Reg Environ Change (2005) 5: 111–137
DOI 10.1007/s10113-004-0092-9

ORIGINAL ARTICLE

N. Pirrone · G. Trombino · S. Cinnirella · A. Algieri
G. Bendoricchio · L. Palmeri

The Driver-Pressure-State-Impact-Response (DPSIR) approach for integrated catchment-coastal zone management: preliminary application to the Po catchment-Adriatic Sea coastal zone system

Received: 22 October 2003 / Accepted: 24 July 2004 / Published online: 13 April 2005

Abstract The European Water Policy and, in particular, the Water Framework Directive (WFD) 2000/60/EC introduced the necessity to evaluate new methodological approaches for the development of Water Management Strategies oriented to support Sustainable Development. In the context of the EUROCAT Project, the Driver-Pressure-State-Impact-Response (DPSIR) framework was identified as a possible analysis framework for the development of management strategies according to the European Water Policy. An ad-hoc DPSIR framework was developed for the Po River Catchment and the North Adriatic coastal zone in order to elaborate possible strategies for controlling and/or reducing eutrophication. This approach combines socio-economic analysis with spatial analysis of pollutant transport and impact on the catchment-coastal zone system. The preliminary evaluation of the DPSIR approach highlighted the fact that the major Driving forces are agriculture and livestock activities and the civil and industrial sectors. Before establishing possible management strategies, it is necessary to assess the relevance of each Driving force on eutrophication in terms of Pressure factors. Combining socio-economic analysis with the evaluation of major nutrient pathways, it is possible to understand the relationship between the socio-economic development of the Po basin and eutrophication in coastal zone. The nutrient loads, i.e. the Pressures deriving from each Driver were evaluated in terms of potential and effective loads. Fifty-one percent of the Nitrogen load (carried in superficial waters) derives from agriculture and livestock (fertilizer use and manure spreading), while 40% from civil and industrial sectors. Concerning phosphorus loads the major contribution is provided by civil and industrial sectors (62% of total phosphorus load). The DPSIR development permits the identification of the impact of socio-economic development on the qualitative state of both marine and superficial waters in terms of interaction between the trophic system and ecological conditions. The qualitative state of the Po River and the main tributaries ranges between the sufficient and good levels evaluated using the Macro-descriptor Pollution Level Index (LIM). The bulk of nutrients discharged into the North Adriatic coastal zone generate the change of environmental conditions in terms of loss of water qualitative state. The assessment of the water qualitative state for marine waters was performed using an appropriate indicator the Trophic Index (TRIX) according to the Italian legislative framework (Dlgs. 152/1999). Knowledge of the main biogeochemical processes of nutrients and the assessments of DPSIR components is the starting point for the scenario analysis.

Keywords DPSIR · Catchment · Coastal zone · Eutrophication · Database · GIS · Socio-economic · Po River · Adriatic Sea

N. Pirrone (✉) · G. Trombino · S. Cinnirella · A. Algieri
Division of Rende, c/o Polifunzionale Università della Calabria,
CNR- Institute for Atmospheric Pollution,
87036, Italy
E-mail: n.pirrone@cs.iia.cnr.it

G. Bendoricchio · L. Palmeri
Dipartimento dei Processi Chimici dell'Ingegneria,
University of Padua, Padua, Italy

Introduction

Over the last few years, the environmental policies in the European Community have been finalized to safeguard water resources from pollution; but since the launch of the EU-Water Framework Directive 2000/60/EC (WFD), Member States have had to promote initiatives aimed at protecting both inland and coastal waters in order to prevent and to reduce pollution, to promote sustainable water use, and to protect the aquatic environment. In particular, the WFD aims to preserve water resources by fixing quality objectives for all water bodies. At a European level, all countries have to achieve water quality objectives (WQOs) as established by the WFD. However, it is not clear how these WQOs should be achieved. The core of the problem is not only to adopt plans and strategies to re-establish the natural equilibrium but to promote socio-economic development that balances both economic growth and environmental protection in order to achieve sustainable development. In this context, it is necessary to develop new methodologies to provide the means to achieve the targets of the WFD.

The evaluation of a new methodological approach able to establish a link between integrated coastal zone management (ICZM) and integrated river basin management (IRBM) as targeted by the WFD was one of the aims of the EUROCAT project. Using the Driver-Pressure-State-Impact-Response (DPSIR) framework, the Response of the coastal zone (CZ) to changing material fluxes is traced back to the individual socio-economic Drivers at the catchment scale. The cause–effect relationship between inland areas and the coast was developed and is being applied in major coastal studies. Human activities localised throughout the river catchment and CZ not only cause environmental pressures (i.e. nutrient loading, heavy metal discharge) but also alter river flow regimes, and sediment fluxes are oriented to a specific issue (i.e. heavy metals, eutrophication).

Our case study evaluates the eutrophication issue for the Po Catchment and the North Adriatic coastal zone. Socio-economic development and, in particular, agricultural activity in the Po basin generates anthropogenic pressures that are the major causes of the eutrophication in the North Adriatic coastal zone.

It is well known that eutrophication is primarily due to an excess of nitrate and phosphate discharges that lead to a shift in the biological structure, and in severe cases even to oxygen depletion, production of toxins, and the collapse of entire aquatic ecosystems. Eutrophication, causing an accelerated growth of algae and higher forms of plant life to produce undesirable effects, results directly from anthropogenic nutrients enrichment.

The Mediterranean Sea is one of the most oligotrophic seas in the world and the problem of eutrophication appears to be limited largely to specific coastal and adjacent offshore areas where numerous and, occasionally, severe eutrophication events occur. This is the case of the Northern Adriatic Sea that receives anthropogenic-enhanced nutrient loads mainly from the Po River (Schrimpf et al. 2003). Nutrient loads enter the sea both directly, through marine and coastal activities, and indirectly, through river flows.

Several institutions have performed studies relating to eutrophication of the North Adriatic Sea and water quality assessment in the Po catchment. The main institutional body responsible for the water management of both the Po basin area and the North Adriatic Sea is the Po River Basin Authority (ABP). The ABP is responsible for the preservation and recovery of territories of the drainage basin, the preservation and regulation of water flows, and the preservation of the CZ. The water policies adopted by the ABP, in order to reduce eutrophication, were used as the reference point to evaluate possible strategies according to the Italian Water Policy. Particular attention was given to the Strategic Plan known as ' *Piano Stralcio per il controllo dell' Eutrofizzazione'* adopted by the ABP (31 January 2001) in order to contain and reduce the eutrophication phenomenon.

This paper presents a preliminary DPSIR framework development for the specific issue of eutrophication. The use of this analysis framework requires the integration of environmental and socio-economic sciences in order to define the effect of anthropogenic pressure on the qualitative state of water in the CZ pertaining to the Po River.

The interaction between socio-economic development and environmental degradation was evaluated with the Driver-Pressure-State (DPS) analysis. Knowledge of the causal mechanisms that result in eutrophication allowed the evaluation of possible scenarios for eutrophication reduction. The scenario analysis is based on biogeochemical models that evaluate the relative contribution of different physical and chemical processes that affect the transport of nutrients at Catchment and CZ scales.

The catchment-coastal zone system

The Po catchment

The Po River basin is the largest Italian catchment covering an area of 74,000 km^2 (Fig. 1). The annual rainfall ranges between 700–1,600 mm with a total rain volume of 78×10^9 m^3 (ABP 1999a). Around 60% of the rain volume is discharged into the Adriatic Sea, while 40% is lost to evaporation, by forest transpiration, in groundwater reservoirs and lakes (ABP 1999a, b).

The contribution from snow melt during the spring time can cause high peaks in water volume discharged from the Alps and Apennines sub-catchments. The northern part of the Po basin includes five large lakes (890 km^2) that enhance a continuous interchange of groundwater and superficial water with the Po River and its tributaries.

The main river crosses the Northern Italy for 650 km and discharges into the Northern Adriatic Sea at an average flow rate of 1,510 m^3 s^{-1} through a delta, which is regarded as one of the most complex estuarine systems in Europe (ABP 1999a, b). Past studies (Vollenweider et al. 1992, 1995; Rinaldi et al. 1995) suggested that river discharges regulate the nutrient concentrations in the Adriatic Sea, which drives the eutrophication and formation of mucilage in the coastal reference zone. For our purpose, the catchment was divided into 33 sub-catchments contributing differently to the total discharge because of differing precipitation and water use.

Forest and bushes cover around 37% of the surface, while only 5% is used for urban purposes. About 8% of

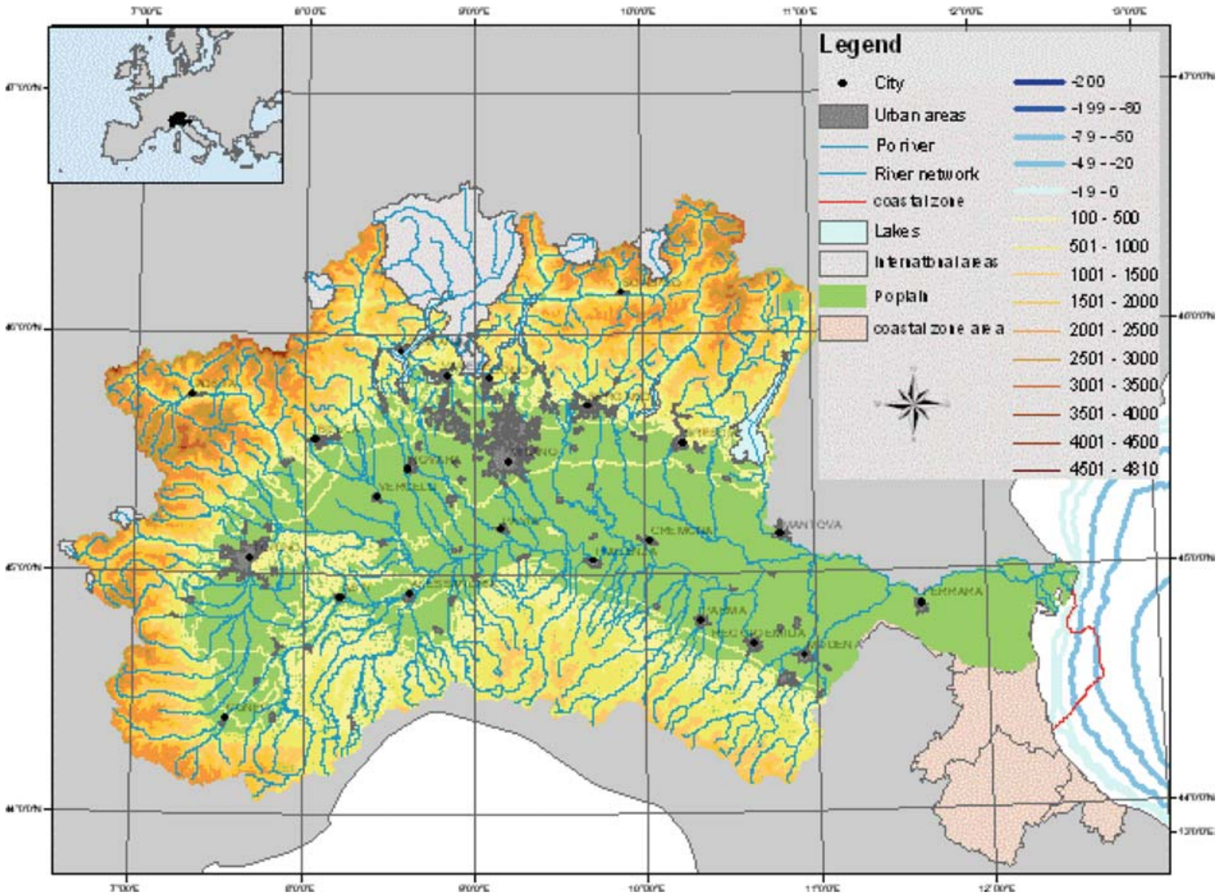


Fig. 1 The Po River catchment and the pertinent coastal zone

the area is rocks and other bare soils with very low water storage capacity and soil conductivity, while loamy sand soils account for 63% (ABP 1999b).

The Po delta covers a surface of 73,000 ha of which 60,000 are reclaimed lands and the remainders are brackish lagoons. Periodical breaches, caused by heavy floods have modified the hydrology and morphology of the Po plain and the configuration of the delta causing a dynamic advancement of the coastline. Sediment loadings carried by the river are discharged at the river mouths, where they are redistributed by wave action causing the formation of sand bars both at the front and at the sides of the mouths (Marabini, 2003).

The North Adriatic coastal zone

Definition A general definition of the coastal zone (CZ) according to the LOICZ-UNEP (Buddemeieret al. 2002) considers "... *the domain surrounding the land–sea interface extending to the landward and seaward limits of marine and terrestrial influences*".

Practical delimitation is to include the landward area to 100 km from the coast (WRI 2000) or to consider the extent from 200 m elevation to 200 m depth as suggested by the LOICZ guidelines and criteria (Pernetta and Milliman 1995).

Having the above in mind, the influence of human activities carried out in the Po catchment on the associated CZ was evaluated on the basis of a specific characterization of the CZ. The basis to account for river catchment influence on a CZ is the river water discharge that transports pollutants, and the magnitude of discharge is often strictly related to watershed extension, uses and management.

Salinity is a good indicator of river discharge influence on water quality. Salinity is a conservative tracer, unbiased by seasonal primary production, and is related to the nutrient content of the water discharged by the river. Hence, it may be chosen as a starting point for applying the methodology.

In our context, the CZ is identified with *the area that is sensible to the influence of the water discharged by the river*. Consequently, if a large discharge is considered, the CZ is large as well, and vice versa. The "sensible area" of the CZ is defined as the area, where *the fluctuation of the water quality parameters is larger than a certain reference target*. The fluctuations are related to their standard deviations (SD) and the fixed quantity could be the SD of a non influenced reference point far from the discharge area (background), or the smallest SD or any other function of the SD.

