

THE APPLICATION OF DPSIR (DRIVING-PRESSURE-IMPACT-STATE-RESPONSE) APPROACH ON SURFACE WATER BODIES

Dimitris ALEXAKIS¹, Ifigenia KAGALOU² & George TSAKIRIS³

- (1) Centre for the Assessment of Natural Hazards and Proactive Planning, Laboratory of Reclamation Works and Water Resources Management, School of Rural and Surveying Engineering, National Technical University of Athens, Athens, Greece, e-mail: dial@survey.ntua.gr
- (2) Department of Ichthyology and Aquatic Environment, School of Agricultural Sciences, University of Thessaly, Volos, Greece, e-mail: ikagalou@uth.gr
- (3) Centre for the Assessment of Natural Hazards and Proactive Planning, Laboratory of Reclamation Works and Water Resources Management, School of Rural and Surveying Engineering, National Technical University of Athens, Athens, Greece, e-mail: gtsakir@central.ntua.gr

ABSTRACT

Between the objectives of the Water Framework Directive (WFD; 2000/60/EC) are the establishment of a framework for the protection of water bodies and the achievement of “good ecological quality status” for all water bodies. This paper presents the methodological approach of DPSIR (Driving-Pressure-Impact-State-Response) as it is applied in Pamvotis lake (NW Greece). The approach is based on determining pressures and impacts, on assessing the ecological status of the water body as well as on defining the response actions for reducing the impacts in the surface water body. Based on DPSIR approach, it is concluded that the main driving forces which lead to pressures in the study area are agricultural activities, alteration of hydrological regime, contamination from the point sources, changes in the land use and fish stocking. The ecological status of the studied water body was assessed by analyzing data series of physical, chemical and biological parameters that are available dating back to the 80s. The range of yearly mean values of selected water quality parameters for Pamvotis lake are: pH 7.04-8.55, total nitrogen (TN) 0.13-0.79 mg L⁻¹ and total phosphorus (TP) 29-389 µg L⁻¹; while in terms of the above parameters the water quality status could be characterized as “High”, “High” to “Good” and “High” to “Bad”, respectively, the overall status shifting to poor conditions. Concerning the biological indices, suggested by the WFD, the low species diversity, the shift to algal dominated conditions, the disappearance of macrophytes and the presence of invasive species suggest a “Poor” ecological status. The impacts on the water body in terms of ecological and chemical status are evaluated. Among others, the response actions needed should include reduction of the application of fertilizers and chemicals in the cultivated land, removal of the point-pollution sources from the catchment, appropriate land use management and biomanipulation.

1 INTRODUCTION

It is well documented that conservation and management of freshwater resources are

directly related to the sustainable living, i.e. to social, economic and environmental aspects (Moss et al. 2003). It is also, recognized that there is an urgent need to address the problems of increasing pollutant loads delivered to many freshwater bodies and to protect or/and increase their biodiversity. The state and evolution of freshwater ecosystems are affected by a variety of biotic and abiotic factors, as well as by natural and human-induced processes that may differ both in duration and intensity. Lake ecosystems tend to maintain a state of equilibrium but their chemical resilience depends on certain site-specific factors and processes (Carpenter et al. 1999). The characterization of the ecological status of lakes has become a legal imperative after the approval of the EC Water Framework Directive (WFD; Directive 2000/60/EC). The WFD is potentially the most significant piece of legislation ever to be enacted in the interests of conservation of fresh and saline ecosystems (Pollard and Huxman 1998). The aim of the WFD is to ensure sustainable management of groundwater, freshwater and marine water in the European Union, such that a minimum “good ecological status” will be obtained by 2015. WFD also establishes an integrated and coordinated framework for the sustainable management of water. Its purposes include preventing deterioration of the quality of water bodies, promoting sustainable water use, and ensuring “enhanced protection and improvement of the aquatic environment”.

The European Water Policy and, in particular the WFD introduced the necessity to evaluate new methodological approaches for the development of strategies contributing to the sustainable water resources management. The DPSIR (Driving-Pressure-Impact-State-Response) model was established as a possible analytical framework for determining pressures and impacts under the WFD (Borja et al. 2006, Pirrone et al. 2005, Kagalou et al. 2011). According to the DPSIR model, there is a chain of causal links starting with “driving forces” (causes) through “pressures” (e.g. pollutants) to “states” (physical, chemical, biological) and “impacts” on ecosystems (structure and function) and eventually leading to “responses” (policy) (EC 2003, Kagalou et al. 2011). DPSIR framework has been adopted by the European Environmental Agency acting as a helpful instrument for the sustainable management throughout the presentation of indicators offering also the feedback needed to policy makers on environmental issues (EEA 1999).

