The Geographic Information System of Grado and Marano lagoon as an integrated management tool

Alfredo Altobelli, Irene Ortolan

In the framework of INTERREG III B CADSES project "TWReferenceNet, Management and sustainable development of protected transitional waters" (Project number: 3B073, 2004-2006) Work Package 1, the department of Biology of the university of Trieste has carried out the following actions:
a) collection and creation of a database with all possible data on chemical-physical characteristics of the Grado and Marano lagoon and on the anthropic pressures present in the lagoon and in the drainage basin,
b) creation of a Geographic Information System that includes all georeferred information on the lagoon and its drainage basin, so that this information can be used for spatial analyses that can give more information,
c) use of Remote Sensing to collect and analyse data on the lagoon,
d) vulnerability analysis of transitional waters and of Ramsar sites.
The study area includes both Grado and Marano lagoon and its drainage basin. In fact, a wider area included between Tagliamento and Isonzo river has been considered, as the information on the anthropic pressures were collected on a Municipality base, even if a Municipality was only partially included in the drainage basin (fig.1 - Grado and Marano lagoon system).
The Grado and Marano lagoonal system is located in Northern Adriatic, at the easternward part there is the Isonzo river, at the westward part the Tagliamento river, southern there is a littoral belt formed by islets of variable stability, and northern there is the coast line, developed irregularly for about 60 km. The area extension is of 16.000 ha, the length is nearly 32 km and the width 5 km (Brambati, 1969).
The distinction between Grado and Marano lagoon derives from the administrative subdivision done between 1866 and 1917, where Marano lagoon belonged to Italy and Grado lagoon to Austria.

Origins and evolution

The origins of Grado and Marano lagoon, with its current features, are rather recent. They date back to the Roman period and in particular to IV-VI century, period in which the lagoon system started to take shape.
The factors that have mainly affected the Grado and Marano lagoon formation seem to be: a sea-level increase of about 2 m in the last 2000 years, the variation of the superficial water network, the influx of Natisone into Isonzo river, the movement of Isonzo river mouth eastwards, the seaward movement of Isonzo and Tagliamento rivers, the constant migration of Isonzo sediments westwards (Brambati, 1992).

A lagoon environment is not a stable system, it is rather dynamic, that is it undergoes to a continuous natural evolution. Until the last century, in Grado and Marano lagoon system the human influence has been scarce. However, in recent years human intervention has caused a change in the spontaneous evolutionary trend. Broadly speaking, the main interventions have been (Gatto & Marocco, 1992):

- *the reclamation of the lagoon surrounding areas;*
- *the embankement of the lagoon borders associated to the reclamation;*
- *the construction of a channel, the «Litoranea Veneta», that cuts the lagoon from the west to the east,*
- *the blockage and regulation of lagoon mouths.*

Morphology, hydrology

From a morphological point of view, the lagoon can be subdivided into three areas (Brambati, 1969):

- *areas above the average high tide level: littoral belts, saltmarshes, coast;*
- *areas between the average high and low tide level: tidal flats, secondary channels;*
- *areas below the average low tide level: main channels, lagoon mouths.*

The littoral belt, element of separation between lagoon and marine environment, is developed for about 20 km, and it is interrupted in six main points by the lagoon mouths. The main features are the islands of Martignano, S. Andrea, Buso, Morgo, Grado and the banks d'Orio and Mula di Muggia. A saltmarsh is any area included within the lagoon and higher than the high tide level. In Grado and Marano lagoon there are two main saltmarsh systems: the first one goes from Martignano island to Marano Lagunare, the second one startes from Morgo island. Furthermore, a good development of saltmarsh areas is recorded in the easternmost part of Grado compartment.

The tidal flats are areas characterised by reduced slopes and by the presence of channels of different depth. The main channels are deeper than 1 m, the secondary channels are as deep as the average low tides, the 'ghebi' are even more shallow.

According to its hydrography, Grado and Marano lagoon can be subdivided into six basins (Dorigo, 1965). In particular, moving westwards, there are the basins of Primero, Grado, Morgo, Porto Buso, S.Andrea and Lignano. They are hydraulically isolated from each other and they receive and discharge the waters from their lagoon mouth and water branches.

In the watershed of Marano and Grado lagoon there are the following updwelling rivers, moving eastwards: Stella, Turgnano, Cormor, Zellina, Corno, Aussa and Natissa. Along the inner lagoon coast there are several artificial channels that gather the waters from the reclaimed areas.

General features of Grado Marano lagoon

Lagoon Surface (km²)	*160*
Drainage basin Area (km²)	*1883*
Lenght of river system (km)	*743*
River carrying capacity m³/s	*77*
Average temperature in 2004 (°C)	*15.23*
Average salinity in 2004 (‰)	*22.44*
Average pH in 2004	*7.95*

GIS as an investigation tool of lagoon features

The main objectives of the work carried out within the TWReferenceNet project, that dealt with gathering and analysing data on the study area in order to create an exhaustive database, are:

1. to identify the potential pollution sources in Grado and Marano lagoon;

2. to gather data on water and sediment pollution, embanking them in the GIS for further analysis;

3. to gather data on contamination of the lagoon biotic component, embanking them in the GIS for further analysis.

