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# Deep-sea Shrimp *Aristeus antennatus* Risso 1816 in the Catalan Sea: a Review and Perspectives

by

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## Abstract

The shrimp *Aristeus antennatus*, is a species mainly characterized by a wide distribution in the Mediterranean Sea. It ranges from 100 m to more than 3 000 m deep. This means that this species colonizes several habitats adapting their population structure and feeding habits to each of them, and finally adapting its life cycle to the colonized habitats (canyons, upper and middle slope –fishing grounds- and lower slope –virgin grounds-). After more than 10 years of experience in the deep fishing of this species in the western Mediterranean, new results are presented about the efficiency of the samplig gears used, and comparison between fished and virgin populations are made. An increase of the abundance around 1 400-1 500 m depth is pointed out, which was not detected previously. *A. antennatus* is an extraordinarily eurybathic species and was detected down to 3300 m depth in a recent exploratory survey carried out in Ionian Sea (Central Mediterranean). Based on these observations three hypotheses about the possible exchange of individuals between fishing and virgin grounds are made. In the light of the discussion, new study perspectives are presented.

*Key words:* Shrimps, *Aristeus antennatus*, trawling, fishing grounds, virgin grounds, Deep-sea, Mediterranean.

## Introduction

The rose shrimp *Aristeus antennatus* is one of the most valued fishery resources in the Mediterranean Sea, and is characterized by a wide bathymetric distribution ranging between *ca*. 100 m and more than 2200 m (Bianchini and Ragonese, 1994; Sardà and Cartes, 1993). Its biology, ecology and fisheries have been largely studied in the Mediterranean Sea (Mura *et al*., 1997; Relini Orsi and Relini, 1979; 1987; Orsi Relini and Relini, 1985; 1998; Ragonese and Bianchini, 1996; Sardà and Demestre, 1987; Martínez-Baños, 1997; García-Rodriguez and Esteban, 1999; Carbonell *et al*., 1999; Bas, 1966; Massutí and Daroca, 1978; Tursi *et al*., 1996; D'Onghia *et al*., 1997, Demestre and Fortuño, 1992; Matarrese *et al*., 1992, 1997; Aquastudio, 1996). General studies covering its whole bathymetric range have been carried out during the last years in the western Mediterranean. (Cartes and Sardà, 1992, 1993; Sardà *et al*., 1994). This species dwells in a wide bathymetric range that can be divided in two depth ranges with well differentiated characteristics. On the upper and middle slope, between 400 and 800 m deep, this species is under a high level of fishing pressure (fishing grounds) and the population is mainly composed by females (Demestre and Martín, 1993; Martínez-Baños, 1997; Tobar and Sardà, 1987). A well-known seasonal mobility pattern is present in this area (Sardà *et al*., 1998a). On the lower slope, between 800 and 2200 m depth, the density is lower, there is no fishing activity (virgin grounds), the sex proportions are not significantly different from 1:1 (Sardà and Cartes, 1993), and no information is available on seasonal population movements at this depth. The study of the life history of *Aristeus antennatus* presents an interesting scenario: the fishing grounds are mainly occupied by females of large-sized individuals in high-density, and the virgin grounds are occupied by smaller-sized individuals and presents low-density. However, *Aristeus antennatus* seems not to be under an overexploited situation in its fishing grounds (Demestre and Lleonart, 1993; Tursi *et al*., 1996; Martínez-Baños, 1997; García-Rodríguez and

Estaban, 1999;). Thus, considering the present status of knowledge of *A. antennatus*, the questions addressed are about the relationship and interaction between both exploited and virgin stocks.

After 10 years of experience on deep-sea biological studies of the *A. antennatus*, the aim of this paper is to review the published data considering experimental catches below 1000 m depth in the Catalan Sea to use all this knowledge in a comparative manner among depth intervals and discuss some new ideas about deep-sea *Aristeus* populations. Then, three hypotheses about the relationship between the two stocks are presented. The three scenarios are first set up and then discussed and with the application of a simulated analysis of the abundance and biomass on both stocks, the authors suggest future perspectives of study.

