POLLUTION AND EUTROPHICATION IN THE VENICE LAGOON

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ABSTRACT

To reduce the effect of the "high water", which involves mainly the City of Venice, a project is underway to install barriers in the three port channels which connect the Venice lagoon to the Northern Adriatic Sea. To have a basis on which to gauge any observed effects in the water quality as a consequence of the reduction of the exchange of water between the lagoon and the open sea, a survey on the most polluted area of the lagoon was carried out over the period of a year. The following parameters were determined: pH, temperature, salinity, transparency, dissolved oxygen, ammoniacal nitrogen, orthophosphate, zinc and total coliforms. The results, compared to those obtained from previous studies, show that situation improved for ammoniacal nitrogen, zinc and coliforms and remained fairly constant for the other parameters. The inner zones of the lagoon are much more exposed to eutrophication as a consequence of a lower circulation of water and higher accumulation of nutrients. Release from sediments appears to play an important role in controlling the water quality in the shallow areas. Frequent algae blooms have been observed during spring and summer seasons. There is no evidence of an attenuation of eutrophic phenomena in recent years.

KEYWORDS

Venice lagoon; eutrophication; nutrients; zinc; coliforms.

INTRODUCTION

The Venice lagoon is a body of water covering 550 km² located on the western side of the Northern Adriatic Sea and in which the City of Venice is situated. The average depth of the lagoon is only 0.6 m and its longest point only 52 km long. The lagoon may be considered formed by three independent basins each of which is connected to the Adriatic Sea by a port channel. The exchange of water between the lagoon and the Adriatic Sea amounts to an average of 230·10⁹ m³/yr (Cossu and de Fraja Frangipane, 1985). The low rate of circulation of water within the lagoon and the pollution load it receives, tends to make the lagoon very susceptible to eutrophication.

In addition to these problems there also exists the "high water" phenomenon which affects the economic and social life of the region, particularly the City of Venice. The high waters are
caused by a combination of factors but principally a high natural tide, the interaction of the wind in South-North direction and natural oscillations in the Northern Adriatic. In this century conditions have worsened because of subsidence of the land under and around Venice and the rising sea level due to the melting of the polar ice caps. To reduce the effect of the "high water" a project is underway to install barriers in the three port channels which connect the lagoon to the open sea. These would be used to close off the lagoon in the event of an exceptionally high tide. Whilst considerably reducing the amount of flooding, the installation of such barriers will reduce the exchange of water between the lagoon and the Adriatic Sea. This could have an effect on the ecosystem and the water quality of the lagoon.

To assess the effect of installing these barriers it is necessary to have a basis on which to gauge any observed changes in the water quality or modifications in the ecosystem. To date, research on the Venice lagoon has been irregular, conducted using different sampling and analysis techniques on different areas of the lagoon over different periods of the year.

In this paper results are given of a survey on the central area of the lagoon carried out regularly over the period of a year. These results were compared to those obtained from other studies in order to ascertain trends in water quality of the lagoon in recent years.

METHODOLOGY

The Study Area

The survey was completed using 15 sampling points located in the central area of the lagoon with the emphasis on obtaining data on pollutants and nutrient concentrations (Figure 1).

![Fig. 1. Location of the sampling stations ("barene" are lands which are flooded only in high tide conditions)](https://iwaponline.com/wst/article-pdf/19/5-6/813/98553/813.pdf)

This central area of the lagoon was chosen as it receives sewage from the towns of Venice, Mestre and Porto Marghera (approximately 300,000 people), only partially treated, and wastewater from the petrochemical plants located in Porto Marghera. It also drains the surrounding 1850 km² of land on which numerous industrial estates and housing conurbations are located in addition to the areas of intensive farming (Cossu, de Fraja Frangipane et al., 1984). In addition to pollutants from these sources, airbourne pollutants, originating from nearby industry,
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A considerable quantity of nitrogen and phosphorus enters the lagoon in this way (Cossu and Giugliano, 1980)

