Chapter 12
Synthesis: The Past, Present and Future of Las Tablas de Daimiel

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Abstract Great strides have been made in our understanding of the ecology of a semiarid floodplain wetland, Las Tablas de Daimiel National Park (TDNP). Continuous interdisciplinary and collaborative research efforts during the last decades helped increase our understanding of basic and applied aspects of the wetland's ecology and biogeochemistry. The main message of this book is that human activity irreversibly altered a unique ecosystem in a few decades which evolved over thousands of years. Hydrological disruptions due to aquifer overexploitation resulting from excessive agricultural irrigation, contamination and a series of management interventions that caused more damage than repair form the core of the problem. However, our knowledge is far from complete, especially concerning means to manage the wetland in a way that guarantees both sustainability and development in times of over-exploitation by humans. In addition to summarizing the contents of this book, we will advocate research approaches that could fill remaining information gaps. Critical to the survival of this wetland will not only be scientific progress. An integration of scientific, cultural and historical knowledge in the interaction cycles between ecological, social, political and economic systems should be the ultimate goal. Without this panarchic approach to understanding ecosystems and their management, sustainable development will remain an eternal oxymoron.

"All human actions have one or more of these seven causes: chance, nature, compulsion, habit, reason, passion, and desire." Aristotle

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12.1 Background and Current State of Las Tablas de Daimel

Wetland science is a rather recent discipline within aquatic sciences (Mitsch and Gosselink 2000). While historically regarded as useless land, recent appreciation of the provision of the many ecosystem services of wetlands (e.g. biodiversity, flood prevention, nutrient and pollution sinks, and resource supply; Constanza et al. 1997) has motivated conservation and restoration efforts worldwide. In addition to the well-known Ramsar List created for wetland conservation purposes, the environmental, social and cultural value of wetland ecosystem around the world has also received the international recognition of the UNESCO through the Man and the Biosphere (MAB) Programme. MAB recognizes the importance of 120 wetland sites as biosphere reserve ecosystems, which is ca 22% of the total MAB sites, and the number continues to rise each year. In fact, Spain is along with Mexico the country with most wetland sites included in the MAB (i.e. seven wetlands). With regard to Europe, since 1992, the European Union LIFE Programme has co-funded around 120 wetlands-related projects across the nature, environment and third countries' thematic components (http://ec.europa.eu/environment/life/publications/lifepublications/lifefocus/documents/wetlands.pdf). The European appreciation of wetlands is also reflected in the recent establishment of the European section of the Society of Wetland Scientists (SWS) and by the activities of the European Pond Conservation Network, among other, often volunteer-based, organizations.

Given this rather recent appreciation, and the fact that Mediterranean limnology is generally not as well advanced as the limnology of temperate aquatic ecosystems (Alvarez-Cobelas et al. 2005), the great strides which have been made in our understanding of the ecology of the unique semiarid floodplain wetland, Las Tablas de Daimiel National Park (TDNP), are therefore all the more remarkable. This book summarizes a continuous, interdisciplinary and collaborative research effort, initiated in the 1980s by S. Cirujano and M. Alvarez-Cobelas and joined later by all contributors of this book and others. It touches on a broad spectrum of topics, including hydrology, sedimentology, paleolimnology, planktology, nutrient dynamics, vegetation science, food web theory, pollution research, and landscape ecology. It allows blending basic and applied research of a wetland at different spatial and temporal scales in a way that has been seldom documented before in the Mediterranean area of Europe and North Africa. We hope that this book serves to stimulate similar research efforts in other Mediterranean areas. Undoubtedly, such efforts will increase our understanding of the uniqueness of Mediterranean aquatic ecosystems, thereby broadening our current limnological paradigm which is biased mainly towards temperate lakes and rivers (Alvarez-Cobelas et al. 2005).

While the wetland has undergone several transitional ecosystem states over geological history, mainly as a result of natural causes (climatic variability) (Chapter 2), this book highlights that the devastating imprints of human action on this wetland have occurred in very recent history; so recent that even the elderly persons in local populations do not recognize the ecosystem they knew from their childhood! Hydrological disruptions due to aquifer overexploitation resulting from excessive agricultural irrigation, contamination and several management interventions that caused more damage than repair form the core of the problem (for an overview of historical impacts see Table 10.1). Figure 12.1 and Box 12.1 summarize the many direct and indirect impacts on the ecosystem resulting from human activity. Most importantly, Fig. 12.1 shows a sustainable human use of wetland resources (vegetation, fish, crayfish) in the 1960s relative to a recent period where no direct use of these resources is made. By contrast, the major human impacts that contributed to large-scale wetland degradation, mainly in form of hydrogeochemical alterations, are highlighted.

It is clear from people's collective memory, and the research documented in this book, that humans changed a wetland in decades which evolved in hundreds of thousands of years. Las Tablas de Daimiel moved inexorably to an alternative, irreversible stable ecosystem state (Angeler et al. 2007), one that is of much concern, however, because the ecological health of TDNP compares with a coma patient whose vital functions are maintained by artificial life support. Without this life support, mainly in form of artificial hydrological management (interbasin water diversion, local groundwater pumping), TDNP would have passed away some time ago, sharing the fate of so many other wetlands, ultimately leading to a loss of cultural, evolutionary and natural heritage from our memories through phenomena related to transgenerational amnesia.

