Short communication

Response of biota to land use changes and water quality degradation in two medium-sized river basins in southwestern Greece

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ABSTRACT

To assess biotic responses to anthropogenic pressures, a seasonal monitoring of benthic macroinvertebrates, physicochemical and hydromorphological parameters has been applied in 11 sites along two highly impacted river basins in southwestern Greece, mainly during the year 2006. In the first river basin, the upper reaches were covered by thick riparian forest, replaced by intensive agriculture and livestock in the mid-reaches, while the lower parts were characterized mainly by agroindustrial activities. The second river basin was impacted by the discharge of raw cheese whey effluents in the mid-reaches, while the lower parts were protected by thick riparian vegetation. The mid- and lower parts of the first river basin (Peiros–Parapeiros rivers) were impaired by dam constructions, agricultural intensity and urbanization. In the second river basin (Vouraikos river), the 3/5 of the river length, located in the mid-reaches, was degraded due to the discharge of untreated cheese whey effluents. Water quality of the lower reaches was highly recovered due to the presence of thick riparian vegetation. Macroinvertebrate diversity was strongly correlated to pollution, as sites with major physicochemical and hydromorphological degradation presented low taxonomic richness and diversity values, while non-impacted sites were characterized by a considerable presence of E.P.T. taxa and higher diversity. The current study indicates the significant impact of land use changes to the water quality, which consequently influence the distribution of biota, pointing out the critical role of the riparian vegetation to the detoxification of surface waters.

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1. Introduction

One of the main issues of the EU Water Framework Directive (2000/60) is the achievement of “good” ecological status for all surface waters by the year 2015. European countries are obliged to assess the ecological quality of their surface water bodies and classify them into five quality classes. Among the biological quality elements that should be used for the assessment, are the benthic macroinvertebrates. Their use as bioindicators appears advantageous and consolidated (Hellawell, 1986) as their sensitivity is correlated with numerous environmental factors, while macroinvertebrate indices are about five times higher than any other biotic index and their number is still growing (Mandaville, 1979; Lucadamo et al., 2007).

Regarding river water quality, two projects that took place a few years ago, funded by the European Union, the AQEM (www.aqem.de) and the STAR project (www.eu-star.at), initiated the effort to standardize the different assessment methods throughout Europe and select the appropriate methodology and biotic indices for application in each country. Along with the inter-calibration process, even the countries that do not have a national assessment system are able to assess their river water quality according to the European accepted standards. In Greece, a national assessment system based on the use of benthic macroinvertebrates is not yet adopted. Several indices have been developed such as the Greek Biotic Index (Kantzaris et al., 2002; Iliopoulou-Georgudaki et al., 2003) the Greek Biotic Metric (Skoulikidis et al., 2004) and the Hellenic Evaluation Score and its Interpretation Index (Artemiadou and Lazaridou, 2005) but each one has its own disadvantages (Artemiadou and Lazaridou, 2005; Gritzalis et al., 2006) and no one is yet considered a national method. A good alternative to these methods is the Intercalibration Common Metrics approach (Buffagni et al., 2001; Buffagni and Erba, 2004) but its application is not feasible in small-scale studies, as it requires a large set of reference data.

Greece is mainly an agricultural country with small industrial units. River water pollution is mainly related to runoffs from fertilizers and untreated effluents of the industry production process. In addition, recently, climate change resulted in severe loss of the drinking water reserves and the construction of dams for better regulation of the water reserves became obligatory. As a result, the riverine environment and the quality status of numerous river basins is continuously impacted by the aforementioned pressures, which lead to habitat degradation, hydrological alterations, inputs...
of organic matter and nutrients (Arthington, 1996; Kay et al., 2001; Allan, 2004). It is remarkable that only few studies based on the response of benthic macroinvertebrates to such pressures have been conducted in southwestern Greece (Kantzaris et al., 2002; Iliopoulou-Georgudaki et al., 2003) while the water quality status is degraded as the anthropogenic impacts are continuously increasing.

