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Effects of Waste Water on Freshwaters in Semiarid Regions

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1. Introduction

Some freshwater ecosystems have received waste water for many centuries (Alvarez-Cobelas & Verdugo, 1995), *i.e.* the Latium wetlands close to Rome or the Thames and the Spree rivers downstream London and Berlin, respectively. The strong development experienced in many areas of the world in the 20th century has resulted in increasing waste water disposal almost everywhere that has increasingly threatened freshwater ecosystems receiving these loadings. The concern of human health and, later, ecosystem health resulted in the implementation of waste water treatment facilities in many developed countries, such as those of Northern and Central Europe, USA, Canada and Japan (Tchobanoglous et al., 2003), which diminished wastewater inputs to freshwater environments. Unfortunately, this has not been the case in many semiarid countries whose economy or, more often, some lack of concern for environmental quality does not enable funding enough for these otherwise expensive facilities. While waste water pollution cannot always be abated, its effects are likely to be diminished if enough water is available to produce both dilution and wash out, as often occurs in cold temperate and tropical environments. Unfortunately, this is not the case in semiarid areas where rainfall is unevenly distributed throughout the year, also showing a strong interannual variability. For example, Fig. 1 depicts the long-term (1945-2006) annual precipitation falling on a semiarid central Spanish area, which results in an average of 418 ± 128 mm/year, ranging 189-857 mm/year.

In fact, traditional approaches to water management in semiarid regions have been based more on the increase of water availability rather than improving the water quality of waste waters to make them feasible for future use. In water shortage scenarios, domestic lifestyle adaptations and optimization of water consumption by both agriculture and industry have been managed to maintain the balance between water supply and demand. However, although this balance could be achieved and the amount of waste water reduced, the characteristic low water flow of semiarid rivers makes impact of waste water discharge in freshwater ecosystems stronger. Streamwater discharge to wetlands and lakes is highly variable over time in semiarid areas. Fig. 2 shows an example of these fluctuating water flows of a semiarid river that drains to a central Spanish wetland (Las Tablas de Daimiel National Park). Semiarid regions of the world are confronted with a largely unpredictable

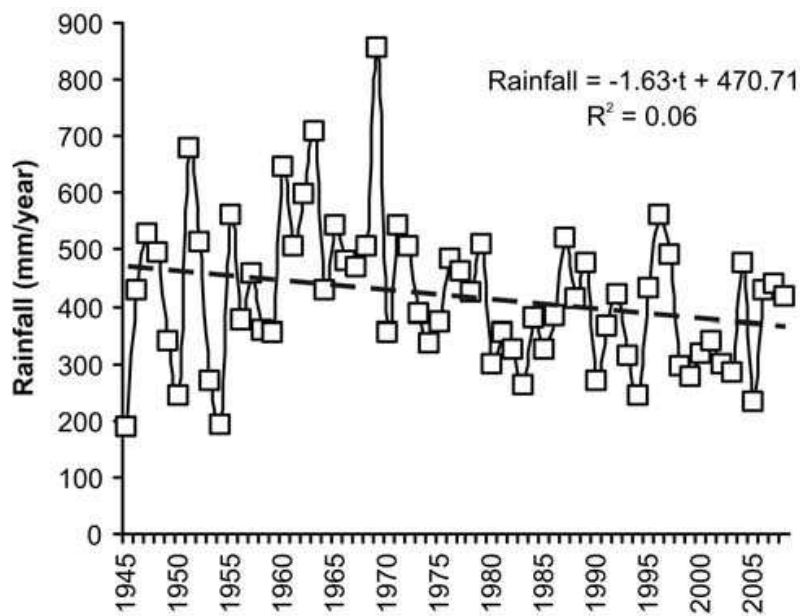


Fig. 1. Long-term series of rainfall in the vicinity of Las Tablas de Daimiel National Park, a freshwater marshland in Central Spain. Data were compiled by the Spanish Meteorological Institute. The long-term trend ($P < 0.05$) is also shown.