Las Tablas de Daimiel is one example were stakeholders, decision makers and local societies had no clues on the far-reaching and complex consequences arising from the causes of their action. Even the layman has the chance to appreciate that something is fundamentally wrong, when contemplating the massive irrigation during the hottest hours of summer days when traveling across central Spain. However, the situation seems not hopeless. As pointed out in the book (Chapter 10), political good will is giving rise to an increased allocation of taxpayer's money and other resources to move away from unsustainable agricultural practices and conserve wetlands, including Las Tablas de Daimiel. But the situation is not without burden. Despite the great advances being made in our understanding of TDNP several knowledge gaps remain. Many of these are of ecological nature, which we highlight in the following section, and which have relevance for rehabilitation purposes. In addition, consideration of the complex interplay between social, political and economic factors will be essential to sound environmental conservation (Gunderson and Holling 2002); otherwise the increased knowledge gain will be merely of scientific value with little application for solving the core of the problem.

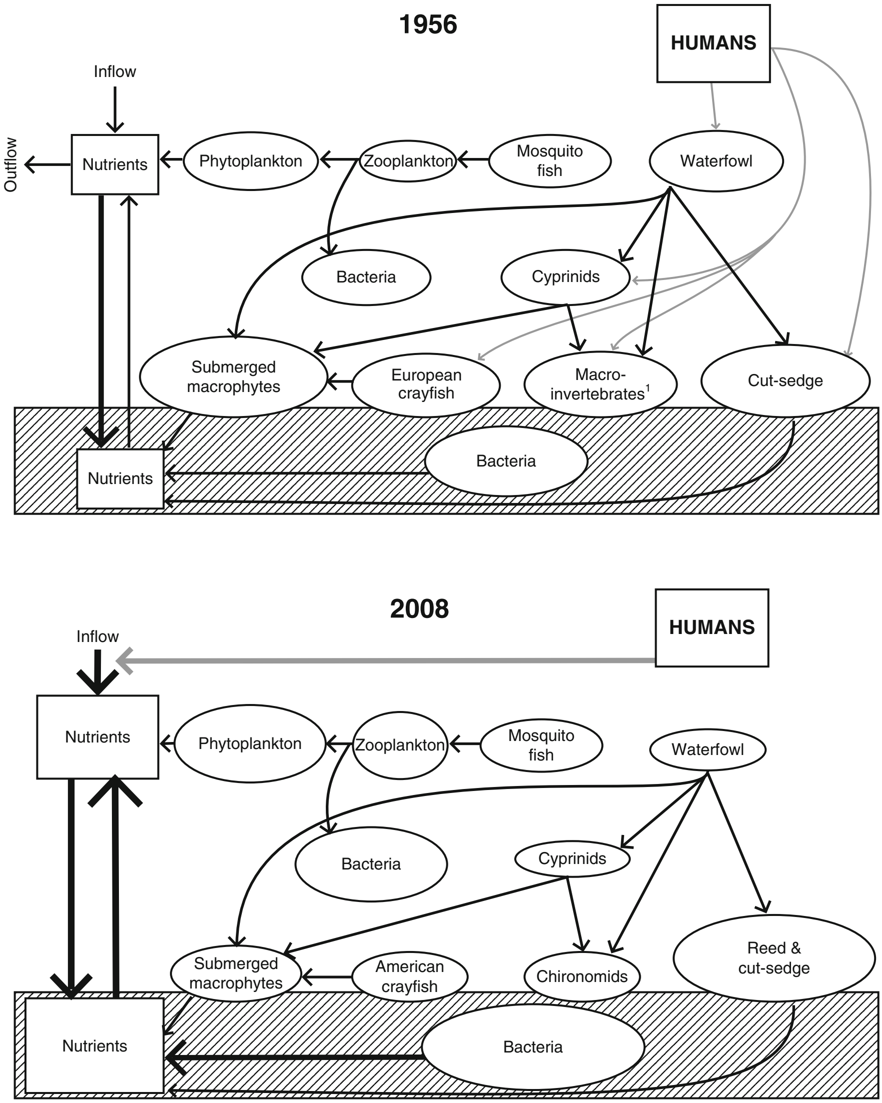

Fig. 12.1 Models comparing simplified ecosystem structure of Las Tablas de Daimiel between periods before (1956) and after (2008) degradation. Boxes and ellipsoids represent qualitatively the abundance of compartments and biological communities. Although bacteria are the sink of all organic matter and waste substances in biota, the arrows have been suppressed to simplify the graph. Note than human influence has been represented differently in each period: in 1956, although humans used the natural resources provided by the wetland, their influence on the ecosystem is almost negligible (*grey fine lines*); contrarily, the influence of human activity on the ecosystem is nowadays negative. Macroinvertebrates from 1956 was composed by mussels, shrimps, insects, crustaceans and sponges

Box 12.1 A comparison of current and past (first half of the twentieth century) conditions of Las Tablas de Daimiel, with emphasis on key hydrological, biogeochemical, ecological and catchment features

Features	Past	Present
Catchment		
Agricultural production	Low	High, unsustainable
Irrigation	Low	Massive
Aquifers	Intact	Severely overexploited
Hydrology		
Conditions	Riverine	Impounded
Surface inflow (Gigüela)	Seasonal	Irregular
Surface inflow (Guadiana)	Regular	Discontinued
Groundwater discharge	Yes	No
Hydroperiod	Regular	Very irregular
Flood frequency	Annual	Decadal
Interbasin transfer	No	Yes
Geomorphology		
Water mills	Functional	Not functional
Dams	Absent	Present
Peat fires	Infrequent	Frequent
Terrain subsidence	No	Yes
Water quality and nutrient cycling		
Quality of water source	Fresh	Oligohaline
Waste water discharge	No	Yes
Eutrophication	Eutrophic-hypereutrtophic[a]	Hypereutrophic
Carbon budget	Higher sink	Lower sink
Nitrogen budget	Transformer	Sink
Phosphorus budget	Transformer	Sink
Bird kills	Rare	Frequent
Fish kills	Rare	Frequent
Turbidity	Low	High
Invertebrates	Diverse, rich	Species poor
Vegetation		
Submerged plants	Diverse, rich	Sporadic, species poor
Emergent plants	Cut-sedge	Reed dominance
Continuity in plant cover	Low	High
Animals		
Fish	Species rich	Species poor
Fish type	Native	Exotic dominance
Crayfish	European[b]	American[c]
Bird abundance	High	Low

