# Phytoplankton biomass and zooplankton abundance on the south coast of Portugal (Sagres), with special reference to spawning of *Loligo vulgaris**

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SUMMARY: The importance of the south-west coast of Portugal as a spawning ground for the long-finned squid, *Loligo vulgaris*, was investigated between May 1993 and May 1994 at a site 3 Km East of Sagres. Hydrographic (temperature and salinity) observations were registered in situ and water samples were collected for laboratory determinations of chlorophyll a. Zooplankton was sampled with a 500 µm plankton net during 10mn trawls. Hydrographic and biological information was related to the occurrence of *L. vulgaris* egg masses at the site. The values of water temperature ranged from 13.0º C in January to 19.2º C in July, and the salinity varied between 35.3‰ in May of 1993 and 38.0 ‰, in November, December and March. The highest values for phytoplankton biomass were recorded in September and May, whereas the maximum zooplankton abundance was recorded between July and September. The most important zooplankton groups included cladocerans, copepods, crustacean larvae, fish eggs and appendicularians. We have concluded that the highest values for zooplankton abundance were recorded when the greater number of egg masses of *L. vulgaris* were observed.

*Key words:* Chlorophyll *a*, phytoplankton, zooplankton, egg masses, *Loligo vulgaris*, Sagres (Portugal).

RESUMEN: BIOMASA FITOPLANCTÓNICA Y ABUNDANCÍA DE ZOOPLANCTON EN LA COSTA MERIDIONAL DE PORTUGAL (SAGRES), CON PARTICULAR ATENCIÓN AL DESOVE DEL CALAMAR *LOLIGO VULGARIS*. – En este trabajo se estudió la importancia de la costa sudoeste de Portugal como zona de puesta del calamar *Loligo vulgaris*. El estudio se llevó a cabo entre mayo de 1993 y mayo de 1994 en el área situada a 3 km al este de Sagres, analizandose las condiciones hidrográficas (temperatura y salinidad) in situ. Además, se recogieron muestras de agua para la posterior cuantificación de la clorofila a en laboratorio. El zooplancton se muestreó realizando arrastres de 10 minutos y utilizando una red de plancton de 500 µm. En el área de estudio se relacionó la biologia del ecosistema y las condiciones hidrograficas de la masa de agua con la ocurrencia de masas de huevos de *L. vulgaris*. Los valores de temperatura del agua variaron entre 13.0º C en enero y 19.2º C en julio, mientras que la salinidad estuvo comprendida entre 35.3 ‰ en mayo de 1993 y 38.0 ‰ en noviembre, diciembre y enero. Por otra parte, los valores más elevados de biomasa de fitoplancton se observaron en septiembre y mayo, mientras que el máximo de abundancia de zooplancton ocurrió entre julio y septiembre. Los grupos mas importantes de zooplancton fueron cladóceros, copépodos, larvas de crustáceos, huevos de peces y apendicularias. Se concluyó que los valores más elevados de abundancia de zooplancton coincidían con las observaciones de un mayor número de masas de huevos de *L. vulgaris*.

*Palabras clave:* Clorofila *a*, fitoplancton, zooplancton, masas de huevos, *Loligo vulgaris*, Sagres, (Portugal).

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## INTRODUCTION

Many studies on short-lived cephalopods indicate that their reproductive strategies are flexible, allowing different components of a population to adapt to a wide range of environmental conditions (Coelho, 1985; Jackson, 1990; O'Dor and Coelho, 1993). For example, the ommastrephidae squid *Illex illecebrosus* has established migration patterns from localised spawning areas to utilise food sources extending from subtropical to polar habitats (Coelho and O'Dor, 1993). These migratory patterns can occur, also, on a more restricted scale, such as in the loliginid squid *Loligo vulgaris*, where there are movements between inshore and offshore sites (Worms, 1983).

Successful management of cephalopod fisheries must take account of these complex migratory patterns (O'Dor and Coelho, 1993). Indeed, Pierce and Guerra (1994) list a number of requirements for complete assessment of a cephalopod fishery including amongst others: a comprehensive knowledge of the species` life cycle, particularly with regard to the distribution of the spawning sites and early life stages; and information on the physical and chemical parameters of the bodies of waters in which the species live, including plankton production, especially in the vicinity of the spawning grounds.

