Research Article

The Impact of Aquaculture on the Water Quality of Maltese Waters

Christopher Rizzo and Alain Le Breton
National Aquaculture Centre, Fort St. Lucian, Marsaxlokk, Malta.

Summary. *The impact of marine fish farming on the water quality of Maltese Waters was monitored monthly over a period of one year. Water samples were collected at different depths in the water column from several stations distributed around six fish farming sites. Physical and chemical parameters were measured: temperature, pH, dissolved oxygen (DO), salinity, turbidity, unionised ammonia, dissolved reactive phosphorous (DRP), nitrate-nitrogen, chlorophyll a. The bacterial flora, faecal coliforms and faecal streptococci, were also investigated. Results show that the impact of local aquaculture on the water column is minimal. Anomalies observed near the offshore cages were in most cases also observed at control sites. Other factors such as climatic conditions, sewage outflows and possible underwater freshwater outlets play a key role in the fluctuation of several of these parameters.*

Keywords: aquaculture, pollution, bacteriology, nitrate, nutrient, phytoplankton

Environmental pollution, whatever its origin, is a major problem encountered by authorities in different countries. Industrial activities are continuously contributing to such pollution and therefore authorities are much involved in ensuring that pressures on the environment remain within sustainable limits that permit natural adjustment. The Mediterranean, being a relatively enclosed sea, is subjected to a high risk of pollution. Thus, continuous monitoring of potential sources of pollution is of prime importance to prevent irreversible damage to the marine environment. With the recent increase of the aquaculture industry in the Mediterranean and around the Maltese Islands, concern has grown over its possible adverse effects on the marine environment. Ackefors and Enell (1990) have observed that the contribution of other industries to the degradation of the environment is much higher than that of fish farming. The extent of impact induced by these latter activities is related to several factors such as the size of the farms in terms of annual production and their location. The evaluation of this effect on the environment is required by the licensing authorities to estimate potential adverse effects that new lease proposals may generate. Environmental impact assessment and monitoring has been done for several years in various countries, even though very few equivalent studies have been reported from the Mediterranean.

The intensive culture of fish in offshore cages leads to the generation of particulate and soluble wastes. The effect of the particulate waste namely, fish faeces and uneaten feed that sinks to the bottom, is currently being studied at the National Aquaculture Centre. A small part of these wastes may be recycled by mineralisation and resuspension processes (Agius and Jaccarini, 1989). These recycled nutrients are difficult to quantify (Wallin and Hakanson, 1991), but are of considerable importance when considering the possible nutrient enrichment effects from a fish farm (Cassar, 1994). The availability of these nutrients is, however, dependant on environmental conditions and may explain the short-lived high nitrate-nitrogen levels (Agius and Jaccarini, 1989). The soluble wastes which are of interest in this review consist mainly of fish excreta (soluble ammonium and urea) and dissolved nitrogen and phosphorous compounds from feeds as they sink to the bottom. The proportion of ammonia is variable, but is usually 80% of fish excreta (Gowen and McLusky, 1988). Soluble nitrogen and phosphorous compounds are an important source of nutrients for phytoplankton. Thus, where phytoplankton is limited by lack of nutrients, an increase in nitrogen and phosphorous levels (hypernutrification) will result in an increased primary production in the water column which in extreme cases may result in O_2 depletion (eutrophication). Eutrophication may also result in an increased turbidity of the water column. Ammonia is also of prime importance. Under alkaline conditions the unionised form is highly toxic to fish, causing branchial hyperplasia. Previous studies have shown ammonia levels in local waters to be below 0.1ppm (De Giovanni, 1991) which is below the level toxic to fish.

The location of fish farming operations plays a major role in the extent of impact on the water column. Wastes produced by marine cage farms undergo a better dispersal when the farm is situated in an exposed site with an efficient water exchange. Except for very enclosed sites, the water exchange at local sites is sufficient to prevent the build-up of phytoplankton and nutrients (Cassar, 1994).