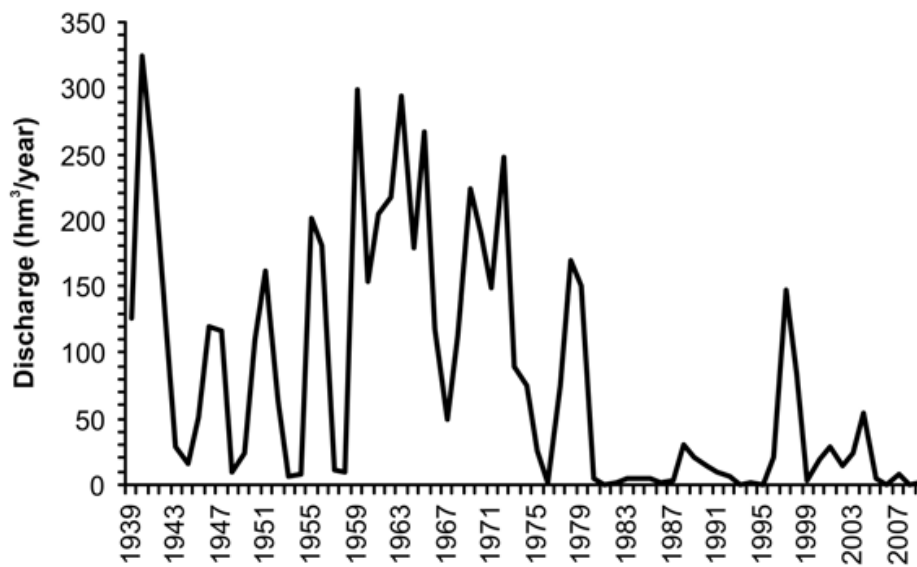


Fig. 2. Long-term water discharge of Gigüela river in central Spain, draining to Las Tablas de Daimiel National Park. In addition to natural changes, there has been a stronger variability from the seventies onwards as a result of groundwater exhaustion that diminished river flow. Data have been gathered by the Guadiana Water Authority, which is the Spanish administrative office dealing with water quantity and quality in the area.

climate, often recognizing water availability as the single most important limiting resource for the conservation of aquatic ecosystems. Besides, the natural fluctuating hydrology is often increased by anthropogenic variability arising from water abstraction for irrigation purposes. This impact is certainly more frequent in semiarid areas whose agriculture heavily relies upon water resources that can be either stored in aquifers or flowing in

streams, thus diminishing the amount of water available for diluting pollutants and cleaning freshwater environments. That is, the high variability of water availability very often experiences a positive feedback as a result of unsustainable agricultural consumption (Postel, 1992), *i.e.* unsustainable irrigation promotes more variability of water availability. Furthermore, this excessive irrigation usually uses groundwater as the main water source, which it is often the single source on which most semiarid ecosystems depend. Already in many semiarid regions aquifer drawdown by irrigation pumping is such that aquifers appear overexploited. Therefore, it is not unusual that semiarid aquatic ecosystems receive sewage as the almost exclusive inflow, becoming the main threat for conservation purposes. These reduced, natural and man-made inputs of water to aquatic environments usually fail to minimize pollution impacts triggered by waste water. The point of view that water is water regardless of its quality results in overlooking the basis of water management in these areas.

Under these scenarios of water management, it is obvious that the information available is rather scarce and, more specifically, hardly addresses the topic of waste water effects on freshwaters in semiarid regions. The conservation of these valuable freshwater ecosystems demands the need to consider water quantity and quality jointly in any water policy.

Ecological effects of waste water on ecosystems located downstream have been the core of much research after the initial studies by Kolkwitz & Marsson (1908) and Streeter & Phelps (1925). Unfortunately, there are pitfalls in this approach. First, it is not of a widespread nature, mostly pertaining to cold temperate areas where water availability is rarely limited. Second, effects are only sought in the changing of biological communities and their species numbers, paying no attention to other processes such as biogeochemical effects, biomass and productivity effects, and food web effects.

The main goal of this chapter is to outline how waste water (either raw or treated) discharges can affect the ecological performance of semiarid freshwaters downstream. We will review the water quality of waste water and later consider both abiotic and biotic effects of those waters on these ecosystems; since there are very few contributions on this topic, we will mainly rely on our own research, mostly reporting unpublished information. We will also suggest some easy-to-use remedial actions to cope with these environmental impacts posed by waste water. To conclude, we will describe some ideas on future research on the topic.

2. Methods

This chapter mostly relies on data of our own because there is not much published evidence on the effects of waste water on the ecological performance of semiarid freshwater ecosystems. Therefore, we will report the studies available on the topic, which are not many. Since we have been working over more than 30 years on these impacts in some Spanish ecosystems, including rivers and wetlands and waste water treatment facilities as well, we will also report unpublished data. Chemical oxygen demand, total nitrogen and total phosphorus contents have frequently been measured following APHA (1989) procedures. Also data compiled by some Spanish offices, such as the Guadiana Water Authority and the National Meteorological Institute, will be used to describe raw and treated waste water quality. Anyway, we will mainly focus on phosphorus because it is often the main factor limiting productivity in lakes (Lewis & Wurtsbaugh, 2008).

