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The influence of land use on water quality and macroinvertebrate biotic indices in rivers within Castilla-La Mancha (Spain)

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ABSTRACT

The influence of land use on water quality and macroinvertebrate biotic indices in rivers within Castilla-La Mancha (Spain)

With the objective to determine the influence of land use on the quality of the fluvial ecosistms within Castilla-La Mancha, Spain, physicochemical variables (conductivity, concentrations of ammonium, nitrite, nitrate, phosphate) and various benthic invertebrates indices (IBMWP, BMWQ and MCLM) were measured. In total, 82 stretches of rivers belonging to the Tajo, Guadiana, Jucar and Segura watersheds were sampled during the summer of 2001. The percentage of every land use type on a regional scale (drainage area) was calculated, obtained from the CORINE Land Cover and tools from ArcGIS 9.0 software. The correlation analysis results showed a significantly strong relationship between nutrients and biotic indices and the urban, forested and dry agriculture uses. For irrigated agriculture, low correlations were found for nutrients (nitrate and phosphate) and biotic indices. Given the importance of agriculture in the Castilla-La Mancha Region (53 % of the area) and the effects on the fluvial ecosystems, this study highlights the need for,improved wastewater treatment, as well as good agricultural management practices and the maintenance of the riparian corridor.

Key words: Non-point source pollution, biological index, benthic invertebrates, dry and irrigated agriculture, urban, forest, nutrients, eutrophication.

RESUMEN

La influencia del uso del suelo en la calidad del agua y los índices bióticos basados en macroinvertebrados en los ríos de Castilla-La Mancha (España)

Con el objetivo de determinar la influencia de los usos del suelo en la calidad de los ecosistemas fluviales de Castilla-La Mancha, se han analizado variables físico-químicas (conductividad eléctrica, nitrato, nitrito, amonio, fosfato) y varios índices de invertebrados bentónicos (IBMWP, BMWQ y MCLM). En total, se muestrearon 82 tramos fluviales pertenecientes a las cuencas del Tajo, Guadiana, Júcar, y Segura, durante el verano de 2001. Se calculó el porcentaje de cada uso del suelo a escala regional (área de drenaje), obtenidos a partir del CORINE Land Cover y herramientas del software ArcGIS 9.0. Los resultados del análisis de correlación mostraron relaciones altamente significativas entre los nutrientes e índices bióticos y los usos urbano, forestal y agrícola de secano. En el caso del uso agrícola de regadío se detectaron correlaciones más débiles con nutrientes (nitrato y fosfato) y los índices bióticos. Dada la importancia de la agricultura en la región de Castilla-La Mancha (53 % de ocupación del suelo) y los efectos en el ecosistema fluvial se apunta la necesidad de mejorar el tratamiento de residuos urbanos, así como unas buenas prácticas aplicadas en la agricultura y mantenimiento del bosque de ribera.

Palabras clave: *Contaminación difusa, índice biológico, invertebrados bentónicos, agricultura de secano y regadío, urbano, forestal, nutrientes, eutrofización.*

INTRODUCTION

Certain nutrients are known to travel from agricultural and urban lands into rivers by means of runoff (e.g. Hynes, 1970; Smart *et al.*, 1981; Osborne & Wiley, 1988; Zamora-Muñoz & Alba-Tercedor, 1999) and influence the distribution and abundance of macroinvertebrates depending on their tolerance or habitat requirements (Townsend *et al.*, 1997). Therefore, it is clear that land management constitutes a pressure to stream physicochemical and biological quality. Before the Water Framework Directive (WFD, European Commission, 2000) was passed, most regulatory criteria for water quality referred solely to chemical quality for human safety (water for irrigation, drinking, and recreation). The Directive has set a goal of achieving "good" chemical and ecological status for all European water bodies by the year 2015. The document specifies that water status should be determined using biological indicators as well as hydromorphological and physicochemical data. Determining the impacts caused by different pressures to ecological health and sustainable management and land development is necessary in order to meet WFD objectives.

