Chapter 4
The Effects of Anthropogenic Stressors on Wetland Loss and Habitat Quality Deterioration in the Upper Guadiana River Basin: A Long-Term Assessment (1970–2000)

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Abstract During the last four decades, around 1,500 km² of dry croplands have been transformed, and are now irrigated in the Upper Guadiana river basin, causing hydrologic overexploitation and wetland desiccation. However, there are no estimations on how anthropogenic stressors have been changing the wetland landscape in the recent past. This chapter focuses on the understanding of how the changes on land-use land-cover (LULC), economic activities and population have driven wetland losses and habitat degradation in the basin from the 1970s. Our results show that 40.5% (2,041.6 ha) of the 5,321 ha of wetlands existing in the early 1970s had disappeared in the last 30 years (1970–2000). Most wetland losses occurred through the period 1978–1990, which registered a rate 127 ha of wetland lost per year. Most affected were floodplain wetlands (47% of total loss) and rain-fed temporary ponds (24%). During the entire period 1978–1999, the loss of wetlands could be significantly related to the loss of natural vegetation, as well as to the reduction of agricultural employment. Habitat quality of wetlands showed a clear pattern of nutrient over-enrichment, as well as a trend towards salinization, the later related to the greater disappearance of most freshwater wetlands (0–2,500 µS cm⁻¹). LULC, economic activities and demography explained around 50% of wetland loss and habitat quality deterioration. Until 1990, the pressure of population growth, combined with the agricultural sector, explained the disappearance of most wetland area. From then on, habitat quality has been more impacted in areas where industry and building sectors had more weight in the socioeconomic development (also densely populated watersheds).

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4.1 Introduction

Human transformation of the Earth's land surface has far-reaching and results in serious consequences for the functioning of hydrological and biogeochemical processes in watersheds (Calder 1998). Changes in vegetation cover and land uses at watershed-scale have been cited to significantly alter downstream hydrological fluxes (DeFries and Eshleman 2004) and water quality (Berka et al. 2001; Houlahan and Findlay 2004), modifying aquatic habitats (Wang et al. 2008; Allan et al. 1997). In fact, land use–land cover changes (LULC hereafter) have been considered a major cause of the global environmental change (Hollis 1992; Riebsame et al. 1994).

It is recognized that historical land use and land management by humans is the first cause of land-cover change around the world (Dale et al. 2000), with agricultural expansion as the principal agent of change (Lambin et al. 2001). Human alteration of the land affects aquatic ecosystems through multiple processes that likely operate from regional to local spatial scales (Allan et al. 1997). Land cover and landscape configuration and evolution respond to multiple human and natural factors (e.g. climate oscillations and economic markets) operating from global to local scales but, also, since LULC patterns are indeed consequences of socioeconomic systems, they are highly dynamic and rarely in a stable equilibrium (Niehoff et al. 2002). Wetland habitats within a watershed respond then, to a greater or lesser degree, to each of these socioeconomic changes, and it is difficult to discriminate between the main drivers of degradation. A clear implication of this perspective is that local conditions are under some degree of regional influence and hard to estimate (Hildrew and Giller 1994). Patterns of LULC and socioeconomic variables are complex, often complicating the understanding of the relationship between those anthropogenic stressors and wetland habitat degradation (Houlahan and Findlay 2004). It includes the scale effects of anthropogenic stressors on wetland degradation. For example, we know that the effects of adjacent land-use on water quality can extend over comparatively large distances (Houlahan and Findlay 2004; Angeler et al. 2008) but, in the practice, it is very difficult to establish. Geographic Information Systems combined with multivariate statistical methods have been shown as useful tools for the assessment of what anthropogenic stressors, such as LULC, population or economy, bear an influence on wetland loss and degradation (Houlahan et al. 2006).

The Upper Guadiana basin is an excellent natural laboratory to evaluate the effects of human-related activities on wetland degradation patterns. The large-scale decline in groundwater levels has been related to the strong increase of the irrigation surface at the basin, as well as to changes in cultivated crop types (high water requirements; Llamas 1988). During the nineteenth century, it has led to the disappearance of half of the existing wetlands in the area (see Chapter 1). These major changes in LULC experienced by the basin were driven by changing social and political circumstances, fluctuating crop prices and various regional, national

and international incentive programs (Mulligan and Burke 1999, see Chapter 10). In addition to the increase in irrigation for the production of high-value crops, set-aside policies and rural–urban migration have also resulted in large scale abandonment of previously cultivated land (Molinillo et al. 1997) which slowly reverts to a semi-natural shrub community, held in check by grazing and fire. All accompanied with an increase in the use of agrochemicals, a raise of the second and third economic sectors, large discharges of poorly treated sewages, etc. All these impacted on wetlands through a dynamic and complex mosaic of LULCs, acting at different spatial and temporal scales. However, we do not know how it occurred and how these anthropogenic stressors have performed on the current wetland landscape.

These issues motivated this study, whose main goal focuses on understanding what main anthropogenic stressors (LULC, economic activities and population growth) have driven wetland losses and habitat degradation in the Upper Guadiana basin from 1970s to 2000, spanning 30 years. For this purpose, we first investigated the loss of wetlands in the basin, as well as habitat quality deterioration for this period, grouping by hydrodynamic types (i.e. water source) and using a multi-scale approach (watershed and local) and multivariate statistical methods.

4.2 Material and Methods

Besides the Upper Guadiana basin, the adjacent Calatrava catchment (Fig. 4.1a) was also included for the analyses in order to incorporate wetlands with contrasting physical and biological functioning (wetlands developed over volcanic rocks) but with similar anthropogenic stressors. This allows us to evaluate the effects of stressors under different physical and biological settings. Since the entire Upper Guadiana basin extends for ca. 2 million hectares, occupying 185 watersheds, and many of them are of no interest in the absence of wetlands of a certain entity (>0.5 ha), the analyses were therefore applied to those watersheds that met the following criteria: (1) those containing large wetlands of high ecological value (e.g. Las Tablas de Daimiel National Park, TDNP hereafter) and (2) those containing temporary ponds of small-medium size (e.g. Ruidera, Calatrava, Riansares and Las Animas). Therefore, five watersheds, subdivided into 44 sub-watersheds (≈40% of total area), containing 94 wetlands (up to 95% of total wetland area), were extracted to be analyzed in this study (Table 4.1).