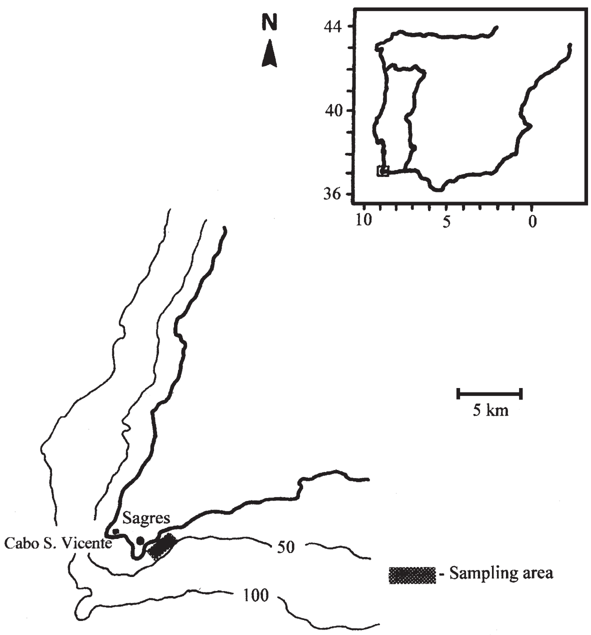


FIG. 1. – Map of the south Portugal showing the sampling site.

A study of the long-finned squid, *Loligo vulgaris*, which forms part of an important resource for the artisanal fishery in southern Portugal has demonstrated a complex population structure (Coelho *et al*., 1994). Mature males and females are present in the population throughout the year, but there are significant differences in the sizes at which males and females achieve maturity. Peaks for spawning activity are lower during the summer and higher during autumn to spring. Incidental observations of egg masses between 1988-1992 at a coastal site near Sagres demonstrates a marked seasonal character, which in contrast to the general pattern, shows a peak for spawning during the summer months. On the basis of these observations, this paper presents results from a more systematic study that has been carried out between May 1993 and May 1994 to determine whether the pattern of egg spawning by *L. vulgaris* at Sagres can be related to hydrological and/or plankton productivity.

## MATERIAL AND METHODS

The study area was located on the south coast of Portugal, approximately 3 km east of the port of Baleeira (Fig. 1). Although the site was coastal, only 1 km offshore, the water was relatively deep with a column of 25 m. Weekly samples were taken from May to September 1993, and continued at monthly intervals between October 1993 and May 1994.

Discrete water samples to determine the phytoplankton biomass were collected at 2 m depth with a Nansen bottle, concurrently with the temperature and salinity measurements. At the same time, water temperature and salinity measurements were made at 0.5 m depth with a submersible CTD probe. The chlorophyll a concentrations were estimated by the absorbance method using the spectrophotometric equations described in Parsons (1984) and Rheinheimer (1977).

Zooplankton samples were collected with a 0.4 m diameter plankton net (500 μm mesh size) during three 10 mn trawls at 1 m depth and preserved with buffered 4% formalin (Unesco, 1968). A flowmeter mounted centrally in the opening of the net measured the volume of water filtered. In the laboratory, these samples were examined under a microscope and the individuals were identified using keys provided in Newell and Newell (1963), Riedl (1983) and Todd and Laverack (1991). The following taxa were considered: cladocerans (*Penilia avirostris*), chaetognaths, fish larvae, ophiurid larvae, crustacean larvae, copepods and appendicularians. The data from the three trawls were combined and the data are presented as mean values.

An underwater system was monitored at each sampling date for the presence of egg masses of the squid, *Loligo vulgaris*. A metal frame supporting a number of artificial floats was located as an egg collector at a convenient site for regular monitoring. In addition, egg masses were recorded during other diving operations adjacent to the egg collector throughout the sampling period.