There has been much research on relating land use to the aquatic biota of streams (e.g. Quinn & Hickey, 1990; Richards & Host, 1994; Harding *et al.*, 1998; Nerbonne & Vondracek, 2001). The effect of land use on a stream ecosystem can vary depending on many factors, including riparian forest buffer quality, watershed size, reach location within its watershed, the presence of other pressures, and the scale on which land use is measured (e.g. Lammert & Allan, 1999; Collier & Quinn, 2003; Roy *et al.*, 2003). The current analysis examines land use on a regional scale, which has been shown to be appropriate for detecting large-scale disturbances (Richards & Host, 1994; Roth *et al.*, 1996).

The chemical variables analyzed here (NH_4^+, NO_3^-, NO_2^- and PO_4^{3-}) have been chosen because they are major components of urban waste and the fertilizers applied throughout the region, which are nitrogen, or phosphorus-based. Nitrogen and phosphorus-containing compounds are known causes of eutrophication (Allan, 1995). During the year 2001, farmers in Castilla-La Mancha used 139 300 tons of nitrogen-based and 65 700 tons of phosphorus-based fertilizers. The average application autonomous community Spain for 2001 was 66 500 tons of nitrogen-based and 35 900 tons of phosphorus-based fertilizer, making the region one of the largest consumers of fertilizer nationwide (IAEST, 2007). Although the region has a relatively low population density, at 1.18 inhabitants/ha, urban waste inputs contribute to stream nutrient enrichment due to insufficient wastewater treatment in many towns, especially those with a low number of inhabitants.

Land use for human activity represents a major industry and therefore a key impact to the biotic integrity of streams in Castilla-La Mancha. With 53 % of the regional land dedicated to agriculture, it is important to determine to what extent this land use affects stream chemistry and the biotic community in order to take steps toward more sustainable development.

To study these anthropogenic effects on regional ecosystems, our research group has used biotic indices based on macroinvertebrate assemblages because the community responds to a variety of impacts (Hering *et al.*, 2004), their use offers a wide range of analytical techniques and the taxonomic keys are well-developed (Hellawell *et al.*, 1986; Bonada *et al.*, 2006). We are applying three different indices because previous research has found that in some cases the BMWQ index (Camargo, 1993) and the MCLM index better distinguish between WFD-defined ecological quality classes for surface water in Castilla-La Mancha (Navarro Llacer, 2006a). The IBMWP index was selected because it has been recognized by the Iberian Limnological Association (AIL) as an effective biological indicator for assessing water quality.

There has been little research on the relationships between land use and the chemical and biotic integrity of running waters in Spain (e.g. Ortiz *et al.*, 2007; Damasio *et al.*, 2008) or in the region of Castilla-La Mancha (Moreno *et al.,* 2006). There are several studies focused on water quality (e.g. Camargo *et al.*, 2005; Oscoz *et al.*, 2006), biological quality (e.g. Palau *et al.*, 1986; Braga, 1987; Figueroa *et al.*, 2005) or other aspects, for example the diversity of the fauna present in running waters of Spain (e.g. Muñoz & Prat, 1994; Bonada *et al.*, 2000). In addition to a national need for analyzing the impact of land use on ecological quality, this research contributes to the understanding of Mediterranean watersheds, which have been shown to have ecological characteristics different from cold temperate watersheds and have not been fully explored to date (Alvarez Cobelas *et al*., 2005).

Previous research on the physicochemical quality of water bodies and its relationship to land use within Castilla, La Mancha, Spain concluded that agricultural fertilizer runoff and urban wastewater discharge are major contributors to river contamination (Moreno *et al.*, 2006). The present study aims to explore the possible effects on the chemistry in addition to the biota of regional rivers due to farming and urban activities. The hypothesis is that the chemical and biological quality will be negatively affected by urban and agricultural land uses, and that forested land will be related to good chemical and biological quality. In addition, we will study possible differences between dry and irrigated farming practices by considering these two variables separately. These effects are explored by applying different biotic indices, with an additional goal of studying index sensitivity to different land uses.