The objective of the paper is the application of the DPSIR scheme, in the frame of WFD, analyzing concurrently each of its components. Therefore, environmental pressures and current water quality data based on an extended monitoring program are addressed, and the impacts along with the policy responses are discussed.

2 MATERIAL AND METHODS

2.1 Study area

Pamvotis lake, NW Greece (39° 40' N, 20° 53' E) is a shallow Mediterranean lake with a mean depth of 4.3 m and a maximum depth of 7.5 m. The lake occupies an area of 22.8 km² and is located next to the city of Ioannina (150,000 inhabitants) (Fig. 1). A database was developed using all the available information, through data collection derived from relevant databases and literature sources (Anagnostidis and Economou 1980, Arapis and Pappas 2004, Economidis 1989, HMRDF 2010, Ganiatsas 1970, Kagalou and Leonardos 2009, Kagalou et al. 2006, Sarika-Hatzinikolaou 1999, Stefanidis 2005, Stefanidis and Papastergiadou 2007, YPECHODE 1998). Data deal with abiotic and biotic variables of the lake and have been examined in terms of homogeneity (i.e. methodological approach, sampling strategies) in order to be comparable. Systematically collected data series of physical and chemical parameters are available over the period 1980-2009 at monthly intervals (one measurement per month). Water quality data from Pamvotis lake are from the Hellenic Ministry of Rural Development and Food. Chemical and physical parameters as nutrients (Nitrogen compounds-TN and

Total Phosphorous-TP), Dissolved Oxygen (DO), pH, Conductivity (CND) were included in the database reflecting the lake's water geochemistry (Table 1). Obviously several gaps in the data series of the chemical and physical parameters were observed. The monitoring station is located at the centre of the Pamvotis lake (Fig.1).



Fig.1 Locality map of the studied surface water body showing the site of the monitoring station

Table 1. Minimum and maximum of yearly mean values of the studied water quality parameters

	T (°C)	pH	CND ($\mu\text{S cm}^{-1}$)	DO (mg L^{-1})	TN (mg L^{-1})	TP ($\mu\text{g L}^{-1}$)
Minimum	8.33	7.04	283	5.08	0.13	29
Maximum	20.89	8.55	380	9.65	0.79	389
N	22	25	26	18	17	17

The selection of ecological indicators for the classification of the lake was based: (a) on the WFD requirements; (b) on their relation to the eutrophication process; and (c) on the availability of data. Quantitative and qualitative phytoplankton data were available only for the period 1998-99 while a previous species list is also available since 1989 (Anagnostidis and Economou 1989). WFD suggest also the monitoring of benthic macroinvertebrates, macrophytes, and fish community in order to be assessed the ecological status. As a first step of DPSIR approach, a list of indicators was selected for each category of the DPSIR for the database development (Table 2). According to WFD the water quality and furthermore the ecological status of a lake should be defined relative to its deviation from the reference conditions which should be different for different lake types (i.e. shallow, deep, cold, warm, small, large, high and low altitude lakes). In Greece, reference conditions have not yet been established neither boundaries of the parameter's determining water quality classes. To overcome this issue we also used the ECOFRAME scheme taking also into consideration the relative literature. We classified Pamvotis lake as "warm" lake (Moss et al. 2003) since the ice cover period is less than two months per year and the mean temperature of the warmest month is more than 25°C (Kagalou et al. 2006, Stefanidis 2005, HMRDF 2010).

Table 2 Dataset of DPSIR indicators

Drivers	Pressure	State	Impact	Response
Agriculture/ Livestock	Fertilizer use, pesticide use, land use change, irrigation, livestock	Water quality concentration of chlorophyll-a, habitat destruction	Deterioration of water quality, eutrophication , conservation status	Agricultural policies, management plans for diffuse pollution loads and point pollution
Urbanization	Growth of urban & semi urban areas, demand for sewage treatment	Dissolved oxygen, nutrients concentration	Eutrophication , increase of oxygen demand, habitat loss	Evaluation of WWTPs, designation of settlement zones
Land use changes	Loss of self- purification, habitat loss	Nutrients “sink- hole”, conservation status	Water quality, habitat loss, species extinction	Implementatio n of WFD
Tourism and Recreation	Recreation demands	Waste disposal, touristic infrastructure/faci lities	Water quality degradation, habitat alterations	Holistic management approach
Nature protection	Demands for conservation , species conservation , climate change (floods/ droughts)	Area demand for nature, populations decline, invasive species	Conservation status, effects on biodiversity	Measures for species and habitats conservation, evaluation of goods and services, community participation
Construction of dikes and spring diversion	Alteration of hydraulic balance	Increase of water retention time	Low dilution capacity	Restoration of hydrological regime
Fish stocking	Degradation of the trophic web	Low biodiversity, loss of macrophytes, turbidity	Increase of eutrophication , persistence of turbid phase, cyanobacteria	Bio- manipulation