The following indices were recorded to determine the structure of the zooplanktonic community:

a) Diversity index, H, where $H = -\sum_{i=1}^{s} p_i.\log_2 p_i$,

where $p_i$ is the proportion of individuals in the *i*-th species (Shannon, 1948), and

b) Evenness, E, where $E = H/\log_2 s$ (Pielou, 1969, 1977).

The evenness, varying between 0 and 1, indicates the degree of equitability of the community.

## RESULTS

The temperature record showed an annual mean water temperature of 15.6º C and with little annual variation (range 6.2º C). There was a winter minimum of 13.0º C and a summer maximum of 19.2º C (Fig. 2). The mean salinity was 37.1‰ with an annual variation of 2.7‰. The higher values (38‰) were recorded in November, December and March and the lower values in May (35.3‰). The salinity was particularly stable from mid-July 1993 through March 1994, ranging from 37‰ to 38‰ (Fig. 2).

### Phytoplankton biomass

The annual mean chlorophyll a concentration was 2.5 mgC.m$^{-3}$. Higher than average chlorophyll a concentrations were observed in May, October and December 1993, as well as April 1994 (Fig. 3).

### Zooplankton abundance

The seasonal trend of the zooplankton abundance is shown in Figure 3. Maxima were recorded in July, August and September, with 21.818 ind.m$^{-3}$, 45.185 ind.m$^{-3}$ and 26.421 ind.m$^{-3}$, respectively. During the other months, the values were always lower than 4.000 ind.m$^{-3}$, except in late September when zooplankton abundance was 7.331 ind.m$^{-3}$.

The higher abundances referred to in these months were due mainly to the cladoceran, *Penilia avirostris,* and copepods. *P. avirostris* contributed 18.878 ind.m$^{-3}$ (July) and 34.286 ind.m$^{-3}$ (August), and cladocerans contributed 8.121 ind.m$^{-3}$ (August). The copepods were also abundant in September, with 4.430 ind. m$^{-3}$ (Fig. 4).

The percentage abundance of the zooplankton groups considered in this study (Fig. 5) shows that *Penilia avirostris* represented 62.13%, followed by copepods (21.20%), fish eggs (5.20%), crustacean larvae (4.19%) and appendicularians (2.56%). The ophiurid and the chaetognath larvae were scarcely represented, with 1.13% and 1.05%, respectively.

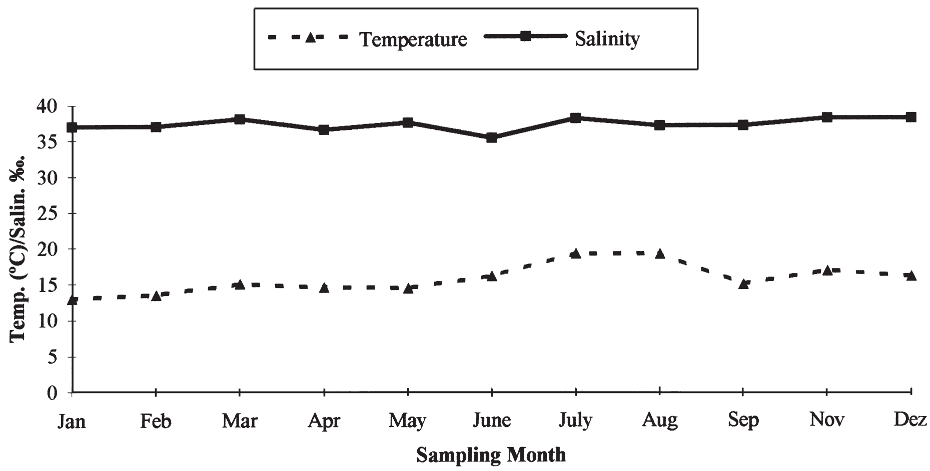


FIG. 2. – Variation of temperature and salinity during the sampling period.