Because there is no reliable estimate of the wetland extent in the Upper Guadiana basin before the 1990s, we first tried to obtain the wetland distribution before this date, as a starting point for the analyses of wetland changes. However, because wetland losses by desiccation were strongest for the period 1950–1970, the starting point of the wetland extension in the basin had to be restricted to the early 1970s, since bibliographic sources could only corroborate the existence of the ancient wetland during this date. Therefore, wetland extent in the early 1970s was obtained
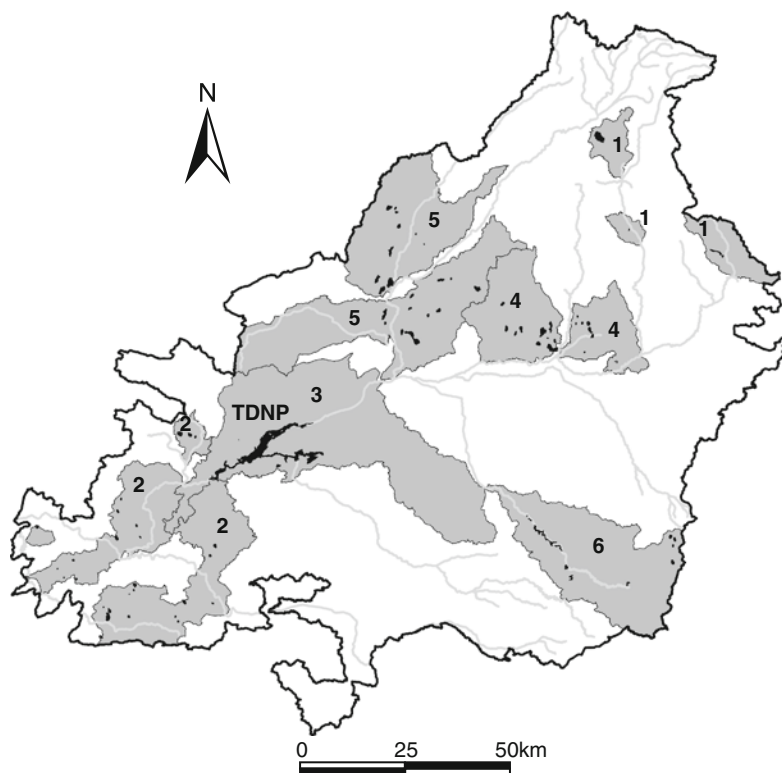
Fig. 4.1 Distribution of wetlands in the Upper Guadiana basin in the early 1970s. Grey areas represent the studied watersheds (1: Blanco, 2: Calatrava, 3: Daimiel, 4: Las Animas, 5: Riansares, and 6: Ruidera)

Table 4.1 Watersheds of the Upper Guadiana basin and associated wetlands considered in this study during early 1970s

Selected watersheds	Watershed area (ha)	Number of water bodies	Total wetland area (ha)	Mean wetland area (ha)	Major and minor wetlands (ha)
Blanco	34,781	4	400.1	100.0 ± 166.1	Capellanes (348) Hito (4)
Calatrava	127,034	27	910.9	33.7 ± 26.6	Nava Grande (106) Dehesa (4)
Daimiel	65,402	3	1,532.0	495.0 ± 582.2	TDNP (1,600) Escoplillo (47)
Las Animas	77,370	19	815.0	42.9 ± 39.1	Manjavacas (139) Hoya Honda (3)
Riansares	176,116	20	1,254.5	62.7 ± 56.0	Taray (231) Salobral (5)
Ruidera	73,439	21	404.5	19.3 ± 22.0	Colgada (103) Redondilla (4)
Total	554,142	94	5,320.8	56.6 ± 157.1	

using a combination of the land use cover, from the 1978 National Land Use/Land Cover map – Spanish Ministry of Agriculture – through identifying the existing unproductive areas, the digital elevation model (DEM, identifying lowland areas), the lithological map (identifying peat deposits or riverbed sediments), the river network (identifying those floodplain wetlands) as well as the topographic maps elaborated during the 1950s (http://www.ign.es/ign/es/IGN/ cartoteca_MapTopo. jsp). Subsequent estimates of wetland area in the study area were computed from the CORINE database for 1990 and 2000 (EEA 2005), corrected by the DEM, lithologic information, bibliographic sources and recent aerial photograph surveys provided by the Castilla-La Mancha regional government in the SIGPAC application (http://pagina.jccm.es/agricul/sigpac.htm). DEM was provided by the Spanish National Centre of Geographical Information (CNIG) at 25 m of resolution, whereas lithological data were taken from digital geologic maps (Magna series 1:50,000) from the Spanish Geological Survey (IGME). LULC were also obtained using the 1978 National Land Use/Land Cover map, and the revised CORINE for 1990 and 2000. Four broad LULC classes were defined, according to the level of naturalness: natural vegetation (comprised by conifers, deciduous forests, holm oaks, scrubland and grasslands), dry croplands (mainly wheat), irrigated croplands (sunflower, corn, and other vegetables, as well as olives and vineyards), and dry-irrigated croplands (a mixture of dry and irrigated croplands). LULC maps at sub-watershed scale were created through establishing synthetic classes defined by dominant land covers.

To test whether the loss or degradation is linked to a particular wetland type, they were hydro-dynamically grouped according their main water sources: rainfall, surface water (river flow) and groundwater, following the hydrogeomorphic classification criteria from Brinson (1993). Lithological information, river network, terrain elevation and groundwater aquifers were combined into a GIS to obtain the following criteria: wetlands fed exclusively by rainfall – rain fed – (relied on impervious substrates – clay, gypsum, metamorphic and volcanic rocks – and away from rivers), those fed mainly by groundwater – groundwater-fed – (relying on permeable substrates – conglomerate, limestone, gravel and sand – leaning on aquifers and located in lowland areas), those fed jointly by rain and groundwater – rain and groundwater fed – (relying on semi-permeable rocks – marl, pyroclastic rock, phreatomagmatic rock and silt) and, finally, those riverside wetlands – floodplains – (connected to the river network), subdividing those floodplain wetlands fed exclusively by river waters –floodplain (surface water) – (relying on impervious rocks) of those receiving contributions from surface and groundwater sources – floodplain (surface and groundwater) – (relying on aquifer substrates).

The degree of wetland habitat degradation by anthropogenic pressure was estimated through water conductivity and phosphorus load. Conductivity was used as an indicator of changes on wetland water sources (e.g. reduction of any water source by prolonged droughts or aquifer overexploitation), while phosphorus was used as a measure of wetland eutrophication, by both point and non-point pollution sources. The data used proceeded from own sources and from Armengol et al. (1975),

Cirujano (1980a, b, c), Velayos et al. (1984 and 1989), Cirujano (1990), Cirujano et al. (1990), MOPU (1990), Cirujano et al. (1992, 1996), Vicente and Miracle (1998), Florin and Montes (1999), Álvarez-Cobelas et al. (2001), and Cirujano and Medina (2002) as well as those provided by the Guadiana Water Authority. Average values measured during the spring season were used for analyses, taking the year with more available data as the most representative for each decade (1970s, 1990s and 2000s). Anthropogenic stressors also included some socioeconomic indicators, grouped by sub-watersheds and municipalities (where the wetland is included), such as population changes and main economic activity (workforce engaged in agriculture, building, industry and service sectors). All information was obtained from the INE base of the National Statistical Institute (INE; http://www.ine.es/intercensal). All spatial information was processed using the ArcGIS 9.2 software package (ESRI 2006).