Sampling

The sampling programme was carried out over the period 12.5.1984 to 18.3.1985. Every two months two complete sampling programmes were made within one or two days of each other - one at high tide, the other at low tide - and undertaken in such a manner that all 15 sampling points were monitored under similar tidal conditions. Altogether 12 sampling surveys were carried out during the survey period. At each point samples of water were taken at the surface and at half depth. Analyses were carried out to determine pH, temperature, salinity, and transparency and measure the concentration of dissolved oxygen, ammoniacal nitrogen, orthophosphate, zinc and total coliforms. Temperature was measured on site by means of reversing and bucket thermometers (± 0.1 °C) and transparency measured by means of a Secchi disc. Sub-surface samples were taken using Van Dorn bottles, and plastic buckets used for obtaining surface samples. All samples were filtered, stabilized and stored at 4 °C and taken to the laboratory for determination of the other parameters. All analysis was completed within 24 h of sampling.

Analytical Procedures

Salinity was determined by titration using silver nitrate and dissolved oxygen determined by the Winkler method. Concentrations of ammonia, orthophosphates and zinc were measured using standard methods (Strickland and Parson, 1972). Absorbance for the ammonia and phosphorus determinations was measured using a Perkin-Elmer 156 spectrophotometer and a Perkin-Elmer model 5000 with an HGA 500 graphite furnace was used for zinc analysis. Total coliforms were determined by membrane filtration with incubation at 44 °C using M-FC Agar.

RESULTS AND DISCUSSION

All experimental data are presented in table 1; a discussion on the findings for each parameter measured is given below:

Temperature and Salinity

Information on the temperature and salinity concentrations in the lagoon enables the amount of dispersion and dilution of waters discharged into the lagoon to be estimated and the degree of exchange with the Adriatic Sea to be assessed. The areas around the mouth of the port channels have the highest salinity values of around 35%. Towards the central zone of the lagoon this gradually reduces and reaches its lowest value near discharges of surface waters from the surrounding land (Dese, Sile and Osellino rivers). Stratification occurs because of the density difference of sea water and river water that flow into the lagoon. Seasonal variations in salinity show that the highest levels of salinity in the lagoon occur during the winter months, when water exchange with the sea is at its greatest, and in the summer months, when dilution from river waters is at its lowest.