The methodology described in Annex 1 was applied to the period 1992–2000, and the years 1992, 1993, 1996 and 2000 were selected as representative of quite differ-

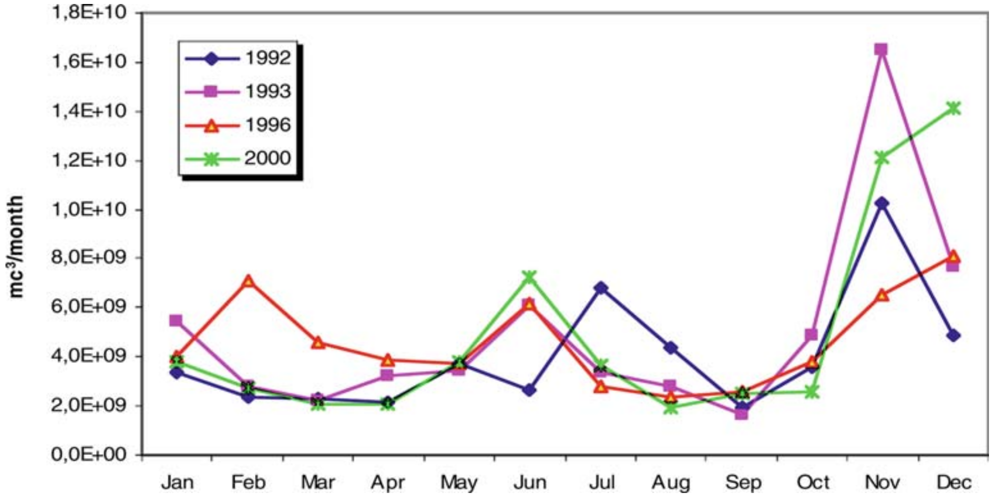


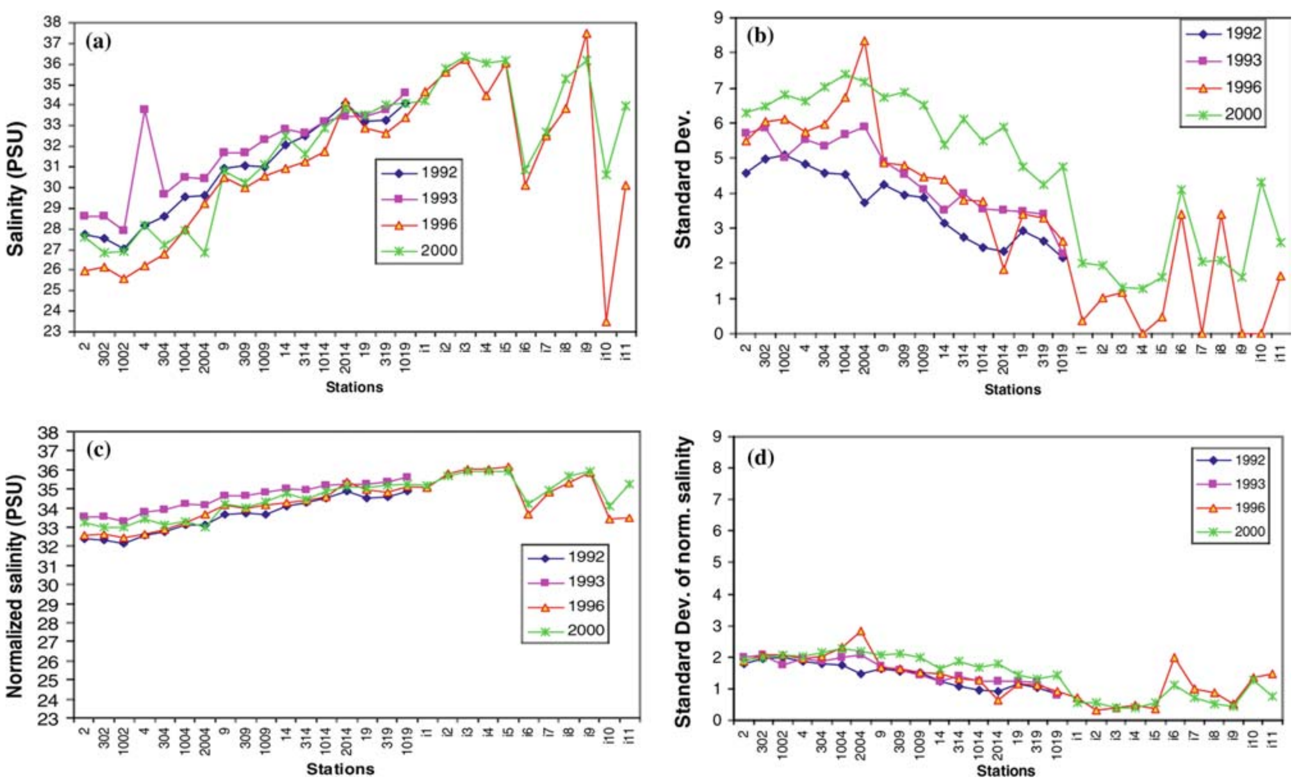
Fig. 2 Po River water discharge at Pontelagoscuro sampling station for the period 1992–2000

ent discharge patterns (Fig. 2). The values of salinity (Fig. 3a, b) were normalized (Fig. 3c, d) and the correlation between average values of salinity and standard deviation for the period 1992–2000 was calculated giving a good correlation ($R^2 = 0.8765$).

The average of the normalized salinity and its SDs for each station (Fig. 4) may be considered as the starting point for the definition of the CZ. The stations displaying the lowest SD belong to an area that is very stable and could be used as a reference. This area identifies the background level of the variation pattern of salinity for the Northern Adriatic. On the other hand, areas characterized by higher (1.0–1.5) SD are certainly more influenced by the river discharge.

Using the values per station obtained by the normalization procedure, a surface is calculated by interpolating the SD with an Inverse Distance Weighting algorithm. The surface clearly depicts the area of influence of the Po River on the CZ. By arbitrarily choosing a limit value for the SD, the CZ boundary may be geographically identified (Fig. 5). Looking at Fig. 5, and particularly at the SD surface contour lines, it is noticeable that the CZ boundary should lie somewhere in the region where SD is greater than 1.0. For the

Fig. 3 Temporal trend of salinity at each monitoring station of NA coastal zone, **a** Average salinity, **b** standard deviations for the averages, **c** normalized values of salinity, **d** and standard deviation of normalized salinity



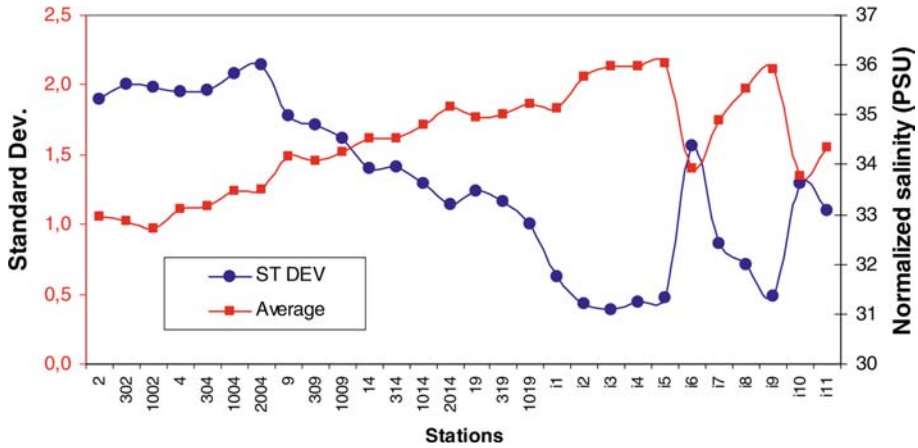


Fig. 4 Average per station of the normalized values of salinity and associated SD

Po River, we may assume as a CZ boundary the contour line corresponding to a SD of 1.5.

Physical characteristics The CZ as above defined has a large variability in salinity that is in the range of 15–40 PSU as a consequence of the substantial fresh water discharge. The lowest values are reported near the coast at the surface, in coincidence with high discharge events, while typical values are in the range of 25–38 PSU.

The surface water temperature varies between 9°C and 28°C, whereas, the bottom layer temperature is more stable with values in the range of 11–15°C. The temperature distribution changes significantly during the year as a consequence of the evolution of the circulation pattern and is characterized by sharp stratification along the profile.

The NA basin displays a very peculiar circulation pattern, high seasonal variability, sharp stratification and very high production rates: almost 20% of the whole fishery production of the Mediterranean Sea comes from Adriatic Sea (COPEMED 2003). The water circulates in an anticlockwise direction, especially when there are also northeasterly and southeasterly winds (Bora and Scirocco) and when the Po discharge is significant, it generates strong density currents (Tomasino 1996).

The annual cycle, controlled by the heat budget at the surface, determines the sequence of two density distribution regimes: vertical stability and circulation in the coastal waters as well as offshore. Vertical mixing is characteristic of the winter period (from December to February), while vertical stability is dominant during the

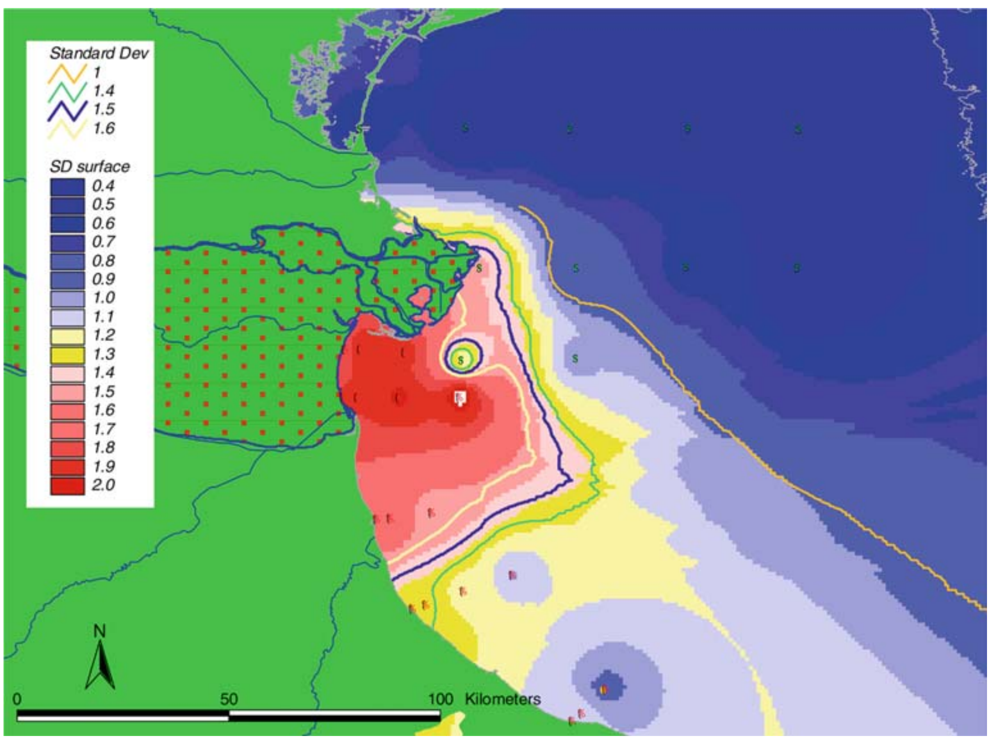


Fig. 5 Interpolated surface for salinity and proposed CZ boundaries

rest of the year (Franco et Michelato 1992). CZ water is characterised by great turbidity, a high concentration of nutrients, which are generally conveyed southward.

A nutrients load generated by about 25×10^6 inhabitants is discharged into NA by the main rivers including Tagliamento, Piave, Brenta, Adige, Po and Reno rivers. The Po River contributes to the nutrient load of the NA with 14,000 Mg year^{-1} P and 100,000 Mg year^{-1} N. These loads impact directly on the coastal area.

The Po River drains annually about 20×10^6 ton year^{-1} of suspended solids that are deposited in the NA coastal zone. The gently sloping sea bed, composed of sand and silt, are subject to significant sediment displacement caused by wave motion. At the mouth of the river, the fresh water with its suspended material generally tends to disperse towards the NE depositing sandy material along the coastal areas. The finest part of the suspended material (loam and clay) is instead pushed towards the pelagic zone, where the main counterclockwise circulation pattern tends to prevail. Thus, the sediment dynamics are related to the river inputs and to marine drifts, with the finest sediment transported in a southerly direction.

Methodology

The DPSIR approach, formerly developed by OECD (1993) in the PSR form, was used to highlight relationships between human activity and environment degradation. It is based on a concept of causality: human activities exert pressures on the environment and change its quality and the quantity of natural resources. Society responds to these changes through environmental, general economic and sector policies. The latter form a feedback loop to pressures through human activities (OECD 1993; EEA 1999).

The DPSIR-approach was adapted to the EUROCAT scale and for the purposes of the project it proved to be necessary to use an indicator nomenclature that is slightly different from the definitions used by OECD and EEA.

The DPSIR approach

Within the EUROCAT project, the DPSIR was applied to the Po catchment–CZ continuum to study the integrated system catchment area and the associated CZ with the specific objective to evaluate policy Response for sustainable management. The selected issue was the eutrophication phenomenon of the Adriatic Sea, but the goal was to identify a policy solution able to:

– Recover a ‘good’ status for the Po river;
– Reduce the nutrient discharge into the Adriatic Sea and consequently the appearance of eutrophication.

The DPSIR approach is a complex analysis framework that can be summarized as follows:

– The *Driving forces* are processes and anthropogenic activities (production, consumption, recreation etc.) able to cause pressures;
– The *Pressures* are the direct stresses, deriving from the anthropogenic system, and affecting the natural environment, i.e. pollutant release;
– The *State* reflects the environmental conditions of natural systems (air, soil and water quality);
– The *Impact* is the measure of the effects due to changes in the state of environmental system;
– The *Response* is the evaluations of actions oriented to solve environmental problems in terms of management strategies.

The development of this framework for the case study highlighted the specific features of each DPSIR element.

The assessment of *Drivers* provides the identification of the major driving forces affecting the Po basin and the North Adriatic coastal zone. The analysis of *Pressures* implies the evaluation of the pressures in terms of nutrient loads focusing on the eutrophication of Adriatic Sea. The assessment of the *State* is the analysis of parameters and combined environmental indicators able to identify the current qualitative state of water bodies. The evaluation of the *Impact* caused by anthropogenic activities is quantified in terms of nutrients loads variation. The *Response* is the evaluation of management strategies according to European and Italian Water Policies for sustainable socio-economic development.

The development of this analysis framework requires the assessment of a scheme able to identify the major nutrient pathways highlighting the relation between the anthropogenic Drivers and the eutrophication phenomenon in the CZ, the adoption of an indicators list for the catchment CZ continuum and the development of a specific database.

Nutrients pathways

In order to understand the interaction between socio-economic activities acting at catchment level and the pressure exerted on the ecosystem, it was necessary to identify the major Driving forces involved in nutrients release and to quantify the Pressure in terms of nutrient loads. The nutrients fluxes (Pressures) caused by anthropogenic activities (Drivers) in the catchment area reach the Northern Adriatic Sea through the river system.