METHODS

Study area

The sample points are located in parts of four watersheds: the Tajo, Jucar, Segura and Guadiana, in Castilla-La Mancha (Fig. 1). Located in southeastern Spain at an average elevation of 600-700 m above sea level, it is a region with a wide variety of environmental and geographical conditions.

The lithology varies in different locations: in the west, siliceous rocks such as quartzite, slate and granite dominate, with calcareous rocks in the eastern areas (limestone, dolomite, sandstone, and conglomerates). In the central area, there is a mixture of the two in the form of detrital sediments, marl, and gypsum (González Martín & Vázquez González, 2000). The main climatic type is Temperate Mediterranean Climate (Köppen, 1900), with dry summers and small rain events distributed throughout the spring and fall and some precipitation in winter (in most of the study area, the average annual precipitation is approximately 600 mm/yr). This climate type is characterized by hot summers, with average temperature above 22 °C and cold winters with average temperatures below 6 °C (Fernandez Garcia, 2000).

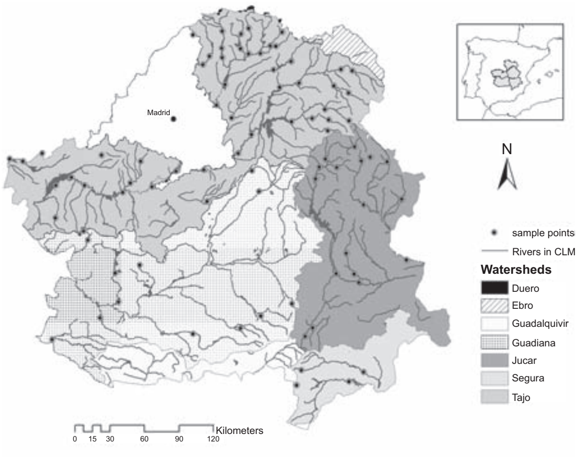

Figure 1. Map of the sampled locations within Castilla-La Mancha, Spain. *Mapa de los tramos muestreados en Castilla-La Mancha, España.*

Agriculture, livestock and industry are the main productive sectors within the region. Previous studies highlight a range of human impacts to regional waterways, including inter-basin transfers, a high degree of regulation by reservoirs and dams, aquifer overexploitation, the entrance and proliferation of invasive species, and ineffective wastewater treatment (Greenpeace, 2005; Navarro Llacer, 2006b). The majority of the land is used for agricultural purposes, encompassing 53 % of the total area. There are 3 732 800 ha dedicated to dry farming, 494 700 ha of irrigated farmland, and 1 583 200 ha of forested land (JCCM, 2002). The population density is lower than the national average, at 4.2 % of the national total, in an area comprising 15 % of that of Spain (INE, 2004).

Table 1. Basic information on the study area. *Información básica sobre el área de estudio.*

	Jucar	Segura	Tajo	Guadiana	Total
Number of points sampled	16	4	51	11	82
Number of rivers sampled	9	4	20	10	43
Range of stream orders	1-4	1-5	1-6	1-5	
Total area of the watershed (km^2)	21 580	16 040	55 769	54 985	
Area within Castilla-La Mancha (km^2)	15 652	4 945	26 762	26 328	58 035
% of watershed in Castilla-La Mancha	73	30	48	48	

Methods

In total, we measured physico-chemical variables at 82 river reaches (Fig. 1, Table 1) by collecting 50 ml water samples in the field during the summer of 2001. We recorded electrical conductivity ($\mu S\ cm^{-1}$) on-site with a portable sensor (Multiline P4 WTW) and used Merck Spectroquant® spectrophotometric kits in the laboratory to obtain concentrations (shown with detection levels) of NH_4^+ (>0.01 mg l^{-1}), NO_3^- (>0.01 mg l^{-1}), NO_2 (>0.005 mg l^{-1}), and PO_4^{3-} (>0.01 mg l^{-1}). We sampled macroinvertebrates qualitatively following the methodology described in the PRECE/GUADALMED project (Jáimez-Cuéllar *et al.*, 2002). This method specifies the collection of kick samples with a 500 µm mesh D-frame net until no new taxa appear and the preservation of a few individuals from each taxon in 70 % alcohol for identification purposes. In the laboratory, we identified the specimens to family level, except oligochaetes and water mites, using a stereomicroscope (OLYMPUS SZ61) in order to calculate the following multimetric biotic indices: IBMWP (Alba-Tercedor *et al.*, 1988), BMWQ (Camargo, 1993), their respective value per taxon indices (IASPT and aBMWQ), and MCLM (Navarro Llacer, 2006a), an index developed specifically for rivers in Castilla-La Mancha.