We have also undertaken chemical and biological measurements in streams, lakes and wetlands over the years. Elemental composition of sediments has also been measured using a CHN Perkin-Elmer analyzer. Species richness of algae, macrophytes and macroinvertebrates have also been recorded in streams and wetlands. Cover, biomass and productivity measurements of phytoplankton, submerged-, emergent- and pleustonic vegetation have also been carried out (see Alvarez-Cobelas et al., 2011, and Alvarez-Cobelas & Cirujano, 1996, for an overview of methods).

3. Wastewater quality

Water supply and treatment often received more priority than wastewater collection and treatment. The trend in human population increase, however, might result in greater emphasis on wastewater treatment. Although there is a growing awareness of the impact of sewage contamination on rivers and lakes, few countries recognize that it may affect valuable ecosystems severely because waste water is deemed for managers and politicians to be ashamed of. Hence, it is not surprising that there are too few studies reporting its effects on valuable ecosystems downstream. Table 1 shows some stagnant water bodies that receive waste water in semiarid areas. It is sure that there will be many more because treatment facilities are less common in these countries than in higher developed countries and because the maintenance of operations, and hence the improvement of water quality of the treated effluents to be discharged to freshwaters, is much better in these countries than in semiarid, mostly poorer countries.

NAME	COUNTRY	LATITUDE	LONGITUDE
Chott Aïn el Beïda (playa lake)	Algeria	32° N	5° E
Nature Park Krpacki rit (floodplain wetland)	Croatia	46° N	19° E
Lake Vistonis, Porto Lagos and Lake Ismanis	Greece	41° N	25° E
Lakes Volvi and Koronia	Greece	40° N	23° E
Cagliari pond	Italy	39° N	9° E
Punte Alberete wetland	Italy	45° N	11° E
Babícora lagoon	Mexico	29° N	108° W
Souss Massa wetlands	Morocco	30° N	10° W
Albufera de Valencia lagoon	Spain	39° N	0° W
Alcázar de San Juan lagoons	Spain	39° N	3° W
Doñana National Park (wetlands and marshes)	Spain	37° N	6° W
El Hondo wetland	Spain	38° N	1° W
Manjavacas lagoon	Spain	39° N	3° W
Las Tablas de Daimiel National Park (freshwater marsh)	Spain	39° N	4° W
Lake Burdur	Turkey	38° N	30° E

Table 1. Some stagnant freshwater ecosystems in semiarid areas which experience wastewater pollution. Most data are either reported in www.ramsar.org or are authors' unpublished data.

One feature of either raw or treated waste water in semiarid areas that deserves mention is the high variability of its water quality indices (Table 2). Besides, in comparison to most temperate countries, domestic wastewater in arid areas like the Middle East are up to five times more concentrated in the amount of chemical oxygen demand per volume of sewage because the domestic water consumption is lower (Al-Salem, 1987). This is extremely high and may cause a large amount of sludge production, high-energy consumption for aeration, operational problems, and high consumption of polymers and clean water for drying the sludge after digestion (Massoud et al., 2009). Could this mean that conventional Western treatment systems may even be technologically inadequate to handle the produced sewage in semiarid regions? Traditional treatment systems are implemented without considering the appropriatedness of the technology for the economy, culture, land, and climate. If the aridity of climate tends to increase the concentration of pollutants in waste waters because water use by the human population living in these regions is often rather low, then the implanted treatment systems must address this peculiarity; otherwise chances of ecologically successful treatment are very limited. Although it is not the purpose of this chapter, there is clear evidence that the application of conventional treatment systems in semiarid countries cause several problems in the waste water plant functioning, revealing its inability to mitigate the adverse effects to freshwater ecosystems. Coupled with this, probably the lack of environmental control mechanisms, the absence of long-term environmental planning and the weakness of the legal requirements are preventing to achieve the necessary improvements to solve the problem of waste water discharges in these regions.

		Alcázar de San Juan	Typical domestic wastewater
Biochemical oxygen demand	(mg O ₂ /L)	25-1750	100-500
Chemical oxygen demand	(mg O ₂ /L)	70-2550	500-1200
Suspended solids	(mg/L)	50-940	250-850
Total nitrogen	(mg N/L)	7-36	20-85
Total phosphorus	(mg P/L)	2-27	6-20

Table 2. Ranges of raw waste water quality entering the treatment plant of Alcázar de San Juan (Central Spain, data gathered by the Guadiana Water Authority) compared to a typical domestic sewage (data reported by Pescod, 1992). The effluent of this facility often flows into Las Tablas de Daimiel National Park, 60 km downstream.

4. Abiotic effects

Waste water may enter freshwater ecosystems either in raw form or treated. In any case, water quality variability in sewage is noteworthy, as Table 2 and Figure 3 clearly depict. For example, total phosphorus concentration in treated waste water can experience high variations in periods of a few years (Fig. 3), ranging from 55 to 173% as CV in the effluent.