The key to understand the complex interaction mechanisms between the catchment and the CZ continuum (i.e. nutrient loads discharged into the river system and then concentrations measured in the Adriatic Sea) is the identification of a scheme able to provide the interface between socio-economic factors (Driving forces) and nutrient dynamics in the river system (water and soil). The adopted scheme is reported in Fig. 6, and shows nutrients released from diffuse (i.e. agriculture and livestock activities) and point (i.e. industry and waste water treatment plants) sources. Nutrients, after being released, are subject to retention and loss pro-

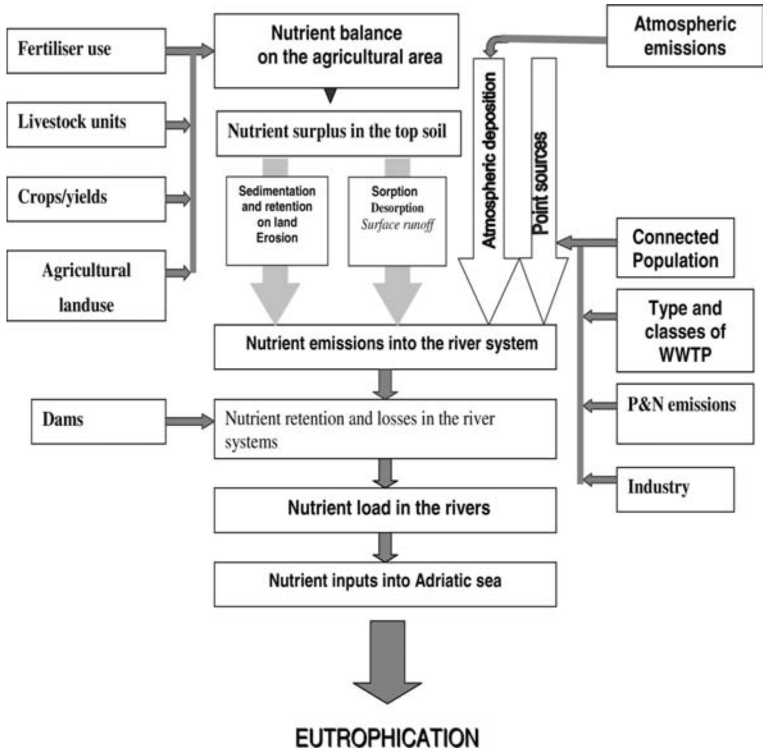


Fig. 6 Integrated qualitative approach of different pathways affecting the transport of nutrient from point and diffuse sources in the Po catchment

cesses (functions of geology, slope and land use) before arriving in the river system. Different pathways of nutrient dynamics were explored including: atmospheric deposition, tile drainage, overland flow, erosion, ground water, waste water treatment plants and urban sewer systems (Fig. 6). Nutrients released from diffuse sources (Fig. 6) are estimated through the nutrient balance in the agricultural area and analysing different parameters including fertilizer use, livestock units, crops/yields and agricultural land use. Nutrient emissions from point sources are reported on the right side of Fig. 6 and involve the analysis of selected socio-economic factors such as population connected to waste water treatment plants (WWTPs), type and classes of WWTP, industry, etc. Nutrient pathways are modelled with the MOdelling-Nutrient-Emissions-in-RIvers-Systems (MONERIS) model developed by Behrendt et al. (2000), which was used for the evaluation of nutrients fluxes at catchment level, for which calibration and sensitivity analysis studies were performed (A. Algieri et al. 2003).

The change of nutrient fluxes, recognized as the Impact on the Adriatic Sea, requires the analysis of the socio-economic situation of the study area during the last 30 years. If eutrophication is the result, evaluation of the Impact provides us with a tool to make hypotheses for future plans of sustainable socio-economic development taking into account the major goals of the WFD, i.e. the reduction of pollution and ecosystem restoration. Naturally, the achievement of this objective implies the evaluation of changes in economic policies, human life-style and legislative restrictions.

Indicators

The evaluation of the DPSIR approach requires the compilation of an appropriate list of indicators able to capture the complexities of the system interactions between river catchment and coastal waters. The availability and reliability of data, the usability of the available data within the modelling framework and sensitivity of indicators to mirror the underlying ecological and economical processes were used as criteria to compile this list. The indicators list contains different types of indicators including social, economic, ecological, physical and chemical indicators.

Under the eutrophication issue, nutrients are the main parameters investigated and refer to a process affecting the specific conditions of the coastal reception area. In the literature, it is possible to find several indicators of the quality of the coastal marine environment. They refer to the eutrophication phenomenon providing us with the capability to study the change of the state of water quality in the CZ. The Trophic Index (TRIX) was selected to describe the eutrophication of the Adriatic Sea (Table 1).

The indicators list represents a selection with the specific function of completing the DPSIR components enabling the identification of all the significant parameters to include in the database. This identification is a continuous process subjected to constant revision primarily driven by model results. A major effort was made to integrate the main socio-economic factors into models (ecological and socio-economic) by choosing representative indicators in order to reproduce the interaction

Table 1 The DPSIR table with selected parameters adopted to identify the major Drivers, Pressures, State, Impact and Response for the Po Catchment-North Adriatic Coastal Zone system

Drivers	Pressure	
	Catchment	Coast
Agriculture and land use change	Agriculture	Riverine input
Production pattern	Fertilizer use	Nitrogen load
Consumption pattern	Pesticide use	Phosphorus load
Amount agricultural production	Agricultural land use	Atmospheric input
Degree of innovation in agricultural practices	Livestock units	Nitrogen deposition
Fisheries		Fisheries
Amount of sold catch		Fish catches
Fishing quotas per year		By-catch
Tonnage of fishing vessels		Trawling
Urbanization	Urbanization	Urbanization
Rate of population growth	Growth of urban areas	Demand for waste disposal
Demand for waste disposal	Demand for waste disposal	Volume of waste water
Population density	Volume of waste water	Volume of sewage
Innovation in waste water treatment techniques	Volume of sewage	
	Type of waste water treatment plants	
	Classes of waste water treatment plants	
Industrial development	Industrial production	Industrial production
Degree of industrial activity	Volume of industrial effluent	Volume of industrial effluent
	Energy demand for industry	
Tourism and recreation		Tourism and recreation
Types of recreation		No. of tourist
Recreation demands		No. of holiday home
		Seasonal population change
		Private maritime traffic
	Climate change	Climate change
	Change in seasonal weather patterns	Sea-level rise
	Floods	Flood-storm events
	Droughts	
Demand for Nature Protection	Demand for Nature Protection	
Political pressure for nature protection	Area demand for nature protection	
Human behaviour in nature		
Socio-economic framework and governance		
Type of governance		
Political priorities		
Economic structure		
Lifestyle		

Table 1 (Contd.)

State Parameters		Impact		Response	
Coast		Coast		Catchment	Coast
Ecology	Socio-economy	Ecology	Socio-economy		
Water quality	Bathing water quality	Water quality	Policy	Regulation of discharge	Creation of buffer
TRIX:	Freq. of failure to Meet bathing WQ	Changed Concentration:	Problems to reach QOs of WFD	Optimisation of Nitrate Directive	Sink zones for nutrients
Concentration of:	Extended of blue flag beaches	Chlorophyll-a		Increase of protected areas	Zonation of land to preserve habitat
Chlorophyll-a		Nitrogen species		Agri-environmental schemes	Increased conservation areas
Nitrogen species		Phosphorus species		Regulation on farming practices	Regulation of commercial traffic
Phosphorus species		BOD, COD		Optimisation of the Urban Waste Water	Creation of recreation zone (land and marine)
BOD		Dissolved oxygen		Directive Optimisation of Water Framework Directive	Special areas of conservation
COD		Change of ecosystem functions and Health			Promotion of eco- tourism
In river		Eutrophication			
Ecological quality:		Mucilage			
EBI		Oxygen depletion			
Chemical quality:		Enhanced oxygen demand (BOD,COD)			
LIM	Nature protection	Bloom frequency, intensity and duration			
Dissolved Oxygen rate (% sat)	%habitat-related tourism. e.g. bird-watching	Fish Kills			
BOD_5 COD	Area of nature reserve open to public	Sediment degradation			
$N\text{-}NH_4$					
$N\text{-}NO_3$					
Ptot					
Escherichia Coli					
	Tourism	Nature protection	Tourism		
	No. of tourist	Habitat loss	Reduced tourism	Increased effluent treatment	Economic incentive For clean technologies use
	Income from tourism	Change in area of Inter-tidal habitat	Reduced recreation Facilities	Inducement to create/use energy from renewable sources	Ban on fossil fuel burning
	No. of holiday home	Change in area of coastal habitat		Economic incentive For clean technologies use	Change in planning laws to take account sea-level rise
	Seasonal population change			Ban on fossil fuel burning	Realignment of coastal defence where suitable
	Importance of tourism for local economy				Enhancement of defences in urban areas
		Bathing water quality			
		Change in bathing WQ			
	Fisheries		Fisheries		

Table 1 (Contd.)

State Parameters		Impact		Response	
Coast		Coast		Catchment	Coast
Ecology	Socio-economy	Ecology	Socio-economy		
	Stock of commercial Shelfish		Change in fisheries benefit		
	Stock of commercial fish				
	Fishing quotas				
	Tonnage of fishing Vessels				
	Local demography				
	Size of current population				
	Rate of population growth				
Climate change	Climate change	Climate change	Climate change		
Catchment discharge	Length of coastal defence	Flooding (habitat loss/gain)	Increased insurance Claims		
Local sea level change	Size of area prone to flooding	Coastal erosion	Reduction in quality/value of farmland from excess water/salt		
Frequency of storm Events	Population living in flood risk area		Increased spend on coastal defence		
			Forced realignment of coastal defence		

mechanisms between economy-driven activities and the biosphere.

Dataset development and implementation

The main objectives of the database construction were:

- The socio-economic description of the study area;
- The use of data that must abide by flux and economic models;
- The completion of the DPSIR analysis through the development of the indicator list.

Because the final objective of the study was the identification of possible management strategies for the reduction of eutrophication, the historical trends of indicators were collected for the development of scenarios.

As the first step, a list of indicators was selected for each category of the DPSIR for the database development. The database was established on the basis of available institutional datasets that were derived from previous research projects on the catchment and CZ. The Po River Basin Authority (ABP) and the Italian Statistic Institute (ISTAT) for the river areas and the Regional Environment Protection Agencies (ARPA-ER) for the sea are the main institutions that made available the datasets used in this study.

The collection of this large amount of data (i.e. data quality measures, socio-economic indicators, biophysical parameters) was managed in the structured form of a multi-layer database (S. Cinnirella et al. 2003) after a validation phase using the Gaussian simulation method (Cinnirella et al. 2005).

The structure of the layers enables a better DPSIR analysis and each layer was involved in the analysis at different level (Fig. 7):

- The ‘‘root’’ layer contain general information that is spatially defined (i.e. administrative and catchment limits, digital terrain model, river and lake quality stations, well quality stations) and was used permanently to spatialize, analyse and visualize a given dataset;
- The ‘‘stem’’ layer includes time series data (i.e., 1971, 1981, 1991, 2001) of all the defined indicators (i.e., agriculture, livestock, industry, population and tourism, nutrients). Data could be integrated/updated frequently and are redundant for model runs;
- The ‘‘leaves’’ layer was derived from model or algorithm results and provides data to assess scenarios.

The database was linked to a Geographic Information System (GIS) based on ArcGis (version 8.2, ESRI, Redlands CA, USA) that was used to improve spatial analysis and visualization.

The multi-layer Database The main base features represent rivers, channels and lakes networks, elevation, watershed borders, gauge stations of superficial and

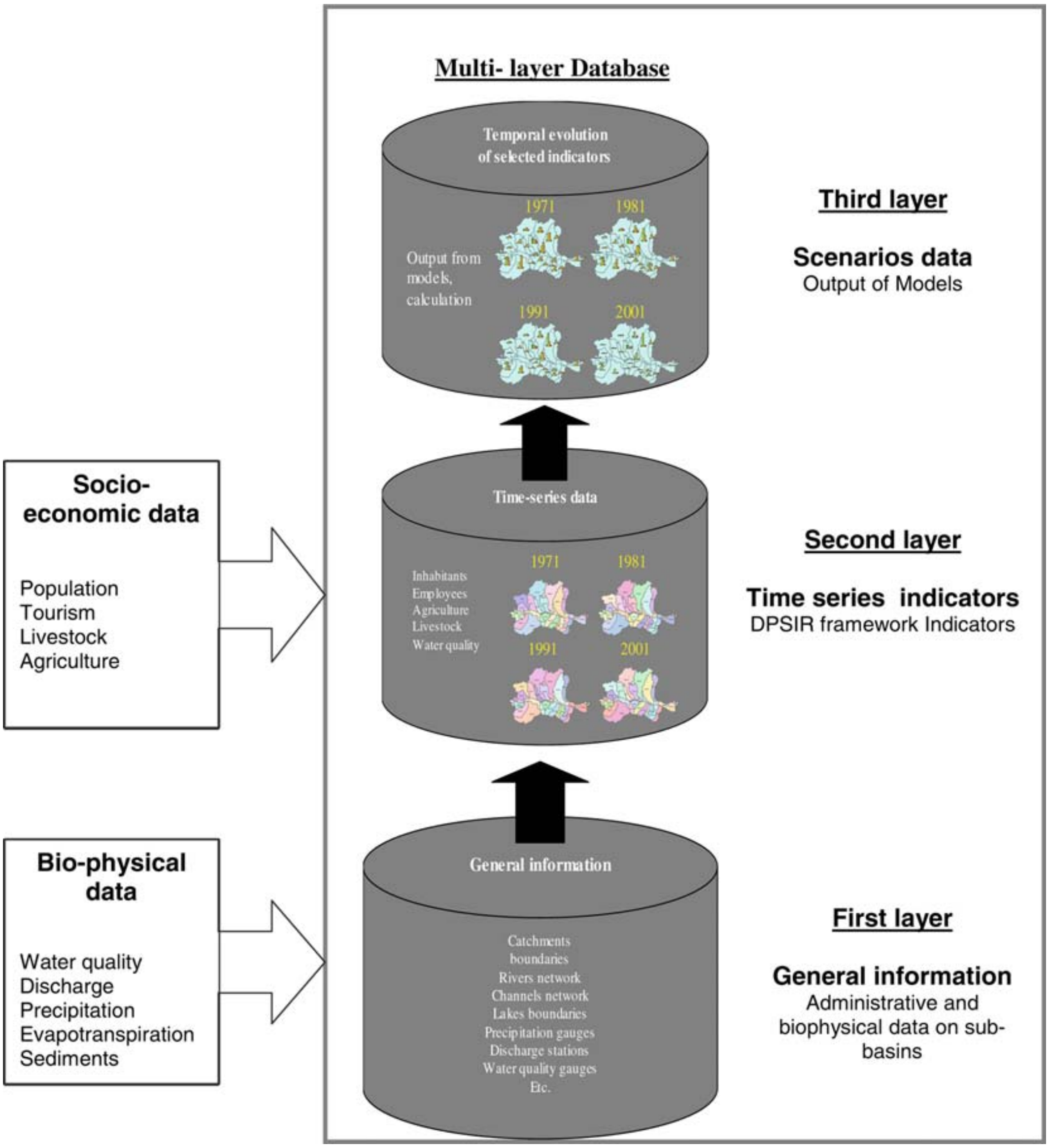


Fig. 7 The multi-layer structure of the database used in the DPSIR framework developed for the Po catchment and Northern Adriatic CZ continuum

groundwater quality, pedology, geology and statistical units, that have an exact geographical reference. In the form of points, arcs or polygons, they serve as a starting point to analyse and develop scenarios.

