# The benthic ecology of some Ria Formosa lagoons, with reference to the potential for production of the gilthead seabream (*Sparus aurata* L.)

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Universidade do Algarve
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# ABSTRACT

Extensive aquaculture is traditional in the Algarve, being practised in lagoons (either in special aquaculture ponds or in water reservoirs of salinas as a supplement to salt production). The fish production can be increased, as a first step, by improving the water circulation, or by utilising additional areas in abandoned salinas. However, in order to do so it is desirable to know about the ecological conditions, for which no information presently exists for the Ria Formosa lagoons. A two-year sampling program was therefore carried out, in four lagoons subjected to different water renewal regimes, with the aim of determining the actual ecological conditions and relating these to the dynamics of water circulation. All the studied lagoons, situated near Olhão, in the Ria Formosa, received the same incoming water through the Marim channel. In one lagoon the water was partially renewed every day. In two other lagoons, the water was renewed according to salt-production requirements, and in the fourth lagoon the water was renewed only fortnightly, during the spring tides.

These different water regimes created a gradient of increasing environmental stress. The most stressed lagoon experienced large environmental variations, mainly of salinity, which were reflected in the benthic populations, represented by a few, abundant and productive, small opportunistic species. In the least stressed lagoon, the benthic populations were more diverse, with organisms characteristic of estuarine or coastal areas, as well as of the Ria Formosa tidal channels. The secondary production in this lagoon was high, when compared with the other lagoons studied and with data from the Ria Formosa and other estuarine or coastal areas. The other two lagoons had intermediate characteristics.

A second environmental gradient of increasing eutrophication was noticed between the least stressed lagoon and the intermediate lagoons, reflected by high biochemical oxygen demand levels. In these lagoons excessive primary production can lead to a deterioration of the water quality and sometimes to depletion of dissolved oxygen, during the neap tides when water renewal is minimal. The benthic populations were less diverse. However, the secondary production in these lagoons can attain high values, comparable to that in the least stressed lagoon.

The main fish species cultured in these lagoons is *Sparus aurata*, a benthic feeder. A field experiment was carried out in one of the lagoons of intermediate stress with the aim of studying possible selective feeding behaviour of the gilthead. The results showed that this fish prefers hard bodied prey, such as the gastropod *Cerithium vulgatum*, but that in the absence of prey of an appropriate size, whatever is available might be taken.

In the final section of this thesis, a simple model is developed to estimate the potential of the study lagoons for the production of gilthead in an extensive aquaculture regime. The model was based on the results of the two-year study of the environmental conditions and on the field experiment carried out on the feeding habits of gilthead. Reported data on *Sparus aurata* growth and food requirements were also used. The simulations indicated that in the least stressed lagoon production of gilthead could yield 20 or 25 g $m^{-2}y^{-1}$ (wet weight) or 250 Kg $ha^{-1}y^{-1}$. In the lagoons experiencing intermediate stress the yield would probably be less or equal to 10 g $m^{-2}y^{-1}$. In the lagoon with the worst environmental conditions, the yield would be lower, probably around 6 g $m^{-2}y^{-1}$ or less.

In the Algarve there are large areas where gilthead production can be implemented, namely in old salinas or as a supplement to salt-production. With minor modifications to improve water renewal in these salinas annual yields of gilthead of 10 to 20 g $m^{-2}y^{-1}$ might be achieved.

## RESUMO

A aquacultura extensiva no Algarve é um método de cultura tradicional, sendo praticada em lagoas costeiras (quer em tanques de aquacultura feitos especificamente para esse fim ou em reservatórios de água de salinas como um suplemento para a produção de sal). A produção de peixe nestas lagoas pode ser aumentada, numa primeira fase, através de pequenas modificações no sistema de circulação de água, ou implementada em velhas salinas abandonadas. Contudo, para a elaboração dos projectos necessários é desejável conhecer as condições ecológicas existentes nas lagoas da Ria Formosa, sobre as quais não existe informação. Com o objectivo de determinar as condições ecológicas actuais e relacioná-las com a dinâmica de circulação de água, foi desenvolvido um programa de amostragem durante dois anos. Foram seleccionadas quatro lagoas costeiras, situadas na Ria Formosa, próximo de Olhão. Todas as lagoas recebiam a mesma água da Ria, através do canal de Marim, mas estavam sujeitas a diferentes regimes de renovação de água. Numa das lagoas a água era renovada parcialmente todos os dias. Em duas outras lagoas, a água era renovada de acordo com as necessidades da produção salina. Na quarta lagoa a água só era renovada quinzenalmente, durante as marés de grande amplitude.

Os diferentes regimes de renovação de água existentes nas lagoas criaram um gradiente ambiental de crescente *stress*. A lagoa com menor renovação de água estava sujeita a variações ambientais muito amplas, principalmente da salinidade da água, que se reflectiram nos povoamentos bentónicos, representados por algumas espécies oportunistas, de pequeno tamanho mas muito produtivas. Na lagoa com maior renovação de água as populações bentónicas eram, pelo contrário, muito diversificadas. Os organismos encontrados são característicos de zonas costeiras e comuns nos canais de maré da Ria Formosa. A produção secundária nesta lagoa é muito elevada, quando comparada com as restantes lagoas estudadas ou com outros sistemas estuarinos ou costeiros. As duas outras lagoas apresentaram características intermédias.

Um segundo gradiente ambiental, de crescente eutrofização, foi notado entre a lagoa de maior renovação de água e as duas lagoas de características intermédias, com ocorrência de elevados níveis de carência bioquímica de oxigénio. Nestas lagoas uma produção primária excessiva pode levar a uma deterioração da qualidade da água e, por vezes, ao

consumo total do oxigénio dissolvido, sobretudo durante as marés mortas quando a renovação de água é mínima. As populações bentónicas presentes eram menos diversificadas. Contudo, a produção secundária pode atingir níveis elevados, comparáveis com os níveis determinados na lagoa com melhores condições ambientais.

O principal peixe cultivado nestas lagoas é a dourada, *Sparus aurata*, que é uma espécie de hábitos alimentares bentónicos. Com o objectivo de estudar o comportamento alimentar da dourada e determinar a existência de uma possível selectividade alimentar, foi montada uma experiência numa das lagoas de características ambientais intermédias. Os resultados desta experiência mostraram que este peixe prefere presas de corpo rígido, como os gastrópodes *Cerithium vulgatum*. No entanto, se não existirem no meio este tipo de presas com um tamanho apropriado, a dourada pode consumir qualquer outra presa.

Na última secção deste trabalho foi desenvolvido um modelo simples para estimar a produção potencial de dourada nas lagoas estudadas, em regime de aquacultura extensiva. O modelo foi baseado nos resultados do estudo feito durante dois anos sobre as características ambientais e na experiência sobre os hábitos alimentares da dourada. Foram ainda utilizados dados retirados de outros investigadores sobre o crescimento e as necessidades alimentares da dourada. As simulações feitas indicam que, na lagoa sujeita a um menor *stress* ambiental, a produção de dourada pode atingir 20 a 25 g $m^{-2}$ $ano^{-1}$ (peso húmido) ou 250 Kg $ha^{-1}$ $ano^{-1}$. Nas lagoas com características intermédias a produção poderá ser de 10 g $m^{-2}$ $ano^{-1}$. Na lagoa sujeita a piores condições ambientais a produção poderá ser inferior a 6 g $m^{-2}$ $ano^{-1}$.

No Algarve existem vastas áreas onde a produção de dourada pode ser implementada, nomeadamente em velhas salinas abandonadas ou como suplemento para a produção de sal. Com pequenas modificações de forma a melhorar a circulação de água poder-se-á atingir rendimentos anuais de dourada de 10 ou 20 g $m^{-2}$ $ano^{-1}$.

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## Some definitions

Meaning of some words as they are used in this Thesis:

| | |
|---|---|
| Lagoon | Salt-water lake with one or more openings to the sea, to an estuary or to a tidal channel. The contact with the tidal water may be intermittent. |
| Lagoon system | Complex of shallow-water lagoons, wetlands, tidal channels, and barrier islands. |
| Aquaculture pond or pond | Water-reservoir excavated, for the purpose of raising fish, in silt or in sandy-silt soils either in wetlands or in abandoned salinas. |
| Salina | Complex of several water-reservoirs of different sizes and depths excavated in silt or in sandy-silt soils for the purpose of producing salt. |

# Chapter I

# INTRODUCTION AND AIMS

# I - INTRODUCTION AND AIMS

## 1.1 Introduction

There are good prospects for the development of aquaculture in continental or coastal waters in developed countries. Aquatic products have become very popular and the demand is often higher than the supply (Billard, 1990).

Portugal has a very good climate with mild winters and hot summers, sites with good conditions of water renewal, moderate tidal range and direct communication with open sea. Many of these areas are already significantly polluted, but in the Algarve region industrial and domestic pollution is not yet significant (Barahona-Fernandes & Dinis, 1980). However, domestic sewage is beginning to adversely affect the area, although this is seasonal. Water quality decreases in the summer months in response to a large influx of tourists combined with a lack of rain and calm weather conditions at sea (Fritz, 1988).

The Algarve region is in a privileged position to compete in marine aquaculture, an industry still to be developed fully in Portugal. At present aquaculture in the Algarve is mostly concerned with the production of the clam, *Ruditapes decussatus*, which represents 92 % of the total regional aquaculture production. The production of the gilthead *Sparus aurata* is also important, representing 4.7 % of the regional production and 6.8 % of sales value. Oyster culture is the third most important activity, representing only 3.2 % of production, and 1 % of sales (Morais & Carvalho, 1992).

### 1.1.1 The Ria Formosa

The Ria Formosa lies along the south of Portugal, extending for about 55 km. It is a true barrier islands system, comprising mainland, backbarrier lagoons, inlet deltas, barrier islands, barrier platforms and shoreface (Pilkey *et al*, 1989).

The system is the westernmost formation in an almost continuous series of wetlands which run eastwards along the Gulf of Cádiz, and it is, therefore, more similar to the Spanish wetlands than to the Portuguese estuaries and lagoon systems of the Atlantic coast (Batty, 1991). Tidal amplitude varies from a maximum of 3.5 m at spring tide to 0.5 m at neap tide which causes an important semi-diurnal and fortnightly tidal fluctuation of the water volume inside the system (Falcão & Vale, 1990). The total area covered by water during spring tides varies between 14.1 and 63.1 $km^2$ (Águas, 1986) and on each tide there is an exchange of 50 to 75 % of the water mass (Sprung, 1994). No relevant freshwater input to the system takes place and salinity remaines around 36 ppt throughout the year, except during sporadic short run-off periods (Falcão & Vale, 1990). A full account of Ria Formosa is given by Monteiro (1989).

Within the Ria Formosa system, comprising a total area of 16300 ha, 2000 ha are occupied by salinas and aquaculture ponds (CCRA, 1984). According to Monteiro (1989), there are only 13 extensive aquaculture systems in operation, occupying about 120 ha. To these figures must be added about 50 to 100 ha of the water reservoirs of salinas used for aquaculture as a supplement to salt-production.

### 1.1.2 The climate in the Algarve

The climate in the Algarve is of the Mediterranean type, with hot, dry summers and mild winters, and some precipitation during the colder months. In the southern coastal areas, the climate is characterised by low precipitation (mean annual value: 400 to 600 mm), mild temperatures (mean annual value: 17 °C) and high solar radiation (mean annual value: 3000 to 3200 h) (Cunha, 1983). The diurnal variation of temperature is, during the winter months, 6 to 9 degrees and during the summer months, 8 to 15 degrees. Another characteristic of this region is the occurrence of winds from the east and south-east, with velocities of 30-40 km/h, more frequent during spring and autumn. The water temperature near the coast varies between 19.5 and 21 °C (mean monthly values), from June to October and between 14 and 17 °C during the other months. The lowest temperatures occur in January and February.

### 1.1.3 Extensive aquaculture

Highly intensive fish production in ponds is not economically justificable, considering the high production costs (Wieniawski, 1990). Even at comparatively low stocking densities, without continuous flow, reasonable levels of fish production can be obtained by stimulating natural pond productivity, especially that of the benthos (Wade & Stirling, 1990).

Polyculture is an appropriate extensive aquaculture technique, when the goal is low-cost production fish. Stocking together fish species with different feeding habits enables a more efficient utilization of pond resources, since grazing pressure is distributed among different niches and levels, and wastes from one species can feed another. Furthermore, growth and yields of some fish species may be higher in polyculture than in monoculture due to positive interactions between species (Milstein, 1990).

Under a given management scheme and set of environmental conditions, a pond will support no more than a "fixed maximum" biomass of a given species of fish. This maximum is called the carrying capacity, and is determined by the resource present in least amount relative to what is required by the fish. In unfertilized and unfed ponds, natural fish food is usually the resource present in the least amount and, therefore, that which determines the carrying capacity of the pond (Cuenco *et al*, 1985c).

Extensive aquaculture is traditional in Portugal, being practiced either in specially constructed ponds or in water reservoirs of salinas. Salinas usually comprise several reservoirs of different size and depth, excavated in the silt and sandy-silt soils. In the production of salt, the water is transferred from the main reservoir (where it is possible to rear fish), comprising approximatly one third of the total salina area, to progressively smaller and shallower ponds, to create a gradient of increasing salinity concentration (Barahona-Fernandes, 1981). The main water reservoirs of salinas are in fact small lagoons in which the environmental conditions are defined and limited by the tidal regime.

Fish are allowed to mature for as long as two years, depending on the local practice. In a selective fishery small fishes are transferred alive after one year to other reservoirs and harvested after a period of growth (Drake *et al*, 1984).

The criteria used in the choice of places and building up of salinas are similar to those used for marine aquaculture, and simultaneous exploitation of salt and fish in salinas is therefore technically possible. Mixed production is possible when there is good communication with the sea and sustained high water quality (Barahona-Fernandes, 1981).

The production of these salina reservoirs is limited by, among other factors, restricted water circulation and the availability of natural food. Productivity depends on the benthic populations present, as almost all the fish species of commercial value feed on these organisms. The species produced are the gilthead sea-bream, *Sparus aurata* L., other sea-breams, *Diplodus* spp., the sea bass, *Dicentrarchus labrax* (L.), the eel, *Anguilla anguilla* (L.) and the sole, *Solea* spp.

The production of fish in extensive aquaculture is about 150 kg $ha^{-1}$ $y^{-1}$ (Clément & Rigaud, 1986). The yield is determined not only by the fertility of water and soil but also by the local climatic conditions. Fish species, fish size and stocking density are also of importance, since these determine the quantity and quality of food necessary. Extensive aquaculture is a true production technology, comparable in yield to agriculture (Stephens, 1990). In aquaculture based on improved water circulation and supplementary feeding, the production can attain 1 to 2 tonne $ha^{-1}y^{-1}$ (Pousão-Ferreira, 1988).

In the Algarve region there is little information about total catches in aquaculture systems. In well-managed systems and with good water renewal a production of 300 kg $ha^{-1}y^{-1}$ can be attained (Dinis *et al*, 1989). In Caldeira do Moinho de Maré, a higher production of about 600 kg $ha^{-1}$ has been attained, (Table 1.1). However, this exceptional site was not harvested for two years. Nevertheless, the yield is probably underestimate, because it was very difficult to control all the fish cages during the three days of the harvest.

The proportion of *S. aurata* in the total catch can vary greatly. *Sparus aurata* represents 30 % of the total catch in Cádiz salina reservoirs, other seabream 15 % and the Mugilids 50 % (Arias, 1980). To increase the production of fish of commercial value, it is a common practice to restock with juveniles caught in the Ria Formosa. Dinis *et al* (1989) refer to a figure of 75% in relation to the total catch in an extensive pond where restocking with wild gilthead seabream was carried out. The total production in that pond, situated in Ria Formosa not very far from the study sites, was 202 Kg $ha^{-1}y^{-1}$. In general, restocking with wild seabream juveniles is done between March and May. After nine to twelve months these fish have attained a marketable size (250 to 300 g).

| | Kg | % |
|---|---|---|
| *Sparus aurata* | 990 | 18.4 |
| Other Sparids | 1190 | 22.1 |
| *Solea* spp | 783 | 14.6 |
| *Anguilla anguilla* | 500 | 9.3 |
| *Dicentrarchus labrax* | 30 | 0.6 |
| Mugilids and Other fish | 1880 | 35.0 |
| Total | 5373 | |
| Kg $ha^{-1}$ | 597 | |

Table 1.1. Total catch in December of 1984 in Caldeira de Moinho de Maré, Marim (Olhão).

### 1.1.4 The biology of *Sparus aurata*

There are few estimates of the abundance and biomass of *Sparus aurata* in the Ria Formosa. According to Monteiro (1989) the species is not very abundant, representing only 1.5 % of total estimated migrant fish biomass. It is present between May, when the mean size is 5.7 cm, and August. In September it migrates to the sea at an approximate size of 18 cm (Monteiro, 1989). There is no information about the juveniles of this species. However, the Ria Formosa system can be compared to a nearby coastal system, the Cádiz Bay. In the tidal creeks of this system, Drake & Arias (1989) found fingerlings smaller than 20 mm (total length), from January till March, and larger than 20 mm but smaller than 41 mm, between January and April. The abundance of the gilthead fingerlings was however very low (Drake & Arias, 1991).

The reproductive period of the fish occurs between October and January, with a maximum in December (Arias, 1980). Reproduction begins in the sea near the estuaries, when the water temperature decreases to 19 °C and stops when its below 14 °C (Lasserre, 1974). The juveniles enter the salinas during the first two or three months of the year (Arias, 1976). In November they reach a commercial size and are caught at a mean size of 24.4 cm and a mean weight of 211.8 g. The total length varies between 23 and 26 cm and the weight between 170 and 270 g, depending on the environmental conditions of each salina (Arias, 1976).

In summary, it can be said than this fish reproduces in the adjacent sea, between October and January. The small fingerlings then enter the lagoon system with its richer food sources and some of these fish enter extensive aquaculture ponds. Here they are retained and are allowed to grow, being harvested when they attain a commercial size.

The availability of fry and juveniles of *S. aurata* can be increased by artificial reproduction in hatcheries. In the Algarve, the production of gilthead fry of about 2 g is already possible in hatcheries (Pousão-Ferreira & Silva, 1989). The spawning season can be lengthened until February and the first fish larvae can be obtained early in October. After a 45-60 day period, during which the larvae are feed with live zooplankton, the juveniles are weaned onto inert food for a further 45 to 50 days until they reach a mean weight of 2 g (Pousão-Ferreira, 1988). By the beginning or middle of January gilthead juveniles are already available for transfer to extensive aquaculture systems. In this way it is possible to produce juveniles until the middle of May.

### 1.1.5 Feeding Habits of *Sparus aurata*

As an adult *Sparus aurata* is a benthic feeder, feeding essentially on gastropods and bivalves, but also on crustaceans. Polychaetes and algae are secondary food and fishes and insects are taken occasionally (Arias, 1980). Small fish, smaller than 20 cm in length, have a diet composed essentially of Copepods. Above this size the diet shifts to small polychaetes and other benthic invertebrates such as crustaceans and Chironomid larvae (Drake & Arias, 1989). As the fish grows larger, the diet changes to bigger and hard-bodied prey (Arias, 1980; Suau & Lopez, 1976, Wassef & Eisawy, 1985).

There is practically no information about the foraging behaviour of the gilthead, especially with regard to prey selection in the field (Drake & Arias, 1989). In a study of gilthead juveniles, Ferrari & Chieregato (1981) found that the prey organisms most abundant in the diet were also those most abundant in the environment, indicating non-selectivity. This is consistent with the findings of Eisawy & Wassef (1984) and Wassef & Eisawy (1985), who claim that the gilthead is a generalised feeder taking whatever is available. In contrast, Rosecchi (1987) found gilthead the most specialised of all the Sparids she studied. Kentouri & Divanach (1986) also found that gilthead larvae were selective when they were able to choose among several prey species. The same conclusion of feeding selectivity was reached by Robert & Parra (1991), for two and three year-old giltheads.

## 1.2 Aims

The present study is an ecologically-based approach to the estimation of the natural biological basis for *Sparus aurata* production in the lagoons of the Ria Formosa. There were five main aims:

1 - To characterise the environmental conditions in three salina reservoirs and one lagoon situated in the Ria Formosa based on physical and chemical data of the water in relation to the requirements of *Sparus aurata* (Chapter II).

2 - To characterise the benthic invertebrate populations at the four sites, compare the data obtained to those from other shallow water coastal systems and to relate them to the environmental conditions (Chapter III).

3 - To estimate the benthic secondary production and to relate this to the environmental conditions and to data from other shallow water coastal systems (Chapter IV).

4 - To carry out a short study of the feeding habits of *Sparus aurata* at one of the study sites in order to assess the degree of feeding selectivity in gilthead with respect to prey species and size (Chapter V).

5 - To develop a model to estimate the potential production of *Sparus aurata* at the four sites studied, based on the secondary production data and on the environmental conditions (Chapter VI).

# Chapter II

# ENVIRONMENTAL CONDITIONS

## Physical and Chemical water data

# II - ENVIRONMENTAL CONDITIONS

## Physical and Chemical water data

### Summary

Little information is available on the environmental conditions existing in the salina reservoirs of Ria Formosa. These lagoons are normally used both as water-reservoirs for salt production and extensive-aquaculture production systems. However, the present low profitability of salt production and the potentially high returns from quality fish production, make improvement and transformation of salina reservoirs for permanent aquaculture production a worthwhile proposition (Barahona-Fernandes, 1981). Many projects have been carried out with that aim, but knowledge of local environmental characteristics is a prerequisite. The present work is a study of the chemical and physical conditions in four selected lagoons. The results obtained were related to the water renewal in each of the lagoons and also to the water quality requirements of the gilthead.

Shallow water lagoons can be highly productive, with high concentrations of Chlorophyll *a* in spite of limitation of some nutrients, such as phosphorus. The results showed that the sites with less water renewal undergo strong environmental variations, with an increase in salinity during the hot summer months and large diurnal variations of temperature and dissolved oxygen. During the summer neap tides the quality of the water deteriorates. The increase in primary production can lead to a rise in pH and to depletion of oxygen. Even at site B, where the water is renewed almost every high tide, there is a danger of oxygen depletion. This situation indicates that care must be taken if gilthead production is to be improved in these areas.

## 2.1 Methods

### 2.1.1 Selection and location of sampling sites

Ten sampling stations were selected in four lagoons (Fig. 2.1), situated near Olhão, in the Ria Formosa. The four lagoons (sites A, B, C and D) were situated very close to each other and receive new water directly from the sea through the Marim channel, allowing between-site comparison of the ecological parameters investigated.

Site A is an unused salina reservoir. The water is renewed only during spring-tides, through a manual tide-gate. The other salina reservoirs, sites C and D, are still in use. At site C there is a manual gate, which can be raised to allow water to enter during high tide, according to salt production needs. At site D there is an automatic tidal gate: water enters when there is a positive difference between the water level outside and inside the reservoir. The same happens in site B (Caldeira de Moinho de Maré - see Table 1.1), where conditions are suitable for aquaculture. It has a wide shallow water area, of about 9 ha, crossed by deep channels.

At each site, one station was selected near the gate and another one at the side opposite. At site B, because of its larger area, a third station was selected, close to the tide-gate. At site A, a third station was selected in the second water reservoir (Fig. 2.1).

This arrangement of the stations allowed comparison not only of differences or similarities between sites, but also within each site. The close proximity of the sites meant that the quality of the incoming water was similar, and that any differences detected would be mainly due to a different water exchange regime at each site.

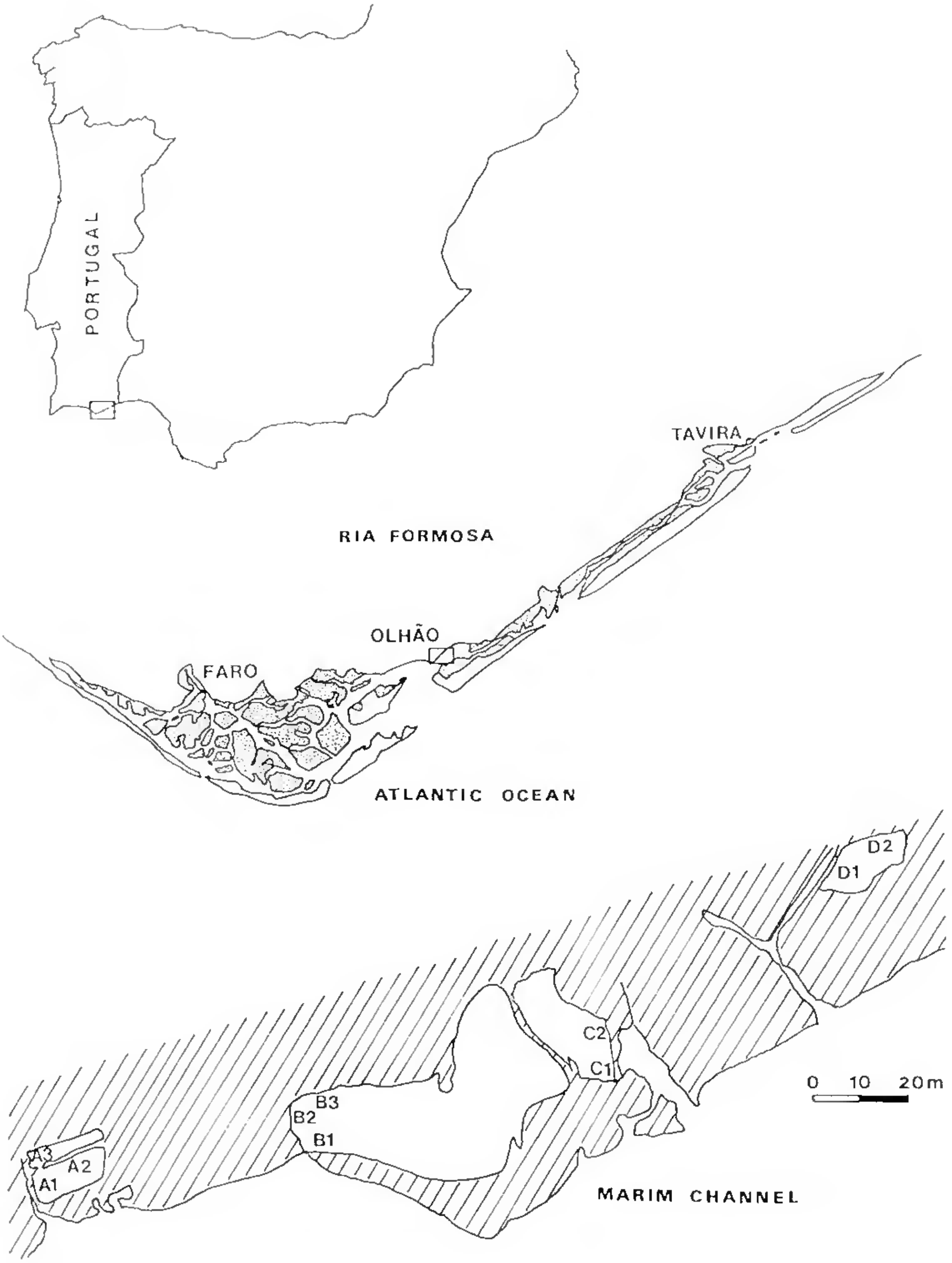


Fig. 2.1. The study area and location of the sampling stations. A1, B1, C1 and D1, near the tide-gates. A2, B3, C2 and D2, interior of the lagoons. A3, second lagoon. B2, middle of the lagoon (considering only the area near the tide-gate).

### 2.1.2 Water analysis methodology

Two water samples were taken every month at each station (Fig. 2.1) over a two year period (December 1984 - November 1986). The samples were taken one during the neap tides, when the water renewal was minimal and the other one week after, during the spring tides. In this way it was possible to record water quality under the two extreme environmental conditions, during the periods of maximal and minimal water renewal. Water samples were always taken from the middle of the water column and during the morning, between 9.30 and 12.00 am.

The following variables were determined using the methods and equipment indicated:

- Temperature, with an Horibe probe.
- Salinity, with a precision salinometer.
- Dissolved oxygen and biochemical oxygen demand (5 days) by the Winkler method.
- pH, with a pH electrode.
- Suspended matter, as total suspended solids dried at 103 - 105°C (Standard Methods, 1985).
- Nutrient (silicate, phosphate, nitrate and nitrite) concentrations, by autoanalysis, according to Strickland & Parsons (1972) and Grasshoff *et al* (1983).
- Chlorophyll *a* and phaeopigments, by flurescence (Pissarra & Cavaco, 1984) and degradation percentage ([Phaeopigments] / ([Phaeopigments] + [Chlorophyll *a*]) ∗ 100).

Temperature was measured *in situ*. The oxygen was fixed immediately after sampling with manganese chloride and alkaline iodide. Water samples for the determination of the remaining parameters were kept in specific bottles, in a thermally insulated container, until arrival at the laboratory.

The samples for nutrient determination were frozen and the concentrations were determined latter by Manuela Falcão from Centro de Investigação Marítima do Sul (CIMS - Delegação de Olhão). The salinity, dissolved oxygen and biochemical oxygen demand were analysed by technical staff at CIMS (Delegação de Faro).

Water samples for pigment concentration and suspended matter were filtered on arrival at the laboratory. The filters for pigment determination were kept frozen until analysis at Instituto Português de Investigação Marítima (Lisbon). The suspended matter was determined immediately.

In 1986 the water temperature and dissolved oxygen were also determined at daybreak and at sunset on three sampling occasions.

## 2.2 Results and discussion

### 2.2.1 Climatic conditions during the period of study

The air temperature measured at the nearest meteorological station, in Faro during the two years of sampling follows the typical variation seen in this region (Fig. 2.2).

Precipitation was more intense during the first year of study, when the highest values occurred in winter (January and February). In the second year it was very dry (Table 2.1) and the precipitation was more evenly distributed throughout the year.

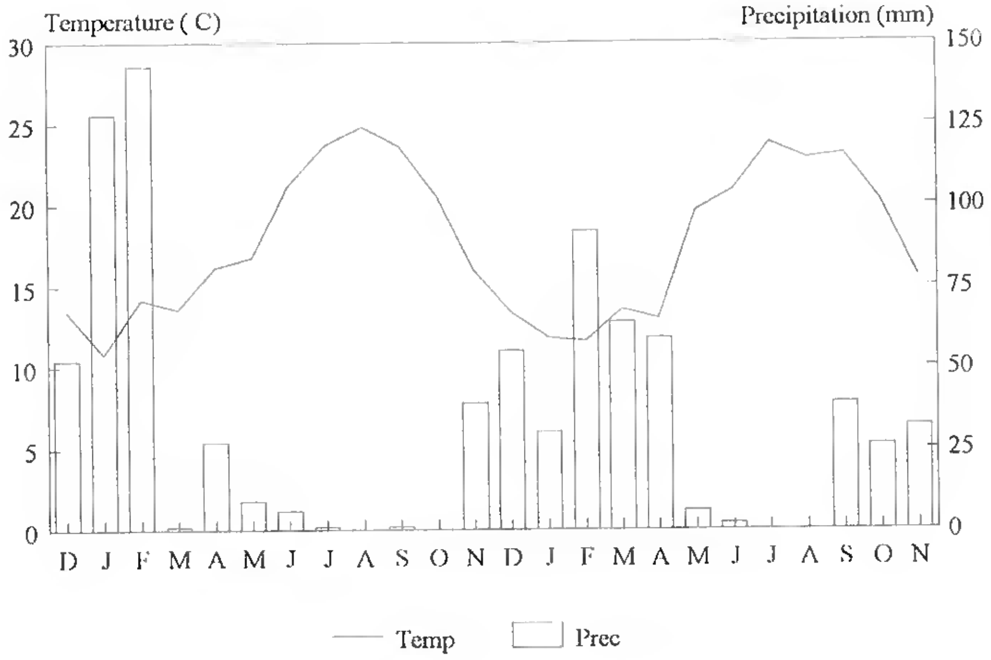


Fig. 2.2. Mean air temperatures and precipitation over the two years of study (1985-1986) at the meteorological station at Faro. Data from the monthly meteorological bulletin for agriculture published by Instituto Nacional de Meteorologia e Geofisica, Lisbon.

| | Temp. (°C) | Prec. (mm) | Total Prec. (mm) |
|---|---|---|---|
| October 1984/March 1985 | 14.3 | 458 | |
| April / September 1985 | 21.0 | 44 | 502 |
| October 1985/March 1986 | 14.5 | 280 | |
| April /September 1986 | 20.5 | 106 | 386 |

Table 2.1 Mean air temperatures and total precipitation during different periods of time at the nearest meteorological station (Faro). Data from the monthly meteorological bulletin for agriculture published by Instituto Nacional de Meteorologia e Geofisica, Lisbon.

### 2.2.2 Temperature

Water temperature closely followed the variation in air temperature (Figs 2.2 and 2.3). Water temperature was higher during the summer and during the first winter values dropped close to 7 °C, at sites A, C and D. At site B, where the water volume is larger than at the other sites, the low air temperatures in winter did not affect the water temperature so much. During the second year, the mean water temperature was higher at site A than at the other sites, perhaps because of the small quantity of water and, consequently lower depth, than at that site during the first year of survey.

The highest temperatures occurred during the neap tides, at all the sampling stations (Appendix A1 - Table 1). The mean annual water temperatures were also higher for neap tides than for spring tides (Fig. 2.4).

At the lagoons with smaller water bodies the temperature variations were higher and more sensitive to the air temperatures. Even at site B, with a large water body and good water renewal the temperature variation was larger than in the Marim channel (Falcão, 1988). According to Eisawy & Wassef (1984), *Sparus aurata* tolerates temperatures between 10° and 33 °C, but decreases feeding activity when the water temperature is below 16 °C (Wassef & Wafaa, 1985). Temperatures below 4 °C are lethal (Labourg, 1976). As the results show, the winter temperatures in the lagoons of the Ria Formosa can fall below 10 °C, but it is unlikely that they would ever decrease to below 5 or 6 °C, even during the night.

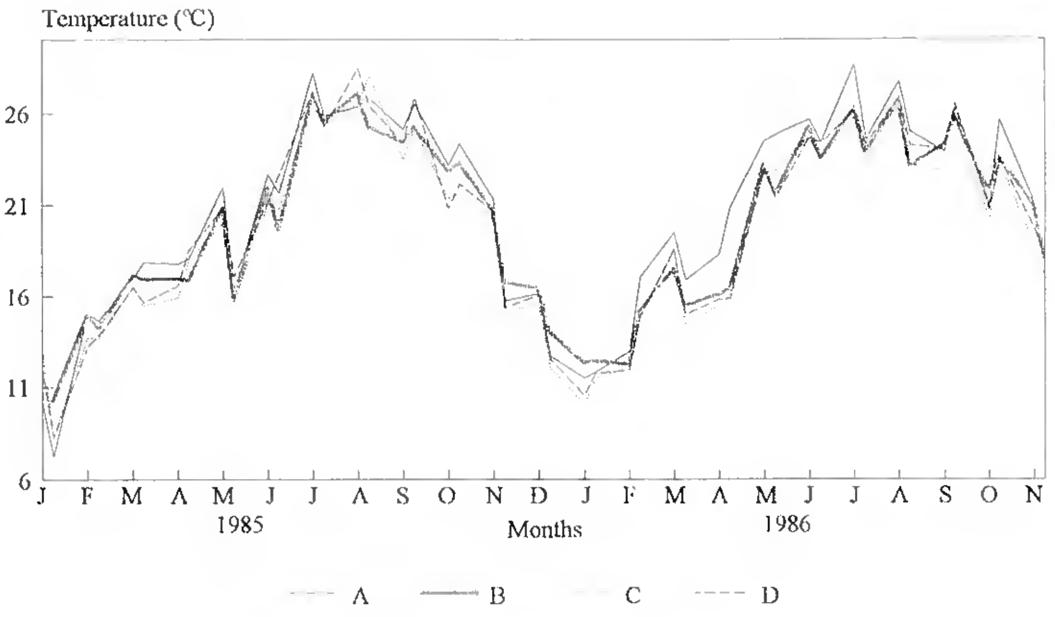


Fig. 2.3 - Variation in mean water temperatures at the four sites over the study period.

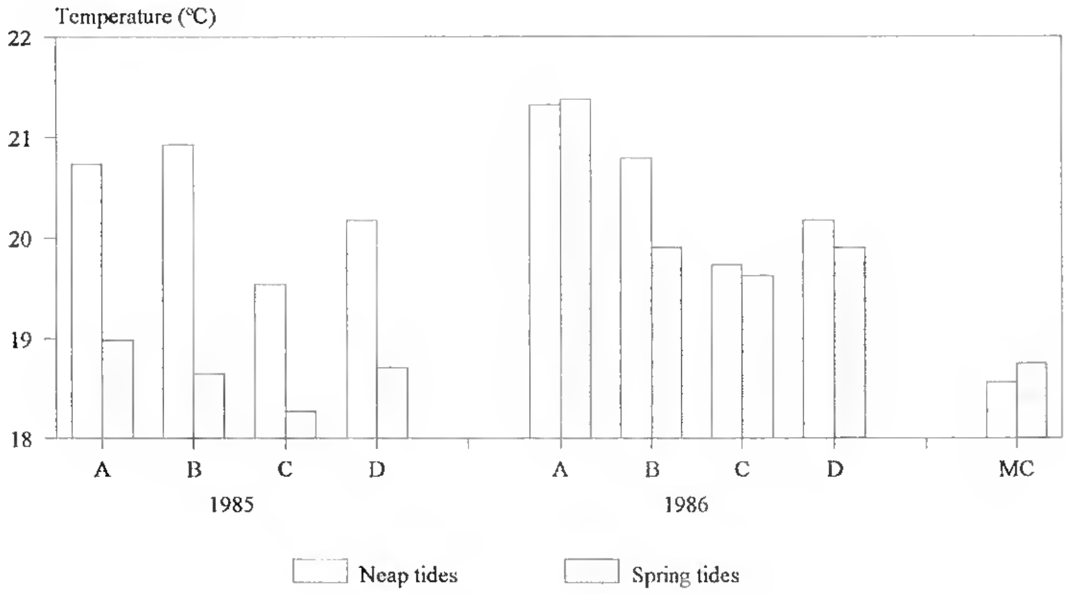


Fig. 2.4 - Mean annual temperatures during the neap and the spring tides at the four sites and in the Marim Channel (MC) in 1986 (Falcão, 1988).

### 2.2.3 Salinity

The mean salinity was relatively constant at site B (Fig. 2.5 and Appendix A1 - Table 2), but this was not so for the other sites where there was a distinct increase during the summer neap tides due to lack of water renewal and to evaporation losses because of the high temperatures. Salinities during the summer months were very high at these sites, exceeding 70 ppt at site A and at site C during the second year.

In the first months of the first year salinity decreased at all sites. The decrease was more pronounced at site A, were it dropped to about 14 ppt, due to high precipitation at this time.

Mean annual salinities were always higher during the neap than the spring tides. There was a general increase in salinity during the second year (Appendix A1 - Table 2 and Fig. 2.5), as a consequence of lower rainfall (Fig. 2.2 and Table 2.1).

Salinities at site B were slightly higher than those recorded in the Marim channel by Falcão (1988) reflecting good water renewal at that site, and similar conditions to those of the Ria Formosa. At the other three sites, the higher salinities were undoubtedly related to the limited water renewal, as has been reported for similar sites in Spain by Lubian *et al* (1985). *Sparus aurata* tolerates salinities of 5 to 44 ppt (Eisawy & Wassef, 1984), although it can also survive at salinities between 42 and 55 ppt (Ben-Tuvia, 1979).

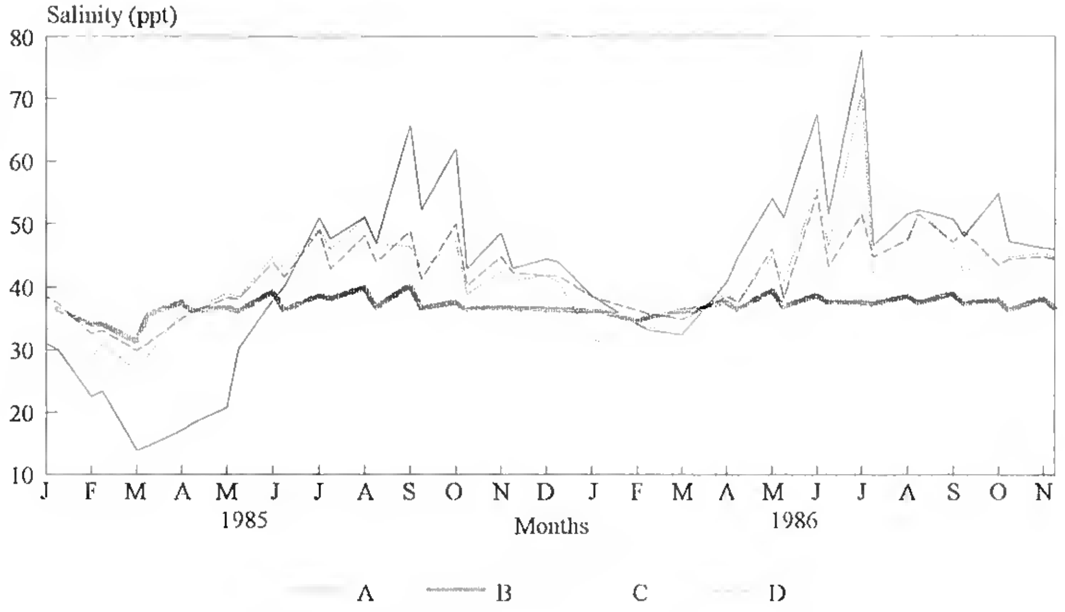


Fig. 2.5 - Variation in mean salinities at the four sites over the study period.

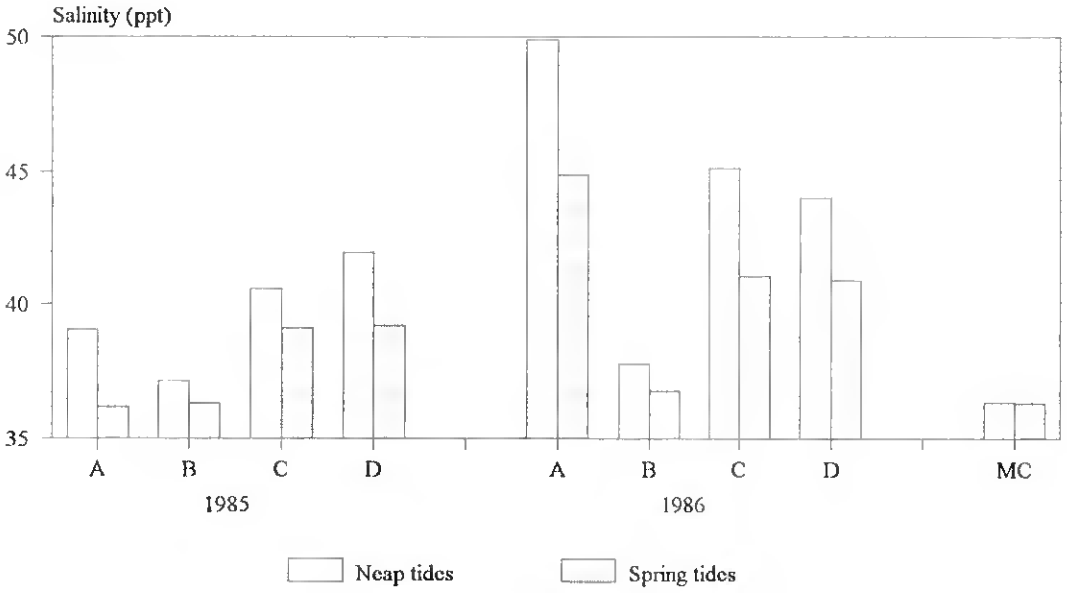


Fig. 2.6 - Mean annual salinities during the neap and the spring tides at the four sites and in the Marim Channel (MC) in 1986 (Falcão, 1988).

### 2.2.4 Dissolved Oxygen

The dissolved oxygen (DO) concentration was higher during the winter months than during the other periods of the year (Fig 2.7), and higher during the neap tides than during the spring tides (Fig. 2.8). The mean DO saturation percentage was near or above 100% and increased slightly during the summer, when there was a larger difference between the neap and the spring tides (Figs. 2.9 and 2.10). During the second summer, the saturation percentage was always greater during neap tides than during spring tides, probably related to the variations of salinity and temperature described above, because the solubility of oxygen decreases with increasing temperature and salinity (Jain *et al*, 1981).

Percentage saturation was sometimes very low, down to 30 to 40 % (Appendix A1 - Table 4) and occasionaly very high, up to 200 %. During the night the levels can probably dropped very low, sometimes below 25 % saturation, a level that must be considered a limit for adequate fish production (Boyd, 1986). However Wajsbrot *et al* (1991) suggested that below 40 % DO saturation the toxicity of ammonia to *S. aurata* increases significantly.

Although significant variations were observed between sites during the two years of study, there is a general trend for oxygen content to be high during the winter and low during the summer, also noted by Ben-Tuvia (1979). Very low oxygen concentrations, sometimes lower than 4 mg $l^{-1}$ and even 3 mg $l^{-1}$ were observed on some occasions (Appendix A1 - Table 3). As the samples were always collected during the morning it is possible that during the night and at daybreak the oxygen concentration could have been lower, perhaps attaining critical values. In the Marim channel and in Barra the oxygen concentrations were never so low (Falcão, 1988).

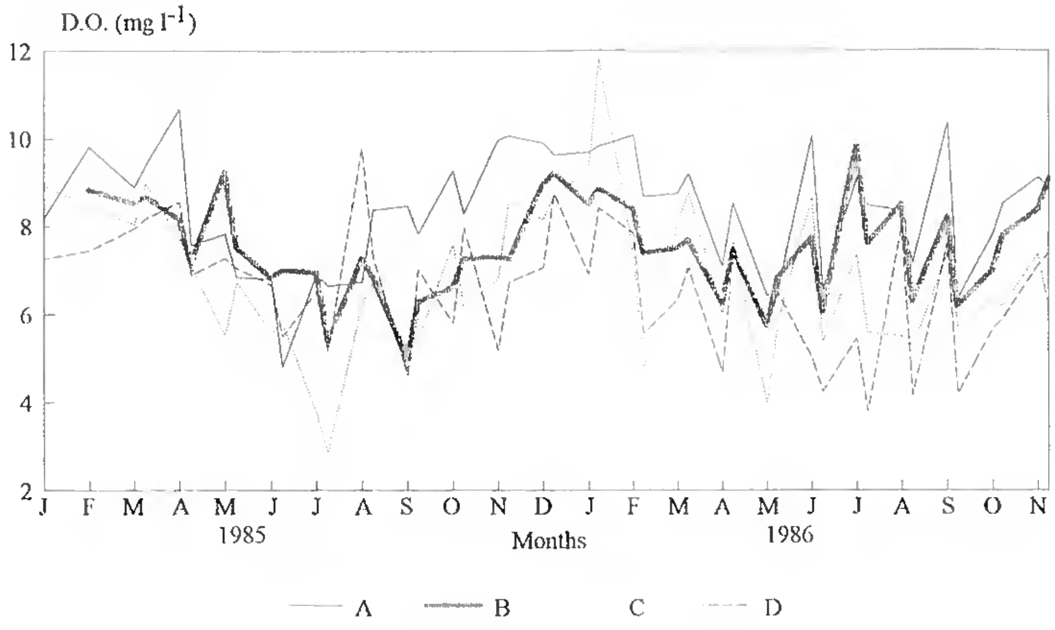


Fig. 2.7 - Variation in mean dissolved oxygen concentration at the four sites over the study period.

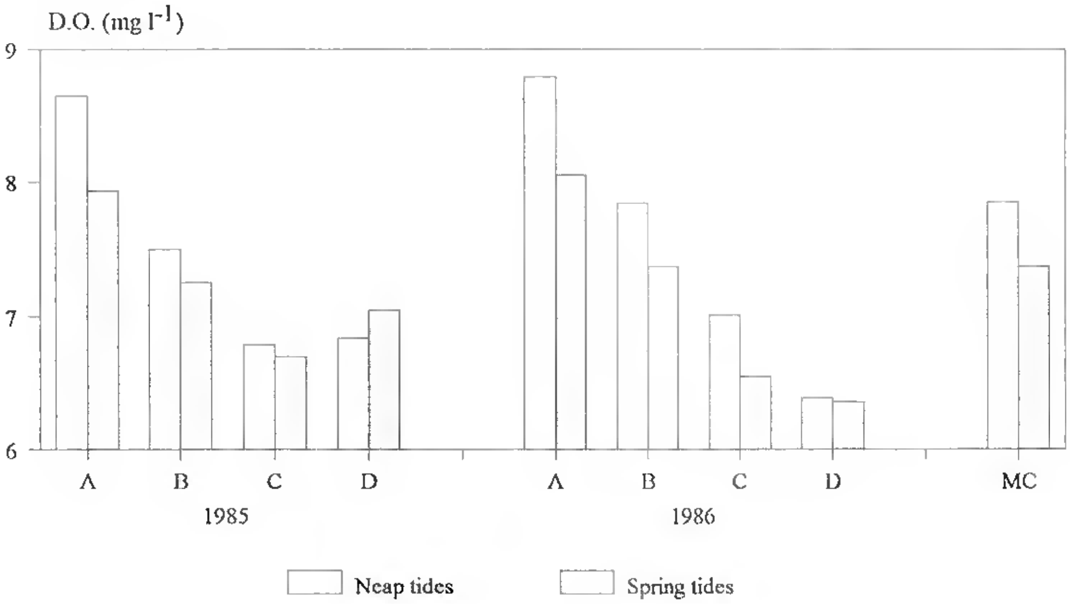


Fig. 2.8 - Mean annual dissolved oxygen concentrations during the neap and the spring tides at the four sites and in the Marin Channel (MC) in 1986 (Falcão, 1988).

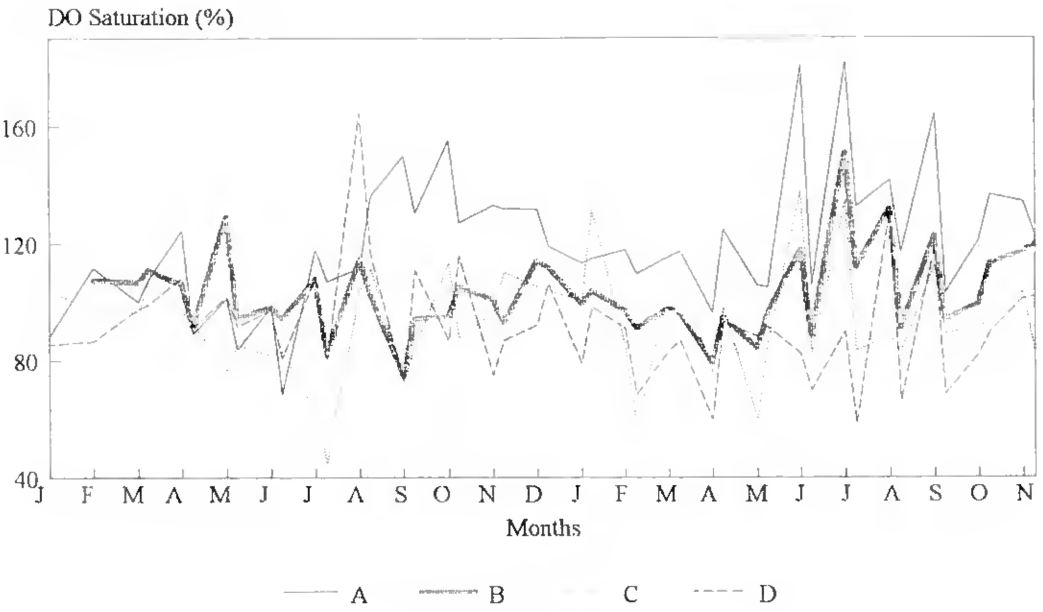


Fig. 2.9 - Variation in dissolved oxygen saturations at the four sites over the study period.

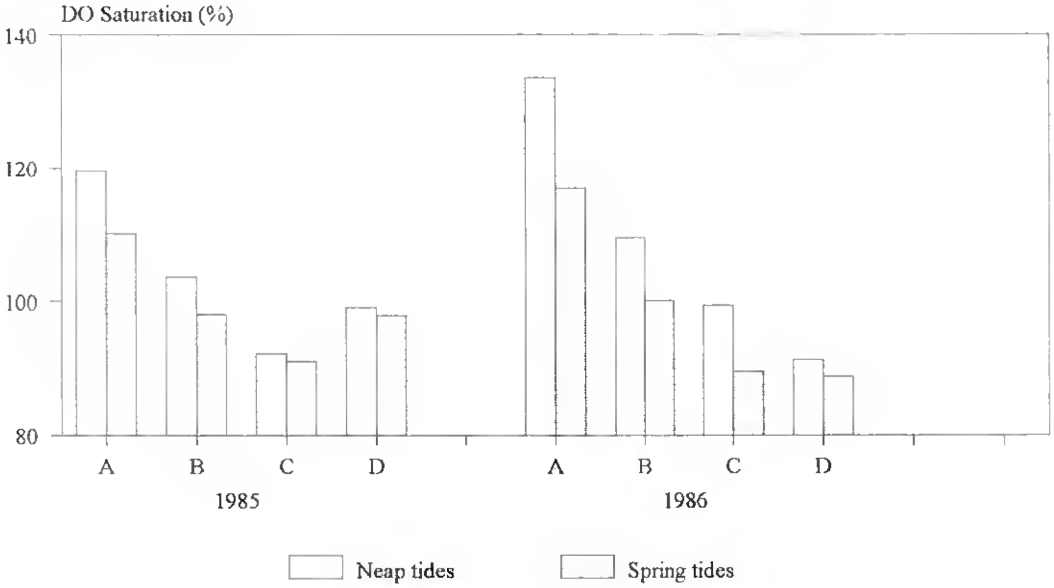


Fig. 2.10 - Mean annual dissolved oxygen saturations during the neap and the spring tides at the four sites.

The results obtained from sampling carried out over three diurnal cycles during 1986 (Fig. 2.11) confirmed these findings on dissolved oxygen concentrations. During the first diurnal cycle, over a neap tide, the weather conditions were poor, with rain and strong winds. Dissolved oxygen concentration and water temperature did not vary greatly and the water was well mixed all day due to the strong winds. During the second cycle, over a spring tide on a sunny day temperature and dissolved oxygen increased during the day. This increase was more noticable during the third cycle, over a neap tide on a sunny day. On this occasion, the oxygen concentrations were sometimes very low, at dawn, close to 3 mg $l^{-1}$ (34 % DO saturation). The highest concentration, towards the end of the afternoon, was 13.5 mg/l (192.5 % DO saturation). These measurements were done at the end of winter, when the salinity and temperatures were low. Arias & Drake (1987) also found extreme oxygen concentrations at daybreak, with values close to 0 mg $l^{-1}$. Krom *et al* (1985a) in a semi-intensively cultured marine fish pond in Israel, found the minimum oxygen concentration half an hour after dawn, and the maximum in mid to late afternoon. The maximal diurnal oxygen variations occurred during the summer months in their study.

The high dissolved oxygen concentrations occasionally observed can also be dangerous to fish. Oxygen supersaturation can be lethal due to gas embolism by bubble formation in the blood capillaries (Krom & Rijn, 1989). Whilst Porter *et al* (1986) found no growth inhibition or mass mortalities of *Sparus aurata* grown in a pond with a diurnal variation from 30% to 250 % DO saturation, Krom *et al* (1985) suggested that 300 % is the lethal limit for *S. aurata*, if fish are exposed to such levels for 1-2 h. Erez *et al* (1990) advised the use of mechanical paddle wheels whenever the oxygen levels are above 16 mg $l^{-1}$ or below 3 mg $l^{-1}$.

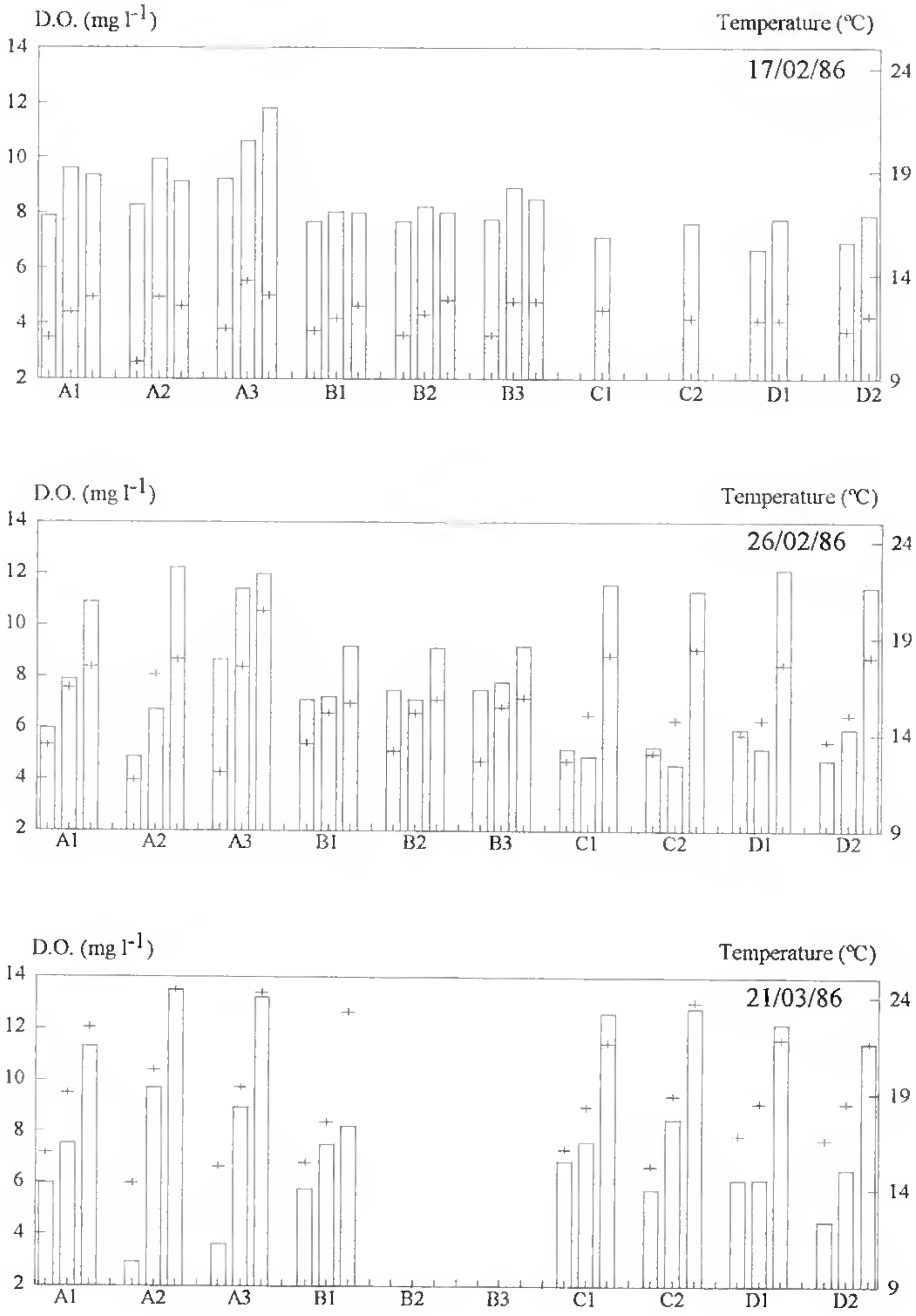


Fig. 2.11. Diurnal cycles of dissolved oxygen concentration (bars) and water temperature (+) at each station. The first values refer to samples taken at daybreak, the second to samples taken during the morning, and the third to samples taken at the end of the afternoon, before sunset.

### 2.2.5 Biochemical Oxygen Demand

In contrast to the variation of dissolved oxygen concentration the BOD levels were higher during the summer months (Fig. 2.12) and a complete depletion of the oxygen sometimes occurred. During the summer of the second year an increase in the dissolved oxygen and in the BOD values was clearly seen during neap tides, followed by a decrease during the spring tides.

Site A had, on average, higher dissolved oxygen and lower BOD levels than the other sites. At site C the BOD level increased considerably between January and March of the second year.

The mean and the maximal BOD values were almost always higher during the neap tides. This was also observed in the Marim channel and in Barra (Fig. 2.13), although the oxygen consumption was two to three times lower.

The BOD gives an estimate of the amount of oxygen required by bacteria to oxidize the decomposable organic matter (Boyd, 1973). It is an indirect measure of biologically degredable material present (Jain *et al* 1981). The increase of BOD levels during the neap tides and during the summer may reflect an accumulation of organic matter during these periods and a corresponding degradation of water quality. Gomez-Parra & Forja (1993) also observed a decrease of BOD between summer and autumn in Cádiz bay reflecting the dependence of bacterial metabolism on temperature.

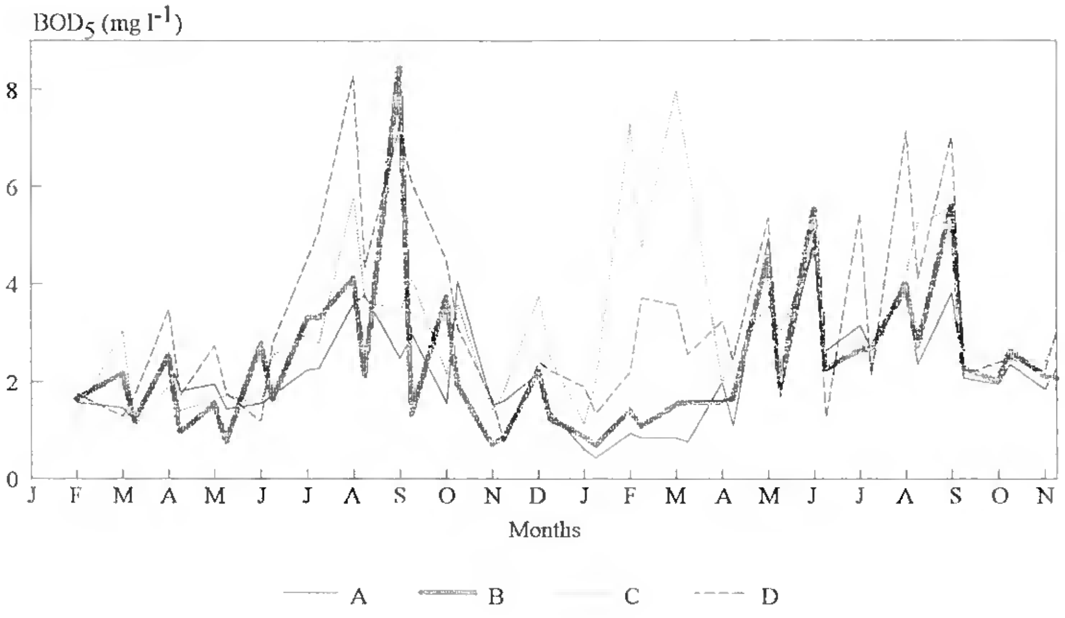


Fig. 2.12. Variation in mean biochemical oxygen demand at the four sites over the study period.

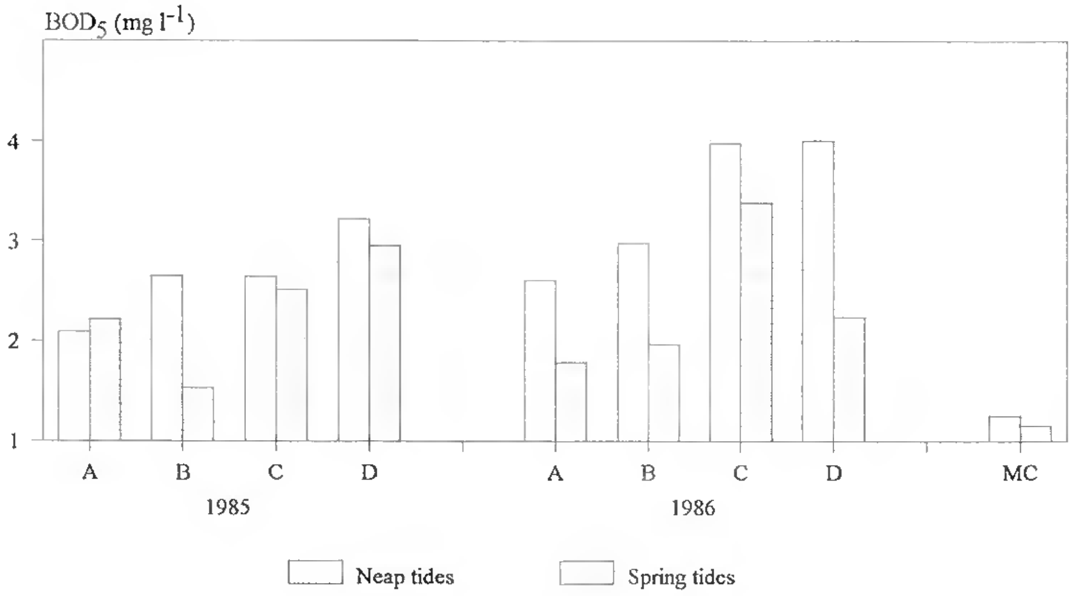


Fig. 2.13. Mean annual biochemical oxygen demand concentrations during the neap and the spring tides at the four sites and in the Marim channel (MC) in 1986 (Falcão 1988).

### 2.2.6 pH

Mean pH values were lower at site B than at the other sites (Figs. 2.14 and 2.15). The pH values observed at site B were similar to the values found in the Marim channel and Barra by Falcão (1988). However, the variation of the mean values at each site was not very pronounced, being between 8 and 8.8 (Appendix A1 - Table 6). At site A, an increase occurred after the first summer. The pH values were usually greater during the neap tides than during the spring tides at all sites.

The pH values observed were slightly higher than the pH of the adjacent sea water, which varied between 7.5 and 8.4 (Krom & Rijn, 1989). The consumption and release of carbon dioxide during photosynthesis and respiration results in changes of pH. The total daily pH variation in aquaculture sea water systems is usually between 7.8 and 9.0, due to the buffer capacity of the seawater. However, Sampayo (1984) reported diurnal variation in pH between 7.6 at dawn and 9 to 9.5 at the end of the afternoon after intense photosynthetic activity in the marine fish ponds from Ria Formosa. Hussenot *et al* (1991) considers that a pH value higher than 8.9 can be dangerous and even lethal for the survival of *S. aurata* larvae, and that the phytoplankton density should be controlled. In improved aquaculture systems this can be achieved by stopping the addition of fertilisers.

### 2.2.7 Suspended matter

The variation of suspended matter was similar to that of salinity and BOD. The concentration of suspended matter was greater during the summer months and during neap tides (Figs. 2.16 and 2.17), and much higher than the concentrations found in the Marim channel and in Barra by

Falcão (1988). At site C there was an abrupt increase during the early part of the second year of survey, also reflected in other parameters.

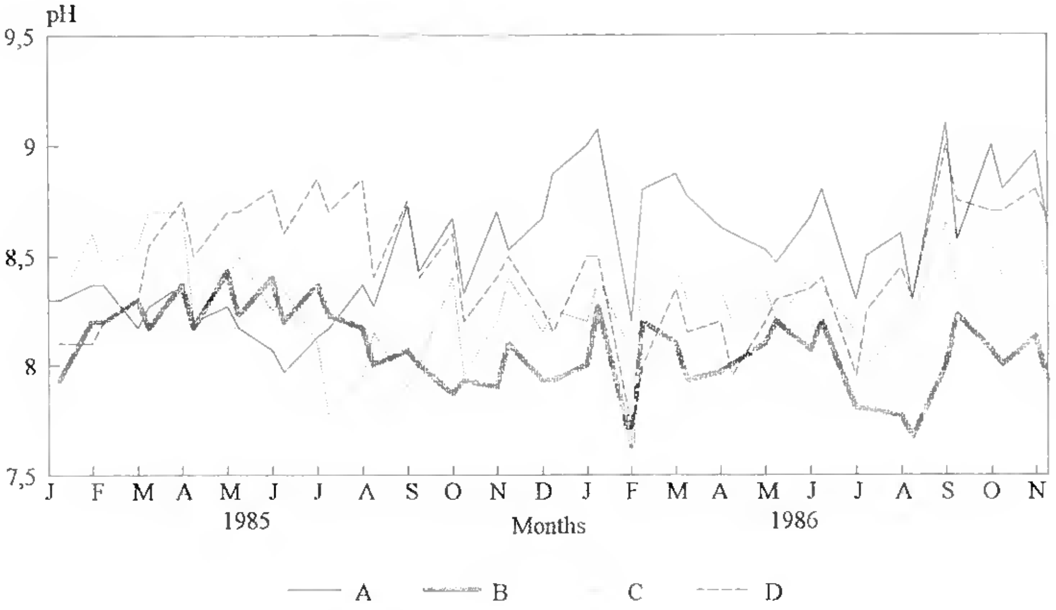


Fig. 2.14 - Variation in mean pH values at the four sites over the study period.

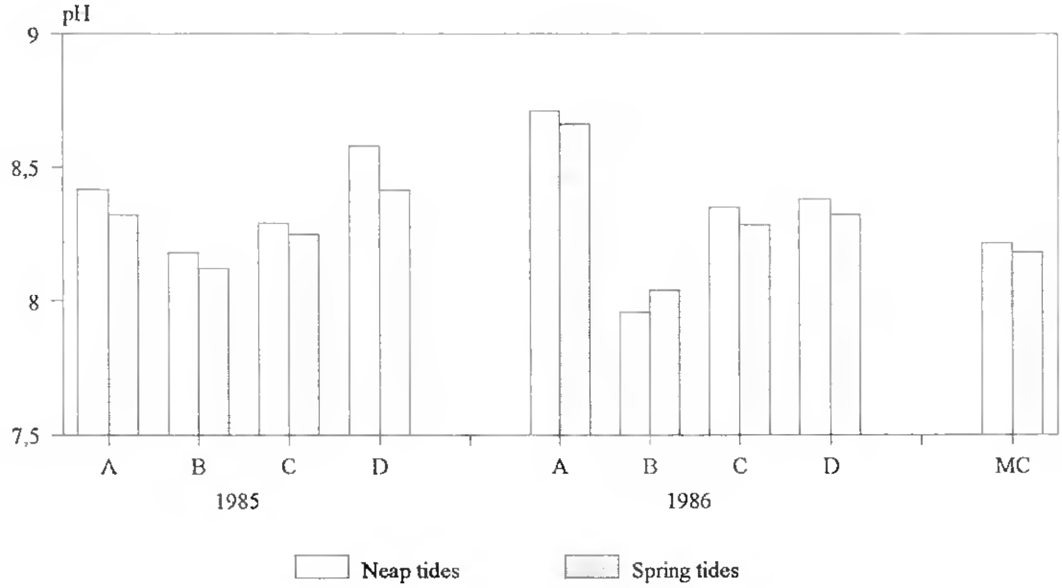


Fig. 2.15 - Mean annual pH during the neap and the spring tides at the four sites and in the Marim channel (MC) in 1986 (Falcão, 1988).

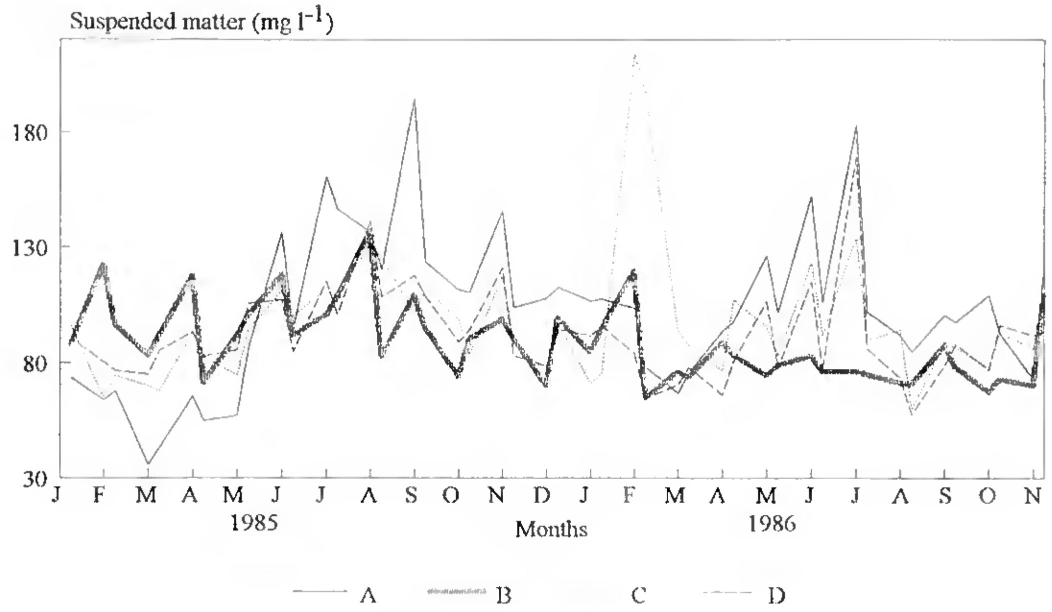


Fig. 2.16 - Variation in mean suspended matter concentrations at the four sites over the study period.

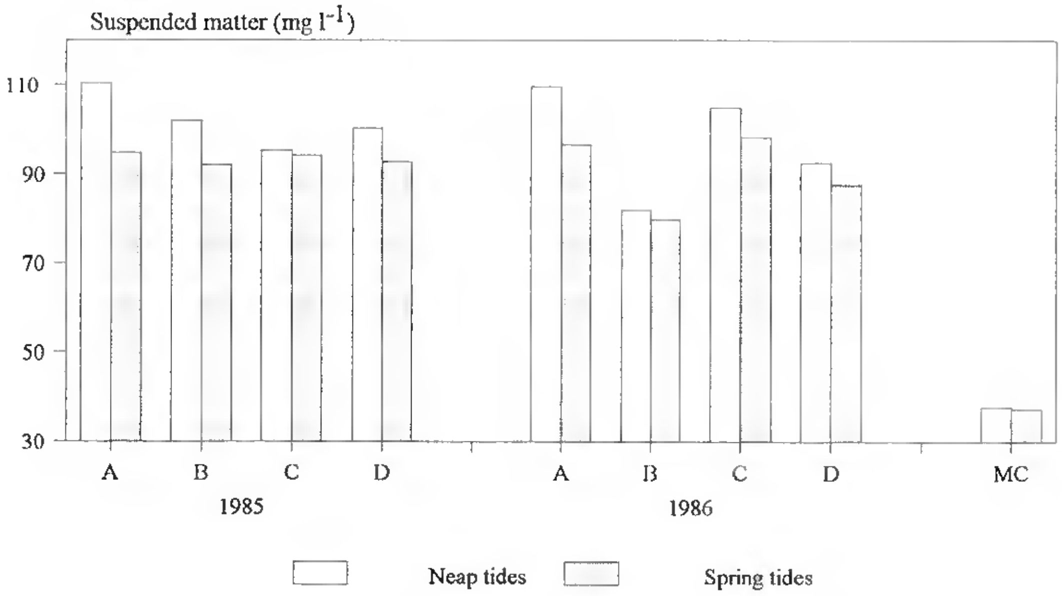


Fig. 2.17 - Mean annual suspended matter concentrations during the neap and the spring tides at the four sites and in the Marim channel (MC) in 1986 (Falcão, 1988).

According to Grassoff *et al* (1983) half of the suspended matter is inorganic in origin. Excessive suspended matter may be harmful to fish and other aquatic life by coating gills, blanketing bottom organisms, reducing solar radiation intensity and thus affecting the whole food chain (Jain *et al* 1981). The feeding activity of several fishes, including *S. aurata*, tends to increase the suspended matter concentration in the water, as these fishes disturb the sediment to capture their prey.

### 2.2.8 Nutrients

Silicate

The concentration of silicate was higher during the spring and summer and during neap tides (Figs. 2.18 and 2.19 and Appendix A1 - Table 8). Falcão (1988) also noticed higher concentrations during the neap tides, although the concentrations in the Ria were two to three times lower than the concentrations found in the study lagoons. The seasonal pattern of variation of silicate concentration was also different in the Ria, concentrations being lower during the spring months and at beginning of summer.

In regions where diatom blooms occur the concentration of silicate decreases in the spring and increases in summer when growth slackens and than increases to a maximum in early winter (Millero & Sohn, 1992). In the study lagoons this variation does not seem to occur, and the increase in silicate concentration during spring and summer might be related to an increase in the biological activity and to a resuspension of the sediment.

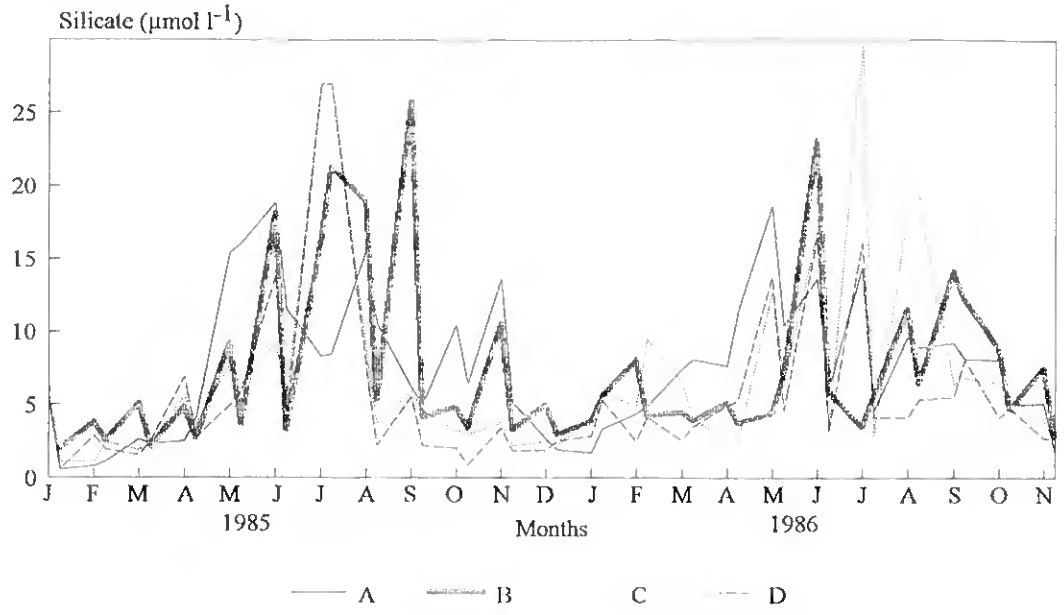


Fig. 2.18 - Variation in mean silicate concentrations at the four sites over the study period.