The first step was to sort out all existing data and to gather the missing ones. Currently at the department of Biology are available both raster and vectorial data that have been embanked in the GIS and not georeferenced data.

RASTER DATA

- *Numeric Regional Map in scale 1:25.000;*
- *Numeric Technical Regional Map in scale 1:5.000;*
- *Landsat 5 TM satelite images belonging to scene 191/28 of the following periods: 29/08/1990, • 26/07/1995, 17/09/1997, 15/05/1998, 25/09/2000, 26/07/2001;*
- *Maps of soil coverage for the Regional flatlands obtained from a supervised classification of Landsat satelite images of the years 1998 and 2000 (Ortolan, 2003);*
- *Aster satelite images acquired on 11/09/2001 and 08/03/2002;*
- *Aisa Eagle sensor hyperspectral images (OGS-HELICA) of 2005;*
- *Digital model of the land with 25m-resolution (derived from the interpolation of isolines from the Numeric Regional Map in scale 1:25.000) and with a resolution of 20 m provided by IGM;*
- *Maps of slopes and geological features from DTM;*
- *Orthophotos from the years 2000 and 2003;*

VECTORIAL THEMATIC MAPS

- *Maps of administrative units (provinces, municipalities), of hurban areas, of viability and rivers;*
- *Map of the landscape units of Friuli Venezia Giulia (Cordara, 1994);*
- *Map of potential vegetation of Friuli Venezia Giulia (Gallizia Vuerich et al., 2001);*
- *Geolithological map in scale 1:500.000;*
- *Map of SAC and SPA in Friuli Venezia Giulia;*
- *Corine Land Cover Map of Friuli Venezia Giulia a scala 1:100.000 (1990 e 2000);*
- *Map of ecological systems of Veneto and Friuli Venezia Giulia in scale 1:250.000 (Project "Chart of Nature", APAT);*
- *Map of habitats of Friuli Venezia Giulia Region in scale 1:50.000 (Project "Chart of Nature", not completed, provided by VIA Service of Friuli Venezia Giulia Region).*

THEMATIC MAPS OBTAINED FROM ISTAT DATA (2001 CENSUS)

For each municipality included in the study area the following maps have been obtained:

- *population density;*
- *total and used agricultural coverage, industrial coverage;*
- *surface devoted to annual cultivation (different types of cereals, ecc.), perennial cultivation (vineyards,*

fruit plantations, tree plantations), stable meadows;
• number and total coverage of agricultural farms for each municipality, with identification of the different categories;
• number of bovines, pigs, chickens, etc for each municipality;
• number of employed in each of the categories included in the census agriculture, industry, tourism, etc.

MAPS DERIVING FROM DATA OBTAINED
FROM COMMISSARIO DELLA LAGUNA AND ARPA FVG

• Map and database of the stations for the analysis of heavy metal bioaccumulation in three mollusc species (lagoon characterization has been carried out by ICRAM, fieldwork and analysis was carried out by Nautilus s.r.l. from Vibo Valentia);
• Map and database of the stations for the analysis of sediments at different depths, investigating the presence of heavy metals, pesticides, oils, PCB, IPA, TBT and other toxic elements (lagoon characterization has been carried out by ICRAM, fieldwork and analysis was carried out by Nautilus s.r.l. from Vibo Valentia);
• Map and database of the stations for the analysis of waters (data from ARPA FVG for the years 1987, 1988, 1989, 1993, 1994 and from 2000);
• Maps of temperature, salinity, pH, oxigen and nutrient concentration (total nitrogen and phosphorous, nitrate, nitrite, ammonium, phosphate) for Grado and Marano lagoon obtained from the interpolation of ARPA FVG data;
• Total nitrogen load (AE/kmq) for municipality (ARPA FVG, 2001);
• River nitrogen load (t/y) for municipality (ARPA FVG, 2001).

FURTHER VECTORIAL THEMATIC MAPS ON THE LAGOON AND ITS DRAINAGE BASIN

• Map of sediments (Brambati, 1996);
• Map of channels (Brambati, 1996);
• Map of basins and currents in the lagoon at high and low tide (Brambati, 1996);
• Map of Hg distribution in the lagoon (Marocco, 1995);
• Map of benthic invertebrates (Orel et al., unpublished, deriving from fieldwork carried out in: 1993-94-95-98 and 2004-2005);
• Fish-eating bird species abundance in focal areas along the lagoon (Sponza et al., 2005, inedito);
• Map of vegetation in lagoon and surrounding areas (Ciriaco & Spoto, 1998, unpublished – modified from Simonetti, 1992);
• Map of the environments of Grado and Marano lagoon in 1990 (Spoto et al., Rapporto Modulo 3 in “Integrated Management of Wetlands”, 1992).
• Map of industries in the Aussa-Corno area and database with available information on pollutants.