Socio-economic indicators, derived from statistical records and on either municipal or provincial scales, were selected, reclassified and combined to obtain a catchment regionalization. The use of spatial overlay under the GIS and the logical-statistical analysis functions help to obtain different matrices of municipalities and provinces. These were related to each sub-catchment in order to obtain a common spatial unit.

Another type of data represent qualitative and quantitative information on major industrial and non-industrial sources of nutrient discharges [mainly Nitrogen (N) and Phosphorus (P)] and toxic inorganic (e.g. heavy metals) and organic (e.g. persistent organic pollutants) chemicals; information on surface run-off, erosion, and atmospheric deposition in the catchment; information on the concentrations of the above mentioned chemicals in river water, groundwater, coastal water, sediments, soils, and atmospheric deposition; information on socio-economic parameters related to the changes of production profiles, agricultural pesticides, ecosystem changes in the CZ due to coastal tourism, aquaculture and fisheries, waste disposal, and overall population.

At the coastal level nutrient concentrations at different sites, water temperature, global irradiance, transparency, O_2, POC, chlorophyll-a concentration, phytoplankton groups composition (Diatoms, flagellates, etc.), benthic fauna (macrobenthos), macroalgae, bacteriological state, seagrasses were collected, as well as details of morphology and fish stock and fisheries activity.

Results

The evaluation of strategies aimed at the reduction of anthropogenic pressure requires the characterization of the socio-economic structure highlighting the relevance of each driver for the economy and at the same time, its specific relationship to the eutrophication. For this purpose, a socio-economic analysis was conducted with the specific aim of quantifying the environmental pressure deriving from the socio-economic structure.

The Po area is strategic for the Italian economy, with a gross regional product reaching 52% of the gross domestic product (GDP) when considering the contribution of the regions within the catchment. Otherwise, taking into account the pertinence of each region to the catchment, the GDP is about 36% of country total (Table 2). The GDP represents the value of the final goods and services produced and most notably the real GDP of the area indicates a consistent activity with a value higher than 600 billion Euro. The greater standard of living defined by the GDP is unaccompanied by a high standard of environmental quality. Therefore, we might argue that a parallel development of economic progress (measured through the GDP increase and the weight of the investment costs) and environmental preservation (measured through ecological indicators) is needed to obtain prosperous conditions of the area.

The contribution to the national economy of each analysed driver could be detected by taking into account a small number of indicators (Table 3 and Fig. 8). Population accounts for 23%, while employment for 36% of the national totals; agricultural surface used (SAU) account for 21%, whereas cattle contribute for 47% and pigs for 67%. A small contribution to the fish catch was also considered in Table 3.

The economic data provided above show a net contribution to national production with 23% for agriculture, 45% for livestock, 32% for silviculture and 11% for fishing reaching a total value of 29% (Fig. 9). Differences among regions show Lombardia as the highest single contributor to production, with more than 45% followed by Piemonte and Emilia Romagna each with contributions of 25% in the area (Table 4).

The economy of the CZ is dominated mainly by tourism and fishing-related activities. Extending our analysis over a larger area that included the southern most populated towns, it was found that in the year 2000, more than 15 million tourists stayed in the province of Rimini, with a high residence time in summer months (7–8 days). Lombardia and Emilia-Romagna contribute with 35% to the catchment-CZ area, while global contribution to national tourism accounts for 19% (Table 5).

In the following sections, Drivers, Pressures, State and Impact for the Po catchment are discussed.

Drivers

The anthropogenic activities included in the productive system are influenced by stakeholder interest and by human-lifestyle, the two most important social factors, however, both the productive structure and the social system are regulated from the Legislative Framework according to the scheme reported in Fig. 10 (Trombino et al. 2004).

The assessment of the Drivers is based on the analysis of the interaction between the socio-economic and ecological systems. It requires the evaluation of human activities and their relevance to environmental pollution. The Driver analysis under the DPSIR framework, was conducted bearing in mind this scheme, and considering the interaction between the socio-economic and ecological systems in terms of nutrient loads.

Agriculture The current state and the evolution of processes which occurred from 1971 to 2001 was made for the agricultural sector. Agriculture is significantly developed in the Po basin, it has the largest cultivated land surface in Italy (34 million ha) and accounts for 35% of the GDP. The agricultural sector in the Po river

Table 2 Gross Domestic Production (GDP), Consumption (C), Investment (I), and Added Value (AV) for each region of the Po catchment and general values for Italy (year 2000 prices). The Add Value of agriculture (AVa), industry (AVi) and commerce (AVc) is also reported

Region	Ratio Region-Catchment (-)	Area (ha)	GDP (€×10^6)	C (€×10^6)	I (€×10^6)	AV (€×10^6)	AVa (€×1^6)	AVi (€×10^6)	AVc (€×10^6)
Piemonte	1.00	2,539,983	101,224	72,920	22,596	92,847	1,980	32,356	14,169
Valle d'Aosta	1.00	326,322	3,069	2,963	698	2,842	36	583	514
Lombardia	1.00	2,386,285	238,022	161,961	44,565	225,012	3,430	79,361	35,779
Trentino-Alto Adige	0.13	1,360,687	25,221	20,405	7,424	23,460	717	5,584	5,725
Veneto	0.05	1,839,122	106,234	78,704	22,030	98,771	2,938	35,153	17,447
Liguria	0.29	542,024	34,984	29,545	5,078	32,118	665	6,002	6,485
Emilia-Romagna	0.63	2,212,309	102,417	74,625	21,076	95,360	3,331	31,949	16,194
Total		11,206,732	611,171	441,123	123,467	570,410	13,097	190,988	96,313
ITALY		30,132,845	1,164,768	928,362	230,952	1,078,352	29,992	305,687	178,666

Table 3 Main contribution of different Drivers to the economy of the Po Catchment area

	Ratio Region-Catchment (-)	Area (ha)	Population (*n*)	Employees (*n*)	Tourists (*n*)	SAU (ha)	Cattle (heads)	Pig (heads)	Fish catch sea (Mg)	Fish catch lakes (Mg)
Piemonte	1.00	2,539,983	4,289,731	1,625,794	8,699,397	1,120,250	819,136	924,162	–	45
Valle d'Aosta	1.00	326,322	120,589	54,096	3,254,401	96,594	38,888	1,072	–	–
Lombardia	1.00	2,386,285	9,121,714	3,681,619	23,846,814	1,104,278	1,609,013	3,809,192	–	1,509
Trentino-Alto Adige	0.13	1,360,687	943,123	400,473	13,651,140	422,373	189,367	22,158	-	95
Veneto	0.05	1,839,122	4,540,853	1,838,589	57,610,399	881,267	932,701	701,685	22,191	470
Liguria	0.29	542,024	1,621,016	520,332	15,252,558	92,483	16,488	1,477	17,470	2
Emilia-Romagna	0.63	2,212,309	4,008,663	1,728,343	37,406,782	1,232,220	622,578	1,552,437	62,619	860
Total		11,206,732	24,645,689	9,849,246	159,721,491	4,949,465	4,228,171	7,012,183	102,280	2,981
ITALY		30,132,845	57,844,017	18,773,824	349,560,269	15,045,899	6,228,457	8,614,016	296,197	4,565

basin area shows an increasing trend that is higher than the national average but lower than the upward trend of other sectors.

In the Po river basin area, the number of municipalities is 3,251 the Total Agricultural Surface (SAT) is 6,458,942 ha while the Agricultural Surface Used (SAU) is 63% of SAT (4,095,852 ha). The number of farming companies is 639,033 with an average dimension of 6.4 ha of SAU. The family-run farming activities (without or with SAU less than 1 ha) are 38% of the total farming companies, while the large or specialized farming companies (with SAU greater than 50 ha) are 1% of the total.

The cultivation type was used as an indicator in order to clarify agricultural evolution and land use change. The Po database stores significant values regarding the evolution of arable, forested and urban areas over the last 30 years (1971–2001) (see also Fig. 11).

Nutrient release from agriculture is associated with the management of agricultural areas (i.e. agricultural practice and fertilizer use), which is the most important element in estimating the relevance of this sector in terms of exerted pressures. The tonnage of fertilizer applied on the SAU for the six main regions of the Po Catchment is reported in Table 6. The highest values are observed for the Veneto, Piemonte and Lombardia regions were the highest level of specialized agriculture is found.

The implementation of Agricultural policies such as the Reg. CEE 1765/92 (PAC), the Best Agricultural Practice guidelines (DM MiPAF 19/04/99) was evaluated in order to understand the evolution of this Driver.

After the PAC implementation the cereal crop distribution in the Po area changed. The increase of cereal cultivation created a decrease in pasture and meadows. The resulting problems include the increase of chemical and organic fertilizer input. After the implementation of the nitrate directive a great effort was made by both Stakeholders (Farmers Association) and Institutions (Environmental agencies) seeking to reduce nutrient release.

Livestock Livestock activity is carried out on 3.1 million ha, and accounts for about 55% of national livestock production. In the early 1990s, approximately 4 million cattle and 5 million pigs were raised in the Po valley.

The main problem connected with livestock rearing is sludge spreading that in most cases is directly distributed on agricultural areas. Released nutrients are routed via the soil/groundwater system (diffuse sources emission). Animal manure is sometimes used for pasture fertilization.

In the last decades, a shift in livestock activity towards industrial activity has lead to its concentration in a few provinces such as Bergamo and Brescia, which are two hot spots in the Po area.

In order to contain pollution coming from livestock activity, the ABP released Deliberation N.12 (1996) that

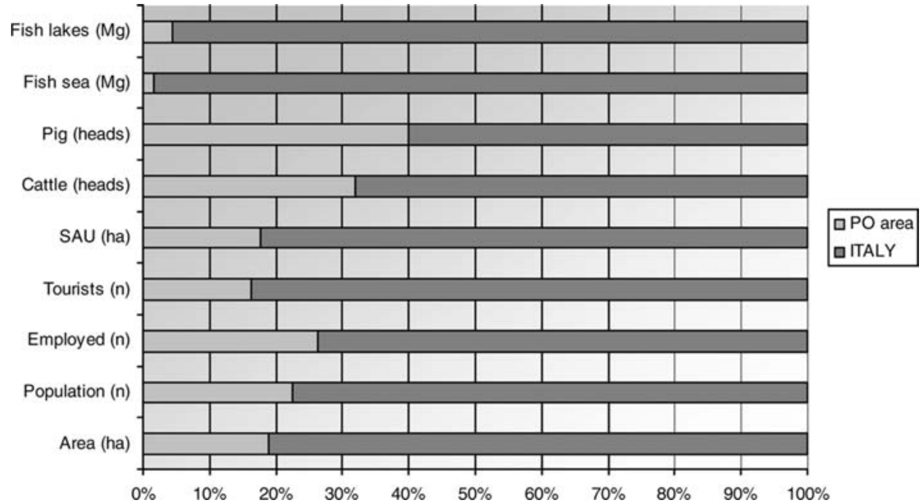


Fig. 8 Main economic indicators adopted to evaluate the national economy

includes a set of restrictions for manure spreading, particularly taking into account the necessity to preserve vulnerable areas.

Industry About 37% of national industry and 46% of the national employed population is located in the Po area, with 3.2 million employees in industry and 2.8 million in the tertiary sector. Among different industrial activities present in the area, chemical and engineering industries, textile, paper and food production are the most important.

The indicators selected to study industrial trends are the number of local enterprises and the number of employees. A detailed analysis of industrial activity was made for each region starting from the National Emission and Sources Inventories (INES database D.L 372/1999) that was established according to the implementation of the Integrated Pollution Prevention and Control (IPPC Directive 96/61/EC). Industrial activity is centred in Lombardia as reported in Table 7, where there is the major concentration of metallurgical and chemical industries. A relevant number of industries is also found in Bergamo and Brescia, which represent two important hot spots of the basin area.

At the environmental level, the increase of industrial activity involves the necessity to improve WWTPs, in order to assure a reduction of nutrient emissions into the river system.

Population and waste water treatment plants The total population amounts to approximately 17 million inhabitants. The population density in the Po basin is 232 p/km^2, the highest density is observed in the Lambro-Olona-Seveso catchment (1,478 p/km^2) while the minimum levels are located in the upper parts of the Trebbia and Parma sub-basins (25 p/km^2).

The sewage system and the number of WWTPs is actually not sufficient to cover population growth and industrial development. After the application of Law 319/76, a system of sewage was developed, covering 85% of the resident population, which are mainly (80%) mixed systems for both sewage and wastewater, while separate systems (20%) were developed only in the last 20 years. Furthermore, industrial waste water that is supposed to be treated independently before reaching civil wastewater plants or discharges, are not treated at all in some small and medium size industries scattered in the Po valley.

In recent years, after the implementation of European Directive 271/91/EC whose specific goal is the improvement of the WWTPs, local authorities and institutions prepared strategic plans to meet European deadlines. The deadlines and goals established by Italian legislation (Laws 36/1994 and 152/1999) concerning sewage systems and waste water treatment plants can be summarized as follows:

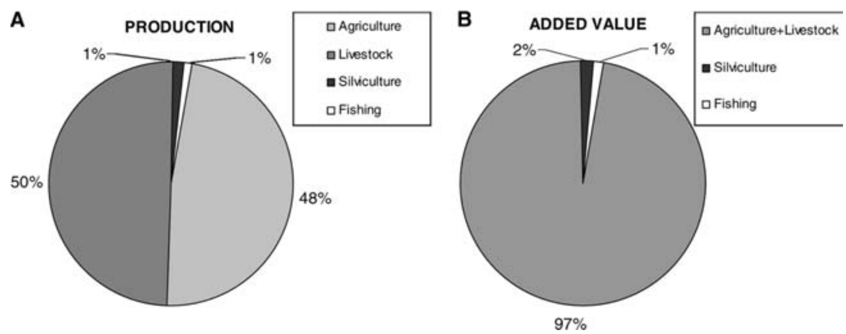


Fig. 9 Percentage contribution of agricultural sectors to Production and Added Value for the Po catchment Area

Table 4 Production and Added Value (year 2000 prices) in different agricultural sectors and per region of the Po Catchment

	Ratio Region-Catchment (-)	Production (€×10^6)						Added Value (€×10^6)			
		Agriculture	Livestock	Agriculture + Livestock	Silviculture	Fishing	Sum	Agriculture	Silviculture	Fishing	Sum
Piemonte	1.00	1,813	1,289	3,250	16	10	3,277	1,958	14	8	1,980
Valle d'Aosta	1.00	17	45	65	0	0	66	36	0	0	36
Lombardia	1.00	1,952	3,478	5,659	110	37	5,807	3,307	93	31	3,430
Trentino-Alto Adige	0.13	622	311	963	50	7	1,020	669	42	6	717
Veneto	0.05	2,323	1,791	4,332	17	189	4,537	2,772	14	152	2,938
Liguria	0.29	605	84	724	5	84	813	594	4	67	665
Emilia-Romagna	0.63	2,855	2,007	5,040	34	106	5,180	3,219	28	83	3,331
Total		10,187	9,005	20,033	232	434	20,699	12,554	195	348	13,097
ITALY		26,285	13,923	42,381	496	1,340	44,217	2,564	417	1,011	29,992

Table 5 The role of tourism in the catchment and coastal zone

	Presences (n)	Average annual residence time (days)
Piemonte	8,699,397	3.3
Valle d'Aosta	3,254,401	4.1
Lombardia	23,846,814	3.1
Trento	13,651,140	5.1
Veneto	57,610,399	4.8
Liguria	15,252,558	4.5
Emilia-Romagna	37,406,782	4.9
Total & Mean	159,721,491	4.3
ITALY	349,560,269	4.3

1. before 2005, 80–90% of population will be connected to sewer systems,
2. before 2005, towns with population of 10.000–15.000 must have WWTPs with primary and secondary treatments.