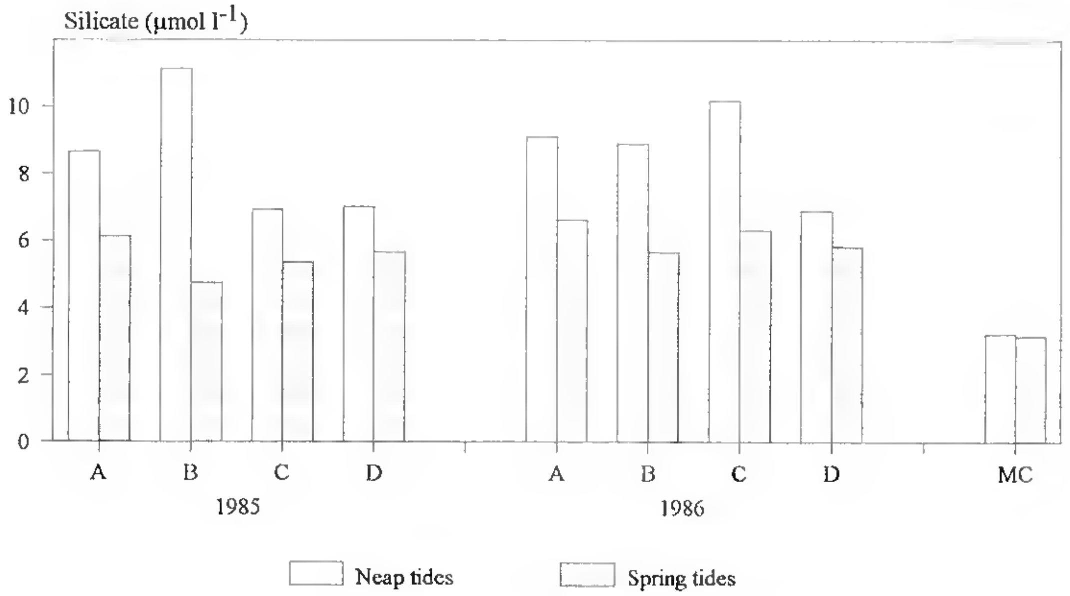


Fig. 2.19 - Mean annual silicate concentrations during the neap and the spring tides at the four sites and in the Marim channel (MC) in 1986 (Falcão, 1988).

Phosphate

The concentration of phosphate was lower during the cold months, and increased at the beginning of spring (Fig. 2.20). The mean concentration was in general greater during the neap tides (Fig. 2.21 and Appendix A1 - Table 9). In summer, a phosphate maximum appears to be a commom feature of shallow marine systems, and its occurence may depend only on the storage of an appreciable amount of organic matter which can be remineralized at warmer temperatures (Nixon, 1982).

In the Marim channel the mean concentration of phosphates was higher than the mean concentrations found in the study lagoons (Fig. 2.21). Bröckel (1990) also found higher phosphate concentrations inside the Ria, but the concentrations in the sea nearby were similar to the concentrations found in the four lagoons.

The mean phosphate content of seawater is about 2 $\mu$mol $l^{-1}$, although in the uppermost layer, the euphotic zone, the level is usually much lower (Grasshoff *et al*, 1983). Below 0.3 $\mu$mol $l^{-1}$, cell division becomes inhibited and P-deficient cells are produced (Millero & Sohn, 1992). The mean concentrations found in the lagoons were around this value, and the minimal values were always below, about 0.1 $\mu$mol $l^{-1}$. The study lagoons might be deficient in phosphates. Motzkin *et al* (1982) also found phosphorus limitation in aquaculture fish ponds in Israel, as did Britton and Johnson (1987) in a Mediterranean salina in France. It is commonly accepted that in coastal waters there is a consistent depletion of nitrogen compared to phosphorus (Valiela, 1984; Millero & Sohn, 1992; Fong *et al*, 1993; Kivi *et al*, 1993), but in contrast Falcão & Vale (1990) have argued that the Ria Formosa is phosphorus rather than nitrogen limited.

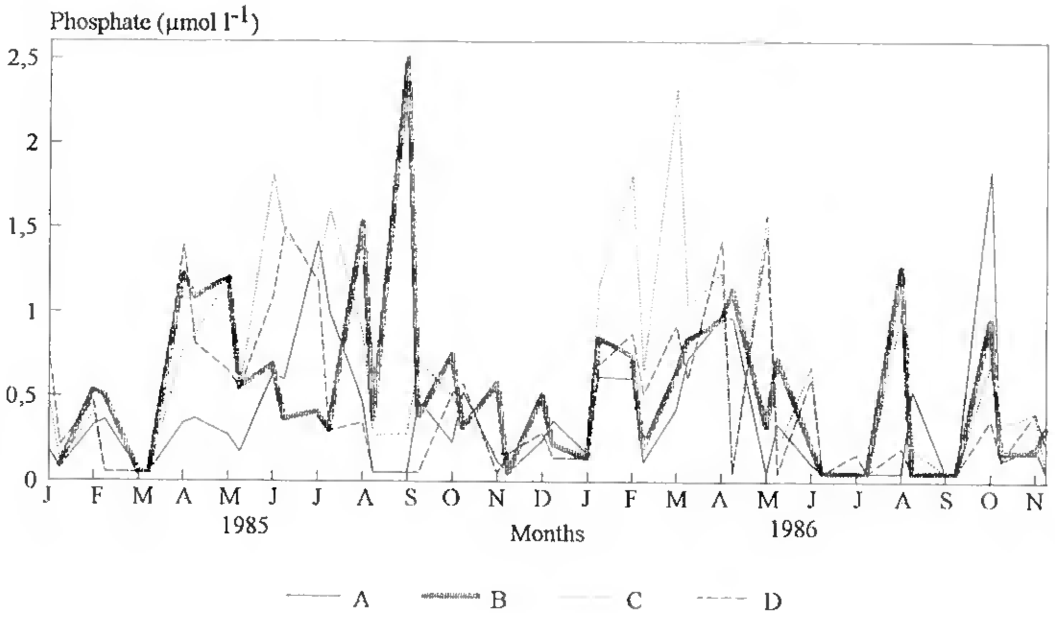


Fig. 2.20 - Variation in mean phosphate concentrations at the four sites over the study period.

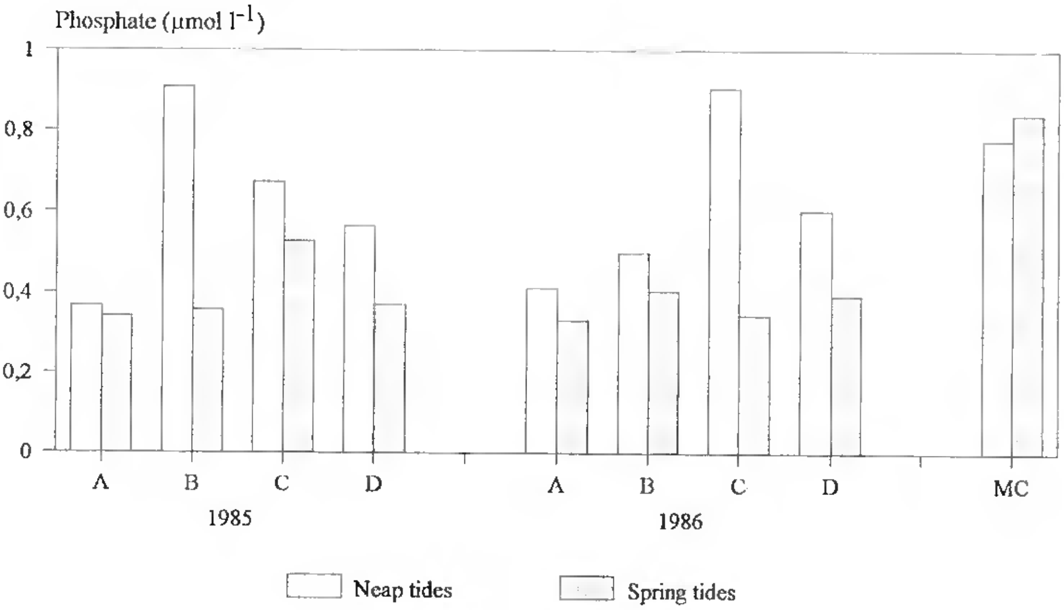


Fig. 2.21 - Mean annual phosphate concentrations during the neap and the spring tides at the four sites and in the Marim channel (MC) in 1986 (Falcão, 1988)

Nitrate

The mean concentration of nitrate varied irregularly (Fig. 2.22), but was slightly higher during the spring tides (Appendix A1 - Table 10). The difference between neap and spring tides was more pronouced during the second year (Fig. 2.23). However, the observed concentrations were very closed to the detection limit of the analysis technique used (0.3 $\mu$mol $l^{-1}$). Falcão (1988) also found higher concentrations in the Ria during spring tides, approximately twice the concentrations observed in the study lagoons, but also very low values during the neap tides. Bröckel (1990) found nitrate concentrations inside the Ria of around 0.87 $\mu$mol $l^{-1}$ but also very low values, of around 0.45 $\mu$mol $l^{-1}$, in the seawater nearby.

In many marine areas nitrate is considered to be the nutrient controlling primary production in the surface layers. If light penetration into the water is sufficient, the uptake rate by primary producers is usually very fast and the nitrate concentration in the surface layers is therefore close to zero (Grassoff *et al*, 1983). When nitrate concentration is below 0.7 $\mu$mol $l^{-1}$, nitrogen deficient cells are produced before cell division stops (Millero & Sohn, 1992). Nitrate seemed to be in low concentrations in the lagoons, as well as in the sea around the Ria Formosa, although Falcão & Vale (1990) concluded that there was an import of nitrate from coastal waters to the Ria.

The ammonia concentration was not measured in this study, but its mean concentration in Ria Formosa is not very high, about 0.89 $NH_4$ $\mu$mol $l^{-1}$ (Benoliel, 1985). However, Falcão & Vale (1990) considered that there was an important flux of ammonia inside the Ria due to the metabolic activity of the animals and to decomposition processes. They also concluded that ammonia could be exported from the Ria to the adjacent coastal waters. If this is the case, nitrogen would not be a limiting factor, for primary production, as ammonia is usually preferred by phytoplankton as the assimilation nitrogen compound (Millero & Sohn, 1992). In marine fish ponds in Israel, phytoplankton took ammonia preferentially, until it was depleted, and only then took up nitrate; this rapid nutrient uptake occurred on a time scale of minutes (Krom *et al*, 1989).

Nitrite

The mean concentration of nitrite increased during the second year (Figs. 2.24 and 2.25 and Appendix A1 - Table 11), and the increase was more pronounced during the summer months. The nitrite concentration was higher during neap tides than during spring tides. The concentrations recorded in the Marim channel and Barra were slightly lower than those found at sites B and D during spring tides, but higher concentrations were also observed during the summer months (Falcão, 1988).

The natural level of nitrite in seawater is usually very low, less than 0.1 $\mu$mol $l^{-1}$. In upwelling areas elevated nitrite values (1-2 $\mu$mol $l^{-1}$) indicate high activity of the primary producers, but high levels may also indicate polluted waters in the vicinity of sewage effluents and in estuaries (Grassoff *et al* 1983). Bröckel (1990) found higher mean concentrations in 1988 and 1989 compared to 1985 and 1986 (Falcão, 1988), around 0.3 $\mu$ mol $l^{-1}$, inside the Ria, but only half this amount in the surrounding sea. However, Benoliel (1985) found lower concentrations 0.19 $\mu$mol $l^{-1}$ in the Ria in 1984. It seems that there has been a general increase in nitrite concentrations inside the Ria, which was reflected in the study lagoons, with concentrations in the present study close to those found by Benoliel (1985) in 1985, and higher concentrations in 1986, even higher than those recorded by Falcão (1988) during the same year. This increase may be due to human sewage, possibly from the camp site at Olhão where the sewage is discharge very close to site A. Camping began at Olhão in the middle of 1985.

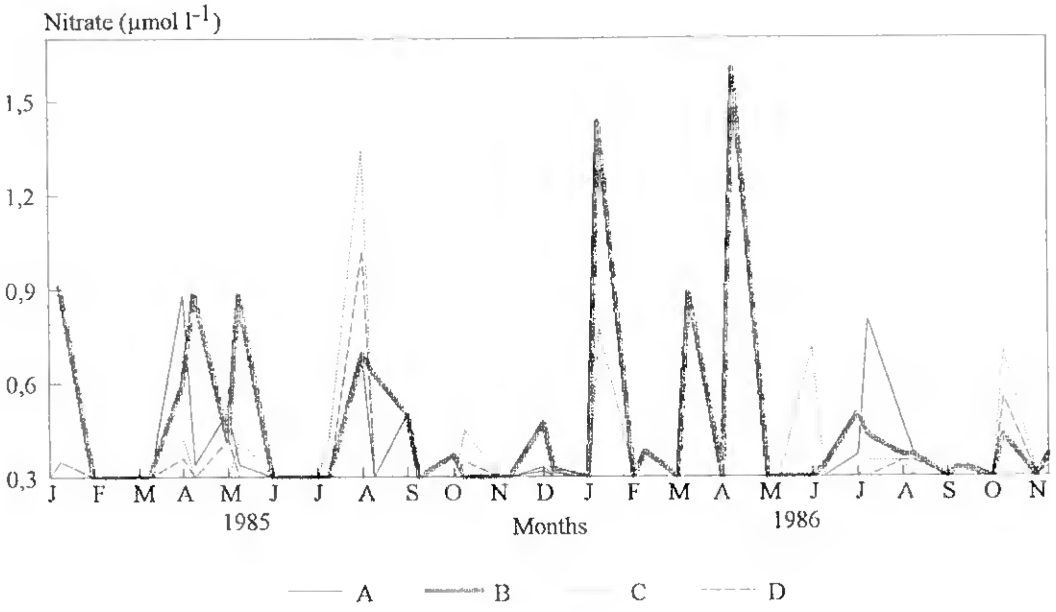


Fig. 2.22 - Variation in mean nitrate concentrations at the four sites over study period.

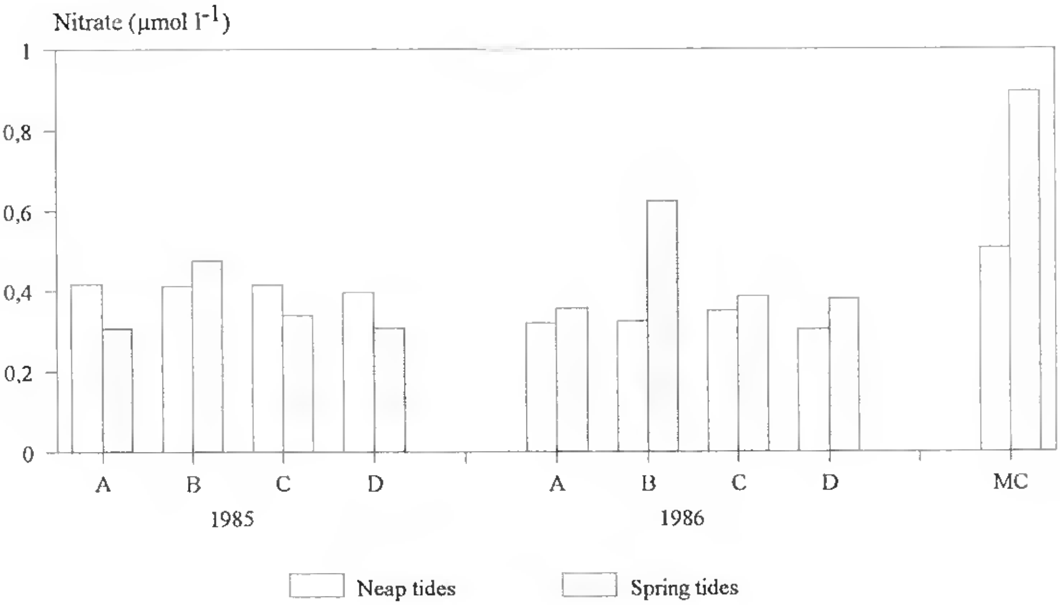


Fig. 2.23 - Mean annual nitrate concentrations during the neap and the spring tides at the four sites and in the Marim channel (MC) in 1986 (Falcão, 1988).

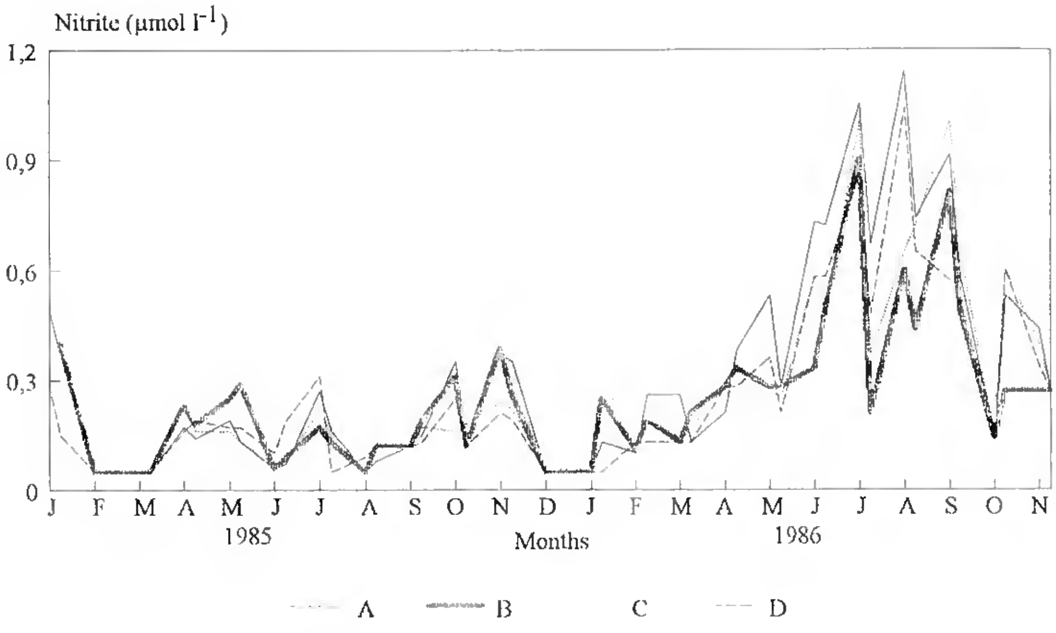


Fig. 2.24 - Variation in mean nitrite concentrations at the four sites over the study period.

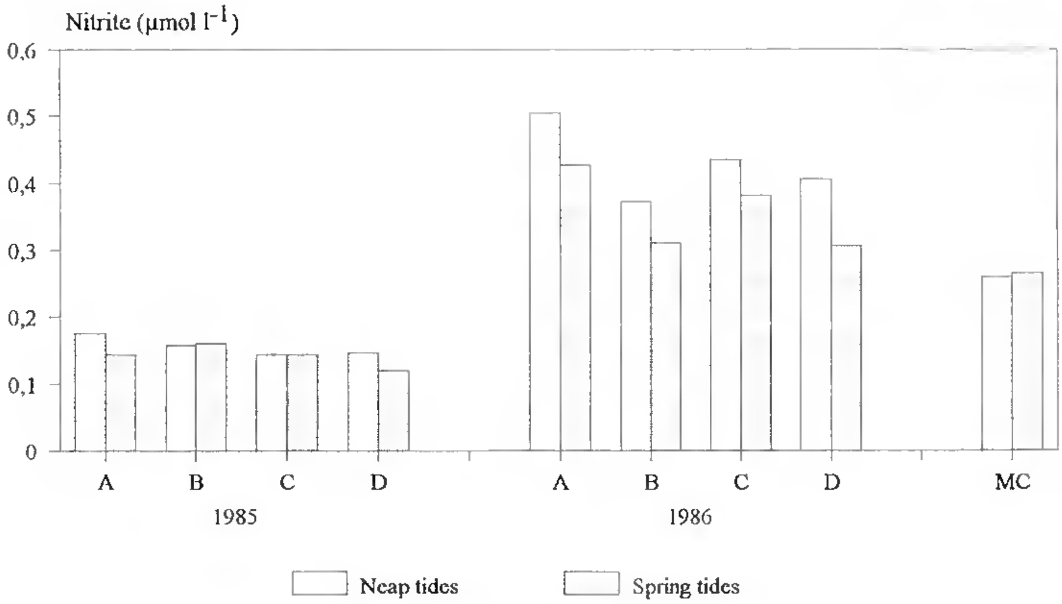


Fig. 2.25 - Mean annual nitrite concentrations during the neap and the spring tides at the four sites and in the Marim channel (MC) in 1986 (Falcão, 1988).

The increase in nitrite concentration during the neap tides could also have been a result of denitrification of nitrate. This process requires a supply of organic compounds and anaerobic conditions (Valiela, 1984), which can probably occur in the saline reservoirs during neap tides, as has been reported by Avnimelech & Zohar (1986). Gomez-Parra & Forja (1993) considered that the mineralization of nitrate to nitrite in Cádiz bay sediments proceeds preferentially through anaerobic metabolic pathways, due to the low dissolved oxygen levels present at this site.

### 2.2.9 Chlorophyll *a* and phaeopigments

Chlorophyll *a* increased at all sites during the hot months of the first year of survey (Fig. 2.26) but was more pronounced at sites C and D. During the second year, the concentration of chlorophyll *a* varied irregularly over time. At site C the concentration increased abruptly in the early part of the second year.

The mean concentration of chlorophyll *a* at site A was lower than at the other sites (Fig. 2.27 and Appendix A1 - Table 12). Mean concentrations were higher at sites B and D during the neap tides, but at site C the opposite was the case.

The concentration of phaeopigments also varied irregularly over the two years (Fig. 2.28). At site A the concentration was lower than at the other sites. At sites B and D the mean concentrations of phaeopigments were higher during the neap tides, whilst at sites A and C, the opposite was observed (Appendix A1 - Table 13).

The mean annual concentration of phaeopigments at site A was similar to the concentration found in the Marim channel and in Barra (Falcão, 1988) but at the other sites the mean concentrations were higher.

The degradation percentage was lower during the summer months and higher, above 50 %, during the winter, indicating that a high percentage of phytopigments occured in a degraded form (Fig. 2.30). During neap tides the degradation percentage was higher than during spring tides (Fig. 2.31 and Appendix A1 - Table 14).

The chlorophyll *a* concentration in the lagoons was higher than those found in the Marim channel (Fig. 2.27), where there were no noticeable differences between the neap and spring tides. At sites B, C and D the mean chlorophyll *a* concentrations were more than twice the concentrations found in the Ria.

Assis *et al* (1984) and Cunha & Massapina (1984) found mean chlorophyll a concentrations similar to those observed by Falcão (1988), close to 1 mg $m^{-3}$. In the coastal water, the chlorophyll concentrations were lower than inside the Ria (Mergulhão & Vilarinho, 1984). The primary production in the lagoons seemed to be higher than in the Ria or in the adjacent coastal waters, perhaps due to the low depth, allowing light to penetrate to the bottom. The phytoplankton production, at these sites, is supplemented by seagrass, benthic algae and epibenthic microflora.

Lubian *et al* (1985) and Arias & Drake (1987) found also high chlorophyll concentrations in the salina reservoirs near Cádiz, and an increase in the concentrations during the periods of no water renewal, followed by a decrease, sometimes abrupt, probably due to an aging of the population. The chlorophyll *a* concentrations in Cádiz were similar to the concentrations found at sites B and D, with an increase during the neap tides, i.e., the periods of reduced water renewal. At sites A and C, the environmental conditions might have been too extreme during the neap tides to allow the development of the phytoplankton.

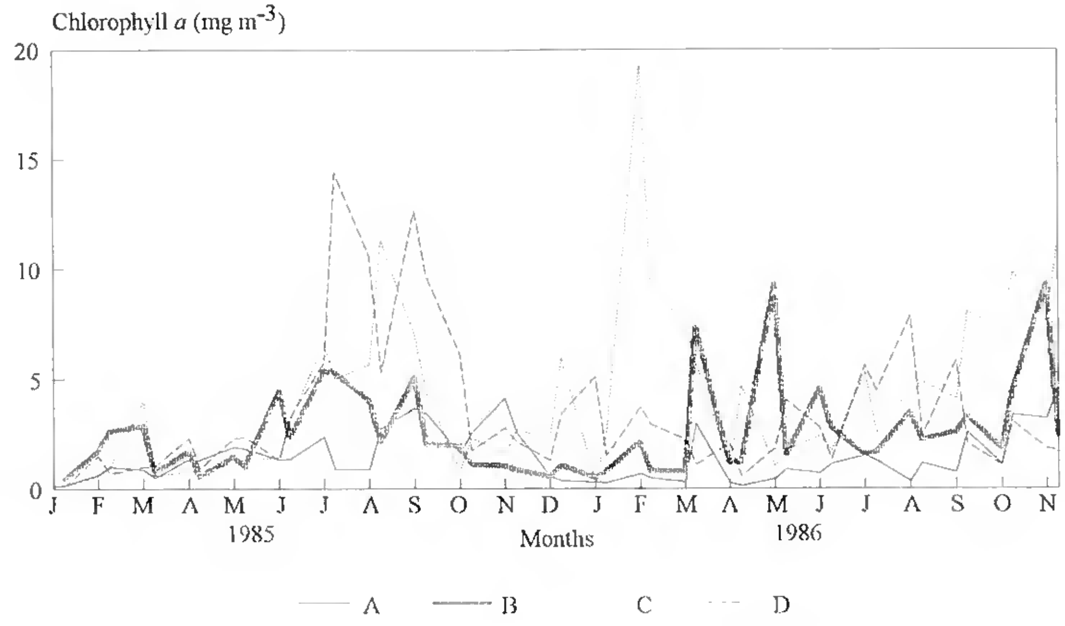


Fig. 2.26 - Variation in mean chlorophyll *a* concentrations at the four sites over the study period.

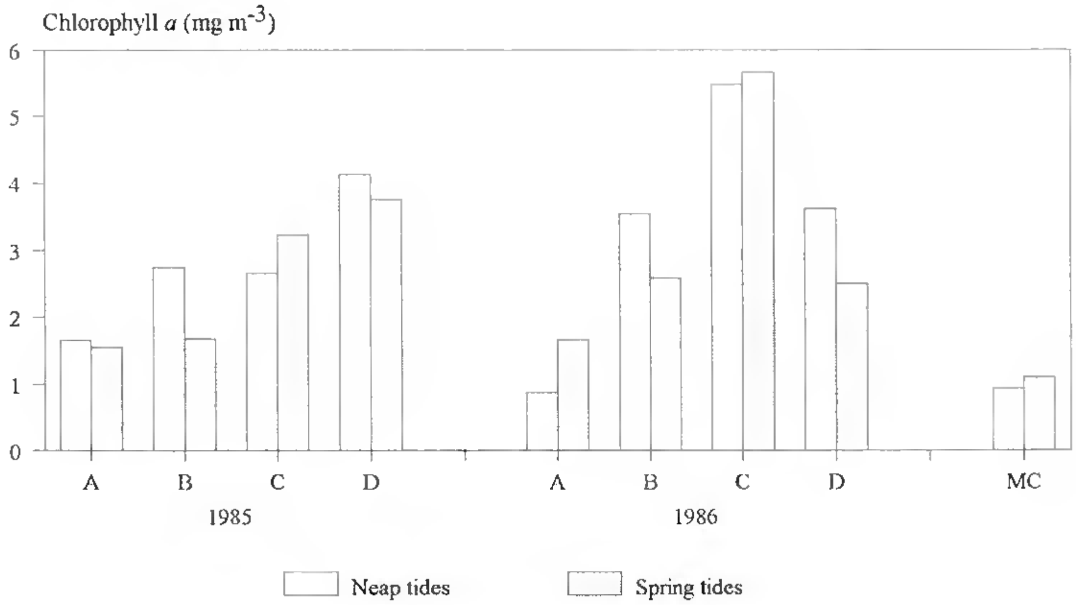


Fig. 2.27 - Mean annual chlorophyll *a* concentrations during the neap and the spring tides at the four sites and in the Marim channel (MC) in 1986 (Falcão, 1988).

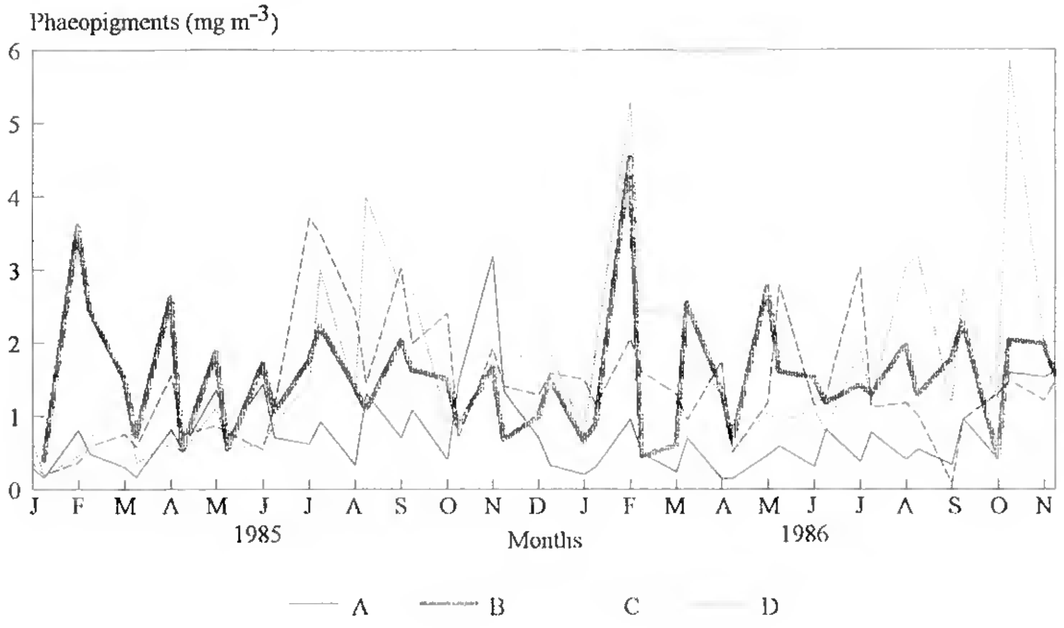


Fig. 2.28 - Variation in mean phaeopigments concentrations at the four sites over the study period.

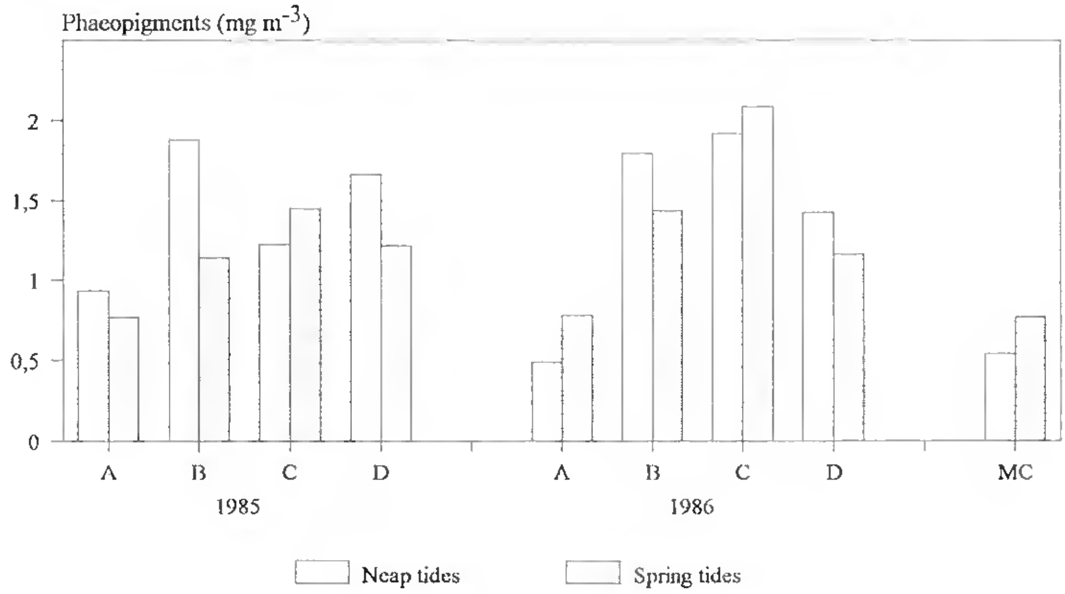


Fig. 2.29 - Mean annual phaeopigments concentrations during the neap and the spring tides at the four sites and in Marim channel (MC) in 1986 (Falcão, 1988).

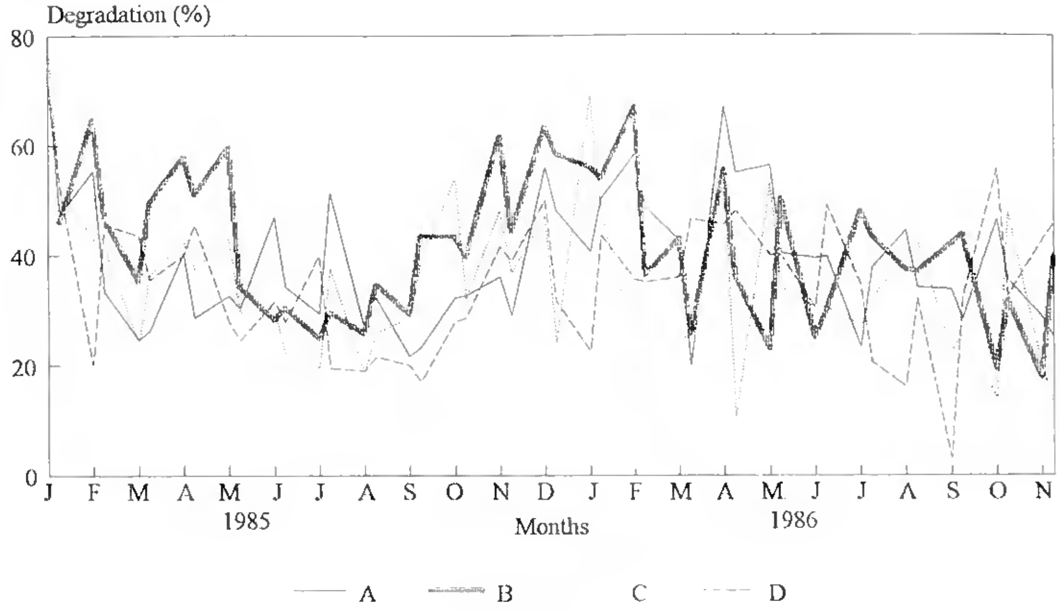


Fig. 2.30 - Variation in mean degradation percentages at the four sites over the study period.

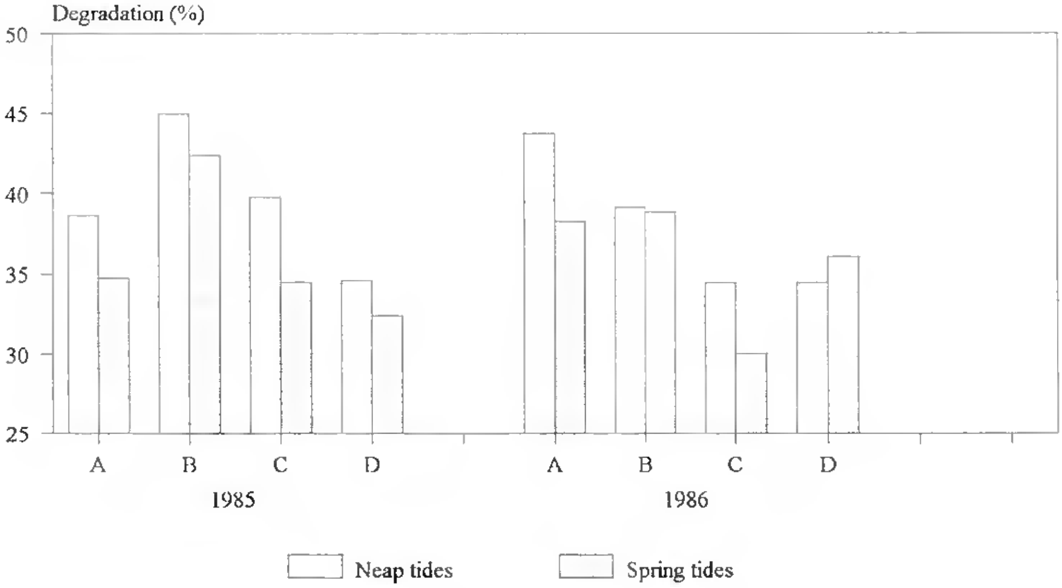


Fig. 2.31 - Mean annual degradation percentages during the neap and the spring tides at the four sites.

At site C, in the beginning of the second year, there was an intense development of phytoplankton, with characteristics of an algal bloom - increase of chlorophyll *a* and suspended matter concentrations, and of BOD levels. The water, during that period, was green and very turbid, and some dead fish were found. Krom *et al* (1989b) considered that in "low flow rate fish ponds" the algal populations have the tendency to overshoot and then collapse.

## 2.3 Conclusions

The salina reservoirs which are used for marine fish culture have limited water circulation. Consequently, they are subject to great variation in environmental conditions, with large daily fluctuations of dissolved oxygen and temperature. Seasonal fluctuations of salinity are also very large, and the supply of nutrients can be deficient, with phosphorus in limiting quantities. The ranges of daily and seasonal fluctuations decrease with the degree of water exchange, and also during spring tides when water renewal is maximal. In lagoons with greater water renewal the environmental conditions are not so extreme. However, even in these lagoons there is danger of oxygen depletion during the hot summer nights. Nevertheless, the primary production can be very high in these lagoons.

During the summer, with the increase in biological activity, the amount of organic matter increases followed by an increase in bacterial activity, in turn supported by the higher temperatures. As a consequence, the biochemical oxygen demand also increases. Salinities can reach values incompatible with marine life, and with the higher temperatures there is a reduction in the solubility of the oxygen, so that oxygen concentrations can be too high at the end of the afternoon or too low, at dawn. An increase in phytoplankton concentrations due to the higher temperatures can also cause an increase in pH, which can reach levels harmful to fish production.

The accumulation of organic matter in the sediment and the occurrence of anaerobic zones can increase the amount of ammonia to levels that become toxic. Fish in the lagoons frequently dug into the sediments for food and were thus exposed to high concentrations of ammonia which can result in retardation of growth in fish (Motzkin *et al* 1982), althought, Porter *et al* (1986) were unable to demonstrate this for *Sparus aurata*.

In addition, Asmus (1986) considered that the seagrass *Zostera noltii*, which covers the bottom of the study lagoons (Chapter 3), assimilates ammonia to such a high degree that the seagrass bed is a sink for ammonia. This may be an advantage in aquaculture systems where production is increased by the addition of food, but where the water quality deteriorates.

In improved aquaculture systems, metabolic wastes from added feed exert an oxygen demand and serve as a source of nutrients for phytoplankton which also requires oxygen. Therefore, as the rate of feed addition increases, phytoplankton increase and water quality deteriorates (Boyd, 1986). However, a controlled increase in the phytoplankton biomass may be useful for supplying dissolved oxygen to the system (Chang & Ouyang, 1988; Erez *et al*, 1990). Aquaculturists can therefore raise dissolved oxygen levels by increasing algal growth, and at the same time improve ammonia concentrations (Smith & Piedrahit, 1988). However, excessive phytoplankton can be a problem and can possibly be controlled by zooplankton and filter-feeders which together can consume all sizes of phytoplankton (Smith, 1985).

# Chapter III

# MACROFAUNA - DENSITY AND SPECIES DISTRIBUTIONS

## Relationships with the environmental data

## III - MACROFAUNA. DENSITY AND SPECIES DISTRIBUTIONS
### Relationship with the environmental data

### Summary

The benthic populations present in a given area reflect the local environmental conditions (Hargrave & Thiel, 1987). Again, no information existed about the benthic populations present in the lagoons of Ria Formosa used for extensive aquaculture and / or salt production. The benthic populations present in the four selected lagoons were therefore characterised and related to environmental conditions.

The benthic populations were characteristic of estuarine or shallow-water coastal communities and reflected a strong gradient, of increasingly stressful environmental conditions, due to the lack of water renewal. On the basis of the benthic communities present the least stressed lagoon was site B and the most stressed site A. The macrofauna of site A consisted of a few abundant species, such as *Capitella capitata*, *Hydrobia ventrosa*, oligochaetes and Chironomid larvae. A second gradient of increasing eutrophication was identified from site B towards sites C and D. Along both these gradients there was a change from well-structured and diverse populations towards populations dominated by a few opportunistic species. The most important environmental factors affecting species and station differentiation were the differences between the maximum and the minimum annual salinity values and the mean annual biochemical oxygen demand.

## 3.1 Methods

### 3.1.1 Sediment

For a complete understanding of the factors governing the distribution and abundance of the benthic populations it is necessary to have good information of the physical proprieties of the sediments in which they live. A study of the granulometry of the sediment was therefore carried out for the first three sampling occasions. One sediment sample was taken at each sampling station (Fig. 2.1) with a 12 cm corer (internal diameter), every two months, in January, March and May of 1985. The samples were washed in hydrogen peroxide solution to destroy the organic matter. They were then rinsed and sieved into the following fractions: gravel (> 2 mm); sand (62 $\mu$m - 2 mm); fine sediment (<62 $\mu$m). The silt (2 $\mu$m - 62 $\mu$m) and clay (< 2 $\mu$m) fractions were separated using the pipette method detailed in Holme & McIntyre (1984).

Samples were classified according to Larsonneur (1977); sediments having less than 5 % by weight of silt and clay were considered as sands, those having more than 5 % and less than 25 % of silt and clay were considered as muddy sands, and those having between 25 % and 75 % of fine sediments were classified as sandy muds.

Organic matter content of sediments was determined by incineration of sediment samples. The samples were dried to constant weight for two days at 60 °C, then burnt for three hours at 450 °C in a muffle furnace to obtain ash weights and, by subtraction, ash-free dry weights (abbreviated as AFDW). Any large macrofauna and vegetation present were removed from samples prior to the analysis.

### 3.1.2 Vegetation

Vegetation samples were taken with a 12 cm corer to determine the main species present at each station (Fig. 2.1). The samples were preserved in 4% formalin, and sent to specialists for identification. Macroalgae were identified by Dr. Rui Santos of the Univesity of Algarve and the angiosperms by Ângelo Pereira of the University of Aveiro.

On one sampling occasion, November 1986, vegetation biomass was estimated at each station. The vegetation from five cores of 12 cm internal diameter at each station was sorted and the AFDW determined.

### 3.1.3 Macrofauna

Core samples were taken every two months, over a two years period (1985-1986), to determine the composition of the benthic macrofauna. Five replicates were taken randomly with a 12 cm corer (internal diameter), to a depth of approximately 25 cm at each of the 10 sampling stations (Fig. 2.1). The sediment was sieved through a 1 mm mesh sieve and the residue preserved in a 4 % neutralised formalin solution with Rose Bengal. The organisms were counted and identified to the species level whenever possible. The term taxon is used hereafter to indicate the lowest level of identification achieved.

The identification of the amphipod species was done by Dr. J.C. Marques of the University of Coimbra and in the second year by S. Cruz of the University of Algarve. Some of the mollusc identifications were confirmed by Carlos Reis (Instituto Português de Investigação Marítima, Lisbon) and by Drs. P. Bouchet, P. Lozovet and B. Métivier, from the Museum National d'Histoire Naturelle, Paris. Some of the polychaete species were identified by Prof. G. Bellan from Station Marine d'Endoume, Marseille.

### 3.1.4 Data analysis

#### 3.1.4.1 Ordination of stations

The taxa compositions of the benthos at each of the stations were compared using multivariate methods, such as Correspondence Analysis (abbreviated hereafter as CA) and Multidimensional Scaling (abbreviated as MDS) following the recommendations of a previous study (Gamito & Raffaelli, 1992). Two data sets were constructed based on the average abundance of taxa at each station at each year. In one of the data sets only the information on the most abundant taxa (those with more than 100 individuals in all the samples over the two years) were considered. In the other data set all the information was analysed, even for rare taxa. NTSYS, version 1.6 (Rohlf, 1990) was used for CA and MDS. CA was carried out on raw data matrices and MDS on Bray-Curtis dissimilarity matrices.

#### 3.1.4.2 Density

Within each of the four sites, the data from each sampling station from each site was pooled, to provide data on mean densities per site on each sampling occasion. Variation of the density of the main major taxonomic groups, polychaetes, molluscs and crustaceans was analysed in this way. For the most abundant taxa annual changes were analysed by sampling station, rather than site.

### 3.1.4.3 Diversity

Taxa diversity was estimated using the Shannon-Wiener function, and the distribution of the individuals between taxa by the evenness measure (Pielou, 1977). Although this diversity index places most weight on the rare species and the evenness measure is always biased upwards (Krebs, 1989), their use is very common in marine benthic ecology and allows data comparisons between studies. The data used in the calculation of these indices was the mean for each of the four sites (i.e., all stations pooled). The logarithmic base used to estimate the Shannon-Wienner index was base 2 logs. The units of this index are therefore bits per individual (Krebs, 1989).

### 3.1.4.4 Rank abundance curves

The rank taxa abundance order was also determined, for each site within each of the study years. The resulting curves allow direct comparison between sites (May, 1975) and were expressed on a logarithmic scale versus taxa rank (Krebs, 1989), although other presentations are also common (e.g., Frontier, 1983). The taxa ranked abundance distributions were also presented on an octave scale, in order to evaluate conformity with Preston's log normal model (Preston, 1948).

### 3.1.4.5 Taxa associations

The association among the most common taxa was analysed by the CA taxa projection plots and by the use of some association indices. As recommended by Field *et al* (1982), the Bray-Curtis measure was used after data standardisation by arithmetic total (Clifford & Stephenson, 1975); an individual taxon abundance was divided by the total abundance of that taxon over all samples. This index has the advantage of not being affected by joint absences but it is dominated by the abundant taxa, and as for any other distance measure, is sensitive to additive and proportional changes in the community (Krebs, 1989). The correlation coefficient was also used as a measure of the covariation between taxa. Two taxa may exhibit a strong positive association with regard to their joint occurrences in the samples, but have a strong negative covariation, when one taxon abundance increases, the other's decreases (Ludwig & Reynolds, 1988). These results were organised in dendrograms, after the application of the UPGMA agglomerative technique (Rohf, 1990).

### 3.1.4.6 Relationships with the environmental data

In order to see how the taxa were associated with the environmental variables studied, Canonical Correspondence Analysis (abbreviate hereafter as CCA) was applied to the data using the program CANOCO (Ter Braak, 1988).

Subsequent to a CA analysis, the ordination diagram is usually interpreted with help of external data by calculating, for example, correlation coefficients between environmental variables and ordination axes or by multiple regression of the ordination axes on environmental variables. In Canonical Analysis, recently developed by Ter Braak (1986, 1988), the regression model is inserted in the ordination, and as a result the ordination axes appear in order of variance explained by linear combinations of environmental variables.

In the present analysis both the mean values of each environmental variable and their variation were considered. The reason for this is as follows: two stations could have similar mean annual values in one environmental variable, e.g. salinity, but the range of variation could be very different and this variation might have more impact on some taxa than the mean value.

Prior to CCA a Principal Components Analysis (abbreviated hereafter as PCA) was performed on the physical-chemical data. An environmental data set was therefore prepared, based on the mean annual values and on the difference between the maximum and the minimum value of each variable, at each sampling station. As the variables are expressed in different units, PCA was carried out after a standardisation of the data, as advised in Pielou (1984). This was done by calculating for each variable the deviation from the mean in units of standard deviation (Manly, 1986).

The PCA would allow the elimination of variables which were highly correlated. This was important because in CCA the number of environmental variables must be smaller than the number of samples (Ter Braak, 1988). Also, if a variable is perfectly correlated with the others, then its canonical coefficient is unstable and does not merit interpretation (Ter Braak, 1986). The PCA would also allow the summary of all the information relative to water quality of each study site within an ordination diagram and would facilitate the interpretation of the environmental characteristics of the stations.

## 3.2 Results and discussion

### 3.2.1 Sediment

The sediment in the lagoons was composed essentially of sand, with a small percentage of fine material (Fig. 3.1). The sediment type is not very different among the four sites studied. At the inner stations, distant from the gate, the percentage of fine sediments increased, probably due to the reduction of the water circulation. At site D, perhaps due to its smaller size, the sediment was quite similar at the two stations studied.

The classification of the sediment granulometry, according to Larsonneur (1977), gave the following results:

Station C1 - Sand.
Stations A1, A3, B1 and B3 - Muddy sand.
Stations A2, B2, C2, D1 and D2 - Sandy mud.

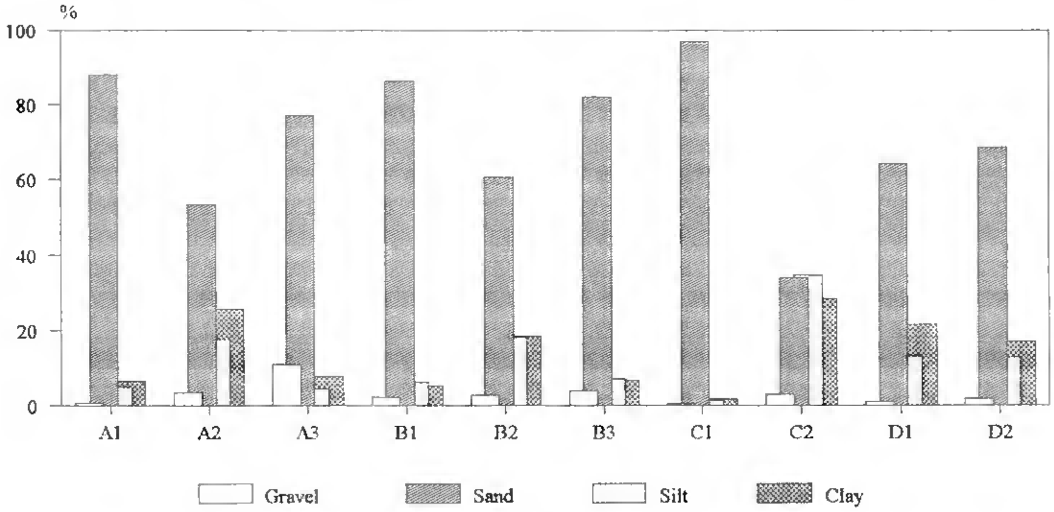


Fig. 3.1. Mean percentage of the sediment classes at all sampling stations.

Determination of organic matter in the sediment was difficult due to the abundant presence of vegetation and fauna. After their removal from the sediment samples, the organic content values were found to vary between 1.3 % and 2.5 % for all stations. Although these organic content values are considered relatively high by Bachelet & Dauvin (1993) when compared with intertidal sands, Hussenot & Reymond (1990) found organic contents of 4 to 6 % in recently prepared ponds. In old ponds, or in aquaculture ponds where intensive culture of shrimps had been made, they found organic contents of 12 to 15 %. Junoy & Vieitez (1992) referred to organic matter contents of 1.7 and 2.4 % in sublittoral sands and muddy sand flats, respectively, in the Ria de Foz (Northwest Spain). However, in the seagrass meadows of *Zostera noltii* they found 6.6 % organic matter in the sediment. In Lagoa de Santo André (West Portugal) the mean organic content of the sediment varied between 6.5 and 16.5 % (Fonseca, 1989) and in Lagoa de Óbidos it was approximately 10 % (Quintino, 1988). In Aveiro, Moreira *et al* (1993) found mean organic contents of 5.5 % and 6.6 % in muddy sands and sandy muds, respectively. It seems that, at all the studied sites, the organic content of the sediment was rather low compared to similar sites elsewhere.

An excess of organic matter can lead to anaerobic conditions in the sediment, associated with sulphate reduction phenomena (Hussenot & Reymond, 1990). The transition between oxygenated and reduced conditions can usually be easily seen by differences in the colour of the sediment and also by smell. The brown superficial oxygenated layer changes to a grey layer immediatly above the black sulphide reduced layer (Gray, 1981).

At site B the sediment seemed to be well oxygenated. The black layer was not apparent till 25 cm depth. At sites C and D, this black layer was closer to the surface, and the characteristic smell of hydrogen sulphide was common. At site A, near the gate, the sediment was clean, but at the inner stations the percentage of fine and compact sediments was large. The reduced layer was not apparent.

### 3.2.2 Vegetation

The lagoons were densely covered by seagrasses. At site B the bottom was covered by *Zostera noltii*, and at sites A and D by *Ruppia* sp. The absence of reproductive structures in plants from most of the samples precluded identification of *Ruppia* to species level, but the species was possibly *R. cirrhosa*. At site C, the bottom was covered by both seagrass species, with the exception of station C1, where no seagrass was found.

Macroalgae were less abundant than the seagrasses. At site A some Chlorophytes were found (*Enteromorpha ramulosa, E. compressa* and *Cladophora* spp.). At site B *Cladophora* spp and *Chaetomorpha* sp occurred and at sites C and D only *Cladophora* spp. The station C1, near the gate, had almost no vegetation.

Fonseca (1989) found *Ruppia cirrhosa* in Lagoa de Santo André during the summer months. During the winter, the dominant species was *Potamogeton pectinatus*, a species less tolerant to high salinities. Britton & Johnson (1987) found *Ruppia cirrhosa* together with the filamentous chlorophycean *Chaetomorpha linum* and the genera *Cladophora* and *Enteromorpha*, which occur in salinities of up to 70 ppt, in French salinas.

The mean biomass of seagrasses and attached macroalgae was quite high at site B and at the inner station of site C, higher than 150 g AFDW $m^{-2}$ (Fig. 3.2). According to Barnes & Hughes (1988), the mean seagrass biomass in temperate areas probably lies near to 500 g DW $m^{-2}$. The highest biomass found, at site B, was 420 g DW m$^{-2}$. These values are similar to the biomasses found by Verhoeven (1980) in a French salina. The species were also the same. Castel *et al* (1989) found lower biomass values in Arcachon Bay where the maximum *Zostera noltii* biomass ranged between 200 and 290 g DW m$^{-2}$. During the periods of normal functioning of Lagoa de Santo André, Fonseca (1989) found biomass values similar to those at sites B, C and D. After the lagoon had been closed to the sea for some time, the vegetation biomass increased, and in some places reached 1000 g AFDW m$^{-2}$.

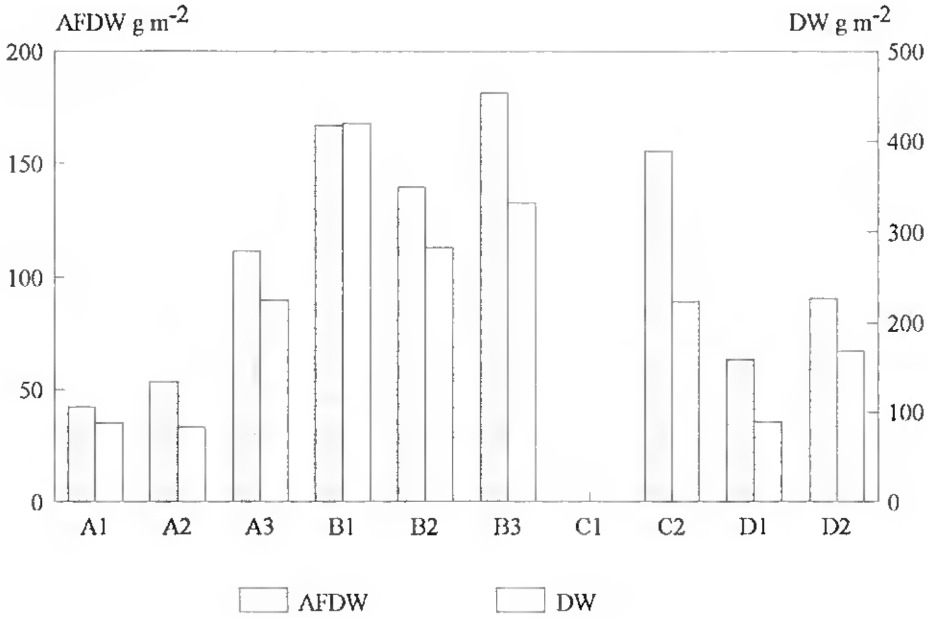


Fig. 3.2. Biomass of the vegetation at all sampling stations, including macroalgae and seagrasses.

### 3.2.3 Macrofauna

#### 3.2.3.1 Ordinations of stations

An exhaustive analysis of the first year data showed that for several multivariate methods, analyses based on two, three, four or five replicates produced similar results (Gamito & Raffaelli, 1992). Therefore, only two replicates per station were analysed for the second year samples, and for the first year only the first two replicates were considered for further data analysis. The raw data can be found in Appendix A3.

Ordination of the stations based on the taxa composition from the first year data was done previously (Gamito, 1989; Gamito & Raffaelli, 1992). These results indicated that the differences between sites were larger than the differences between stations. In the two-dimensional plots of the first two ordination axes, the stations within each of the sites were grouped close to each other, independently of the time of sampling.

The ordination of the stations using all data for each year (Figs. 3.3 and 3.4) shows again that the differences between sites were larger than the differences between the stations within each site. The first ordination axis denotes a gradient of increasing stressful conditions, from site B towards site A, with sites C and D occupying an intermediate position. Both multivariate analyses showed that the projection within the two dimensional plot of the stations in the second year moved towards the left-hand side of the first axis, that is, towards an increasingly stressful environment. This was also observed in the analysis using the reduced data set, where only the most abundant taxa were considered (Figs. 3.5 and 3.6). This analysis shows that there is a degree of redundancy in the full taxa matrix, as a subset of taxa used closely reproduces the patterns defined by the full data set (c.f. Gray *et al*, 1988). This is probably because site differences are so great, that any reasonably large group of taxa will show the same pattern of variation.

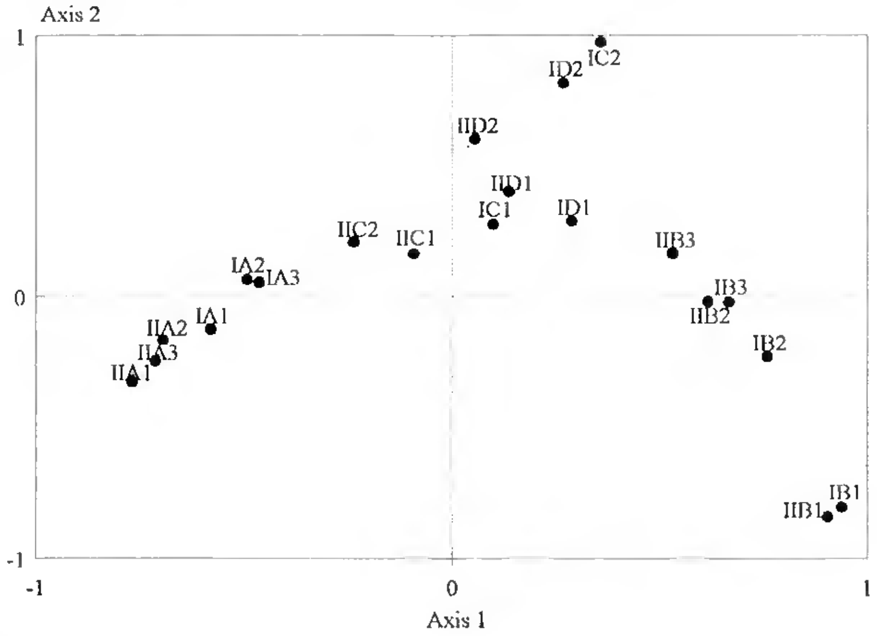


Fig. 3.3. Position of the stations on the first two axes of Correspondence analysis (total data matrix). Eigenvalues: I - 33.9 %, II - 16.8 %, III - 9.4 %. The first character indicates the year of survey (I-1985, II-1986) and subsequent ones indicate the site and station.

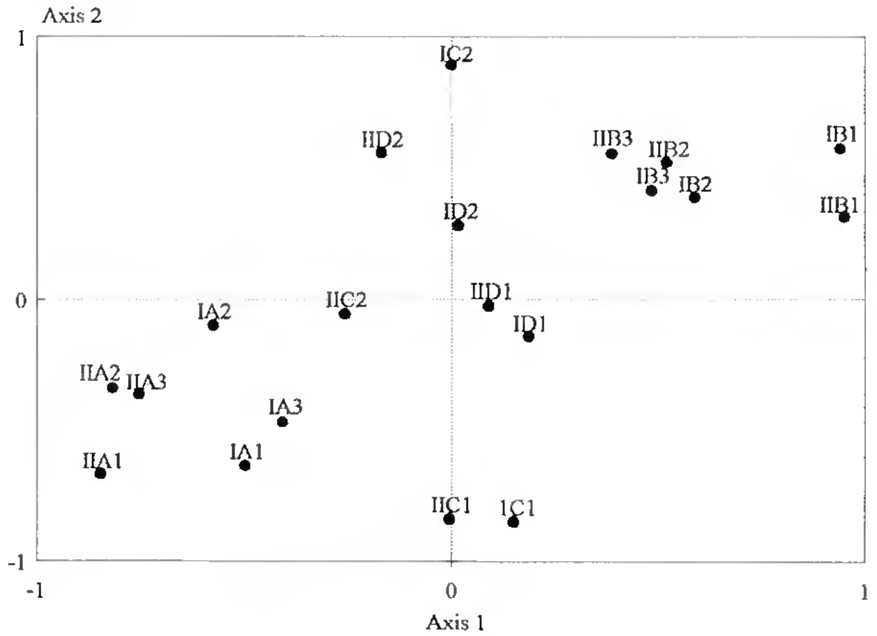


Fig. 3.4. Position of the stations on the two axes of Multidimensional Scaling (total data matrix). Final Stress: 0.178. The first character indicates the year of survey (I-1985, II-1986) and subsequent ones indicate the site and station.

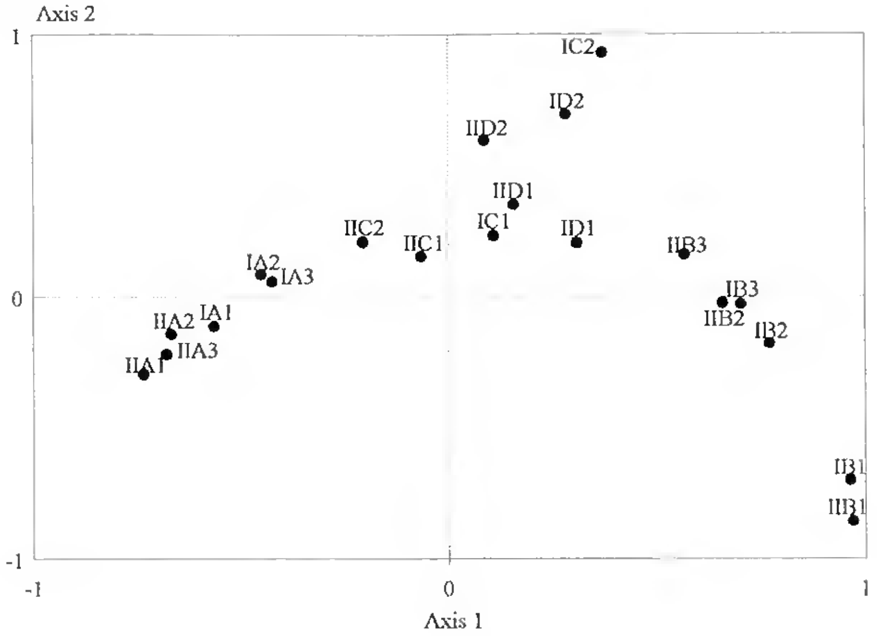


Fig. 3.5. Position of the stations on the first two axes of Correspondence analysis (reduced data matrix, 23 taxa). Eigenvalues: I - 39.2 %, II - 19.0 %, III - 10.5 %. The first character indicates the year of survey (I-1985, II-1986) and subsquent ones indicate the site and station.

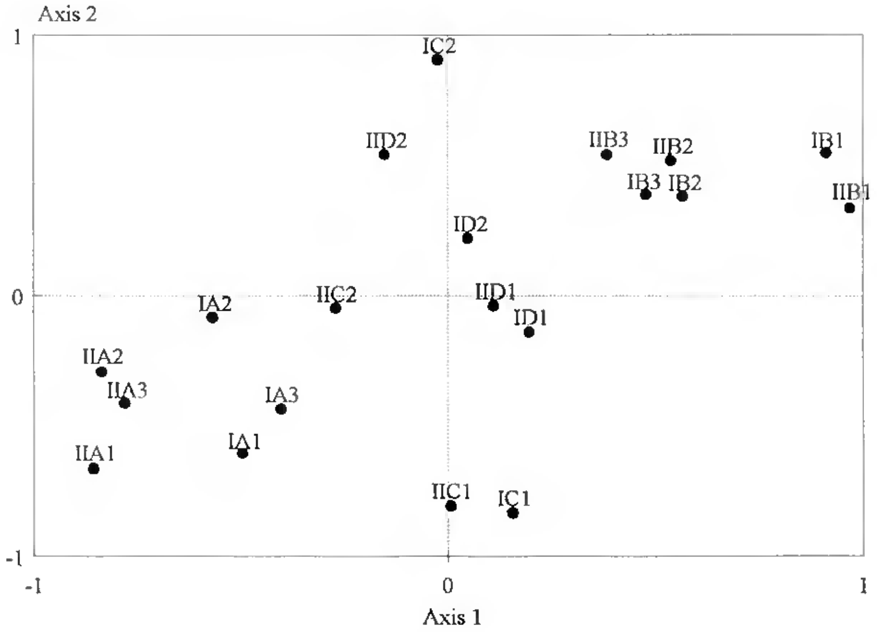


Fig. 3.6. Position of the stations on the two axes of Multidimensional Scaling (reduced data matrix, 23 taxa). Final Stress: 0.170. The first character indicates the year of survey (I-1985, II-1986) and subsquent ones indicate the site and station.

3.2.3.2 Density

The mean densities of organisms were quite high, between 5000 and 14000 individuals $m^{-2}$ (Fig. 3.7). At all sites there was an increase in the mean density during the second year, which was more pronounced at site A. This increase was mainly due to an increase in the mean density of molluscs at all sites. In contrast, the mean density of polychaetes decreased during the second year. Crustaceans and the other taxonomic groups (mainly Chironomids, Echinoderms and Phoronids) were not so representative as were the other main taxonomic groups, and their abundance varied in an irregular way.

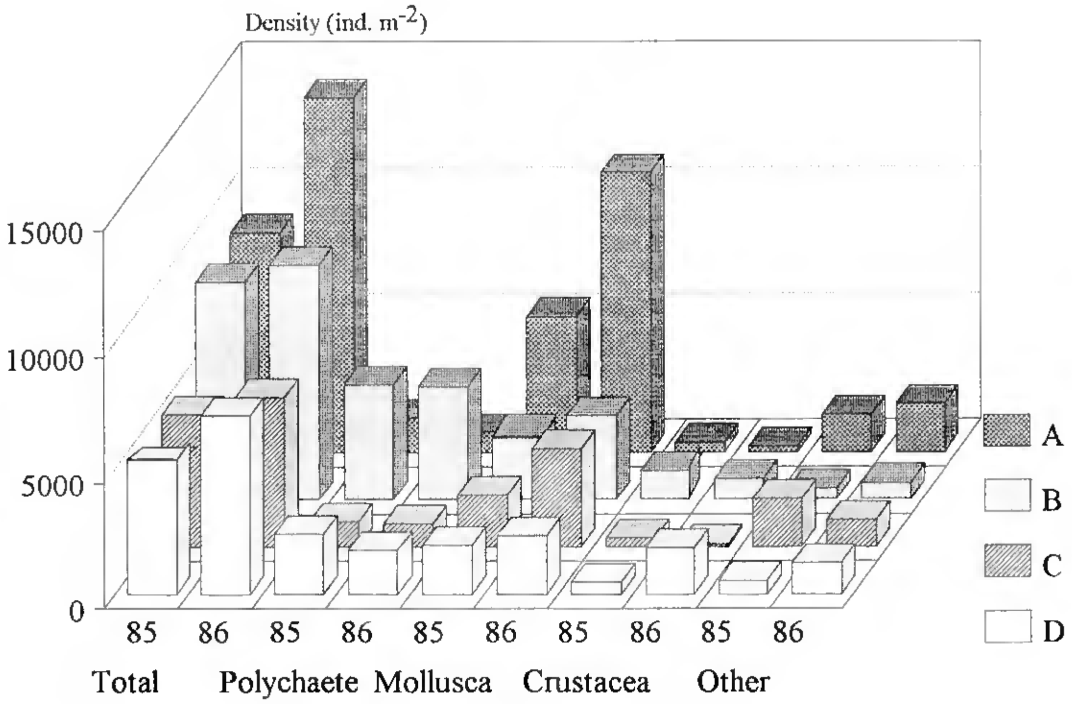


Fig. 3.7. Mean annual densities at the four sites. Each pair of values refer to the sampling year.

The density of macrofauna was higher during the cold months and decreased during the hot weather (Fig. 3.8). This was more pronounced at site A, during the second year. At that site, the density of organisms almost doubled during the beginning of the second year, followed by a decrease in July. In September and November, there was again an abrupt increase in the density of organisms, to almost to 21000 ind. $m^{-2}$.

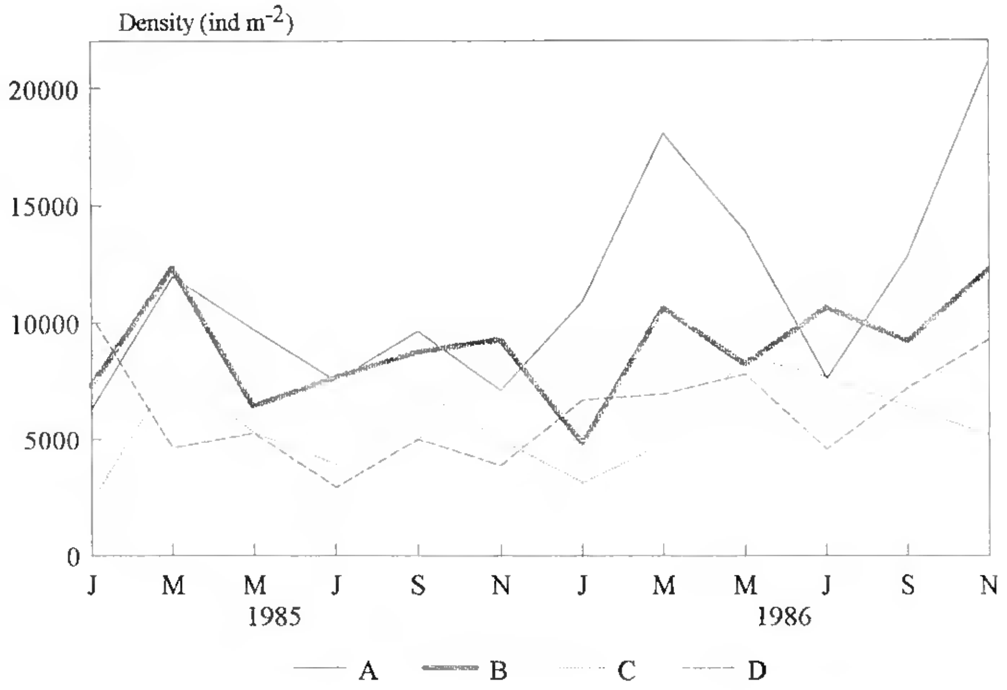


Fig. 3.8. Variation in mean total invertebrate densities at the four sites over the study period.

Reise (1978) found higher densities in a seagrass bed in the Wadden sea compared to the lagoons studied here. He recorded densities close to 50000 ind. $m^{-2}$, but lower densities, of 10000 ind. $m^{-2}$, in unvegetated areas nearby. Castel *et al* (1989) found even higher macrofauna densities in Arcachon, of 61000 ind. $m^{-2}$ in *Zostera* beds and 16000 ind. $m^{-2}$ in unvegetated areas. However, Bachelet & Dauvin (1993) found densities from 89 to 52000 ind. $m^{-2}$ in intertidal sands of Arcachon Bay. Junoy &

Viéitez (1992) in their study in Ria de Foz (Northwest Spain), found the highest macrofauna densities in the seagrass meadows, with densities greater than 20000 ind. $m^{-2}$ and only 200 ind. $m^{-2}$ in the sandy beaches. When compared with nearby unvegetated areas, seagrass meadows contain a dense and strikingly rich assemblage of invertebrates and vertebrates (Orth *et al*, 1984; Almeida, 1988).

In some Portuguese estuaries the mean macrofauna density was less than in the lagoons studied, with 624 ind. $m^{-2}$ in Mira estuary (Andrade, 1986) and 466 ind. $m^{-2}$ in Mondego estuary (Marques *et al* 1993). Costa *et al* (1984) found also low macrofauna densities, with a maximal density of only 4200 ind. $m^{-2}$ in Sado estuary.

In Portuguese lagoons studied elsewhere, the mean macrofauna density was higher than the values referred to for estuaries. Quintino (1988) found mean densities between 7000 and 18000 ind. $m^{-2}$ in Lagoa de Óbidos, but the mean density in Lagoa de Albufeira was lower, varying between 3000 and 10000 ind. $m^{-2}$. Fonseca (1989) found mean densities between 1000 and 3000 ind. $m^{-2}$ in Lagoa de Santo André, during 1978/79 but an increase up to about 70000 ind. $m^{-2}$ in January 1984. This increase coincided with an eutrophication period due to the closing of the lagoon to the sea. In fish ponds from Arcachon, Amanieu *et al* (1978) found densities between 150 and 18000 ind. $m^{-2}$ but Thimel & Labourg (1987) refer to mean densities of 8000 to 25000 ind. $m^{-2}$.

From these studies it can be seen that there is a general trend of increasing density of organisms in vegetated areas over unvegetaded areas, and higher densities in lagoons when compared to estuaries. The mean densities found in the study lagoons are broadly similar to the values found in other lagoons or in vegetated estuarine areas.

3.2.3.2.1 Polychaetes

Polychaetes were more abundant at site B than at the other sites (Fig. 3.9), and their density increased in March of each year. At this site polychaete species were recorded which were not present at the other sites (Fig. 3.10), as *Euclymene palermitana* and *Notomastus latericeus*. *Heteromastus filiformis* and *Streblospio dekhuyzeni* were present at all sites except at site A, but were more abundant at site B.

*Capitella capitata* was more abundant at sites A and D, but almost absent from site B. One species, *Scolaricia typica*, was found only at site C, near the gate (Appendix A3). Its density was low, but it was always present in all sampling months during the first year of study. In the second year this species was never recorded, even when five replicates samples were examined.

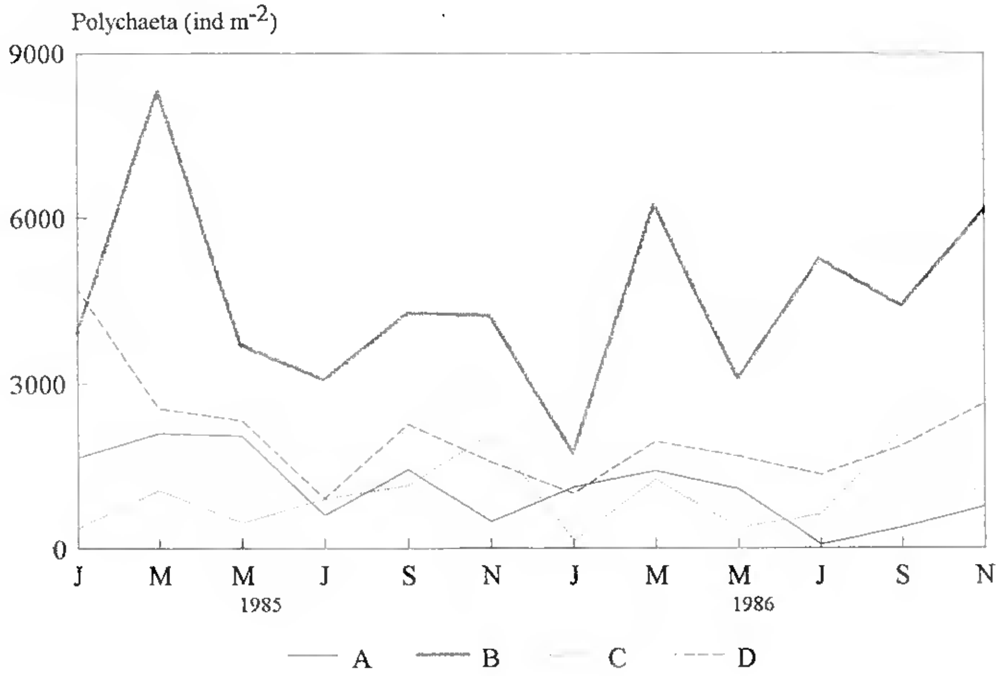


Fig. 3.9. Variation in mean number of polychaetes at each site over the study period.

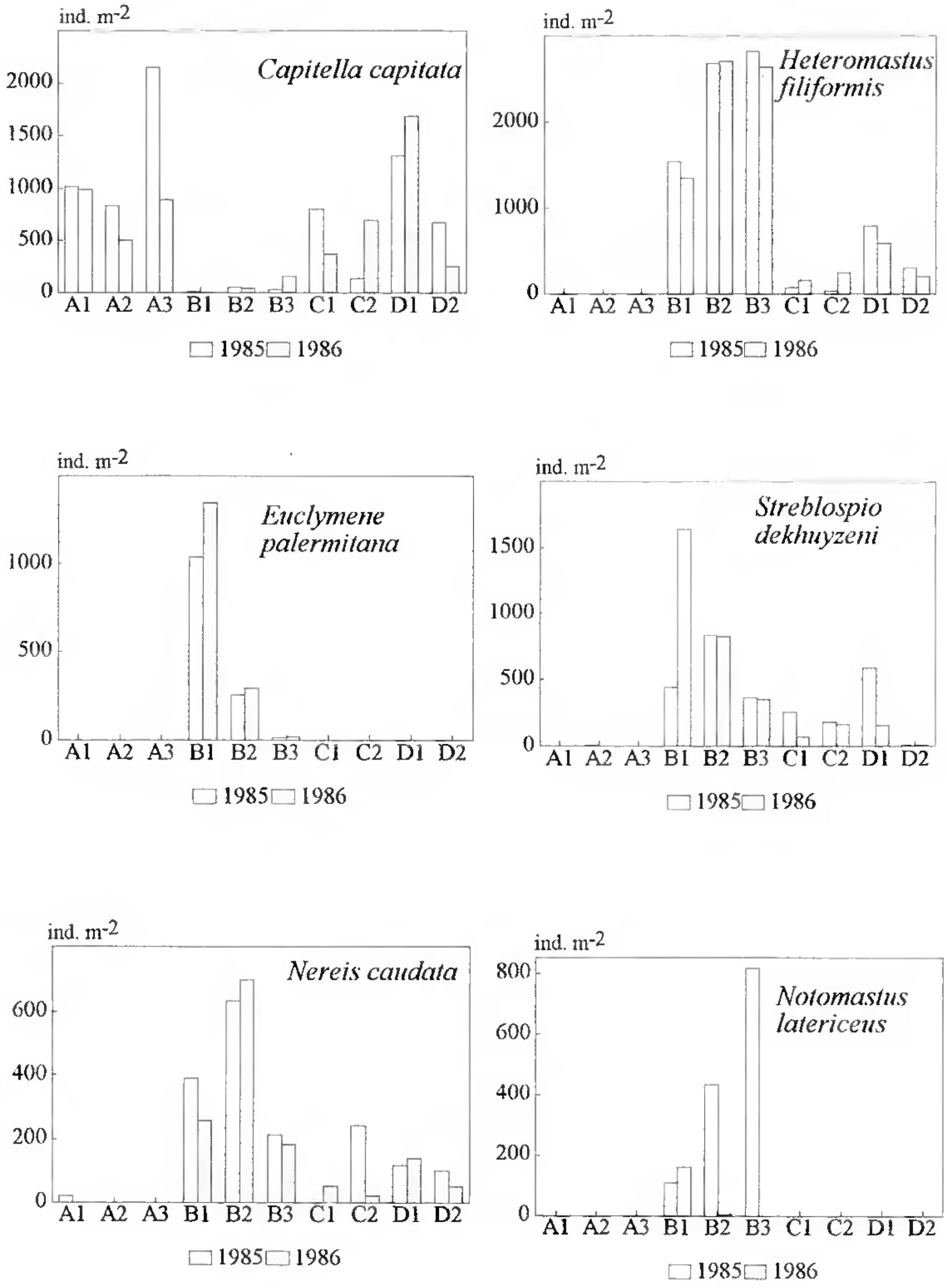


Fig. 3.10. Mean annual densities of the most abundant polychaete species, at all stations.