3 RESULTS AND DISCUSSION

3.1 Characterization of a surface water body

The typology scheme was based on the typology criteria according the Annex II of the WFD including size, altitude, geology, and depth (System A) as well as according selected criteria of System B and additional criteria. Annex II of the WFD suggests two choices to a typology of lakes. The first choice is System A, based upon ecoregions

(Annex XI) and obligatory factors such as geology, size, altitude, depth. System B is the second choice, which includes also a wide range of optional factors (Annex II).

3.1.1 Ecoregion

According to Annex XI of the WFD, Pamvotis lake belongs to the “Hellenic Western Balkan” ecoregion.

3.1.2 Altitude

According to System A of Annex II of the WFD, three altitude classes are indicated: lowland (< 200 m a.s.l), mid-altitude (200-800 m a.s.l) and high- altitude (> 800 m a.s.l). Pamvotis lake is classified as mid-altitude category since it is situated at 470.25 m a.s.l.

3.1.3 Maximum and mean depth

System A of Annex II of the WFD, suggests three mean depth classes as follows: very shallow (<3 m), shallow (3-15 m) and deep lakes (>15 m). Pamvotis lake has a max depth ($Z_{\max}$) of 8.0 m and a mean depth (Z_{mean}) of 4.3 falling to the shallow lakes category while the ratio of $Z_{\text{mean}}/Z_{\max}$ is equal to 0.56.

3.1.4 Surface area-size

The lake occupies an area of 22.8 km² and it belongs to the “large class size” according the Annex II while the catchment area is about 330 km².

3.1.5 Geology

The Directive requires three types of geology (i.e. calcareous, siliceous and organic) without any indication of possible parameters that should be indicative for the above types. According to this classification Pamvotis lake falls into calcareous category (Tzedakis et al. 2002).

3.1.6 Mixing regime

Pamvotis lake is a polymictic lake appearing a slight thermal stratification during a brief period in mid-summer (Kagalou et al. 2008).

3.1.7 Structure of lake shore

Across the southern part of the lake (i.e. the urban part) there is no lake shore. Roads, settlements and touristic infrastructures have destroyed the natural lake shore. In the remnant part of the shore (i.e. the north-eastern part) where natural depositions takes place, there are emergent vegetation (YPECHODE 1998).

3.2 Identification and estimation of driving forces and pressures

Agriculture in the catchment area is dominated by vegetable crops, fruit trees and vineyards. Farming practices are highly intensive with extensive use of fertilizers and pesticides. In Table 3 the tonnage of several fertilizer types and pesticides per cultivated species applied in the area are presented (Arapis and Pappas 2004). Nutrients (nitrogen and phosphorus) release is associated with the farming practices and they are among the major pressures exerting from this sector. In order to estimate the pollution load the following classification was made for different land uses, using different export

coefficients (Table 4) (Mattikalli and Richards 1996, UNEP/MAP 2002). Livestock activity is carried out intensively in the entire area and consist the most important sector in the local economy mainly based in sheep/goats farming while poultry farms are also a very important sector of activities in the area accounting for the 18.3 % of the national poultry production. Specifically in the catchment area of Pamvotis lake the pig farming is also common (1018 tons/year) while the annual production of honey is about 40 tons/year. The main pollutants related to animal breeding are oxygen reducing organic substances (expressed by Biological Oxygen Demand-BOD), nitrogen and phosphorus. Taking into consideration literature data (WHO 1978) the emission factors were estimated in order to evaluate the pressure exerting from this sector (Tables 5 and 6) (Arapis and Pappas 2004, WHO 1978).

Irrigation is intensively practiced in the Pamvotis catchment, covering the 70% of the total requirements for irrigation use. The total irrigated area is about 2850 ha/year (average value corresponding to the last 10 years), while the average annual water volume for irrigation purposes is about $12 \times 10^6 \text{ m}^3$ (Arapis and Pappas 2004). This results in high intra-annual water level fluctuations influencing also the concentration of nutrients. Irrigation networks are also quite old whereas the pricing policy, set by the official local organization of Reclamation (GOEV), underestimates the full cost of the resource.