More restrictive measures are adopted by the ABP, which is responsible for the reduction of eutrophication in the North West Adriatic Sea. All ABP regulations, like the WWTP improvements, are implemented at a local level by the Regions (Emilia Romagna, Lombardia and Piemonte) that have the responsibility to include them in the Regional Protection plans.

Legislative framework A report on relevant Environmental National and International Treaties and Regulations was made in order to complete the frame of the driving forces. It was analysed the response of the Italian Legislation (reception of European Environmental Directives), and the impact of legislative restrictions. The connection between environmental degradation and evolution of the legislative framework was preliminary evaluated (Trombino et al. 2002), an exhaustive analysis of possible legislative strategies for eutrophication reduction and ecosystem restoration can be found in G. Trombino et al. (2004).

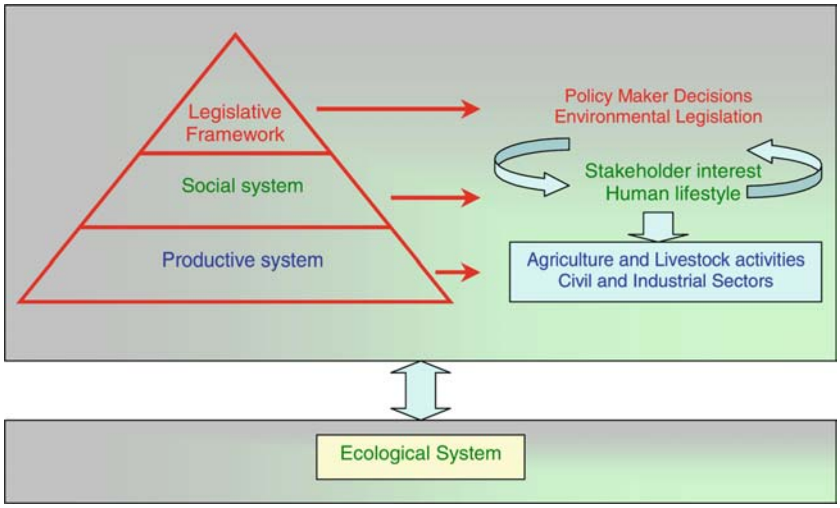
Pressures

The situation in the Po catchment shows an area heavily affected by anthropogenic pressures; organic load is equivalent to that produced by 114 million inhabitants, though the total population is approximately 17 million inhabitants (ABP 1999a, b).

*The description of the environmental Pressures provides the measure of **how** the driving forces acting at catchment level release nutrients into the environment.*

The most interesting aspect investigated is the evaluation of nutrient loads, i.e. anthropogenic Pressures from a socio-economic perspective. The relevance of each Driver on the eutrophication is estimated using a socio-economic matrix (Table 8) that evaluates the nitrogen and phosphorus loads (Trombino et al. 2003). The potential loads of nutrients that may enter into the

Fig. 10 Conceptual structure of the ecological and socio-economic systems interaction adopted to develop the scenario analysis



river system are estimated multiplying the Reference Units (animals, hectares, employees and inhabitants) selected for each driver category with their respective loading factors (LF) (Table 8). LF use is clarified by ABP (1999a, b).

The historical trends of potential nitrogen and phosphorus loads were estimated in order to understand the relationship between socio-economic evolution of the Po Basin area and the progressive ecosystem degradation (Figs. 12, 13). For this purpose socio-economic datasets from the last 30 years were combined with the socio-economic matrix, the latter is useful for modelling activities and scenario analysis because it provides the interface between socio-economic development and the expected change of nutrient fluxes (Pressures exerted from Driving Forces).

State

The State is the starting point of the scenario analysis providing us with both the current qualitative state of superficial and coastal waters and the percentage of parameter (nutrient) reduction that should be achieved in order to reach WQOs.

The state evaluation was made both at catchment level and at coastal zone level having in mind that the eutrophication phenomenon of the Adriatic Sea is directly connected to the nutrient loads discharged from the Po River.

As established by the Italian Water Framework Directive Legislative Decree 152/99, two combined indicators are used for the classification of the qualitative state of superficial waters: the extended biotic index (EBI), as the ecological indicator, and the Macro-descriptors Pollution Level (LIM) as the chemical indicator. The latter is calculated on the basis of a set of

Fig. 11 Land use changes in the Po River Basin Area

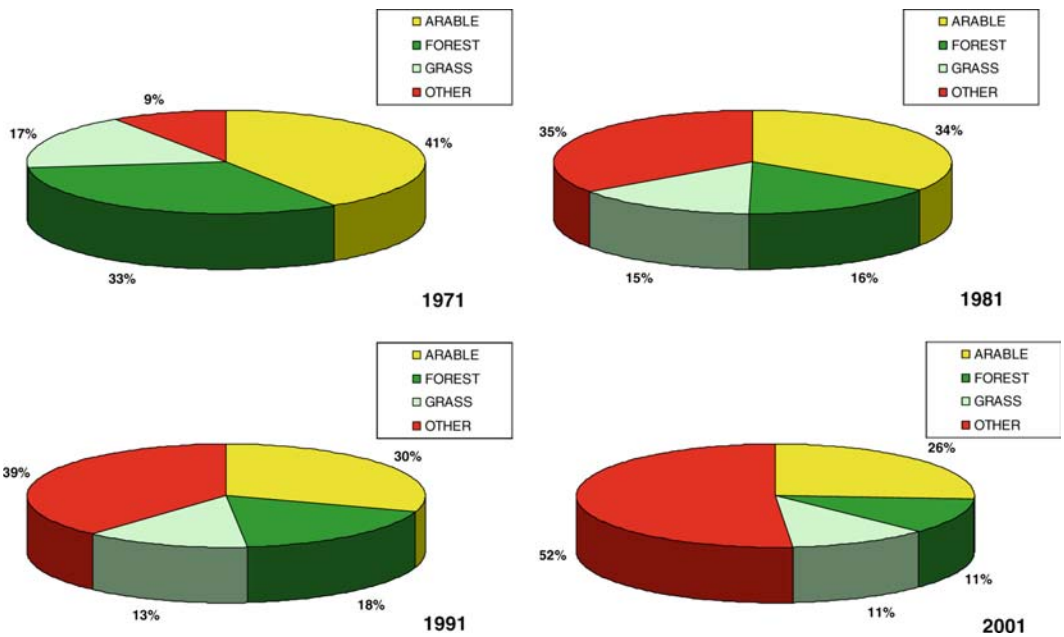


Table 6 Amount of fertilizer used for agriculture in the Po Catchment versus the total amount used in Italy

Region	Fertilizer Units distributed on the arable lands (Mg $year^{-1}$)			
	N	P_2O_5	K_2O	Others
Piemonte	131.1	79.5	67.6	14.2
Valle d'Aosta	37.6	38.1	13.0	0.0
Lombardia	137.8	74.6	88.6	19.8
Veneto	173.8	120.1	114.4	11.8
Emilia Romagna	67.9	51.6	18.9	4.4
Liguria	143.7	182.3	210.1	51.3
Italy	96.0	75.0	50.0	12.0

macro-descriptors i.e. N–NO_3, N–NH_4, P-tot concentrations, BOD_5, COD, Dissolved Oxygen Rate and *Escherichia coli*. Qualitative river state is classified in five classes: *Elevated, Good, Sufficient, Bad and Very bad*, which are derived by combining the EBI and the LIM levels and assuming the result to be the worse of the two. The classification of the Po River and the main Tributaries is reported in the Figs. 14 and Fig. 15. The two figures show the Po river water discharge, the position of the main tributaries and their qualitative classification in order to understand the neuralgic points. The LIM (Fig. 14) shows qualitative levels between *Good* and *Sufficient* except for the part of river connected to the Lambro (Milan Area) discharge. Combining the LIM and the EBI indices (as prescribed by the Law 152/99), the qualitative state ranges between *Sufficient* and *Bad* levels. This result shows that the river ecosystem is seriously damaged. Biodiversity loss is an evident aspect outlined by the EBI distribution and is probably the result of the major economic development in the last 20 years.

The LIM classification is in good agreement with the nutrient reduction observed in the last 10 years, after the application of environmental strategies in order to reduce eutrophication. More details about the connection between the environmental legislative decree and the environmental response observed are under evaluation (G. Trombino et al., 2004).

The assessment of the state of the Northern Adriatic Sea was made using the Trophic Index (TRIX) indicator that is recognized, at a national level, as the only available State indicator able to describe the qualitative state of marine waters. This indicator refers to the liquid matrix without taking into account sediments or biota. The TRIX index is calculated by combining four parameters, Dissolved Oxygen, Chlorophyll-a, Total Phosphorus and Inorganic Nitrogen. It is a meaningful indicator for the description of eutrophication of coastal waters which are strongly influenced by soil input like the Adriatic Sea, because the TRIX is directly connect to the main Drivers (i.e. population density) and the main Pressure factors (i.e. productive activities and potential organic loads). The TRIX values for the Adriatic Sea were extracted from the ANPA (National Agency for Environmental Protection) Annual Report and it shows a Qualitative Water State '*Poor*' as defined in Law 152/99 (Fig. 16a, b).

Impact

As illustrated above, the WQOs fixed by Italian Law 152/99 are very far from the targets that should be achieved by December 2016 when all water bodies' classes must be 'Good'. Having in mind the development of environmental policies that would assure sustainable development, institutions such as the Po River Basin Authority and National and Regional Environmental Agencies promoted a set of measures and implemented a number of Strategic Plans aimed to reduce eutrophication level in the Northern Adriatic Sea.

Table 7 Number of industrial Plants and industrial hot-spots in the Po River basin

Region	Metallurgical Industries	Energy Production Industries	Waste Disposals	Chemical Industries	Mineral Industries
Valle d Aosta	4				1
Piemonte	59	29	38	39	8
Lombardia	210	31	102	162	25
Emilia Romagna	81	15	54	40	22

Hot-Spots

Region	Province	Industrial Hot Spots
Piemonte	Torino	78
	Cuneo	47
Lombardia	Milano	132
	Bergamo	110
	Brescia	111
	Mantova	66
	Varese	59
Emilia Romagna	Ravenna	38
	Modena	41

Table 8 The socio-economic matrix reports the loading factor and the potential load for each selected indicator of the driving forces. The unit (U) is different for each driving force and specifically are hectares (ha) for the agriculture and heads (h) for livestock, population and employees

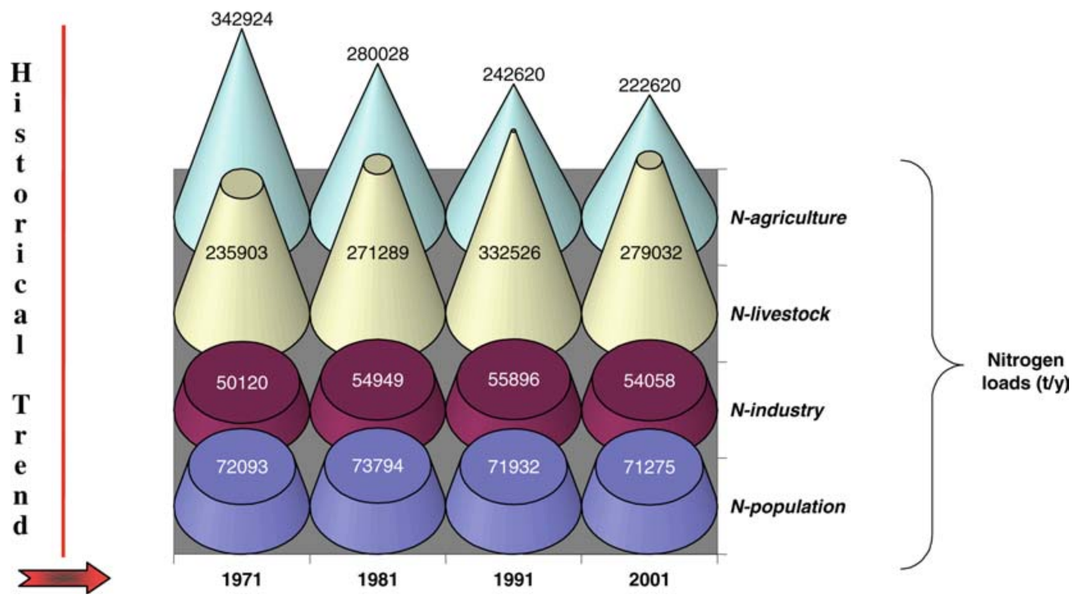
Driving Forces	Selected Indicators	Loading factor		Potential loads	
		N (kg U^{-1} $year^{-1}$)	P (kg U^{-1} $year^{-1}$)	N (ton $year^{-1}$)	P (ton $year^{-1}$)
Agriculture	Cereals	110	35	242,619	86,885
	Wheat	200	45		
	Horticulture	120	65		
	Fodder Plants	40	40		
	Vineyard	100	20		
	Olive trees	110	35		
	Orchards	110	35		
	Citrus Orchards	110	35		
Livestock	Pigs	15	4.5	332,526	68,020
	Cattle	60	9		
	Sheep	7	2.8		
	Poultry	0.5	0.2		
	Equine	58	9		
Population	Inhabitants	4.5	0.6	71,932	9,590
Industry	Employees	10	0.1% of civil	55,896	959

In order to evaluate possible management strategies, it is necessary to understand the environmental response to changing nutrient fluxes. This implies a detailed assessment of the impact in terms of nutrient variation registered in the Po River system and the appearance of algal-bloom, mucilage and red tides in the Adriatic Sea.