Pearson product-moment correlation was used at sub-watershed scale to evaluate the effects of changes in LULC, population and economic activity (independent variables) on the wetland loss rate per periods (1978–1990, 1990–2000 and 1978–2000). Changes were computed from differences between periods, taking positive values when the variable increased and negative when it decreased. The mechanistic patterns underlying wetland's habitat quality (water quality: phosphorus loading and conductivity) and wetland losses from 1970 to 2000 were determined using redundancy analysis (RDA). This method allows to determine the relative importance of local and regional conditions on the spatial-temporal variability of our dependent variables (habitat quality and wetland area). Partial RDA analyses allowed decomposing the inertia (variance) into various components attributed to different sets of explanatory variables (Ter Braak 1988). Local conditions were those of existing LULC from a buffer of 100 m around the wetlands, and socioeconomic variables were those represented by the municipalities intersected by the wetlands. Regional conditions were those of its sub-watershed by LULC and socioeconomic variables. Therefore, we decomposed variance attributable to explanatory variables as follows:

1. Local variation [L]: variation explained by local conditions that covary with regional variables.
2. Regional variation [R]: variation explained by regional conditions that covary with local variables.
3. Pure local variation [L|R]: the fraction of variation that can be explained by local conditions independently of any regional condition.
4. Pure regional variation [R|L]: the fraction of variation that can be explained by regional conditions independently of any local characteristic.
5. The variation explained by combined local and regional variables [L + R].
6. The shared/confounded variation explained simultaneously by local and regional conditions [L∩R] ([L∩R] = [L] – [L|R] = [R] – [R|L]).
7. The total percentage of unexplained variance (100 – [L + R]).
8. We run RDA models for water quality parameters and for wetland area independently. We explicitly considered all variables every year.

4.3 Wetland Cover and Extent of Hydrodynamic Types in the Early 1970s

The Upper Guadiana basin landscape consists of a spatially discontinuous complex of numerous small temporary ponds, occupying a very small area in the studied watersheds (<1%), with the exception of TDNP, which occupies ≈2% of (Fig. 4.1). Although the elevation gradient of catchments ranges 430–1,203 m, most wetlands are concentrated in lowland areas, between 600 and 700 m. Only the Blanco and Ruidera watersheds record wetland habitats at higher elevations (>800 m; Fig. 4.1).

Our estimates indicated that, in the early 1970s, the total wetland area in the studied watersheds extended over 5,321 ha, distributed into 94 water bodies (Table 4.1). On that date, the mean surface of each individual wetland reached 56.6 ha, although highly variable spatially (Table 4.1). For example, the region most prone to wetland development appeared linked to La Mancha Occidental aquifer (23 or 04.04, see Fig. 1.4), concentrating 40.3% of the total wetland area. Here, the mean surface of a water body reached 119.3 ha. By contrast, other zones such as those linked to Altomira aquifer represented only 0.8% of the total wetland area. Small wetlands appeared in the Campo de Montiel aquifer (≈20 ha). 39.7% of wetland area (37 water bodies) in the basin was not linked to any aquifer system and could be considered as temporary rain-fed wetlands.

Other previous approaches to the total wetland area in La Mancha Húmeda were performed before the contemporary degradation amounting 25,000 ha (see Chapter 1). In the early 1970s, however, the observed differences with our estimates are not contradictory, considering that our methodology allowed no return to the landscape situation prior to the generalized wetland desiccation in the region, which started from the 1950s. Most of the large floodplain wetlands associated to the Gigüela and Záncara rivers (see Fig. 1.2) were already lost in the early 1970s (e.g. Tablas de Arenas de San Juan, Tablas de Villarta de San Juan, Tablas de Villarrubia and Tablas del Záncara; Heras et al. 1971; Cirujano 1980b; Álvarez-Cobelas and Cirujano 1996). However, the extent of these wetlands before desiccation is not precisely known.

From the hydrodynamic point of view, in the early 1970s most wetlands in the Upper Guadiana basin were temporary water bodies, exclusively fed by rainwater (39.5%; Table 4.2). In contrast, 36% of wetlands developed over floodplains, most of them receiving water from both surface and groundwater sources (Table 4.2). Wetlands fed jointly by rain and ground waters accounted for 14.5% of the total wetland area in the basin (Table 4.2). In the early 1970s, finally, wetlands fed mainly by groundwater (relying on permeable aquifers) represented around 10% of the total wetland surface (Table 4.2). Spatially, most rain fed wetlands concentrated at the Riansares watershed (50%), whereas floodplain wetlands were restricted to the Daimiel and Ruidera watersheds (96%, Table 4.2). Floodplain wetlands fed exclusively by river flows only appeared in the Blanco watershed, representing only 3% of the total wetland area on its watershed (Table 4.2). Most wetlands fed by

Table 4.2 Area of wetlands (ha) according to their hydrodynamic functioning in the studied watersheds of the Upper Guadiana basin during the early 1970s

Watershed	Rainfed	Rain and groundwater fed	Floodplain (surface water)	Floodplain (surface and ground waters)	Ground water-fed	Total
Blanco	347.9	42.0	10.3	0	0	400.1
Calatrava	481.4	239.5	0	51.3	138.7	910.9
Daimiel	0	46.9	0	1,485.0	0	1,532.0
Las Animas	201.0	395.0	0	21.7	197.3	815.0
Riansares	1,054.4	4.7	0	0	195.4	1,254.5
Ruidera	14.1	42.8	0	347.5	0	404.5
Total	2,102.7	771.0	10.3	1,905.5	531.4	5,320.8

both rain and groundwater concentrated at the Calatrava and Las Animas watersheds (82%), while wetlands depending on groundwater as the main source appeared homogenously distributed along watersheds (Table 4.2).

4.4 Land Use–Land Cover Changes and Socioeconomic Indicators During 1978–2000

Dry cropland was the dominant land cover in the basin throughout the studied period (1978–2000; Table 4.3). In 1978, this LULC occupied 70% of the territory in question, reducing its extension to 55% in 1990, at the expense of dry-irrigated cropland, which grew by 15% (Fig. 4.2a). Throughout 2000, dry croplands increased to nearly their original extension, covering 63% of total land area (Fig. 4.2a). Despite the apparent human pressure on the Upper Guadiana basin, natural vegetation appeared as the second dominant LULC, occupying 21% in 1978, and even increasing slightly to 23 % during the period 1990–2000 (Fig. 4.2a). This LULC was dominant in the Ruidera watershed, covering 52–55% of its area (Table 4.3). Irrigated croplands appeared as the third LULC in the studied area, increasing from 27,352 ha in 1978 to 37,322 ha in 2000 (from 5% to 7% of total area; Fig. 4.2a). Urban areas occupied the smallest portion of watersheds (3%), increasing slightly (≈1%) during the entire studied period (Fig. 4.2a).