## Materials and Methods

Thirty exploratory surveys have been carried out in the Catalan-Balearic basin (Figure 1), with a total of 171 hauls, on board of the *R/V García del Cid* (38 m length and 1200 HP) between 1987 and 1998 (Table 1) and were used in the present analysis. Two trawl system were used: OTSB-14 (Marinovich model, used by Haedrich and Horn,. 1970 and Sulak, 1984, among others); and OTMS (used by Sardà *et al*., 1998 b). Both gears were trawled by means of a single cable. OTSB-14 and OTMS have similar overall dimensions, and a codend of 15 mm (stretched mesh) was used in both gears. Nevertheless OTMS has a more modern design in terms of hydrodynamics. The main differences are: lateral opening (OTMS: 13 m; OTSB-14: 8m), height (OTMS: 1.8 m; OTSB-14: 0.8 m), and length of bridles (OTMS: 32 m; OTSB-14: 3 m). The gear working dimensions were measured with the remote acoustic system SCANMAR. The haul durations were 1 hour. The data obtained with the Marinovich trawl system were used only to study qualitative parameters, and never quantitative aspects. The reason to use only OTMS trawl data on quantitative aspects is that this trawl system is considered more efective for the capture of this species, so we avoid the comparative problems arising when comparing different gears. The standard biological measures taken as size (CL mm), weight (g), sex-ratio or maturity stages have been explained in previous papers (see Sardà and Demestre, 1987; Demestre and Fortuño, 1992). The significance of the different results has been tested by different procedures, such as Student's *t*-test, ANOVA or Kolmogorov-Smirnov tests according to the kind of data. The overall data presented in this work have been published separately before, but the results have been re-worked and presented under a integrated point of view with the main objective of obtaining new perspectives of study.

An approximate estimation of the deep-sea shrimp abundances by means of the swept area method has been made using abundances from OTMS only. For this purpose a concrete area has been defined occupying a total surface of 1740 miles$^2$ (Figure 1). The fishing grounds (upper and middle slope) surface have been stimated in 120 miles$^2$ and the virgin grounds (lower slope) surface in 1620 miles$^2$. Estimations of the number of individuals were undertaken after calculations of the mean densities obtained by comercial ships on the fishing grounds (400-800 m depth) and after the mean densities obtained by the research vessel on the virgin grounds (800-2200 m depth). The biomass and density were referred to miles$^2$ extrapolated from the commercial boats in the fishing grounds and for the experimental OTMS in the virgin grounds.

## Results

*The importance of the trawl system*

The catch obtained with the OTMS gear are over 5 times the catches obatined by the OTSB gear (Figure 2, comparison between figs A-B and C-D). For the first time, an important increase of the abundance of *A. antennatus* is detected between 1400 and 1800 m (Figure 2, E); however, there is a global biomass decrease with depth (Figure 2, F). This means that around 1000 m, the mean-size decreases drastically, whereby different size frequencies can be shown to be present in the two populations.

*Does female maturity stages change with depth?*

The proportion of mature females by size class intervals (only considering maturity stages IV, V and VI) between May and August (Figure 3), is similar at all depths and no significative differences were observed among them. Although some gaps at some depth intervals exist, we did not find evidence on variations of the reproductive period with depth.

*Sex -ratio*

Above 800 m the population is dominated by females (arround 70%, Figure 4, A). Below 1000 m, in the lower slope, the sex-ratio changes and males dominate the population in a proportion of 2:1 approximately. On the other hand, below 800 m (Figure 4 B), there are indications of seasonal variations are presented. It is during summer when a major prevalence of females exists on the upper slope (400 m) and the middle slope (600 –700 m).

*Size distributions: are there different growth patterns with depth?*

The modal progression in the size distribution (Figure 5) indicates that the bigger individuals concentrate on shallower waters (< 800 m), consisting mainly of adult females which present a wide and frequently unimodal histogram. The largest proportion of small individuals (< 20 mm CL), appears more frequently in the deepest grounds (> 1000), and the highest concentration of these sizes (<15 mm CL) appears at depths below 1500 m. The modal progression for fe males can be followed through different depths (Figure 6), and no evidence of different growth patterns among depth interval for females can be observed. A progression line can be drawn following the first cohort until 24 mm CL. However, the scarce number of individuals in some samples (due to the species low density at this great depths and sampling difficulties), is a main limitation to apply this method. Nevertheless it presents the advantage to be able to study the size frequency in a very wide size range distribution.

*What do we know about recruitment?*

The first recruitment signal was observed in March, arround 1200 m depth, with occurence of individuals between 11 and 12 mm CL (Figure 5). They correspond probably to individuals of 6 mm of CL that can be caught in December (Sardà and Cartes, 1997) at 1200 m depth; the peaks can be followed in females along time until the individuals attain sizes of 22-24 mm of CL, which correspond approximately to one-year olds. The pattern appears very marked in the deep-sea (dotted and black histograms), differentiating their distributions from the individuals of the fishing grounds (white color histogram) (Figure 6 for annual size frequencies).

**Aspects for discussion and perspectives of study.**

*Aristeus antennatus* is a eurybathic species with the widest depth distribution observed in the Mediterranean for any megafaunal species, including fishes and cephalopods (recent unpublished data point to the existence of *A. antennatus* deeper than 3000 m, Deseas, 2001). This species would thus have a strong adaptative plasticity, adapting its life cycle to different habitats where energetic supply diminishes with depth. Although some biological parameters such as reproduction and growth can be similar at different depths, other parameters such as density or mean size vary greatly. Considering the existence of an exploited stock above 1000 m depth and a virgin stock below this depth, it is worth to investigate the realtionships between the different bathymetric populations of this species and what is the flow of individual exchange among populations.