At site A the density of *C. capitata* varied between 800 and 2000 ind. m$^{-2}$, during the first year. In the second year the density of this species decreased to 500 and 1000 ind. m$^{-2}$. The density of *H. filiformis* varied between 200 and 700 ind. m$^{-2}$ at site B. Reise (1977) found densities between 3600 and 6800 ind. m$^{-2}$ for *C. capitata* and 25 to 50 ind. m$^{-2}$ for *H. filiformis* in a seagrass bed of the Wadden Sea. Labourg (1978) refers to the presence of *C. capitata* in the fish ponds of Arcachon only after a summer dystrophic crisis. Junoy & Viéitez (1992) found lower densities of the two species mentioned above in Northwest Spain, but they also found *Scolaricia typica* at low densities. Britton & Johnson (1987) and Arias & Drake (1987) refer only to the presence of Nereids in the French and Spanish salinas, respectively.

#### 3.2.3.2.2 Molluscs

Molluscs were more abundant at site A than at the other sites (Fig. 3.11). This fact was mainly due to the high density of the gastropods *Hydrobia ulvae* and *H. ventrosa* (Fig. 3.12). *H. ulvae* was also abundant at the other sites, except at site B, where it was rare. *H. ventrosa* was only present at site A during the first year of study. During the second year its density increased for more than the double at that site, and it became to appear at site C. *Abra ovata* was the most abundant bivalve species. It was found at all sites. The second most abundant bivalve was *Loripes lacteus*, at site B, and *Cardium glaucum* at site A (it was only found there). The other *Cardium* species, *C. edule* was present at the other sites, but in low numbers (Appendix A3). The gastropods *Cerithium vulgatum* and *Bittium reticulatum* were abundant at all sites, except at site A, where they were absent. The gastropod *Mesalia brevialis* was only found at site B.

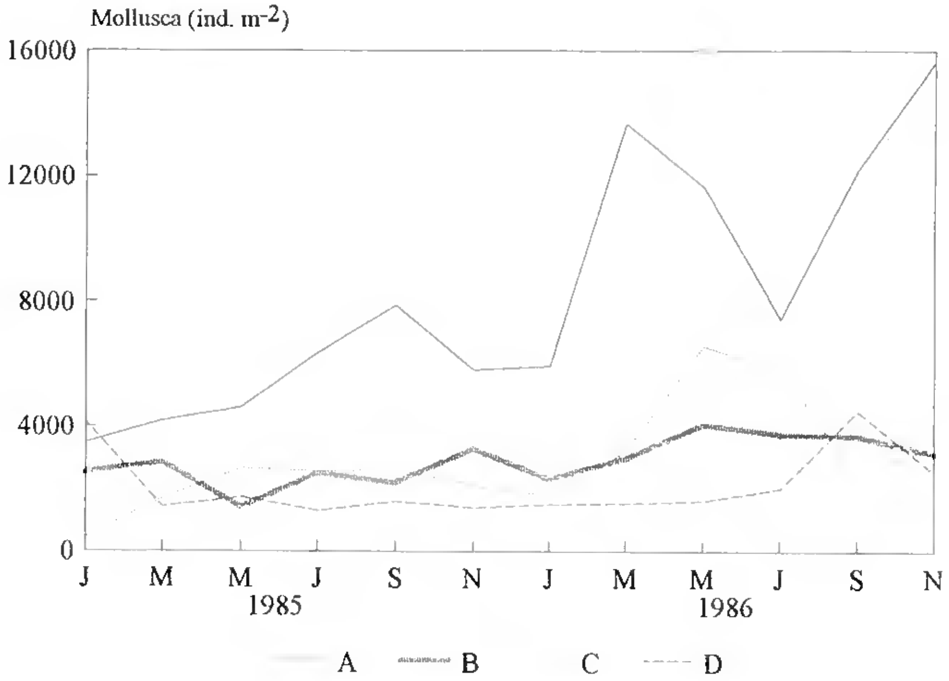


Fig. 3.11. Variation in mean density of molluscs at each site over the study period.

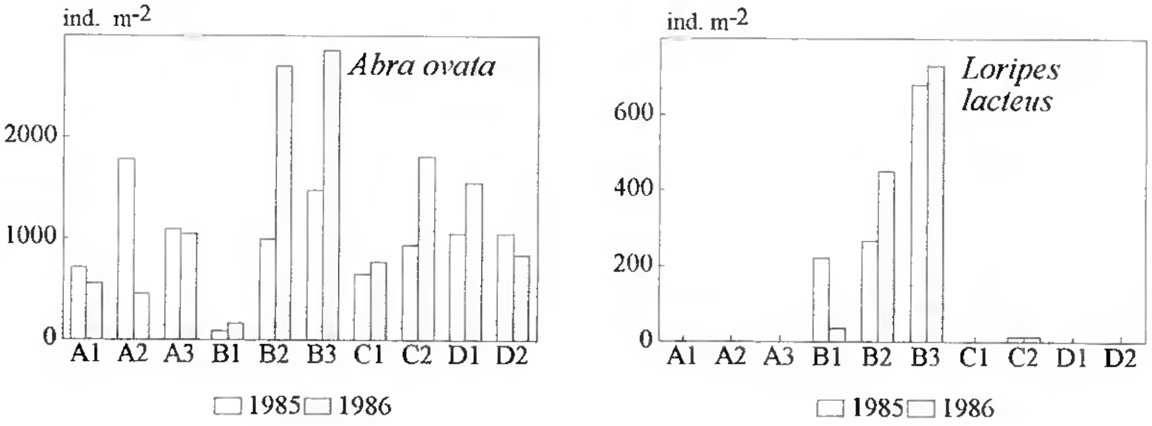


Fig. 3.12. Mean annual densities of the most abundant species of molluscs, at all stations.

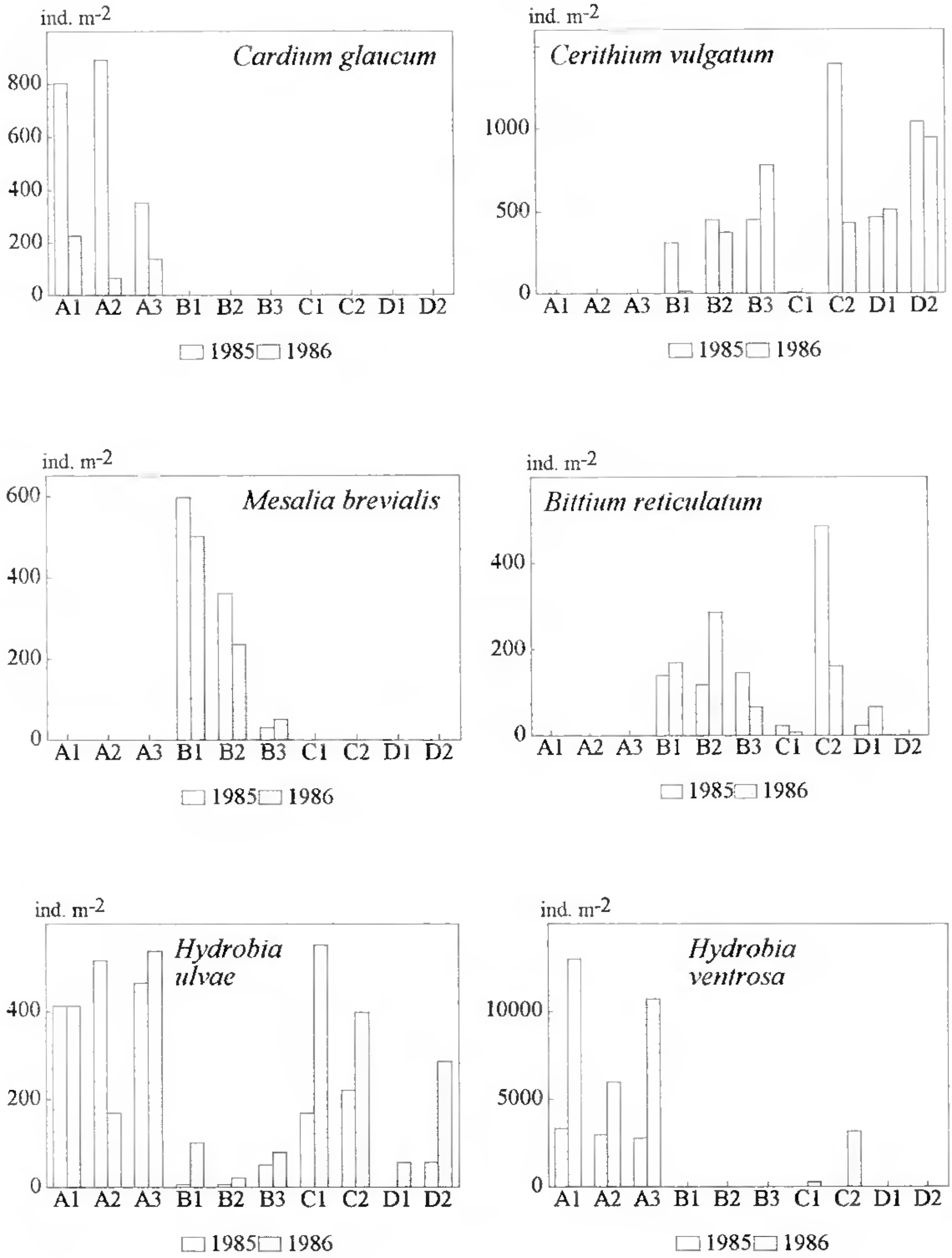


Fig. 3.12 (cont.). Mean annual densities of the most abundant species of molluscs at all stations.

The mean density of *A. ovata* ranged between 88 ind. $m^{-2}$ at station B1, during 1985 and 2800 ind. $m^{-2}$ at station B3, in 1986. The density of *C. glaucum* ranged between 66 and 892 ind. $m^{-2}$, at site A. The densities of *A. ovata* are somewhat higher than the densities found in the French Mediterranean salinas and the density of *C. glaucum* is lower: *A. ovata* ranged between 200-1220 and 800-1580 ind. $m^{-2}$ and *C. glaucum* ranged between 430-6070 ind. $m^{-2}$ and 31-1525 ind. $m^{-2}$ (Guelorget & Perthiusot, 1983; Britton & Johnson, 1987).

At site A, the density of *H. ulvae* was close to 400 ind. $m^{-2}$. At the other sites its density was usually lower. The density of *H. ventrosa* was very high at site A. During the first year its mean density was about 3000 ind. $m^{-2}$. During the second year its density increased to 6000-13000 ind. $m^{-2}$. The density of Hydrobiidae species in South France was about 18000 ind. $m^{-2}$ (Britton & Johnson, 1987) and in Northwest Spain it can reach densities of more than 16000 ind. $m^{-2}$ in the seagrass meadows (Junoy & Viéitez, 1992). In the salina reservoirs of Cádiz, Spain, the density of Hydrobiidae ranged between 5000 and 21000 ind. $m^{-2}$ (Arias & Drake, 1987).

### 3.2.3.2.3 Crustaceans

Crustaceans were not so abundant as polychaetes and molluscs (Fig. 3.13). Their density varied in an irregular and uninterpretable way. At site B they were more abundant during the hot months, but at the other sites the opposite was the case. During July and September the density of crustaceans was lower than during the cold months. An accentuated increase in crustacean density can be seen at site D during the second winter. In contrast, at site A crustaceans almost disappeared.

The cumacean *Iphinoe tenella* was relatively abundant at site B, but was not found at the other sites (Fig. 3.14). Its highest abundance was reached at station B1, during the second year, with a mean density of 300 ind. $m^{-2}$. The amphipods *Gammarus* spp., *Microdeutopus gryllotalpa* and *Ampelisca diadema* were present at all sites as well as the isopod *Idotea chelipes*. These last two species were, nevertheless, almost absent from site A. *Gammarus* spp. was quite abundant at site A during the first year, with 700. ind $m^{-2}$ at station A2, but it was not found at that site during the second year.

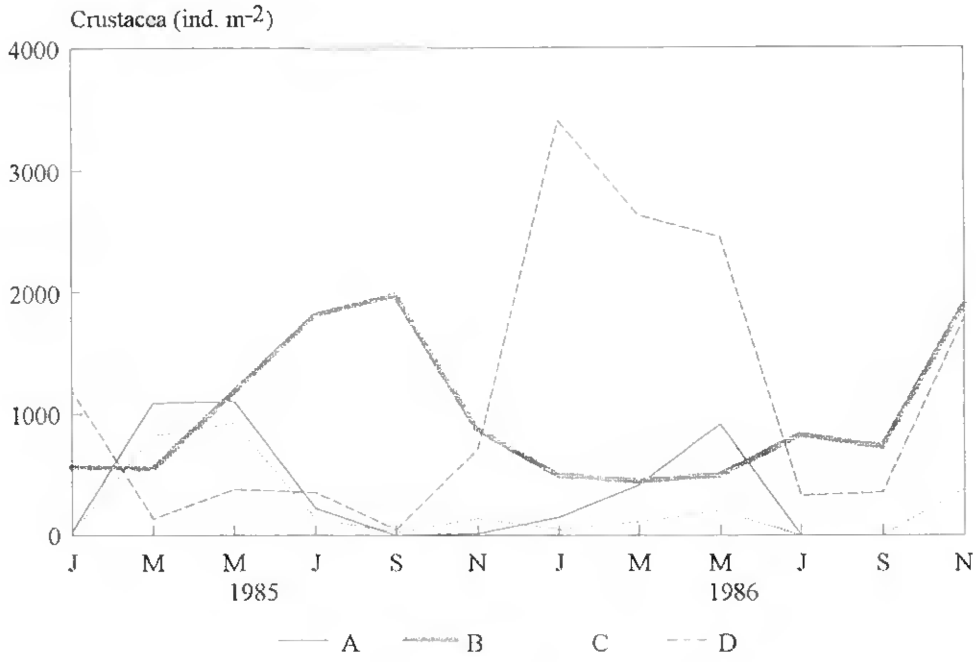


Fig. 3.13. Variation in mean density of crustaceans at each site over the study period.

The crustacean species and their mean densities found at site B were quite similar to the ones found in the *Zostera* meadows in Northwest Spain (Junoy & Viéitez, 1992). Labourg (1979) refers to other crustacean species as being abundant in the fish ponds of Arcachon, like the amphipod *Corophium insidiosum* and the isopod *Cyathura carinata*. This last species was also found at sites B and C, but at very low densities (Appendix A3). Arias & Drake (1987) only refer to the amphipod *Microdeutopus gryllotalpa* in Cádiz salinas.

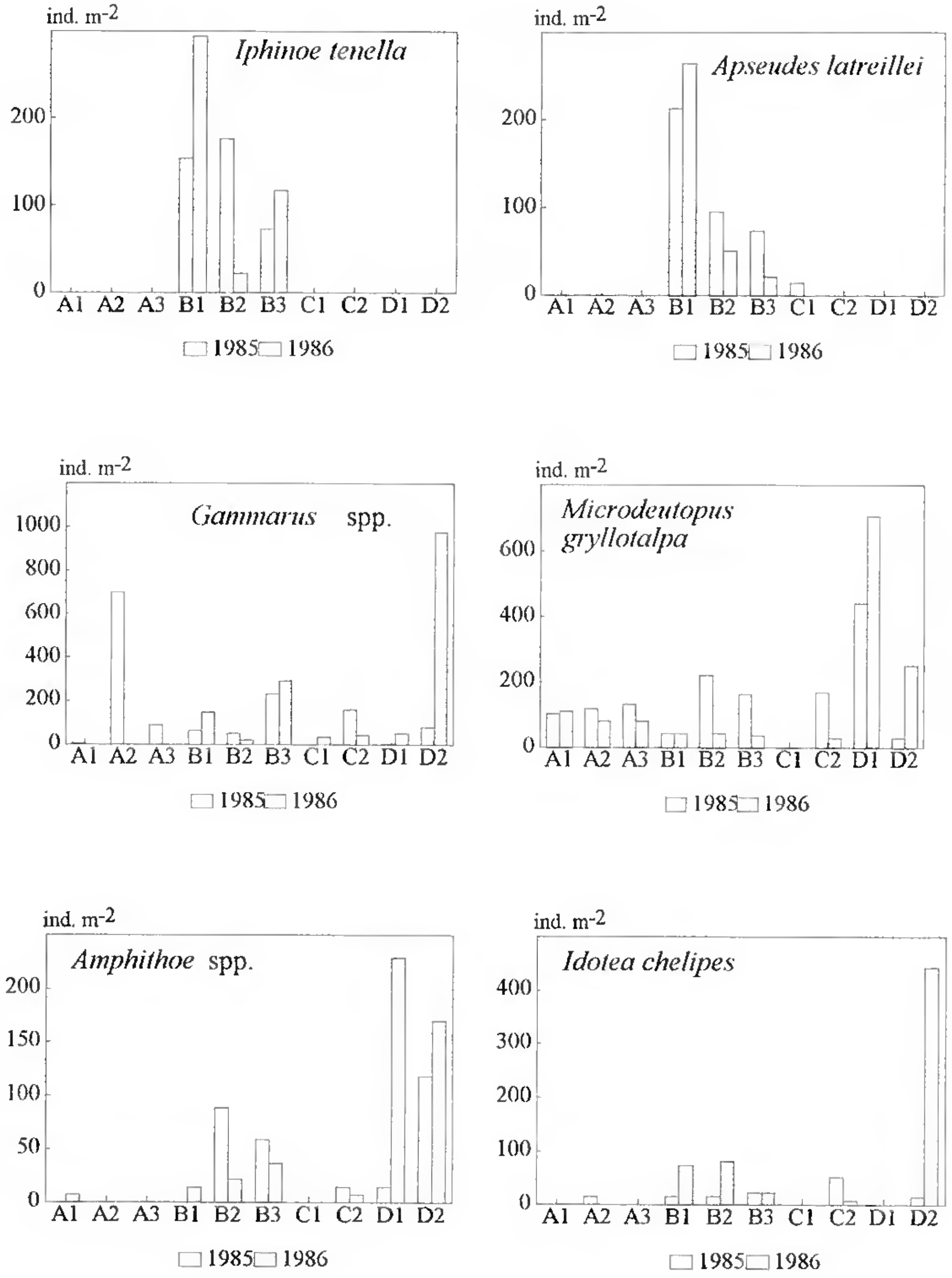


Fig. 3.14. Mean annual densities of the most abundant species of crustaceans, at all stations.

### 3.2.3.2.4 Other taxonomic groups

The most abundant taxa in this group were the insect larvae, the oligochaetes and the phoronids. The insect, *Chironomus salinarus*, was more abundant at site A, but it was also present at sites C and D (Fig. 3.15). The highest density was found at station A2, where it ranged between 3000 and 4000 ind $m^{-2}$. The oligochaetes, *Tubifex* sp., were more abundant at the inner stations of sites B, C and D. At station C2 its mean density was higher than 3000 ind. $m^{-2}$, during the first year. During the second year its density decreased to values close to 1000 ind. $m^{-2}$. The phoronids, *Phoronis* sp. were present only at site B, with densities between 50 and 600 ind. $m^{-2}$.

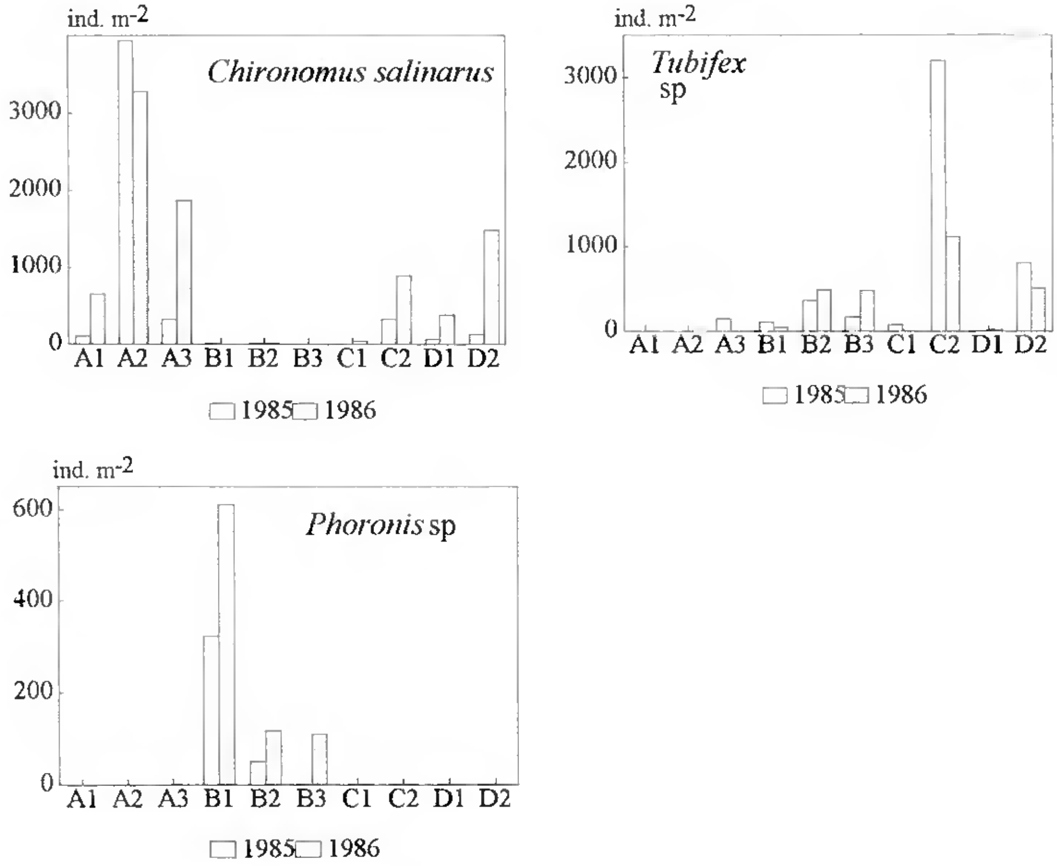


Fig. 3.15. Mean annual densities of chironomid larvae, oligochaetes and phoronids, at all sampling stations.

In a salina in Cádiz, Arias & Drake (1987) found densities of *C. salinarius* of between 5000 and 11000 ind. $m^{-2}$. Similar densities were found in the fish ponds of Arcachon (Labourg, 1979) for this species, where the oligochaetes were also abundant, densities attaining approximately 3000 ind. $m^{-2}$.

### 3.2.3.3 Diversity

The number of different taxa was higher at site B, close to 40, during the two years (Fig. 3.16). At site D the number of taxa was close to 20. At site C about the same number of taxa were found as at site D, but during the second year, this decreased to less than 15. At site A the number of taxa varied around 10 during the first year, but during the second year of survey this number halved.

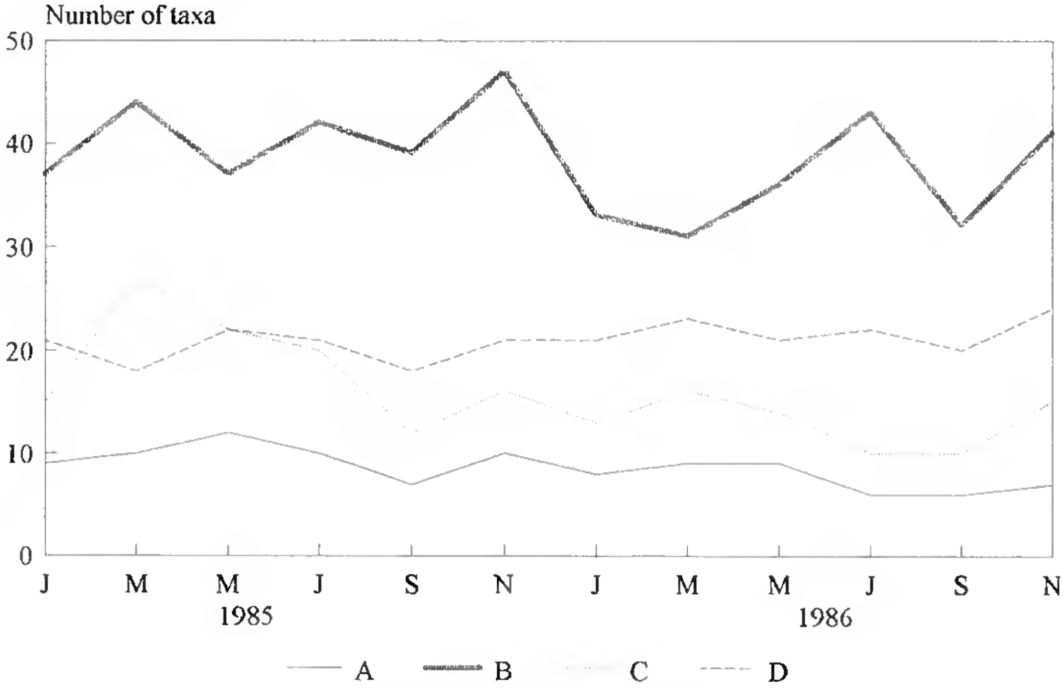


Fig. 3.16. Variation in the total number of different taxa at each site over the study period.

The between-site differences described above were also reflected in the diversity estimates (Fig. 3.17). The Shannon-Wiener index was highest at site B and lowest at site A. At sites C and D index values were sometimes similar to those at site B, mainly due to a more even distribution of individuals among the taxa, as seen in the evenness values (Fig. 3.18). During the hot months of the second year the dominance of a few taxa increased abruptly at site A producing the lowest evenness values recorded.

Amanieu *et al* (1978) and Labourg (1979) also found low numbers of species, between 2 and 20 species, in the fish ponds of Arcachon. The Shannon-Wiener index values they recorded were usually lower than 1 bit, and the evenness values were rarely above 0.70. Junoy & Viéitez (1992) found also low diversity in the seagrass meadows of Northwest Spain, between 0.19 and 2.16 bits, and evenness values were extremely low, between 0.02 and 0.19, mainly due to the presence, in very high densities, of the gastropod *Hydrobia ulvae*. In Portuguese lagoons, Fonseca (1989) also found low global diversity values in Lagoa de Santo André, between 0.5 and 1.5 bits, with the highest values at those stations near the opening to the sea. In Lagoa de Albufeira the diversity was higher, between 2 and 3.5 bits, and around 3 bits in Lagoa de Óbidos, but with low evenness values between 0.3 to 0.6 (Quintino, 1988).

At sites A, C and D the number of taxa decreased slightly during the hot months of July and September, paralleled by a decrease in diversity index values. Labourg (1979) noted similar variations in Arcachon, but in a more pronounced way due to heavy mortalities during the summer dystrophic crisis.

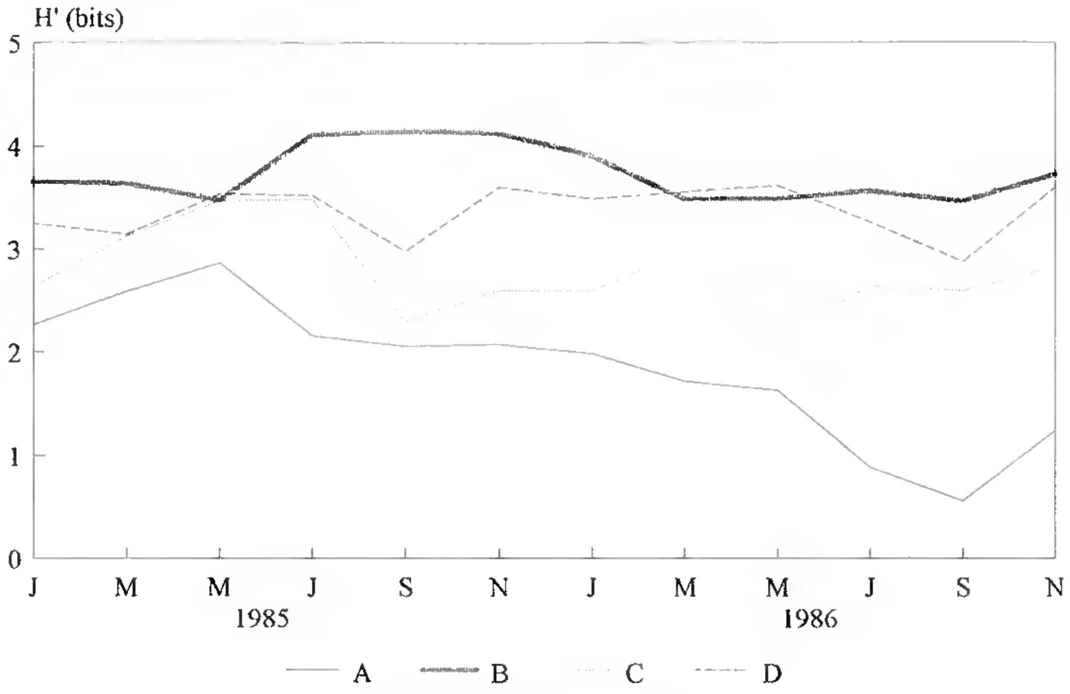


Fig. 3.17. Variation in the Shannon-Wiener index at each site over the study period.

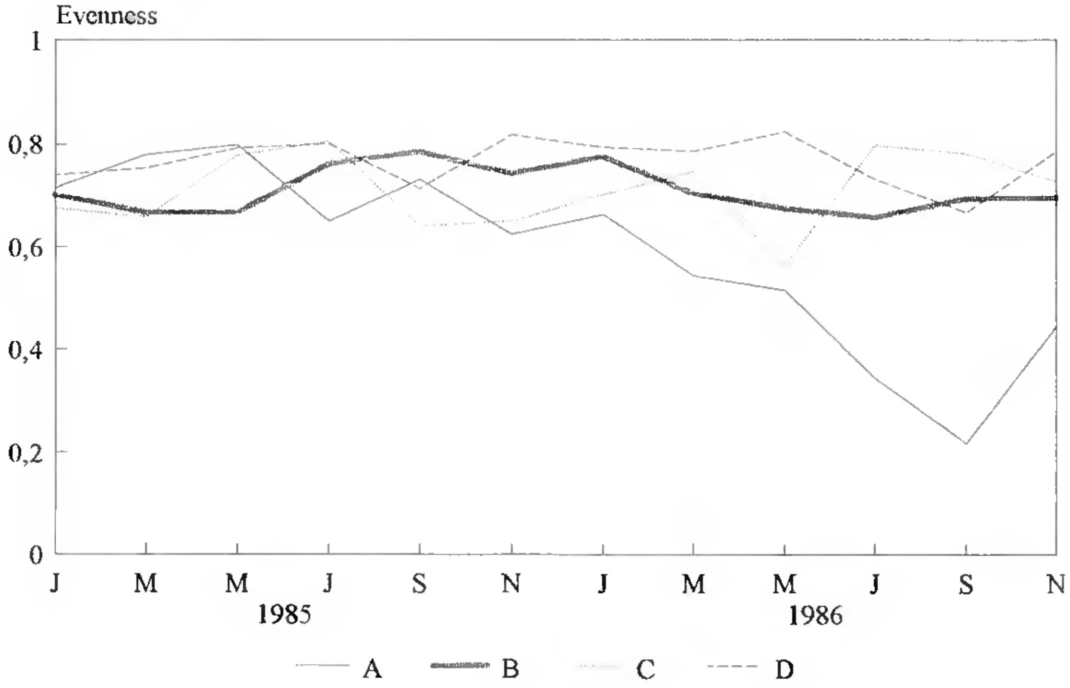


Fig. 3.18. Variation in Evenness at each site over the study period.

### 3.2.3.4 Rank abundance curves

The rank abundance curves (Figs. 3.19 to 3.22) all have a reverse S-shaped format, possibly denoting log-normal distributions, although the data from site A approximate a straight line indicating a logarithmic series. Log-normal distributions are ubiquitous and occur when species relative abundances are governed by the conjunction of a variety of independent factors, whilst the logarithmic series occur when the organisation of the community is controled by a single dominant factor (May, 1975). The log-normal distribution implies that most species occur in minimal abundance (Krebs, 1989), whereas in the log-series model there are only few very abundant or very rare species (Amanieu *et al*, 1981).

Although the log-normal distribution is a usefull model for describing species abundance relationships, in practice it is very difficult to fit to marine benthic data (Hughes, 1986). In fact only at site B does the taxa abundance distributions resemble a log-normal distribution (Fig. 3.23). At the other sites, there is no convincing evidence of conformation to any distribution type and therefore no attempt was done to fit any model distribution to the data.

Site A is characterised by having a low taxa diversity, and is dominated by *Hydrobia ventrosa, Chironomus salinarus, Capitella capitata* and *Abra ovata.* During the second year of study diversity decreased at this site so that the number of different taxa almost halved and dominance by *H. ventrosa* doubled. In contrast to site A, site B is characterised by a high diversity of taxa, about 70 different taxa being recorded. Here the dominant species were *Heteromastus filiformis*, *A. ovata* and *Streblospio dekhuyzeni.*

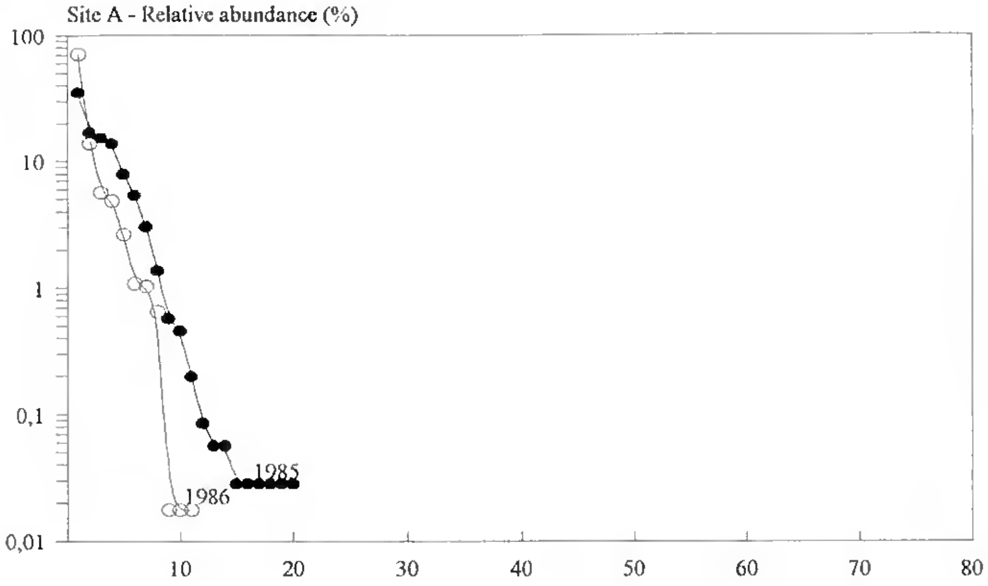


Fig. 3.19. Rank abundances at site A, in each year. First rank species: 1985 - 1. *Hydrobia ventrosa*, 35 %, 2. *Chironomus salinarus*, 17 %, 3. *Capitella capitata*, 15 %, 4. *Abra ovata*, 14 %. 1986 - 1. *H. ventrosa*, 70 %, 2. *C. salinarus*, 14 %, 3. *C. capitata*, 6 %, 4. *A. ovata*, 5 %.

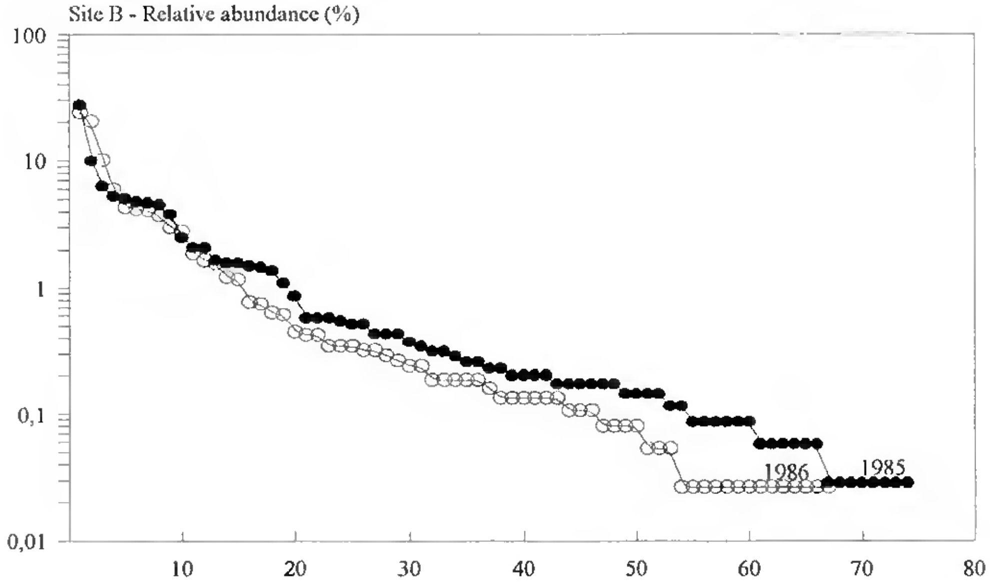


Fig. 3.20. Rank abundances at site B, in each year. First rank species: 1985 - 1. *Heteromastus filiformis*, 27 %, 2. *Abra ovata*, 10 %, 3. *Streblospio dekhuyzeni*, 6%, 4. *Notomastus latericeus*, 5 %. 1986 - 1. *H. filiformis*, 24 %, 2. *A. ovata*, 21 %, 3. *S. dekhuyzeni*, 10 %, 4. *Euclymene palermitana*, 6 %.

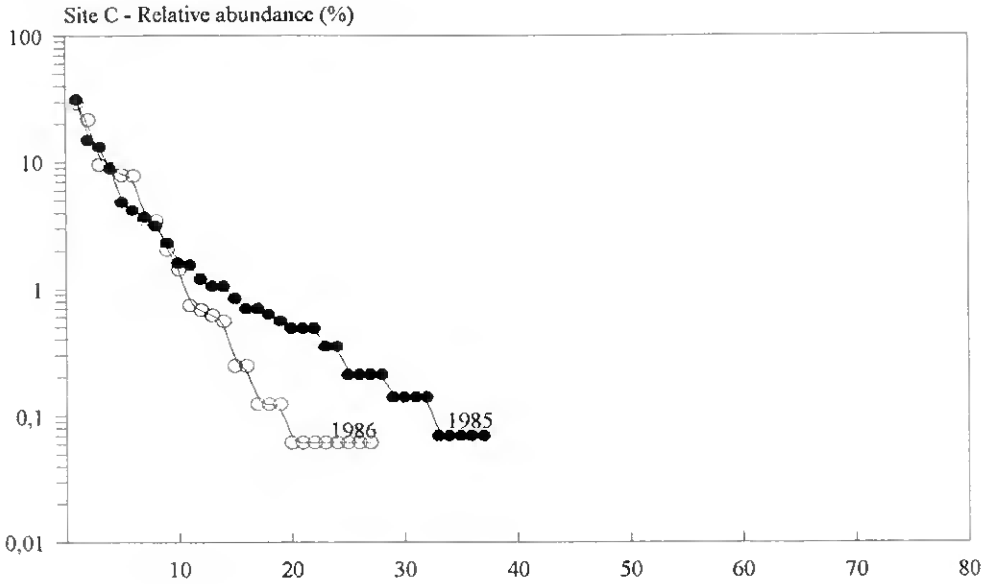


Fig. 3.21. Rank abundances at site C, in each year. First rank taxa: 1985 - 1. Tubificidae, 31 %, 2. *Abra ovata*, 15 %, 3. *Cerithium vulgatum*, 13 %, 4. *Capitella capitata*, 9 %. 1986 - 1. *Hydrobia ventrosa*, 30 %, 2. *A. ovata*, 22 %, 3. Tubificidae, 10 %, 4. *C. capitata*, 9 %.

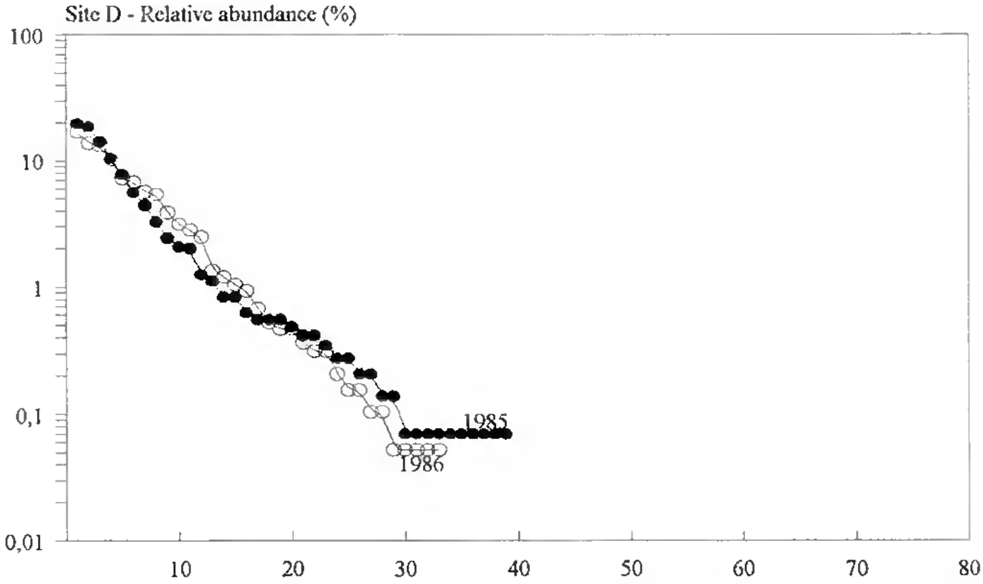


Fig. 3.22. Rank abundances at Site D, in each year. First rank species: 1985 - 1. *Abra ovata*, 20 %, 2. *Capitella capitata*, 19 %, 3. *Cerithium vulgatum*, 14 %, 4. *Heteromastus filiformis*, 10 %. 1986 - 1. *A. ovata*, 17 %, 2. *C. capitata*, 14 %, 3. *Chironomus salinarus*, 13 %, 4. *C. vulgatum*, 10 %.

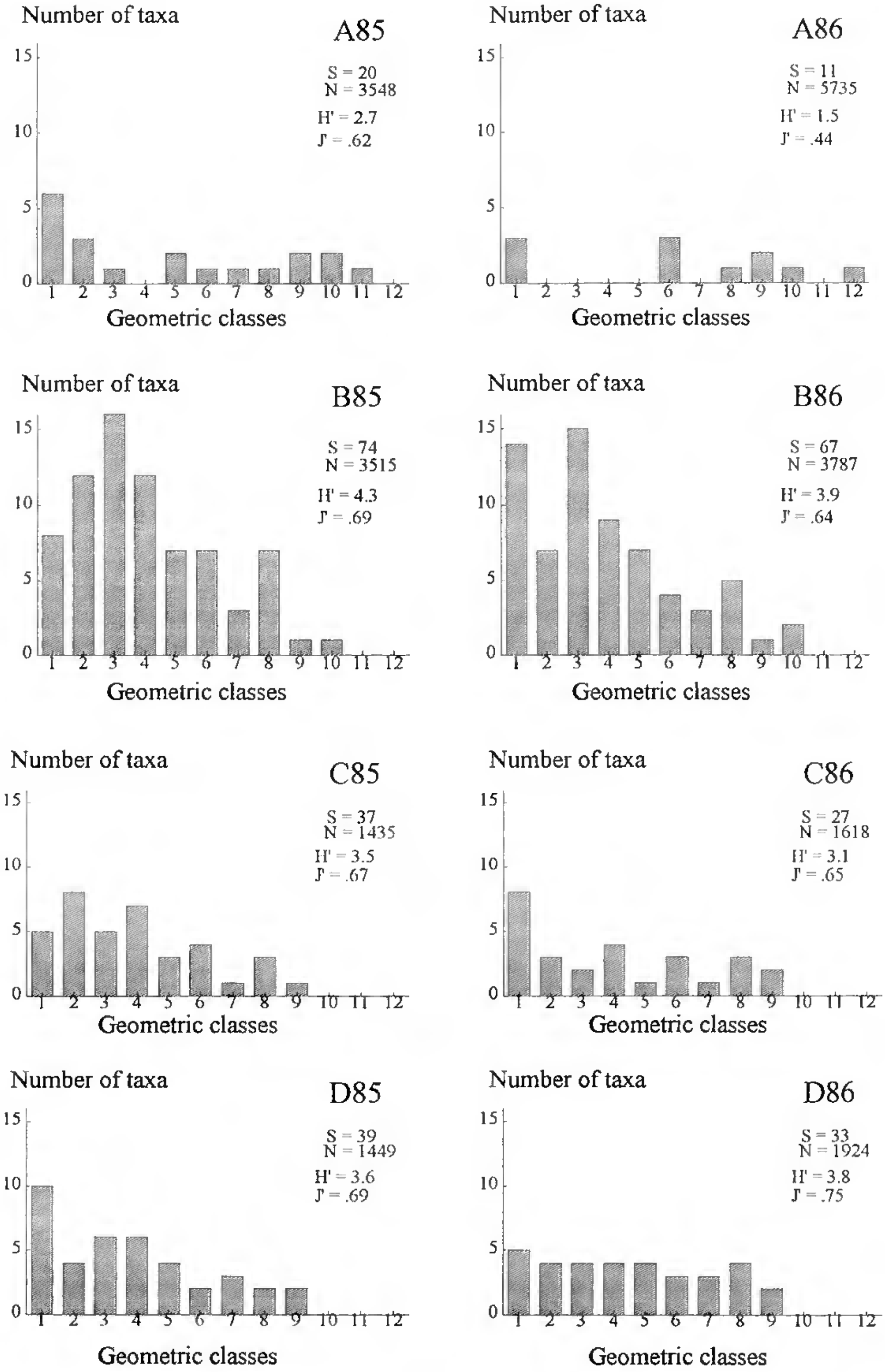


Fig. 3.23. Distributions of individuals among taxa, at each site and in each year. S - Total number of species; N - total number of individuals; H' - Shannon-Wiener function; J' - evenness.

Sites C and D showed intermediate characteristics, with fewer taxa than at site B. The dominant taxa at site C were Oligochaetes, *A. ovata* and *Cerithium vulgatum*, during the first year. During the second year, *H. ventrosa* became the most important species. At site D the dominant species were *A. ovata*, *C. capitata* and *C. vulgatum*.

During the second year of study a decrease in the number of taxa was seen at all sites. This was more pronounced at sites A and C and at the latter there was a change in dominance, with *H. ventrosa* becoming the most dominant species. This species was only present at site A during the first year.

Most of the dominant taxa at these sites are deposit feeders (Appendix A2), although *H. ventrosa* and *C. vulgatum* can also be herbivores, feeding on macrophytes and on the epiphytic layer growing on seagrasses.

### 3.2.3.5 Taxa Associations

All of the methods used to define taxa associations (Correspondence Analysis, Bray-Curtis distance and the Pearson Correlation Coefficient) produced similar results (Figs. 3.24 and 3.25). Four main groups of taxa can be recognized, although the separation among the groups is not absolute but rather a continous replacement of taxa by others. The results of all analyses are summarized in Fig. 3.26. By comparing the CA ordinations plots of stations (Fig. 3.5) and taxa (Fig. 3.24) it is clear that the first group of taxa corresponds to those stations at site A, the second group of taxa to sites C and D, the third group to stations B2 and B3, and the fourth group to station B1.

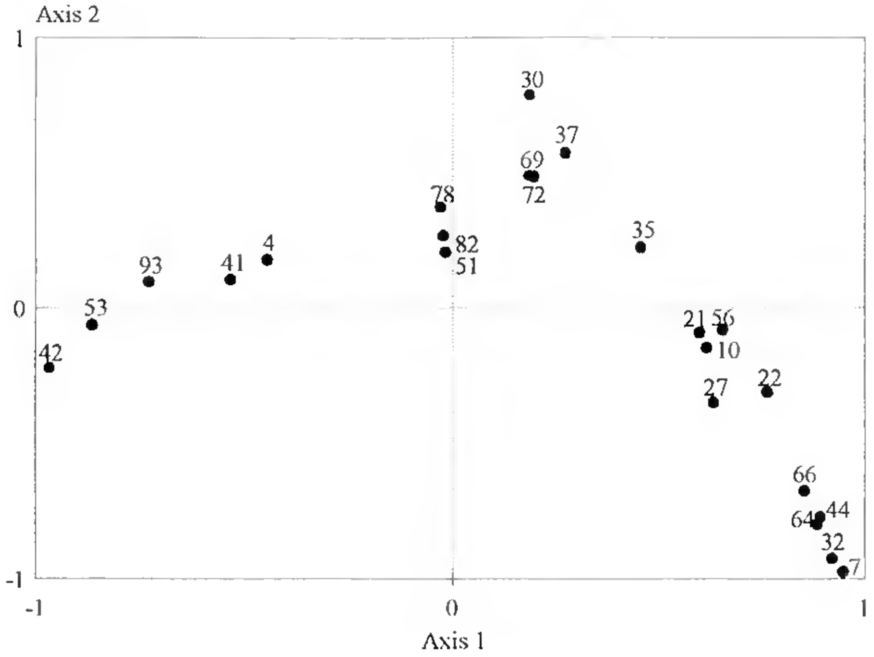
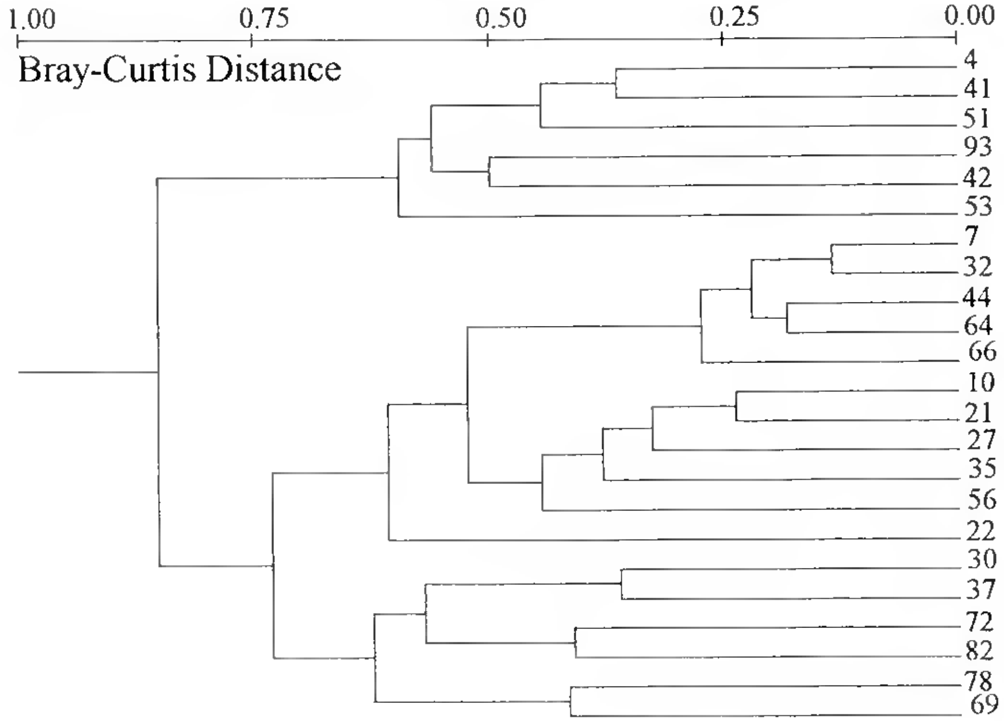


Fig. 3.24. Position of the taxa on the first two axes of Correspondence Analysis (reduced data matrix, 23 taxa). Eigenvalues: I - 39.2 %, II - 19.0 %, III - 10.5 %. Taxa names:

4- *Capitella capitata*
7- *Euclymene palermitana*
10- *Heteromastus filiformis*
21- *Nereis caudata*
22- *Notomastus latericeus*
27- *Streblospio dekhuyzeni*
30- Tubificidae
32- *Phoronis* sp.
35- *Bittium reticulatum*
37- *Cerithium vulgatum*
41- *Hydrobia ulvae*
42- *H. ventrosa*

44- *Mesalia brevialis*
51- *Abra ovata*
53- *Cardium glaucum*
56- *Loripes lacteus*
64- *Apseudes latreillei*
66- *Iphinoe tenella*
69- *Idotea chelipes*
72- *Amphitoe* spp.
78- *Gammarus* spp.
82- *Microdeutopus gryllotalpa*
93- *Chironomus salinarus*

Group I species are characteristic of site A, for example *Hydrobia ulvae* and *H. ventrosa*, *Capitella capitata*, *Chironomus salinarius* and *Cardium glaucum*. The last species listed was exclusive to site A. The other species in this group were also present at other sites, although less abundant.



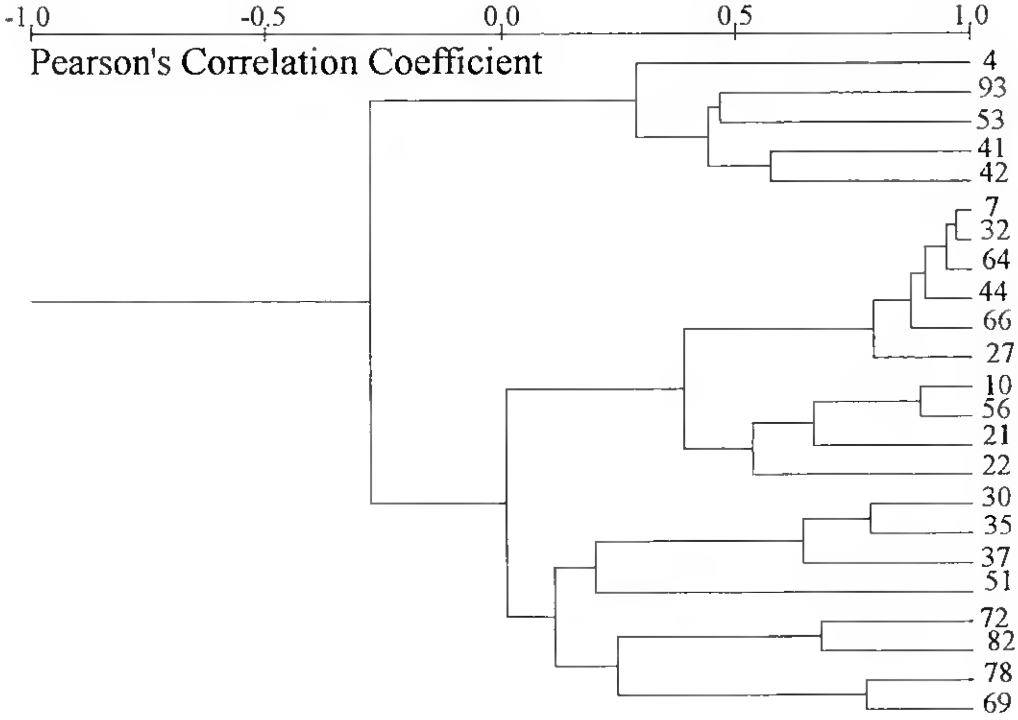


Fig. 3.25. Dendrograms of taxa associations among the 23 most abundant taxa. For taxa identification see legend in Fig. 3.24.

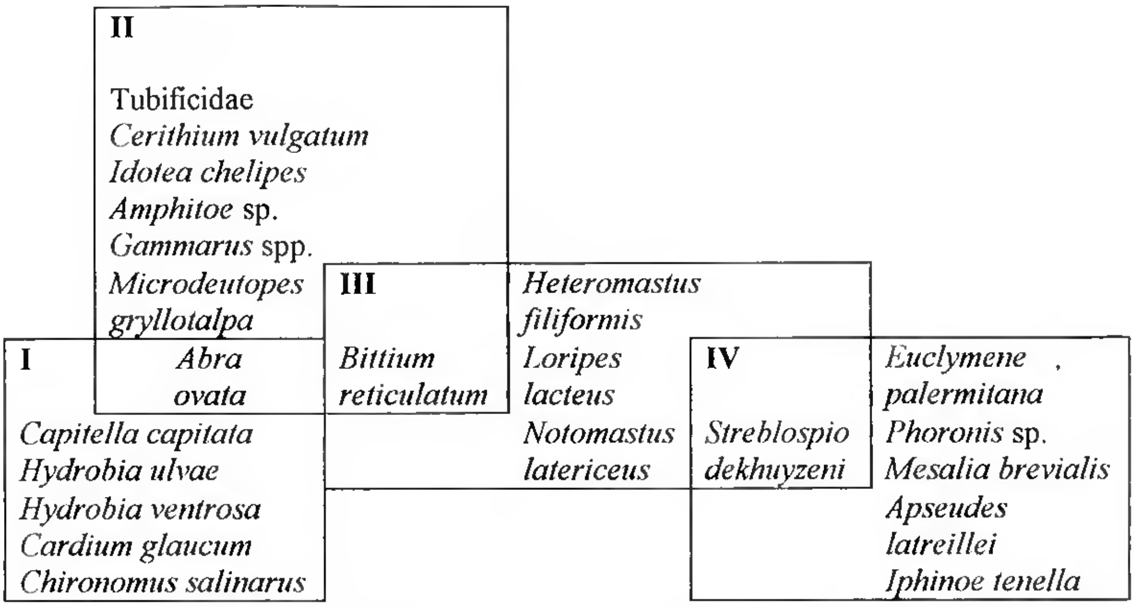


Fig. 3.26. Summary of taxa grouping from multivariate analyses shown in Figs. 3.24 and 3.25.

*Abra ovata* is a special case. In Cluster Analysis it was grouped either into Group I (Bray-Curtis distance) or into Group II (Pearson correlation coefficient). In the CA ordination its projection was close to the taxa of group II. But its projection close to the origin of the axes can have several meanings. The species may be ubiquitous, or unrelated to the ordination axes, or have a bimodal distribution, or it may simply have a habitat-optimum near the centre of the sampled range of habitats (Ter Braak & Prentice, 1988). Inspection of Fig. 3.12 suggests that the species is indeed distributed widely over the gradient sampled.

Group II taxa are characteristic of sites C and D, although they are also present, sometimes, at the other sites, for example *Idotea chelipes*, Tubificidae, *Amphitoe* spp., *Gammarus* spp., *Microdeutopes gryllotalpa* and *Cerithium vulgatum*. The last species listed was not present at site A. *M. gryllotalpa* was projected close to *A. ovata* (Fig. 3.24) and inspection of Fig. 3.14 suggests that this species is also widely distributed over the gradient sampled.

The gastropod *Bittium reticulatum* occupies an intermediate position between group II and III. It was abundant at site B and also at station C2 (Fig. 3.12).

Group III species are characteristic of site B, but are also found at sites C and D, for example *Heteromastus filiformis* and *Nereis caudata*. *Loripes lacteus* was abundant at site B, but also occurred at site C.

*Streblospio dekhuyzeni* occupies an intermediate position between Groups III and IV. It was more abundant at site B but was also present at sites C and D (Fig. 3.10).

Group IV is formed by taxa exclusive to site B, like *Euclymene palermitana*, *Mesalia brevialis*, *Iphinoe tenella* and *Phoronis* sp.. *Apseudes latreillei* was also present at station C1, although at low densities, and only during the first year.

Most of the taxa mentioned above are characteristic of *Abra* communities of organic muds of estuaries and other sheltered regions (Thorson, 1957) or of the "Biocoenose Lagunaire Euryhaline et Eurytherme" of Pérès & Picard (1964). However, is difficult to delimit any of the four groups (or indeed all of the groups together) into one such community type. Rather seems to be a replacement of most of the taxa along a gradient of increasingly stressful environmental conditions. Some taxa, from group IV and III apparently do not tolerate these stressful conditions, whilst other taxa, like *Abra ovata*, seem to cope equally well in any of the environmental condition within the ranged studied.

Amanieu (1967), Amanieu *et al* (1978) and Labourg (1979) found similar taxa in the fish ponds of Arcachon, namely *Abra ovata* and *H. ventrosa* and also the same vegetation: *Chaetomorpha*, *Enteromorpha*, *Cladophora*, *Ulva*, *Ruppia* and *Zostera*. They also refer the crustaceans *Cyathura carinata* and *Palaemonetes varians*, which were present, as well, in fish ponds and salina reservoirs, although at low densities. Britton

& Johnson (1987) recorded the same taxa in a Mediterranean salina in South France, and Arias & Drake (1987) in the salinas of Cádiz, South Spain.

Apparently, the same taxa occur in the same type of habitat. However, it is not easy to categorise the taxa recorded here into the six different "confinement" regions defined by Guelorget & Perthiusot (1983) and used by Frisoni & Guelorget (1986) and Thimel & Labourg (1987). For instance, the taxa occurring in high densities at site B belong to "confinement" regions II, III, IV and also V. Site A would be characteristic of regions IV and V.

### 3.2.3.6 Relationships with the environmental data

PCA ordinations of both stations and variables (as a biplot - Gabriel, 1971), indicated a strong gradient along axis one (Figs. 3.27 and 3.28). At one side of the axis, with high mean salinity, pH and suspended matter values, as well as large variations of these variables, were the stations of site A. Temperature variation was also important at that site, as was the mean concentration of dissolved oxygen. Nitrite and silicate had higher mean concentrations in that side of the axis but, as the lengh of the arrows were short, their importance in stations differentiation were minor.

On the other side of axis one were projected all the other stations, characterised by smaller concentrations and smaller variations of the variables mentioned above, but with higher densities of phytopigments and also higher concentrations of phosphates and nitrates. Mean BOD and its variation were also higher at these sites.

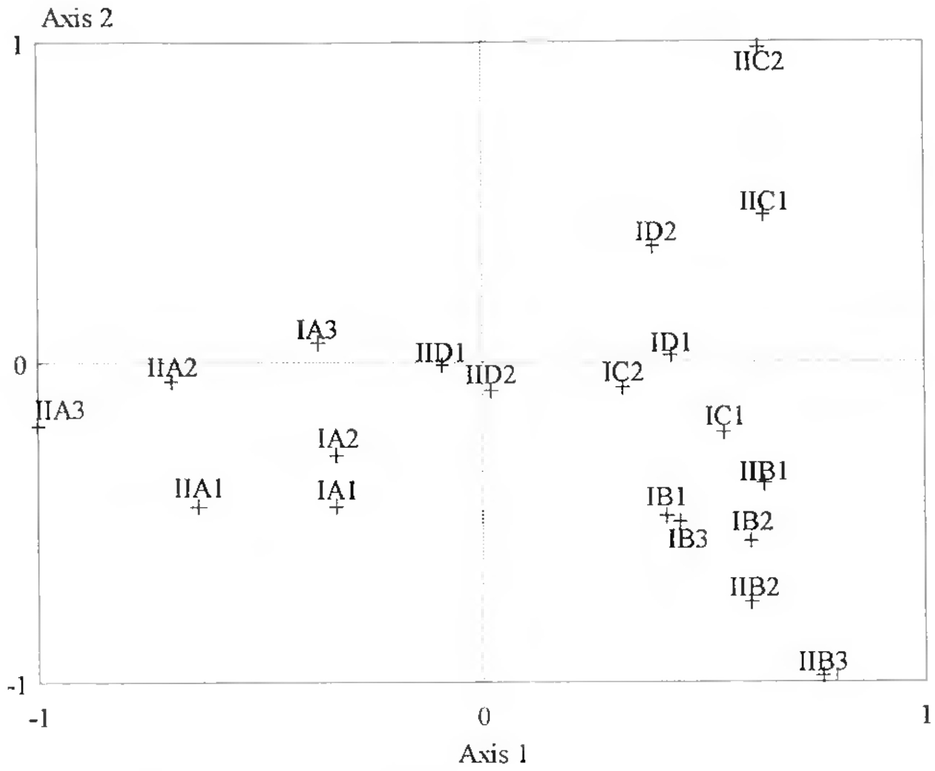


Fig. 3.27. Position of the stations on the first two axes of Principal Components Analysis (physical-chemical water data). The first character indicates the year of survey (I-1985, II-1986) and subsequent ones the site and station. Eigenvalues: I- 27 %; II- 19 %; III- 16 %; IV- 11 %.

On the basis of these patterns, axis one could represent a gradient of increasing stagnancy or less water renewal ("confinement"), whilst axis two represents a secondary gradient, of BOD, chlorophyll *a* and phaeopigments concentrations, as well as dissolved oxygen variations. This second axis separates stations at site B from some of the stations at sites C and D and can be classified as a gradient of increasing eutrophication subjected to phytoplankton blooms, when extreme values of dissolved oxygen can occur, followed by "crashes", with high ammonia and low oxygen concentrations (Krom *et al*, 1989) and high BOD values. This is certainly the case for site C where a dystrophic crisis occurred during the second year of survey.

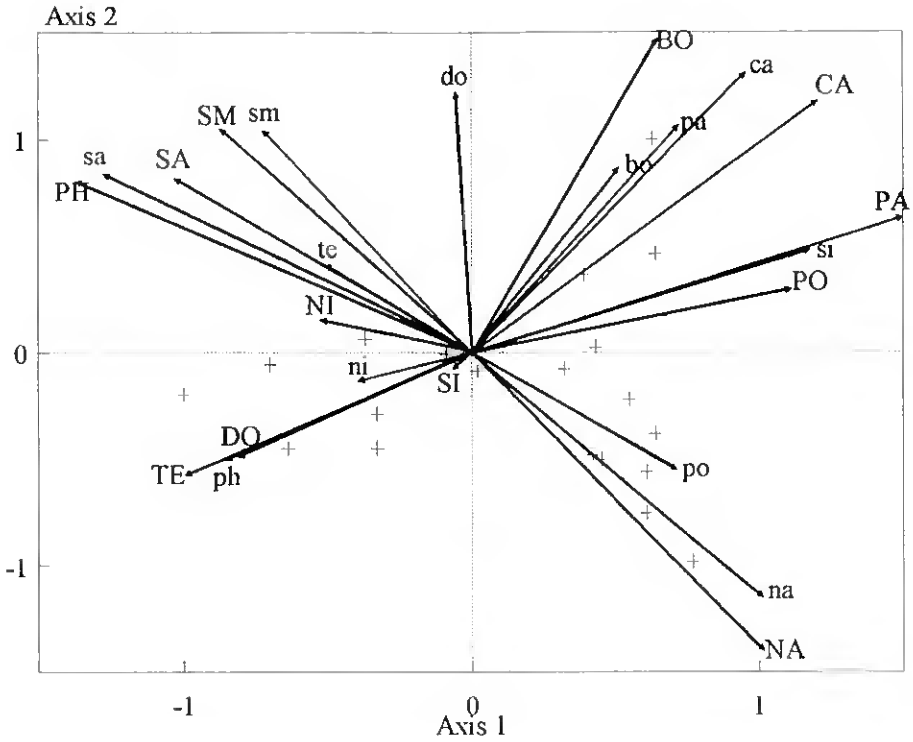


Fig. 3.28. Projection of the factors on the first two axes of Principal Components Analysis (physical-chemical water data). Codes: BO- Biochemical Oxygen Demand; CA- Chlorophyll *a*; DO- Dissolved Oxygen; NA- Nitrates; NI- Nitrites; PA- Phaeopigments; PH- pH; PO- Phosphates; SA- Salinity; SI- Silicates; SM- Suspended matter; TE- Temperature. Capital letters refer to mean annual values and small letters to maximum-minimum values of a variable.

Some variables were placed very close to each other in the ordination diagram. The cosine of the angle formed by any pair of vectors drawn from the origin of the axes to the positions of the variables is equal to the correlation coefficient between those variables, due to the previous standardisation of the data (Lebart *et al*, 1982). The smaller the angle the higher the correlation coefficient. High correlations occur between the mean and maximum-minimum values of chlorophyll *a*, BOD, nitrate, nitrite, suspended matter and salinity and thus only the mean values of these variables were used in further analysis, apart from salinity. The amplitude of salinity variation was more important for differentiating between stations than were their mean values, as was indicated by the length of the arrows. The maximum-minimum salinity values were therefore included in further analysis.

The results of CCA, incorporating the eighteen environmental variables selected in the PCA are shown in Fig. 3.29. The ordinations of the stations and of the taxa are similar to the ordinations obtained by the CA, and the projections of the environmental vectors are not very different from those derived in the PCA. However, in the CA, the maximum-minimum values of salinity and pH and the mean suspended matter and pH are more correlated with axis I, than in the PCA.

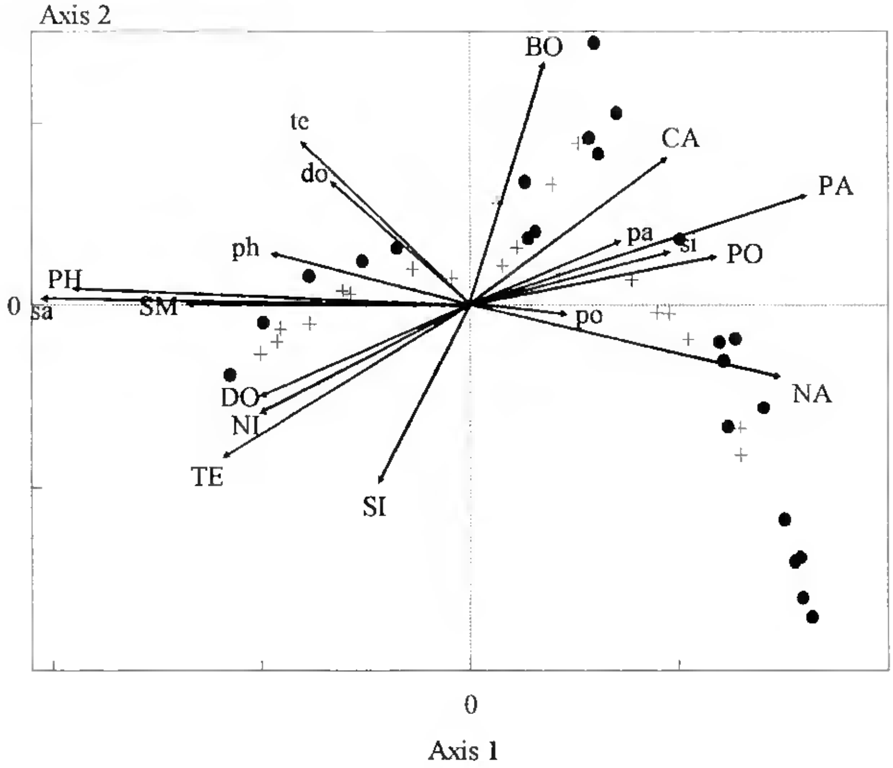


Fig. 3.29. Ordination diagram based on Canonical Correspondence Analysis of the taxa reduced data matrix with respect to eighteen environmental variables. • - Taxa co-ordinates; + - Stations co-ordinates. Codes: as in Fig. 3.29. Eigenvalues: I- .72; II- .35; III- .19; IV- .17. Percentage variance accounted for by axes: I- 39.6 and I+II- 58.5 %.

The interpretation of the CCA ordination diagram is done in the same way as a biplot. The length of an arrow is a measure of the importance of an environmental variable; the more important variables have the longer arrows (Ter Braak, 1986). Inspection of Fig. 3.29 indicates that the most important variables are mean nitrate and phaeopigment concentrations, mean BOD and temperature, and also the maximum-minimum salinity and pH values.

If the number of environmental variables approaches the number of sites, then the environmental variables are strongly correlated with each other. Under these conditions, the effects of different environmental variables on community composition cannot be separated, the canonical coefficients become unstable and the Variable Inflation Factor (VIF) is large (Ter Braak, 1986). In the present analysis the VIF of the environmental variables were all greater than 20, and some of the variables had to be eliminated and the CCA repeated.

Variables were eliminated on the basis of inspection of PCA ordination diagram (Fig. 3.28). Seven main groups of intercorrelated variables were identified, and from within each group only one variable, denoting the name of the group, was selected for further analysis. The groups were:

- Salinity group, comprising the mean and maximum-minimum values of salinity and suspended matter, the mean values of pH and nitrite, and the maximum-minimum value of temperature.
- BOD group, comprising the mean BOD values and the maximum-minimum values of BOD and phaeopigments.
- Chlorophyll a group, comprising the mean and maximum-minimum values of this variable.

- Phaeopigments group, comprising the mean concentrations of phaeopigments and phosphates, and the maximum-minimum values of silicates.
- Nitrates group, comprising the mean nitrate concentration and the maximum-minimum values of nitrates and phosphates.
- Temperature group, comprising the mean values of temperature, dissolved oxygen, silicates, and the maximum-minimum values of pH and nitrites.
- Dissolved oxygen - the maximum-minimum values.

The CCA results of the analysis based on only these seven environmental variables (Fig. 3.30) gave VIF values below the recommended value of magnitude 20. The eigenvalues decreased a little, but the taxa-environment correlations were similar to the previous CCA, so the canonical coefficients can be properly interpreted (Ter Braak, 1986).

The ordinations of the stations and of the taxa obtained were not very different from those in the CA ordinations (compare Figs. 3.5 with 3.31 and 3.24 with 3.32). According to Ter Braak (1986), when this occurs the measured environmental variables account for the main variation in the taxa data.

The maximum-minimum salinity, and the related environmental variables, are strongly correlated with axis one, and it seems that this grouping is the main factor influencing group I species (*Capitella capitata*, *Hydrobia ulvae*, *H. ventrosa*, *Cardium glaucum* and *Chironomus salinarus*). This group of species can tolerate high salinity as well as large variations in salinity, suspended matter and pH. Other environmental factors, such as high temperatures and large dissolved oxygen variations, also influence this group of species, although to a smaller extent. Other environmental variables are also important for these species, but their influence is negative: lower concentrations of phosphates and nitrates, and consequently lower primary production indicated by the concentrations of chlorophyll a and phaeopigments are negatively associated with group I species. Of course, the lower primary production might be also a consequence of the high salinities. Clearly, group I species can tolerate harsh environmental conditions caused by limited water exchange.

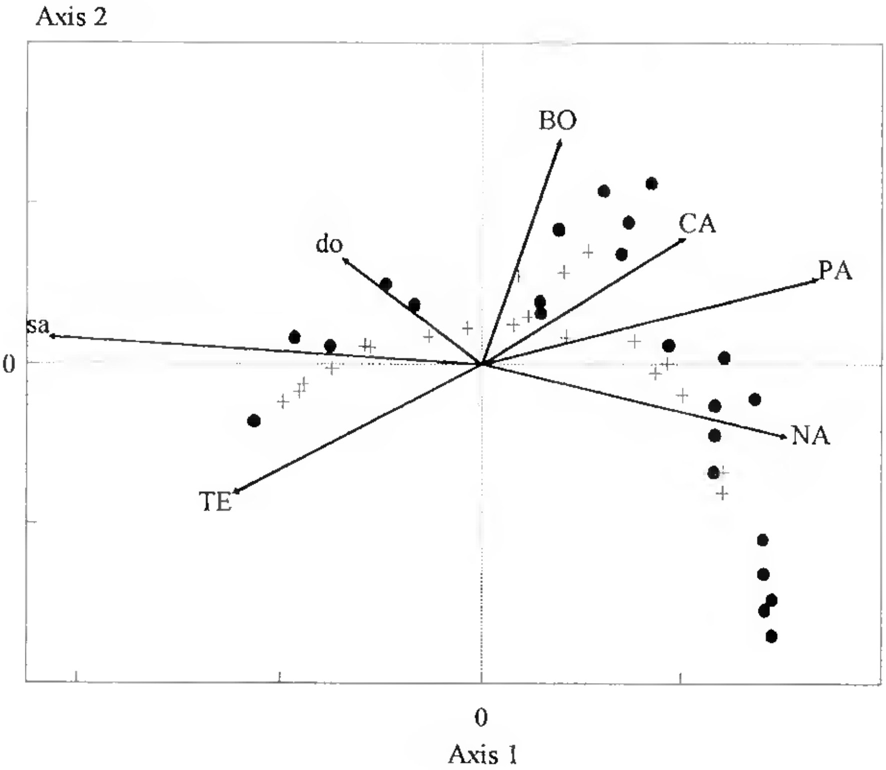


Fig. 3.30. Ordination diagram based on Canonical Correspondence Analysis of the taxa reduced data matrix with respect to seven environmental variables. • - Taxa co-ordinates; + - Stations co-ordinates. Codes: as in Fig. 3.28. Eigenvalues: I- .70; II- .24; III- .15; IV-.10. Percentage variance accounted for by axes: I- 55.2; axes I+II- 74.0 %.

Group II taxa (*Cerithium vulgatum*, *Idotea chelipes*, *Amphitoe* spp., *Gammarus* spp., *Microdeutopus gryllotalpa* and tubificid oligochaetes), apparently do not tolerate such high salinities and temperatures. However, this group can tolerate large dissolved oxygen variation and degraded habitats as indicated by the high BOD values associated with the group.

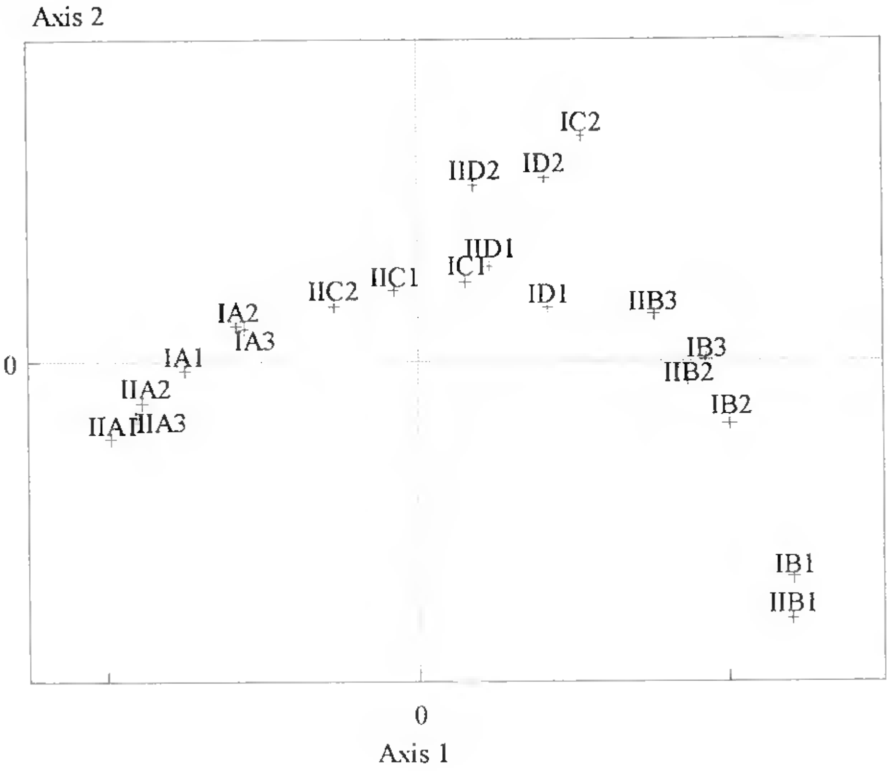


Fig. 3.31. Ordination diagram based on Canonical Correspondence Analysis of the taxa reduced data matrix with respect to seven environmental variables. + - Stations co-ordinates. Codes: as in Fig. 3.27. Eigenvalues: I- .70; II- .24; III- .15; IV-.10. Percentage variance accounted for by axes: I- 55.2; axes I+II- 74.0 %.

Groups III and IV, apparently do not tolerate high variation in salinity, temperature and dissolved oxygen. These groups are composed of the polychaetes *Heteromastus filiformis*, *Nereis caudata*, *Notomastus latericeus*, *Streblospio dekhuyzeni*, *Euclymene palermitana*, the molluscs *Bittium reticulatum*, *Loripes lacteus*, *Mesalia brevialis*, the crustaceans *Apseudes latreillei* and *Iphinoe tenella*, and the phoronids. Together with *Abra ovata* and *Microdeutopus gryllotalpa*, they are characteristic of estuarine or shallow-water habitats and are frequent in the Ria Formosa lagoon system (Reis *et al*, 1986, Sprung, 1993, 1994).