Nutrients trend

The time series analysis of nitrogen and phosphorus loads at the outlet station Pontelagoscuro, define the nutrient bulk discharged into the Adriatic Sea and the trend of this bulk during the last 20 years as reported in Fig. 17 and Fig. 18. The left part of the two figures shows the historical trend of nutrient concentrations. As discussed earlier, the nitrogen and phosphorus concentrations are the result of the interaction between ecosystem and socio-economic system (Fig. 10). Hence is necessary to improve our understanding of the relationship between socio-economic mechanisms and the ecological state of superficial waters in order to evaluate possible management strategies aimed to reduce the eutrophication. This aspect was investigated by ABP in the context of the '*Piano Stralcio per il controllo dell'Eutrofizzazione*' (Strategic plan for eutrophication reduction). Using the SIMCAT model, the ABP estimated Pressures exerted by the main Driving forces in terms of nutrient concentrations as reported in Table 9. The model runs were made removing each driving force in order to highlight the relative pressure of each socio-economic activity. Table 9 shows that Phosphorus concentrations measured at Pontelagoscuro station come

Fig. 12 Trends of potential Nitrogen loads calculated for each Driving force acting in the Po Area



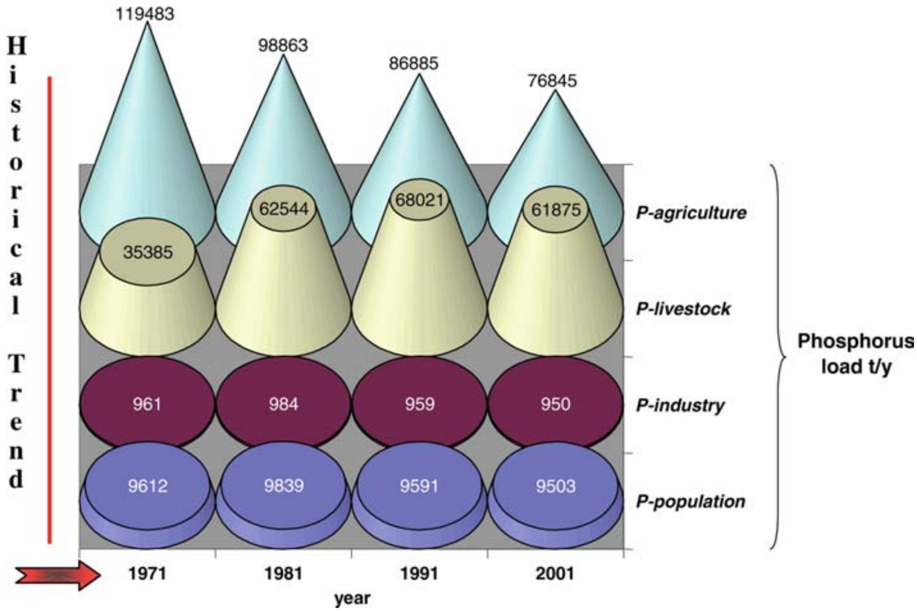


Fig. 13 Trends of potential Phosphorus loads calculated for each Driving force acting in the Po Area

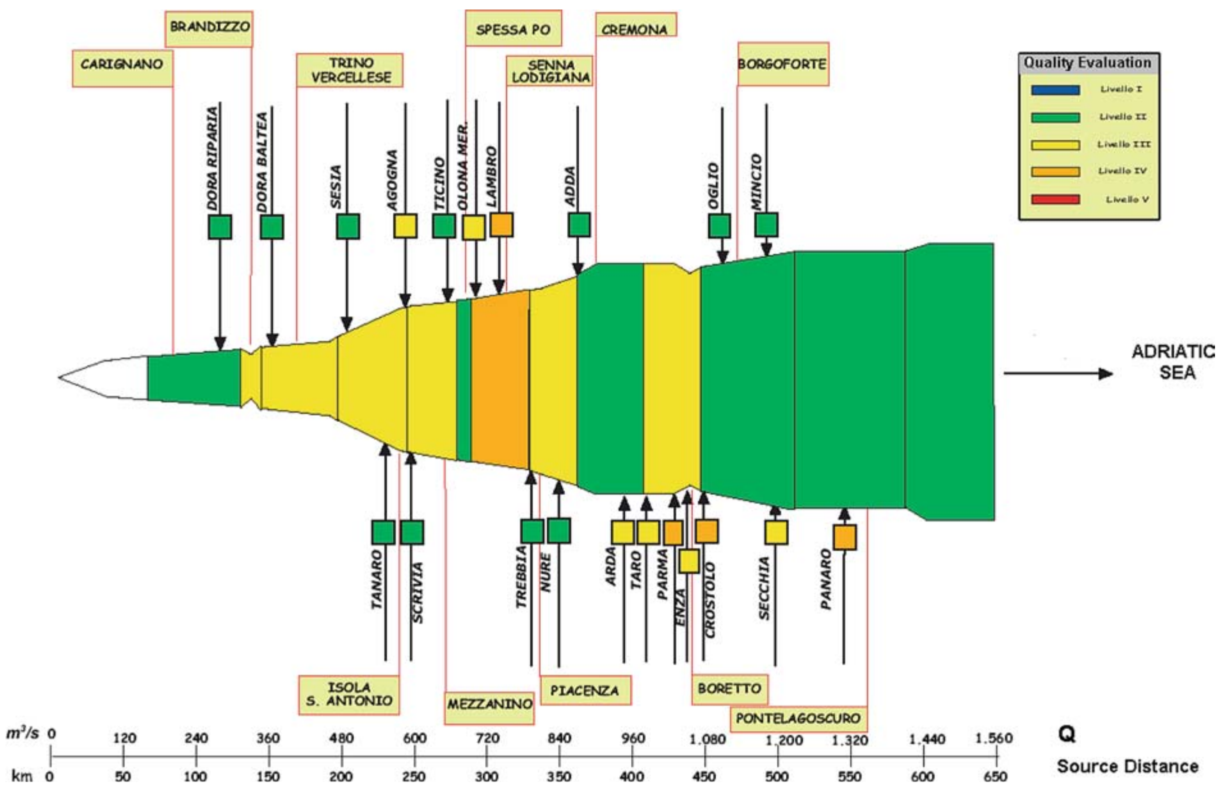
predominantly from urban systems (71%) while only 28% is connected to the agricultural and livestock sectors. Nitrogen concentrations is also connected to urban systems (52%), and 48% to agriculture-livestock activities.

Impact in coastal zone

The impact of socio-economic activities at catchment level affects the CZ and depends upon a complex combination of different mechanisms that act with different time scales and are characterized by different scales (geographic) of influence.

The assessment of the Impact in the CZ is related to the evaluation of both ecological and socio-economic factors (Table 1). The most important ecological

Fig. 14 Evaluation of Macro-descriptors Pollution Level (*LIM*) for the Po River and the main Tributaries. Qualitative level is evaluated using Macro descriptors on the basis of the table reported in the DL 152–1999



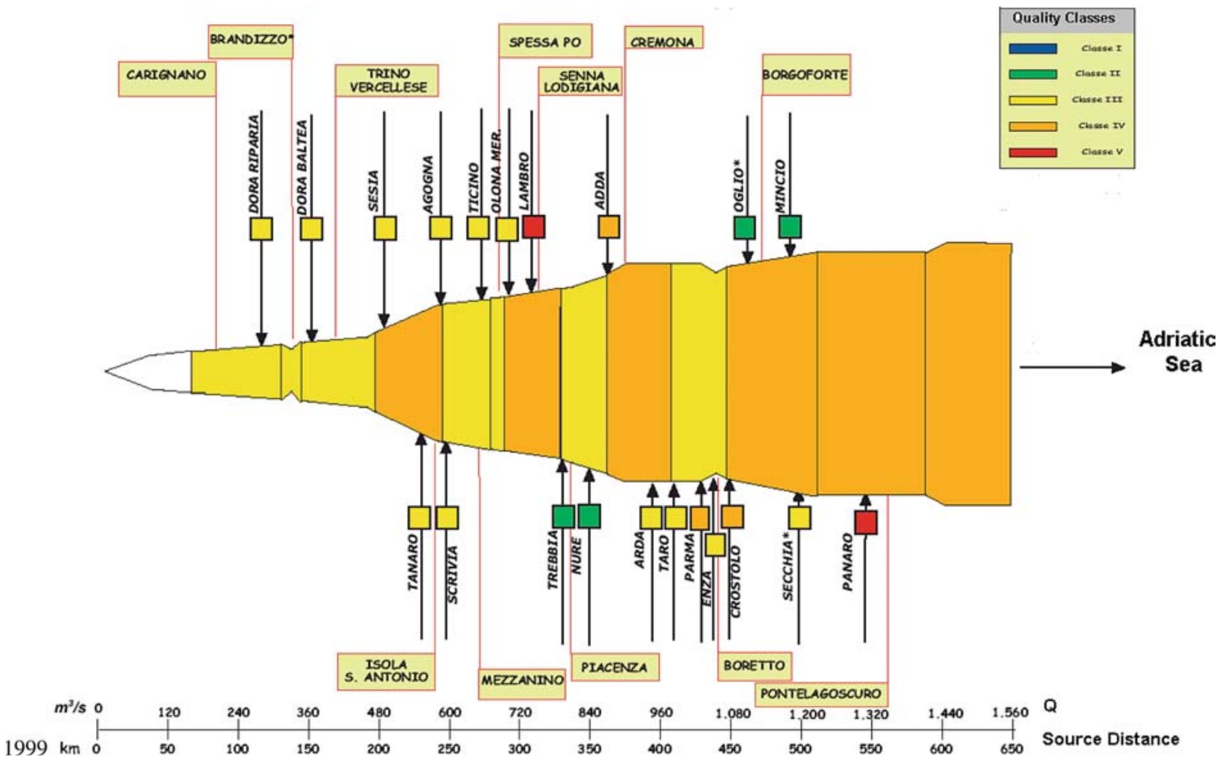


Fig. 15 Evaluation of extended biotic index (*EBI*) for the Po River and the main Tributaries. Qualitative classification was made using EBI and according also to DL 152–1999

parameters are Oxygen, Chlorophyll-α and nutrient concentrations (Fig. 19) as well as the appearance of algal blooms and mucilage. Fig. 19 shows long term trend (1990–1998) of average values of Dissolved Oxygen (DO), Chlorophyll-α, Total Nitrogen and Total Phosphorus.

Dissolved oxygen Coastal areas, particularly those characterized by eutrophication, can display quite high surface oxygen concentrations. However, a few meters under the surface, these concentrations are drastically reduced and under particular conditions may reach critical values. DO is measured weekly along the coastal area of the NA. In summer, the most critical period, the values observed are in the range 6.1–8.1 mg l^{-1} in surface waters and 2.8–5.6 mg l^{-1} in deep waters.

Chlorophyll-α Chlorophyll-α displays average and maximal values that are higher than those reported anywhere else along the Italian coast. This is certainly associated with the Po catchment influence. As for DO, chlorophyll-α is measured weekly along the coastal area and in the open sea as well. Highest concentrations are observed in the coastal area in January (40 g l^{-1}) and are due to the extended diatom blooms that characterize the entire coastal area. Lower values are observed for surface waters (6.2–7.4 g l^{-1}) and for deep waters (2.8–5.6 g l^{-1}).

Nutrients NH_4^+ concentrations are generally higher in proximity to the coast, decreasing towards the open sea. This distribution shows that ammonia concentrations are due to local algal bloom events. These are fostered by the loads associated with the discharge of the river system and coastal anthropogenic loads. Nitrite and nitrate concentrations follow typical seasonal patterns, with highest values in winter (up to 2 μmol l^{-1}, NO2 and 30–40 μmol l^{-1} NO3 in December), and lowest in the May–September period, when the discharge from the Po catchment is lower. Ammonia nitrogen shows highest concentrations in December (5 μmol l^{-1}) and in August (4 μmol l^{-1}), when salinity in the coastal area is high.

Total phosphorus shows a very variable pattern. This variability is strongly associated with many algal blooms appearing during the year. The low value of <0.6 (μ mol l-1) was observed in June, and highest values (up to 1.2 μ mol l-1) in autumn when, as with ammonia, the higher concentrations are observed along the coast. Total phosphorus also displays a negative gradient along the North–South coast transects with highest value of 8 (μ g^{-1}) in the southern part of the NA basin.

Primary production and mucilage Even if reported in the past, algal bloom events are now more frequently observed (Degobbis et al. 1995). They are becoming chronic and are of growing importance in biomass production. The most important plankton groups involved are diatoms and dinoflagellates. These blooms appear most frequently along the coast from the Po delta spreading towards the South for up to 250 km. The blooms are accompanied by drastic hypolimnic oxygen depletion that causes a major mortality of benthonic

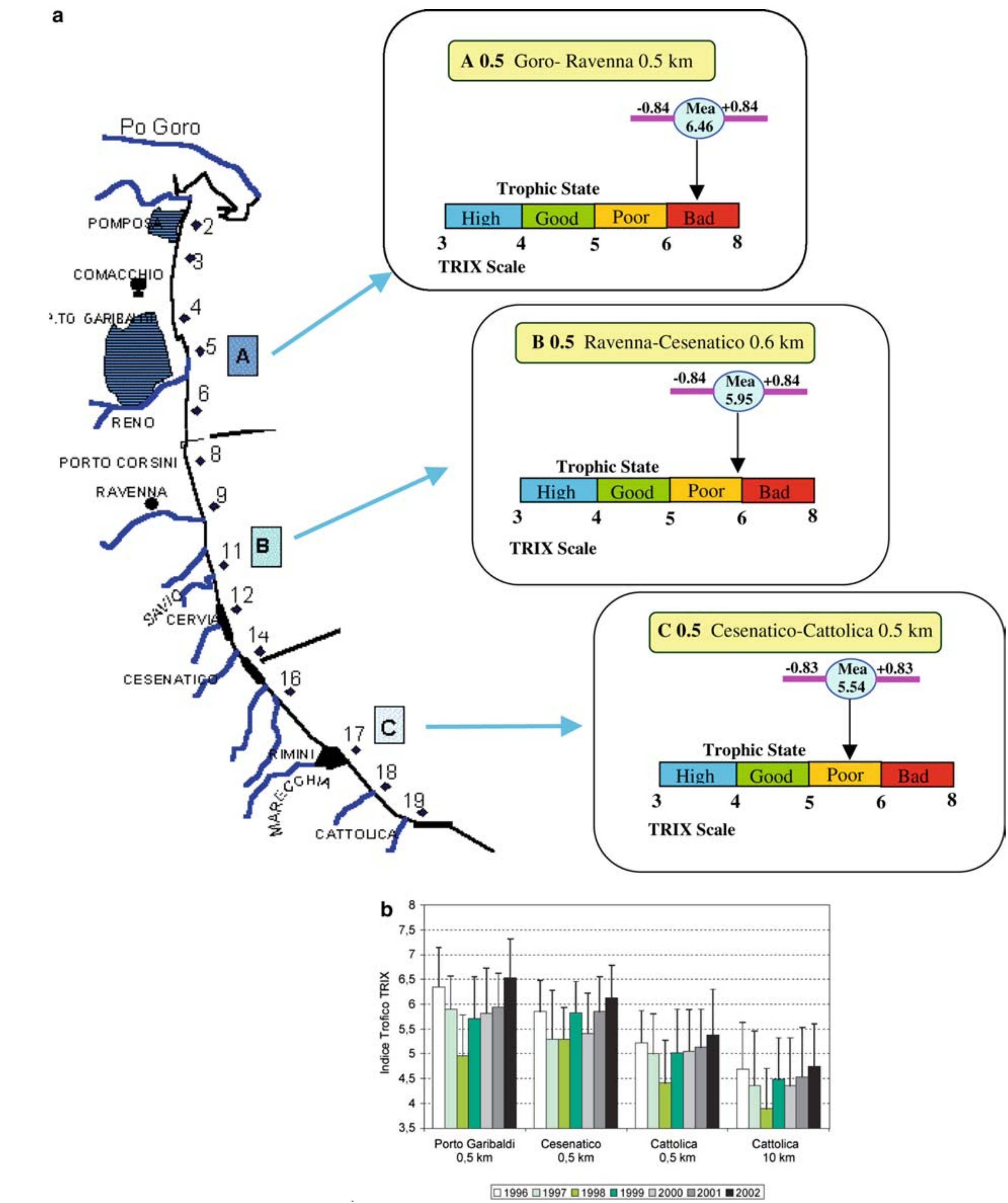


Fig. 16 Distribution of average values of the TRIX for sub-areas *A, B, C* of the North Adriatic Coastal Zone for the year 2002 (**a**). Comparison of average values of TRIX Index for different sampling stations (1996–2002) (**b**)

animals leading to a negative impact on fishery activity. During summer, these blooms impact also on the tourism that on the Italian Adriatic coastal area can be as high as 40–50 million visitors per year. As result of phytoplankton activity, polysaccharide exudates entrap suspended organic and inorganic material to form the so called "mucilage" (MARBENA 2003).