NOT GEOREFERRED DATA

• Temperature and rains;
• Map of soil in scale 1:50.000 of Friuli Venezia Giulia flatlands and hills around Tagliamento river (Comel et al., 1982);
• Map of soil in scale 1:100.000 included in ERSA publication: “Suoli e paesaggi del Friuli Venezia Giulia.
1. Pianura e colline del Pordenonese.” (Michelutti et al., 2003);
• Number of tourists in the most important areas bordering the lagoon;
• Number of boats in the touristic harbours;

• Number of inhabitants associated to water purifying plants in lagoon drainage basin;
• Ylenia Viso, 2004. Meccanismi di trasporto e dispersione del mercurio di provenienza isontina nel Golfo di Trieste. Tesi di laurea, Dipartimento di Scienze Geologiche, Ambientali e Marine, Università di Trieste.
During data mining the following main problems were detected:
1. the detail of information,
2. the updating of data,
3. the standardization of sampling methods (where, when, why).

The available maps that have been included in the GIS have often a low resolution (1:50.000, or in the best cases 1:25.000), whereas it would be good to have 1:10.000 maps to obtain more information on the lagoon and analyse in detail its biological characteristics and habitats.
The data should be constantly updated, but in this case in continuum monitoring is required. Such monitoring is carried out only by ARPA FVG in specific lagoon stations and only on water characteristics. To be more useful, such data should be extrapolated to the entire lagoon, so that for instance the monthly, seasonal and annual trends of temperature and salinity, or of nitrate and phosphate, can be evidentiated. It would also be good to obtain information on other indicators, such as BOD, COD, etc, that are only seldom gathered by ARPA FVG, and also to carry out regular biomonitoring on specific bioindicators.
Another basic factor is the standardization of sampling methods. In particular, the stations should be distributed along a regular network over the entire lagoon, and not only in channels. In this way the data could be extrapolated to describe the lagoon state in the correct way.
The biggest problem faced during data mining was to find and gather all avaliable data. Indeed, even if they were public data, in many cases it was hard to obtain them. A good way to solve this problem could be the centralization of data gathering and management for the lagoon and drainage basin (for instance by Friuli Venezia Giulia Region). The best option would be to gather all data in a single 'site' and to facilitate their access (putting them on the web if possible), similarly to what has been done for the Venice lagoon.

Case studies presented at Grado Workshop

In the framework of Grado workshop, three case studies focused on the lagoon and its drainage basin have been presented. In all cases the use of GIS and/or Remote Sensing has been of vital importance to obtain some results from the existing data:
1. The integrated assessment of Grado and Marano lagoon drainage basin, in order to identify the municipalities more at risk of groundwater pollution due to nitrogen used in agriculture (aim: development of alternative scenarios to reduce environmental impact of agriculture);
2. Use of available data on sediments and bioaccumulation to evaluate the effects of industrial pollution on Grado and Marano lagoon;
3. Use of Remote Sensing to extrapolate information on seagrass bed distribution in Grado lagoon.

To focus on the problem of human impacts on lagoon ecosystems, the DPSIR model suggested by the European Environmental Agency was used, were:

D = Driving forces,
P = Pressures,
S = State,

I = Impacts,
R = Responses;

the different indicators for each category are described as:
Driving forces: human activities that have an impact on the environment (transport, industry, agriculture, etc)
Indicators of pressures: pressures are all factors created by the different productive sectors. For instance, the number of mines that extract mercury or industries that use mercury in their productive processes.
Indicators of state: the modifications of the state of the environment are mainly related to the air, water and soil quality, and the changes in grade of naturality. For instance the level of mercury in sediments, the bioavailability of mercury.
Indicators of impact: these modifications can have some impacts on man and ecosystem. Heavy metals bioaccumulated in bivalves.
Indicators of response: The responses are the interventions that are done to restore the environment or in any case to limit its degradation. For instance the National Program of restoration of polluted sites, the definition of SACs and SPAs, the Ramsar Convention.

First case study: Integrated assessment of Grado and Marano lagoon drainage basin to identify the municipalities at higher groundwater pollution risk caused by nitrogen used in agriculture (final aim: development of alternative scenarios to reduce the environmental impact of agricultural sources in lagoon)

This case study has been developed in the framework of the project CADSES IIIB "ISOTEIA": Integrated System for the promotion of Territorial / Environmental Impact Assessment in the framework of spatial planning (3B093), of which the Department of Biology of the University of Trieste is partner. The aim of our project was to develop a method that allows to assess and solve the environmental problems caused by agricultural pollution, and we have applied this method to the case of Grado and Marano lagoon.