[a] The ancient wetland was eutrophic although the clear water state was maintained by nutrient outflows which currently occur only during extreme floods

[b] *Austropotamobius pallipes*, which was also introduced during the seventeenth century

[c] *Procambarus clarkii*, introduced during the 1950s

12.2 Missing Research Links: The Ecological Challenge

This book clearly demonstrates the past of TDNP before agricultural expansion in central Spain and its current ecological status as a result of ecologically unsound approaches taken to water resource management (Angeler et al. 2007). The reader may have noted that restoration has been invoked, albeit timidly, several times in the book to guide future development of TDNP. This timidity is intentional! The major state shift produced in TDNP (e.g. dam construction) created new self-reinforcing feedback loops, which act in concert with other stressors (contamination and exotic species). Although in the very unlikely case that a "self-sustaining" hydrology (e.g. aquifer restoration, approximation of natural hydroperiod and flood frequency regimes through artificial water resource management; see Chapter 3) is re-established in TDNP, restoration of its pristine conditions will still be impossible. Climate change will further increase the uncertainty regarding rehabilitation outcomes (Harris et al. 2006), particularly considering the increased aridity predicted for the Mediterranean region (Gao and Giorgi 2008).

Wetland scientists have traditionally put much emphasis in restoring abiotic disturbance regimes, hoping that nature does the job of bringing the biota back. However, such a restoration strategy hardly achieved desired wetland rehabilitation goals (see e.g. the Field of Dreams hypothesis by Palmer et al. (1997)). Zedler (2000) highlighted that wetland science is burdened with examples of ignoring or violating ecological theory. While it is perhaps true that hydrological disturbance regime is the single most important driver of ecological processes in wetlands (Mitsch and Gosselink 2000), biotic components must not be ignored in wetland restoration. However, it is not just the species or sets of species that should receive primary focus, but critical functional groups that may be able to enhance resilience to future disturbance (Bellwood et al. 2004). Restoration ecology as a science can only advance through research at the interface between landscape ecology and ecosystem ecology, linking abiotic and biotic processes, and this in turn will permit solving lingering ecological questions (Falk et al. 2006). It is clear that wetland restoration and conservation success depends on the advance on ecological knowledge. We believe that expanding the research spectrum in TDNP can contribute to this advance.

In the following we will highlight several research approaches that could be useful for this task. We acknowledge that our list is not complete and the outlined research approaches are speculative and intentionally described superficially because the maturation of these ideas will require further interdisciplinary collaboration in an extended research network to cope with particular topics that fall outside our scientific expertise. Furthermore, converting these ideas into practice will ultimately depend on many factors that the authors and editors of this book cannot control (see Section 12.3). However, we believe that these points represent core issues that could provide relevant information for a sound adaptive management in the future. We highlight with an asterisk topics which we think should receive priority in future research agendas.

12.2.1 Research at the Local Scale

12.2.1.1 Wetland Hydrology*

Las Tablas de Daimiel, as most wetland ecosystems, is not a homogeneous system. Some questions about the water cycle of Las Tablas de Daimiel remain unsolved (see Chapter 3). Water infiltration through the wetland is the least well known component of the water cycle of this wetland. Whilst wetland infiltration rates are always assumed to be spatially uniform and almost constant on monthly scales, water budget computations show that it operates with great spatial and temporal variability as a function of soil physical properties. Despite the recognized importance of infiltration in the water cycle, it still needs to be thoroughly assessed in TDNP. A detailed spatial model of wetland inundation is also lacking currently, but will be needed to understand the main flooding patterns during wetting and drying cycles. Therefore, the lack of this information currently limits optimal management designs regarding water supply to the wetland, and complicates predictions of climate change impacts on wetland hydrology. The following aspects highlight hydrological research needs for the future:

- In situ infiltration essays, using isotopic tracers, need to be carried out with high spatial and temporal resolution, taking the heterogeneity in soil physical properties into account.
- Modeling hydrological processes at adequate spatial and temporal scales.

12.2.1.2 Wetland Biogeochemistry and Climate Change

Numerous uncertainties about wetland biogeochemistry need to be explored in the future. For example, while nutrient cycling in the water column is well known, very little research has been devoted to sediment biogeochemistry. Because of their implications for global warming as well as for ecosystem functioning, decomposition processes need to be examined in wetland soils and microbial processes should be studied under anaerobic conditions during flooding. Stable isotope enrichment experiments could help to trace most biogeochemical processes in wetland sediments. The immediate effects of climate change (atmospheric CO_2 enrichment and increase of air temperature) on macrophtye and invasive plant growth and nutrient transformations will also need to be explored with detail. The following points provide some suggestions for the research agenda in the next years:

- Main nutrient transformations at the water–sediment interface.
- Assessment of carbon, nitrogen and phosphorus transformations in wetland soils, particularly those occurring under anaerobic conditions during flooding events. Denitrification process and rates in the wetland under contrasted hydrological conditions.
- Nutrient releases from wetland sediments and wind-induced resuspension.

- The effects of drying/rewetting cycles on wetland nutrient dynamics.
- Net carbon exchange and CO_2/CH_4 emission rates under contrasted hydrological conditions at the ecosystem level.