In an effort to add more data on the water quality of the rivers in southwestern Greece, an ecological quality assessment of 11 sites located in two medium-sized river basins of the region was conducted using chemical, hydromorphological and biological data, leading to (i) gathering of primary data concerning macroinvertebrate assemblages in southwestern Greece, (ii) application of the Water Framework Directive 2000/60 for water quality classification, (iii) comparison of different biological indices in order to select the most appropriate for ecological classification (iv) assessment of the role of the riparian vegetation to water detoxification and (v) estimation of major anthropogenic impacts and the response of biota to pollution.

2. Materials and methods

2.1. Study area

Two river basins were selected (Fig. 1): (i) The river basin of Peiros and its large tributary, Parapeiros river, which is mainly influenced by agricultural, municipal and industrial activities, while the construction of dams is continuously altering the natural environment. (ii) The river basin of Vouraikos, impacted by livestock, agriculture and discharge of raw cheese whey effluents, while a NATURA 2000 area, Vouraikos Gorge, is located in the particular river basin and the protection of its biodiversity is obligatory according to the European Directive 92/43/EEC (European Union Council, 1992). Peiros and its tributary originate from different points and after a distance of almost 10 km, whenever this was possible.

2.2. Site selection

The selected sites (n = 11) were chosen according to the following parameters: (i) allocation of source or diffuse pollution, (ii) length of rivers and (iii) accessibility of the area. Each site was selected mainly according to the change of anthropogenic pressures (Table 1) with a final aim to allocate one site for every pressure change and within a distance of almost 10 km, whenever this was possible.

2.3. Data collection

The STAR River Habitat Survey methodology (Buffagni and Kemp, 2002; Environment Agency, 2003) was applied in order to integrate data concerning the riverbed, banks and catchment area alterations into two indices, the Habitat Quality Assessment (HQA) and the Habitat Modification Score (HMS). Hydromorphological assessment of each site was applied once during winter. Biological and physicochemical data were gathered during three sampling campaigns conducted during spring, summer and winter of the year 2006, extended until spring 2007 for four sites of Peiros–Parapeiros river basin due to the initiation of the dam construction. At each sampling site and during each season, measures of water temperature, pH, dissolved oxygen, conductivity and total dissolved solids were recorded. Moreover, water samples were transferred to the lab and analyzed for major ions (\(\text{Cl}^-\), \(\text{NO}_3^-\), \(\text{NO}_2^-\), \(\text{NH}_4^+\), \(\text{PO}_4^{3-}\), \(\text{SO}_4^{2-}\) and TSS—total suspended solids).

The STAR AQEM methodology (AQEM consortium, 2002; Furse et al., 2006) was applied for macroinvertebrate collection. At each site, a sample of 20 replicates distributed according to the share of microhabitats was taken using either a Surber sampler of 0.25 m \(\times\) 0.25 m and a mesh size of 500 µm, or a hand net of the same characteristics. In total, 34 samples were collected during all seasons from the 11 selected sites and almost 82,000 individuals belonging to 81 families were recorded. The macroinvertebrate taxa were identified to family level or in a lower taxonomic level whenever this was possible. All data collected were stored into the AQEMdip 2.6 database.
2.4. Data analysis

Canonical Correspondence Analysis (Ter Braak, 1986) was performed in order to analyze the physicochemical characteristics of the water and identify correlations between environmental and biological parameters at each sampling site. In addition, cluster analysis (Bray–Curtis similarity, Group average) was used to search for groups among sampling sites according to the observed macroinvertebrate taxa while the ANOSIM test (Clarke, 1993) was used in order to check for seasonal variation between samples. Chemical classification of sites was achieved by application of the Nutrient Classification System (Skoulikidis et al., 2006).

Biological classification according to the macroinvertebrate taxon list obtained from each site, was conducted by the combination of the HES/AHES system (Artemiadou and Lazaridou, 2005) with the BBI (De Pauw and Vanhooren, 1983). Most biological indices assign a score at each macroinvertebrate family, depending on how tolerant each family is on pollution and the sum of all scores provides a number, which enables classification. The allocation of the right score is the key for a confident classification and these two systems seem to describe well the quality of each site in Greece, as indicated by other studies (Lucadamo et al., 2007; Artemiadou et al., 2008). Other indices such as the IBMWP (Alba-Tercedor and Sánchez-Ortega, 1978) and the IBE (Ghetti, 1997), as well as the Functional Feeding Groups (FFGs) were calculated using the ASTERICS (AQEM/STAR Ecological River Classification System) software and compared with the current classification system. Ecological classification of sites was achieved by applying the final RefCond guidelines for the relevant contribution of the physicochemical, hydromorphological and biological quality elements to the ecological quality status (RefCond, 2003).

