ASSESSMENT OF WATER QUALITY STATUS IN THE COASTAL AREA CLOSE TO THE LAGOON OF VENICE. FIRST YEAR OF ACTIVITY

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Abstract.

In this manuscript we describe major results of the first year of activities of CORILA project 3.13. The project aims to contribute to the assessment of water quality status in the coastal area that is connected to the lagoon and to a deeper understanding of the interaction between the lagoon of Venice and this coastal area.

The main goal is to synthesize and integrate results coming from different research projects and monitoring activities, so to eventually provide ‘typical condition’ and scales of variability for the area.

Here we illustrate how we constructed the project data set, by collation, comparison and check, of different data sets, and we present results of first elaborations.

1. Introduction.

Venice is one the most studied sites in the world, but up to few years ago most of the projects consisted in individual researches, and there was a lack in concerted basin-wide efforts, as well as in attempts to integrate existing knowledge in a common frame and from a systemic viewpoint.
This research aims at partially filling this gap, by providing a contribution to the assessment of water quality status in the coastal area that is connected to the lagoon, and to a deeper understanding of the interaction between the lagoon of Venice and this coastal area. The research will result as an important piece of information in the analysis of the integrated system composed by the drainage basin, the lagoon and the coastal area, and might provide interesting indications of the role played by lagoon systems in buffering impacts of drainage basin on coastal sea. Results will also provide a contribution to management of coastal area by local authorities.

Main goal is to synthesize and integrate results coming from different research projects and monitoring activities. Historical data referring to the coastal area will be collected in a common database, and a retrospective analysis will be performed in order to identify ‘typical condition’ of the area, as well as typical variability around it, also depending on space (distance from tributaries and/or lagoon inlets) and tie of the year. Analysis of long term trends will be performed too.

The emerging picture will be confronted with those of similar ecosystems, and discussed also with reference to existing legislation and to indexes proposed in scientific literature to assess water quality or status. This should give some elements to local authorities too, about water quality standards and maximum permissible load to be enforced in future regulation.

Indeed, local authorities are active participants of the project, through their technical chapters that are in charge of monitoring water quality parameters in coastal area.

Finally we’ll consider the possibility to evaluate an integrated biogeochemical budget of the Lagoon-coastal system.

In this manuscript we resume the first year of activities, which consisted mainly in the identification of the project data set, by collation, comparison and check, of different data sets, and in a first characterization of scale of variabilities for major parameters.

2. Identification of the Data Set.

The dataset is composed of two main parts: the first one was collected by ARPAV (regional agency for environmental prevention and protection in Veneto) and contains data about the coastal area within 3 nautical mile from the coastline, lasting from 1985 until now, Fig. 1a, while the second part is relative to off shore data of the North Adriatic Sea, starting from the beginning of the last century, Fig. 1b.

In the present paper we focus on the second dataset that consists of a large collection of published and unpublished data, 113,986 records, covering the area of the Northern Adriatic Sea comprised between 44° 30’ and 45° 45’ of latitude and 12° 18’ and 13° 56’ of longitude. The oldest datasets were collated in the ATOS dataset, spanning from 1911 to 1980 (Russo et al., 2002), then from 1990 to 1994 data were collected in the frame of a monitoring project named “Progetto Alto Adriatico”. Other data come from the PRISMA II project for the period 1995-1998 and the most recent data, from 1999 to 2001, were gathered in the frame of Interreg II project.

Only surface data, the first measurement of each cast profile but above the depth of 2 meters, were considered in the present dataset. Then, the resulting dataset comprises a total of 6322 casts that are distributed all over the basin, Fig. 1b. The density of casts
increases along few transects, while the areas less covered are the Croatian coast and the area in front of the Grado-Marano lagoon.

The list of variables includes physical parameter as temperature, salinity, dissolved oxygen, pH and Secchi disk, and six trophic parameters: as nitrate, nitrite, ammonia, phosphate, silicate, chlorophyll a.

Fig. 1a, b. Casts location map for the two parts of the dataset: a) coastal dataset, b) off-shore dataset.