Table 3. Quantities of various types of fertilizers and pesticides used in the contributing area of Pamvotis lake

Crop	Fertilizers $\text{kg ha}^{-1}\text{yr}^{-1}$	Insecticides	Acaricides	Fungicides	Mixed (type11-15-15)
corn	500	5-10 kg	600 gr	-	441.2
tobacco	800-1000	100-150 kg	-	200-250 gr	—
vegetables	2000	0.3-0.5 L	0.3 L	200-300 gr	116.8
vineyards	500	0.5 L	1 L	250-300 gr	118.5
grain	500	-	0.1 L	-	150

Table 4. Export coefficients for land use

land use category	TN ($\text{kg N ha}^{-1}\text{yr}^{-1}$)	TP ($\text{kg P ha}^{-1}\text{yr}^{-1}$)
forests	3	0.1
cultivated land	5	0.5
grassland	5	0.5
irrigated area	8	0.5

A significant part of the lake shoreline, across the lake perimeter, has been drought up and used mainly for urban development of the city of Ioannina. The problem in fact continues even today and this particular area is still under development to accommodate recreational (e.g. new hotels, fun parks, entertainment infrastructure, etc) and agriculture activities. The alteration of the area's land use during the period 1945-1970 is significant, since the extent of many wetland habitats has been decreased by 57.8%, particularly of the littoral zone of the lake. Additionally, from 1970 till today, the urban areas increased by 216.4% with a consequent construction of roads that resulted in

diminishing the area occupied by the riparian zone (scrubs 38.7%), and the reeds expanded (17.2%) mainly as a result of the increased nutrients inflow to the lake and water level decline (Papastergiadou et al. 2010).

A major perturbation to Pamvotis lake occurred in 1974 with the construction of dikes in the N-NW area of the lake. Two primary effects resulted from the construction of the dikes: (a) the dikes caused an alteration in the hydraulic connection between the karst aquifer of the adjacent mountain (Mitsikeli) and the lake; and (b) after the construction of the dikes the springs (previously inflowing into the lake) have since given quite low discharge acting rather as sink holes. Then, the springs discharged directly into the outflow channel rather than replenishing the lake from its northern part.

Table 5. Factors concerning production rates for animal farming waste (Kg/tn of animal weight/d)

farm animal	BOD	TN	TP
pigs	1.0	0.50	0.15
poultry	1.5	0.33	0.22

Table 6. Annually produced organic load from most common animal farming in Pamvotis catchment area

farm animal	BOD (tons)	TN (tons)	TP (tons)
pigs	640	110	22
poultry	ns	2700	950

Tourism and recreation in the broader area is continuously increasing, illustrating a promising development trend. Although touristic activity focused on the lake and on the small historic islet, it is now mostly characterized by the absence of planning, arbitrary buildings and roads construction without prior impact assessment of potential threats especially in protected habitats along the lake shoreline.

Hydromorphological alterations as the constructed outlet (Lapsista channel), roads and the embankments along the lake perimeter caused a fragmentation in the ecosystem of the lake reducing catchment scale connectivity creating also barriers for organism's dispersion and migration. Water level fluctuations can seriously affect habitats and thus community structure. It is also anticipated that climate change will create new pressures to the lake ecosystem. Additionally the expansion of cultivations and urban areas have eliminated the wetland habitats (e.g. wet meadows, fens, pastures) mainly in the northern and southern parts of the lake and also decreased the riparian zone, with negative effects to the entire ecosystem and especially to avifauna.

Since 1986, the lake has been stocked with the exotic herbivorous Asian species (*Ctenopharygodon idella*) and planktivorous species (*Hypophthalmichthys molitrix*, *Aristichthys nobilis*) in order to control the excessive vegetation and to support fishery. Common carp species (*Cyprinus carpio*) are systematically introduced annually at annual basis. Both the common carp and the introduced Asian carps, which were very abundant in '90s, are known to destroy submerged aquatic vegetation directly by damaging macrophyte beds thus limiting the nursery habitats. Moreover, high abundances of these species diminish light availability by re-suspending the sediment and increase nutrient loading. Specifically during the period 1986-2005, 9.3×10^6 larvae of common carp and 4×10^6 larvae of Asian carps were introduced in the lake (data deriving from Greek Ministry of Agriculture, Dept. of Fisheries and Aquaculture). The fish community of the lake is currently dominated by planktivorous (*Rutilus ylikiensis*) and some benthivorous species (Leonardos et al. 2008).