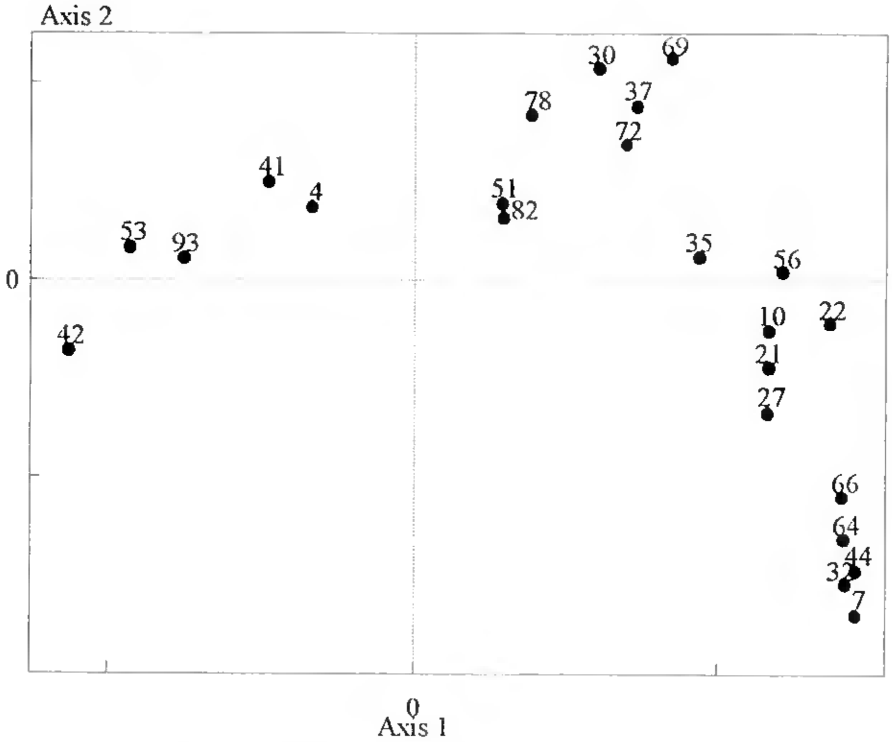


Fig. 3.32. Ordination diagram based on Canonical Correspondence Analysis of the taxa reduced data matrix with respect to seven environmental variables. • - taxa co-ordinates. Codes: as in Fig. 3.24. Eigenvalues: I- .70; II- .24; III- .15; IV-.10. Percentage variance accounted for by axes: I- 55.2; axes I+II- 74.0 %.

## 3.3 Conclusions

The lagoons studied support dense populations of invertrebates, with higher densities than in some Portuguese estuaries. The total macrofauna density did not differ significantly between the several sites, but there was a clear shift in taxa composition from the least stressed site, B, with a highly diverse population, towards the most stressed site, A, where only few taxa occurred. In the least stressed lagoon, the bottom was covered by *Zostera noltii* and in the more stressed lagoon by *Ruppia* cf. *cirrhosa*. Mean annual densities, between 5000 and 14000 ind. $m^{-2}$, were higher than in a Ria Formosa *Zostera* bed, where the densities of macrofauna varied between 2000 and 12000 ind. $m^{-2}$ (Sprung, 1994).

Sediment granulometry did not differ dramatically between stations. The sediment was usually sandy or muddy sand near the gates at all sites, and sandy mud in the inner stations, due to the reduced water circulation. However, water quality was a significant factor for discriminating between stations, and this is reflected in the benthic populations present.

A strong environmental gradient underlies the study sites, the ends of which are defined by sites A and B, with sites C and D in an intermediate position. Site B had similar characteristics to the shallow-water or coastal marine systems, whereas site A had characteristics of an environment under great stressful, due to very restricted water renewal. Sites C and D showed intermediate stress characteristics, but were subjected to dystrophic crisis accompained by a degradation in the water quality. A second gradient of increasing eutrophication could then be distinguished between site B and sites C and D.

Along both these gradients there was a decrease in taxa diversity, accompanied by a decrease in evenness. At extreme conditions only opportunistic taxa such as *Capitella capitata*, Chironomid larvae and *Hydrobia ventrosa* occurred. There was a shift from well structured benthic populations towards situations dominated by those few taxa capable of surviving harsh environmental conditions. These observations are contrary to those of Amanieu & Lasserre (1982), who argue that the lagoon environment places the benthic populations under stress, forcing them gradually organise themselves into structured, well-balanced communities which conform to the logarithmic series model and with a high taxa evenness.

The environmental change of increasing salinity, that occurred during the second year, was accompanied by a degradation of water quality, which was reflected in the composition of the benthic community. There was a decrease in taxa diversity, and in some extreme situations, a change in taxa dominance, towards opportunists. For example, *Hydrobia ventrosa* became the dominant species at site C, after a dystrophic crisis. High densities of this species could be a warning signal for aquaculturists, although it might be detected too late to save the fish.

The benthic populations were characteristic of estuarine or shallow water coastal communities. Some species such as *Abra ovata* and *Microdeutopus gryllotalpa*, are ubiquitous, throughout all the gradients studied. Other taxa, such as the polychaetes *Euclymene palermitana* and *Notomastus latericeus*, the Phoronids, the molluscs, *Mesalia brevialis*, *Loripes lacteus*, and the crustaceans, *Apseudes latreillei* and *Iphinoe tenella*, apparently do not tolerate large environmental variations. Taxa such as the polychaetes, *Heteromastus filiformis*, *Nereis caudata*, and *Streblospio dekhuyzeni*, the oligochaetes, the molluscs, *Bittium reticulatum* and *Cerithium vulgatum*, and the crustaceans, *Idotea chelipes*, *Amphitoe* spp and *Gammarus* spp, can cope with large environmental variation and temporary water quality degradation. However, these taxa apparently do not tolerate extremely high salinity variation.

# Chapter IV

# MACROFAUNA PRODUCTION

## Relationships with the environmental data

# IV - MACROFAUNA PRODUCTION

## Relationships with the environmental data

### Summary

In an unfertilised pond, with no addition of food, the natural benthos is the resource which determines the carrying capacity of the pond (Cuenco *et al*, 1985 c). The gilthead is a benthic feeder, feeding essentially on gastropods and bivalves, and also on crustaceans. The production of the macrofauna in lagoons is then likely to be an important limiting factor for gilthead production.

The secondary production was therefore determined for each of the four study lagoons by applying P:B ratios taken from the literature, essentially for the nearby shallow-water *Zostera noltii* banks of the Ria Formosa (Sprung, 1994). The most stressed lagoons support large populations of small, but highly productive organisms. However, the production of small organisms was even higher in the least stressed lagoons which, together with their better water quality, makes these the lagoons more suitable to support high densities of fish.

The environmental factors thought to be the most important in limiting production in these lagoons were the differences between the maximum and minimum salinity and the mean annual biochemical oxygen demand.

## 4.1 Methods

### 4.1.1 Biomass determination

Two replicate cores were taken for biomass determinations, at each of the sampling stations (see Chapter 3 for methodology). The data from the stations within each site were pooled, providing an estimate of the total site biomass for a range of taxonomic or functional groups, each sampling month.

Because of the large number of samples which had to be processed ash free dry weight (AFDW) was only determined for a portion of the samples. Some conversion factors, based on these determinations and on literature were used to convert dry weight into AFDW for the remainder samples. This was thought sufficiently precise for the aims of the present study.

Dry weights were determined by drying the samples at 60 °C untill they reached constant weight, usually after a minimum of 48 hours. The larger molluscs were dried for another 24 hours. After cooling in desiccators, samples were weighed on a precision balance, to the nearest 0.1 mg.

For many taxa it was not practical to estimate biomass separately from other taxa. In most cases the taxa were grouped into similar kinds of organisms or higher taxonomic groups and an overall weight determined.

For the biomass determination of some gastropods (*Cerithium vulgatum* and *Mesalia brevialis*) with a large length range, individuals were separated into 1 mm length classes, ranging from 3.5 to 33.5 mm. Mean individual dry weight was determined for each class interval and the log-log regression of mean weight against length class calculated to allow later determination of the biomass of those species from size frequency structure, as was done by Pihl & Rosenberg (1982). This procedure was necessary because most of the gastropods shells had to be broken or perforated to verify the presence of the organism inside. For the numerous Hydrobiidae and Rissoidae gastropods individual size did not vary markedly and the entire sample was weighed, and the mean individual weight also determined.

Bivalve molluscs smaller than 10 mm in length were weighed as a group. The specimens larger than 10 mm were weighed separately. Polyplacophora were also weighed separately from other groups.

All polychaetes were weighed as a single group, unless taxa were very abundant, in which case they were weighed separately and their mean individual weight determined. If any specimen was clearly much larger than the others, around 10 times the mean size, then its individual weight was determined. That was the case for polychaetes in the families Eunicidae, Glyceridae, Lumbrinereidae, Nephtyidae and Nereidae. Oligochaetes were weighed with the polychaetes.

Smaller crustaceans, such as isopods, amphipods, mysids and cumaceans, were weighed jointly, but larger decapod crustaceans, like *Upogebia*, *Carcinus*, *Palaemonetes* and *Diogenes*, were weighed individually.

Chironomid larvae were weighed separately from the other taxonomic groups, as were Phoronid and Echinodermata individuals.

For each of the four sites global biomass was determined as follows: data from each of the stations was pooled to provide biomass at each sampling month. This was then divided by the total sampling area. For sites A and B the total area was 0.068 $m^2$ (2 replicates x 3 stations x 0.0113 $m^2$). For sites C and D the total area was 0.045 $m^2$ (2 replicates x 2 stations x 0.0113 $m^2$).

Polychaetes, oligochaetes and any nemerteans present were pooled as a large taxonomic group, the Annelids. Although this is not strickly taxonomic correct, nemerteans were so rare that the samples were almost annelids, *sensu stricto*. Polyplacophora, bivalves and gastropods were pooled together as molluscs, crustaceans formed another group and the chironomids, phoronids and echinoderms were pooled as another group. Specimens of large size (>10 mm) were grouped separately as large crustaceans, large molluscs, etc.

Although the taxonomic approach was used, for ease sample processing and data presentation, biomass was separated into functional groups: the small surface organisms and the large deep-burrowing bivalves or the mobile decapod crustaceans and the large gastropods, perhaps too large to be eaten by small fish. This functional approach allows the comparison of biomass and production between locations containing different species of similar taxa. Such functional-group approach has proven very useful in the analysis of predator-prey interactions in other systems (Steneck & Watling, 1982; Raffaelli, 1985), where it has been argued that functional groups, as opposed to classic taxonomic groups, may better represent the prey categories perceived by fish.

The AFDW of the most abundant taxa was determined after the samples had been in the oven at 60 °C and in the muffle furnace at 450 °C for 4 h. At least five replicate samples were use for each taxon. The ratio between AFDW and DW gives the conversion factor for each taxon. The results were verified using other data (Sprung, unpublished) for the same taxa in the Ria Formosa. For the less abundant taxa conversion factors were determined using the raw data of Sprung (unpublished). The mean of these factors provided a general conversion factor used for each taxonomic group.

### 4.1.2 Production determination

The most preferable way to estimate production is to use cohort analysis, as proposed by Crisp (1984). However, this method is extremely laborious and time consuming, and production is often estimated from mean annual biomass values. Banse & Mosher (1980) described an empirical relationship between the P:B ratio of the population and the size of the species at maturity and Schwinghamer *et al* (1986) gives an equation relating the P:B ratio to the mean body weight of a species. However, the application of these equations, especially in non-boreal habitats, is not straightforward, as demonstrated by studies on the Ria Formosa (Sprung, 1993). Rainer (1985) recommends the utilisation of P:B ratios for fisheries' purposes and Asmus (1987) considers these ratios a useful way to characterise the potential production of a population. Asmus also points out that a fixed P:B ratio should not be used when there is considerable variation in individual size.

Bearing these points in mind, macrofauna production was estimated by applying P:B ratios from Ria Formosa production data (Sprung, 1994) to each of the groups described above.

### 4.1.3 Data analysis

The relationships between the annual biomasses at each station and the environmental data were explored using CCA, as described for the taxa abundance data in Chapter 3. The biomass data was thus organised into twelve classes: annelids, gastropods, bivalves and crustaceans with less than 1 mm; the same taxonomic groups with greater than 1 mm; the phoronids, echinoderms, chironomids and polyplacophora were kept in separate groups. The data were root transformed prior to analysis to scale down differences between groups in biomass (Clark & Green, 1988).

For physical-chemical data, the seven most important variables were used - the maximum-minimum values of salinity and dissolved oxygen, the mean annual temperature, BOD, chlorophyll a, phaeopigments and nitrate concentration.

## 4.2 Results and discussion

### 4.2.1 Mean Individual weights and conversion factors

The length (cm) / weight (g) relationship of *Cerithium vulgatum* ($w_c$) and of *Mesalia brevialis* ($w_m$) were, respectively:

$w_c = 0.059543\, l^{2.83441}$ ; $w_m = 0.053107\, l^{2.54021}$ $(p<0.05)$

The regression lines of log(length) versus log(weight) were used to determine the weight of all gastropods of these species. The mean dry weight of the most abundant taxa found at the four sites are shown in Table 4.1.

Table 4.2 shows the conversion factors used to estimate AFDW from DW and to convert mean AFDW annual biomass into production estimates. The conversion factors determined were not dissimilar to those in Ruhmor *et al* (1987) except for molluscs. Different conversion factors were used for the two molluscs size groups, the factor being greater for the smaller individuals and less for the larger ones. For bivalves smaller than 10 mm, a factor of 0.15 was adopted. For the larger bivalves a factor of 0.1 was used. In the small sized group of gastropods was found a conversion factor of 0.1 and in the large sized group of gastropods was found a factor close to 0.08.

| Taxa | Length (mm) | Weight (g) |
|---|---|---|
| Nemertina | | 0.0005 |
| Oligochaeta (Tubificidae) | | 0.0003 |
| Polychaeta: | | |
| *C. capitata* | | 0.0004 |
| *H. filiformis* | | 0.0035 |
| *H. norvegica* | | 0.0030 |
| *N. caudata* | | 0.0050 |
| *N. latericeus* | | 0.0055 |
| *S. typica* | | 0.0003 |
| *M. sanguinea* | | 0.1108 |
| Crustacea: | | |
| *Amphitoe ramondi* | | 0.0008 |
| *Apseudes latrellei* | | 0.0004 |
| *Carcinus maenas* | | 0.0060 |
| *Gammarus sp.* | | 0.0009 |
| *Idotea chelipes* | | 0.0011 |
| *Siphonoecetes sp.* | | 0.0001 |
| *S. hookeri* | | 0.0073 |
| *Microdeutopos sp.* | | 0.0001 |
| *M. gryllotalpa* | | 0.0002 |
| *P. varians* | | 0.0264 |
| Chironomidae | | 0.0005 |
| Sipuncula | | 0.0003 |
| Phoronidae | | 0.0030 |
| Echinodermata: | | |
| *Amphiura sp.* | | 0.0012 |
| Mollusca: | | |
| L. cinereus | <5 | 0.0011 |
| L. cinereus | <10 | 0.0044 |
| L. cinereus | >10 | 0.0103 |
| Bivalvia: | | |
| *Abra ovata* | <5 | 0.0221 |
| *Abra ovata* | <10 | 0.0468 |
| *Abra ovata* | >10 | 0.0838 |
| *C.edule* | 14 | 0.4127 |
| *C.edule* | 15 | 0.4127 |
| *C.edule* | 16 | 0.6330 |
| *C.edule* | 22 | 1.0761 |
| *C.edule* | 23 | 1.3888 |
| *C.edule* | 24 | 2.2876 |
| *C.edule* | 28 | 2.5871 |
| *C. edule* | 33 | 4.7318 |
| *C. edule* | 35 | 4.1158 |
| *C. glaucum* | 15 | 0.2611 |
| *C. glaucum* | 17 | 0.3906 |
| *C. glaucum* | 18 | 0.7558 |
| *C. glaucum* | 19 | 0.9167 |
| *Loripes lacteus* | <5 | 0.0040 |
| *Loripes lacteus* | <10 | 0.0274 |
| *Loripes lacteus* | >10 | 0.1384 |
| *Loripes lacteus* | 14 | 0.3972 |
| *Loripes lacteus* | 16 | 0.4934 |
| *R. decussatus* | 30 | 3.1859 |
| *R. decussatus* | 33 | 6.4442 |
| *V. aurea* | 14 | 0.1700 |
| *V. aurea* | 15 | 0.2377 |
| *V. aurea* | 20 | 0.5400 |
| Gastropoda: | | |
| *B. reticulatum* | <5 | 0.0042 |
| *B. reticulatum* | <10 | 0.0155 |
| *B. reticulatum* | >10 | 0.0232 |
| *C. mediterraneus* | 17 | 0.5645 |
| *Cyclope neritae* | 7 | 0.1085 |
| *Cyclope neritae* | 8 | 0.1334 |
| *Cyclope neritae* | 9 | 0.1662 |
| *Cyclope neritae* | 11 | 0.3515 |
| *Jujubinus sp.* | | 0.0563 |
| *Haminea hydatis* | | 0.0112 |
| *Amyclina corniculum* | 5 | 0.0095 |
| *Amyclina corniculum* | 6 | 0.0223 |
| *Amyclina corniculum* | 7 | 0.0336 |
| *Amyclina corniculum* | 8 | 0.0700 |
| *Amyclina corniculum* | 9 | 0.0792 |
| *Amyclina corniculum* | 11 | 0.1616 |
| *Amyclina corniculum* | 12 | 0.2267 |
| *Amyclina corniculum* | 13 | 0.2313 |
| *Amyclina corniculum* | 14 | 0.3049 |
| *Amyclina corniculum* | 8 | 0.0691 |
| *Amyclina corniculum* | 9 | 0.0883 |
| *Amyclina corniculum* | 10 | 0.1206 |
| *Hydrobia ulvae* | | 0.0093 |
| *H. ventrosa* | | 0.0018 |
| *Rissoa menbranacea* | | 0.0104 |
| *S. pfeifferi* | 10 | 0.1308 |
| *T. trunculus* | 22 | 0.8183 |
| *T. trunculus* | 35 | 2.6695 |

Table 4.1. Mean individual dry weights of the most abundant taxa. Less abundant taxa were not weighed separately but as a group (see text).

| Dimension | Taxonomic groups | DW-AFDW | P:B ratio |
|---|---|---|---|
| < 10 mm | Annelida | 0.7 | 3.5 |
| < 10 mm | Mollusca | 0.12 | 2.5 |
| < 10 mm | Bivalvia | 0.15 | 3.6 |
| < 10 mm | Gastropoda | 0.1 | 1.8 |
| < 10 mm | Crustacea | 0.7 | 3.0 |
| < 10 mm | Chironomidae | 0.7 | 2.4 |
| < 10 mm | Echinodermata | 0.3 | 2.5 |
| < 10 mm | Phoronidae | 0.3 | 2.4 |
| > 10 mm | Annelida | 0.7 | 0.5 |
| > 10 mm | Bivalvia | 0.1 | 0.5 |
| > 10 mm | Gastropoda | 0.08 | 0.5 |
| > 10 mm | Crustacea | 0.3 | 0.5 |

Table 4.2. Factors used to convert Dry Weight (DW) into Ash Free Dry Weight (AFDW) and P:B ratios for various groups.

P:B ratios used for taxonomic groups smaller than 10 mm (Tab. 4.2) were based on the data obtained by Sprung (1994) for *Zostera* beds of the Ria Formosa. For larger taxa lower P:B ratios were used. Larger organisms have, in general, lower P:B ratios than smaller organisms (Baird *et al*, 1985). Loo & Rosenberg (1989), for instance, indicated a P:B ratio between 0.5 and 3.3 for *Cardium edule* of 5-10 mm and a ratio of 0.05 to 0.3 for *C. edule* of 15-20 mm, although these values were obtained for cold Swedish waters. Asmus (1987) quotes a P:B ratio of 3.4 for *Mytilus edulis* juveniles, a ratio of between 1 and 2 for small individuals of the same species, and a ratio of 0.2 for large individuals, of 4 or 5 years of age. There is little information about the variation with size of the production of polychaetes, but Beukema (1981) gives a P:B ratio of 0.69 for adults of *Arenicola marina* and a P:B of 2 for juveniles. A P:B ratio of 0.5 was used for all of the taxonomic groups larger than 10 mm. This value may be too large for some taxa, or too low for others.

### 4.2.2 Variation in mean annual biomass

The total annual biomass was much lower at site A than at the other sites (Fig. 4.1). Total biomass decreased, during the second year at all sites. If taxa smaller than 10 mm are considered the difference between the sites is not so marked, but is higher at site B (Fig. 4.2). For these smaller organisms there was an increase in biomass during the second year of study, except at site A, where biomass decreased.

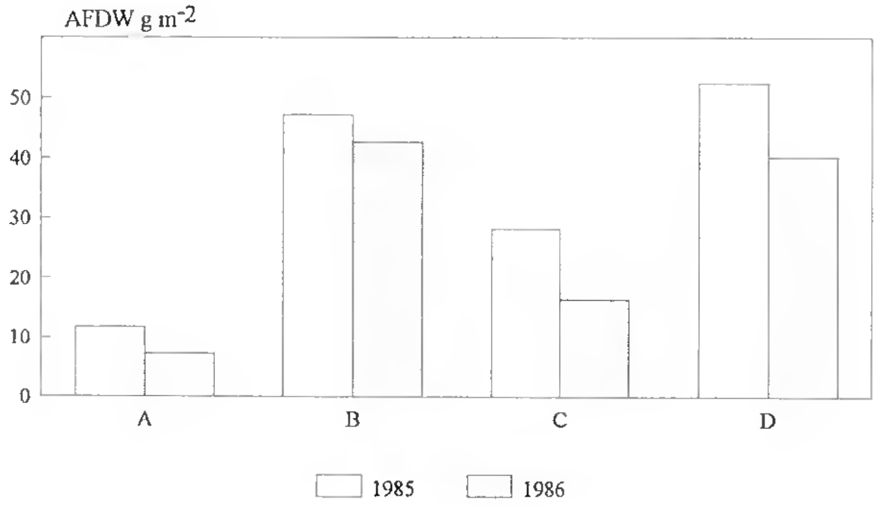


Fig. 4.1. Total mean annual biomass at the four sites in the two years of study.

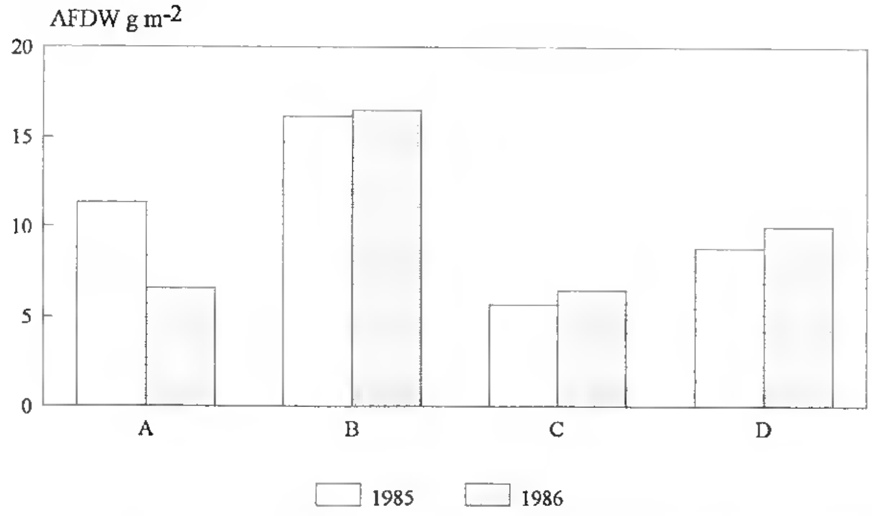


Fig. 4.2. Mean annual biomass of the benthic fauna smaller than 10mm at the four sites in the two years of study.

Molluscs contributed most to the total biomass, followed by the annelids (Fig. 4.3). At site A the main contribution to total biomass came from the molluscs smaller than 10 mm (Fig. 4.4). There was a decrease in biomass in January and also in July and September, which was more pronounced during the second year. At site B the large molluscs and crustaceans dominated in terms of biomass (Fig. 4.5). There was a decrease in total biomass in January of both years of study and also in July and September of the first year.

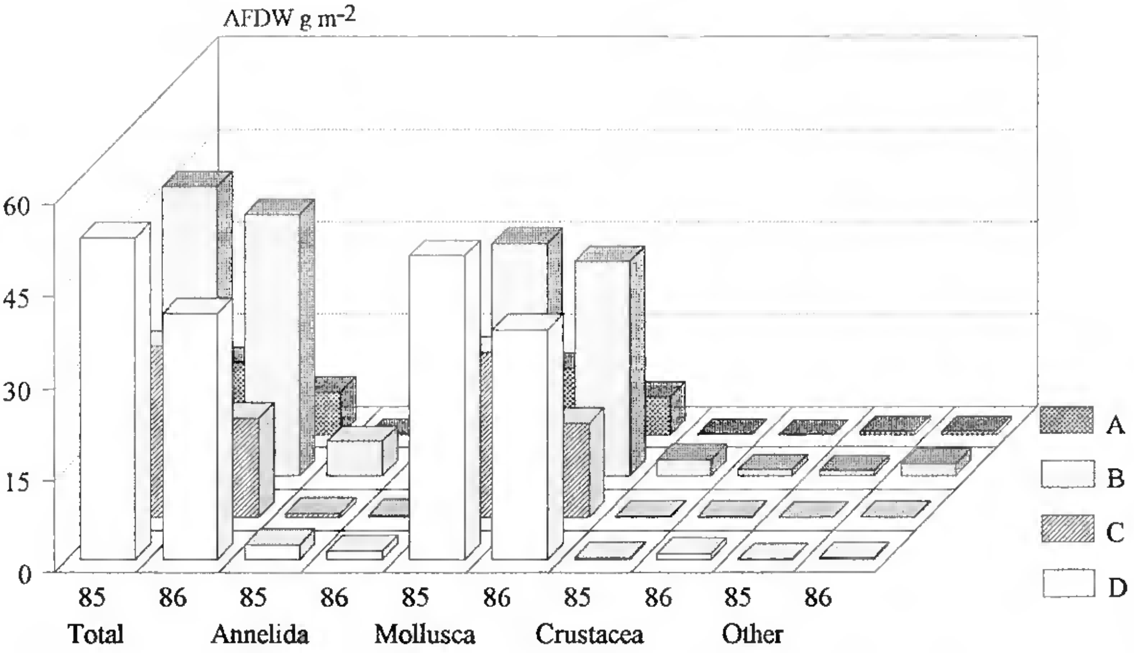


Fig. 4.3. Mean annual biomasses at the four sites. Each pair of values refer to the sampling year.

At sites C and D (Figs. 4.6 and 4.7), annelids were less important in terms of biomass than at site B. During the second year of study, at both sites C and D, there was an increase of annelids and molluscs smaller than 10 mm, in July and September. The biomass of larger molluscs varied in an irregular way with season but at site C there was a significant decrease during the second year.

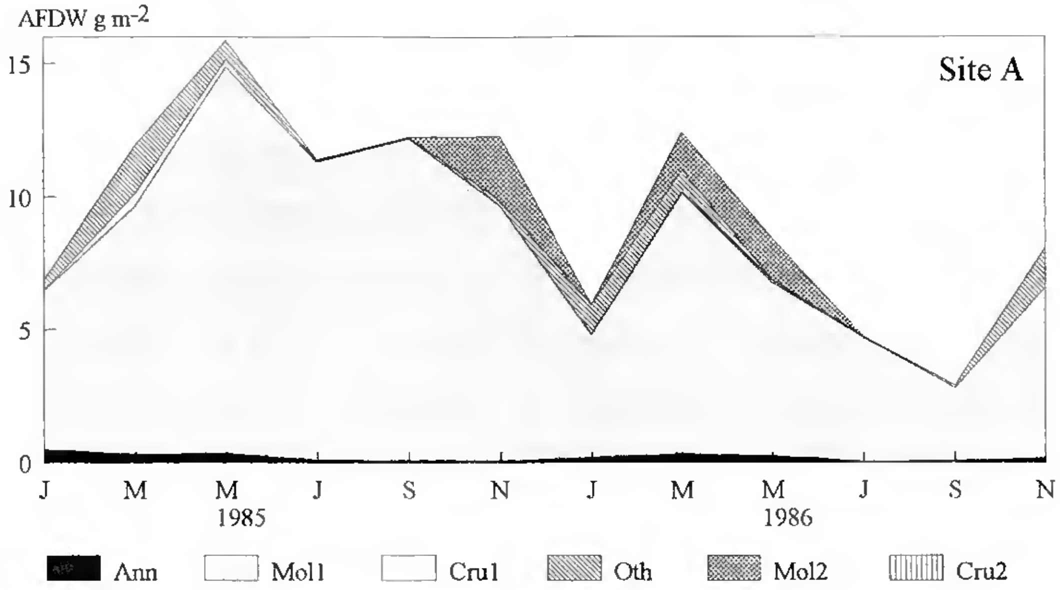


Fig. 4.4. Annual variation of biomass at site A during the two years. Ann: Annelida; Mol1: Molluscs<10mm. Cru1: Crustacea<10mm. Oth: Other groups (Chironomids, Phoronids and echinoderms). Mol2: Molluscs>10mm. Cru2: Crustaceans>10mm.

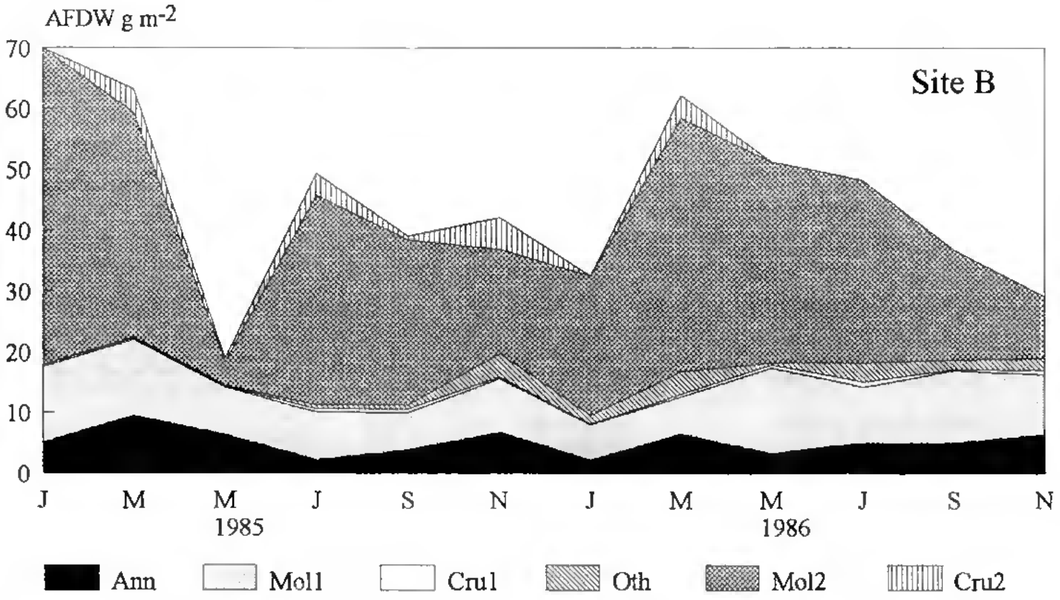


Fig. 4.5. Annual variation of biomass at site B during the two years. Ann: Annelida; Mol1: Molluscs<10mm. Cru1: Crustacea<10mm. Oth: Other groups (Chironomids, Phoronids and echinoderms). Mol2: Molluscs>10mm. Cru2: Crustaceans>10mm.

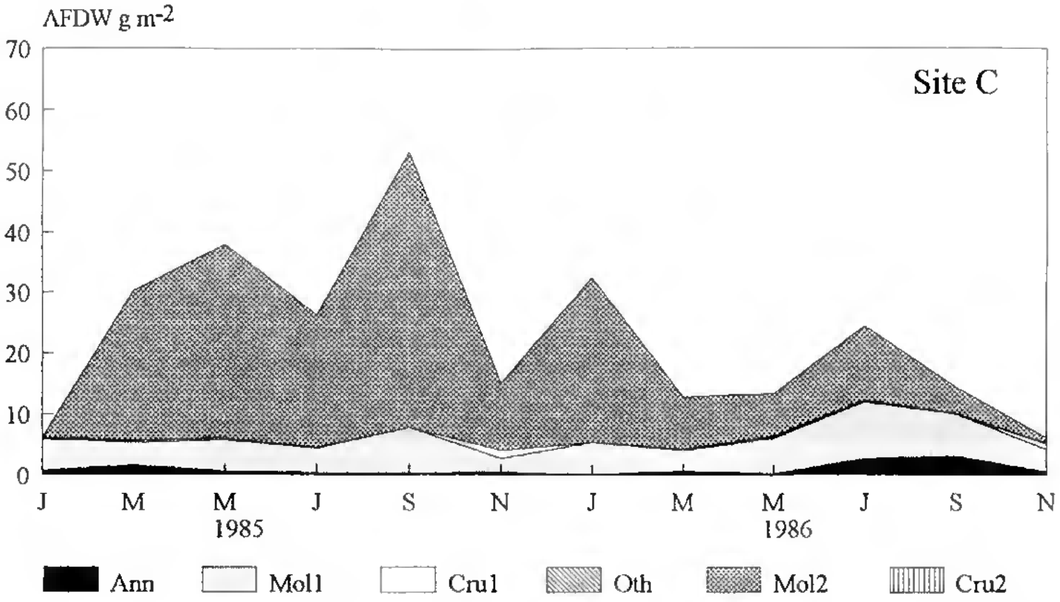


Fig. 4.6. Annual variation of biomass at site C during the two years. Ann: Annelida; Mol1: Molluscs<10mm. Cru1: Crustacea<10mm. Oth: Other groups (Chironomids, Phoronids and echinoderms). Mol2: Molluscs>10mm. Cru2: Crustaceans>10mm.

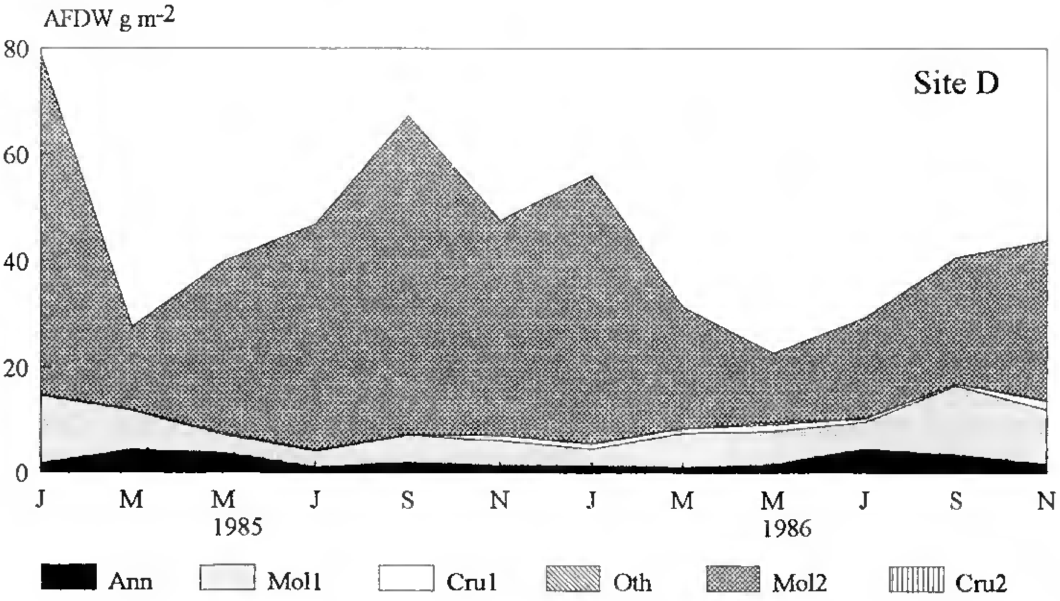


Fig. 4.7. Annual variation of biomass at site D during the two years. Ann: Annelida; Mol1: Molluscs<10mm. Cru1: Crustacea<10mm. Oth: Other groups (Chironomids, Phoronids and echinoderms). Mol2: Molluscs>10mm. Cru2: Crustaceans>10mm.

Total biomass varied between 7 and 51 g AFDW $m^{-2}$. Beukema (1976, 1981) found a mean annual biomass of 27 g AFDW $m^{-2}$, in the Wadden Sea intertidal zone with highest biomass values in excess of 100 g AFDW $m^{-2}$ on *M. edulis* or *C. edule* banks and values lower than 10 g AFDW $m^{-2}$ limited to places with strong currents or with a percentage of silt content above 30 %. In a German seagrass bed Asmus (1987) found a mean biomass of 30 g AFDW $m^{-2}$.

Englemoer *et al* (1984) recorded a mean biomass of 3.2 g AFDW $m^{-2}$ in Banc d'Arguin, Mauritania, whilst Wolff *et al* (1993) refer to a mean biomass of 17.0 g AFDW $m^{-2}$ in the tidal flats of the same area. In terms of food supply to predators these rather low biomasses values could be compensated for by rapid and continuous turnover (Baird*et al*, 1985).

Hussenot & Reymond (1990) refer to macrofauna biomasses in French shrimp culture ponds variyng between 11 and 21 g AFDW $m^{-2}$. The differences they found between extensive and semi-intensive aquaculture regimes were not very large, the biomasses being smaller in the semi-intensive regime. These biomass values were similar to the biomasses found at sites A and at site C during the second year of survey.

At sites B and D biomass was much higher than at site A, near 45 g and 50 g AFDW $m^{-2}$ respectively. Sprung (1994) recorded lower biomasses, of about 17 g AFDW $m^{-2}$ in *Zostera* beds from the Ria Formosa. However, the density of macrofauna was lower than the densities found in the two sites, between 2000 and 7000 individuals $m^{-2}$. In a previous study of the Ria Formosa, Rufino *et al* (1984) reported higher macrofauna biomasses, between 42 g and 95 g AFDW $m^{-2}$ in muds and muddy sands, respectively, although they conceded that these values might be overestimated, as they selected high density sites.

### 4.2.3 Annual production

The total production was significantly higher at site B than at the other sites (Fig. 4.8 and Table 4.3). There was, at all sites, a decrease in production during the second year, which was more pronounced at site A. However, if only the production of small sized organisms is considered, the results were different (Fig. 4.9 and Table 4.3). During the second year there was an increase of the production by small organisms except at site A, where a decrease in production was noted.

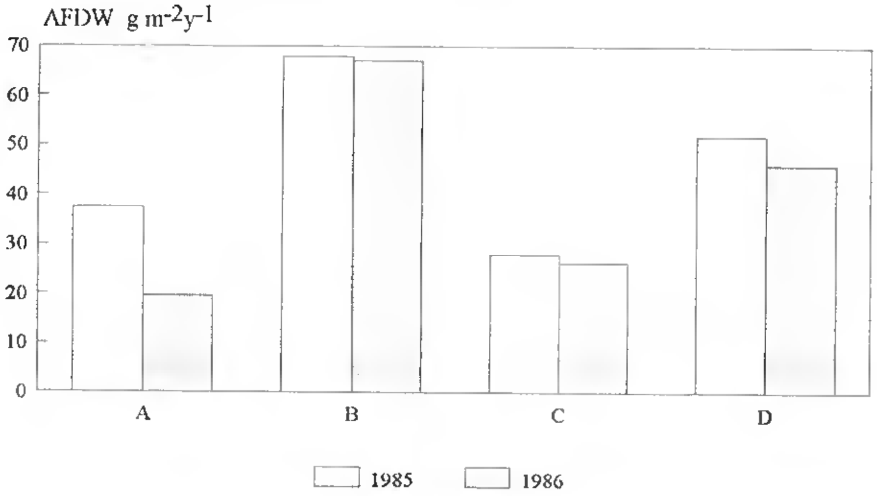


Fig. 4.8. Total annual production of macrofauna at the four sites in the two study years.

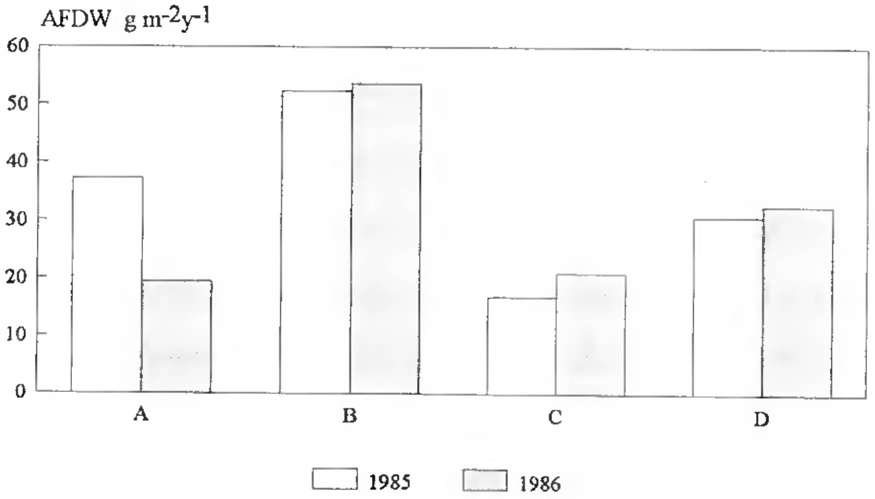


Fig. 4.9. Production of macrofauna smaller than 10 mm at the four sites in the two study years.

|  |  | Annual Biomass AFDW g $m^{-2}$ |  | Production AFDW g $m^{-2}y^{-1}$ |  | P:B ratios |  |
|---|---|---|---|---|---|---|---|
| **Year** | **Site** | **B<10mm** | **BTotal** | **B<10mm** | **BTotal** | **B<10mm** | **BTotal** |
| 1985 | A | 11.3 | 11.8 | 37.1 | 37.3 | 3.3 | 3.2 |
| 1986 | A | 6.6 | 7.1 | 19.3 | 19.6 | 2.9 | 2.8 |
| 1985 | B | 16.2 | 47.2 | 52.4 | 67.9 | 3.2 | 1.4 |
| 1986 | B | 16.5 | 43.5 | 53.7 | 67.1 | 3.2 | 1.5 |
| 1985 | C | 5.7 | 28.1 | 16.8 | 28.0 | 3.0 | 1.0 |
| 1986 | C | 6.5 | 17.2 | 20.9 | 26.3 | 3.2 | 1.5 |
| 1985 | D | 8.9 | 51.4 | 30.5 | 51.8 | 3.4 | 1.0 |
| 1986 | D | 10.1 | 37.4 | 32.5 | 46.2 | 3.2 | 1.2 |

Table 4.3. Mean annual biomass, annual production and final P:B ratios of the macrofauna smaller than 10 mm (B<10mm) and of the total macrofauna (BTotal).

Site B turned out to be a site with a high secondary production, of about 67 g AFDW $m^{-2}y^{-1}$, higher than the productions determined for other coastal or estuarine areas (Asmus, 1987; Warwick & Price, 1975; Wolff & Wolf, 1977). Site D, with a production between 46 and 52 g AFDW $m^{-2}y^{-1}$ had a production similar to the production estimates obtained by Sprung (1994) in a *Zostera* bed of the Ria Formosa, where he found a production of 54 g AFDW $m^{-2}y^{-1}$. Warwick *et al* (1978) studied a *Venus* community with a relatively high biomass, 46 g AFDW $m^{-2}$, but with a low production, of only 26 g AFDW $m^{-2}y^{-1}$ and a P:B of 0.6. These authors suggested that the *Abra* communities would have higher P:B ratios than the *Venus* or *Macoma* communities. However, the final P:B ratios found were similar to those of the *Macoma* community described by Wolff & Wolf (1977) and lower than the mean P:B ratio found for the *C. edule / Scrobicularia plana* community in NW Spain (Anadon, 1980).

Site A had a high potential production relative to its low biomass, which is typical of unstable areas where the macrofauna is composed essentially of a few opportunistic species (Anadon, 1980). The lower production rates found in the other sites (B, C and D) point to a lower biomass turnover rate and to the accumulation of organic material in large individuals.

### 4.2.4 Relationships with the environmental data

The CCA ordination plots are similar to those obtained by the application of the same technique to the reduced taxa abundances data set (compare, for instance, Fig. 3.30 with Fig. 4.10). The projection of the stations is again done along axis one (Fig. 4.11). At one end of the axis, under the influence of large variations in salinity, dissolved oxygen and temperature, were projected the site A stations, with high biomasses of small gastropods and small bivalves and also of Chironomid larvae (Fig. 4.12). Towards the other end of axis one, were projected site B stations, with higher biomasses of annelids and larger gastropods. Chlorophyll *a*, phaeopigment and nitrate concentrations were higher at these stations, and the variations of salinity, temperature and dissolved oxygen were less pronounced. Again, there is a slight displacement of the projection of the second year stations towards the left side of axis one.

In this analysis, the inner station of site B, station B3, was projected close to the stations of sites C and D, characterised by having higher biomasses of larger bivalves and echinoderms than the other stations. The BOD was higher at those stations, but the influence of the other environmental variables also seems important.

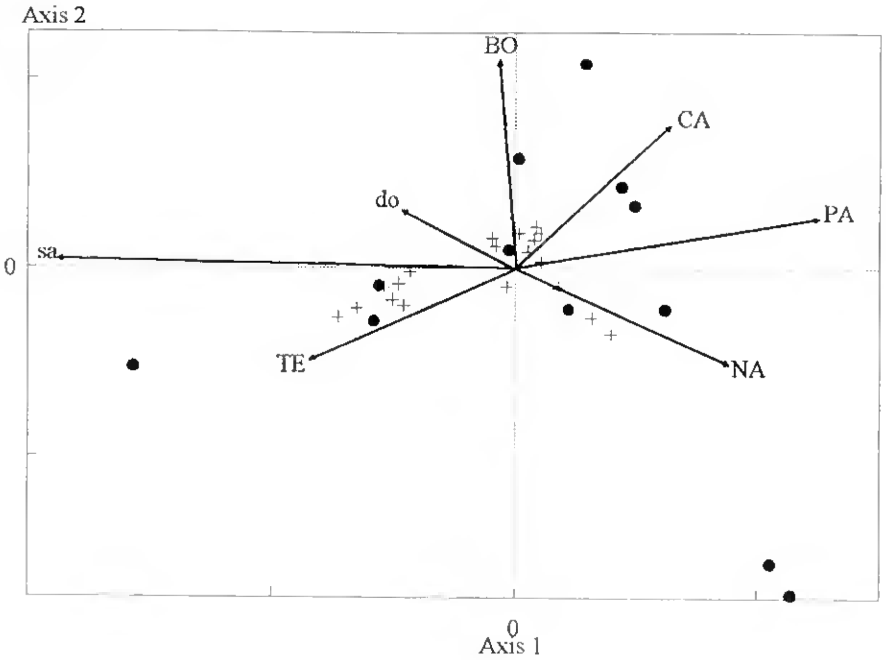


Fig.4.10. Ordination diagram based on Canonical Correspondence Analysis of the biomass data matrix with respect to seven environmental variables. • - Biomass groups co-ordinates; + - Stations co-ordinates. Codes: as in Fig. 3.28. Eigenvalues: I- .22; II- 0.08; III- .06; IV- .02. Percentage variance accounted for by axes: I- 56.4; I+II- 77.5 %.

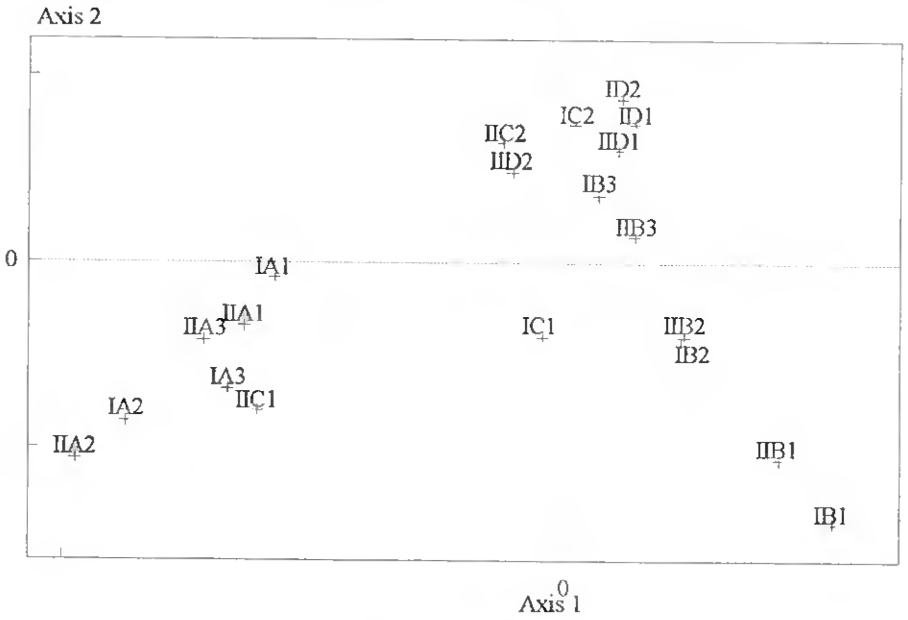


Fig.4.11. Ordination diagram based on Canonical Correspondence Analysis of the biomass data matrix with respect to seven environmental variables. + - Stations co-ordinates. Codes: as in Fig. 3.27. Eigenvalues: I- .22; II- 0.08; III- .06; IV- .02. Percentage variance accounted for by axes: I- 56.4; I+II- 77.5 %.

Small crustaceans, projected close to the origin of the axes, seemed to not have any importance for differentiating between stations (Fig. 4.12) as they occur in small biomasses at all sites (Figs. 4.4 to 4.7). Station C1, with lower biomass values than the other stations, was projected close to the origin of the axes in the first year of survey (Fig. 4.11) but in the second year, it was projected close to site A stations, due to an increase in small molluscs mostly *Hydrobia ventrosa*.

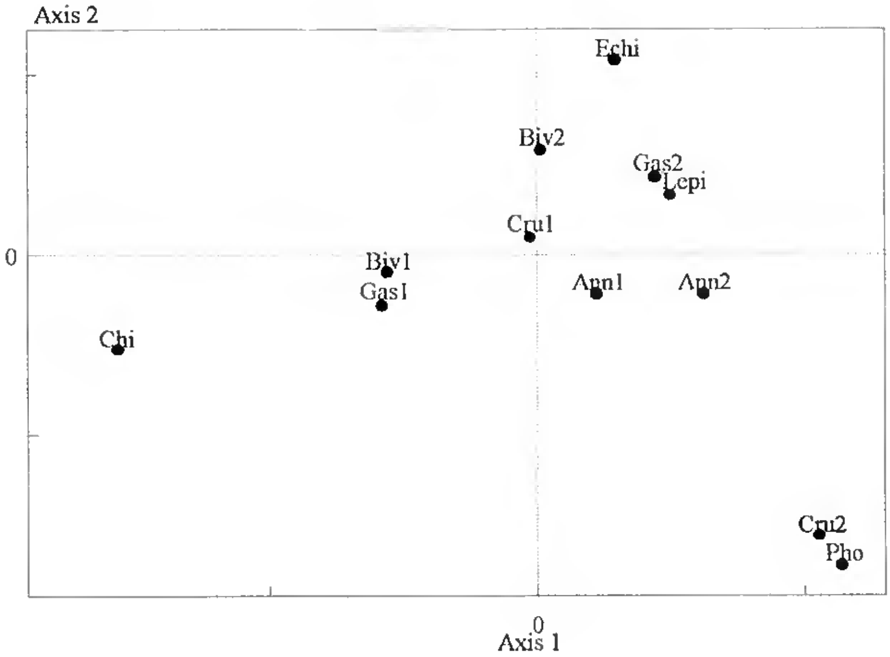


Fig.4.12. Ordination diagram based on Canonical Correspondence Analysis of the biomass data matrix with respect to seven environmental variables. • - Biomass groups co-ordinates. Eigenvalues: I- .22; II- 0.08; III- .06; IV- .02. Percentage variance accounted for by axes: I- 56.4; I+II- 77.5 %. Codes:

Ann1 - Annelids < 10 mm
Ann2 - Annelids > 10 mm
Biv1 - Bivalves < 10 mm
Biv2 - Bivalves > 10 mm
Cru1 - Crustaceans < 10 cm
Cru2 - Crustaceans > 10 mm
Gas1 - Gastropods < 10 mm
Gas2 - Gastropods > 10 mm
Chi - Chironomids
Ech - Echinoderms
Lepi - Polyplacophora
Pho - Phoronids

## 4.3 Conclusions

The lagoon (site B) and the salina reservoirs, sites C and D had higher biomasses and higher secondary production, when compared with other temperate estuarine or coastal systems, indicating promising potential for aquaculture production. However, their management must be undertaken carefully as conditions can very easily change to those seen at site A. Here, the stressful environmental conditions due to limited water renewal encourages high density populations of small-sized organisms. As discussed in Chapter 3, at this site the most abundant species were *Hydrobia ventrosa*, *Chironomus salinarius* and *Capitella capitata*, all of which had small mean dry weights (Table 4.1). These findings are in agreement with those of Hargrave & Thiel (1983) and Schwinghamer (1981) who found that in the absence of exogenous disturbance, biomass may accumulate in large organisms, while environments characterised by variability or persistent physical stress appear to be dominated by communities of small-sized organisms.

The most stressed lagoons support large populations of small, opportunistic benthic invertebrates. Because of their small size and life history traits these species are likely to be very productive (Pearson & Rosenberg, 1978) and have the potential, at least, to support high stocks of benthic feeding fish, such as *Sparus aurata*. An important feature of these prey species is that they live at or close to the sediment water-interface, making them highly available to fish. In contrast, the lagoons which experience least stress support longer-lived, slower reproducing species which have a high individual biomass, but which often live deeper beneath the sediment surface. Whilst the biomass of these species may be greater than those in the more stressed sites, their productivity and their availability to fish may be much less. However, the productivity of small-sized organisms was larger, in the less stressed lagoon. This lagoon seems to be the most suitable site to support high densities of fish, not only because of the large quantities of food available, but also because of a better water quality.

The differentiation of the stations based on biomass values grouped in higher taxonomic groups gave similar results to the results obtained in the analysis based on the species abundance data or on the species reduced data matrices. The reduction of the number of replicates at each station, previously analysed in another work (Gamito & Raffaelli, 1992), also did not significantly affect the differentiation of stations, there being much redundancy in the data, and a very strong ecological gradient among the studied sites. For its detection a significant less amount of sampling effort and laboratory work would be necessary.

Stressed environments caused by a limited water renewal share similarities with stressed environments due to pollution. Pollution-induced changes in community structure may be equally apparent using a non-taxonomic analysis, such as a sizes-structured approach (Schwinghamer, 1988), or a major taxonomic approach (Warwick, 1988) as based on the more demanding and time-consuming analysis of species abundances. In future research work, on this kind of lagoons it might be useful to adopt a functional group or major taxonomic group approach, as has been shown to be successful here.

# Chapter V

# FEEDING SELECTIVITY of *Sparus aurata*

# V - FEEDING SELECTIVITY OF *Sparus aurata*

## Summary

With the aim of studying the feeding of gilthead in an extensive aquaculture regime, an experiment was undertaken in a salina water reservoir (Site D). The experiment comprised four treatments: an enclosure with giltheads of average length approximately 20 cm, an enclosure with 16 cm average length giltheads, a caged area without giltheads to control for any caging effects on the benthos and an uncaged area (control) located between the cages. The four treatments were dispersed within two blocks located in two different parts of the lagoon.

Differences in the benthic macrofauna at the two locations (blocks) were reflected in the gut contents of the fish. The most frequent prey organisms found at one of the locations were the gastropods, *Cerithium vulgatum*, *Bittium reticulatum* and *Hydrobia ulvae*. At the other location the dominant prey were Chironomid larvae and Bryozoans (growing on *Ruppia* sp. leaves), together with *B. reticulatum* and *H. ulvae*. In spite of the high abundance of *C. vulgatum* in the latter location, these individuals were too large to be taken by the giltheads. This experiment showed that gilthead prefer hard-bodied prey, but that in the absence of prey of an appropriate size, whatever is available will be taken.

## 5.1 Methods

### 5.1.1 Experimental design

The experiment was carried out at site D, an area of intermediate stress (see Chapters 2 and 3). The experiment comprised four treatments (Fig. 5.1).

- 15 large giltheads (20 cm length) maintained in a caged area of 2,5 x 8 m (20 $m^2$);
- 15 small-sized giltheads (16 cm length) maintained in a caged area of 2 x 5 m (10 $m^2$);
- A caged area of about 5 $m^2$ area without fish to control for any effects on the benthos of the presence of the cage itself ;
- An uncaged area, the control, sited between the cages.

The fish were thus maintained at different densities. This was done to ensure equivalent fish biomass in the two treatments. Stocking large fish at higher densities would have resulted in a very large fish biomass and overcrowding which would have confounded subsequent interpretation of results. All giltheads were produced in the Experimental Station of IPIMAR - Centro de Investigação Marítima do Sul.

The four treatments were dispersed within two blocks, D and E, on either side of the reservoir gate (Fig. 5.1). The cages were constructed of 2 cm mesh fish net strung around vertical supports and dug well into the bottom to ensure complete enclosure of the fish. The tops of the cages, projected well above the water level, were covered with netting to exclude piscivorous birds.

The cages were set up on 23/05/91, during a neap tide when the water level was at a minimum. The cages were left undisturbed and without fish for 21 days in order to minimise any short-term effects caused by disturbance during setting up of the experiment.

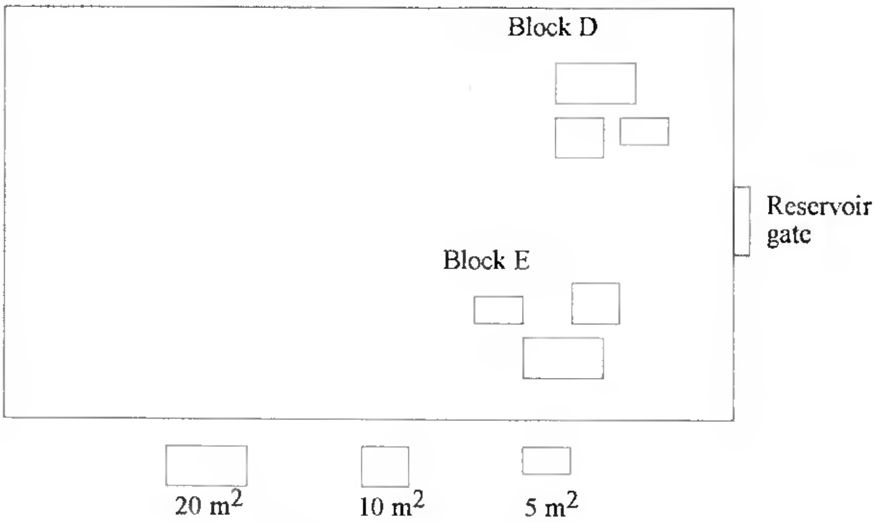


Fig. 5.1. Schematic view of the experimental set-up.

In order to assess the abundance of benthic invertebrates within the experimental areas, 3 samples were taken with a 12 cm diameter corer to a depth of 20 cm within each of the treatments, ensuring that sampling was dispersed throughout each treatment area. Each sample was washed over 1 mm and 350 $\mu$m mesh sieves, the material retained preserved in 70 % alcohol containing Rose Bengal and the fauna identified. Benthic sampling was carried out just prior to, and at the end of the experiment (10 and 20/06/91).

Two groups of giltheads of about 16 and 20 cm average length were maintained in separate tanks for four days at the IPIMAR Experimental Station (Olhão), having previously been anaesthetised with Phenol-Ethanol 0.15 ml $l^{-1}$, weighed and measured. On 14/06/91 groups of 15 giltheads of similar length were placed in portable tanks filled with

50 l salt water, each with two aerators and transportated the few kilometres to the field site where they were transfered to the cages as quickly as possible. The operation took place early in the morning to avoid any effects of the hot weather. Fish were not reweighed or measured at this time in order to minimize stress from handling.

Fish were introduced to cages during a spring tide when environmental conditions are not extreme at this site (Gamito, 1989). Fish were allowed to feed for a period of six days, after which time (20/02/91) they were caught, measured and weighed, and the guts removed and preserved in 70 % alcohol.

The guts were opened under a stereomicroscope, and all the organisms present identified as far as possible. For food material which was difficult to identify, further examinations were made for polychaete setae or arthropod appendages. Opercula of the gastropod *Cerithium vulgatum*, one of the most common prey, were measured to facilitate comparisons of size of prey in guts with those sizes available. This was made possible by establishing the relationship between shell length and operculum length from field samples, all measurements being made with a micrometric ocular.

### 5.1.2 Data Analysis

Differences in mean length and weight of fish at the beginning and at the end of the experiment were analysed by means of an ANCOVA test (Sokal & Rohlf, 1981). The percentage of each of the prey taxon, as well as the percentage of soft and hard-bodied prey taxa were determined separately for each group of giltheads in each block. Prey selection was evaluated using the Forage Ratio and Ivlev's electivity index (Krebs, 1989). Forage ratios greater than 1.0 indicate preference and values less than 1.0 indicate avoidance. The ratio ranges from zero to infinity. Electivity ranges from -1.0 to +1.0, with positive values indicating preference and negative values indicating avoidance.

To avoid problems of pseudoreplication (Hurlbert, 1984), the data from the three benthic samples from each treatment area were pooled and the counts expressed as number of individuals per 0.01 $m^2$. The relative abundance, in percentage, were determined, for each taxon, in each treatment.

To compare the faunal assemblages within the different treatments and between the two blocks, at the beginning and at the end of the experiment, the multivariate techniques of MDS and CA were applied, using the package NTSYS, version 1.6. The data were square root transformed prior to MDS analysis in order to reduce the importance of dominant taxa on the analysis (Field *et al*, 1982).

Finally, in order to assess the suitability of the experimental design for detection of gilthead predation effects, *a posteriori* Power Analysis was carried out (Cohen, 1977; Hall *et al*, 1990).

## 5.2 **Results and discussion**

### 5.2.1 Preparation of the giltheads groups used in the experiment

The mean weight and length of each gilthead group, together with the standard deviation and maximal and minimal values, are given in Table 5.1. No mortality occurred during the transportation of the giltheads to the experimental site. Fish biomass was similar in the two treatments (127-131 g $m^{-2}$).

The production of fishes in extensive aquaculture, that is, culture using natural production as the only source of nutrition, is about 150 kg ha$^{-1}$y$^{-1}$ (Clément & Rigaud, 1986), but production of 300 kg ha$^{-1}$y$^{-1}$ (30 g m$^{-2}$y$^{-1}$) can be attained in well-managed systems with good water renewal (Dinis *et al,* 1989). However, under exceptional conditions as at site B, the production can be higher than 60 g m$^{-2}$y$^{-1}$ (see table 1.1), indicating a biomass of fish of at least 60 g m$^{-2}$ at harvesting. The biomass used in this experiment was even higher, but over a short time and only during the spring tides, making it unlikely that environmental parameters would became limiting, as high salinity or high levels of BOD (see previous chapters). The utilisation of predator densities above those usually found under natural conditions might be expected to produce an effect similar to that of normal densities during a longer period of time, avoiding at the same time possible long-term cage effects.

| | **Small giltheads** | | | **Large giltheads** | |
|---|---|---|---|---|---|
| | **Weight (g)** | **Length (cm)** | | **Weight (g)** | **Length (cm)** |
| **Mean** | 84.5 | 15.9 | **Mean** | 174.3 | 20.1 |
| **std** | 20.86 | 0.93 | **std** | 17.27 | 0.57 |
| **Max** | 120.7 | 17.5 | **Max** | 213.5 | 21.0 |
| **Min** | 47.9 | 14.5 | **Min** | 135.5 | 19.0 |
| **Biomass** | **(g m$^{-2}$)** | 126.8 | **Biomass** | **(g m$^{-2}$)** | 130.7 |
| **Density** | **(ind. m$^{-2}$)** | 1.5 | **Density** | **(ind. m$^{-2}$)** | 0.75 |

Table 5.1. Groups of giltheads selected at the Experimental Station - CIMS (Olhão). Mean weights and lengths, standard deviation and maximal and minimal values, in each group.

It is unlikely that other fish naturally occurring in the lagoon would have been trapped in the cages during their placement. The presence of the workers in the area and the disturbance they caused would have scared away any such fish.

### 5.2.2 Gilthead capture

Because of the high density of the seagrass *Ruppia* sp. in the area it was not possible to use fishing nets effectively and fish had to be caught by hand. The cages in block D yielded 14 and 11 fish, from the 10 $m^2$ and 20 $m^2$ cages, respectively, while the 10 $m^2$ and 20 $m^2$ cages from block E yielded 1 and 8 fish, respectively.

Fish which were not recaptured could either have died, escaped from the cage, or evaded capture. Although no dead fish were observed in the cages during the experiment, these may have been consumed by crabs *Carcinus maenas*, which occurred at considerable densities inside the cages. However, on the day following the harvesting, during the dismantling of the cages, several giltheads were seen inside the cages. Given the problems encountered during harvesting, it seems likely that fish were simply not caugh and mortality was probably negligible.

### 5.2.3 Condition of fish

On average, fish weight declined over the six day period (Figs. 5.2 and 5.3). This was not unexpected, since the transfer of fish from the laboratory to the field site and the harsher conditions prevailing there would have been stressful. Also, the fish had until transfer been raised on an artificial diet and were inexperienced in searching for natural food.

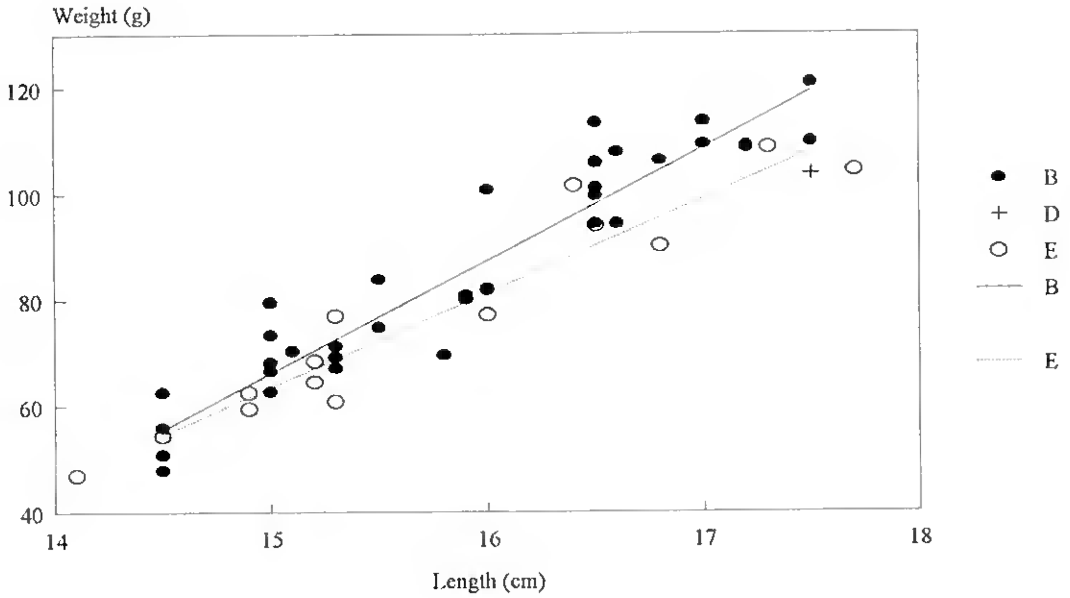


Fig. 5.2. Length / weight relationship of the 16 cm size group of giltheads. B - Beginning of experiment. End of experiment: D - Block D, E - Block E, and respective regression lines. The ANCOVA test results were F=4.908 with 1 and 47 d.f. for the adjusted means, and F=3.372 with 1 and 47 d.f. for the slopes.

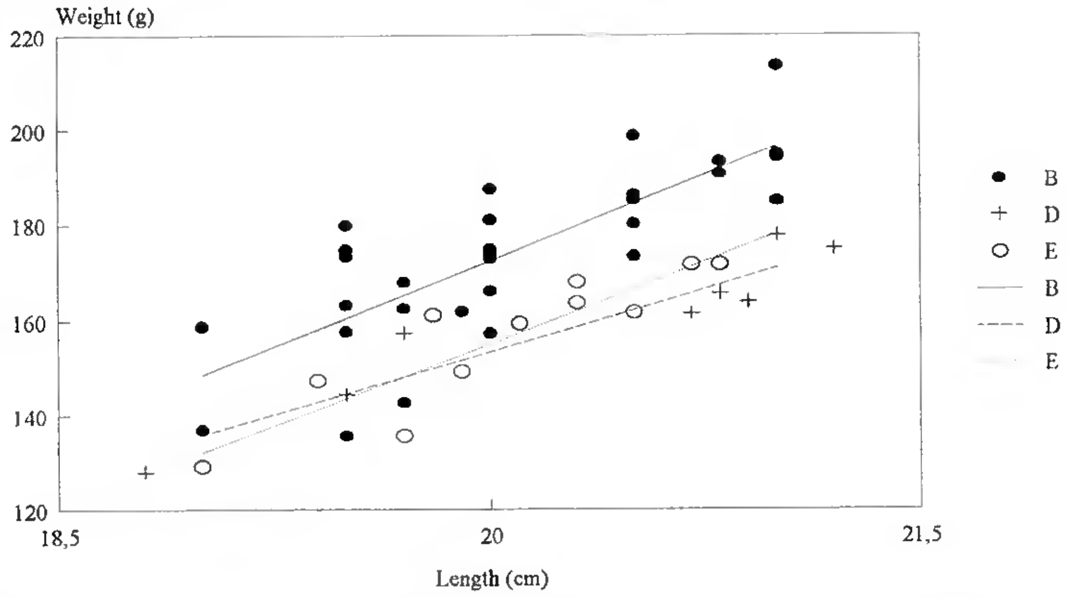


Fig. 5.3. Length / weight relationship of the 20 cm size group of giltheads. B - Beginning of experiment. End of experiment: D - Block D, E - Block E, and respective regression lines. The ANCOVA test results were F=14.808 with 2 and 48 d.f. for the adjusted means and F=4.432 with 2 and 46 d.f. for the slopes.

### 5.2.4 Benthic invertebrates

Since no meiofauna organisms were found in fish guts, the material retained by the smaller sieve (355 $\mu$m) was not analysed further. The macrofauna samples from the 10 $m^2$ enclosure of block D were also not analysed, as only one fish was caught there, making the application of feeding selectivity indices meaningless.

The densities of all the taxa found in the two blocks are given in Table 5.2. The dominant species, in terms of numbers, were the gastropod *Cerithium vulgatum* and the polychaete *Heteromastus filiformis*, in block E. In block D, the dominance of *C. vulgatum* is less pronounced, oligochaetes being the most abundant taxon.

These between-block differences are clearly evident in the MDS and CA plots (Figs. 5.4 and 5.5). Two distinct groups can be seen in the ordinations, corresponding to the two blocks. In block D, the two control samples are also separated from the treatments and this is more pronounced in the CA plots. A higher density of Nereid polychaetes was observed in these controls (Table 5.2). There is no separation of the outside samples from those in the cage controls, indicating an absence of cage effects, and neither are there any evidence of differences due to the presence of fish.

In Block E there was a reduction in *C. vulgatum* abundance (Table 5.2) which is more pronounced in the cage with smaller fish suggesting, at first sight, that this could be due to gilthead predation. However, snail abundance was even lower in samples from outside the cage and this predation hypothesis must be rejected. In previous sampling done at this site such high densities of *C. vulgatum* were not recorded. The mean density in 1985 and 1986 was about 7 individuals 0.01 $m^{-2}$ (Appendix A3). Overall, the invertebrate data recorded from within the two blocks were broadly similar to those found in that earlier years (Gamito, 1989 and Appendices A2 and A3).

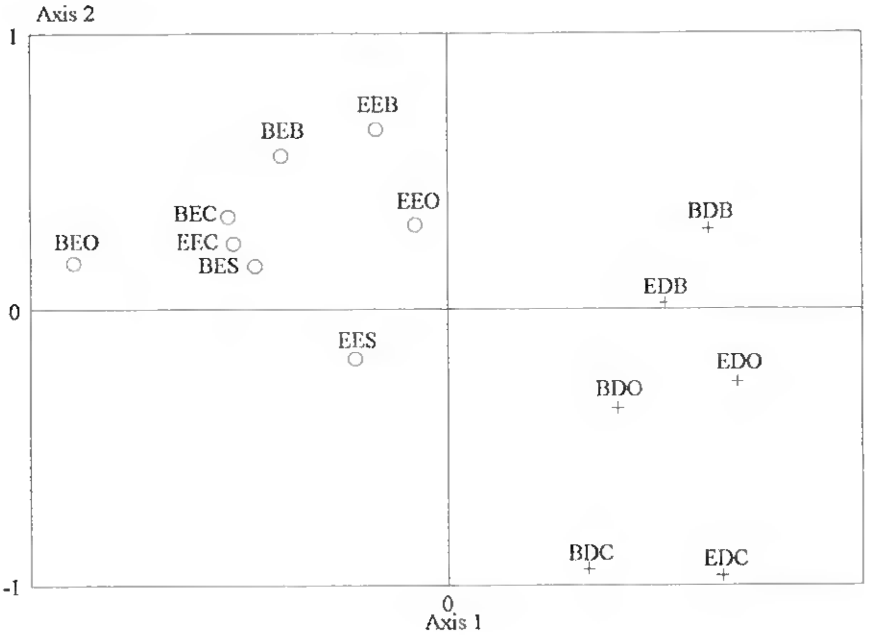


Fig. 5.4. MDS plot of macrofauna samples. First letter: B - Beginning of the experiment; E - End. Second letter: D - Block D; E - Block E. Third letter: B- Big cage; C - Control; S - Small cage; O - Outside.

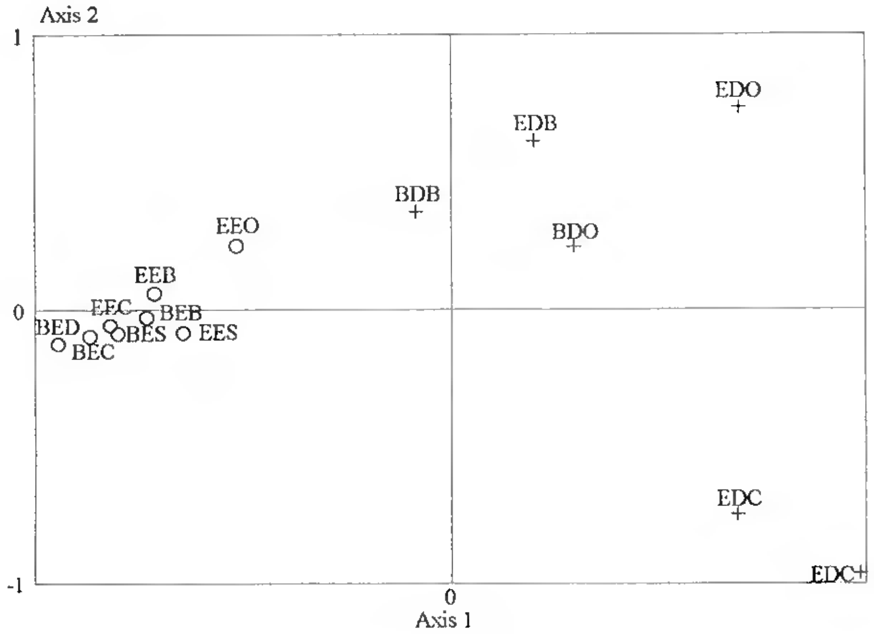


Fig. 5.5 CA plot of macrofauna samples. First letter: B - Beginning of the experiment; E - End. Second letter: D - Block D; E - Block E. Third letter: B- Big cage; C - Control; S - Small cage; O - Outside.

| **BLOCK D**<br>**Numbers 0.01 m$^{-2}$** | **Outside** | | **Control** | | **Large Cage** | |
|---|---|---|---|---|---|---|
| | **B** | **E** | **B** | **E** | **B** | **E** |
| Nemertina | 0.5 | 0.3 | 0.0 | 0.0 | 0.0 | 1.7 |
| *Aonides oxycephala* | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 |
| *Capitella capitata* | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 |
| *Heteromastus filiformis* | 14.5 | 11.3 | 4.5 | 2.0 | 20.0 | 11.7 |
| *Lumbrinereis gracilis* | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.7 |
| *Marphysa sanguinea* | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Nereis caudata* | 5.0 | 1.0 | 14.5 | 20.3 | 2.5 | 0.0 |
| Phyllodocidae | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 |
| *Polydora polybranchia* | 0.0 | 0.0 | 2.5 | 0.7 | 0.0 | 0.0 |
| Syllidae - type 1 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 |
| Oligochaeta | 29.0 | 60.7 | 26.5 | 24.7 | 11.0 | 33.3 |
| *Abra ovata* | 0.7 | 2.0 | 1.0 | 1.3 | 0.0 | 0.3 |
| *Bittium reticulatum* | 1.0 | 1.7 | 1.3 | 0.7 | 0.7 | 1.0 |
| *Cardium edule* | 0.0 | 0.3 | 0.0 | 0.3 | 0.0 | 0.0 |
| *Cerithium vulgatum* | 16.7 | 10.3 | 15.3 | 9.0 | 14.0 | 20.7 |
| *Amyclina corniculum* | 0.7 | 1.0 | 2.3 | 0.7 | 0.7 | 1.0 |
| *Rissoa membranacea* | 0.7 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| Amphipoda | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *Idotea chelipes* | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 |
| *Palaemonetes varians* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| Chironomidae | 0.0 | 1.7 | 0.5 | 0.0 | 2.0 | 2.0 |
| **Total (0.01 m$^{-2}$)** | **69** | **89** | **71** | **60** | **50** | **69** |

| **BLOCK E**<br>**Numbers 0.01m$^{-2}$** | **Outside** | | **Control** | | **Small cage** | | **Large cage** | |
|---|---|---|---|---|---|---|---|---|
| | **B** | **E** | **B** | **E** | **B** | **E** | **B** | **E** |
| Nemertina | 0.5 | 3.7 | 2.5 | 1.3 | 1.0 | 0.0 | 0.0 | 0.7 |
| *C. capitata* | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 0.3 | 0.0 | 0.0 |
| *H. filiformis* | 16.5 | 17.0 | 13.5 | 9.7 | 17.0 | 10.7 | 32.5 | 22.7 |
| *L. gracilis* | 0.0 | 0.7 | 1.0 | 0.7 | 1.0 | 0.0 | 2.0 | 1.3 |
| *M. sanguinea* | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| *N. caudata* | 0.5 | 0.0 | 1.5 | 0.3 | 1.0 | 1.7 | 4.5 | 1.3 |
| Phyllodocidae | 0.0 | 0.3 | 1.5 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 |
| Syllidae - 1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 |
| Syllidae - 2 | 0.5 | 0.0 | 1.5 | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 |
| Oligochaeta | 2.0 | 16.7 | 4.5 | 6.0 | 6.5 | 5.3 | 8.0 | 11.3 |
| *A. ovata* | 3.0 | 1.3 | 1.7 | 4.7 | 3.3 | 1.3 | 0.7 | 0.0 |
| *B. reticulatum* | 2.3 | 0.7 | 1.0 | 2.0 | 1.3 | 0.3 | 1.0 | 0.3 |
| *C. edule* | 0.0 | 0.7 | 0.3 | 0.0 | 0.3 | 0.3 | 0.0 | 0.0 |
| *C. vulgatum* | 142.7 | 48.3 | 95.0 | 76.3 | 96.3 | 40.7 | 94.0 | 87.0 |
| *A. corniculum* | 3.3 | 0.7 | 0.3 | 2.3 | 2.3 | 2.3 | 2.0 | 0.0 |
| *H. ulvae* | 1.7 | 4.7 | 0.3 | 1.3 | 0.0 | 0.0 | 11.0 | 0.3 |
| *L. cinereus* | 1.0 | 0.3 | 0.0 | 0.7 | 0.3 | 0.3 | 0.0 | 0.0 |
| *R. membranacea* | 0.7 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 |
| Amphipoda | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *P. varians* | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| Chironomidae | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.5 | 0.3 |
| Syngnathidae | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| **Total (0.01m$^{-2}$)** | **175** | **92** | **122** | **105** | **131** | **63** | **156** | **125** |

Table 5.2. Numbers 0.01 m$^{-2}$ of every taxon at the beginning (B) and end (E) of the experiment, in Blocks D and E, in each treatment.