3. Modelling circulation in the coastal area

Understanding the circulation pattern in the coastal area facilitates the interpretation of the spatial distribution of dissolved substances, as well as the set up of an integrated biogeochemical budget of the Lagoon-coastal system. For this reason a primitive equation, three-dimensional finite element model will be applied to the area, to simulate and investigate the current field. Presently the model is being tested, after the introduction of a better parameterization of baroclinic pressure gradients into the conservation momentum equations [Cucco and Umgiesser, 2004; Bellafiore, 2005], and implementation of boundary conditions [Bellafiore and Umgiesser, 2005 this issue]
4. Analysis of the dataset and assessment of the scales of variabilities

4.1 Numerical abundance and spatial coverage of the dataset

The annual and monthly distributions of the number of casts are presented respectively in Figs. 3a and 3b. The dataset includes historical data from the period 1911-1916, but the number of samples is relevant only after 1971, and only after 1986 it is homogenously high. During the last decade, at least 250 casts per year were collected, except during 1991 and 1997, when only 178 and 140 were gathered. The ‘richest’ year is 1993, with about 600 casts, but also in years 1987, 1992 and 2001 there are more than 400 data. Most of the data were collected during spring and summer months, with usually more than 600 casts per month, while January, with less than 200 casts, is the less rich month, Fig. 3b.
Fig. 3a, b: annual and monthly cast distributions.

Fig. 3 shows that the availability of data varies greatly from year to year and from month to month, but also the spatial distribution of casts varies greatly from a period to another period. As an example, Fig. 4, underlines well the differences in spatial distribution and data coverage in casts collected during summers 1976 and 2001, as a result of different sampling strategies adopted in different studies. Furthermore, coverage varies from month to month, and it is quite poor if a temporal interval shorter than one year is considered. The consequence is that, in order to get a reasonably homogeneous coverage both in space and in time, one needs to aggregate the data over longer temporal window, to be selected on the basis of abundance of data during the years, Fig 3, and temporal evolution of some selected variables, Fig. 5.

Fig. 3 shows that a continuous dataset could be constructed with data down to 1986, even if 1986 and 1988 have less than 130 casts. The graphics of fig.5 indicate that during this period no trend is clearly detectable from time evolutions of statistical indexes which describe the frequency distribution of data. However, we decided to consider data starting from 1990, when the PPA project started, since from then there should be a standardization of sampling and analysis methodologies.

Therefore data of the period 1990-2001 had been aggregated and analysed as a homogeneous pool of data for calculating the reference annual mean and the reference seasonal evolution for the variables. As a result of the selection, the analysed dataset consists of 4007 casts, and since the number of data depends on the variable, the present dataset contains almost 4000 observations for salinity, temperature and density, but less than 800 observations for nutrients and chlorophyll, Tab.1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>3979</td>
</tr>
<tr>
<td>salinity</td>
<td>3996</td>
</tr>
<tr>
<td>Density</td>
<td>3977</td>
</tr>
<tr>
<td>Nitrate</td>
<td>689</td>
</tr>
<tr>
<td>Phosphate</td>
<td>709</td>
</tr>
<tr>
<td>Silicate</td>
<td>726</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>522</td>
</tr>
</tbody>
</table>

Tab.1: number of valid observations in the 1990-2001 dataset for each variable.
Fig. 4: spatial distribution of casts collected during summer of 2001 (DX) and of 1978 (SX).

Fig. 5: evolutions of box-plot of the annual distribution of data over the whole basin for temperature (Temp), salinity (Sal), nitrate (no3), phosphate (po4), silicate (sio4) and chlorophyll (chl). Each box-plot reports the median (black dot), the mean (empty diamond), the interquartile range (box) and the range min-max (vertical black bar) of the distribution of all the data collected in the study area during each year from 1961 to 2001.
Data were aggregated spatially, too, in order to provide a homogeneous base for geostatistical analysis. The Northern Adriatic Sea domain was subdivided in a grid of 5x5 km, as in Fig. 6, and casts which fallen in each of the bins pooled. This size of the grid enable one to get a minim number of data in each ‘active’ bin, and therefore a ‘robust’ data set, while preserving the possibility to observe spatial variability. Of course there are bins in which no data are present, as illustrated in fig. 6 and fig. 7, in which coverage and abundance for respectively salinity and nitrate are illustrated, as proxies for database consistence of physical and trophic parameters.

The analysis of the 4 maps of Fig. 6 and 7 makes clear that most of salinity data is collected along 3 meridian and 4 parallel transects and that the area in front of the Po delta has the greatest number of data. Spatial coverage of nitrate data is quite poor when compared to the one of physical variables. Three transects are detectable, and again the area in front of Po delta is the most sampled one.

Fig. 6: number of salinity data in each cell of the grid of 5km for the four seasons (winter, spring, summer and fall) of the 1990-2001 data.
4.2 Spatial distribution and seasonal variability

A first representation of spatial distribution of water quality parameters can be obtained by plotting the median of the observations falling within each bin. Examples for seasonal sea surface distribution salinity and nitrate are given in the maps of Fig. 8 and 9 respectively. Cells without data are blanked in the maps. The median was preferred to the mean because it is a more robust statistical index when the distribution of the data is not normal.