To assess non-point pollution, we reclassified CORINE Land Cover (CLC, 2000) land use maps into dry agriculture, irrigated agriculture, urban and forested areas, and calculated land use percentages within the entire upstream drainage basin using ESRI® ArcGIS™ 9.0 software. This method is recommended by the IMPRESS manual for WFD implementation (European Commission, 2003).

Statistical analysis

In order to study the relationships between land use, biotic indices and physico-chemical variables, we performed a Spearman Rank correlation analysis. We used this non-parametric analysis because some of the variables did not have a normal distribution. The correlation analysis was employed to find the associations among the entire group of variables. Next, we plotted points from the correlation matrix using a Principal Components Analysis (Fry, 1999) to determine the influence of each of the variables on sample point quality and find out if there is a quality gradient. These analyses were carried out using the XLSTAT 3.4™ package (Fahmy, 1998).

RESULTS

Descriptive statistics for the variables analyzed can be found in Table 2, showing an array of conditions throughout the study area. High conductivity values were found in the middle to low reaches. Overall, nutrient concentrations were not very high, although they presented a range of values, which indicated different levels of quality in regional waterways. Biotic indices also ranged from low quality to very high, for example the IBMWP index had values from 11 to 310. Dry agricultural land and forested land reached the highest percentages of land use (79.8 % and 99.6 %, respectively), while irrigated agriculture and urban land both had maximum values close to 15 %.

Results from the correlation analysis showed land use and physicochemical variables to be strongly correlated for all land uses except irrigated

Table 2. Descriptive statistics for variables measured in the analyses. *Estadísticos descriptivos de las variables medidas en los análisis.*

	N	Mean	Standard deviation	Minimum	Maximum
COND	82	914.67	710.46	28.50	4355.00
NH4	82	0.46	1.92	0.01	14.91
NO3	82	3.36	4.99	0.06	30.00
NO2	82	0.10	0.23	0.00	1.49
PO4	82	0.52	1.60	0.00	12.00
IBMWP	82	155.85	70.92	11.00	310.00
BMWQ	82	243.93	108.10	21.00	480.00
IASPT	82	3.95	0.81	1.57	5.93
aBMWQ	82	6.20	1.19	3.00	9.25
MCLM	82	26.34	8.87	8.82	46.76
Urban	82	1.10	2.44	0.00	16.10
Dry Agriculture	82	22.44	18.94	0.00	79.80
Irrigated agriculture	82	2.49	2.20	0.00	14.17
Forest	82	29.58	18.24	0.83	99.61

agriculture (Table 3). Urban land use showed positive correlations ($p < 0.001$) for all physicochemical variables and had the highest coefficients with nitrite and phosphate. Dry agriculture was positively correlated to all physicochemical variables and had the largest coefficients with conductivity and nitrate. Forested land was negatively correlated to all physicochemical variables, with especially high coefficients for nitrate. Irrigated agriculture was significantly correlated with nitrate and phosphate with lower coefficients and weaker significance, as shown in Table 3.

Table 3. Correlation coefficients between physicochemical variables, biotic indices, and land use percentages. The level of significance is also presented: $*p < 0.05$, $**p < 0.01$ and $***p < 0.001$. *Coeficientes de correlación entre las variables físico-químicas, índices bióticos y porcentajes de los usos del suelo. El nivel de significancia está señalado:* $*p < 0.05$, $**p < 0.01$ y $***p < 0.001$.