Locally, no long term studies have been performed to measure and quantify the effect of the aquaculture industry on the marine environment. The objective of this study was to determine the extent of the impact on the water quality by local fish farming activities, and to provide background information for future studies.

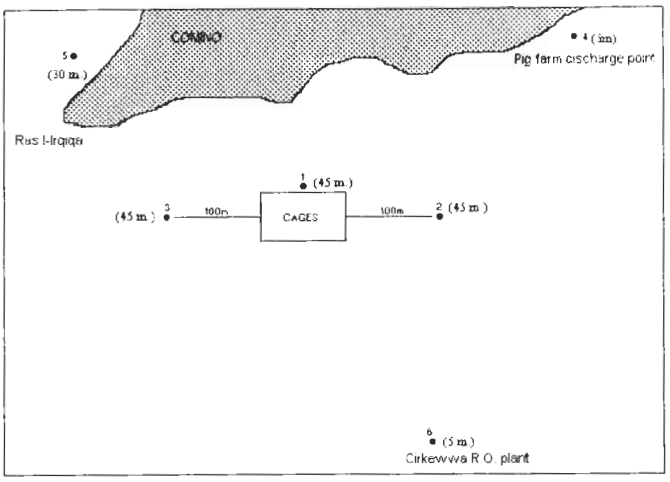

Fig. 1a - Site A

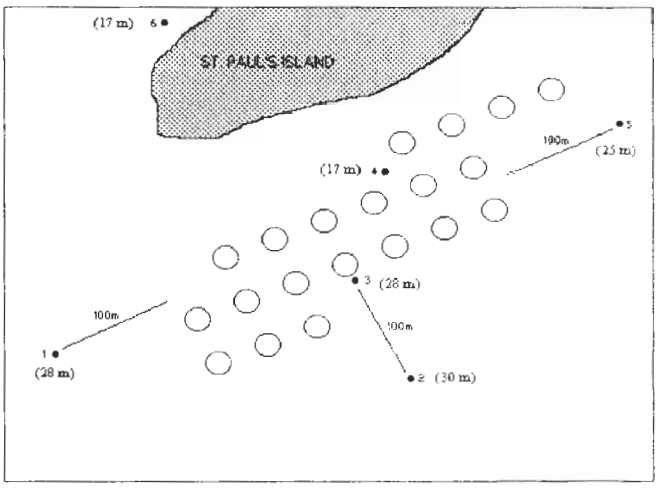

Fig. 1b - Site B

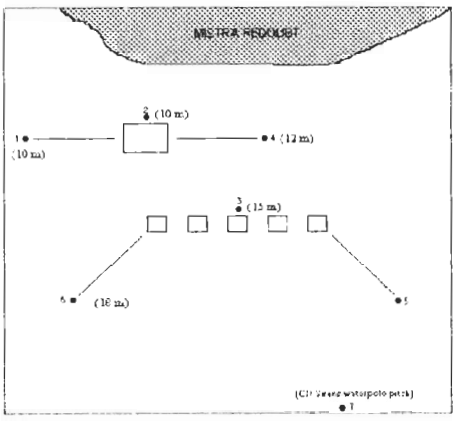

Fig. 1c - Site C

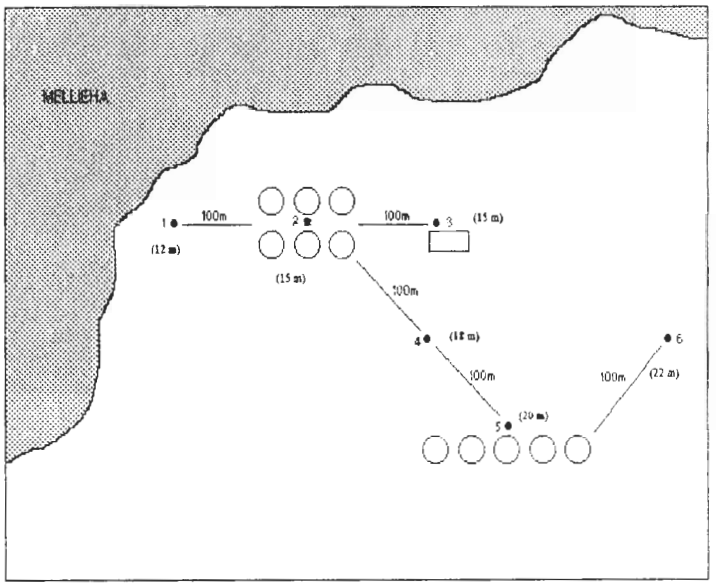

Fig. 1d - Site D

Fig. 1e - Site E

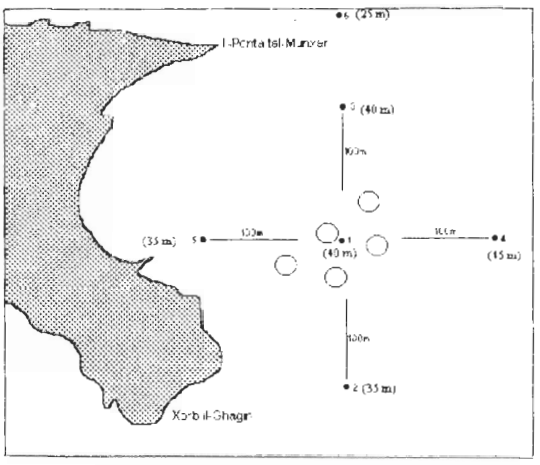

Fig. 1f - Site F

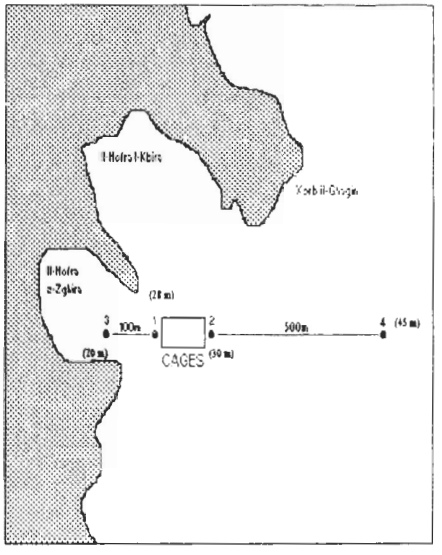

Figure 1. Fish farming sites monitored for their impact on water quality. The location of the samples spots and the control points are represented with the respective water depths.

Materials and Methods

Sample sites and sampling spots description

Water samples were collected monthly from thirty-five sampling stations distributed around six local on-growing units. At each site, sampling spots were chosen either in the vicinity of the cages or at one hundred metres outside the rearing units. The control points were situated in an independent zone or in an area where a potential source of water contamination was present, which can affect the site, was identified. The locations of all the sampling spots with the correspondent water depths are presented in Figures 1a, 1b, 1c, 1d, 1e, 1f.

