitude and longitude of the upper-left corner of the pixel. nt= not trawlable; X= not considered.

	12°00'E	12°10'E	12°20'E	12°30'E	12°40'E	12°50'E	13°00'E	13°10'E	13°20'E	13°30'E
36°20'N	X	X	nt	15	nt	nt	50	100	X	X
36°10'N	X	X	30	35	nt	nt	30	80	X	X
36°00'N	10	nt	5	40	20	nt	nt	nt	nt	nt
35°50'N	30	70	10	30	50	10	nt	nt	nt	nt
35°40'N	5	nt	5	70	25	nt	nt	60	X	X
35°30'N	50	90	10	50	15	30	nt	5	X	X
35°20'N	100	100	80	80	30	20	40	10	X	X
35°10'N	100	90	80	80	50	30	40	80	X	X

Table 69 - "Scores" attributed to the different pixels around the Pelagie islands (boxed) by the red shrimp, *Aristaeomorpha foliacea*, fishermen. The geographical reference is the latitude and longitude of the upper-left corner of the pixel. Fishing ground scores: 5= below average; 6= average; 7= good; 8= very good. nt= not trawlable; X= not considered; -= not fished.

	12°00'E	12°10'E	12°20'E	12°30'E	12°40'E	12°50'E	13°00'E	13°10'E	13°20'E	13°30'E
36°20'N	X	X	nt	6	nt	nt	7	8	X	X
36°10'N	X	X	6	6	nt	nt	7	7	X	X
36°00'N	6	nt	-	7	-	nt	nt	nt	nt	nt
35°50'N	5	7	6	6	7	7	nt	nt	nt	nt
35°40'N	-	nt	6	6	6	nt	nt	7	X	X
35°30'N	5	6	-	6	7	7	nt	7	X	X
35°20'N	7	7	8	7	6	7	7	6	X	X
35°10'N	7	7	7	7	7	8	7	7	X	X

The fishing intensity can be calculated by various effort measurements; it has been evaluated "directly" only for trawling, since it is the elective catching method for red shrimps. The "intensity" of hauling is reported in the "grid pixels"; it has been assessed by season on the base of a "grade" (0 to 10 scale), using a "proxy" measure, that represents the willingness of the captains to go in a particular area. This measure should be multiplied by the trawlable percentage to obtain a relative measure for each pixel. The "quality" of the actually trawled grounds around the Pelagie islands is considered good or quite good in 59% of the cases. It is interesting to note that good grounds are frequently exploited by many boats at a time, and the radar screen can show 8-10 trawlers around.

Distribution of effort by local or industrial activity

Large vessels leave Sicily and go to the different areas to trawl for shrimps, not caring too much of the islands around; as an example, in the same trip they may fish near the Pelagie, and far away. Smaller vessels make a temporary base in Lampedusa or Pantelleria, particularly during the spring-summer period, and transship their catch as fresh (there are regular commercial flights to Palermo): many are trawlers, but some are polyvalent. That makes it difficult to have precise figures of the distribution of effort by local or industrial activity: as a rough estimates for the whole area it could be 80% large vessels, 15% medium-size boats, 5% (or less) artisanal.

Fisheries management

No specific management rule has been developed for red shrimp fisheries. The general feeling is that these resources are particularly resilient to the fishing pressure and that their evolution might be partially independent from fishery patterns. This assumption is based on the observation that only the upper portion of the population is (at the moment) both accessible and economically remunerative. Another reason of optimism derives from the idea that the catchability coefficient (*sensu* Alveson) would be less than

the unit and that the high fecundity will guarantee from a recruitment-overfishing condition.

Aristaeomorpha foliacea is actually managed neither according to total allowable catch or quota (TAC or ITQ) nor size limit measure because the very small mesh size commonly used (less than 20 mm side) does fish "everything". The severity of winter weather cannot be considered a "natural" management measures because the fishing periods begin and lasts mainly according to the availability of red shrimps or the other resources. In Italy, a non-specific compulsory fishing ban (45 days per year, split in periods) has been introduced in the last years, but its effectiveness in reducing the total fishing effort has not been clearly demonstrated. Incidentally, in Spain, as a non-specific regulatory measure, the boats are only allowed one-day trips (from 06 a.m. to 06 p.m.).

Regulations

There are at least three bodies ruling the fisheries in the Sicilian Channel: the European Union, the Italian government, and the Sicilian government (that has stronger powers than an American state); that produces a maze of conflicting (but rarely enforced) regulations. As a matter of fact, for the swordfish fisheries the bureaucracy generated about 30 laws and by-laws in 18 months!

The management tools are in general not stock- or species-specific. The principal way to regulate the effort is to control the number of boat permits. The trawl net can not be geared with rock-hoppers nor "cookies"; the mesh size in use for the cod-end is almost always smaller than the minimum legal size of 20 mm side (which is already very small).

Near the lower left edge of the Pelagie area lies the "Mammellone", a shallow zone where trawling is forbidden (but you know fishermen ...). You may also consider as "closed" a few areas of ammunition dumping. The Italian law permits trawling beyond 3-mile from shore or 50-m depth, whichever comes first. The "No fishing on weekends" management tool is not implemented in the Sicilian Channel fisheries, but other Italian areas (Adriatic) are using it. "Protected areas" are sometimes as such only on paper; the

same is true for the 3-mile fishing interdiction (artisanal gear excluded) around the entire Italian coast.

The 45-day ban is easily checked and enforced, since boats should stay idle on their port of call. In Italy, gear is seldom inspected, and officials do close their eyes when on patrol; the situation is even worse in the other countries surrounding the Sicilian Channel. Besides the Italian limit of 12 miles, there are no particular rules on foreign vessels; it should be kept in mind that the European Union regulates the bilateral fishery agreements. In any event, the presence of foreign trawling vessels in the area is a rare occurrence.

DISCUSSION

Population structure

The most apparent characteristic in the LFDs is the clear separation of the juvenile and the adult components, both for females and males. This separation is maintained as time progresses until at least late autumn; the old juveniles are integrated into the adult component in spring, when the new recruits appear. The discrimination among adult year classes is not equally easy, but the presence of multiple cohorts is evident. Also Spedicato *et al.* (1994) find larger red shrimps at greater depth; *Aristeus antennatus* behaves similarly (Relini *et al.*, 1993).

Size structure in a unit stock is the integrated result of growth and mortality; still, problems in modeling and interpretation arise from the fact that, even with the constraints of stationarity (i.e. random fluctuations in reproduction, recruitment, growth and mortality), the relationship between length structure and demographic parameters is not bi-unique (Rosenberg and Beddington, 1988).

Morphometry

Morphometric analysis and relative growth studies (where postmolt *vs.* premolt is a special case) are widely used, especially for heavily armoured crustaceans, such as lobsters and crabs, because of their hard integument and the possibility of abrupt changes during the ontogenesis. The search for splines, not only in the ontogenetic development (for instance, the "puberty molt"), but also for changes in the relationships likely related to variations in growth rates (Somerton, 1980; Hartnoll, 1982), and for sex-specific allometry related to sexual dimorphism (Hartnoll, 1982; Lovett and Felder, 1989) permits to split the life history of hard-armored crustaceans in homogeneous periods.

In *Aristaeomorpha foliacea*, like in the companion species *Aristeus antennatus*, growth occurs almost continuously because the exoskeleton is more flexible and molting

is frequent ("diecdysis molting cycle"; Dall *et al.*, 1990). Furthermore, maturity processes are more gradual and sexual maturity, mating and spawning occur over a large size-age range. No terminal molt is known for this species (Hartnoll, 1985; Sardà and Demestre, 1987; Ragonese *et al.*, 1994; Ragonese and Bianchini, 1995). The above features can explain why, despite some "apparent" discontinuities in the parameters scatterplots, no "disharmony" was statistically detected for female *Aristaeomorpha foliacea*. The same happens in *Aristeus antennatus* females (Sardà *et al.*, 1995).

A different picture regards males of Aristeids which reach a smaller size in respect to females and undergo an abrupt change in the rostrum length, a short rostrum representing the most apparent macroscopic morphometric feature of male adulthood. The shortening process does not seem directly related to maturation, at least in *Aristeus antennatus* (Sardà and Cartes, 1994). Different hypotheses have been proposed for the eco-functional role of rostrum shortening (Pérez Farfante, 1987; Sardà and Demestre, 1989). The TL-CL plot of males of *Aristaeomorpha foliacea* suggested another discontinuity in the range 25-28 mm CL. In fact, the graphical representation indicates that two other physiological changes, the storage of spermatophores and the welding of petasma, precede the shortening of the rostrum. Consequently, the presence of disharmonies in males other than the macroscopic jump related to the rostrum shortening seem justified. For the rostrum, the change from long to short condition occurs almost abruptly between 29 and 33 mm CL (primarily in 31-32 mm range). For the petasma and *ampullae* characters, the transition is more gradual. Above 33-35 mm CL, all males are apparently "fully mature".

The weight-carapace length regressions show a statistically significant negative allometry in females, more pronounced than that observed in males. One implication of this result lies in the violation of the isometric assumption, which is central to many models that incorporate growth, such as the yield-per-recruit model of Beverton and Holt, where carapace length is used as an index of size.

Regressions of CL *vs.* non-standard (TL; OL) measures permitted the conversion of historical records in standard length frequency distributions (Ragonese *et al.*, 1997),

making them comparable with recent data (Fig. 82) from the same fishing grounds (south of Marettimo). The strength of the recruit class appears the most striking difference among older and present LFD (but it might depend only on stochastic processes, not on modified demographic conditions), whereas the consistency of largest females seems to be more or less comparable despite 20 years of exploitation. The presence of irregular grounds in the examined red shrimp fishing area, where only few obligated-track hauls can be made, creates refuges from harvest, allowing a natural protection against overfishing, unlike other zones in the Sicilian Channel where a decrease in catch per unit of effort is evident.

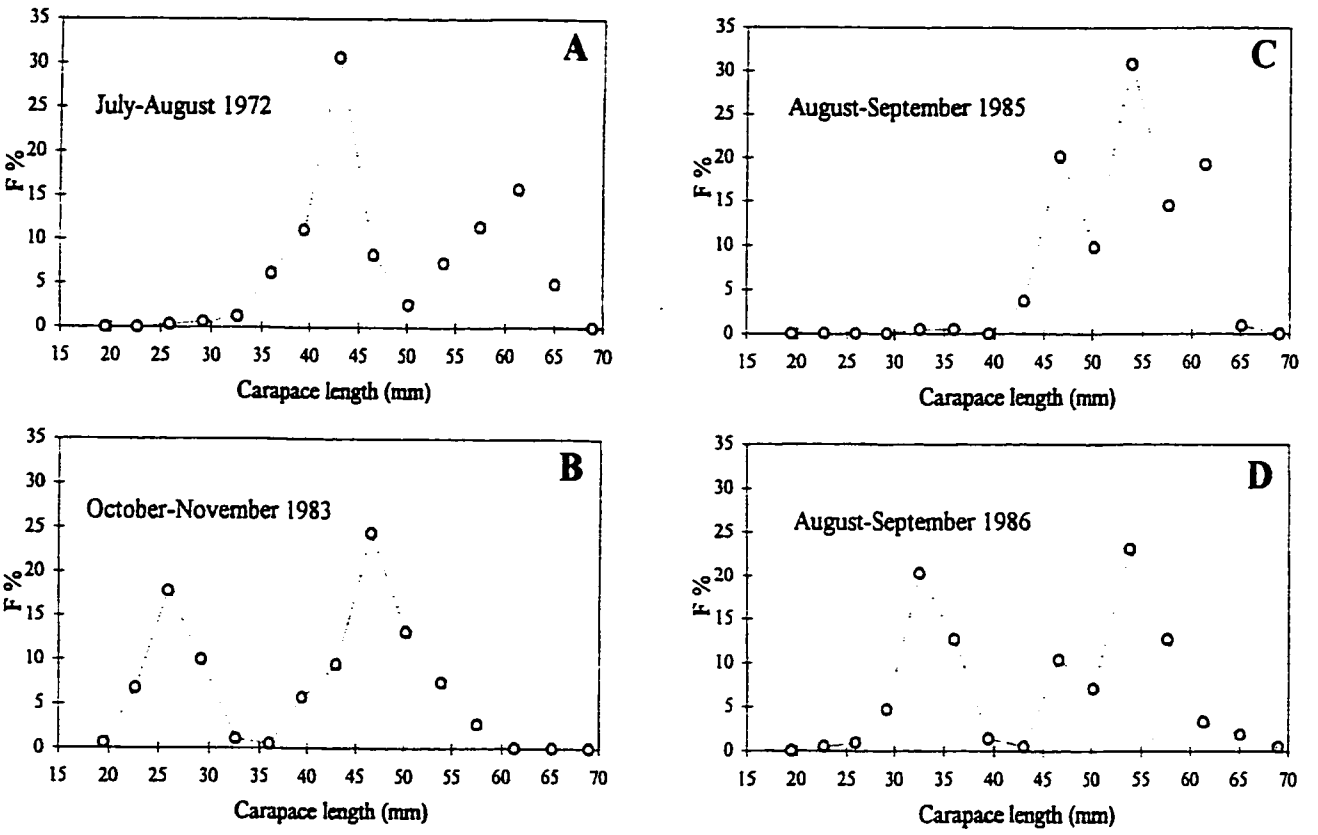


Fig. 82 - Comparison between *Aristaeomorpha foliacea* females length frequency (%) distributions from the same area but different periods. Source: **A**: Arena and Li Greci, 1973; **B**: Arena, 1985; **C** and **D**: Ragonese, 1995 (from Ragonese *et al.*, 1997).

Scanty data are available on the various *Aristaeomorpha foliacea* morphometric relationships and only length-weight relationships can be reasonably compared (Ragonese *et al.*, 1997). These data are presented in Table 70, together with the more abundant estimates derived for the companion species *Aristeus antennatus*. The estimated coefficients are comparable and grouped by species (Fig 83), with the exception of the population off the Tuscanian coasts (code N in Table 70 and Fig. 83). The estimates indicate that females of *Aristaeomorpha foliacea* weigh more than females of *Aristeus antennatus* of the same carapace length, with the above-mentioned exception.

Table 70 - Weight-length relationships for females of *Aristaeomorpha foliacea* (*Af*) and *Aristeus antennatus* (*Aa*) in different areas; model: $W = a\,CL^b$ (from Ragonese *et al.*, 1997). (letter codes for Fig. 83).

species	a	b	area	authority	code
Aa	0.0026	2.47	Catalan Sea	Demestre 1990	A
Aa	0.0035	2.38	Valencia	Lleonart 1990	B
Aa	0.0018	2.58	Murcia	Martinez Baños *et al.* 1988	C
Aa	0.0023	2.49	Portugal	Ribeiro Cascalho & Arrobas 1982	D
Aa	0.0060	2.24	Central Tyrrh. Spr+Sum	Ardizzone *et al.* 1988	E
Aa	0.0031	2.41	Central Tyrrhenian	Minervini *et al.* 1988	F
Aa	0.0023	2.49	Southern Portugal	Santos & Cascalho 1994	G
Aa	0.0017	2.60	SE Spain (Murcia)	Martinez Baños & Mas 1994	H
Aa	0.0030	2.43	SE Spain (Ibiza)	Martinez Baños & Mas 1994	I
Aa	0.0030	2.41	Majorca	Carbonell 1994	J
Aa	0.0030	2.45	Northern Tyrrhenian	Righini & Abella 1994	K
Af	0.0011	2.63	Central Tyrrh. Spr+Sum	Ardizzone *et al.* 1988	L
Af	0.0005	2.87	Central Tyrrhenian	Minervini *et al.* 1988	M
Af	0.0032	2.44	Northern Tyrrhenian	Righini & Abella 1994	N
Af	0.0011	2.69	South Tyrrh. Aut+Spr+Sum	Spedicato *et al.* 1994	O
Af	0.0013	2.64	Strait of Sicily	Ragonese *et al.* 1997	P

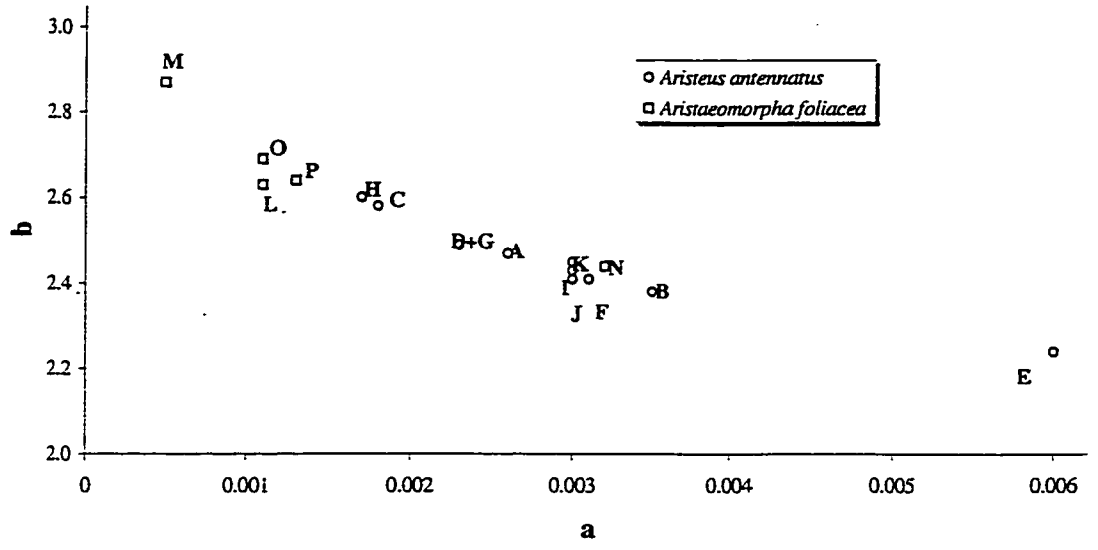


Fig. 83 - Parameters of the weight-length relationships for females of *Aristaeomorpha foliacea* (squares) and *Aristeus antennatus* (circles) in different areas; model: $W = a\,CL^b$ (modified from Ragonese *et al.*, 1997). (letter codes in Table 70).

From the comparison of measures taken on fresh or defrosted shrimps, it appears that measures taken on the preserved samples are systematically and significantly lower; however, the differences are so small in absolute values as to be unimportant in data processing.

Growth

Despite their exoskeleton, shrimps are suited to continuous growth models, given that the carapace is fairly elastic and that molting is frequent and asynchronous (Cobb and Caddy, 1989; Dall *et al.*, 1990): moreover, a VBGF can be used to model shrimp growth (Parrack, 1979), at least female growth. More sophisticated growth curves could be used for a better fit, providing a more "flexible" shape or seasonality, but such complicated curves will seldom be justified (MacDonald, 1987).

The estimates of the growth parameters are used in every further development of the population dynamics and of the resources assessment. Any bias in the estimates propagates and intensifies through the process (Majkowski *et al.*, 1987). Nevertheless, the determination of the VBGF parameters is often conducted with inadequate instruments, and the output results are used even when they do not satisfy the requirements for further analyses (e.g., for ANALEN sensitivity, that L_∞ must be substantially greater that L_{max}).

A frequently used tool for LFD analysis (Hilborn and Walters, 1992) is the non-parametric procedure of ELEFAN (Majkowski *et al.*, 1987), notwithstanding its intrinsic weakness, among which are the unsubstantiated theoretical basis of the fitting procedure and its subjectivity. The Bhattacharya's method is also highly subjective and requires trading among different imprecisions; the tools provided for supporting decisions are only indicative. Even the modal progression analysis that is performed on the separated modes may follow different routes (resulting in multiple outputs). The MIX procedure is more flexible in separating the "age" classes of a LFD; still, it has several of the same problems of the Bhattacharya's method.

The difficulty in accepting many MULTIFAN estimates resides in the "absence" of certain classes, or in the presence of spurious ones, with results that contrast with the ancillary biological knowledge of the species and of the fishery. The MULTIFAN procedure permits the introduction of various factors (seasonality, bias, etc.) and their simultaneous, "multiple" fluctuation. For *Aristaeomorpha foliacea* of the Sicilian Channel, none of possibilities improved the "single" fluctuation output enough to justify the introduction of a new parameter to be estimated. Many trials demonstrate the shortcomings of a program such as MULTIFAN, in which the "mathematical" improvements did not correspond to biologically-sound estimates. The most disturbing aspect of MULTIFAN is that the variability associated with the results is fairly small, producing the "illusion" of good estimates. Moreover, small variations in the "framing" of the analysis (size of the K-age grid, seed values, etc., that should be almost uninfluential) produced divergent results in "corresponding" situations.

In absolute values, in spring the carapace length of the juvenile component ranges 12-28 mm, with a peak at 20-23 mm. In summer the carapace length of juveniles falls mainly in the range 20-30 mm with a peak at 25-27 mm. The progression of the juvenile mode is therefore 4-5 mm in 2.5 spring months.

The growth has been studied also in other populations of Mediterranean *Aristaeomorpha foliacea*. Leonardi and Ardizzone (1994), using the MPA after Bhattacharya's deconvolution, obtain for females in Central Tyrrhenian Sea: CL_∞= 73.2 mm, K/year= 0.62 and t_0= 0.2 year. With the same method, Spedicato *et al.* (1994) obtain in Southern Tyrrhenian Sea: CL_∞= 70.8 mm, K/year= 0.47 and t_0= -0.3 year. In the Italian Ionian Sea, D'Onghia *et al.* (1998) find CL_∞= 69.8 mm, K/year= 0.45 and t_0= -0.2 year for the females, and CL_∞= 49.7 mm, K/year= 0.42 and t_0= -0.3 year for the males (incidentally, the females estimates of four years earlier were CL_∞= 74.2 mm, K/year= 0.50). Wurtz (unpublished), using Sardinian LFDs from Cau *et al.* (1982), produces an estimates for *Aristaeomorpha foliacea* of CL_∞= 66.3 mm or 45.3 mm and K/year= 0.51 or 0.79 for females and males respectively.

The values of φ' for females from other areas are in general agreement with the results of the present study. Comparing the growth performance (Francis, 1996) of the red shrimp in the Sicilian Channel with that of other shrimps, the φ'= 1.7 (K expressed in weeks) puts the females of *Aristaeomorpha foliacea* in the category of "larger *Metapenaeus*" (1.62 ±0.27: Dall *et al.*, 1990) and near the values of its companion species, *Aristeus antennatus* (1.5: Yahiaoui *et al.*, 1986; 1.5: Sardà and Demestre, 1987; 1.7: Ragonese and Bianchini, 1991; but also 2.1: Orsi Relini and Relini, 1985). Unfortunately, this index, despite its popular use, does not allow for an estimate of variability and, consequently, differences can not be tested statistically, in contrast to the possibility offered by the omega test (Gallucci and Quinn, 1979).

More studies have been produced on the growth of the companion species *Aristeus antennatus*. The parameters of the VBGF for females (and males, if available) are reported in Table 71 for comparative purposes.

All the results report to a VBGF model that is widely utilized and considered physiologically sound. Still, males show a clear linear relation for CL_{mean} *vs.* age above the length of sexual maturity. The VBGF remains the "least inadequate" among the possible curvilinear models (VBGF, potential, Gompertz's) but the residual plots are in general unacceptable.

Table 71 - Parameters of the VBGF for *Aristeus antennatus* from different Mediterranean locations (data from Bianchini and Ragonese eds., 1994).

AUTHOR	ZONE	females			males		
		CL_∞	K	t_0	CL_∞	K	t_0
dos Santos and Ribeiro Cascalho	Portugal	75.4	0.36	-0.3	45.0	0.26	-1.4
Martinez Baños and Mas	Spain (Murcia)	75	0.38	-0.5	52	0.27	-0.9
Carbonell	Spain (Baleares)	74.0	0.38	-0.1	46.0	0.47	-0.1
Demestre	Spain (Cataluña)	75.2	0.35	-	49	0.37	-
Orsi Relini and Relini	Italy (Liguria)	76	0.3	-	-	-	-
Arculeo *et al.*	Italy (N. Sicily)	69.4	0.34	-	-	-	-
Ragonese *et al.*	Italy (S. Sicily)	71	0.51	-	-	-	-
D'Onghia *et al.*	Italy (Ionian)	66.2	0.93	-0.1	54.6	0.99	-0.1
Yahiaoui	Algeria	67.5	0.35	-	37.5	0.42	-

Mortality

Mortality is the most variable parameter to estimate (Neal and Maris, 1985), especially when different exploitation hypotheses (Mathews *et al.*, 1987) are considered. The constraints for the estimation of mortality are stronger than those for the estimation of growth; in fact, the classical methodologies require that the sample is representative of each age class and that the stationarity hypothesis is fulfilled. These conditions are only

rarely met, due to fluctuations in recruitment, varying levels of exploitation and non-uniform catchabilities. An approach that simply uses the ratio between recruits and total catch, such as Heincke's, is probably the most suited for the estimation of the total mortality when constraints are seriously violated. The survivorship of *Aristaeomorpha foliacea* is considered a "type III curve" (Deevey, 1947), with mortality high in the juveniles, and reduced in the adults (D'Onghia *et al.*, 1998). In the Sicilian Channel the species does not clearly appear as belonging to the Z-dominated or to the K-dominated group (Barry and Tegner, 1990), since the Z/K ratio changes in the earlier trawl surveys and the selectivity study data sets.

The steady-state assumption of Heincke's approach to estimate the annual total mortality rate Z can be accepted, given the relative stability, in both recruitment and fishing pattern, reported for the Sicilian fishery in the last decade (Arena, 1985; Ragonese *et al.*, 1994c). The estimate of Z is consistent with the hypotheses of a life span longer than that of coastal shrimps, and of a not-too-high F. In fact, the (trawl) fishing mortality does not act continuously nor over the whole distribution area, given the presence of canyons and other ruggedness and the red shrimp supposed behaviour of dispersal over the demersopelagic domain.

The estimation of the natural mortality is more difficult, because the empirical approaches based on correlation (Vetter, 1988) could not be applied to shrimps (Sparre *et al.*, 1989). When improperly used (such as the Rikhter and Efanov's method in temperate waters), they tend to grossly overestimate the natural mortality. The use of the empirical approach of Alagaraya ($M_{0.01}$) suggests a life span (for unexploited shrimp stocks) longer than that assessed from the modal deconvolution of LFDs. In fact, the exploited segment may grow faster as a compensation effect (Frèchette and Parsons, 1983), or mortality may slow down for the larger specimens.

Determining a natural mortality value is a critical and always difficult choice (Vetter, 1988), particularly for deep-water shrimps. The situation is further complicated by the possibility that F is age- or size-dependent, since also the females of *Aristaeomorpha foliacea* could be more vulnerable when aggregated to spawn, as is

supposed for the similar species *Aristeus antennatus* (Demestre and Lleonart, 1993). The value of M could be smaller than that expected for unexploited populations (Mathews *et al.*, 1987) if the hypothesis of reduced predation (due to the removal of predators by the commercial fishery) is accepted, together with the opportunistic, flexible role of the red shrimp, thus placed at the top of its trophic web (Lagardère, 1971) in a practically density-independent situation. Moreover, an inverse relationship between F and M has been suspected for short-living highly predated animals (Cobb and Caddy, 1989). According to this hypothesis, over a wide range of exploitation regimes, as F increases, M would decrease, resulting in a "constant" value of Z. However, deep-water red shrimps should not be considered "highly-predated animals" (Demestre and Martin, 1993).

Sexual parameters and reproduction

The Sicilian stock seems to agree with the maturation behaviour of North African populations (Azous, 1972), while showing a shorter, more defined reproductive activity in comparison to other Mediterranean red shrimps, either of the same species (Cau *et al.*, 1982) or of the companion *Aristeus antennatus* (Relini Orsi and Relini, 1979; Sardà, 1988).

For the males of *Aristaeomorpha foliacea*, the discontinuity in the range 25-28 mm CL, may reflect some less apparent maturity processes such as storage of spermatophores in the terminal *ampullae* and the "welding" of the copulatory organ, the petasma (Holthuis, 1987), all of which are considered as indexes of sexual maturity in Aristeid males (Relini Orsi and Relini, 1979; Sardà and Demestre, 1987, 1989). Even if the presence of disharmonies in males other than the macroscopic jump at 31 mm CL might be expected, present data did not allow a statistical confirmation. One explanation could lie in a slight discrepancy (or high variability) in the maturation processes among different cohorts of males; in fact, trawl data suggest three gradual and overlapping patterns in the relationships between proportions of males with *ampulla seminalis* filled with spermatophores, with welded petasma and with short rostrum. As a matter of fact,

the rostrum shortening in Aristeids is described as drastic (Cau *et al.*, 1982), or as gradual but marked both with seasonality and coexistence of three different (long, short and intermediate) types (Sardà and Demestre, 1989), or as a gradual but slow and continuous process (Perez Farfante, 1987).

Recruitment

A discrete recruitment, with one or two unequal overlapping peaks, seems the rule for deep-water shrimps (Pauly *et al.*, 1984). The presence of abundant adult animals *vs.* the recruits suggests a considerable life span. The lack of very small animals in the earlier trawl surveys samples is probably ascribable to the sampling periods; nevertheless, given the practical isolation of the recruits component, the subsequent bias and changes of the parameter estimates should be negligible. The observed inter-annual differences in recruitment confirm the aleatory nature of this process, whose factors are still unknown. With the present state of knowledge of the red shrimp biology, there are no actual suggestions as to which stock-recruitment model is more appropriate. It is worth noting that one of the most striking differences in the natural history of red and violet shrimps is the timing of their recruitment peak, which occurs respectively in spring and summer.

Yields

The catch from the selectivity study was obtained with experimental hauls that mimicked the commercial ones both in time length and in fishing grounds. The overall mean hourly catch was 11.1 kg/h of red shrimps. The two selectivity study surveys lasted 40 days, i.e. about 1/5 of the yearly fishing days in the Sicilian Channel off-shore boats (the rest being ascribable to compulsory fishing halt, maintenance, travel time, bad weather). Considering the percent of the fishing activity that is directly aimed at the red shrimp resources (estimated at 80%), a boat similar to the F/V "Sant'Anna" should land around 13.5 tons of red shrimps per year. Given 1050 tons of total red shrimp landings

per year, there should be 79 "Sant'Anna"-landings-equivalents in the Sicilian Channel. Weighing the engine power of all the boats of Mazara (i.e. 80% of the Sicilian Channel fishing fleet) by the relative proportions spent on the red shrimp grounds, there are in effect 77 "Sant'Anna"-fishing-power-equivalent boats (*circa* 78,000/1012 HP). These calculations independently confirm the present landing estimates for the red shrimp resources of the Sicilian Channel. Of course, there is high variability among zones and seasons, and even within the same zone and season. The problem of what influences the presence of one red shrimp species or the other remains open, since no relationship (positive or negative) is evident between the capture of *Aristeus antennatus* and that of *Aristaeomorpha foliacea*.

The catch per hour in the earlier trawl surveys is a lot lower, but it is not comparable, since the hauls were not specifically targeted at red shrimps. It is worth noting that for the same area Arena and Li Greci (1973) report 25 kg/h of red shrimps (both species pooled) in the early '60s. As a matter of fact, Levi (1990) reports in the area a constant and almost linear decrease of the index of the catch-per-unit-of-effort from 2.1 to 1.1 (1959-1983, all commercial species combined), and a total catch reaching its maximum at 69.300 tons in the late 70s (effort= 55000 GRT).

Differences in daylight and night fishing

The common belief that red shrimps are caught more in daylight than during the night has been verified; still, the values from this study are far from those (weight ratio night/daylight = 6.2%) reported by Rainer (1992) for an Australian population of *Aristaeomorpha foliacea*. Moreover, it appears that on average the captured animals are effectively larger in the night hauls; the length frequency distributions show that a relative "disappearance" of the smaller fraction from the catch is mainly responsible for this situation.

The red shrimps are not strictly benthic animals, and they normally inhabit the water layers close to the bottom being able to carry out horizontal and vertical displacements (Cartes *et al.*, 1993; Sardà *et al.*, 1994). It is generally agreed upon that

Aristaeomorpha foliacea, searching for food (Rainer, 1992), does move into the water column during the night, therefore becoming less vulnerable to demersal trawling; the present results might suggest that the feeding activity is shorter or less frequent for the large-size shrimps, which remain longer on the grounds, making them relatively more fishable during the night in comparison with the smaller (and younger) fraction. Conversely, the more sedentary *Aristeus antennatus* does not show significant differences in the mean size between night and daylight catches. If the hypothesis of a different diel behaviour among sizes is true, this should influence many parameters, e.g. the natural mortality (Ragonese *et al.*, 1994b), which are of great importance for the stock assessment and the management of the red shrimp resources.

Selectivity

The cod-end selectivity is fairly predictable when it involves those aspects that can be reduced to statistical analysis but the underlying mechanisms of this process are still poorly understood (MacMullen, 1981), especially for shrimps, even though the amount of knowledge has kept increasing in the last years. Mesh selection is very variable and for shrimps and shrimp-like animals the selection ogives tend to be shallow, thus resulting in a wide selection range (Briggs, 1986). Generally speaking, the broad retention fraction of the LFD will depend on the season and gear configuration as clearly indicated by the variability in the selection ratios as evidenced by the differences in the mean values and the corresponding standard deviation.

The overall results for the red shrimp show with the 16/14 gear configuration (GC) practically everything is retained regardless of season, with a selection ratio (n) below 0.5%. With the 20/14 GC, the totality of adults is retained and very few juveniles manage to escape, resulting in a mean selection ratio of less than 3% and 0.5% in number and weight (y). Almost all adults are retained by the 24/14 GC whereas almost all the juveniles belonging to the smallest classes (CL< 20 mm) are sieved out and collected in

the cover (Fig. 84). This means that in spring the percent of juveniles escaping is consistent, but in summer it is small, due to the increase in size of this component.



Fig. 84 - A typical "OUT" component of the catch with the gear configuration 24/14 (haul 015, spring survey) in the red shrimps fishery.

With the 28/14 GC, the largest females (CL> 46 mm) are retained whereas a large fraction of juveniles and a small amount of adult males and females are able to escape from the cod-end, regardless of the season (Fig. 85). The fraction escaping from the largest mesh (45/14 GC) is higher than that retained and practically no juvenile is hauled, with a mean selection ratio of 67-70% (n) and 60-61% (y).

It is well known that, contrary to fish, shrimp escapement happens not only in the codend but also all along the body of the gear (Vendeville, 1990). In fact, unlike most fish species, shrimp have no directional avoidance reaction when stimulated; according to underwater observations, when shrimps hit the netting, they will normally react with a few tail beats, jumping backwards, in a random direction (Valdemarsen, 1988; Isaksen *et al.*, 1992). Shrimps can also "avoid" the gear passing under the ground rope (Goeden

et al., 1990). Unfortunately, no such information is available for *Aristaeomorpha foliacea* and *Aristeus antennatus*, but there is no reason to consider a different behaviour whilst it is very unlikely that the avoidance could play an important role, given the features of the gear employed by Sicilian fishermen.



Fig. 85 - A typical "OUT" component of the catch with the gear configuration 28/14 (haul 002, spring survey) in the red shrimps fishery.

Shrimps are not "motivated" to escape throughout the mesh but they escape through the different meshes if their size is small enough, hitting casually the netting panels i.e., by a "filtering" process (Valdemarsen, 1988). Experiments in several countries with different techniques and direct underwater observations have confirmed this passive filtering, which can also explain why the haul time and the catch level are important factors in shrimp selectivity (Berry and Hervey, 1965; in Vendeville, 1990): mesh clogged by the shrimp and other animals do not allow any further escapement to passive animals who do not try to escape actively (Valdemarsen, 1988). Furthermore, there is some evidence that selection for shrimp and prawn takes place throughout the trawl and if

changes in cod-end mesh size would affect the mesh choice in other trawl parts, codend selectivity alone should not be used as a measure of the overall effect (Wileman, 1988).

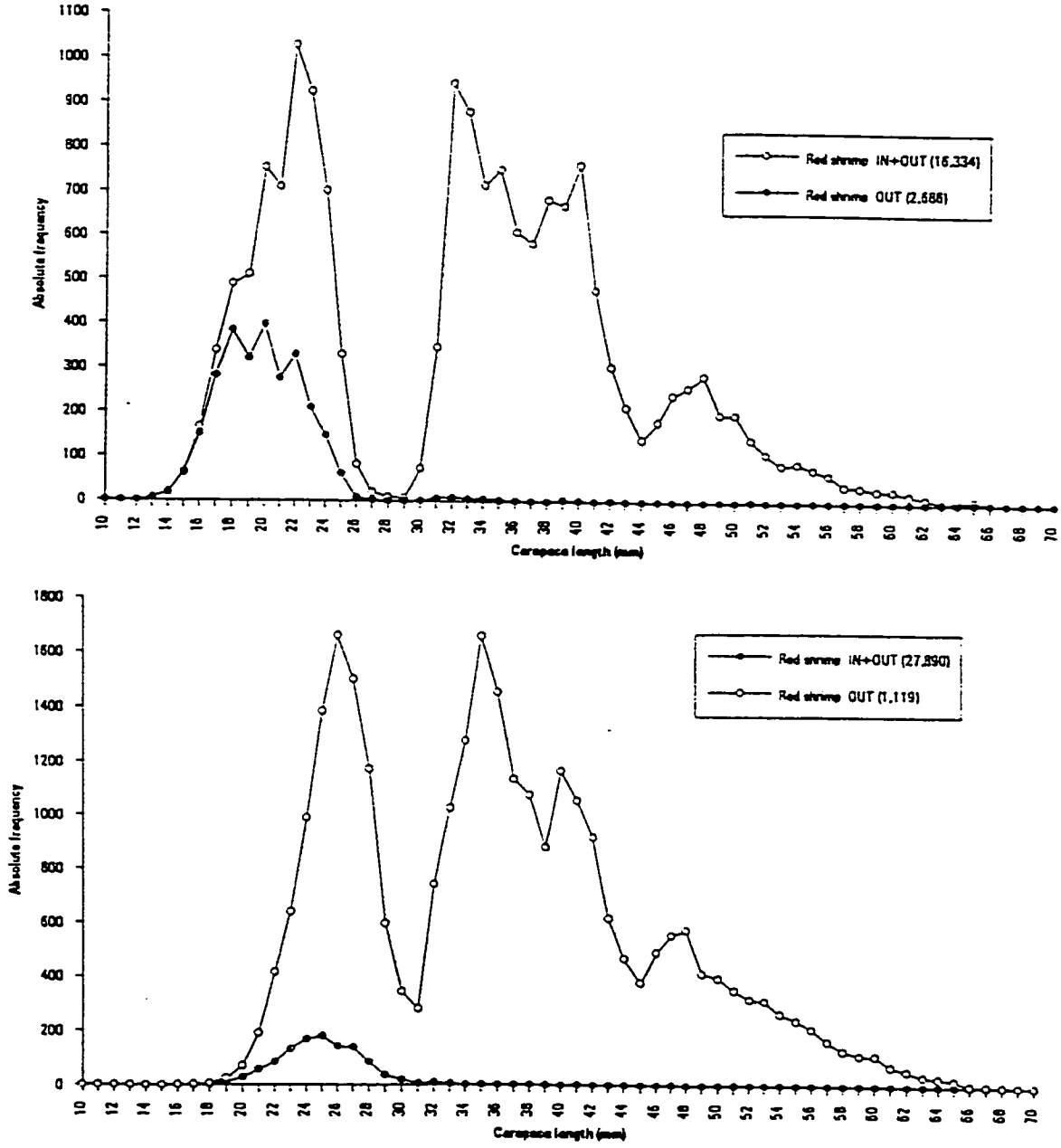


Fig. 86 - Only a fraction of the juveniles of *Aristaeomorpha foliacea* escape with the gear configuration 24/14 in spring (top), and almost nothing in summer (bottom).

Catch level is only one of the several factors influencing the selectivity process in shrimps and shrimp-like organisms (Briggs, 1986; Wileman, 1988; see also the introduction) but very scarce information are available in the case of shrimps. It is likely however that for moderate catch levels (less than 200-300 kg; Valdemarsen, 1988) the codend remains the most important area for size selectivity of shrimp. Obviously, the codend characteristics (the length, especially; Stewart and Galbraith, 1989) will also have an influence on the selection process. In the case of discrete recruitment, the fishing season also influences the selection process, since the young-of-the-year become fully recruited to the gear, and the new juveniles are absent or still too small to be fished (Fig. 86).

According to the review by Garcia and Le Reste (1981), selection factors for peneid shrimps fall in a narrow range: 0.3 - 0.5 (referred to catchable CL range and stretched mesh opening, following the definition of Wileman, 1988). The selection ogives, however, are often very variable for both extrinsic (i.e., due to the test and trial condition) and intrinsic (characteristic of the species) factors (Vendeville, 1990). Successive estimate tend to fall in the same range in spite of the specific and behavioural differences (cf.: El Musa, 1982; Lhomme and Garcia, 1984; Shumway *et al.*, 1985; Wileman, 1988). It is worth noting that similar values of the selection factors have been estimated for Norway lobster too (Briggs, 1986); a mean value of 0.48 (sd= 0.095) can be derived from the data reported by Briggs (1986) and that estimate is close to those generally used in the assessment of these animals (for example, see Cardador, 1993). Unfortunately, no previous estimates are available for *Aristeus antennatus* and *Aristaeomorpha foliacea*; the only past record of selection experiments refers to that carried on by Vives (1965) on a Western Mediterranean population of *Aristeus antennatus*. The conclusion of the author was that both the 12 mm and 19 mm mesh (side) were non-selective. Although this lack of possible comparisons, the selection factor estimated in the present study (SF= 0.42, expressed as mesh opening, *sensu* Wileman, 1988) falls in the preceding range.

Both the logistic and the Gompertz's models adequately fit the observed data (Fig. 87). The Gompertz's model usually approaches the first points better but, since the first classes are poorly represented, the "best" graphical fitting does not necessarily correspond to the best maximum likelihood fitting, in which the number of specimens in each length class plays an important role. The main differences between the two models are in the lower limit of the selection range (i.e., CL25%) while the CL50% estimates are practically unaffected. Since the determination of the size at 50% of retention is univocal in the logistic model and not in Gompertz's model, the former has generally been preferred, except when departure from symmetry was radical.

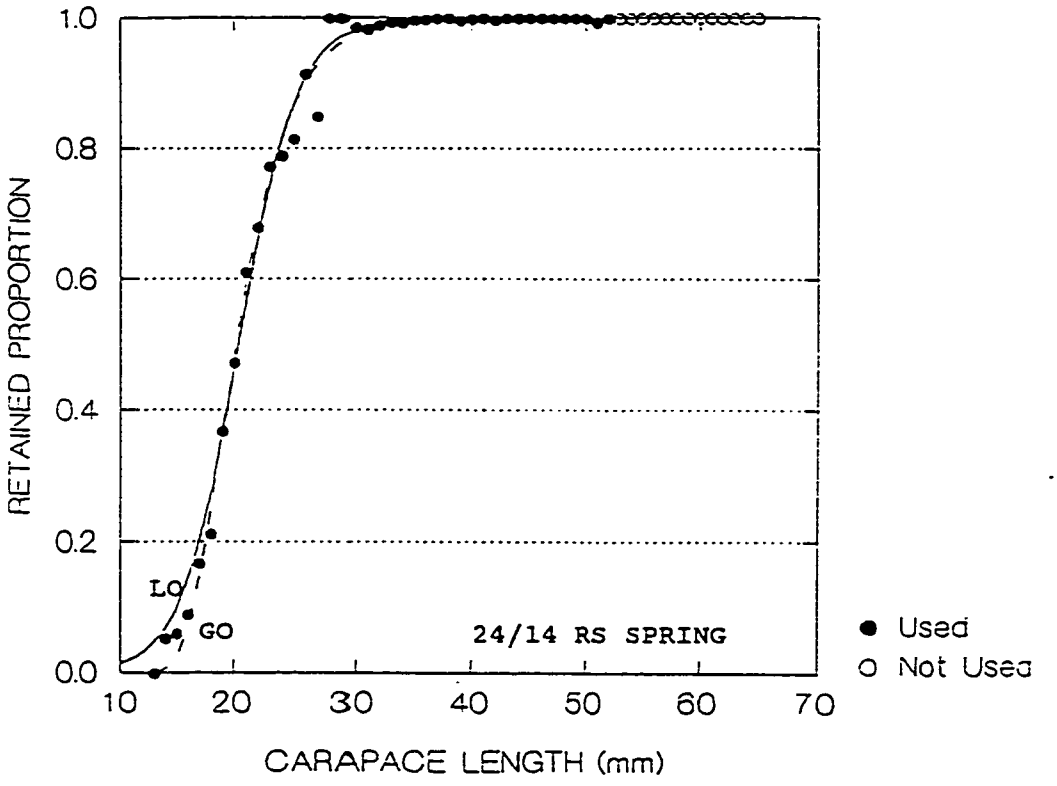


Fig. 87 - Retained proportion *vs.* carapace length (mm) of *Aristaeomorpha foliacea*, fitted by a logistic (solid line) or a Gompertz's (broken line) curve (gear configuration 24/14, spring survey).

Length at 50% of retention and selection factors *vs.* mesh size

One of the implicit assumption in selectivity studies is the direct proportionality between the length at 50% of retention and the mesh size (constant slope), which implies the consequent independence between the selection factor and the mesh size (i.e., SF= constant). Non-linearity at small mesh size is expected whenever the relationship between size at 50% and mesh size has a non-zero intercept even if that relationship is linear over the range of mesh size examined (Liu *et al.*, 1985). Therefore, it is inappropriate to extrapolate the estimates beyond the range of mesh sizes, 20, 24 and 28 mm, for which the relationships between the retained proportion and mesh size were defined and described satisfactorily.

The figures for the optimal length at first capture are quite unrealistic to be effectively adopted by the fisheries, even though the point estimate l_c* derived for the red shrimp (38.6 mm) is in agreement with the size of maximum reproductive potential (40 mm) estimated by Ragonese and Bianchini (1994). Theoretically, according to the estimated selection factor (SF= 0.843), the adoption of a mesh size of 45-47 mm side would be required to achieve such an optimal size (38-40 mm). Present results, however, have demonstrated that such extrapolation is not feasible, since the selectivity process is not well definable when the 45/14 GC was in use.

Control hauls

The reduced resistance of the net to towing when larger mesh size are used is a well-known phenomenon. It was considered an important cause of the observed increase of gear efficiency (among other things, catching more large-size fish) when large meshes were used (cf. Beverton and Holt, 1957). The red shrimp results, with lower catches in the 28/00 (slightly) and 45/00 (consistent) gear configurations, show an opposite trend but are consistent with the passive "filtering" of the shrimp. The increase in the flow of water through the large mesh helps the shrimps to escape, in a way largely independent from their size. The reduction of fuel consumption consequent to the reduced drag-net should compensate the slight loss in catch expected by mounting the 28 mm mesh.

Effect of sex on selectivity

From the sign of the Z statistic, positive in many cases, it is evident that if any difference occurs it is not in relation of the escape ability of males; i.e. short rostred males were retained more than long rostred females of corresponding carapace length. Moreover, the plot indicates clearly that the females are tendencially less retained than males of corresponding carapace length and especially in the larger classes (CL>40 mm) where on the contrary the rostrum effect might be highly expected. This effect cannot be the result of a drastic rostrum damage (never recorded) in escaped females because only specimens with quite integer rostrum have been considered in the test. Note that the anomalously low retention of females in the 34 and 35 mm CL classes is probably an artifact due to the small sample size.

An explanation might be that more females are able to escape than males notwithstanding the long rostrum, because the formers are more active and powerful in escaping. An analogous interpretation was proposed to explain why, by increasing the mesh size, large Norway lobsters escape more than do small Norway lobsters (Briggs, 1986). Such interpretation could be supported by the comparison between the two gear configurations, where significant differences are less in the 45/14 GC than 28/14 GC. However, the above interpretation is in contrast with the "classical" hypothesis of passive filtering of shrimps in the codend. Another explanation is that males do not bent as much as females, therefore presenting a greater "surface" when escaping through the mesh than females of similar CL. As a consequence, the results can be considered inconclusive as to the rostrum effect and there is no special need to maintain the separation of the two components, considering moreover that such difference concerns only few length classes.

Body engagement pattern

The shortening of the rostrum in adult males of red shrimp represents the most striking difference in the body shape in respect to females. The hypothesis that this process might have any influence on the selectivity pattern is the basic reason for the

usual splitting of samples in two components: adult males *vs.* adult females and juveniles. In fact, a greater proportion of retention was expected *a priori* for the females because of the longer rostrum, but a qualitative evaluation presents a broad parity between sexes; conversely, the statistical analysis actually reverts the initial hypothesis, and shows that males are retained more, with significant differences. However, males and females do not overlap very much, and consequently in some cases the sample size could be too small and the result of the test might be taken as indicative only.

Besides an improbable more active role of females in escaping, a possible explanation is that males do not bend as much as the females because of the presence of the petasma, therefore presenting a greater "surface" when escaping through the net than females of equal carapace length. Moreover the weights by sex indicate that above the size of adulthood (shortening of the rostrum) males are effectively bigger than females of equal carapace length.

Even if the proposed elliptic model is only an approximate approach to the reality, this study demonstrates a previously unknown morphological differences between sexes of the red shrimp *Aristaeomorpha foliacea* (folded males are significantly higher than females of the same carapace length, while the latter are larger, but not-significantly, than males of similar size), that influences the fishing selectivity. That notwithstanding, in practice the overall escapement rate should not change dramatically with sex, since the resulting "elliptic surface" is not statistically different (despite the slight but consistent hedge of the males), and given that this phenomenon interests only a few size classes.

By-catch

The ratio by-catch/red shrimps is highly variable and depends on the "cleanliness" of the grounds, that results from intense fishing activity. At the beginning of the fishing season and/or in secluded areas, the ratio is higher, above the unit value, while it goes down with the progressing of the exploitation; during these studies, a few hauls were "clean", yielding only shrimps. The phenomenon is reported by others too, and has been

hypothesized as a direct prey/predator relationship (Bombace and Li Greci, 1970); more recently, the phenomenon has been ascribed to indirect technological interference, taking in consideration that many of the fish species are not at all predators of the shrimp and that the phenomenon is quickly reversible. When considering only red shrimp and by-catch fishes, the former prevails on the latter in 34% and 47% of the spring and summer hauls respectively, while they are more or less balanced in 8% of the hauls in both season, and the situation is reversed in 21% and 15% of the spring and summer hauls respectively. The minimum red shrimp/fish ratio was 1:14 and 1:4 in spring and summer respectively.

Limited data are available on the relevance of the discard and by-catch in the Sicilian Channel especially for the red shrimp fisheries (Levi and Andreoli, 1996). For such bathyal fishery, the estimated average yield over the deep bottoms is about 5.6 kg/h for a percentage of discards of about 42% (94% of which are fish). According to a rough estimation, a figure of about 400 t of discard for each year could be considered realistic (Andaloro, 1985). This number is a consequence of the differential distribution of the fishing effort in the area; according to Andaloro (1985) and Milazzo (1988), in fact, only a slight fraction of the global fishing effort exerted in the Sicilian Channel affects the mesobathyal bottoms and consequently the total by-catch or discard is lower than the other trawled bottoms, where discards can be roughly estimated in the order of magnitude of several thousands of tons/year (Andaloro, 1985; Milazzo, 1988).

Despite the great variability, some general rules about the amount and type of trawl by-catch can be drawn from the specific literature (Chopin and Arimoto, 1995; Hall, 1996) and personal experience: a) finfish are those which contribute most; b) the size is generally small; c) few species dominate the catch. The estimation procedure, however, is also complicated by the strongly positively skewed distribution of the observed values; the most common procedure is to use the shrimp catch to evaluate the by-catches according to the ratio-estimator method.

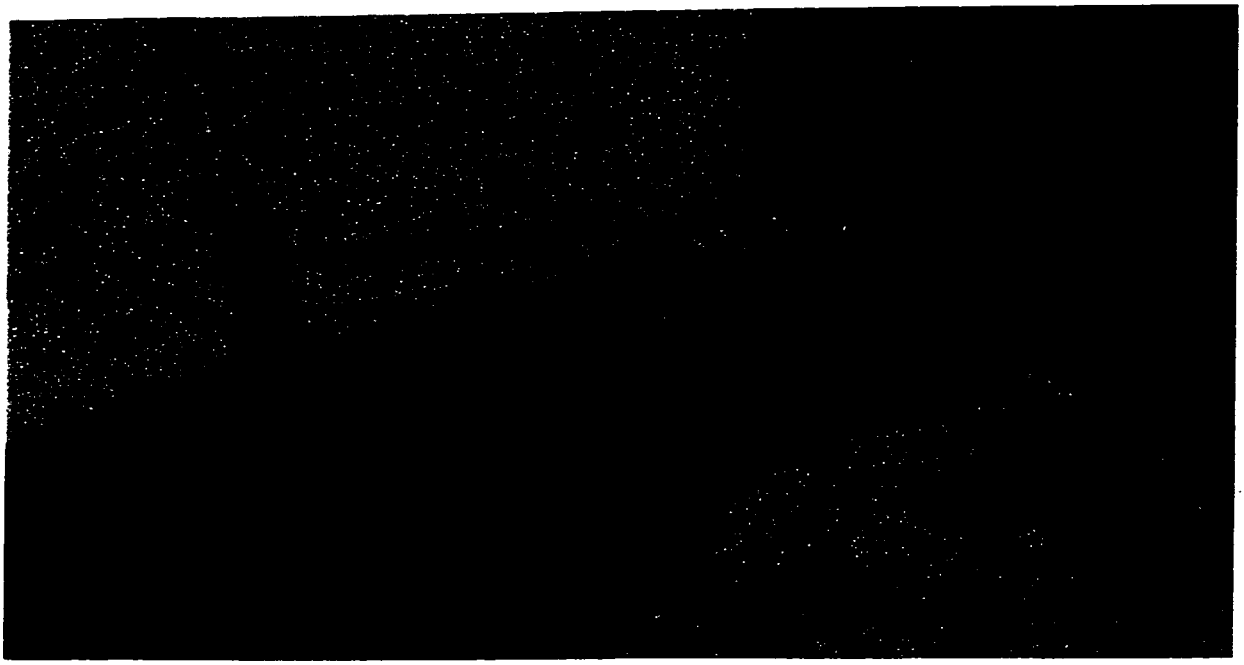


Fig. 88 - Only a very limited number of organisms does escape from the 20 mm mesh, presently used in the shrimp fishery of the Sicilian Channel (haul 009, spring survey).