Under this point of view, three simple hypotheses for the exchange of individuals between fishing grounds and virgin grounds are presented, assuming different levels of exchange between both populations and fishing mortality constant for fished stocks (Figure7):

*Hypothesis 1*: The number of individuals on the fishing grounds is larger than the number of individuals on the virgin grounds:

- The exchange of individuals flows from fishing grounds to virgin grounds.
- The virgin stock from the lower slope grounds does not contribute to the maintenance of the fishing stock.
- The fished stock would ultimately become overexploited

*Hypothesis 2*: The number of individuals on the fishing grounds is equal to the number of individuals on the virgin grounds:

- There is an exchange of individuals between fishing grounds and virgin grounds in both directions. Each stock contributes to their mutual maintenance.
- The fished stock would be in equilibrium.

*Hypothesis 3*: The number of individuals of the fishing grounds is smaller than the number on individuals of the virgin grounds:

- The exchange of individuals flows from virgin grounds to fishing grounds
- The virgin stock from the lower slope grounds contributes to the maintenance of the fishing stock
- The fished stock would be permanently underexploited

In order to determine which of the hipotheses is more likely to correspond to the current situation, an approximate estimation of the shrimp biomass and abundance over the fished grounds and in the wide virgin area between Barcelona coast and Mallorca island was made. According to previous results, we take into account that it is in the exploited areas where most of the biomass is found and reproductive females occur (Sardà *et al.* , 1994). The average trawl catch was estimated in a very approximate way for a wide range of biological conditions (no variables such as year, season, size-frequencies or distribution patterns have been considered in this calculations), from Figure 1 as 200 individuals/h (183 kg/mile$^2$ and aprox. 4 000 ind/mile$^2$;) on the fishing grounds and 70 ind/h (12 kg/mile$^2$ and aprox. 10 000 ind/ mile$^2$) on the virgin grounds. Then the overall virgin biomass occupying the non-exploited grounds is not significantly larger than the biomass on the fishing grounds (Figure 8), neither in weight nor in reproductive capacity, only in number. This represents a situation closely resembling hypothesis 3. However, the female proportion and the female mean size, as indicated in the previous results of this study, decrease drastically. Note that these estimations are very approximate and don't have any statistical significance. They must be interpreted as a general approximation to the reality while more accurate data are expected. Nevertheless this data have the importance to be the first data available on deep-sea densities.

## Conclusion

The data here presented give a global vision of the populational structure of the deep-sea shrimp in all its distribution range. The discussion would be focused on the following concepts as perspectives for topic future studies:

1) In spite of important structural differences in the mean size (decrease with depth) and in the sex-ratio (males proportion increase with depth) in deepest populations being detected, there are no isolated populations with differentiated growth patterns nor evidence of non-coincident reproductive periods. Then we should assume that the internal biological clock responsible of the growth and the reproduction control, doesn't vary with depth and presents the same pattern by different depths.

2) The authors suggest that there exists a population adaptation in abundance and size to the energy available on the sea floor (Company and Sardà, 1998). The shrimp population from the upper slope (fishing grounds) receives five times more energy input (of organic carbon) than the individuals inhabiting the virgin grounds (5 g org C m$^{-2}$ y$^{-1}$ to 200 m; 1.2 gr m$^{-2}$ y$^{-1}$ to 2000 m in Western Mediterranean) (Miquel *et al*. 1994). The distribution of the quality and quantity of the scarce food resources on the deeper waters is not enough to modify the reproductive endogenous rhythm or the growth rate. We suggest that a density-dependent compensation exists, in the sense that the available food can maintain enough basal metabolism to complete the vital cycles in the individuals that inhabit the virgin grounds, at expense of small size and density (smaller females, recruits and hight occurrence of males i deeper waters).

3) We could suggest that the deep-sea shrimp follows the general models announced by Gage and Tyler (1990), that prevents competitive exclusion in promoting high size diversification to resource partitioning, or that the juvenile individuals are subject to low predator pressure. This could explain the highest presence of small individuals at higher depths.

4) Regarding the previous hypotheses set forth, the actual situation looks like pattern 3. However due to that: i) the maximum reproductive stock occurs in the exploited areas, ii) the virgin biomass from the virgin grounds presents very limited reproductive capacity and iii) in absence of the knowledge of migrations among different depth (which have not yet been demonstrated), we should apply the Precautionary Principle to protect exploited stocks and avoid the fishing exploitation in deeper waters.

5) The enzymatic analyses carried out by Sardà *et al*.. (1998c), assure sufficient genetic flow to consider that *A. antennatus* is a homogeneous population in the whole Mediterranean basin. Therefore, there is no reasonable

indication at the moment, to allow us to expect that Mediterranean sub-populations can be considered as a metapopulation, in a global ecological context.