12.2.1.3 Plant Ecology

Although macrophytes are probably the most studied wetland community (see Chapter 7), there are still some scientific gaps that need to be evaluated in future research:

- Genetics of cut-sedge and population dynamics
- Genetics and population dynamics of charophytes
- Macrophyte dynamics and nutrient cycling under combined effects of elevated atmospheric CO_2 and air temperature using a FACE (Free-air CO_2 enrichment) approach

12.2.1.4 Macroinvertebrate Ecology

Despite macroinvertebrates forming a key group of organisms in wetlands (Batzer et al. 1999), there is not much information available for TDNP. It is reasonable to assume that the structure of the invertebrate community and the functions they fulfill in the wetland have been dramatically altered as a result of the compounded impacts (contamination, exotic species invasions) inflicted by humans. Preliminary studies using benthic macroinvertebrates to evaluate water quality according to the BMWP' assessment scheme (an adaptation of the British Monitoring Working Party Programme for quality assessment of Spanish waters; Alba-Tercedor and Sánchez-Ortega 1988) supports this conjecture. Judged from the calculated scores, the wetland can be classified as strongly degraded (M. Alvarez-Cobelas, 2007 unpublished data).

The wetland has also been invaded by an exotic crayfish, the American red swamp crayfish (*Procambarus clarkii* Girard), which caused an extinction of the European crayfish *Austropotamobius pallipes* (also introduced during seventeenth century) through transmission of fungal parasites (Aphanomycosis). *Procambarus clarkii* is a highly fecund, voracious predator and efficiently feeds on submerged vegetation. It also shows an extensive burrowing behaviour, causing impact in ecosystems through structural habitat alteration and biological interference with other species (Geiger et al. 2005). Given its ability to alter biological and biogeochemical processes in wetlands, this species certainly qualifies as an ecosystem engineer (Jones et al. 1997). In TDNP only some preliminary impact assessment studies have been carried out. Angeler et al. (2001, 2003b) have studied the impact of *P. clarkii* on water and sediment quality and submerged vegetation using experimental enclosures. The results showed that the cover of submerged macrophytes in the mesocosms was soon eradicated in the presence of the crayfish. Upon loss of the vegetation cover, this species increased water turbidity and contributed to a nutrient transfer from the sediments to the water column. This highlights that the effects of *P. clarkii* work to maintain TDNP in its degraded state. The following points highlight research approaches to be pursued in the future:

- Management plans to control population densities of *P. clarkii* (see discussions in Chapter 9).
- Understanding the trophic ecology of *P. clarkii*, including its impacts on food web structure and function, using correlative and manipulative studies. Complementary approaches based on gut content and stable isotope analyses could be useful for this task.
- Routine monitoring of invertebrate community structure at adequate spatial and temporal scales. From the applied perspective this could make an important contribution for complying with the European Water Framework Directive, and serve the administration as a tool for habitat quality evaluation and management decision making. From the basic ecological side, the monitoring data could help address a variety of research questions related to environmental drivers of structural and functional dynamics of macroinvertebrate communities.

12.2.1.5 Microbial Ecology

Microbial processes have not been well studied in TDNP. Our information is so far restricted to the dynamics of heterotrophic bacteria and autotrophic picoplankton in the water column (Chapter 6 and references therein). The recent application of molecular methods started to reveal the diversity of microbial communities in the wetland (MA Rodrigo et al., 2009 unpublished data). Addressing the following points could help increase our understanding of the ecological role of microbial communities in TDNP:

- Microbial communities as a food web base that fuels secondary production through the microbial loop
- Quantifying the relative importance of autotrophic versus heterotrophic processes in ecosystem metabolism
- Microbial communities and processes in wetland soils involved in carbon dioxide, methane or nitrogen emissions
- Microbial processes in wetland soils as a function of recurring wetting/drying events
- Changes of microbial processes and community compositions under elevated atmospheric CO_2 and temperature
- Assessing the role of virus ecology in microbial processes
- Sanitary issues: microbial communities and processes as drivers of disease outbreak (botulism)

12.2.1.6 Vertebrate Ecology

Fish and bird ecology have not been enough studied in the wetland. Most existing data provided information relative to abundance and species richness; however, many basic aspects on their community ecology remain unknown. Besides, the ecology of these groups should be approached from larger spatial scales (regional or watershed). Although vertebrates could be considered marginal on ecosystem functioning, our ecological knowledge of the wetland ecosystem would be incomplete if these communities are neglected. Some aspects that could be addressed in the future:

- Fish population dynamics
- Effects on water quality
- Waterfowl and passerine population dynamics
- Habitat distribution along with man-made change in the catchment

12.2.1.7 Food Web Ecology

Chapter 9 presents a conceptual model that summarizes how manipulation of specific target communities in the wetland could help improve the environmental quality of TDNP. Despite the management appeal of the model, its reductionist nature should be emphasized because it was largely inspired by theory and empirical evidence coming from only small-scale manipulative experiments. Its value for guiding management, through manipulation of key communities (vegetation, fish, crayfish), should be tested in the future with a focus on:

- Allochthonous and autochthonous organic matter pathways through food webs using stable isotopes
- C:N:P stoichiometry in the food webs
- Food web lengths and connectivity in manipulated and non-manipulated food webs
- Trophic position and energy supply to food web components in manipulated and non-manipulated food webs evaluated through stable isotopes
- Food web stability as a function of natural and anthropogenic disturbance regimes

12.2.1.8 Evolutionary Ecology

Many wetlands harbor an impressive reservoir of dormant propagule stages in their sediments that can be useful for evolutionary research. These propagule banks integrate the environmental history of a site and its terrestrial catchment (Brendonck and De Meester 2003), and provide different research opportunities:

- Assessing the ecological integrity and/or the impact of anthropogenic stress in wetlands through comparative studies of the structure of emerged communities (Angeler and García 2005).
- Using a resurrection ecology approach to assess ecological and evolutionary change over time (Kerfoot et al. 1999; Kerfoot and Weider 2004). Resurrection ecology has so far made use of resting eggs from water flea (*Daphnia*) that have undergone different dormancy periods (years to decades) within a lake. Resurrected organisms can be studied comparatively using evolutionary/genetic and experimental approaches. Both approaches combined can provide insights

into how the dimensions of species' ecological niches have shifted over time and could help reveal whether direct effects of, for example, climate change (increased temperatures and atmospheric CO2 concentrations and hydrological alterations) or other anthropogenic stressors (e.g., contamination, landuse change, exotic species) have caused microevolution (Angeler 2007). A resurrection ecology approach seems particularly suitable for disentangling the effects of the multiple anthropogenic stressors that have affected TDNP in recent history, and it will be interesting to compare patterns between organisms that occupy different trophic positions in the food webs (i.e. *Daphnia* vs algae vs protozoa).

12.2.1.9 Genetic Diversity

Molecular techniques are increasingly finding their place in ecological research (Hughes et al. 2008). Recent studies demonstrate that diversity at the genetic level of populations enhances resilience to disturbance events (Altermatt and Ebert 2008; Reber et al. 2008). Genetic data can also provide insight into extinction risks of sexually reproducing species resulting from loss of genetic diversity (Stockwell et al. 2003). Research in TDNP is almost exclusively based on "morphological" biodiversity. Determining the genetic structure and variability in populations of native and exotic species could address the following points:

- Biogeographic patterns, dispersal ecology, and conservation status of emblematic and rare wetland taxa at local and regional scales
- Impact of exotic species and other stressors on the genetic structure of populations of native species
- Community and ecosystem resilience based on the genetic patterns of populations
- The impact of genetic diversity in food web configurations and functions

12.2.2 Research Beyond the Wetland Boundary

Several of the points raised in the last section highlight that research approaches must be extended from the local wetland scale to regional scales to fully understand the ecology of TDNP. Given the higher ratio between catchment size and habitat size in Mediterranean areas relative to temperate regions (Alvarez-Cobelas et al. 2005), catchment-scale processes could have a disproportionate effect on local wetland biota and biogeochemical processes. Although the catchment of TDNP and other catchments are heavily influenced by agricultural practices (Chapter 4), local scale phenomena (pollution) seem to swamp the negative effects arising from land use in the surroundings of TDNP (Chapter 5). However, scales and hierarchies are critical to evaluating landscape-level impacts in local wetland ecology. For example, Angeler et al. (2008) have shown that the negative impacts of land use on the populations of two emblematic branchiopods are visible at very broad spatial scales that extend the catchment boundaries. Their study suggests that atmospheric flux of pollutants can contribute to degrade distant ecosystems. This example highlights an extreme challenge to wetland conservation. In this section we will deal with landscape ecological approaches that could help increase our understanding of the interaction of ecological processes in TDNP with those in its surrounding catchment(s).

12.2.2.1 Landscape Ecology and Biogeochemistry*

Here we refer to a landscape approach for highlighting the relevance of landscape structure and processes and landuse patterns across different spatial and temporal scales on local wetland integrity (including biogeochemical and ecological processes). While spatial hierarchies of landuse patterns can provide insight to contemporary landscape-level pressures on TDNP, a historical component should not be ignored. In their seminal paper, Harding et al. (1998) invoked "the ghost of land use past" to explain present-day diversity of stream invertebrates and fish in watersheds with different land-use history. Whole watershed land use in the 1950s was the best predictor of present-day diversity, whereas riparian land use and watershed land use in the 1990s were comparatively poor indicators. Their findings indicate that past land-use activity, particularly agriculture, may result in long-term modifications to and reductions in aquatic diversity, regardless of reforestation of riparian zones. The following research approaches could be useful for determining landscape effects on the ecology of TDNP.

- Accurate assessment and delineation of the historical extent (before 1940s) of wetlands at "La Mancha Humeda" in order to evaluate main landscape factors and processes (geomorphology, geology, hydrology, land uses, etc.) contributing to wetland occurrence and persistence. This could reveal wetland degradation patterns and the main pathways of biodiversity loss.
- Discerning between historical and current landuse effects on wetland integrity. This could help reveal whether current biodiversity elements in the wetland are still the result of the ghost of land use past before large-scale conversion into agricultural lands or whether agricultural use of the catchments has already contributed to diversity loss after accounting for the effects of local contamination. If current diversity is still explained by historical factors, when and at which temporal lags will the negative effects of landuse change be manifest in TDNP? What will be the magnitude of impact, in term of species extinctions, arising from a potential lagged landuse impact? To what extent do other landscape-level phenomena (e.g. habitat fragmentation) interact with landscape structure and landuse patterns to mediate in the strength of impact?
- A logical point following from the previous is that restoration and conservation efforts adopting a Forbes' (1887) view of aquatic ecosystems as isolated microcosms in a terrestrial matrix are erroneous. In fact, Chapter 8 highlights that despite local conservation efforts, the number and diversity of waterfowl is decreasing in the wetland. This suggests that diversity is impoverishing at regional scales (loss of γ diversity) leading to a reduction of spatial turnover (decreased β diversity), and finally local (α) diversity loss. Research approaches

outlined in the next point could be helpful for studying such phenomena with more detail.