From 1978 to 2000, land devoted to agriculture increased in all watersheds, except in Calatrava (from 70% to 59%) and Ruidera (from 46% to 43%) where the area of natural vegetation increased. The most complex pattern appeared in irrigated lands, which behaved differently from watersheds throughout the study period. The area devoted to irrigation showed a diminishing trend in Calatrava (from 15,710 ha in 1978 to 8,749 ha in 2000) and Las Ánimas (from 2,676 ha in 1978 to 1,709 ha in 2000). The Riansares and Daimiel irrigation croplands, however, increased strongly (from 5,187 ha to 10,274 ha (twofold) and from 2,422 to 10,579 ha (fourfold), respectively, in the period 1978–2000). Although in the Blanco watershed the land devoted to irrigation only represented 2%, it increased

Table 4.3 Dominant land uses (% of total area), population (inhabitants × 1,000) and main sector of economic activities (>50% of occupancy) in the Upper Guadiana basin in each studied watershed, from 1978 to 2000. Watersheds: Bla: Blanco, Cal: Calatrava, Dai: Daimiel, Ani: Las Animas, Ria: Riansares, and Rui: Ruidera; land uses: Dry croplands, Natural: natural vegetation; main economic activities: Agri: agriculture, Serv: services

|	Dominant land use			Population			Main activity		
	1978	1990	2000	1978	1990	2000	1978	1990	2000
Bla	Dry (83%)	Dry (84%)	Dry (84%)	7.98	7.10	6.02	Agri (59%)	Agri (51%)	Serv (46%)
Cal	Dry (57%)	Dry (42%)	Dry (44%)	153.17	159.21	164.81	Serv (37%)	Serv (42%)	Serv (58%)
Dai	Dry (50%)	Dry (54%)	Dry (53%)	41.77	42.02	42.59	Agri (46%)	Serv (32%)	Serv (42%)
Ani	Dry (87%)	Dry (71%)	Dry (86%)	28.39	28.19	28.08	Agri (46%)	Serv (34%)	Serv (43%)
Ria	Dry (82%)	Dry (60%)	Dry (82%)	74.35	75.34	75.65	Agri (43%)	Serv (30%)	Serv (39%)
Rui	Natural (52%)	Natural (55%)	Natural (55%)	15.29	14.55	13.14	Agri (52%)	Agri (31%)	Serv (39%)
Total	Dry (69%)	Dry (55%)	Dry (64%)	320.95	326.41	330.29	Agri (42%)	Serv (35%)	Services (47%)
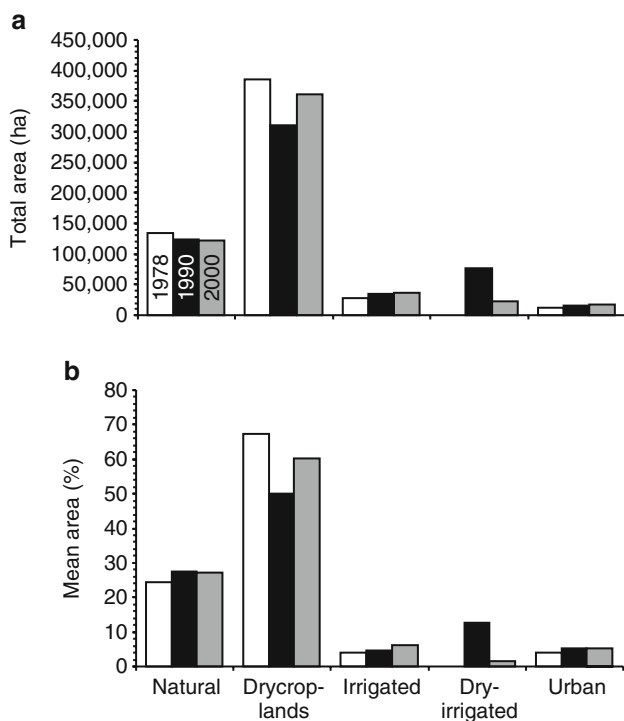
Fig. 4.2 Patterns of the main land use changes in the Upper Guadiana basin during 1978–2000. (**a**) Total area covered by the main land uses in the studied sub-catchments; (**b**) Mean percentage of occupancy of adjacent land uses around wetlands of the Upper Guadiana basin (buffer: 100 m)

twofold from 1978. The observed reduction of croplands in the Calatrava watershed could partially be explained by a tendency to a decline in agriculture, due to the application, from 1993, of the European Agro-Environmental Programs on water demands for irrigation (Programs 2078/2092 and 1257/1999). This Policy, conceived as a vehicle to recover the overexploited aquifer through farmer income compensation, was developed to reduce during 5 years the volume of water used for irrigated lands (Viladomiu and Rosell 1997). Despite compliance with the environmental policy, as has been demonstrated previously, LULC changes were not applied consistently throughout the studied watersheds. In fact, in the Daimiel watershed, which includes the core area of the overexploited Llanura Manchega aquifer, as well as the TDNP wetland, and where implementation of this measurement should have been more effective, there was no perceived reduction of the irrigated croplands.

At local wetland scale (wetland buffer of 100 m), land uses presented a similar pattern to that of its watersheds (Fig. 4.2b). Dry croplands appeared as the dominant land use in wetland surroundings, followed by natural vegetation (Fig. 4.2b). The main difference was the increased weight of the urban areas, occupying up to 5% of wetland surroundings. Anyway, overall the situation in 2000 was not very different

than that in 1978: 68% vs. 71% of agricultural lands, and 27% vs. 24% of natural vegetation (Fig. 4.2). However, in some individual wetlands there was a great contrast between the patterns. In TDNP, for example, in 1978, 53% of the surrounding area was dominated by irrigation crops, whilst 42% exhibited natural vegetation; from 1990 on, 93% of the surrounding wetland was occupied by natural vegetation. In the Carrizosa wetland at the Calatrava watershed, dry-cropland occupying 100% of the wetland surroundings was changed to natural vegetation (100%) in 1990. Other wetlands experienced an increase of irrigation in the surroundings, such as the Laguna Cueva Morenilla at the Ruidera watershed (0–33%), at the expense of the natural vegetation (85–66%), or the Laguna Grande de Quero at Riansares watershed (0–37%), with dry-croplands (100–0%).