6) Given the gaps of knowledge in the aspects related to the eclosion, larval distribution and mobility among virgin and slope grounds, an increase of the scientific effort in these fields should be encouraged in future studies.

We can thus confirm that *Aristeus antennatus* is a deep-sea shrimp with a wide bathymetric range, which can be found from relatively shallow waters (since 80 m in north Africa, Nouar *pers. comm.*) to deep-sea waters (at least 2200 m depth. Sardà *et al*. 1994, and 3300 m from non-published data). No deeper adequate samplings have been conducted in the Mediterranean, and it is possible that its downwards distribution exceeds this depth. No reference exists for any other species of crustacean (or fish) covering such a huge bathymetric range. For these reasons, the authors consider this species as of great interest and its scientific study should be given priority for three main reasons: first, for the limited knowledge existing between the exploited and the unexploited population fractions. Second, for the existing shortcomings in the knowledge of its real distribution and its ecological role in deep-sea environments, coupled to its contribution to biodiversity in the Mediterranean sea. Third, for the enormous possibilities that the study of its metabolism can contribute to the knowledge of the adaptive processes in deep-sea organisms.

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Table 1. Sampling cruises and gears used in this study.

| Gear-Cruise | Date | Nº.of hauls | Nº.ind. caught |
|---|---|---|---|
| *Marinovich* | | | |
| BATHOS II | September 1987 | 4 | 72 |
| BATHOS III | Juny 1988 | 23 | 151 |
| BATHOS IV | July 1988 | 11 | 147 |
| BATHOS V | October 1988 | 17 | 127 |
| ZONAP I | May 1992 | 23 | 405 |
| *OTMS* | | | |
| RETRO I | April 1991 | 8 | 1745 |
| RETRO II | December 1991 | 9 | 1021 |
| RETRO III | March 1992 | 9 | 732 |
| RETRO IV | July 1992 | 9 | 2200 |
| BATMAN I | March 1994 | 26 | 2696 |
| QUIMERA I | October 1996 | 21 | 1724 |
| QUIMERA II | May 1998 | 11 | 1219 |
| DESEAS* | Juny 2001 | 25 | 483 |
| Total | 13 cruises | 196 | 12722 |

* *non-published data*

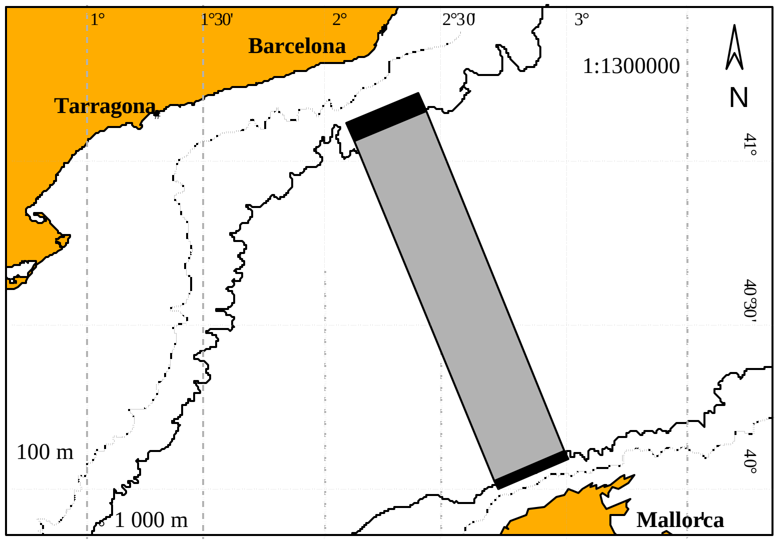


Fig. 1. Study area on the Western Mediterranean. Rectangle represents the area were simulated abundances are estimated. Dotted rectangle, virgin grounds; black rectangles, fished areas.