In the Adriatic Sea, there were a long series of environmental changes and/or fluctuations which date back to the 18th century:

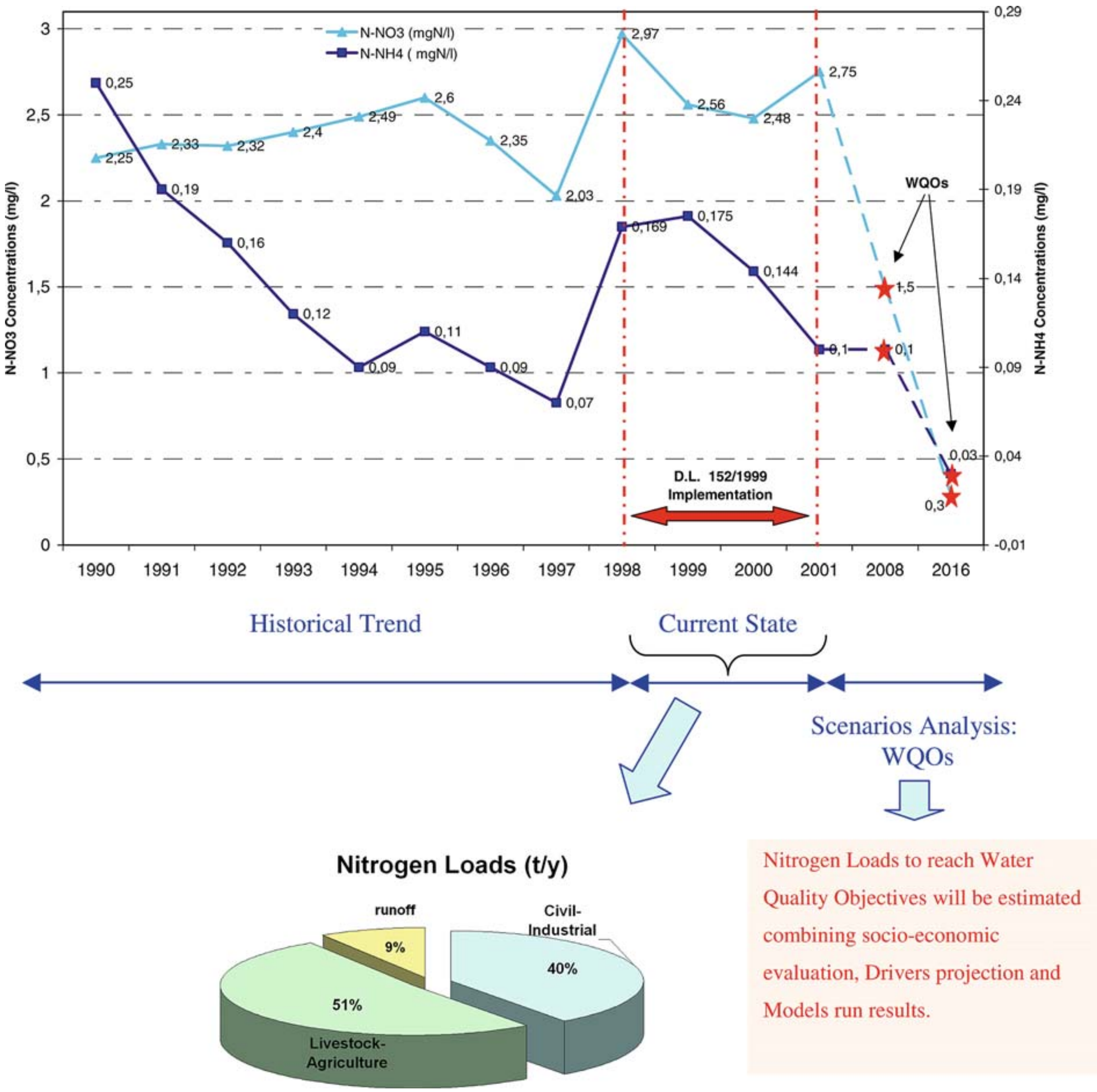


Fig. 17 N–NH_4, N–NO_3 concentrations measured at Pontelagoscuro station. The *left part* of the figure shows the nutrients trend and the current situation while the *right part* shows Water Quality Objectives of the DL 152–1999. Combining measured concentrations and pressure analysis is possible to assess the relevance of each socio-economic factor into Nitrogen loads

– Mucilage events were registered since 1729, however reliable information are available since 1872, and thereafter almost every 10 years until 1930 (Fonda Umani et al. 1989). There is some doubt over a record in 1950, but they definitely did not reappear in the 1960s and 1970s (Fig. 20).
– Red tides along the Emilia Romagna coasts and in some other restricted Adriatic environments appeared at the end of 1960s (Fonda Umani 1996) and reached their largest diffusion in the early 1980s. Red tides and mucilage events appear to exclude each other.

Table 9 Pressures Analysis. The current state evaluation of nitrogen and phosphorus concentration (mg/l) was made with SIMCAT model by ADBP

Nutrient	Current state (mg/l)	Current State without agricultural contribution (mg/l)	Current State without urban contribution (mg/l)
P (average value)	0.14 (100%)	0.10 (71%)	0.03 (28%)
N (average value)	2.3 (100%)	1.2 (52%)	1.1 (48%)

Nitrogen and phosphorus concentrations were calculated considering the contribution of all driving forces (2nd column), without the agricultural contribution (3rd column), and without urban contribution (4th column). Within brackets is reported the relative contribution of the driver

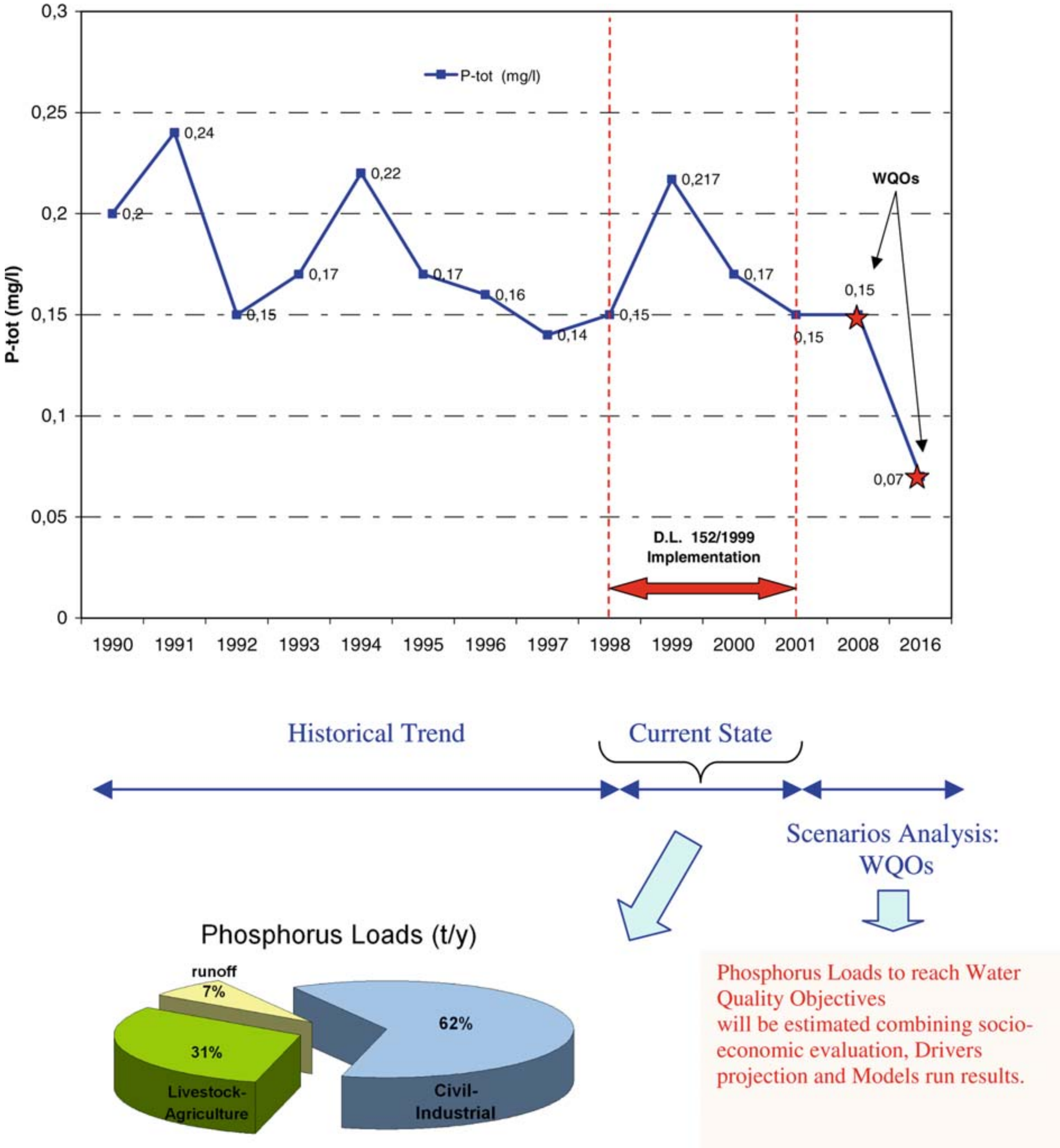


Fig. 18 P-tot concentrations measured at Pontelagoscuro station. The *left part* of the figure shows the nutrients trend and the current situation while the *right part* shows Water Quality Objectives of the DL 152–1999

– Massive swarms of Jelly reached their maximum at the beginning of ‘80s, and affected netzoo-plankton communities; reducing their biomass and biodiversity (Cataletto et al. 1995) thus leading to an increase of ungrazed phytoplankton, whose biomass reached extremely high values.
– Ungrazed red tides and ungrazed phytoplankton caused an increase of phytodetritus sedimentation with consequent bottom oxygen consumption which sometimes gave rise to benthic mass mortality.
– Reduction in benthic communities could have increased the refractory carbon storage at the bottom, and via diffusion in the whole water column, and possibly this can be one of the causes of colloidal carbon increase, which eventually leads to mucilage aggregation.

It seems that in the years affected by mucilage, there is a ‘‘diversion’’ from the ‘‘usual’’ food web evolution, mostly due to an increase in primary production ,which in turn seems to be due to higher photosynthetic efficiency (Fonda Umani et al. 2002).

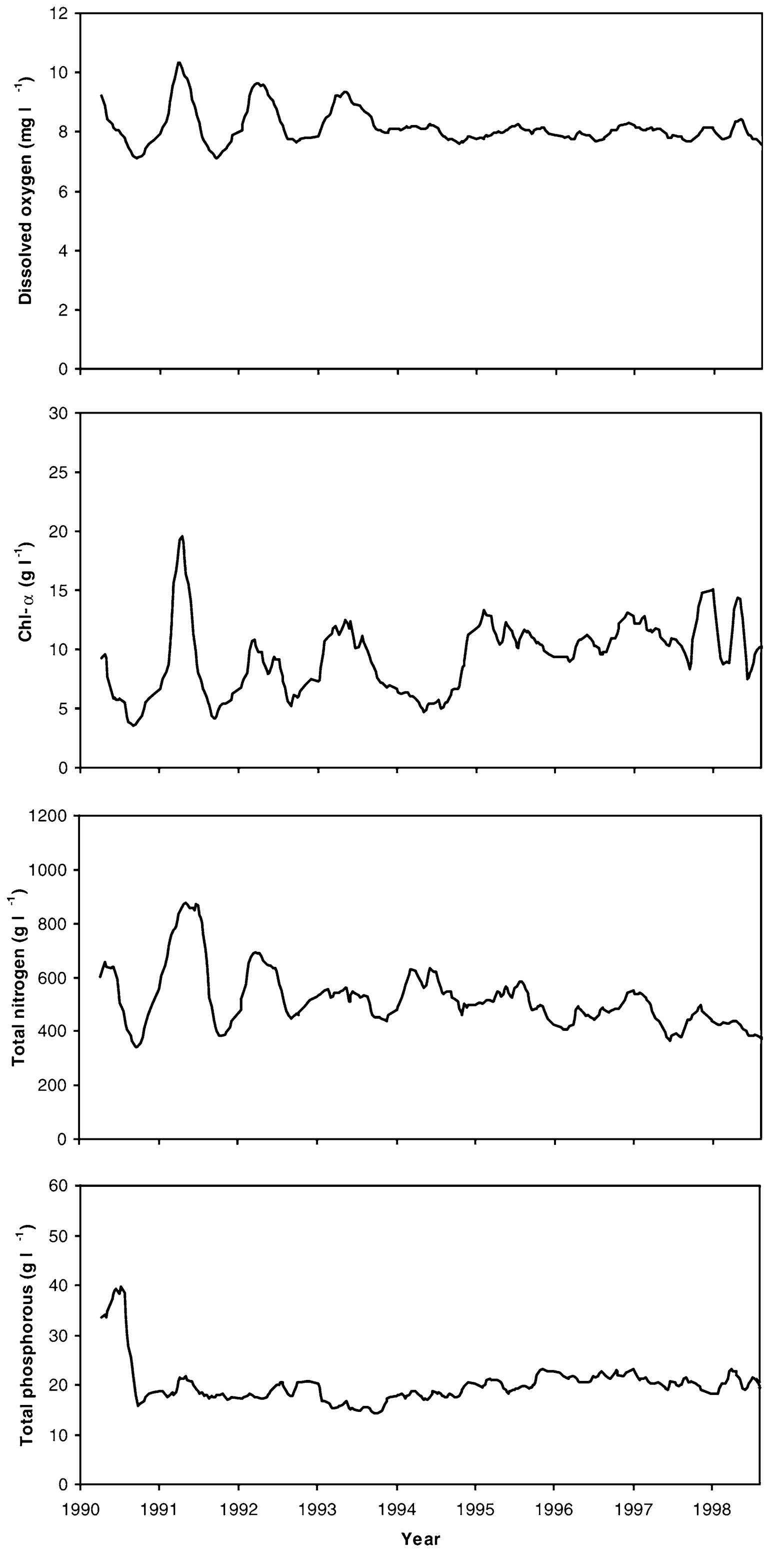


Fig. 19 Historical trends of Dissolved Oxygen, Clorophyll-α, Total nitrogen and Phosphorus measured in CZ. Data were visualized in the average form ($n = 16$)

Response and set-up of scenarios

The preliminary assessment of the DPSIR approach performed for the Po Catchment and NA CZ continuum provides clear identification of Driving forces. They are the sources of environmental pressure in terms of nutrient release considering the alteration of the qualitative status of fresh and marine waters.