Currents were not monitored. One site (Figure 1a) is particularly affected by strong east or west currents which are in the axe of the units. Surface and deeper currents can eventually be observed simultaneously with an opposite direction.

Main characteristics of the rearing facilities and management

The production units followed during this survey are each of a volume 3000-4500m^3, equipped with Dunlop or Bridgetone type cages. In site A, the unit is composed of two groups of five cages, while in site B and D the unit is composed of 19 and 9 cages respectively. The site C is equipped with a group of 4 small Dunlop cages and a group of Jetflot cages. Four Farm Ocean cages, each of a capacity of 3500m^3, constitute the site E. The biomass in the cages fluctuates from 10$kg.m^{-3}$ to a maximum of 30$kg.m^{-3}$ in some cages of market size fish.

In 1996, 1550 tonnes of fish were produced. More than 90% of which were sea bream *Sparus aurata,* the rest being sea bass *Dicentrarchus labrax*. Two different type of feed, steam-pressed or extruded, are distributed and the total amount of food employed this year was approximately 4000 tonnes. The steam pressed feed has an average composition of 48% protein, 12% lipid, 10% ash, 8% moisture and 2% fibre. The extruded feed contain 46% protein, 16% to 22% lipid 10% ash, 8% moisture and 2% fibre. The percentage of carbohydrate is calculated by substraction. The size of the pellets distributed depends on the size and the age of the fish and range from 1.0mm to 6mm.