### 5.2.5 Fish gut contents

All the stomachs and intestines contained some benthic material, indicating that, in spite of being produced and fed in an artificial environment, giltheads had succeded in finding food in the natural environment.

The giltheads in block D had ingested large amounts of *Ruppia* sp., most fragments containing encrusting Bryozoan colonies (Table 5.3). The stomachs and intestines also contained the gastropods, *Bittium reticulatum*, *Hinia costulata* and *Rissoa* sp., and one *Cerithium vulgatum*, as well as some Chironomid larvae and traces of polychaetes.

The stomachs and intestines of the block E giltheads contained mostly *C. vulgatum*, as well as the other taxa referred to in block D (Tables 5.4 and 5.5). Some Nereid polychaetes, the gastropod *Hydrobia ulvae*, one *Cardium edule* and some chitons *Lepidochitona cinereus* were also found.

In the two size groups of giltheads from block E there were not large differences in the variety of prey taken, but the presence of some polychaetes and one nemertean in the smaller giltheads guts should be noted. However, the main difference between the two fish size classes was in the quantity of gastropods ingested. 20 cm giltheads consumed many more gastropods than the smaller, 16 cm fish, especially *C. vulgatum*. 16 cm giltheads had a mean number of 11 *C. vulgatum* per fish, whilst 20 cm fish had a mean of about 32 gastropods.

The gilthead recovered from the 16 cm fish cage of block D, contained one *Abra ovata*, one chironomid larva and one *Bittium reticulatum*.

| **BLOCK D - 20 cm Giltheads** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Stomachs** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **%** |
| Polychatea | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 18.2 |
| Chironomidae | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 27.3 |
| *Bittium reticulatum* | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 0 | 36.4 |
| *Cerithium vulgatum* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 9.1 |
| *Amyclina corniculum* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 9.1 |
| *Rissoa membranacea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Scales | | | | | | 1 | | | |
| Bryozoa | + | + | + | +++ | | +++ | ++ | +++ | |
| *Ruppia* sp. | ++ | + | ++ | + | | ++ | ++ | + | |
| Veg.1 | | | | | | | | | |
| Veg.2 | | | | | | | | + | |
| Veg.3 | | | | | | | ++ | | |
| **Stomachs+Intestines** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **%** |
| Polychaeta | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 19.0 |
| Chironomidae | 1 | 0 | 0 | 2 | 1 | 2 | 0 | 1 | 33.3 |
| *Bittium reticulatum* | 0 | 2 | 0 | 1 | 0 | 3 | 1 | 0 | 33.3 |
| *Cerithium vulgatum* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4.8 |
| *Amyclina corniculum* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 4.8 |
| *Rissoa membranacea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4.8 |
| Scales | 2 | | | | | 1 | | | |
| Bryozoa | ++ | ++++ | + | ++++ | ++ | +++ | +++ | +++ | |
| *Ruppia sp.* | ++ | ++ | ++ | ++ | + | +++ | +++ | ++ | |
| Veg.1 | | | | | | | + | | |
| Veg.2 | | | | | | | + | + | |
| Veg.3 | | | | | | | ++++ | | |
| Spawn | | + | | | | | | + | |

Table 5.3. Stomach and intestine contents of the 20 cm block D giltheads. Qualitative data: + < 5 portions or "branch", ++ < 10, +++ < 20 and ++++ < 40.

| **BLOCK E - 16 cm Giltheads** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stomachs** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **%** |
| Nemertina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Nereidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 3.3 |
| Chironomidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| *B. reticulatum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1.7 |
| *C. vulgatum* | 4 | 3 | 4 | 3 | 2 | 5 | 5 | 8 | 1 | 3 | 4 | 1 | 6 | 2 | 85.0 |
| *A. corniculum* | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 5.0 |
| *H. ulvae* | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3.3 |
| *L. cinereus* | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.7 |
| *R. membranacea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Scales | | | 1 | | | 1 | 20 | | | | | | | | |
| Bryozoa | | | | | | | | | | + | | | | + | |
| *Ruppia sp.* | + | | ++ | | | + | + | + | | + | + | +++ | | | |
| Veg.1 | | | | | | | | | | | | + | | | |
| Veg.2 | | | | | | + | | + | | | | + | | | |
| **Stom.+Int.** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **%** |
| Nemertina | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0.6 |
| Nereidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1.1 |
| Chironomidae | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.1 |
| *B. reticulatum* | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1.7 |
| *C. vulgatum* | 11 | 15 | 8 | 5 | 4 | 15 | 19 | 22 | 1 | 8 | 12 | 6 | 14 | 16 | 88.1 |
| *A. corniculum* | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2.3 |
| *H. ulvae* | 1 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 3.4 |
| *L. cinereus* | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.1 |
| *R. membranacea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0.6 |
| Scales | | | 1 | | | 1 | 20 | | | | | | | | |
| Bryozoa | | | | | | | | | | + | | | | + | |
| *Ruppia sp.* | + | | ++ | | | + | + | + | | + | + | +++ | | | |
| Veg.1 | | | | | | | | | | | | ++ | | | |
| Veg.2 | | | | | | + | | + | | | | + | | | |

Table 5.4. Stomach and intestine contents of the 16 cm block E giltheads. Qualitative data: + < 5 portions or "branch", ++ < 10, +++ < 20 and ++++ < 40.

| **BLOCK E - 20 cm Giltheads** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stomachs** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **%** |
| Chironomidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| *B. reticulatum* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| *C. vulgatum* | 4 | 6 | 1 | 1 | 3 | 6 | 4 | 4 | 5 | 24 | 3 | 96.8 |
| *C. edule* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1.6 |
| *H. ulvae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1.6 |
| *R. membranacea.* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Scales | | | | | | | | | | 1 | | |
| Bryozoa | + | | | | | | | | | | | |
| *Ruppia sp.* | + | +++ | | | ++ | + | | + | + | + | | |
| Veg.1 | | | | | | | | | | | | |
| Veg.2 | | + | | | | + | | | | | | |
| Veg.3 | | | | | | ++ | + | | | | | |
| **Stomachs+Intestines** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **%** |
| Chironomidae | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0.3 |
| *B. reticulatum* | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1.4 |
| *C. vulgatum* | 45 | 36 | 8 | 7 | 23 | 41 | 24 | 48 | 38 | 31 | 45 | 94.5 |
| *C. edule* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.3 |
| *H. ulvae* | 3 | 0 | 0 | 0 | 0 | 0 | 4 | 1 | 2 | 0 | 1 | 3.0 |
| *R. membranacea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0.5 |
| Scales | | | | | | | | | | 1 | | |
| Bryozoa | ++ | | | +++ | ++ | | ++ | + | ++ | | ++ | |
| *Ruppia sp.* | ++ | +++ | | | +++ | +++ | + | + | | + | + | |
| Veg.1 | | | | | + | | + | | | | | |
| Veg.2 | | + | | | | + | | | | | | |
| Veg.3 | | | | | | ++ | + | | | | | |

Table 5.5. Stomach and intestine contents of the 20 cm block E giltheads. Qualitative data: + < 5 portions or "branch", ++ < 10, +++ < 20 and ++++ < 40.

Within block E, fewer soft-bodied prey, such as polychaeta and Chironomid larvae and more hard-shelled molluscs were taken by larger fish (Fig. 5.6). This is consistent with previous work on gilthead diet which suggest that fish switch to larger and harder prey taxa as they grow (Arias, 1980; Suau & Lopez, 1976; Wassef & Eisawy, 1985). However, in block D the large 20 cm gilthead took more soft-bodied than hard bodied-prey.

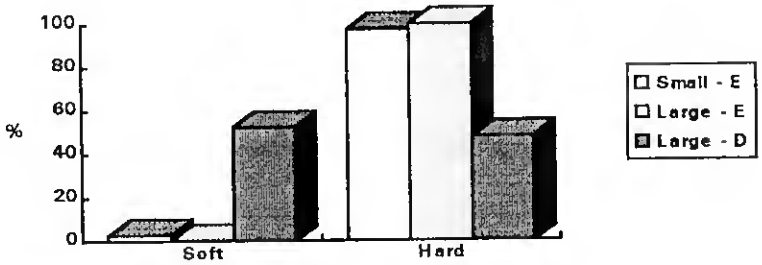


Fig. 5.6 Frequency of soft and hard-bodied prey in fish gut contents in blocks D and E.

Several authors have noted that giltheads eat large amounts of bivalves. Rosecchi (1987), for instance, reports a bivalve occurrence of 55 % in giltheads greater than 10 cm in length. Similarly, Wassef & Eisawy (1985) found a 36 % occurrence of bivalves, in reared giltheads between 16 and 25 cm length. In the present study no such preference for bivalves was observed. Bivalves, *Cardium edule* and *Abra ovata,* were recorded from only two gilthead guts. However, the density of those bivalves was not particularly high, about 4 to 20 ind. $m^{-2}$ for *Cardium*, and about 130 ind. $m^{-2}$ for *Abra*. Also, the experimental fish had been reared in an artificial environment and had never had to search for food, let alone dig in the sediment to catch buried prey.

Crustaceans were noticeably absent from the guts, in spite of their presence in the environment. They have been recorded by other authors as a frequent prey of gilthead. This result may be due to the low density of crustaceans in the environment but prey size may also be an important factor. The prawn *Palaemonetes varians* found in the sediment samples, and the crabs seen during the gilthead fishing, were large and probably not available to the giltheads used in the experiment. Amphipods and isopods, which were present at low densities of 3 to 6 ind. $m^{-2}$, were the only crustacean prey likely to have been ingested.

As well as prey abundance and size, there is also the question of the availability of different prey. Gastropods are usually more available to fish, being on top of the sediment or on seagrass leaves. The polychaetes, particularly the most abundant species *Heteromastus filiformis*, are sometimes wound round the sea grass stems, but they can also burry in the sediment, to a depth of 15 cm (Fauchald & Jumars, 1979). Polychaetes from the families Nereidae and Eunicidae (*Lumbriconereis gracilis* and *Marphysa sanguinea)* are errant species, but they can frequently be found in burrows or galleries dug in the sediment (Fauchald & Jumars, 1979; Fish & Fish, 1989). The same is not the case for *Capitella* sp., which are detritic and live in the superficial layer of muddy-sand sediments (Fish & Fish, 1989), as well as Oligochaetes and Chironomid larvae. The bivalves *Abra ovata* and *Cardium edule* burrow in the sediment, but in the superficial layer, and are probably relatively available to benthic feeding fish. Thus, gastropods, some polychaete species, Chironomid larvae and oligochaetes are probably the more available prey for giltheads.

### 5.2.6 Selectivity indices

The results of the forage fatio and the Ivlev's electivity index calculations confirm the preference of both sizes of the gilthead for molluscs, in both of the blocks (Table 5.6). As a taxon, gastropods are preferred, if *C. vulgatum* is not included in the analysis. In block E, the giltheads selected *C. vulgatum*, but in block D, fish appeared to avoid this species.

Considering soft-bodied prey, such as polychaetes, oligochaetes and chironomid larvae, the results indicate that the fish did not select these in block E, but in block D these were not similarly avoided, the values being close to one and zero for the forage ratio and the electivity index, respectively.

| | **Forage ratio** | | | **Electivity index** | | |
|---|---|---|---|---|---|---|
| **Stomachs** | **E16** | **E20** | **D20** | **E16** | **E20** | **D20** |
| Soft body preys | 0.12 | 0.00 | 0.67 | -0.79 | -1.00 | -0.20 |
| Molluscs | 1.35 | 1.44 | 1.72 | 0.15 | 0.18 | 0.27 |
| *C.vulgatum* | 1.32 | 1.41 | 0.32 | 0.14 | 0.17 | -0.52 |
| Other gastropods | 2.77 | 6.02 | 16.52 | 0.47 | 0.71 | 0.89 |
| **Stomachs+Int.** | **E16** | **E20** | **D20** | **E16** | **E20** | **D20** |
| Soft body preys | 0.10 | 0.01 | 0.77 | -0.82 | -0.98 | -0.13 |
| Molluscs | 1.36 | 1.44 | 1.50 | 0.15 | 0.18 | 0.20 |
| *C.vulgatum* | 1.37 | 1.37 | 0.17 | 0.16 | 0.16 | -0.71 |
| Other gastropods | 2.15 | 9.84 | 15.57 | 0.36 | 0.82 | 0.88 |

Table 5.6 Forage ratio and Ivlev's electivity index for the giltheads stomach contents and stomach and intestin contents. E16 - Giltheads of 16 cm length, block E. E20 and D20 - Giltheads of 20 cm length, blocks E and D, respectively.

It is not possible to quantify objectively seagrass availability in the environment in relation to that consumed by the giltheads. None of the possible indices for measurement of dietary preferences can, therefore, be applied to seagrass. The same is true of the other taxa for which only qualitative information could be obtained. However, examination of Table 5.2 suggests that in block E the giltheads avoided these taxa, whilst in block D they consumed them actively, sometimes having their guts filled with leaves and other vegetation.

### 5.2.7 Fish predation on *Cerithium vulgatum*

The foregoing results raise the question: Why did the giltheads from block E preferentially select *C. vulgatum* and those from block D avoid this species? In block D the density of *C. vulgatum* was lower than that measured in block E, but nevertheless the density was 14 to 15 ind. 0.01 $m^{-2}$ or 1400 ind $m^{-2}$, which is high. More important perhaps was the size of *C. vulgatum* in the two blocks. In block D the mean length was quite large, possibly making them unavailable for giltheads. From measurements of *C. vulgatum* opercula found in the stomachs and intestines and in the environment, it appears that giltheads select smaller snails, avoiding the larger ones (Figs. 5.7 and 5.8). Also, 16 cm giltheads selected smaller gastropods than 20 cm giltheads. In block D, only one gilthead ate a small *C. vulgatum*. The individuals of this species were probably all large in this block.

As there is an approximately linear relationship between total *Cerithium* length and maximal operculum length (Fig. 5.9), it is possible to establish the actual length of this species eaten by the gilthead. The 16 cm giltheads preferentially ate *Cerithium* between 4 and 7 mm in length, whilst 20 cm giltheads took slightly larger snails, between 5 and 8 mm. None of the fish consumed *Cerithium* larger than 10 mm, in spite of the large numbers of this size class in the environment.

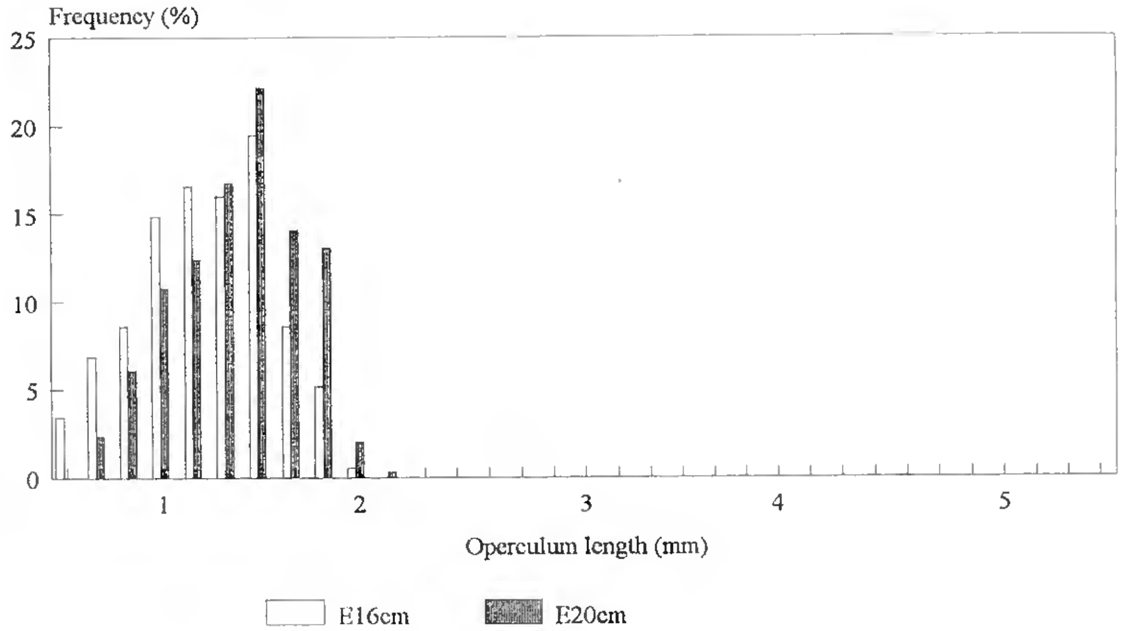


Fig. 5.7. Size frequency distribution of opercula found in giltheads guts.

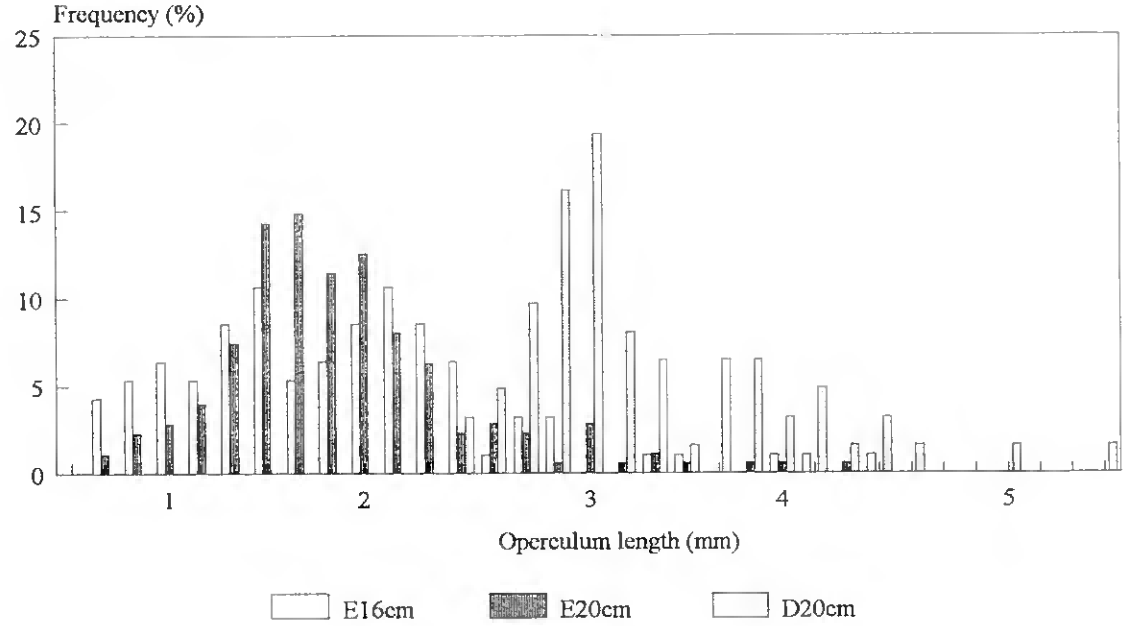


Fig. 5.8. Size frequency distribution of opercula found in the environment.

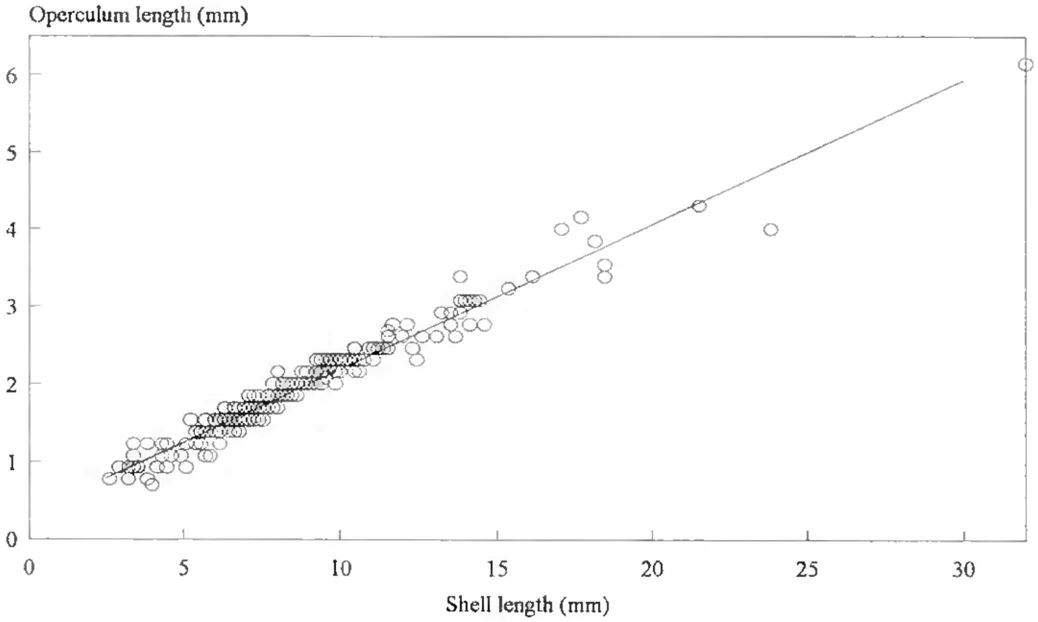


Fig. 5.9. Relationship between operculum length and shell length in *Cerithium vulgatum*. Data based on snails from D20, E16 and E20 areas. $y = 0.326 + 0.187\,x$.

According to Kuhl & Kuipers (1979), the main factors affecting prey selection by fish are the length of the prey and its density. In block D, most of the gastropods present were large, with the exception of *Bittium reticulatum* and *Hinia costulata*. These were both generally smaller than 10 mm in length and were actively taken by the giltheads. *Hydrobia ulvae*, which is smaller than the other gastropods, was not found in the environment nor in the giltheads from block D, but was present and was captured by fish in block E. Giltheads from block D captured other prey such as polychaetes and Chironomid larvae, and also consumed a greater proportion of sea grass and bryozoa probably because gastropods of an appropriate size were absent from that block. This is consistent with the hypothesis that the gilthead is not a specialised predator and will eat whatever food is available (Eisawy and Wassef, 1984).

### 5.2.8 Effects of fish predation on the benthos

With only two treatment replicates (blocks) is not sensible to carry out detailed comparison of faunal densities between treatments, for example by ANOVA. To do this one would have to use more than two blocks. It should be remember that the experiment was designed to analyse of prey selectivity in the gilthead, not their effect on benthic community structure and composition. Nevertheless, the results can be used to find out how well such a design could detect effects of gilthead predation on a given prey. To do this power analysis was carried out with *C. vulgatum* as prey, as this species was the most abundant in the environment and in the gut contents. Power analysis enables an estimation of number of blocks necessary to detect a given reduction in prey density. For the purposes of the present analysis, only three treatments were assumed: large fish (20 cm giltheads), control cages and outside samples. For each treatment there were two replicates (blocks), as the three subsamples taken within each replicate cannot be considered individual samples but pseudoreplicates (Hurlbert, 1984). The common standard deviation of *Cerithium* density will be large because of the small sample size and is further increased by the large difference in density between the two blocks.

The analysis (Fig. 5.10) shows that with the experimental design used, there is only a 10 % chance of detecting a 90 % reduction in *C. vulgatum* density due to gilthaed predation, and only a 5 % chance of detecting a 10 % reduction. To detect a reduction in *C. vulgatum* of 25 % with a 50 % certainty, an experiment with at least 20 - 25 blocks would be necessary. This would not be feasible, given the size of the lagoon (10000 $m^2$) and the effort required in setting up the experiment. With 10 blocks there would be a 25 % chance of detecting a 25 % reduction in prey. Thus it is unlikely that the effect of gilthead on prey community structure and composition can be evaluated through manipulative caging experiments without enormous effort.

In theory, gilthead need a daily ration of food corresponding to 2 % of body weight (wet weight of fish / dry weight of food, Ziljstra, 1979). If only *C. vulgatum* is eaten, a fish biomass of 130 g m$^{-2}$ would consume, per day, 80 to 85 gastropods m$^{-2}$, in the range 7 to 8 mm in length. After 6 days, about 500 gastropods m$^{-2}$ would have been consumed. The observed densities in the areas were about 8000 gastropods m$^{-2}$. Predation by gilthead would therefore reduce the density of *C. vulgatum* by about 6 %. From the foregoing power analysis, it would have been impossible to detect an effect of this size with the experimental design used.

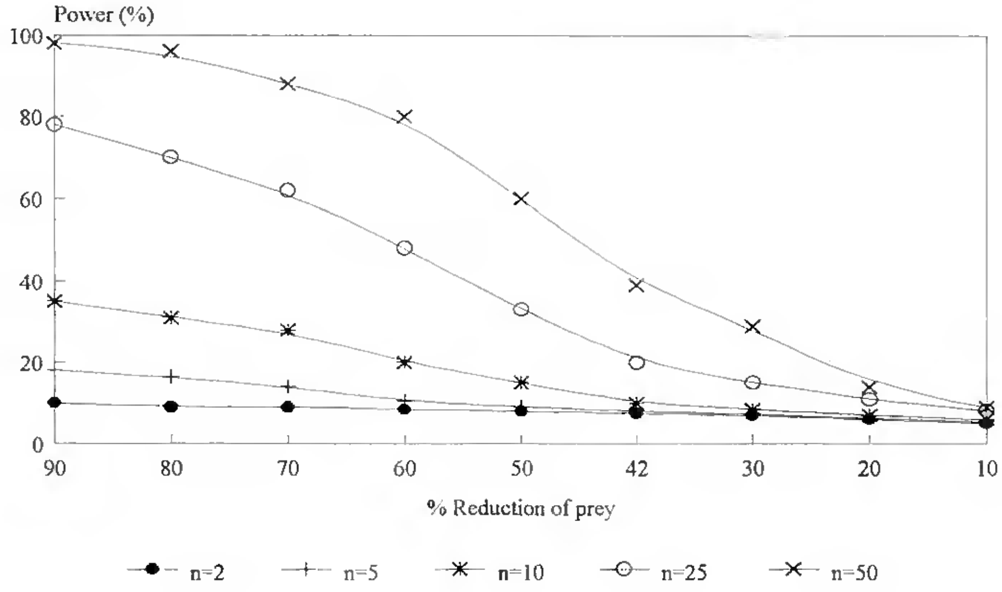


Fig. 5.10. Ability (power) to detect reductions in density of the gastropod *Cerithium vulgatum* for experimental designs using 2, 5, 10, 25 or 50 replicates.

## 5.3 **Conclusions**

Despite a certain amount of confusion about the feeding selectivity of the gilthead (Ferrari & Chieregato, 1981; Drake & Arias, 1989; Eisawy & Wassef, 1984; Kentouri & Divanach, 1986; Robert & Parra, 1991 and Rosecchi, 1987), the results of the present experiment indicate that the gilthead preferentially consumes gastropod molluscs, but that it can also eat other organisms, such as polychaetes and chironomids, if there are not enough molluscs or if molluscs are present but of an inappropriate size. The 16 cm and 20 cm giltheads selected gastropods smaller than 10 mm total length. A reduction in the number of soft bodied prey, such as chironomids and polychaetes, was also observed in the diet of larger giltheads when there was suitable gastropod prey available.

The gilthead is an omnivore, eating not only animals but also vegetable material. It is a generalist predator, as is characteristic of many other predators from estuarine or lagunar environments. This feature contributes to its success in aquaculture, both in extensive and intensive culture systems.

# Chapter VI

# POTENTIAL PRODUCTION of *Sparus aurata*

# VI - POTENTIAL PRODUCTION OF *Sparus aurata*

## Summary

A simple model was developed to simulate the production of benthos and its consumption by a population of *Sparus aurata*. The model was based on the environmental data and secondary production estimates described in the previous chapters for the four study lagoons and on published information on *Sparus aurata* growth and feeding.

The model was a first attempt to describe the potential of the study lagoons for the production of gilthead in an extensive aquaculture regime. The results of the simulations confirmed the exceptional potential of site B, where the maximal annual yield of gilthead was estimated to be around 22 - 25 g $m^{-2}$ (250 kg $ha^{-1}$). At site D, the maximal annual production of gilthead would probably not exceed 10 g $m^{-2}$ (100 kg $ha^{-1}$), and at the other two sites the yield would be even lower.

Yield could be improved to a certain extent by increasing initial fish density, but care would have to be taken to make sure that there was sufficient food.

## 6.1 Introduction

The carrying capacity in an extensive aquaculture system will depend on the amount of food available in relation to the food requirement of each species. The food requirement of a species can be approximately assessed by computing an estimated daily requirement of the species stock per unit biomass. Although this method does not provide precise estimates it indicates the possible level (order of magnitude) of food requirements and predation pressure in an area (Zijlstra, 1979). Zijlstra determined the total annual food consumption of each fish species by multiplying the biomass of fish by the number of days the fish feed and by the daily feeding requirement.

The daily requirement, expressed as a ratio of body weight, may vary widely. Usually, this ratio is expressed as dry food percentage of wet body weight (DW/WW) per day (Hepher, 1988). For intensively cultured *Sparus aurata*, the daily ratio advised for a commercial firm can vary from 4.4 % for young fish at a temperature of 22 - 24 °C, to 0.7 % for large fish of more than 500 g weight at 12 °C. For fish between 40 and 100 g the ratio can vary between 1.0 %, at low water temperatures, and 2.2 %, at higher temperatures.

These ratios are in agreement with Tandler *et al* (1982), who indicate daily feeding ratios of 2.49 to 3.36 % body weight per day (DW of food / WW of fish), for young *S. aurata* of 0.5 - 15 g in weight. The food used was commercial pellets with added attractants. Pousão-Ferreira *et al* (1989) refer to a daily feeding ratio of 0.5 to 2 % for 110 g mean weight giltheads, depending on the water temperature (13.5 - 23 °C). Fernández-Palacios *et al* (1989) refer to a ratio varying from 2.5 %, for 40 g gilthead, to 1.6 %, for 100 g mean weight giltheads, for water temperatures between 18.5 and 22 °C. Klaoudatos & Apostolopoulos (1986) estimated a maintenance requirement of 2.077 % body weight (WW of food / WW of fish), for 10 month old *S. aurata*, with body length between 13.2 and 16 cm and body weight between 69 and 75.9 g. The food ration used was chopped jack mackerel without bones and skin, and the temperature varied between 24-26°C. It seems than a feeding ratio between 1 and 2 % would be admissible for giltheads larger than 200 g (that is, one year old giltheads).

Assuming a total gilthead biomass varying between 4.5 g $m^{-2}$ (150 kg $ha^{-1}y^{-1}$, with 30 % gilthead, see Chapter I) and 22.5 g $m^{-2}$ (300 kg $ha^{-1}y^{-1}$, 75 % gilthead), and a daily feeding ratio varying between 1 and 2 %, the total food consumed would vary between 16.4 and 161 DW g $m^{-2}$. The conversion ratio of DW into AFDW can vary widely, between 0.08 and 0.7 (see table 4.2), depending upon whether the fauna is composed mainly of small polychaetes or large gastropods. Considering a mean conversion factor of 0.4, the total food consumption could vary between 6.56 and 64 AFDW g $m^{-2}y^{-1}$. This last figure would imply that at sites A and C with a gilthead production of 22 g $m^{-2}y^{-1}$, a daily feeding ratio of 2 % would not be possible, because the macrofauna production would not be large enough to support the fish consumption. These estimates are only approximate but greater precision would be achieved following further published experimental work.

## 6.2 Conceptual model

A simple model will be developed in the next sections. The model will simulate the production of benthos and its consumption by a population of *Sparus aurata*. The expected final yield of giltheads will be determined in this way. The model will be based on the environmental information described in the previous chapters relative to the four studied sites and on published data on *Sparus aurata* growth and feeding.

The first section will describe the individual growth of the gilthead. Afterwards the growth will be extrapolated to a population of a known initial mean individual weight and with a given density.

The next section will describe the feeding of the gilthead. Again, the individual feeding behaviour will provide the basis. The feeding will then be generalised to the whole population.

The third section will describe the growth of the benthos and the effect of *Sparus* predation on benthic production will be simulated.

The fourth section will describe the forcing functions, in this case, the main environmental factors and their effect both on *Sparus* growth and on benthos growth. The results obtained by the application of canonical correspondence analysis were used to select the most important environmental factors, the mean BOD variation and the difference between the maximal and the minimal salinity concentrations. The mean water temperature will also be considered, as it is known to effect growth.

The last section will attempt to relate the growth of the fish to the growth of the benthos, under the effect of the forcing functions. The availability of appropriate fish food will be considered.

The model will simulate the fluxes of energy from the two size classes of benthos to the fish population (Fig. 6.1). It will be a dynamic model, as the variables defining the system will be a function of time (see Jørgensen, 1986, for definitions).

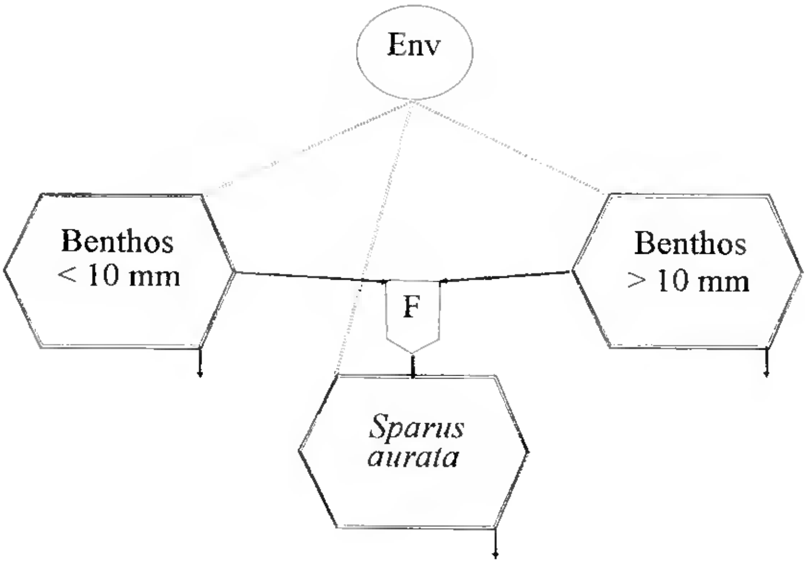


Fig. 6.1 Conceptual model. Env - Environmental forcing functions - temperature, BOD and difference between the maximal and minimal salinity values during a neap-spring cycle. Growth of benthos smaller or larger than 10 mm, and growth of a population of *Sparus aurata* of a known initial weight and density. F - Feeding on both classes of benthos by the fish population, depending on fish size and food availability.

Although the model describes fluxes of energy, the state variables will be expressed in units of biomass, to allow a direct comparison with the data already obtained in the previous chapters. The model will simulate the growth of benthos in AFDW g $m^{-2}y^{-1}$. The growth of the fish population will be expressed in different biomass units, in WW g $m^{-2}$ $y^{-1}$, to facilitate direct comparison with aquaculture texts. However, the consumption of benthos by the fish population (function F) will be converted into AFDW g $m^{-2}y^{-1}$, instead of being expressed in the usual way, that is, in % of DW of food / WW of fish. This function, F, will be the connecting link among the three state variables.

### 6.3 *Sparus aurata* growth

Tandler *et al* (1982) presented the following equation describing the relative daily growth rate (g) of *S. aurata* (percentage weight increase $g^{-1}$ fish weight $day^{-1}$) based on forty-six weight classes:

$$\ln g = 1.9218 - 0.4831 \ln W \quad \text{or} \quad g = 6.8332\ W^{-0.4831} \qquad (1)$$

Where W is the weight of the fish and g the relative daily growth rate. From this equation is possible to determine the weight of a fish after any period of time. The daily growth (in grams) is given by:

$$W_i = g / 100\ W_{i-1} + W_{i-1}$$

Where $W_i$ is the final weight and $W_{i-1}$ the initial weight. The weight $W_t$, after a period of time t, would be:

$$W_t = \sum_{i=1} [(0.068332\ W_{i-1}{}^{-0.4831}) * W_{i-1} + W_{i-1}] \qquad (2)$$

Where i = 1, 2, ..,t; t = total number of days considered.

Applying those equations, a fish with an initial weight of 5 g will attain, after a year (t=365 days), a weight of 242.5 g. A fish with an initial weight of 2 g will weigh of 215.5 g, after the same time interval (Fig. 6.2). The daily rate of growth decreases as the fish becomes heavier, that is, as fish grow larger, the weight increases by a smaller percentage of their current body weight.

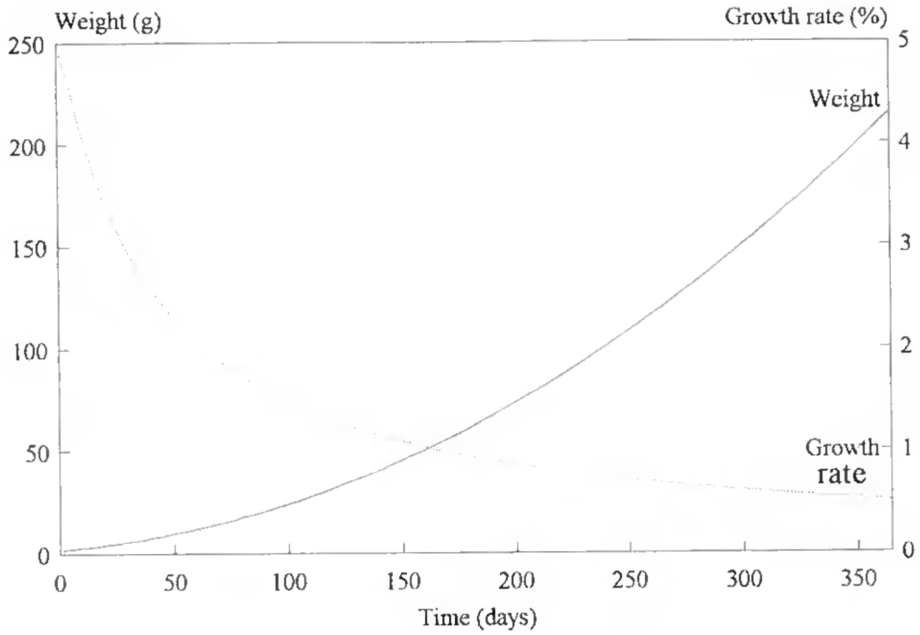


Fig. 6.2. Weight and daily growth rate (%) of *Sparus aurata* during one year. Initial weight 2 g and final weight 215.5 g.

Klaudatos & Apostolopoulos (1986) refer to 10 month old giltheads grown in Greece as having a mean weight of 76 g. By application of equation (2) it can be calculated that a gilthead with an initial weight of 2 g will weigh 76 g after 205 days (approximately 7 months). A 2 g gilthead can be produced in three or four months (Pousão-Ferreira, 1988), which means that a gilthead of 76 g is approximately 10 months old. It seems that the Greek data are in accordance with Tandler's equation, which was developed for the warm waters of Israel. Furthermore, the relative daily growth rates found by application of equation 1, or by Klaudatos & Apostolopoulos (1986) are similar for giltheads with a mean weight of 76 g. The rates are 0.84 % and 0.89 % respectively. However, the data of Francescon *et al* (1988) indicate a higher growth rate. These authors refer to fish weighing of 89 g after six months, in a semi-intensive aquaculture regime and a initial weight of 2.4 g.

The relationship between the length (L in cm) and weight (W in g) of the gilthead is given by (Monteiro, 1989):

$$W = 0.0108\ L^{3.085} \qquad (3)$$

From this equation it can be concluded that a gilthead of 2 g has an approximate length of 5.4 cm. Wild fingerlings of this length are found only in May in the Ria Formosa (Monteiro, 1989). In Cádiz the situation is similar, until April only giltheads smaller than 4.1 cm are found (Drake & Arias, 1989). The same is the case in Arcachon (Labourg *et al*, 1985). It is, therefore, to be expected that fish weighing 215 g will occur only in April or May of their second year.

However, Arias (1980) refers to giltheads of mean length of 24.4 cm and mean weight of 211.8 g caught in November in the Cádiz salt-pans. That implies a higher daily grow rate. Dinis *et al* (1989) also refer to similar catches in Ria Formosa. Labourg (1976) refer to giltheads of a mean length 28 cm and mean weight 300 g after only one year and a half. These data refer to the colder French waters of Arcachon, where a lower growth rate is to be expected. However, Frentzos and Sweetman (1989) also refer to a market size of 300 g only after 14 to 18 months, in the warm waters of Greece. It seems, therefore, that there is some confusion concerning the growth rate of *S. aurata*.

The mean specific growth rate (SGR) is given by (see Winberg, 1971 or Knights, 1985):

$$SGR = (\ln W_t - \ln W_0) / \text{time}$$

Where $W_t$ is the final weight and $W_0$ the initial weight. The time is equal to the total number of days considered. SGR is assumed to be constant during the interval of time considered. For a gilthead with an initial weight of 2 g and a final weight of 215.5 g, the SGR is equal to 0.01282. If the period of time considered is small enough, the instantaneous rate of growth (dW/dt) is then (Cuenco *et al*, 1985a):

$$dW/dt = SGR * W$$

Where dW/dt is the instantaneous rate of growth of weight W, SGR is the constant of growth, and t is time. The growth can, in this way, be described by an exponential expression, relating the weight of the fish to time (Hepher, 1988, Wienberg, 1971):

$$W = W_0 \, e^{SGR \, t}$$

Where W is the fish weight after a time t in days, SGR is the constant of growth, and $W_0$ is the initial weight. If $W_0 = 2g$, $SGR = 0.01282$ and $t = 365$ days, than $W = 215.4$ g.

Although the exponential growth equation can be easily developed from experimental data, and is application well explained in aquaculture books (Hepher, 1988 and Tytler & Calow, 1985), its use is only applicable to short periods of time (Winberg, 1971; Cuenco *et al*, 1985a). It can not be applied for long periods during which the growth rate decreases substantially with increase in body weight (see Fig. 6.2). Winberg (1971) developed an expression that he called "the parabolic growth" where the SGR decreases proportionally to the weight of the fish:

$$SGR = 1/W \, dW/dt = N \, W^{-n} \tag{4}$$

and

$$dW/dt = N \, W^{(1-n)} \tag{5}$$

Where N is a constant relating the metabolic loss of an individual of unit size and the utilisation of assimilated food for growth and n is a constant such that $0<n<1$ (Wienberg, 1971). The values of N and n can be found for *Sparus aurata* by the comparison of expressions 1 and 4. In this case, the differential expression to describe the growth of the gilthead would be:

$$dW/dt = 0.068332\ W^{0.5169}$$

The integral form of this expression shows the weight as a function of time (adapted from Winberg, 1971):

$$W = (n\ N\ t + W_0^{n})^{(1/n)}$$

Applying the parameters already estimated for the gilthead, and considering a fish of an initial weight of 2 g, this last expression can be written as:

$$W = (0.4831 * 0.068332 * t + 2^{0.4831})^{2.07} \qquad (6)$$

After one year (t = 365 days) the weight is 216.9 g. The development of this expression corresponds closely to the curve described by expression 2 (Table 6.1).

The full development of the gilthead would imply that the growth rate tends to zero as the definitive size and weight is approached. However, because growth efficiency decreases as individuals grow, farmers should slaughter their animals young (Reiss, 1989). As a consequence, the application of other growth expressions of limited growth such as the logistic equation (Wienberg, 1971; Jørgensen, 1986) do not seem to be justifiable in the present model.

Due to the intervention of the fish farmer, the conditions in the fish pond are different from those of natural waters. The growth rate is maximised by the control of the environmental conditions (Hepher, 1988). According to Reiss (1989) the maximal growth rate in fish may be obtained by making n equal to 0.61. The value determined by Tandler *et al* (1982) is slightly smaller.

| Time (days) | Tandler's growth (g) | Exponential growth (g) | Parabolic growth (g) |
|---|---|---|---|
| 1 | 2.10 | 2.03 | 2.10 |
| 10 | 3.09 | 2.27 | 3.10 |
| 50 | 9.95 | 3.80 | 10.05 |
| 100 | 24.37 | 7.21 | 24.60 |
| 150 | 45.48 | 13.68 | 45.88 |
| 200 | 73.44 | 25.98 | 74.02 |
| 250 | 108.35 | 49.31 | 109.14 |
| 300 | 150.31 | 93.61 | 151.33 |
| 350 | 199.41 | 177.71 | 200.67 |
| 365 | 215.54 | 215.39 | 216.87 |

Table 6.1. *Sparus aurata* growth according to Tandler *et al* (1985) and to exponential or parabolic growth equations.

Using the program SYSL - System Language Program, a short program to describe the growth of *Sparus aurata* might be:

```
TITLE SPARUS GROWTH
INTEG RKM
* S - Exponential growth, W - Parabolic growth
*
PARAM SGR=0.01282,N=0.068332,AB=0.5169
INCON S0=2.,W0=2.
*
      DST=SGR*S
      DWT=N*W**AB
```

```
      S=INTGRL(S0,DST)
      W=INTGRL(W0,DWT)
*
TIMER FINTIM=365.,DELT=0.05,DELGR=3.65
*
PREPAR S,W
PSAVE
PLOTS MERGE,MODEL=97,IOPORT=97
GRAPH SAME,TIME,S,W
*
END
STOP
```

The last model was developed considering only the growth of a single fish. If a population of a certain density per square metre is considered the daily rate of growth is the same, but the constant N will be different. Expression 1 must be rewritten as:

$$\ln g = \ln (N * 100) - 0.4831 \ln (W * d) \qquad (7)$$

Where d is the density of the fish population (number of individuals $m^{-2}$). Joinning the two expressions, 1 and 7, N can than be determined:

$$1.9218 - 0.4831 \ln W = \ln (N * 100) - 0.4831 \ln (W*d)$$

$$\ln (N * 100) = 1.9218 + 0.4831 ( - \ln W + \ln W + \ln d)$$

$$= 1.9218 + 0.4831 \ln d$$

Considering a biomass of *Sparus aurata* varying between a minimal value of 4.5 g and a maximal value of 22.5 g $m^{-2}$, the corresponding density will vary between 0.021 and 0.104 individuals $m^{-2}$, for a population composed of fish of 215.5 g mean final weight. However, if a mortality of about 30 % is expected to occur (Pousão-Ferreira, 1988) then the initial density should be 30 % higher, that is 0.027 and 0.136 individuals $m^{-2}$, considering a final biomass of 4.5 and 22.5 g $m^{-2}$

respectively. The initial weight will vary correspondely with the initial density. The new parameters, and the respective codes, are summarised in table 6.2.

The differential equation of the *Sparus aurata* growth considering a constant mortality rate M, is than:

$$dW/dt = N\ W^{(1-n)} - M\ W$$

For a mortality of 30 % the value found for the constant M, after simulation, is 0.00133.

| **Biomass** g m$^{-2}$ | **Mortality** % | **Density** ind m$^{-2}$ | **Initial Weight** g | **Code** | **N** | **Code** |
|---|---|---|---|---|---|---|
| 4.5 | 0 | 0.020882 | 0.04176 | L0 | 0.01054 | NL |
| 4.5 | 30 | 0.027146 | 0.05429 | LM0 | 0.01197 | NLM |
| 22.5 | 0 | 0.104408 | 0.20882 | H0 | 0.02294 | NH |
| 22.5 | 30 | 0.135731 | 0.27146 | HM0 | 0.02604 | NHM |

Table 6.2. Parameters used in the *Sparus aurata* growth model according to different final biomasses, considering either zero mortality or a mortality of 30 % and corresponding Codes used in the model. The initial and final individual weights considered were 2 g and 215.5 g respectively.

The program written in SYSL language to describe the four growth curves, using only the "parabolic" growth expression, can be found in Appendix A4 - Model 1. The corresponding plot can be seen in Fig. 6.3. The final biomass is the same, with or without 30 % of mortality, but the shape of the growth curve is slightly different.

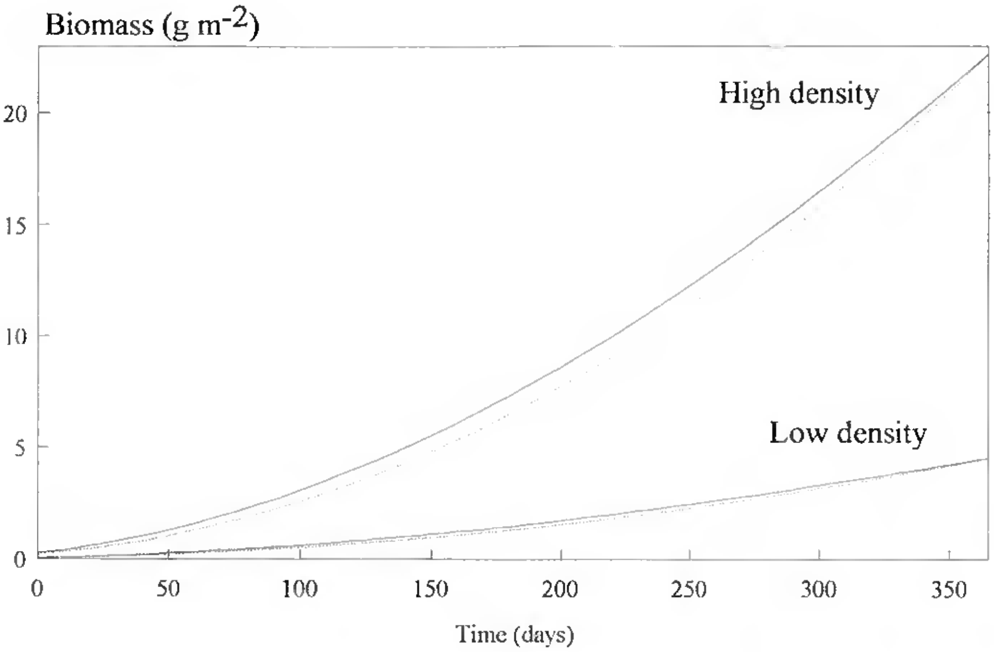


Fig. 6.3. Simulation of *Sparus aurata* growth with different densities and with (full line) or without (dashed line) mortality. Initial individual mean weight: 2 g.

## 6.4 *Sparus aurata* food consumption

As a fish increases in weight, its relative food requirement decreases (Cuenco *et al*, 1985b). According to Klaoudatos & Apostolopoulos (1986) the relationship between the daily rate of feeding - f (% Wet Weight of food / fish Wet Weight - WW/WW) of *Sparus aurata*, and the daily rate of growth - g, follows a first order linear regression: $g = 0.18676\ f - 0.38795$. From this equation, the daily rate of feeding can be estimated, as well as the quantity of food consumed per day and the total food consumed during a period of time.

The daily rate of feeding ($f_i$ - in percentage), in the i th day, is then:

$$f_i = (g_i + 0.38795) / 0.18676 \qquad (8)$$

The quantity of food consumed each i th day ($df_i$ - in grams) will depend on the weight of the fish:

$$df_i = W_i * (f_i / 100) \qquad (9)$$

From this last expression the total food consumed during a period of time of t days can be determined ($TC_t$ - Total food consumed in grams):

$$TC_t = \Sigma\, df_i$$

or

$$TC_t = \sum_{i=1} W_i * (f_i / 100) \qquad (10)$$

Where i = 1, 2,.., t; t = total number of days considered.

A fish with an initial weight of 5 g would have consumed 1984 g of food in one year during which it would have reached a weight of 242.5 g. A fish with an initial weight of 2 g and a final weight of 215.5 g would have consumed 1744 g of food after a year (Fig. 6.4). The daily rate of feeding is high when the fish is small and the daily growth rate is high, and decreases to a mean rate of 5 % after one year.

Klaoudatos & Apostolopoulos (1986) determined the relationship between f and g, feeding the fish with pieces of jack mackerel without bones or skin. All the calculations were done using wet weights (WW). The result must also be expressed as the percentage of WW food / WW fish. The conversion factor of WW into AFDW after laboratory measurements using jack mackerel gave a factor of 0.19 if only meat without skin and bones is considered or a factor of 0.21 for meat with skin and bones (Table 6.3). A mean factor of 0.20 will be used.

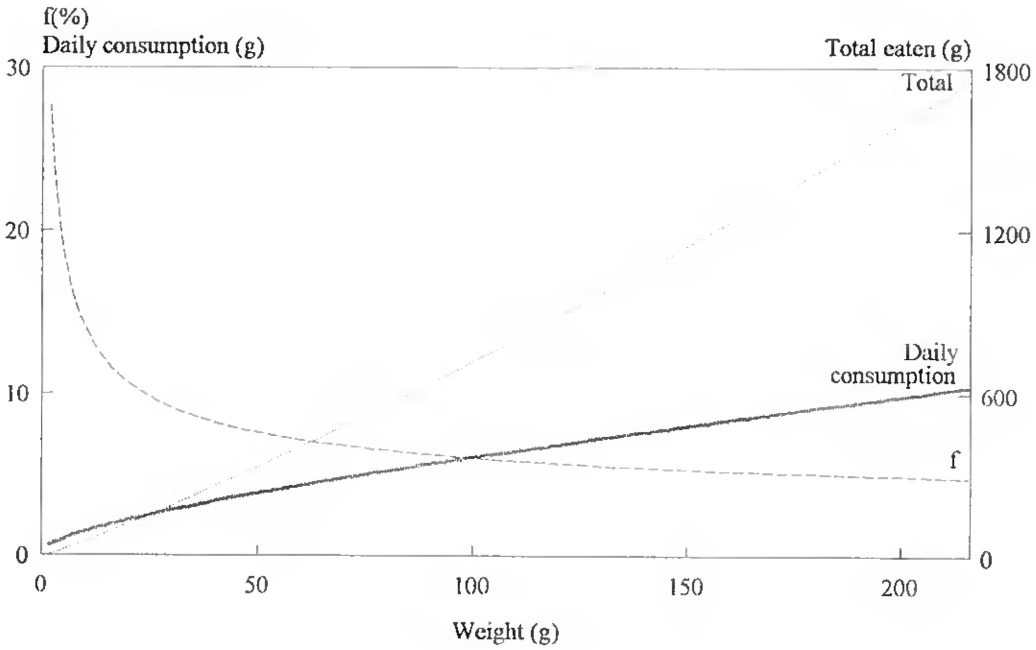


Fig. 6.4 - Relationship between daily rate of feeding f (%) and daily consumption with fish body weight and total food consumed after a year. Initial fish weight: 2 g.

| | DW/WW | AFDW/WW | AFDW/DW |
|---|---|---|---|
| Only meat | 0.21 | 0.19 | 0.92 |
| Meat with skin and bones | 0.27 | 0.21 | 0.80 |

Table 6.3. Conversion factors of wet weight (WW) into dry weight (DW) or ash free dry weight (AFDW) considering only jack mackerel meat or meat with skin and bones.

The results shows that a fish with an initial weight of 5 g and a final weight of 242.5 g, would have consumed, after a year, 396.8 AFDW g of food. The conversion of this results into total food consumed per unit area will give, assuming again a biomass of fish of 4.5 or 22.5 g $m^{-2}$, a consumption of 7.36 to 36.82 AFDW g $m^{-2}$ of food. If a population of fish with an initial mean weight of 2 g is considered, the total food consumed after a year will vary between 7.28 and 36.42 AFDW g $m^{-2}$, depending on fish density. An annual consumption of 36 or 37 AFDW g $m^{-2}$ would be higher than the annual production estimated in two of the four lagoons studied (Sites A and C). Those lagoons do not have a natural potential to support such a high density of fish without the addition of food.

Applying the expressions mentioned previously, a fish of 200 g will have a daily rate of growth of 0.528 % and a daily rate of feeding of 4.91 %. It will consume 9.8 g of meat (WW) per day or 2.06 DW g, which gives an approximate percentage of 1 % of body weight (DW of food / WW of body weight). This value is lower than the recommended percentage rate of feeding of 1.3 to 1.6 % given by the commercial diet producers or referred to in the bibliography. However, if the food consumptions are converted into caloric content, than the difference may be smaller, because the caloric content of fish meat is higher than that of commercial diets. Fish has an average caloric content of 5 kcal $g^{-1}$ DW (Crisp, 1984). This value can be higher, for instance Evans (1984) indicates 5.5 kcal $g^{-1}$ DW for *Pleuronectes platessa* and *Pomatoshictus minutus*. The caloric content of the food consumed daily by a gilthead of 200 g would vary between 10.3 and 11.3 Kcal.

The energy content of commercial diets can be determined by the expression (Winberg, 1971):

$$\text{Caloric value (kcal } g^{-1}) = (5.65\,P + 4.10\,C + 9.45\,F) / 100$$

Where P, C and F represent the percentage of content of protein, carbohydrate and fat, respectively. The application of this expression gives an energy content of only 4.31 kcal $g^{-1}$ DW in a commercial diet frequently used in Portuguese aquaculture systems. Fernández-Palacios *et al* (1989) referred to three commercial diets used in *S. aurata* feeding with an energy content varying form 4.3 to 4.8 kcal DW $g^{-1}$. As the caloric content is 16 to 28 % lower than if a fish meat based diet is used, the difference in the feeding ratio is not so high.

Assuming again a daily consumption of 9.8 g of meat (WW) by a fish of 200 g, and a conversion factor of WW into AFDW of 0.2 (Table 6.3), a daily consumption of benthic preys of 1.96 AFDW g is obtained. Brey *et al* (1988) indicate a mean value of 23.1 KJ $g^{-1}$ AFDW, for benthic invertebrates, or 5.5 Kcal $g^{-1}$ AFDW. The consumption of 1.96 AFDW g of benthos will correspond to a daily consumption of 10.78 Kcal. This value lies inside the interval already determined when fish meat is considered. It seems that expression 8 and the conversion factor from WW into AFDW of 0.2 can be used in the model.

To have an idea of how much prey corresponds to a biomass of benthos of 1.96 AFDW g, some back calculations are needed. Assuming that a fish of 200 g can already eat prey of 10 mm, and that a *Cerithium vulgatum* of that size has a mean DW weight of 0.05954 g (see fig. 4.1) and a mean AFDW of 0.006 g (see table 4.2), a fish of 200 g would have to consume, daily, approximately 330 gastropods of 10 mm. This number seems high but it is in accordance with the findings of Robert & Parra (1991). Those authors recorded a daily ingestion of 500 or more small clams by giltheads of 25 cm length.

Klaoudatos & Apostolopoulos (1986) indicate a daily rate of growth of 0.893 for giltheads with a mean weight of 76.2 g, and a daily ratio of feeding of 7.0 %, the satiation level for this class of fish. The application of Tandler *et al* (1982) relative daily growth equation gave a growth rate slightly lower, of 0.842 and a lower f, of 6.6 %. This could signify that the growth equation was determined at conditions close to the satiation level, and that the results would not be very different from an optimal situation where the gilthead feeds the whole year round. However, at optimal conditions the daily growth rate would, perhaps, be slightly higher and, consequently, the feeding rate would also be higher.

The development of expressions 8 and 9, together with expression 1, gives:

$$df_i = W_i * ((6.8332\ W_i^{-0.4831} + 0.38795) / 0.18676) / 100$$

$$df_i = W_i * (0.365881\ W_i^{-0.4831} + 0.020773)$$

The integration of this expression, if written in a differential form will give the total food consumed (equivalent to expression 10):

$$dF/dt = W * (0.365881\ W^{-0.4831} + 0.020773) \qquad (11)$$

Where:

$$F_{t+1} = F_t + W_t * (0.365881\ W_t^{-0.4831} + 0.020773)$$

If we subtract F from expression 11, we will have the daily food consumed written in a differential form:

$$dF/dt = W * (0.365881\ W^{-0.4831} + 0.020773) - F \qquad (12)$$

The initial value of F, for a fish of 2 g is:

$$F_0 = 2 * (0.365881 * 2^{-0.4831} + 0.020773) = 0.565 \text{ g}$$

A model written in SYSL language to describe the daily food consumption by *Sparus aurata* can be found in Appendix A4 - Model 2. The plot resulting from this model is represented in Fig. 6.5.

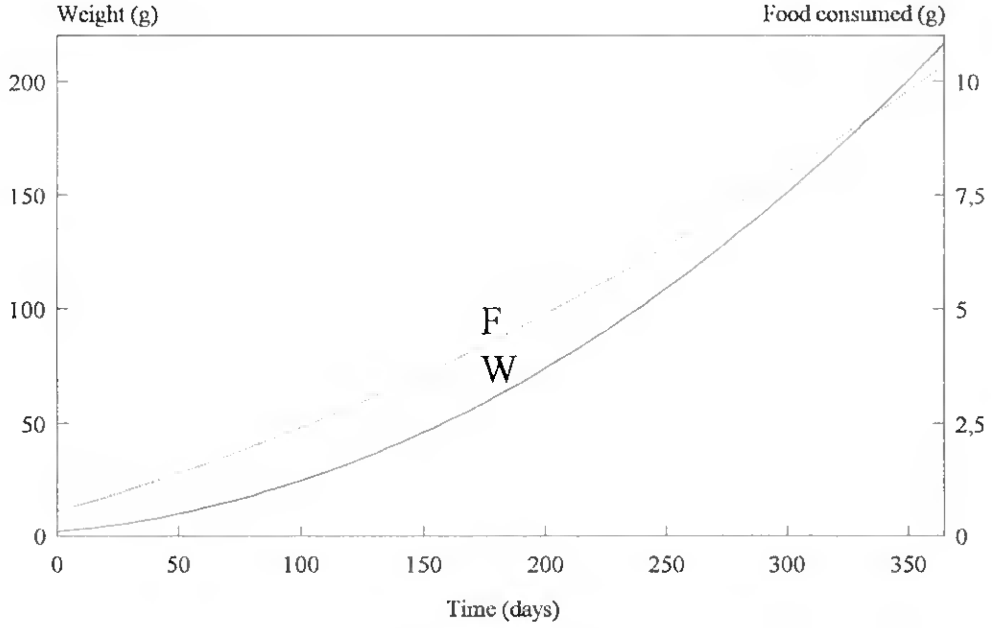


Fig 6.5. Simulation of the relationship between *Sparus aurata* growth (W) and daily food consumed (F) during one year. Initial weight 2g.

The growth constant N will be different if a fish population of a certain density is considered instead of a single fish, as has been demonstrated in the last section (see expression 7 and its development). In this case, expressions 11 and 12 must also be changed. The constant 0.365881 must be replaced by N/0.18676.

As all the determinations of benthic production were done in AFDW g $m^{-2}$ units it would be of interest for the model to express the daily food consumption in AFDW g of food $m^{-2}$. Assuming again a mean conversion factor of WW into AFDW of 0.20, expression 12 must be rewritten as:

$$dF/dt = (W * (N / 0.18676\ W^{-0.4831} + 0.020773)) * 0.2 - F$$

The parameters necessary to model the growth of a population of *Sparus aurata,* with a mortality of 30 % and a final biomass of 4.5 or 22.5 g m-2, considering again an individual initial fish weight of 2 g and a final weight of 215.5 g, are summarised in table 6.4.

|  | Low density | Code | High density | Code |
|---|---|---|---|---|
| Initial weight | 0.05429 | LM0 | 0.27146 | LH0 |
| N | 0.01197 | NLM | 0.02604 | NHM |
| NF | 0.064093 | FCL | 0.139430 | FCH |
| Initial F | 0.003069 | FL0 | 0.015340 | FH0 |

Table 6.4. Parameters used in *Sparus aurata* growth and feeding model according to different final biomasses with a mortality of 30 % and corresponding codes used in the model. N - growth constant, NF - growth constant used in the daily food consumption expression. Initial F - food consumed by the initial fish population on day 0. The initial and final individual fish weights considered were 2 g and 215.5 g respectively.

The program written in SYSL language, to describe the growth of the two fish populations and their corresponding daily food consumption can be found in Appendix A4 - Model 3. The resulting plot from this model is represented in fig. 6.6.

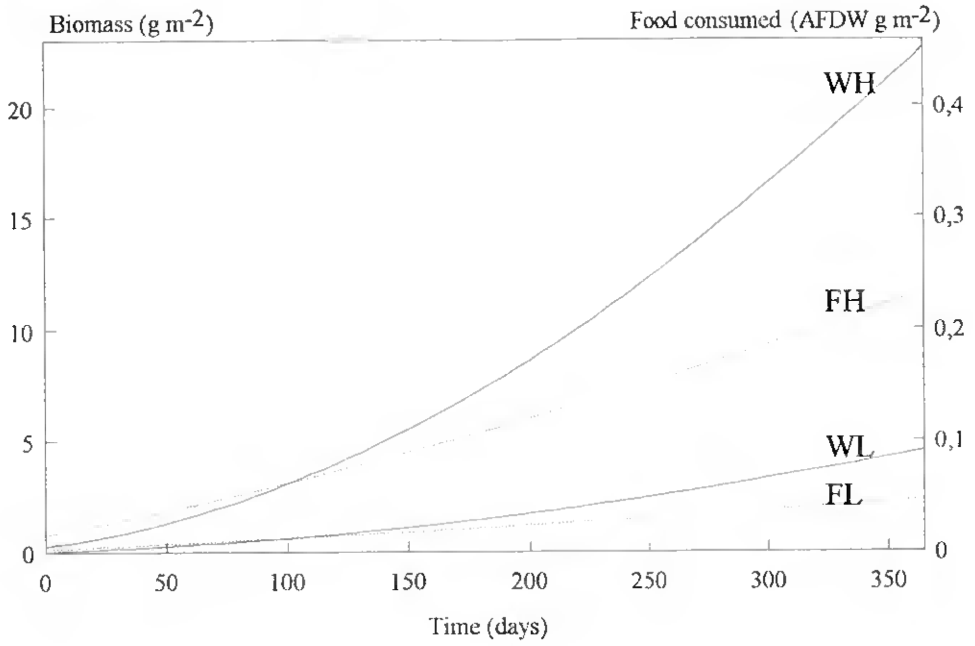


Fig. 6.6. Simulation of *Sparus aurata* growth considering different initial densities (WH - High density, WL - Low density) and the corresponding daily food consumptions (FH - high density population food consumption and FL - low density population food consumption).

## 6.5 Benthic Production

In the cool temperate waters of Northern Europe there is an increase in benthic production during the warm months (Beukema, 1974; Pihl & Rosenberg, 1982). The same happens in the warm waters of Ria Formosa (Sprung, 1994). However, in some of the studied sites, due probably to the simultaneous increase in salinity and deterioration of the environment, the biomass of benthic organisms decreases during the summer months (see Chapter 4).

In a preliminary model, as a simplification, the benthic production was assumed to be constant over all months of the year. The relationship between production and time must then be linear. Every month the benthic biomass is increased by a constant quantity. The function B, which gives the increase in benthic biomass due to production is:

$$B_t = PB * t + B_0$$

Where t is the time in days, PB the daily benthic increment and $B_0$ is the initial biomass, which in the model, as a simplification, corresponds to the mean annual biomass. PB can be determined dividing the annual production by the number of days. Taking for example the total benthic production and annual biomass in site A during the first year of study, 1985 (see Table 4.3), $B_0 = 11.8$ and $PB = 37.3 / 365 = 0.10219$. A differential expression to described this increase can be written as:

$$dB/dt = PB$$

Of course not all the production is available as food for the gilthead. Part of it is spent as reproductive effort or is consumed by other predators. As a simplification, this lost (MB) will be considered constant and equal to 30 % of the total production divided by the time. The differential equation to describe the benthic growth will be:

$$dB/dt = PB - MB$$

The parameters PB and MB are different at each site, as they vary with the total production estimated. Their values have been determined for each site at each year of study (Table 6.5).

If a population of giltheads is present, the benthic production will decrease by a quantity F taken daily. In this case the differential equation must be changed to:

$$dB/dt = PB - MB - F$$

Where:

$$B_{t+1} = B_t - MB_t - F_t$$

A model considering only the benthic production and its decrease due to the predation by *Sparus aurata*, taking the benthic parameters for site A during the first year, and a final fish biomass of either 4.5 or 22.5 g $m^{-2}$ can be found in Appendix A4, Model 4. The model was modified to allow the simulation of the benthos biomass variation at site B. The results of these simulations can be seen in Fig 6.7.

| **Benthos** | **Site / Year** | **Biomass** AFDW g $m^{-2}$ | **Production** AFDW g $m^{-2}y^{-1}$ | AFDW g $m^{-2}$ $d^{-1}$ | AFDW g $m^{-2}$ $d^{-1}$ |
|---|---|---|---|---|---|
| | | $B_0$ | | PB | MB |
| <10mm | A 85 | 11.3 | 37.1 | 0.10164 | 0.03049 |
| <10mm | 86 | 6.6 | 19.3 | 0.05288 | 0.01586 |
| <10mm | B 85 | 16.2 | 52.4 | 0.14356 | 0.04307 |
| <10mm | 86 | 16.5 | 53.7 | 0.14712 | 0.04414 |
| <10mm | C 85 | 5.7 | 16.8 | 0.04603 | 0.01381 |
| <10mm | 86 | 6.5 | 20.9 | 0.05726 | 0.01718 |
| <10mm | D 85 | 8.9 | 30.5 | 0.08356 | 0.02507 |
| <10mm | 86 | 10.1 | 32.5 | 0.08904 | 0.02671 |
| | | $B_0$ | | PB | MB |
| >10mm | A 85 | 0.5 | 0.2 | 0.00055 | 0.00016 |
| >10mm | 86 | 0.5 | 0.3 | 0.00082 | 0.00025 |
| >10mm | B 85 | 31.0 | 15.5 | 0.04247 | 0.01274 |
| >10mm | 86 | 27.0 | 13.4 | 0.03671 | 0.01101 |
| >10mm | C 85 | 22.4 | 11.2 | 0.03068 | 0.00921 |
| >10mm | 86 | 10.7 | 5.4 | 0.01479 | 0.00444 |
| >10mm | D 85 | 42.5 | 21.3 | 0.05836 | 0.01751 |
| >10mm | 86 | 27.3 | 13.7 | 0.03753 | 0.01126 |
| | | $B_0$ | | PB | MB |
| Total | A 85 | 11.8 | 37.3 | 0.10219 | 0.03066 |
| Total | 86 | 7.1 | 19.6 | 0.05370 | 0.01611 |
| Total | B 85 | 47.2 | 67.9 | 0.18603 | 0.05581 |
| Total | 86 | 43.5 | 67.1 | 0.18384 | 0.05515 |
| Total | C 85 | 28.1 | 28.0 | 0.07671 | 0.02301 |
| Total | 86 | 17.2 | 26.3 | 0.07205 | 0.02162 |
| Total | D 85 | 51.4 | 51.8 | 0.14192 | 0.04258 |
| Total | 86 | 37.4 | 46.2 | 0.12658 | 0.03797 |

Table 6.5. Parameters PB and MB (daily benthic production and daily benthic losses) at each site and in each year of study, according to the class of benthos considered (< or > than 10 mm maximal length or total).

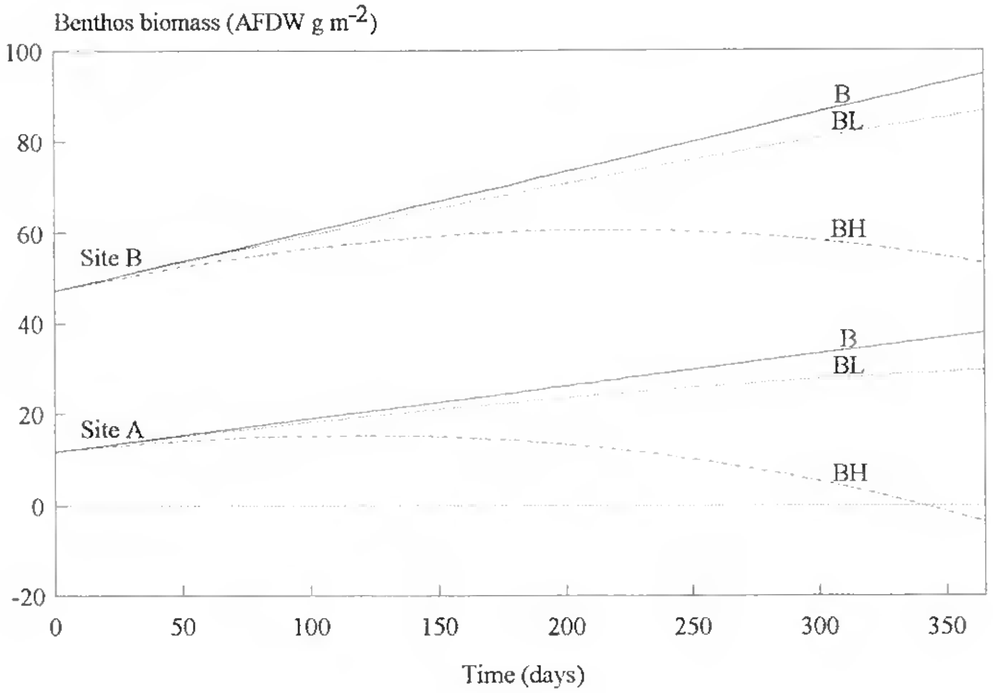


Fig. 6.7. Simulation of benthic biomass (total biomass) at sites A and B, in 1985, considering no predation by *Sparus aurata* (B), predation by a low density population (BL) or predation by a high density population (BH).

## 6.6 Environmental factors

There are several expressions relating temperature and growth (e.g. Jørgersen, 1986) but most of them take into account the optimal temperature for the species in consideration. As there is no information about the optimal temperature for most of the benthic species from Ria Formosa, the expression proposed by Chen *et al.* (1975 in Jørgersen, 1986) was chosen:

$$FT_t = K\,20 * KOT^{(TE_t - TM)}$$

Where K20 and KOT are constants, TM is the mean temperature during the year in consideration and TE the temperature at time t at each site. If K20=1 and KOT=1.05 the function FT will vary around unity (Fig. 6.8). Growth rate, multiplied by this function, will vary. During the hot summer months the rate will increase and during the winter it will slow down.

There is little information about the influence of environmental factors on the benthic populations of Ria Formosa, but as it was shown in Chapters 3 and 4, the differences in salinity between the neap and the spring tides were strongly related to the benthic populations present in the fish ponds studied. In sites with less water renewal the variation of salinity was large and the populations present were characterised by small opportunistic species. The lack in water renewal had also as a consequence large variations of other factors, such as pH and suspended matter, and low primary production. The decrease in benthic biomass during the summer months in the sites with less water renewal can signify that large environmental variations affect benthic adversely. In contrast to what normally happens with the seasonal increase of temperature, these variations had a negative influence on the growth and development of the populations. We can then consider a new function, FS:

$$FS_t = 1.05^{(SM - SA_t)}$$

Where $SA_t$ is the difference between the salinity in the neap and the closest spring tide studied at time t and SM is the mean of all the SA values. The SM for site A was very large when compared with the SM for site B. The SM of the other sites had an intermediate value (Table 6.6). It was assumed in the model that the SM of site B expressed a "normal" salinity variation for a fish pond with good water renewal and that any deviation from this value would be negatively reflected in the benthic populations. For this reason, the SM considered refers only to site B, in each of the two years studied. The variation of this function was larger at site A (Fig. 6.9) and also at site C during the second year.

The mean annual variation of BOD was also related to the benthic populations, more specifically at the intermediate sites. Again it was assumed that its effect could be negative for the development of the populations, as it is an indicator of water quality. Low BOD values are considered "good " for life, so a new function, FB, similar to the previous one was introduced:

$$FB_t = 1.05^{(BM - BO_t)}$$

Where $BO_t$ is the BOD observed at time t and BM is the mean of all the BOD values of the year in consideration, for all sites. The smallest variation of this function was observed at site A, and the highest at sites C and D (Fig. 6.10).

The inclusion of only the mean value verified at site B or the mean value verified at all sites was a difficult decision to make. In the case of the first function, the inclusion of the mean temperature verified at site B instead of the mean temperature of all sites would favour the sites with less water renewall, where, at the time of day the sampling was done, values were higher than at site B. This fact was a consequence, essentially, of the smaller dimensions and volumes of the water bodies. In order to make the model more "realistic" the mean annual temperature of all sites was chosen. The same was done with the mean annual BOD values.

The combined effect of all three forcing functions (temperature, maximum-minimum salinity values and BOD) on growth, will be equal to the product of the three functions, PD:

$$PD = FT * FB * FS$$

The temperature function is higher than unity during the summer, but the other two functions can be lower during the same period of time, and consequently the growth rate will decrease. The mean annual variation of this function was close to unity, at site B, but lower than unity at the other sites (Fig. 6.11 and table 6.6).

The same approach was done for *Sparus* growth, as there is also little information about optimal intervals for growth in natural environments. The mean temperatures found at the studied sites are close to the optimal, but the salinity values can be sometimes too high for development, and even for survival.

The mortality rate, since it is subtracted from the growth equation, could not be multiplied directly by the function PD, as this would decrease the mortality rate (and consequently increase growth) when the environmental conditions were adverse. A new function was developed, MP:

$$MP = 2 - PD$$

This function is the reverse of PD. Both functions vary around the unity. When MP is higher than unity PD is lower than unity, and biomass will increase by a smaller quantity than when the reverse is the case, that is when the environmental conditions are favourable, PD will be higher than unity and MP lower than unity.

The variation of the three forcing functions and of the other two related functions, PD and MP, were determined by Model 5 (Appendix A4).

|  | A | B | C | D |  | A | B | C | D |
|---|---|---|---|---|---|---|---|---|---|
|  | Temperature |  |  |  |  | FT |  |  |  |
| 85 | 19.69 | 19.74 | 18.90 | 19.26 | 85 | 1.06 | 1.04 | 1.02 | 1.04 |
| 86 | 21.35 | 20.24 | 19.67 | 19.65 | 86 | 1.00 | 0.96 | 0.93 | 0.95 |
|  | TM85: 19.40 |  | TM86: 20.23 |  | T | 1.03 | 1.00 | 0.98 | 0.99 |
|  | Salinity (Max-Min) |  |  |  |  | FS |  |  |  |
| 85 | 7.986 | 1.771 | 2.686 | 3.350 | 85 | 0.79 | 1.00 | 0.96 | 0.94 |
| 86 | 9.684 | 1.691 | 6.060 | 3.669 | 86 | 0.76 | 1.00 | 0.85 | 0.93 |
|  | SM85: 3.948 |  | SM86: 5.276 |  | T | 0.78 | 1.00 | 0.91 | 0.93 |
|  | BOD |  |  |  |  | FB |  |  |  |
| 85 | 2.140 | 2.229 | 2.574 | 3.134 | 85 | 1.02 | 1.02 | 1.00 | 0.98 |
| 86 | 2.194 | 2.429 | 3.673 | 3.213 | 86 | 1.04 | 1.03 | 0.98 | 1.00 |
|  | BM85: 2.519 |  | BM86: 2.877 |  | T | 1.03 | 1.02 | 0.99 | 0.99 |
|  | PD |  |  |  |  | MP |  |  |  |
| 85 | 0.81 | 1.04 | 0.96 | 0.91 | 85 | 1.19 | 0.96 | 1.04 | 1.09 |
| 86 | 0.76 | 0.97 | 0.75 | 0.86 | 86 | 1.24 | 1.03 | 1.25 | 1.14 |
| T | 0.78 | 1.01 | 0.85 | 0.88 | T | 1.22 | 0.99 | 1.15 | 1.12 |

Table 6.6. Mean annual temperature and BOD, and mean annual Maximum-Minimum salinity values. Mean annual values of the forcing functions: FT - temperature, FS - Salinity, FB - BOD, PD - Joint effect of FT, FS and FB. MP - forcing function on the mortality rate.