3.3. Ecological status assessment and analysis of impacts

The different pressures on ecosystems caused by both human intervention and physical factors rarely act separately. Moreover ecosystems, respond to a “context-dependent” way to anthropogenic stressors, rendering it difficult to predict accurately the effect of a given pressure. Since WFD does not suggest pH, TN and TP boundary values for lake classification, the ECOFRAME system proposed by Moss et al. (2003) was applied in order to determine the chemical status of Pamvotis lake (Table 7) as well as the guidelines proposed for the intercalibration technical report of Mediterranean lakes.

Table 7. Mean values of water quality parameters of the studied surface water body and chemical status classification according to ECOFRAME system

YEAR	pH	TN (mg L ⁻¹)	TP (μg L ⁻¹)
1981	7.95	0.14	192
1982	8.00	0.55	390
1983	7.46	0.29	94
1984	7.37	0.56	102
1985	7.61	0.38	129
1986	7.34	0.64	102
1987	7.15	0.29	64
1988	7.15	0.45	161
1989	7.43	0.73	213
1990	7.58	No data	No data
1991	7.29	0.79	101
1992	7.28	0.22	81
1993	7.04	No data	No data
1994	7.69	No data	No data
1995	7.63	No data	No data
1996	7.79	No data	No data
1997	7.57	No data	No data
1998	7.57	No data	No data
1999	7.78	No data	No data
2000	7.62	No data	No data
2001	7.60	No data	No data
2002	8.18	0.35	117
2003	8.23	0.46	90
2004	8.04	0.32	29
2005	No data	No data	No data
2006	No data	0.13	148
2007	No data	No data	No data
2008	8.55	0.21	33
2009	8.42	0.15	45

High	Good	Moderate	Poor	Bad
------	------	----------	------	-----

Chemical status characterization of Pamvotis lake according to the classification system

of ECOFRAME (Moss et al. 2003) was carried out based on yearly means calculated from monthly observations (Table 7). Considering the pH mean values, during all the time period studied, the Pamvotis lake water is characterized as “High” (Table 7). In terms of TN the Pamvotis lake water quality status can be classified as “High” during the years 1981-1985, 1987, 1988, 1992, 2002-2004, 2006, 2008 and 2009; while it is characterized as “Good” during the years 1986, 1989 and 1991. In terms of TP, the Pamvotis lake water exhibits “High” quality during the year 2004, scores “Good” quality during the years 2008 and 2009, presents “Moderate” quality during the years 1983, 1984, 1987, 1992 and 2003, exhibits a “Poor” status during the years 1985, 1986, 1991, 2002 and 2006 and present a “Bad” quality during the years 1981, 1982, 1988 and 1989. Before the full operation of the sewage treatment plant (year 1994), in terms of TN and TP the Pamvotis water quality status is classified as “High” to “Good” and “Moderate” to “Bad”, respectively; while after the operation of the treatment plant it is classified as “High” according to TN and “High” to “Poor” according to TP (Table 7). Concerning algal community, the only available data are those from the period 1998-1999 (Romero et al. 2002) focusing on phytoplankton diversity and abundance. In the Pamvotis Lake: the following diversity of species was recorded: 67 diatoms, 68 Chlorophytes and 83 Cyanophytes; while the most common species were the following: *Cyclotella* sp., *Melosira granulata*, *Selanastrum gracile*, *Scenedesmus* sp., *Pediastrum* sp., *Dinobryon divergens*, *Ceratium Hirundinella*, *Euglena viridis*, *Aphanocapsa elachista*, *Microcystis aeruginosa*, *Microcystis* sp., *Aphanothece* sp. *Aphanizomenon flos-aquae*. The monthly average biovolume for the three taxonomic groups was, 450×10^6 , 200×10^6 and 350×10^6 , respectively. The only comparable data are those of Kagalou et al. (2008) indicating that 10 years later there was a high increase of cyanophytes species since the period March- October 2005, where their abundance increased about 10 times (i.e. *Microcystis* sp. 12×10^3 , *Anabaena* sp. 9×10^4). According WFD guidelines the proportion of cyanophytes would be a valuable measure since their occurrence is synonymous to a heavily polluted and eutrophicated water body. Applying the Mediterranean Lake type (LM8), the index of the “percentage (%) contribution of cyanobacteria” was suggested. The contribution of cyanobacteria to the total biovolume of phytoplankton is considered as a reliable, meaningful and easy-to-use indicator, bearing in mind the following reasons: (a) most of cyanobacteria species show a strong preference for eutrophic conditions; (b) cyanobacterial blooms are highly visible, widespread indicators of eutrophication; and (c) because of the toxicity of some bloom taxa, blooms can pose serious water quality and animal and human health problems.