	COND	NH_4	NO_3	NO_2	PO_4	IBMWP	BMWQ	IASPT	aBMWQ	MCLM	Urban	Dry Agriculture	Irrigated Agriculture
COND													
NH_4	0.42***												
NO_3	0.62***	0.43***											
NO_2	0.60***	0.73***	0.63***										
PO_4	0.32**	0.52***	0.30**	0.48***									
IBMWP	−0.55***	−0.48***	−0.50***	−0.54***	−0.62***								
BMWQ	−0.53***	−0.47***	−0.48***	−0.51***	−0.63***	0.99***							
IASPT	−0.41***	−0.51***	−0.40***	−0.41***	−0.61***	0.76***	0.74***						
aBMWQ	−0.34**	−0.48***	−0.33**	−0.35**	−0.63***	0.72***	0.72***	0.96***					
MCLM	−0.42***	−0.34**	−0.37***	−0.47***	−0.51***	0.88***	0.89***	0.45***	0.44***				
Urban	0.45***	0.32**	0.46***	0.51***	0.61***	−0.66***	−0.65***	−0.55***	−0.50***	−0.57***			
Dry Agriculture	0.62***	0.20	0.69***	0.40***	0.35**	−0.67***	−0.65***	−0.49***	−0.43***	−0.57***	0.60***		
Irrigated Agriculture	0.18	0.10	0.22*	0.14	0.22*	−0.32**	−0.34**	−0.22*	−0.27*	−0.29**	0.30**	0.33**	
Forest	−0.38***	−0.25*	−0.53***	−0.27*	−0.47***	0.60***	0.58***	0.58***	0.52***	0.48***	−0.56***	−0.77***	−0.27**

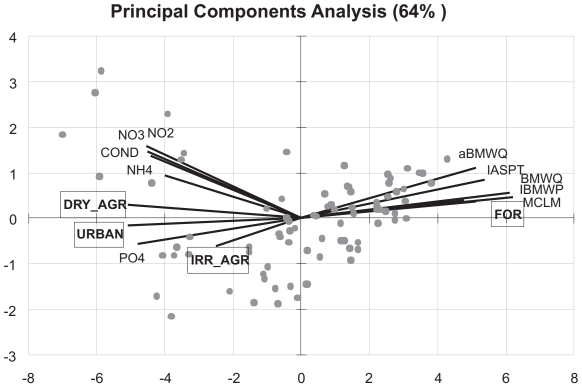

Figure 2. Graph of the results of the Principal Components Analysis showing the sampling points and variables. Axis 1 explains 54 % of the data variability and axis 2 explains 10 % of it. The land use types are abbreviated: DRY_AGR is dry agriculture, IRR_AGR is irrigated agriculture, and FOR is forested. *Gráfico de los resultados del Análisis de Componentes Principales que muestra las estaciones de muestreo y los variables. El eje 1 explica el 54 % de la variabilidad de los datos y el eje 2 explica 10 %. Los usos de suelo están abreviados: DRY_AGR es agricultura en secano, IRR_AGR es agricultura de regadío y FOR es forestal.*

All physico-chemical variables showed negative, significant correlations with all biotic indices (Table 3). Phosphate was the nutrient with the strongest correlation ($r > 0.5$) to all biotic indices.

High correlations were observed between the biotic indices and the urban and dry farming land uses, both of which were negative. There were positive, highly significant correlations between forested land and all the indices. Irrigated agriculture was significantly correlated with biotic indices, but yielded lower correlation coefficients and significance in general, as was seen in the correlation with nutrients as well.

These results were also reflected in the Principal Components Analysis (PCA) plot (Fig. 2). Along axis 1 (54 % of data variability), the PCA graph presented a clear gradient of ecological quality as explained by the variables studied. On the positive side of axis 1, forested land was grouped together with all biotic indices, indicating higher quality in sample points on that side of the axis. All nutrients and land uses for human purposes were located on the negative side of the x-axis. As seen in the correlation analysis, the PCA showed dry agriculture as having a closer relationship with nutrients than irrigated agriculture. Contrary to what was expected, irrigated agriculture posed a lesser impact on ecological quality than dry agriculture. Axis 2 only represented 10 % of data variability and did not have an interpretable pattern.