- So far, the hydrology of the Upper Guadiana catchment has been assessed only very superficially, causing high uncertainty regarding potential consequences of climate change on catchment hydrology. More gauge stations are needed to develop accurately distributed hydrological models at the watershed scale.
- Nutrient cycling throughout watershed, including surface and below-ground processes, must be assessed for understanding nutrient export dynamics in the catchment during both dry seasons and storm events. In addition, in-stream biogeochemical processes need to be evaluated, because processes related to nutrient transformation in, and supply to, the hyporheic zone are not well understood.
- Diffuse pollution assessment is still lacking which is important given the great weight of agriculture in the catchment. Nonpoint sources of nutrients trigger wetland eutrophication processes during flood pulse events. Alternative improved land use management practices in uplands must be addressed in order to reduce the overall load to TDNP.

12.2.2.2 Metacommunity Ecology*

Metacommunity ecology emphasizes the connection of local communities within defined spatial units through dispersal (Holyoak et al. 2005). While metacommunity ecology is still based largely on theory, a growing body of studies tests its assumptions empirically. Research in TDNP holds potential to inform metacommunity ecology from a hierarchical point of view:

- Local-scale metacommunity processes: Floodplain wetlands may serve as excellent model ecosystems for studying community structure across spatial and temporal scales. The constituent communities of mosaic-like floodplains are arrayed along disturbance gradients and are connected by flood pulsing (Middleton 1999). Preliminary research suggests that the extreme spatial and temporal variability of flood regimes in Mediterranean areas provides unique opportunities to study metacommunity dynamics during periods of high connectivity (flooding situation) and/or fragmentation of sites (drought effects) within the wetland, respectively (Angeler et al. 2010). Further research could provide insight into mechanisms regulating hierarchical metacommunity dynamics.
- Regional-scale metacommunity processes: TDNP forms part of a previous extensive network of aquatic ecosystems within "La Mancha húmeda" wetlands area (Chapter 1). Since the onset of agricultural overexploitation, the network has become dramatically altered as a result of wetland loss and increased fragmentation between sites. A regional metacommunity approach holds potential to determine the connection of TDNP with other wetlands in the region under current landscape settings. This could help determine several aspects, including TDNP as a source or sink of populations, species and consequently gene flow between TDNP and other aquatic ecosystems, and the community specificity of such processes.

12.2.2.3 Water Resource Management**

Several calls have been made in the book for the need of an effective water resource management at the catchment scale. Aquifer restoration must be only considered as a strategy that may work in the long-term after substantial changes in current productivity regimes. However, ultimate goal of water management at the catchment scale must be the restoration of aquifer to levels existing in the 1970s when groundwater discharge was a very significant source for wetland inundation. This is the most problematic issue because aquifer recovery depends on the balance between water inputs (mainly rainfall) and outputs (mainly irrigation) and it is unclear that groundwater recharge will be enough to achieve aquifer replenishment. Groundwater recharge will be impaired by ongoing rainfall decrease resulting from climate change in Central Spain. In the meantime, other water sources such as water diversions or the use of treated waste waters could provide an option to artificial management of wetland hydroperiod. Currently, interbasin water diversions appear the most feasible alternative to sustain the wetland hydroperiod in the short-term. However, this alternative must carefully consider the efficiency of water transfer to the wetland because much of the diverted water is currently lost either through evaporation, infiltration or illegal extractions. Furthermore, it carries risk of exotic species introductions and deprives other places of water. Several recommendations are given in Chapter 10 to increase the success of this approach.

The environmentally sound application of treated waste water is currently illusive given the limitations to reduce nutrient contents and contamination loads in treated waste waters to levels acceptable for release to natural systems. Unfortunately, there exists precedence where discharge of treated waste water caused severe eutrophication problems and a fundamental change of natural temporary to permanent hydroperiods. If the use of treated waste water is to become an option the following points must be considered:

- Creation of subsurface flow wetlands to guarantee further treatment of waste waters before discharge to TDNP. This technology should be designed to reduce as much as possible the evaporative and transpiration loss of water, while decreasing the nutrient content and contamination loads below critical levels.
- This technology should be used to simulate as much as possible the fluctuating hydroperiod and flood frequency regime present in Mediterranean-type aquatic ecosystems. Excess water accumulating during dry periods could be used for recharging exhausted aquifers and/or moderate irrigation purposes.
- Landuse practices should move towards command and control schemes, whereby the types of crops, allocated water for, and the timing of irrigation are more strictly controlled. Such schemes should also envision tracking down, and destroying, illegal wells and imposing severe punishments to those who continue to construct them.

12.3 The Future: The Socioeconomic Challenge

Even if we succeed in advancing our ecological knowledge of TDNP, will this knowledge gain be enough for sound management of the ecosystem and its catchment? It is increasingly recognized that ecological systems depend a great deal on, and interact with social and economic factors (Folke et al. 2005; Levin 2006), which give rise to a complex system known as a panarchy (Gunderson and Holling 2002). Changes in the interaction cycles between the components in these panarchies is definitely the main reason for the environmental deterioration of TDNP, with the changes in the social and economic components (increasing productivity and wealth) being the main drivers of change in the ecological component (degradation). The major effects of socioeconomic factors, which ultimately resulted in the deterioration of TDNP, support the conjecture that in present-day societies, social parameters might be the control of the greater panarchical system (Leuteritz and Ekiba 2008). The capacity to adapt to environmental change, i.e. resilience, can therefore be explained as the collective variable that captures and demonstrates the overall behavior of the system resulting from ecological, social and economic factors. As such, if an area loses environmental resilience, social assets and institutional capacity, in may become "… an accident waiting to happen" (Holling 2001, p. 396).