Although temperature variations in the lagoon are principally dependant upon meteorological and climatic conditions it was found that the temperature of the lagoon was greatly influenced by tidal currents from the Adriatic Sea entering the lagoon. The effect was most marked during summer and winter but reduced during spring (March – April) and autumn (September – October) when isothermic conditions were found between the sea and the lagoon. A marked variation of temperature with depth was not found; differences were generally in the order of tenths of a degree centigrade and were thought to be due to stratification occurring because of salinity
### TABLE 1 Minimum, maximum and average ($\bar{x}$) of the experimental data.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
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<td>0.44</td>
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| $\text{DO, } \%_{\text{sat.}}$ | 56.8 | 73.7 | 67.2 | 80.0 | 64.2 | 55.3 | 67.5 | 21.3 | 23.8 | 78.9 | 34.4 | 57.9 | 62.0 | 72.9 | 64.8 |
| max        | 133.0 | 136.0 | 152.6 | 147.0 | 151.5 | 168.8 | 175.2 | 163.3 | 167.6 | 139.4 | 156.0 | 151.1 | 154.2 | 136.6 | 139.4 |
| min        | 95.6 | 106.9 | 114.6 | 116.3 | 120.8 | 112.5 | 113.5 | 117.0 | 122.0 | 115.1 | 100.3 | 123.7 | 120.3 | 112.2 | 111.0 |
| $\bar{x}$  | 25.9 | 25.2 | 29.6 | 28.4 | 29.9 | 35.5 | 45.7 | 45.0 | 41.5 | 25.7 | 44.3 | 33.6 | 29.8 | 23.9 | 35.1 |
| $\text{Salinity, } \%_{0}$ | 11.82 | 25.02 | 25.58 | 29.10 | 30.60 | 26.70 | 28.10 | 29.80 | 30.10 | 30.80 | 13.51 | 26.70 | 25.70 | 21.30 | 13.90 |
| max        | 35.12 | 36.95 | 35.12 | 36.90 | 36.24 | 34.30 | 35.40 | 35.90 | 36.11 | 34.10 | 33.28 | 33.50 | 32.50 | 32.50 | 32.50 |
| min        | 27.96 | 30.69 | 30.75 | 33.39 | 34.60 | 31.26 | 30.55 | 32.03 | 32.32 | 33.27 | 25.29 | 30.61 | 29.59 | 29.59 | 29.59 |
| $\bar{x}$  | 6.26 | 3.10 | 2.62 | 2.05 | 1.97 | 1.96 | 1.54 | 1.54 | 1.43 | 1.67 | 5.39 | 2.00 | 2.47 | 3.57 | 6.37 |
| $N-NH_4^+$ | 4.9 | 2.5 | 4.4 | 2.7 | 1.4 | 3.8 | 10.3 | 3.1 | 1.0 | 1.0 | 2.6 | 3.0 | 2.3 | 2.5 | 3.3 |
| $\mu$mol l$^{-1}$ | 117.6 | 97.5 | 64.6 | 29.1 | 18.6 | 62.8 | 64.0 | 31.3 | 31.1 | 27.1 | 79.0 | 32.8 | 17.7 | 28.3 | 60.6 |
| max        | 48.5 | 32.4 | 16.2 | 9.3 | 5.6 | 23.8 | 21.1 | 12.6 | 8.8 | 7.3 | 44.5 | 11.9 | 6.5 | 8.7 | 16.1 |
| $\bar{x}$  | 38.1 | 25.7 | 10.3 | 6.2 | 6.0 | 14.6 | 16.2 | 8.0 | 8.9 | 6.1 | 25.3 | 7.4 | 3.5 | 6.2 | 14.2 |
| $P-P_{PO_4}$ | 1.8 | >1.0 | >1.0 | >1.0 | >1.0 | 2.2 | >1.0 | >1.0 | >1.0 | >1.0 | 1.5 | >1.0 | >1.0 | >1.0 | >1.0 |
| $\mu$mol l$^{-1}$ | 19.7 | 12.9 | 5.3 | 3.5 | 2.4 | 17.6 | 9.2 | 3.9 | 3.8 | 2.2 | 17.5 | 5.0 | 2.1 | 3.1 | 4.6 |
| max        | 8.8 | 4.6 | 2.5 | 1.2 | 0.8 | 4.6 | 4.9 | 2.4 | 1.3 | 0.9 | 7.4 | 2.6 | 1.2 | 1.1 | 1.8 |
| $\bar{x}$  | 6.9 | 3.0 | 1.5 | 1.5 | 0.6 | 3.4 | 1.8 | 2.4 | 0.9 | 0.5 | 3.5 | 1.2 | 0.5 | 0.8 | 1.4 |
| $Zn, \text{ } \mu g l^{-1}$ | 4.3 | 6.6 | 3.5 | 2.1 | 0.1 | 5.3 | 4.3 | 1.8 | 0.5 | 0.1 | 4.3 | 1.8 | 0.9 | 0.1 | 0.9 |
| max        | 62.4 | 125.7 | 55.1 | 44.6 | 29.1 | 55.1 | 43.0 | 27.7 | 65.6 | 174.5 | 89.3 | 29.4 | 29.9 | 97.1 | 33.3 |
| $\bar{x}$  | 20.1 | 34.3 | 20.1 | 12.5 | 8.3 | 19.5 | 20.4 | 10.9 | 10.7 | 23.6 | 32.1 | 9.4 | 8.5 | 22.7 | 8.2 |
| $\sigma$   | 11.7 | 30.5 | 13.2 | 9.6 | 7.0 | 14.4 | 10.1 | 6.3 | 13.2 | 39.7 | 21.3 | 6.8 | 7.4 | 24.7 | 8.4 |
| $\text{Coli, } \text{ } b.u./100 ml$ | 476 | 249 | 121 | 25 | 27 | 167 | 139 | 208 | 80 | 40 | 375 | 165 | 68 | 46 | 100 |