The studied watershed had a population of 320,949 in 1978, increasing by 9,339 inhabitants (2.9%) until 2000 (Table 4.3). Population density increased slightly from 57.9 to 59.6 inhabitants km^{-2} in the 1978–2000 period, below the Spanish mean (74.6–82.2 inhabitants km^{-2}, INE 2008; Fig. 4.3). Annual population growth rate was of 1.7% in the period 1978–1990, decreasing afterwards until 1.2%. Both rates were lower than those registered for these periods at national scale (3.15% and 4.19%, respectively; INE 2008). In the 1978–2000 period, the Calatrava, Daimiel and Riansares watersheds increased their population by 7.5%, 2.0% and 1.5% respectively, while Blanco, Ruidera and Animas lost population (26%, 14% and 1%, respectively; Table 4.3).

In 1978, the main economic activity in the study area was agriculture, employing 42% of the workforce, followed by the service sector (31%). This appeared as a common pattern throughout all watersheds (Fig. 4.3). The former sector suffered a serious setback, decreasing to 15% in 2000; this is compensated by employment in services (47% in 2000). This is consistent with the national trend, while the Upper Guadiana basin retained its greater importance of agriculture in the economy (the occupancy in the agriculture sector in Spain: from 22% to 7%, for the period 1978–2000; Cano-Soler et al. 2000). Employment in industry grew slightly until 18% in 1990 (14% in 1978), maintaining its occupancy at the same rate in 2000. Employment in the building sector, which was the main driver of the Spanish economy during the study period (from 6% in 1978 to 14% in 2005; INE 2008), grew here far above the national mean, from 13% to 22%. In the watersheds, agricultural employment remained as an important sector in Blanco only, whereas in the others areas it was relegated to the last place (Fig. 4.3). Highest growth in industrial employment was recorded at the Riansares watershed; Daimiel and Calatrava watersheds, however, showed a strong growth in building activity, which appeared as the second largest source of employment (Fig. 4.3).

4.5 Wetland Losses from 1970 to 2000

During the 1970–2000 period, 40.5% of the total wetland area disappeared from the studied territory. It showed a loss of 2,041.6 ha of wetlands in 30 years. Most wetland disappearances occurred throughout the period 1978–1990 (1,529.3 ha) but
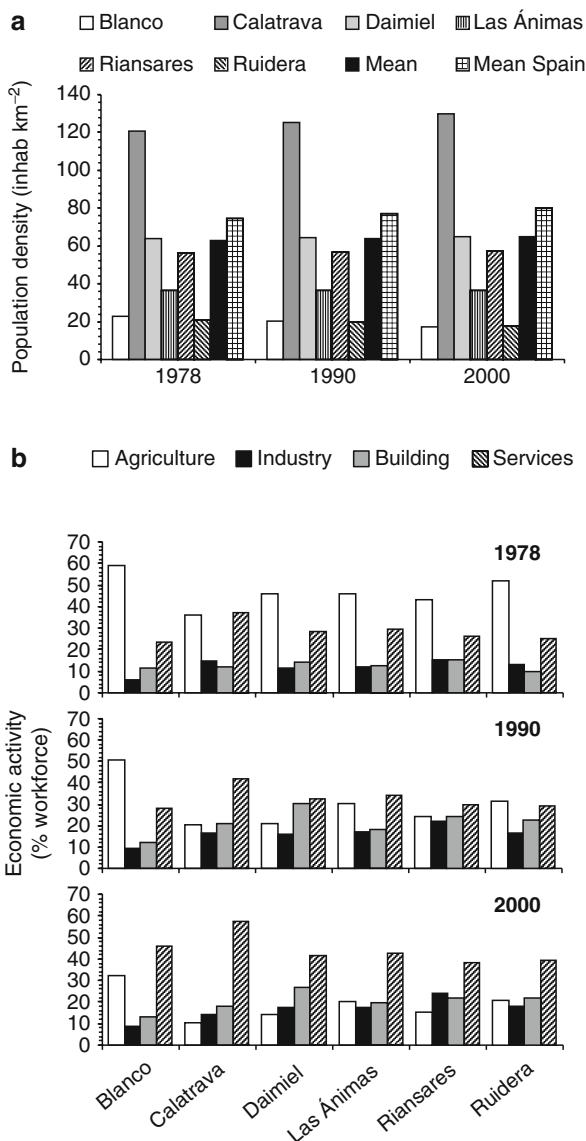
Fig. 4.3 Population growth (**a**) and economic activities (**b**) in the studied sub-catchments of the Upper Guadiana basin, from 1970 to 2000

this could not be comparatively attributed to any observed prolonged drought cycle associated to this period (see Chapter 3, Fig. 3.11a). From 1970 to 1978, 455.9 ha of wetlands were drained, and later reduced to 86.4 ha in the period 1990–2000. Annual rates of wetland losses peaked in the period 1978–1990, when 127 ha year^{-1} of wetlands were transformed, declining strongly from then on down, to 9 ha year^{-1}.

During the period 1970–1978, the wetland loss rate reached 57 ha year⁻¹. This temporal pattern coincides with other regions of North America, such as the Mississippi River delta plain (Bernier et al. 2006) rather than with northern Europe and the northern Mediterranean, where wetland losses have been ongoing for hundreds of years (Brinson and Malvárez 2002). Daimiel and Calatrava were the watersheds suffering the greatest wetland losses for the entire study period (63% and 60% of wetlands existing *ca.* 1970, respectively), most occurring in the period 1978–1990 (Fig. 4.4). On the other hand, the Blanco and Ruidera watersheds only showed wetland losses until 1978 (12% and 22% of total wetlands, respectively; Fig. 4.4). Riansares was the watershed that preserved more wetlands, losing 10% of its original area as it existed in the early 1970s (Fig. 4.4).
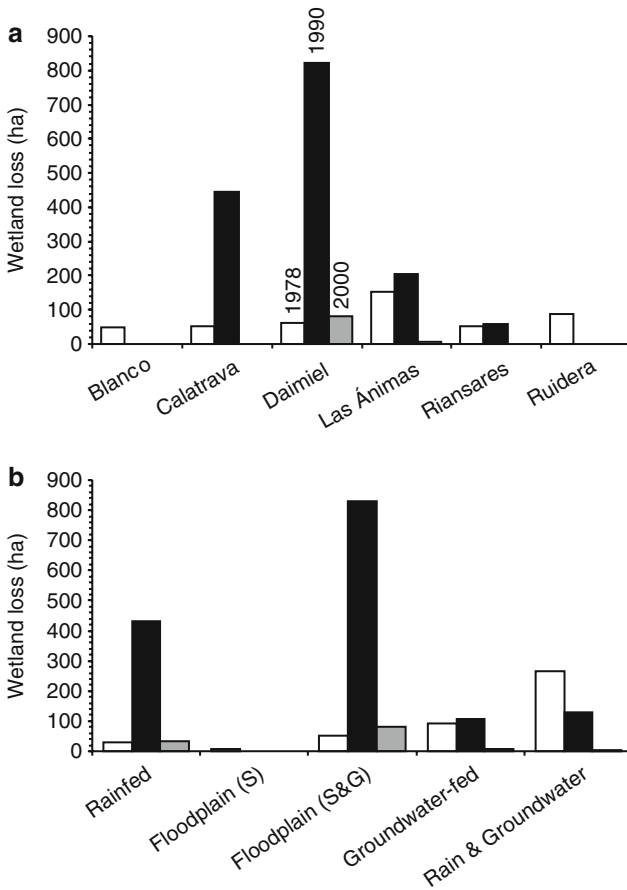