Present results clearly indicate that mesh sizes below 24 mm side are practically non-selective for red shrimps and more generally for the other companion species (Fig. 88). In fact, even though characterized by a high variability, the mean selection ratios give an idea (yet indicative, given the high variability) of the consequence of adopting the legal mesh size: only small-size conger eel and hake could receive some benefits, the selection ratio for such species being about 32% and 16% (in number), and 13% and 8% (in weight). For the other species or categories the escapement ratio would be very low, in any case less than 10% in number and almost insignificant considering the weight.

Even not considering the largest gear configuration (45/14), for which the mean selection ratios were generally very high (with few exceptions, such as the case of the squid *Todarodes sagittatus* or the flatfish *Lepidorhombus boscii*), the adoption of the 24 mm or 28 mm mesh side would, as a rule, improve the escapement. By adopting the 28 mm mesh side, for example, mean selection ratios (in number) of 13%, 23%, 19% and

32% respectively for red shrimp, violet shrimp, Norway lobster and rose shrimp, should be expected. This loss in number could appear too high to fishermen, but it must be considered that in term of loss in weight the above figures become 7%, 11%, 14% and 26%. Except for the case of the rose shrimps, the percentage loss in term of economic return are further reduced since the escaped animals are small-size and less-priced juveniles, most of which already illegally retained (e.g., the Norway lobster).

The effects of adopting the 28 mm mesh side would be more evident for the roundfish: the expected mean selection ratios in number would be about 75%, 13%, 37% 33%, 13%, 20%, 17%, and 16% for *Conger conger*, *Helicolenus dactylopterus*, *Merluccius merluccius*, *Micromesistius poutassou*, *Mullus surmuletus*, *Phycis blennoides*, *Etmopterus spinax* and *Galeus melastomus*. The corresponding loss in weight would be 71%, 6%, 15%, 29%, almost 0%, 10%, 14% and 8%; so the most part of the loss in weight is represented by small-size animals with the only exception of conger eel which, however, has practically no economic value for red shrimp trawlers.

For what concerns the fish which represent a target for other fisheries in the Strait of Sicily, the case of hake is the most appealing; the 28 mm mesh side would allow the escapement of about one third of hakes with a limited loss in weight (13%) and a minimal reduction in the economic return; in fact, frozen juveniles of hake have practically no market in Sicily. The adoption of the 28 mm mesh side would imply, on the average: no loss for sharks and skates and a loss of about 53%, 46% and 12% (in weight) for other bony fish, crustaceans and cephalopods; considering that such categories include mainly small-size and less-priced organisms, it is evident the benefits for both the fishery (for example, reduction of the handling time and improvement of the catch quality) and the ecosystem (a reduction of the degree of "stress").

The options to deal with the by-catch, two basic approaches can be identified: a) better utilization; b) minimization (Alverson and Hughes, 1996). The choice will depend on the general context; for example, in those fisheries of poor or developing countries, where a large proportion might be used as food, the first option is the most appealing one (IDRC, 1982; Saila, 1983). In other situation, such as that of the most part

of industrialized countries, where by-catches of shrimp trawlers represent the target of other valuable fisheries or rare or protected animals, the second option seems the more realistic to pursuit (Andrew and Pepperell, 1992).

In the specific case of deep-water fisheries such as that of red shrimp, the second option warrants the most attention also because the surviving probability of discard animals is expected to be null or minimal. As a consequence of the quick depressurization (which determines the breakage of the gas-bladder), change in temperature (at least in Summer) and the long sorting time aboard, in fact, discard animals are expected to die after being hauled up or immediately after their reintroduction in the sea. According to observations made in this study, floating fish and cephalopods, even though still vital, were immediately eaten by sea birds and possibly dolphins or other unidentified pelagic animals, whereas crustaceans (which seemed not preyed upon by birds) appeared to be shocked when returned to the sea.

The impact of the red shrimp trawling on species that are targeted by other fisheries (Crowder and Murawski, 1998), such as hake or red mullet, seems on the contrary quite low, especially when compared with the large amount of juveniles caught by the direct fisheries. Also it is unlikely that the discard practice would increase red shrimp harvesting, an hypothesis quite realistic in other situations (cf. Sheridan *et al.*, 1984); in this study, in which the same (almost identical) hauls were replicated, no evidence of "previously-fished" animal was gathered.

Anthropic waste

Among the anthropic waste, iron drums and tanks are the most dangerous because often they hold ship paints, oils and other material of not-well determined origin, producing tinting and soiling of the catch. The stones (the "mazzare") used by fishermen coming from Malta or the southern coasts of Sicily to anchor the "cannizzati", a fishing aggregating device (FAD) to catch epipelagic fish, produce mechanical damages of the catch. Actually, this FAD is composed by a floating canvas formed by palm leaves inserted in a polystyrene body, anchored in the deep bottoms by a parallelepiped block of

rock ("mazzara") linked to the canvas by a synthetic narrow line; after one fishing season the line is cut or the canvas is simply abandoned and a new "cannizzato" is placed at sea.

The problem of anthropic waste is not new in the area considered; Arena and Li Greci (1973) have already noted the large amount of garbage in the Sicilian Channel but in less quantity (few kg in 3-4 hours of haul). Until recently, no significant correlation (Fig. 89) has been demonstrate between volume of anthropic litter on the fishing grounds and commercial yield of red shrimp (Bianchini and Ragonese, 1999). Certainly, the Sicilian Channel presents a better situation in respect to other area of the Mediterranean Sea (Ragonese *et al.*, 1994) but more attention should be devoted to this problem.

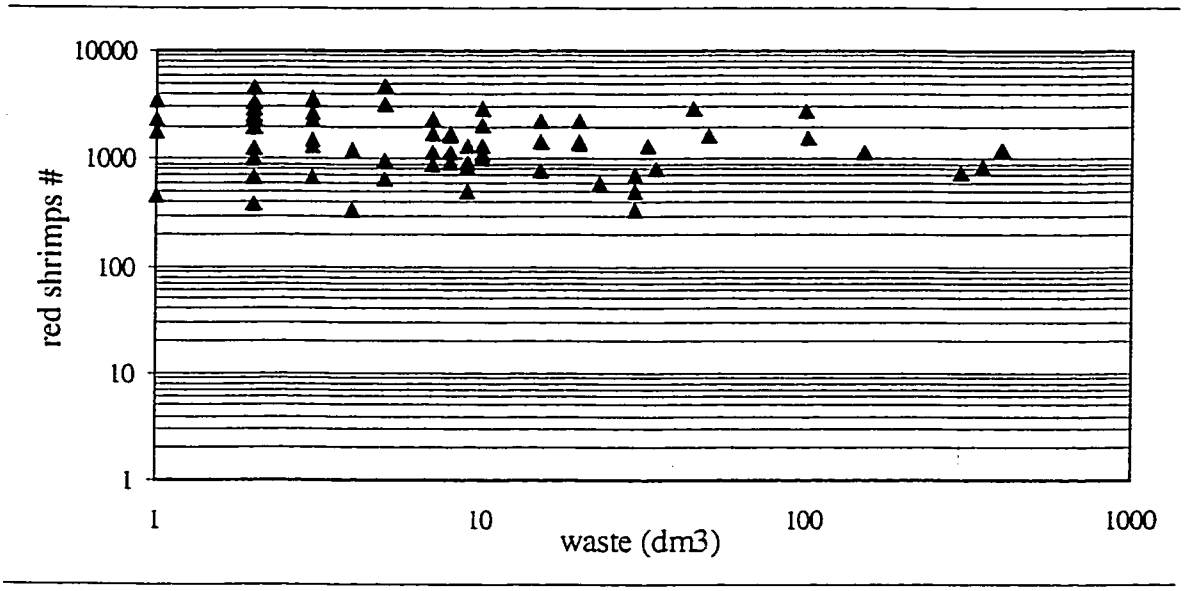


Fig. 89 - Catch of red shrimps *vs.* volume of anthropic litter, per haul in the Sicilian Channel.

Predation upon red shrimps

Even considering the limit of this rough approach, results tend to confirm that red shrimps are not systematicly preyed upon by the most common accompanying fish species. This conclusion is in contrast with Arena and Li Greci (1973) who considered the red shrimps as a prey of squaliforms and gadoids on the basis of the preliminary note of Bombace and Li Greci (1970). In fact, there is lack, or minimal, occurrence of red

shrimps in the stomachs of the predator fish caught during this study; even in the large-size specimens of *Lophius* sp. (more than 18 kg of body weight), *Conger conger* (9 kg), *Centrophorus* sp. (from 2 to 5 kg), *Heptranchias perlo* (2.7 kg) and *Hexanchus griseus* (more than 11 kg). Considering that the largest fish (an anglerfish, *Lophius budegassa*, of 20.6 kg) was caught together with 800 red shrimps (14 kg), it is noteworthy that none was found in the stomach of this large-mouth and voracious fish.

Virtual population

The virtual population reconstruction is based on the assumption that the length-frequency data that are used are representative of the commercial landings of the Sicilian Channel.

In the analysis of the actual catch from the selectivity study, using the length-structured data all values are 10-15% higher that those obtained with age classes; similarly, in the analysis from the earlier trawl surveys, all values using the length-structured data are greater, but just a little 5% higher, that those obtained with age classes. This trend is still present in the virtual population reconstruction performed on the selectivity study data, while the critical age (and the corresponding critical CL size) are higher in the age-restructured data from the earlier trawl surveys.

There are substantial differences in the virtual population reconstruction from the selectivity study and that from the earlier trawl surveys: just considering the example from the age-restructured data, the virtual population reconstructed on the basis of the selectivity study data has a mean CL of 23.6 mm, a critical length of 31.6 mm and an average weight of 944 tons, with the turnover at 145.6%; the virtual population reconstructed on the basis of the earlier trawl surveys data has a mean CL of 27.5 mm, a critical length of 48.9 mm and an average weight of 1584 tons, with the turnover at 110.2%. On the contrary, the critical age for the virgin stock is 2.54 y (critical length 54.8 mm) in all the cases considered.

Speaking of the economic aspects, the virtual population calculated from age-restructured data from the selectivity study has an average value of 20 billion liras (22 billion liras when calculated for length-structured data). The critical age for value is 1.4 y for the actual stock (corresponding to a critical length of 40 mm); the turnover is 160%. The virtual population calculated both from age- or length-structured data obtained from the earlier trawl surveys has a higher average value of 35 billion liras, and the critical age for value is 1.9 y for the actual stock (corresponding to a critical length of 48 mm); the turnover lowers to 118%.

Yield-per-recruit

The yield-per-recruit results are based on the assumption that pooled length-frequency data collected during the earlier trawl surveys and the selectivity study are representative of the commercial landings of the Sicilian Channel. The weakness of this assumption can produce misleading results; nevertheless, even real commercial data from other red shrimp fisheries are not fashioned for the theoretical requirements of the virtual population analysis, i.e. their catch curve is multimodal and does not present a smoothed profile. Assumptions and constraints of the models must be checked, and their robustness verified, especially in situations where the mathematical functions are applied out of their original context: the question is "do crustaceans really behave like fish?".

As expected, the shape of all the yield-per-recruit curves suggests a rapid increase of Y/R for small increments of F, and thereafter the curves flatten out, without any evidence of a clear maximum. In the hypothesis of a high natural mortality (e.g., M= 0.8), the yield-per-recruit could be increased even by raising only F (i.e., the population should be underexploited); on the contrary, for the estimated M= 0.5 that has been preferred, gains in the Y/R could not be obtained without changing the age of first capture.

Even on the same set of data, the different approaches to the yield-per-recruit analysis (the beta-modified Beverton and Holt's, the Thompson and Bell's and the VIT's) produce qualitatively different scenarios, i.e. the present level of exploitation appears

situated on the right or left side of the maximum yield-per-recruit value. On the other hand, the quantitative estimates are of course different among the various approaches, but not far from each other, since the response surfaces are quite flat at the summit. The comparison between the values obtained with data structured by size or age-restructured data shows that the general picture remains almost the same.

Conversely, in the economic analysis, the three different approaches that have been used produce qualitatively similar scenarios, i.e. the present level of economic exploitation appears situated always on the right hand of the yield-per-recruit curve, as well as self-consistent quantitative estimates. As already said, the classical Beverton and Holt's approach does not allow to estimate an economic yield-per-recruit in cases (as it is for the red shrimps) where unit prices depend on size. In fact, the present innovative approach with the incomplete beta function, that uses a price function as if it were a growth function, seems to behave well, at least when applied to the Sicilian red shrimp fishery.

Biological yield-per-recruit

The biological yield-per recruit of the present exploitation regimen (20 mm mesh) that results using the Thompson and Bell's approach on the selectivity study data seems of slight underfishing; still a minimal increase in the yield-per-recruit would require a disproportionate increase in the effort, with an unacceptable rise in the risks and all the negative consequences on the environment.

Also the yield-per-recruit estimated from the earlier trawl surveys data suggests a situation of slight underfishing, since the present fishing mortality appears situated on the left hand of the yield-per-recruit curve, the value of the present yield-per-recruit is almost at its maximum, and the present standing biomass-per-recruit is above one third of the virgin stock biomass. Notwithstanding the apparent situation of underfishing, the pursuit of the safer $F_{0.1}$ strategy would cause a decrease of the present yield-per-recruit, given the flatness of the summit. Moreover, just a small adjustment of the range of data to be analyzed results in a different yield-per-recruit curve, where the fishing factor for the $F_{0.1}$

strategy is almost 50% lower, and F_{max} switches from above to below F_{actual} (i.e. the shrimp resources seem to pass from slightly underfished to lightly overfished).

On the contrary, the estimates from the selectivity study suggest a situation of overfishing, with a yield-per-recruit value near the maximum, the present fishing mortality situated on the right hand of the yield-per-recruit curve, well over the fishing mortality that produces the maximum yield-per-recruit, and the present standing biomass-per-recruit only a small fraction of the virgin stock biomass-per-recruit. A drastic reduction of F will bring the level of exploitation to the level of the $F_{0.1}$ strategy without consistent changes in the yield-per-recruit. In the meantime, the standing biomass per recruit should reach a much safer level.

Notwithstanding the different approach, the shape of the Y/R curves of the Sicilian population of *Aristaeomorpha foliacea* obtained from the earlier trawl surveys resembles those of Ragonese and Bianchini (1996) for *Aristeus antennatus* in the same area and of Demestre and Lleonart (1993) off the Catalan coasts.

It is interesting to compare the Sicilian red shrimp fishery with the most stable fishery of *Aristeus antennatus* off the North-Western Mediterranean coasts of Spain; application of Y/R model, based on length cohort (LCA) and virtual population (VPA) analysis have indicated a sort of equilibrium condition at the optimum level even though the flatness of the yield curves makes difficult to find a clear MSY values. These results could be explained mainly because only a portion of the population (that above 800 m) is available to the fisheries and that these populations show a (moderately) high turnover rate. As regards the problem of fluctuations, the availability of more than 15 years of statistical data on catch and effort allows to appreciated only an unexplained decrease at the beginning of the 80s, probably not correlated to high effort pressure.

Red shrimp populations are generally considered resilient to exploitation, mainly because only the upper fraction of the stock is available to the trawl (Demestre and Lleonart, 1993; Demestre and Martin, 1993; Sardà *et al.*, 1993). Given the high fishing pressure exerted on the demersal resources of the Mediterranean Sea (Anon., 1989), a condition of underexploitation is unlikely for the resources of *Aristaeomorpha foliacea* of

the Sicilian Channel. Therefore a reduction of the fishing pressure is in theory required in any event: if the overexploitation scenario is the right one, to bring the fishing mortality back on the left hand side of the yield-per-recruit curve; if the situation is of maximum biological exploitation, to pursue safer strategies such as the $F_{0.1}$, with minimal loss in the yield-per-recruit.

Economic yield-per-recruit

The economic yield-per recruit of the present exploitation regimen (20 mm mesh) resulting from the Thompson and Bell's approach is near the maximum (on the right hand side), on a very flat response surface. The data from the selectivity study show again that the present fishing mortality is situated on the right hand side of the economic yield-per-recruit curve, but in this case well over the fishing mortality that produces the maximum economic yield-per-recruit; even the safer $F_{0.1}$ strategy shall provide better economic results than the present exploitation regimen. Similarly, the economic yield-per-recruit estimated by the VIT program suggests a situation of overfishing, with an economic yield-per-recruit 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 the level of the $F_{0.1}$ strategy with even a substantial increase in the economic yield-per-recruit.

The data from the earlier trawl surveys show that the present fishing mortality is slightly situated on the right hand of the economic yield-per-recruit curve and that the value of the present economic yield-per-recruit is almost at its maximum. Notwithstanding a situation of almost eumetric fishing, the pursuit of the safer $F_{0.1}$ strategy would cause only a modest decrease of the economic yield-per-recruit (less than 5%), while the fishing mortality would be reduced by one third.

From the economic point of view, a reduction of the fishing pressure is required in any event, since it should permit both to pursue safer exploitation strategies and to increase the economic returns.

Sensitivity

Sensitivity analyses should be carried out routinely (Laurec and Mesnil, 1987), and not only as an exercise of "high thinking"; in fact, parameters estimation is sometimes just an educated guess, and the results and conclusions coming from their use are often misleading.

The sensitivity analysis performed using the VIT program shows that the yield-per-recruit results are influenced very strongly by the slope parameter of the weight-length relationship; incidentally, this result supports and strengthens the necessity of using the beta function in case of allometric growth. An error on the CL_∞ estimate carries a lesser effect, which is often compensated by the reverse incorrect estimate of K. A variation of M causes almost proportional changes, but of opposite sign than with "a" and K. Finally, as expected, the yield-per-recruit is almost insensitive to errors in $F_{terminal}$. The economic yield-per-recruit results are even more influenced by the slope parameter of the value-length relationship: a mis-estimate of 3% (below or above the "true" b) produces a 40-50% variation in the output, i.e. the economic yield-per-recruit might pass from 200 to 500; even a 1% rounding creates a 15% difference in the economic yield-per-recruit.

In ANALEN the sensitivity in the selectivity study scenario confirms that the stock is (heavily) overfished (but the analytical approach is associated with large coefficients of variation. In the scenario from the earlier trawl surveys the ANALEN sensitivity shows that the yield-per-recruit increases, suggesting a lightly underfished stock, a trend already apparent in the VIT analysis of the same data.

Transitional period

The VIT program, using the virtual population reconstruction performed on age-restructured data, permits to examine the transitional behaviour of the fishery, when passing from the old steady-state to the new equilibrium. The data sets from the selectivity study and from the earlier trawl surveys produce different results, when examining both the biological or the economic yield-per-recruit (Table 72).

Table 72 - Transitional results for *Aristaeomorpha foliacea* in three scenarios of fishing mortality reduction, with various data sets.

F reduction	15% (sudden)	25% (sudden)	35% (smooth)
Selectivity study data			
% biological short-term drop	-8	-14	≈-2/2
% biological long-term gain	4	6	8
% long-term standing stock increase	14	26	41
% economic short-term drop	-7	-13	≈-3/2
% economic long-term gain	7	11	15
Earlier trawl surveys data			
% biological short-term drop	-10	-18	≈-11/7
% biological long-term loss	-2	-4	-7
% long-term standing stock increase	10	19	30
% economic short-term drop	-10	-17	≈-9/7
% economic long-term loss	0	-1	-3

The selectivity study data show that after the drop that follows the reduction of the fishing mortality, the yield-per-recruit recovers almost immediately and stabilizes at an 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 percent value that is almost equal to the F reduction. Speaking in economic terms, the initial drop is slightly smaller, and the long-term gain higher, up to one half of the F reduction.

On the contrary, the earlier trawl surveys data show that after the drop that follows the reduction of the fishing mortality, the yield-per-recruit never fully recovers and stabilizes at a lower level in 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 percent value that is almost two thirds the F reduction. Speaking in economic terms, the initial drop is slightly smaller, as well as the long-term losses.

Stochastic recruitment

There are not enough information as to decide which stock-recruitment model, Beverton and Holt's (1957) or Ricker's (1954), should be preferred. Therefore, just a stochastic variability of modest intensity (log-normal distribution, variance= 0.5) has been applied to the "constant recruitment" situation on the data from the selectivity study. The biological yield-per-recruit, over a period of 15 years, stays on average 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 sudden or smoothed way; the same "reasonable" behaviour is shown by the economic yield-per-recruit. 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, even in a stationary situation, are almost unpredictable (Walters, 1987), and a "bad" year that follows any management intervention, such as the increase in the legal mesh size, risk to be mis-interpreted by the fishermen.

Yield scenarios

Using the ANALEN program on the selectivity study data, it is apparent that an increase in the mesh size from 20 mm to 24 mm, or even to 28 mm, produces only a marginal loss in the short term (Table 73), offset by a gain in the long run (Table 74). This effect is more marked when passing to the larger mesh; this is the case of both the catch and of its value.

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

Table 73 - Short-term economic productions of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size (from ANALEN). Yields in billion liras (continuous curve); present situation underlined.

	F multipliers					
mesh	0.70	0.80	0.90	1.00	1.10	1.20
28	17.14	19.58	22.03	24.48	26.93	29.38
24	17.37	19.86	22.34	24.82	27.30	29.78
20	17.51	20.01	22.51	25.00	27.51	30.01

Table 74 - Long-term economic productions of *Aristaeomorpha foliacea* in different exploitation scenarios, varying fishing mortality and/or mesh size (from ANALEN). Yields in billion liras (continuous curve); present situation underlined.

	F multipliers					
mesh	0.70	0.80	0.90	1.00	1.10	1.20
28	28.73	28.32	27.79	27.20	26.60	25.99
24	27.80	27.28	26.65	25.98	25.29	24.60
20	27.06	26.46	25.76	25.00	24.26	23.52

Catch variability and fishing effects

The hypothesis under the fact that the fishing activity has a positive effect on yields is that when there is no exploitation, red shrimps populations are depressed by predators, and by interspecific (for food) and intraspecific (food, cannibalism) competition, and as a consequence, the yields are generally low although the catch is composed mainly by large sized animals; when exploitation begins, predators and large-size shrimps are mostly removed and as a consequence, both recruitment and production increase dramatically and so do the commercial yields; in conclusion, the first effect of fishing is to reduce the natural mortality and consequently the total mortality remains quite stable despite a strong increase of the fishing mortality. Against this theory is the fact that these species at top levels in the trophic chain and consequently the basic assumption (low level in the food web) is not respected. Furthermore, when historical series are available and analyzed contrasting results are manifest.

As a matter of fact, the higher catches of red shrimps in some places after first trials and the apparent positive correlation between the degree of "cleanliness" of the bottoms with red shrimps yields have been confirmed in most cases and places but other factors than the classical ecological hypothesis must be considered. One of the most attractive could be the turbulence effect determined by trawling (for example, the clouds of suspended particulate and mud). Fish would escape from these areas whereas red shrimps would be more attracted since they (or other decapods) could feed easily on the benthic animals exposed by trawling. The fact that when trawling operations are stopped the same areas show a quick recovery to the previous situation could support this hypothesis.

Fishing boats, gear and equipment

In oceanic fisheries such as the case of Australia, there is a vessel size constraint because small boats (less than 18-20 m) could not trawl safely the offshore bottoms;

furthermore, new vessels would require an average daily catch of more than 900 kg per day to achieve the break-even point. In the Mediterranean Sea, fishing grounds are usually closer to the landing places and as consequence the size of the boat is not so critical. Constraints arose mainly from the technical requirements for an efficient trawling of the deep bottoms where commercial concentrations of red shrimps usually occurs; nevertheless, large boat (up to 700-1,000 HP) are used by fishers from Mazara del Vallo in the Sicilian Channel.

Italian statistics on the number of boats by gear type are unreliable, for "political reasons": since the European Community requested that the Italian government reduce the number of trawlers, many boats are now registered as "multipurpose" or "polyvalent", even if they are geared 90% of the time with trawl nets. In any event, it is true that in the last few years the Italian fishing fleet has been drastically reduced, but boats are more efficient; in Mazara about 30 medium-to-large trawlers (15%) have been decommissioned since 1992.

Management

The Mediterranean fisheries of deep-water shrimps do not present great problems of mixed-stock management, since they are almost monospecific. No specific management rule has been developed for the *Aristaeomorpha foliacea* and *Aristeus antennatus* fisheries. The general feeling is that these resources are particularly resilient to the fishing pressure and that their evolution might be partially independent from fisheries patterns. This assumption is based on the observation that only the upper portion of the population is (at the moment) both accessible and economically remunerative. Another reason of optimism derives by the idea that the catchability coefficient should be less than the unit value and that even showing a growth rate slower than the coastal peneids, the high fecundity of red shrimps will guarantee against a recruitment-overfishing condition. The severity of winter cannot be considered a "natural" management measure because the fishing periods begin and last mainly according to the availability of red shrimps.

Aristaeomorpha foliacea and *Aristeus antennatus* are actually managed neither according to total allowable quota (TAC or ITQ) nor size-limit measures given the small mesh size commonly used (less than 20 mm side) and the difficulty of enforcing the legal mesh size (20 mm). In Italy, a non-specific compulsory fishing ban (45 days per year, split in 3 periods) has been introduced in the last few years (Levi, 1991), but its effectiveness in reducing the global fishing effort has not been clearly demonstrated yet. In Spain, as a non-specific regulatory measure, the boats are restricted to one-day trips (from 06.00 am to 06.00 pm) (Tobar and Sardà, 1992; Demestre and Martin, 1993).

Exploitation of under-sized red shrimps is considered a poor utilization of the resource from an "ethical" point of view (Valdemarsen, 1988), since small meshes lead to large by-catches, most of which are discarded (Sheridan *et al.*, 1984; Andrew and Pepperell, 1992).

CONCLUSIONS AND RECOMMENDATIONS

Biology

The biological aspects such as growth and mortality have a general bearing on the natural history of shrimps, but they are also necessary for reconstruction of the population-at-large. Since the biological parameters are in general obtained as an approximation of the true values, and are used repeatedly in the models, out-of-range estimates can propagate and produce havoc in the assessment; especially when dealing with unconsolidated situations. In such cases, a sensitivity analysis, either by calculus or by stochastic simulation should be carried out. Ancillary information should always be incorporated in the search for the parameter estimation, or should be used for a no-nonsense check of the results.

Estimates must be regularly updated to reflect the present status of the population, and highly variable phenomena such as the recruitment need to be reassessed every time, at least until a pattern of their variation is established in relation to other biological or oceanographic variables. The decision to pool data from different locations, seasons, fisheries, etc. may be helpful in damping the intrinsic variability, but on the other hand may mask extrinsic differences, such as the presence of different stocks or populations, or temporal cycles.

For *Aristaeomorpha foliacea*, the only fact that can be taken as definitive is that the growth is allometric, with an exponent of about 2.6. Even the von Bertalanffy growth function, that is of widespread use, is sometimes not fitted to explain the actual data, at least with a single set of parameter estimates; in fact, K does probably vary with age ("broken" model), and the estimated CL_∞ is in general substantially lower (15-20%) than the CL of the oldest classes. The modal separation is highly subjective, even when using computational instruments that are deemed to be "objective"; in any event, at least in the Sicilian Channel, there are a minimum of four age-classes, with five or six being a more

probable guess; the young-of-the-year are always easily discriminable, and their entry in the fishery is discrete.

Different methods produce different mortality estimates. Given that the Sicilian red shrimps are intensely exploited, the coupled estimates of annual Z= 0.95 and M= 0.5 appear to be the most probable for the females, also in view of what was assumed in the literature. Therefore, the exploitation ratio (E= F/Z) is 0.47, a reasonable estimate given that exploitation of this species begins at an early age. Incidentally, the mortality for the males is estimated around a lower Z= 0.45. *Aristaeomorpha foliacea* adults appear to be at the top level of the trophic web.

The female sexual maturity is indicated by the presence of the spermatophores on the thelycum, that is almost a constant above 40 mm CL, while the males present three features in sequence, that are completed above 30 mm CL: fusion of the petasma, production of spermatophores, and the striking shortening of the rostrum. The ovaries become mature after the spermatophores have been laid, and summer is the peak season.

Fisheries

The red shrimp yields are highly variable, depending on location and time of the year; nevertheless, on the 400-700 m deep bottoms of the Sicilian Channel, *Aristaeomorpha foliacea* is the most important resource, and represents the majority of the catch in number and weight. When targeting the red shrimps, the present hourly catch is around 11 kg/h, less than half of what the rate was in the '60s. Speaking of diel variations in abundance, it has been demonstrated that a night haul yields a smaller catch than during daylight, but more large shrimps are caught in proportion to daylight hauls.

The by-catch in shrimp fisheries is a worldwide concern and is considered an undesirable effect to be reduced, even when the by-catch itself may be valuable. In the specific case of the Mediterranean red shrimps, the fishery can be generally considered as monospecific, because none of the other economically important species is caught at the same time in such a quantity as to represent a sought-after species for fishermen.

The implication in fishery dynamics of an appropriate estimation of L50% is related to the optimal theoretical utilization of a resource along with the rate of fishing mortality. The behaviour of the selectivity curves and the parameters estimates, however, indicate that red shrimp and violet shrimp do not conform completely to the selection process generally observed in fish (for which a steeper ogive and higher selection factor are normally observed). Incidentally, a previously unknown sexual characteristic (adult males are "bulkier" than females of corresponding size) compensate the rostrum advantage, making the selectivity comparable on both sexes.

The yield-per-recruit estimates require commercial statistics that are seldom collected in the Sicilian Channel; moreover, 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 seem to work in many cases, at least when dealing with short- and medium-term issues. In the *Aristaeomorpha foliacea* fishery, the shape of all the yield-per-recruit curves suggests a rapid increase of Y/R for small increments of F, and thereafter the curves flatten out, without any evidence of a clear maximum. For the estimated M= 0.5 that has been preferred, gains in the Y/R could not be obtained without changing the age of first capture. Notwithstanding that, even on the same set of data, the different approaches to the yield-per-recruit analysis produce qualitatively different scenarios, i.e. the present 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 (Fig. 90). 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 been already evidenced in the companion species *Aristeus antennatus* in the same area.

The yield-per-recruit estimated from the earlier trawl surveys data suggests a situation of slight underfishing, since the present fishing mortality appears situated on the left hand side of the yield-per-recruit curve, the value of the present yield-per-recruit is

almost at its maximum, and the present standing biomass-per-recruit is above one third of the virgin stock biomass. On the contrary, the estimates from the selectivity study suggest a situation of overfishing, with a yield-per-recruit value near the maximum, the present fishing mortality situated on the right hand side of the yield-per-recruit curve, well over the fishing mortality corresponding to the maximum yield-per-recruit, and the present standing biomass-per-recruit representing only a small fraction of the virgin stock biomass-per-recruit. A drastic reduction of F will bring the exploitation to the level of the $F_{0.1}$ strategy without consistent changes in the yield-per-recruit. In the meantime, the standing biomass-per-recruit should increase and reach a much safer level.

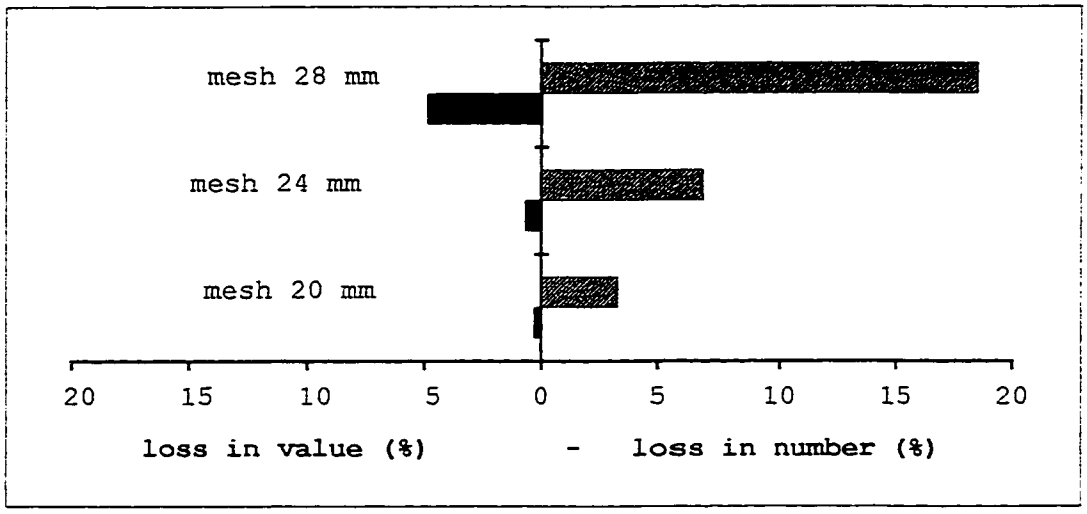


Fig. 90 - Short-term loss of the catch of *Aristaeomorpha foliacea* in number and value (%), following an increase in mesh size.

The transitional behaviour of the fishery, when passing from the old steady-state to the new equilibrium has been examined. The selectivity study data show that after the initial drop that follows the reduction of the fishing mortality, the yield-per-recruit recovers almost immediately and stabilizes at an higher level in 3-4 years. On the other hand, the earlier trawl surveys data show that after the drop that follows the reduction of the fishing mortality, the yield-per-recruit never fully recovers and stabilizes at a slightly lower level in a few years.

A stochastic variability of modest intensity was applied to the "constant recruitment" situation on the data from the selectivity study. The yield-per-recruit stays on average in acceptable limits, that are near those expected in a steady-state, deterministic situation. Nevertheless, ample fluctuations are possible, since the 95% confidence intervals have borders as low as less than half or as high as three times of the corresponding deterministic realizations. Therefore, the actual outcomes, even in a stationary situation, are unpredictable, and a "bad" year that follows any management intervention, such as the increase in the legal mesh size, risks to be mis-interpreted by the fishermen as the "ominous effect" of the new regulations.

Management

The starting point for the management of a fishery is knowledge of what is already going on, obtained by personal experience, interviews with the fishermen, examination of log-books, and reciprocal trust between parties. These are essential for the assessment of the present situation. For this reason, the "intensity" of hauling has been reported in GIS "fishing grid" pixels; it has been assessed by season on the base of a "grade" (0 to 10 scale), using a proxy measure, that represents the willingness of the captains to fish a particular ground. The "quality" of the actual trawled grounds in the area examined is considered good or quite good in 60% of the cases.

In the economic analysis, the various scenarios are qualitatively similar, i.e. the present level of economic exploitation appears situated always on the right hand of the yield-per-recruit curve. The innovative approach with the incomplete beta function, that uses a price function as if it were a growth function, seems to behave well, at least when applied to the Sicilian red shrimp fishery. Again, the two approaches to the economic yield, i.e. the classical "price stanzas" and the *ad hoc* continuous price function, produce close estimates, therefore allowing the use of the price function in the ANALEN procedure too.

From the data of the selectivity study , the economic yield-per-recruit 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 the level of the $F_{0.1}$ strategy with even a substantial increase in the present economic yield-per-recruit. Conversely, the data from the earlier trawl surveys show that the present fishing mortality is almost at its maximum. Even in this case, the pursuit of the safer $F_{0.1}$ strategy would cause only a modest decrease of the economic yield-per-recruit, while the fishing mortality will be reduced by one third.

Taking as reference the F_{max} point, which by the way is still applied in the European Union regulations, the level of exploitation for the red shrimp resources in the Sicilian Channel appears close to the optimal harvest strategy, but very near the maximum or on the right hand of the curve; when considering 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 Sicilian Channel, 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.

Aristaeomorpha foliacea in the Sicilian Channel is caught before reaching the maximum reproductive potential; moreover, undersize animals are worthless in economic terms. This growth overfishing could be controlled, for the advantage of both the fishermen and the environment, by raising and enforcing the legal mesh size, and by moving the present seasonal fishing ban to a more appropriate period. Under any scenario, even a small delay in the age at first capture would result in an increase of the yield-per-recruit, without any appreciable economic harm, even short-term.

The Mediterranean fisheries of deep-water shrimps do not present great problems of mixed-stock management, since they are almost monospecific. Therefore, a preliminary, conservative management intervention would require replacing the compulsory general fishing halt with more "targeted" interruptions, such as shifting the

halt for the red shrimp fisheries to the spring recruitment period. In fact, the alternative of concentrating in the summer all the 45 days of the annual fishing ban seems not practicable because it is the season in which the fishing activity peaks. Another typical management intervention, that of area closures and refuges, does not need to be specifically implemented, since already more than 50% of the shrimp habitat is effectively not trawlable, given the presence of deepest trenches and steep canyons.

Since the mesh size presently in use (18-20 mm, side) is not selective, the most efficient and feasible management tool is a substantial increase of the cod-end mesh size. Incidentally, an important corollary of this study is that, at least for the red shrimp and the violet shrimp, there is no reason to force fishermen to mount the legal mesh (20 mm side) since it is not selective at all, not only for deep-water shrimps but also for the most of the companion species, some of which represent the targets of other fisheries carried on in the Strait of Sicily.

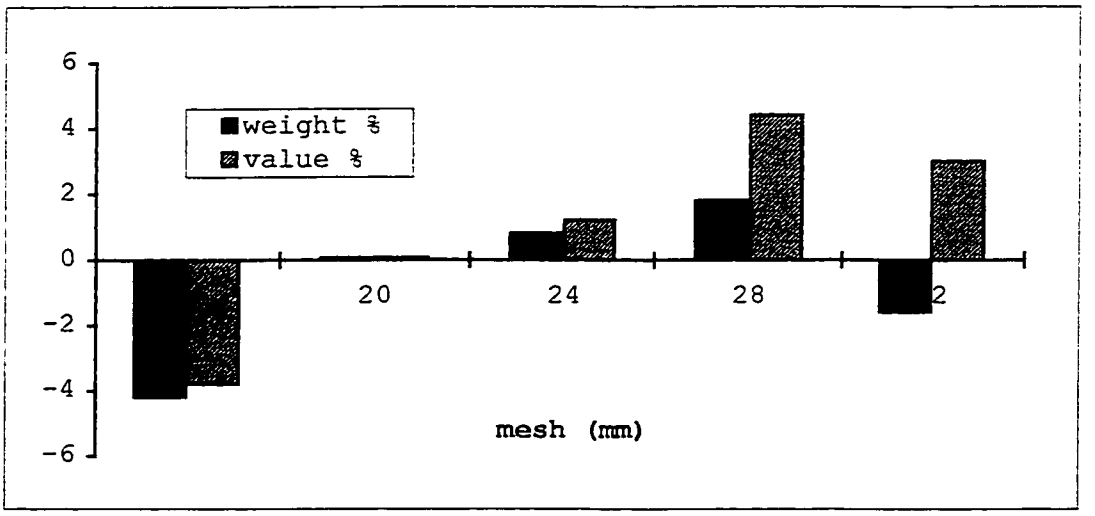


Fig. 91- Long-term variation of the catch of *Aristaeomorpha foliacea* in weight and value (%), following an increase (or a reduction) in mesh size.

From the reproductive point of view, it must be pointed out how, even using larger mesh side such as the 28 mm, the length at 50% of retention still remains quite low and far from the size at which the bulk of the population becomes sexually active. In fact,

the adoption of an "optimal" mesh size, corresponding, for example, to the size of maximum reproductive potential, is not feasible. This does not mean that the mesh size cannot be regulated, but only that it has to be determined empirically, trading theorical considerations for practical goals. The adoption of a mesh side of 28 mm in the codend employed for red shrimp fisheries is strongly recommended because only positive effects, although not drastic, can be expected (Fig. 91). This new mesh size means an increment of 50% of the mesh actually in use and of 40% of the legal mesh, and it is close to those mesh sides generally recommended to catch shrimps (about 30 mm side). Speaking of the by-catch, the enlargement of the mesh goes in the direction of the more logical option of achieving its reduction instead of attempting an (unlikely) better utilization of the same. Moreover, even if the resources of *Aristeus antennatus* in the Sicilian Channel are not worth an *ad hoc* management plan, they too would benefit by the establishment of a larger mesh size.

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 having a reduced economic value. Changes in mesh size and type (e.g., squared *vs.* diamond mesh) represent the main management instruments 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 (at present, often the illegal 18 mm) 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. 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).

In general, at present the Mediterranean fisheries are not managed with quantitative adaptative tools (such as Total Allowable Catches, TACs, that are readjusted every year, already used on the European Atlantic side) but are controlled mainly by fixed qualitative instruments such as limited licensing, time closures, premiums for decommissioning fishing vessels. Among the few quantitative measures, although still non-adaptative, are the highly correlated minimum landing size and minimum mesh size. Simply speaking, the management process in the Mediterranean is more economy- than biology-based. Therefore, the knowledge of the population dynamics and the stock assessment are insufficient, and other "parameters" should be taken into consideration, e.g. the fishermen's economic behaviour, the market reactivity, the financial incentives toward "social" goals.

There are at least three bodies ruling the fisheries in the Sicilian Channel: the European Union, the Italian government, and the Sicilian government (which has stronger powers than an American state); that produces a maze of conflicting (but rarely enforced) regulations. The management tools are in general not stock- or species-specific. The principal measures for regulating the effort are the control over the number of boat permits and a 45-day fishing ban, easily checked and enforced, since boats should stay idle in their port of call. Conversely, gear is seldom inspected; the situation is even worse in the other countries surrounding the Sicilian Channel.

No specific management rule has been developed for red shrimp fisheries. The general feeling is that these resources are particularly resilient to the fishing pressure and that their evolution might be partially independent from fishery patterns. This assumption is based on the observation that only the upper portion of the population is (at the moment) both accessible and economically remunerative. Another reason for optimism is derived from the idea that the catchability coefficient would be less than unity and that the high fecundity will guarantee that a recruitment-overfishing condition does not occur.

Aristaeomorpha foliacea is not actually managed by size limit measure because the very small mesh size commonly used does fish "everything". The severity of winter weather cannot be considered a "natural" management measures because the fishing

periods begin and last mainly according to the availability of red shrimps or the other resources.

In the near future, Italy is bound to ratify and implement many European regulations that in fact were drafted for different fisheries situations, and that require a drastic reduction of the global fishing effort. Even with these policies in force, if fishermen can establish some sort of mutual cooperation, they could use a common "collecting" strategy to improve the value of their catch, which could be sold fresh at least in part, and to increase the number of days at sea, since they would not need to leave the fishing grounds to land their catch. Moreover, exploratory surveys have shown that the red shrimps are present, with fewer but larger specimens, even in the deepest trenches: in the future, fishermen can be expected to fish those areas too. Also, they will most probably explore, develop and start using other "virgin" areas. It can be deemed that the overall situation of the fisheries will not change much in the short run, with the assured gain in efficiency compensating for the likely reduction of the hardware.

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, to bring the fishing mortality back on the left hand of the yield-per-recruit curve; if the situation is of maximum biological exploitation, to pursuit safer strategies such as the $F_{0.1}$, with minimal loss in the yield-per-recruit. From the economic point of view, a reduction of the fishing pressure is again required in any event, since it should permit both to pursue safer exploitation strategies and to 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 red shrimp fishery will benefit of the two proposed management measures directly, by the increased value of the catch, by the fact that the exploitation regimen becomes less risky for the resource, by the reduced costs of towing a "lighter" gear, by the lower labour of sorting the commercial catch; indirectly, by the

improved environmental conditions: even if the sieved-out animals are dead, their biomass would be left on the oligotrophic deep-water grounds.

Research

The fisheries for red shrimps in the Mediterranean yield very high-quality, abundant and specific catches; they fall within the new areas of interest concentrating on exploited and pristine deep-water communities. Scientific work must be fomented to improve understanding of those aspects of the life cycles and fisheries for these species, capable of contributing new ideas and perspectives adding to the existing knowledge. Action should respond to current problems, which, on account of their geographic range and conceptual scope, can only be undertaken through international cooperation (Bianchini and Ragonese, 1994).

In fact, the following singular aspects make up the present situation of the species *Aristaeomorpha foliacea*: it is, or has been, heavily exploited in the Western Mediterranean; exploitation is in its inception in the Central Mediterranean; the Eastern Mediterranean population is small but pristine. Given this situation, answers to the following questions should be sought:

- what possible specific causes are responsible for the total disappearance of *Aristaeomorpha foliacea* in certain areas of the Mediterranean;
- which species have taken over the ecological niche freed by the disappearance of *Aristaeomorpha foliacea*, and what are the trophic relationships between the species now occupying the depth range formerly occupied by *Aristaeomorpha foliacea*;
- what relations, direct or indirect (trophic chain), actually exist between the biological factors and the stocks abundance and fluctuations;
- what management measures could prevent a repetition of overexploitation in the Central Mediterranean;
- what management measures for the unexploited *Aristaeomorpha foliacea* stocks should be timely implemented in the Eastern Mediterranean;

- what is the true population size of *Aristaeomorpha foliacea*, including prawns in canyons and on untrawlable ground; the estimation should be made using acoustics, underwater photography and direct observation, covering also the distribution and abundance of pristine, unexploited populations;
- what fishery technology research should be promoted to develop a semi-pelagic gear and assess the feasibility of fishing off the grounds, a practice more environment-friendly, and assessment should be made of the risks associated with the potential harvesting of populations on rocky grounds;
- what is the spawning stock-recruitment relationship; intensive studies should be carried out including identification of larval stages and their distribution in the water column and distribution of juveniles.

In addition to providing answers to the issues highlighted above, the scope of the preceding objectives will facilitate the interpretation of the adaptability of species capable of colonizing the ecological niches in the depth ranges inhabited by *Aristaeomorpha foliacea* and *Aristeus antennatus* as well as by other species in the genera *Plesionika*, *Sergestes*, *Pasiphea*, *Parapandalus*, and the establishment of common fisheries policy guidelines by consensus among the different countries capable of preventing sudden, drastic depletion of red shrimps stocks that will result in implementation of biologically/ecologically-based management.

Further issues to be addressed include:

- synchronism in spawning cycles and frequency and number of spawnings per area;
- vertical structure of shoals and migrations;
- use of remote sensing and biological importance of direct observation;
- analyses of catch-effort ratios and trial applications of production models;
- morphometric and genetic characteristics;
- setting up of a standard data base on catches, efforts, demography and biology.

GLOSSARY

virtual population analysis: used not in strictly-speaking manner, but following Megrey's (1989) advice "... In the USA, the name VPA commonly has been used more as a generic descriptive title than as a reference to a specific method of stock assessment. ...".

selectivity pattern: it refers to the different factors, including the type of net, the catch level, the haul duration, etc., which may influence the selectivity estimation (Gulland and Rotchschild, 1984).

escape factor (EF): the ratio between length of the animal and mesh opening (MacMullen, 1981).

length about 0: the size at which shrimps begin to be retained in the cod-end.

length about 1: the size above which all shrimps entering the cod-end are held (corresponding to the asymptote).

l_c: the (theoretical) size at which the escaping and retention proportions are equal, conventionally the size corresponding to the retained proportion of 50%; usually defined as the "size at first capture" under the "knife-edge" assumption (Beverton and Holt, 1957).

length at 25%: the (theoretical) size corresponding to $p= 0.25 * p_{max}$.

length at 75%: the (theoretical) size corresponding to $p= 0.75 * p_{max}$.

$l_{75\%}$-$l_{25\%}$: the range of selection (Wileman, 1988), or selection span (Pope *et al.*, 1975), herein the "defined" selection range.

$(l_{75\%}-l_{25\%})/l_c$: the relative interval of selection (Chevaillier and Laurec, 1990).

selection range: the range of individual lengths over which a fishing gear exercises selection (MacMullen, 1981), herein the "generic" selection range.

selection ratio: a) the ratio between the "defined" selection range and the cod-end mesh size (Wileman, 1988). b) the ratio of the number of animals escaping into the cover to the total number caught in both cod-end and cover (OUT/(IN+OUT)), regardless of the size, for a given cod-end mesh size; the latter is a useful although rough (given its variability and dependence from the sampled length frequency distribution) index of the ability of certain species to escape (Liu *et al.*, 1985) and was adopted in the present study.

l_s: the "average selection size" (Gulland, 1969), i.e. the size at which the number of larger individuals retained by the net is equal to the number of smaller individuals escaping (given that the different classes have the same number of specimens); it represents a rough adaptation to asymmetric situations.

selection factor (SF): strictly speaking it is the ratio between one l_c and the corresponding mesh size, bar or opening (Wileman, 1988); generally it corresponds to the coefficient of proportionality between l_c and the corresponding mesh size for a given species and gear; as a rule, a direct linear proportionality (no intercept) is assumed between the two variables (Jensen, 1949 in Liu *et al*, 1985; Beverton and Holt, 1957; Pope *et al.*, 1975; Chevaillier and Laurec, 1990).

coefficient of selectivity: is a synonym of the "selection factor".

plus-class: the age- or length-class that groups all animals above a given threshold.

F_c: the current fishing mortality rate F.

$F_{0.1}$: the fishing mortality rate F at which the slope of the Y/R curve is 10% of its value when Z= M, i.e. when the stock is not exploited (Gulland and Borema, 1973).

F_{max}: the fishing mortality rate F producing the maximum yield-per-recruit in a given fishing situation.

critical age: the age at which the cohort reaches its maximum biomass.

critical length: length at which the cohort reaches its maximum biomass.

total biomass balance: the equation by which, in a stock at equilibrium, inputs (recruitment and growth) are balanced by the outputs (natural and fishing mortalities).

turnover: the percent ratio of the total biomass balance and the mean biomass, D/B_{mean}.

B_{max}: biomass of the critical class.

B_{mean}: mean standing biomass.

D: annual biomass balance.

$\$_{mean}$: mean standing value.

$\$_{max}$: value of the critical class.

$D: annual value balance.

$Y/R: economic yield-per-recruit.

GC: gear configuration of the terminal part of the experimental trawl net, expressed as ratio of the (variable) mesh size of the cod-end and that of the cover (presence= 14; absence= 00).

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Appendix A

SYNOPSIS OF BIOLOGICAL DATA ON THE RED SHRIMPS, IN PARTICULAR *ARISTAEOMORPHA FOLIACEA* (RISSO, 1827) OF THE MEDITERRANEAN SEA

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Introduction

Deep-water shrimps (or prawns, as they are called by Australian scientists) represent an important commercial and ecological group around the world (Longhurst and Pauly, 1987; see also references in Sardà *et al.*, 1993) even though heterogeneous from a systematic point of view (Dore and Frimodt, 1987). With some exceptions (for example, the pink shrimp *Pandalus borealis*; Shumway *et al.*, 1985; Pearson and Frèchette, 1983) their life cycles are generally not so well documented (at least in some areas) and their spatio-temporal patterns are still not well understood (Sardà *et al.*, 1993) even though a large amount of information has been piling up in the last two decades. The interest toward these deep-water animals derived also from their supposed potential (cf. Suseelan, 1974); as a matter of fact, since coastal peneids shrimps are in general fully or overexploited (Gulland and Rothschild, 1984), it is likely that deep-water shrimps should give a substantial contribute to any future increase in shrimps production.

This section summarizes the available biological data for the two most important species at present, at least for the Mediterranean Sea: *Aristaeomorpha foliacea* and *Aristeus antennatus*.

Identity and morphology

Aristaeomorpha foliacea and *Aristeus antennatus* are marine crustaceans belonging to the Aristeidae (or Aristaeidae), a family which is distinguished from the other three members of the superfamily Penaeoidea (Decapoda Natantia, suborder Dendrobranchiata) for the lack of a postorbital spine (present in Solenoceridae), the presence of a well developed "prosartema" in the first antennular segment (present only as a vestigial structure in Sicyoniidae), the occurrence of an appendix interna at the base of the endopod of males (lacking in Peneidae) and for the upper (dorsal) antennular flagellum, markedly shorter than the other, and inserted near the base of the 3rd article of the antennular peduncle (Pérez Farfante, 1988; Dall *et al.*, 1990). Some distinctive morphometric characters are presented in Fig. 92.