In figure 3, the bar graphs show the mean values for nutrient concentrations at certain percentages of land use, with standard error bars. Nutrients increased with an increase in urban land

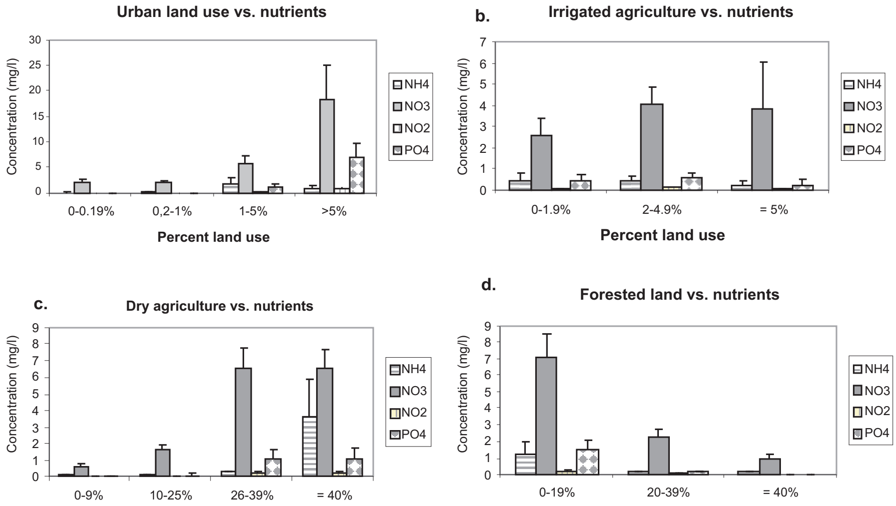

Figure 3. Mean nutrient concentrations as a function of different percentages of land use, with standard error bars. *Concentraciones medias de nutrientes a distintos porcentajes del uso del suelo, con barras del error estándar.*

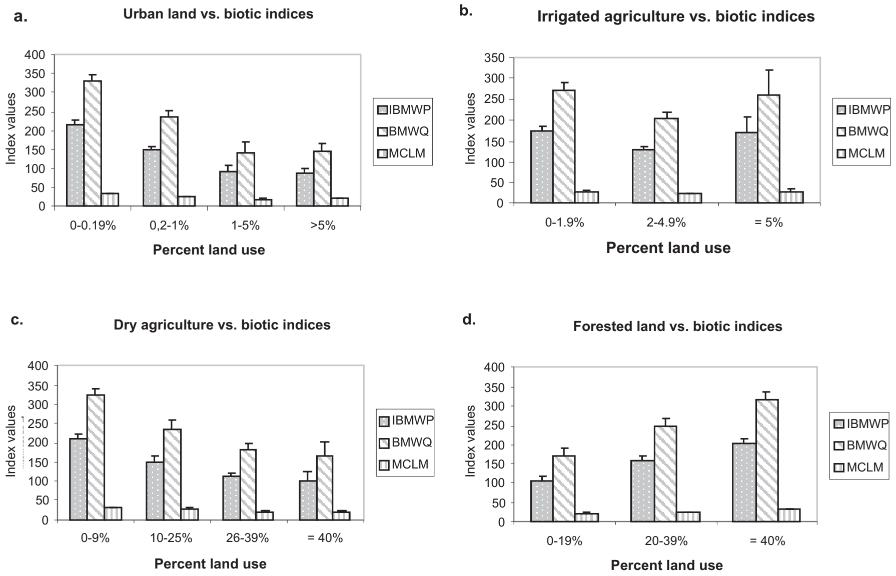

Figure 4. Mean biotic index values as a function of different percentages of land use, with standard error bars. *Valores medios de índices bióticos a distintos porcentajes del uso del suelo, con barras del error estándar.*

percentage (Fig. 3a), demonstrating an obvious change in nitrate and phosphate concentrations. There were no clear patterns for mean nutrient concentrations when compared to irrigated land use percentages (Fig. 3b). However, in figure 3c, nitrate concentration clearly increased with the percent of dry agriculture, and especially high values could be seen at 25 % cover, while phosphate experienced a smaller but drastic increase and the mean values for ammonium experienced a jump at around 40 %. Figure 3d shows an increase in forested land and a decrease in all nutrient concentrations, especially nitrate.