3. Results

3.1. Ecological quality

Taking into account the ecological quality at all seasons in both river basins, five sites (45%) showed good environmental conditions, three sites (27%) presented moderate ecological quality and the remaining were characterized by high levels of pollution and alterations, leading to poor ecological quality (Table 2). The impacted sites of Peiros–Parapeiros river basin were located in the lower parts of the river course and accounted for about half of the river length, while in Vouraikos river basin, impairment was observed in the mid-courses due to source pollution from untreated cheese whey effluents.

3.2. Macroinvertebrate assemblages

Macroinvertebrate assemblages were strongly related to environmental conditions (Fig. 2). Taxonomic richness was positively correlated to habitat quality ($r = 0.574; p < 0.01$) and presented negative correlation to agricultural intensity ($r = -0.565; p < 0.01$) and physicochemical quality ($r = -0.378; p < 0.05$). Diversity (Shannon–Wiener index) was positively correlated to habitat quality ($r = 0.508; p < 0.01$) and showed negative correlation to

Table 2

Ecological quality, according to the RefCond guidelines, indicated by chemical, biological and hydromorphological classifications and the three combined.

<table>
<thead>
<tr>
<th>Site</th>
<th>Chemical</th>
<th>Hydromorphological (HMS)</th>
<th>Biological</th>
<th>Ecological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pe1</td>
<td>Good</td>
<td>High</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Pe2</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Pe3</td>
<td>Moderate</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Pe4</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Pa1</td>
<td>Good</td>
<td>Moderate</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Pa2</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>V1</td>
<td>Good</td>
<td>Pristine</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>V2</td>
<td>Poor</td>
<td>Pristine</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>V3</td>
<td>Poor</td>
<td>Pred. unmodified</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>V4</td>
<td>Good</td>
<td>Pristine</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>V5</td>
<td>Good</td>
<td>Signif. modified</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Pred.: predominantly, Signif.: significantly.

The results of the case study are depicted as ecological classification according to the application of the demands of the Water Framework Directive 2000/60. Chemical, hydromorphological and biological quality were combined according to the RefCond guidance in order to gain the final ecological quality status, which ranges from High to Bad (High, Good, Moderate, Poor and Bad).
Fig. 2. Major correlations between biological data and physicochemical or hydromorphological data. (A) Habitat quality (HQA) and taxa richness (number of families). (B) HQA and diversity (Shannon–Wiener index). (C) HQA and E.P.T. taxa richness. (D) Agricultural intensity (% land cover) and taxa richness. (E) Box plot between physicochemical quality (NCS—Nutrient Classification System) and diversity. (F) Box plot between physicochemical quality (NCS) and E.P.T. taxa richness. Each point (graphs A–D) represents one site at one season. It should be noted that certain sites were dry during summer season and no sampling could be applied. Major correlations between physicochemical–hydromorphological indices and biological characteristics of the water column are depicted. Each spot represents one sample and the line drawn represents the linear equation that best fits the data. NCS: study sites are classified according to the concentration of $\text{NO}_3^-$, $\text{NO}_2^-$, $\text{NH}_4^+$ and $\text{PO}_4^{3-}$ ions.

Physicochemical quality ($r = -0.408; p < 0.01$). E.P.T. index presented positive correlation with habitat quality ($r = 0.608; p < 0.01$) and negative with agricultural intensity ($r = -0.455; p < 0.01$) and physicochemical quality ($r = -0.495; p < 0.01$). Heavily impacted sites were characterized by low taxonomic richness, low E.P.T. and diversity values (Shannon–Wiener index), while sites with optimal physicochemical and hydromorphological status were characterized by a considerable increase of the aforementioned parameters.