The next task is to build future projections and scenario analysis, which combine socio-economic and legislative factors, and their feedback into the system framework, with ecosystem restoration and 'Sustainable Development' as the two fundamental criteria.

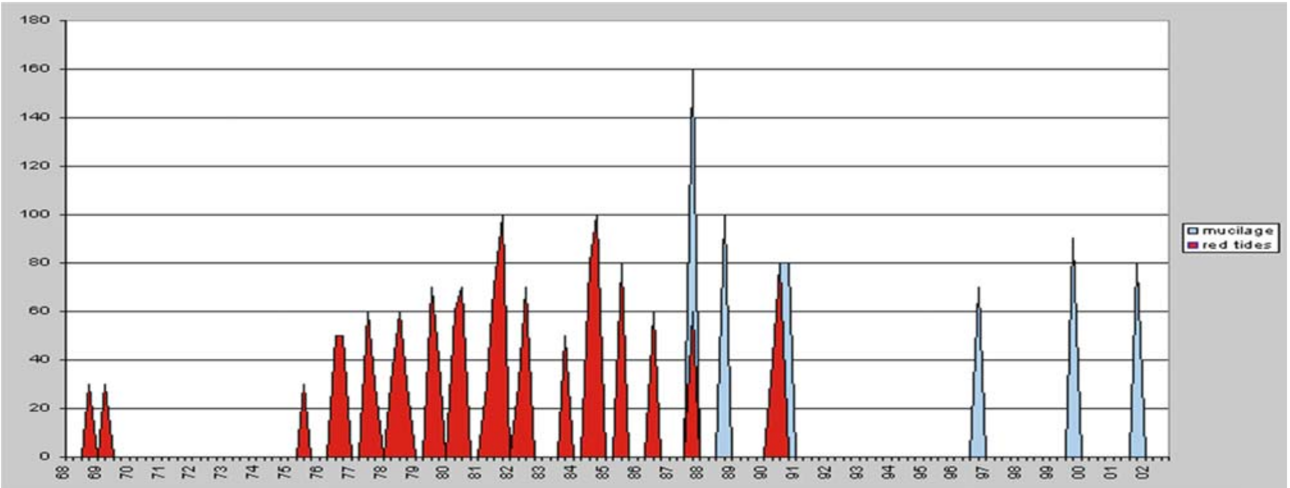


Fig. 20 Mucilage and red tides events in the Adriatic Sea (from MARBENA, 2003)

Possible future development of the socio-economic activities will be evaluated using different storylines that derive from the analysis of Drivers behaviour over the last 20 years.

The socio-economic change of the last 20 years both at catchment level and in the CZ shows an increase for each productive sector, but the nutrient loads decreased. This effect is connected to the implementation of environmental legislation aimed at the eutrophication reduction. The evaluation of environmental benefits deriving from the implementation of environmental legislation is under evaluation (G. Trombino and N. Pirrone, submitted) and will be used as a starting point for the development of water management strategies.

Combining socio-economic development with the implementation of the European Water Policies, different policy package (i.e. hypothesis for Business As Usual (BAU) and Policy Target (POT) scenario types) are evaluated. The scenario analysis evaluates the effect of different strategies using ecological and socio-economic models, i.e. the MONERIS model at catchment scale, the WASP model in CZ and the DEFINITE model for the cost-effectiveness analysis.

In this preliminary phase the platform to use an integrated modelling system able to evaluate the relative contribution of nutrient pathways associated with selected Driving forces aimed to evaluate the integration between biogeochemical mechanism of nutrients in the Po Basin Area and the resulting concentrations in the analysed CZ was prepared. As mentioned in the previous sections, the development of this innovative application of the DPSIR approach required the capability to manage different type of parameters and use them for the specific model needs.

The MONERIS model was used to reproduce the current situation in terms of nutrients concentrations and loads after a preliminary phase of calibration performed for selected periods (1990–1995 and 1996–2001). The modelled nutrient loads at catchment level will be linked to the CZ model for the evaluation of the coastal response corresponding to a change of the nutrients balance in the catchment area. In this way the effect of the different catchment management scenarios are propagated to the CZ model. MONERIS and WASP results are able to evaluate the effects of management strategies elaborated for each policy package.

Management strategies will be evaluated according to the feedback of the Policy Advisory Board (PAB) which includes members of the main Italian Environmental Institutions and Stakeholder Associations and performing a cost-effectiveness analysis.

The evaluation of the DPSIR framework as a tool to develop possible strategies to support the implementation of the new European Water Policy is the goal of the EUROCAT Project (http://www.cs.iia.cnr.it/EUROCAT/project.htm).

The Po Cat Consortium is preparing the evaluation and the scenario 'Business As Usual' and 'Policy Target'. The information generated from the scenarios should assist policy makers in their search for efficient, effective and equitable coping strategies and policy options for integrated and sustainable CZ management.

The scenario evaluations will take into account the Implementation of European Water policies on a regional scale giving particular relevance to the Po River Basin Authority planning activities for eutrophication reduction, the main environmental legislation, and their effects on ecosystem restoration. Evaluating the evolution of legislation over the last decades compared with the evolution of the eutrophication phenomenon it should be possible to understand the rule of governance, which seems to be the driving force able to control the other drivers. The outcome of EUROCAT should be considered as a contribution to further elaborate the current institutional strategies.

Acknowledgements This study is part of the EUROCAT project founded by the European Commission DG-Research (Contr. No. EVK1-CT-2000-00044). EUROCAT is also part of the European Land Ocean Interaction Studies (ELOISE) network. We would like to thank the "Autorità di Bacino del Po" (Po Watershed Authority) for providing part of the data. Special thanks to Prof. Passino for providing the data and allowing its use.

Annex 1

Given the standard oceanographic sampling procedures, an expected situation would be to have parameters ($P_{s,t}$) measured in a certain number of sampling stations (s) over the time (t). In order to draw the CZ boundary, a two step procedure was implemented.

The first step normalizes the data over each single period (e.g. 1 year) to the minimum and maximum of the parameter for all the sampling stations in the given period with the following equation:

$$P^N_{s,t} = \frac{P_{s,t} - \min P_t}{\max P_t - \min P_t}$$

where max $P_t = \mathrm{Max}_s P_{s,t}$ and min $P_t = \mathrm{Min}_s P_{s,t}$ are the maximum and minimum for the period t. This first normalization is used to compare the (yearly) average situation in the CZ and allows the study of the effect of different (yearly) river discharge patterns.

In the second step, a further normalization is applied in order to differentiate the parameter spatially. The normalized values of the parameter are transformed in such a way that their minima and maxima (min and max of $P^N{}_{s,t}$ for each station) match the corresponding minimum and maximum of the average values (min and max of $< P_s > \; = \; < P_{s,t} >_t$) calculated for each sampling station on the whole dataset (totality of all the observation periods):

$$P^0_{s,t} = \min P + P^N_{s,t}(\max P - \min P)$$

where $\max P = Max_s \langle P_{s,t} \rangle_t$ and $\min P = Min_s \langle P_{s,t} \rangle_t$ are the maxima and minima of the averages for each sampling station calculated over the whole observation period, with $P^0{}_{s,t} \in$ [min P, max P].

In order to evaluate the effect of the stochastic long-term variability on each sampling station, the average of the observation period is defined as:

$$P^0_s = \left\langle P^0_{s,t} \right\rangle_t.$$

Correspondingly a standard deviation value ($\sigma\ P^0{}_s$) can be calculated for each sampling station. Indeed, these last values give information on the variability pattern of the parameter and allow the identification of the area of influence of the river discharge. Still a certain degree of arbitrariness remains, notably the choice of a limit range for the standard deviation.

References

ABP (1999a) Inquinamento delle acque superficiali e sotterranee. Autorità di Bacino del Po, Sottoprogetto 2.1. Parma

ABP (1999b) Uso del suolo e agricoltura. Autorità di Bacino del Po, Sottoprogetto 4.1. Parma

Algieri A, Cinnirella S, Trombino G, Pirrone N (2003) Sensitivity Analysis of the MONERIS Model: A First Step Toward the Model Calibration for the Po Catchment. In: Proceedings of European Conference on Coastal Zone Research: an ELOISE Approach, Gdańsk, Poland, 24–27 March

Behrendt H, Huber P, Kornmilch M, Optiz D, Schmoll O, Scholz G, Uebe R (2000) Nutrient Emissions into River Basins of Germany. Report No. UBA-Texte 23/00: 1–288, Umweltbundesamt Berlin, Berlin

Buddemeier RW, Smith SV, Swaney DP Crossland CJ (2002) The role of the coastal ocean in the disturbed and undisturbed nutrient and carbon cycles. LOICZ Reports & Studies No. 24, ii + 83 pages, LOICZ IPO, Texel

Cataletto B, Feoli E, Fonda Umani S, Sun Chen Y (1995) Eleven years net-zooplankton community in the Gulf of Trieste: time series analysis. ICES J Mar Sci 52:669–678

Cinnirella S, Trombino G, Pirrone N (2003) A Multi-Layer Database for the Po Catchment-Adriatic Costal Zone Continuum Structure for the Dpsir Framework Developed for the Implementation of the Water Framework Directive. In: Proceedings of European Conference on Coastal Zone Research: an ELOISE Approach, Gdańsk, Poland, 24–27 March

Cinnirella S, Buttafuoco G, Pirrone N (2005) Stochastic analysis to assess spatial distribution of groundwater nitrate concentrations in the Po Catchment (Italy). Environ Pollut 133:569–580

Copemed (2003) Advice, Technical Support and Establishment of Cooperation Networks to Facilitate Coordination to Support Fisheries Management in the Western and Central Mediterranean. Available at: http://www.faocopemed.org/en/index.htm

Degobbis D, Fonda Umani S, Franco P, Malej A, Precali R, Smodlaka N (1995) Changes in the Northern Adriatic Ecosystem and appearance of hypertrophic gelatinous aggregates. Sci Total Environ 165:43–58

EEA (1999) Environmental indicators: typology and overview. In: Smeets E, Weterings R (eds) Technical report no 25, p 19

Fonda Umani S (1996) Pelagic biomass and production in the Adriatic Sea. In: Palomera J, Rubies P (eds) The European Anchovy and its Environment. Sci Mar 60(Suppl):65–77

Fonda Umani S, Ghirardelli E, Specchi M (1989) Gli episodi di "mare sporco" nell'Adriatico dal 1729 ai giorni nostri. Regione Autonoma Friuli-Venezia. Giulia Dir Ref Ambiente, p 178

Fonda Umani S, Del Negro P, Larato C, De Vittor C, Pecchiar I, Azam F (2002) Major interannual variations in microbial dynamics in the Gulf of Trieste (Northern Adriatic Sea) and their ecosystem implications. SAME 8. Abstract Book

Franco P, Michelato A (1992) Northern Adriatic Sea: oceanography of the basin proper and of the western coastal zone. Sci Total Environ (Suppl):35–62

Marabini F (2003) The Po River delta evolution and the climatic changes. Marine Geology online papers. Available at: http://www.bo.ismar.cnr.it/testi/servizi/divulgazione/marabini%20po/podelta.htm

MARBENA (2004) Creating a long term infrastructure for MARine Biodiversity research in the European economic area and the Newly Associated states. Electronic Conference. Available at: http://www.vliz.be/marbena/index.htm

Organisation for Economic Cooperation and Development (OECD) (eds) (1993) OECD Core set of Indicators for Environmental Performance Reviews. Environment Monographs 83, Paris

Pernetta JC, Milliman JD (eds) (1995) Land-Ocean interactions in the coastal zone: implementation plan. IGBP Report No. 33. International Biosphere-Geosphere Programme, Stockholm, p 215

Rinaldi A, Vollenweider RA, Montanari G, Ferrari CR, Ghetti A (1995) Mucilages in Italian seas: the Adriatic and Tyrrhenian Seas, 1988–1991. Sci Total Environ 165(1–3):165–183

Schrimpf W, Druon JN, Dobricic S, Stips A (2003) Monitoring and assessment of eutrophication in coastal and marine waters of the Mediterranean and Black Sea. Presented in The IASON Conference

Tomasino MG (1996) Is it feasible to predict slime blooms or mucilage in the Northern Adriatic Sea? Ecol Model 84:189–198

Trombino G, Pesenti E, Pirrone N (2002) Evaluation of significant anthropogenic pressures and assessment of their impact on water bodies in the Po river Basin Area. In: Proceedings of SWAP Conference, 2–5 September, Norwich

Trombino G, Palopoli P, Pirrone N (2003) Implications of socio-economic development and national and European Legislation on the evolution of eutrophication in the Po River Basin Area. Presented at the European Conference on Coastal Zone Research: an ELOISE Approach, Gdańsk, Poland, 24–27 March

Trombino G, Pirrone N, Cinnirella S, Algieri A (2004) The influence of environmental legislation of the integrated river basin coastal zone management the Po catchment and North Adriatic Sea case study. In: Proceedings of the European Geosciences Union 1st General Assembly Nice, France, 25–30 April. Geophysical Research Abstracts, 6: 06960

Vollenweider RA, Rinaldi A, Montanari G (1992) Eutrophication, structure and dynamics of a marine coastal system: ten-year monitoring along the coast of Emilia-Romagna (Northwest Adriatic Sea). In: Vollenwider RA, Marchetti R, Viviani R (eds) Marine Coastal Eutrophycation. Sci Total Environ (Suppl):63–108

Vollenweider RA, Montanari G, Rinaldi A (1995) A statistical inferences about the mucilage events in the Adriatic Sea, with special reference to recurrence patterns and claimed relationship to sun activity cycles. Sci Total Environ 165(1–3):213–224

WRI (2000) World Resources 2000–2001. People and ecosystems. The fraying web life. World Resources Institute, Washington, p 389