The method developed gives an integrated assessment of both the drainage basin and the lagoon, as this is a multifunctional and complex ecosystem. Despite being partially protected by the Ramsar convention, the lagoon is strongly polluted by several sources deriving from agriculture, industry, transport, tourism, aquaculture. Part of the lagoon and its drainage basin has been declared Polluted Site of National Interest (SIN) (D.M. 468/2001). This work analyses alternative solutions to reduce the environmental impact from agricultural sources. The topic has been examined and analysed with an interdisciplinary ecological-economic approach: the study was focused on the threat deriving from hyper-eutrophication of transitional waters caused by nitrates and phosphates.

To formulate hypotheses of alternative management policies a decision support system was used, in order to assess the reliableness of different agronomic systems in terms of ecological/economic sustainability, and a spatial DSS was created to analyse the spatial distribution of alternative systems and their efficiency in reducing nitrogen input.

General indications have been given to the public administration to decide where environmental protection measures should be applied (for instance the reduction of nitrate input) and the correct public fundings. This work could give good indications for the development of the Regional Rural Development Plan (2007-2013). This is the first time that this methodology is used in Friuli Venezia Giulia. The scenarios have been developed with the aim of reducing the total nitrogen percolation in lagoon from the areas characterised by intensive agriculture. The 'zero option', that is the maintenance of the current state of cultivated lands, is compared to the possibility of converting part of the main coltures in alternative coltures, that can be used for the production of biomass and energy. Taking into account the real pollution risk, it has been hypothesised to reduce the surface devoted to 'cash crops' (corn, soy, beetroot) with a surface percentage (5, 10, 25, 50% depending on the risk class) to be used for the cultivation of poplar, stable meadow or reedbed Arundo donax.

The methodology was based on the development of a DSS and a SDSS and has followed the following steps:

- *acquisition and elaboration of basic GIS layers for the study area;*
- *standardization of the factors taken into account;*
- *elaboration of risk maps derived from factors' combination;*
- *definition of alternatives;*
- *estimation of criteria and distribution of weights for DSS;*
- *ranking of the alternatives and choice of the best ones;*
- *definition of decisional rules to be applied to the alternatives on the territory;*
- *creation of impact maps for all the alternatives;*
- *territorial statistics of the impact of alternatives;*
- *elaboration of indications for decision makers.*

In the contest of Grado Workshop only the two first points have been described, in order to highlight how the GIS was used to analyse existing data and to assess the driving forces (agriculture) that exert a pressure on the drainage basin (cultivation intensity and irrigation) in relation to the lagoon state, and in particular to the distribution of nitrogen in the lagoon.

Acquisition and elaboration of basic GIS layers for the study area

The three main coltures have been selected, considering the distribution and economic importance at the regional level: (i) corn, (ii) soy and (iii) beetroot. They cover 65% of the agricultural surface used in the study area (ISTAT 2003).

The work was carried out on a municipality scale because all available data are given at such scale. The 69 municipalities included in the study area are subdivided by the Rural Development Plan into two areas (A and B) on the base of the different capability of the soil to reduce nitrogen percolation (fig. 2).

In the Rural Development Plan (2002-2006) the maximum nitrogen quantities that can be used as fertilizers for the different cultivations are described: (i) corn = 350 kg/ha in zone A and 270 kg/ha in zone B, (ii) soy = 50 kg/ha both in zone A and B, and (iii) beetroot = 150 kg/ha in both zones. The fertilization rates have been linearly standardized on the base of the highest value.

On the base of the existing data, three factors have been chosen as basic GIS layers:

- *surface of main cash-crops per municipality, to estimate the impact on the base of fertilization levels;*
- *aquifer vulnerability;*
- *irrigated surface per municipality.*

On the base of statistics, a map has been developed for each cultivation, with indication of the average surface devoted to corn, soy and beetroot in each municipality (km2). The three maps have been associated in a single crop intensity (CI) map, based on the maximum nitrogen quantities used for fertilization and defined by the Rural Development Plan(fig. 3).

Such a map has been obtained applying the following index:

$$CI = \sum_{i=1,3} (S_i * W_i)$$

where Si is the area of the 'i'-colture and Wi the impact of such colture in terms of impact due to nitrogen fertilization. The aquifer vulnerability has been calculated on the base of a vulnerability map provided by the Dep. of Geology of the University of Trieste. It is subdivided into 7 vulnerability classes that go from very low (0) to very high (6), with a spatial resolution of 200x200 m.

It has then been calculated a map of the vulnerability index (V) per municipality (fig. 4), based on the proportion of each vulnerability class in each municipality according to the following formula:

$$V = \sum_{7}^{i=1} \frac{\left[\left(\frac{Si}{Sm} \right) \times W \right]}{6}$$

where Si is the area of the i-class of vulnerability, Sm the total municipality area, Wi the rank given to each area (from 0 to 6).