Maps of salinity show the presence of a gradient from the coast to off shore mainly due to rivers runoff during all the four seasons. The area in front of Po river presents the most marked gradient, but the signature of other rivers are also recognizable. In fact, low salinity values are visible in the area close to the Isonzo, in the gulf of Trieste, mainly in fall, and in the most coastal cells close to Tagliamento, Livenza and Adige-Brenta rivers.

Fig. 7: number of nitrate data in each cell of the grid of 5km grid for the four seasons (winter, spring, summer and fall) of the 1990-2001 data.
Fig. 8: seasonal sea surface salinity distribution; the value of each cell was calculated as the median of the 1990–2001 data.

The number of bins without data, blanked in the figure, is higher when considering maps of nitrate, fig.9, and therefore spatial patterns of nutrient concentration are harder to identify. Nevertheless, the influence of nutrient input from the Po river (higher concentration) is clearly visible in all the four seasons, and the impact of other rivers can be recognized from season to season: Isonzo on the right end of coastline in the map of fall, the Adige-Brenta at the left of the Venice lagoon during all the season, and the Piave and Livenza at the right of Venice lagoon in the summer and fall maps.
Results depicted in fig. 8 and 9 can be used also for assessing scale of spatial variability over the whole basin. In particular, for each of the seasons it is possible to compute a measure of dispersion, as the ratio between half of interquartile range and the median value of the distribution of bin values.

The comparison among spatial variability in the different seasons is presented in Fig. 10 for 13 variables. The figure puts in evidence that the variability of trophic variables (right panel in the graph, right axis) can be twice as great as the variability of physical variables (left panel, left axis). In particular variability of nutrients and chlorophyll is always higher than 50% and can reach values up to 250%, while the variability of physical parameters, is always less than 10%, with the noticeable exception Secchi disk.

The variability of all the nutrients, except NO2, is maximum during fall due to the gradients induced by river input, while the highest variability for chlorophyll is observed during spring. This compare well with analysis of monthly Po river runoff in the period 1988-1999 (Russo et al., 2002), which shows that the maximum outflow occurs in October and November. Spatial variability of temperature is instead maximum
during winter and spring, when heat flux and intrusion of southern water mass generate the highest spatial gradients.

4.3 Spatial interpolation of gridded data

Spatial distribution of median values such as the ones reported in fig. 8 and 9 can be spatially interpolated, in order to provide more intuitive representation of the field. Different geostatistical methodologies are available for this elaboration, including kriging, objective analysis, and gridding techniques.

As an example of possible result, and a first attempt on spatial interpolation of data, we have utilized ordinary kriging in the present application. This is an interpolation procedure that generates an estimated surface from a scattered set of points with z values, basing on the assumption that the spatial variation in the phenomenon represented by the z values is statistically homogeneous throughout the surface; that is, the same pattern of variation can be observed at all locations on the surface (regionalized variable theory). The spatial variation is quantified by the semi-variogram, that is estimated by the sample semi-variogram, in turn computed from the input point data set by fitting a theoretical function. Confidence (error bands) in the interpolation can be quantified.

Here we present interpolation performed using ordinary kriging algorithms. The parameter needed in the interpolation were set, after some numerical experiments, as in tables 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Salinity</th>
<th>nitrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>lag</td>
<td>10 km</td>
<td>20 km in winter, 10 km in the other seasons</td>
</tr>
<tr>
<td>semi-variance model</td>
<td>Gaussian</td>
<td>exponential</td>
</tr>
<tr>
<td>Search radius</td>
<td>50 km</td>
<td>50 km</td>
</tr>
<tr>
<td>Minimum number of data</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Tab. 2: values of kriging parameters for salinity and nitrate.
The figures 11 and 12 show the estimated surfaces of salinity and nitrate seasonal data and the uncertainty associated with the data. The spatial patterns roughly evidenced in the discrete maps of Fig. 9 and 10 are clearly visible in the interpolated ones (figures 11 and 12).

Contours lines superimposed to the property field give a measure of uncertainty. It is easy to see that the estimations of salinity maps is more reliable than that ones of nitrate. In fact, the uncertainty values associated with the salinity data are much lower than the salinity values; whereas the uncertainty values associated with nitrate data often exceed data themselves. This is due to the better coverage of salinity data with respect to that of nitrate data and to the much lower variability range of salinity data compared to that of nitrate data.

Fig. 11: kriging of the seasonal salinity distribution for 1990-2001 data. The maps report the uncertainty associated to the reconstructed fields, (red line contour).
Fig. 12: kriging of the seasonal nitrate distribution for 1990-2001 data. The maps report the uncertainty associated to the reconstructed fields, (blue line contour).

References.

Bellafiore, 2005. Tesi di laurea Università di Padova