Foul odors and tastes, oxygen depletion, fish kills, and drinking/ recreational impairment are symptoms of bloom-infested waters. Since the boundary value for Good/moderate conditions is proposed to be 28.5% (Poikane 2009), Pamvotis lake is classified into “Poor” to “Bad” conditions with a monthly contribution of cyanobacteria of 30% while during the sensitive dry period this percentage increases to 40-50%.

Freshwater benthic communities have long been used as bioindicators for monitoring pollution and anthropogenic influences (Moss et al. 2003). The benthic fauna of Pamvotis lake was found to be very limited with a total of ten species belonging to five taxonomic groups. The oligochaete community comprised the 80% of the total benthic fauna with *Potamothrix bavaricus* and *Potamothrix hammoniensis*, being the dominant benthic species represented more than 61% of the total benthic fauna. *Chironomus plumosus* is the most abundant chironomid species contributing with about 6 % of the total benthic fauna, and *Chaoborus flavicans* with 19% is the important dipteran. According to Moss et al. (2003) the proposed index for evaluating the ecological conditions in terms of macroinvertebrates is the ratio of Oligochaetes to Chironomides abundance. This ratio for Pamvotis lake is about 4. The boundaries for the “moderate” conditions are between 0.5-1 while when the ratio is >1 the recorded conditions are characterized as “Poor”.

The plant community, especially the submerged vegetation, is among the key variables for the function of a lake ecosystem. Emerged macrophytes are also very important concerning the littoral habitats. In the framework of ECOFRAME (Moss et al. 2003) three measures are suggested for the lake ecology assessment: Namely the plant community composition, the plant diversity and the plant abundance. Concerning plant community in Pamvotis lake (data by Stefanidis 2005) showed that there is a dominance of emergent species and also a serious decline of submerged vegetation which is an indication of eutrophication. Plant community is mainly composed of extensive communities of nymphaeids and canopy forming poorly rooted plants (*Ceratophyllum* sp., *Lemna* sp., *Nuphar* sp.) suggesting poor ecological conditions. Concerning the submerged plant abundance, it can be described by “absence or some plants visible but sparse” which also suggest “Poor” to “Bad” conditions.

WFD specifically asks for the fish community information since it is considered as a key biological monitoring component. Trends in one or more fish communities can be used to monitor the ecological functioning and “health” of a particular ecosystem (Coates et al. 2007). The first metric is the faunal composition and according to recent fish data (Leonardos et al. 2008), Pamvotis lake accommodates only 4 native fish species, which are under serious threat, and 20 translocated fish species, thus suggesting “a very impacted site”. The ratio of planktivorous to piscivorous fish biomass is extremely valuable, as a metric, reflecting the ecological conditions (Moss et al. 2003, Jeppesen et al. 1997). The proposed boundary for the moderate state is between 0.2-0.5, while for the “Poor” to “Bad” conditions is <0.2 . In Pamvotis lake the 93% of the total fish fauna are planktivorous species; while the 4.5% of the fish fauna are Piscivorous species. The founded ratio is approximately 0.05 very far even from the boundary of the “Bad” conditions.

3.4 Proposed Responses

The assessment of the DPSIR approach provides a quite clear identification of pressures and the subsequent impacts of the qualitative status of the Pamvotis lake. The next step is to set up future projects concerning restoration and sustainable management practices. It is obvious that Pamvotis lake has a long eutrophication history due to the heavy point and non-point loading of nutrients, with frequent cyanophyte blooms. Lake restoration efforts were traditionally focused on reducing the external phosphorus loading, originated from the point- pollution sources (i.e. sewages), but they are still high enough to maintain eutrophic conditions. Besides the further reduction in external P-loading, the removal of some P-rich sediment may allow a more effective response and recovery. Diffused pollution load by agricultural activities (livestock impacts included) constitute also a major source of nutrient’s release. Reducing diffuse P-loading has become a major issue since it is related to the achievement of good ecological status by 2015, according to WFD. Although agri-environmental measures were introduced in Greece through the application of the Council Regulation (EEC/No 2078/92) only limited measures and especially organic farming, were implemented during the previous period. A possible suggestion could be the application of good agricultural practices along with the establishment of strictly protected zones in the catchment area where, at least, the land cultivation should be practised based on ecological criteria.