The index V varies from 0 (case where all municipalities are included in the lowest vulnerability class) to 1 (case where all municipalities are included in the highest vulnerability class). The third factor (fig. 5) shows the total irrigated surface per municipality derived from the regional statistics.

Standardization of territorial factors

Using the software GIS IDRISI 32 release 2, the factors have been standardized with the FUZZY method using a monotonically increasing linear function, before creating the risk maps.
By standardizing them, all values have been included in the range 0-255, and the highest values have been given to the pixels of the three factors characterised by the highest values.

Elaboration of the risk maps

To build the risk maps, the following criteria were used: the risk of contamination of the aquifer with nitrogen used as a fertilizer is proportional to the nitrogen input, the aquifer vulnerability and the irrigated surface.
To calculate the risk, the MCE (Multi Criteria Evaluation) by IDRISI was used with the mode "Weighted linear combination" (WLC), considering two approaches to weigh the factors:

- *WLC1, giving the same weight to all factors (0.33);*
- *WLC2, giving a higher weight (0.4) to the factors "cultivation intensity" and "aquifer vulnerability" and a lower weight to "irrigation" (0.2).*

The risk index has been subdivided into 4 classes of equal width, from low to very high.
As the map obtained by giving different weights to the different factors indicates higher risk values, we have chosen to continue the DSS/SDSS analysis processes with such an approach. It is apparent the existence of a correlation between the WLC2 risk map that shows the nitrogen distribution in the lagoon (average annual values, 2004) (Fig.6).
The map of the average annual distribution of total nitrogen in Grado and Marano lagoon has been obtained by extrapolating the punctual data provided by ARPA FVG to the entire lagoon.
Data have been collected in the periods 1987-89, 1993-94 and from 2000. The sites of sampling used from 2000 are different from those used in previous years (Fig. 7). The extrapolation was carried out using the module SPLINE of the software GIS ArcMap 8.3 and 9. For the year 2004, the seasonal and annual maps of temperature, salinity, pH, dissolved oxigen concentration (Fig. 8 a, b, c, d), total nitrogen, ammonium nitrogen, nitrites, nitrates,total phosphorous and phosphates (Fig. 9 a, b, c, d, e, f). Observing the average temperature and salinity distribution, it is clear that Grado lagoon is warmer and more salty than Marano lagoon, that is with stronger marine characteristics. Indeed, almost all rivers have their mouths in Marano lagoon, giving important freshwater inputs, whereas only Natissa river has its mouth in Grado lagoon. On the other hand, Marano lagoon is characterised by higher nutrient concentrations, indicating that rivers and groundwaters are rich in nitrogen and phosphorus.
The sources of such pollutants are mainly the intense agricultural activities, as it is highlighted also by the following case study.

Second case study: Use of available data on sediments and bioaccumulation to evaluate the effects of industrial pollution on Grado and Marano lagoon

The results obtained from the data concerning the Grado and Marano lagoon characterization carried out by ICRAM in 2003, and in particular the heavy metal concentrations found in bivalves (impact) and in sediments (status), have been the input to develop this case study. In order to determine the source of heavy metal pollution in the lagoon, the analysis was focused on the industrial sector, which is the driving force. The pressure exerted by industries was quantified by the numer of employees in the different industrial sectors in the two widest industrial areas of the drainage basin: Udine industrial area (ZIU) and Aussa-Corno industrial area.
In ZIU area the most important sectors are the siderurgic and the metalmechanic ones, whereas in ZIAC area it is the chemical sector. Caffaro chemical industry in Torviscosa and the industrial area on the right side of Corno river are the main source of heavy metals that concentrate in the lagoon (Fig. 10). After the Grado and Marano lagoon was declared a Polluted Site of National Interest, the necessity of monitoring sediments and bioaccumulation in target species became urgent.
The lagoon characterization was carried out by ICRAM in 2003. According to the initial protocol, the sampling sites were located both in the main channels and inside the lagoon (Fig.11). In addition, a series of monitoring sites were located along Aussa and Corno rivers and Banduzzi channel. Due to logistical difficulties, the sampling sites were reduced to the rivers and the main channels (Fig.12).
Monitoring and analysis were carried out by Cooperativa Nautilus a.r.l. in Vibo Valentia.
According to the original tables provided by the Lagoon Authority, a map of sampling sites was produced and a database with all collected data was associated to it (Fig.12).