Sampling procedures

Water samples for chemical analysis were collected at three different depths (1m, 10m, 20m) in the water column by means of a 3-litre capacity Van Dorn water sampler. They were transported to the laboratory in plastic containers which were disinfected and rinsed with sterile deionised water. Samples were analysed immediately. If the analysis had to be delayed, they were deep-frozen in a domestic type freezer at -20°C.

Bacteriology samples were collected and transported in sterile containers held in iced coolers. They were processed on arrival at the laboratory.

Physical and chemical parameters

Physical parameters were measured in the field at the time of sampling. Water temperatures were recorded at three different depths (1m, 10m and 20m) using a digital thermometer. The pH and DO content were measured using a portable Oxyguard Handy pH meter and an Oxyguard Handy Mark 1 oxygen meter respectively. The salinity was measured at the surface only, using a portable Atago S/Mill refractometer, whilst the turbidity was evaluated by lowering a Secchi disc vertically into the water column.

Chemical and bacteriological analysis methods

The determinations of nitrate-nitrogen, DRP and Chlorophyll *a*, were carried out using standard procedures (Strickland and Parsons, 1972). Unionised ammonia levels were measured using the standard method described by Stirling (1985). Bacteriological analysis, determination of faecal coliforms and faecal streptococci were carried out using the reference method for water bacteriology (Anonymous, 1975).

Results

Temperature shows seasonal variation with an average minimum of 15.7°C in January and an average maximum of 26.9°C in August. No evident differences were observed throughout the year between the control sites and the samples taken from the vicinity of the cages (Figure 2).

No seasonal variation in surface salinities at the six different sampling areas was noticed. Average surface salinities at the six sites range from 35.4 to 38.5 ppt which is within known norms for local waters. Furthermore, no obvious differences are observed in surface salinities at the different sampling areas. Figure 2 shows a comparison of the annual variation of surface salinities at control sites and at the cage areas.

No particular seasonal variation was seen in pH values, even though there was a slight gradual decrease during summer. pH values varied from 6.48 in July to 8.49 in December. Figure 2 shows no difference between pH values recorded at control sites and in the vicinity of the cages. No correlation was observed with increasing depth.

Seasonal variation in DO levels was observed (Figure 2). The average dissolved oxygen values ranged from 5.64 to 8.34mgL^{-1}. No obvious difference was observed between the control site and the cage area even though occasionally average DO levels near the cages were found to be slightly lower. No readings were taken during the month of August. The turbidity is related to climatic conditions with average values ranging from a minimum of 6m in autumn and winter to a maximum of 27m in August. No particular differences were observed between Secchi depths at control sites and those in the vicinity of the cages.

Unionised ammonia levels were generally very low at all sampling areas, and in the majority of cases were