**Nutrients and Eutrophic Parameters**

The concentrations of ammonia found at the various sampling points is shown in Figure 2. These differences. An example of typical temperature variations found at one of the sampling points is shown in Figure 5.
values have been compared - after graphic elaboration by the Authors - to those obtained from previous studies undertaken approximately 15 years ago (MLLPP, 1972). In 1962-64, the concentration of ammonia in the lagoon between the industrial areas and the City of Venice was very high, with average values of between 360 – 3700 μmole/l, the maximum levels being found in the canals flowing through the industrial areas (Tiso, 1966). The situation today, however, is that high levels of ammonia are only found in the body of water between Porto Marghera and the City of Venice. Outside this zone the concentration of ammonia rapidly diminishes. The reduction in these ammonia levels, particularly notable in the area near to Porto Marghera, is without doubt connected to the numerous preventive measures undertaken by industry in the area to minimise pollution by modifications to factory processes, wastewater treatment, etc. At the concentrations found in this study ammonia is not toxic but acts as a stimulant to eutrophic conditions.

Although levels of phosphorus in the lagoon were found not have changed over the last 15 years, significantly high concentrations of orthophosphate in the major part of the lagoon were confirmed by this study (Figure 3). Maximum concentrations were found in the body of water near San Giugliano (Sampling station 11), where numerous wastewater treatment plants from the Mestre area discharge. In shallow areas of the lagoon the levels of orthophosphate were generally found to be higher than in the channels or deep areas - opposite to the trend for ammonia. This is because of phosphorus release by sediments in the lagoon which has the greatest influence on phosphorus concentration (Cossu et al., 1984).

From the study on ammonia and phosphorus levels it is evident that accumulation of these nutrients in the lagoon is governed by the anthropogenic load, the exchange of lagoon water with sea water and low circulation of water in the inner zones of the lagoon.

The annual mean values of other parameters indicative of the eutrophic state of the lagoon, pH and transparency, are shown in Figure 4. Variation in the pH of the lagoon show that values around the channels connecting the lagoon to the open sea vary between 8.2 - 8.4, values typical
Fig. 3. Areal distribution of annual mean concentrations of orthophosphate in lagoon water in different periods (see caption of Figure 2)

Fig. 4. Areal distribution of pH and transparency (annual mean values)

of the Adriatic. In the inner zones fluctuations are larger. Values ranging from 7 to 9 were found in the area near Porto Marghera where effluents from some large industrial complexes discharge to the lagoon.
The transparency of the lagoon water was also found to vary significantly, from 0.5m, close to the mainland and near the mouths of the larger rivers, to 2.5m near the channels connecting the lagoon to the Adriatic. Wide fluctuations of dissolved oxygen have been observed (Tab. 1) in connection with the cycle of the eutrophic phenomena.

The seasonal variations of nutrients and eutrophic parameters are depending mainly on the biocycle (assimilation and regeneration processes). Discharges of pollutants into the lagoon are also linked to a seasonal cycle. Domestic discharges are greater during the summer months (tourist season) than during the winter months. Similarly seasonal variations may be observed in surface water run-off, (Cossu and de Fraja Frangipane, 1985).

To illustrate the seasonal variations observed during the survey, data obtained from sampling point 8 are shown in Figure 5, for different situations of tide and depth. The sampling point 8 is located in an area (South of Venice) where frequent macrophyte blooms are observed (Figure 6).