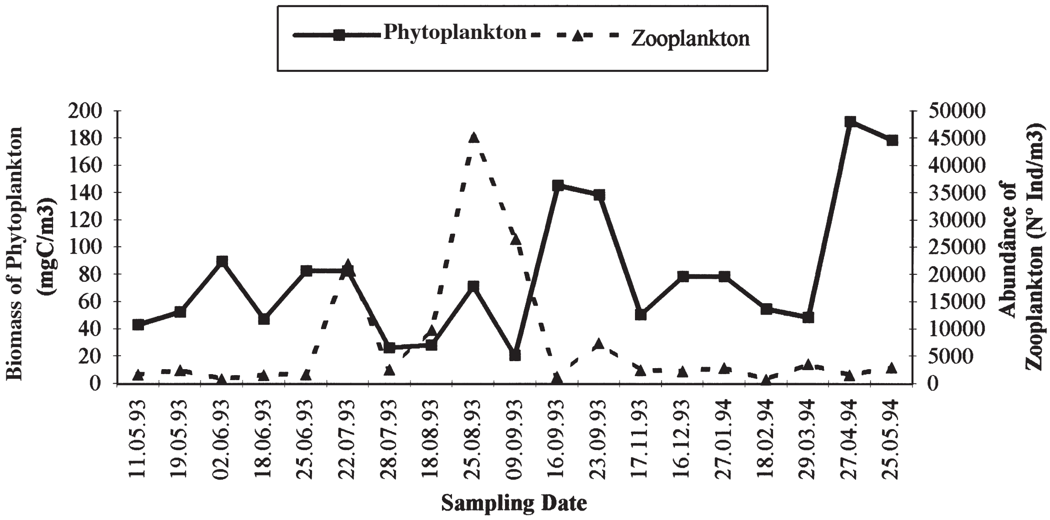


FIG. 3. – Comparison between seasonal variation of phytoplancton biomass and zooplankton abundance.

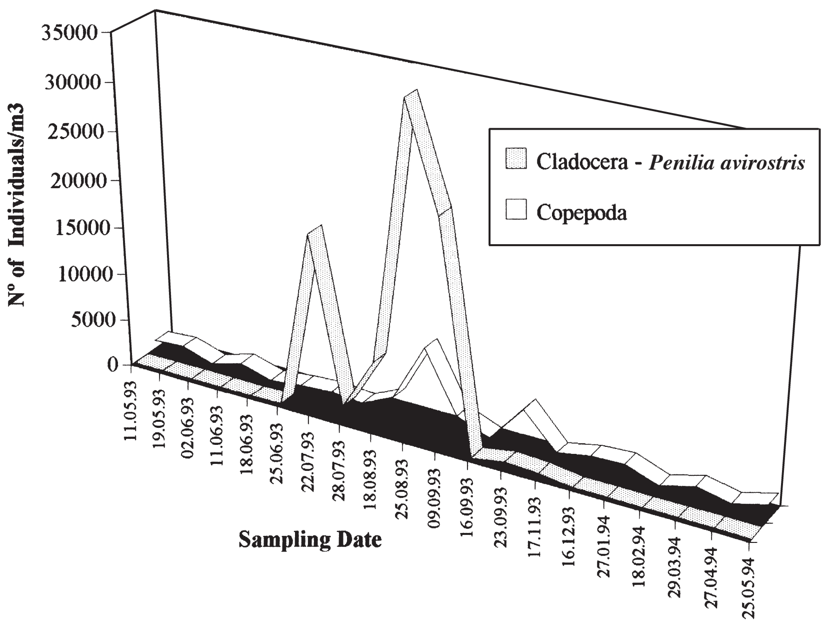


FIG. 4. – Seasonal variation in the abundance of the two main zooplankton groups (Copepods and *Penillia avirostris*).

## Diversity and evenness

The values for the diversity index showed irregular variation throughout the year. The higher values were observed in May (1.80 bits), June (1.66), September (1.60) and November (1.76). Lower values were calculated in July (0.59) and September (0.45). The values of evenness were always lower than 0.7 with minimum values of 0.217 and 0.174 for July and September, respectively (Fig. 6).