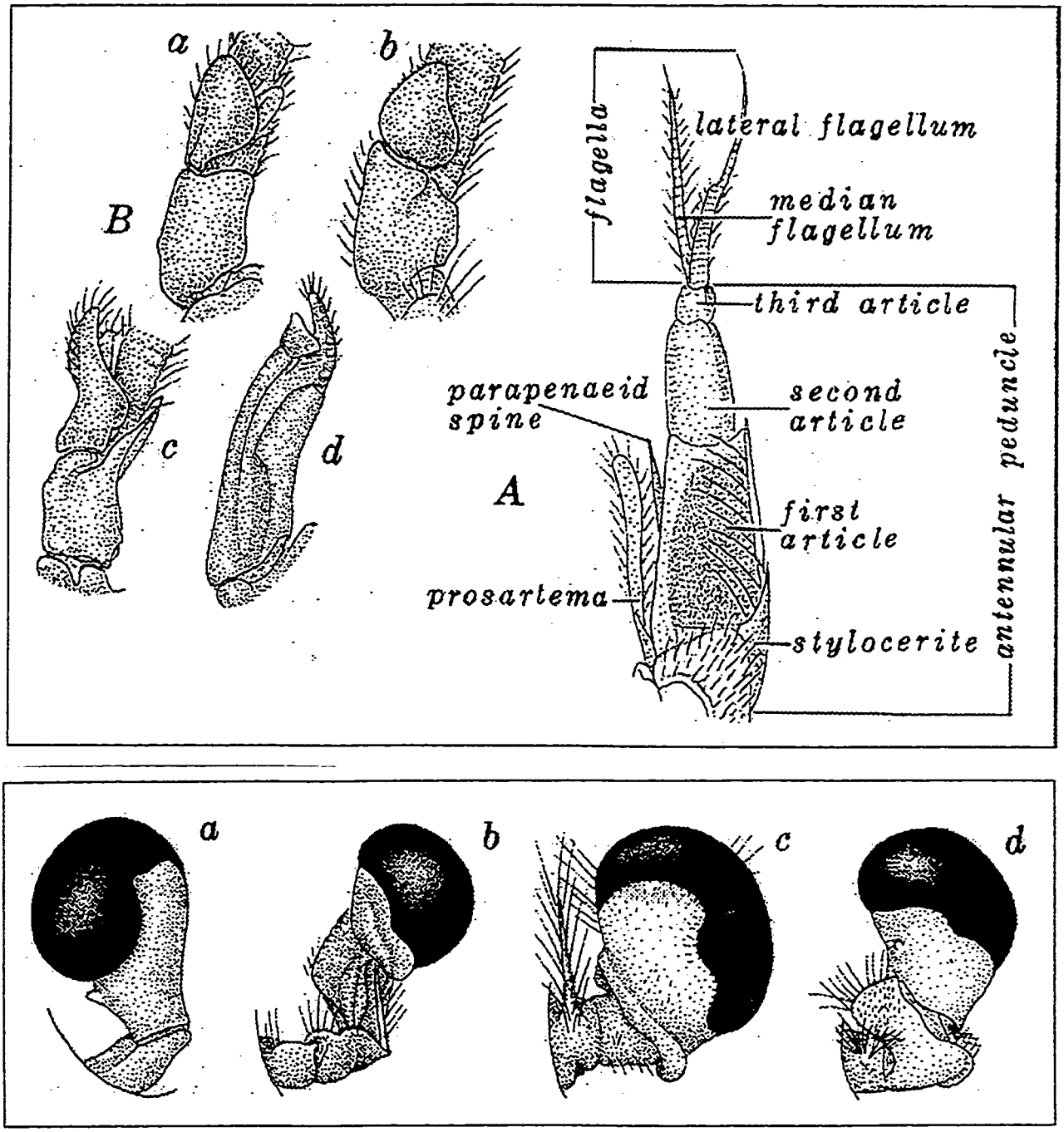


Fig. 92 - Characters used in keys to penaeoids. A. Antennula. B. Types of appendices masculinae in penaeoid families: **a.** Aristeidae; **b.** Penaeidae; **c.** Solenoceridae; **d.** Sicyoniidae. C. Types of eyes in the families: **a.** Aristeidae; **b.** Penaeidae; **c.** Sicyoniidae; **d.** Solenoceridae. (from Pérez Farfante, 1988)

The family includes three genera of commercial important shrimps (*Aristaeomorpha*, *Aristeus* and *Plesiopenaeus*; Holthuis, 1980; 1987). These animals reach a large size (22-35 cm, total length, TL) and generally inhabit, together with some carideans shrimps, the outermost continental shelf and the upper slope, being able however to live also in deeper water (down to 1,000-2000 m). Opposite to the typical life cycle of their close relative, the coastal penaeid shrimps (Garcia and Le Reste, 1981; Garcia, 1985), the larvae of deep-water shrimps do not move inshore (Dall *et al.*, 1990).

At the moment, the systematic location of the two Mediterranean species, *Aristaeomorpha foliacea* and *Aristeus antennatus*, can be described as follows:

Phylum: Arthropoda
Class: Malacostraca
Subclass: Eumalacostraca
Superorder: Eucarida
Order: Decapoda
Suborder: Dendrobranchiata
Superfamily: Penaeoidea
Family: Aristeidae
Genus: *Aristaeomorpha*; *Aristeus*

The basic specific distinctive features, derived mainly from Zariquiey Alvarez (1968), Roper and Sweeney (1981), Holthuis (1987) and Pérez Farfante (1988), can be summarized as follows:

a) *Aristaeomorpha foliacea* (Fig. 93a) - Body setose; rostrum either long and bent upward, its dorsal margin bearing 4-6 rather stout teeth equally spaced along its base and some (2-6) small denticles extending almost to the tip (females and young males), or much shorter (it does not go beyond the antennular scale; the "stylocerite") and bearing only the 4-6 basal teeth (adult males). The number of teeth, however, can be variable given the occurrence of regenerative phenomena. In both sexes there are no

teeth on the ventral side of the rostrum. Grooves and crests on carapace rather well developed, particularly the dorsal keel ("postrostral" crest) and the branchiocardic groove (but absence of a true *carina*); antennal, branchiostegal and hepatic spines present. Abdomen (pleon) slightly keeled along the dorsal midline of third segment, the keel becoming strongly developed on the following three segments (4^{th} to 6^{th}) on all of the above three abdominal segments (4^{th} to 6^{th}) the keel ends posteriorly in a sharp point.

b) *Aristeus antennatus* (Fig. 93b) - Body polished and carapace smooth (slippery). Rostrum with three dorsal teeth, short in males but long and bent upward and pointed in females. In both sexes there are no teeth on the ventral side of the rostrum. Carapace without hepatic spine and *carina*. Cervical sill short, that does not reach the dorsal region. Median dorsal keel on abdomen rudimentary on posterior half of the 3^{rd} segment, ending in a small sharp tooth. The keel completes and becomes much more conspicuous on segment 4-6 with the posterior tooth strong in segment 4^{th} and 5^{th}, and somewhat reduced in segment 6^{th}. Exopod of second pair of maxillipeds short, barely reaching the distal end of endopod; *carpus* of 5^{th} pair of pereiopods clearly longer than *merus*.

As the general case in deep-water shrimps, *Aristaeomorpha foliacea* and *Aristeus antennatus* have red colour and this explains why in the Mediterranean they are generally known as "red shrimps". Colors are however transient and are almost lost after preservation (Voss, 1955); natural chromatic pattern can be also altered in consequence of diseases or handling process.

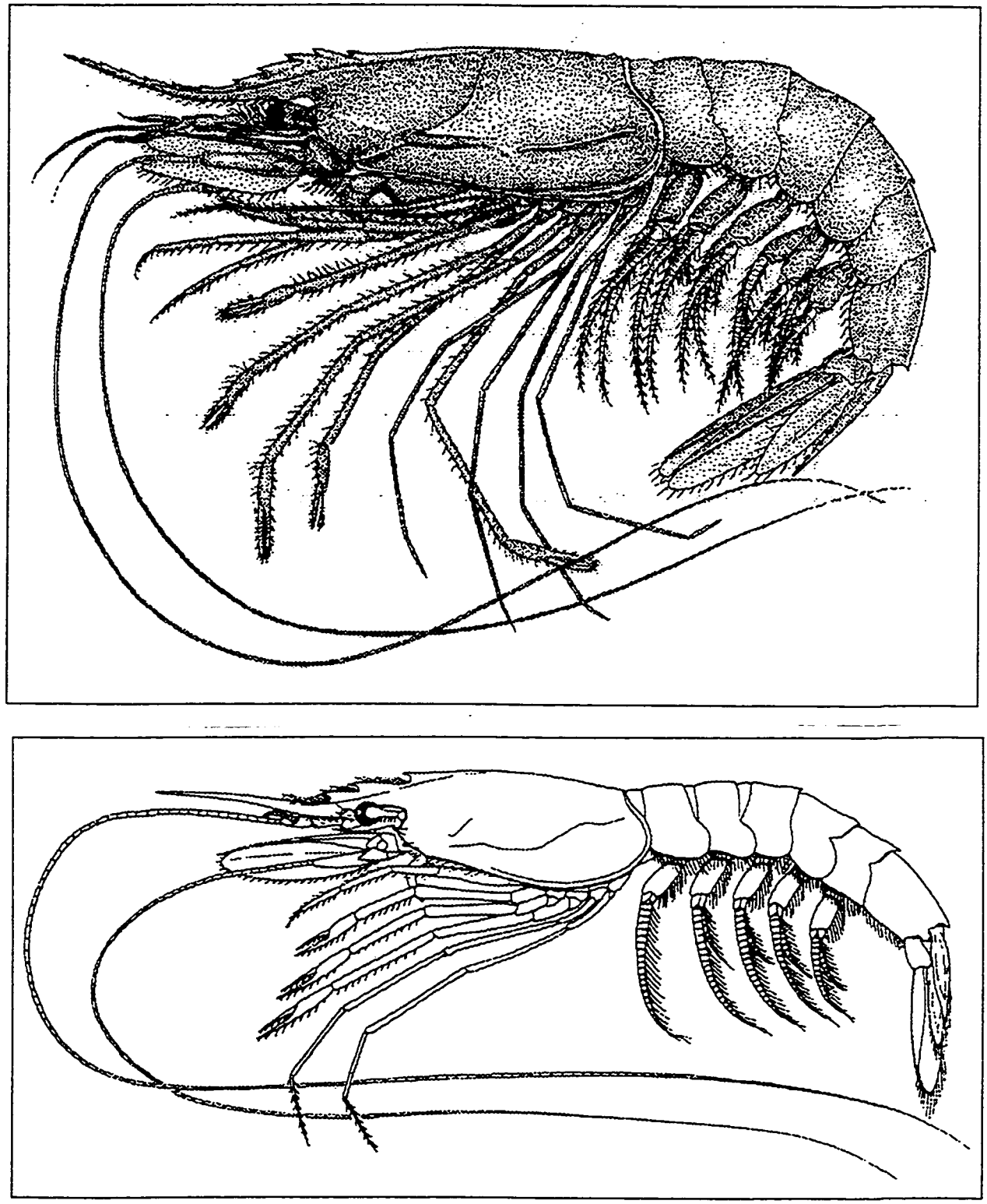


Fig. 93 - a: *Aristaeomorpha foliacea*; b: *Aristeus antennatus*.

In *Aristaeomorpha foliacea*, the colour is wine-red, with dark-violet reflections on the upper side of carapace; in mature females, i.e. almost ready to spawn, the dorso-lateral sides of the carapace and the dorsal portion of the abdomen assume a darker coloration as a consequence of the black colour of the mature ovary. In *Aristeus antennatus*, the colour is pale red, nacreous pink, profusely interspersed with violet on the dorsal regions of carapace and around the joints of the abdominal segments. In mature females, both the dorsolateral carapace and abdomen assume a marked lilac colour which derives from the underlying purple-violet colour of the mature and turgid ovary.

In both species the carapace may remain impregnated of these colors for a period after spawning. Blackening of the carapace can also occur in both species, few hour after, as a consequence of natural or microbial-induced oxidation of the tissue (see below).

Both species are regarded as a delicacy, and are highly prized food in many Mediterranean countries (Davidson, 1972) and in North America. The flesh is well flavored if the catch has been handled properly. The deep and uniformly bright red color, assumed by the shrimps after cooking results most appealing (Dore and Frimodt, 1987). Blackening and off flavor, however, can reduce their palatability (see the exploitation section).

Synonymy and subspecies

Both *Aristaeomorpha foliacea* and *Aristeus antennatus* are distinctly recognized from their few congeners, and are unanimously considered as valid species. Formerly reported with the names of *Penaeus antennatus* and *Penaeus foliacea* (Brian, 1942), several different scientific names have been used since the original description (Holthuis, 1980): *Penaeus meridionalis*, Hope, 1851; *Aristeus foliaceus* - Smith, 1885; *Aristeus rostridentatus* - Bate, 1888; *Penaeopsis foliaceus* - Ortmann, 1890; *Aristaeomorpha giglioliana* - Wood-Mason, 1892; *Plesiopenaeus foliaceus* - Faxon, 1895; *Aristaeomorpha mediterranea* - Adensamer, 1898; *Aristeus japonicus* - Yokoya, 1933 for *Aristaeomorpha foliacea* and *Sycionia duvernoii* - Risso, 1844 for *Aristeus antennatus*.

None of the before-mentioned names is still in use (Roper and Sweeney, 1981; Holthuis, 1987). Some confusion still persists for the Indo-West Pacific records of the genus *Aristaeomorpha*. In the past, these records were identified as a distinct species, *Aristaeomorpha rostridentata* but successive studies considered it not as valid species but as slight variety of the red shrimp *Aristaeomorpha foliacea* and consequently they were synonymized with the latter species. Thereafter, most of these records revealed to correspond to a different species of the same genus, *Aristaeomorpha woodmasoni* (Suseelan, 1974; Holthuis, 1980).

Even though some doubts persists among zoologists as concerning the different populations of the red shrimp (Dore and Frimodt, 1987; Holthuis, 1987), the Indo-Pacific specimens caught off Madagascar and Mozambique (Brinca *et al.*, 1983; Dietrich, 1987), Australia (Kensley *et al.*, 1975; Grey *et al.*, 1983) and New Zealand (Webber *et al.*, 1990) are all ascribed to the species *Aristaeomorpha foliacea*.

Standard common and vernacular names

According to the FAO vernacular nomenclature, the following names are recommended for the two red shrimps considered: Giant red shrimp (English), Gambon rouge (French), Langostino moruno (Spanish) and Blue-and-red shrimp (English), Crevette rouge (French), Gamba rosada (Spanish) for *Aristaeomorpha foliacea* and *Aristeus antennatus* respectively.

However, the most common vernacular names throughout the world are (Massuti, 1963; Holthuis, 1980; Dore and Frimodt, 1987):

- Algeria: *Aristaeomorpha foliacea* - Kam'rn
- Australia: *Aristaeomorpha foliacea* - Red prawn
- France: *Aristaeomorpha foliacea* - Grande crevette rouge; *Aristeus antennatus* - Crevette rouge
- Germany: *Aristaeomorpha foliacea* - Rote Garnele
- Greece: *Aristaeomorpha foliacea* and *Aristeus antennatus* - Garida

- Israel: *Aristaeomorpha foliacea* - Ariston adom; *Aristeus antennatus* - Aristit
- Italy: *Aristaeomorpha foliacea* - Gambero rosso; *Aristeus antennatus* - Gambero viola
- Japan: *Aristaeomorpha foliacea* - Tsunonagachihiroebi; *Aristeus antennatus* - Hikarichihiroebi-zoku
- Morocco: *Aristaeomorpha foliacea* - Crevette royale
- New Zealand. *Aristaeomorpha foliacea* - (Royal) red prawn
- Spain: *Aristaeomorpha foliacea* - Gamba roja; *Aristeus antennatus* - Chorizo blanco, Gamba, Moruno
- Tunisia: *Aristaeomorpha foliacea* and *Aristeus antennatus* - Gambri ahmar
- USA : *Aristaeomorpha foliacea* - Spanish red shrimp
- Venezuela: *Aristaeomorpha foliacea* - Langostino rojo
- Yugoslavia: *Aristaeomorpha foliacea* - Kozika crvena

Cytomorphology, protein specificity and biochemical studies

Decapods are characterized by a high and variable number of chromosomes without any modal value. Deiana *et al.* (1993) have investigated the chromosome pattern in *Aristaeomorpha foliacea* finding a diploid number of 74-78 chromosomes.

As concerns the protein specificity, different attempts have been made in the last years in order to discriminate substocks or unit population in *Aristeus antennatus* and studies are still in progress (Sardà, pers. com.). Preliminary results indicate that no substantial variation exits in the enzymatic patterns of *Aristeus antennatus* coming from different locations (Sardà, pers. com.). No such studies have been implemented for *Aristaeomorpha foliacea.*

The amount and composition of carotenoid pigments in *Aristaeomorpha foliacea* have been investigated (Fernandez and Burgos, 1981): up to 53 types of pigments were isolated, some of which not previously described in decapod crustaceans; ketocarotenoid were dominant, followed by xanthophyllis. A very complex carotenoid mixture has been evidenced, both in the flesh and carapace, with *Aristaeomorpha foliacea* resulting to be a

rich source of carotenoids. Since decapods, as well as other animals, are not able to synthesize these pigments by themselves, the composition depends mainly on the specific "geographical diet" of the animals.

The lipids content and evolution in red shrimps, have been analyzed by different authors (Trotti and Manfredi, 1971; Cattaneo, 1974).

Calcium metabolism, an important physiological process linked to the molting of crustaceans, has been investigated in *Aristeus antennatus* by Sardà *et al.* (1989). The results put in evidence the relevance of the gastric epithelium for long-term Ca storage in this species, which lacks (as the general case of low calcified crustaceans) the gastroliths in the stomach.

Distribution or where these species occur

Aristaeomorpha foliacea is a widespread species with an areale larger than that of *Aristeus antennatus* (Fig. 94a, b). *Aristaeomorpha foliacea* is found in the Mediterranean Sea (now rare in the Adriatic), Eastern Atlantic (off Morocco and South-Western Sahara and Portugal), South Africa, Northern-Western Atlantic (from Venezuela and the Gulf of Mexico to North Carolina), Indian Ocean and Western Pacific, including Japan, Australia and New Zealand (Voss, 1955; Richardson and Yaldwyn, 1958; Kensley *et al.*, 1975; Burukovsky and Romensky, 1979; Roper and Sweeney, 1981; Holthuis, 1980; 1987; Grey *et al.*, 1983; Dietrich, 1987; Perez Farfante, 1988; Webber *et al.*, 1990).

Aristeus antennatus is mainly distributed in the Mediterranean Sea and the Eastern Atlantic from Portugal to the Cape Verde Islands (Roper and Sweeney, 1981; Holthuis, 1980; 1987; Demestre, 1990).

Both *Aristaeomorpha foliacea* and *Aristeus antennatus* have been considered as demersal, nectobenthic, bathypelagic or mesopelagic species since their ability to swim and move along the water column. Based on feeding analysis, *Aristeus antennatus* seems to be more linked to the substratum than *Aristaeomorpha foliacea*.

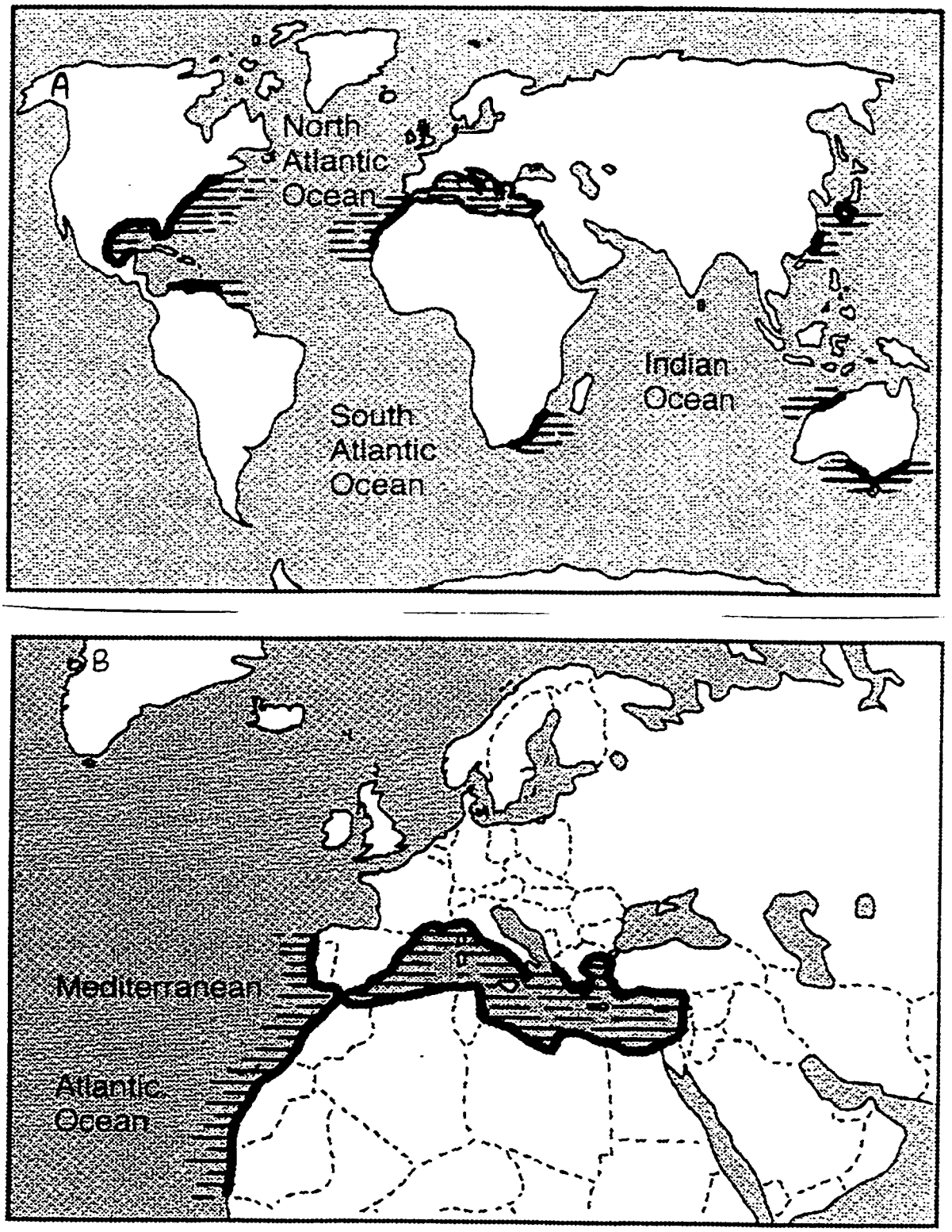


Fig. 94 - Geographic distribution of a: *Aristaeomorpha foliacea* and b: *Aristeus antennatus*.

Aristaeomorpha foliacea and *Aristeus antennatus* are generally considered as deep and soft-mud loving animals although neither the depth (i.e., light penetration) nor the nature of the substratum are exclusive factors in driving or controlling their spatial distribution and high or low occurrence in a certain area.

Both red shrimps are characteristic species of that assemblage recognized for bathyal mud bottoms in the Mediterranean Sea (Pérès and Picard, 1964; Pérès, 1982; 1985). They usually inhabit the deep and cold waters, from the edge of the continental shelf (about 200-300 m), to the upper and middle level of the continental slope and, at least in the case of *Aristeus antennatus*, down to the lower level of the slope (till 2200 m: Sardà and Cartes, 1993; Sardà *et al.*, 1993).

Sometimes, when special conditions exists, they are able to reach lesser depth, around 80 m and 150 m for *Aristeus antennatus* and *Aristaeomorpha foliacea* respectively (Bombace and Sarà, 1972; Holthuis, 1987; Campillo *et al.*, 1991). Generally, the mesobathyal (upper slope) level, i.e. the depth in the range 500-800 m, represents the preferential bathymetric range, where the bulk of both populations are found (Carpine, 1970; Pérès, 1985; Ragonese, 1989; Sardà *et al.*, 1993). The abundance both in weight and number decreases with the depth below the 700-800 m level but recent studies have demonstrated that *Aristeus antennatus* is present diffusely, although the yields are very low (Sardà, 1993), till the 2200 m (Cartes and Sardà, 1992; Sardà, 1993; Sardà *et al.*, 1993), mainly as smaller specimens (Sardà and Cartes, 1993).

Geographical distribution of red shrimps in the Mediterranean

Spanish Mediterranean

Aristaeomorpha foliacea is almost non-existent in the Western part of the Mediterranean, where *Aristeus antennatus* is abundant and commercially exploited, especially in the North-Eastern Alboran Sea, in the Valencia and Eivissa Channel and in

the Catalonian waters (Martin, 1991; Demestre, 1994; Martìnez-Baños, 1994; Sardà and Cartes, 1994; Carbonell, 1994; Carbonell *et al.*, 1998).

French Mediterranean

Aristaeomorpha foliacea and *Aristeus antennatus* were inconsistently exploited by the fishermen of the Gulf of Lions during the '60s; thereafter, the need of *ad hoc* gear, the distance of the fishing grounds, the time limitations imposed by conservation policies, and the scanty hourly catch reduced the fishery to almost nil (Campillo, 1994).

It is interesting to note that *Aristaeomorpha foliacea* seems to have disappeared from the fishing grounds of the Gulf of Lions: in 1959, the red shrimp catch was evenly split between the two species, considering the depth range of 400-1000 m; on the contrary, since 1984 (and at least til 1991), *Aristaeomorpha foliacea* is totally absent from the catch. On the contrary, around the East coast of Corsica, *Aristaeomorpha foliacea* is always dominant over *Aristeus antennatus*, during the surveys of 1957, 1965 and 1991.

Ligurian Sea

Catches of the two species of red shrimps, *Aristeus antennatus* and *Aristaeomorpha foliacea*, were documented from the period 1930-1940 on the levels of 400-500 m on the same bottoms. After the reappearance of *Aristeus antennatus* in 1985 and its boom in 1987, the catch of *Aristaeomorpha foliacea* on the bottoms of Portofino, which had came to an end in the '70s, is up to now insignificant in commercial terms: the relative abundance of *Aristaeomorpha foliacea* and *Aristeus antennatus* is nearly 3%-97% (Orsi Relini & Relini, 1994).

Northern Tyrrhenian Sea

The Viareggio and Livorno bottom trawling fleets exert a very low fishing pressure on red shrimps. This is due to three main reasons: the relatively poor yields obtained operating on the nearest fishing grounds; the practically null importance of red

shrimps fishery by-catch; and the relatively long distance between harbors and fishing grounds (Righini & Abella, 1994).

Even considering all surveys pooled, only a small number of specimens were caught and always deeper than 550 m; altogether, *Aristaeomorpha foliacea* smallest female specimen is 25 mm CL while the largest is 57 mm CL; the smallest male of *Aristaeomorpha foliacea* is 31 mm CL and the biggest one 39 mm CL

Mature females of both species are present during the summer; practically all the females of *Aristaeomorpha foliacea* are mated (100% during the spring surveys and 86% in summer). In summer, the lower limit of CL of mated females is 40 mm and the upper limit 56 mm CL; during spring they are 40 mm and 55 mm CL respectively.

Southern Tuscany archipelago

The vertical distribution of *Aristaeomorpha foliacea* ranges in a bathymetric interval between 430-650 m (the maximum sampling depth). More abundant catches are observed at depth more than 500 m, up to 5 kg/h, on bottoms characterized by *Isidella elongata* (Mori *et al.*, 1994). The observed size range is comprised between 14-44 mm CL for males and between 15-66 mm CL for females.

Females with the spermatophores on the thelycum are observed throughout the year, with the highest presence in March (93.7%) and April (84.6%), and the lowest in November (10.4%). The frequency distribution of the female gonadic stages shows that reproduction takes place during a long spawning season between the end of April and the second half of September. In April females begin the gonad maturation at size bigger than 45 mm CL; in September the completion of gonad maturation is reached also by specimens smaller than 37 mm CL (probably representing the newborns of the year before): the smallest mature females are observed at the size of 28 mm CL. The size at onset of sexual maturity is estimated at 47.0 ±4.7 mm CL. Histological analyses suggest that the largest individuals have at least two successive breeding episodes. Mature males are observed throughout the year; their minimum size at maturity is 29 mm CL, and males greater than 32 mm CL always result mature. Recruitment occurs during spring.

Latium coast

The length frequency distributions of *Aristaeomorpha foliacea* in the three main fishing zones (Civitavecchia, Fiumicino, Terracina) points out a descent during spring on bottoms between 300-450 m, followed by a progressive bathymetric migration to 600-650 m (the only place where it is possible to catch males above 35 mm CL and females above 45 mm CL), of the cohorts of young individuals (18-20 mm CL) (Leonardi & Ardizzone, 1994).

The length frequency distributions show three peaks of females and two peaks of males; the female samples allow to obtain a von Bertalanffy curve defined by the parameters: CL= 73.19 mm (SD= 3.816); k= 0.62 (SD= 0.081);t_0= 0.19 (SD= 0.053).

The total mortality (Z), calculated using the "linearized length-converted catch curve" of Pauly is Z= 1.979 (SD= 0.147). To evaluate the natural mortality (M), the Pauly's empirical formula in logarithmic form was used (temperature fixed at 13°C), resulting in M= 1.01, from which descends a fishing mortality F= 0.97.

The sex-ratio is close to 1:1 until 450 m; beyond this depth it changes greatly in different areas, suggesting a differentiated distribution for the two sexes. The percentage of mated females above 35 mm CL varies from season to season, with a maximum in spring. The slight decline in summer can be justified by hypothetical multiple reproductive cycles during the season. In fact, when the mating reaches its maximum in spring, the development of the gonads is just beginning, with almost 90% of the females in stages I and II, whilst the real reproductive season starts only in summer with high percentages in stages III and IV; after the deposition at the beginning of the summer, another set of couplings should follow, which would justify the presence of many spermatophores also in this season.

The analysis of the frequencies of pre-ovulatory females allows to locate the reproductive season between the middle of May and September, with a maximum occurring in July and August. The presence of spermatophores on some females smaller than 35 mm CL and the length reached by a small percentage of them in the first summer

after birth do not consent to exclude the possibility of reproduction during the first year, but most of the individuals have the first deposition only during the second summer of life.

The relative abundance of the two species of red shrimp is nearly 70%-30%, respectively for *Aristaeomorpha foliacea* and *Aristeus antennatus*.

Southern Tyrrhenian (Campania)

The most abundant catches are observed in the deepest stratum and the highest relative density is in the two sub-areas of Salerno Gulf and Cape Bonifati. The autumn catches are generally more abundant than in the other seasons.

The mean size (carapace length) increases according to the depth: at 200-450 m it ranges around 30 mm CL, but at 450-700 m it is around 40 mm CL (Spedicato *et al.*, 1994). The length-weight relationship pattern showed that the females weight increases through the seasons (from autumn to summer), confirming a late spring-summer spawning season. The length frequency distributions show a spring recruitment with a discontinuous pattern, as emphasized by the lack of some classes in the spring and summer length frequency distributions.

The growth parameters L= 70.85 mm (95% confidence interval: 53.85-87.85 mm) and k= 0.467 (95% confidence interval: 0.266-0.667) were estimated separating the length frequency distributions by Bhattacharya's method and then performing the modal progression analysis, whose data were used as input for regression. The value of W was 102.45 g and t_0= -0.277 year.

The total mortality Z/year= 1.353 ((95% confidence interval: 0.96-1.75) was first estimated by length-converted catch curve summarizing the length frequency distributions. The graph mirrored the length frequency distributions, showing some humps. Thereafter, the total mortality Z/year= 1.294 (95% confidence interval: 1.15-1.44) was estimated again by Jones and van Zalinge's method; this last value was chosen as input to calculate the fishing mortality, because of its less wide confidence interval. Natural mortality was calculated by Pauly's (M= 0.6), Taylor's (M= 0.488) and

Gunderson and Dygert's (M= 0.565) formulas; the mean value M= 0.55 was then employed to calculate the fishing mortality, F= 0.741 and the exploitation rate E= 0.574.

To apply the yield-per-recruit model, $CL_{50\%}$= 34.3, $t_{c50\%}$= 1.15 and t_r= 0.434 were calculated by selection ogive. The actual yield-per-recruit as function of F and t_c were respectively 10.43 g and 10.46 g. Both these values were in the upper ascending branch of the curve.

The sex-ratio estimates were generally close to 1:1 except in spring 1991 (sex ratio 3:1 in favour of the females). The frequency occurrence of mature females (3-stage maturation scale) was ranging from 6% to 50% in spring (May samples) and from 9% to 42% in summer (August samples), stressing a late spring-summer spawning season. The length of the smallest mature female was 38 mm CL.

Southeastern Tyrrhenian Sea

The fisheries between Capo Suvero (Calabria) and Palermo (Sicily) employ about 100 vessels, of 40 tons and 270 HP in average, but only a few are fishing at depths inhabited by the red shrimps (Greco *et al.*, 1994). The red shrimps catch per boat per day is generally very low, from 10 kg/d/boat to 20 kg/d/boat (both species of red shrimps pooled). In the most profitable fishery, West of Milazzo, the total landings went down regularly from 72 t in 1985 to 35 t in 1993. Commercially, all shrimps are marketed together in Calabria.

The proportion of *Aristeus antennatus* and *Aristaeomorpha foliacea* varies according to year, season and location, but altogether the two species are quite even, with a small prevalence of *Aristaeomorpha foliacea*; in the Calabrian side, of lower productivity anyhow, the relative dominance is reverted. Strangely enough, probably because of different fishing grounds, commercial landings are in favour of *Aristeus antennatus*, in a ratio of 2:1, even in the Sicilian sectors. Experimental catches of *Aristaeomorpha foliacea* are 3.5 kg/h in average, with a maximum of 9.8 kg/h in autumn 1991 near Milazzo, on the same grounds identified as nursery area. In general, recruits appear in February-March.

Aristaeomorpha foliacea annual length frequency distributions show only one modal size at 34 mm CL; the largest female is 64 mm CL. In *Aristaeomorpha foliacea* the sex proportion is 55-60% in favour of females; the size at first maturity, on the basis of presence of spermatophores on the thelycum, is 34 mm CL for the females, while males present a fused petasma at 31-34 mm CL; in general, shrimps above 50 mm CL are females.

Sardinia

A tight correlation appears between the presence of *Aristaeomorpha foliacea* and the salinity of water; in fact, the absence of *Aristaeomorpha foliacea* on the Ligurian Sea could be explained by the almost complete disappearance in that region of the "Eastern or intermediate water". Briefly, it seems that salinity rather than temperature determines the distribution of the two companion species (Murenu *et al.*, 1994). The fishery is carried out over deep-water muds (facies at *Isidella elongata*), characterized, for what concerns Decapoda by *Plesionika*, *Pasiphaea*, *Parapandalus*, *Policheles*; bony fishes are mainly represented by *Hymenocephalus italicus* and macrurids.

During summer, the largest quantity of *Aristaeomorpha foliacea* is caught in daylight at the deepest grounds (650-740 m), but the greatest number of large-size animals is recorded in the hauls just after sunset between 550-600 m, by the way the same hauls which during the day produced a lot of small-size shrimps. In winter, the depth distributions and diel cycles resemble that of summer, but the largest concentration of middle-size individual is found higher, between 550-600 m. Winter produces smaller catch and sometimes small quantity (1-2 kg/h) of *Aristaeomorpha foliacea* are found even in the transition zone.

Aristaeomorpha foliacea populations make, at least where the slope is very steep and broken by gaps, vertical movements related only to hydrological phenomena; in Sardinia by the way, the vertical migration has been verified for both species. The diel cycle of vertical displacement is definitely of smaller scale than the seasonal migration (in the order of 150-200 m) and is probably linked to the trophism.

Algeria

According to the official statistics, the red shrimp fisheries (both species pooled) varied between 1000-4000 t per year during the '80s, representing 3-4% by weight and 10% by value of the total landings of Algeria. *Aristaeomorpha foliacea* is captured almost exclusively in the Gulf of Annaba; in daylight it is found between 400-600 m of depth, in the temperature range of 13.5-13.3°C, while during the night the limits expand to 350-650 m and 13.5-12.9°C (the optimal catches, 50 to 250 individuals/h, still rests at 400-600 m and 13.4-13.3°C). More detailed observations show some differences between daylight and night, but of a relative amplitude (Yahiaoui, 1994).

The individual sizes of the catch in the area are comprised from a minimum of 23 mm of CL (both sexes), and a maximum of 67 mm and 45 mm, respectively for males and females; the sex-ratio is almost exactly 1:1. Notwithstanding the limited sample (720 specimen), a LFD analysis has been carried out, resulting in a CL around 44-45 mm and 65-73 mm for males and females respectively, a growth parameter K higher for the males (0.66 versus 0.45-0.56), and an instant total mortality (Z) lower in the males (0.79) than in the females (0.91) of *Aristaeomorpha foliacea*

Sicilian Channel

The area of the Central Mediterranean Sea between the Sicilian and North-African coasts (the Sicilian Channel "*sensu lato*") is considered a "Unitary Management Area" (UMA) for demersal resources (Ragonese, 1989). The 1000 m isobaths encompass the North-West (Capo S. Vito/Sicily - Cap Ferat/Algeria) and the South-East (Capo Murro di Porco/Sicily - Capo Misurata/Libya) limits. In the fisheries of the Sicilian Channel, the "potential" fishing area encompasses around 25,000 km^2. Those grounds are furrowed by many non-trawlable canyons. The bottom temperature is stable in time all over the area, at around 13.5°C. The regional distribution of *Aristaeomorpha foliacea* presents three or four areas of greater importance, interspersed with 20% of "dry" hauls: at smaller scale, densities seem of the "contagious" type, i.e. hypergeometric, with patches of higher

concentration. In fact, the bathymetric map suggests two main distributional zones for this species in the Sicilian Channel ("West" and "East" side of the Strait of Sicily). Between them there is a narrow passage with sufficient depth (200-400 m) to allow adult shrimps to move from one side to the other. In addition, the results of the experimental trawl surveys suggest the East zone could be further divided into a "Far-South" and a "South-East" zone, partially separated by two deep elongate depressions, each deeper than 1000 m, known as "Pantelleria trough" and "Malta trough". Notwithstanding those discontinuities, the use of a "unitary management area" approach seems realistic: in fact, differences between West and East shrimps (those in the West are larger) have been noted by other authors (Arena, 1985) but it has been difficult to support an hypothesis of "more than one stock" because of the limited time series of comparable data. At present, the catch per hour in experimental surveys is around 3 kg/h, with peaks at 9 kg/h. It is worth noting that the literature shows a decreasing trend: 25 kg/h in the early '60s, 8 kg/h in 1972, 5 kg/h 10 years ago.

The vertical distribution, again from experimental surveys, ranges from depths of 400 m up to at least 820 m. The giant red shrimp is distributed in a wide depth range (300-1000 m) but shows a marked preference for (or a higher vulnerability to trawling on) muddy bottoms located between 500 m and 750 m; larger catches are reported to occur especially where narrow depressions or canyons notch the sea-bed. The lower bathymetric limit for this species is probably deeper than 1000 m, but trawling at these depth is technically difficult and unprofitable because the small number of shrimps captured at those depths is not adequately compensated by the increase in individual size. The giant red shrimp probably migrates vertically (they are almost exclusively trawled during daylight hours), and seem not to be limited to a specific type of soft bottom. For example, they are often captured along with the burrowing Norway lobster (*Nephrops norvegicus*). However, the giant red shrimp supposedly prefers the temperature of the so called "Eastern water" (13.5°C), an intermediate stratum of warm and salty water which originates in the Eastern Mediterranean Sea and flows towards the Strait of Gibraltar (Ghidalia and Bourgois, 1961; Bombace and Sarà, 1972).

Tunisia

Over the Sentinelle bank the relative abundance is nearly 80%-20%, at La Galite 50%-50% and between Morocco and Algeria nearly 0-100%, respectively for *Aristaeomorpha foliacea* and *Aristeus antennatus* (Ben Mariem, 1994). Between the Sisters' Rocks (off Tabarka) and the Skerki Channel, trawl surveys carried out in 1959-61 and 1980 showed a catch of *Aristaeomorpha foliacea* from 8 kg/h to 25 kg/h. Moreover, the yield is made of large animals, indicating a good fishery potential for this area. From Skerki to the Pantelleria channel, *Aristaeomorpha foliacea* catches are consistent only below 600 m, thus showing a bathymetric distribution deeper than that of the previous zone; the yield ranges 10-15 kg/h, showing again an interesting fishery potential.

Ionian Sea

Minimum and maximum carapace length were 16 mm and 72 mm in *Aristaeomorpha foliacea* females; males ranged from 16 mm to 51 mm CL (D'Onghia *et al.*, 1994). The modal components in *Aristaeomorpha foliacea* were clearly distinct; no more than two modes were exhibited in the size composition of males. Very small individuals were observed in almost every survey, with periods of recruitment restricted for *Aristaeomorpha foliacea* (contrary to the rather continuous for *Aristeus antennatus*).

Females at stages III and IV and specimens with spermatophores on the thelycum were mainly found in spring. During this season, the presence of spermatophores seemed to be rather uniformly spread over the sampled length range of both species. Mature females were observed in size classes larger than 34 mm CL in *Aristaeomorpha foliacea*; in autumn, spermatophores were observed only on females larger than 40 mm CL. A high percentage of mature males was fished in each survey. The smallest fully mature individual and the size at first maturity were (but these values change during the reproductive season of the species): *Aristaeomorpha foliacea* females 35 mm and 39 mm CL, males 27 mm and 29 mm CL. The growth parameters estimates for *Aristaeomorpha foliacea* females are: $CL_\infty = 74.18$ mm with k/year= 0.503 and $t_0 = 0.086$ year. Specimens

smaller than 20 mm CL, observed in every season, made up a very small fraction of the whole catch (less than 5% on average).

Aristeus antennatus is the main target species and is more abundant than *Aristaeomorpha foliacea*, the proportion in numbers is about 13.5%-86.5% (Matarrese *et al.*, 1994). A total annual landing of 236 t for "red shrimps" (both species), relating to 1982, is reported in the whole area (*Aristeus antennatus* has been estimated at 101 t in the Southern area, between Crotone and Capo Spartivento). Two zones exist where fishing on *Aristeus antennatus* and *Aristaeomorpha foliacea* is carried out: one on the North between Taranto and Gallipoli (Apulian coast) and the other, a wider zone, in the South between Cariati and Capo Spartivento (Calabrian coast). In the first zone the trawlers which work on red shrimps grounds are about 25, ranging from 8 tonnes to 44 tonnes: their preferential fishing period is July-September. In the Southern area there are about 50 units which make up two different groups of trawlers: one, constituted by 30 small vessels, operates by daily fishing, while the other, composed of approximately 20 larger units (up to 90 tonnes), makes longer trips to more distant grounds; along the Calabrian coast the preferential fishing period for red shrimps is January-July.

The hourly catches of both species exhibited very high change in each survey: these ranged from zero to 16.2 kg/h for *Aristeus antennatus* and from zero to 4.6 kg/h for *Aristaeomorpha foliacea*. However, the majority of hauls presented zero values of yield, and catches greater than 4 kg/h and 1 kg/h, for *Aristeus antennatus* and *Aristaeomorpha foliacea* respectively, were rather rare. This fact confirms an aggregate distribution of the species in the area. However, across the Ionian Sea there are zones, deeper than 400 m, where *Aristeus antennatus* and *Aristaeomorpha foliacea* were never caught during the study and some others never exploited commercially because of the very soft muddy bottoms not suitable for fishing. The catch mostly consisted of *Aristeus antennatus,* which represented 73.5% in weight; the yield of *Aristaeomorpha foliacea* was greater only during April-May 1987. The largest catches of both species were generally in spring, confirming observation from landings in the Crotone fishery.

Eastern Sicily

Aristaeomorpha foliacea is the less common and less abundant of the two species, being the average catch very low, at a maximum of 0.66 kg/h (Pipitone & Andaloro, 1994). Specimens are caught at depths of 145-680 m, being the highest occurrence between 400-700 m; the depth range along the Eastern coast of Sicily seems broader than usually reported: this is probably due to the steepness of the bottom and to the presence of submarine canyons, which are likely to facilitate the vertical displacements of benthopelagic species. *Aristaeomorpha foliacea* sizes ranged 28-45 mm CL for males and 16-65 mm CL for females.

Eastern Mediterranean Sea

In Greece *Aristaeomorpha foliacea* has been reported from the Aegean Sea in general and from the North Euboikos Gulf, at a station where also *Aristeus antennatus* is present at a depth of 140 m from muddy bottom; the species has also been reported all around Crete (Thessalou-Legaki, 1994).

Old, "historical" data report the shrimp in southwestern Turkey at 1242 m and off Egypt at 725 m. *Aristaeomorpha foliacea* is also reported from Larnaca Bay in Cyprus.

In Israel, *Aristaeomorpha foliacea* is characterized as commercial and reported in the same localities and depths as *Aristeus antennatus*. The species is found on muddy grounds along the Mediterranean coast of Israel deeper than 300 m: it is fished in the Haifa area throughout the year in the 70-80 m depth range on the edge of a submarine canyon, where it is caught only in the middle of the night from 22:00 to 03:00. The annual catch is around 20 t, and during winter and spring (December-April) the catch is greater (5-30 kg/h) than during May to November.

Where do larvae live and what are they like?

Females of red shrimps release their eggs directly into the sea. A demersal laying of the eggs was considered as an hypothesis by Heldt (1955) according to the lack of nauplii at the surface. Eggs hatch as nauplius, but some differences exist between the two species. Larvae and postlarvae distribution pattern are to a large extent still unknown in deep-water shrimps (Arrobas and Ribeiro Cascalho, 1987; Sardà *et al.*, 1993). Systematic research of aristeid larvae have had been carried on by Madame Heldt (1955); after some unsuccessful attempts, she was able to collect, using a plankton net hauled in horizontal direction, 15 and 37 larval stages for *Aristaeomorpha foliacea* and *Aristeus antennatus* respectively, around the Balearic Islands, in September. Heldt's description of the first four larval stages of *Aristaeomorpha foliacea* (Fig. 95) and *Aristeus antennatus* (Protozoea I, II and III and Mysis I) remains till now the only reference to these species (Pessani and Robotti, 1992).

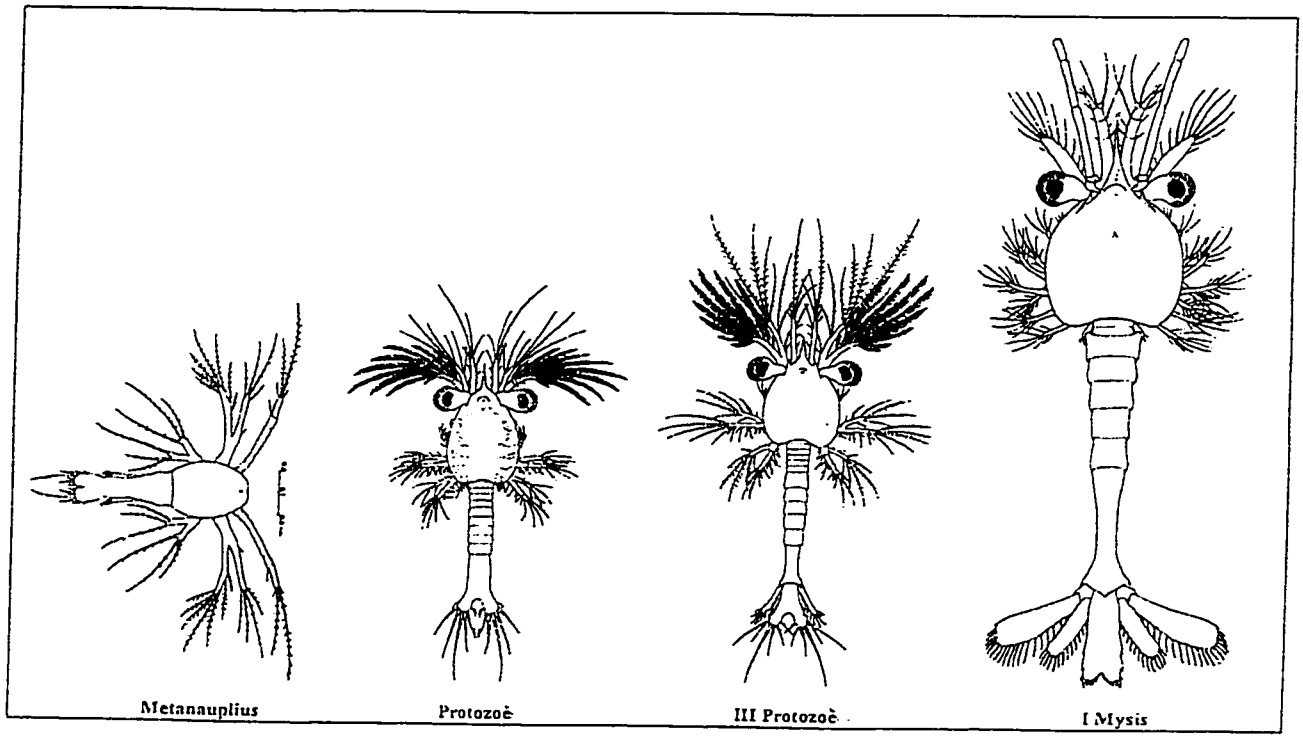


Fig. 95 - Larval stages of *Aristaeomorpha foliacea* (from Heldt, 1955).

The larvae of *Aristaeomorpha foliacea* and *Aristeus antennatus* present the following common characters: the presence of the 3rd maxilliped (Protozoea I), the lack of spines on the 1st, 2nd, 3rd ,4th and 5th abdominal segment and a rudimentary or null development of the 4th and 5th pair of pleopods (Protozoea III and Mysis I).

Beside the larger size and darker red colour of the *Aristeus antennatus* larvae compared to those of *Aristeus antennatus*, the main distinctive features were: at Protozoea II and III, the forward projecting of the anterior part of the carapace, which was absent in *Aristeus antennatus*, the different *furca* and the relative length of antennae (A1 shorter than A2 in *Aristeus antennatus*); at the Protozoea III, the uropod length (smaller in *Aristeus antennatus*); at the Mysis, the spination patter (presence of pterigistomian spines in *Aristeus antennatus*), the relative length of the A2 endopodite (longer than the exopodite in *Aristaeomorpha foliacea*) and, finally, the shape of the telson.

As previously quoted, Madame Heldt was not able to catch any larva, by applying collectors directly to the commercial bottom trawl; she thought that the occurrence of the larvae collected at the surface might have been a consequence of the presence, around the Balearic Islands, of ascensional currents of water which could have been able to carry the larvae hatched in deep water to the surface layers. Besides the masterpiece work done by Madame Heldt, very limited information is available on red shrimps larvae. Some sporadic quotation can be found in literature: for example, Kurian, cited by Karlovac (1959), reported one larva of *Aristaeomorpha foliacea*, caught in the lower Adriatic Sea, in December, close to Mljet island. The capture of other few larvae of *Aristeus antennatus*, always pelagic, collected in July and September, is reported by Sardà (1986).

Assuming that larvae spend most of their time as epipelagic plankton, it is likely that the duration of this delicate phase of the life might be inversely correlated to the surface temperature which would lead to an hastened development (Arrobas and Ribeiro Cascalho, 1987). Larvae are passively transported by the currents and it is likely that bad (for the shrimp) hydrological conditions could affect occurrence and abundance of postlarvae. A such effect has been advocated to explain the fluctuation in the abundance of the stocks of red shrimps (Orsi Relini and Relini, 1987; Martínez-Baños *et al.*, 1991).

Where do the adults live?

Although some degree of geographical variation can be detected, it is evident that *Aristeus antennatus* and *Aristaeomorpha foliacea* occur preferentially in the upper level of the mesobathyal "horizon" (400-800 m). This sub-zone represents the richest, most diversified and the best documented among the three subzones in which is commonly divided the bathyal plane (Pérès, 1985).

Seasonal (but not truly "migratory") and nictemeral (day-based) movements, resulting in variable distribution patterns of these species, have been widely described and documented in the literature. Inter-years variation has also been reported (see below and also the fishery section) affecting one or the two species combined.

Table 75 - Decline of red shrimps catches in the central-eastern Ligurian Sea. (rare = few specimens/day/trawler) (modified from Relini and Orsi Relini, 1987).

Depth (m)		1930-1940	1946-1955	1956-1973	1976-1980	1981-1984	1985-1994
200 300 400	Epibathyal level	*A. antennatus* + *A. foliacea*	*A. antennatus* + *A. foliacea*	scarce *A. antennatus* + *A. foliacea*	rare *A. antennatus* + rare *A. foliacea*	rare *A. foliacea*	rare *A. foliacea*
500 600 700 800	Mesobathyal level	(no fishing activity)	(no fishing activity)	*A. antennatus* + rare *A. foliacea*	*A. antennatus* + rare *A. foliacea*	rare or absent *A. antennatus* + rare *A. foliacea*	explosive frequency *A. antennatus* + rare *A. foliacea*
Catch/day/trawler		100-200 kg	100-400 kg (up to 1000 kg)	0-50 kg (up to 100 kg)	0-30 kg (up to 100 kg)	_	commercial interesting

Either one of the species might change abruptly its distribution and abundance in localized areas where a period of lacking can last for many years before the return, more or less sudden, without any evident explanation. The most famous case study concerns

the red shrimp fisheries in the Ligurian Sea (Relini and Orsi Relini, 1985; 1987), whose evolution in time is summarized in Table 75.