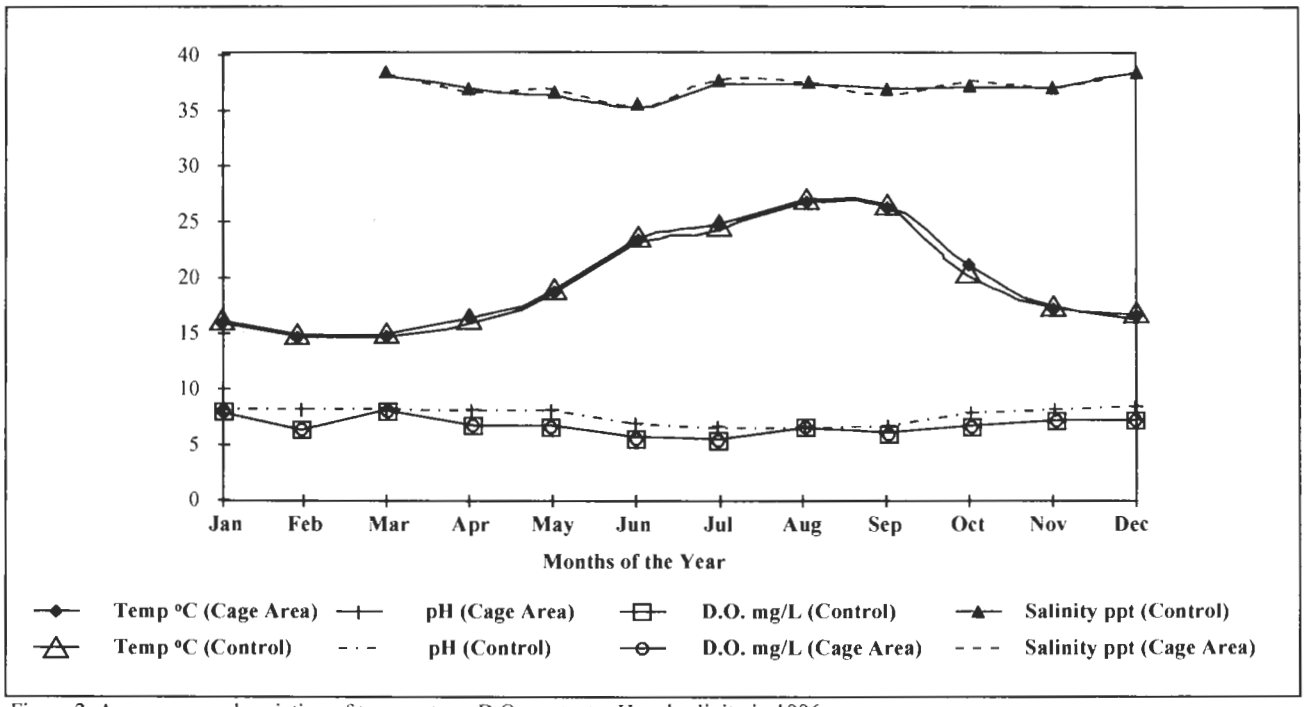

Figure 2. Average annual variation of temperature, D.O. content, pH and salinity in 1996.

never detected by the method employed. When unionised ammonia was detected, levels were found to lie between 0.001mg/L and 0.094mg/L. No particular differences were observed between control sites and samples from the vicinity of the cages.

Figure 3 shows the annual variation of nutrient levels and phytoplankton biomass during 1996. DRP levels were found to be rather constant even though a slight increase was observed during July. No difference in DRP levels between the control sites and the cage units at all sampling areas were noticed. Average DRP levels recorded ranged between 0.03 and 0.31mg/L. No correlation was observed between DRP levels and increase in depth. Nitrate-nitrogen levels fluctuate frequently throughout the year and were always higher than DRP levels. The average nitrate-nitrogen levels recorded over this one year period ranged between a minimum of 0.23 and a maximum of 4.98mg/L. No relationship was observed with increasing depth. Figure 3 shows a marked difference in nitrate-nitrogen levels between the control sites and the cage areas during April and December. Chlorophyll *a* levels fluctuate moderately within known norms (0.06 to 0.97mgm^{-3}). No difference was observed between the control sites and the cage areas. No correlation with increasing depth was seen.

Faecal coliforms were detected occasionally at very low levels and are not clearly seen in Figure 4. Faecal *Streptococci* were continuously detected, with greater amounts recorded during spring and summer.

Discussion

Water temperatures were observed to fluctuate seasonally with higher temperatures being recorded during the summer months. Higher temperatures are known to reduce the solubility of gases (Roberts, 1989), which explains the reduction in DO levels observed during the summer period both in the vicinity of the fish farms and at the control sites. This effect coupled with the enhanced oxygen consumption of the cultured fish makes DO levels a critical factor for ongrowing activities during this period. Even though in summer a drop in DO levels is recorded inside the cages themselves, there was no significant impact on the surrounding water. This is indicative of efficient water exchange around the cage units and that the drop in DO levels in the surrounding waters cannot be attributed to fish farming activities.