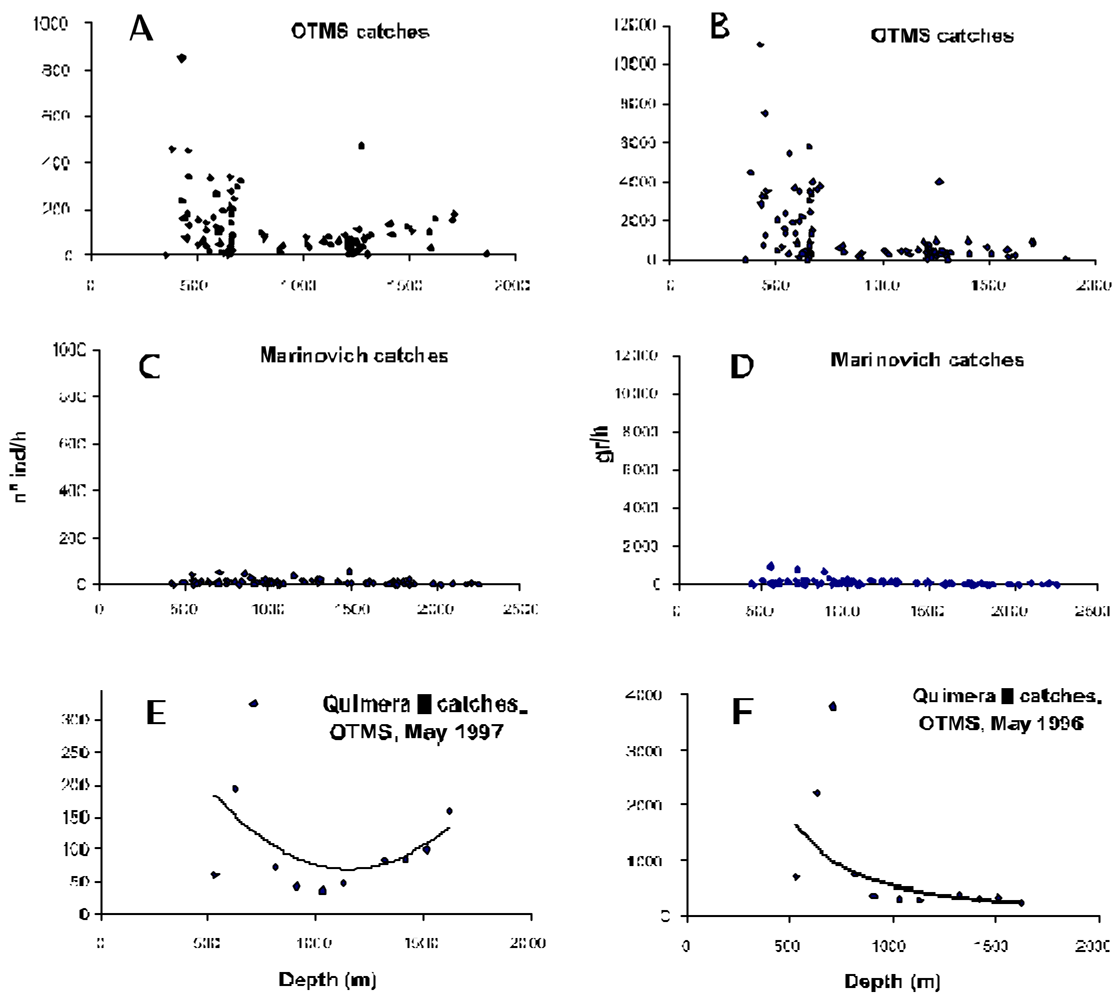


Fig. 2. Bathymetric abundance and biomass of A. antennatus captured by different gears. See letter references in the text.