Fig. 4.4 Wetland losses in the Upper Guadiana basin for the periods 1970–1978, 1979–1990 and 1991–2000 by studied catchments (**a**) and by hydrodynamic categories (**b**)

Taking into account hydrodynamic types, wetland losses were in accordance with their relative extension in the study area. Floodplain wetlands fed jointly by surface and ground waters were the most desiccated, accounting for 47% of total wetland losses in the basin for the period 1970–2000, with its main focus on the period 1978–1990 (Fig. 4.4). Most affected by desiccation were, however, floodplain wetlands fed by surface water, whose size was reduced by 62%. Although, for the studied period, rain-fed temporary wetlands scored second in losses (24% of total losses; Fig. 4.4), in 2000, 86% of those existing in the early 1970s were maintained. The other wetland hydrodynamic type most affected by desiccation was that fed by rain and groundwater, which accounted for 19% of total wetland losses (Fig. 4.4), with 52% of its original surface disappearing until 2000. Finally, from 1970 to 2000, groundwater-fed wetlands have been reduced by 39%, but this only accounted for 10% of their total losses (Fig. 4.4). Contrarily to what has been observed in other wetland-rich regions around the world (Bedford and Preston 1988), wetland losses in the Upper Guadiana basin seem not to be influenced by ecosystem landscape positions, rather by their abundance in the landscape. While floodplain and rain-fed wetlands were subject to strong losses during the study period, it probably indicated that anthropogenic stresses affected the areas more than the distribution pattern of the wetlands in the basin, as also observed by Zhang et al. (2009) in the wetlands of the Sanjiang Plain (China).

4.6 Wetland Habitat Quality Evolution During the Period 1978–2000

The trophic state of the Upper Guadiana wetlands during the period 1978–2000 is shown in Fig. 4.5. The studied wetlands drew a clear pattern of nutrient over-enrichment. While most wetlands were mesotrophic in 1978, with a large percentage of poor nutrient (oligotrophic) wetlands, time trend has been towards an increasing wetland trophic level through P-enrichment. Therefore, the 14% of wetland area being eutrophic and hypereutrophic rose to 65% in 1990, and to 83% in 2000 (Fig. 4.5). In 1990, oligotrophic wetlands virtually disappeared (<1%; Fig. 4.5).

Water conductivity also displayed a general pattern toward an increase of salinity in the studied wetlands (Fig. 4.5). However, this should be understood by considering the conductivity of the disappearing wetlands for the entire period. From 1990 wetlands increased their conductivity, falling into the category 2,500–20,000 µS cm^{-1} (Fig. 4.5). Only two water bodies really became more saline (Laguna de Alcahozo – Las Ánimas watershed – and TDNP). This pattern appeared because majority of disappeared wetlands in the basin were those ranging from 0 to 2,500 µS cm^{-1} (84% and 70% in 1990 and 2000, respectively).
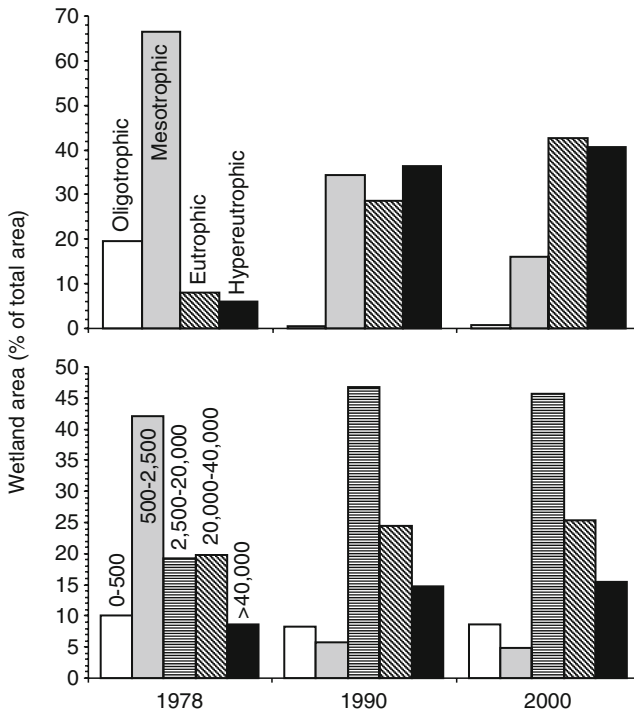
Fig. 4.5 Temporal trends on trophic status (upper) and water conductivity (lower) of wetlands in the Upper Guadiana for the period 1978–2000. Oligotrophic: <0.01 mg P l^{-1}, mesotrophic: 0.01–0.06 mg P l^{-1}; eutrophic: 0.06–0.1 mg P l^{-1}; hypereutrophic: >0.1 mg P l^{-1}; conductivity measured in µS cm^{-1}

4.7 Patterns on Wetland Loss and Habitat Quality Deterioration: the Influence of the Main Anthropogenic Stressors at Local and Regional Scales

The loss of wetlands in the Upper Guadiana basin during the period 1978–2000 could be significantly related to the loss of natural vegetation, as well as to the reduction of the employment in the agriculture sector (Table 4.4). Similarly, the increase of irrigated lands, urban areas and the growth of the industry and building activities also significantly reduced the wetland area in the basin (Table 4.4). While the period 1978–1990 did behave similarly during the entire period (including the increase of dry-croplands), for the subsequent period, the increase of irrigation, population and the strong occupancy in the service sector accounted for the wetland desiccation, along with the loss of employment in the agricultural sector (Table 4.4).