Both species, which did constitute flourishing stocks (Brian, 1939; 1942; Relini Orsi, 1973) at epibathyal (from 1930 to 1955) and mesobathyal (from the '50s onwards) levels, changed their relative dominance (*Aristeus antennatus* became more abundant than *Aristaeomorpha foliacea*), collapsed at the middle of the '80s, showing some sign of recovery in the last years (after 1990) and limited to the *Aristeus antennatus* (Relini *et al.*, 1993; Orsi Relini and Relini, pers. com.). Different factors such as overfishing, environmental decay, unfavorable hydrological conditions, predation pressure on juveniles and diseases were taken in consideration by Relini and Orsi Relini, (1985; 1987) who did not find any definitive correlation with the observed evolution of the red shrimps populations. Analogous cases, even not so well studied as the previous one, were identifiable in the specific literature. Demestre (1990) wrote about a reduction in the abundance of *Aristeus antennatus* off the Catalan coasts but not so dramatic as in the Ligurian Sea. For the same area, Martin (1989) has evidenced a periodicity of 10 years in the abundance evolution of the *Aristeus antennatus* fisheries. Another example is the recent disappearance of *Aristaeomorpha foliacea* off the coasts of the Gulf of Lion (Campillo *et al.*, 1990), where the species has been previously reported as quite common (Maurin, 1962), or the occurrence of *Aristeus antennatus* (even though in small quantities) in the Eastern sector of the Strait of Sicily (Ragonese and Bianchini, 1992), where the species was not expected at least at that depth range (Bombace and Sarà, 1972).

Along the Northern coasts of Sicily, *Aristeus antennatus* is actually the dominant species (AA.VV., 1990) while *Aristaeomorpha foliacea* was the preeminent species (7:1 in the Gulf of Patti) in the 70s (Arena and Bombace, 1970; GFCM, 1970). Furthermore, both species were reported by fishermen as quite abundant in the deep areas of the Adriatic Sea; at the end of the '70s, very low yields of these species were reported (Scaccini *et al.*, 1970) whereas at present they have almost disappeared from that sea (Holthuis, 1987).

That marine populations of fish and other organisms fluctuate according to different patterns is a well known and documented phenomenon (Caddy and Gulland, 1983; Laevastu and Favorite, 1988). In the case of red shrimps however, the limited historical series of data and the typical lack of statistical catch-and-effort data do not allow to check if the phenomenon follows any cyclic (as suggested by Martin, 1989) or chaotic pattern or if it can be directly connected to the exploitation regime. At the present, none of the explanations which have been advocated can be considered to be fully satisfactory (see below). Fishers usually talk about an alternance of "good" and "bad" years as concerning catches, but the periodicity is far to be constant; for example, one every two years seems the rule in the Gulf of Castellammare (Arculeo, pers. com.) while 2-3 years of good catches were indicated by the Southern Sicily trawl fishers. Since the exploitable life span of these stocks can be generally estimated in 2-3 years, periodicity of less than this period could be ascribable to other factors than recruitment success, for example, changes in the distribution of adults as a consequence of hydrological events (see also the fishing section).

Where *Aristaeomorpha foliacea* and *Aristeus antennatus* come from?

According to different authorities (i.e., Barnard, 1950; Hall, 1964; Carpine, 1970) both *Aristaeomorpha foliacea* and *Aristeus antennatus* populations in the Mediterranean Sea immigrated from the Atlantic warm waters.

What factors do affect or control the movements of red shrimps?

As previously stated both red shrimps species represent a characteristic component of the bathyal facies of the macrofauna of soft-compact mud, originally colonized by the invertebrate *Isidella elongata* (the so called "*Isidella* bottoms"; Pérès, 1985). *Isidella* is a large-sized articulate gorgonian, which requires a firm substrate underlying the mud to which anchor itself (Pérès, 1982). The abundance of this animal,

once forming wide and dense beds or "prairies" over the muddy bottoms, has been strongly depressed as a consequence of the intense trawling (see the fishery part in this section). The drastic depauperation of the beds of *Isidella*, however, does not seems to have influenced the red shrimps (cf. Arena and Li Greci , 1972).

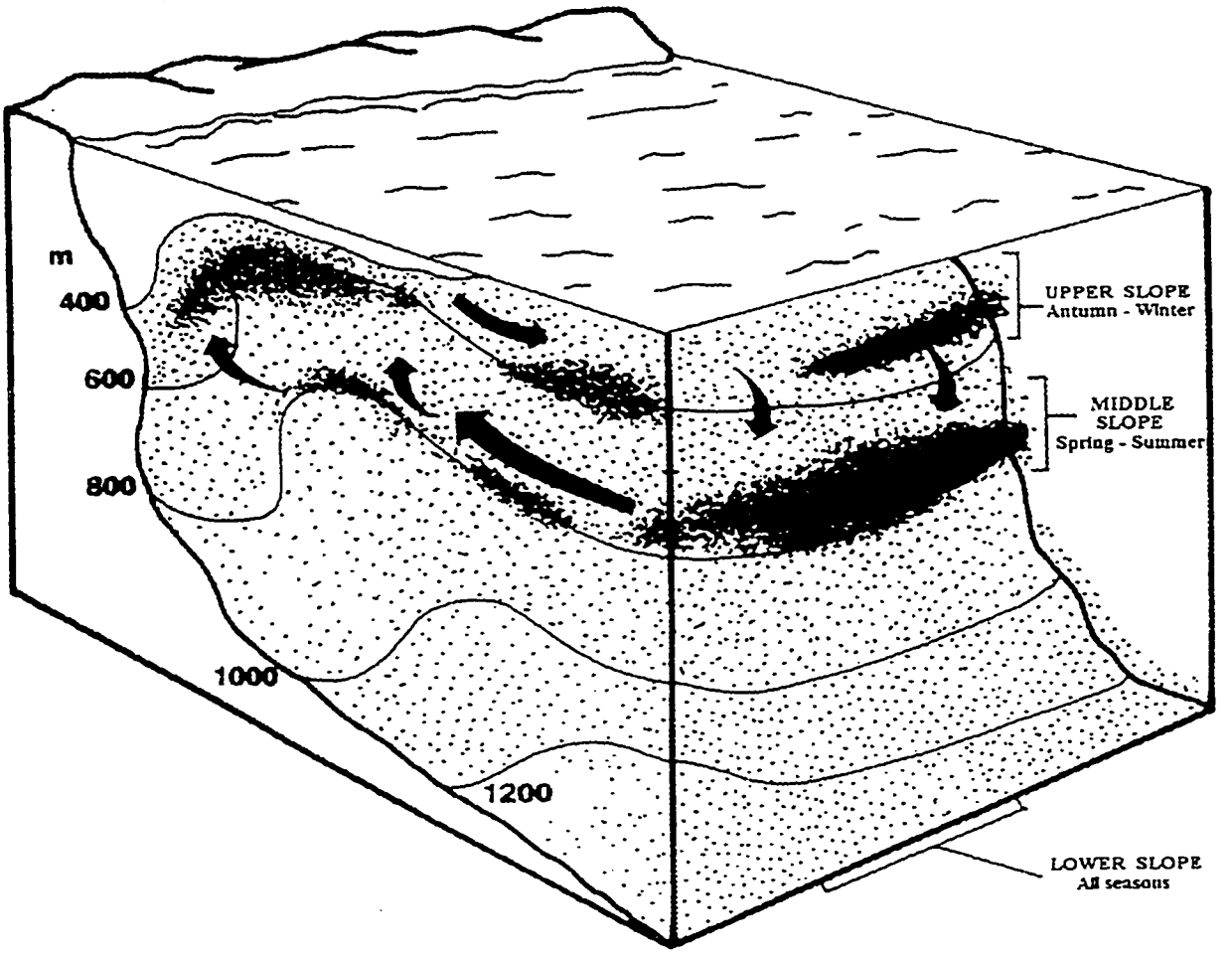


Fig. 96 - The distribution pattern of *Aristeus antennatus* according to Sardà *et al.* (1993).

Both *Aristeus antennatus* and *Aristaeomorpha foliacea* species are able to carry out wide horizontal and vertical displacements (Lagardère, 1971/72; Orsi-Relini and Relini, 1986), especially where the slope is steeper (Maurin, 1962). These movements, however, can be ascribed neither to true migration nor to reproductive or feeding

exigencies which never have been reported for these species. *Aristeus antennatus* and *Aristaeomorpha foliacea* tend to concentrate (Fig. 96) and to shoal, or become more available to the gear, during mating and spawning (cf. Wadley, 1992; Sardà *et al.*, 1993). They are also more aggregated at the bottom and more available (or vulnerable) to the trawl during daylight (or full moon) and thereafter tend to disperse up in the column of water during the night (Maurin, 1960; Arena and Li Greci, 1973; Orsi Relini and Relini, 1979; Demestre, 1990).

It must be pointed out that red shrimps are not strictly benthic animals and that they normally inhabit the water layer close to the bottom (Figueiredo, 1989), being able to swim along the water column, as also demonstrated by the successful use of mid-water trawls (Graham and Gorman, 1985).

Why these shrimps show this behaviour? The different facies of the bathyal mud are largely correlated with the firmness and compactness of the substrata (Pérès and Picard, 1964); consequently, a key-role of the substratum in explaining the occurrence of red shrimps has been repeatedly assumed by different authors (Brian, 1939; Maurin, 1962; Sarà, 1969). Effectively, the above assumption was supported tautologically by the available data itself, because trawls were (and still are) the elective gears to capture these animals and deep trawling operates only on suitable muddy bottoms.

Furthermore, the first stomach content analyses assessed a preeminent role of the substrata, having revealed the presence, among other items (see the feeding section), of remains of benthic organisms; one of this was the sea cucumber (holothurians) *Synapta*, which lives in the soft-mud bottoms but not in those with a larger detritus or sand component. Maurin (1962; 1965) evidenced that red shrimps were generally not caught (apparently lacking) on even typical mesobathyal, bottoms but colonized by the sestonophagous sea star *Brisingella coronata*. This invertebrate (Fig. 97) is a large-size (up to 70 cm) asteroid with a variable number (9-12) of erected and bent arms, red colored, inhabiting the sandy-muddy bottoms of the Mediterranean and Atlantic Sea, being quite common in the upper sub-zone (Pérès, 1985).

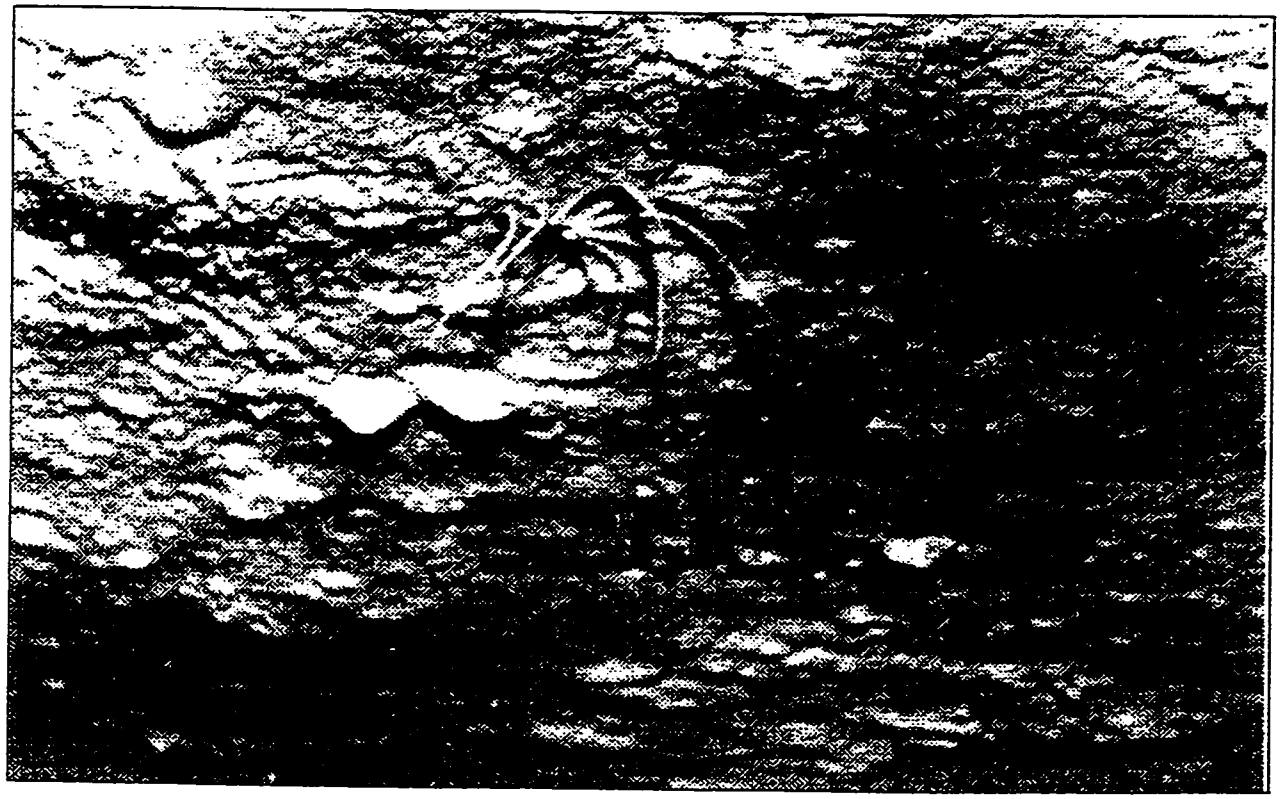


Fig. 97 - The sea star *Brisingella coronata.*

The main role of the substratum in controlling the distribution pattern of red shrimps was put in discussion when the respective occurrence of the two species in the catches was analyzed taking into account the different geographical locations. It was evident that, at least in the Mediterranean Sea, red shrimps were caught in a different fashion (one prevalent on the other or both species being more or less equally represented) according to the characteristics of the water instead of the bottoms. The two species showed a different even subtle preference, mainly for temperature (close to 12.8°C for *Aristeus antennatus* and 13.5°C for *Aristaeomorpha foliacea*) and less for salinity (38.4 ppt for *Aristeus antennatus* and 38.5 ppt for *Aristaeomorpha foliacea*). A similar explanation of why *Aristeus antennatus* were caught in other places than *Aristaeomorpha foliacea* in the Ligurian Sea had already been given to Brian by fishers in the middle of the '40s (Brian, 1942).

Such correlation between deep-water shrimps occurrence and hydrological characteristics of the water body was pioneered by the classic paper of Ghidalia and Bourgois (1961); these authors attempted a different interpretation of the distribution pattern of red shrimps by comparing the information available for the different areas of the Mediterranean and Eastern Atlantic and proposed the so-called "hydrological hypothesis".

By considering that no proofs existed about the rooting habits of red shrimps (such the case for other peneids, e.g. *Penaeus kerathurus* or *Parapenaeus longirostris*), Ghidalia and Bourgois come to the conclusion that the distribution and abundance of *Aristeus antennatus* and *Aristaeomorpha foliacea*, at least in the Atlantic-Mediterranean area, was mainly linked to the hydrological structure of the water masses in each specific sub-area. *Aristeus antennatus* would have preferred the deeper (or bottom) waters, colder and less saline than the Eastern or Levantine (or intermediate) water; the latter were preferred instead by *Aristaeomorpha foliacea*. The reported occurrence of *Aristeus antennatus* at upper level (at about 200 m) were explained with the special similarity of halothermic conditions of the upper Northern water and the bottoms ones during the winter (Ghidalia and Bourgois, 1961; Arena and Bombace, 1970; Bombace and Sarà, 1972; see Fig. 98).

These different kinds of waters, in conformity to the classic model of water circulation in the Mediterranean sea (see the "Area description" section), were considered as layers of waters flowing each over the other (the first two in opposite direction) and forming a sort of stratified "hydrological levels" each of which, touching the bottoms, may have drastic influence on the faunistic assemblages. The above mentioned three-layer stratification would roughly correspond to the three horizons, not well definable indeed, recognized for the bathyal plane (Pérès and Picard, 1964; Bombace and Sarà., 1972; Pérès, 1982; 1985), i.e. the upper, middle and lower slope (Sardà *et al.*, 1993). A change in the depth boundaries between the hydrological strata, as a consequence of the seasons or special features in the bottom or coastal orography, would have resulted in a change in the red shrimp distribution pattern.

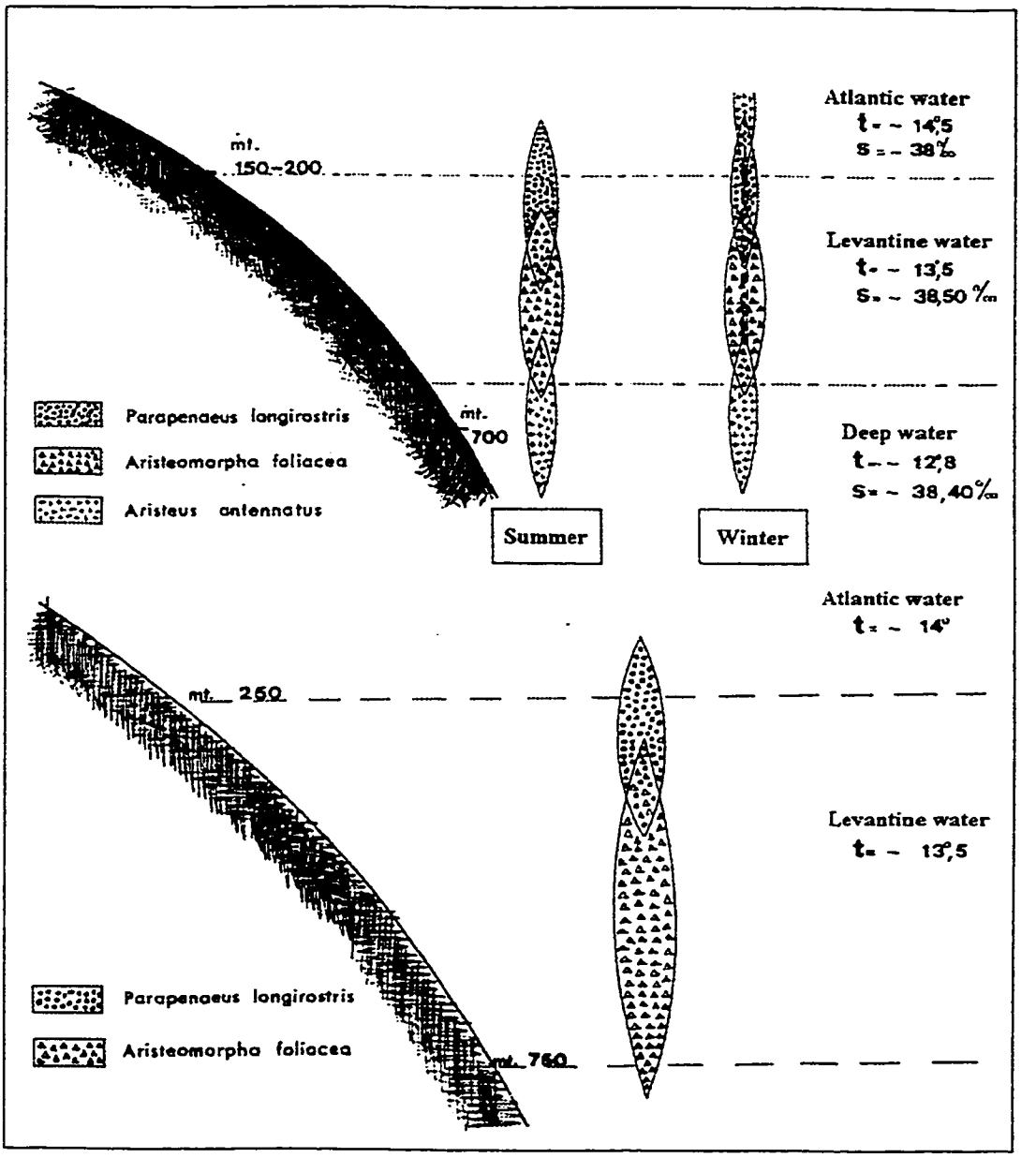


Fig. 98 - The distribution pattern of the deep water shrimps in the Sicilian waters according to the hydrological hypothesis (from Bombace and Sarà, 1972). Top: Northern Coasts of Sicily; bottom: Sicilian Channel (East of Pantelleria).

The above considerations were proposed to explain why *Aristaeomorpha foliacea* was sometimes found first, in respect to *Aristeus antennatus*, living at the greatest or lowest depth and sometimes the contrary happened (Ghidalia and Bourgois, 1961) or why

in some areas one species is almost dominant or exclusive (Bombace and Sarà , 1972). The hypothesis is amazing but it is not completely sustainable and still not directly supported. First of all, the water circulation pattern in the Mediterranean Sea seems to be quite more complex than previously believed, as suggested by recent modelling (see Appendix B). Furthermore, the analysis of the evolution in the hydrology in the Ligurian Sea, in relation to change in red shrimps distribution patterns (Relini and Orsi-Relini, 1987), led to the conclusion that a more meandering flow of water masses, complicated by ever-changing eddies, represents an unstable environment sometimes unfavorable to some aspect of life cycle of red shrimps. The changes in the current pattern might have affected the transport of eggs and larvae, but no evidence was found of a direct linkage between red shrimps and the hydrological conditions (Relini and Orsi Relini, 1987).

In the Mediterranean Sea, *Aristeus antennatus* and *Aristaeomorpha foliacea* were also reported as common occurrences over the bathyal bottoms off Israel and in the Eastern basin where the water is warmer (14-16°C) and saltier (39 ppt) than in the Western basins (Oren *et al.*, 1971). According to the "hydrological hypothesis", *Aristeus antennatus* could have never been caught in such "Eastern" waters.

The detection around Sardinia (Cau, 1992) of a cline in the distribution of the two red shrimps with *Aristaeomorpha foliacea* decreasing in a South-North direction, could be interpreted according to the hydrological hypothesis; in fact, a branch of intermediate water (IW) flows Northwards after having left the Strait of Sicily (see Appendix B). However, the same branch of IW keeps going in a North-West direction, influencing the coasts of France and Spain where *Aristaeomorpha foliacea* is almost absent.

Finally, both red shrimps are caught in oceanic waters whose temperature and saline content are lower than the Mediterranean Sea (down to 7-10°C and less than 35 ppt) but at the a very similar depth range (mainly between 400-800m); such is the case for *Aristeus antennatus* off Congo (Bianchi, 1992), and *Aristaeomorpha foliacea* in the Indian (8°-11°C the optimum range; Dietrich, 1987) and Pacific (Wadley, 1992) oceans.

Direct (bathyscaph and "ROV"; Pérès, 1982; Fredj, pers. com.) and indirect (day-night comparison of catches (Maurin, 1960; Sarà, 1969; Sardà *et al.*, 1993) have

already indicated that the physical habitat of these species might be more structured and complex than previously believed. The two species tend to aggregate within the trenches and canyons which notch the bottoms of the upper slope, along the steep sides of the sea mountains (guyots) and along the slope of the middle and, at least for *Aristeus antennatus*, lower sub-zones (Sardà *et al.*, 1993) apparently showing specific (Pérès, 1982) but different preferences according the locations (Massuti, 1959).

Particularly, there are differences between inside and outside the canyons and top and bottom; Pérès (1982) found *Aristeus antennatus* associated with *Funiculina quadrangularis*, a large sea pen which usually prefers the muddy bottoms above 400 m (Maurin, 1962) in the upper sub-zone, inside a canyons at a depth unusual for *Funiculina.* According to Massuti (1959), however, *Aristaeomorpha foliacea* was believed to live inside whereas *Aristeus antennatus* occurred outside.

Searching for food (Lagardère, 1971/72; Rainer, 1992) was considered the main explanation for nictemeral movements, whereas adaptation to hydrological change of different body masses of water and different phototropic reactions have been proposed for the seasonal displacements. Detailed diet studies (see the "Feeding" section) and more controlled observations on day-night catch variations (Cartes *et al.*, 1993) have confirmed that the distribution pattern of red shrimps, and consequently their behaviour, is the result of a complex and still not well understood interaction of many different environmental and biological factors; for example the above mentioned authors found highest abundance of *Aristeus antennatus* at nighttime inside a canyon while the opposite situation was observed during daytime.

The above conclusion must not surprise since the bathyal assemblages in the Mediterranean show an high heterogeneity as a consequence of the orography which determines local turbulence; besides the nature of the substratum (Pérès, 1985), the distribution of the bathyal species seems also to be strongly influenced by the current patterns which transport food particles, especially for detritus feeders and limivorous macrobenthic animals (Pérès, 1982).

In order to attempt a discrimination between the supposed different facies in the bathyal populations, some "transitional depth boundaries" have been identified (around 400 m, 1,200-1,400 m and 1,900-2,000 m: Carpine, 1970; MacPherson , 1991; Cartes and Sardà, 1992; Sardà and Cartes, 1993) but the true consistence of these more or less subjective limits is not well understood (Pérès, 1982); on the contrary it is confirmed the role of submarine canyons as points of high energy and biomass levels (Cartes, 1991; Sardà *et al.*, 1993).

Again, it is full of difficulty to apply to red shrimps ecological generalization such as the phenomena of shifting in depth preference according to the geographical area, the "Ekman's sub-emergence" or the "equatorial emergence" observed by Burukowsky (1989) in the distribution of shrimps of the tropical Eastern Atlantic. Practically, according to the sub-emergence hypothesis, we could expect a deeper occurrence of red shrimps in the Mediterranean than in the Atlantic as a consequence of their preference for cold water (which is found deeper in the Mediterranean Sea); however, as previously stated, red shrimps also occur above the continental shelf (*Aristeus antennatus*), and in warmer waters (*Aristeus antennatus* and *Aristaeomorpha foliacea*).

Some evidences tend to indicate in the dissolved oxygen concentration one of the factor influencing both occurrence and abundance of red shrimps (Bianchi, 1992; and pers. com.); this cannot be the case for the Mediterranean Sea, where the O_2 is high throughout even if it decreases with depth (see the "Area Description" section).

Light irradiance and penetration in the sea could play an important role in influencing both distribution and catchability pattern in red shrimps (i.e., some light threshold); the hypothesis that both quality and intensity of the light into the sea could be an important environmental factor (see also the "Reproduction" session) was already supposed by Ghidalia and Bourgois (1961). These authors put in evidence the correlation between size and depth and linked this observation to a positive phototrophic response in juveniles. It has previously been cited the general trend of higher catches during daytime even though some exceptions are reported (for example, Arrobas and Ribeiro Cascalho, 1987). Sardà and Demestre (1987) found some positive correlation between the moon

cycle and the capturability of *Aristeus antennatus* (i.e., higher yields with full moon, a phenomenon well known to fishers). Recent data, however show that small-size animals also occur in deep waters, as an adaptative response to the typical paucity of food and lower predation pressure at the lowest bathyal levels (Sardà *et al.*, 1993).

Tobar and Sardà (1993) have demonstrated that maximum values in the catch (and catchability or availability) correspond to a specific time (0-2 h from sunrise), indicating a light threshold below which *Aristeus antennatus* changes its behaviour. The causes are not known, but the authors thought they might be related to bottom hugging or predation defense behaviour.

In conclusion, even if an unifying hypothesis is lacking, the present level of knowledge suggests that both *Aristaeomorpha foliacea* and *Aristeus antennatus* are eurybathic species which show an opportunistic behaviour also in respect to other environmental factors such as salinity, light, oxygen, and nature of bottoms. *Aristeus antennatus* seems more linked to the substratum than *Aristaeomorpha foliacea*, at least on the basis of frequency of benthic preys. It is likely that these species are able to expand their areale by colonizing (or recolonizing) different zones when food and general condition are favorable, contracting to more delimited preferential habitats when unfavorable conditions exists.

Size and morphometry

Different body measures have been used for these prawns and the most important are presented in Fig. 99 (see Ragonese *et al.*, 1994, for reference): a) total body length, from the tip of the rostrum to the extremity of the telson, recorded on the "gently" stretched animal (Holthuis, 1980; Arena, 1985), herein "TL"; b) total "curvilinear" length, i.e. following the natural shape of the dead animals (Balestra *et al.*, 1975; Balestra *et al.*, 1975); c) body length or "ocular" length, practically TL minus the rostrum length, being the distance from the sockeye margin to the extremity of the telson (hereby OL); and d) the oblique carapace length (OCL, hereby CL), from the inner margin of the sockeye to the posterior median hinge of the carapace.

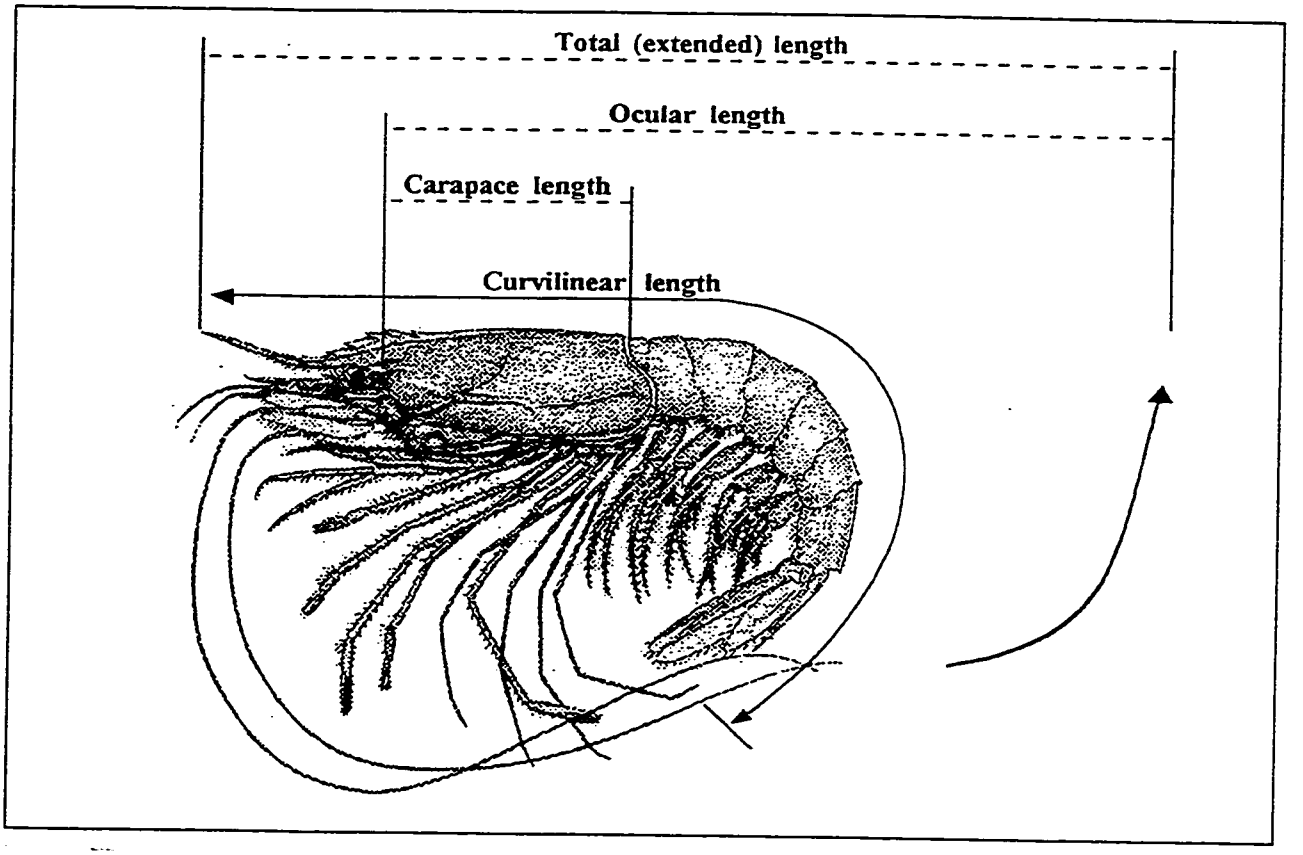


Fig. 99 - Different body measures used in red shrimps.

The use of TL is generally discouraged since the frequent occurrence of specimens with damaged rostrum (Mayrat, 1964) and because it is considered inaccurate due to the curvature of the body (Holthuis, 1980). Another difficulty in using TL derives from the drastic change in the rostrum length in males (Fig. 100); however, in this case, the analysis of carapace length *vs.* rostrum length can give useful information about the maturative processes. In males the relationship changes drastically (rostrum length is reduced) in the size class where the transition from immature to mature condition occurs. Data on *Aristaeomorpha foliacea* of the Strait of Sicily (Ragonese *et al.*, 1994) suggest that the main difference concerns the intercept but not the slope of the relationship (Table 76).

Table 76 - Morphometric estimates for *Aristaeomorpha foliacea* (modified from Ragonese *et al.*, 1997).

F	TOTAL *vs.* CARAPACE LENGTH									
	Model	N	a	S.e. a	b	S.e. b	r2	I	N-test	R-test
E	**Linear**	349	38.842	1.0532	3.355	0.0271	0.978	5.48	0.011	0.282
	Log linear	349	2.3763	0.0216	0.7546	0.0060	0.978	5.44	0.001	0.656
M	**Allometric**	349	10.695	0.2344	0.7566	0.0059	0.979	5.36	0.014	0.497
	OCULAR *vs.* CARAPACE LENGTH									
A	Model	N	a	S.e. a	b	S.e. b	r2	I	N-test	R-test
	Linear	393	20.413	0.5258	2.884	0.0133	0.992	2.95	0.068	0.843
L	**Log linear**	393	1.8389	0.0135	0.8343	0.00375	0.992	2.89	0.014	0.505
	Allometric	393	6.2345	0.0939	0.8367	0.0040	0.992	2.90	0.042	0.426
E	WEIGHT *vs.* CARAPACE LENGTH									
	Model	N	a	S.e. a	b	S.e. b	r2	I	N-test	R-test
S	**Log linear**	394	-6.6472	0.0427	2.6418	0.0118	0.992	1.24	0.655	0.381
	Allometric	394	0.001711	0.000187	2.5695	0.02868	0.986	1.90	< 0.001	0.206
	TOTAL *vs.* CARAPACE LENGTH									
	Model	N	a	S.e. a	b	S.e. b	r2	I	N-test	R-test
	Linear (1)	104	33.918	2.695	3.563	0.107	0.916	3.93	0.642	< 0.001
M	**Linear (0)**	111	16.125	4.090	3.568	0.115	0.898	3.38	1	< 0.001
	Log linear (1)	104	2.4997	0.07078	0.7188	0.02207	0.912	3.93	0.496	< 0.001
A	**Log linear (0)**	111	1.7856	0.1025	0.8897	0.02876	0.898	3.36	0.981	< 0.001
	Allometric (1)	104	11.920	0.8491	0.7257	0.02200	0.914	3.96	0.713	< 0.001
L	**Allometric (0)**	111	6.0121	0.6075	0.8875	0.02825	0.898	3.38	1	< 0.001
	OCULAR *vs.* CARAPACE LENGTH									
E	Model	N	a	S.e. a	b	S.e. b	r2	I	N-test	R-test
	Linear	241	6.2162	0.9059	3.509	0.02969	0.983	2.79	0.464	0.004
S	Log linear	241	1.5252	0.02611	0.9378	0.00772	0.984	2.74	0.278	0.008
	Allometric	241	4.5133	0.1454	0.9432	0.0093	0.983	2.80	0.456	0.008
	WEIGHT *vs.* CARAPACE LENGTH									
	Model	N	a	S.e. a	b	S.e. b	r2	I	N-test	R-test
	Log linear	241	-7.3681	0.06499	2.873	0.0192	0.989	0.64	0.525	0.220
	Allometric	241	0.000895	0.000084	2.774	0.0265	0.985	0.79	0.008	0.081

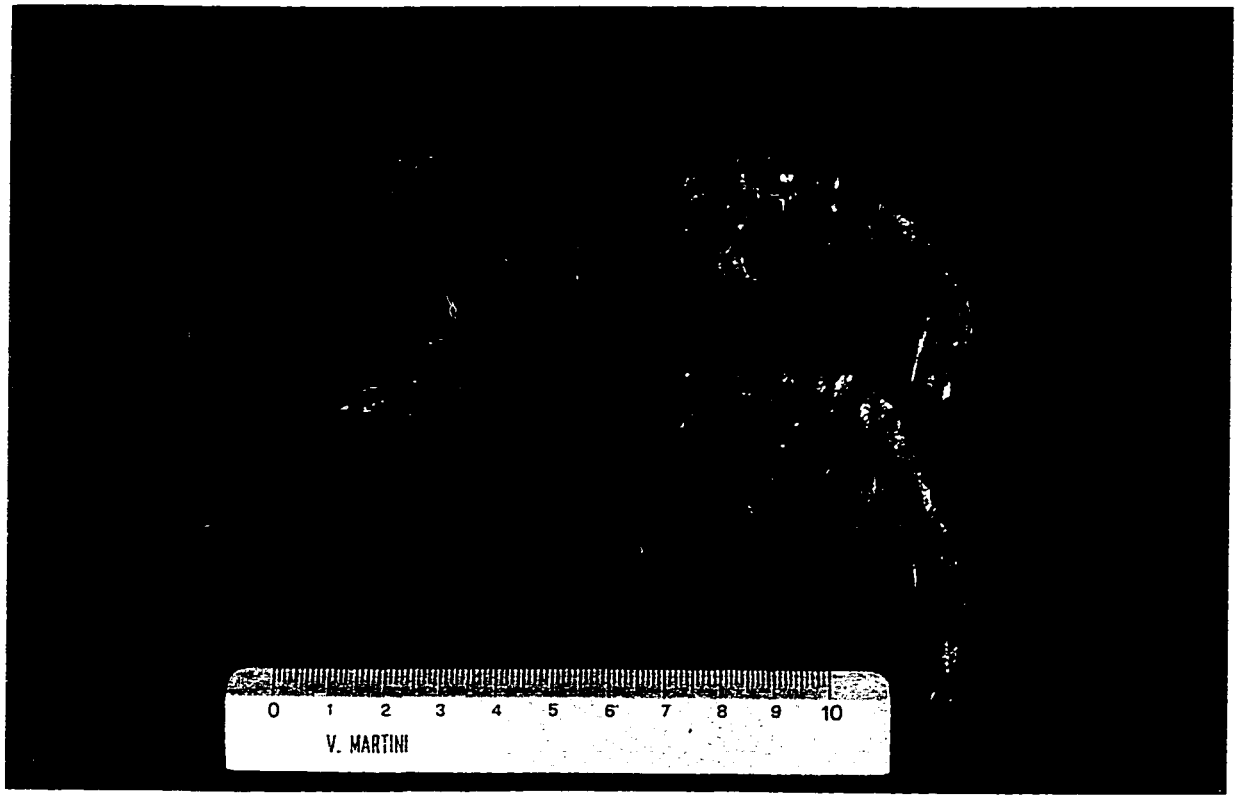


Fig. 100 - Sexual dimorphism in *Aristaeomorpha foliacea*. Adult males (bottom) shows a shorter rostrum than females (top).

The CL has been already suggested as the preferable measure for shrimps and prawns since many years (Mayrat, 1964; Holthuis, 1980; Frèchette and Parson, 1983) and nowadays it is the standard method to measure shrimps.

Although some geographical variation exists, the figures generally reported in literature suggest for *Aristaeomorpha foliacea* a maximum sizes range (CL) of about 70-80 mm and 40-45 mm for females and males respectively. For *Aristeus antennatus* the range is slight lower, both in females (65-70 mm) and in males (35-40 mm). The smallest fished specimens of both species fall in the range of 10-15 mm CL. Published morphometric relationships are summarized in Table 77. The most streaking feature is the

negative allometric relationship (b< 3) between weight and carapace length that resulted in all the different populations. Different length-length relationships, for example, curvilinear versus linear, have been used by different authors.

Table 77 - Morphometric data on red and violet shrimps. FEC indicates the fecundity.

SPECIES	SEX	VARIABLE Dependent	Independent	MODELTYPE	a	b	PLACE	AUTHOR
AA	F	TW	CL	Power	0.00264	2.466	Catalan Sea	Demestre (1990)
	M	"	"	"	0.00402	2.318		
AA	F	"	"	Power	0.0035	2.38	Valencia	Lleonart (1990)
	M	"	"	"	0.0053	2.25		
AA	F	"	"	Power	0.0018	2.58	Murcia	Martìnez-Baños
	M	"	"	"	0.0033	2.40		*et al.* (1988)
AA	F	"	"	Power	0.0023	2.49	Portugal	Ribeiro Cascalho
	M	"	"	"	0.0023	2.48		(1982)
AA	C	TW	CL	Logistic	-3.188	2.823	Sardinia	Cau, relations
	C	"	"	"	-2.662	2.495		triennium '85-'87
AF	C	"	"	Power	0.0074	2.134	Southern	Greco *et al.*
AA	C	"	"	"	0.0091	2.074	Tyrrhenian	(1988)
AF	F	TW	CL	Power	0.0009-0.0004	2.03-3.03	Central	Ardizzone
	M	"	"	"	0.002-0.0003	2.23-2.95	Tyrrhenian	*et al.* (1988)
	F	"	"	Power	0.00049	2.87	Central	AA.VV. (1988)
	M	"	"	"	0.00052	2.92	Tyrrhenian	
AA	F	FEC	CL	Power	0.0069	2.80		
	F	FEC	TW	"	6.459	1.10	Catalan Sea	Demestre (1990)
	F	FEC	OW	"	135.25	0.99		
AA	F+M	TW	TL	Power	0.06951	2.842	Catalan Sea	Bas (1965)
AA	F	TL	CL	Linear	33.89	2.46	Algeria	Yahiaoui *et al.* (1986)

Another interesting result was that Balestra *et al.* (1975) found a more proportional increment in height than length in the carapace of *Aristaeomorpha foliacea* whereas the opposite happens in *Aristeus antennatus* (Balestra *et al.*, 1975).

Food, feeding behaviour and trophic relationships

Brian (1931; 1945), by stomach contents analysis, considered both species as carnivorous and opportunistic animals. The author found a great heterogeneity of food items: from foraminifera to fish, crustaceans (including other decapods such as *Pasyphea* species), cephalopods (both decapods and octopus), echinoderms (crinoids and sea cucumbers), even vegetables remains such as pieces of leaves of the sea grass *Posidonia oceanica* or derived from terrestrial plant (Brian, 1931). Food items were found mixed with mud in the stomachs of both species and the author thought that these species were able to eat the food present over or inside the muddy bottom (detritivorous habit). By observing the occurrence of fish vertebrae and scales, Brian arrived to the conclusion that they were able to behave as scavenger too.

The euryphagic behaviour was successively supported and preferred, in respect to the carnivorous one, by different authors: Bas (1959) also found plates of the echinoderm *Synapta*, a sea cucumber which mainly inhabits soft muddy bottoms with low detrital component. Maurin and Carries (1968) reported the occurrence of sponges, crustacean, fish remains and plenty of foraminifera, supporting an opportunistic feeding behaviour.

The first comprehensive analysis of the feeding habits of red shrimps is due to Lagardère (1971/72); the author investigated the diet of shrimps living along the slope of Atlantic Morocco. The conclusions produced a different picture for the two species; *Aristaeomorpha foliacea* resulted to be an active predator, directly or indirectly, of benthopelagic decapods such as *Plesionika martia*, *Pasiphaea* sp. and *Meganyctiphanes norvegica*. *Aristaeomorpha foliacea* preyed upon these species mainly during the day (when the latter approach the bottom) reducing its activity during the night. *Plesionika* species resulted to be the most important prey and these species on their turn prey upon

euphasids and *Pasiphaea* sp., being day predators but able to integrate the diet with bottom detritus. The diet was not substantially different for males and females. The same author linked the feeding displacements to the theory of the "ladder trophic chain" of Vinogradov (1977). His most important conclusion was that *Aristaeomorpha foliacea* and *Plesiopenaeus edwardsianus* should be considered as predators at the third level and, as consequence, there may be some concern about their resilience to exploitation.

At similar results arrived a recent study of a population of *Aristaeomorpha foliacea* trawled in Eastern Australia (Rainer, 1992); the shrimps feed both on midwater (night) and demersal (day) preys mainly represented by crustacean (40%), foraminifera (15%), fish (8.1%), coelenterates (6.7%) and squids. In contrast to the conclusion of Lagardère (1971/72), *Aristaeomorpha foliacea* resulted to be both diurnal and nocturnal feeder. A nocturnal displacement along the water column was evidenced by comparing the day and night catches; catch rates by demersal trawl resulted to be up to 16.5 times higher during the day.

Also in the Mediterranean-Lusitanic area, *Aristaeomorpha foliacea* is nowadays reported as a preeminent carnivorous animal (Roper and Sweeney, 1981; Gristina *et al.*, 1992). In particular, Gristina *et al.* (1992) found pieces of leaves of the sea grass *Posidonia oceanica* and considered this occurrence as accidental; in the selectivity samples gathered in the present research, however, rest of vegetables (such rhizomes of *Posidonia* and leaves, still green, and brown algae, such *Cystoseira* sp.) were often observed in the codends. Although a mid-water capture cannot be excluded, these remains, likely carried by the strong currents, could represent an integrative source of vitamins in the red shrimps diet.

It must be pointed out that, as outlined in the description of the area, the prairies of *Posidonia oceanica* are extremely common and flourishing on the infralittoral bottoms (down to 30-40 m) of the continental shelf and of the so-called "banks".

The work of Lagardère (1971/72) dealt also with *Aristeus antennatus*, giving a different picture in respect to *Aristaeomorpha foliacea* but close to what previously supposed by Brian (1931; 1942) and later confirmed by other authors (Cartes and Sardà,

1989). *Aristeus antennatus* resulted to be an opportunistic random feeder, less active and slower in the movements than *Aristaeomorpha foliacea*. According to the frequency of benthic preys, *Aristeus antennatus* is more linked to the bottom where it is able to dig in search of bivalves, and macruran burrowing crustaceans (e.g. *Calocaris macandreae*). *Polycheles* sp., amphipods , ophiuroids, isopods, bony fish, Natantia decapods, and other minor categories mixed with mud, represent common items in the diet of *Aristeus antennatus* (Relini Orsi, 1973; Relini Orsi and Wurtz, 1979; Cartes and Sardà, 1989; Mura *et al.*, 1993). It must be pointed out that also in *Aristeus antennatus* stomachs rests of *Posidonia oceanica* can be found (Mura *et al.*, 1993).

Specifically speaking of *Aristaeomorpha foliacea* in the Sicilian Channel (Pipitone *et al.*, 1994), about 12% of the examined stomachs are empty. The highest percentage of empty stomachs (19%) is recorded in spring, the lowest (7%) in winter. Taking into account the seasons, the general trend shows that decapod crustaceans are always the most frequent preys ($50\% \leq F \leq 65\%$), followed by bony fishes ($39\% \leq F \leq 54\%$), unidentified crustaceans ($19\% \leq F \leq 52\%$) and cephalopods ($14\% \leq F \leq 23\%$). In particular, small *Pasiphaea sivado* are the most frequent item identified among decapods (up to $F = 13\%$ in summer), and macrurids among fishes (up to $F = 16\%$ in spring). Foraminifera occur in 16% (summer) to 68% (winter) of stomachs, always in very small amounts. The only prey items showing a strong seasonal occurrence are diphyid siphonophores ($F = 41\%$ in spring) and benthic gastropods ($F = 24\%$ in autumn). The comparison among small (<40 mm CL) and large (≥40 mm CL) *Aristaeomorpha foliacea* shows that decapods and fishes have always the highest percent occurrence in both groups; on the contrary, cephalopods were eaten in greater amounts by large specimens, as well as shrimps and siphonophores, while small specimens consumed more frequently benthic molluscs and, with a few exceptions, foraminifera.

In conclusion, Crustacea Natantia (*Plesionika, Sergestes robustus, Pasiphaea* and *Solenocera*) play a determinant role in the diet of *Aristaeomorpha foliacea*, which can be defined as a "holozoic" predator. The different feeding habits were thought as a plausible explanation of why *Aristaeomorpha foliacea* and *Aristeus antennatus* are practically not

vulnerable to baited pots (cf. Arena and Li Greci, 1973), even though both *Aristaeomorpha foliacea* and *Aristeus antennatus* species are also considered as scavengers.

If the analysis of the diet seems to be straightforward, more controversy characterizes the problem of what species prey up on red shrimps. First of all, even though the faunistic complexity at the epi- and meso-bathyal levels is lower than that at the infra- and circa-littoral levels, many species are commonly associated with red shrimps and can be considered as companion species (most of them are cosmopolitan). Many of these co-occurring species could represent potential predators or competitors for food (preying upon Decapoda Natantia or on the same benthic prey) of red shrimps.

For the Mediterranean Sea, the following taxa can be considered among the most common and interesting co-occurrence for the trophic interactions:

- among cartilaginous fish:

  Centrophorus sp., *Etmopterus spinax*, *Chimaera monstrosa*, *Scyliorhinus canicula*, *Galeus melastomus*, *Heptranchias perlo*, *Hexanchus griseus*, *Squalus* sp., *Dalatyas* (*Scymnorhinus*) *licha* (MacPherson, 1980, found pieces of *Aristeus antennatus* in the stomach of this species), different skates;

- among bony fish:

  Notacanthus bonapartei, *Hoplostethus mediterraneus*, *Phycis blennoides*, *Lepidopus caudatus*, *Merluccius merluccius*, *Gadiculus argenteus*, Macrurids (*Hymenocephalus italicus*, *Nezumia aequalis*, *Coelorhinchus coelorhynchus* and other), *Conger conger*, *Micromesistius poutassou*, *Stomias boa*, *Nettastoma melanurum*, *Molva elongata*;

- among crustacean:

  Plesionika martia, *Plesionika edwardsi*, *Plesionika gigliolii*, *Heterocarpus* sp., *Polycheles typhlops*, *Geryon longipes*, *Paromola cuvieri*, *Sergestes* sp., *Pasiphaea sivado*, *Pasiphaea multidentata*;

- among cephalopods:

Todarodes sagittatus (Demestre, 1990, found remains of *Aristeus antennatus* in the stomach of this squid), *Abralia* sp. (Rainer, 1992, found this species in the stomach of *Aristaeomorpha foliacea*), *Pteroctopus tetracirrhus*, *Bathypolypus sponsalis*, *Scaeurgus unicirrhus*, *Rossia macrosoma*, *Sepietta* sp.

Penaeid shrimps are generally considered a very attractive prey (Dall *et al.*, 1990) and a delicacy for fish (Brewer *et al.*, 1991) but many studies show that this observation cannot be generalized (see papers in Gulland and Rothschild, 1984), especially for deep-water red shrimps. Most fishermen believe intuitively that *Aristeus antennatus* and *Aristaeomorpha foliacea* are preyed upon by many of the companion fish and sharks and this feeling has been supported by the scientific community (cf.: Massuti, 1959; Oliver, 1959; Pérès, 1985). In the Sicilian Channel, Sarà (1969), Bombace and Li Greci (1970) and Arena and Li Greci (1973) considered the red shrimps as preys for skates and sharks (such as *Galeus*, *Scymnorhinus*, *Centrophorus* and *Chimera*) and bony fish (such *Lophius*, *Merluccius*, *Micromesistius* and *Phycis*). Analysis of hake stomachs (Andaloro *et al.*, 1985) revealed that fish and euphasids, but not decapod crustaceans, represents the bulk of the prey, at least in Southern Sicily. Successive analyses by different authors and places tend to demonstrate, however, that these deep-water shrimps have no systematic predator (but the man) among the companion species, at least during their adult phase of life (Relini and Orsi Relini, 1987; Fig. 101; Demestre, 1990; Demestre and Martin, 1993). On the contrary, an active predation is supposed or reported for the pelagic (juvenile) stage of life; for example, *Micromesistius poutassou* is considered an active feeders on larvae and juveniles of *Aristeus antennatus* (Bas, 1959; Orsi Relini and Relini, 1985) and it is likely that in these delicate stage of life deep-water red shrimps undergo an higher mortality due to predation.