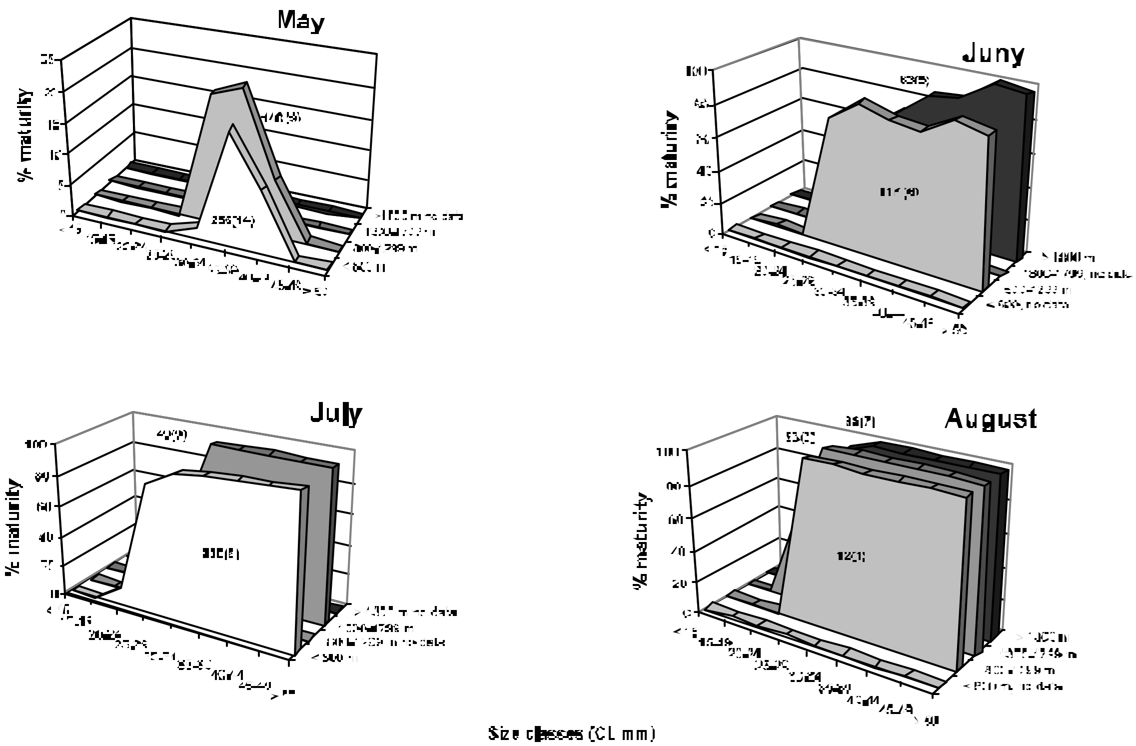


Fig. 3. Percent of maturity stages (IV, V and VI) of A. antennatus during the maturity period by depth and size intervals. Numbers are individuals analyzed. Between brackets, number of hauls by depth intervals.

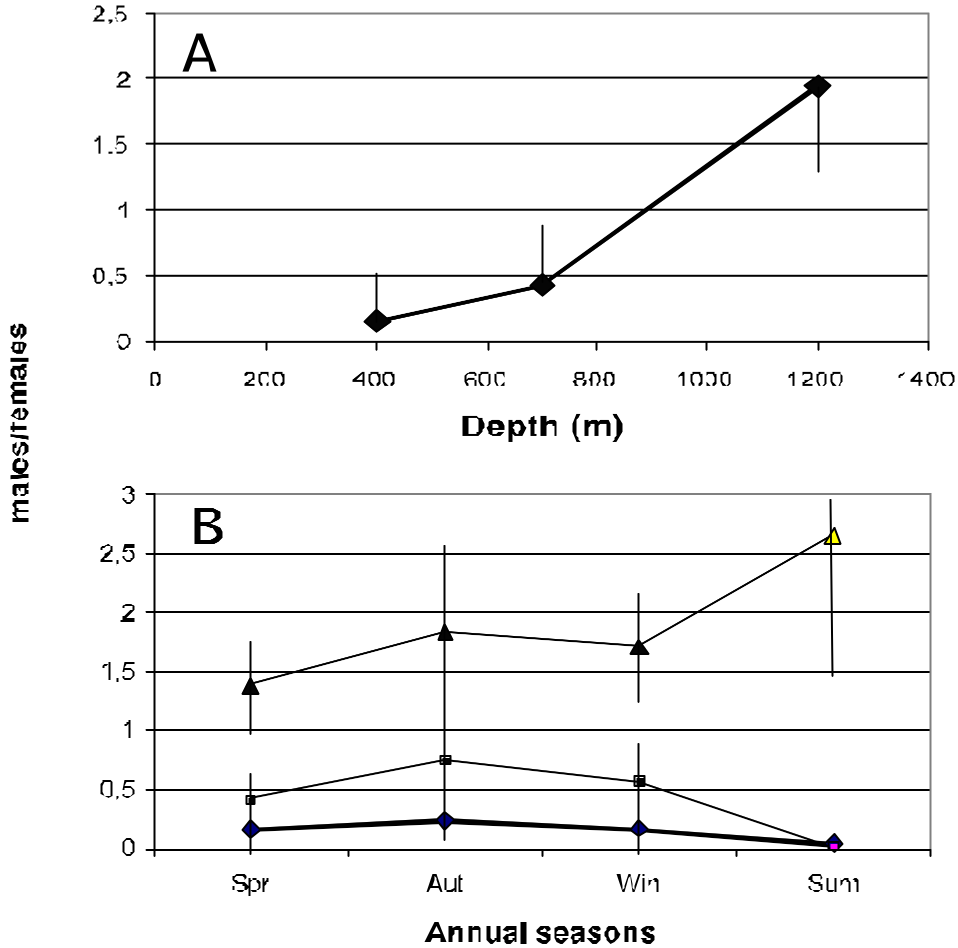


Fig. 4. A, sex-ratio of A. antennatus by different depth intervals. B, sex-ratio by different seasons and depths: diamonds, 400 m; squares, 700 m; and triangles, 1200 m.