The analytical data show the occurrence of peak assimilation process, with super-saturation of oxygen and ammoniacal nitrogen depletion. The small variation of orthophosphate concentration observed is thought to be because the uptake of phosphorus by algae is compensated by the release of phosphorus from sediments (Cossu et al., 1984, 1985).

From the experimental data and from other surveys (Cossu and de Fraja Frangipane, 1985) there is no evidence of an attenuation of the eutrophic phenomena in recent years. This is thought to be because of several reasons: accumulation of nutrients in sediments, increasing eutrophic effect of the ammoniacal nitrogen which in the past was present at toxic level for algae growth, production of phytostimulating substances by biological wastewater treatment plants discharging in areas with low water circulation (Giaccone, 1985).

**Zinc**

From studies on heavy metals in the sediments of the Venice lagoon (Degobbis and Pavoni, 1985) zinc has been shown to be the best heavy metal to use as a tracer of the pollution deriving from industries in the Porto Marghera area. From data collected during 1976-77 (Tecneco, 1978) and 1984-85 (This study) it can be shown that there has been an improvement in the situation. There are now fewer areas which have concentration above 40 μg/l and they are strictly located around the industrial zone.

**Coliforms**

Microorganisms of faecal origin are a good indicator of pollution from domestic origin. It was found that coliform levels have reduced over the last 20 years. Counts of 10 000 b.u./100 ml were reported to have been found in samples of water taken from the lagoon near densely populated areas in 1968 (Majori et al., 1969). On samples of water taken from the same area during this survey counts varying between 500 - 4000 b.u./100 ml were found, with lower values in high tide conditions, indicating a considerable reduction in bacterial pollution.

**CONCLUSIONS**

The Venice lagoon presents environmental problems linked to a heavy load of nutrients and pollutants of anthropogenic origin (domestic and industrial wastewaters, agricultural run-off, atmospheric fall-out). The relatively low exchange of water between the lagoon and the open sea, the low circulation of water in the inner parts of the lagoon, the shallow water column, favour high accumulation of nutrients and pollutants in the lagoon water. The results of this survey however show an improvement in the situation in the recent years. This is more evident
Fig. 5. Seasonal variations of different parameters at sampling point B (see Figure 1) - HT, LT = high and low tide; s = surface; d = half depth.
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Fig. 6. TM (Thematic Mapper) image of the Venice lagoon from the satellite Landsat 5, 3.7.1985 (Alberotanza and Bergamasco, 1985) - Reflectance of lagoon water is represented - The white spot to the South of Venice was due to an algae bloom.

for parameters such as ammonia, zinc and total coliforms, and reflects the effects of the measures undertaken by industry and municipality to minimize pollution (modification to factory processes, wastewater treatment plants, etc.). Nevertheless there is no evidence of an attenuation of eutrophic phenomena and frequent algae blooms are observed. This is thought to be because of accumulation of nutrients in sediments and, paradoxically, reduction of ammonia concentration below toxic levels and production of stimulating algae growth substances by biological wastewater treatment plants. Due to this last reason diverting of treated effluents outside the Venice lagoon is being taken into consideration. The most critical conditions for eutrophication occur during spring and summer seasons when the load of nutrients is higher, the exchange of water with the open sea is lower and light and temperature are favourable for biological assimilation of nutrients. In the same period release from sediments plays an important role, particularly in controlling the phosphorus concentration in the shallow water areas.

This study represents the first attempt to interpret the state of pollution within the lagoon as a basis on which to gauge modifications in the water quality as a consequence of the installation of barriers in the three port channels. On the basis of this study an annual research programme has been defined. This includes a sampling and analysis programme at the mouth of each of the three channels and at various defined points throughout the lagoon with the aim of producing a system on which changes of water quality can be regularly monitored. A mathematical model will be developed to enable water quality forecasts to be made.
ACKNOWLEDGEMENT

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REFERENCES