## Patterns of egg deposition

Egg masses were observed at depths between 2 metres and 35 metres, with most of the observations between 20-30 m. No sampling was carried out at depths greater than 35 metres because of the limitations imposed by SCUBA diving. A total of 102 egg masses were identified between the beginning of May 1993 and May 1994. The monthly distribution pattern of eggs was relatively consistent, with the first eggs

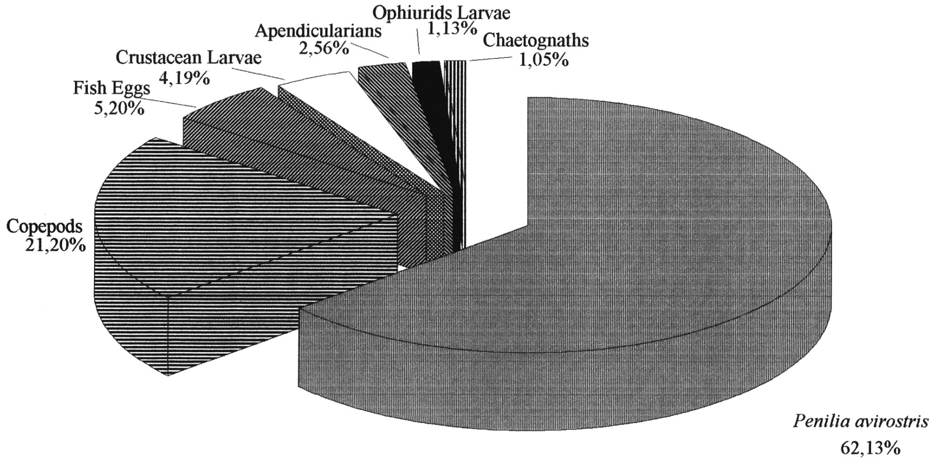


FIG. 5. – Percentage abundance, by numbers, of each zooplankton group.

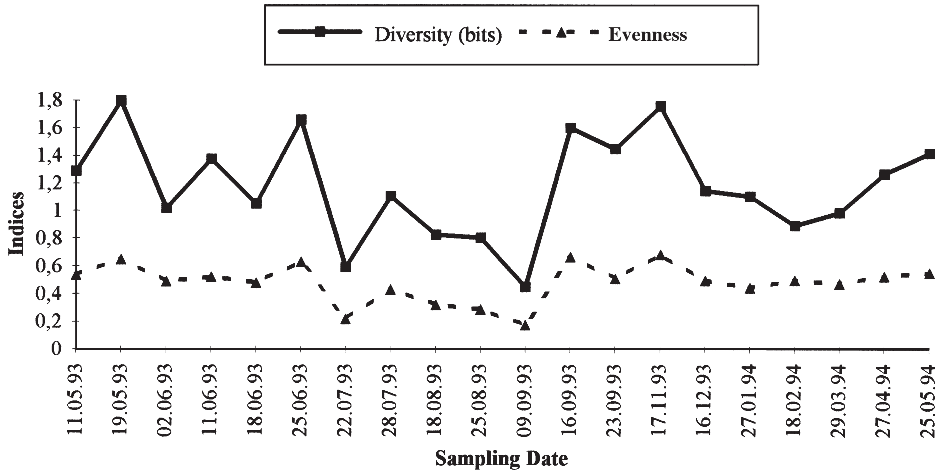


FIG. 6. – Variation of diversity and evenness indices in the zooplankton community during the annual cycle.