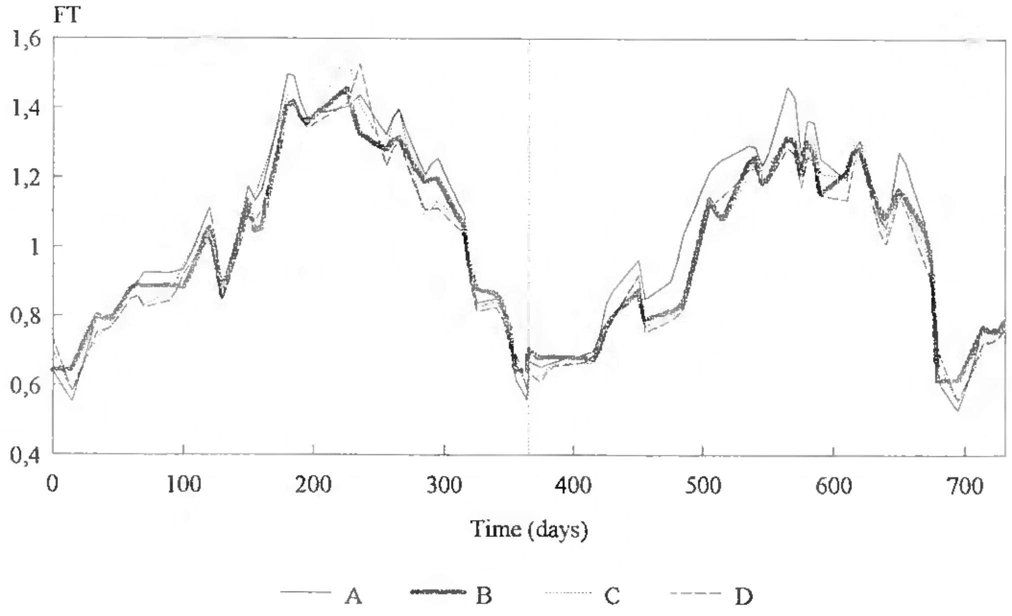


Fig. 6.8. Variation of the forcing function Temperature (FT) during the two years of study.

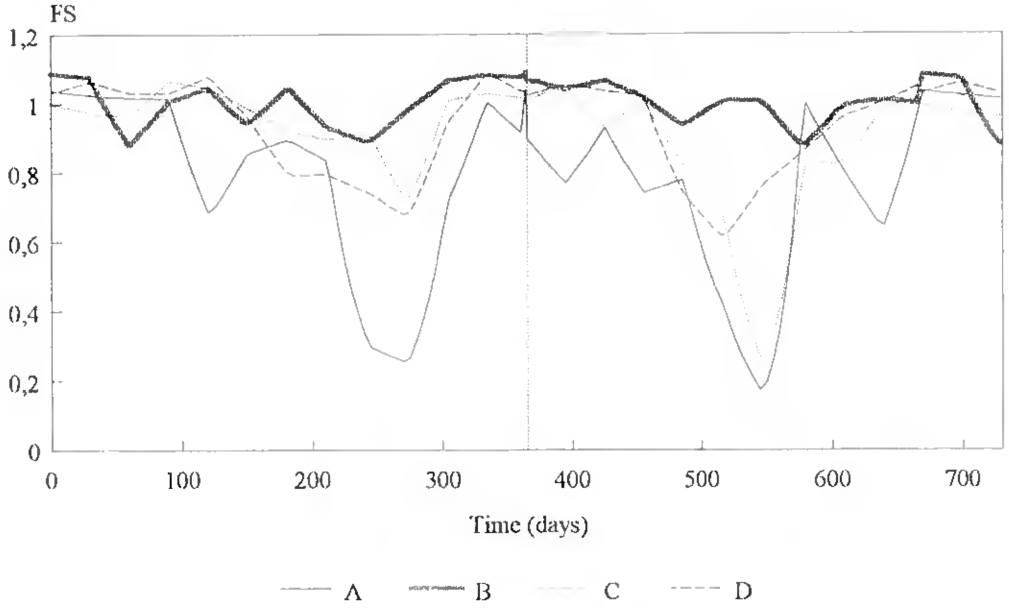


Fig. 6.9. Variation of the forcing function Maximum-Minimum Salinity (FS) during the two years of study.

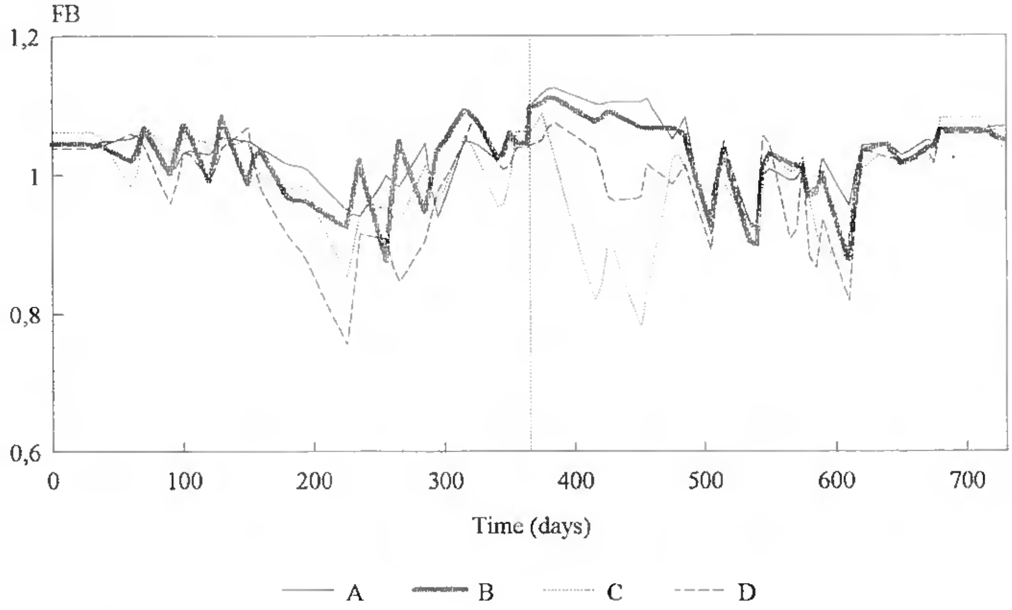


Fig. 6.10. Variation of the forcing function BOD (FB) during the two years of study.

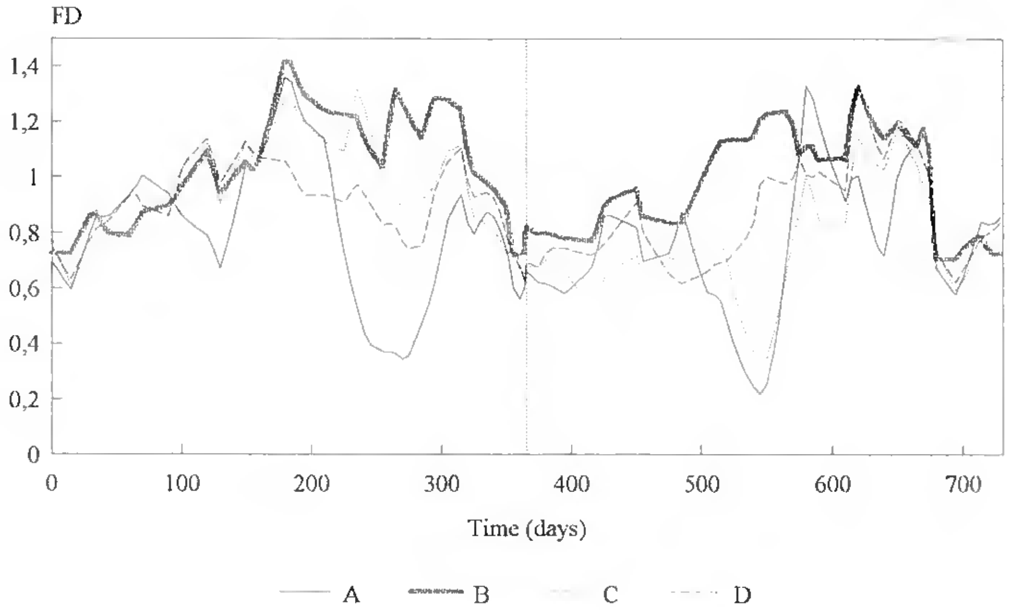


Fig. 6.11. Variation of the joint effect (PD) of the three forcing functions, FT, FS, and FB, during the two years of study.

The biomass of *Sparus aurata* or of benthos, at any time t, must include the two functions, PD and MP (see Model 6 - Appendix A4):

$$\text{Biomass} = \text{Growth rate} * \text{PD} - \text{Mortality rate} * \text{MP}$$

The inclusion modified the previous results of Fig. 6.7 (compare with Fig. 6.12). At site B, due to the favourable conditions, the final biomass of benthos is higher than when the environmental factors were not considered. The final biomass of *Sparus aurata* is also higher. Although site A has a lower final fish biomass, and consequently a lower predation rate, the final biomass of benthos is also lower, due to the adverse environmental conditions.

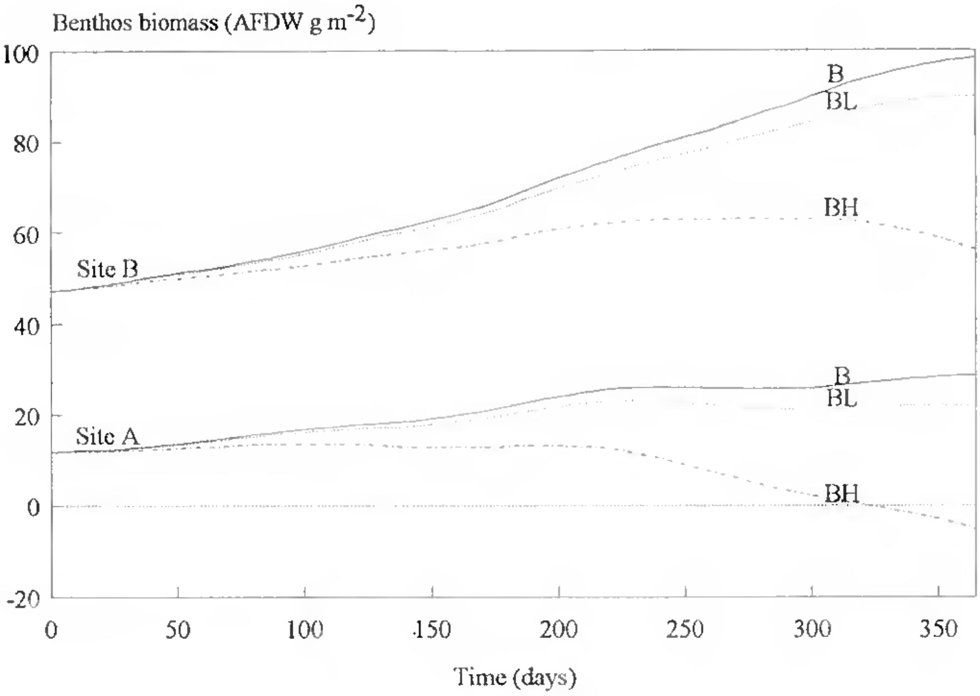


Fig. 6.12. Simulation of the total benthic biomass at sites A and B, in 1985, with the influence of the environmental factors: mean temperature and BOD and maximum-minimum salinity values. B - No predation, BL - Predation by a low density *Sparus aurata* population, BH - Predation by a high density *Sparus aurata* population.

## 6.7 Final model

The preceding sections have analysed, separately, the growth of the gilthead and benthos, the feeding and the effect of feeding on benthos. In the final section the effects of the main environmental factors were added. However, the experiments described in Chapter V showed that feeding habits change from soft prey towards larger, hard-bodied prey during fish growth. These conclusions were in accordance with other works on the same subject.

It is, therefore, necessary to modify the model such that the gilthead can change feeding habits. When no food is available the fish must stop feeding and growth must also stop, or even decrease. In order to maintain biomass, the consumption of benthos must not exceed production, so that the biomass would not reach values so low as to prevent recovery. Furthermore, negative biomasses which are generated by the simulations done in the last two sections (with the parameters defined for site A for a high density fish population) are meaningless.

In the final model it was assumed that the gilthead, after some months, would change their feeding habits to prey larger than 10 mm. This is also a simplification. In nature, the fish probably change their feeding in a gradual way, and this change must depend also on prey availability and abundance. The consideration of all these factors would make the model extremely complex, and no information exists on the parameters and selective values necessary to make the model run in this way.

The model adopted stipulates that after 330 days the gilthead stops feeding on benthic prey smaller than 10 mm and, instead, feeds exclusively on prey larger than 10 mm. After 330 days, a fish with an initial weight of 2 g will weight 180 g (see expression 6). The results in Chapter V showed that giltheads with 174 g mean weight do not eat prey larger than 10 mm, but it is known that larger giltheads do eat this size of prey (Arias, 1980; Robert & Parra, 1991).

The simulation of this hypothetical feeding behaviour was done by the introduction of a switch, the variable BF. If this variable is equal to zero, the fish feeds exclusively on benthic prey smaller than 10 mm. This happens when the variable time, in days, is smaller than 330. When time is higher than 330 the fish changes to larger prey. However, if the consumption of these prey exceeds the prey production then the fish changes again to feeding on smaller prey.

The commands used in the program were:

```
IF (TIME .LT. 330.) BF = 0.
IF (TIME .GE. 330.) BF = 1.
IF (BW2 .LT. BW20) BF = 0.
```

Where LT means less than (<) and GE mean greater or equal (≥) and BW2 refers to the biomass of the benthos with a dimension larger than 10 mm. BW20 refers to the initial biomass of that class of benthos. The production of benthos will be decreased by the quantity F multiplied by the variable BF. If the value of this variable is equal to zero, the production of benthos will not decrease, that is, the giltheads are not feeding on that class of benthos.

These conditional commands were not considered sufficient to make the model run in a "realistic" way. If any food were available the fish would, nevertheless, go on feeding and growing. If there was not enough production of the larger benthos class, the fish would switch to the smaller class of benthos, and consume it to exhaustion, and even to negative biomass values.

Another switch, called AF, was introduced to solve these problems. If AF was equal to one, enough benthic production was available, and the fish could eat the class of benthos appropriate to its size (depending of the value of the variable time). If the production of both classes of benthos was not sufficient to compensate the predation pressure, than the variable AF is equal to zero. That means that no food is available and consequently the fish stops growing and its biomass may decrease. Klaoudatos & Apostolopoulos (1985) determined a daily loss of 0.3888 % of the body weight of the fish in case of starvation. This new parameter was introduced into the model.

Finally, if the production of the small class of benthos is not enough to compensate the predation pressure when the fish is still small (before day 330) then no food is available, as the fish has not yet attained a size appropriate for larger items of food.

The new commands introduced in the model were:

```
IF (BW1 .GE. BW10 .OR. BW2 .GE. BW20) AF = 1.
IF (BW1 .LT. BW10 .AND. BW2 .LT. BW20) AF = 0.
IF (BW1 .LT. BW10 .AND. TIME .LT. 180.) AF = 0.
```

After the introduction of these switches, the biomass of fish would be, at any time t, determined by:

$$dS/dt = \text{Growth} \ast PD \ast AF - \text{Mortality} \ast MP - (1-AF) \ast 0.00388 \ast W$$

Where PD and MP are the environmental forcing functions (see section 6.6) and AF the switch that determines wether or not the fish population has enough food to eat. The biomass of the benthos larger than 10 mm would be, at any time t:

$$dB/dt = \text{Growth} \ast PD - \text{Mortality} \ast MP - \text{Fish feeding} \ast BF \ast AF$$

The biomass of the other class of benthos is determined by a similar expression, after the replacement of BF by (1-BF).

The fish feeding is not affected by these switches. The quantity of food the fish eats depends only on the fish biomass. If the fish biomass decreases, because of adverse environmental conditions, the quantity of food ingested also decreases. The influence of the environment is not direct, that is, the forcing functions act by reducing the biomass of fish. The way the expression of fish feeding is written does not allow the use of the switch AF (see expression 12). If the fish do not eat (AF=0) their feeding, at that time t, must be equal to the quantity of food the population would potentially eat minus the quantity of food eaten previously. In this way the feeding at any time t will not decrease to unrealistic values, and will only depend on fish biomass at any time t. However, this expression influences benthos biomass only when AF is equal to 1. The final model can be found in Appendix A4, Model 7.

The results of the simulations using this last model, with data from the four sites and considering a low or a high density population of *Sparus aurata* can be seen in Figs. 6.13 to 6.20.

At site A, it seems that there is enough food to support a low density population of giltheads (Fig.s 6.13 and 6.14). However, the environmental conditions do not allow a full development of the fish population and the yield might be lower than expected. Instead of a yield of 4.5 g $m^{-2}$ only a yield of 2.9 or 2.6 g $m^{-2}$ is possibly obtained. This site does not have the environmental conditions to support a high density population of giltheads. The production of benthos is not sufficient to feed all the population, and the final yield is very low, when compared with the expected 22.5 g $m^{-2}$. The yield would be 6.1 g $m^{-2}$, during the first year, and 3.4 g $m^{-2}$, during the second year.

The production of benthos at site B allows the development of the high density population (Figs. 6.15 and 6.16) With this high density population, the production of the larger class of benthos is almost all consumed, as well as the production of the smaller benthos. It seems that density of fish is the highest that the site can support without the addition of food. The favourable environmental conditions verified during the first year would allow a yield higher than expected, for both populations of fish, of 5 and 25 g $m^{-2}$, respectively.

The environmental conditions encountered at site C during the second year, could reduce the yield drastically (Figs. 6.18), from 4.3 to 2.6 or from 6.6 to 4.7 g $m^{-2}$. With a low density of fish, the food would not be a limiting factor, but the adverse environmental conditions during the second year would provoke a yield almost half of the yield possible during the first year. The yield obtained with a high density fish population would be slightly higher than at site A, but also with a strong reduction during the second year.

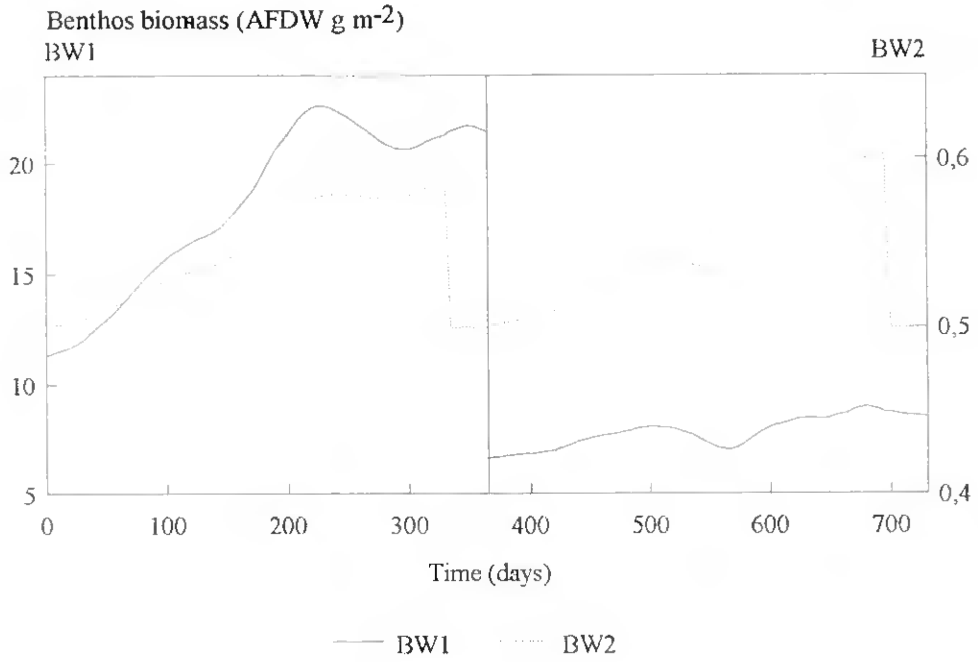
Site D has natural conditions to support relatively high densities of fish (Figs. 6.19 and 6.20). The production of benthos was sufficient to sustain the high density of fish during the first months. However, during the last months the production was no longer sufficient to support the large giltheads. The production of the smaller size-class of benthos is not sufficient, and the fish is not yet big enough to eat the larger size-class of benthos. The expected yield for the low density population would vary between 3.8 and 3.4 g $m^{-2}$. The high density fish population would suffer a greater reduction during the first months of the second year but this reduction would be compensated afterwards by the fact that the production of the small class of benthos would be almost sufficient to sustain the fish population. The yields would vary between 9.3, in the first year, and 9.6 g $m^{-2}$, during the second year.

The slightly worse environmental conditions at site D, during the first year, compared to the conditions encountered at site C, result in a lower yield of the low density fish population. This expected yield is, of course, also lower than at site B, where the environmental conditions are exceptional for extensive aquaculture. Nevertheless, it seems that at all sites the secondary production is sufficient to sustain a low fish density population, and that the yield obtained would be similar to the yields usually obtained by extensive aquaculture (30 % of 150 Kg $ha^{-1}$). In some sites, due to the adverse environmental conditions, the yield can decrease, some times to values close to half of the expected production.

With the exception of site B, the environmental conditions would have to be improved, and the water renewal increased for aquaculture, even at the sites still being simultaneously used in salt production. An increase in initial fish density in order to increase the final harvest, without any structural change at these sites, would not produce the required results.

Another simulation was done, for site D, for a population of *Sparus aurata* with a density intermediate to the other two densities (Fig. 6.21). The expected final yield would be 13.5 g $m^{-2}$, without the effect of the environmental forcing functions, but the results were 9.80 and 9.82 g $m^{-2}$, for the first and the second year of simulation. During the first year, in spite of a more favourable environment, the production of benthos was not sufficient to sustain the predation by the fish. During the last months there was not enough available food. Nevertheless, with a reduced density of fish, when compared with the high density population (0.08 and 0.14 ind. $m^{-2}$, respectively) the yield obtained is similar. It seems that 10 g $m^{-2}$, approximately, is the maximal yield at site D. At sites A and C the maximal yield is, probably, lower.

a)



b)

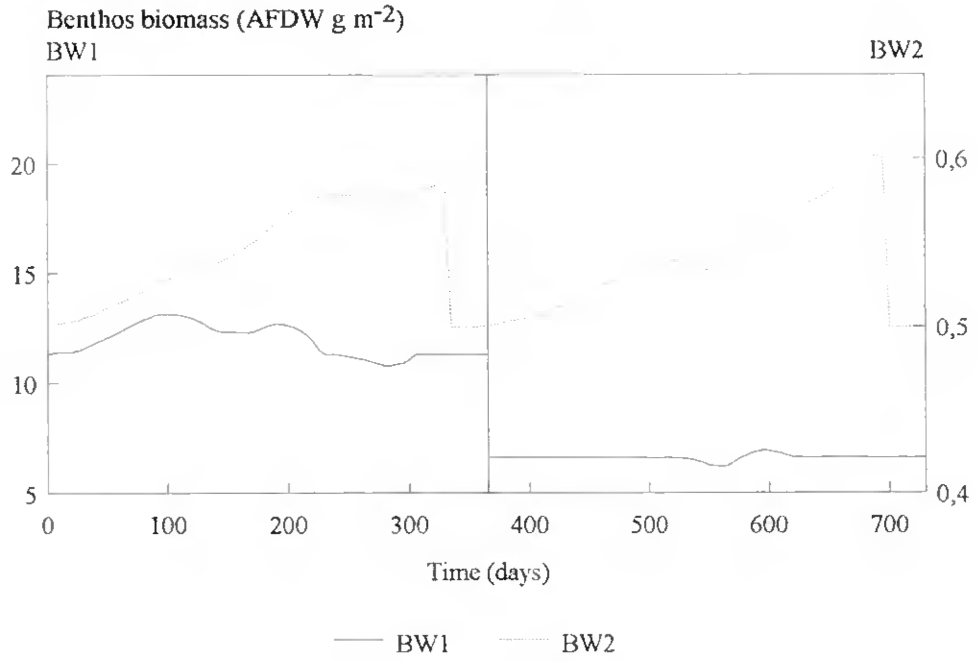
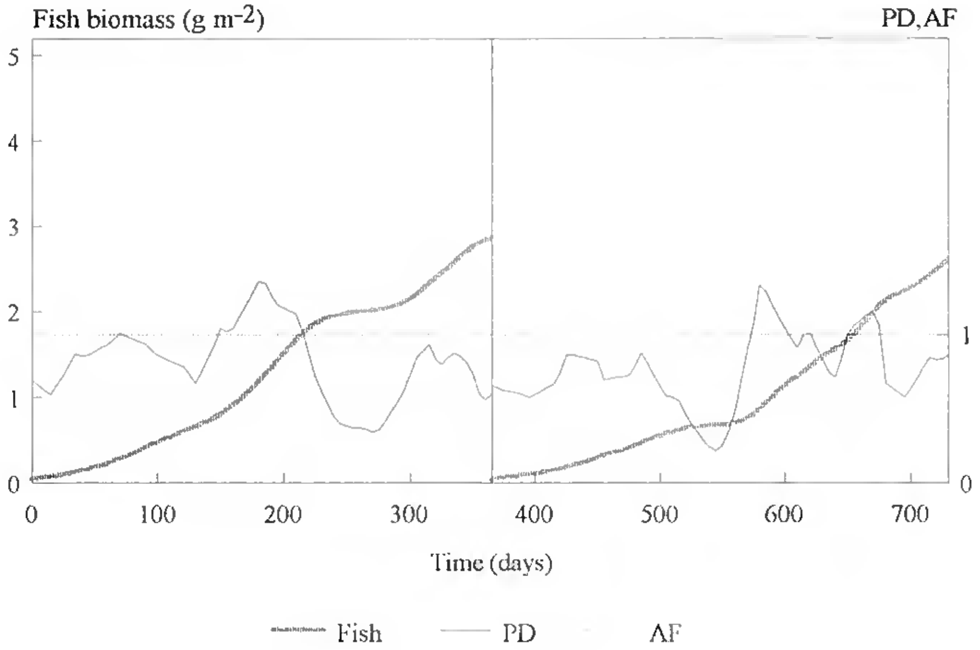


Fig. 6.13. Simulation of the biomass variation of the two classes of benthos at site A, subject to a low (a) or a high (b) density population of *Sparus aurata*. BW1 - benthos smaller than 10 mm, BW2 - benthos larger than 10 mm.

a)



b)

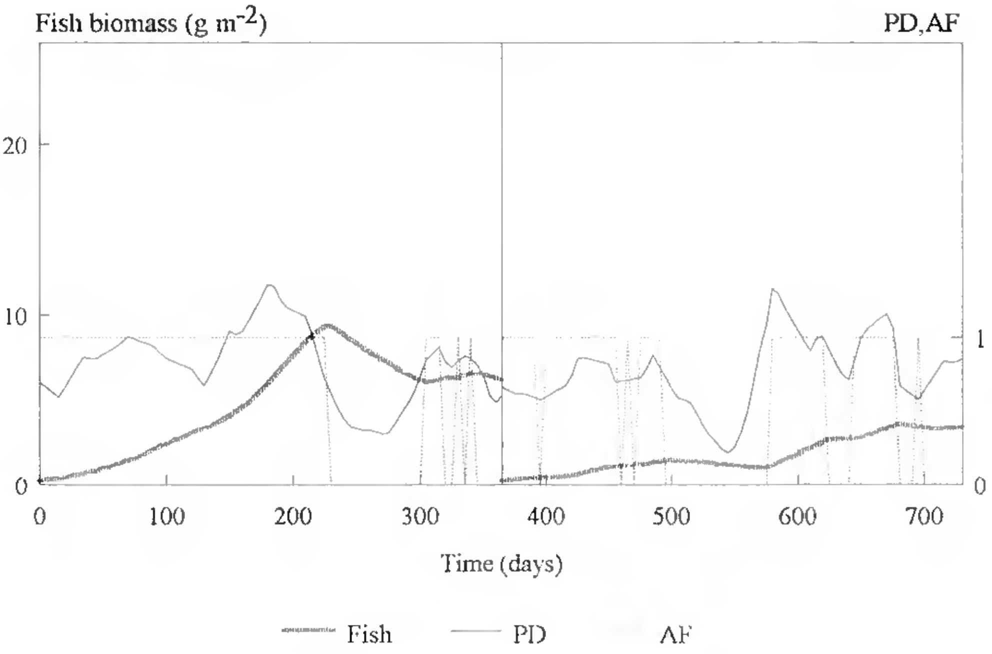
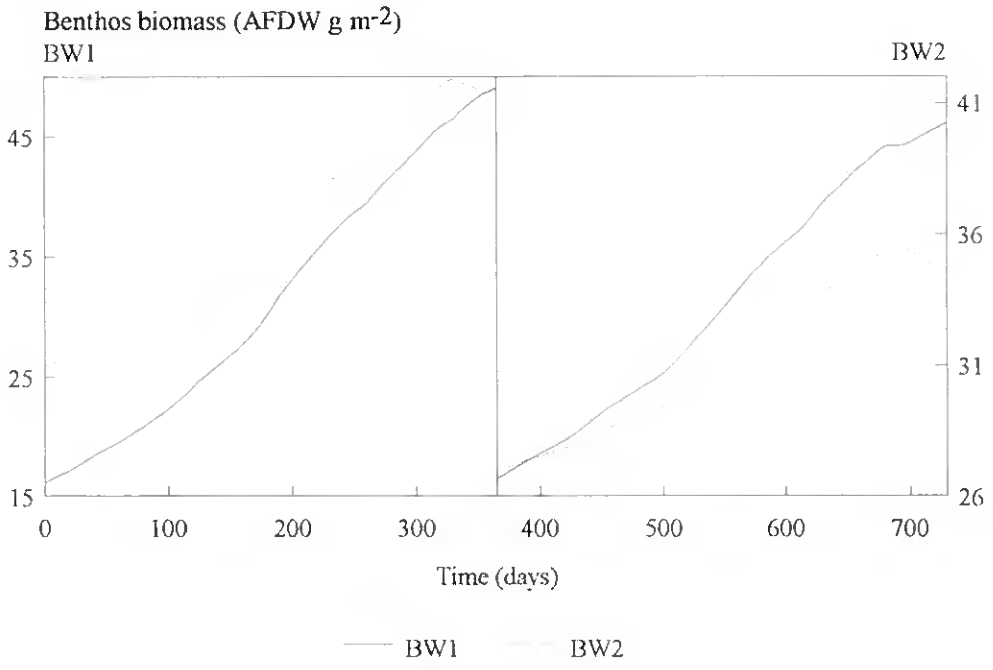


Fig. 6.14. Simulation of the growth of a low density (a) or high density (b) population of *Sparus aurata* at site A. PD - Environmental forcing functions; AF - Availability of food (0 - no food).

a)



b)

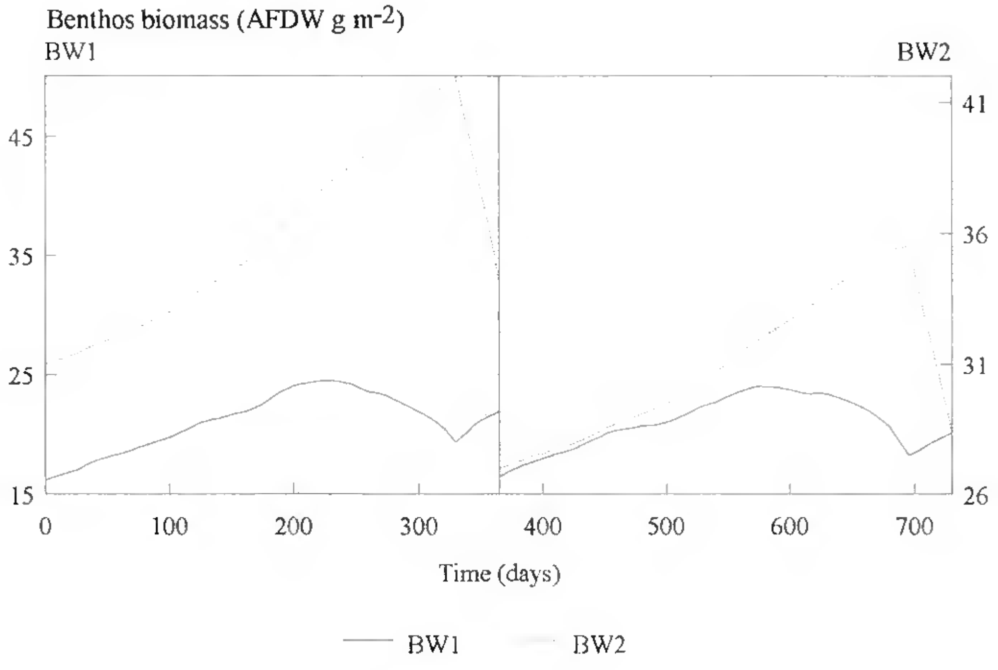
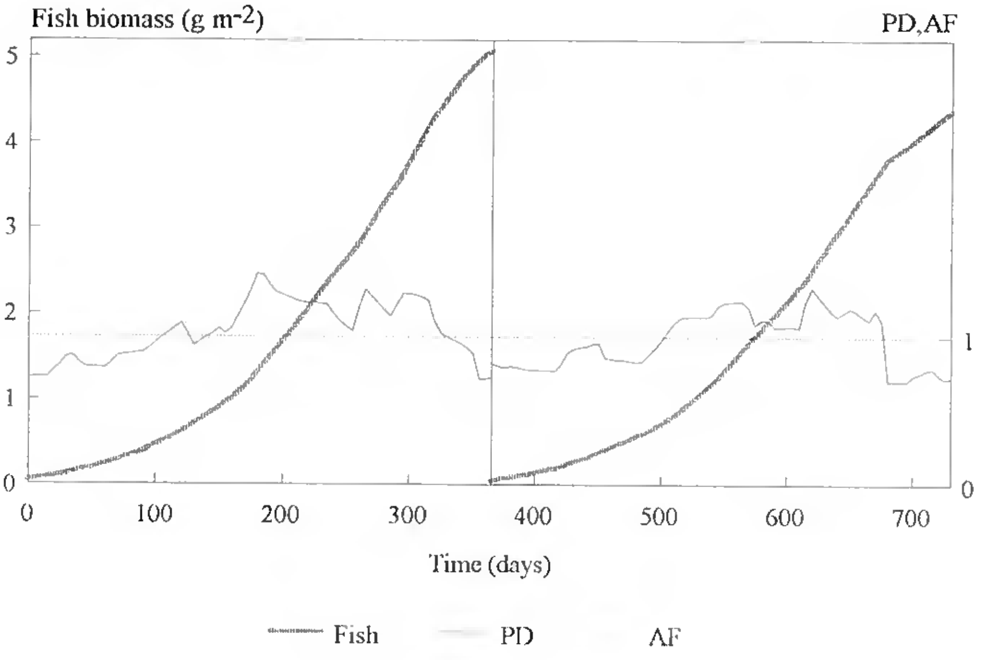


Fig. 6.15. Simulation of the biomass variation of the two classes of benthos at site B, subject to a low (a) or a high (b) density population of *Sparus aurata*. BW1 - benthos smaller than 10 mm, BW2 - benthos larger than 10 mm.

a)



b)

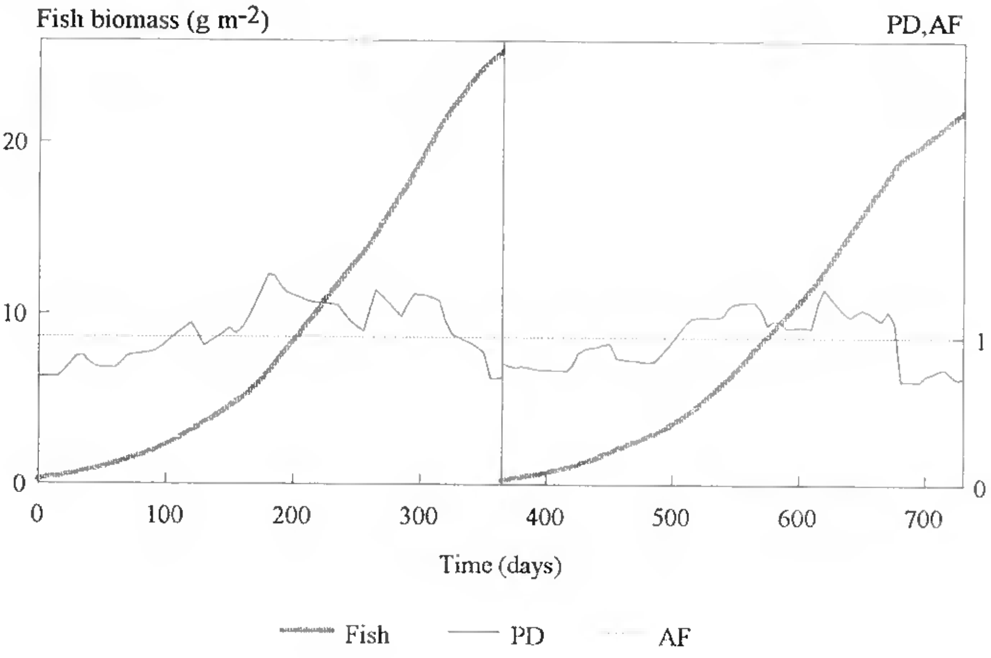
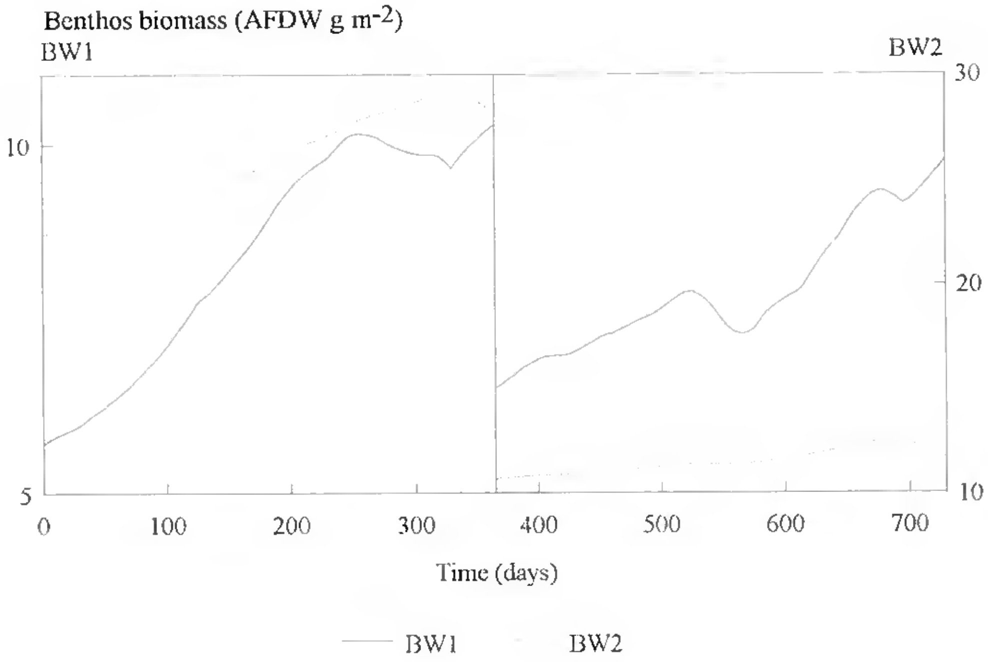


Fig. 6.16. Simulation of the growth of a low density (a) or high density (b) population of *Sparus aurata* at site B. PD - Environmental forcing functions; AF - Availability of food (0 - no food).

a)



b)

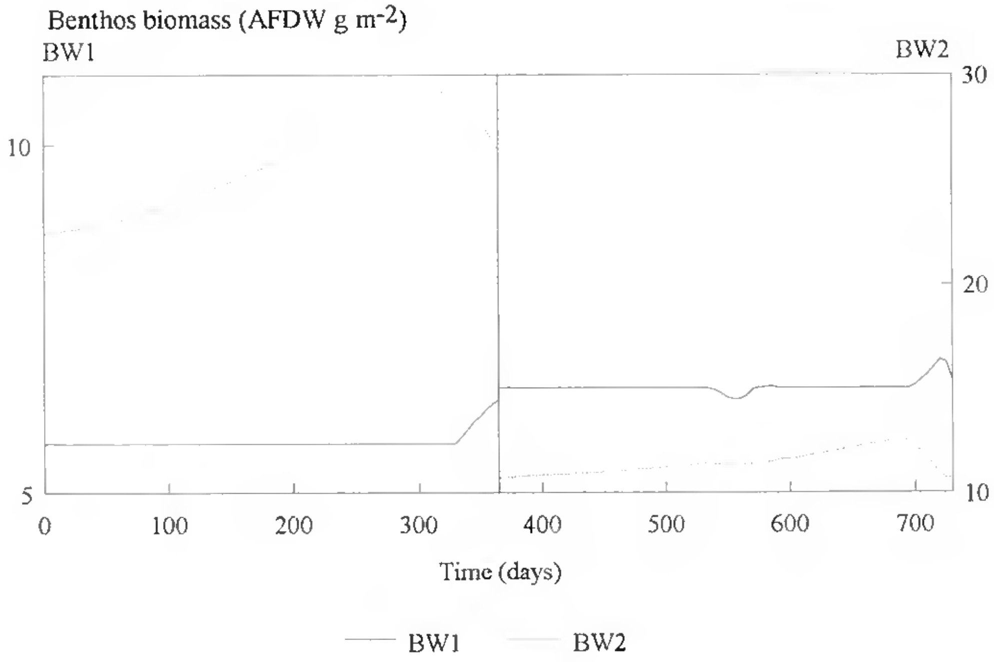


Fig. 6.17. Simulation of the biomass variation of the two classes of benthos at site C, subject to a low (a) or a high (b) density population of *Sparus aurata*. BW1 - benthos smaller than 10 mm, BW2 - benthos larger than 10 mm.

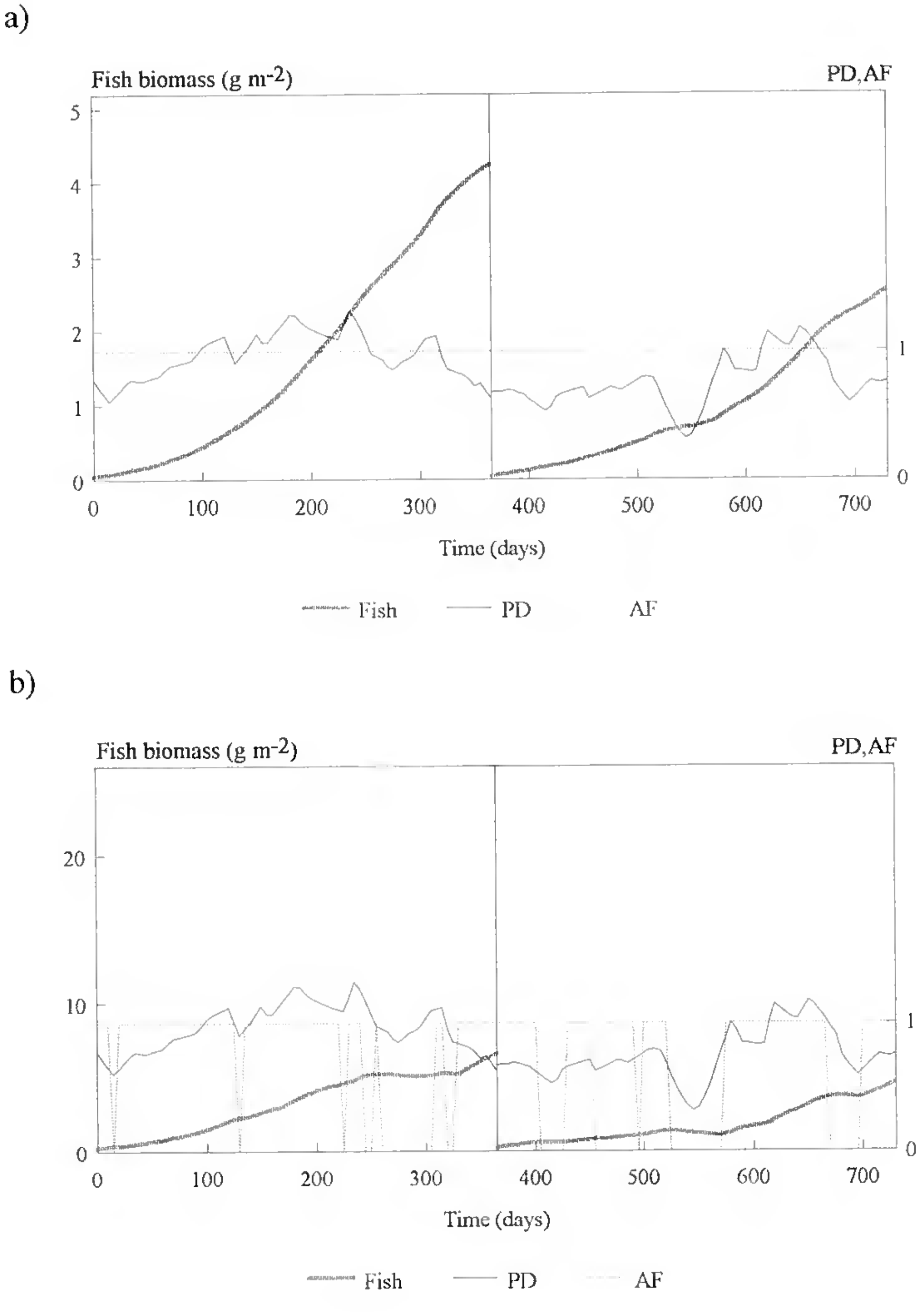
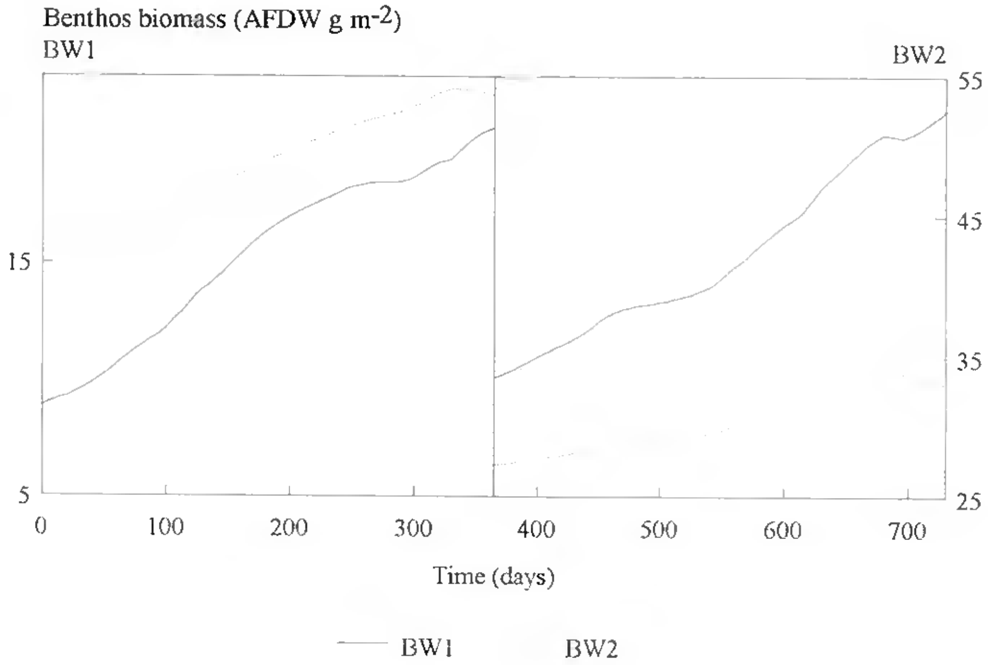


Fig. 6.18. Simulation of the growth of a low density (a) or high density (b) population of *Sparus aurata* at site C. PD - Environmental forcing functions; AF - Availability of food (0 - no food).

a)



b)

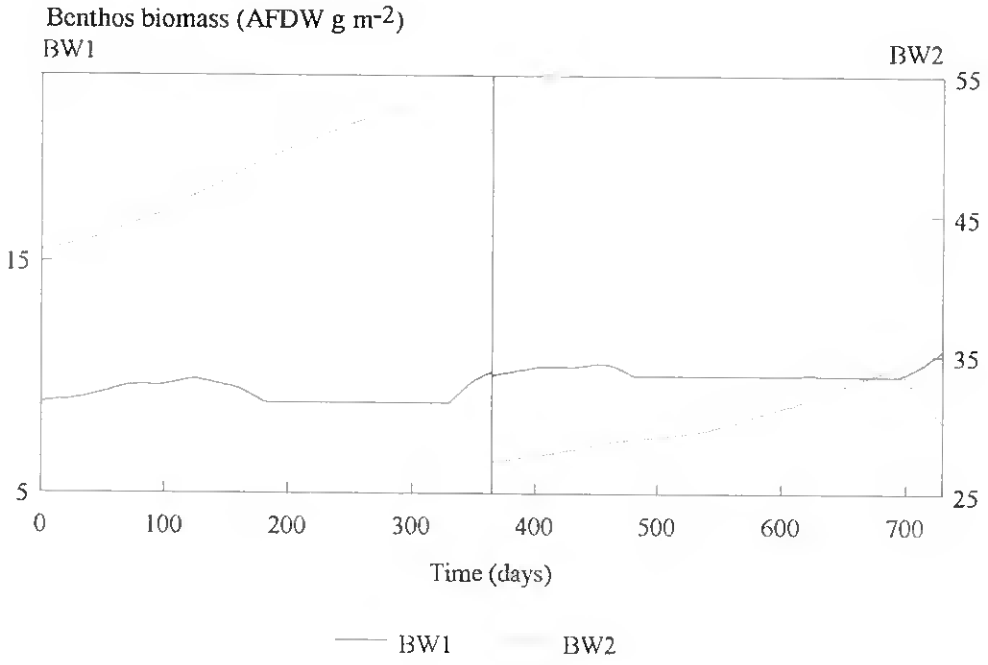
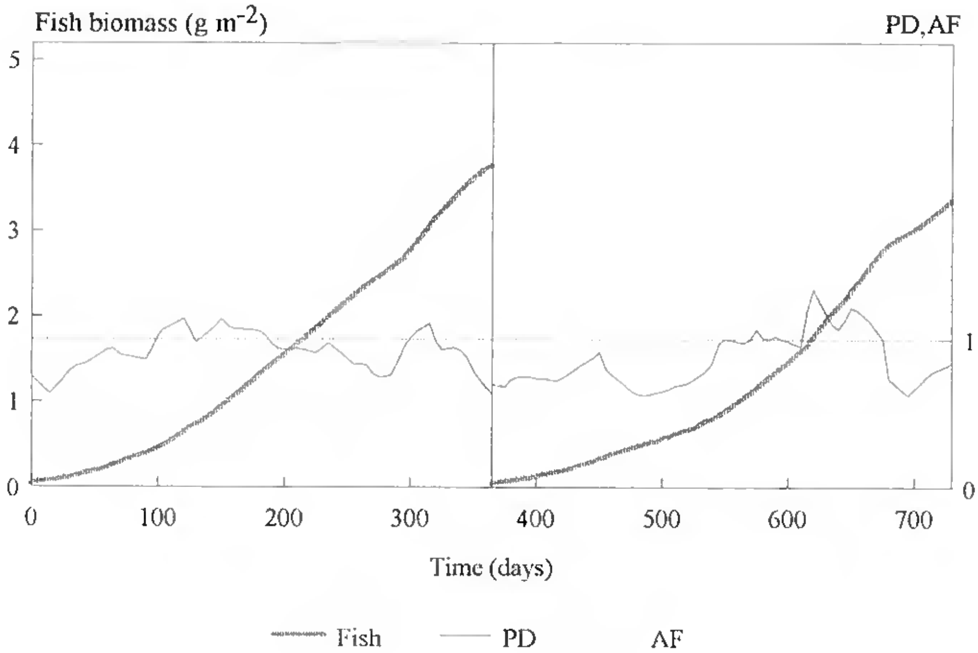


Fig. 6.19. Simulation of the biomass variation of the two classes of benthos at site D, subject to a low (a) or a high (b) density population of *Sparus aurata*. BW1 - benthos smaller than 10 mm, BW2 - benthos larger than 10 mm.

a)



b)

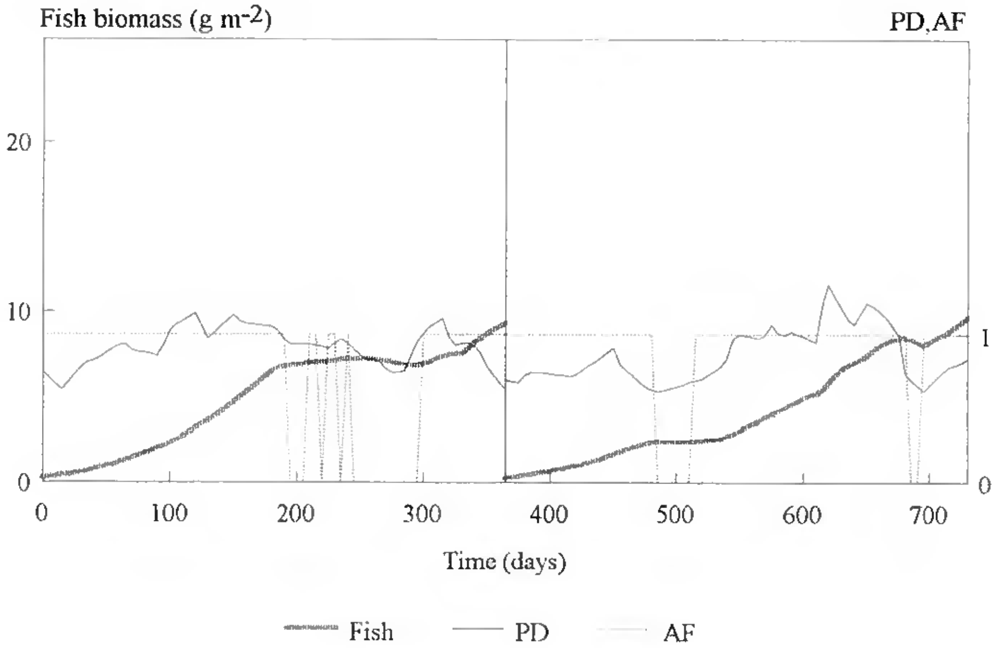
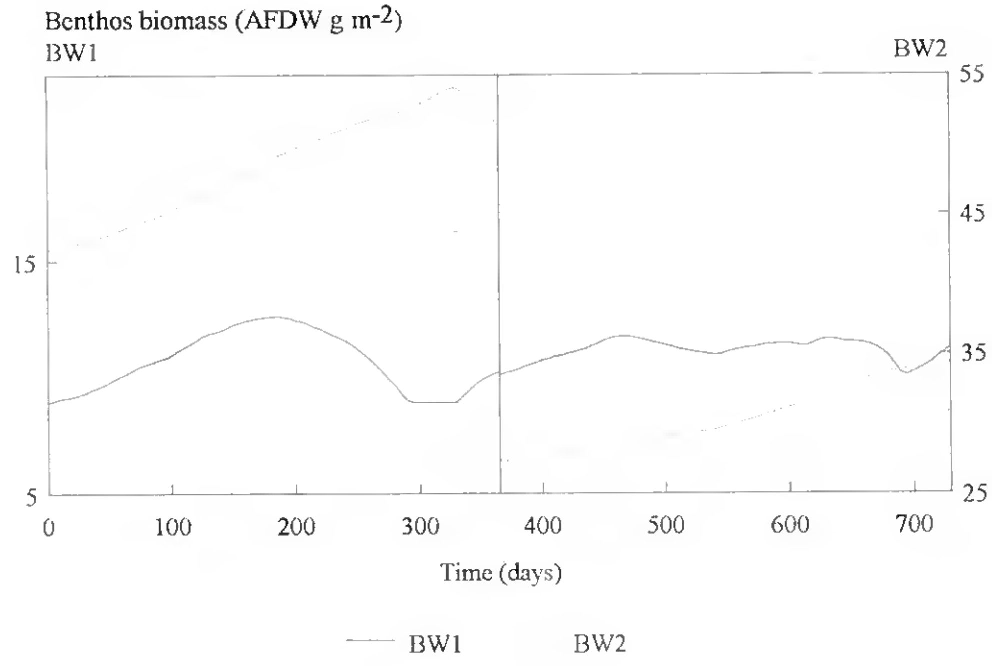


Fig. 6.20. Simulation of the growth of a low density (a) or high density (b) population of *Sparus aurata* at site D. PD - Environmental forcing functions; AF - Availability of food (0 - no food).

a)



b)

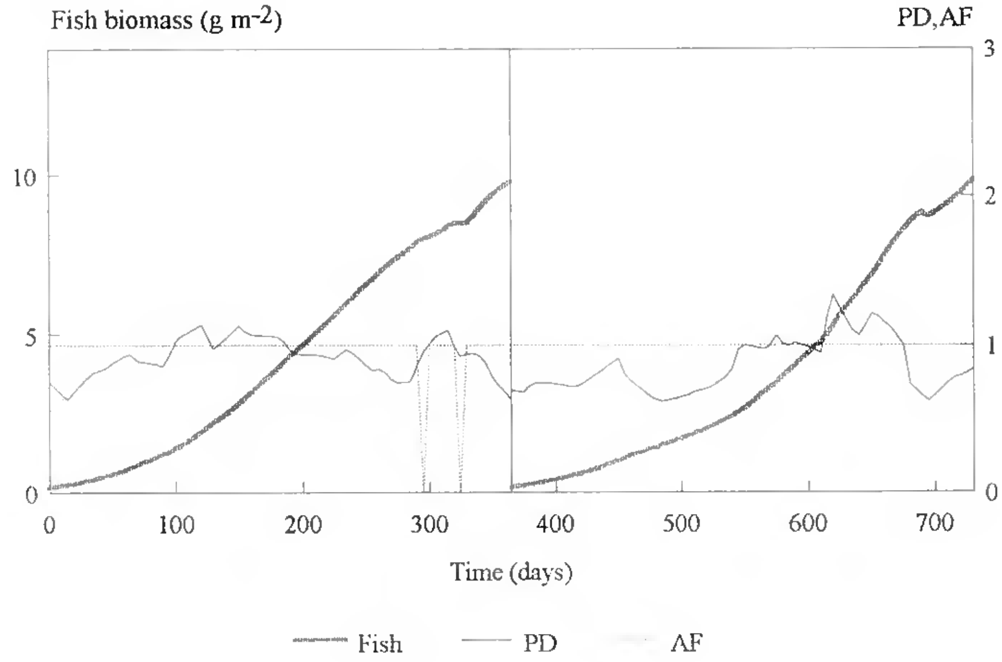


Fig. 6.21. a) Simulation of the biomass variation of the two classes of benthos, at site D, subject to a mean density population of *Sparus aurata*. BW1 - benthos smaller than 10 mm, BW2 - benthos larger than 10 mm. b) Simulation of the growth of the mean density fish population. PD - Environmental forcing functions, AF - Availability of food (0 - No food).

## 6.8 Sensitivity analysis

The model built in the last sections is based on several assumptions. The main assumption is the effect of the environmental forcing functions both on benthos growth and on fish growth. There is no information about these effects under natural conditions, nor in systems similar to the studied lagoons of Ria Formosa. It is known that gilthead can tolerate a large range of salinity (Ben-Tuvia, 1979; Eisawy & Wassef, 1984) but the lethal limits are not precisely known. The large variations in salinity in some of the lagoons can be lethal but this can also depend on the rate of variation. If variation is gradual, the fish population can perhaps sustain itself with, probably, some abnormalities in their development and with an increase in mortality. Pisanty (1980) refers to a high incidence of fish with abnormal eyes and affected livers due to the excessive increase of salinity. It is known that at site C and even at site A, on some occasions, giltheads have been caught, although no precise data exist.

The results from the simulations already done are credible and similar to the known information about other extensive aquaculture systems. The model was verified and the results compared with what was expected. The next step is to carry out a sensitivity analysis (Jørgensen, 1986).

In ecological modelling most of the parameters used are taken from books of ecological parameters, for instance from Jørgensen *et al* (1991). Those parameters are given not necessarily as constants but as approximate values or intervals. In the present model the parameters were taken from the experimental results of other researchers. The validity of the values used is, therefore, not in doubt. Nevertheless, in this section some parameters will be changed and the results of doing this discussed.

The potential production of the benthos was determined through the application of P:B ratios (see Chapter 4). In the model, it was assumed that production was regular throughout the year. However, the introduction of the environmental forcing functions modified this assumption, slowing down the production rate during adverse environmental conditions, and increasing it when the conditions were favourable. The model could, in this way, describe the variation of benthos biomass in a more realistic form. However, an assumption of a constant reproductive effort of 30 % might be unrealistic. There is little information about the reproductive effort in invertebrates. The reproductive effort might be related to larval type (Havenhand & Todd, 1979) and it is known that larger species invest relatively less energy in their offspring (Reiss, 1989). Furthermore, it can increase with body size and age, as it happens with the mussel, *Mytilus edulis* (Bayne *et al*, 1983). The chosen percentage of 30 % had the purpose of including not only the reproductive effort but also predation by other invertebrates or other species of fish.

The reproductive effort / predation by other species was increased by 15 % for the small benthos. Again, a mean density population of giltheads at site D, was considered. During the first year of simulation, the availability of food decreased even more. Consequently the yield also decreased, from 9.80 to 8.89 g $m^{-2}$. During the second year, the decrease in the quantity of available preys provoked a lack of food during the last months of simulation. The yield decreased from 9.82 to 8.66 g $m^{-2}$. The final biomass of benthos did not change significantly, as the predator density is close to the limit, so that all the production is consumed. A 15 % decrease in the availability of food produced a decrease in the yield of between 9 and 12 %.

The sensitivity of a parameter is defined as the quotient between the variation of the state variable and the variation of the examined parameter (both variations expressed in percentages - adapted from Jørgensen, 1986). The sensitivity was then equal to 0.62, for the first year, and 0.79 for the second. According to Jørgensen (1986) these values are high, and care must be taken in the determination of this parameter. However, if a low density fish population was considered, the effect of a 15 % change would be negligible.

Gilthead growth rate might be higher than the rate given by Tandler *et al* (1982) (see section 6.3). In order to examine this possibility, growth was increased and new simulations were done. The parameter (1-n) (see equation 5) was increased by 15 % and the value changed from 0.5169 to 0.5944. This value is close to the value of 0.61 defined for fish populations by Reiss (1989). The corresponding parameter in the feeding differential equation had also to be changed, from -0.4831 to -0.4056 (see equation 12).

A new simulation was done considering the mean density fish population at site D. The results obtained were very similar to the previous results. There was an increase in the annual yield from 9.80 to 10.06 g $m^{-2}$, for the first year, and from 9.83 to 10.24 g $m^{-2}$, for the second year. A 15 % increase in this parameter led only to an increase of between 2.7 and 4.2 % in the fish yield. The sensitivity of this parameter varied between 0.18 and 0.28.

However, if individual fish growth is considered, an increase of 15 % in the parameter (1-n) would give an increase in fish weight, after 365 days, to 407 g (see equation 6). A commercial weight of 215 g would be attained after 273 days, that is, approximately after 9 months. These results are now similar to the information given by Arias (1980). The 15 %

increase in the parameter led to a similar yield after one year, but the fish could be harvested earlier which can be an advantage from a commercial point of view. On day 275 the yield would be 8.16 g $m^{-2}$, instead of 7.45 g $m^{-2}$, if no parameter was changed. During the second year, as the environmental conditions were worse, the yield would be only 6.92 g $m^{-2}$, instead of 6.34 g $m^{-2}$.

The time of year at which fish are introduced into the ponds can also be important. In the model it was considered that the fish were introduced in January, assuming that 2 g fish are already available. In nature this size of fish is available only in April. Their growth in extensive aquaculture ponds could benefit from a more favourable environment (see Fig. 6.11).

Several parameters influence the population growth rate. Some of them, such as the mortality rate and the environmental forcing functions, as well as the initial fish density, can be important. The effect of a 15 % increase in one parameter is, therefore, not so pronounced as when only individual fish growth is considered.

A large number of new simulations would be necessary to determine the sensitivity of the several parameters considered in the model, with different initial densities of fish, and at the four studied sites. In this section only the two parameters of the most doubtful validity were analysed. The reproductive effort / predation rate appears to be important but its precise value depends on many factors such as the individual life history of each benthic species and also on the predators present.

## 6.9 Conclusions / Final remarks

"Theoretical ecology has suffered from the fact that it deals with systems that are close to being intractable, it being difficult often to decide what are the relevant state variables" (DeAngelis, 1988). The need for simple ways of expressing the relationships between entities encourages the use of models. Ecological research has a particular need for its use (Jeffers, 1982).

Extensive aquaculture models are difficult to formulate due to the complexity of the food web and a narrow scientific base (Van Dam, 1990). The present model attempts to represent a small portion of the pond ecosystem. It is an empirical model with low predictive value, based on data from extensive aquaculture systems. Furthermore, it includes information on growth and feeding rates mostly obtained from intensive or artificial aquaculture systems. Consequently, several assumptions have had to be made.

No attempt has been made to simulate the effect of management techniques such as fertilisation of ponds or addition of artificial food. By fertilising a pond, the amount of natural food can be increased, thereby increasing carrying capacity (Cuenco *et al*, 1985c). However, little information is available on the relationship between fertilization and increase of production and, consequently, on amount of natural food available to fish, and also on consequences for the water quality. Furthermore, the definition of water quality is a difficult task (Cacho, 1990). Further increases in the amount of food available to the fish can be provided by artificial feed. In this manner, pond carrying capacity will no longer be limited by the amount of available fish food, but by the supply of dissolved oxygen required by the fish and the accumulation of harmful metabolic wastes, chiefly ammonia and carbon dioxide (Cuenco *et al*, 1985c). In intensive rearing conditions, the percentage of deformed individuals of *S. aurata* can increase up to 48 %, reducing the commercial value (Francescon *et al*, 1988).

The present model is a first attempt to describe the potential of the studied lagoons for the production of gilthead, in an extensive aquaculture regime. The results of the simulations confirmed the exceptional potential of site B for extensive aquaculture practice. This first approach must be validated, but for its validation much research work is still needed.

# GENERAL CONCLUSIONS

## GENERAL CONCLUSIONS

The benthic fauna present in the four study lagoons is characteristic of estuarine and shallow water coastal communities. The analysis of the macrofauna allowed the detection of two environmental gradients: the strongest gradient was related to increasingly stressful conditions due to limited water exchange, with large variations in environmental factors occurring at some sites. The second gradient was related to increasing eutrophication, and a consequent deterioration of water quality. Along both gradients there was a decrease in macrofauna diversity and evenness.

Under the harsh environmental conditions found at one lagoon, site A, only a limited number of species can survive. However, these species can be highly productive. At the least stressed lagoon, site B, the benthic populations are diverse and long-lived species were well-represented in addition to the short-lived but more productive smaller organisms, so that secondary production was very high. The production of food available for gilthead predation was then highest in the least stressed lagoon, where the environment was also more favourable for fish growth.

Some invertebrate species, such as the bivalve *Abra ovata* and the amphipod *Microdeutopus gryllotalpa*, are ubiquitous and present throughout the two gradients. Other taxa, such as the polychaetes *Euclymene palermitana* and *Notomastus latericeus*, Phoronids, the molluscs, *Mesalia brevialis* and *Loripes lacteus*, and the crustaceans, *Apseudes latreillei* and *Iphinoe tenella*, apparently do not tolerate large environmental variations. They were found only in the least stressed lagoon, and outside the lagoons, in the tidal channels of Ria Formosa (Reis *et al*, 1986; Sprung, 1994).

Other taxa, although also present in the least stressed lagoon and in the tidal channels, can cope with large environmental variations and temporary water degradation. These include the polychaetes, *Heteromastus filiformis*, *Nereis caudata*, and *Streblospio dekhuyzeni*, Tubificid oligochaetes, the gastropods, *Bittium reticulatum* and *Cerithium vulgatum*, and the crustaceans, *Idotea chelipes*, *Amphitoe* spp and *Gammarus* spp. However, these taxa apparently do not tolerate extremely high salinity variations. They are present in abundance in the two salina water reservoirs which are still used for salt production, sites C and D. These species have been observed in other water reservoirs of salinas from the Ria Formosa.

The simultaneous sampling of the benthic macrofauna and chemical and physical characteristics of the water, permitted the formal relating of environmental conditions to the presence of taxa groups. Furthermore, the presence of the same taxa inside some of the lagoons and outside in the channels permits generalisation of these relationships to the Ria Formosa system. The gradual disappearence of less tolerant species when the environmental conditions become more adverse, has also been observed in other coastal lagoons (Fonseca, 1989; Labourg, 1978; Quintino, 1988), whilst the more resistant species, occurring in the most stressed lagoon are very similar to those reported for salinas worldwide (Britton, 1987).

The large variation of the tidal amplitude at Ria Formosa, not only between high and low water, but also between the spring and the neap tides, causes a significant semi-diurnal and fortnightly fluctuation in water level. The man-made lagoons or water reservoirs of salinas have a tidal gate which prevents the water escaping during the low tides, but due to natural losses mainly from evaporation and infiltration, the water level can fall to low levels. Whist these can be compensated for during the high spring tides, during periods of neap tides the high tide level is insufficient to add water to the system and physico-chemical conditions deteriorate.

Depending on a variety of factors, such as mean water volume, mean depth and also the mean bottom level in relation to the sea level, the exchange of water into and out of a lagoon varies greatly. Lagoons with low mean depth and low volume, and with a high bottom level in relation to the sea level, undergo large scale environmental fluctuations, as at one of the study lagoons, site A. The characteristics of this site are similar to other lagoons of Southern Europe and North Africa. During the winter, the salinity at this site can decrease greatly due to heavy rainfall, whilst during the summer, evaporation increases the salinity to values in excess of 70 p.p.t. There is also a large diurnal fluctuation in temperature, dissolved oxygen and pH.

The macrofauna of these lagoons is represented by a few small, but abundant, opportunistic organisms, such as *Capitella capitata*, *Hydrobia ventrosa*, oligochaetes and Chironomid larvae. The production of gilthead in such lagoons can be difficult, not only because of the adverse environmental conditions but also because of the low secondary production. The maximum yield of fish is predicted to be less than 6 g $m^{-2}$.

In lagoons with a relatively better water renewal, the environmental fluctuations will not be so large. The macrofauna is consequently more diverse and the secondary production will be higher. The gilthead has then better conditions for growth, and the maximum yield may attain 10 g $m^{-2}$. However, in these lagoons there is the danger of dystrophic crisis accompanied by a deterioration of the water quality, which will be deleterious both to benthos and fish.

These features probably characterise the water reservoirs of the salinas from the Ria Formosa. Small modifications at the tidal-gate and the deepening of some channels may be necessary to improve the environmental conditions so as to avoid the possibility of dystrophic crisis.

In lagoons where the water exchanges on almost every tide, the environmental conditions allow the development of a diverse and productive benthic population. The maximum yield of gilthead in these lagoons can be in excess of 22 - 25 g $m^{-2}$. Nevertheless, in these lagoons, care must also be taken in fish production. The high productivity of these sites in terms of secondary production of benthos and fish, but also primary production, can lead to oxygen depletion during the night or at day-break. These systems appear to be in unstable equilibrium, being easily disrupted. An attempt to further improve fish production by fertilisation or by adding food could provoke a rapid deterioration of the water quality and endanger all the production. In the Ria Formosa, massive fish mortalities in aquaculture systems operating a semi-intensive regime are often reported. The main cause of these mortalities seems to be a sudden algal bloom followed by oxygen depletion.

The gilthead is benthic feeder and prefers to eat hard-bodied prey, but in the absence of prey of an appropriate size, whatever is available can be taken. This generalist characteristic, together with the capacity to tolerate large variations in environmental factors, makes the gilthead an appropriate species to use in extensive aquaculture. In the Algarve there are large areas where gilthead production can be implemented, namely in the water reservoirs of salinas. With small modifications to improve water circulation and renewal, annual yields of 10 to 20 g $m^{-2}$ can probably be achieved.