At local scale, the RDA analyses showed that wetland area variance during 1990–2000 was explained by a first axis (explaining 41% of total variance, p < 0.001),

Table 4.4 Pearson product–moment correlations (r values) of the effects of changes (independent variables) in land use (ha), population (inhabitants) and economic activities (inhabitants employed in each economic activity) on wetland area disappearance (ha loss per period; dependent variable) at sub-watershed scale in the Upper Guadiana from 1978 to 2000. Marked correlations are significant at $p < 0.05$

Changes	Wetland losses		
	1978–1990	1990–2000	1978–2000
Natural vegetation	0.94*	−0.58	0.93*
Dry-croplands	−0.71*	0.71	−0.20
Irrigated lands	−0.93*	−0.99*	−0.92*
Dry-irrigated	−0.44	−0.67	−0.35
Urban	−0.92*	−0.71	−0.87*
Population	−0.02	−0.96*	0.00
Agriculture	0.90*	0.97*	0.91*
Industry	−0.67*	−0.42	−0.61*
Building	−0.85*	0.66	−0.82*
Services	−0.38	−0.97*	−0.22

which included as main explanatory variables the population employed in industry and building as well as population density, all positively correlated (Fig. 4.6a and Table 4.5). Therefore, for this period, conservation of wetland's size appeared to be better in industrialized areas as compared to agricultural and services zones, where almost all wetlands were previously lost, in the period 1978–1990. The second axis, which was not statistically significant, explained 6% of the variance, and was positively related to the wetland's size in 1970–1978 (Fig. 4.6). The percentage of dry and irrigated croplands was positively correlated with this second axis, whereas the correlation was negative in the case of percentage of natural vegetation (Fig. 4.5). Hence, in watersheds dominated by agricultural uses, large wetlands were formerly present, but were lost until 1990, whereas in those watersheds with high percentage of natural vegetation there was an abundance of small ponds, which were better preserved throughout the study period.

From 1990–2000, water quality changes at local scale were at first explained by a first axis justifying 41% of total variance ($p < 0.001$; Fig. 4.6b). The main significant explanatory variables related to the axis were population dedicated to the industry and population density, positively; and population dedicated to services, negatively (Fig. 4.6b and Table 4.6). According to these, water quality conditions deteriorated in the most industrialized and populated areas for this period. Negatively related to this first axis were good quality wetlands habitats located in areas where the service sector developed strongly, and were lost in the period 1978–1990. Most of these wetlands belonged to the rain-fed hydrodynamic category. The second axis, which was not statistically significant, explained 5% of the variance, and, in 1978, was positively related to water quality conditions (Fig. 4.6b). Here, the percentage of dry and irrigated croplands was positively correlated, whereas the percentage of natural vegetation was negatively correlated. It indicated how the best wetland habitat quality was found in areas surrounded by natural vegetation.
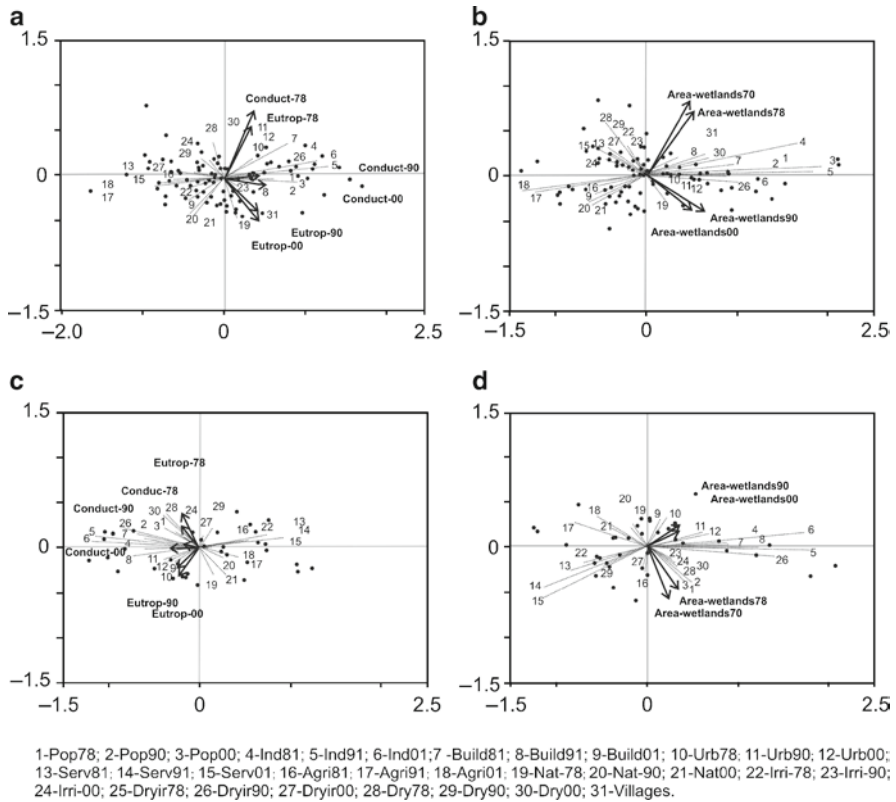
Fig. 4.6 Biplots of the partial RDAs applied on wetland area (**b** and **d**) water quality variables (**a** and **c**) using all variables (land use-land cover, economic activities and population) derived at local scale (L; panels **a** and **b**) and regional scale (R: panels **c** and **d**) for the years 1978, 1990 and 2000. Abbreviations legend: Pop: population; economical activities, Ind: industry, Serv: services, Build: building, Agri: agriculture; land-uses, Nat: natural vegetation, Dry: dry croplands, Dryir: dry-irrigation croplands, Irri: irrigation crops

Similarly to local conditions, changes in wetland area at regional scale during 1990–2000 were explained by a first axis (explaining 45% of total variance, $p < 0.001$), where population dedicated to industry and building sectors were positively related, whereas population dedicated to services was negatively (Fig. 4.6c and Table 4.5). As at local scale, industrialization at watershed scale led to a better conservation of the wetland area. On the opposite side, the growth of the services sector contributed to greater loss of wetlands (Fig. 4.6c). The second axis, explaining 5% of variance ($p < 0.001$), was negatively related to the wetland area in 1970–1978 (Fig. 4.6c). Percentage of dry croplands and population density were positively correlated with this second axis, whereas the percentage of natural vegetation was negatively correlated (Fig. 4.6c and Table 4.5). High population combined with agriculture uses contributed to the disappearance of large wetlands in 1990; contrarily, wetland conservation increased in watersheds dominated by natural vegetation.