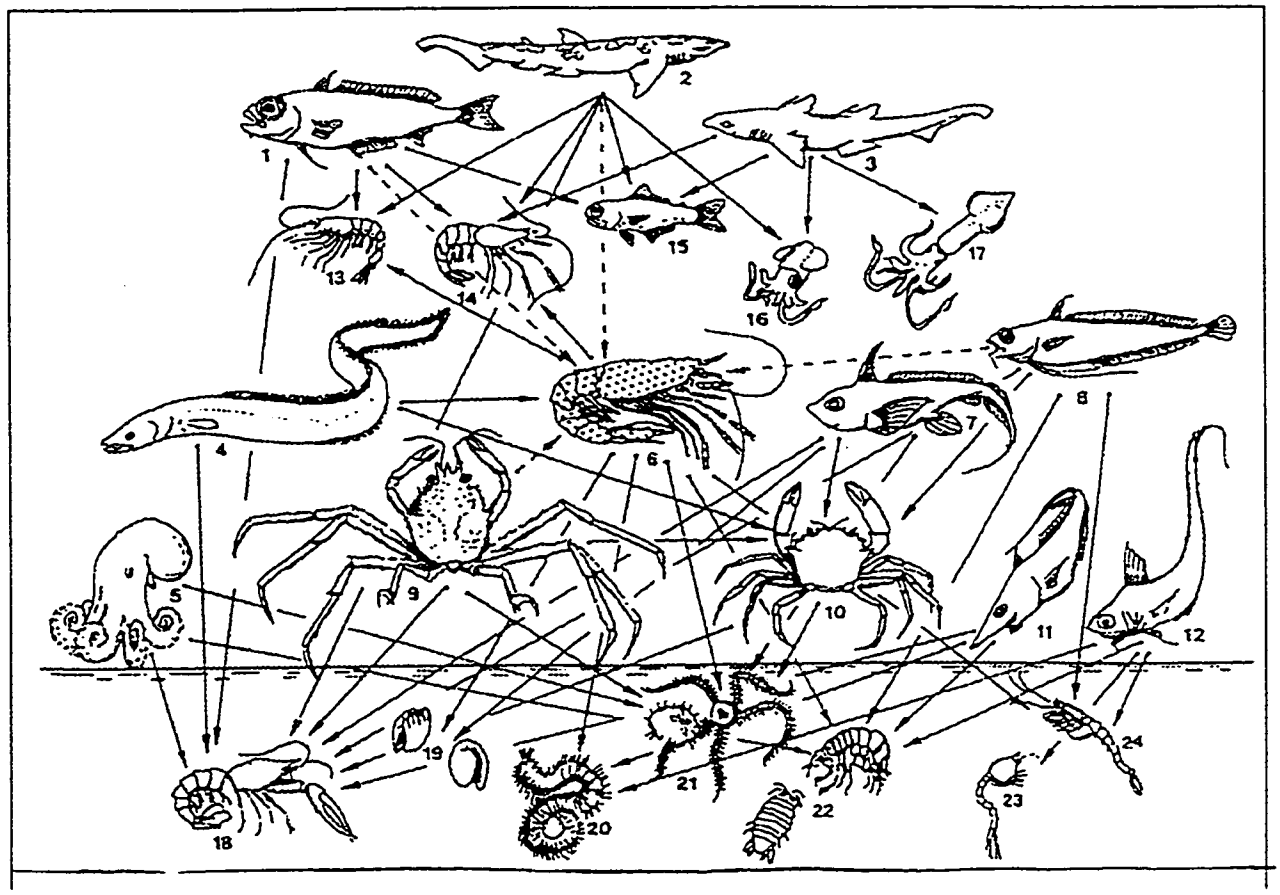


Fig. 101 - Food web concerning *Aristeus antennatus* on the basis of present knowledge of the diet of the main organisms investigated on the Ligurian bathyal fishing grounds. 1) *Moro moro*, 2) *Galeus melastomus*, 3) *Etmopterus spinax*, 4) *Conger conger*, 5) *Bathypolipus sponsalis*, 7) *Chimaera monstrosa*, 8) *Phycis blennoides*, 9) *Paromola cuvieri*, 10) *Geryon longipes*, 11) *Trachyrhynchus trachyrhynchus*, 12) *Nezumia aequalis*, 13) *Meganyctiphanes norvegica*, 14) *Pasiphaea multidentata*, 15) Myctophidae, 16) *Heteroteuthis dispar*, 17) Teuthoidea, 18) *Calocaris macandreae*, 19) Bivalvia, 20) Polichaeta, 21) *Ophiocten abyssicolum* and *Hemiaster expergitus*, 22) Isopoda and Amphipoda, 23) Cumacea, 24) Mysidacea (from Relini and Orsi Relini, 1987).

On the other side, many companion species of red shrimps are competitors for food. For *Aristeus antennatus* such is the case of the macrurid *Nezumia aequalis*, which prey on the burrowing decapod *Calocaris macandreae* and on *Sergestes* sp. and *Pasiphaea* sp. (Relini Orsi and Wurtz, 1979) or of the crab *Geryon longipes* which feeds on the same benthic prey. A lower predation pressure than in the higher bathyal levels and an adaptation to the paucity of food have been proposed by Sardà and Cartes (1993) to explain the slight shift towards smaller sizes (but with presence of mature animals) observed for *Aristeus antennatus* caught down to 2,200 m.

Sex-ratio

First of all, it must be pointed out that the sex proportions derived by trawl-data do not necessarily correspond to the those of the population. Although a high variability can be observed in single shot and between different periods and areas (especially for *Aristeus antennatus*), some general trend appears evident for each species from literature. In *Aristaeomorpha foliacea* females tend to be slightly more represented than males but, on the overall, the sex ratio (SR; expressed as the number of females over total sexed specimens) approaches the expected value of 50%; in *Aristeus antennatus*, females outnumber males (60%<SR<92%). A large variability is reported also as concerning the sex-ratio depth relationship. In the Strait of Sicily, no relationship was found (Ragonese; pers. obs.). In *Aristaeomorpha foliacea* and *Aristeus antennatus*, females seems the be more abundant in the upper and middle levels whilst males seems to be more abundant going deeper (Arrobas and Ribeiro-Cascalho, 1987; Sardà *et al.*, 1993). An exploration of the deep slope (down to 1,800-2,200 m) in the Western Mediterranean, however, gave a predominance of *Aristeus antennatus* females over males below 1800 m (Sardà and Cartes, 1993).

By considering the size, the SR decrease, more or less linearly, from about the 50% value (juveniles) to 0% value above 40-44 mm (for an example, see Sardà and Demestre, 1987); the largest animals are all females. For population in the Strait of Sicily,

where the juveniles are well separated by the adults, the sex ratio of the young of the year (age class 1+) is 50% (Ragonese *et al.*, 1994). Differential distribution, growth and mortality patterns (likely to reduce intraspecific competition) have been considered as plausible explanations of these features (Wenner, 1972; Sardà and Demestre, 1987).

Growth

As the general case for crustaceans, growth in red shrimps is accomplished mainly by a continuous alternance of ecdysis (molt) and anaecdysis (intermolt) cycles which separate the different stages or "instar" (Hartnoll, 1985). The molt occurs rapidly (it takes a few minutes; Sardà, 1986) and it does not represent a true discontinuity in the life cycle of the shrimp (Pessano, 1960). The flexibility of the exoskeleton in such not-hard-armoured animals allows for a moderate growth ("stretching") also during the intermolt period (Garcia, 1985; Caddy, 1987). Since any hard component in the body is lost during molting, the individual age cannot be directly estimates in wild shrimps, while rearing and tagging (marking) and releasing experiments are very difficulty to carry on in *Aristeus antennatus* and *Aristaeomorpha foliacea*, given the depth of occurrence, the behaviour and the food requirements. Rearing red shrimps, however, is feasible: attempts have already been done (Sardà, 1986; Di Natale, pers. com.) even though the mortality rate was very high (Sardà, 1986). The presence of spermatophores on thelycum is not a constraints to molt, at least in captivity (Sardà, 1986).

The basic data to assess growth in shrimps, i.e. increment at molt and frequency of molting (Hartnoll, 1985; Caddy, 1987), are lacking for *Aristaeomorpha foliacea* and scanty for *Aristeus antennatus* respectively. In *Aristeus antennatus*, the molt stage has been judged by microscopic observation of the integumentary setae of the pleopods of the last segments (Sardà and Demestre, 1985; 1987; Demestre, 1990). The classification of the molt stages and the methodology of assessing them by pleopod observation were developed by Drach (1939) and Drach and Tchernigovtzeff (1967); the method, even though modified, has been routinely used in shrimp (cf. Smith and Dall, 1985). For

Aristeus antennatus, the before mentioned authors reported some estimate of the intermolt period and molt frequency for juveniles (CL<23 mm), medium-size mature animals (24-43 mm) and senile specimens (<44 mm). The intermolt period last about 46 days and molt frequency varies with size; it passes from 3-4 events per year in juveniles to 1-2 molts (before and after the spawning) per year in older animals. Demestre (1990) put in evidence the lack of molt synchronism in *Aristeus antennatus*; specimens molt almost continuously all the year round even though a peak in the molting activity has been detected in correspondence with the spawning season. A decreasing molting frequency with size or age is the general rule in shrimps (Hartnoll, 1982; 1985).

At the moment, length frequency distributions (LFD) analysis represents the only suitable method to study the dynamics of red shrimps populations. Generally, two main approaches are used: a direct analysis of the LFD, by non-parametric (such as the "Compleat ELEFAN"; Gayanilo *et al.*, 1989; see Pauly *et al.*, 1984 for an example of its application on shrimps) or parametric (such as MIX: MacDonald and Pitcher, 1979; or MULTIFAN: Baelde, 1994) programs or indirectly, by a preliminary resolution of the LFD in its Gaussian components and successive linkage of the modes (i.e., modal progression analysis). All these methods assume explicitly a direct relationship between individual age and length, and a lack of synchronism in molting, making the growth an almost continuous process, at least at the population level. The main problems in using LFDs are the representativeness of the samples and the degree of overlapping between the different Gaussian components.

In red shrimps a different pattern exists between *Aristeus antennatus* and *Aristaeomorpha foliacea*: the latter shows usually a multimodal LFD with at least two (males) and three (females) evident peaks; the former shows a more smoothed shape. By considering total (or ocular) length, bimodal LFDs have been often reported for both *Aristeus antennatus* and *Aristaeomorpha foliacea* (cf. Arena, 1985).

By pooling seasons, both species show generally a predominance of adults over juveniles (i.e., the polygons of the frequency are negatively skewed). It is interesting to note that such a shape is expected for stable population of relatively long-living species

(Hartnoll and Bryant, 1990) whose mortality rate is lower than growth rate (cf. Powell in Pauly, 1984). The above patterns occur almost universally in literature whatever the area considered (Cau *et al.*, 1982; Sardà and Demestre, 1987; Arrobas and Ribeiro Cascalho, 1987; Relini and Orsi Relini 1987; Ragonese, 1989; Campillo *et al.*, 1990; Wadley, 1992; Ragonese *et al.*, 1994).

By analyzing LFDs, three components were found for the *Aristaeomorpha foliacea* population in Western Australia (Wadley, 1992); 26.2, 43.4 and 51.8 mm of CL for the 1st, 2nd and 3rd year class respectively in females and 27.2, 38.8 and 46.5 mm CL for males. Always in *Aristaeomorpha foliacea*, two and three components, for males and females respectively were found by Wurtz (unpublished data based on Cau *et al.*, 1982; Fig. 102), whereas up to four well-represented components by seasons were derived by Ragonese *et al.* (1994).

At least three age groups were identified for *Aristeus antennatus* females, with an average CL between 26-33 (I) , 39-42 (II) and 48-56 (III) in the Catalan Sea (Sardà and Demestre, 1987; Sardà, 1988). A detailed analysis of the same population yielded 4-5 cohorts whose modal length (CL, mm) was estimates between 11-15, 27-31, 39-40, 49 and 56 (Demestre, 1990). Always in *Aristeus antennatus*, a West-East and South-North cline in the proportion of larger sized animals in the samples coming from different areas was evidenced; particularly, in the Ligurian Sea *Aristeus antennatus* reach a larger size than in other areas (Relini and Orsi Relini, 1987; Sardà, 1988).

A reduction in intraspecific competition as a consequence of rarefaction or of the scarce number of juveniles (almost absent in the Ligurian bottoms) has been proposed to explain this phenomenon; as previously stated, a different duration of the larval stage with different sea surface temperatures can not be excluded.

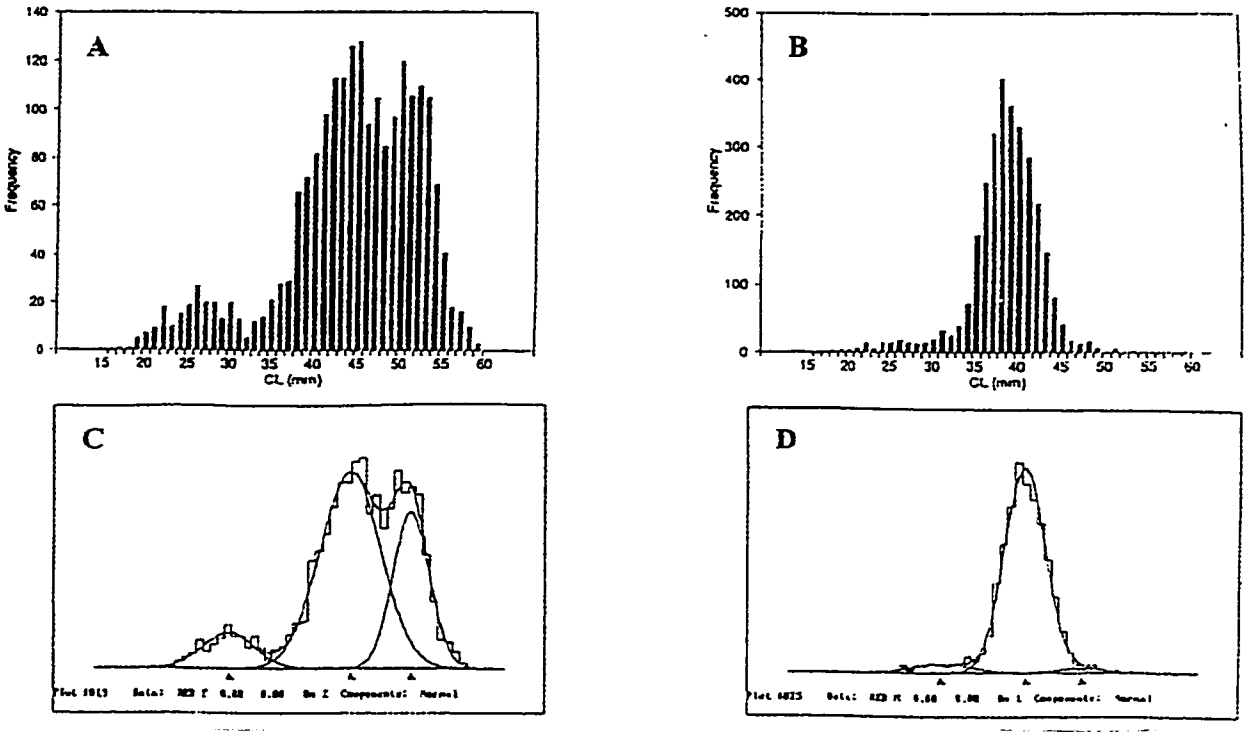


Fig. 102 - *Aristaeomorpha foliacea*: length-frequency in December 1987 (Ligurian Sea) for females (A) and males (B); analysis of normal components showing means (triangles) for females (C) and males (D) (from Cau *et al.*, 1982).

By considering the seasonal evolution of the LFDs, a different pattern results for the two species. In *Aristaeomorpha foliacea*, in general, the recruitment is more or less discrete and some modal progression can be detected (Cau *et al.*, 1982; Wadley, 1992; Ragonese *et al.*, 1994; Fig. 103). On the contrary, *Aristeus antennatus* shows a quite long recruitment period and stable (or erratic) LFDs, without any well defined progression, even suggesting sometimes a negative progression of the LFDs (Relini and Orsi-Relini, 1987; Sardà, 1988; Sardà, 1993; Sardà *et al.* 1993). An almost discrete recruitment was however observed in the *Aristeus antennatus* population of the Strait of Sicily (Ragonese and Bianchini, 1992).

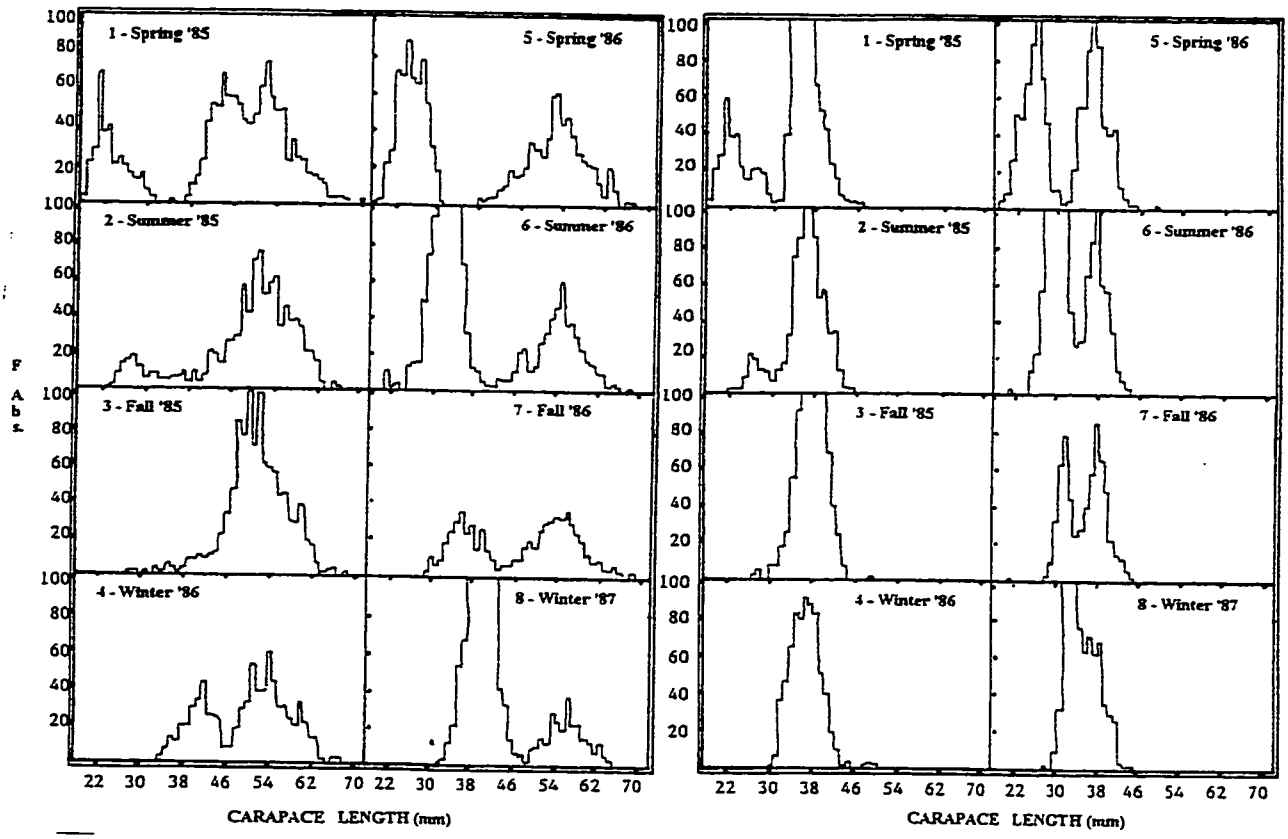


Fig. 103 - *Aristaeomorpha foliacea*: LFDs by survey and season (left: females; right: males).

The classical approach to analyze the size increments at molt by deriving the post-molt *vs.* pre-molt relationship (the well known "Hyatt's diagram"), has never been used in red shrimps and there is no estimate of the so called "growth factor" (Botsford, 1985) for these animals. It must be pointed out that even when available, such data might not be immediately transformed in length-at-age data (Easton and Misra, 1988). The most common way to represent length (CL)- age relationship is the model of von Bertalanffy (a.k.a. VBGF) which, in its "special" version (Ricker, 1979; Pauly, 1987), is written as:

$$L_t = L_\infty (1\text{-}\exp\text{-}K(t\text{-}t_0))$$

where L_∞ is the theoretical asymptotic size; K is a constant (Brody's coefficient) which is related to the rapidity of approaching L_∞; and t_0 indicates the theoretical age at "zero size" which should have the animal if the same animal has followed the same growth law;

practically, t_0 becomes a location parameter (i.e., a family of curves with the same L_∞ and K but different t_0 values).

As the general case, the VBGF has been recognized as a useful model to describe growth in shrimps (Parrack, 1978; Pauly *et al.*, 1984; Garcia, 1985; Moffitt and Polovina, 1987). Few estimates have been presented for both red and violet shrimps and are summarized in Tab. 78. Geographical differences exist but on the overall the results fall in the same range of values, suggesting slower growth rates and longer life cycles than these of the more investigated coastal peneids (Fig. 104).

Table 78 - Growth and mortality estimates for red and violet shrimps. Legend: CL_∞, K and t_0 = VBGF parameters; Z, M, and F = total, natural and fishing mortality respectively; t_{max} = maximum age.

AREA	SPECIES	CL_∞	K/year	t_0	Z	M	F	t_{max}	AUTHOR
Catalan sea	*A. antennatus*	76	0.3	-0.07	-	0.5	0.79-1.74	5	Demestre & Lleonart (1993)
"	*A. foliacea*	76	0.3	-	-	-	-	-	Sardà & Demestre (1987)
Sicily Strait	*A. foliacea*	65.5	0.67	0	0.65	0.42	0.23	-	Ragonese *et al.* (1994)
"	*A. foliacea*	71	0.51	0	-	-	-	-	Ragonese & Bianchini (1992)
"	*A. foliacea*	64	0.75	-	-	-	-	-	Ragonese (1989)
Sardinia	*A. foliacea*	66.3	0.051	-	-	-	-	-	Wurtz (unp.) on Cau *et al.* (1982)
Ligurian Sea	*A. antennatus*	63	1.71	0.44	-	-	-	-	Orsi Relini & Relini (1985)
Algeria	*A. antennatus*	63.5	0.33	-	1.59	0.47	1.12	-	Yahiaoui (1990)
"	*A. antennatus*	65.1	0.37	0.007	1.115	0.472	-	-	Yahiaoui (1986)
Ionian Sea	*A. antennatus*	66.2	0.93	-	-	-	-	-	Matarrese *et al.* (1992)
Castellammare	*A. antennatus*	69.4	0.337	-	-	-	-	-	Arculeo *et al.*. (1992)

More complicated growth curves could be used (for example, the log-log or Gompertz's curve) or have been suggested as alternative to the VBGF for shrimps (see Ricker, 1979 for a description of the different growth models and Easton and Misra, 1988 for some specific alternatives). Generally, these models hold more parameters than the

special VBGF, allowing more flexibility (for example, taking in account seasonality) and a better fit to the data. However, such complicated curves will seldom be justified (Mac Donald, 1987) because in most cases the gain in the goodness of fitting does not compensate for the increased complexity. Other approaches, such as the matrix method (PROJMAT; Basson *et al.*, 1988) or different software (such as SLCA; Shepherd, 1987), normally employed for fish, seem suitable also for shrimps but they have never been used in *Aristeus antennatus* and *Aristaeomorpha foliacea*.

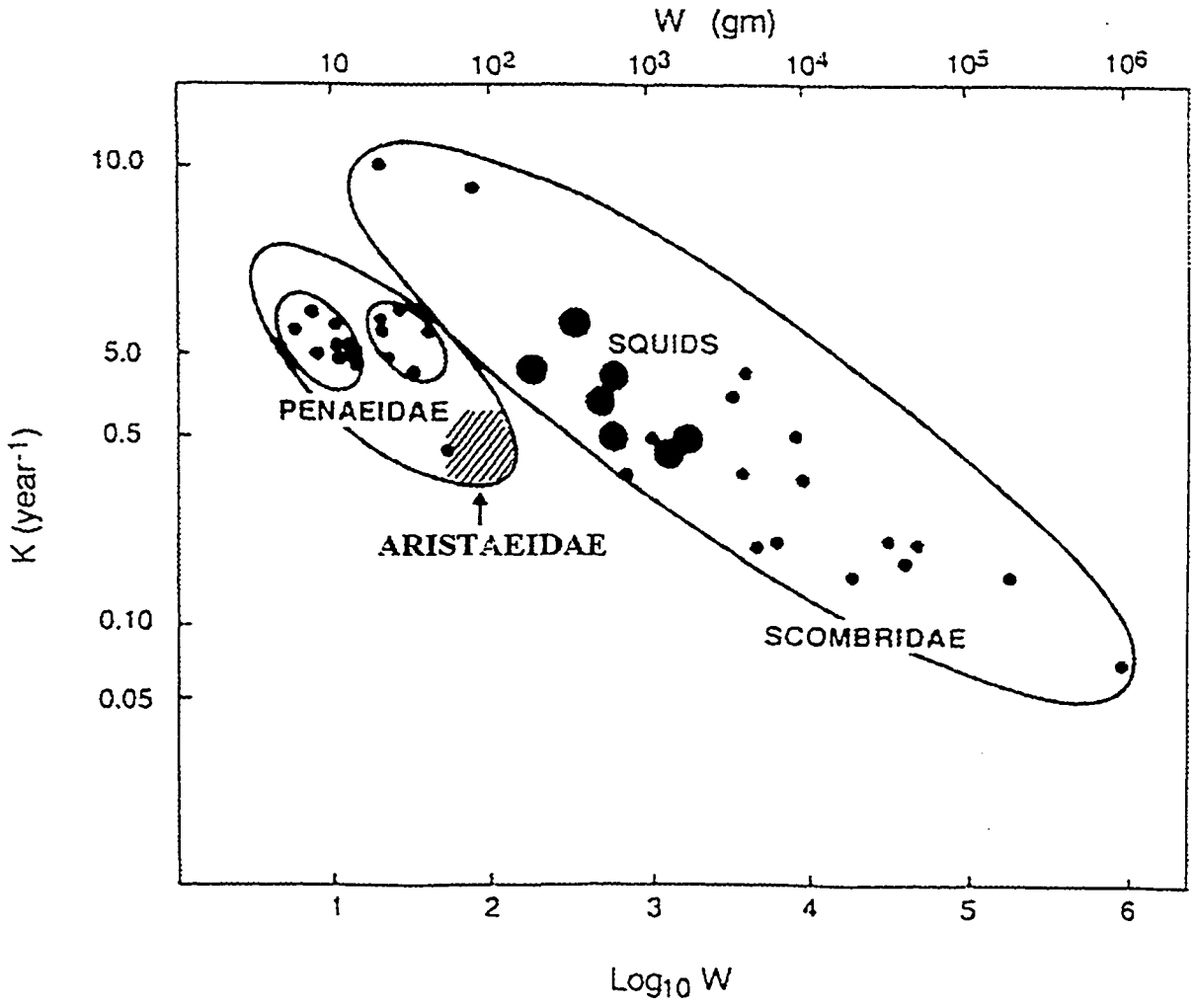


Fig. 104 - Auximetric grid showing ellipsoids for different aquatic animals. The shading indicates the area where the growth parameter of deep-water shrimps fall (from Dall *et al.*, 1990).

Different problems exist; first of all, since in most cases mean length at age have been used, fitting a growth function to the mean sizes (as those derived by MPA) is not always biologically realistic (Knight, 1968; MacDonald and Greene, 1988). Secondly, many packages (such as the "Compleat ELEFAN") do not give any direct estimate of the variance-covariance matrices. Ragonese and Bianchini (1992) have applied the bootstrapping technique (Efron, 1981) to *Aristeus antennatus* from the Sicilian Channel and compared the results with the estimates derived by fitting the mean size obtained with the MIX program. By plotting the different pair of bootstrapped estimates (L_∞ and K) derived by ELEFAN, the typical ellipsoid shape of bivariate (and correlated) parameters appeared, with the MIX estimates falling almost in the center of the ellipse.

Furthermore, the occurrence of fast- and slow-growing estimates were evidenced in both *Aristaeomorpha foliacea* and *Aristeus antennatus* species by using ELEFAN (Ragonese 1989; Ragonese and Bianchini, 1992; Ragonese *et al.*, 1994). Interclass variability in growth rate are considered a common feature in shrimps (for example, see Pearson and Frèchette, 1983). Beside the natural variability in growth, one plausible interpretation is that juveniles and adults (of the same cohort) could have a slightly different growth rates, resulting in lower estimates of L_∞ and higher values of K when juveniles are more represented, and the opposite when adults are the bulk of the samples. The message is that if the samples are good enough and many years are available, the estimates of the growth parameters become more trustworthy. Effectively, beside the exigency to avoid biases, the sample size is the most crucial point in analyzing LFDs (Caddy, 1986; France *et al.*, 1991). Obviously, no specific line can be drawn but as a rule of thumb samples with hundreds of specimens are required (Hoenig *et al.*, 1987) and this number must be greater when many age groups are expected (France *et al.*, 1991).

Another critical point in assessing growth is represented by the high correlation between L_∞ and K; several manipulations of the VBGF have been proposed in order to reduce this problem (Sparre *et al.*, 1989) and some indexes of growth performance were adopted also in shrimps (Dall *et al.*, 1990). The basic aim of these indexes is that of

giving only one figure to represent the growth pattern by combining both parameters; in the specific case the Munro's phi' was used:

$$phi' = \log_{10}K + 2\log_{10}CL_{\infty}$$

For "peneids" shrimps (Dall *et al.*, 1990) the index values fall in the range 1-2, with slight differences between the genus *Penaeus* (1.91), *Metapenaeus* (1.62) and other smaller species (1.32). For *Aristeus antennatus* and *Aristaeomorpha foliacea* the index falls in the range 1.4-3.8. For the red shrimps of the Sicilian Channel, the values are around 3.4.

Mortality

Different methods have been used to estimate the instantaneous coefficients of mortality (Z) in red shrimps (Table 78), always according to the negative exponential model (i.e., $N_t = N_0 \exp{-Z(t-t_0)}$). Generally, the methods are the classical ones used for fish (see Sparre *et al.*, 1989 for a review). Some specific approaches for shrimps have been proposed (see Caddy, 1987) but generally they require detailed information.

Jones and van Zalinge (1981) used an autocorrelated model to estimates Z/K and consequently Z if K is known; this method, however, seems to overestimate the mortality, at least in coastal peneids (Garcia, 1985). Samples representative of the true consistency of different cohorts are required for mortality estimates; in fact, the components in the sample must be representative not only of the modal length but also of the class strength (Hoenig *et al.*, 1987). In case of discrete recruitment, the Heinke's formulation (in Ricker, 1975; see Garcia and Le Reste, 1981 for an application to shrimps) could allow a reasonable estimation of total mortality; in fact the main assumption of the method is that the population is in a stable situation. The formulation can be expressed as:

$$Z = -\ln(1-C_0) \text{ where } C_0 \text{ is the ratio } C_1/C_{all}$$

derived from $C_x = L_x \exp(-r_x)/ \text{Sum } l_x \exp(-r_x)$; for $r = 0$ the above formula reduces to $C_x = L_x/\text{Sum } l_x$.

This method has been applied to *Aristeus antennatus* and *Aristaeomorpha foliacea* of the Sicilian Channel resulting in reasonable estimates of Z (Ragonese and Bianchini, 1992; Ragonese *et al.*, 1994). For *Aristeus antennatus*, total mortality estimates (higher than those derived in the Sicilian Channel) have been derived by applying length-converted cohorts analysis to LFDs based on landings (Demestre and Lleonart, 1993).

As concern that part of total mortality ascribable to "natural factors" (M), the situation becomes more critical. Universally, M represents the most difficult parameter to estimate in fishery science (Vetter, 1988). The general approach is to use some of the empirical formulations available in literature (Vetter, 1988; Sparre *et al.*, 1989), since mortality data on virgin populations of shrimps (i.e., Z very close to M) are not commonly found. In shrimps, particularly, the molt further complicates the analysis since it is likely that the natural mortality could be correlated with the frequency of molting (Caddy, 1987). Another problem is the assumption of invariance of M in respect to an increase of the fishing mortality (F), one classic hypothesis in fisheries studies. At least in coastal shrimps the independence between M and F has been questioned by some authors (see Longhurst and Pauly, 1987). The rationale is that (fast-growing and short-living) shrimps support a higher predation mortality in the virgin than in the exploited situation; in fact (long-living) predators are removed by fishing, the predation pressure is therefore lowered and M is reduced (see also Cobb and Caddy, 1989). Consequently a fraction of the F will "balance" the reduction in M (i.e. Z will remain quite stable in a wide interval of exploitation regimes); according to this hypothesis, using an estimate of M derived from virgin populations will lead to an optimistic value of the exploitation ratio (E=F/Z). On the contrary, if one get an estimate of M using data coming from an exploited population, an underestimation of M and an overestimation of the E ratio could occur.

In peneids shrimps, the estimates of M fall in a wide interval (0.5-26 ! per year) but values above 3-4/year (i.e., a survival rate of less than 5% for year) are evidently inconsistent; a reasonable range could be 1.5-2.0/year (Caddy, 1987). Since coastal shrimps live for 12-18 months *vs.* the 4-6 years estimated for red shrimps, lower values

are expected for the latter. Indeed, available estimates suggest a range for M of 0.4-1.0 per year (Table 78). Low values of M are generally reported for other deep-water shrimps such as *Pandalus* sp. (0.2-0.8; Frèchette and Parsons, 1983), *Hymenopenaeus robustus* (M=0.77; Pauly *et al.*, 1984) and *Heterocarpus* sp. (M=0.75; Moffitt and Polovina, 1987) or large sized coastal shrimps such *Metapenaeus dobsoni* (M=0.75; Smith and Devary, 1990). For *Aristeus antennatus* and *Aristaeomorpha foliacea* the available estimates are reported in Table 78 but values used are about 0.5/year; the value of 0.2/year provisionally assumed by Sardà (1988) is likely an underestimate of the natural mortality rate of the population.

Reproduction and fecundity

Reproduction in penaeoids shrimps is considered primitive because fertilized eggs are not brooded but spawned free into the water (Bauer, 1991). The most recent papers on the morphology, structure and function of the reproductive system of the deep-water shrimps are those of Demestre and Fortuno (1992) for *Aristeus antennatus*, and of Levi and Vacchi (1988), for *Aristaeomorpha foliacea*.

First of all, red shrimps are dioecious animals, i.e. the sexes are separate, and neither evident nor systematic case of hermaphroditism has been described. For both *Aristaeomorpha foliacea* and *Aristeus antennatus* the gonopores open on the proximal article (*coxa*) of the 3rd pair of pereiopods in females (but are scarcely visible in immature specimens) and on the 5th (or adjacent sternite) in males.

Male external genitalia consist of an *appendix masculina* (a process, modification of the flagellum, of the endopod of the second pleopod) and a "copulatory" structure, the petasma, resulting from a modification of the endopods of the first pleopods. In both species the petasma is morphologically complex (lateral and median lobe, *lobuli*, spines etc.) but it can be considered completely open; it appears as flattened plates with the ventral *costae* not turned ventrally (Perez Farfante, 1988; Bauer, 1991). In *Aristaeomorpha foliacea*, the dorsolateral lobules overreach the ventromedian ones

whereas in *Aristeus antennatus* the two emipetasma join at the internal lobe level by means of special features (*cincinnuli*); ventral *costa* falls short of the terminal margin of ventrolateral lobule. The petasma is involved in handling and transferring the spermatophore. It acts likely by pushing the twin emi-spermatophores emitted from each terminal ejaculatory duct (terminal *ampulla*, see below) of the male to the thelycum of female; in both species the spermatophore shows a complex structure, well described by Orsi Relini and Tunesi (1987) and Demestre and Fortuno (1992) for *Aristeus antennatus* and Tunesi (1987) for *Aristaeomorpha foliacea*. Red shrimps spermatophores resulted to be non substantially different to those of other peneids such as *Penaeus kerathurus*.

Female external genitalia consist of the thelycum, situated on the ventral side of the two last thoracic segments, associated with the emispermatophore (emitted by the male during copulation) attachment. The thelycum is formed by the modification (protuberances, depressions or plate-like deformation) of the sternite of the same thoracic segments between which the thelycum is placed. In *Aristaeomorpha foliacea*, the thelycum has on sternite XIV a posterior protuberance short, rounded, relatively thin and clearly free. In *Aristeus antennatus*, the thelycum is broad, quadrangular in shape and bound by one anterior, two lateral and one posterior protuberance, the latter reduced in respect to that of *Aristaeomorpha foliacea*. Thelyca display spines and setae which are more developed in adult shrimps (Demestre and Fortuno, 1992) and in both species they result to be different from those of other peneids (Orsi Relini and Tunesi, 1987; Tunesi, 1987), confirming the taxonomic relevance of these structures. In both species, females lack seminal receptacles and their thelyca are considered relatively simpler than in other Penaeoidaea ("open thelyca", a primitive condition according to Bauer, 1991) even though *Aristaeomorpha foliacea* thelycum appears more complicated than that of *Aristeus antennatus* (Tunesi, 1987).

Ovary structure in *Aristeus antennatus* and *Aristaeomorpha foliacea* reflects the general reproductive system of peneids females; it is a bilobed, elongate and symmetric (along the longitudinal axis of the body) tubular organ joined by bridges which goes from the cephalic to the abdominal region. In fact, three regions, cephalic (paragastric),

thoracic (lateral) and abdominal (caudal) are generally recognized but their development during the maturation process occurs simultaneously (Demestre, 1990). In both *Aristeus antennatus* and *Aristaeomorpha foliacea* the thoracic part of the ovary is split in eight tubular expansions which tend to wrap the hepatopancreas; from the 8th, most abdominal (in *Aristeus antennatus*), or 6th (in *Aristaeomorpha foliacea*) lobule origins the oviduct (one for each side) which leads to the gonopore (Brian in Relini-Orsi, 1973; Demestre, 1990). The ovarian parenchyma is divided in lobules (in *Aristeus antennatus*) or in tubular units (in *Aristaeomorpha foliacea*); the latter species shows the largest ovary, both in volume and weight but, since *Aristaeomorpha foliacea* eggs are also more voluminous, the fecundity is normally higher in *Aristeus antennatus*. The number of ova ranges between 100,000-250,000 and 50,000-900,000 for *Aristaeomorpha foliacea* and *Aristeus antennatus* respectively (Orsi Relini and Semeria, 1983; Demestre, 1990; Yahiaoui *et al.*, 1993). The fecundity-size scatterplots are generally fitted by a curvilinear relationship, even though negatively allometric ($b<3$) and showing a high dispersion (see Table 77 for some estimates of the exponent).

The male gonad is a paired, symmetric organ placed in the posterior part of the cephalothorax. It is formed by a small lobular testicle and a *vas deferens* which presents three sections; proximal, medium and distal: the latter, the *ampulla terminalis*, is larger than the previous ones and hosts the emispermatophore. Spermatozoa are small, almost isodiametric corpuscles (Medina, 1995a, b; Demestre *et al.*, 1997).

As the general (but not absolute) case for crustaceans (Adiyodi, 1985; Hartnoll, 1985), mating in *Aristeus antennatus* and *Aristaeomorpha foliacea* is believed to occur between a mature male and a soft (postmolt), advanced (but still not fully mature) female. However, even though this is the rule for penaeoids shrimps that have closed thelyca (Bauer, 1991), the same requires further demonstration to be accepted for species like *Aristeus antennatus* and *Aristaeomorpha foliacea*, which have open thelyca (Orsi Relini and Relini, 1979). Sardà (1986), during rearing experiences, did observe molt occurrence also in mated females and data from the Sicilian Channel (Ragonese and Bianchini, 1994) indicate a 100% presence of spermatophore in females above a certain size, whatever the

season considered. Multiple mating (up to 2-3 spermatophores on a thelycum) could be observed in a small fraction (<10%) of the females (Orsi Relini and Relini, 1979; Demestre, 1990). As previously stated, eggs are released externally, directly into the water but it is not clear where they spend the embryonic phase. It is likely that spawning occurs during the night (Orsi-Relini and Relini, 1979). The eggs hatch as nauplii, but there are differences between the two species.

Table 79 - Macroscopic identification of gonad maturation in *Aristaeomorpha foliacea* (from Levi and Vacchi, 1989).

Type	Appearance through carapace	Color of fresh specimens just after dissection	Other macroscopic aspects	Oocyte diameter (mm)
I	Ovary not detectable	Flesh-colored	Ovary very thin; threadlike with flaccid lobes	0.10-0.20
II	Ovary not detectable	Light gray	Ovary little developed, small but turgid lobes; frontal lobes not folded and not lateral to stomach	0.21
III	Ovary clearly evident; frontal lobes separate	Dark gray	Ovary well developed; big and turgid lobes; frontal lobes folded and covering most of stomach, but separate from each other	0.38
IV	Ovary dark and clearly evident; frontal lobes united dorsally	Black	Ovary highly developed; swollen lobes occupying almost entire dorsal part of cephalothorax; frontal lobes united, covering stomach almost entirely	0.41

Sexual maturation in female red shrimps is macroscopically monitored by observing the change in colour of the ovary (Table 79), as it accumulates caroproteins during the maturation process. The amount of these pigments, which are black in *Aristaeomorpha foliacea* (Orsi Relini and Relini, 1987; Levi and Vacchi, 1989) and purple-violet in *Aristeus antennatus* ("astaxantoviolina"; Ceccaldi, 1958; Orsi Relini and Semeria, 1983; Demestre, 1990; Demestre and Fortuno, 1992) were put in correspondence to the microscopic features of ovaries; therefore, scales of macroscopic maturity are available for both species (Arculeo *et al.*, 1995). In the case of

Aristaeomorpha foliacea, the first stage should be split in two substages ("juvenile" or "virginal", unmated, and "adult recovering" or "precocious juvenile", mated) according to the presence of the spermatophore on thelycum (Ragonese and Bianchini, 1994). Individual maturity of ovary seems to be a rapid process during for about one (Arrobas and Ribeiro Cascalho, 1987) or two months (Orsi Relini and Relini, 1979; Orsi-Relini, 1982) and a rapid delivery of the ovary is suggested, as is the general case of peneids (Orsi Relini, 1982).

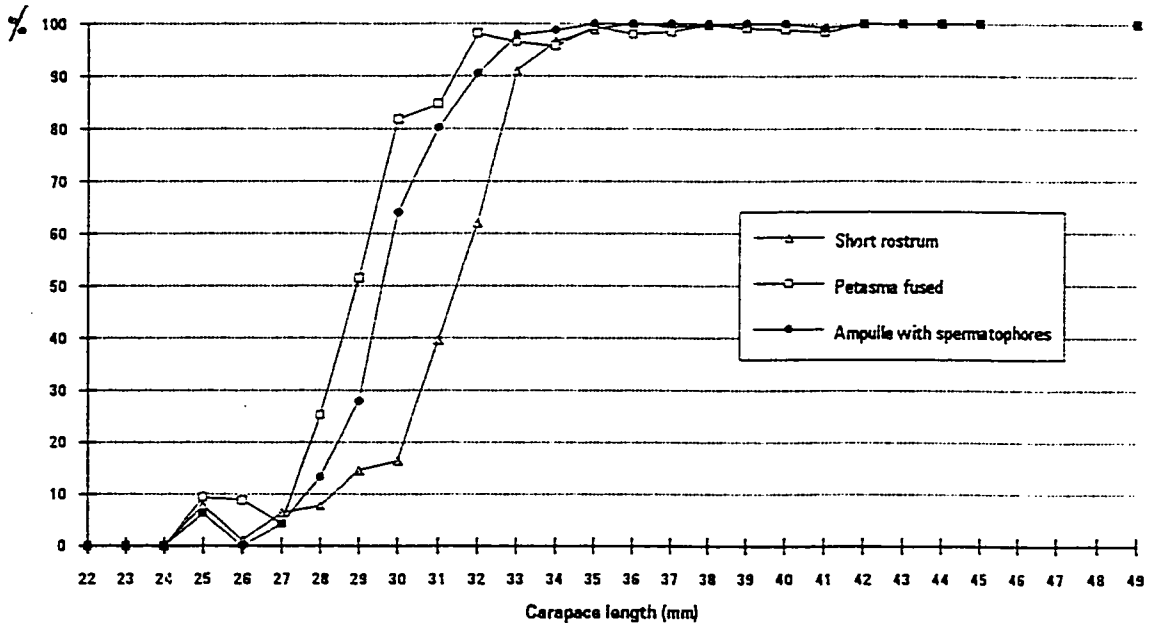


Fig. 105 - The ogives corresponding to the "mature" males of *Aristaeomorpha foliacea* according to three different criteria (from Ragonese *et al.*, 1997).

A shortened rostrum (a process which occurs mainly in summer: Sardà and Demestre, 1989; Demestre, 1990), which is considered a requirement for mating (Palombi, 1938), a fused petasma and the presence of emispermatophore inside the terminal ampullae are the macroscopic characters used to assess the maturity condition in males. In contrast with what was previously believed (Bas, 1965), the shortening of the

rostrum occurs quite abruptly (Cau *et al.*, 1982; Demestre, 1990; Demestre and Sardà, 1992; Ragonese *et al.*, 1994). Above a certain size, all males are mature and apparently always ready to mate, at least morphologically. Generally this size is of about 20 mm and 30-33 mm CL for *Aristeus antennatus* and *Aristaeomorpha foliacea* respectively. In Fig. 105 the ogives corresponding to the three maturative processes in the *Aristaeomorpha foliacea* of the Sicilian Channel (based on Ragonese *et al.*, 1994) are compared; between 28 and 31 mm CL more than 50% of males show positive indexes of maturity and above 32-33 mm CL all males can be considered as mature. By studying an Australian population, however, Wadley (1992) has found slightly lower values for petasma (18 mm), sperm development (20 mm) and shortening of rostrum (30 mm).

The gonad development and spawning of adult females of red shrimps take place over several months, usually starting in spring and lasting to early fall but the peak of sexual activity and spawning occurs generally in summertime. The presence of "*granuli corticales*" in the oocyte is a clear index of completed maturity; Demestre (1990) based her estimates of fecundity in *Aristeus antennatus* from the Catalan Sea on this observation. Always the same author found for the *Aristeus antennatus* off the Catalan Sea the highest values of the gonadosomatic index and presence of spermatophore between June and August, and a size at 50% of maturity from 24 to 28 mm CL according to the criterion in use (% of mature or % of mated females); by combining the two criteria the maximum of the reproductive potentiality was observed in the range 36-40 mm CL.

Also for the *Aristaeomorpha foliacea* of the Sicilian Channel (Ragonese *et al.*, 1994) the two criteria were combined to figure out the intersection points taken as the reference size at 50% of maturity, resulting in a carapace length of 40 mm; mature females were observed almost only in summer and the 100% of mature animals was never observed, even in the largest classes.

It is worth to note that the fat content in *Aristaeomorpha foliacea* goes down from spring to summer with a minimum value in September-October (Cattaneo, 1974); even if this minimum coincides with the maximum reproductive activity, the author associated it to a single molt requirement, contrary to what thought by Trotti and Manfredi (1971) and

Relini-Orsi (1973). For *Aristeus antennatus* a shift in the period of maximum reproductive activity has been suggested; the peak moves from May (Atlantic Morocco), to September (Gulf of Lion) and July-September (Italy). Portugal and Spain stain in a middle situation (Sardà, 1988). However, the combined analysis of the data would suggest that such differences could be mainly a consequence of natural inter-years variability. With some exceptions (such the Australian population of *Aristaeomorpha foliacea*, where mature females were found all year round; Wadley, 1992), the breeding season goes from spring to late summer with the peak in summer, whatever the region considered (at least in the Atlantic-Mediterranean situations).

When the two species are present on the same area, a shift in the phasing of the reproductive period has been described (Follesa *et al.*, 1998a; 1998b). In the Balearic region and the Ligurian Sea, ovary maturation begins in summer and continue to early winter in *Aristeus antennatus* whilst spring-summer is the period for *Aristaeomorpha foliacea* (Massuti 1963; Relini-Orsi and Pestarino, 1978; Orsi-Relini and Relini, 1985); an analogous anticipation of *Aristaeomorpha foliacea* in respect *Aristeus antennatus* (of about a month) was detected in the Sardinian Strait (Mura *et al.*, 1992). However, early summer to fall seems a preferred period for *Aristeus antennatus* independently from *Aristaeomorpha foliacea* presence and latitude at least in the Mediterranean Sea; in fact, it has been reported since the beginning in the Ligurian Sea, when *Aristeus antennatus* was caught with *Aristaeomorpha foliacea* (Brian, 1942), and also for the Southern Tyrrhenian Sea (Arculeo *et al.*, 1992) and the Ionian Sea (Matarrese *et al.*, 1992) where *Aristeus antennatus* is the dominant red shrimp.

The above considerations apply also to *Aristaeomorpha foliacea*, for which the peak period seems to fall between May-June to July (Massuti, 1963; Roper and Sweeney 1981). Exceptions exist: for *Aristeus antennatus* off the Catalonian (Mediterranean) and the Southern Portuguese coasts (Atlantic), the period seems anticipated; but Demestre and Martin (1993) found the highest proportion of mature females between June and August, inside a larger maturative period lasting from May to October. Arrobas and Ribeiro-Cascalho (1987), for *Aristeus antennatus* in the Southern Portuguese coast, found

a breeding season from spring to summer, with the greatest intensity in summer. The functional activity of the ovary of *Aristeus antennatus* off Western Mediterranea Sea is evident from May to September with a maximum in summer (Demestre and Fortuno, 1992).

Shrimps generally mature over a wide size-interval (cf. Easton and Misra, 1988) and the same occurs in *Aristeus antennatus* and *Aristaeomorpha foliacea*; the minimum mating and spawning size is variable but females of both red shrimps are occasionally able to mature at very small size. Females of CL<20 mm and <30 mm, (for *Aristeus antennatus* and *Aristaeomorpha foliacea* respectively) are often found already mated and with the ovary in advanced state of maturation. However, the size at massive maturation or the size at the onset of sexual maturation (SOM), usually considered as the size at which 50% of the females are mature, are higher and generally around 35-40 mm CL. As concerns the number of spawning pulses in the same breeding season, at least three spawnings are generally estimated in *Aristeus antennatus* (Orsi Relini and Relini, 1979; Sardà, 1988; Demestre, 1990).

Parasites, diseases and abnormalities

Scanty information exists on parasitoses of deep-water shrimps. One of the most typical symptoms of parasitic infection is the "cotton tail", in which the muscles in the abdomen become opaque and whitish, that can be caused by many pathogens such as viruses, bacteria and fungi (Dall *et al.*, 1990). This pathology has been observed in red shrimps (Relini and Orsi Relini, 1987). The most common macro parasite seems to be a bopyrid isopod, which affects the branchial cavity (Relini and Orsi Relini, 1987; Wadley, 1992).

The above diseases however has not been detected in the *Aristeus antennatus* population of the Catalan Sea population, even though a large amount of specimens have been examined (Demestre and Martin, 1993).

Exploitation

Gears and equipment

The otter trawl is the almost universally used gear in red shrimps fisheries. Attempts to use traps were unsuccessful (Arena and Li Greci, 1973). Mid-water trawl (i.e., more pelagic) has been successfully employed for *Aristaeomorpha foliacea* at the edge of the shelf (Gorman and Graham, 1974) and, considering the swimming abilities of these prawns, the use of such pelagic gear should be encouraged. Types of nets differ from one area to the other but generally a single-rigged net is employed. Potter and Dredge (1985) used a triple-rigged net in an exploratory survey off the Eastern coasts of Australia with limited success. The headline range from 12-15 m to 27-30 m and the height is generally lower than 1.5 m, and much lower (<1 m) in the Italian case (Fiorentini and Cosimi, 1981). High vertical opening gears were also employed and some improvement has been reported in the yields (Figueiredo, 1989). In the Strait of Sicily, the results of analogous experiences were not conclusive as a consequence of the limited number of trials (Sarà, 1969). The footropes are usually rigged with chain hung in bights, but rubber discs and spacer bobbins (called "diavoloni" in Europe) could improve the gear performance by reducing the amount of bottom debris (Graham and Gorman, 1985).

Mesh size in the codend is the prime factor in determining selection by the net (see the final report), and protecting the younger animals is universally recognized as beneficial for the red shrimp resources. Nevertheless, the mesh size in use is generally very small (around 40 mm mesh opening).

Boats

In oceanic fisheries such as the case of Australia, a vessel size constraint exists because small boats (less than 18-20 m) could not trawl safely the off-shore bottoms (Potter and Dredge, 1985). By the way, new vessels require an average daily catch of more than 900 kg per day to achieve the break-even point, also considering the low market prices (Potter and Dredge, 1985).

In the Mediterranean Sea, a relatively close sea, fishing grounds are usually closer to the landing places and as consequence the size of the boat is not so critical (Bas *et al.*, 1985). Constraints arose mainly because of the technical requirements (such as winch drums big enough to hold the long wires and sufficient horse power) for an efficient trawling of the deep bottoms where the commercial concentrations of red shrimps usually occurs. In Spain, the typical trawler (called "Bou" or "Quillat") falls in the range of 15-35 m of length, and averages 70 GRT and 600 HP of engine (Demestre, 1990).

In the Strait of Sicily, larger boat (up to 700-1000 HP) are used almost exclusively by fishers from Mazara del Vallo (Southern coats); financial support by the Italian government in the past, high storage capacity and fishing power were the principal reasons for such an evolution of the fleet more than the distance of the fishing grounds. Trawlers, in fact, can quite easily take refuge in the ports of the Pelagic Islands (Pantelleria and Lampedusa) located in the Strait of Sicily, or even in Malta.

Only few fishing vessels, coming both from Sicily and continental Italy, exploit the red shrimps grounds all year round; usually fishers change their targets according to the seasons and availability of other resources, mainly red mullets (*Mullus barbatus* and *M. surmuletus*) or pink shrimps (*Parapenaeus longirostris*). According to Bas (1959) some interference between fishing boats operating at the same level was suspected; the opposite, however, seems to occurs in such deep fishery (see below).

Fisheries

Both *Aristaeomorpha foliacea* and *Aristeus antennatus* are potentially or actually very important commercial species throughout their whole distribution area. However, *Aristaeomorpha foliacea* is not or very scantily commercialized in the Western Atlantic (Holthuis, 1980; Perez Farfante, 1988) and in New Zealand, where its potentiality has been evidenced since the '50s (Richardson and Yaldwin, 1958). In Australia, only a small fishery has been developed off-shore the Western coasts; yet experimental surveys have indicated strong potentiality of *Aristaeomorpha foliacea* and other Aristeids species (*Aristeus* sp.) throughout the whole Australian continent slope (Potter and Dredge, 1985;

Rainer, 1992; Wadley, 1992). Marketing (it is less certain for deep-water prawns), handling (blackening and body texture) and logistic (only a small part of the fleet, actually involved in coastal peneids fishery, would be able to move and fish the depths were the red shrimp live) problems have prevented this fishery to grow (Graham and Gorman, 1985; Potter and Dredge, 1985). In the other oceanic distribution areas, both species are commercially fished to some extent (Roper and Sweeney, 1981; Brinca *et al.*, 1983; Dore and Frimodt, 1987) but effectively the only true specific fisheries are those of the Mediterranean Sea (GFCM, 1970; Holthuis, 1987).