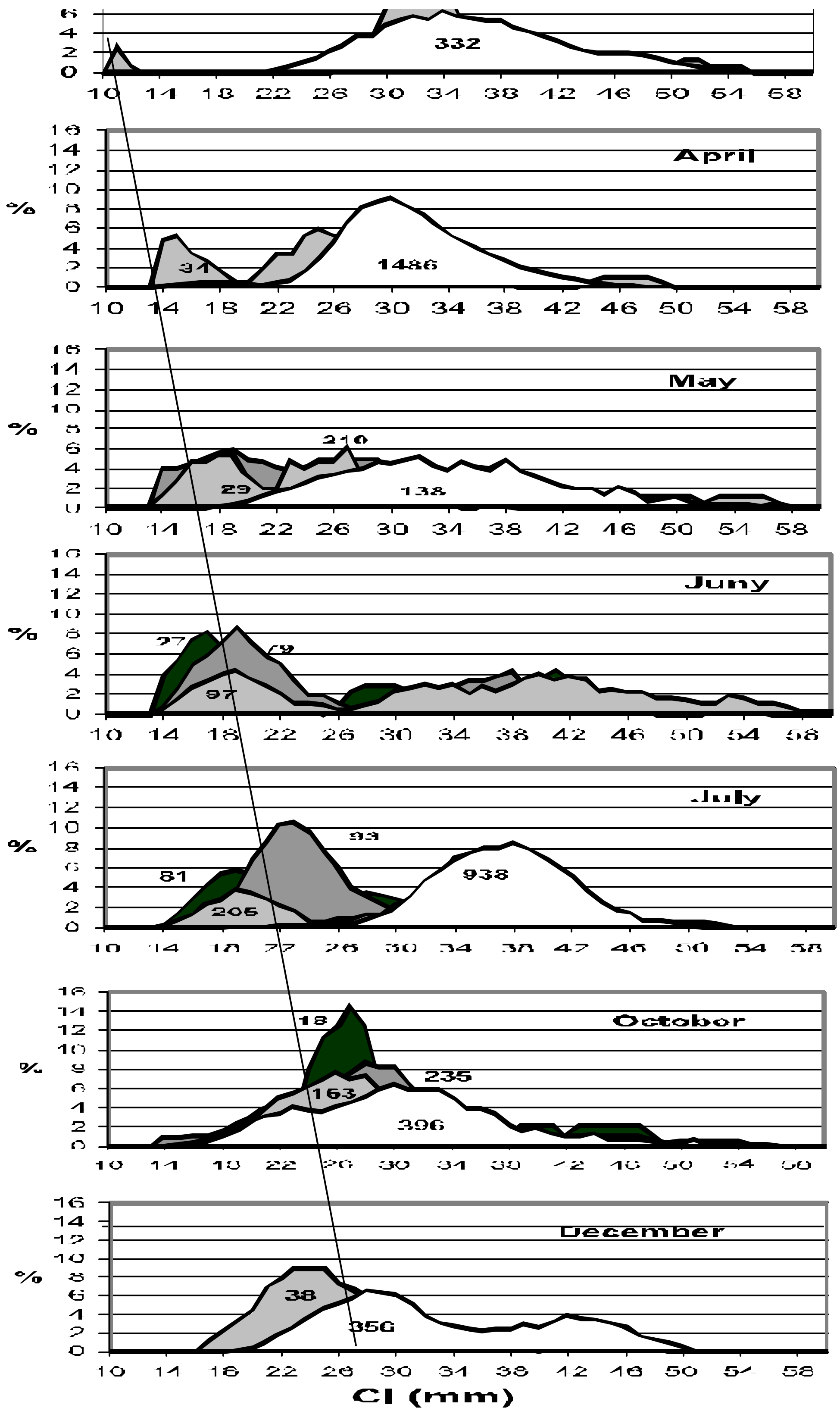


Fig. 5. Female size frequencies distribution of A. antennatus by depth. White, < 800 m; clear dotted, 800-1299 m; dark dotted, 1300-1799 m; and black, >1800 m. Number represents individuals measured.