Throughout human history, we can observe how "large-scale" socioeconomic and policy forces have led to low-resilience land use systems that eventually collapsed. For example, Fraser (2003) shows how a combination of economic policy, population growth and industrialization caused land use patterns in Ireland to shift from being relatively diversified (ca. 1820), towards being dominated by the potato. This system collapsed resulting in famine in the 1840s. Similarly, laissez-faire approaches to trade and the British thirst for tea in the Victorian period led to almost deforestation of Sri Lanka (Schweinfurth 1982) and created a system that collapsed in the 1870s when El Niño-induced droughts claimed tens of thousands of victims (Davis 2001). The importance of socioeconomic and policy drivers in creating vulnerable rural economy and land use systems is such that some development economists argue that these collapses are not so much environmental tragedies as human-engineered problems (Sen 1981). Nevertheless there is an environmental component to many such crises and as we look towards the future it is likely that the frequency and/or duration of environmental shocks increase, in Spain (Moreno 2005) and elsewhere (IPCC (International Panel on Climate Change) 2007).

It seems counterintuitive that humans deliberately continue to destroy their environment in times when their unsustainable actions are well recognized. However, these attributes may in essence reflect the inability of taking action because past socioeconomic drivers may have created "rigidity traps" that reduced the margin of taking effective action, i.e. the possibility to adapt and maintain resilience. Even though the examples from Ireland and Sri Lanka provide proof for the existence of such rigidity traps, it is by far not the aim of this essay to speculate about the existence of these in the case of the "TDNP panarchy". We have neither the necessary means, nor is it the scope of this book, to empirically evaluate how narrow such rigidity traps could be in Spain, nor do we have the necessary training in economy or sociology to evaluate their contributions to shaping future panarchies. In fact, the whole panarchy seems to be currently (still) resilient! However, as the focus of this book is the ecology of TDNP, we are interested in how social or economic factors can influence the ecological component of this particular panarchy in the future. On the basis of some simple indicators, we suggest that socioeconomic factors can provide obstacles to efficient ecological management in general, and especially in the case of the TDNP wetland, in the future.

The first obstacle is of economic and institutional nature. During the last decade, Spain has seen an economic growth to miraculous extents, according to media and general public opinion. However, this economic growth, as in other countries such as Ireland, was based mainly on a dramatic expansion of the construction business while relatively few efforts have been made to invest in alternative sources to sustain economic growth and create a functional redundancy in economy (i.e. creating conditions that would allow mitigation of the impacts if the construction business collapses). This situation especially affects rural areas where the rapid economic growth has not led to changes in patterns of natural resource exploitations which already gave signs of exhaustion decades ago. The created rigidity in Spain's economy soon became notable upon the onset of the global economic crisis, induced by the crash of the loan system in the USA, and which brought the Spanish construction business close to collapse. The consequences of this collapse are far-reaching, and are particularly notable in sectors that do not generate money in the short term. Although governmental plans considered an increase of the budget for R&D with the aim to create mechanisms that could better mitigate similar crisis in the future, these intentions are currently frustrated by the high unemployment rates derived from the economic crisis. Money is needed for social purposes rather than for R&D. As a result, the stipulated budget for R&D has been reduced by the Ministry of Science and Innovation and the Ministry of Environment. If according to the hypothesis of Leuteritz and Ekiba (2008) this budgetary reduction reflects a socioeconomic or institutional parameter that helps explain Spain's sustainability, it is reasonable to assume that a revolution of the ecological component in Spain's panarchy will be unlikely. In other words environmental conservation will likely not be straightforward.

In addition to this institutionally mediated limitation there is a social component which may ultimately feed back to reinforce institutional processes. Social movements develop through several stages (Moyer et al. 2001), from initial rising of concern, through to gaining popular attention and political support, to a point where the concerns and values of the movement are widely accepted in the community and the moral authority of powerholders and decision makers resisting values of the movement collapses. In many rural parts of Spain the movement is still in the very early steps, if non-inexistent, with overexploitation of water resources or loss of biological capital not being seen as an environmental threat by a grand part of the population. Paradoxically, dedicating water resources to environmental management is often interpreted as a waste of water that could be used for agriculture, tourism or other forms of human consumption. A recent example clearly highlights the overwhelming influence of the sociological component in the overall functioning of Spain's society and environmental perceptions.

The Spanish media offer generally a biased vision of environmental problems through sensationalist news where only extreme phenomena such as prolonged droughts or, very recently, peat fires in TDNP are highlighted. By contrast, the factors that caused large-scale degradation of the wetland in the long term receive hardly any coverage by the media. Because environmental degradation is not a main concern of the population, politicians are not under pressure to solve these problems. As a result, mitigation measures are taken in response to medial sensationalism to show the public operational capacity rather than trying to implement large-scale rehabilitation measures to solve the core of the problem. After the recent explosive news that TDNP's peat is on fire, the regional and national governmental authorities decided to show its political will to change, once and for all, the severe environmental situation of the wetland. Hence, they declared to divert urgently 20 hm^3 of water to TDNP, using an unfinished pipe designed to transport exclusively drinking water to the cities Ciudad Real and Puertollano from the Tagus basin (El País newspaper, October 14, 2009; http://www.altoguadiana.es/ES/AREA_COMUNICACION/DOSSIER_PRENSA/2009/DOC/PDF/2009_OCTUBRE_14.pdf). This measurement like most others adopted in the historical management of the wetland (see Chapter 10) will extinguish the peat fires, moving the attention of the media and the public to other topics, and let the wetland in a continued struggle of survival.