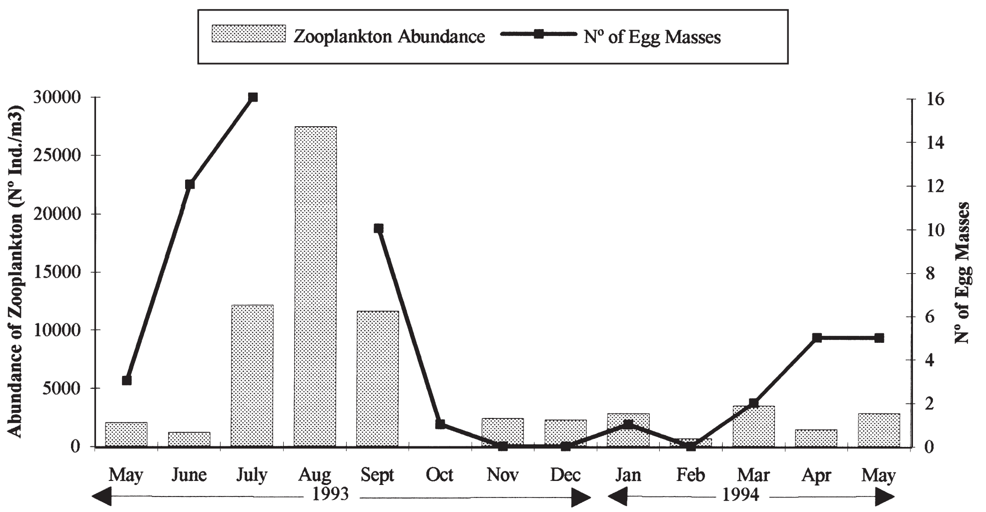


FIG. 7. – Comparison between the pattern of egg laying by *L. vulgaris* and zooplankton abundance.

appearing towards the end of March, rising to a peak in June to July, and then tailing off rapidly after September (Fig. 7). Most of the eggs had between 15-30 fingers in each cluster, although as many 60 were counted. A similar pattern can be observed with respect to the seasonal variation of the zooplankton abundance (Fig. 7).

Although level of sampling in shallow waters was limited, egg deposition in depths of less than 15 metres appeared to be restricted to the peak summer months of June to August. Due to technical limitations, no data on egg deposition was obtained during August.

## DISCUSSION

The cladoceran *P. avirostris* and the copepods were the most abundant taxa recorded during this study. Despite the higher abundance of *P. avirostris,* this species only occurred between late June and both November. Similar results have been recorded by Riedl (1983), for the Mediterranean Sea, and Gonçalves *et al*. (1988) and Sousa-Santos (1988) for the South coast of Portugal. The sharp increase in the abundance of *P. avirostris* after June might be related to the high fertility of this species (Levinton, 1982).

The occurrence of chaetognaths throughout the year indicated that the sea water was within the limited range of pH and salinity that can be tolerated by these individuals (Neto and Paiva, 1984). The relatively low abundance of amphipods, bivalves, foraminiferans and the polychaetes was probably due to the selectivity of the plankton net for individuals smaller than 500 μm (Wickstead, 1976).

The values obtained for the Shannon diversity index indicate that the zooplankton communities were heterogeneous, particularly when the variation between the maximum and minimum values of this index was higher. According to Margaleff (1986) values for the diversity index lower than 5.0 bits indicate stable communities. However, all the values calculated for evenness were below 0.7, which suggests that the zooplankton communities are not in evenness. Values greater or equal to 0.8 are usually considered as indicators of equitability in the communities (Daget, 1976). The lower values for evenness were obtained when *Penilia avirostris* was the clearly dominant species.

The highest values for phytoplankton biomass were recorded during spring and late summer-early autumn and were typical for productive waters. There was no clear relationship with respect to the variation in zooplankton biomass. This might be related to the diet of the dominant groups (cladocerans and copepods) which feed mainly on protozoans (Sanders and Wickham, 1993). Nevertheless, the higher abundance of phytoplankton biomass (September-May) did correspond to lower values of zooplankton abundance. The abundance and successional changes in the phytoplankton community are generally linked to those of the herbivorous copepod community (Heinrich, 1962). In temperate waters, this has a seasonal cycle with the biomass of phytoplankton increasing in spring, followed by a higher abundance of zooplankton (Burford *et al*., 1995). The seasonal variation in copepod abundance is consistent with a successional pattern in the phytoplankton community and could explain the relatively unstable nature of the plankton community in the coastal waters off Sagres.