Aristaeomorpha foliacea and *Aristeus antennatus* began to constitute the target of artisanal and semi-industrial trawl fishing since the '30s in the Ligurian Sea (Brian, 1942) and Balearic Sea (Oliver, 1959; Massuti, 1963). According to Santucci (1935), the first trawlers fishing the epibathyal depth arrived to catch 10-200 kg/day of red shrimp and in some periods the captures went up to 1000 kg/day/boat (Brian, 1942; Orsi Relini, 1973). Nowadays, thousands of tons of these species are landed along all the Mediterranean coasts. Indeed, the Mediterranean red shrimps fisheries can be considered monospecific (Sardà, 1988; Demestre and Martin, 1993). In the Eastern Atlantic, the giant scarlet prawn, *Plesiopenaeus edwardsianus*, is the target of the fishing vessels (Roper and Sweeney, 1981) whereas in Australia, the royal red prawn, *Haliporoides sibogae* (Beadle, 1993), and *Metanephrops* species (Wallner and Phillips, 1988) represent the main targets of the deep fisheries (by the way, no separate figures are reported for *Aristaeomorpha foliacea* in Australian or New Zealand statistics).

As stated in the distribution section, the *Aristeus antennatus* and *Aristaeomorpha foliacea* fisheries in the Mediterranean Sea are often distinct, even if somewhere a degree of overlapping does exist. The main *Aristaeomorpha foliacea* fisheries are located in the Strait of Sicily (Ragonese, 1993) and in Southern Sardinia (AA.VV., 1990; Cau, 1992), whereas *Aristeus antennatus* catches occur in the Western basin (Sardà, 1988; Demestre and Lleonart, 1993) and in the Ionian Sea (Matarrese *et al.*, 1992), according to a sort of West-East and North-South gradients in the reciprocal dominance.

The catch is commercialized fresh (iced) or, more frequently, frozen. Fast sorting and quick storage is essential to prevent the development of melanosis, off-flavors (i.e., iodoform smell; Graham and Gorman, 1975) and microbial spoilage. The main problem faced by the pioneers red shrimps fishers was indeed the insurgence of the "black-spot" (or melanosis) phenomenon (Ruello, 1975; Ogawa *et al.*, 1975); it is an unaesthetic (but not dangerous to consumers) blackening of the head and tail, just few hours after capture, as a consequence of the enzymatic (tyrosinase) degradation of the amino acid tyrosine naturally present in the tissues or made available by microbial activity. The dark colour is produced by melanin pigments which are formed first on the internal shell and only in advanced stages on the underlying meat. Icing or chilling alone do not prevent this phenomenon, even if they are able to delay it for few hours if the catch is handled properly; one remedy was to behead the shrimps just after the capture, a measure still adopted in many overseas fisheries (Gorman and Graham, 1975). Mediterranean consumers, however, do prefer whole shrimps and as a consequence red shrimps were landed in limited amounts or not at all, if the fishing grounds were located far from the landing places such as is the case of the fisheries of the Strait of Sicily. In Mazara del Vallo, for example, the deep sea red shrimps fishery has been limited by the lack of freezers till the end of the '60s (Scaccini *et al.*, 1970). That can also explain the old tradition of the Balearic and Ligurian fisheries, whose fishing grounds are close to the mainland. The problem has been solved by the practice of a dip in a solution of a reducing salt (usually sodium metabisulphite, at 1.5-2.5% in sea water: Monod 1964; Graham and Gorman, 1985). Sicilian fishermen usually exceed the legal concentrations in order to be on the "safe" side against the black-spot; that can cause some problem because it may tend to mask an actual spoilage of the catch. It must be pointed out that "melanosis" is commonly not a consequence of pathology such as is the case of "cotton-tail shrimps", due to infection of Microsporidae (Monod, 1964). Furthermore, the red prawns smelt iodoform if not stored properly and this phenomenon is more pronounced in some peculiar populations, even just after capture (Gorman and Graham, 1975).

Catch variability and fishing effects

Pioneers who begun to study red shrimps were so impressed by the wide distribution and abundance of these species, to image a virtually infinite resilience to the exploitation; Boutan and Argilas (1927), studying the populations off the Algerian coasts, thought that these resources would not be reduced for a very long time by fishing pressure and at the same conclusion arrived Brian (1931) for the populations inhabiting the Ligurian Sea. Unfortunately, successive experiences have reduced the optimism about the resilience of these species.

The variability in yields among years, indeed a normal characteristic of all fisheries (Laevastu and Favorite, 1988), appears particularly pronounced for at least some stocks of red shrimps. An example is represented by data coming from the Australian *Aristaeomorpha foliacea* fisheries. Gorman and Graham (1975) reported for the New South Wales: "in contrast to the results of the previous year, the catches of the red prawns were uniformly low and we did not locate the species anywhere in commercial quantities". Almost ten years later, Potter and Dredge (1985) reported mean catch levels of *Aristaeomorpha foliacea* ranging from 0.1 kg/h to 13.8 kg/h with peaks up to 35 kg/h in Southern and central Queensland, yields anyhow lower than those corresponding to royal red prawns *Haliporoides sibogae*. Few years later, Wallner and Phillips (1988) described a deep-water fishery in the North West of Australia in which *Aristaeomorpha foliacea* was the most important prawn species, accounting for 212 t in 1987. Finally, a multidisciplinar project (Rainer, 1992) revealed a sharp decline in *Aristaeomorpha foliacea* yields.

Beside the famous change in *Aristeus antennatus* and *Aristaeomorpha foliacea* stocks of the Ligurian Sea (Orsi-Relini and Relini, 1985; Relini and Orsi Relini, 1987) such apparently improvise collapse or absence of one species or of the other or of both the red shrimps in specific areas has been reported many times and for many different places (Maurin and Di Meglio, 1961; Campillo *et al.*, 1991; Matarrese *et al.*, 1992).

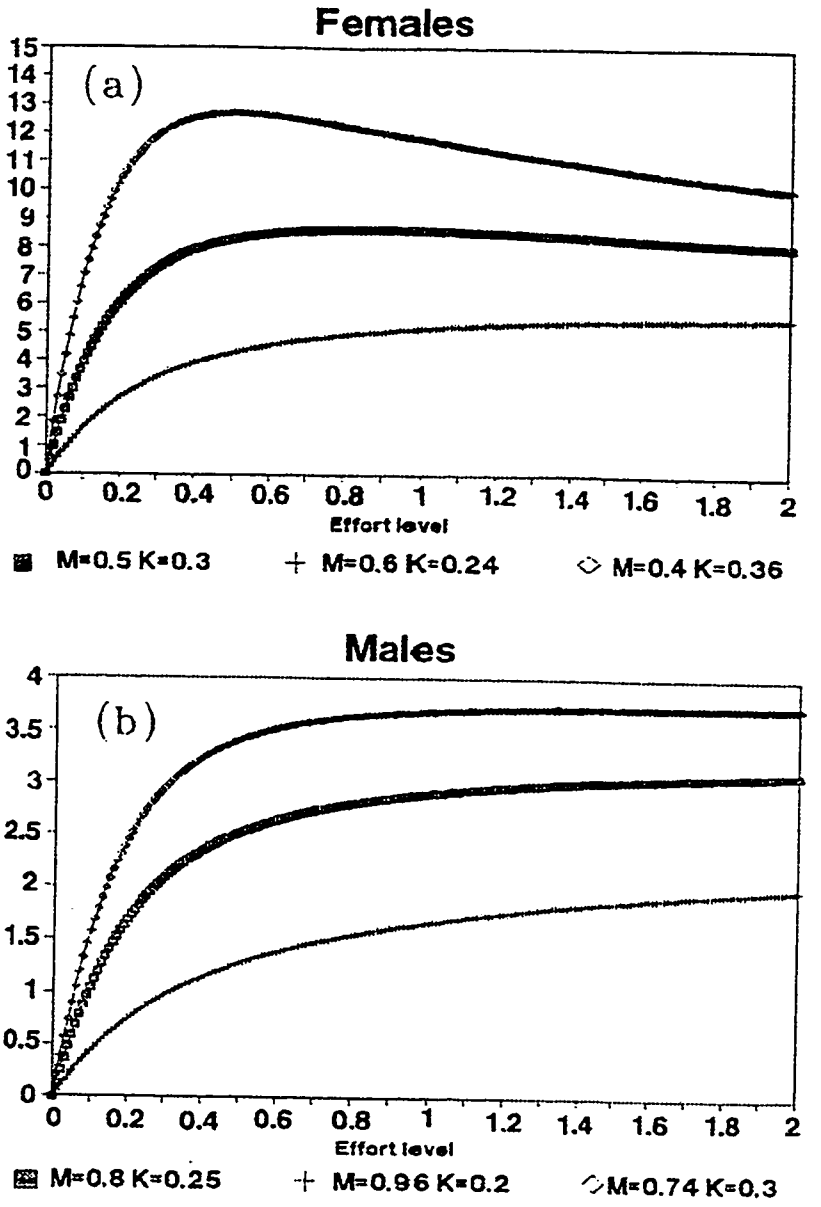


Fig. 106 - Curves of yield-per-recruit *vs.* fishing mortality for females (a) and males (b) of *Aristeus antennatus*. The fishing mortalities are represented in relative values, varying from 0, no fishing mortality, to 2, fishing mortality double to the actual (1). The central curves are those obtained with the reference parameter values. The lower curves were calculated with a natural mortality (M) 20% higher than its reference value, and the growth rate (K) 20% lower than its reference value. The upper curves were calculated inversely (from Demestre and Lleonart, 1993).

One of the most stable fishery is that of *Aristeus antennatus* off the North West Mediterranean coasts of Spain. Application of a Y/R model, based on length cohort analysis (LCA) and virtual population analysis (VPA) (Demestre and Lleonart, 1993; Demestre and Martin, 1993) has indicated a sort of equilibrium condition around the optimum level (MSY) even though the flatness of the yield curves makes difficult to find a clear MSY values (Fig. 106). These results could be explained mainly because only a portion of the population (that above 800-1,000 m) is available to the fisheries and that these populations show a (moderately) high turnover rate (even though lower than those observed for the most notorious coastal peneids species).

As concern the problem of fluctuations, the availability of more than 15 years of statistical data on catch and effort allowed the authors to appreciate only an unexplained decrease at the beginning of the '80s, likely not correlated to high pressure of the fishing effort. Declines in the catch rates (catch per unit of effort, "cpue") have been often described for such fisheries even if no clear relation seems to exists between yield and fishing effort, for examples, the decline in the catches in the Ligurian Sea between the '50s and '60s (Orsi Relini, 1973) or the decrease in average yield in the Sicilian Channel (Ragonese, 1989). On the contrary, many scientists and all the fishermen think that some fishing effort has a positive effect on yields, at least at the beginning of the exploitation and in a wide range of efforts. The same general hypothesis has been advanced for different areas by different authors (Oliver, 1959; Sarà, 1969; Arena and Bombace, 1970; Massuti, 1971; Bombace and Sarà, 1972; Arena and Li Greci, 1973; Arena, 1985) and can be summarized as follows:

a) when no exploitation exists, red shrimps populations are depressed by predators (sharks, skates and bony fish), interspecific (for food) and intraspecific (food, cannibalism) competition; as a consequence, the yields are generally low although the catch is composed mainly by large-size animals;

b) when the exploitation begins, predators (called by fishers "parasite" species) and large-sized shrimps are largely removed and the constraints of the previous point disappear; as a consequence, both recruitment and production increases dramatically and so do the commercial yields.

This theory is sound and apparently not in contrast with the general views of ecology (i.e., the "r" and "K" strategies) and the dynamics of exploited populations; the most streaking examples are the recovery of the world resources after the war halt (Beverton and Holt, 1957) and the "boost" of cephalopods in the Gulf of Thailand, following a decades of high intensive trawl fishing which had strongly reduced long-living and top predator fish (Pauly, 1984). As concerning shrimps, this theory has been formalized by the same school of though: practically, the first effect of fishing is to reduce the natural mortality and consequently the total mortality remains quite stable even with a strong increase of the fishing mortality (Longhurst and Pauly, 1987).

Different arguments were proposed to sustain the above hypothesis, but they have never been statistically proved. First of all, man is probably the most important predator of red shrimps, at least in the post-recruited phase of the life; secondly, the feeding habits place these species at the top levels in the trophic chain and consequently the basic assumption of the positive reaction (low level in the food link) is voided.

Furthermore, when historical series are available and analyzed, contrasting results are apparent; changes in landings in the Balearic Islands, examined by Massuti (1971), showed a decrease in both *Aristaeomorpha foliacea* and *Aristeus antennatus* but an increase in the average size and a non-corresponding decrease in many of the assumed predators. Indeed, the decrease in landing at the Balearic Islands after several years of plentiful catches were linked to high fishing pressure.

In the Sicilian Channel, Arena and Li Greci (1973) reported mean commercial catches of red shrimps at the beginning of such fisheries (1960) of about 30 kg/h, with peak catches up to 90 kg/h; after about 20 years of active exploitation the figures were between 2-11 kg/h (Arena, 1985) suggesting some fishing effect; only in the grounds around the Egadi Archipelagos, where trawling is limited by the rugged nature of the bottoms, the yields resulted to be comparable.

By comparing red shrimps with both gadoid (hake) and sharks catches (in Arena, 1985) only positive correlations were found (Ragonese, pers. obs.). As a matter of fact, the higher catches of red shrimps after the first hauls and the apparent positive correlation

between degree of "cleanliness" of the bottoms and red shrimps yields have been confirmed in the most part of cases and places, but other factors than the classical ecological hypothesis must be called in cause. One cause could be the turbulence effect determined by trawling (for example, the clouds of suspended solids and mud): fish would escape from these areas whereas red shrimps would be more attracted since they (or other decapods) could feed easily on the benthic animals exposed by trawling (see for example, Arena and Bombace, 1970). The fact that when trawl is stopped the same areas show a quick recovery to the previous situation could support this hypothesis.

Generally, the fishery shows peaks of activity and higher catches during the good season and the breeding and spawning periods (i.e. spring and summer). Since the ridiculous mesh sizes commonly employed by Mediterranean trawlers (Caddy, 1990), the exploited size range is quite wide (15-70 mm, CL) and symptoms of growth overfishing are evident, also considering that the economic value of juveniles is quite lower than that of the adult component. Instead, VPA analysis tend to show that mature animals are those suffering the high fishing mortality (Demestre and Martin, 1993) so delaying the size of first capture could improve the economic performance of the fishery. It must be pointed out that the Catalan fisheries yield annually about 350 t of *Aristeus antennatus* for a value of about 13 million of U.S. $ (Demestre and Martin, 1993); in the Sicilian Channel, more than 1,000 t per year have been landed in the last years.

Fishing is generally carried out continuously but seasonality in red shrimps fisheries can result as a consequence of bad weather or the presence of other targets. For the Mediterranean waters, a common pattern exists: generally speaking, the first hauls are carried on in late winter and early spring then, as the schools of red shrimps are detected and the yields considered to be remunerative by fishermen, the main season starts with diversion of fishing power from circalittoral and epibathyal bottoms. The fishing season ends practically at the beginning of autumn, even though some units keep on fishing till winter (Orsi Relini and Relini, 1987; Arrobas and Ribeiro Cascalho, 1987). As a consequence, the peak of fishing season coincide with the peak of maturity and breeding activity and likely with the moment in which the shoaling is maximum (Wadley, 1992).

Appendix B

OUTLINE OF THE STUDY AREA FEATURES AND BIONOMY

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Generalities

The body of water between the southern coasts of Sicily and the northern coasts of Africa represents the transition between the western and eastern basins of the Mediterranean Sea. It is not easy to define its boundaries precisely. The ancient "Mare Africanum" has been generally quoted as the "Sicilian Channel" till few years ago, whereas the "Strait of Sicily" was referred to the straight line linking Sicily (Capo Boeo, near Marsala) to Africa (Capo Bon). French authors have also used the name of "Mer Pelagienne" to indicate the side of the Sicilian Channel facing the eastern coasts of Tunisia (for an example, see Pérès, 1985) but this denomination is no more in use.

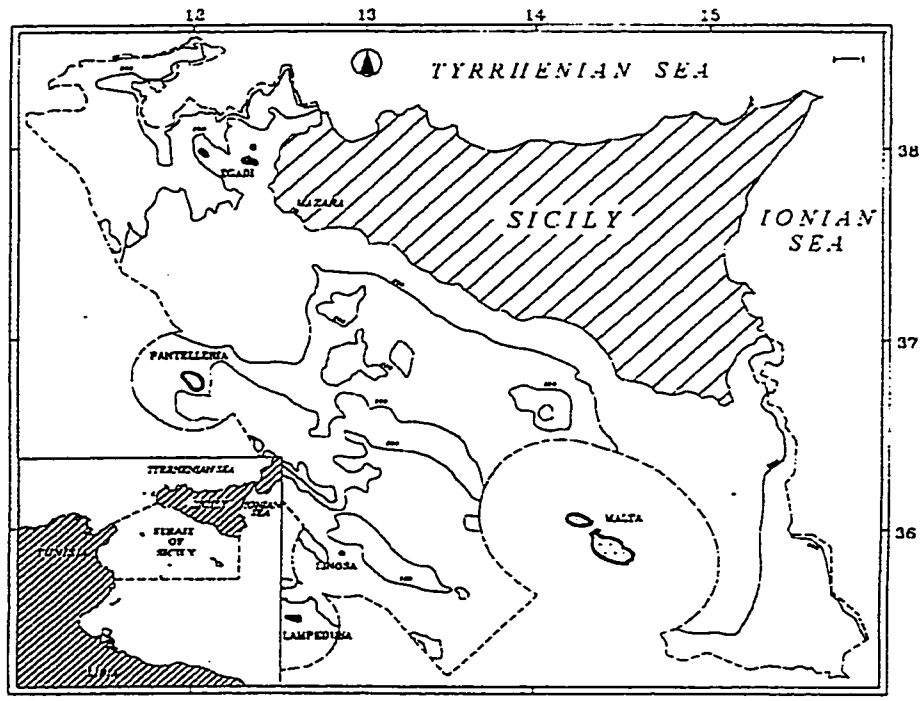


Fig. 107 - Official delimitation of the Strait of Sicily (small frame) and the area surveyed by the Institute of Mazara del Vallo.

Generally speaking, the "Sicilian Channel" has been defined as an irregular trapezoid delimited between the 10° and 15° meridian East and 35° and 38° parallel North (Colantoni, 1975). An official definition has been recently introduced (Cassio, 1993): strictly speaking the Strait of Sicily includes the sea area close to the Sicilian southern coasts (Fig. 107) delimited at West by the straight line between Capo Boeo

(Sicily) and Cape Bon (Tunisia) and at east by an arbitrary limit. Broadly speaking, and in this paper, the name is referred to all the waters from the southern Sicilian and the North African coasts delimited at West by the Skerki Bank and at east by the isobath of 1,000 m which separates the area from the Ionian basin.

General morphology and hydrological features

The Strait of Sicily is a relatively shallow area with a complex bottom orography (Colantoni, 1975). The 1,000 m isobath is surpassed only in the central area where there are 3-4 depressions which work as decantation basins. According to Morelli (1972), the maximum depth of the three main basins are 1,317 m (Pantelleria basin), 1,721 m (Malta basin) and 1,529 m (Linosa basin). These depressions are situated close to one another in a SE direction forming a sort of deep valley splitting the area in two sectors, which has been defined by Ragonese (1993) as South East and Far South zones. The valley communicates with the Western and Eastern Mediterranean Sea by a narrow sill, NW of Pantelleria island (400-500 m deep), and a wider channel, SE of Malta (500-600 m deep), respectively. By the way, a "sill" is a critical bathymetric restriction preventing exchange of waters of the same depths inside and outside a basin (Hopkins, 1985).

Total surface is above 111,000 km^2. The average depth is estimated at about 352 m (Colantoni, 1975). Half of the area falls inside the 0-200 m isobaths, while the depth range for red shrimps (400-800 m) can be estimated at about 28% of the area. Morphologically, the Strait of Sicily belongs to the continental shelf and slope but other morphologic sub-units of the slope are usually identified: basins, seamounts (guyots) and "banks" (Colantoni, 1975). Along the southern coasts of Sicily, the shelf is wider (ca 100 km) in front of Mazara (Adventure bank) and Capo Passero (Malta bank); it becomes narrow (less than 20 km) in the central area. In this side, the location of the shelf edge ("shelf break") is estimated at about 123 m (Colantoni, 1975). On the coast of Tunisia, the shelf is narrow in front of Capo Bon and wide in the southeastern sector, reaching a maximum extension of 162 km. The slope shape is extremely irregular, incised by many canyons, trenches and steep declives, intervalled

by subhorizontal and more accessible (trawlable) traits. It is furrowed transversally by the deep before mentioned basins (>800 m) and interrupted by "guyots" and "banks".

As previously stated, the basins work as decantation pools along the NW-SE direction. Sediments tend to pile up and fill these basins; the most important are those of Pantelleria, Gela, Linosa and Malta. The seamounts are generally of small size, sub-conic in shape and of volcanic origin; two of them emerge to form the Pantelleria and Linosa islands. Volcanism has been and is still active in the area (Colantoni, 1975). The raise and successive wash-out of the Ferdinandea island (now the Graham bank), in front of Sciacca, occurred in the 18th century (Mazzarella, 1991) represents the most famous evidence of the volcanic activity in this area. "Banks" are typical morphologic units in the Strait of Sicily (Colantoni, 1975); their tops raise above the 200 m isobath and show a sub-flattened surface with signs of abrasion; in fact they have been exposed to the surface repeatedly during the glaciations in the Quaternary period.

Due to its preeminent role as a bridge for the western and eastern basin (the two basic hydrological units recognized for the Mediterranean Sea; Sverdrup *et al.*, 1942), the Strait of Sicily has been widely investigated, especially in the '60s, in order to elucidate the water masses properties such density and circulation and the budget analysis (De Maio *et al.*, 1972a, b; De Maio *et al.*, 1974; Moretti *et al.*, 1974; Grancini and Michelato, 1982). Basically, the hydrology of the area resembles that of the Mediterranean Sea at large; the latter is considered a "zonal ocean" being completely severed from the waters of the world oceans. It can be defined a "negative" or "concentration" sea or, more precisely from an oceanographic point of view, as a sea with a "negative thermohaline circulation" (Hopkins, 1985) i.e., a sea with a negative hydrological balance: the gains (rainfall and rivers runoffs) are not able to compensate the loss (evaporation). Balance is allowed by the superficial influx of water (about 1 million of $m^3.s^{-1}$; Allain, 1970) from the Atlantic thru the Gibraltar strait, which forms a sill 320 m deep. This mass of water flows above an underlying counter current of Mediterranean origin, the former being richer in plankton and poorer in nutrients than the latter (Margaleff, 1985).

Classically, four hydrological main body of water, with different thermohaline characteristics, are recognized in the Mediterranean Sea (Gorgy and Shaheen, 1963; Allain, 1970; Berland *et al.*, 1988):

a) Surface layer : it corresponds to the water coming from the Atlantic thru the Gibraltar Strait and is known as Atlantic water (called also Northern Atlantic Water, NAW; hereafter AW). Its lower limit is marked by a minimum of temperature in the western basin whereas a slow decrease occurs in the eastern basin. The AW is generally found between 0- and 100-250 m (somewhere to 500 m) in the Western and Central Mediterranean and between 0-50 m in the Eastern Mediterranean, at least in Summer (Berland *et al.*, 1988). A thin (0-20 m) homogeneous surface layer, with variable thermohaline characteristics but well separated from the waters below by a pronounced thermocline, has been distinguished in Summer (Berland *et al.*, 1988).

b) Intermediate layer: it is mainly originated in the levantine basin (in fact it is also named "Intermediate Levantine Water", ILW, or more simple "Levantine water", hereafter LW). It derives from the AW when the latter becomes colder and more saline in Winter. It is characterized by a maximum of salinity and flows westwards below the AW. Obviously, there are other places in the Mediterranean Sea where the LW is formed. A mixing layer is often recognized between the two masses of water (Grancini and Michelato, 1982). LW is generally warmer than the underlying deep water (see below) and often warmer than the overlying AW. In the western basin, a temperature maximum is found at the same depth, whereas in the eastern basin a gradual decrement is found. It is generally found at 200-600 m but somewhere deeper and up to 40-50 m in the levantine basin, at least in Summer (Berland *et al.*, 1988). The formation of intermediate water can also occur locally and in varying quantities in the western basin and sometimes it is distinguished as Western Mediterranean Intermediate water, WMIW (Hopkins, 1985).

c) Transition layer: it lies at the lower limit of LW where both temperature and salinity decrease rapidly. It is generally found at 600-1,500 m.

d) Deep layer: it is found only at great depths. The temperature increases adiabatically toward the bottom but it is fairly constant at about 12-13°C. Less information are available for this type of water. It is typically recognized below 1,900 m.

The above representation is a simplification of the real situation. A recent evaluation of the seasonal circulation of the upper 800 m of the Mediterranean Sea, from climatological data and using an inverse model (Tziperman and Malanotte Rizzoli, 1991), has evidenced a more dynamic situation in the water circulation. Basically, the AW follows a complex pattern in the western basin (Hopkins, 1985). After having influenced the Algero-Provenzan basin, flowing eastwards, mainly along the North African coasts, the AW splits in two branches while approaching the Strait of Sicily: one of these moves in the Tyrrhenian basin, while the other flows towards the Ionian and Levantine basins (Hopkins, 1985). AW has a saline content of about 37 parts per thousands (ppt) (36.5 ppt at the origin) when approaching the Strait of Sicily.

Flowing mainly in west-south direction its saline content increases gradually as a consequence of the strong evaporation (38.2-38.9 ppt in the eastern basin). An analogous increase in temperature occurs in Summer; in this season a thermocline can be found at about 50 m. The O_2 concentration increases continuously down to 50-80 m (5-6 ml/l) and thereafter decreases, always remaining in good concentrations (>4 ml/l), as is generally the case for the Mediterranean Sea, whose waters are well oxygenated throughout (Margaleff, 1985; Berland *et al.*, 1988).

For the sill in Strait of Sicily, Morel (1971; in Hopkins, 1985) has estimated that the outflowing AW changes from 37.0 ppt to 37.3 ppt in transit whereas the incoming subsurface water changes from 38.8 to 38.7 ppt. AW arrives to have 39 ppt in the levantine basin where, in Winter, cools at 15-16°C and sinks to form the LW (Gorcy and Shaheen, 1963). Recent elaborations (Tziperman and Malanotte Rizzoli, 1991) have suggested that the path of AW in the Ionian basin and in the Strait of Sicily forms a meander in all season but Winter; a more complex situation has been also described (see for example, Ovtchinnikov, 1976). The two representations are compared in Fig. 108. Especially in the latter area the flow of AW could have not been well resolved but a deeper influence (down to 250-300 m) has been evidenced (Tziperman and Malanotte Rizzoli, 1991).

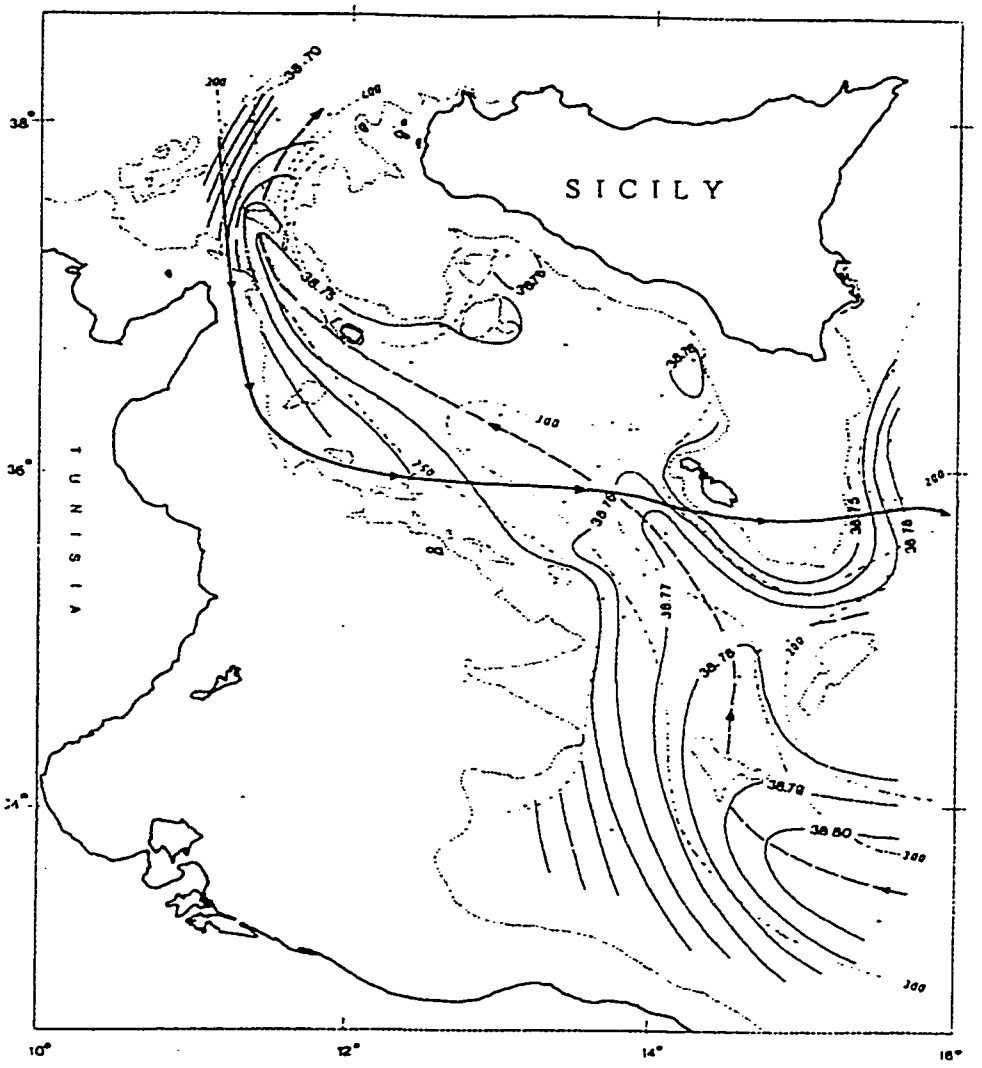


Fig. 108 - The Atlantic water (straight arrow) and the underlying eastern water (dotted arrow) movements pattern in the Strait of Sicily (from Tziperman and Malanotte Rizzoli, 1991).

In the Strait of Sicily, the LW influences mainly the depth range between 150-200 and 1,000-1,200 m (Allain, 1970) or less (200-600 m), according to other authors, e.g., Bombace and Sarà, 1972. LW is more saline (38.5-38.8 ppt) than AW (38 ppt): both masses of water flow overlap. The bulk of these bodies of water follow the same path but in opposite directions, diverging only at the two extremities (De Maio *et al.*, 1974; Hopkins, 1985). The boundary layer has been estimated to coincide with the isohaline of 38 ppm (Moretti, 1974-75).

According to the inverse model (previously quoted) results, the deep water circulation seems to become well discriminated from that of the surface at about

500-600m, resulting a level of discrimination (no motion level) at about 400 m. The most striking features resulting by the application of the inverse model were that the LW, after leaving the Strait of Sicily, flows mainly northwards crossing the waters in front of Sardinia, France, Spain and the Balearic islands (Tziperman and Malanotte Rizzoli, 1991). The above description is a simplification of the real situation because the complex orography and the (sub-arid) climatic condition affect the current pattern; in fact rainfall (200-400 mm/year in Sicily; Cruzado, 1985) is among the lowest in the Mediterranean lands and, at least in the southern part of the Strait of Sicily, evaporation exceeds by 8-9 times the precipitation (Hopkins, 1985).

The presence of limited and narrow sills allowing a limited water exchange at the east side, enhances the formation of strong currents; as an example, the Adventure Bank, in front of Mazara, is almost continuously swept by very strong currents, which prevent the accumulation of terrigenous detritus (Colantoni *et al.*, 1985). The exchanges of water are mainly limited between surface and 500 m. Below that level, the water is quite homogeneous and the exchange occurs mainly by vertical mixing (Moretti, 1974-75). In the Strait of Sicily, the AW extends its influence down to 150-200 m (and more, up to 250-300 m according to other authors; e.g., Bombace and Sarà, 1972) where it meets and partially mixes with the LW. Its surface temperature varies according the seasons (about 15°C and more than 22°C in Winter and Summer respectively) and its saline content is about 37.5 ppt; flowing towards the eastern basin waters become cooler and more saline. The LW has about 14.2°C and 38.7 ppt when reaching the Strait of Sicily, where its influence extends down to 600-800 m. Bathythermograms evidenced a general situation of homeothermy (13-14°C), with the exclusion of the surface layers (50-100 m) in summer.

Trophic conditions

The biological productivity of the Mediterranean Sea is known to be among the lowest in the world and that it is mainly a consequence of the relatively low concentration of some biologically important chemical nutrients (biogenic elements) such as N, P and C, except perhaps in the vicinity of large rivers (Cruzado, 1985).

The Mediterranean Sea, even being a closed ocean, seems to be well adapted to avoid excessive eutrophication since it looses deep water rich in nutrients thru the Gibraltar Strait, a loss which is compensated by the surface water rich in plankton but relatively poor in nutrients (Margaleff, 1985); as an example, the average phosphate concentration of the Atlantic water when it cross the Gibraltar strait was estimated at about 0.20 mat.g/l (Béthoux, 1981). Even though some upwelling phenomenon has been reported at least in the westernmost sector under the influence of strong winds (Margaleff, 1985; Salusti and Zambianchi, 1985), the Mediterranean is generally not considered very productive in term of primary production.

Primary production varies according to the complex hydrology already evidenced ranging from about 80-90 $gC.m^{-2}.year^{-1}$, in the Western Mediterranean, to 6-20 $gC.m^{-2}.year^{-1}$ in the eastern basin (Sournia, 1973; Béthoux, 1981). The Western Mediterranean is more productive than the eastern basin and this has been explained by the different direct and indirect (river runoffs) inputs of nutrients as a consequence of human activities especially, in the case of semi-enclosed areas such the Gulf of Lions (FAO, 1992). From satellite images, the phytoplankton pigment concentration in the Mediterranean Sea generally falls in the range 0.15-0.6, with low concentrations (<0.05-0.15) in the levantine basin and higher values (>0.6) in special areas and on the shelf (FAO, 1992). The above figures suggest little biomass of phytoplankton, which is mainly represented by nannoplanctonic organisms (Berland *et al.*, 1988).

Characteristically, the nutrients concentration remains very low in the upper layers of water; the order of magnitude is 10 and 100 $mgat.m^{-2}$ for phosphate and nitrate respectively. The nitracline is located below the phosphatocline. Considering that both the C/P and N/P ratio in the organisms are usually high, it seems evident that phosphorous represents the most important limit in the Mediterranean plankton (Berland *et al.*, 1988). The chlorophyll biomass is generally low in the euphotic layer and its level of maximum concentration is found at about 65-80 m and 80-120 m in the western and eastern side respectively (Berland *et al.*, 1988) and, on the average, it occurs at about 100 m in Summer (Margaleff, 1985).

Traditionally, the Mediterranean Sea has been considered as an oligotrophic sea but this idea has been recently reviewed; particularly, the role played by microbial

activity and fragile macrozooplankton and micronecton (jellyfish, tunicates and other mucilaginous organisms) in enhancing efficiency in the utilization of the energy budgets and in the transferring of the energy from upper to deeper levels has been reevaluated (Jacques, 1989). The productivity of pelagic fish, comparable to that of other oceans considered more productive, supports the idea that in the Mediterranean Sea mechanisms others than the classical ones are able to enhance the general biological productivity.

As concerning the Strait of Sicily, the huge amount of solar energy received (on the average 650-763 $kj.cm^{-2}.year^{-1}$; Cruzado, 1985), the strong current pattern and the practical lack of river runoffs and limited rainfall have a negative impact on plankton populations (by the way, the offshore waters of the Strait of Sicily are very clean and transparent). In fact, satellite data reveals that the Strait of Sicily is an area of moderate phytoplankton crops (Chisolm, 1992); on the contrary, the same conditions allowed a flourishing of benthic vegetation.

Bionomy

Different studies on the benthic communities in the Strait of Sicily (Giaccone *et al.*, 1972; Cinelli *et al.*, 1979), have evidenced the dominance of rheophilic species, and with an Atlantic affinity. Large prairies of the seagrass *Posidonia oceanica*, which represents the most widespread and typical ecosystem in the Mediterranean phytal zone (Pérès and Picard, 1964), characterize wide extensions of the infralittoral bottoms down to 40-50 m (Cinelli *et al.*, 1979; Cinelli; 1980). Among the rhizome of this seagrass and in the circalittoral levels there are assemblages of the red algae (*Peyssonnelia*, *Lithophyllum*, *Lithothamnium*, etc.). The hard substrates in the infralittoral and the deeper bottoms of the circalittoral are colonized by wide populations of large brown algae such as *Cystoseira*, *Sargassum*, and especially *Laminaria rodriguezi* (Suriano *et al.*, 1992).

The sandy bottoms swept by unidirectional and oscillating currents between 40-120 m (but also at lower depth, between the seagrasses), especially nearby the Lampedusa island, host populations of calcareous red algae in "*forma aegagropila*",

the so-called "free melobesia" or "Maerl" (Pérès and Picard, 1964); different species and genera characterize this facies, the most important being *Lithophyllum*, *Mesophyllum*, *Pseudolithophyllum* and *Neogoniolithon* species (Giaccone *et al.*, 1972).

Bottoms between 30-50 m and 150-200 m are all ascribed, using the Pérès and Picard's (1964) classification, to the "circalittoral" layer, mainly characterized by kind and quantity of light penetration, that determines the biological aspects; the next, deeper level, generally associated with the continental slope and the deep steeps around the banks, is the "bathyal" layer. Considering the bathymetrics that are or could be trawled, this last bionomic layer can be split in two bands, "epi-bathyal" and "meso-bathyal", using as divide the 450 m depth (Arena, 1985).

Speaking of the hard substrates of the circalittoral layer, the Mediterranean shows a peculiar biocoenotic series named after the red coral, *Corallium rubrum*, the "coralligenous bottoms". They are characterized by: calcareous red algae (*Pseudolithophyllum expansum*), seaweeds (*Cystoseira zosteroides*, *C. spinosa*, *Vidalia volubilis*, *Udotea petiolata*, *Halimeda tuna*), sponges, cnidaria (*Eudendrium ramosum*, *Nemertesia tetrasticha*, *Campanularia alta*, *Muricaea chamaeleon*, *Eunicella cavolini*, *Alcyonium acaule*, *A. coralloides*, *Astroides calycularis*), polychaetes (*Serpula vermicularis*, *Eunice siciliensis*, *E. schizobranchia*), brachiopods (*Argyrotheca cuneata*), bryozoans (*Adeonella calveti*, *Porella cervicornis*, *P. concinna*, *Hippodiplosia fascialis*, *Myriozoum truncatum*, *Retepora* sp., *Schismopora avicularis*), crustaceans (*Lissa chiragra*), echinoderms (*Hacelia attenuata*, *Ophidiaster ophidianus*), sea squirts (*Rhodosoma verecundum*) and bivalves (*Chlamys pes-felis*, *Lima squamosa*) (Pérès and Picard, 1964).

Pérès and Picard (1964) describe another circalittoral biocoenosis of the hard bottoms, that of the "off-shore rocks": the characteristic group is that of the sponges (*Poecillastra compressa*, *Rhizaxinella pyrifera*, *Phakellia ventilabrum*, *Suberites carnosus*, *Acanthella acuta*, *Axinella polypoides*, *A. verrucosa*, *A. damicornis*, *Ciocalypta penicillus*, *Erylus discophorus*, *Ircinia muscarum*, *I. oros*, *Tylodesma inornata*, *Petrosia dura*), together with the cnidaria (*Corallium rubrum*,

Paralcyonium elegans, *Alcyonum acaule*); some species, e.g. the sea urchin *Cidaris cidaris*, are considered as outsiders coming from the bathyal zone.

The biocoenosis of the "coastal deposits" belongs to the soft bottoms and is characterized by the seaweed *Cryptonemia tunaeformis*, the sponge *Bubaris vermiculata*, the cnidaria *Sarcodyctyon catenatum*, the echinoderms *Genocidaris maculata* and *Ophioconis forbesi*, the molluscs *Lima loscombei*, *Propeamussium incomparabile*, *Chlamys flexuosa*, *Laevicardium oblungum*, *Cardium deshayesi*, *Tellina donacina*, *Eulima polita*, *Drillus maravignaae*. A frequent but not constant presence is that of the brown seaweed *Laminaria rodriguezi*, while the red seaweed *Halarachinion spatulatum* together with the sponge *Haliclona simulans* represent a peculiar facies.

In the area of the Sicilian Channel, the circalittoral bottoms between 65 m and 105 m are often sandy, with grains from coarse to very fine, nearly muddy, interspersed with abundant larger detritus of organic origin, such as shell fragments, calcareous plants and, less frequently, bryozoan remnants. Volcanic sands is present on the Adventure bank, while around and south of Lampedusa sand is of terrestrial origin; in the last areas there are large "Maerl" zones with free melobesia built by the red algae *Lithothamnium fruticulosum* and *Phymatolithon calcareum*. The occurrence of *L. fruticulosum* has been previously stated, for the coastal detrital assemblages by Pérès (1985): in such a situation the sediment is sprinkled with irregular nodules, which are formed by the superposition of these calcareous seaweeds. Melobesia populations represent in the Mediterranean a real facies in the biocoenosis of the coastal deposits (Pérès and Picard, 1964): particularly in the Western Mediterranean, Maerl bottoms are present in the 25-40 m band, and seldom reach 60-65 m of depth in very transparent waters. Soft seaweeds are abundant too, in the biocoenosis in general and over the Adventure bank in particular: at higher levels the green seaweed *Cladophora prolifera* is predominant, elsewhere are common *Dictyota dichotoma*, *Cutleria multifida*, *Padina pavonica*, *Halopteris filicina*, *Stypocaulon scoparium*, *Vidalia volubilis*, *Codium bursa*, *Laminaria rodriguezi*. The last species is epiphytic on the above mentioned nodules: on both these two species, i.e. the kelp and the calcareous seaweeds forming nodules, there are many epizootic species, such as

hydroids and bryozoans (Pérès, 1985). Rich and strong is the presence of the sponges, with *Suberites domuncula*, *Axinella verrucosa*, *A. polypoides*, *Acanthella acuta*, *Crambe crambe*, *Petrosia ficiformis*, *Haliclona cratera*, *Dysidea avara*, *D. fragilis*, *Cacospongia scalaris*, *Ircinia fasciculata*, *I. oros*, *Hippospongia equina*.

A non-peculiar distribution is shown by the cnidaria *Aglaophenia pluma*, *Alcyonium palmatum*, *Pennatula phosphorea*. This last species is typical of a particular kind of terrigenous mud-shelf assemblage, characterized by a viscous mud, and it is often associated with *Veretillum cynomorium* (Pérès, 1985); within the *Alcyonium* facies the rate of fine particles sedimentation is very low, which allows the significant development of sessile species, such as *A. palmatum*, and some hydroids and bryozoans (Pérès, 1985). Common are also the sea pen *Pteroides griseum* and the polychaetes *Hyalinoecia tubicola*, *Hermione histrix*, *Eunice vittata* and *Salmacina dysteri*.

Gastropods are both various and abundant (e.g. *Calliostoma granulatum*, *Astraea rugosa*, *Bittium reticulatum*, *Naticarius hebraeus*, *Cassidaria echinophora*, *Tonna galea*, *Bolinus brandaris*, *Buccinulum corneum*, *Conus ventricosus*); bivalves are mainly occurrent with the species *Arca noae*, *Spondylus gaederopus*, *Anomia ephippium*, *Acanthocardia echinata*, *Venus verrucosa*, *Hiatella arctica*, *H. rugosa*, *Pecten jacobaeus* (assumed to be characteristic of whole Western Mediterranean (Pérès, 1985); cephalopods presences are patchy, with *Eledone moschata*, *E. cirrhosa*, *Octopus vulgaris*, *Sepia officinalis* and *Loligo vulgaris*.

Around Lampedusa, the crustacean galatheid *Munida curvimanna* is observed on sandy-muddy grounds, while *Galathea strigosa* lives on the Maerl bottoms (GFCM, 1970). With a more diffused distribution are the macrurid crustaceans *Alpheus glaber* (defined as mud loving species, typical of the terrigenous mud shelf assemblages (Pérès, 1985)), *Pontocaris cataphractus*, *Plesionika edwardsi*, *Parapandalus narval*, and the hermit crabs *Dardanus arrosor*, *D. calidus*, *Pagurus bernhardus* (all in symbiosis with the sea anemone *Calliactis parasitica*), *P. prideaux* (symbiotic with *Adamsia palliata*), *P. sculptimanus* and *P. alatus* (both frequently associated with the sponge *Suberites domuncula*). Many crabs are present, such as *Macropipus depurator*, *Homola barbata*, *Pisa armata*, *Inachus dorsettensis*,

Parthenope angulifrons, *Macropodia longirostris*, *Calappa granulata*, *Dorippe lanata*, *Ethusa mascarone*, *Pilumnus hirtellus*. Bryozoans with wide distribution range are *Flustra haerbacea*, *Hippodiplosia foliacea*, *H. fascialis*, *Bugula avicularia*, *Cellaria fistulosa*, *Porella cervicornis*, *Myriozoum truncatum*. Echinoderms are frequent, both sea stars (*Sphaerodiscus placenta*, *Ophidiaster ophidianus*, *Hacelia attenuata*, *Hechinaster sepositus*, *Anseropoda membranacea* and *Marthasterias glacialis*) and sea urchins, such as *Sphaerechinus granularis*, *Psammechinus microturbeculatus* (characteristic in the western basin; Pérès, 1985) and *Cidaris cidaris* (an opportunistic species, very common in the offshore rocky-bottom assemblages). These mesolittoral bottoms are inhabited by many tunicates, such as *Ascidia mentula*, *Phallusia mammillata*, *Halocynthia papillosa*, *Aplidium conicum*, *Diazona violacea*.

Many fishes of commercial interest live in the mesolittoral layer, among which the most important red mullets, both the rocky one (*Mullus surmuletus*) and the muddy one (*M. barbatus*), and the pandora bream (*Pagellus erythrinus*); common are other demersal species such as the sea robins *Lepidotrigla cavillone*, *Aspitrigla cuculus*, *A. obscura*, *Trigloporus lastoviza*, the weevers *Trachinus radiatus*, *T. araneus*, *T. draco*, the stargazer *Uranoscopus scaber*, the flatfishes *Solea kleini*, *Microchirus ocellata*, *Monochirus hispidus*, *Citharus linguatula*, the scorpionfishes *Scorpaena notata* and *S. scrofa*, the combers *Serranus hepatus*, *S. cabrilla*, *S. scriba*. Also present are the horse-mackerels *Trachurus trachurus* and *T. mediterraneus*, and the picarels *Spicara smaris* and *S. flexuosa*. Other species, such as *Raja montagui*, *Pagellus centrodontus*, *Arnoglossus thori*, *Capros aper* and *Trigla pini*, are found near the lower border of this bathymetric layer, i.e. around 150 m (GFCM, 1970). The Sicilian Channel presents some species of sub-tropical attitude, such as the Portuguese sole *Synaptura lusitanica*, the corb *Umbrina ronchus*, *Cynoponticus ferox*, *Facciolella oxyrhyncha*, *Epigonus constanciae* (Fredj and Maurin, 1987).

In the Sicilian Strait, the hard bottoms of deeper bathymetric zones, those of the bathyal layer, are characterized (Arena, 1985) by many huge "buildings" produced by madrepores (*Madrepora oculata*, *Lophelia prolifera*), generally forming scattered clumps, that gives origin to the "white coral assemblages" biocoenosis (Pérès and

Picard, 1964), locally known as "cannelleri": those presents strong, stony corms that make extended surfaces of the grounds between 300 m and 450 m dangerous for the fishing activity, or even untrawlable altogether. Another white coral, *Dendrophyllia cornigera*, less hard but still an obstacle for fishing, lives at higher depths: in fact, it colonizes rocky substrates exposed to hydrodynamism, while the former corals prefer finer sediments. These species are often in association with non-colonial species such as *Caryophylla armata* and *Desmophyllum cristagalli* (Pérès, 1985).

The white corals biocoenosis hosts cnidaria (*Muricaea bebricoides*), bivalves (*Arca nodulosa*, *A. obliqua*, *Spondylus gussoni*, *Chlamys bruei*), polyplacophores (*Hanleya hanleyi*), polychaetes (*Harmothoe longisetis*, *Phyllodoce madeirensis*, *Vermiliopsis multicristata*, *Lagisca extenuata*, *Leocrates atlanticus*, *Pholoe dorsipapillata*), shrimps (*Pandalina profunda*) and barnacles (*Verruca* sp.).

The epibathyal layer extends between 200-250 m and 400-450 m, whose bottoms are generally muddy, with a consistent fraction of fine sand; their biocoenoses are poorer and less varied than those of the mesolittoral. The most typical biological indicator species is the sea pen *Funiculina quadrangularis*, even if it is now quite rare especially on the trawlable grounds; the occurrence of such a species is closely related to the abundance of the food supply. The pink (or white) shrimp *Parapenaeus longirostris*, an important target for the fishery, is often associated with the presence of *Funiculina*. Near Pantelleria and Levanzo, at depths of 300-400 m, the substrate has a higher proportion of sand, and the characteristic fauna is represented by *Cidaris cidaris*, *Nephrops norvegicus*, *Lophelia prolifera* and *Madrepora oculata* (Sarà, 1969).

In any event, those characterizing species are seconded by sponges (*Asconema setubalense*, *Pheronema grayi*, *Thenea muricata*), cnidaria (*Rosalinda incrustans*, *Thanmostoma cidaritis*, *Campanulina paniculata*, *Isidella coronata*, *Hormanthia coronata*, *Actinauge richardi*), echinoderms (*Odontaster mediterraneus*, *Ceramaster hystricis*, *Brisingella coronata*, *Ophiocten abyssicolum*, *Leptometra celtica*, *Mesothuria intestinalis*), bryozoans (*Triticellopsis tissieri*), polychaetes (*Aphrodite pallida*, *Harmothoe johnstoni*, *Leocrates atlanticus*, *Leanira tetragona*), various crustaceans and molluscs (Pérès and Picard, 1964). In a few zones, the brachiopod *Terebratula vitrea* is dominant, but always associated with *F. quadrangularis*.

The sponge *Thenaea muricata* is common, as well the sea pen *Pennatula rubra* and the sea anemones *Amphiantus dohrni* (that conglomerates mud and detritus at its basal disk), *Adamsia palliata* (symbiotic with the hermit crabs *Pagurus variabilis*, *P. alatus*, *Anapagurus laevis*), *Calliactis parasitica* (symbiotic with *Dardanus arrosor* and *Pagurus bernhardus*) (Arena, 1985). A wide distribution show the sea urchins *Odontaster mediterraneus* and *Astropecten irregularis pentacanthus*, species that belong to the lower part of the shelf and may occur from the coastal detrital assemblage down to different depths, depending on the quality and quantity of food supply (Pérès, 1985).

Among the crustaceans of this layer, the pink shrimp *Parapenaeus longirostris* is the most interesting; the Norway lobster, *Nephrops norvegicus*, is caught here too; frequent are other smaller shrimps, such as *Solenocera membranacea*, and the Atlantic shrimps (Pérès, 1985) *Plesionika martia*, *P. heterocarpus*, *P. antigai* (this last one assumed to be typical of the bathyal zone of the North African side, since it is missing from other Western Mediterranean areas); the galatheid *Munida curvimanna* is listed as very common within the profile (Pérès, 1985). *Microcosmus sulcatus* represents the sea squirts of the epibathyal layers.

Cartilaginous fishes are well and constantly represented in the layer, with the dogfishes *Etmopterus spinax*, *Squalus blainvillei*, *Scyliorhinus canicula* and the skates *Raja oxyrinchus*, *R. clavata*, *R. asterias*, *R. radula*, *R. miraletus*. Among the bony fishes are: the argentine (*Argentina sphyraena*), the green-eyes (*Chlorophthalmus agassizi*), the horse mackerel (*Trachurus trachurus*), the fork-beard (*Phycis blennoides*), the ling (*Molva dipterygia macrophthalma*), the hake (*Merluccius merluccius*), the poor cod (*Trisopterus minutus capelanus*), the pout (*Gadiculus argenteus argenteus*), the rat-tail fish (*Hymenocephalus italicus*), the John dory (*Zeus faber*), the boarfish (*Capros aper*), the spinefish (*Macroramphosus scolopax*), the scabbard (*Lepidopus caudatus*), the dragonet (*Synchiropus phaeton*), the rockfish (*Helicolenus dactylopterus*), the scorpionfish (*Scorpaena elongata*), the sea robins (*Trigla lyra* and *Peristedion cataphractum*), the turbots (*Lepidorhombus boscii* and *Lepidorhombus whiffiagonis*) (Maurin, 1962; Arena, 1985); for this depth, the blue whiting (*Micromesistius poutassou*) is the most diffused fish in the Western

Mediterranean (GFCM, 1970). Besides the previous species, the Sicilian Channel fisheries fish also: horse mackerel (*Trachurus* spp.), red mullet (*Mullus barbatus*), picarel (*Centracanthus cirrus*), pandora bream (*Pagellus erythrinus*) and, in front of western Libya, sea bream (*Pagrus pagrus pagrus*) (Scaccini *et al.*, 1970).