Figure 4 shows the response of the biotic indices to increasing percentages of each land use type. Mean values of biotic indices experienced a clear decrease with an increase in urban and irrigated farmland and an increase with higher percentages of forested land. Once again, there was no clear pattern for irrigated agriculture, as index values decreased and then increased with increasing occupation.

DISCUSSION

These variables (nutrients, biotic indices) are important for understanding some of the ways in which human activities strain river ecosystems, in this case due to land use. Chemical analyses alone may miss important point source contributions if they occur well before or after the sampling date (*sensu* Metcalfe, 1989; Rueda *et al.,* 2002). However, biotic indices offer information on how long-term point and non-point source pollution affect the biotic community. We chose the physicochemical variables included in this study because of their known origin in fertilizer compounds and urban waste as well as for their role in eutrophication of surface waters and the resulting impacts to the biota (Allan, 1995).

In the present study, the nutrients associated with fertilizer (nitrogen and phosphorus-containing compounds) and urban waste (nitrogenous compounds and phosphate) showed relationships with land use and biotic indices. The correlations between land use, biotic indices, and physicochemistry support the hypothesis that land use affects stream ecological quality.

As expected, urban and agricultural uses had negative correlations to biotic and chemical quality, while forested land was positively correlated. Dry agriculture was strongly correlated to all nutrients, especially nitrate, and had negative correlations with all biotic indices. Results similar to those seen in the present study have been reported throughout the world in studies that analyze the effects of land use on nutrients as well as biotic communities (Richards & Host, 1993; Cuffney *et al.,* 2000; Fitzpatrick *et al.* 2001). Cuffney *et al.* (2000) found relationships between biotic indices and ammonia, nitrate, nitrite, and phosphorus, while Fitzpatrick *et al.* (2001) found decreases in macroinvertebrate metrics and stream chemical quality with the increase in the percent of agricultural land. In the present study (Figure 3c), there is a clear increase in NH_4^+ at 40 % dry agricultural land. Ometo *et al.* (2000) also found higher NH_4^+ concentrations in a watershed with 62 % farmland, than in a watershed with a higher percentage of forested land.

Irrigated agriculture showed weaker significant correlations ($r < 0.3$) with nitrate, phosphate and the biotic indices with respect to other land uses. We had expected a stronger impact by irrigated farmland due to nutrient runoff from the combination of fertilizer application and irrigation. However, it appears that dry agriculture had more of an effect on ecological quality.

Urban land showed strong correlations with nutrients and biotic indices. Results (Fig. 3a) show an abrupt increase in nutrients at 1 % urban land, especially for nitrate and phosphate. Phosphorus-containing compounds may originate in household and industrial detergents, while nitrogenous compounds can be a product from wastewater (Allan, 1995; Rueda *et al.,* 2002). Roy *et al.* (2003) also found nitrogen and phosphorus-containing compounds to be positively correlated with the percentage of urban areas, similar to the trends in our analysis.

In contrast to the effects caused by agricultural and urban land uses, forested land showed negative correlations with all the nutrients. The strongest, negative correlations were for nitrate and phosphate (Table 3). We observed a progressive decrease in nutrients with an increase in the percent of forested land (Fig. 3d), and therefore a lower capacity to retain nutrients below 20 % forested land. As forested land increased, there was an increase in biotic index values (Fig. 4d). This is logical because natural vegetation has a capacity to absorb and reduce runoff to rivers, acting as a buffer for the stream (Allan & Johnson, 1997; Corbacho *et al.*, 2003). Roy *et al.* (2003) also found nitrogen and phosphorus-containing compounds to be negatively correlated with the percentage of forested lands. The effect of forested land on the watershed level has been shown by the experimental removal of forest in the Hubbard Brook watershed, which caused a 41-fold increase in nitrate concentrations, disruption of the nitrogen cycle, and altered concentrations of other ions (Likens *et al.*, 1970).