Sediment samples were collected in the sites:

Canale Aussa Corno Banduzzi	*Canale Marano*
Canale Barbana	*Canale Molino*
Canale Belvedere	*Canale Taiada*
Canale Cialisia	*Canale Videra Porto Casoni*
Canale Coron	*Cassa di colmata Marano A*
Canale Lovato	*Foce Aussa Corno*

The cores were carried out at different depths, depending on the site characteristics:

0- 20 cm	*280-300 cm*
30-50 cm	*330-350 cm*
100-120 cm	*380-400 cm*
180-200 cm	

Sampling sites were dislocated every 150 m at Aussa-Corno mouth, every 50 m (sometimes 10 m) inside the channels.
From the analysis of 0-20 cm cores it is apparent that in many cases the sediments are characterised by heavy metal concentrations that are higher than the legal maximum values. In fig.13 a,b,c the Hg, Cd and As boxplots are illustrated. Hg and Cd are over the threshold indicated by DM 367/2003 (0.3 mg/kg) in all channels. As is over the threshold (12 mg/kg) at least in some parts of all channels, with the exception of Molino channel, Aussa-Corno river mouth, Corno river northern than the industrial area, Banduzzi, Aussa river northern than Banduzzi.

The distribution of mercury in the lagoon has been studied extensively. The concentration is over the legal threshold (DM 367/2003) throughout the lagoon, but the highest concentrations are found in Banduzzi and Barbana channel. In the first case, Hg comes from Caffaro industries in Torviscosa, that have used it for centuries. In the second case, Hg comes from Isonzo river mouth entering the lagoon in Primero mouth. Such a metal comes from Idria mines in Slovenia (Hg enters the Isonzo river in Slovenian, 50 km from its mouth).

With concern to bioaccumulation, the measures are carried out on three sample series, in order to:

- *describe the level of contamination of an organism that has been in contact with the substance throughout its life cycle (native adult organism), considering both water and suspended matter (filtrator) as veicles of toxic elements;*
- *describe the contamination time of an organism of adult size coming from areas outside the lagoon, exposed for 4 weeks to water and particulate matter coming from the sampling sites;*
- *describe the level of contamination of a benthic organism of adult size that is in contact with the sediments coming from the sampling sites.*

Mytilus galloprovincialis and Cerastoderma sp. has been used as follows:

- *sampling of Mytilus galloprovincialis grown close to the sampled channels, following the Mussel Watch protocol;*
- *placement and analysis after 4 weeks of Mytilus galloprovincialis coming from not contaminated areas;*
- *sampling of Cerastoderma sp. grown in the sampling sites.*

127 samples have been collected in the following critical areas: Aussa and Corno rivers and Banduzzi channel; Aussa-Corno river mouth; Marano, Molino, Cialisia, Coron, Lovato, Videra-Porto Casoni, Taiada, Belvedere, Barbana channels (Fig. 14).
Monitoring was carried out between February and April 2003, in the period of maximum gonadic development of the species and in absence of intoxication from biotoxins.
Arsenicum concentration values found in molluscs (Fig 15 a) are very low (0.1 to 0.4 mg/kg) in transplanted mussels, whereas the native mussels are characterised by higher As concentrations, reaching 1.3 mg/kg in Aussa, Corno and Banduzzi and 1.7 in Coron (Fig. 15 b).
The highest concentrations have been found in Cerastoderma sp., with values of 1.5 mg/kg in Coron channel, 1.3 in Marano channel and in Aussa Corno river mouth, with values of 1.2, 1.6, 3.7 (Fig. 15 c). Cadmium concentrations are higher than the legal threshold (reg.(CE) N.466/2001) of 1.0 mg/kg. The values are rather homogeneous in all transplanted mussels (Fig. 16 a), between a range of 2 mg/kg and 6 mg/kg, with two maximum of 12.47 and 14.47 in Marano sites.
Native mussels show more diverse Cd values, with higher concentrations in Coron channel (28.63 and 22.16 mg/kg), in Cialisia channel (19.54 amd 15 mg/kg), a maximum of 10 mg/kg in Aussa Corno river mouth and of 11.27 in Taiada channel (Fig. 16 b).
In Cerastoderma the concentration reaches high values (between 16.81 and 28.62) in Coron channel and in Aussa Corno river mouth (22.1 mg/kg), and shows medium-high values in Barbana (13.97 mg/kg), Lovato and Videra-Porto Casoni (ca 10 mg/kg) and in Taiada (9.32 mg/kg) (Fig. 16 c). Hg concentrations are higher than the legal maximum of 0.5 mg/kg (Reg CE 466/2001) in all specimen.
In transplanted mussels the values are rather homogeneous, ranging from 0.6 mg/kg to 1.2 mg/kg, with two peaks in Marano channel (4.82 mg/kg) and in Barbana channel (2.98 mg/kg) (Fig. 17 a).