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# Appendices

**A1 - Physical-Chemical data**
Mean and standard deviation (std)
Maximum (Max) and minimum (Min) values
Number of samples (N)

**A2 - Macrofauna species list and identification keys used**

**A3 - Macrofauna data**
Numbers (ind. 0.023 $m^{-2}$) of each taxon at each station

**A4 - Models**

Table 1

| Temperature (°C) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 20.0 | 5.06 | 27.7 | 10.8 | 12 | 18.8 | 6.13 | 26.5 | 7.4 | 12 |
| **A1 - 86** | 20.8 | 5.51 | 27.5 | 11.6 | 11 | 21.1 | 5.01 | 26.9 | 11.6 | 11 |
| **A2 - 85** | 21.9 | 4.18 | 28.7 | 15.8 | 11 | 19.4 | 6.22 | 27.3 | 7.6 | 12 |
| **A2 - 86** | 22.0 | 5.83 | 29.8 | 11.7 | 11 | 21.9 | 4.61 | 27.0 | 12.5 | 11 |
| **A3 - 85** | 20.3 | 5.55 | 28.2 | 9.6 | 12 | 18.7 | 6.14 | 26.7 | 6.7 | 12 |
| **A3 - 86** | 21.1 | 5.37 | 28.5 | 11.2 | 11 | 21.2 | 4.83 | 25.7 | 11.4 | 11 |
| **B1 - 85** | 20.4 | 4.36 | 26.9 | 14.1 | 11 | 18.4 | 5.38 | 25.8 | 9.3 | 12 |
| **B1 - 86** | 20.3 | 5.17 | 25.9 | 11.9 | 11 | 19.8 | 4.69 | 25.7 | 11.9 | 11 |
| **B2 - 85** | 21.1 | 4.21 | 27.4 | 15.3 | 11 | 18.6 | 4.99 | 25.5 | 10.8 | 12 |
| **B2 - 86** | 21.1 | 5.47 | 26.6 | 12.1 | 10 | 19.9 | 4.45 | 25.7 | 12.5 | 11 |
| **B3 - 85** | 21.2 | 4.12 | 27.4 | 15.4 | 11 | 18.9 | 4.93 | 25.6 | 10.7 | 12 |
| **B3 - 86** | 21.0 | 5.69 | 27.4 | 11.5 | 10 | 20.1 | 4.44 | 25.9 | 12.8 | 11 |
| **C1 - 85** | 19.4 | 4.62 | 26.8 | 13.0 | 12 | 18.2 | 6.06 | 28.1 | 8.0 | 12 |
| **C1 - 86** | 19.6 | 5.29 | 26.0 | 10.5 | 11 | 19.7 | 5.08 | 26.7 | 11.2 | 11 |
| **C2 - 85** | 19.7 | 4.77 | 27.3 | 13.0 | 12 | 18.3 | 5.94 | 28.0 | 8.7 | 12 |
| **C2 - 86** | 19.8 | 5.49 | 26.2 | 9.7 | 11 | 19.5 | 4.71 | 24.9 | 11.8 | 11 |
| **D1 - 85** | 19.7 | 5.09 | 28.1 | 12.0 | 12 | 18.7 | 6.01 | 26.7 | 8.3 | 12 |
| **D1 - 86** | 20.1 | 5.56 | 26.9 | 10.5 | 11 | 19.9 | 4.99 | 26.6 | 11.9 | 11 |
| **D2 - 85** | 20.7 | 4.89 | 28.8 | 13.3 | 11 | 18.7 | 5.93 | 27.0 | 8.2 | 12 |
| **D2 - 86** | 20.2 | 5.51 | 26.8 | 10.6 | 11 | 19.9 | 5.06 | 26.4 | 11.6 | 11 |

Table 2

| Salinity (ppt) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 37.6 | 16.04 | 60.0 | 14.4 | 12 | 35.7 | 11.93 | 50.0 | 14.7 | 12 |
| **A1 - 86** | 49.4 | 12.67 | 73.6 | 32.5 | 11 | 44.6 | 6.25 | 52.4 | 34.2 | 11 |
| **A2 - 85** | 38.5 | 17.00 | 60.5 | 14.2 | 11 | 35.9 | 12.15 | 50.5 | 14.7 | 12 |
| **A2 - 86** | 49.4 | 12.61 | 75.8 | 32.6 | 11 | 44.7 | 6.13 | 52.1 | 34.4 | 11 |
| **A3 - 85** | 41.0 | 20.91 | 76.5 | 13.3 | 12 | 37.0 | 13.32 | 56.5 | 14.3 | 12 |
| **A3 - 86** | 50.9 | 16.13 | 83.7 | 29.9 | 11 | 45.3 | 8.09 | 52.6 | 29.2 | 11 |
| **B1 - 85** | 37.2 | 2.71 | 40.7 | 31.3 | 11 | 36.4 | 1.03 | 38.2 | 33.9 | 12 |
| **B1 - 86** | 37.5 | 1.51 | 39.5 | 34.5 | 11 | 36.8 | 0.78 | 37.7 | 35.1 | 11 |
| **B2 - 85** | 37.0 | 2.59 | 40.2 | 31.3 | 11 | 36.3 | 0.94 | 38.2 | 34.0 | 12 |
| **B2 - 86** | 37.7 | 1.44 | 39.5 | 34.6 | 10 | 36.7 | 0.74 | 37.7 | 35.1 | 11 |
| **B3 - 85** | 37.3 | 2.66 | 40.1 | 31.3 | 11 | 36.3 | 0.94 | 38.2 | 34.1 | 12 |
| **B3 - 86** | 38.2 | 1.87 | 41.6 | 34.6 | 10 | 36.7 | 0.63 | 37.5 | 35.3 | 11 |
| **C1 - 85** | 40.6 | 7.93 | 51.0 | 26.7 | 12 | 39.1 | 5.59 | 47.0 | 29.2 | 12 |
| **C1 - 86** | 45.1 | 10.95 | 70.1 | 32.0 | 11 | 41.1 | 5.96 | 52.1 | 31.6 | 11 |
| **C2 - 85** | 40.6 | 8.04 | 51.0 | 26.6 | 12 | 39.2 | 5.61 | 47.0 | 29.0 | 12 |
| **C2 - 86** | 45.1 | 11.44 | 71.8 | 31.9 | 11 | 41.0 | 6.33 | 52.5 | 30.5 | 11 |
| **D1 - 85** | 41.8 | 6.93 | 50.0 | 29.9 | 12 | 39.1 | 3.97 | 43.0 | 31.0 | 12 |
| **D1 - 86** | 44.1 | 6.35 | 54.4 | 34.9 | 11 | 42.2 | 5.36 | 51.6 | 35.8 | 11 |
| **D2 - 85** | 42.1 | 7.11 | 50.0 | 29.9 | 11 | 39.3 | 4.31 | 46.0 | 31.0 | 12 |
| **D2 - 86** | 43.9 | 6.32 | 54.9 | 34.9 | 11 | 39.6 | 5.40 | 51.6 | 35.8 | 11 |

## Table 3

| Dissolved Oxygen (mg $\text{l}^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Neap tides** | | | | | **Spring tides** | | | | |
| | **Mean** | **std** | **Max.** | **Min.** | **N** | **Mean** | **std** | **Max.** | **Min.** | **N** |
| **A1 - 85** | 7.4 | 1.96 | 9.8 | 4.6 | 12 | 7.4 | 2.11 | 10.3 | 3.3 | 10 |
| **A1 - 86** | 7.7 | 1.65 | 9.6 | 4.2 | 11 | 7.2 | 1.15 | 9.2 | 5.4 | 11 |
| **A2 - 85** | 9.5 | 2.01 | 12.3 | 6.5 | 11 | 8.8 | 1.86 | 11.0 | 6.0 | 10 |
| **A2 - 86** | 10.0 | 1.35 | 13.0 | 8.1 | 11 | 8.8 | 1.55 | 10.9 | 6.3 | 11 |
| **A3 - 85** | 9.1 | 1.08 | 11.0 | 7.5 | 12 | 7.6 | 1.85 | 9.8 | 5.0 | 10 |
| **A3 - 86** | 8.7 | 1.66 | 11.9 | 6.8 | 11 | 8.2 | 1.94 | 11.4 | 5.4 | 11 |
| **B1 - 85** | 6.2 | 1.92 | 8.2 | 2.0 | 10 | 7.0 | 1.25 | 8.9 | 5.0 | 10 |
| **B1 - 86** | 7.6 | 1.27 | 9.2 | 5.4 | 11 | 7.2 | 1.06 | 8.8 | 5.7 | 11 |
| **B2 - 85** | 7.8 | 1.35 | 9.7 | 5.0 | 11 | 7.4 | 1.39 | 10.8 | 5.7 | 10 |
| **B2 - 86** | 7.6 | 1.54 | 10.4 | 5.0 | 10 | 7.6 | 0.91 | 9.2 | 6.4 | 11 |
| **B3 - 85** | 8.6 | 1.27 | 10.4 | 5.7 | 11 | 7.4 | 0.90 | 9.0 | 5.5 | 10 |
| **B3 - 86** | 8.3 | 1.19 | 10.4 | 6.5 | 10 | 7.4 | 1.24 | 9.5 | 5.5 | 10 |
| **C1 - 85** | 5.9 | 2.05 | 8.6 | 2.9 | 12 | 6.8 | 1.75 | 9.1 | 2.9 | 10 |
| **C1 - 86** | 6.1 | 1.65 | 8.6 | 3.6 | 11 | 5.8 | 1.74 | 8.5 | 2.7 | 10 |
| **C2 - 85** | 7.7 | 1.54 | 9.6 | 4.6 | 12 | 6.6 | 2.12 | 10.1 | 2.8 | 10 |
| **C2 - 86** | 8.0 | 2.69 | 12.9 | 4.0 | 11 | 7.3 | 2.97 | 15.3 | 4.6 | 11 |
| **D1 - 85** | 6.3 | 1.48 | 8.3 | 4.2 | 12 | 6.9 | 1.30 | 8.5 | 4.6 | 10 |
| **D1 - 86** | 5.9 | 1.56 | 7.8 | 3.9 | 11 | 5.4 | 1.66 | 8.3 | 3.3 | 10 |
| **D2 - 85** | 7.3 | 2.07 | 11.3 | 3.5 | 11 | 7.2 | 1.01 | 9.1 | 5.3 | 10 |
| **D2 - 86** | 6.9 | 1.02 | 8.1 | 5.1 | 11 | 7.3 | 1.66 | 8.7 | 3.8 | 11 |

## Table 4

| DO Saturation (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Neap tides** | | | | | **Spring tides** | | | | |
| | **Mean** | **std** | **Max.** | **Min.** | **N** | **Mean** | **std** | **Max.** | **Min.** | **N** |
| **A1 - 85** | 99 | 18.8 | 127 | 65 | 12 | 102 | 28.4 | 128 | 47 | 10 |
| **A1 - 86** | 115 | 28.1 | 146 | 67 | 11 | 104 | 13.5 | 126 | 86 | 11 |
| **A2 - 85** | 131 | 33.6 | 190 | 85 | 11 | 124 | 33.9 | 181 | 86 | 10 |
| **A2 - 86** | 153 | 35.4 | 215 | 114 | 11 | 130 | 22.7 | 154 | 86 | 11 |
| **A3 - 85** | 129 | 26.1 | 169 | 87 | 12 | 104 | 23.5 | 142 | 74 | 10 |
| **A3 - 86** | 133 | 36.2 | 216 | 93 | 11 | 117 | 17.5 | 142 | 88 | 11 |
| **B1 - 85** | 83 | 21.8 | 105 | 30 | 10 | 94 | 10.5 | 112 | 77 | 10 |
| **B1 - 86** | 105 | 22.1 | 137 | 74 | 11 | 97 | 12.5 | 123 | 83 | 11 |
| **B2 - 85** | 107 | 14.2 | 128 | 77 | 11 | 100 | 13.3 | 132 | 86 | 10 |
| **B2 - 86** | 106 | 25.6 | 160 | 72 | 10 | 102 | 9.8 | 121 | 87 | 11 |
| **B3 - 85** | 120 | 18.4 | 153 | 85 | 11 | 101 | 10.6 | 118 | 84 | 10 |
| **B3 - 86** | 117 | 22.8 | 161 | 92 | 10 | 100 | 12.5 | 125 | 81 | 10 |
| **C1 - 85** | 79 | 19.4 | 104 | 48 | 12 | 93 | 19.7 | 120 | 46 | 10 |
| **C1 - 86** | 84 | 14.2 | 101 | 58 | 11 | 81 | 20.0 | 104 | 43 | 10 |
| **C2 - 85** | 105 | 20.1 | 139 | 77 | 12 | 90 | 23.1 | 130 | 44 | 10 |
| **C2 - 86** | 115 | 48.8 | 204 | 61 | 11 | 98 | 30.0 | 170 | 55 | 11 |
| **D1 - 85** | 88 | 19.8 | 138 | 61 | 12 | 96 | 16.9 | 124 | 69 | 10 |
| **D1 - 86** | 84 | 22.9 | 129 | 55 | 11 | 76 | 16.6 | 97 | 52 | 10 |
| **D2 - 85** | 110 | 30.8 | 191 | 78 | 11 | 99 | 11.7 | 118 | 82 | 10 |
| **D2 - 86** | 99 | 20.8 | 132 | 65 | 11 | 102 | 16.6 | 120 | 59 | 11 |

## Table 5

| BOD - Biochemical Oxygen Demand (mg $l^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| A1 - 85 | 2.3 | 0.94 | 3.6 | 1.4 | 10 | 1.9 | 0.58 | 3.0 | 1.3 | 10 |
| A1 - 86 | 2.1 | 1.28 | 4.8 | 0.5 | 11 | 1.6 | 1.00 | 3.6 | 0.3 | 11 |
| A2 - 85 | 2.0 | 0.55 | 3.0 | 1.4 | 11 | 2.5 | 1.82 | 7.2 | 1.1 | 10 |
| A2 - 86 | 2.9 | 1.88 | 6.4 | 0.7 | 11 | 2.1 | 0.99 | 3.4 | 0.5 | 11 |
| A3 - 85 | 2.0 | 0.96 | 4.4 | 1.1 | 11 | 2.2 | 1.18 | 4.3 | 1.1 | 10 |
| A3 - 86 | 2.9 | 1.78 | 5.1 | 0.7 | 11 | 1.6 | 0.78 | 2.5 | 0.5 | 11 |
| B1 - 85 | 2.2 | 0.89 | 3.8 | 0.4 | 9 | 1.5 | 0.78 | 3.4 | 0.8 | 10 |
| B1 - 86 | 3.0 | 2.20 | 8.0 | 0.6 | 11 | 2.1 | 0.88 | 3.7 | 0.6 | 11 |
| B2 - 85 | 2.4 | 1.01 | 4.2 | 0.4 | 10 | 1.5 | 0.78 | 3.2 | 0.8 | 10 |
| B2 - 86 | 3.0 | 1.54 | 5.3 | 0.7 | 10 | 1.8 | 0.60 | 2.7 | 0.7 | 11 |
| B3 - 85 | 3.3 | 2.02 | 7.4 | 1.2 | 11 | 1.5 | 0.97 | 3.3 | 0.4 | 10 |
| B3 - 86 | 2.9 | 1.89 | 6.4 | 0.8 | 10 | 2.0 | 0.82 | 3.4 | 0.8 | 10 |
| C1 - 85 | 2.4 | 1.06 | 4.3 | 1.2 | 10 | 2.6 | 1.11 | 4.2 | 1.0 | 10 |
| C1 - 86 | 4.1 | 1.98 | 7.5 | 1.1 | 11 | 3.2 | 1.59 | 6.9 | 1.9 | 10 |
| C2 - 85 | 2.9 | 1.74 | 7.3 | 1.4 | 11 | 2.4 | 1.20 | 4.2 | 1.0 | 10 |
| C2 - 86 | 3.9 | 2.78 | 8.4 | 1.0 | 11 | 3.6 | 1.87 | 7.8 | 2.2 | 11 |
| D1 - 85 | 2.9 | 1.89 | 7.3 | 1.2 | 10 | 3.1 | 1.71 | 6.0 | 0.8 | 10 |
| D1 - 86 | 3.8 | 1.57 | 7.0 | 1.9 | 11 | 2.1 | 0.57 | 3.2 | 1.4 | 10 |
| D2 - 85 | 3.5 | 2.38 | 9.2 | 1.1 | 11 | 2.8 | 1.74 | 6.2 | 0.8 | 10 |
| D2 - 86 | 4.2 | 2.56 | 8.1 | 1.2 | 10 | 2.4 | 1.48 | 5.6 | 1.1 | 11 |

## Table 6

| pH | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| A1 - 85 | 8.3 | 0.24 | 8.7 | 7.9 | 12 | 8.3 | 0.23 | 8.7 | 7.8 | 12 |
| A1 - 86 | 8.6 | 0.42 | 9.2 | 7.8 | 11 | 8.6 | 0.24 | 9.0 | 8.2 | 11 |
| A2 - 85 | 8.4 | 0.29 | 8.8 | 8.0 | 11 | 8.3 | 0.25 | 8.9 | 7.9 | 12 |
| A2 - 86 | 8.7 | 0.28 | 9.1 | 8.2 | 11 | 8.7 | 0.22 | 9.0 | 8.4 | 11 |
| A3 - 85 | 8.5 | 0.24 | 8.9 | 8.1 | 12 | 8.3 | 0.23 | 9.0 | 8.2 | 12 |
| A3 - 86 | 8.8 | 0.25 | 9.1 | 8.4 | 11 | 8.7 | 0.30 | 9.3 | 8.3 | 11 |
| B1 - 85 | 8.2 | 0.19 | 8.4 | 7.9 | 11 | 8.2 | 0.29 | 9.0 | 7.9 | 12 |
| B1 - 86 | 8.0 | 0.15 | 8.1 | 7.6 | 11 | 8.0 | 0.18 | 8.2 | 7.7 | 11 |
| B2 - 85 | 8.2 | 0.19 | 8.4 | 7.9 | 11 | 8.1 | 0.13 | 8.3 | 7.9 | 12 |
| B2 - 86 | 8.0 | 0.18 | 8.2 | 7.6 | 10 | 8.0 | 0.21 | 8.3 | 7.6 | 11 |
| B3 - 85 | 8.2 | 0.28 | 8.5 | 7.6 | 11 | 8.1 | 0.14 | 8.3 | 7.9 | 12 |
| B3 - 86 | 8.0 | 0.20 | 8.2 | 7.6 | 10 | 8.1 | 0.27 | 8.7 | 7.7 | 11 |
| C1 - 85 | 8.3 | 0.28 | 8.7 | 7.8 | 12 | 8.2 | 0.24 | 8.7 | 7.8 | 12 |
| C1 - 86 | 8.3 | 0.19 | 8.6 | 8.0 | 11 | 8.3 | 0.13 | 8.4 | 8.0 | 11 |
| C2 - 85 | 8.3 | 0.24 | 8.7 | 8.0 | 11 | 8.2 | 0.29 | 8.7 | 7.7 | 12 |
| C2 - 86 | 8.4 | 0.21 | 8.7 | 8.0 | 11 | 8.3 | 0.13 | 8.5 | 8.0 | 11 |
| D1 - 85 | 8.6 | 0.25 | 8.8 | 8.1 | 11 | 8.4 | 0.22 | 8.7 | 8.1 | 12 |
| D1 - 86 | 8.3 | 0.41 | 9.0 | 7.6 | 11 | 8.3 | 0.31 | 8.8 | 7.9 | 11 |
| D2 - 85 | 8.6 | 0.30 | 9.0 | 8.1 | 11 | 8.4 | 0.21 | 8.7 | 8.1 | 12 |
| D2 - 86 | 8.4 | 0.34 | 9.0 | 7.8 | 11 | 8.3 | 0.23 | 8.7 | 8.0 | 11 |

## Table 7

| Suspended Matter (mg $l^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 99 | 42.4 | 162 | 35 | 11 | 89 | 29.4 | 155 | 47 | 12 |
| **A1 - 86** | 103 | 33.9 | 173 | 56 | 11 | 98 | 18.4 | 132 | 68 | 11 |
| **A2 - 85** | 110 | 43.9 | 185 | 38 | 11 | 95 | 29.3 | 136 | 42 | 12 |
| **A2 - 86** | 115 | 30.5 | 179 | 72 | 11 | 98 | 15.1 | 124 | 80 | 11 |
| **A3 - 85** | 123 | 66.8 | 237 | 36 | 11 | 100 | 37.5 | 158 | 41 | 12 |
| **A3 - 86** | 110 | 39.2 | 196 | 60 | 11 | 94 | 15.5 | 119 | 65 | 11 |
| **B1 - 85** | 98 | 27.0 | 141 | 53 | 11 | 93 | 17.3 | 120 | 68 | 12 |
| **B1 - 86** | 89 | 20.4 | 130 | 60 | 11 | 82 | 13.7 | 109 | 55 | 11 |
| **B2 - 85** | 105 | 27.1 | 152 | 64 | 11 | 90 | 14.4 | 115 | 66 | 12 |
| **B2 - 86** | 84 | 14.1 | 116 | 70 | 10 | 83 | 12.8 | 112 | 66 | 11 |
| **B3 - 85** | 103 | 22.4 | 155 | 84 | 11 | 94 | 11.4 | 112 | 71 | 12 |
| **B3 - 86** | 72 | 18.9 | 113 | 46 | 10 | 75 | 14.4 | 106 | 56 | 11 |
| **C1 - 85** | 86 | 23.5 | 121 | 55 | 11 | 91 | 16.3 | 122 | 68 | 12 |
| **C1 - 86** | 101 | 30.0 | 164 | 63 | 11 | 97 | 32.6 | 186 | 62 | 11 |
| **C2 - 85** | 105 | 22.1 | 148 | 75 | 11 | 97 | 19.4 | 128 | 67 | 12 |
| **C2 - 86** | 109 | 54.5 | 264 | 76 | 11 | 99 | 40.6 | 208 | 58 | 11 |
| **D1 - 85** | 101 | 22.3 | 152 | 75 | 11 | 87 | 11.4 | 111 | 71 | 12 |
| **D1 - 86** | 100 | 44.9 | 226 | 65 | 11 | 80 | 12.2 | 96 | 56 | 11 |
| **D2 - 85** | 100 | 24.3 | 129 | 60 | 11 | 99 | 16.3 | 133 | 70 | 12 |
| **D2 - 86** | 85 | 17.5 | 112 | 60 | 11 | 96 | 15.3 | 111 | 54 | 11 |

## Table 8

| Silicates (µmol $l^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 8.0 | 5.72 | 17.4 | 1.0 | 12 | 5.9 | 4.45 | 13.9 | 0.8 | 12 |
| **A1 - 86** | 10.0 | 6.78 | 22.7 | 2.0 | 11 | 6.6 | 3.54 | 11.5 | 1.0 | 11 |
| **A2 - 85** | 9.4 | 7.91 | 22.0 | 0.7 | 11 | 6.3 | 5.39 | 16.9 | 0.6 | 12 |
| **A2 - 86** | 10.7 | 7.02 | 24.0 | 2.0 | 11 | 7.6 | 4.79 | 18.2 | 2.2 | 11 |
| **A3 - 85** | 8.6 | 7.36 | 23.4 | 0.7 | 12 | 6.1 | 5.21 | 17.5 | 0.4 | 12 |
| **A3 - 86** | 6.7 | 2.68 | 10.5 | 1.3 | 11 | 5.6 | 2.80 | 10.2 | 1.7 | 11 |
| **B1 - 85** | 11.6 | 7.84 | 27.0 | 2.8 | 11 | 5.1 | 6.03 | 23.9 | 1.4 | 12 |
| **B1 - 86** | 8.4 | 7.48 | 28.1 | 1.9 | 11 | 6.2 | 3.21 | 12.1 | 2.2 | 11 |
| **B2 - 85** | 10.4 | 7.44 | 27.0 | 2.8 | 11 | 4.7 | 4.64 | 18.9 | 2.3 | 12 |
| **B2 - 86** | 7.9 | 5.87 | 21.7 | 3.2 | 10 | 5.6 | 3.50 | 13.7 | 3.1 | 11 |
| **B3 - 85** | 11.5 | 7.88 | 23.8 | 3.7 | 11 | 4.5 | 5.30 | 21.2 | 1.9 | 12 |
| **B3 - 86** | 10.4 | 8.28 | 28.7 | 3.2 | 10 | 5.3 | 2.16 | 10.8 | 3.3 | 11 |
| **C1 - 85** | 7.0 | 6.87 | 27.0 | 0.7 | 12 | 5.4 | 6.96 | 27.0 | 0.9 | 12 |
| **C1 - 86** | 10.1 | 7.83 | 28.7 | 1.9 | 11 | 6.9 | 6.10 | 23.3 | 1.9 | 11 |
| **C2 - 85** | 6.9 | 6.87 | 27.0 | 1.5 | 12 | 5.3 | 7.08 | 27.0 | 1.3 | 12 |
| **C2 - 86** | 10.2 | 9.01 | 30.3 | 1.9 | 11 | 5.6 | 3.69 | 15.3 | 2.1 | 11 |
| **D1 - 85** | 7.0 | 7.22 | 27.0 | 0.9 | 12 | 4.8 | 7.15 | 27.0 | 0.6 | 12 |
| **D1 - 86** | 6.1 | 4.55 | 15.0 | 2.0 | 11 | 4.8 | 2.22 | 9.3 | 2.2 | 11 |
| **D2 - 85** | 7.0 | 7.57 | 27.0 | 1.5 | 11 | 6.5 | 10.38 | 30.0 | 0.3 | 12 |
| **D2 - 86** | 7.6 | 6.77 | 19.8 | 2.4 | 11 | 6.8 | 1.32 | 6.9 | 2.8 | 11 |

Table 9

| Phosphate ($\mu$mol l$^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 0.3 | 0.38 | 1.3 | 0.1 | 12 | 0.3 | 0.35 | 1.1 | 0.1 | 12 |
| **A1 - 86** | 0.5 | 0.76 | 2.5 | 0.1 | 11 | 0.3 | 0.38 | 1.2 | 0.1 | 11 |
| **A2 - 85** | 0.4 | 0.48 | 1.6 | 0.1 | 10 | 0.4 | 0.48 | 1.6 | 0.1 | 12 |
| **A2 - 86** | 0.4 | 0.56 | 1.8 | 0.1 | 11 | 0.4 | 0.49 | 1.5 | 0.1 | 11 |
| **A3 - 85** | 0.4 | 0.46 | 1.3 | 0.1 | 12 | 0.3 | 0.27 | 0.9 | 0.1 | 12 |
| **A3 - 86** | 0.4 | 0.49 | 1.3 | 0.1 | 11 | 0.3 | 0.33 | 0.8 | 0.1 | 11 |
| **B1 - 85** | 1.0 | 0.76 | 2.5 | 0.1 | 11 | 0.3 | 0.32 | 1.1 | 0.1 | 12 |
| **B1 - 86** | 0.4 | 0.38 | 1.1 | 0.1 | 11 | 0.5 | 0.45 | 1.0 | 0.1 | 11 |
| **B2 - 85** | 0.7 | 0.77 | 2.5 | 0.1 | 11 | 0.3 | 0.32 | 1.1 | 0.1 | 12 |
| **B2 - 86** | 0.3 | 0.39 | 1.1 | 0.1 | 10 | 0.5 | 0.47 | 1.3 | 0.1 | 11 |
| **B3 - 85** | 1.1 | 0.76 | 2.5 | 0.1 | 11 | 0.4 | 0.38 | 1.1 | 0.1 | 12 |
| **B3 - 86** | 0.8 | 1.15 | 3.7 | 0.1 | 10 | 0.3 | 0.39 | 1.2 | 0.1 | 11 |
| **C1 - 85** | 0.8 | 0.78 | 2.4 | 0.1 | 12 | 0.6 | 0.54 | 1.6 | 0.1 | 12 |
| **C1 - 86** | 0.9 | 0.72 | 2.1 | 0.1 | 11 | 0.2 | 0.35 | 1.1 | 0.1 | 11 |
| **C2 - 85** | 0.5 | 0.37 | 1.2 | 0.1 | 12 | 0.5 | 0.56 | 1.6 | 0.1 | 12 |
| **C2 - 86** | 0.9 | 0.89 | 2.5 | 0.1 | 11 | 0.4 | 0.62 | 2.1 | 0.1 | 11 |
| **D1 - 85** | 0.6 | 0.45 | 1.5 | 0.1 | 12 | 0.4 | 0.44 | 1.4 | 0.1 | 12 |
| **D1 - 86** | 0.6 | 0.51 | 1.4 | 0.1 | 11 | 0.3 | 0.44 | 1.3 | 0.1 | 11 |
| **D2 - 85** | 0.5 | 0.56 | 1.5 | 0.1 | 10 | 0.4 | 0.45 | 1.6 | 0.1 | 12 |
| **D2 - 86** | 0.6 | 0.53 | 1.5 | 0.1 | 11 | 0.5 | 0.14 | 0.4 | 0.1 | 11 |

Table 10

| Nitrates ($\mu$mol l$^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 0.4 | 0.20 | 1.0 | 0.3 | 12 | 0.3 | 0.03 | 0.4 | 0.3 | 12 |
| **A1 - 86** | 0.3 | 0.12 | 0.7 | 0.3 | 11 | 0.4 | 0.27 | 1.2 | 0.3 | 11 |
| **A2 - 85** | 0.4 | 0.25 | 1.0 | 0.3 | 11 | 0.3 | 0.00 | 0.3 | 0.3 | 12 |
| **A2 - 86** | 0.3 | 0.03 | 0.4 | 0.3 | 11 | 0.3 | 0.09 | 0.6 | 0.3 | 11 |
| **A3 - 85** | 0.4 | 0.19 | 0.8 | 0.3 | 12 | 0.3 | 0.03 | 0.4 | 0.3 | 12 |
| **A3 - 86** | 0.3 | 0.06 | 0.5 | 0.3 | 11 | 0.4 | 0.10 | 0.6 | 0.3 | 11 |
| **B1 - 85** | 0.4 | 0.19 | 0.8 | 0.3 | 11 | 0.4 | 0.21 | 1.0 | 0.3 | 12 |
| **B1 - 86** | 0.3 | 0.03 | 0.4 | 0.3 | 11 | 0.5 | 0.29 | 1.2 | 0.3 | 11 |
| **B2 - 85** | 0.4 | 0.16 | 0.7 | 0.3 | 11 | 0.6 | 0.40 | 1.3 | 0.3 | 12 |
| **B2 - 86** | 0.4 | 0.19 | 0.9 | 0.3 | 10 | 0.6 | 0.53 | 2.0 | 0.3 | 11 |
| **B3 - 85** | 0.4 | 0.09 | 0.6 | 0.3 | 11 | 0.5 | 0.32 | 1.1 | 0.3 | 12 |
| **B3 - 86** | 0.3 | 0.00 | 0.3 | 0.3 | 10 | 0.7 | 0.88 | 2.9 | 0.3 | 11 |
| **C1 - 85** | 0.4 | 0.28 | 1.3 | 0.3 | 12 | 0.4 | 0.09 | 0.6 | 0.3 | 12 |
| **C1 - 86** | 0.4 | 0.25 | 1.1 | 0.3 | 11 | 0.4 | 0.28 | 1.2 | 0.3 | 11 |
| **C2 - 85** | 0.4 | 0.32 | 1.4 | 0.3 | 12 | 0.3 | 0.05 | 0.4 | 0.3 | 12 |
| **C2 - 86** | 0.3 | 0.06 | 0.5 | 0.3 | 11 | 0.4 | 0.24 | 1.1 | 0.3 | 11 |
| **D1 - 85** | 0.4 | 0.26 | 1.2 | 0.3 | 12 | 0.3 | 0.03 | 0.4 | 0.3 | 12 |
| **D1 - 86** | 0.3 | 0.00 | 0.3 | 0.3 | 11 | 0.3 | 0.12 | 0.7 | 0.3 | 11 |
| **D2 - 85** | 0.4 | 0.17 | 0.8 | 0.3 | 11 | 0.3 | 0.03 | 0.4 | 0.3 | 12 |
| **D2 - 86** | 0.3 | 0.03 | 0.4 | 0.3 | 11 | 0.4 | 0.04 | 0.4 | 0.3 | 11 |

## Table 11

| Nitrites (µmol $l^{-1}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 0.2 | 0.18 | 0.6 | 0.1 | 12 | 0.1 | 0.10 | 0.4 | 0.1 | 12 |
| **A1 - 86** | 0.5 | 0.46 | 1.6 | 0.1 | 11 | 0.5 | 0.33 | 1.1 | 0.1 | 11 |
| **A2 - 85** | 0.1 | 0.12 | 0.3 | 0.1 | 11 | 0.1 | 0.11 | 0.4 | 0.1 | 12 |
| **A2 - 86** | 0.5 | 0.36 | 1.0 | 0.1 | 11 | 0.4 | 0.21 | 0.8 | 0.1 | 11 |
| **A3 - 85** | 0.2 | 0.14 | 0.4 | 0.1 | 12 | 0.2 | 0.13 | 0.5 | 0.1 | 12 |
| **A3 - 86** | 0.5 | 0.42 | 1.1 | 0.1 | 11 | 0.4 | 0.23 | 0.7 | 0.1 | 11 |
| **B1 - 85** | 0.1 | 0.10 | 0.3 | 0.1 | 11 | 0.2 | 0.12 | 0.4 | 0.1 | 12 |
| **B1 - 86** | 0.3 | 0.27 | 1.0 | 0.1 | 11 | 0.3 | 0.16 | 0.7 | 0.1 | 11 |
| **B2 - 85** | 0.2 | 0.15 | 0.5 | 0.1 | 11 | 0.2 | 0.10 | 0.4 | 0.1 | 12 |
| **B2 - 86** | 0.4 | 0.29 | 1.0 | 0.1 | 10 | 0.3 | 0.11 | 0.5 | 0.1 | 11 |
| **B3 - 85** | 0.2 | 0.14 | 0.4 | 0.1 | 11 | 0.2 | 0.12 | 0.4 | 0.1 | 12 |
| **B3 - 86** | 0.4 | 0.40 | 1.3 | 0.1 | 10 | 0.3 | 0.15 | 0.7 | 0.2 | 11 |
| **C1 - 85** | 0.1 | 0.10 | 0.3 | 0.1 | 12 | 0.1 | 0.10 | 0.4 | 0.1 | 12 |
| **C1 - 86** | 0.4 | 0.31 | 1.0 | 0.1 | 11 | 0.4 | 0.23 | 0.8 | 0.1 | 11 |
| **C2 - 85** | 0.2 | 0.11 | 0.4 | 0.1 | 12 | 0.1 | 0.10 | 0.3 | 0.1 | 12 |
| **C2 - 86** | 0.5 | 0.36 | 1.1 | 0.1 | 11 | 0.3 | 0.19 | 0.7 | 0.1 | 11 |
| **D1 - 85** | 0.1 | 0.10 | 0.3 | 0.1 | 12 | 0.1 | 0.06 | 0.2 | 0.1 | 12 |
| **D1 - 86** | 0.4 | 0.42 | 1.5 | 0.1 | 11 | 0.4 | 0.27 | 0.9 | 0.1 | 11 |
| **D2 - 85** | 0.1 | 0.08 | 0.3 | 0.1 | 11 | 0.1 | 0.06 | 0.2 | 0.1 | 12 |
| **D2 - 86** | 0.4 | 0.28 | 1.0 | 0.1 | 11 | 0.2 | 0.22 | 0.7 | 0.1 | 11 |

## Table 12

| Chlorophyll *a* (mg $m^{-3}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 2.2 | 2.23 | 7.2 | 0.1 | 12 | 1.5 | 1.10 | 3.5 | 0.2 | 12 |
| **A1 - 86** | 0.9 | 0.98 | 2.9 | 0.1 | 11 | 1.8 | 1.95 | 6.0 | 0.1 | 11 |
| **A2 - 85** | 1.4 | 0.81 | 3.4 | 0.8 | 11 | 1.9 | 1.51 | 4.5 | 0.2 | 12 |
| **A2 - 86** | 0.7 | 0.67 | 2.3 | 0.1 | 11 | 1.5 | 2.14 | 7.7 | 0.2 | 11 |
| **A3 - 85** | 1.4 | 2.12 | 7.7 | 0.2 | 12 | 1.2 | 1.01 | 3.0 | 0.2 | 12 |
| **A3 - 86** | 1.0 | 1.39 | 4.4 | 0.1 | 11 | 1.6 | 1.11 | 2.9 | 0.1 | 10 |
| **B1 - 85** | 2.6 | 1.85 | 7.0 | 0.6 | 11 | 1.8 | 1.53 | 5.6 | 0.5 | 12 |
| **B1 - 86** | 3.5 | 3.81 | 11.0 | 0.4 | 11 | 2.8 | 2.11 | 8.0 | 0.8 | 11 |
| **B2 - 85** | 3.2 | 2.38 | 8.2 | 0.6 | 11 | 1.6 | 1.25 | 4.7 | 0.3 | 12 |
| **B2 - 86** | 3.8 | 3.84 | 11.1 | 0.5 | 10 | 2.6 | 1.70 | 5.7 | 0.8 | 11 |
| **B3 - 85** | 2.5 | 1.57 | 4.7 | 0.5 | 11 | 1.6 | 1.49 | 5.5 | 0.4 | 12 |
| **B3 - 86** | 3.4 | 2.23 | 6.2 | 0.3 | 10 | 2.3 | 2.29 | 8.4 | 0.7 | 11 |
| **C1 - 85** | 2.8 | 2.94 | 8.6 | 0.1 | 12 | 3.4 | 3.28 | 11.5 | 0.2 | 12 |
| **C1 - 86** | 5.7 | 6.41 | 23.3 | 0.2 | 11 | 4.8 | 3.37 | 12.7 | 1.7 | 11 |
| **C2 - 85** | 2.5 | 2.23 | 6.5 | 0.1 | 12 | 3.1 | 3.03 | 11.2 | 0.2 | 12 |
| **C2 - 86** | 5.3 | 4.40 | 15.1 | 0.4 | 11 | 6.6 | 5.67 | 18.0 | 0.7 | 11 |
| **D1 - 85** | 4.2 | 4.82 | 15.7 | 0.1 | 12 | 3.8 | 4.23 | 13.5 | 0.2 | 12 |
| **D1 - 86** | 4.4 | 3.70 | 11.9 | 0.9 | 11 | 2.2 | 1.37 | 5.2 | 0.6 | 11 |
| **D2 - 85** | 4.1 | 3.51 | 9.7 | 0.8 | 11 | 3.7 | 4.30 | 15.2 | 0.1 | 12 |
| **D2 - 86** | 2.9 | 1.29 | 5.2 | 1.0 | 11 | 2.8 | 1.87 | 7.2 | 0.5 | 11 |

### Table 13

| Phaeopigments (mg m$^{-3}$) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 0.6 | 0.36 | 1.2 | 0.1 | 12 | 0.6 | 0.47 | 1.4 | 0.1 | 12 |
| **A1 - 86** | 0.3 | 0.18 | 0.8 | 0.2 | 11 | 0.6 | 0.57 | 2.2 | 0.2 | 11 |
| **A2 - 85** | 1.0 | 0.82 | 3.3 | 0.3 | 11 | 0.9 | 0.78 | 3.1 | 0.2 | 12 |
| **A2 - 86** | 0.7 | 1.00 | 3.3 | 0.1 | 11 | 0.8 | 0.77 | 3.0 | 0.2 | 11 |
| **A3 - 85** | 1.2 | 2.22 | 7.8 | 0.2 | 12 | 0.8 | 0.83 | 2.8 | 0.1 | 12 |
| **A3 - 86** | 0.4 | 0.31 | 1.0 | 0.1 | 11 | 0.9 | 0.63 | 1.9 | 0.1 | 10 |
| **B1 - 85** | 1.8 | 1.09 | 4.7 | 0.8 | 11 | 1.0 | 0.75 | 2.9 | 0.4 | 12 |
| **B1 - 86** | 1.8 | 1.66 | 5.9 | 0.4 | 11 | 1.4 | 0.71 | 2.7 | 0.4 | 11 |
| **B2 - 85** | 2.3 | 1.37 | 5.2 | 1.0 | 11 | 1.2 | 0.75 | 2.8 | 0.2 | 12 |
| **B2 - 86** | 2.0 | 1.17 | 4.0 | 0.5 | 10 | 1.5 | 0.69 | 2.6 | 0.4 | 11 |
| **B3 - 85** | 1.5 | 0.48 | 2.4 | 0.8 | 11 | 1.2 | 1.09 | 4.4 | 0.4 | 12 |
| **B3 - 86** | 1.6 | 0.96 | 3.6 | 0.5 | 10 | 1.4 | 0.89 | 3.2 | 0.5 | 11 |
| **C1 - 85** | 1.1 | 0.76 | 3.0 | 0.3 | 12 | 1.4 | 1.34 | 4.6 | 0.2 | 12 |
| **C1 - 86** | 1.8 | 1.37 | 4.7 | 0.6 | 11 | 1.7 | 0.82 | 2.9 | 0.5 | 11 |
| **C2 - 85** | 1.4 | 0.68 | 2.5 | 0.3 | 12 | 1.5 | 1.11 | 3.3 | 0.2 | 12 |
| **C2 - 86** | 2.1 | 1.40 | 5.8 | 0.9 | 11 | 2.5 | 2.41 | 9.1 | 0.6 | 11 |
| **D1 - 85** | 1.4 | 0.77 | 2.6 | 0.4 | 12 | 1.2 | 0.89 | 3.4 | 0.2 | 12 |
| **D1 - 86** | 1.5 | 1.09 | 4.5 | 0.0 | 11 | 1.0 | 0.29 | 1.4 | 0.5 | 11 |
| **D2 - 85** | 2.0 | 1.47 | 5.1 | 0.3 | 11 | 1.3 | 0.89 | 3.6 | 0.2 | 12 |
| **D2 - 86** | 1.4 | 0.54 | 2.2 | 0.1 | 11 | 1.3 | 1.22 | 5.0 | 0.5 | 11 |

### Table 14

| Degradation (%) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Neap tides | | | | | Spring tides | | | | |
| | Mean | std | Max. | Min. | N | Mean | std | Max. | Min. | N |
| **A1 - 85** | 32.2 | 20.52 | 83.0 | 13.0 | 12 | 29.3 | 9.46 | 50.0 | 14.0 | 12 |
| **A1 - 86** | 38.9 | 20.33 | 70.0 | 8.0 | 11 | 32.1 | 12.49 | 54.0 | 12.0 | 11 |
| **A2 - 85** | 39.6 | 13.94 | 58.0 | 15.0 | 11 | 34.7 | 14.83 | 62.0 | 15.0 | 12 |
| **A2 - 86** | 50.2 | 14.72 | 72.0 | 19.0 | 11 | 43.0 | 13.86 | 72.0 | 25.0 | 11 |
| **A3 - 85** | 44.1 | 15.96 | 65.0 | 18.0 | 12 | 40.3 | 9.79 | 61.0 | 24.0 | 12 |
| **A3 - 86** | 42.0 | 16.43 | 68.0 | 17.0 | 11 | 39.7 | 9.82 | 56.0 | 23.0 | 10 |
| **B1 - 85** | 44.3 | 15.25 | 68.0 | 18.0 | 11 | 38.7 | 10.40 | 60.0 | 26.0 | 12 |
| **B1 - 86** | 40.5 | 18.90 | 73.0 | 8.0 | 11 | 36.8 | 11.86 | 57.0 | 23.0 | 11 |
| **B2 - 85** | 46.8 | 19.93 | 73.0 | 21.0 | 11 | 44.4 | 6.60 | 53.0 | 37.0 | 12 |
| **B2 - 86** | 40.5 | 16.63 | 67.0 | 20.0 | 10 | 39.8 | 8.74 | 54.0 | 27.0 | 11 |
| **B3 - 85** | 43.7 | 17.70 | 68.0 | 24.0 | 11 | 43.9 | 16.32 | 77.0 | 25.0 | 12 |
| **B3 - 86** | 36.4 | 17.78 | 61.0 | 18.0 | 10 | 39.9 | 14.19 | 75.0 | 25.0 | 11 |
| **C1 - 85** | 35.9 | 19.68 | 87.0 | 13.0 | 12 | 33.1 | 9.15 | 52.0 | 17.0 | 12 |
| **C1 - 86** | 32.5 | 19.47 | 70.0 | 14.0 | 11 | 28.9 | 15.00 | 61.0 | 9.0 | 11 |
| **C2 - 85** | 43.6 | 15.75 | 70.0 | 19.0 | 12 | 35.9 | 8.55 | 52.0 | 23.0 | 12 |
| **C2 - 86** | 36.4 | 17.76 | 68.0 | 14.0 | 11 | 31.2 | 16.93 | 75.0 | 10.0 | 11 |
| **D1 - 85** | 33.9 | 17.08 | 72.0 | 13.0 | 12 | 31.8 | 12.60 | 52.0 | 17.0 | 12 |
| **D1 - 86** | 35.4 | 12.55 | 56.0 | 10.0 | 10 | 34.3 | 10.23 | 47.0 | 15.0 | 11 |
| **D2 - 85** | 35.3 | 9.26 | 51.0 | 22.0 | 11 | 32.9 | 11.08 | 54.0 | 17.0 | 12 |
| **D2 - 86** | 33.5 | 14.20 | 55.0 | 6.0 | 11 | 38.0 | 8.09 | 51.0 | 26.0 | 11 |

## Appendix A2

### List of taxa

| Codes used: | | | Feeding type: |
|---|---|---|---|
| | **Cnidaria** | | |
| | **Anthozoa** | | |
| 1 Para | *Paranemonia cinecea* | (Contarini,) | C |
| | **Nemertina** | | |
| 2 Neme | Nemertina n.i. | | C |
| | **Annelida** | | |
| | **Polychaeta** | | |
| 3 Aoni | *Aonides oxycephala* | Sars, 1862 | D |
| 4 Capi | *Capitella capitata* | (Fabricius, 1780) | D |
| 5 Cirr | Cirratulidae | | D |
| 6 Cten | *Cirriformia tentaculata* | Montagu, 1808 | D |
| 7 Eucl | *Euclymene palermitana* | (Grube, 1840) | D |
| 8 Glyc | *Glycera convoluta* | Keferstein, | C |
| 9 Gypt | *Gyptis propinqua* | Marion & Bobretzky, 1875 | C |
| 10 Hete | *Heteromastus filiformis* | (Claparède, 1864) | D |
| 11 Hydr | *Hydroides norvegica* | Gunnerus, 1768 | F |
| 12 Jasm | *Jasmineira* sp. | | F |
| 13 Lagi | *Lagis koreni* | Malmgren, 1866 | D |
| 14 Lani | *Lanice conchilega* | (Pallas, 1766) | D |
| 15 Lumb | *Lumbrinereis gracilis* | (Ehlers, 1868) | C,N |
| 16 Marp | *Marphysa sanguinea* | Montagu, 1815 | C,H |
| 17 Meli | *Melinna palmata* | Grube, 1869 | C,D |
| 18 Merc | *Mercierella enigmatica* | (Fauvel, 1923) | F |
| 19 Nain | *Nainereis laevigata* | Mesnil & Caullery, 1898 | D |
| 20 Neph | *Nephtys hombergii* | Savigny, 1818 | C |
| 21 Nere | *Nereis caudata* | (Della Chiaje, 1841) | O |
| 22 Noto | *Notomastus latericeus* | Sars, 1850 | D |
| 23 Phyl | *Phyllodoce paretti* | (Blainville, 1849) | C |
| 24 Poly | *Polydora polybranchia* | (Haswell, 1885) | D |
| 25 Scol | *Scolaricia typica* | Eisig, 1914 | D |
| 26 Spio | *Spio filicornis* | (Müller, 1776) | D |
| 27 Stre | *Streblospio dekhuyzeni* | Horst, 1909 | D |
| 28 Syl1 | Syllidae - Type 1 | | C |
| 29 Syl2 | Syllidae - Type 2 | | C |
| | **Oligochaeta** | | |
| 30 Olig | Tubificidae n.i. | | D |
| | **Sipuncula** | | |
| 31 Sipu | Sipuncula n.i. | | D |
| | **Phoronidae** | | |
| 32 Phor | *Phoronis* sp. | | F,D |
| | **Mollusca** | | |
| | **Poliplacophora** | | |
| 33 Lepi | *Lepidochitona cinereus* | (L., 1767) | H |
| | **Prosobranchia** | | |
| 34 Amyc | *Amyclina corniculum* | (Olivi, 1792) | N,D |
| 35 Bitt | *Bittium reticulatum* | (Da Costa, 1778) | D,H |
| 36 Caly | *Calyptraea chinensis* | (L., 1758) | C,D |
| 37 Ceri | *Cerithium vulgatum* | Bruguière, 1792 | H,D |

|  |  |  |  |  |
|---|---|---|---|---|
| 38 | Conu | *Conus mediterraneus* | (Bruguière, 1792) | C |
| 39 | Cycl | *Cyclope neritae* | (L., 1758) | C,N |
| 40 | Hini | *Hinia incrassata* | (Muller, 1776) | C,N |
| 41 | Hulv | *Hydrobia ulvae* | (Pennant, 1977) | H,D |
| 42 | Hven | *Hydrobia ventrosa* | (Montagu, 1803) | H,D |
| 43 | Juju | *Jujubinus sp.* |  | H,D? |
| 44 | Mesa | *Mesalia brevialis* | Lamarck, 1843 | ?F,D |
| 45 | Riss | *Rissoa membranacea* | (Adams, 1894) | H,D |
| 46 | Spha | *Sphaeronassa pfeifferi* | Philippi, 1848 | C,N |
| 47 | Trun | *Truncułariopsis trunculus* | L., 1758 | C |
|  |  | **Opisthobranchia** |  |  |
| 48 | Aply | *Aplysia* sp. |  | H |
| 49 | Hami | *Haminea hydatis* | L., 1758 | C |
| 50 | Turb | *Turbonilla* sp. |  | P |
|  |  | **Bivalvia** |  |  |
| 51 | Abra | *Abra ovata* | (Philippi, 1836) | D |
| 52 | Cedu | *Cardium edule* | (L., 1758) | F |
| 53 | Cgla | *Cardium glaucum* | Bruguière, 1792 | F,D? |
| 54 | Corb | *Corbula gibba* | (Olivi, 1792) | F |
| 55 | Lept | *Lepton* sp. |  | F? |
| 56 | Lori | *Loripes lacteus* | (L., 1758) | F,D |
| 57 | Myti | Mytilidae | *1 | F |
| 58 | Rudi | *Ruditapes decussatus* | L., 1758 | F |
| 59 | Scro | *Scrobicularia plana* | (Da Costa, 1778) | F,D |
| 60 | Vene | *Venerupis aurea* | (Gmelin, 1970) | F |
|  |  | **Crustacea** |  |  |
|  |  | **Balanidae** |  |  |
| 61 | Bala | *Balanus amphitrite* | Darwin, 1854 | F |
|  |  | **Leptostraca** |  |  |
| 62 | Neba | *Nebalia bipes* | Fabricius, | F |
|  |  | **Mysidacea** |  |  |
| 63 | Gast | *Gastrossacus spinifer* ? | (Goes, 1864) | C,D |
|  |  | **Tanaidacea** |  |  |
| 64 | Apse | *Apseudes latreillei* | (Milne Edwards, 1828) | D,F |
| 65 | Lsav | *Leptochelia savignyi* | (Kroyer, 1842) | D |
|  |  | **Cumacea** |  |  |
| 66 | Iphi | *Iphinoe tenella* | Sars, 1878 | D |
|  |  | **Isopoda** |  |  |
| 67 | Cyat | *Cyathura carinata* | (Kroyer, 1847) | D |
| 68 | Cymo | *Cymodoce truncata* | Leach, 1818 | D |
| 69 | Idot | *Idotea chelipes* | (Pallas, 1776) | O |
| 70 | Shoo | *Sphaeroma hookeri* | Leach, 1814 | H,D |
|  |  | **Amphipoda** |  |  |
| 71 | Ampe | *Ampelisca diadema* | (Costa, 1853) | D |
| 72 | Amph | *Amphithoe* spp. | *2 | H,D |
| 73 | Coro | *Corophium acherusicum* | Costa, 1851 | D,F |
| 74 | Dexa | *Dexamine spinosa* | (Montagu, 1813) |  |
| 75 | Elas | *Elasmopus rapax* | Costa, 1853 |  |
| 76 | Eric | *Ericthonius brasiliensis* | (Dana, 1852) |  |
| 77 | Gella | *Gammarella fucicola* | (Leach, 1814) |  |
| 78 | Gamm | *Gammarus* spp. | *3 | D,H |
| 79 | Leuc | *Leucothoe incisa* | Robertson, 1892 |  |
| 80 | Mita | *Melita palmata* | (Montagu, 1804) | D,H |
| 81 | Mche | *Microdeutopus chelifer* | (Bate, 1862) |  |
| 82 | Mgry | *Microdeutopus gryllotalpa* | Costa, 1853 | D,H |
| 83 | Msp. | *Microdeutopus* sp. |  | D,H |

| | | | | |
|---|---|---|---|---|
| 84 | Mver | *Microdeutopus versiculatus* | (Bate, 1856) | |
| 85 | Peri | *Perioculodes longimanes* | (Bate & Westwood, 1868) | |
| 86 | Phot | *Photis longicauda* | (Bate & Westwood, 1862) | |
| 87 | Siph | *Siphonoetes* spp. | *4 | D,H |
| | | **Decapoda** | | |
| 88 | Call | *Callianassa tyrrhena* | (Petagna, 1792) | D |
| 89 | Carc | *Carcinus maenas* | (L., 1758) | O |
| 90 | Diog | *Diogenes pugilator* | (Roux, 1892) | F,D |
| 91 | Pala | *Palaemonetes varians* | (Leach, 1814) | O |
| 92 | Upog | *Upogebia pusilla* | (Petagna, 1792) | D |
| | | **Insecta** | | |
| | | **Chironomidae** | | |
| 93 | Chir | *Chironomus salinarius* ? | Kieffer, 1915 | D,H |
| | | **Echinodermata** | | |
| | | **Ophiuroidea** | | |
| 94 | Achi | Amphiura chiajei ? | Forbes, 1843 | D,C |
| | | **Chordata** | | |
| | | **Osteichthyes** | | |
| 95 | Syng | Syngnathus acus | L., 1758 | C |

| | | |
|---|---|---|
| *1 | Mytilidae | |
| | *Modiolus modiolus* | (L., 1767) |
| | *Mytilaster minimus* | Poli, 1795 |
| *2 | *Amphithoe* spp. | |
| | *A. ramondi* | Audouin, 1826 |
| | *A. rubricata* | (Montagu, 1808) |
| *3 | *Gammarus* spp. | |
| | *G. chevreuxi* | Sexton, 1913 |
| | *G. insensibilis* | Stock, 1966 |
| *4 | *Siphonoetes* spp. | |
| | *S. kroyeranus* | Bate, 1856 |
| | *S. sabatieri* | de Rouville, 1894 |
| | *S. neapolitanus* | Schiecke, 1979 |
| | *S. dellavallei* | Stebbing, 1899 |

**Feeding type:**
**C** - Carnivores
**D** - Deposit-feeders (detritus, microphytobenthos)
**F** - Filter-feeders (plankton, detritus)
**H** - Herbivores (macroalgae, macrophytes)
**N** - Necrofags
**O** - Omnivores
**P** - Parasites

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| A1 | 1985 | | | | | | 1986 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | M | M | J | S | N | J | M | M | J | S | N |
| 1 Para | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 Neme | - | - | - | - | - | - | - | - | - | - | - | - |
| 3 Aoni | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 Capi | 1 | 6 | 36 | 10 | 61 | 24 | 68 | 24 | 7 | 1 | 16 | 18 |
| 5 Cirr | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 Cten | - | - | - | - | - | - | - | - | - | - | - | - |
| 7 Eucl | - | - | - | - | - | - | - | - | - | - | - | - |
| 8 Glyc | - | - | - | - | - | - | - | - | - | - | - | - |
| 9 Gypt | - | - | - | - | - | - | - | - | - | - | - | - |
| 10 Hete | - | - | - | - | - | - | - | - | - | - | - | - |
| 11 Hydr | - | - | - | - | - | - | - | - | - | - | - | - |
| 12 Jasm | - | - | - | - | - | - | - | - | - | - | - | - |
| 13 Lagi | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 Lani | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 Lumb | - | - | - | - | - | - | - | - | - | - | - | - |
| 16 Marp | - | - | - | - | - | - | - | - | - | - | - | - |
| 17 Meli | - | - | - | - | - | - | - | - | - | - | - | - |
| 18 Merc | - | - | - | - | - | - | - | - | - | - | - | - |
| 19 Nain | - | - | - | - | - | - | - | - | - | - | - | - |
| 20 Neph | - | - | - | - | - | - | - | - | - | - | - | - |
| 21 Nere | - | - | - | 1 | 1 | 1 | - | - | - | - | - | - |
| 22 Noto | - | - | - | - | - | - | - | - | - | - | - | - |
| 23 Phyl | - | - | - | - | - | - | - | - | - | - | - | - |
| 24 Poly | - | - | 16 | - | - | - | - | - | - | - | - | - |
| 25 Scol | - | - | - | - | - | - | - | - | - | - | - | - |
| 26 Spio | - | - | - | - | - | - | - | - | - | - | - | - |
| 27 Stre | - | - | - | - | - | - | - | - | - | - | - | - |
| 28 Syl1 | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 29 Syl2 | - | - | - | - | - | - | - | - | - | - | - | - |
| 30 Olig | - | - | - | - | - | - | - | - | - | - | - | - |
| 31 Sipu | - | - | - | - | - | - | - | - | - | - | - | - |
| 32 Phor | - | - | - | - | - | - | - | - | - | - | - | - |
| 33 Lepi | - | - | - | - | - | - | - | - | - | - | - | - |
| 34 Amyc | - | - | - | - | - | - | - | - | - | - | - | - |
| 35 Bitt | - | - | - | - | - | - | - | - | - | - | - | - |
| 36 Caly | - | - | - | - | - | - | - | - | - | - | - | - |
| 37 Ceri | - | - | - | - | - | - | - | - | - | - | - | - |
| 38 Conu | - | - | - | - | - | - | - | - | - | - | - | - |
| 39 Cycl | - | - | - | - | - | - | - | - | - | - | - | - |
| 40 Hini | - | - | - | - | - | - | - | - | - | - | - | - |
| 41 Hulv | 16 | 12 | 2 | 8 | 11 | 7 | 14 | 16 | 4 | 6 | 11 | 5 |
| 42 Hven | 45 | 110 | 42 | 109 | 86 | 64 | 103 | 309 | 246 | 60 | 459 | 588 |
| 43 Juju | - | - | - | - | - | - | - | - | - | - | - | - |
| 44 Mesa | - | - | - | - | - | - | - | - | - | - | - | - |
| 45 Riss | - | - | - | - | - | - | - | - | - | - | - | - |
| 46 Spha | - | - | - | - | - | - | - | - | - | - | - | - |
| 47 Trun | - | - | - | - | - | - | - | - | - | - | - | - |
| 48 Aply | - | - | - | - | - | - | - | - | - | - | - | - |
| 49 Hami | - | - | - | - | - | - | - | - | - | - | - | - |
| 50 Turb | - | - | - | - | - | - | - | - | - | - | - | - |

| A1 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 Abra | 6 | - | 5 | 21 | 30 | 35 | 33 | 17 | 5 | 13 | 4 | 4 |
| 52 Cedu | - | - | - | - | - | 1 | - | - | - | - | - | - |
| 53 Cgla | 5 | 25 | 47 | 4 | 22 | 6 | 1 | 4 | 3 | - | 1 | 22 |
| 54 Corb | - | - | - | - | - | - | - | - | - | - | - | - |
| 55 Lept | - | - | - | - | - | - | - | - | - | - | - | - |
| 56 Lori | - | - | - | - | - | - | - | - | - | - | - | - |
| 57 Myti | - | - | - | - | - | - | - | - | - | - | - | - |
| 58 Rudi | - | - | - | - | - | - | - | - | - | - | - | - |
| 59 Scro | - | - | - | - | - | - | - | - | - | - | - | - |
| 60 Vene | - | - | - | - | - | - | - | - | - | - | - | - |
| 61 Bala | - | - | - | - | - | - | - | - | - | - | - | - |
| 62 Neba | - | - | - | - | - | - | - | - | - | - | - | - |
| 63 Gast | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 64 Apse | - | - | - | - | - | - | - | - | - | - | - | - |
| 65 Lsav | - | - | - | - | - | - | - | - | - | - | - | - |
| 66 Iphi | - | - | - | - | - | - | - | - | - | - | - | - |
| 67 Cyat | - | - | - | - | - | - | - | - | - | - | - | - |
| 68 Cymo | - | - | - | - | - | - | - | - | - | - | - | - |
| 69 Idot | - | - | - | - | - | - | - | - | - | - | - | - |
| 70 Shoo | - | - | - | - | - | - | - | - | - | - | - | - |
| 71 Ampe | - | - | - | - | - | - | - | - | - | - | - | - |
| 72 Amph | - | - | - | - | - | - | - | - | 1 | - | - | - |
| 73 Coro | - | - | - | - | - | - | - | - | - | - | - | - |
| 74 Dexa | - | - | - | - | - | - | - | - | - | - | - | - |
| 75 Elas | - | - | - | - | - | - | - | - | - | - | - | - |
| 76 Eric | - | - | - | - | - | - | - | - | - | - | - | - |
| 77 Gell | - | - | - | - | - | - | - | - | - | - | - | - |
| 78 Gamm | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 79 Leuc | - | - | - | - | - | - | - | - | - | - | - | - |
| 80 Mita | - | - | - | - | - | - | - | - | - | - | - | - |
| 81 Mche | - | - | - | - | - | - | - | - | - | - | - | - |
| 82 Mgry | - | - | 14 | - | - | - | 3 | 8 | 4 | - | - | - |
| 83 Msp. | - | - | - | 6 | - | 1 | 7 | 4 | 3 | - | - | - |
| 84 Mver | 1 | - | - | - | - | - | - | - | - | - | - | - |
| 85 Peri | - | - | - | - | - | - | - | - | - | - | - | - |
| 86 Phot | - | - | - | - | - | - | - | - | - | - | - | - |
| 87 Siph | - | - | - | - | - | - | - | - | - | - | - | - |
| 88 Call | - | - | - | - | - | - | - | - | - | - | - | - |
| 89 Carc | - | - | - | - | - | - | - | - | - | - | - | - |
| 90 Diog | - | - | - | - | - | - | - | - | - | - | - | - |
| 91 Pala | - | - | - | - | - | - | - | - | - | - | - | - |
| 92 Upog | - | - | - | - | - | - | - | - | - | - | - | - |
| 93 Chir | 1 | 3 | 9 | - | - | 2 | 77 | - | - | 3 | 2 | 7 |
| 94 Achi | - | - | - | - | - | - | - | - | - | - | - | - |
| 95 Syng | - | - | - | - | - | - | - | - | - | - | - | - |

| A2 | 1985 | | | | | | 1986 | | | | | |
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| | J | M | M | J | S | N | J | M | M | J | S | N |
| 1 Para | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 Neme | 1 | 1 | - | - | - | - | - | - | - | - | - | - |
| 3 Aoni | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 Capi | 4 | 19 | 45 | 8 | 33 | 4 | 6 | 37 | 19 | 4 | 1 | 2 |
| 5 Cirr | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 Cten | - | - | - | - | - | - | - | - | - | - | - | - |
| 7 Eucl | - | - | - | - | - | - | - | - | - | - | - | - |
| 8 Glyc | - | - | - | - | - | - | - | - | - | - | - | - |
| 9 Gypt | - | - | - | - | - | - | - | - | - | - | - | - |
| 10 Hete | - | - | - | - | - | - | - | - | - | - | - | - |
| 11 Hydr | - | - | - | - | - | - | - | - | - | - | - | - |
| 12 Jasm | - | - | - | - | - | - | - | - | - | - | - | - |
| 13 Lagi | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 Lani | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 Lumb | - | - | - | - | - | - | - | - | - | - | - | - |
| 16 Marp | - | - | - | - | - | - | - | - | - | - | - | - |
| 17 Meli | - | - | - | - | - | - | - | - | - | - | - | - |
| 18 Merc | - | - | - | - | - | - | - | - | - | - | - | - |
| 19 Nain | - | - | - | - | - | - | - | - | - | - | - | - |
| 20 Neph | - | - | - | - | - | - | - | - | - | - | - | - |
| 21 Nere | - | - | - | - | - | - | - | - | - | - | - | - |
| 22 Noto | - | - | - | - | - | - | - | - | - | - | - | - |
| 23 Phyl | - | - | - | - | - | - | - | - | - | - | - | - |
| 24 Poly | - | - | - | - | - | - | - | - | - | - | - | - |
| 25 Scol | - | - | - | - | - | - | - | - | - | - | - | - |
| 26 Spio | - | - | - | - | - | - | - | - | - | - | - | - |
| 27 Stre | - | 1 | - | - | - | - | - | - | - | - | - | - |
| 28 Syl1 | - | - | - | - | - | - | - | - | - | - | - | - |
| 29 Syl2 | - | - | - | - | - | - | - | - | - | - | - | - |
| 30 Olig | - | - | - | - | - | - | - | - | - | - | - | - |
| 31 Sipu | - | - | - | - | - | - | - | - | - | - | - | - |
| 32 Phor | - | - | - | - | - | - | - | - | - | - | - | - |
| 33 Lepi | - | - | - | - | - | - | - | - | - | - | - | - |
| 34 Amyc | - | - | - | - | - | - | - | - | - | - | - | - |
| 35 Bitt | - | - | - | - | - | - | - | - | - | - | - | - |
| 36 Caly | - | - | - | - | - | - | - | - | - | - | - | - |
| 37 Ceri | - | - | - | - | - | - | - | - | - | - | - | - |
| 38 Conu | - | - | - | - | - | - | - | - | - | - | - | - |
| 39 Cycl | - | - | - | - | - | - | - | - | - | - | - | - |
| 40 Hini | - | - | - | - | - | - | - | - | - | - | - | - |
| 41 Hulv | 5 | 9 | 10 | 19 | 13 | 14 | 3 | 5 | 8 | 4 | - | 3 |
| 42 Hven | 5 | 3 | 51 | 126 | 124 | 99 | 78 | 152 | 221 | 138 | 93 | 129 |
| 43 Juju | - | - | - | - | - | - | - | - | - | - | - | - |
| 44 Mesa | - | - | - | - | - | - | - | - | - | - | - | - |
| 45 Riss | - | - | - | - | - | - | - | 1 | - | - | - | - |
| 46 Spha | - | - | - | - | - | - | - | - | - | - | - | - |
| 47 Trun | - | - | - | - | - | - | - | - | - | - | - | - |
| 48 Aply | - | - | - | - | - | - | - | - | - | - | - | - |
| 49 Hami | - | - | - | - | - | - | - | - | - | - | - | - |
| 50 Turb | - | - | - | - | - | - | - | - | - | - | - | - |

| A2 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 Abra | 1 | 26 | 43 | 69 | 101 | 2 | 1 | 19 | 34 | 8 | - | - |
| 52 Cedu | - | - | - | - | - | - | - | - | - | - | - | - |
| 53 Cgla | 22 | 55 | 26 | 9 | 9 | - | 2 | 4 | 3 | - | - | - |
| 54 Corb | - | - | - | - | - | - | - | - | - | - | - | - |
| 55 Lept | - | - | - | - | - | - | - | - | - | - | - | - |
| 56 Lori | - | - | - | - | - | - | - | - | - | - | - | - |
| 57 Myti | - | - | - | - | - | - | - | - | - | - | - | - |
| 58 Rudi | - | - | - | - | - | - | - | - | - | - | - | - |
| 59 Scro | - | - | - | - | - | - | - | - | - | - | - | - |
| 60 Vene | - | - | - | - | - | - | - | - | - | - | - | - |
| 61 Bala | - | - | - | - | - | - | - | - | - | - | - | - |
| 62 Neba | - | - | - | - | - | - | - | - | - | - | - | - |
| 63 Gast | - | - | - | - | - | - | - | - | - | - | - | - |
| 64 Apse | - | - | - | - | - | - | - | - | - | - | - | - |
| 65 Lsav | - | - | - | - | - | - | - | - | - | - | - | - |
| 66 Iphi | - | - | - | - | - | - | - | - | - | - | - | - |
| 67 Cyat | - | - | - | - | - | - | - | - | - | - | - | - |
| 68 Cymo | - | - | - | - | - | - | - | - | - | - | - | - |
| 69 Idot | - | - | 2 | - | - | - | - | - | - | - | - | - |
| 70 Shoo | - | - | - | - | - | - | - | - | - | - | - | - |
| 71 Ampe | - | - | - | - | - | - | - | - | - | - | - | - |
| 72 Amph | - | - | - | - | - | - | - | - | - | - | - | - |
| 73 Coro | - | - | - | - | - | - | - | - | - | - | - | - |
| 74 Dexa | - | - | - | - | - | - | - | - | - | - | - | - |
| 75 Elas | - | - | - | - | - | - | - | - | - | - | - | - |
| 76 Eric | - | - | - | - | - | - | - | - | - | - | - | - |
| 77 Gell | - | - | - | - | - | - | - | - | - | - | - | - |
| 78 Gamm | - | 66 | 24 | 5 | - | - | - | - | - | - | - | - |
| 79 Leuc | - | - | - | - | - | - | - | - | - | - | - | - |
| 80 Mita | - | - | - | - | - | - | - | - | - | - | - | - |
| 81 Mche | - | - | - | - | - | - | - | - | - | - | - | - |
| 82 Mgry | - | - | 13 | 3 | - | - | - | 7 | 4 | - | - | - |
| 83 Msp. | - | - | - | - | - | - | - | 1 | 27 | - | - | - |
| 84 Mver | - | - | - | - | - | - | - | - | - | - | - | - |
| 85 Peri | - | - | - | - | - | - | - | - | - | - | - | - |
| 86 Phot | - | - | - | - | - | - | - | - | - | - | - | - |
| 87 Siph | - | - | - | - | - | - | - | - | - | - | - | - |
| 88 Call | - | - | - | - | - | - | - | - | - | - | - | - |
| 89 Carc | - | - | - | - | - | - | - | - | - | - | - | - |
| 90 Diog | - | - | - | - | - | - | - | - | - | - | - | - |
| 91 Pala | - | - | - | - | - | - | - | - | - | - | - | - |
| 92 Upog | - | - | - | - | - | - | - | - | - | - | - | - |
| 93 Chir | 59 | 280 | 124 | 21 | 22 | 29 | 144 | 144 | 13 | 2 | - | 142 |
| 94 Achi | - | - | - | - | - | - | - | - | - | - | - | - |
| 95 Syng | - | - | - | - | - | - | - | - | - | - | - | - |

| A3 | 1985 | | | | | | 1986 | | | | | |
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| | J | M | M | J | S | N | J | M | M | J | S | N |
| 1 Para | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 Neme | - | - | - | - | - | - | - | - | - | - | - | - |
| 3 Aoni | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 Capi | 107 | 116 | 41 | 22 | 2 | 4 | 1 | 34 | 47 | - | 8 | 31 |
| 5 Cirr | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 Cten | - | - | - | - | - | - | - | - | - | - | - | - |
| 7 Eucl | - | - | - | - | - | - | - | - | - | - | - | - |
| 8 Glyc | - | - | - | - | - | - | - | - | - | - | - | - |
| 9 Gypt | - | - | - | - | - | - | - | - | - | - | - | - |
| 10 Hete | - | - | - | - | - | - | - | - | - | - | - | - |
| 11 Hydr | - | - | - | - | - | - | - | - | - | - | - | - |
| 12 Jasm | - | - | - | - | - | - | - | - | - | - | - | - |
| 13 Lagi | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 Lani | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 Lumb | - | - | - | - | - | - | - | - | - | - | - | - |
| 16 Marp | - | - | - | - | - | - | - | - | - | - | - | - |
| 17 Meli | - | - | - | - | - | - | - | - | - | - | - | - |
| 18 Merc | - | - | - | - | - | - | - | - | - | - | - | - |
| 19 Nain | - | - | - | - | - | - | - | - | - | - | - | - |
| 20 Neph | - | - | - | - | - | - | - | - | - | - | - | - |
| 21 Nere | - | - | - | - | - | - | - | - | - | - | - | - |
| 22 Noto | - | - | - | - | - | - | - | - | - | - | - | - |
| 23 Phyl | - | - | - | - | - | - | - | - | - | - | - | - |
| 24 Poly | - | - | - | - | - | - | - | - | - | - | - | - |
| 25 Scol | - | - | - | - | - | - | - | - | - | - | - | - |
| 26 Spio | - | - | - | - | - | - | - | - | - | - | - | - |
| 27 Stre | - | - | - | - | - | - | - | - | - | - | - | - |
| 28 Syl1 | - | - | - | - | - | - | - | - | - | - | - | - |
| 29 Syl2 | - | - | - | - | - | - | - | - | - | - | - | - |
| 30 Olig | - | 20 | - | - | - | - | - | - | - | - | - | - |
| 31 Sipu | - | - | - | - | - | - | - | - | - | - | - | - |
| 32 Phor | - | - | - | - | - | - | - | - | - | - | - | - |
| 33 Lepi | - | - | - | - | - | - | - | - | - | - | - | - |
| 34 Amyc | - | - | - | - | - | - | - | - | - | - | - | - |
| 35 Bitt | - | - | - | - | - | - | - | - | - | - | - | - |
| 36 Caly | - | - | - | - | - | - | - | - | - | - | - | - |
| 37 Ceri | - | - | - | - | - | - | - | - | - | - | - | - |
| 38 Conu | - | - | - | - | - | - | - | - | - | - | - | - |
| 39 Cycl | - | - | - | - | - | - | - | - | - | - | - | - |
| 40 Hini | - | - | - | - | - | - | - | - | - | - | - | - |
| 41 Hulv | 12 | 6 | 4 | 6 | 12 | 23 | 10 | 15 | 33 | 11 | 2 | 2 |
| 42 Hven | 106 | 18 | 63 | 12 | 101 | 80 | 135 | 336 | 199 | 238 | 251 | 295 |
| 43 Juju | - | - | - | - | - | 1 | - | - | - | - | - | - |
| 44 Mesa | - | - | - | - | - | - | - | - | - | - | - | - |
| 45 Riss | - | - | - | - | - | - | - | - | - | - | - | - |
| 46 Spha | - | - | - | - | - | - | - | - | - | - | - | - |
| 47 Trun | - | - | - | - | - | - | - | - | - | - | - | - |
| 48 Aply | - | - | - | - | - | - | - | - | - | - | - | 1 |
| 49 Hami | - | - | - | - | - | - | - | - | - | - | - | - |
| 50 Turb | - | - | - | - | - | - | - | - | - | - | - | - |

| A3 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 Abra | 3 | 15 | 10 | 40 | 20 | 60 | 23 | 48 | 28 | 25 | 7 | 11 |
| 52 Cedu | - | - | - | - | - | - | - | - | - | - | - | - |
| 53 Cgla | 12 | 6 | 11 | 10 | 6 | 3 | 1 | 2 | 7 | 3 | 1 | 5 |
| 54 Corb | - | - | - | - | - | - | - | - | - | - | - | - |
| 55 Lept | - | - | - | - | - | - | - | - | - | - | - | - |
| 56 Lori | - | - | - | - | - | - | - | - | - | - | - | - |
| 57 Myti | - | - | - | - | - | - | - | - | - | - | - | - |
| 58 Rudi | - | - | - | - | - | - | - | - | - | - | - | - |
| 59 Scro | - | - | - | - | - | - | - | - | - | - | - | - |
| 60 Vene | - | - | - | - | - | - | - | - | - | - | - | - |
| 61 Bala | - | - | - | - | - | - | - | - | - | - | - | - |
| 62 Neba | - | - | - | - | - | - | - | - | - | - | - | - |
| 63 Gast | - | - | - | - | - | - | - | - | - | - | - | - |
| 64 Apse | - | - | - | - | - | - | - | - | - | - | - | - |
| 65 Lsav | - | - | - | - | - | - | - | - | - | - | - | - |
| 66 Iphi | - | - | - | - | - | - | - | - | - | - | - | - |
| 67 Cyat | - | - | - | - | - | - | - | - | - | - | - | - |
| 68 Cymo | - | - | - | - | - | - | - | - | - | - | - | - |
| 69 Idot | - | - | - | - | - | - | - | - | - | - | - | - |
| 70 Shoo | - | - | - | - | - | - | - | - | - | - | - | - |
| 71 Ampe | - | - | - | - | - | - | - | - | - | - | - | - |
| 72 Amph | - | - | - | - | - | - | - | - | - | - | - | - |
| 73 Coro | - | - | - | - | - | - | - | - | - | - | - | - |
| 74 Dexa | - | - | - | - | - | - | - | - | - | - | - | - |
| 75 Elas | - | - | - | - | - | - | - | - | - | - | - | - |
| 76 Eric | - | - | - | - | - | - | - | - | - | - | - | - |
| 77 Gell | - | - | - | - | - | - | - | - | - | - | - | - |
| 78 Gamm | 1 | 8 | 2 | 1 | - | - | - | - | - | - | - | - |
| 79 Leuc | - | - | - | - | - | - | - | - | - | - | - | - |
| 80 Mita | - | - | - | - | - | - | - | - | - | - | - | - |
| 81 Mche | - | - | - | - | - | - | - | - | - | - | - | - |
| 82 Mgry | - | - | 18 | - | - | - | - | 4 | 7 | - | - | - |
| 83 Msp. | - | - | - | - | - | - | - | 4 | 16 | - | - | - |
| 84 Mver | - | - | - | - | - | - | - | - | - | - | - | - |
| 85 Peri | - | - | - | - | - | - | - | - | - | - | - | - |
| 86 Phot | - | - | - | - | - | - | - | - | - | - | - | - |
| 87 Siph | - | - | - | - | - | - | - | - | - | - | - | - |
| 88 Call | - | - | - | - | - | - | - | - | - | - | - | - |
| 89 Carc | - | - | - | - | - | - | - | - | - | - | - | - |
| 90 Diog | - | - | - | - | - | - | - | - | - | - | - | - |
| 91 Pala | - | - | - | - | - | - | - | - | - | - | - | - |
| 92 Upog | - | - | - | - | - | - | - | - | - | - | - | - |
| 93 Chir | 16 | 7 | - | - | - | 22 | 30 | 33 | 4 | 1 | 16 | 170 |
| 94 Achi | - | - | - | - | - | - | - | - | - | - | - | - |
| 95 Syng | - | - | - | - | - | - | - | - | - | - | - | - |