The positioning of variables and land uses on the PCA graph also show this quality gradient (Fig. 2). Dry agriculture and urban land were grouped with nutrients, and had a clearly negative effect on the biological and physicochemical quality of regional rivers. However, forested land affected river quality in a positive manner and was plotted very close to the biotic indices. The pressure exerted by irrigated farmland was not as clear, although this practice was expected to contribute more nutrients due to increased runoff (Hynes, 1970). The sample points clearly covered a wide range of quality in regional streams, from sample points with good quality and a high percentage of forested area to reaches with high nutrient concentrations and modified land use characteristics.

In comparing index sensitivity to land use pressures, the biotic indices showed significant correlations to all types of land use and nutrients, with high coefficients and levels of significance (Table 3). Therefore, there was no difference in sensitivity to specific land use pressures. Nonetheless, these correlations are important, as they show that the biota is a better indicator of long-term impacts than chemical analyses alone (Metcalfe, 1989; Rueda *et al.,* 2002). Solimini *et al.* (2000) compared the responses of different indices to stream quality and found the Spanish indices (IASPT and aBMWQ) to be more precise than the EBI (Woodiwiss, 1978) and IBE (Ghetti, 1986) in detecting the impacts due to organic pollution by nitrogen compounds and phosphate. We applied various indices, including the MCLM index, which was developed specifically for the study area. The results showed that the MCLM had correlations with land use and physicochemistry, but did not detect the impact of increasing percentages of land use on the biota as well as the IBMWP and BMWQ indices (Fig. 4).

Recently, steps have been taken to improve water quality in Castilla-La Mancha based on the knowledge that nutrient input can be reduced from urban sources with secondary and specialized wastewater treatment (Castro, 2007) and from agricultural sources by reducing fertilizer applications and maintaining a riparian buffer strip (Corbacho *et al.,* 2003). A project funded by the European Union's FEDER grant program was carried out to inform local farmers on techniques to reduce water and fertilizer needs, with information available online (FEDER, 1999; CREA SIAR, 2001). In addition, public policy is promoting the construction and improvement of wastewater treatment systems in all towns with 2000 or more inhabitants and tertiary treatment in environmentally sensitive areas in order to reduce nutrient input to streams within the region (Directive 91/271/EC, European Commission, 1991). Since 1983, approximately 200 wastewater treatment plants have been built. There are also riparian corridor restoration projects in place for the watersheds studied here (CHJ, 2002; Maceira Rozados, 2007; CHG, 2007; Maceira Rozados, 2008). These initiatives are steps in the right direction for conserving regional waterways, but the current analysis highlights the need for continued work in the future to better manage farming practices and urban planning as well as maintain riparian corridor quality in order to comply with the WFD goal of meeting 'good' ecological quality standards by the year 2015.

CONCLUSIONS

This study uses relatively simple methods to analyze some of the pressures that human activities impose on the quality of streams. The use of physico-chemical variables related to agricultural and urban runoff and qualitative sampling methods to derive biotic indices is sufficient to analyze the biological and chemical quality of regional waterways. Dry agriculture was shown to have more of an effect on water quality than irrigated agriculture, and further research is needed to examine the local effects of agricultural runoff on rivers.

Research on the relationships between land use and the biotic community are not common within Spain, making this approach even more important in a national context. The assessment of both physicochemical and biotic index responses to land use types is important because not all land use types are related to nutrient concentrations, but all biotic indices have strong correlations with land uses. Currently in Castilla-La Mancha fertilizer management practices, riparian restoration and wastewater treatment plants are an improvement in order to reduce stream input, although their efficiency has not been tested. Nonetheless, the results highlight the importance and pressure of farming, at 53 % of land use, within the region and the need for improvements to stream systems in order to sustainably manage riverine ecosystems and comply with WFD objectives.

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