In the majority of cases a temperature gradient was observed with increasing depth (thermocline). During the winter months when there is sufficient mixing of the water due to wave action and underwater currents, this temperature gradient was found to be approximately 0.8°C. In summer, this temperature gradient is much larger (-3°C) as a result of less efficient mixing due to the favourable climatic conditions. Rainwater and terrestrial run-off do not significantly influence the surface salinity which was more or less constant throughout the year at the sites studied. This is obviously aided by the fact that all fish farms are situated in relatively open sites.

Levels of unionised ammonia were in the majority of cases below the detection limit of the method employed. When detected, no significant difference was recorded between the control sites and the cage units. This further supports the results showing adequate water exchange and minimal impact of fish farming activities on the marine environment.

The turbidity is greatly dependant on climatic conditions. Lower Secchi depths were observed during the winter months. During this period, the transparency of the water is reduced by terrestrial run-off following heavy rainfall, agitation of the sediments due to strong underwater currents and wave action. The results have shown that the

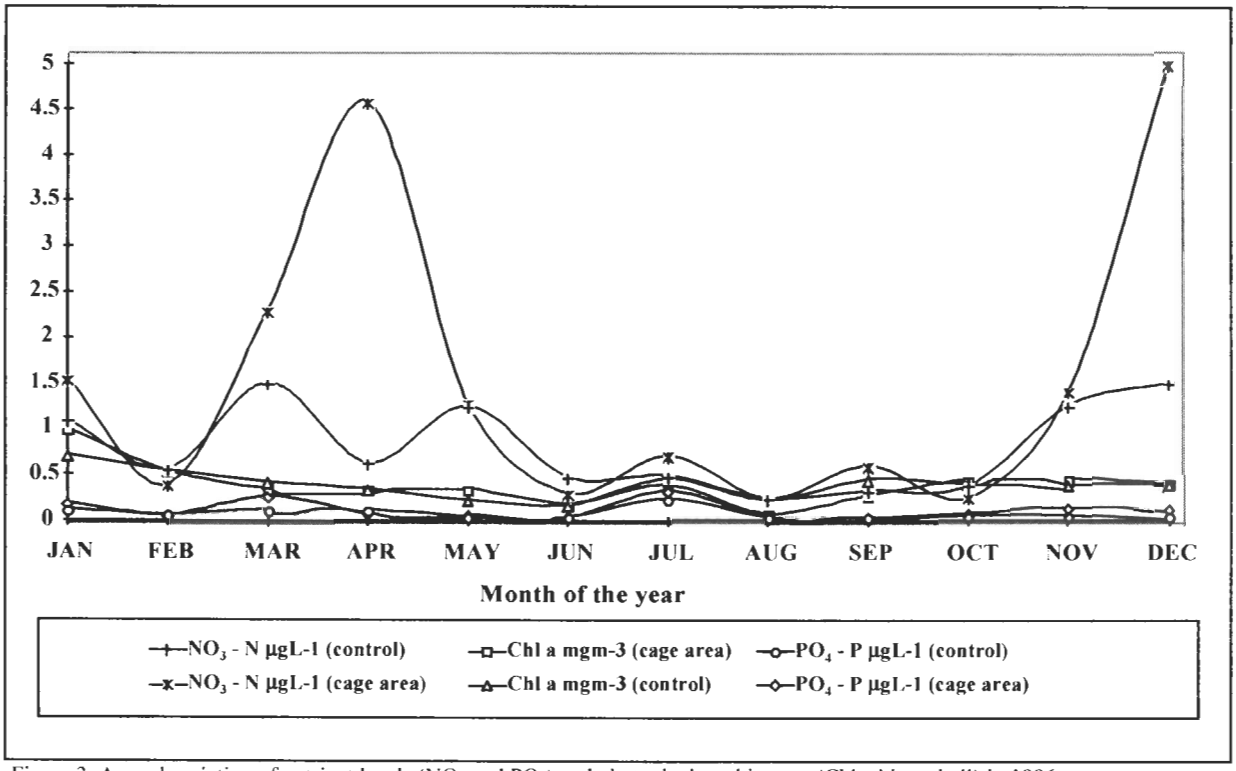

Figure 3. Annual variation of nutrient levels (NO_3 and PO_4) and phytoplankton biomass (Chl, chlorophyll) in 1996.