In native mussels, the highest concentrations are found in Aussa river mouth (29.3 mg/kg), secondary peaks are found in Videra-Porto Casoni channel (16.51 mg/kg), Cialisia channel (14.32 mg/kg), Coron channel (12.45 mg/kg) (Fig. 17 b).
In Cerastoderma the highest concentrations are found in Coron (17.96 and 10.99 mg/kg), Cialisia (10.54mg/kg) and Aussa Corno river mouth (13.72, 13.13 and 6.85 mg/kg) (Fig. 17 c).
The analysis of data collected in Grado and Marano lagoon in the last 15 years highlights:
• a significant sediment contamination with Hg;
• a significant Hg accumulation in filtering organisms;
• a recent increasing trend in the contamination of specific areas and of Tapes, sometimes over the legal threshold (0,5 mg/kg);
• at present, no contamination has been found in fish and humans.
The environmental and sanitary control using bioindicators is an efficient method to prevent the risks of Hg pollution in lagoons.

Third case study: Use of Remote Sensing to extrapolate information on the distribution of seagrass beds in Grado Lagoon.

The aim of this work was to analyse the morphology of Grado lagoon system using remote images at different spatial resolutions.
Remote sensing is based on the discrimination of different territorial elements (soil, vegetation, water, buildings, etc) by describing the spectral characteristics of such elements. It is therefore possible to carry out remote measures, based on the spectral response of different body surfaces in the visible and infrared portions of the visual electromagnetic spectrum. Such measures allow both to describe physical characteristics of an area, and parameters such as humidity or temperature.

Sensors used:

1. *Landsat TM 5 , image of 25/09/2000*
   spectral resolution: 7 bands
   spatial resolution: VNIR-SWIR (30 m), TIR (120 m)

2. *Aster , images of 11/09/2001 (high tide) and 08/03/2002 (low tide)*
   resolution: 14 bands
   spatial resolution: VNIR (15 m), SWIR (30 m), TIR (90 m)

3. *Aisa Eagle hyperspectral sensor (OGS-HELICA)*
   spectral resolution: 244 bands (63 bands)
   spatial resolution: VNIR (0.71 m – 1 m)

The aim was to describe the different lagoon habitats and in particular the seagrass bed distribution. The vegetation maps available are not complete, and the distribution is based on punctual sampling rather than on the analysis of lagoon areas (Figure 18). Hence, a complete map of seagrass distribution in Grado and Marano lagoon does not exist yet, although Poldini et al. have produced a map of lagoon habitat in 2005 (scale 1:10000). Such map is available at the VIA Service of FVG Region.
Seagrass beds are an important biotic component of lagoonal ecosystems, they colonize mainly muddy areas and they tend to develop and spread over extended areas, identified as seagrass beds. In Grado lagoon the following species are found: Cymodocea nodosa, Zostera marina, Zostera noltii, Ruppia maritima. Seagrass beds are of the utmost importance in the general ecology and primary productivity of the lagoon, and they contribute to the protection of lagoon bottoms from erosion. At present, seagrasses cover only a small percentage of lagoon bottoms, whereas they were more developed in the past. The OGS Institute has an AISA Eagle 1K system produced by Specim (www.specim.fi). It is a pushbroom system composed by an hyperspectral sensor, a GPS/INS sensor and an unit to acquire data implemented in a PC. The entire system is mounted on an Aerospatiale AS350 helicopter, allowing a very high operative flexibility (Fig. 19).

The main technical characteristics of the system are:
- *spectral interval: 400 - 970 nm (Visible - Infrared)*
- *spectral bands: 244*
- *spatial resolution: 0.71 m*

On 7 april 2005 (tide +40 cm) an image was taken with Aisa Eagle (OGS-HELICA) sensor, with a spatial resolution of 0.71 m (1m) and a spectral resolution of 244 bands (63 bands). The image is 800 wide and 5 km long, and it describes the area from Lignano mouth towards Marano. This image describes the area in extreme detail, even detecting fishing nets (Fig. 20 a), channel signaling poles (Fig. 20 b) and bottom tracks deriving from clam mechanical collection (Fig. 20 c).
A supervised classification of such an image has allowed to discriminate different water depths, different types of bottom, bivalve banks, seagrass beds (Fig. 21). Such information was extrapolated to the entire Grado lagoon on the base of Aster images. Two images have been used: one acquired on 11/09/2001 at high tide (+ 8 cm), the second on 08/03/2002 at low tide (-22 cm). Emerged areas were distinguished from submerged areas by visualizing the images in a grey scale and associating lower values of pixel digital number to the darker areas and higher values to the lighter areas. The threshold value that discriminate emerged from submerged areas was defined, and then the "Density slicing" ENVI software function was used in order to subdivide the images in different classes. The interpolation of the two images has allowed to discriminate three classes: submerged, emerged and intertidal areas.
The areas that were not in the classes water or land were further classified by an unsupervised Isodata method. Twelve classes were identified, then further associated in 6 classes, but the description was not satisfying. Hence, the 6 spectral bands of the two images were overlapped in a single file, so that both high tide and low tide contributions could be described. The map shown in figure 22 was obtained.
The accuracy of the description provided by this map was verified by ovelapping it to the map obtained with the punctual description of seagrass distribution (Fig. 18).
In particular Ruppia maritima is found in fishfarms, Zostera marina and Z. noltii inside the lagoon and Cymodocea nodosa at the Grado lagoon mouth and in the paralagoonal sandy area included between Grado and Porto Buso. Indeed, Ruppia maritima can be found only in still waters, Zostera marina and Z. noltii are typical of tem-