There appeared to be a close relationship between the spawning of egg masses of *L. vulgaris* and the abundance of zooplankton, with the number of egg masses increasing during the periods of higher zooplankton abundance. It is probable that the dominant zooplankton, *P. avirostris* and the copepods, are important prey in the diet of *L. vulgaris* paralarvae. Yang *et al*. (1983, 1986) and Turk *et al*. (1986) have demonstrated that copepods, *Mysidopsis* spp, *Palaemonetes* spp and both crustacean and fish larvae provide an important food source for the hatchlings of the squid species. Feeding studies carried out on natural populations have shown that small planktonic crustaceans contribute a major portion of the diet of such cephalopod stages (Vecchione, 1987; Passarella and Hopkins, 1991), and the zoeae of decapod crustaceans have been found in the stomach contents of squid paralarvae (Vecchione, 1991). Furthermore, Villanueva (1994) showed that first feeding and growth in planktonic *L. vulgaris* paralarvae can be successfully stimulated using decapod zoeae, from hatching to a size of about 7 mm. From this point onwards, larger prey is required, so mysidacean shrimp could be an important prey item.

Much more work must be done to understand the mechanisms that control planktonic production in this area of the South coast of Portugal. However, this initial approach has demonstrated both high primary production and zooplankton abundance, when compared to other sites along the South coast of Portugal (Cunha, 1993). This higher productivity is probably related to the upwelling effect (Fiuza, 1982, 1983), which provides a supply of nutrients throughout the water column. However, the extent to which upwelling events regulate the paralarvae populations and ultimately the juvenile and adult populations of *L. vulgaris* will be modified by the mobility of juvenile and adults and the lack of spatially defined populations.

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## REFERENCES

Burford, M. A., Rothlisberg P. C. and Wang, Y. – 1995. Spatial and temporal distributions of tropical phytoplankton species and biomass in the Gulf of Carpentaria, Australia. *Mar. Ecol. Prog. Ser.* 118: 255-266.

Coelho, M. L. – 1985. Review of the influence of oceanographic factors on cephalopod distribution and life cycles. *NAFO Sci. Counc. Stud.*, 9: 47-57

Coelho, M. L. and O'Dor, R. K. – 1993. Maturation, spawning patterns and mean size at maturity in the short-finned squid Illex illecebrosus. In: T. Okutani, R.K. O'Dor and T. Kubodera (eds.): *Recent Advances in Fisheries Biology,* pp. 79-89, Shimizu Tokai University Press, Tokyo.

Coelho, M. L., Quintela, J., Bettencourt, V., Olavo, G. and Villa, H. – 1994. Population structure, maturation patterns and fecundity of the squid *Loligo vulgaris* from southern Portugal. *Fish. Res.*, 21: 87-102.

Cunha, M. E. – 1993. Variabilidade estacional do zooplancton na plataforma continental portuguesa. *Boletim Uca,* 1: 229-241.

Daget, J. – 1976. *Les modèles mathématiques en ecologie*. Masson, Paris, 172pp.

Fiuza, A. F. G. – 1982. *The Portuguese coastal upwelling system. In: Actual Problems of Oceanography in Portugal,* pp. 45-71, JNICT, Lisboa.

Fiuza, A. F. G. – 1983. Upwelling patterns off Portugal. In: E. Suess and J. Thiede (eds.): *Coastal Upwelling: its sediment record, Part A.* , pp. 85-98, Plenum Press, New York.

Gonçalves, J. M. A., Sousa-Reis, C. A. and Monteiro, A. S. – 1988. *Estrutura de comunidades zooplanctónicas na Ria Formosa (Zona das Quatro-águas-Tavira).* 5º Congresso do Algarve, 1(63): 413-418.

Heinrich, A. K. – 1962. The life histories of plankton animals and seasonal cycles of plankton communities in the oceans. *J. Cons. Int. Explor. Mer* 27: 15-24.

Jackson, G.D. – 1990. Age and growth of the tropical nearshore loliginid squid Sepioteuthis lessoniana determined from statolith growth-ring analysis. *Fish. Bull.* 88: 113-118.

Levinton, J. S. – 1982. Seasonal changes and breeding of the holoplankton. In: *Plankton and productivity in the oceans,* 3: 333-347.

Margalef, R. – 1986. *Ecologia*. 3ª Ed. Omega Ed., Barcelona, 951pp.