A remedial strategy should also include the increase of spring water inputs in order to improve the flushing rate and hopefully the water quality. Concerning biomanipulation measures, it seems that a substantial management of fish community could act as a ‘reverse switch’ for the recovery of Pamvotis lake and the re-establishment of the submerged vegetation. Planktivorous fish removal may lead in a consequence of changes in the nutrient levels, as it has happened in many other cases, and thus in the improving of the water clarity. It is understood that increased urbanization and, generally, land use changes have led to the deterioration of the habitats, the extinction of fish species, the degradation of spawning and nursery areas. Among the most

important steps for lake conservation was achieved by its designation as a “Natura 2000 site” through the implementation of Habitats Directive (92/43/EEC).

4 CONCLUSIONS

The paper presented an application of DPSIR (Driving-Pressure-Impact-State-Response) methodology to Pamvotis lake in North-western Greece. The chemical and ecological status of this water body was assessed based on boundary values derived by the ECOFRAME system. It was concluded that due the low species diversity, the shift to algal dominated conditions, the disappearance of the macrophytes and the presence of invasive species, the ecological status of the lake was characterised as “Poor”. Further, the impacts of the water body in terms of chemical and ecological status were evaluated. Based on the above evaluation, the following response actions covering the entire contributing area of the lake are proposed: (a) reduction of the application of fertilizers and agrochemicals in the cultivated land; (b) removal of the point-pollution sources from the catchment; and (c) appropriate land use management and biomanipulation. It is expected that the systematic application of these actions will improve the ecological status of the lake even before the deadline year set by WFD.

Acknowledgements. The authors are grateful to the Hellenic Ministry of Rural Development and Food for kindly providing water quality data and to all the scientists who have contributed to the long-term dataset of Pamvotis lake.

REFERENCES

- Anagnostidis, K. and Economou, A. (1980). Limnological studies of Lake Pamvotis (Ioannina) Greece. *Archiv fur Hydrobiologie* 89:313-342.
- Arapis, Th. and Pappas, E. (2004) *Management Plan for Lake Pamvotis*. OIKOS E.P.E., Unpublished Technical Report (in greek)
- Beklioglu, M., Romo, S., Kagalou, I. (2007). State of the art in the functioning of shallow Mediterranean lakes: workshop conclusions. *Hydrobiologia*, 584:317-326
- Borja, A., Galparosa, I., Solaun, O., Muxica, I., Tello, E-M., Uriarte, A., Valencia, V. (2006). The European Water Directive and the DPSIR: a methodological approach to assess the risk of failing to achieve good ecological states. *Estuarine, Coastal and Shelf Sciences*, 66:84-96.
- Carpenter, S., Ludwig, D., Brock, W. (1999). Management of eutrophication for lakes subject to irreversible change. *Ecological Applications*, 9:751-771.
- Economidis, G. (1989). Management study of Lake Pamvotis, Municipal Co. of Lake Ioannina, 1989 (in greek).
- Coates, S., Anwar, A., Robson, M. (2007). Efficiency of a multi-metric fish index as an analysis tool for the transitional fish component of the WFD. *Mar. Sci. Bull.*, 55:225-240.
- EC (2003) Common implementation strategy for the Water Framework Directive (2000/60/EC). Guidance documents n.º3 Analysis of Pressures and Impacts.
- EEA (1999). Environmental indicators: Typology and overview, European Environment Agency, Technical Report, no 25.
- Ganiatsas, K.A. (1970). Flora and vegetation of Lake Pamvotis. Ipirotiki Estia, 20p., Thessaloniki, Greece. (in greek)
- Hellenic Ministry of Rural Development and Food (HMRDF) (2010). Dataseries of quality and quantity parameters of surface waters and groundwaters of Greece. Athens. (in greek)
- Jepesen, E., Jensen, P., Sondergaard, E., Lauridsen, T., Pedersen, J., Jensen, L. (1997) Top-down control in freshwater lakes: the role of nutrient state, submerged macrophytes and water depth. *Hydrobiologia* 342/343:151-161.