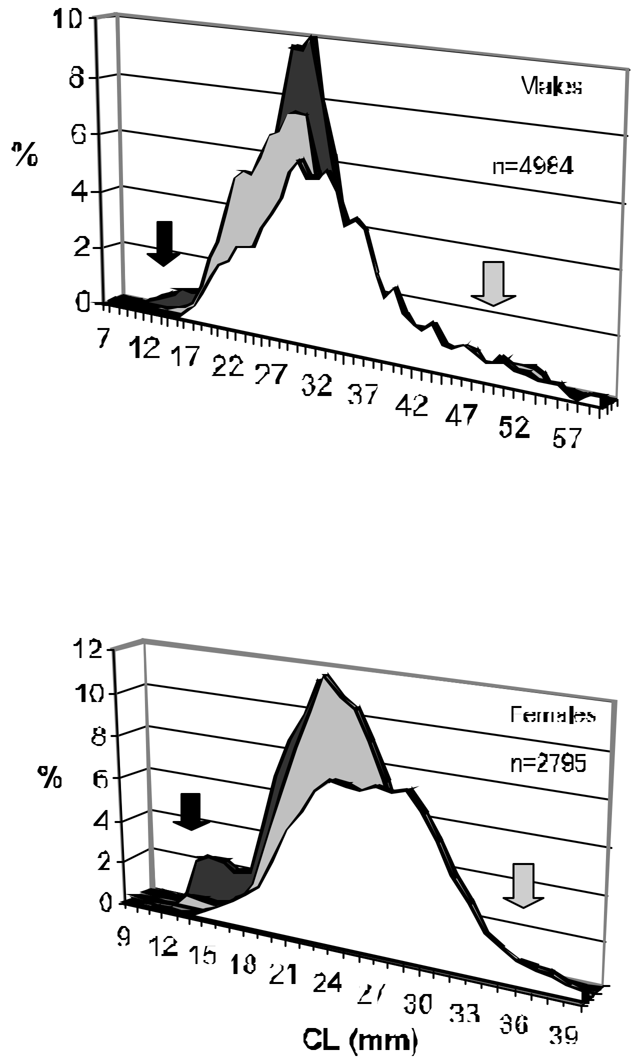


Fig. 6. Total size frequency distributions of A. antennatus by depth and sex. White, <.1000 m; dotted, 1000-1500 m; black, > 1500 m. Black arrow, juvenile in deep samples. Dotted arrow, adult individuals in shallow waters.

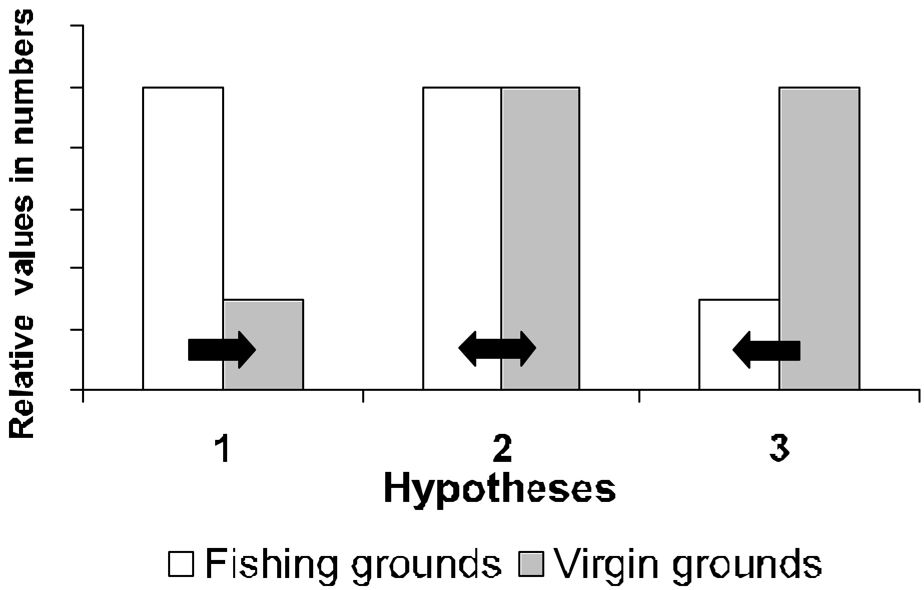


Fig. 7. Hypothetical exchange between individuals from fishing and virgin grounds. Numbers represents different hypothesis. Arrow, direction of the individual flow. Explanation in the text.

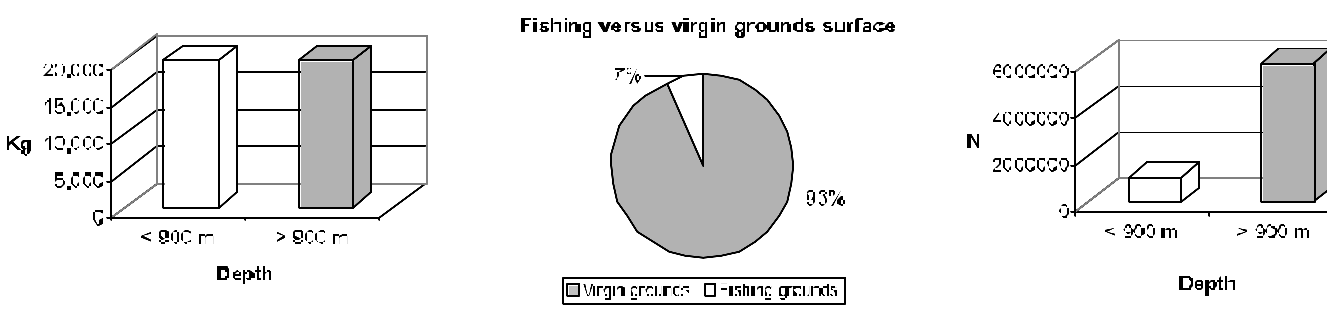


Fig. 8. Comparative biomass (kg) and abundance (N) of A. antennatus between fishing grounds and virgin grounds selected by simulation procedures (See also Figure 1).