Neto, T. and Paiva, I. – 1984. *Algumas considerações sobre o zooplancton da Costa Algarvia. 3º Congresso do Algarve,* 1(57): 443-441.

Newell, G. E. and Newell, R. C. – 1963. *Marine plankton. A pratical guide*. Hutchinson ed, London, 5ª ed., 244pp.

O'Dor, R. K. and Coelho, M. L.- 1993. Big squid, big currents and big fisheries. In: T. Okutani, R.K. O'Dor and T. Kubodera (eds.): *Recent Advances in Fisheries Biology,* pp. 385-396, Shimuzu Tokai University Press, Tokyo.

Parsons, T. R. – 1984. Determination of chlorophylls and total carotenoides: spectrophotometric method. In: *A manual of chemical and biological methods for seawater analysis*. Pergamon press, Oxford, 4: 101-107.

Passarella, K. P. and Hopkins, T. L. – 1991. Species composition and food habits of the micronektonic cephalopod assemblage in the Eastern Gulf of Mexico. *Bull. Mar. Sci.*, 49: 683-659.

Pielou, E. C. – 1969. *An introduction to mathematical ecology*. Wiley Interscience, New York.

Pielou, E. C. – 1977. *Mathematical ecology*. John Wiley and Sons, New York.

Pierce, G.J. and Guerra, A. – 1994. Stock assessment methods used for cephalopod fisheries. *Fish. Res.*, 21: 255-285.

Rheinheimer, G. – 1977. Microbial ecology of a brackish water environment. *Ecol. Stud.*, 25: 1-291.

Riedl, R. – 1983. *Fauna e flora del Mar Mediterraneo*. Omega Ed. Barcelona.

Sanders, R. W. and Wickham, S. A. – 1993. Planktonic protozoa and metazoa: predation, food quality and population control. *Mar. Microb. Food Webs,* 7: 197-223.

Shannon, C. E. – 1948. A mathematical theory for communications. *Bull. Syst. Tech. J.,* 27: 379-423.

Sousa-Santos, M. C. – 1988. *Ciclo anual do zooplancton na Ria de Alvor. 5º Congresso do Algarve,* 1: 427-435.

Todd, C. D. and Laverack, M. S. – 1991. *Coastal marine zooplankton. A practical manual for students*. Cambridge University Press.

Turk., P.E., Hanlon, R. H., Bradford, L. A. and Yang, W. T. – 1986. Aspects of feeding, growth and survival of the european squid *Loligo vulgaris* Lamarck, 1799, reared through the early growth stages. *Vie Milieu,* 36: 9-13.

UNESCO - 1968. *Zooplankton sampling. Monographs on Oceanographic Methodology*. The Unesco Press, Paris, 174pp.

Vecchione, M. – 1987. Juvenile ecology. In: P.R. Boyle (ed.): *Cephalopod Life Cycles. Species accounts*. Vol. 2, pp. 61-84, Academic press, London.

Vecchione, M. – 1991. A method for examining the structure and contents of the digestive tract in paralarval squids. *Bull. Mar. Sci.,* 49: 300-308.

Villanueva, R. – 1994. Decapod crab zoeae as food for rearing cephalopod paralarvae. *Aquaculture,* 128:143-152.

Wickstead, J. H. – 1976. Marine zooplankton. *Stud. Biol.:* 62: 1-60.

Worms, J. – 1983. *Loligo vulgaris*. In: P.R. Boyle (ed.): *Cephalopod Life Cycles. Species accounts*. Vol. I, pp.143-158, Academic press, London.

Yang, W. T., Hanlon, R. H., Krejci, M. E., Hixon, R. F. and Hulet, W. H. – 1983. Laboratory rearing of *Loligo opalecens,* the market squid of California. *Aquaculture,* 31: 77-88

Yang, W. T., Hanlon, R. H., Krejci, M. E., Hixon, R. F. and Hulet, W. H. – 1986. Growth, behaviour, and sexual maturation of the market squid, *Loligo opalescens,* cultured through the life cycle. *Fish. Bull.,* 84: 771-798

Scient. ed.: M. Alcaraz