After the blind overexploitation of own resources the claim of water from other regions is becoming a solidarity issue in Spain. Castilla-La Mancha diverts water from the Tagus basin to Murcia area to maintain its productive orchards after this region exhausted its water resources. We are thus far away from inducing a socially mediated transformation of the "irrigation catchments" to a "post-irrigation society". While farmers of Murcia rise in masse to seek water from the Tagus basin, which is situated over 500 km away, the people of La Mancha region make no claims for their own water resources, especially regarding its use for mitigating environmental problems. In fact, environmental problems are not perceived by the population of Castilla-La Mancha as one of the top ten concerns, which include unemployment and economic crisis (54%). Shortage of water for agricultural activities (12%) occupies the fourth place (survey conducted by the regional government in 2008; http://www.soitu.es/soitu/2008/07/15/info/1216144867_524007.html). Without fundamental changes in basic perceptions within societies, there will also be no resistance of powerholders and decision makers to make change. On the contrary, even if an environmental consciousness exists at institutional levels it may be the fear to lose votes, and an election, if changes are made that the broad public does not understand or likely not accept.

On the basis of the socioeconomic and ecological characteristics outline above we provide a conceptual construct for TDNP (Fig. 12.2), which could be useful for evaluating and understanding complexly interacting factors in this particular socio-economic-ecological system. Although the model is clearly of a reductionist nature, the highlighted interactions will definitely play a major role in determining whether

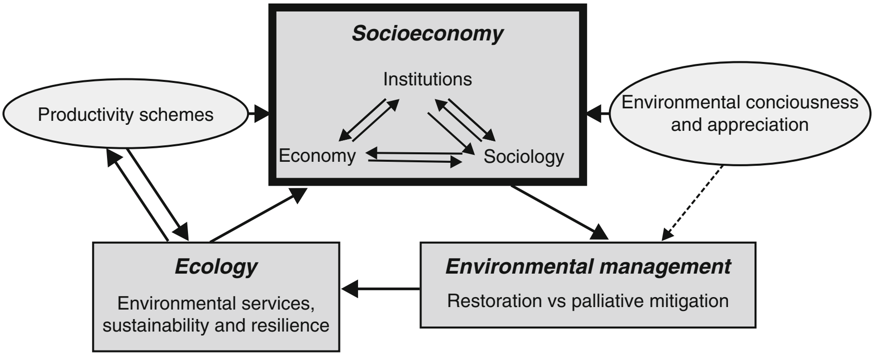

Fig. 12.2 Model of interaction cycles between ecological and socioeconomic components in the panarchy of Las Tablas de Daimiel. The strength of the arrows reflects the strength of potential relationships. For more details see text

environmental management of the wetland can adopt integral rehabilitation schemes to achieve a certain self-maintenance of the wetland, or continue to be of purely mitigative nature to palliate the adverse effects of human impact, i.e. maintaining the current artificial life support machinery. The model shows complex feedback mechanisms between socioeconomic factors and ecological components that are mediated by productivity schemes (i.e. factors that currently contribute to economic sustainability (i.e. agricultural productivity) at the cost of ecological sustainability in the TDNP area) and social perceptions of the environment (ellipsoids in Fig. 12.2). The model emphasizes especially the mutual dependence between the current productivity scheme and the ecological component in this complex interaction cycle. It reflects the adverse impacts of current agricultural practices on the ecological component which in turn will feed back negatively to the productivity regime once critical thresholds are exceeded. It seems logical if current productivity regimes based on agriculture continue to degrade the environment in the long-term, ecological resilience may be lost, and the whole system, including the socio-economic component in this area, may become sensitive to large-scale environmental perturbations. Once the whole system loses the capability to adapt to disturbances, and thus its ability to sustain itself, it will require interventions by national or international agencies to mitigate the impact from these perturbations. It is obvious in our human-centered world that under such circumstances the major focus of rescue will be on securing the quality of life for humans rather than aiming at securing the basis which supports all life on earth, i.e. a healthy environment.

The current economic crisis is very instructive how the "health" of the socioeconomic component itself feeds back to the ecological component through decreased devotions of part of the governmental budgets to R&D. The emphasis of the box comprising the socioeconomic component in Fig. 12.2 highlights the key role which social and economic factors play in the overall functioning of a panarchic system (Leuteritz and Ekiba 2008). It is obvious that socioeconomic constraints, reflected for example through decreased funding opportunities, will limit on one hand the advance of science, and on the other hand the implementation of sound environmental management schemes. In this chapter we have highlighted several research gaps that currently limit our understanding of the ecological functioning, and consequently restoration and conservation of TDNP. If these gaps are not closed through research, it is unlikely that a straightforward adaptive management of this wetland will be able. It is clear from the model that a change in the productivity regime will be required to reduce the competition for limited water resources between economic productivity and environmental conservation. It is unclear, however, to what degree climate change will affect the whole panarchical systems in a future which is predicted to be substantially drier, and when new scenarios for water resource competition will arise. Spain is in serious need of a national water plan that satisfies a minimum of ecological criteria. Crucial to this task will be the involvement of communities and the establishment of a new, nationally consistent water entitlement and trading system that provides security to both water users and the environment (e.g. Wenthworth Group 2003).

12.4 Conclusion

Las Tablas de Daimiel is becoming one of the most well-studied Mediterranean wetland ecosystems in Europe. It serves as a case study that demonstrates the adverse impacts of human activities on wetlands ecological integrity in Mediterranean Europe where one resource is fundamentally limiting: water. Within the "TDNP panarchy", water availability was a driver of the interaction cycles between its ecological and socioeconomic components in the past, and will with great certainty continue to affect these interactions in Spain's warmer future. Climate change adds uncertainty making their outcomes hard to envisage. However, one fact is clear: without revolutions in the socioeconomic components, mainly in form of changed productivity systems, the ecological part of these interaction cycles faces a bleak future. Thus, although scientists continue to enquire about the ecological understanding about our environment, the risk is currently high that social or economic constraints limit the implementation of this knowledge to a sound management of resilience.

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