The northern part of the Channel, i.e. the western Sicily, does not show significant differences from the other areas (Arena and Li Greci, 1973), while in the southernmost part (in front of Capo Passero) are present the wreckfish *Polyprion americanus*, the grouper *Epinephelus guaza* and various sea robins *Trigla* spp. (Scaccini *et al.*, 1970). Maurin (1970), speaking in particular of the zone south of Lampedusa, reports *Trisopterus minutus capelanus*, *Aspitrigla cuculus*, *Callionymus maculatus*) even below 250 m; he does not find *Etmopterus spinax* nor *Hoplostethus mediterraneus*, quite common elsewhere in the Mediterranean at the same depth, while *Galeus atlanticus* and *Coelorhinchus coelorhynchus* are rare; moreover, *Chlorophthalmus agassizi* is abundant only at 400 m; the author explains those findings with a slide of certain elements, typical of this layer, toward greater depths.

The bottoms below 400-450 m belong to the mesobathyal layer; they are muddy, with a large proportion of compacted, oxidized, yellow sediments, and smaller surfaces of reducing, gray mud. The characteristic facies of this bionomic stratum is that at *Isidella elongata* (Gorgonacea), that is associated with the red shrimps *Aristaeomorpha foliacea* and , depending on the zones, *Aristeus antennatus*. Part of the same facies are the brachiopod *Tenebratula vitrea* and the echinoderm *Brisingella coronata* (GFCM, 1970).

Besides the red shrimps, other crustaceans, some of which with a pelagic attitude (Arena, 1985), are: *Sergestes robustus*, *S. arcticus*, *S. corniculum*, *Pasiphaea multidentata* (mainly around Levanzo and Pantelleria; Sarà, 1969), *Pontocaris lacazei*, *Polycheles typhlops*, and more shrimps; a few spiny lobsters *Palinurus mauritanicus* are also caught here; frequent are also the crabs *Paromola cuvieri*, *Geryon longipes*, *Ebalia cranchii*, *E. tuberosa*, *Monodaeus couchii*.

The cephalopods are not abundant, but anyway represented by *Pteroctopus tetracirrhus*, *Scaeurgus unicirrhus* and *Neorossia caroli*, *Rossia macrosoma*, *Todaropsis eblanae*, *Todarodes sagittatus*, *Illex coindetii* (Arena, 1985). Other

characteristic elements of the mesobathyal layer are the gastropods *Aporrhais serresianus* and *Fusinus rostratus*, and the sea cucumber *Mesothuria intestinalis*.

Fishes are the most abundant component of the mesobathyal, with a dominance of cartilaginous fish such as the dogfish *Galeus melastomus* and the rabbit fish *Chimaera monstrosa* (Maurin, 1962; Arena, 1985); also frequent at those depths is *Centrophorus uyato* (Scaccini *et al.*, 1970). Bony fishes are strongly represented by the rat-tail fishes *Hymenocephalus italicus*, *Nezumia sclerorhynchus*, *Coelorhinchus coelorhynchus*, the snake eel *Nettastoma melanurum* and many myctophids (Arena, 1985). Other regular presences are *Stomias boa*, *Centrolophus niger*, *Hoplostethus mediterraneus*, *Squalus blainvillei*, *Notacanthus bonapartei*, *Macrurus aequalis*, *Chlorophthalmus agassizi*, *Etmopterus spinax*, *Phycis blennoides*, *Micromesistius poutassou*, *Gadiculus argenteus argenteus*, *Molva dipterygia macrophthalma*, *Merluccius merluccius*, *Macroramphosus scolopax*, *Capros aper*, *Lophius budegassa*, *Lophius piscatorius*, *Lepidorhombus boscii* and more (Pérès and Picard, 1964).

South-East of Pantelleria, besides the already mentioned species, are common *Centrophorus granulosus*, *Raja oxyrinchus*, *Gaidropsarus megalokynodon*, *Helicolenus dactylopterus*, *Macropipus turberculatus* and *Desmophyllum cristagalli* (Bourgois and Farina, 1961; Bombace and Sarà, 1972); non rare is also *Callanthias ruber*, a species living close to the epibathyal border (Bombace and Sarà, 1972).

In western Sicily (i.e. the northern part of the Sicilian Channel), the mesobathyal layer shows some typical and exclusive species, such as the sponges *Pheronema grayi* and *Poecillastra compressa*, the cnidaria *Lophogorgia sarmentosa*, *Madrepora oculata*, *Lophelia prolifera*, *Dendrophyllia cornigera*, *Calliactis parasitica* and *Amphianthus dohrni*, the crab *Anamanthia rissoana*, the gastropods *Natica millepunctata*, *Lunatia fusca*, *Buccinum humphreysianum* and *Fusinus rostratus*, the cephalopods *Bathypolypus sponsalis*, *Heteroteuthis dispar*, *Alloteuthis media*, *Abralia veranyi*, *Histioteuthis reversa*, *Chiroteuthis veranyi* and *Octopoteuthis sicula* (Arena and Li Greci, 1973); in the northernmost area, the fishes *Chlorophthalmus agassizi* and *Aulopus filamentosus* are present too (Scaccini *et al.*, 1970).

Appendix C

EXTENSION OF THE MODEL OF BEVERTON AND HOLT'S TO CONSIDER ALLOMETRY (THE BETA FUNCTION)

Besides the classical integration of Beverton and Holt (1957) and the computational technique based on Thompson and Bell (1934) for estimating the yield-per-recruit, a less used approach makes it is possible to limit the calculations and to consider a non-cubic length-weight relationship, by expressing the yield utilizing the incomplete beta function.

R. Jones (1957) has generalized the Beverton and Holt's model in case the relation size-weight is not necessarily isometric, i.e. when $b \neq 3$ in the equation $W = a * L^b$. The calculations seem to get more complicated but an elegant integration produces simple relations. The total production of cohort is given by:

$$Y = F \int_{t_c}^{\infty} N(t)\ W(t)\ dt$$

with $N(t) = R\ e^{-M(t_c - t_r)}\ e^{-Z(t-t_c)}$ for $t > t_c$

and $W(t) = a\ L_\infty^{\ b}\ (1 - e^{-K(t-t_0)})^b$

hence: $W(t) = W_\infty\ (1 - e^{-K(t-t_0)})^b$

$$Y = F\ R\ e^{-M(t_c - t_r)} W_\infty \int_{t_c}^{\infty} e^{-Z(t-t_c)}\ (1 - e^{-K(t-t_0)})^b\ dt$$

or by writing $e^{-Z(t-t_c)} = e^{-Z(t-t_0)}\ e^{-Z(t_0-t_c)}$

$$Y = F\,R\,e^{-M(t_c-t_r)}e^{-Z(t_0-t_c)}W_\infty \int_{t_c}^{\infty} e^{-Z(t-t_0)}\,(1-e^{-K(t-t_0)})^b\,dt$$

By making the change of variable in the integral, i.e. $y = e^{-K(t-t_0)}$, the result, after a few rearrangements, is the relation (Jones, 1957; Gulland, 1969)

$$Y = R\,W_\infty e^{M(t_r-t_0)}\,g\,(1-c)^{-g} \int_0^{1-c} y^{(m+g-1)}\,(1-y)^b\,dy$$

keeping Gulland's notations (1969), i.e.:

$1-c = 1-l_c/L_\infty = e^{-K(t_c-t_0)}$, l_c being the length on first capture, associated to $t = t_c$

$m = M/K$

$g = F/K$

The integral $\int_0^{1-c} y^{(m+g-1)}\,(1-y)^b\,dy$

defines a function called incomplete beta (since the complete integration is from 0 to 1, not from 0 to 1-c). It is normally noted $B_{1-c}(m+g, b+1)$.

It does not usually possess a simple expression, but it is possible to use tables (Wilimovsky and Wiklund, 1963) or appropriate computerized modules which can be found under "Eulerian functions" (BlackBox, 1996).

The equation of complete production of a cohort thus becomes:

$$Y = R\,W_\infty\,e^{M(t_r-t_0)}\,g\,(1-c)^{-g}\,B_{1-c}(m+g, b+1)$$

This expression can be written differently, using the exploitation rate $E = F/Z$. Thus, $g = F/K$ can be written, since $F = (M\,E)/(1-E)$,

M/K E/(1 -E)= m E/(1 -E)

Thus:

$$Y = RW_\infty e^{M(t_r - t_0)} \left[m \frac{E}{1-E} (1-c)^{\frac{mE}{1-E}} B_{1-c}\left(m \frac{1}{1-E}, b+1\right) \right]$$

The expression in brackets only depends on:

$E = F/Z$ $\quad m = M/K$ $\quad c = l_c/L_\infty$ $\quad b$

for b and M/K known, it only depends on E and c. The importance of the ratio M/K is not surprising: this ratio summarizes the balance sheet between natural morality and relative growth. E represents the level of exploitation and $c = l_c/L_\infty$ corresponds to the fraction of the linear growth realized at the time when the animal enters the exploited phase.

On the interval of (t_i, t_{i+1}), the production Y_i can also be obtained by using incomplete beta functions. Indeed:

$$Y_i = \frac{N_i W_\infty}{K} F_i e^{Z_i(t_i - t_0)} \left(B_{1-c_i}(m+g, b+1) - B_{1-c_{i+1}}(m+g, b+1)\right)$$

N_i is the effective at the beginning of the interval (t_i, t_{i+1}), $1 - c_i = e^{-K(t_i - t_0)}$ and $1 - c_{i+1} = e^{K(ti+1-t0)}$.

The above algorithm is made of two parts; the first being a sort of "constant" since it does not contain the parameters (F or T_c) which depend on the fishing. The two quantities that refer to the beta function are obtainable by numerical integration packages (BlackBox, or from *ad hoc* tables (Wilimovsky and Wiklund, 1963), once the parameters M/K, F/K, b and c were set (Fig. 109).

Despite the apparent complexity, the Jones (1957) formulae are simple, and bring to expressions enough treatable to be used in an ordinary isometric situation too (Beverton and Holt, 1966). In any event, even in case of allometry, it is not always necessary to apply the Jones' formulae, since the errors are small when the parameters of

the growth curve are derived in relation to the cubic root of the weight, and not in relation to the actual length (Paulik and Gales, 1964). Moreover, for many purposes the age of exit from the fishery can be considered infinite and the equation is simplified by the deletion of the final term of the incomplete beta function. It must be noted here that, while b rarely departs appreciably from b= 3 in fish, the same is not true for shrimps, where b is often substantially below the isometric value; again, since the shrimps are somehow "short-lived", the age of exit from the fishery is an important parameter. Of course, when the basic assumptions are not fulfilled, it is always possible to express the yield as the summation of the yields in numerous small time intervals, within which size and number changes can be ignored (Gulland, 1988).

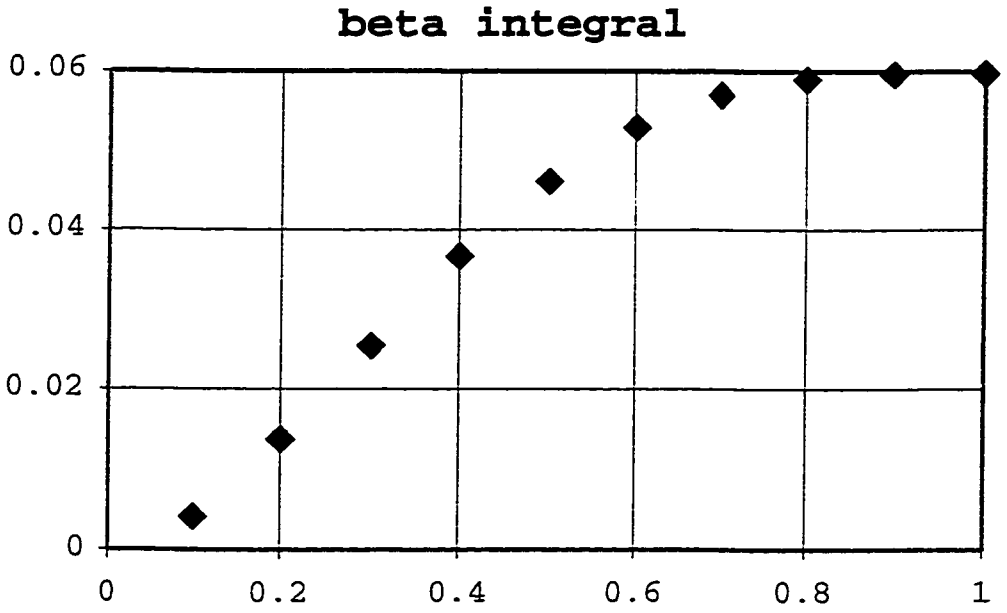


Fig. 109 - Shape of the beta function for b= 2.642, K= 0.6, M= 0.5, F= 0.45.

Appendix D

ESTIMATION OF THE GROWTH PARAMETERS FOR *ARISTAEOMORPHA FOLIACEA*

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DISCUSSION OF RESULTS FROM BHATTACHARYA METHOD

Given that the logarithm of a Gaussian is a concave quadratic and that its derivative is therefore a negative-slope linear, a scatterplot of the first differences of the logarithms of a LFD with multiple modes (real components) shows a series of negative linear regression lines. (pages 55-57 of Titterington *et al.*, 1985) On this premise is based the Bhattacharya's (1967) method for deconvoluting a LFD in its normal components (Fig 110, from data from the earlier trawl surveys).

Linosa South-East, all the "valid" females

The **SE Spring** data set was first analyzed with an "automatic", macroscopic approach: the highest and lowest points in each straight run of the linearized regression plot were always taken as "belonging" to the component. Five groups were easily separated: the total χ^2 was 541 (15 d.o.f.), with only the contribution from class 22 above 100 (212; 894 actual individuals *vs.* 552 expected).

group	mean	StD	population	S.I.
1	20.1	2.54	5003	-
2	38.8	2.61	6473	7.25
3	47.4	2.45	2302	3.40
4	53.7	3.18	612	2.24
5	60.7	1.04	31	3.07

In the following "reasoned" analysis, the researcher's decisions are more personal, mired at maximizing the visual fitting; this "personal feeling" suggested a 6-group subdivision (mainly deriving from a split of the first assemblage, that probably must be reunited for the growth analysis), even if the first and last separation indexes were too

low. The total χ^2 was 177 (11 d.o.f.), with the highest contributions at only 62 (class 40; 827 actual individuals *vs.* 1087 expected) and 29 (class 30; 60 *vs.* 30).

group	mean	StD	population	S.I.
1	18.9	2.30	2810	-
2	22.5	1.75	2500	1.78
3	38.9	2.48	6129	7.78
4	47.3	2.52	2347	3.35
5	53.9	2.38	584	2.68
6	56.8	2.73	51	1.16

The **SE Summer** data set was thereafter analyzed: it should be said that, even at the simplest visual glance, this LFD appeared quite nasty to interpretation. Four groups were separated with the "automatic" approach: the total χ^2 exceeded 999, a meaningless value, with maximal contributions from classes 36 (154; 3596 actual individuals *vs.* 4421 expected), 38 (350; 2178 *vs.* 3243), 40 (197; 2716 *vs.* 2076) and 42 (398; 2763 *vs.* 1893).

group	mean	StD	population	S.I.
1	24.9	2.47	13806	-
2	41.4	2.42	12576	6.74
3	49.2	3.99	9442	2.45
4	55.8	2.46	862	2.03

A further step was to leave the analysis as "impersonal" as possible, but correcting to exclude points that appeared evidently not to strictly belong to their putative component. Again, four groups appeared as separated: the total χ^2 lowered to 713 (15 d.o.f.), with contributions above 100 only from class 38 (322; 2178 *vs.* 3193).

group	mean	StD	population	S.I.
1	24.9	2.47	13806	-
2	41.4	2.42	12576	6.74
3	47.8	2.61	7601	2.58
4	54.4	2.87	2712	2.39

Two more "reasoned" analyses were tried, both producing 5 groups. First, the following groups appeared as separated: the total χ^2 was 638 (12 d.o.f.), with only class 44 contributing more than 100 (102; 1906 *vs.* 2402).

group	mean	StD	population	S.I.
1	25.3	2.55	14257	-
2	41.0	2.24	11236	6.54
3	47.9	2.08	8055	3.19
4	53.6	2.90	3114	2.31
5	60.7	1.44	34	3.24

A slightly different "reasoning" resulted in the groups below, with a total χ^2 of 622 (12 d.o.f.), and no contribution over 100.

group	mean	StD	population	S.I.
1	25.3	2.55	14257	-
2	41.0	2.24	11234	6.54
3	47.9	2.08	8058	3.19
4	53.7	2.82	3083	2.35
5	59.7	1.80	65	2.63

Linosa North-East, all the "valid" females

The **NE Spring** data set was first analyzed with an "automatic", macroscopic approach: again, the highest and lowest points in each straight run of the linearized regression plot were always taken as "belonging" to the component. Four groups were separated: the total χ^2 was 298 (15 d.o.f.), with only the contribution from class 32 above 50 (73; 41 actual individuals *vs.* 12 expected).

group	mean	StD	population	S.I.
1	20.8	2.64	1526	-
2	41.2	2.31	5382	8.23
3	49.5	2.31	3665	3.61
4	55.6	3.02	1069	2.31

A further step was to leave the analysis as "impersonal" as possible, but "tuning" it with small corrections in the inclusion of "marginal" points. One, quite useless, trial was to force a last group (even if the separation index was too low), thus resulting in five groups: the total χ^2 lowered to 277 (but with only 13 d.o.f.), again with only the contribution from class 32 above 50 (73; 41 actual individuals *vs.* 12 expected).

group	mean	StD	population	S.I.
1	20.8	2.64	1526	-
2	41.2	2.31	5382	8.23
3	49.5	2.31	3665	3.61
4	55.5	2.52	1014	2.50
5	59.1	2.47	83	1.42

Another useless trial was to "postpone" the entry of the first classes, keeping the simplest 4-group hypothesis: the total χ^2 raised to 468 (15 d.o.f.), with the contribution of class 32 at 215 (41 actual individuals *vs.* 6 expected).

group	mean	StD	population	S.I.
1	20.9	2.80	1557	-
2	41.2	2.17	5312	8.19
3	49.4	2.36	3714	3.63
4	55.7	3.01	1058	2.33

The most useless trial of these "macroscopic" analyses was to "postpone" the entry of the first classes and in the meantime to "flatten" the second Gaussian, keeping the simplest 4-group hypothesis: the total χ^2 jumped to 561 (16 d.o.f.), with the contribution of class 30 at 135 (27 actual individuals *vs.* 4 expected).

group	mean	StD	population	S.I.
1	21.3	2.45	1618	-
2	41.2	2.71	5437	7.71
3	49.6	2.14	3483	3.46
4	55.2	3.27	1113	2.07

In the following more "reasoned" analysis, the "researcher's feeling" suggested a 6-group subdivision, even if the last separation index was too low and the second group was a totally spurious artifact. The total χ^2 was 215 (12 d.o.f.), with the highest contributions at 50 (class 14; 86 actual individuals *vs.* 41 expected) and 40 (class 42; 833 *vs.* 1035).

group	mean	StD	population	S.I.
1	21.3	2.44	1618	-
2	33.8	1.90	98	5.74
3	41.3	2.27	5203	3.59
4	49.5	2.29	3649	3.61
5	55.5	2.53	1019	2.50
6	59.1	2.47	82	1.43

Even eliminating the last component to regain the 5-group hypothesis, the second group remained a spurious artifact. the total χ^2 was 301 (15 d.o.f.), with the highest contribution at 62 (class 12; 22 actual individuals *vs.* 5 expected).

group	mean	StD	population	S.I.
1	21.3	2.45	1618	-
2	33.8	1.89	98	5.73
3	41.2	2.17	5152	3.68
4	49.4	2.36	3715	3.63
5	55.6	3.17	1069	2.21

The **NE Summer** data set was thereafter analyzed, and four groups were separated by the "automatic" approach: the total χ^2 was 167 (13 d.o.f.; quite good for this sample size), with maximal contributions from classes 34 (27; 398 actual individuals *vs.* 307 expected) and 46 (26; 347 *vs.* 456).

group	mean	StD	population	S.I.
1	25.4	2.54	1328	-
2	42.6	2.24	1854	7.17
3	50.4	1.82	1099	3.88
4	56.5	3.21	1070	2.41

A further step was to leave the analysis as "impersonal" as possible, but correcting to exclude points that appeared evidently not to strictly belong to their putative component. Again, four groups appeared as separated: the total χ^2 lowered to 51.8 (14 d.o.f.), with highest contributions from classes 26 (12.5; 15 actual individuals *vs.* 36 expected) and 34 (10.9; 398 *vs.* 337).

group	mean	StD	population	S.I.
1	25.8	2.72	1347	-
2	42.2	1.97	1744	6.96
3	50.5	2.57	1318	3.64
4	57.3	2.89	974	2.50

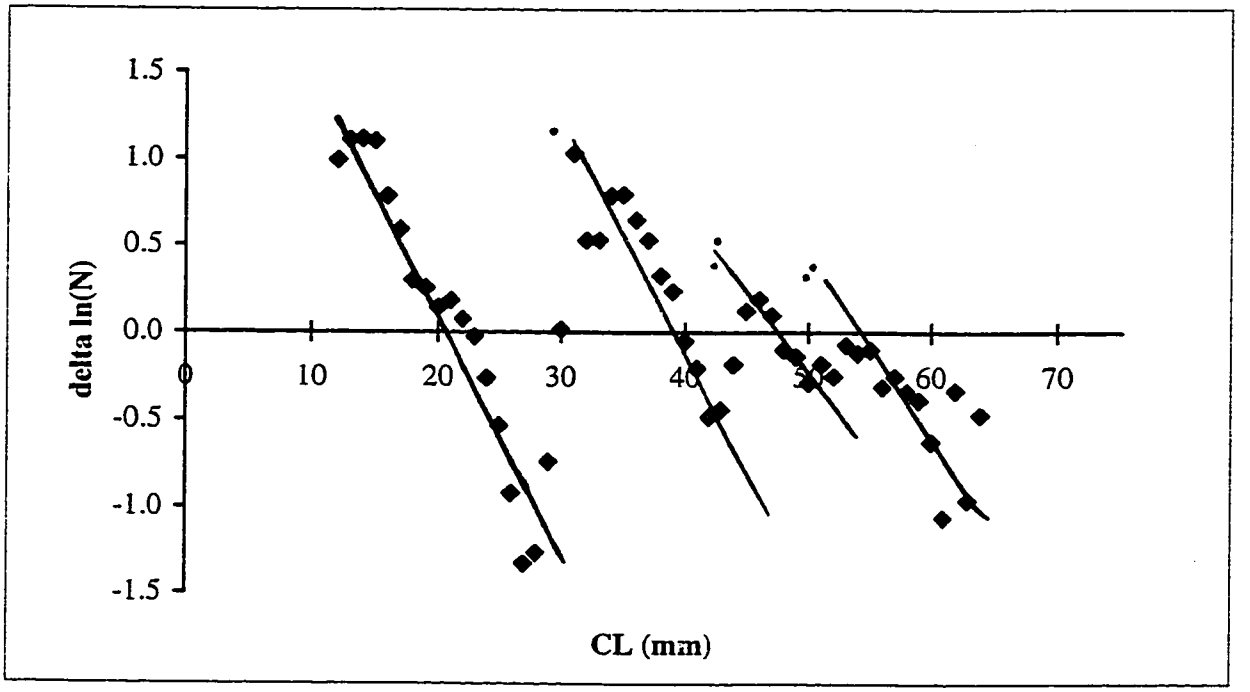


Fig. 110 - Bhattacharya's deconvolution of *Aristaeomorpha foliacea* LFDs from the selectivity study, NE of Linosa in the summer.

A more "reasoned" analysis was also tried, again producing 4 separated groups: but the total χ^2 worsened (56.1; 13 d.o.f.); only class 34 contributed more than 10 (10.8; 398 *vs.* 338).

group	mean	StD	population	S.I.
1	25.9	2.61	1346	-
2	42.2	1.97	1746	7.09
3	50.5	2.57	1318	3.64
4	57.3	2.93	976	2.49

Influence of dimension of data set

The Bhattacharya's method is highly subjective and requires some sort of trading among different imprecisions; the indexes that are provided, standard deviation of the means, correlation, χ^2 are only indicative. As an example, one of the data sets (NE, both spring and summer) was multiplied by a factor of 0.1 and by a factor of 10, and treated in "automatic": while the results were almost identical, such was not the case for the χ^2. An example (NE Summer) follows (reminder of actual data, total χ^2 of 167 with 13 d.o.f.).

Data reduced by 1/10, NE Summer, with a total χ^2 of 18.0 (10 d.o.f.), and no contribution over 2.5.

group	mean	StD	population	S.I.
1	25.4	2.74	134.4	-
2	42.6	2.27	185.3	6.86
3	50.4	1.71	107.7	3.96
4	56.5	3.18	108.3	2.46

Data increased by 10, NE Summer, with a total χ^2 over 999, a meaningless value, and 7 contribution over 100.

group	mean	StD	population	S.I.
1	25.4	2.54	13281	-
2	42.6	2.24	18538	7.17
3	50.4	1.82	10988	3.88
4	56.5	3.21	10695	2.41

DISCUSSION OF RESULTS FROM MIX

The results obtained by the Bhattacharya were used as seeds for the MIX procedure. A tentative with the reduction of the number of classes, by doubling the length interval to 2 mm, has not improved the results. As could seen in detail in the results for Linosa North-East, the lognormal and gamma distribution options did not significantly influence the final outputs. The incorporated search for the Bertalanffy parameters did not produce reasonable results (low $CL_\infty \approx 55$ mm; high $K \approx 0.9$), therefore a non-linear regression with SYSTAT was preferred.

Linosa South-East, all the "valid" females

After a preliminary assessment of the performance of the "lognormal" and "gamma" distribution options on the kind of data available, the **SE Spring** data set was analyzed with the "normal" option only. The decision of using 4 "age" groups produced (total $\chi^2 = 96$; 42 d.o.f.):

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	20.6 ±0.08	2.57 ±0.057	0.37 ±0.01
2	39.8 ±0.08	2.21 ±0.066	0.41 ±0.01
3	47.4 ±0.22	1.86 ±0.257	0.13 ±0.03
4	52.8 ±1.24	3.61 ±0.564	0.09 ±0.03

while the use of 5 "ages" resulted in (total $\chi^2 = 122$; 43 d.o.f. without estimating StD):

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	21.6 ±0.07	2.40	0.37 ±0.01
2	39.8 ±0.08	2.40	0.41 ±0.01
3	48.0 ±0.22	2.40	0.16 ±0.01
4	54.5 ±0.88	2.40	0.05 ±0.01
5	58.3 ±2.50	2.40	0.01 ±0.01

Also the **SE Summer** data set was analyzed with the "normal" option only. The decision of using 4 "age" groups produced (total χ^2= 80; 37 d.o.f.):

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	26.2 ±0.04	2.29 ±0.031	0.39 ±0.01
2	41.8 ±0.07	1.85 ±0.051	0.29 ±0.01
3	48.0 ±0.12	1.82 ±0.146	0.18 ±0.02
4	53.4 ±0.52	3.30 ±0.243	0.14 ±0.02

while the use of 5 "ages" resulted in (total χ^2= 80; 35 d.o.f.):

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	26.2 ±0.04	2.28 ±0.031	0.39 ±0.01
2	41.8 ±0.07	1.85 ±0.051	0.29 ±0.01
3	48.1 ±0.13	1.86 ±0.146	0.19 ±0.02
4	53.7 ±0.48	3.08 ±0.240	0.13 ±0.02
5	60.8 ±0.47	0.60 ±0.522	0.00 ±0.00

Linosa North-East, all the "valid" females

The **NE Spring** data set was analyzed with the all the three distribution options. The 4 "age" groups hypothesis produced:

Normal (total χ^2= 99; 41 d.o.f.)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	22.4 ±0.15	2.69 ±0.107	0.14 ±0.01
2	42.1 ±0.08	2.15 ±0.065	0.45 ±0.01
3	50.0 ±0.15	1.71 ±0.149	0.25 ±0.03
4	55.3 ±0.77	3.31 ±0.380	0.17 ±0.03

Lognormal (total χ^2= 105; 41 d.o.f.)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	22.6 ±0.17	3.06 ±0.128	0.14 ±0.01
2	42.1 ±0.08	2.09 ±0.066	0.45 ±0.01
3	50.1 ±0.17	1.77 ±0.148	0.26 ±0.03
4	55.9 ±0.63	3.01 ±0.305	0.15 ±0.02

Gamma (total χ^2= 104; 41 d.o.f.)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	22.6 ±0.17	2.96 ±0.120	0.14 ±0.01
2	42.1 ±0.08	2.09 ±0.065	0.45 ±0.01
3	50.0 ±0.16	1.75 ±0.147	0.26 ±0.03
4	55.7 ±0.68	3.10 ±0.326	0.15 ±0.03

while the use of 5 "ages", without estimating StD, resulted in:

Normal (total χ^2= 130; 43 d.o.f.)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	22.4 ±0.13	2.25	0.14 ±0.01
2	42.0 ±0.08	2.25	0.44 ±0.01
3	50.4 ±0.13	2.25	0.31 ±0.01
4	56.9 ±0.25	2.25	0.09 ±0.01
5	60.9 ±0.94	2.25	0.00 ±0.00

Lognormal (total χ^2= 164; 43 d.o.f.)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	22.3 ±0.13	2.33	0.14 ±0.01
2	42.2 ±0.08	2.33	0.45 ±0.01
3	50.6 ±0.15	2.33	0.32 ±0.01
4	57.1 ±0.32	2.33	0.09 ±0.01
5	60.3 ±1.34	2.33	0.01 ±0.00

Gamma (total χ^2= 153; 43 d.o.f.)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	22.3 ±0.13	2.30	0.14 ±0.01
2	42.1 ±0.08	2.30	0.45 ±0.01
3	50.5 ±0.14	2.30	0.31 ±0.01
4	57.0 ±0.29	2.30	0.09 ±0.01
5	60.6 ±1.14	2.30	0.01 ±0.00

Also the **NE Summer** data set was analyzed with the three options, but only within the 4 "age" groups, resulting in:

Normal (total χ^2= 26; 39 d.o.f.; P<0.95)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	26.9 ±0.15	2.42 ±0.106	0.25 ±0.01
2	43.2 ±0.12	1.83 ±0.094	0.33 ±0.01
3	50.7 ±0.31	1.83 ±0.302	0.16 ±0.04
4	57.2 ±0.64	3.37 ±0.363	0.25 ±0.03

Lognormal (total χ^2= 32; 39 d.o.f.; P<0.80)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	26.9 ±0.15	2.51 ±0.114	0.25 ±0.01
2	43.3 ±0.12	1.83 ±0.098	0.33 ±0.01
3	50.9 ±0.35	1.90 ±0.307	0.18 ±0.03
4	57.6 ±0.56	3.11 ±0.309	0.24 ±0.03

Gamma (total χ^2= 29; 39 d.o.f., P<0.85)

group	mean ±s.e.	StD ±s.e.	proportions ±s.e.
1	26.9 ±0.15	2.47 ±0.110	0.25 ±0.01
2	43.2 ±0.12	1.83 ±0.097	0.33 ±0.01
3	50.9 ±0.33	1.87 ±0.302	0.18 ±0.03
4	57.4 ±0.58	3.19 ±0.324	0.24 ±0.03

Non-linear regressions

Both Quasi-Newton and Simplex have been used as minimization algorithms for the non-linear regressions of the CL mean values (by "age" component) resulting from MIX: the possible coefficients were CL_∞, K and t_0, but since latter was always imprecisely estimated (asymptotic s.e. of $t_0 \approx t_0$ itself) it has been dropped altogether. Since the hatching time is unknown, the date of putative birth for the recruits was set at the previous-year's August, September or October (Fig. 111). Therefore, the analysis produced the following results:

South-East, August: CL_∞= 58.0 ±0.96 and K= 0.62 ±0.025 (s.e.= 0.58)

South-East, September: CL_∞= 56.6 ±0.85 and K= 0.70 ±0.025 (s.e.= 0.57)

South-East, October: CL_∞= 55.3 ±0.96 and K= 0.79 ±0.035 (s.e.= 0.93);

North-East, August: CL_∞= 62.2 ±1.34 and K= 0.60 ±0.035 (s.e.= 0.99)

North-East, September: CL_∞= 60.6 ±1.20 and K= 0.67 ±0.035 (s.e.= 1.00)

North-East, October: CL_∞= 59.1 ±1.26 and K= 0.75 ±0.050 (s.e.= 1.42);

Pooled, August: CL_∞= 60.1 ±1.35 and K= 0.61 ±0.035 (s.e.= 2.15)

Pooled, September: CL_∞= 58.6 ±1.20 and K= 0.68 ±0.035 (s.e.= 2.15)

Pooled, October: CL_∞= 57.2 ±1.14 and K= 0.77 ±0.035 (s.e.= 2.48).

From the behaviour of the mean s.e. of the regressions, September has been chosen as putative birth date, and the decision to keep the two zone separated has been supported.

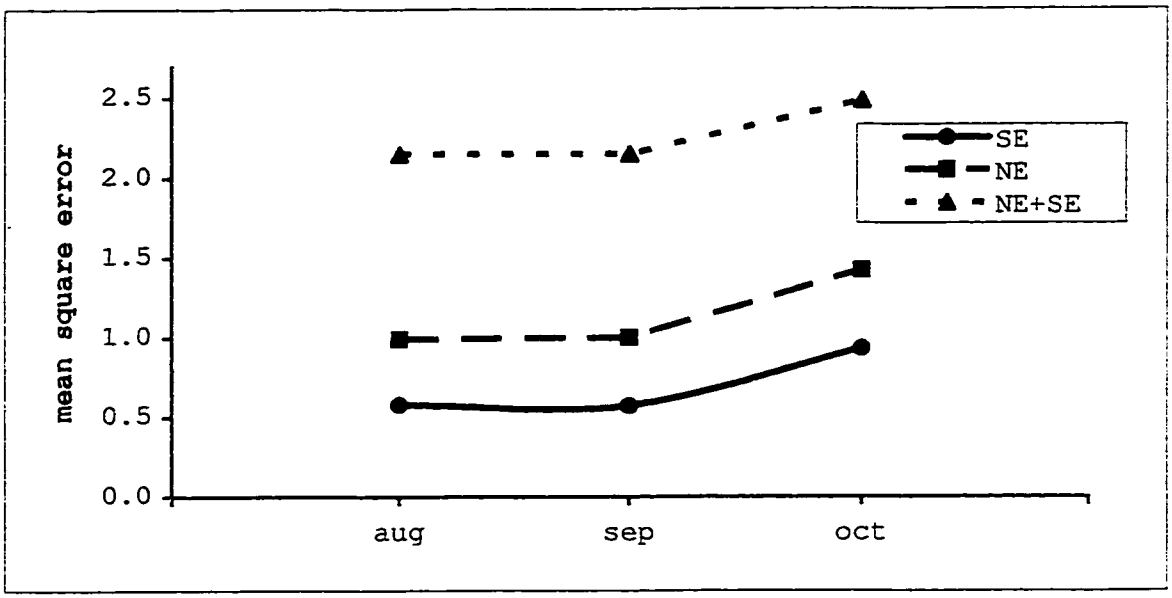


Fig. 111 - The mean square error of the MIX estimates on the seasonal LFDs of *Aristaeomorpha foliacea* females, depending on the date of putative birth (August, September or October).

DISCUSSION OF RESULTS FROM MULTIFAN

Linosa South-East, all the "valid" females

The first search with Multifan, that implied a **simple** systematic search on the age-K grid [classes 3 to 7; K from 0.35 to 0.875 (by 0.075 increments); sample I= y1,m1,w3 sample II= y1,m4,w1], produced the best MLE at K= 0.8 with "age" 7 [1918 (15 prmtr)], and sub-optimal MLEs at K= 0.65 with "age" 4 [1842 (9 prmtr)], at K= 0.725 with "age" 5 [1893 (11 prmtr)] and with "age" 6 [1905 (13 prmtr)]; the maximum improvement was between "ages" 3 and 4 [67 (+2 prmtr)], followed by that between "ages" 4 and 5 [50 (+2prmtr)], but still significant (in terms of χ^2) ones between "ages" 5 and 6 or "ages" 6 and 7. Having opted for a "life span" of 5 classes [1893 (11 prmtr), penalty 0.31], that represent a compromise of the biological knowledge and the best MLEs, with K= 0.725 the resulting proportions and average CL were (Fig. 112):

"age"	1	2	3	4	5
sample I	0.36	0.43	0.17	0.00	0.04
sample II	0.40	0.33	0.19	0.00	0.07
mean length of I	20.2	39.2	48.4	52.8	55.0

For these results, the StD of length in sample I was estimated at 2.47, and the age 1 of sample I at 0.60 y; the corresponding CL_∞ was 57.0 mm, quite short for the available biological knowledge of the area(> 64 mm). The major problem in accepting these Multifan estimates resides in the "absence" of the fourth class, and that was even worse with longer life spans.

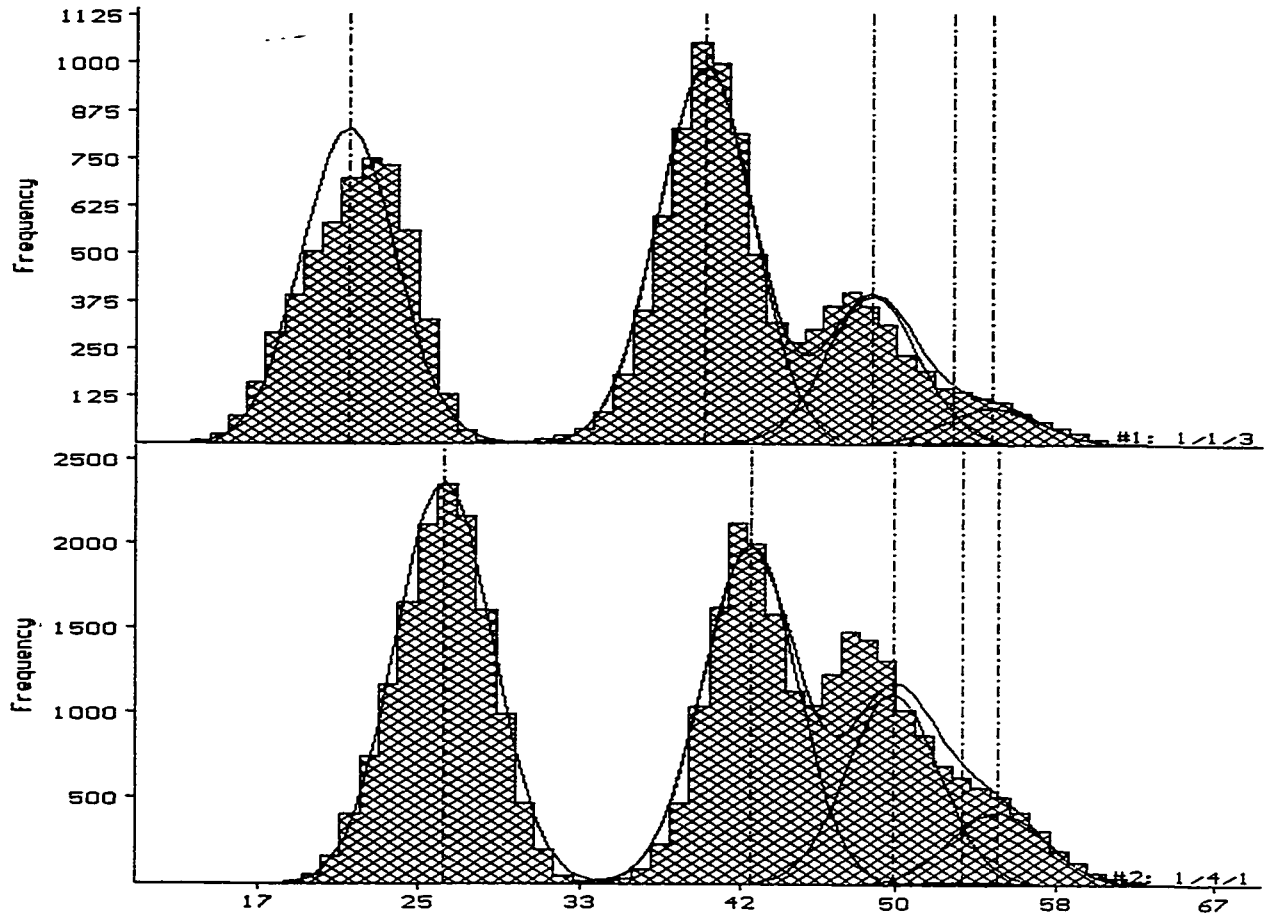


Fig. 112 - MULTIFAN separation of *Aristaeomorpha foliacea* females from Linosa South-East, by simple search (5-year hypothesis).

Conversely, renouncing to maximize the overall MLE, thus opting for a relatively short "life span" of 4 classes [1842 (9 prmtr), penalty 0.007], with K= 0.65 the resulting proportions and average CL were:

"age"	1	2	3	4
sample I	0.39	0.44	0.13	0.04
sample II	0.41	0.35	0.17	0.07
mean length of I	20.2	39.2	48.4	52.8

For these results, the StD of length in sample I was estimated at 2.55, and the age 1 of sample I at 0.65 y; the corresponding CL_∞ was improved at 59.8 mm. As could be easily

seen, the third peak of the LFDs has not been "absorbed" well; to try to overcome this problem, the fitting curves were constrained with fixed proportions and/or boundaries but, even if the eye was satisfied, all the analytical elements worsened sensibly.

The second search with Multifan, that implied a systematic search on the same age-K grid allowing **StD** to vary, produced the best MLEs again in the K= 0.8-"age" 7 position [1925 (16 prmtr)], and sub-optimal MLEs at K= 0.65 with "age" 4 [1843 (10 prmtr)] and at K= 0.725 with "age" 5 [1902 (12 prmtr)] or "age" 6 [1918 (14 prmtr)], all with significant improvements [(+2 prmtr)]. Having opted again, for the already said reasons, for a "life span" of 4 classes [1843 (10 prmtr), penalty 0.007], the resulting proportions and average CL were:

"age"	1	2	3	4
sample I	0.39	0.44	0.13	0.03
sample II	0.41	0.35	0.17	0.07
mean length of I	20.5	39.3	49.1	54.2

As before, for these results, the age 1 of sample I was estimated at 0.65 y and the corresponding CL_∞ was 59.8 mm. The StD varied from 2.61 to 2.48 (average 2.54), with a ratio of 0.95. The introduction of an additional parameter to be estimated (StD) is not justified by improved results with the 4 "ages" hypothesis; conversely, even improved, the outcomes for other "ages" remain biologically unsatisfying.

The following step, that implied the varying of two "**seasonal**" parameters, growth amplitude and growth phase, on the same age-K grid, changed the position of the best MLEs to the K= 0.725 column [1897 (13 prmtr)-1923 (15 prmtr)], with significant improvements up to 6 "ages". Having opted again, since the problem of the "ghost class" did persist, for a "life span" of 4 classes [1847 (11 prmtr), penalty 0.007], the resulting proportions and average CL were:

"age"	1	2	3	4
sample I	0.39	0.44	0.13	0.04
sample II	0.41	0.35	0.18	0.07
mean length of I	20.6	39.4	49.1	54.2

For these results, the StD of length in sample I was estimated at 2.55, and the age 1 of sample I at 0.66 y; the corresponding CL_∞ was always 59.8 mm. The seasonal growth amplitude was 0.10, and its phase 0.54. The introduction of two additional parameters to be estimated (SGA and SGP) is not justified by improved results.

The next possibility of single fluctuation, that implying the **bias** in the first class due to capture processes on the same age-K grid, almost mimicked the initial search, suggesting only a negligible bias. Therefore, the introduction of the additional bias parameters in the model is not justified by improved results.

The last and most important possibility offered by the Multifan procedure, that allowing the estimation of **K** in the same starting age-K grid, produced "flat" MLEs contours, meaning that the maximum for each "age" was spread over a range of K values, about 0.2 wide; still, Multifan suggested K= 0.635 for "age" 4 [1843 (10 prmtr)], K= 0.731 for "age" 5 [1893 (12 prmtr)] and K=0.772 for "age" 7 [1928 (16 prmtr)]; the maximum improvement remained between "ages" 3 and 4 [66 (+2 prmtr)], with still large ones between "ages" 4 and 5 [50] and "ages" 5 and 6 [27]. Since the previous problems could not be overcome, and having therefore opted again for a "life span" of 4 classes [1843 (10 prmtr), penalty 0.007], the resulting proportions and average CL were (Fig. 113):

"age"	1	2	3	4
sample I	0.39	0.44	0.14	0.04
sample II	0.41	0.35	0.18	0.06
mean length of I	20.6	39.3	49.2	54.4

For these results, the StD of length in sample I was estimated at 2.56, and the age 1 of sample I at 0.66 y; K moved to 0.635, and the corresponding CL_∞ changed to 60.3 mm, a quite reasonable estimate. It should be remembered that, improvements or not, it is deemed always necessary to let K vary.

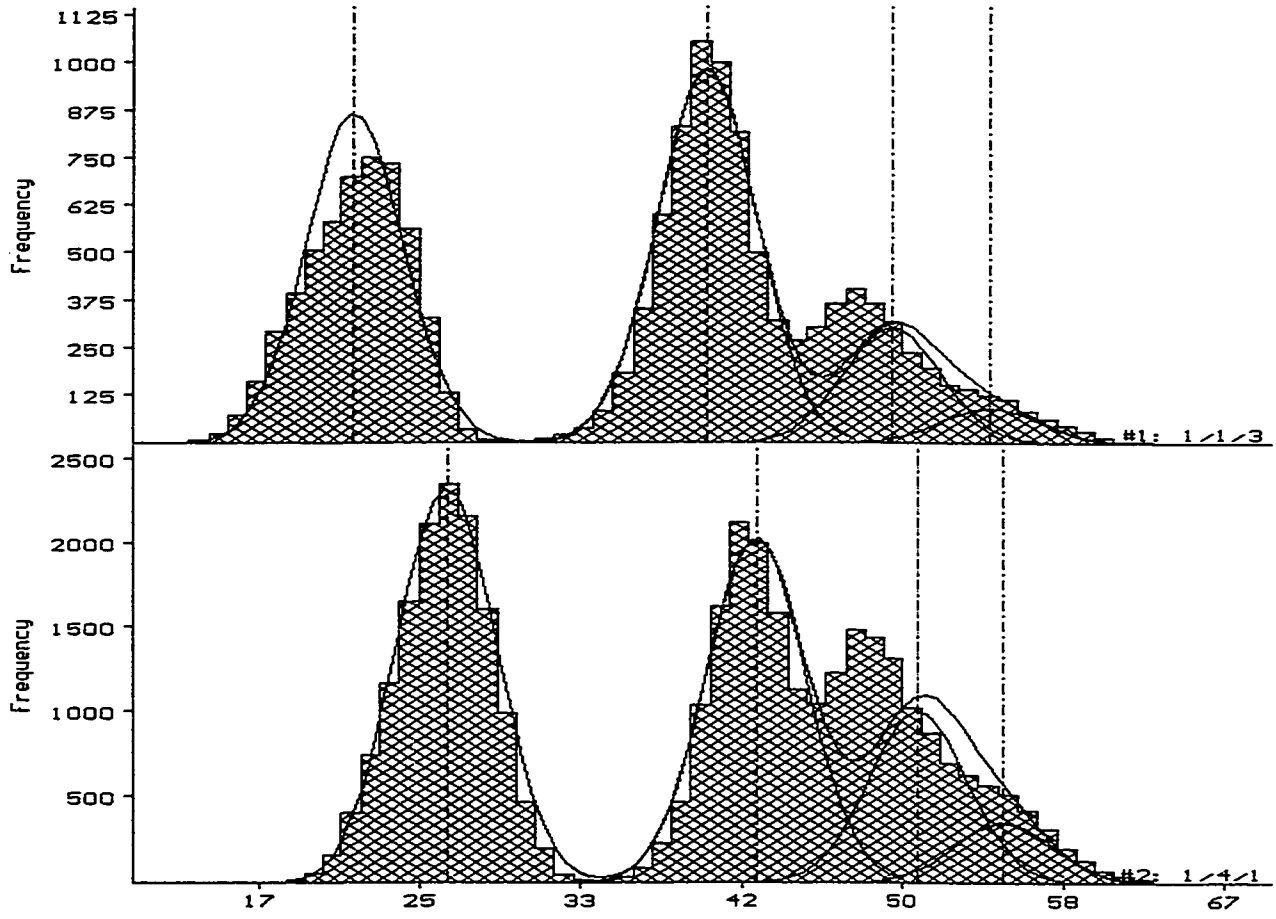


Fig. 113 - MULTIFAN separation of *Aristaeomorpha foliacea* females from Linosa South-East, by K-fluctuating search (4-year hypothesis).

Being this the finally preferred search, the instantaneous annual total mortality rate (Z) was computed too: utilizing both seasonal samples, it resulted 0.71; utilizing only the summer sample, i.e. considering that the first component was not fully recruited in spring, Z dropped at 0.63.

It is interesting, at least for the former analysis, to report the StD of the estimates:
first length= 0.064; last length= 0.115; average StD= 0.091; first age= 0.001;
CL_∞= 0.266; K= 0.008;
and a few correlation coefficients:
L1/L2= 0.19; age1/L1= 0.38; age1/L2= -0.70; CL_∞/L1= 0.18; CL_∞/L2= 0.95;
CL_∞/age1= -0.52; CL_∞/K= -0.88; K/L1= -0.56; K/L2= -0.77; K/age1= 0.09.

The Multifan procedure permits "multiple" fluctuations, that are almost always with K varying and another parameter. Of such types, none has improved the "single" fluctuation output enough to justify the introduction of a new parameter to be estimated. By the way, the search allowing the estimation of **all** the parameters in the same starting age-K grid did produce the very best MLE of the whole process [1946 (20 prmtr)]; that is probably not a real maximum of the objective function, since the Hessian matrix is not positively definite.

Linosa South-East, large specimens only

This data set (that has been prepared after removal of the data in the first mode) has been treated on the basis of the previous results, thus as one "single-shot" allowing the fluctuation of **K** in a 3-5/0.200-0.625 age-K grid (the ages are in fact equivalent to 3+1, 4+1 and 5+1), and analyzing in more detail "age" 4+1 in the area that produces about CL_∞= 70 [2030 (10 prmtr), penalty 0.018]. The resulting proportions and average CL were (Fig. 114):

"age"	1	2	3	4	5
sample I	--	0.65	0.25	0.08	0.02
sample II	--	0.52	0.33	0.12	0.02
mean length of I	--	39.4	47.4	53.2	57.6

For these results, the StD of length in sample I was estimated at 2.41, and the age 1 of sample I at 2.71 y; K moved to 0.308, and the corresponding CL_∞ changed to 69.6 mm, a quite reasonable estimate.