Table 4.5 Percentage of variance explained by main explanatory variables (land use-land cover (LULC) types, economic activities and population) on temporal dynamic of wetland area during 1978–1990–2000, by partial redundancy analysis (RDA). P-level represented between parentheses

	Local (L)	Only local (L|R)	Regional (R)	Only regional (R|L)
Total R^2 (%)	32 (0.001)	NS	43 (0.001)	10 (0.038)
LULC				
Natural vegetation 1978			5 (0.004)	
Dry croplands 1990			3 (0.028)	
Economic activities				
Industry 1990	15 (0.001)		19 (0.001)	
Services 1990			6 (0.004)	2 (0.027)
Building 1978			2 (0.044)	2 (0.045)
Building 1990	5 (0.006)			6 (0.001)
Building 2000	3 (0.039)			
Population				
Number of towns	5 (0.011)			
Population 1978	4 (0.009)			
Population 2000			3 (0.030)	

At regional scale, water quality conditions during 1990–2000 were explained by a first axis (45% of total variance, p < 0.001; Fig. 4.6d). Here, explanatory variables were population devoted to the industry, positively, and population devoted to the services and agriculture, negatively (Fig. 4.6d and Table 4.6). As noted at local scale, industrialization significantly deteriorated water quality, while agriculture and services maintained it in better conditions. Unfortunately, most of these wetlands had already disappeared in 1990. The second axis of the RDA analysis explained 4% of variance (p < 0.001). In 1978–1990, it was negatively related to water quality conditions, through population (negatively) and the percentage of urban uses (positively; Fig. 4.6d and Table 4.6). Thus, the increase of population as well as the size of towns in the watershed had negative effects on wetland habitat quality.

High co-variation between local and regional factors was observed, explaining wetland area and water quality during the years of the study (Fig. 4.7). The pure effects of local conditions (L|R) in both the wetland area and water quality were not statistically significant, due to the great co-variation with the regional ones (Tables 4.5 and 4.6). However, the pure effect of regional factors (R|L) was significant in relation to the population working in the building and service sectors (Tables 4.5 and 4.6). The trend was for co-variation to descend through time, whereas the role of pure regional conditions increased. This dynamic breaks the link between local and regional conditions, reducing the total explained variance (Fig. 4.7).

Because the unexplained variance in RDA analyses appeared to be relatively high, our results proved how wetland losses and habitat quality degradation in the

Table 4.6 Percentage of variance explained by the significant explanatory variables (land use-land cover (LULC) types, economic activities and population) on the temporal dynamic of water quality (conductivity and eutrophication) during 1978–1990–2000, by partial redundancy analysis (RDA). P-level represented between parentheses

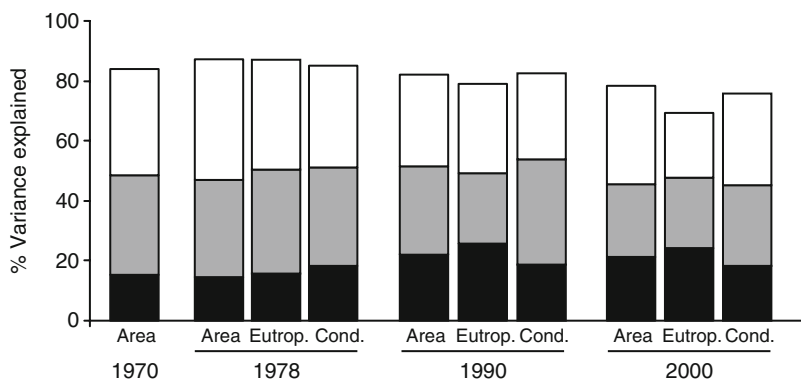|	Local (L)	Only local (L|R)	Regional (R)	Only regional (R|L)
Total R² (%)	25 (0.001)	NS	39 (0.001)	8 (0.006)
LULC				
Urban 2000			2 (0.060)	
Economic activities				
Industry 1990			26 (0.001)	
Industry 2000	17 (0.001)			
Services 1978	5 (0.007)			
Services 1990			3 (0.006)	2 (0.056)
Building 19901				6 (0.001)
Agriculture 1990			5 (0.006)	
Population				
Population 1978	3 (0.040)			
Population 2000			3 (0.021)	

Fig. 4.7 Variance partitioning (%) of wetland variables: wetland area, eutrophication and conductivity through time by means of partial RDA. Three different components are given: pure regional variation [R|L] (*black area*), co-variation (the shared local and regional variation [L|R]; *grey area*), and the unexplained variation (100 − [L + R]; *white*). Pure local variation [L|R] was not significant and is, therefore, not shown

Upper Guadiana basin are driven, both at local and regional scales, by complex processes, difficult to estimate with the data available. Wetland disappearance and degradation have been forced by a complex matrix of anthropogenic variables, including those used here (LULC, population density and economic activities) but not only by them, which, directly or indirectly, drive landscape alteration processes. Diverse anthropogenic stressors have been shown to affect wetland integrity at watershed scale, through changes in hydrology and non-point source pollution

(Wang et al. 1997; Jones et al. 2001; Gergel et al. 2002; Tang et al. 2005; Uuemaa et al. 2007). In our case, landscape variations driven by LULC changes, intrinsically linked to economic activities and demography, were capable of explaining close to 50% of wetland changes in area and habitat quality. Pressure of population growth, combined with the agricultural sector, explained wetland area depletion until 1990. Habitat quality, which worsened from 1990 on, has had a greater impact on areas where industry and building sectors had more weight on the socioeconomic development (also densely populated). From 1990, better habitat quality conditions appeared in the areas dedicated to service and agricultural activities. Finally, throughout the study period, it was found that those areas dominated by natural vegetation appeared to strongly increase wetland conservation, improving habitat quality.

Our results agree with those obtained by others authors in similar agriculturally impacted regions (e.g. Liu et al. 2004; Zhang et al. 2009). Agricultural development, frequently the dominant human activity in wetland-rich areas, is the major cause of wetland loss (Turner 1991). Nonpoint source pollution such as that derived from agricultural practices, has been cited as the main cause for water quality degradation (Hemond and Benoit 1988; Bhaduri et al. 2000; Tuteja et al. 2003; Moss 2008). On the contrary, in the Upper Guadiana basin, wetland habitat quality has been negatively impacted, from the 1990s onwards, mainly through secondary economic activities. This could be explained by three main causes: (i) large wetlands appeared in most economically developed watersheds (with more industry, services and a dense population), (ii) semi-arid climate limits runoff at storm events and point sources from secondary and tertiary sectors, therefore, they have more weight on the total discharges entering the wetlands, and (iii) agriculture has been in economic recession from the mid-1990s. This trend concurs with the recent overview by Brinson and Malvárez (2002), who note that the more industrialized countries are likely to conserve their remaining, already impacted, wetlands, while nations with less industrialization are now experiencing accelerated losses, and may continue to do so for the next several decades.

From the 1970s, human activity in the Upper Guadiana has clearly been the main cause of wetland disappearance and degradation. High co-variation at both local and regional scales has significantly impacted on wetland degradation. However, the temporal trend shows that anthropogenic stressors operating at regional scale will have more weight on wetland conservation. Therefore, future conservation of wetland habitats depends on integrated management of natural resources at watershed scale. Although environmental policies regulating industrial and urban wastewater discharges are considered in the 7th EU Water Framework Directive, wetland sustainability in the Upper Guadiana basin requires an additional effort to adapt the availability of natural resources to economic development.

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