Grouping of samples through cluster analysis revealed the differences in taxa composition between impacted and non-impacted sites (Fig. 3). Three groups were formed in a similarity level of 38%. Group A consisted of heavily impacted sites of Vouraikos
river basin, which presented low diversity values, dominated by pollution tolerant taxa such as Chironomidae, Tubificidae and Asellidae, group B consisted of moderate and heavily polluted sites of Peiros–Parapeiros river basin, which presented a different taxa distribution, dominated by Gomphidae, Ephemeroptera and Caenidae due to the different types of pollution (mainly agricultural and industrial runoffs) and group C consisted of optimal and good quality sites of both river basins, with high diversity and E.P.T. values. Chironomidae was the most abundant taxon (13%), followed by Asellidae (8.02%), indicating the high levels of pollution in the two river basins. The abundance and richness of scrapers presented an inverse upstream–downstream correlation (Spearman’s $r = 0.548; p < 0.01$), mainly due to the stable substrates of the upstream sites, which favor scraper colonization (Douglas, 1958; Monaghan and Soares, 2010) while gatherers/collectors presented negative correlation to the water quality ($r = -0.562; p < 0.01$).

3.3. Responses of benthic macroinvertebrates to pollution

Agriculture and urbanization presented positive correlation to HMS and negative to HQA values. Conductivity and TDS were also positively correlated. According to Canonical Correspondence Analysis (Fig. 4), the highest impacts on quality and macroinvertebrate distribution were associated with changes in conductivity and agriculture intensity, as well as hydromorphological alterations provoked by the dam construction and dissolved oxygen reduction due to eutrophication from raw dairy effluent discharges. The first axis of the CCA plot accounted for the 30.5% of the overall variance and was dominated positively by pH, conductivity and agricultural intensity. The second axis accounted for the 14.8% of the overall variance and was mostly related negatively to HQA. The third CCA axis accounted for the 10.3% of the overall variance and was dominated positively with dissolved oxygen concentration. The three axes accounted for the 55.5% of the overall variation.

Regarding macroinvertebrate distribution, taxa of the bottom quadrants such as Perlidae, Perlodidae, Potamidae, Blephariceridae and Helophoridae seem to prefer sites with rich habitat quality, while Bithyniidae, Erpobdelididae, Asellidae, Simuliidae, Planorbidae, Chaoboridae and Valvatidae of the upper quadrants, are mostly found in modified sites, influenced by agricultural activities. Moreover, taxa of the upper right quadrant such as Glossiphonidae, Erpobdelididae and Simuliidae are found at sites with high conductivity values provoked by various anthropogenic activities.

4. Discussion

4.1. Ecological quality

The results of the study indicate water quality degradation in both river basins, due to the various anthropogenic pressures along the course of the rivers. In the first river basin (Peiros–Parapeiros), 50% of the selected sites, which represent almost 20 km of the river length, was impacted, presenting an ecological status, which did not fulfill the demands of the EU Water Framework Directive (2000/60). Agricultural activities in the mid-reaches in combination to agroindustrial discharges in the lower parts, as well as the construction of dams, in the mid-courses of both rivers were the major degradation factors. In the second river basin (Vouraikos river), 60% of the selected sites, representing almost 15 km of the river length, was impacted mainly due to discharge of raw cheese whey effluents from a unit located in the mid-course of the river, resulting in poor ecological status at all seasons. However, parts of the lower reaches, represented by site V4, which pass through the Vouraikos gorge are recovered, pointing out the significant role of the riparian vegetation to the detoxification of the water. The particular site, surrounded by thick riparian forest, receives pollution load from untreated cheese whey effluents. In contrast to sites V2 and V3, which lack any riparian vegetation, the particular site (V4) presented “good” to “high” quality status. This steep quality rise can only be explained due to the presence of the riparian forest, which absorbed high amount of the incoming pollution load.

4.2. Macroinvertebrate assemblages

Macroinvertebrate assemblages varied significantly along the longitudinal gradient of both river basins. The upper reaches were characterized by coarse substratum, mainly large or small cobbles and pebbles and low levels of fine inorganic matter, due to the absence of anthropogenic pressures and the presence of thick riparian forest. The aforementioned characteristics favor the colonization of pollution sensitive macroinvertebrate taxa, attached to the cobble substratum (Boyero and Bailey, 2001) and all sites...
located in the upper reaches, which presented high physicochemical quality and low hydromorphological alterations, were characterized by high diversity, richness and a high value of E.P.T taxa.