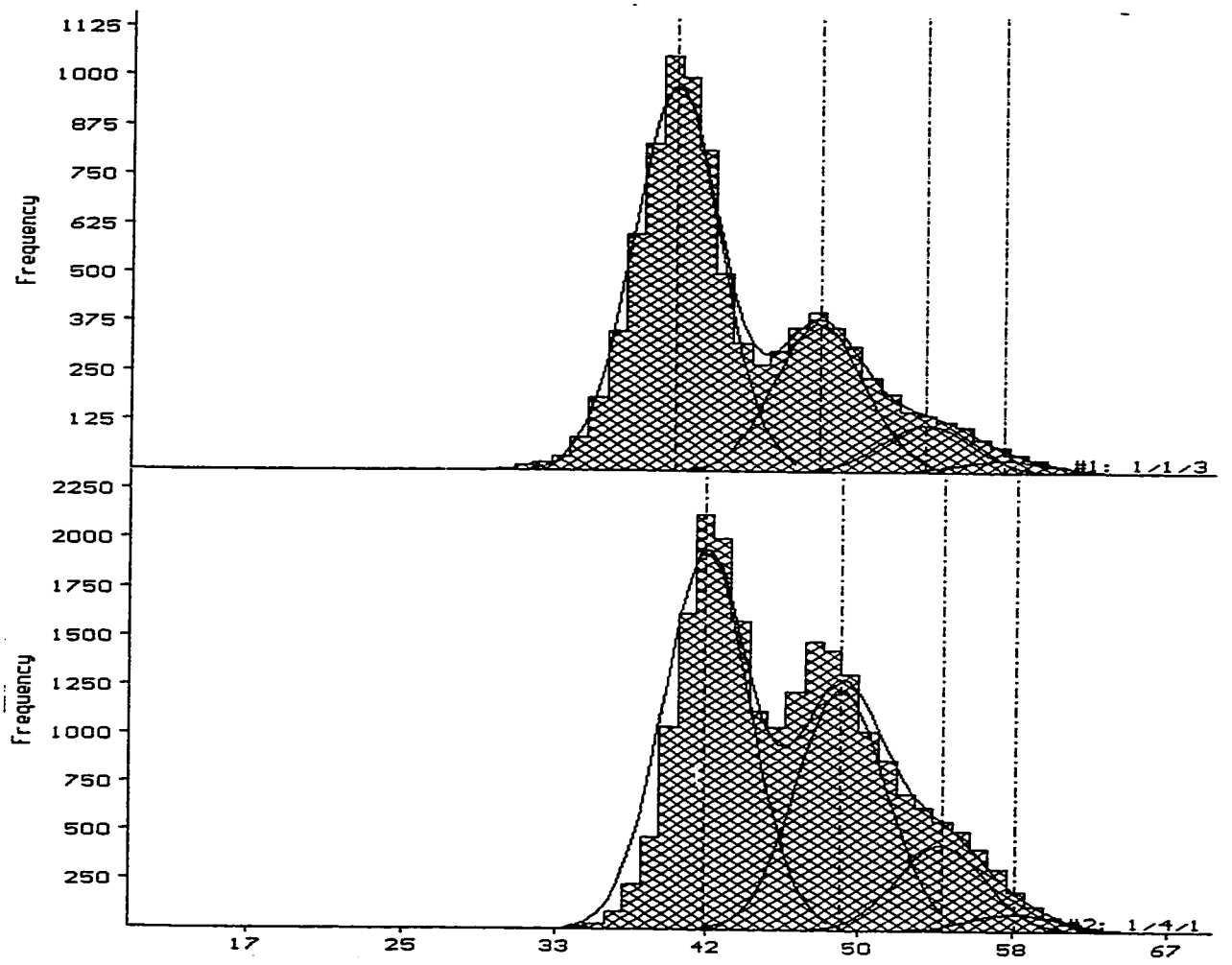


Fig. 114 - MULTIFAN separation of *Aristaeomorpha foliacea* females from Linosa South-East, large specimens only.

The instantaneous annual total mortality rate (Z) was computed utilizing both seasonal samples (all large shrimps are always fully recruited), resulting a Z of 0.97.

It is also interesting to report the StD of the estimates:

first length= 0.027; last length= 0.159; average StD= 0.046; first age= 0.016; CL_∞= 0.285; K= 0.002;

and a few correlation coefficients:

L1/L2= 0.03; age1/L1= 0.05; age1/L2= -0.88; CL_∞/L1= -0.11; CL_∞/L2= 0.93; CL_∞/age1= -0.66; CL_∞/K= -0.51; K/L1= -0.03; K/L2= -0.19; K/age1= 0.31.

Linosa North-East, all the "valid" females

The first search with Multifan, that implied a **simple** systematic search on the age-K grid [classes 3 to 7; K from 0.35 to 0.875 (by 0.075 increments); sample I= y1,m1,w3 sample II= y1,m4,w1], produced the best MLE at K= 0.725 with "age" 7 [1838 (15 prmtr)], and sub-optimal MLEs at K= 0.575 with "age" 4 [1755 (9 prmtr)], at K= 0.650 with "age" 5 [1829 (11 prmtr)] and with "age" 6 [1835 (13 prmtr)]; the maximum improvement was between "ages" 3 and 4 [82 (+2 prmtr)], followed by that between "ages" 4 and 5 [74 (+2prmtr)]. It is interesting to note that the K values for the North-East area have shifted one step down than those for the South-East zone. Having opted for a "life span" of 5 classes [1829 (11 prmtr), penalty 0.009], that represent a compromise of the biological knowledge and the best MLEs, with K= 0.650 the resulting proportions and average CL were (Fig. 115):

"age"	1	2	3	4	5
sample I	0.13	0.44	0.33	0.04	0.06
sample II	0.25	0.35	0.23	0.02	0.16
mean length of I	21.2	40.3	50.2	55.4	58.1

For these results, the StD of length in sample I was estimated at 2.46, and the age 1 of sample I at 0.66 y; the corresponding CL_∞ was 61.1 mm, somehow shorter than the available biological knowledge for the area(> 64 mm).

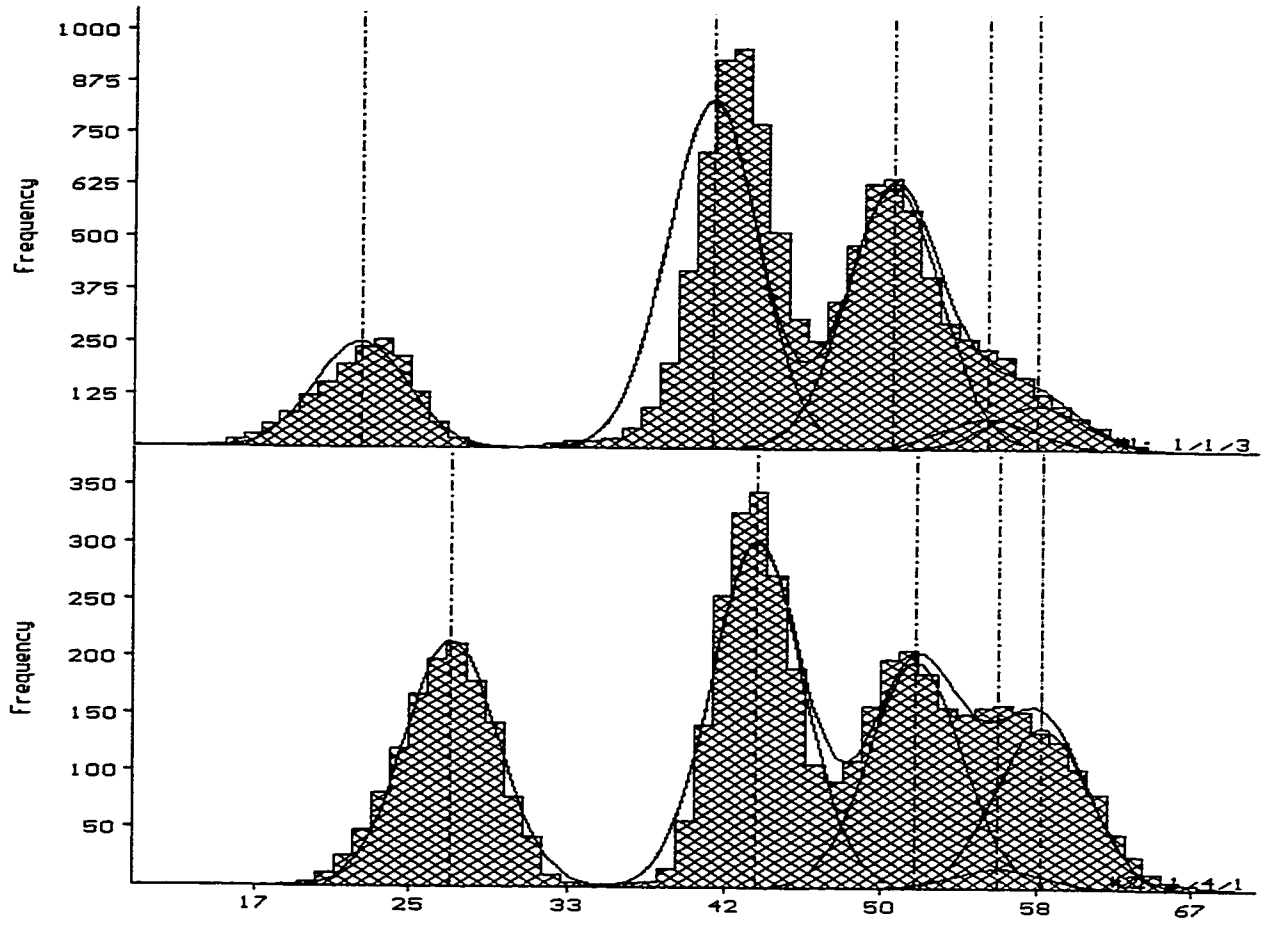


Fig. 115 - MULTIFAN separation of *Aristaeomorpha foliacea* females from Linosa North-East, by simple search (5-year hypothesis).

The major problem in accepting these Multifan estimates resides in the large "inversion" of the final proportions [average, 0.03 at age 4 *vs.* 0.11 at age 5]. It has to be noted the better estimation of CL_{∞}, and the lower performance of NE data (1829) *vs.* SE (1893), understandable given the smaller database (only 5,400 *vs.* 36,700 animals in the second seasonal survey).

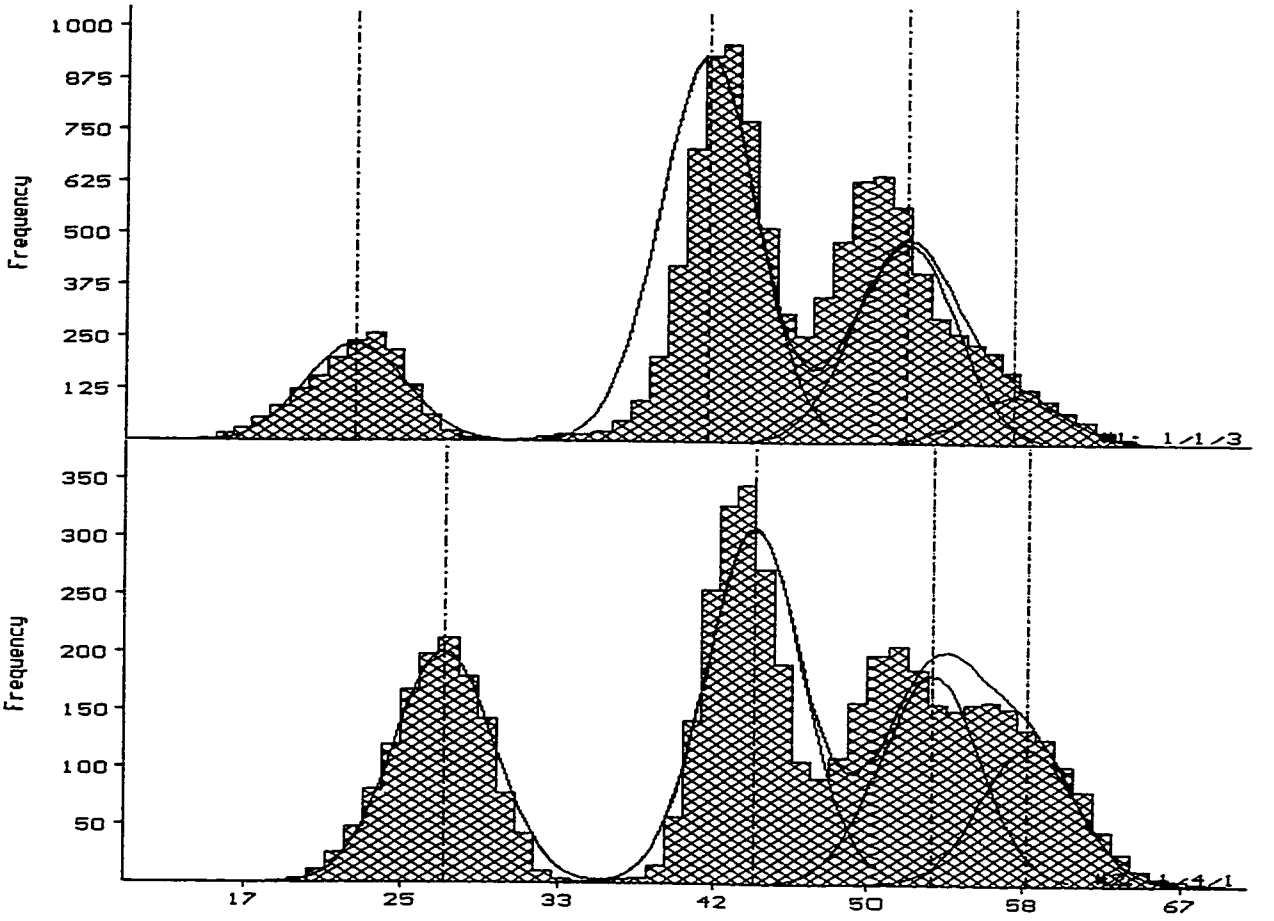


Fig. 116 - MULTIFAN separation of *Aristaeomorpha foliacea* females from Linosa North-East, by simple search (4-year hypothesis).

For sake of comparison with the South-East area, the "life span" of 4 classes [1755 (9 prmtr), penalty 0.006] is reported too, whose resulting proportions and average CL with K= 0.575 were (Fig. 116):

"age"	1	2	3	4
sample I	0.13	0.53	0.27	0.06
sample II	0.25	0.38	0.23	0.15
mean length of I	21.4	40.6	51.4	57.5

For these results, the StD of length in sample I was estimated at 2.64, and the age 1 of sample I at 0.69 y; the corresponding CL_∞ was 65.3 mm, on line with the available

biological knowledge for the area (> 64 mm). Notwithstanding the good CL_∞ and the consistency of the "life span" with the South-East, confronting Fig. 1154 and Fig. 116 shows that the fitting of the latter is unsatisfactory, particularly around the third peak.

The second search with Multifan, that implied a systematic search on the same age-K grid allowing **StD** to vary, produced the best MLEs again in the K= 0.725-"age" 7 position [1839 (16 prmtr)], and sub-optimal MLEs at K= 0.575 with "age" 4 [1758 (10 prmtr)] and at K= 0.650 with "age" 5 [18292 (12 prmtr)] or "age" 6 [18378 (14 prmtr)]; nevertheless, the maximum improvements [71 (+2 prmtr)] happened between "ages" 4 and 5, and the corresponding MLE was almost optimal. Having opted again, and with more "feelings" for the above reasons, for a "life span" of 5 classes [1829 (12 prmtr), penalty 0.009], the resulting proportions and average CL with K= 0.650 were:

"age"	1	2	3	4	5
sample I	0.13	0.44	0.33	0.04	0.05
sample II	0.25	0.35	0.23	0.02	0.16
mean length of I	21.2	40.3	50.2	55.4	58.1

As before, for these results, the age 1 of sample I was estimated at 0.66 y and the corresponding CL_∞ was 61.1 mm. The StD varied from 2.50 to 2.42 (average 2.46), with a ratio of 0.97.

The following step, that implied the varying of two "**seasonal**" parameters, growth amplitude and growth phase, on the same age-K grid, produced MLEs with a maximum improvement between "ages" 3 and 4 [93 (+2 prmtr)] and still important ones between "ages" 4 and 5 [68] or 5 and 6 [21]. Having tried again, for sake of consistency, only a "life span" of 5 classes [1840 (13 prmtr), penalty 0.009], the resulting proportions and average CL with K= 0.650 were:

"age"	1	2	3	4	5
sample I	0.13	0.44	0.33	0.03	0.06
sample II	0.25	0.35	0.23	0.02	0.16
mean length of I	21.6	40.5	50.4	55.5	58.2

For these results, the StD of length in sample I was estimated at 2.48, and the age 1 of sample I at 0.67 y; the corresponding CL_∞ was 61.1 mm again. The seasonal growth amplitude was fixed at 0.187, and its phase at 0.571. Notwithstanding the better fit, the introduction of two additional parameters to be estimated (SGA and SGP) is not justified by improved results.

The next possibility of single fluctuation, that implying the **bias** in the first class due to capture processes on the same age-K grid, showed a sampling bias of 0.34 only with the 7 "age" hypothesis, that reduced the age 1 of sample I from 0.69 to 0.59. Therefore, the introduction of the additional bias parameters in the model is not justified.

The last and most important possibility offered by the Multifan procedure, that allowing the estimation of **K** in the same starting age-K grid, produced "flat" MLEs contours, meaning that the maximum for each "age" was spread over a range of K values, about 0.25 wide; still, Multifan suggested K= 0.591 for "age" 4 [1756 (10 prmtr)], K= 0.658 for "age" 5 [1830 (12 prmtr)], and K= 0.800 for "age" 6 [1841 (14 prmtr)]; the maximum improvement remained between "ages" 3 and 4 [84 (+2 prmtr)], with still a very large one between "ages" 4 and 5 [71]. Using the usual "life span" of 5 classes [1830 (12 prmtr), penalty 0.001], the resulting proportions and average CL were (Fig. 117):

"age"	1	2	3	4	5
sample I	0.13	0.44	0.33	0.04	0.06
sample II	0.25	0.35	0.22	0.01	0.17
mean length of I	21.2	40.3	50.2	55.4	58.0

For these results, the StD of length in sample I was estimated at 2.46, and the age 1 of sample I at 0.65 y; K moved to 0.658, and the corresponding CL_∞ changed to 60.9 mm. It should be remembered that, improvements or not, it is deemed always necessary to let K vary.

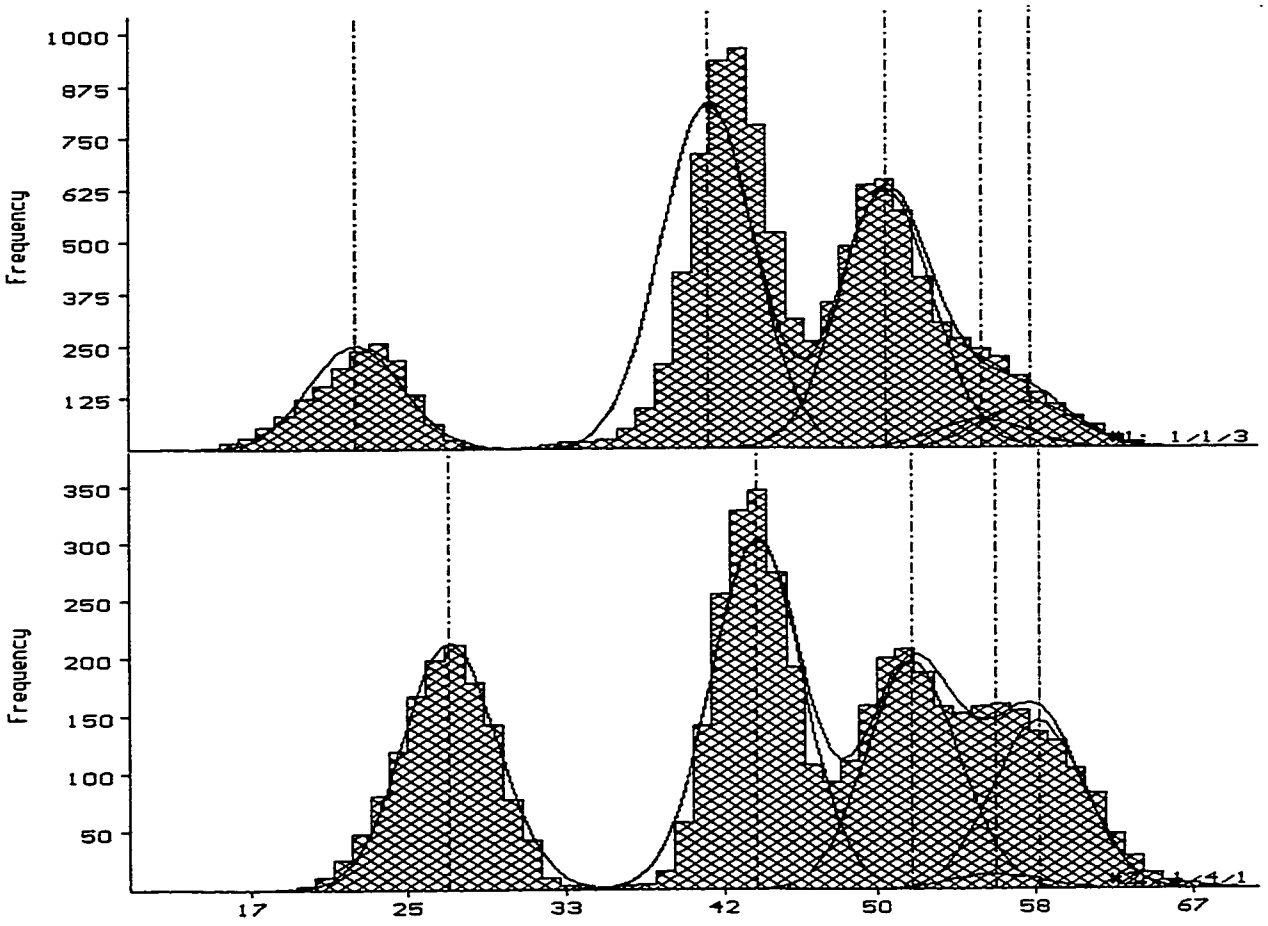


Fig. 117 - MULTIFAN separation of *Aristaeomorpha foliacea* females from Linosa North-East, by K-fluctuating search (5-year hypothesis).

Being this the finally preferred search, the instantaneous annual total mortality rate (Z) was computed too: utilizing only the summer sample, i.e. considering that the first component was not fully recruited in spring, Z resulted an unrealistic 0.38.

It is interesting, at least for the former analysis, to report the StD of the estimates: first length= 0.091; last length= 0.132; average StD= 0.101; first age= 0.001; CL_∞= 0.206; K= 0.008;
and a few correlation coefficients:
L1/L2= 0.20; age1/L1= 0.08; age1/L2= -0.94; CL_∞/L1= -0.06; CL_∞/L2= 0.94; CL_∞/age1= -0.90; CL_∞/K= -0.71; K/L1= -0.58; K/L2= -0.77; K/age1= 0.50.

The Multifan procedure permits "multiple" fluctuations, that are almost always with K varying and another parameter. Of such types, the first "multiple", that allowing the estimation of **K** and **StD** on the same original age-K grid, produced very similar "best" MLEs in a large K range. The maximum improvement was between "ages" 4 and 5 [67 (+2 prmtr)], with still significant ones between "ages" 3 and 4 [47 (+2 prmtr)] and 5 and 6 [13 (+2 prmtr)]. The best final approach is to test for the "life span" of 4 classes (for comparison with the South-East area shrimps), of 5 classes (for consistency and because of the ancillary biological information) and of 6 classes (given the higher MLE). Following the option for a "life span" of 4 classes [1763 (11 prmtr), penalty 0.006], the resulting proportions and average CL were:

"age"	1	2	3	4
sample I	0.13	0.44	0.35	0.07
sample II	0.24	0.36	0.23	0.17
mean length of I	21.5	40.1	50.7	56.8

For these results, the StD of length in sample I fluctuated from 2.37 to 2.86 (average 2.61), with a ratio of 1.21 (note the direction of the increase); the age 1 of sample I was estimated at 0.72 y; K moved to 0.559, and the corresponding CL_∞ was 64.9 mm.

Following the option for a "life span" of 5 classes [1830 (13 prmtr), penalty 0.009], the resulting proportions and average CL were:

"age"	1	2	3	4	5
sample I	0.13	0.44	0.33	0.04	0.06
sample II	0.25	0.35	0.22	0.02	0.17
mean length of I	21.2	40.3	50.2	55.4	58.1

For these results, the StD of length in sample I fluctuated from 2.49 to 2.43 (average 2.46), with a ratio of 0.98 (again, note the direction of the change); the age 1 of sample I was estimated at 0.65 y; K moved to 0.657, and the corresponding CL_∞ was 60.9 mm.

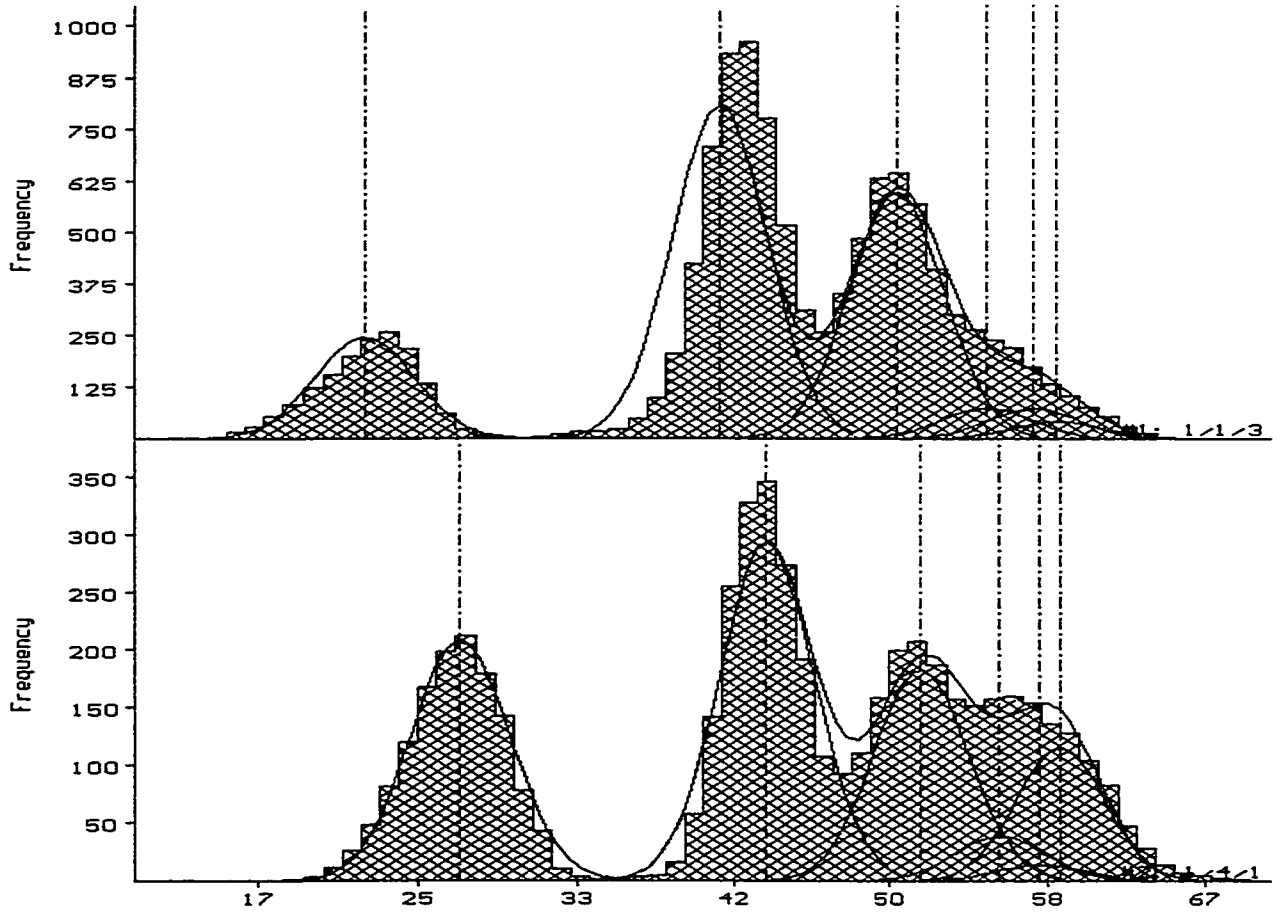


Fig. 118 - MULTIFAN separation of *Aristaeomorpha foliacea* females from Linosa North-East, by K- and StD-fluctuating search (6-year hypothesis).

On the contrary, following the option for a "life span" of 6 classes [1843 (15 prmtr), penalty 0.011], the resulting proportions and average CL were (Fig. 118):

"age"	1	2	3	4	5	6
sample I	0.14	0.44	0.32	0.04	0.04	0.02
sample II	0.25	0.35	0.21	0.05	0.02	0.13
mean l. I	21.1	40.4	50.1	55.0	57.5	58.8

For these results, the StD of length in sample I fluctuated from 2.60 to 2.34 (average 2.47), with a ratio of 0.90; the age 1 of sample I was estimated at 0.63 y; K moved to 0.682, and the corresponding CL_∞ lowered to 60.0 mm.

It is interesting, at least for the former analysis, to report the StD of the estimates:

5 classes: first length= 0.093; last length= 0.134; average StD= 0.101; first age= 0.001; CL_∞= 0.207; K= 0.007;

6 classes: first length= 0.090; last length= 0.184; average StD= 0.097; first age= 0.002; CL_∞= 0.217; K= 0.008;

and a few correlation coefficients:

5 classes: L1/L2= 0.21; age1/L1= 0.06; age1/L2= -0.94; CL_∞/L1= -0.05; CL_∞/L2= 0.94; CL_∞/age1= -0.91; CL_∞/K= -0.77; K/L1= -0.59; K/L2= -0.77; K/age1= 0.50;

6 classes: L1/L2= 0.39; age1/L1= -0.32; age1/L2= -1.00; CL_∞/L1= 0.08; CL_∞/L2= 0.95; CL_∞/age1= -0.96; CL_∞/K= -0.75; K/L1= -0.61; K/L2= -0.89; K/age1= 0.84.

The above tentatives clearly show the shortcomings of a program such as Multifan, in which the "mathematical" increases do not correspond to biologically-sound estimates: in fact, for example, the empty "age" classes are a sure artifact, and the decrease of the CL_∞.is another misfit. Of all other "multiple" fluctuations, none has improved the "single" fluctuation output enough to justify the introduction of a new parameter to be estimated. By the way, the search allowing the estimation of **all** the parameters in the same starting age-K grid did produce the very best MLE of the whole

process [1873 (20 prmtr)]; that is probably not a real maximum of the objective function, since the Hessian matrix is not positively definite.

Linosa North-East, large specimens only

This data set (that has been prepared after removal of the data in the first mode) has been treated on the basis of the previous results, thus as one "single-shot" allowing the fluctuation of **K** in a 3-5/0.200-0.625 age-K grid (the ages are in fact equivalent to 3+1, 4+1 and 5+1), and analyzing in more detail "age" 4+1 in the area that produces about CL_∞= 70 [2025 (10 prmtr), penalty 0.007]. The resulting proportions and average CL were Fig. 119):

"age"	1	2	3	4	5
sample I	--	0.50	0.35	0.12	0.03
sample II	--	0.46	0.27	0.18	0.10
mean length of I	--	41.6	49.7	55.6	59.8

For these results, the StD of length in sample I was estimated at 2.15, and the age 1 of sample I at 2.72 y; K moved to 0.325, and the corresponding CL_∞ changed to 70.8 mm, a very good estimate.

The instantaneous annual total mortality rate (Z) was computed utilizing both seasonal samples (all large shrimps are always fully recruited), resulting a Z of 0.73.

It is also interesting, to report the StD of the estimates:

first length= 0.026; last length= 0.133; average StD= 0.037; first age= 0.034; CL_∞= 0.694; K= 0.010;

and a few correlation coefficients:

L1/L2= 0.18; age1/L1= 0.16; age1/L2= 0.79; CL_∞/L1= 0.11; CL_∞/L2= 0.94; CL_∞/age1= 0.95; CL_∞/K= -0.99; K/L1= -0.15; K/L2= -0.88; K/age1= -0.98.

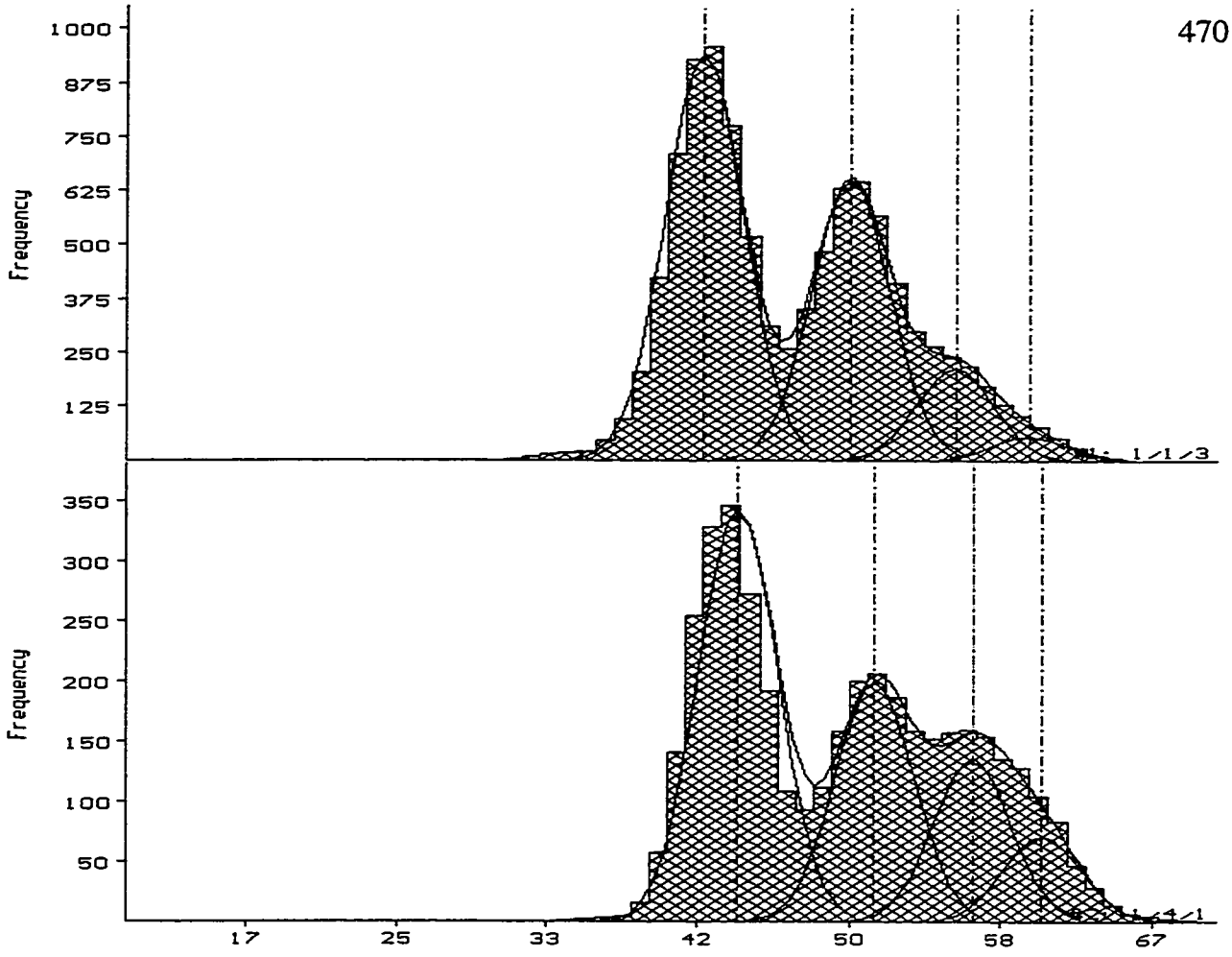


Fig. 119 - MULTIFAN separation of *Aristaeomorpha foliacea* females from Linosa North-East, large specimens only.

Linosa South-East and North-East, all the "valid" males

For the males, given their lesser importance in the fishery, the Multifan procedure has been "shortened", following the estimation steps in a more "automatic" fashion. Therefore, only the terminal estimates, with varying K, are reported.

Males from Linosa South-East, analyzed with variable **K** in the starting age-K grid [classes 3 to 5; K from 0.2 to 1.2 (by 0.2 increments); sample I= y1,m1,w3 sample II= y1,m4,w1], were assigned a "life span" of 3 classes [1153 (7 prmtr), penalty 0.026], and the resulting proportions and average CL were:

"age"	1	2	3
sample I	0.37	0.58	0.04
sample II	0.33	0.59	0.08
mean length of I	21.2	33.7	37.9

For these results, the StD of length in sample I was estimated at 2.51, and the age 1 of sample I at 0.70 y; K was 1.08, and the corresponding CL_∞ 40.1 mm, a reasonable estimate.

It is interesting, to report the StD of the estimates:

first length= 0.065; last length= 0.100; average StD= 0.101; first age= 0.003; CL_∞= 0.132; K= 0.004;

and a few correlation coefficients:

L1/L2= 0.04; age1/L1= 0.04; age1/L2= -0.98; CL_∞/L1= -0.51; CL_∞/L2= 0.83; CL_∞/age1= -0.28; CL_∞/K= -0.23; K/L1= -0.04; K/L2= -0.14; K/age1= 0.02.

Males from Linosa North-East, analyzed with variable **K** in the starting age-K grid [classes 3 to 5; K from 0.2 to 1.2 (by 0.2 increments); sample I= y1,m1,w3 sample II= y1,m4,w1], were assigned a "life span" of 3 classes [1152 (7 prmtr), penalty 0.009], and the resulting proportions and average CL were:

"age"	1	2	3
sample I	0.11	0.79	0.10
sample II	0.26	0.54	0.20
mean length of I	22.3	34.4	38.5

For these results, the StD of length in sample I was estimated at 2.55, and the age 1 of sample I at 0.74 y; K was 1.08, and the corresponding CL_∞ 40.6 mm, a reasonable estimate (note that K is identical among South-East and North-East males).

It is interesting, to report the StD of the estimates:

first length= 0.118; last length= 0.123; average StD= 0.294; first age= 0.004; CL_∞= 0.219; K= 0.004;

and a few correlation coefficients:

L1/L2= -0.04; age1/L1= 0.45; age1/L2= -0.98; CL_∞/L1= -0.81; CL_∞/L2= 0.83; CL_∞/age1= -0.87; CL_∞/K= -0.10; K/L1= -0.05; K/L2= -0.09; K/age1= -0.07.

Discussion on a reduced data set

It has been deemed necessary to explore the behaviour of Multifan when working on a data set of smaller dimension; with this in mind, the data set of Linosa North-East females has been reduced to 1/5 of the original size. The comparison of the two sets of analyses show only slightly different results.

The first search for reduced Linosa North-East, that implied a **simple** systematic search on the age-K grid, produced the best MLEs in the K= 0.725 column [1698 (9 parameters to be estimated)-1748 (13 prmtr)] and for the "age" 7 in the K= 0.8 column [1744 (15 prmtr)], with a maximum improvement between "ages" 4 and 5 [46 (+2 prmtr)], the sole significant (in terms of χ^2). Having opted for a "life span" of 5 classes [1745 (11 prmtr), penalty 0.58] that, besides been the one to be compared, represent the "best" MLE, the resulting proportions and average CL were:

"age"	1	2	3	4	5
sample I	0.14	0.51	0.27	0.04	0.04
sample II	0.24	0.38	0.21	0.04	0.12
mean length of I	21.1	41.1	51.0	56.0	58.4

For these results, the StD of length in sample I was estimated at 2.42, and the age 1 of sample I at 0.61 y; the corresponding CL_∞ was 60.8 mm, just a little shorter than that

obtained with the complete data set (61.1 mm). The "inversion" of the final proportions seems reduced.

Skipping for sake of simplicity the trials on reduced Linosa North-East with oscillating StD, seasonality or bias, the last possibility offered by the Multifan procedure, that allowing the estimation of **K**, produced the best MLEs [1699 (10 prmtr)-1763 (14 prmtr)] in the both the K= 0.650 and K= 0.725 columns, but the maximum laid at "age" 7 in column K= 0.8 [1772 (16 prmtr)], just marginally higher than in column k= 0.725 (1771); the function improvements (respectively: 47; 17; 8) were always significant. With the usual "life span" of 5 classes, the resulting proportions and average CL were:

"age"	1	2	3	4	5
sample I	0.14	0.50	0.27	0.03	0.05
sample II	0.24	0.38	0.21	0.04	0.13
mean length of I	21.0	41.1	51.0	55.8	58.1

For these results, the StD of length in sample I was estimated at 2.41, and the age 1 of sample I at 0.60 y; K moved to 0.714, and the corresponding CL_∞ to 60.4 mm (they are K= 0.66 and CL_∞=60.9 with the original data).

It is interesting, at least for the former analysis, to report the StD of the estimates: first length= 0.109; last length= 0.127; average StD= 0.071; first age= 0.001; CL_∞= 0.190; K= 0.006;
and a few correlation coefficients:
L1/L2= 0.14; age1/L1= 0.07; age1/L2= -0.98; CL_∞/L1= -0.31; CL_∞/L2= 0.90; CL_∞/age1= -0.97; CL_∞/K= -0.57; K/L1= -0.60; K/L2= -0.86; K/age1= 0.73;

On reduced Linosa North-East, allowing the simultaneous estimation of **K** and **StD**, Multifan produced very similar "best" MLEs in the K range 0.6-08. The maximum improvement remained between "ages" 4 and 5, with still significant ones between "ages"

5 and 6, and 6 and 7. This time, the approach has been to test for both "life span" of 5 classes (for consistency) and "life span" of 7 classes (given the higher MLE). Following the option for a "life span" of 5 classes, the resulting proportions and average CL were:

"age"	1	2	3	4	5
sample I	0.14	0.51	0.27	0.03	0.05
sample II	0.24	0.38	0.21	0.04	0.13
mean length of I	21.0	41.1	51.0	55.8	58.2

For these results, the StD of length in sample I fluctuated from 2.37 to 2.45 (average 2.41), with a ratio of 1.03 (note the direction of the increase); the age 1 of sample I was estimated at 0.60 y; K moved to 0.713, and the corresponding CL_∞ was 60.4 mm (they are K= 0.66 and CL_∞=60.9 with the original data).

On the contrary, following the option for a "life span" of 7 classes, the resulting proportions and average CL were:

"age"	1	2	3	4	5	6	7
sample I	0.13	0.47	0.31	0.02	0.03	0.03	0.01
sample II	0.24	0.36	0.21	0.04	0	0	0.14
m.l. I	20.9	41.1	50.6	55.1	57.2	58.1	58.6

For these results, the StD of length in sample I fluctuated from 2.34 to 2.28 (average 2.31), with a ratio of 0.98; the age 1 of sample I was estimated at 0.58 y; K moved to 0.757, and the corresponding CL_∞ lowered to 59.0 mm.

By the way, the **simple** systematic search on the reduced data set for Linosa South-East produced the best MLEs in the K= 0.725 column, with a maximum improvement between "ages" 4 and 5. This time, just for comparison, having opted for a "life span" of 5 classes, the resulting proportions and average CL were:

"age"	1	2	3	4	5
sample I	0.40	0.38	0.16	0.02	0.03
sample II	0.40	0.34	0.17	0.02	0.07
mean length of I	20.6	38.9	48.0	52.6	54.8

For these results, the StD of length in sample I was estimated at 2.35, and the age 1 of sample I at 0.64 y; the corresponding CL_∞ remained at 57.0 mm. Altogether, even in the simple, "deterministic" search, the size of the data set did not produce unacceptably different results.

Discussion on pooling data

The "valid" females of the two fishing zones, Linosa South-East and Linosa North-East, were pooled together, to examine the behaviour of the estimates [on an age-K grid of: classes 3 to 6; K from 0.35 to 0.85 (by 0.1 increments); sample I= y1,m1,w3 sample II= y1,m4,w1], even if it appears just from the visual analysis of the fitting curves in the everything-fixed search that combining the zones is not the right choice.

Limiting the discussion to only the variable-K estimates, the best MLEs [1823 (14 prmtr)-1911 (18 prmtr)] were in the columns from K= 0.65 to K= 0.85, and the maximums (all equal) laid at "age" 6. Even these fittings were never good; for consistency, only the usual "life span" of 4 and 5 classes are considered. For the 4-classes results, the StD of length in sample I was estimated at 2.78, and the age 1 of sample I at 0.55 y; K moved to 0.69, and the corresponding CL_∞ to 60.0 mm. For the 5-classes results, the StD of length in sample I was estimated at 2.73, and the age 1 of sample I at 0.51 y; K moved to 0.727, and the corresponding CL_∞ to 58.4 mm.

Discussion on variability of mortality estimates

On the reduced data set, mortality estimates were produced too: in Linosa North-East, with variable K, having opted for a "life span" of 5 classes [1746 (12 prmtr), penalty 1.08, every other estimate equal], and a selectivity of 0.22 for the first "age" (and 1.00 thereafter), the resulting instantaneous total mortality rate (annual basis) was 0.68. Changing the "life span" to 6 classes, and the selectivity to 0.23 for the first "age", Z (annual basis) resulted 0.67. Finally, changing the "life span" to 7 classes, and the selectivity to 0.25 for the first "age", Z (annual basis) remained at 0.67. It appears that the trials with different "life spans" produced similar mortality estimates.

Discussion on grid influence

It has been deemed necessary to explore the behaviour of Multifan when the location of the age-K grid varies; with this in mind, the data set of Linosa South-East males was employed on three grids (sample I= y1,m1,w3 sample II= y1,m4,w1), keeping everything else constant:

A) age classes 3, 4 and 5, K from 0.2 to 1.2, by 0.2 increments (the one against which the others were compared);

B) age classes 3, 4 and 5, K from 0.8 to 1.2, by 0.2 increments; and

C) age classes from 2 to 6, K from 0.2 to 0.8, by 0.1 increments (K out of "true" boundaries).

The "true" results for Linosa South-East males are supposed to be: K= 1.08, CL_∞= 40.6 mm, StD of length in sample I= 2.55, age 1 of sample I= 0.74 y. In the simple search, the MLE of the "age 3 - K= 0.8", "age 3 - K= 1.0" and "age 4 - K= 1.0" locations were respectively 1134, 1149 and 1148 (A) against 1144, 1154 and 1162 (B); thus the differences were 10, 5 and 14, and the preliminary estimates of CL_∞s varied of only 0.3 mm. Nevertheless, proceeding toward the more "complicated" Multifan estimates,

such as those with varying K, the situation worsen. Even if the proportions of the age vectors are close to each other for A (0.037, 0.58, 0.04; 0.33, 0.59, 0.08) and B (0.36, 0.57, 0.07; 0.34, 0.56, 0,11), the results may be misleading, for example in assessing mortality. Something similar happens for the parameters; in fact:

- for the "true" results, the StD of length in sample I was estimated at 2.51, and the age 1 of sample I at 0.70 y, K was 1.08, and the corresponding CL_∞ 40.1 mm;
- for the "other" results, the StD of length in sample I was estimated at 2.30, and the age 1 of sample I at 0.76 y, K was 0.99, and the corresponding CL_∞ 40.7 mm.

Therefore, given the StD of the estimates:

"true" average StD= 0.101; first age= 0.003; CL_∞= 0.132; K= 0.004;

"other" average StD= 0.197; first age= 0.003; CL_∞= 0.163; K= 0.007;

the range of the StD of length in sample I and of CL_∞ for the two sets of values does overlap, and does not for the values of the age 1 of sample I and of K.

Looking at an "out of range" location, the MLE of point "age 4 - K= 0.6" in the simple search was 1112 *vs.* 1082 for A and C respectively, a difference of almost 3%; this difference produced a preliminary estimate of CL_∞ of 39.3 (C) against a corresponding CL_∞= 40.6 (A), a (too) large difference for the same starting point. By the way, the ancillary biological information ask for subjective decisions on the "best" MLE to proceed with, sometimes with differences greater than 5% from what suggested by Multifan.

It must be emphasized that these trials were deliberately performed "out of tune" with the regular procedure, to simulate extreme situations. Overall, the three sets of analyses do show different results in "corresponding" situations, in general slightly but badly in case of wrong seed values; what seems more "risky" is the fact that the variability associated with the different estimates seems fairly small, an optimistic and misleading result.

Earlier trawl surveys, all the "valid" females

For the females of the earlier trawl surveys, that were only marginally used for the assessment of the growth parameters, the Multifan procedure has been performed only for sake of completeness. Therefore, only the final estimates are reported.

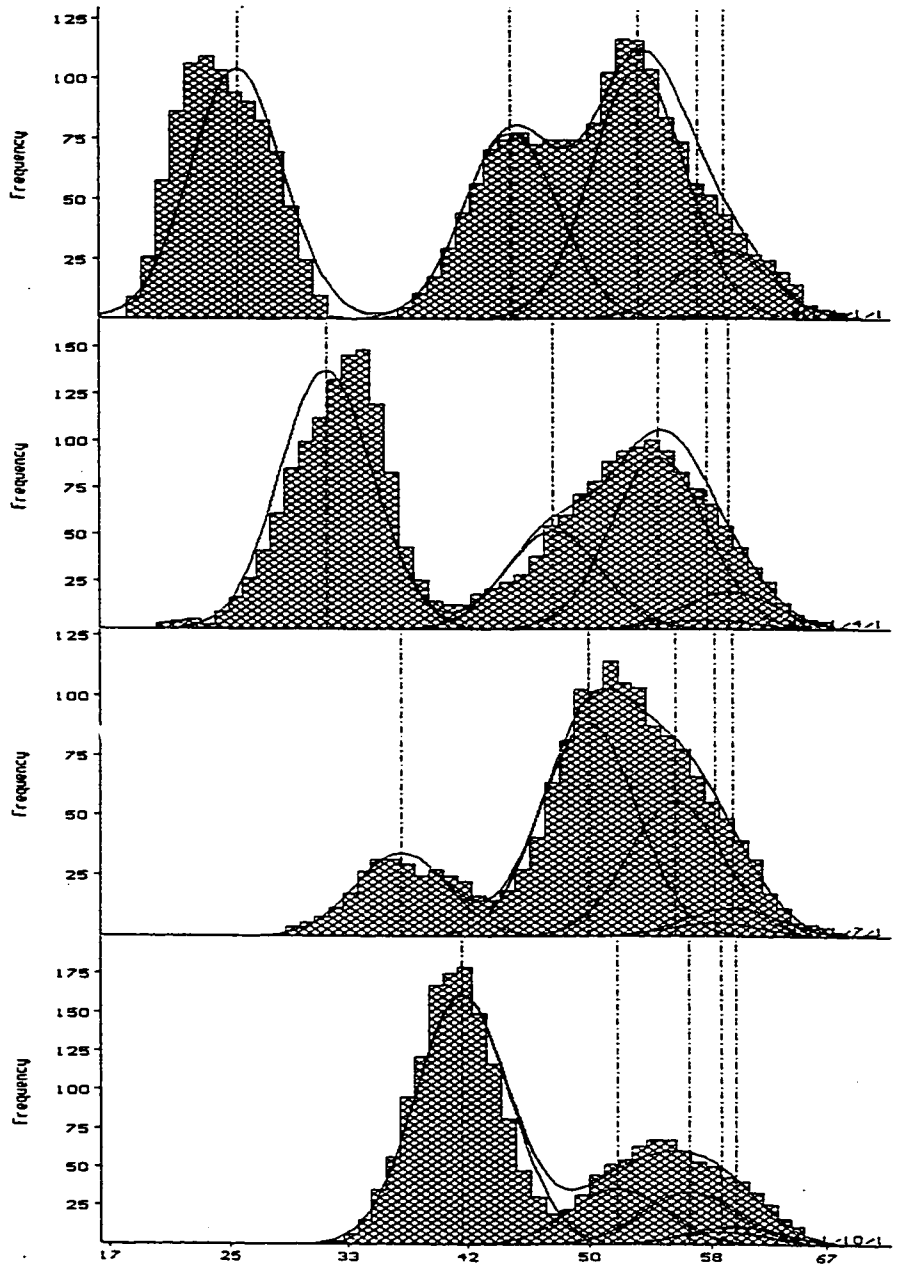


Fig. 120 - MULTIFAN separation of *Aristaeomorpha foliacea* females from the earlier trawl surveys, pooled by like-season.

Females from the eight earlier trawl surveys, pooled by season, analyzed in the starting age-K grid [classes 3 to 6; K from 0.2 to 1.2 (by 0.2 increments); sample I= y1,m1,w1 and thereafter regularly spaced], were assigned a "life span" of 5 classes [3443, penalty 0.032], and the resulting average CL were respectively 25.6, 44.8, 53.6, 57.6 and 59.5 mm (Fig. 120).

For these results, the StD of length in sample I was estimated at 3.25, and the age 1 of sample I at 0.70 y; K was 0.78, and the corresponding CL_∞ 61.1 mm, quite a low estimate.

CURRICULUM VITAE AND MAJOR PUBLICATIONS OF MARCO BIANCHINI

Born January 10. 1950 in Rome

"Laurea" in Biological Sciences (Hydrobiology) - University of Rome 1973

"Laurea" in Natural Sciences - University of Rome 1982

"Laurea" in Geography - University of Rome 1995

Diploma of Institute of Fisheries Management (UK) - 1992 (Bulleid Mem. prize)

National Research Council Researcher 1974/87; Senior researcher 1988/present

Lecturer of "Nutrition aquatic environment", "Aquaculture"- Univ. Viterbo 87-94

Lecturer on quantitative management of wildlife - Milano Polytechnics 1990

Grad. School Oceanography/URI (USA) Scholarship 1980/82

Grad. School Oceanography/URI (USA) Senior Scholarship 1985

Consulting: Italy, Greece, Kenya, Tunisia, India, Guinea, Senegal, Zaire, Somalia

62 referred and 47 other scientific papers, 1 patent, 68 conference abstracts

Italian delegate for Biomass Conversion OCSE (1978/85)

Member of UNESCO/MAB Working Group "Species and its productivity"

Head of the "Slipper lobsters" project of Merchant Marine Ministry 1993/97

Certified biologist; Certified Fisheries Scientist (AFS)

Professional Ass.: SIBM, AIIAD, AIN, EAS, AFS, AIFRB (fellow), IFM

Eur. Aquac. Soc.: Board of Directors 1991/94; Secretary 1992/94; NLO 1991/92, 99/2000

Aquaculture Committee (SIBM): chairman 94/95; secretary 86/89, 92/93; member 98/99

Editorial board: J. Ecobiol., Aquacult. Internat., Biol. Mar. Medit., Quad. Ist. Brunelli

Study fields: Marine biology; Fishery (eel fishery, trawling in Italy, small scale fishery for LDC); Aquaculture (eel, prawns, minor species, restocking); Ethology (eel); Nutrition (prawns, trout); Population dynamics, stock assessment, marking

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