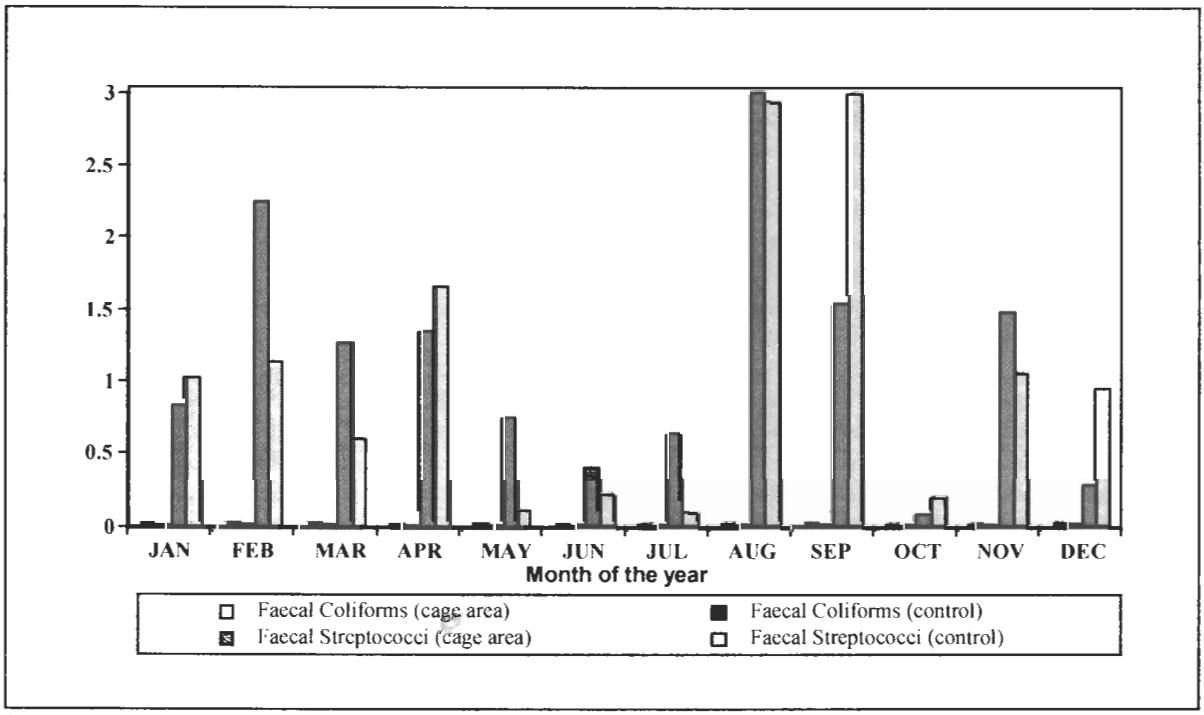

Figure 4. Average variation of faecal bacteria in 1996.

input of nutrients from fish farming activities are minimal. The latter, when combined with inputs of nitrogen and phosphorous compounds from terrestrial run-off and resuspension processes, never reach levels that may cause hypernutrification. This explains why no lower Secchi depths linked to an increase in phytoplankton biomass were recorded. The results of DO obtained during the winter confirm this observation. Therefore the low Secchi depths recorded during the winter months cannot be attributed to fish farming activities but to climatic conditions. In this study, no differences in Secchi depths were observed between control sites and cage areas during this study.

The main impact of fish farming activities on the environment is due to nutrient levels generated from fish feeds and fish excreta. An increase in the feeding regime and fish metabolism during the summer period might be correlated with higher levels of nitrate-nitrogen and DRP. Previously, results have shown that fluctuations in these