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| | J | M | M | J | S | N | J | M | M | J | S | N |
| 1 Para | - | - | - | 1 | - | - | 1 | - | - | - | - | - |
| 2 Neme | - | 1 | 1 | 1 | - | - | - | - | - | - | - | - |
| 3 Aoni | - | - | - | 2 | - | - | 3 | 2 | - | - | 1 | 3 |
| 4 Capi | - | 2 | - | - | - | - | - | - | - | - | - | 1 |
| 5 Cirr | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 Cten | - | - | - | 1 | - | - | - | - | - | - | - | - |
| 7 Eucl | 15 | 33 | 22 | 7 | 3 | 61 | 25 | 47 | 23 | 8 | 39 | 41 |
| 8 Glyc | 1 | - | 4 | - | - | 5 | 2 | 2 | 2 | - | - | 2 |
| 9 Gypt | - | - | - | - | - | - | - | - | - | - | - | - |
| 10 Hete | 61 | 49 | 42 | 23 | 22 | 12 | 16 | 39 | 32 | 13 | 30 | 53 |
| 11 Hydr | - | - | - | - | - | 5 | - | - | - | - | - | - |
| 12 Jasm | 3 | 1 | - | - | - | 1 | 1 | - | - | 2 | 1 | - |
| 13 Lagi | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 Lani | - | - | - | - | - | - | - | 2 | - | - | - | - |
| 15 Lumb | - | - | - | - | - | - | - | - | - | - | - | 1 |
| 16 Marp | - | - | - | - | - | - | - | - | - | - | - | - |
| 17 Meli | - | - | - | - | - | - | - | - | - | - | - | - |
| 18 Merc | - | - | - | - | - | - | - | - | - | - | - | - |
| 19 Nain | - | - | - | - | - | 5 | - | - | - | - | - | - |
| 20 Neph | 1 | 1 | - | - | - | - | - | - | - | 1 | - | - |
| 21 Nere | - | 3 | 4 | 15 | 19 | 12 | 2 | 9 | 2 | 1 | 5 | 16 |
| 22 Noto | - | 2 | 5 | 5 | 1 | 2 | - | 8 | 4 | 8 | - | 2 |
| 23 Phyl | - | - | - | - | - | - | - | 5 | - | 2 | - | - |
| 24 Poly | - | 2 | - | - | - | 1 | 1 | - | 2 | - | - | - |
| 25 Scol | - | - | - | - | - | - | - | - | - | - | - | - |
| 26 Spio | - | - | 1 | 2 | - | - | - | - | - | - | 1 | - |
| 27 Stre | 33 | 20 | 6 | - | 1 | - | - | 6 | - | 129 | 19 | 69 |
| 28 Syl1 | 2 | 2 | 1 | - | - | - | - | - | - | - | - | - |
| 29 Syl2 | - | 2 | - | - | - | - | 1 | 3 | - | - | - | 1 |
| 30 Olig | 10 | 2 | 1 | 1 | 1 | - | - | - | 1 | - | 2 | 3 |
| 31 Sipu | - | - | - | - | - | - | - | - | - | - | - | - |
| 32 Phor | - | - | 1 | 6 | 6 | 31 | 10 | 35 | - | 29 | 1 | 8 |
| 33 Lepi | - | - | - | 3 | - | 1 | - | - | - | - | - | - |
| 34 Amyc | - | - | - | - | - | - | - | - | - | 2 | - | 2 |
| 35 Bitt | - | 4 | - | - | 1 | 14 | 3 | 15 | 3 | 2 | - | - |
| 36 Caly | - | - | - | 1 | - | - | - | - | - | - | - | - |
| 37 Ceri | 34 | - | - | 3 | 5 | - | - | - | - | 1 | - | 1 |
| 38 Conu | - | - | - | 1 | - | 1 | - | - | - | - | - | - |
| 39 Cycl | 1 | 2 | - | - | - | 1 | 2 | - | - | - | - | - |
| 40 Hini | - | - | - | 1 | - | - | - | - | - | - | - | - |
| 41 Hulv | - | - | - | - | 1 | - | - | 1 | 3 | 5 | 5 | - |
| 42 Hven | - | - | - | - | - | - | - | - | - | - | - | - |
| 43 Juju | - | - | - | - | - | - | - | - | - | - | - | - |
| 44 Mesa | - | 3 | 18 | 15 | 15 | 30 | 23 | 24 | 5 | 6 | 4 | 6 |
| 45 Riss | - | - | - | - | - | - | - | - | - | - | - | - |
| 46 Spha | - | - | - | - | - | - | - | - | - | - | - | - |
| 47 Trun | - | - | 1 | 1 | - | - | - | - | - | - | - | - |
| 48 Aply | - | - | - | - | - | - | - | - | - | - | - | - |
| 49 Hami | - | - | - | - | - | - | - | - | - | - | - | - |
| 50 Turb | - | - | - | - | - | - | - | - | - | - | - | - |

| B1 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 Abra | 1 | 4 | 3 | 1 | 1 | 2 | - | 2 | 1 | 10 | 1 | 8 |
| 52 Cedu | - | 1 | - | 1 | - | - | - | - | 1 | 1 | - | - |
| 53 Cgla | - | - | - | - | - | - | - | - | - | - | - | - |
| 54 Corb | - | - | - | - | - | - | - | - | - | - | - | - |
| 55 Lept | - | - | - | 38 | - | - | - | 1 | - | - | - | - |
| 56 Lori | 4 | 6 | 11 | 4 | 3 | 2 | 1 | 1 | 2 | 1 | - | - |
| 57 Myti | - | - | - | - | - | - | - | - | - | - | - | - |
| 58 Rudi | - | - | - | - | - | - | - | - | 1 | - | - | - |
| 59 Scro | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 60 Vene | - | - | - | - | - | - | - | - | - | - | - | - |
| 61 Bala | - | - | - | - | - | - | - | - | - | - | - | - |
| 62 Neba | 3 | - | - | - | - | - | - | - | - | 2 | - | 1 |
| 63 Gast | - | - | - | - | - | - | - | - | - | - | - | 1 |
| 64 Apse | - | 4 | 3 | 18 | 2 | 2 | 5 | 15 | 1 | 1 | 1 | 13 |
| 65 Lsav | - | - | - | - | - | - | - | - | - | - | - | 2 |
| 66 Iphi | - | 3 | 4 | 10 | - | 4 | - | - | - | 4 | - | 36 |
| 67 Cyat | - | - | - | - | - | - | - | - | - | - | - | - |
| 68 Cymo | - | - | - | 2 | - | 1 | - | - | - | - | - | 2 |
| 69 Idot | 1 | - | - | 1 | - | - | - | - | - | - | - | 10 |
| 70 Shoo | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 71 Ampe | - | - | - | - | - | - | - | - | - | - | - | - |
| 72 Amph | - | - | - | - | - | - | - | - | - | - | - | 2 |
| 73 Coro | 5 | - | - | 22 | - | 1 | - | - | - | - | 2 | - |
| 74 Dexa | - | - | - | - | - | - | - | - | - | - | - | - |
| 75 Elas | - | - | - | - | - | - | - | - | - | - | - | - |
| 76 Eric | - | - | - | - | - | - | - | - | - | - | - | - |
| 77 Gell | - | - | - | 4 | - | - | - | - | - | - | - | - |
| 78 Gamm | 9 | - | - | - | - | - | - | 1 | - | - | - | 19 |
| 79 Leuc | - | - | - | 3 | - | 3 | 2 | - | - | - | - | 3 |
| 80 Mita | - | - | - | - | - | - | - | - | - | - | - | - |
| 81 Mche | - | - | - | - | - | - | - | - | - | - | - | - |
| 82 Mgry | 5 | - | - | - | 1 | - | - | - | - | - | 2 | 4 |
| 83 Msp. | - | - | - | - | 2 | 1 | - | - | - | - | 4 | 6 |
| 84 Mver | - | - | - | - | - | - | - | - | - | - | - | - |
| 85 Peri | - | - | 2 | 1 | - | - | - | - | - | 1 | - | - |
| 86 Phot | - | - | - | - | - | - | - | - | - | - | - | - |
| 87 Siph | - | 2 | 25 | 1 | - | - | 1 | - | - | - | 1 | - |
| 88 Call | - | - | - | - | - | - | - | - | - | - | - | - |
| 89 Carc | - | - | - | - | - | - | - | - | - | - | - | - |
| 90 Diog | - | 1 | - | - | - | 1 | - | - | - | - | - | - |
| 91 Pala | - | - | - | - | - | - | - | - | - | - | - | - |
| 92 Upog | - | - | - | - | - | - | - | - | - | - | - | - |
| 93 Chir | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 94 Achi | - | - | - | - | - | - | - | - | - | - | - | - |
| 95 Syng | - | - | - | - | - | - | - | - | - | - | - | - |

| **B2** | **1985** | | | | | | **1986** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **J** | **M** | **M** | **J** | **S** | **N** | **J** | **M** | **M** | **J** | **S** | **N** |
| **1 Para** | - | 4 | 1 | - | - | - | - | - | - | 2 | - | - |
| **2 Neme** | 1 | - | - | - | 1 | 6 | 1 | - | - | 1 | - | 2 |
| **3 Aoni** | - | - | - | - | 3 | - | - | 2 | - | 2 | - | - |
| **4 Capi** | - | 7 | - | - | 1 | - | - | 1 | 1 | 1 | 3 | - |
| **5 Cirr** | 7 | - | - | - | - | - | - | - | - | - | - | - |
| **6 Cten** | - | 2 | 1 | - | 11 | 1 | - | - | 2 | - | - | - |
| **7 Eucl** | - | 2 | 2 | - | 6 | 25 | 1 | 28 | 2 | 3 | 4 | 2 |
| **8 Glyc** | - | - | 1 | - | - | - | 1 | 2 | 2 | - | - | - |
| **9 Gypt** | - | - | - | 2 | 2 | 1 | - | - | - | - | - | 2 |
| **10 Hete** | 53 | 80 | 54 | 34 | 73 | 69 | 23 | 74 | 39 | 84 | 65 | 82 |
| **11 Hydr** | - | - | - | - | 11 | - | - | - | - | 1 | - | - |
| **12 Jasm** | - | - | - | - | - | 1 | - | - | - | 2 | - | - |
| **13 Lagi** | - | - | 1 | 1 | - | - | - | - | - | - | - | - |
| **14 Lani** | - | 1 | - | - | - | - | - | - | - | - | - | - |
| **15 Lumb** | - | - | - | - | - | - | - | - | - | - | - | - |
| **16 Marp** | - | - | - | - | - | - | - | - | 2 | - | 1 | - |
| **17 Meli** | - | - | - | - | - | - | - | - | - | - | - | - |
| **18 Merc** | - | - | - | - | - | - | - | - | - | - | - | - |
| **19 Nain** | 1 | - | - | - | - | - | - | - | - | - | - | - |
| **20 Neph** | - | - | - | - | - | - | - | - | - | - | - | - |
| **21 Nere** | 12 | 18 | 4 | 7 | 25 | 20 | 5 | 14 | 3 | 23 | 4 | 46 |
| **22 Noto** | 6 | 26 | 11 | 14 | 2 | - | - | 1 | - | - | - | - |
| **23 Phyl** | - | - | - | - | 2 | 6 | - | 1 | - | - | - | - |
| **24 Poly** | 1 | - | 2 | - | 4 | 1 | 1 | - | 4 | 2 | - | 1 |
| **25 Scol** | - | - | - | - | - | - | - | - | - | - | - | - |
| **26 Spio** | - | - | - | - | - | - | - | - | - | - | - | - |
| **27 Stre** | 17 | 63 | 4 | 6 | 7 | 16 | - | 20 | 12 | 8 | 17 | 55 |
| **28 Syl1** | 2 | 3 | - | - | 7 | 1 | 1 | - | - | - | - | 1 |
| **29 Syl2** | - | 3 | 1 | - | - | 1 | - | - | - | - | - | 1 |
| **30 Olig** | 8 | 28 | 2 | 2 | 3 | 7 | 1 | 6 | 12 | 13 | 5 | 31 |
| **31 Sipu** | - | - | - | - | - | 2 | - | - | - | - | - | - |
| **32 Phor** | - | 1 | - | - | - | 6 | 4 | - | 1 | 1 | 1 | 9 |
| **33 Lepi** | - | - | - | - | - | - | - | 1 | 3 | - | - | - |
| **34 Amyc** | 1 | 1 | 1 | - | - | 2 | - | 1 | 1 | - | - | - |
| **35 Bitt** | - | 9 | 4 | 2 | - | 1 | 14 | 4 | 14 | 6 | - | 1 |
| **36 Caly** | - | - | - | 1 | - | - | - | - | - | 1 | - | - |
| **37 Ceri** | 24 | 30 | - | - | 1 | 6 | 5 | 15 | 12 | - | 19 | - |
| **38 Conu** | 1 | - | - | - | - | - | - | - | - | - | - | - |
| **39 Cycl** | - | - | 1 | - | 1 | 1 | - | - | 1 | - | - | - |
| **40 Hini** | - | - | - | 1 | - | 4 | - | - | - | - | - | - |
| **41 Hulv** | - | - | - | - | 1 | - | - | - | 2 | - | 1 | - |
| **42 Hven** | - | - | - | - | - | - | - | - | - | - | - | - |
| **43 Juju** | - | - | - | - | 7 | - | - | - | - | 1 | - | 1 |
| **44 Mesa** | 3 | 27 | - | 7 | 5 | 7 | 4 | 9 | 4 | 1 | 10 | 4 |
| **45 Riss** | 2 | 1 | - | - | - | 1 | - | - | - | 2 | - | 8 |
| **46 Spha** | - | - | - | - | - | - | - | - | - | - | - | - |
| **47 Trun** | - | - | - | - | - | - | - | - | - | - | - | - |
| **48 Aply** | - | - | - | - | - | - | - | - | - | - | - | - |
| **49 Hami** | - | - | - | - | - | 3 | - | - | - | - | - | 1 |
| **50 Turb** | - | 1 | - | - | - | - | - | - | - | - | - | - |

| B2 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 Abra | 16 | 28 | 35 | 11 | 5 | 40 | 14 | 38 | 45 | 84 | 66 | 119 |
| 52 Cedu | - | - | - | 1 | 3 | - | - | - | 1 | - | - | - |
| 53 Cgla | - | - | - | - | - | - | - | - | - | - | - | - |
| 54 Corb | - | 1 | - | - | - | - | - | - | - | - | - | - |
| 55 Lept | - | - | - | - | - | - | - | - | - | - | - | - |
| 56 Lori | 6 | 9 | 3 | 4 | 8 | 6 | 9 | 21 | 6 | 1 | 9 | 15 |
| 57 Myti | - | - | - | - | - | - | - | - | - | - | - | - |
| 58 Rudi | - | - | - | - | - | - | - | - | 1 | - | 1 | - |
| 59 Scro | - | - | - | - | - | - | - | - | - | - | - | - |
| 60 Vene | - | - | - | - | - | 3 | - | - | - | 1 | - | - |
| 61 Bala | - | - | - | - | - | - | - | - | - | - | - | - |
| 62 Neba | - | 3 | - | 1 | 1 | 1 | - | - | - | - | - | - |
| 63 Gast | - | - | - | - | - | - | - | - | - | - | - | - |
| 64 Apse | 3 | - | 1 | 6 | 3 | - | 1 | 6 | - | - | - | - |
| 65 Lsav | - | - | - | - | - | - | - | - | - | - | - | 7 |
| 66 Iphi | 1 | 2 | 1 | 5 | 6 | 9 | 1 | 1 | 1 | - | - | - |
| 67 Cyat | - | 1 | - | - | - | - | - | - | - | - | - | - |
| 68 Cymo | 1 | - | - | - | 16 | 10 | - | - | 2 | - | 1 | - |
| 69 Idot | - | - | - | - | - | 2 | - | - | 5 | 1 | 4 | 1 |
| 70 Shoo | - | - | 3 | - | - | - | - | - | - | - | - | - |
| 71 Ampe | - | - | 1 | - | 3 | - | - | - | - | - | - | - |
| 72 Amph | - | - | - | - | 9 | 3 | - | - | - | 1 | 2 | - |
| 73 Coro | - | - | - | 22 | 20 | 1 | - | - | - | 2 | - | - |
| 74 Dexa | - | - | - | - | - | - | - | - | 1 | 3 | - | 1 |
| 75 Elas | - | - | - | - | - | - | - | - | 1 | - | - | - |
| 76 Eric | - | - | - | - | - | - | - | - | - | - | 1 | - |
| 77 Gell | - | - | - | - | - | 1 | - | - | - | - | - | - |
| 78 Gamm | - | - | - | 1 | 5 | 1 | - | - | - | - | 3 | - |
| 79 Leuc | - | - | - | - | - | - | - | - | - | - | - | - |
| 80 Mita | - | 1 | - | - | - | - | - | - | - | - | - | - |
| 81 Mche | - | - | - | - | - | - | - | - | - | - | - | - |
| 82 Mgry | - | - | - | - | 29 | 1 | - | - | - | 4 | 1 | 1 |
| 83 Msp. | - | - | 1 | - | - | 2 | 2 | - | 1 | 6 | 4 | 1 |
| 84 Mver | - | - | - | - | - | - | - | - | - | - | - | - |
| 85 Peri | - | - | - | - | - | - | - | - | - | - | - | - |
| 86 Phot | - | - | - | - | - | - | - | - | - | 1 | - | - |
| 87 Siph | - | - | 31 | - | - | - | - | - | - | - | - | 1 |
| 88 Call | - | - | - | - | - | - | - | 1 | - | - | - | - |
| 89 Carc | - | - | - | - | - | - | - | - | - | 1 | - | - |
| 90 Diog | - | - | 1 | 1 | 1 | - | - | 1 | - | - | - | - |
| 91 Pala | - | - | - | - | - | - | - | - | - | - | - | - |
| 92 Upog | - | - | - | - | - | - | - | - | - | - | - | 1 |
| 93 Chir | - | 1 | - | - | - | - | - | - | - | - | 1 | - |
| 94 Achi | - | - | - | - | - | - | - | - | - | - | - | - |
| 95 Syng | - | - | - | - | - | - | - | - | - | - | - | - |

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| | J | M | M | J | S | N | J | M | M | J | S | N |
| 1 Para | 1 | - | - | 1 | - | - | 3 | - | - | 1 | - | - |
| 2 Neme | - | - | - | - | - | 1 | - | - | - | 2 | - | 1 |
| 3 Aoni | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 Capi | - | 5 | - | - | - | - | - | 3 | 4 | - | 15 | - |
| 5 Cirr | - | - | - | - | - | - | 2 | - | - | - | - | 1 |
| 6 Cten | - | - | - | - | 4 | - | - | 5 | - | - | - | - |
| 7 Eucl | - | 1 | - | - | 1 | - | - | - | 3 | - | - | - |
| 8 Glyc | 2 | 1 | - | 1 | - | - | - | - | - | 1 | 2 | - |
| 9 Gypt | - | - | - | - | - | - | - | - | - | - | - | - |
| 10 Hete | 32 | 138 | 46 | 76 | 55 | 36 | 24 | 136 | 64 | 60 | 54 | 20 |
| 11 Hydr | - | - | - | - | 4 | - | - | - | - | - | - | - |
| 12 Jasm | - | - | - | - | - | - | - | - | 1 | 4 | 1 | - |
| 13 Lagi | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 Lani | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 Lumb | - | - | - | - | - | - | - | - | - | - | - | - |
| 16 Marp | - | 1 | - | - | - | 1 | - | - | - | - | - | - |
| 17 Meli | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 18 Merc | - | - | - | - | - | - | - | - | - | - | - | - |
| 19 Nain | - | - | - | - | - | - | - | - | - | - | - | - |
| 20 Neph | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 21 Nere | 4 | - | - | 4 | 18 | 3 | 4 | 2 | - | 2 | - | 17 |
| 22 Noto | 10 | 70 | 29 | 2 | - | - | - | - | - | - | - | - |
| 23 Phyl | - | - | - | - | - | - | 3 | - | 1 | 1 | - | - |
| 24 Poly | - | 1 | 1 | - | - | - | - | - | 2 | - | - | - |
| 25 Scol | - | - | - | - | - | - | - | - | - | - | - | - |
| 26 Spio | - | - | - | - | - | - | - | - | - | - | 4 | - |
| 27 Stre | 2 | 25 | 7 | 6 | 9 | 1 | - | 12 | 3 | - | 33 | - |
| 28 Syl1 | - | - | - | - | - | - | 1 | - | - | - | - | - |
| 29 Syl2 | - | - | - | - | - | - | - | - | - | - | 1 | - |
| 30 Olig | 1 | 6 | 2 | 6 | 1 | 7 | 1 | 22 | 21 | 3 | - | 20 |
| 31 Sipu | - | - | - | - | - | - | - | - | - | - | - | - |
| 32 Phor | - | - | - | - | - | - | - | - | 2 | - | 13 | - |
| 33 Lepi | 10 | 2 | - | - | 3 | - | 3 | 1 | 1 | - | - | - |
| 34 Amyc | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 1 | 2 | 1 | 3 | 1 |
| 35 Bitt | - | 3 | - | 11 | 6 | - | 3 | 2 | 3 | 1 | - | - |
| 36 Caly | - | - | - | - | - | - | - | - | - | - | - | - |
| 37 Ceri | - | 2 | - | 30 | 15 | 14 | 19 | 24 | 20 | 27 | 9 | 7 |
| 38 Conu | - | - | - | - | - | - | - | - | - | - | - | - |
| 39 Cycl | - | 6 | - | - | - | 2 | - | 1 | - | - | - | - |
| 40 Hini | - | - | - | - | - | - | - | - | - | - | - | - |
| 41 Hulv | 1 | 6 | - | - | - | - | - | - | 1 | 2 | 8 | - |
| 42 Hven | - | - | - | - | - | - | - | - | - | - | - | - |
| 43 Juju | - | - | 1 | - | 1 | - | - | - | - | - | - | - |
| 44 Mesa | - | 4 | - | - | - | - | - | 4 | - | - | 2 | 1 |
| 45 Riss | - | - | - | - | - | - | 1 | - | - | 1 | - | - |
| 46 Spha | 1 | 1 | - | - | - | 2 | - | - | - | - | - | - |
| 47 Trun | - | - | - | - | - | - | - | - | - | - | - | - |
| 48 Aply | - | - | - | - | - | - | - | - | - | - | - | - |
| 49 Hami | - | - | - | - | - | - | - | - | - | - | - | - |
| 50 Turb | - | - | - | - | - | - | - | - | - | - | - | - |

| B3 | J | M | M | J | S | N | J | M | M | J | S | N |
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| 51 Abra | 41 | 22 | 12 | 17 | 55 | 54 | 47 | 22 | 112 | 80 | 95 | 32 |
| 52 Cedu | 1 | 2 | - | - | 2 | - | - | - | - | - | - | - |
| 53 Cgla | - | - | - | - | - | - | - | - | - | - | - | - |
| 54 Corb | - | - | - | - | - | - | - | - | - | - | - | - |
| 55 Lept | - | - | - | - | - | - | - | - | - | - | - | - |
| 56 Lori | 23 | 18 | 4 | 14 | 9 | 24 | 8 | 16 | 30 | 19 | 19 | 7 |
| 57 Myti | - | - | - | 1 | - | - | - | - | - | - | - | - |
| 58 Rudi | - | - | - | - | - | - | - | - | 2 | - | - | - |
| 59 Scro | - | - | - | - | - | - | - | - | - | - | - | - |
| 60 Vene | - | - | - | - | - | - | - | - | - | - | - | - |
| 61 Bala | - | - | - | - | - | - | - | - | - | - | - | - |
| 62 Neba | - | - | - | - | 1 | 1 | - | - | 4 | - | - | - |
| 63 Gast | - | - | - | - | - | - | - | - | - | - | - | 3 |
| 64 Apse | 5 | 4 | 1 | - | - | - | 1 | 1 | - | - | - | 1 |
| 65 Lsav | - | - | - | - | - | - | - | - | - | - | - | - |
| 66 Iphi | 1 | - | 2 | - | 1 | 6 | - | - | - | 2 | 3 | 11 |
| 67 Cyat | - | - | - | - | - | - | - | - | - | - | - | - |
| 68 Cymo | - | - | - | - | - | - | - | - | - | - | - | - |
| 69 Idot | - | - | 1 | 1 | - | 1 | - | - | - | 1 | 1 | 1 |
| 70 Shoo | - | 2 | 1 | - | - | - | - | - | - | - | - | - |
| 71 Ampe | 1 | - | - | - | - | - | - | - | - | - | - | - |
| 72 Amph | - | - | - | - | 8 | - | 1 | - | - | 4 | - | - |
| 73 Coro | - | - | - | - | 2 | - | - | 1 | - | 2 | 4 | - |
| 74 Dexa | - | - | - | - | - | - | - | - | - | - | - | - |
| 75 Elas | - | - | - | - | - | - | - | - | - | - | - | - |
| 76 Eric | - | - | - | - | - | - | 2 | - | 1 | - | 1 | - |
| 77 Gell | - | - | - | - | - | - | - | - | - | - | - | - |
| 78 Gamm | - | - | - | 20 | 10 | 2 | 8 | - | 15 | 12 | 5 | - |
| 79 Leuc | - | - | - | - | - | - | - | - | - | - | - | - |
| 80 Mita | - | - | - | - | - | - | - | - | - | - | - | - |
| 81 Mche | - | - | - | - | - | - | - | - | - | - | - | - |
| 82 Mgry | - | 2 | - | 4 | 11 | 5 | 3 | - | - | - | 2 | - |
| 83 Msp. | - | 1 | - | - | 3 | - | 6 | 3 | - | 3 | 7 | 1 |
| 84 Mver | - | - | - | - | - | - | - | - | - | - | - | - |
| 85 Peri | - | - | - | - | - | - | - | - | - | - | - | - |
| 86 Phot | - | - | - | - | - | - | - | - | - | - | - | - |
| 87 Siph | 3 | 10 | 1 | - | - | - | - | - | - | 3 | - | - |
| 88 Call | - | - | - | - | - | - | - | - | - | - | - | - |
| 89 Carc | - | - | - | - | - | - | - | - | 1 | 2 | - | - |
| 90 Diog | - | 1 | - | - | - | - | - | - | - | - | - | - |
| 91 Pala | - | - | - | - | - | - | - | - | - | - | - | - |
| 92 Upog | - | - | - | - | - | - | - | - | - | - | - | - |
| 93 Chir | - | - | - | - | - | - | - | - | - | - | - | - |
| 94 Achi | - | - | - | - | 6 | - | - | - | - | - | - | - |
| 95 Syng | - | - | - | - | - | - | - | - | - | - | - | - |

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| | J | M | M | J | S | N | J | M | M | J | S | N |
| 1 Para | - | - | - | 1 | - | - | - | - | - | - | - | - |
| 2 Neme | - | 2 | - | - | - | 3 | - | - | - | - | - | - |
| 3 Aoni | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 Capi | 3 | 2 | 2 | 10 | 26 | 66 | - | 13 | - | 9 | - | 29 |
| 5 Cirr | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 Cten | - | - | - | - | - | - | - | - | - | - | - | - |
| 7 Eucl | - | - | - | - | - | - | - | - | - | - | - | - |
| 8 Glyc | - | 1 | 2 | - | - | 2 | - | - | - | - | - | - |
| 9 Gypt | - | - | - | - | - | - | - | - | - | - | - | - |
| 10 Hete | 1 | - | - | 6 | - | 3 | - | - | 7 | 2 | 4 | 9 |
| 11 Hydr | - | - | - | - | - | - | - | - | - | - | - | - |
| 12 Jasm | - | - | - | - | - | - | - | - | - | - | - | - |
| 13 Lagi | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 Lani | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 Lumb | - | - | - | - | - | - | - | - | - | - | - | - |
| 16 Marp | - | - | - | - | 1 | - | - | - | - | - | - | - |
| 17 Meli | - | - | - | - | - | - | - | - | - | - | - | - |
| 18 Merc | - | - | - | - | - | - | - | - | - | - | - | - |
| 19 Nain | - | - | - | - | - | - | - | - | - | - | - | - |
| 20 Neph | - | - | - | - | - | - | - | - | - | - | - | - |
| 21 Nere | - | - | - | - | - | - | - | 5 | - | - | 2 | - |
| 22 Noto | - | - | - | - | - | - | - | - | - | - | - | - |
| 23 Phyl | - | - | - | - | - | - | - | - | - | - | - | - |
| 24 Poly | - | - | - | - | - | - | - | - | - | - | - | - |
| 25 Scol | 3 | 6 | 4 | 4 | - | - | - | - | - | - | - | - |
| 26 Spio | - | 1 | - | - | - | - | - | - | - | - | - | - |
| 27 Stre | - | 4 | - | 3 | 7 | 21 | 1 | 1 | - | 5 | - | 3 |
| 28 Syl1 | - | - | - | - | - | - | - | - | - | - | - | - |
| 29 Syl2 | - | - | - | - | - | - | - | - | - | - | - | - |
| 30 Olig | - | 4 | 1 | 3 | 2 | 1 | - | - | 1 | - | - | 1 |
| 31 Sipu | - | - | - | - | - | - | - | - | - | - | - | - |
| 32 Phor | - | - | - | - | - | - | - | - | - | - | - | - |
| 33 Lepi | - | - | - | - | - | - | - | - | - | - | - | - |
| 34 Amyc | - | - | - | - | - | - | - | - | - | - | - | - |
| 35 Bitt | - | 2 | - | - | - | 1 | 1 | - | - | - | - | - |
| 36 Caly | - | - | - | - | - | - | - | - | - | - | - | - |
| 37 Ceri | - | - | - | - | 1 | - | - | - | - | - | - | - |
| 38 Conu | - | - | - | - | - | - | - | - | - | - | - | - |
| 39 Cycl | - | - | - | - | - | - | 1 | - | - | - | - | - |
| 40 Hini | - | - | - | - | - | - | - | - | - | - | - | - |
| 41 Hulv | 1 | 6 | 8 | 1 | 6 | 1 | 3 | 1 | 2 | 66 | 3 | - |
| 42 Hven | - | - | - | - | - | - | - | - | 2 | 39 | 1 | - |
| 43 Juju | - | - | - | - | - | - | - | - | - | - | - | - |
| 44 Mesa | - | - | - | - | - | - | - | - | - | - | - | - |
| 45 Riss | - | - | - | - | - | - | - | - | - | - | - | - |
| 46 Spha | - | - | - | - | - | - | - | - | - | - | - | - |
| 47 Trun | - | - | - | - | - | - | - | - | - | - | - | - |
| 48 Aply | - | - | - | - | - | - | - | - | - | - | - | - |
| 49 Hami | - | - | - | - | - | - | - | - | - | - | - | - |
| 50 Turb | - | - | - | - | - | - | - | - | - | - | - | - |

| C1 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 Abra | - | 2 | 8 | 2 | 5 | 71 | 4 | 27 | 3 | 3 | 28 | 40 |
| 52 Cedu | - | - | - | - | - | - | - | - | - | - | 7 | - |
| 53 Cgla | - | - | - | - | - | - | - | - | - | - | - | - |
| 54 Corb | - | - | - | - | - | - | - | - | - | - | - | - |
| 55 Lept | - | - | - | - | - | - | - | - | - | - | - | - |
| 56 Lori | - | - | - | - | - | - | - | - | - | - | - | - |
| 57 Myti | - | - | - | - | - | - | - | - | - | - | - | - |
| 58 Rudi | - | - | - | - | - | - | - | - | - | - | - | - |
| 59 Scro | - | - | - | - | - | - | - | - | - | - | - | - |
| 60 Vene | - | - | - | - | - | - | - | - | - | - | - | - |
| 61 Bala | - | - | - | - | - | - | - | - | - | - | - | - |
| 62 Neba | - | - | - | - | - | - | - | - | - | - | - | - |
| 63 Gast | - | - | - | - | - | - | - | - | - | - | - | - |
| 64 Apse | 1 | - | - | - | 1 | - | - | - | - | - | - | - |
| 65 Lsav | - | - | - | - | - | - | - | - | - | - | - | - |
| 66 Iphi | - | - | - | - | - | - | - | - | - | - | - | - |
| 67 Cyat | - | - | - | - | - | - | - | - | - | - | - | - |
| 68 Cymo | - | - | - | - | - | - | - | - | - | - | - | - |
| 69 Idot | - | - | - | - | - | - | - | - | - | - | - | - |
| 70 Shoo | - | - | - | - | - | - | - | - | - | - | - | - |
| 71 Ampe | - | - | - | - | - | - | - | - | - | - | - | - |
| 72 Amph | - | - | - | - | - | - | - | - | - | - | - | - |
| 73 Coro | - | - | - | - | - | - | - | - | - | - | - | - |
| 74 Dexa | - | - | - | - | - | - | - | - | - | - | - | - |
| 75 Elas | - | - | - | - | - | - | - | - | - | - | - | - |
| 76 Eric | - | - | - | - | - | - | - | - | - | - | - | - |
| 77 Gell | - | - | - | - | - | - | - | - | - | - | - | - |
| 78 Gamm | - | - | - | - | - | - | - | - | 5 | - | - | - |
| 79 Leuc | - | - | - | - | - | - | - | - | - | - | - | - |
| 80 Mita | - | - | - | - | - | - | - | - | - | - | - | - |
| 81 Mche | - | - | - | - | - | - | - | - | - | - | - | - |
| 82 Mgry | - | - | - | - | - | - | - | - | - | - | - | - |
| 83 Msp. | - | 1 | - | - | - | - | - | - | - | - | - | 1 |
| 84 Mver | - | - | - | - | - | 1 | - | - | - | - | - | - |
| 85 Peri | - | - | - | - | - | - | - | - | - | - | - | - |
| 86 Phot | - | - | - | - | - | - | - | - | - | - | - | - |
| 87 Siph | - | - | - | - | - | - | - | - | - | - | - | - |
| 88 Call | - | - | - | - | - | - | - | - | - | - | - | - |
| 89 Carc | - | - | - | - | - | - | - | - | - | - | - | - |
| 90 Diog | - | - | - | - | - | - | - | - | - | - | - | - |
| 91 Pala | - | - | - | - | - | - | - | - | - | - | - | - |
| 92 Upog | - | - | - | - | - | - | - | - | - | - | - | - |
| 93 Chir | - | - | - | - | - | - | - | - | - | - | 5 | 1 |
| 94 Achi | - | - | - | - | - | - | - | - | - | - | - | - |
| 95 Syng | - | - | - | - | - | - | - | - | - | - | - | - |

| C2 | 1985 | | | | | | 1986 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **J** | **M** | **M** | **J** | **S** | **N** | **J** | **M** | **M** | **J** | **S** | **N** |
| **1 Para** | 1 | 1 | 3 | 2 | - | 4 | - | - | - | - | - | - |
| **2 Neme** | 1 | - | 1 | - | - | - | - | - | - | - | - | - |
| **3 Aoni** | - | - | - | - | - | - | - | - | - | - | - | - |
| **4 Capi** | 1 | 5 | 8 | 5 | - | - | - | 9 | 3 | 5 | 78 | - |
| **5 Cirr** | - | - | - | - | - | - | - | - | - | - | - | - |
| **6 Cten** | - | - | - | - | - | - | - | - | - | - | - | - |
| **7 Eucl** | - | - | - | - | - | - | - | - | - | - | - | - |
| **8 Glyc** | - | - | - | - | - | - | - | 1 | - | - | - | - |
| **9 Gypt** | - | - | - | 1 | - | - | - | - | - | - | - | - |
| **10 Hete** | 2 | - | 1 | 1 | 1 | - | 4 | 8 | 3 | 7 | 12 | - |
| **11 Hydr** | - | - | - | - | - | - | - | - | - | - | - | - |
| **12 Jasm** | - | - | - | - | - | - | - | - | - | - | - | - |
| **13 Lagi** | - | - | - | - | - | - | - | - | - | - | - | - |
| **14 Lani** | - | - | - | - | - | - | - | - | - | - | - | - |
| **15 Lumb** | - | - | - | - | - | - | - | - | - | - | - | - |
| **16 Marp** | - | - | - | - | - | - | - | - | - | - | - | - |
| **17 Meli** | - | - | - | - | - | - | - | - | - | - | - | - |
| **18 Merc** | - | - | - | - | - | - | - | - | - | - | - | - |
| **19 Nain** | - | - | - | - | - | - | 1 | - | - | - | - | - |
| **20 Neph** | - | - | - | - | - | - | - | - | - | - | - | - |
| **21 Nere** | 6 | 18 | 4 | 3 | - | 2 | - | 1 | 1 | - | 1 | - |
| **22 Noto** | - | - | - | - | - | - | - | - | - | - | - | - |
| **23 Phyl** | - | 2 | - | - | - | - | - | - | - | - | - | - |
| **24 Poly** | - | - | - | - | - | - | - | - | - | - | - | - |
| **25 Scol** | - | - | - | - | - | - | - | - | - | - | - | - |
| **26 Spio** | - | - | - | - | - | - | - | - | - | - | - | - |
| **27 Stre** | - | 1 | - | 7 | 17 | - | 1 | 19 | 3 | - | - | - |
| **28 Syl1** | 1 | 8 | - | - | - | - | - | - | - | - | - | - |
| **29 Syl2** | - | - | - | - | - | - | - | - | - | - | - | - |
| **30 Olig** | 46 | 165 | 45 | 8 | 152 | 18 | 51 | 6 | 11 | 10 | 71 | 4 |
| **31 Sipu** | - | - | - | - | - | - | 1 | - | - | - | - | - |
| **32 Phor** | - | - | - | - | - | - | - | - | - | - | - | - |
| **33 Lepi** | - | - | - | 2 | 1 | - | - | - | - | - | - | - |
| **34 Amyc** | 1 | 1 | 1 | 6 | - | 1 | - | - | 2 | - | - | - |
| **35 Bitt** | - | 3 | 35 | 21 | 7 | - | 11 | 6 | - | 4 | - | 1 |
| **36 Caly** | - | - | - | - | - | - | - | - | - | - | - | - |
| **37 Ceri** | - | 30 | 60 | 28 | 60 | 11 | 18 | 10 | 7 | 13 | 5 | 5 |
| **38 Conu** | - | - | - | - | - | - | - | - | - | - | - | - |
| **39 Cycl** | - | - | - | - | - | - | - | - | - | - | - | - |
| **40 Hini** | - | - | - | - | - | - | - | - | - | - | - | - |
| **41 Hulv** | 1 | 6 | 3 | 16 | 3 | 1 | 14 | 7 | 16 | 6 | 3 | 8 |
| **42 Hven** | - | - | - | - | - | - | - | 71 | 222 | 28 | 17 | 96 |
| **43 Juju** | - | - | - | - | - | - | - | - | - | - | - | - |
| **44 Mesa** | - | - | - | - | - | - | - | - | - | - | - | - |
| **45 Riss** | - | - | - | - | - | - | - | - | - | - | - | - |
| **46 Spha** | 1 | 1 | - | 1 | - | - | - | - | - | - | - | - |
| **47 Trun** | - | - | - | - | - | - | - | - | - | - | - | - |
| **48 Aply** | - | - | - | - | - | - | - | - | - | - | - | - |
| **49 Hami** | - | 7 | - | 1 | - | - | - | - | - | - | - | - |
| **50 Turb** | - | - | - | - | - | - | - | - | - | - | - | - |

| C2 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **51 Abra** | 16 | 18 | 6 | 40 | 35 | 12 | 28 | 23 | 43 | 106 | 46 | - |
| **52 Cedu** | - | 1 | - | - | - | - | - | - | - | - | - | 5 |
| **53 Cgla** | - | - | - | - | - | - | - | - | - | - | - | - |
| **54 Corb** | - | - | - | - | - | - | - | - | - | - | - | - |
| **55 Lept** | - | - | - | - | - | - | - | - | - | - | - | - |
| **56 Lori** | 1 | - | - | - | 1 | - | - | 1 | 1 | - | - | - |
| **57 Myti** | - | - | - | - | - | - | - | - | - | - | - | - |
| **58 Rudi** | - | - | - | - | - | - | 1 | - | - | - | - | - |
| **59 Scro** | - | - | - | - | - | - | - | - | - | - | - | - |
| **60 Vene** | - | - | - | - | - | - | - | - | - | - | - | - |
| **61 Bala** | - | - | - | - | - | - | - | - | - | - | - | - |
| **62 Neba** | - | 5 | 9 | 1 | - | - | - | - | - | - | - | - |
| **63 Gast** | - | - | - | - | - | - | - | - | - | - | - | 2 |
| **64 Apse** | - | - | - | - | - | - | - | - | - | - | - | - |
| **65 Lsav** | - | - | - | - | - | - | - | - | - | - | - | - |
| **66 Iphi** | - | - | - | - | - | - | - | - | - | - | - | - |
| **67 Cyat** | - | - | - | - | - | - | - | 1 | - | - | - | - |
| **68 Cymo** | - | - | - | - | - | - | - | - | - | - | - | - |
| **69 Idot** | - | 2 | 5 | - | - | - | 1 | - | - | - | - | - |
| **70 Shoo** | - | - | 2 | 1 | - | - | - | - | - | - | - | - |
| **71 Ampe** | - | - | - | - | - | - | - | - | - | - | - | - |
| **72 Amph** | - | - | 2 | - | - | - | - | - | 1 | - | - | - |
| **73 Coro** | - | - | - | - | - | - | - | - | - | - | - | - |
| **74 Dexa** | - | - | - | - | - | - | - | - | - | - | - | - |
| **75 Elas** | - | - | - | - | - | - | - | - | - | - | - | - |
| **76 Eric** | - | - | - | - | - | - | - | - | - | - | - | - |
| **77 Gell** | - | - | - | - | - | - | - | - | - | - | - | - |
| **78 Gamm** | - | 6 | 14 | 2 | - | - | - | 3 | 3 | - | - | - |
| **79 Leuc** | - | - | - | - | - | - | - | - | - | - | - | - |
| **80 Mita** | - | - | - | - | - | - | - | - | - | - | - | - |
| **81 Mche** | - | 5 | 5 | - | - | - | - | - | - | - | - | - |
| **82 Mgry** | - | 18 | 5 | - | - | - | - | - | - | - | - | 4 |
| **83 Msp.** | - | - | - | 2 | - | - | 1 | 1 | - | - | - | 6 |
| **84 Mver** | - | - | - | - | - | - | - | - | - | - | - | - |
| **85 Peri** | - | - | - | - | - | - | - | - | - | - | - | - |
| **86 Phot** | - | - | - | - | - | - | - | - | - | - | - | - |
| **87 Siph** | - | - | - | - | - | - | - | - | - | - | - | - |
| **88 Call** | - | - | - | - | - | - | - | - | - | - | - | - |
| **89 Carc** | - | - | - | - | - | - | - | - | - | - | - | - |
| **90 Diog** | - | - | - | - | - | - | - | - | - | - | - | - |
| **91 Pala** | - | - | - | - | - | 5 | - | - | - | - | - | 4 |
| **92 Upog** | - | - | - | - | - | - | - | - | - | - | - | - |
| **93 Chir** | 20 | 21 | 3 | - | - | 1 | - | 4 | 49 | 45 | 7 | 16 |
| **94 Achi** | - | 4 | 3 | - | - | - | - | - | - | - | - | - |
| **95 Syng** | - | - | - | - | - | - | - | - | - | - | - | - |

| D1 | 1985 | | | | | | 1986 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | M | M | J | S | N | J | M | M | J | S | N |
| 1 Para | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 Neme | - | - | - | - | - | - | - | 1 | 1 | - | - | - |
| 3 Aoni | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 Capi | 64 | 31 | 7 | 7 | 50 | 19 | 5 | 57 | 23 | 16 | 47 | 81 |
| 5 Cirr | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 Cten | - | - | - | - | - | - | - | - | - | - | - | - |
| 7 Eucl | - | - | - | - | - | - | - | - | - | 1 | - | - |
| 8 Glyc | - | 2 | 1 | - | - | - | - | - | - | - | - | - |
| 9 Gypt | - | - | - | - | - | - | - | - | - | - | - | 2 |
| 10 Hete | 33 | - | 4 | 9 | 33 | 29 | 26 | 14 | 15 | 7 | 10 | 8 |
| 11 Hydr | - | - | - | - | - | - | - | - | - | - | - | - |
| 12 Jasm | - | - | - | - | - | - | - | - | - | - | - | - |
| 13 Lagi | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 Lani | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 Lumb | - | - | - | - | 2 | 2 | 1 | 2 | 7 | 1 | 1 | 6 |
| 16 Marp | - | - | 2 | - | 3 | 1 | - | 2 | 7 | - | 1 | 3 |
| 17 Meli | - | - | - | - | - | - | - | - | - | - | - | - |
| 18 Merc | 8 | - | - | 2 | - | - | - | - | - | - | - | - |
| 19 Nain | - | - | - | - | - | - | - | - | - | - | - | - |
| 20 Neph | - | - | - | - | 1 | - | - | - | - | - | - | - |
| 21 Nere | 2 | - | 1 | 6 | 1 | 6 | 2 | 1 | 1 | 8 | 1 | 6 |
| 22 Noto | - | - | - | - | - | - | - | - | - | - | - | - |
| 23 Phyl | 2 | - | 2 | 1 | - | 2 | 2 | 3 | 1 | - | 2 | 1 |
| 24 Poly | 1 | 5 | 7 | 2 | - | - | - | 2 | 4 | - | - | - |
| 25 Scol | - | - | - | - | - | - | - | - | - | - | - | - |
| 26 Spio | - | - | - | - | - | - | - | - | - | - | - | - |
| 27 Stre | 40 | 23 | 4 | 3 | 6 | 4 | 4 | 2 | 9 | 3 | 1 | 3 |
| 28 Syl1 | - | - | 1 | - | 2 | 1 | - | - | - | - | - | - |
| 29 Syl2 | 1 | - | - | - | - | - | - | - | - | - | - | - |
| 30 Olig | - | - | - | - | 1 | 1 | - | - | - | - | - | 4 |
| 31 Sipu | 1 | - | - | - | - | - | - | - | - | - | - | - |
| 32 Phor | - | - | - | - | - | - | - | - | - | - | - | - |
| 33 Lepi | - | - | - | 1 | - | - | - | - | - | 1 | 1 | - |
| 34 Amyc | - | - | 2 | 1 | - | - | - | - | 3 | 4 | 2 | 1 |
| 35 Bitt | - | - | 1 | 2 | - | - | 1 | 4 | 2 | 1 | - | 1 |
| 36 Caly | - | - | - | - | - | - | - | - | - | - | - | - |
| 37 Ceri | 31 | 1 | 3 | 7 | 9 | 12 | 13 | 6 | 6 | 16 | 15 | 13 |
| 38 Conu | - | - | - | - | - | - | - | - | - | - | - | - |
| 39 Cycl | - | - | - | - | - | - | - | - | - | - | - | - |
| 40 Hini | - | - | - | - | - | - | - | - | - | - | - | - |
| 41 Hulv | - | - | - | - | - | - | 2 | - | - | 3 | - | 3 |
| 42 Hven | - | - | - | - | - | 1 | - | - | - | 2 | - | 1 |
| 43 Juju | - | - | - | - | - | - | - | - | - | - | - | - |
| 44 Mesa | - | - | - | - | - | - | - | - | - | - | - | - |
| 45 Riss | - | - | - | - | - | - | 1 | 3 | 1 | - | - | 1 |
| 46 Spha | - | - | - | - | - | - | - | - | - | - | - | - |
| 47 Trun | - | - | - | - | - | - | - | - | - | - | - | - |
| 48 Aply | - | - | - | - | - | - | - | - | - | - | - | - |
| 49 Hami | 2 | 1 | - | 1 | 1 | - | 1 | - | - | - | - | - |
| 50 Turb | - | - | - | - | - | - | - | - | - | - | - | - |

| D1 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **51 Abra** | 49 | 8 | 21 | 17 | 21 | 26 | 23 | 39 | 39 | 34 | 50 | 26 |
| **52 Cedu** | 2 | - | - | - | 1 | 1 | - | 2 | - | - | - | 4 |
| **53 Cgla** | - | - | - | - | - | - | - | - | - | - | - | - |
| **54 Corb** | - | - | - | - | - | - | - | - | - | - | - | - |
| **55 Lept** | - | - | - | - | - | - | - | - | - | - | - | - |
| **56 Lori** | - | - | - | - | - | - | - | - | - | - | - | - |
| **57 Myti** | - | - | - | - | - | - | - | - | - | - | - | - |
| **58 Rudi** | - | - | - | 1 | - | - | - | - | - | - | 1 | 1 |
| **59 Scro** | - | - | - | - | - | - | - | - | - | - | - | - |
| **60 Vene** | - | - | - | - | - | - | - | - | - | - | - | - |
| **61 Bala** | 7 | - | - | - | - | - | - | - | - | - | - | - |
| **62 Neba** | - | - | - | - | - | - | - | - | - | - | - | - |
| **63 Gast** | - | - | - | - | - | - | - | - | - | - | - | - |
| **64 Apse** | - | - | - | - | - | - | - | - | - | - | - | - |
| **65 Lsav** | - | - | - | - | - | - | - | - | - | - | - | - |
| **66 Iphi** | - | - | - | - | - | - | - | - | - | - | - | - |
| **67 Cyat** | - | - | - | - | - | - | - | - | - | - | - | - |
| **68 Cymo** | - | - | - | - | - | - | - | - | - | - | - | - |
| **69 Idot** | - | - | - | - | - | - | - | - | - | - | - | - |
| **70 Shoo** | - | - | - | - | - | - | - | - | - | - | - | - |
| **71 Ampe** | 1 | - | - | - | - | - | - | - | - | - | - | - |
| **72 Amph** | 1 | - | - | 1 | - | - | - | - | - | - | 5 | 26 |
| **73 Coro** | - | - | - | - | - | - | - | - | - | - | - | - |
| **74 Dexa** | - | - | - | - | - | - | - | - | - | - | - | - |
| **75 Elas** | - | - | - | - | 1 | - | - | - | - | - | - | - |
| **76 Eric** | - | - | - | - | - | - | - | - | - | - | - | - |
| **77 Gell** | - | - | - | - | - | - | - | - | - | - | - | - |
| **78 Gamm** | - | - | 1 | - | - | - | 2 | 2 | - | 1 | - | 2 |
| **79 Leuc** | - | - | - | - | - | - | - | - | - | - | - | - |
| **80 Mita** | - | - | - | - | - | - | - | - | - | - | - | - |
| **81 Mche** | - | - | - | - | - | - | - | - | - | - | - | - |
| **82 Mgry** | 21 | - | 6 | 14 | - | 19 | 56 | 7 | 8 | 1 | 5 | 19 |
| **83 Msp.** | - | - | - | - | 1 | - | 27 | 8 | 8 | 3 | 3 | 14 |
| **84 Mver** | 1 | - | - | - | - | - | - | - | - | - | - | - |
| **85 Peri** | - | - | - | - | - | - | - | - | - | - | - | - |
| **86 Phot** | - | - | - | - | - | - | - | - | - | - | - | - |
| **87 Siph** | - | - | - | - | - | - | - | - | - | - | - | - |
| **88 Call** | - | - | - | - | - | - | - | - | - | - | - | - |
| **89 Carc** | - | - | - | - | - | - | - | - | - | 1 | - | - |
| **90 Diog** | - | - | - | - | - | - | - | - | - | - | - | - |
| **91 Pala** | - | 1 | - | - | - | 4 | - | - | - | - | - | - |
| **92 Upog** | - | - | - | - | - | - | - | - | - | - | - | - |
| **93 Chir** | 2 | 1 | - | 4 | 2 | 1 | 8 | - | 23 | 15 | 3 | 3 |
| **94 Achi** | - | - | - | - | - | - | - | - | - | - | - | - |
| **95 Syng** | - | - | - | - | - | - | - | - | - | - | - | - |

| D2 | 1985 | | | | | | 1986 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | J | M | M | J | S | N | J | M | M | J | S | N |
| 1 Para | - | - | - | - | - | - | - | - | - | - | - | - |
| 2 Neme | - | - | 2 | - | - | - | - | - | 1 | - | - | - |
| 3 Aoni | - | - | - | - | - | - | - | - | - | - | - | - |
| 4 Capi | 16 | 22 | 50 | 2 | 2 | - | 1 | - | - | 12 | 18 | 4 |
| 5 Cirr | - | - | - | - | - | - | - | - | - | - | - | - |
| 6 Cten | - | - | - | - | - | - | - | - | - | - | - | - |
| 7 Eucl | - | - | - | - | - | - | - | - | - | - | - | - |
| 8 Glyc | - | - | - | - | - | - | - | - | - | - | - | - |
| 9 Gypt | - | - | - | - | - | - | - | - | - | - | - | 1 |
| 10 Hete | 9 | 18 | 6 | 7 | 1 | 1 | 4 | 4 | 9 | 8 | 2 | 2 |
| 11 Hydr | - | - | - | - | - | - | - | - | - | - | - | - |
| 12 Jasm | - | - | - | - | - | - | - | - | - | - | - | - |
| 13 Lagi | - | - | - | - | - | - | - | - | - | - | - | - |
| 14 Lani | - | - | - | - | - | - | - | - | - | - | - | - |
| 15 Lumb | - | - | - | - | - | - | - | - | - | - | - | - |
| 16 Marp | - | - | - | - | - | - | - | - | - | - | - | - |
| 17 Meli | - | - | - | - | - | - | - | - | - | - | - | - |
| 18 Merc | 31 | - | - | - | - | 6 | - | - | - | - | - | - |
| 19 Nain | - | - | - | - | - | - | - | - | - | - | - | - |
| 20 Neph | - | - | - | - | - | - | - | - | - | - | - | - |
| 21 Nere | 5 | 1 | 7 | 1 | - | - | - | - | - | 4 | 1 | 2 |
| 22 Noto | - | - | - | - | - | - | - | - | - | - | - | - |
| 23 Phyl | 2 | 13 | 11 | 1 | 1 | - | - | - | - | - | - | - |
| 24 Poly | - | - | 1 | - | - | - | - | - | - | - | - | - |
| 25 Scol | - | - | - | - | - | - | - | - | - | - | - | - |
| 26 Spio | - | - | - | - | - | - | - | - | - | - | - | - |
| 27 Stre | - | - | 1 | - | - | - | - | 1 | - | - | - | - |
| 28 Syl1 | - | - | - | - | - | - | - | - | - | - | - | - |
| 29 Syl2 | - | - | - | - | - | - | - | - | - | - | - | - |
| 30 Olig | 4 | 22 | 30 | 10 | 40 | 4 | 8 | 13 | 14 | - | 1 | 34 |
| 31 Sipu | - | - | - | - | - | - | - | - | - | - | - | - |
| 32 Phor | - | - | - | - | - | - | - | - | - | - | - | - |
| 33 Lepi | - | - | - | - | - | - | - | - | - | - | - | - |
| 34 Amyc | - | - | 2 | - | - | - | - | 1 | 5 | - | 3 | 1 |
| 35 Bitt | - | - | - | - | - | - | - | - | - | - | - | - |
| 36 Caly | - | - | - | - | - | - | - | - | - | - | - | - |
| 37 Ceri | 21 | 25 | 35 | 19 | 30 | 11 | 21 | 5 | 3 | 14 | 51 | 34 |
| 38 Conu | - | - | - | - | - | - | - | - | - | - | - | - |
| 39 Cycl | - | - | - | - | - | - | - | - | - | - | - | - |
| 40 Hini | - | - | - | - | - | - | - | - | - | - | - | - |
| 41 Hulv | - | - | - | - | - | 8 | 1 | 1 | - | - | 32 | 5 |
| 42 Hven | - | - | - | - | - | - | - | - | - | - | - | 1 |
| 43 Juju | - | - | - | - | - | - | - | - | - | - | - | - |
| 44 Mesa | - | - | - | - | - | - | - | - | - | - | - | - |
| 45 Riss | - | - | - | - | - | - | - | - | 1 | - | - | - |
| 46 Spha | - | - | - | - | - | - | - | - | - | - | - | - |
| 47 Trun | - | - | - | - | - | - | - | - | - | - | - | - |
| 48 Aply | - | - | - | - | - | - | 1 | - | - | - | - | - |
| 49 Hami | - | - | 7 | - | - | - | - | - | - | - | - | - |
| 50 Turb | - | - | - | - | - | - | - | - | - | - | - | - |

| D2 | J | M | M | J | S | N | J | M | M | J | S | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **51 Abra** | 81 | 28 | 9 | 9 | 10 | 5 | 4 | 9 | 14 | 16 | 48 | 23 |
| **52 Cedu** | 2 | 2 | - | 1 | 1 | - | 1 | 1 | - | 1 | 1 | - |
| **53 Cgla** | - | - | - | - | - | - | - | - | - | - | - | - |
| **54 Corb** | - | - | - | - | - | - | - | - | - | - | - | - |
| **55 Lept** | - | - | - | - | - | - | - | - | - | - | - | - |
| **56 Lori** | - | - | - | - | - | - | - | - | - | - | - | - |
| **57 Myti** | - | - | - | - | - | - | - | - | - | - | - | - |
| **58 Rudi** | - | - | - | - | - | - | - | - | - | - | - | - |
| **59 Scro** | - | - | - | - | - | - | - | - | - | - | - | - |
| **60 Vene** | - | - | - | - | - | - | - | - | - | - | - | - |
| **61 Bala** | - | 1 | - | - | - | - | - | - | - | - | - | - |
| **62 Neba** | - | - | - | - | - | - | - | - | - | - | - | - |
| **63 Gast** | - | - | - | - | - | - | - | - | - | - | - | - |
| **64 Apse** | - | - | - | - | - | - | - | - | - | - | - | - |
| **65 Lsav** | - | - | - | - | - | - | - | - | - | - | - | - |
| **66 Iphi** | - | - | - | - | - | - | - | - | - | - | - | - |
| **67 Cyat** | - | - | - | - | - | - | - | - | - | - | - | - |
| **68 Cymo** | - | - | - | - | - | - | - | - | - | - | - | - |
| **69 Idot** | - | 1 | 1 | - | - | - | 4 | 17 | 35 | 4 | - | - |
| **70 Shoo** | - | - | - | - | - | - | - | - | - | - | - | - |
| **71 Ampe** | - | - | - | - | - | - | - | - | - | - | - | - |
| **72 Amph** | 10 | - | - | - | - | 6 | 19 | 1 | - | 1 | - | 2 |
| **73 Coro** | - | - | - | - | - | - | - | - | - | - | - | - |
| **74 Dexa** | - | - | - | - | - | - | - | - | - | - | - | - |
| **75 Elas** | - | - | - | - | - | - | - | - | - | 1 | - | - |
| **76 Eric** | - | - | - | - | - | - | - | - | - | - | - | - |
| **77 Gell** | - | - | - | - | - | - | - | - | - | - | - | - |
| **78 Gamm** | 4 | 1 | 4 | - | - | 2 | 32 | 54 | 35 | 3 | - | 9 |
| **79 Leuc** | - | - | - | - | - | - | - | - | - | - | - | - |
| **80 Mita** | - | - | - | - | - | - | - | - | - | - | - | - |
| **81 Mche** | - | - | - | - | - | - | - | - | - | - | - | - |
| **82 Mgry** | 4 | - | - | - | - | - | 5 | 16 | 10 | - | 1 | 2 |
| **83 Msp.** | - | 2 | 2 | 1 | - | 1 | 9 | 14 | 14 | - | 1 | 3 |
| **84 Mver** | 5 | - | - | - | - | - | - | - | - | - | - | - |
| **85 Peri** | - | - | - | - | - | - | - | - | - | - | - | - |
| **86 Phot** | - | - | - | - | - | - | - | - | - | - | - | - |
| **87 Siph** | - | - | - | - | - | - | - | - | - | - | - | - |
| **88 Call** | - | - | - | - | - | - | - | - | - | - | - | - |
| **89 Carc** | - | - | - | - | - | - | - | - | - | - | - | - |
| **90 Diog** | - | - | - | - | - | - | - | - | - | - | - | - |
| **91 Pala** | - | - | 3 | - | - | - | - | - | 1 | - | 1 | 4 |
| **92 Upog** | - | - | - | - | - | - | - | - | - | - | - | - |
| **93 Chir** | 2 | - | 5 | 3 | 7 | 2 | 20 | 23 | 53 | 24 | 19 | 63 |
| **94 Achi** | - | - | - | - | - | - | - | - | - | - | - | - |
| **95 Syng** | - | - | - | 1 | - | - | - | - | - | - | - | - |

## Model 1

Growth of a low or a high density population of *Sparus aurata*, considering either no mortality or a mortality of 30 %.
Initial fish weight = 2 g.

```
TITLE SPARUS GROWTH
INTEG RKM
* L - Low density, H - High density, Mortality 30 %
* Density: dl=0.020882,dlm=0.027146,dh=0.104408,dhm=0.135731
* Initial W=2g, Final W=215.5g. Biomass 4.5 or 22.5 g/m2.
*
PARAM AB=0.5169,NL=0.01054,NLM=0.01197,NH=0.02294,NHM=0.02604,...
               ML=0.00133,MH=0.00133
INCON L0=0.04176,LM0=0.05429,H0=0.20882,HM0=0.27146
*
*
      DLT=NL*L**AB
      DLMT=NLM*LM**AB-ML*LM
      DHT=NH*H**AB
      DHMT=NHM*HM**AB-MH*HM
      L=INTGRL(L0,DLT)
      LM=INTGRL(LM0,DLMT)
      H=INTGRL(H0,DHT)
      HM=INTGRL(HM0,DHMT)
*
TIMER FINTIM=365.,DELT=0.05,DELGR=3.65
*
PREPAR L,LM,H,HM
PSAVE
PLOTS MERGE,MODEL=97,IOPORT=97
GRAPH SAME,TIME,L,LM
GRAPH SAME,TIME,H,HM
GRAPH SAME,TIME,L,LM,H,HM
*
END
STOP
□
```

## Model 2

Daily food consumption by *Sparus aurata*: Individual growth and feeding. Initial fish weigh = 2 g.

```
TITLE SPARUS feeding
INTEG RKM
* W - Parabolic growth
* F - Food consumption  f0=(FC*W0**(-FN1)+FK)*W0
PARAM FK=0.020773,N=0.068332,N1=0.5169,FC=0.365881,FN1=0.4831
INCON W0=2.,F0=.565
*
INITIAL
      W=W0
      F=F0
DYNAMIC
      DWT=(N*W**N1)
      DFT=((FC*W**(-FN1)+FK)*W)-F
      W=INTGRL(W0,DWT)
      F=INTGRL(F0,DFT)
*
TIMER FINTIM=365.,DELT=1.,DELGR=5.
PREPAR F,W
PSAVE
PLOTS MERGE,MODEL=97,IOPORT=97
GRAPH SAME,TIME,W,F
*
END
STOP
□
```

# Model 3

Growth of two fish populations and corresponding daily food consumptions (low and high density populations).

```
TITLE SPARUS growth and feeding
INTEG RKM
* L - Low density, H - High density, Mortality 30 %
* dlm=0.027146, dhm=0.135731
* Final weight=215.5 g. Per m2: wfl=4.5g/m2, wfh=22.5g/m2
* Conversion factor WW - AFDW = 0.2
*
PARAM AB=0.5169,NL=0.01054,NLM=0.01197,NH=0.02294,NHM=0.02604,...
      ML=0.00133,MH=0.00133,FN1=0.4831,FK=0.020773,...
      CF=0.2,FCL=0.064093,FCH=0.139430
INCON LM0=0.05429,HM0=0.27146,FL0=0.003069,FH0=0.015340
*
INITIAL
      LM=LM0
      FL=FL0
      HM=HM0
      FH=FH0
DYNAMIC
      DLMT=NLM*LM**AB-ML*LM
      DFLT=((FCL*LM**(-FN1)+FK)*LM)*CF-FL
      DHMT=NHM*HM**AB-MH*HM
      DFHT=((FCH*HM**(-FN1)+FK)*HM)*CF-FH
      LM=INTGRL(LM0,DLMT)
      FL=INTGRL(FL0,DFLT)
      HM=INTGRL(HM0,DHMT)
      FH=INTGRL(FH0,DFHT)
*
TIMER FINTIM=365.,DELT=0.05,DELGR=5.
*
PREPAR LM,FL,HM,FH
PSAVE
PLOTS MERGE,MODEL=97,IOPORT=97
GRAPH SAME,TIME,LM,FL,HM,FH
*
END
STOP
□
```

# Model 4

Benthic biomass production and consumption by a low or by a high density fish population. (Parameters defined for site A, total biomass of benthos).

```
TITLE SPARUS growth and feeding on benthos
INTEG RKM
* B - Benthos production, BH and BL - Benthic Production and
* predation by low or high density fish population
PARAM AB=0.5169,NL=0.01054,NLM=0.01197,NH=0.02294,NHM=0.02604,...
      ML=0.00133,MH=0.00133,FN1=0.4831,FK=0.020773,...
      CF=0.2,FCL=0.064093,FCH=0.139430,...
      PB=0.10219,MB=0.03066
INCON LM0=0.05429,HM0=0.27146,FL0=0.003069,FH0=0.015340,...
      BL0=11.8,BH0=11.8,B0=11.8
*
INITIAL
      LM=LM0
      FL=FL0
      HM=HM0
      FH=FH0
      B=B0
      BL=BL0
      BH=BH0
DYNAMIC
      DBT=PB-MB
      DLMT=NLM*LM**AB-ML*LM
      DFLT=((FCL*LM**(-FN1)+FK)*LM)*CF-FL
      DBLT=PB-MB-FL
      DHMT=NHM*HM**AB-MH*HM
      DFHT=((FCH*HM**(-FN1)+FK)*HM)*CF-FH
      DBHT=PB-MB-FH
      B=INTGRL(B0,DBT)
      LM=INTGRL(LM0,DLMT)
      FL=INTGRL(FL0,DFLT)
      BL=INTGRL(BL0,DBLT)
      HM=INTGRL(HM0,DHMT)
      FH=INTGRL(FH0,DFHT)
      BH=INTGRL(BH0,DBHT)
*
TIMER FINTIM=365.,DELT=0.05,DELGR=5.
*
PREPAR LM,FL,HM,FH,B,BL,BH
PSAVE
PLOTS MERGE,MODEL=97,IOPORT=97
GRAPH SAME,TIME,LM,FL,BL
GRAPH SAME,TIME,HM,FH,BH
GRAPH SAME,TIME,B,BL,BH
*
END
STOP
□
```

# Model 5

Environmental Forcing functions: FT - Mean temperature, FB - Mean BOD, FS - Maximum-minimum salinity.

```
TITLE ENVIRONMENTAL FACTORS
*
PARAM TM=19.40,BM=2.519,SM=1.771,...
      TIF=351.,TIFS=365.,TIFB=351.
*
      TIMT=AMOD(TIME,TIF)
      TA=AFGEN(TTAA,TIMT)
      TB=AFGEN(TTAB,TIMT)
      TC=AFGEN(TTAC,TIMT)
      TD=AFGEN(TTAD,TIMT)
      TIMB=AMOD(TIME,TIFB)
      BA=AFGEN(BTAA,TIMB)
      BB=AFGEN(BTAB,TIMB)
      BC=AFGEN(BTAC,TIMB)
      BD=AFGEN(BTAD,TIMB)
      TIMS=AMOD(TIME,TIFS)
      SA=AFGEN(STAA,TIMS)
      SB=AFGEN(STAB,TIMS)
      SC=AFGEN(STAC,TIMS)
      SD=AFGEN(STAD,TIMS)
*
AFGEN TTAA=0.,10.20,15.,7.23,34.,15.03,43.,14.63,63.,16.97,...
      70.,17.83,91.,17.77,101.,18.07,122.,22.00,129.,16.37,...
      150.,22.67,157.,21.67,182.,28.20,193.,25.87,225.,26.37,...
      235.,26.83,256.,25.10,263.,26.50,286.,23.17,293.,24.33,...
      315.,21.30,323.,15.73,343.,16.13,351.,12.70,375.,11.50,...
      382.,11.83,417.,12.93,426.,17.00,450.,19.50,455.,16.87,...
      477.,18.27,484.,20.90,506.,24.47,513.,24.83,539.,25.63,...
      546.,24.40,568.,28.60,576.,24.53,582.,27.70,589.,24.97,...
      610.,23.90,618.,26.27,639.,20.97,651.,25.60,672.,21.07,...
      680.,17.93
AFGEN TTAB=15.,10.27,34.,14.93,43.,14.27,63.,17.10,...
      70.,16.90,91.,16.97,101.,16.80,122.,20.87,129.,15.93,...
      150.,21.93,157.,19.63,182.,26.90,193.,25.57,225.,27.10,...
      235.,25.20,256.,24.43,263.,25.23,286.,22.83,293.,23.27,...
      315.,20.70,323.,16.73,343.,16.40,351.,14.00,375.,12.27,...
      382.,12.40,417.,12.23,426.,15.20,450.,17.50,455.,15.40,...
      477.,16.07,484.,16.40,506.,23.17,513.,21.60,539.,25.27,...
      546.,23.53,568.,26.27,576.,23.87,582.,26.63,589.,23.13,...
      610.,24.27,618.,25.77,639.,21.73,651.,23.57,672.,20.93,...
      680.,18.03
AFGEN TTAC=0.,13.00,15.,8.35,34.,13.70,43.,13.65,63.,16.50,...
      70.,15.45,91.,15.90,101.,17.95,122.,20.05,129.,15.65,...
      150.,21.10,157.,20.75,182.,27.05,193.,25.35,225.,26.50,...
      235.,28.05,256.,23.50,263.,25.20,286.,21.35,293.,21.70,...
      315.,20.20,323.,15.15,343.,15.55,351.,12.00,375.,10.10,...
      382.,11.50,417.,12.10,426.,14.85,450.,18.60,455.,14.45,...
      477.,15.45,484.,16.05,506.,22.70,513.,22.90,539.,24.65,...
```

```
      546.,23.45,568.,25.75,576.,23.20,582.,25.95,589.,23.15,...
      610.,22.85,618.,25.80,639.,20.15,651.,23.35,672.,18.70,...
      680.,17.05
AFGEN TTAD=0.,12.00,15.,8.25,34.,13.20,43.,13.80,63.,16.45,...
      70.,15.65,91.,16.55,101.,18.55,122.,20.85,129.,17.05,...
      150.,21.25,157.,22.65,182.,27.20,193.,25.30,225.,28.45,...
      235.,26.40,256.,24.35,263.,26.85,286.,20.80,293.,22.15,...
      315.,20.65,323.,15.35,343.,16.05,351.,12.50,375.,10.55,...
      382.,11.75,417.,11.90,426.,14.85,450.,18.50,455.,14.95,...
      477.,15.80,484.,15.85,506.,23.00,513.,21.35,539.,24.70,...
      546.,24.35,568.,26.05,576.,24.30,582.,26.85,589.,24.20,...
      610.,24.05,618.,26.50,639.,20.70,651.,23.50,672.,19.75,...
      680.,18.05
*
* MEAN TEMP:A85 19.69;B85 19.74;C85 18.9;D85 19.26
* A86 21.35;B86 20.24;C86 19.67;D86 19.65;
* M85  19.40;M86 20.23
*
AFGEN BTAA=34.,1.58,63.,1.47,70.,1.18,91.,2.56,...
      101.,1.80,122.,1.95,129.,1.44,...
      150.,1.56,157.,1.71,182.,2.24,193.,2.27,225.,3.60,...
      235.,3.77,256.,2.47,263.,2.98,286.,1.56,293.,4.03,...
      315.,1.54,323.,1.61,343.,2.17,351.,1.40,375.,0.62,...
      382.,0.44,417.,0.94,426.,0.86,450.,0.85,455.,0.77,...
      477.,1.99,484.,1.10,506.,4.93,513.,2.05,539.,4.81,...
      546.,2.62,568.,3.14,576.,2.66,582.,3.82,589.,2.36,...
      610.,3.82,618.,2.07,639.,1.95,651.,2.36,672.,1.84,...
      680.,2.28
AFGEN BTAB=34.,1.64,63.,2.17,70.,1.20,91.,2.53,...
      101.,0.96,122.,2.88,129.,0.78,...
      150.,2.78,157.,1.65,182.,3.30,193.,3.30,225.,4.12,...
      235.,2.11,256.,5.38,263.,1.34,286.,3.74,293.,1.92,...
      315.,0.72,323.,0.85,343.,2.21,351.,1.25,375.,0.88,...
      382.,0.70,417.,1.42,426.,1.09,450.,1.54,455.,1.58,...
      477.,1.59,484.,1.65,506.,4.57,513.,1.89,539.,5.54,...
      546.,2.25,568.,2.64,576.,2.67,582.,4.00,589.,2.73,...
      610.,5.61,618.,2.27,639.,2.01,651.,2.65,672.,2.10,...
      680.,2.06
AFGEN BTAC=34.,1.29,63.,3.03,70.,1.09,91.,1.91,...
      101.,1.41,122.,1.62,129.,1.72,...
      150.,1.54,157.,2.54,182.,2.97,193.,2.78,225.,5.80,...
      235.,3.66,256.,3.44,263.,4.11,286.,2.16,293.,3.59,...
      315.,1.41,323.,1.80,343.,3.75,351.,2.48,375.,1.14,...
      382.,2.04,417.,7.29,426.,4.73,450.,7.98,455.,6.65,...
      477.,1.99,484.,2.69,506.,3.55,513.,3.02,539.,4.64,...
      546.,2.15,568.,2.91,576.,2.34,582.,4.20,589.,5.25,...
      610.,5.54,618.,2.75,639.,2.19,651.,2.49,672.,2.39,...
      680.,2.94
AFGEN BTAD=34.,1.74,63.,1.30,70.,1.70,91.,3.47,...
      101.,1.72,122.,2.74,129.,1.76,...
      150.,1.18,157.,2.79,182.,4.51,193.,5.08,225.,8.29,...
      235.,4.34,256.,4.51,263.,6.09,286.,4.48,293.,3.11,...
      315.,1.64,323.,0.78,343.,2.41,351.,2.23,375.,1.89,...
      382.,1.35,417.,2.21,426.,3.70,450.,3.57,455.,2.56,...
```

```
      477.,3.23,484.,2.45,506.,5.36,513.,1.68,539.,5.00,...
      546.,1.26,568.,5.44,576.,2.12,582.,7.14,589.,4.11,...
      610.,7.03,618.,2.15,639.,2.40,651.,2.47,672.,2.22,...
      680.,3.03
*
* MEAN BOD: A85  2.14;B85 2.229;C85 2.574;D85 3.134
* A86 2.194;B86 2.429;C86 3.673;D86 3.213
* M85 2.519;M86 2.877
*
AFGEN STAA=0.,0.99,30.,1.23,60.,1.40,90.,1.45,121.,9.74,...
      151.,4.92,182.,4.00,212.,5.50,243.,26.50,273.,30.00,...
      304.,8.50,334.,1.60,365.,3.92,395.,7.03,425.,3.15,...
      455.,7.82,486.,6.80,517.,19.90,547.,38.50,578.,1.40,...
      608.,6.00,639.,10.90,669.,1.10
AFGEN STAB=0.,0.05,30.,0.26,60.,4.36,90.,1.66,121.,0.85,...
      151.,3.03,182.,0.77,212.,3.26,243.,4.23,273.,2.16,...
      304.,0.47,334.,0.15,365.,0.31,395.,0.88,425.,0.38,...
      455.,1.32,486.,3.06,517.,1.52,547.,1.53,578.,4.52,...
      608.,1.83,639.,1.46,669.,1.79
AFGEN STAC=0.,1.78,30.,2.26,60.,2.53,90.,0.47,121.,0.82,...
      151.,2.00,182.,3.50,212.,4.00,243.,3.50,273.,8.63,...
      304.,1.57,334.,1.17,365.,1.45,395.,0.64,425.,3.08,...
      455.,1.56,486.,5.71,517.,9.50,547.,30.12,578.,5.70,...
      608.,5.60,639.,2.00,669.,1.30
AFGEN STAD=0.,1.09,30.,0.50,60.,1.11,90.,1.11,121.,0.20,...
      151.,2.55,182.,6.50,212.,6.45,243.,7.87,273.,9.89,...
      304.,2.89,334.,0.04,365.,1.18,395.,0.57,425.,0.93,...
      455.,1.25,486.,7.93,517.,11.80,547.,7.20,578.,4.80,...
      608.,2.50,639.,1.60,669.,0.60
*
* MEAN SALI:A85 7.986;B85 1.771;C85 2.686;D85  3.35
* A86 9.684;B86 1.691;C86  6.06;D86 3.669
* M85 3.948;M86 5.276
* MEAN: A  8.80;B  1.73;C  4.30;D  3.50;T  4.58
*
      FTA=1.05**(TA-TM)
      FTB=1.05**(TB-TM)
      FTC=1.05**(TC-TM)
      FTD=1.05**(TD-TM)
      FBA=1.05**(BM-BA)
      FBB=1.05**(BM-BB)
      FBC=1.05**(BM-BC)
      FBD=1.05**(BM-BB)
      FSA=1.05**(SM-SA)
      FSB=1.05**(SM-SB)
      FSC=1.05**(SM-SC)
      FSD=1.05**(SM-SD)
      PA=FTA*FBA*FSA
      PB=FTB*FBB*FSB
      PC=FTC*FBC*FSC
      PD=FTD*FBD*FSD
*
TIMER FINTIM=365.,DELT=0.05,DELGR=5.,TIME=0.
*
```

```
PREPAR FTA,FTB,FTC,FTD,FBA,FBB,FBC,FBD,FSA,FSB,FSC,FSD,..
       PA,PB,PC,PD
PSAVE
PLOTS MERGE,MODEL=97,IOPORT=97
GRAPH SAME,TIME,FTA,FTB,FTC,FTD
GRAPH SAME,TIME,FBA,FBB,FBC,FBD
GRAPH SAME,TIME,FSA,FSB,FSC,FSD
GRAPH SAME,TIME,PA,PB,PC,PD
*
END
*
PARAM TIF=680.,TIFS=669.,TIFB=680.,...
      TM=20.23,BM=2.877,SM=1.691
TIMER TIME=365.,FINTIM=730.
*
END
STOP
□
```

## Model 6

Effect of forcing functions on benthic biomass production and consumption by a low or by a high density fish population. (Parameters defined for site A, total biomass of benthos).

```
TITLE SPARUS growth and feeding on benthos
* Effect of environmental forcing functions
INTEG RKM
* L - Lower density, H - Higher density, Mortality 30 %
* dlm=0.027146, dhm=0.135731
* Final weight=215.5 g. Per m2: wfl=4.5g/m2, wfh=22.5g/m2
* Conversion factor WW - AFDW = 0.2
* Site A - 1985
*
PARAM AB=0.5169,NL=0.01054,NLM=0.01197,NH=0.02294,NHM=0.02604,...
      ML=0.00133,MH=0.00133,FN1=0.4831,FK=0.020773,...
      CF=0.2,FCL=0.064093,FCH=0.139430,...
      PB=0.10219,MB=0.03066
*
INCON LM0=0.05429,HM0=0.27146,FL0=0.003069,FH0=0.015340,...
      BL0=11.8,BH0=11.8,B0=11.8
*
      TIMT=AMOD(TIME,351.)
      TE=AFGEN(TTEM,TIMT)
      BO=AFGEN(TBOD,TIMT)
      TIMS=AMOD(TIME,365.)
      SA=AFGEN(TSAL,TIMS)
*
AFGEN TTEM=0.,10.20,15.,7.23,34.,15.03,43.,14.63,63.,16.97,...
      70.,17.83,91.,17.77,101.,18.07,122.,22.00,129.,16.37,...
      150.,22.67,157.,21.67,182.,28.20,193.,25.87,225.,26.37,...
      235.,26.83,256.,25.10,263.,26.50,286.,23.17,293.,24.33,...
      315.,21.30,323.,15.73,343.,16.13,351.,12.70
AFGEN TSAL=0.,0.99,30.,1.23,60.,1.40,90.,1.45,121.,9.74,...
      151.,4.92,182.,4.00,212.,5.50,243.,26.50,273.,30.00,...
      304.,8.50,334.,1.60,365.,3.92
AFGEN TBOD=34.,1.58,63.,1.47,70.,1.18,91.,2.56,...
      101.,1.80,122.,1.95,129.,1.44,...
      150.,1.56,157.,1.71,182.,2.24,193.,2.27,225.,3.60,...
      235.,3.77,256.,2.47,263.,2.98,286.,1.56,293.,4.03,...
      315.,1.54,323.,1.61,343.,2.17,351.,1.40
*
      FT=1.05**(TE-19.40)
      FS=1.05**(1.733-SA)
      FB=1.05**(2.519-BO)
      PD=FT*FS*FB
      MP=2-PD
*
      DBT=PB*PD-MB*MP
      DLMT=NLM*LM**AB*PD-ML*LM*MP
      DFLT=((FCL*LM**(-FN1)+FK)*LM)*CF-FL
```

```
        DBLT=PB*PD-MB*MP-FL
        DHMT=NHM*HM**AB*PD-MH*HM*MP
        DFHT=((FCH*HM**(-FN1)+FK)*HM)*CF-FH
        DBHT=PB*PD-MB*MP-FH
*
        B=INTGRL(B0,DBT)
        LM=INTGRL(LM0,DLMT)
        FL=INTGRL(FL0,DFLT)
        BL=INTGRL(BL0,DBLT)
        HM=INTGRL(HM0,DHMT)
        FH=INTGRL(FH0,DFHT)
        BH=INTGRL(BH0,DBHT)
*
TIMER FINTIM=365.,DELT=0.05,DELGR=5.
*
PREPAR FH,FL,LM,HM,B,BL,BH
PSAVE
PLOTS MERGE,MODEL=97,IOPORT=97
GRAPH SAME,TIME,LM,HM
GRAPH SAME,TIME,FH,FL
GRAPH SAME,TIME,B,BL,BH
*
END
STOP
□
```

# Model 7

Final model: *Sparus* growth and predation on two size classes of benthos.
Effects of environmental forcing functions.
(Parameters defined for a low density fish population at site A)

```
TITLE ENVIRONMENTAL FACTORS Sparus growth feeding on benthos
* Site A - Low density fish
*
* Initial weight=2 g; Final weight=215.5 g
* W - Sparus growth (g/m2)
* AB - Sparus growth rate; NW - Sparus constant dependent
* on fish density; MW - Sparus mortality rate
*
* F - Sparus feeding (AFDW g/m2)
* FN - Sparus growth; FK & FC - Feeding constants
* CF - Conversion factor (WW/AFDW)
*
* B - Benthos growth (AFDW g/m2)
* PB - Benthos growth rate; MB - Predation by other predators or
* reproductive effort
* BW1 AND BW2 - Benthos < or > than 10 mm
*
INTEG RKM
PARAM AB=0.5169,NW=0.01197,MW=0.00133,MR=0.00388,...
      FN=0.4831,FK=0.020773,CF=0.2,FC=0.064093,...
      PB1=0.10164,MB1=0.03049,PB2=0.00055,MB2=0.00016,...
      AF=1.,BF=0.,TM=19.40,BM=2.519,SM=1.771,...
      TIF=351.,TIFS=365.,TIFB=351.,TIGR=330.
INCON W0=0.05429,F0=0.003069,BW10=11.3,BW20=0.5
AFGEN TTEM=0.,10.20,15.,7.23,34.,15.03,43.,14.63,63.,16.97,...
      70.,17.83,91.,17.77,101.,18.07,122.,22.00,129.,16.37,...
      150.,22.67,157.,21.67,182.,28.20,193.,25.87,225.,26.37,...
      235.,26.83,256.,25.10,263.,26.50,286.,23.17,293.,24.33,...
      315.,21.30,323.,15.73,343.,16.13,351.,12.70,375.,11.50,...
      382.,11.83,417.,12.93,426.,17.00,450.,19.50,455.,16.87,...
      477.,18.27,484.,20.90,506.,24.47,513.,24.83,539.,25.63,...
      546.,24.40,568.,28.60,576.,24.53,582.,27.70,589.,24.97,...
      610.,23.90,618.,26.27,639.,20.97,651.,25.60,672.,21.07,...
      680.,17.93
AFGEN TBOD=34.,1.58,63.,1.47,70.,1.18,91.,2.56,...
      101.,1.80,122.,1.95,129.,1.44,...
      150.,1.56,157.,1.71,182.,2.24,193.,2.27,225.,3.60,...
      235.,3.77,256.,2.47,263.,2.98,286.,1.56,293.,4.03,...
      315.,1.54,323.,1.61,343.,2.17,351.,1.40,375.,0.62,...
      382.,0.44,417.,0.94,426.,0.86,450.,0.85,455.,0.77,...
      477.,1.99,484.,1.10,506.,4.93,513.,2.05,539.,4.81,...
      546.,2.62,568.,3.14,576.,2.66,582.,3.82,589.,2.36,...
      610.,3.82,618.,2.07,639.,1.95,651.,2.36,672.,1.84,...
      680.,2.28
AFGEN TSAL=0.,0.99,30.,1.23,60.,1.40,90.,1.45,121.,9.74,...
      151.,4.92,182.,4.00,212.,5.50,243.,26.50,273.,30.00,...
```

```
      304.,8.50,334.,1.60,365.,3.92,395.,7.03,425.,3.15,...
      455.,7.82,486.,6.80,517.,19.90,547.,38.50,578.,1.40,...
      608.,6.00,639.,10.90,669.,1.10
INITIAL
      F=F0
      W=W0
      AF=1.
      BW1=BW10
DYNAMIC
      TIMT=AMOD(TIME,TIF)
      TE=AFGEN(TTEM,TIMT)
      TIMB=AMOD(TIME,TIFB)
      BO=AFGEN(TBOD,TIMB)
      TIMS=AMOD(TIME,TIFS)
      SA=AFGEN(TSAL,TIMS)
      FT=1.05**(TE-TM)
      FB=1.05**(BM-BO)
      FS=1.05**(SM-SA)
      PD=FT*FB*FS
      MP=2-PD
NOSORT
      IF ( TIME .LT. TIGR ) BF=0.
      IF ( TIME .GE. TIGR ) BF=1.
      IF ( BW2 .LT. BW20 ) BF=0.
      IF ( BW1 .LT. BW10 .AND. BW2 .LT. BW20 ) AF=0.
      IF ( BW1 .GE. BW10 .OR. BW2 .GE. BW20 ) AF=1.
      IF ( BW1 .LT. BW10 .AND. TIME .LT. TIGR ) AF=0.
SORT
      DWT=NW*W**AB*PD*AF-MW*W*MP-(1-AF)*MR*W
      DFT=((FC*W**(-FN)+FK)*W)*CF-F
      DBW1T=PB1*PD-MB1*MP-F*(1-BF)*AF
      DBW2T=PB2*PD-MB2*MP-F*BF*AF
      W=INTGRL(W0,DWT)
      F=INTGRL(F0,DFT)
      BW1=INTGRL(BW10,DBW1T)
      BW2=INTGRL(BW20,DBW2T)
*
TIMER FINTIM=365.,DELT=0.5,DELGR=5.,TIME=0.
*
PREPAR W,F,BW1,BW2,BF,AF,PD
PSAVE
PLOTS MERGE,MODEL=97,IOPORT=97
GRAPH SAME,TIME,W,F,BW1,BW2
GRAPH SAME,TIME,BF,AF,PD
*
PARAM TIF=680.,TIFS=669.,TIFB=680.,TIGR=695.,...
      PB1=0.05288,MB1=0.01586,PB2=0.00082,MB2=0.00025,...
      AF=1.,BF=0.,TM=20.23,BM=2.877,SM=1.691
INCON W0=0.05429,F0=0.003069,BW10=6.6,BW20=0.5
TIMER TIME=365.,FINTIM=730.
*
END
STOP
□
```