The mid- and lower reaches of both river basins were characterized by high sedimentation due to the absence of riparian vegetation, which inhibits the delivery of fine sediments to streams (Peterjohn and Correll, 1984; Robinson et al., 1996; Chakona et al., 2008), presenting high amounts of sand, small pebbles and silt. Although in general, diversity, richness and E.P.T. values were lower, in comparison to the upper reaches, the sites of the first river basin, which were influenced mainly by agricultural runoffs,
presented a different taxa distribution to those of the second river basin, which were affected by eutrophication due to the discharge of cheese whey effluents. Bithyniidae, Erpobdellidae, Simulidae, Planorbidae, Chaoboridae and Valvatidae were mainly found in sites affected by agriculture, while, high amounts of red Chironomidae, Tubificidae and Asellidae were found in the sites impacted by cheese whey effluent discharge, indicating different responses of macroinvertebrate taxa to different types of pollution.

It is remarkable that one site, which is located downstream the cheese manufacturing unit and its macroinvertebrate distribution would normally be characterized by low diversity and low E.P.T. values, presented the highest values of richness, diversity and E.P.T., due to the presence of thick riparian vegetation, which absorbs the incoming pollution, inhibits sedimentation and protects the coarse substratum of the site, enabling colonization of sensitive macroinvertebrate taxa. The crucial role of the riparian vegetation to the detoxification of the water is reported by several authors, which indicate improvements in stream physical habitat structure and biotic health indices from systems with regenerating riparian forests (Scarsbrook and Halliday, 1999) as well as those with remnant riparian forests within agricultural catchments (Storey and Cowley, 1997; Lazorchak et al., 1998; Tavzes et al., 2006; Nyiogi et al., 2007), while Miserendino and Masi (2010) point out that the maintenance of good conditions of vegetation adjacent to rivers will enhance water quality and the environment for stream communities.

### 4.3. Macroinvertebrate responses to pollution

In the first river basin, which is partially influenced by agroindustrial runoff, the quality ranged from high to poor. Macroinvertebrate response to the increasing pollution (depicted as increased hydromorphological alterations and physicochemical quality degradation) was characterized by loss of diversity and richness, while all pollution sensitive families vanished from previously optimal sites after the initiation of the dam construction in both rivers. Heptageniidae family, which possesses high scores in all biotic indices (as it is considered a pollution sensitive family), was identified in the current study not only in high and good quality sites but also, unexpectedly, in moderate and poor ones. This could be attributed to the steep rise of TSS levels (almost 8000%—from 7 mg/L to 869 mg/L) simultaneously with the initiation of the dam construction, as many inhabitants would disappear immediately due to the presence of thick riparian vegetation, which absorbs the incoming pollution, inhibits sedimentation and protects the coarse substratum of the site, enabling colonization of sensitive macroinvertebrate taxa.

The role of the riparian vegetation to the cleaning of the water has been proven crucial in this study, as all sites surrounded by thick riparian forest, presented good ecological quality, high values of diversity, richness and E.P.T. index, although they were heavily impacted by cheese whey effluents. The current study indicates biological quality loss due to agro-industrial runoffs and hydro-morphological alterations and points out the need for restoration of the riparian vegetation along the mid- and lower reaches of the rivers. The long-term presence of the riparian vegetation has been proven that enhances water detoxification, macroinvertebrate colonization and physicochemical quality improvement, leading to restoration of the habitat quality and maintenance of the health of the riverine ecosystem.

### References


The ecological quality status of almost half of the river length investigated is not the one required by the Water Framework Directive 2000/60 and action plans must be applied in order to achieve good quality standards according to the aforementioned directive. The role of the riparian vegetation to the cleaning of the water has been proven crucial in this study, as all sites surrounded by thick riparian forest, presented good ecological quality, high values of diversity, richness and E.P.T. index, although they were heavily impacted by cheese whey effluents. The current study indicates biological quality loss due to agro-industrial runoffs and hydro-morphological alterations and points out the need for restoration of the riparian vegetation along the mid- and lower reaches of the rivers. The long-term presence of the riparian vegetation has been proven that enhances water detoxification, macroinvertebrate colonization and physicochemical quality improvement, leading to restoration of the habitat quality and maintenance of the health of the riverine ecosystem.


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