perate waters and especially colonize intertidal areas or areas where currents are low and temperature and salinity excursions are high. Cymodocea nodosa grows in proximity of lagoonal mouths, where water currents and recharge are high, salinity is similar to the sea one and the bottoms are covered by sand. In order to further verify the accuracy of figure 22, the map was compared to that created to discriminate intertidal, emerged and submerged areas. A good correspondence between the two maps and the real situation was found.
In conclusion, the analysis of Aster multispectral images with a spatial resolution of 15 m appears a good method to obtain a morphological description of lagoon systems.

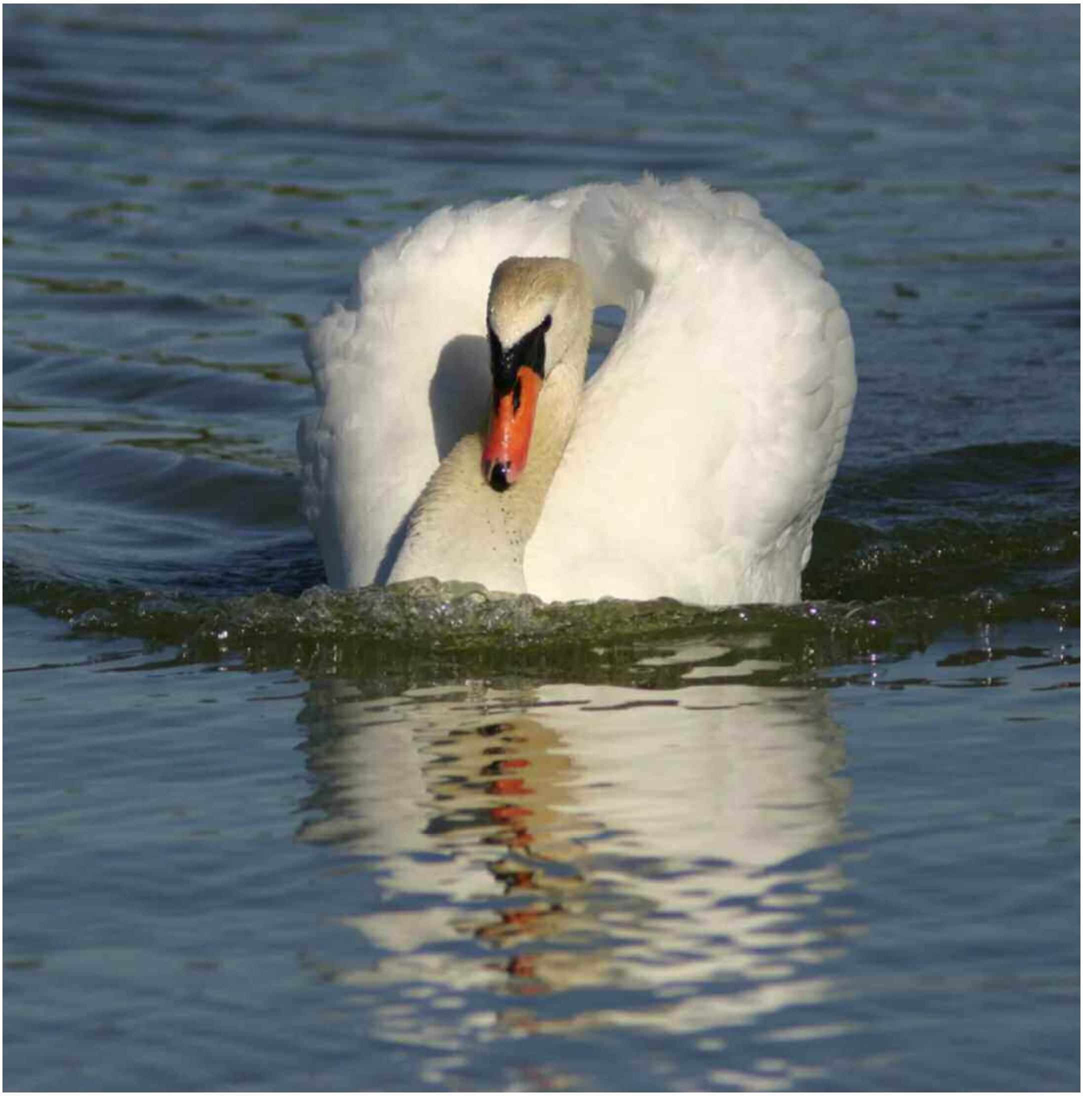

Foto Glauco Vicario