- Kagalou I., Economidis G., Leonardos I., Papaloukas C. (2006). Assessment of a Mediterranean lentic ecosystem (Lake Pamvotis, Greece) using benthic macroinvertebrate community. *Limnologica*, 36:269-278
- Kagalou, I., Papastergiadou E., Leonardos I. (2008). Long term changes on eutrophication process in a shallow Mediterranean lake ecosystem of W. Greece: response after the reduction of external load. *Journal of Environmental Management*, 87 : 497–506.
- Kagalou, I. and Leonardos, I. (2009) Typology, classification and management issues of Greek Lakes: implication of the Water Framework Directive (2000/60/EC). *Environ Monit Assess*, 150: 469-484.
- Kagalou I., Leonardos I., Anastasiadou C., Neofytou C. (2011) The DPSIR approach for an integrated river management framework. A preliminary application on a Mediterranean site (Kalamas River-NW Greece). *Water Res. Manage.* (under review)
- Leonardos, I., Kagalou, I., M. Tsoumani and Economidis P.S. (2008). Fish fauna in a Greek lake: biodiversity, introduced fish species over a 80-year period and their impacts on the ecosystem. *Ecology of Freshwater Fish*, 17:165-173.
- Mattikalli, N., Richards, K. (1996). Estimation of surface water quality changes in response to and use changes: application of the export coefficient model using remote sensing and GIS system. *J. Environ. Manage.* 48:263-282.
- Moss, B., D. Stephen, C. Alvarez, E. Becares, W. van de Bund, S. E. Collings, E. van Donk, E. de Eyto, T. Feldmann, C. Fernandez-Alaez, M. Fernandez-Alaez, R. J. M. Franken, F. Garcia-Criado, E. M. Gross, M. Gyllstrom, L.-A. Hansson, K. Irvine, A. Jarvalt, J.-P. Jensen, E. Jeppesen, T. Kairesalo, R. Kornijow, T. Krause, H. Kunnap, A. Laas, E. Lill, B. Lorens, H. Luup, M. R. Miracle, P. Noges, T. Noges, M. Nykanen, I. Ott, W. Peczula, E. T. H. M. Peeters, G. Phillips, S. Romo, V. Russell, J. Salujoe, M. Scheffer, K. Siewertsen, H. Smal, C. Tesch, H. Timm, L. Tuvikene, I. Tonno, T. Virro, E. Vicente and D. Wilson (2003) *The determination of ecological status in shallow lakes—a tested system (ECOFRAME) for implementation of the European Water Framework Directive. Aquatic Conservation: Marine and Freshwater Ecosystems* 13: 507–549.
- Papastergiadou, E., Kagalou, I., Stefanidis, K., Retalis, A., Leonardos, I. (2010). Effects of Anthropogenic Influences on the Trophic State, Land Uses and Aquatic Vegetation in a Shallow Mediterranean Lake: Implications for Restoration. *Water Res. Manage.*, 24, 415-435.
- Pirrone, N., Troubino, G., Cinnirela, S., Algieri, A., Benbricchio, G., Palmeri, L. (2005). The DPSIR approach for integrated catchment-coastal zone management: preliminary application to the Po catchment-Adriatic Sea coastal zone system. *Reg. Environ. Change*, 5:111-137.
- Poikane, S. (2009) Water framework Directive intercalibration report (Part 2: lakes) EC & JRS.
- Romero, J., Kagalou, I., Imberger, J., Hela, D., Albanis T., Bartzokas, A. (2002). Seasonal water quality of shallow and eutrophic Lake Pamvotis, Greece: Implications for restoration. *Hydrobiologia*, 471, 91–105.
- Sarika-Hatzinikolaou M. (1999). *Floral and phytosociological study of aquatic ecosystems of Epirus*. PhD Thesis, University of Athens, Greece. (in greek).
- Stefanidis, K. (2005). *Ecological research of Lake Pamvotis: Investigation of relationships between aquatic vegetation and water quality*. MSc Thesis, University of Patras, Greece, 136 p. (in greek).
- Stefanidis, K. and Papastergiadou, E. (2007). Aquatic vegetation and related abiotic environment in a shallow urban lake of Greece. *Belgian Journal of Botany*, 140 (1):25-38.
- Tzedakis P.C., Lawson, I.T., Frogley, M.R., Hewitt, G.M., Preece, R.C. (2002). Buffered tree populations changes in a Quaternary refugium: evolutionary implications. *Nature* 297:2044-2047.
- UNEP/MAP. (2002). *Guidelines for the preparation of the baseline budget of pollutant release-Methodology and Emission factors*.
- WHO (1978) *Technical Report Animal Wastes*, Copenhagen
- YPECHODE (1998) *Specific Environmental Study of Lake Pamvotis* (in greek).