These strong variations in waste water inputs give rise to strong variations in pollution contents in the reception streams, which is also altered by streamflow fluctuations. Figure 4 shows the dramatic changes in total nitrogen and phosphorus concentrations in a semiarid river that has experienced waste water inputs since the early seventies in central Spain. If current European regulations of nutrient levels at the entrance of environmentally-protected areas were applied (e.g. total phosphorus contents in the waste water effluent lower than 2 mg P/L), this river would be demonstrated to experience at least one episode of strong pollution per year in recent decades.

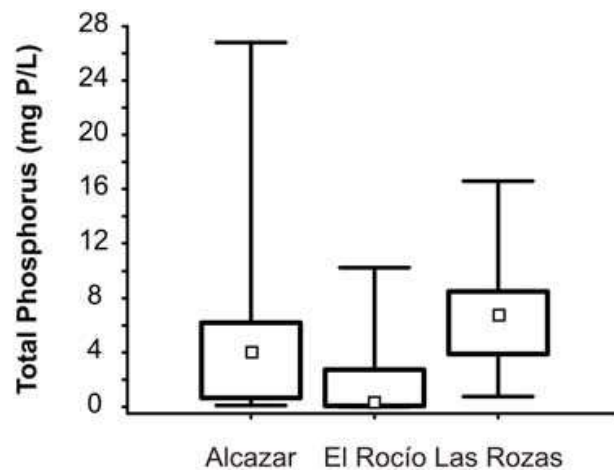


Fig. 3. Box-whisker plots of total phosphorus in effluents of waste water treatment facilities in semiarid Spain. Alcázar treated waste waters reach Las Tablas de Daimiel National Park, El Rocío treated waste waters enter Doñana National Park, and Las Rozas treated waste water are discharged to small brooks and streams running through the municipal territory of this city.

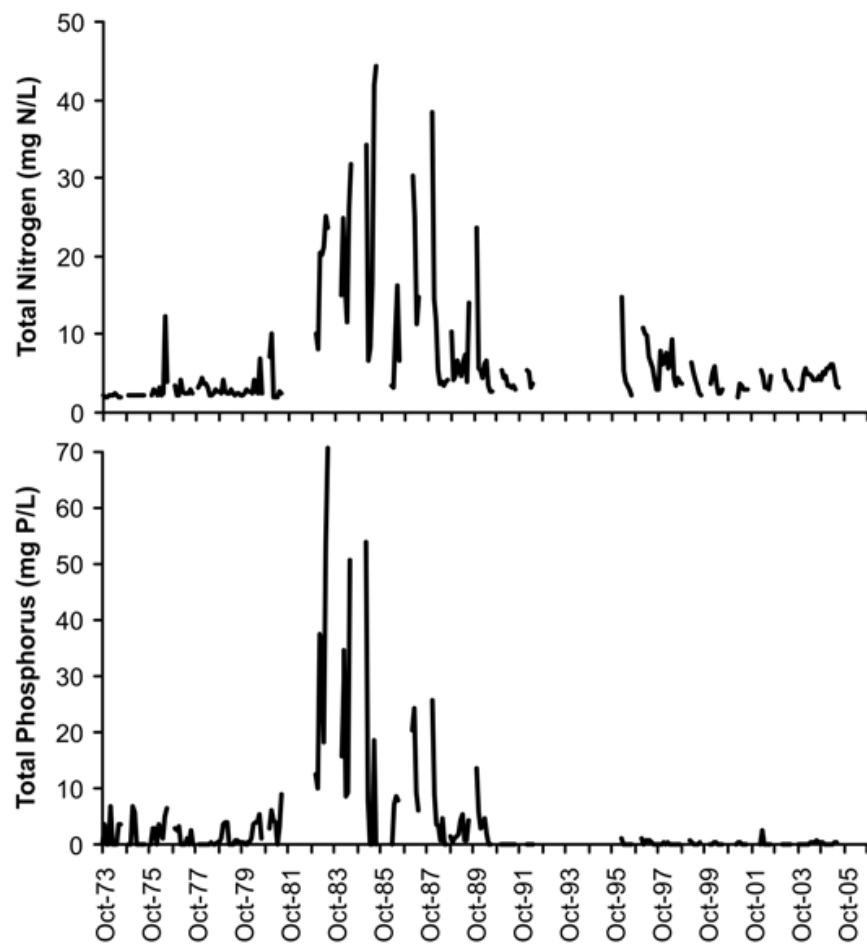


Fig. 4. Monthly total nitrogen and phosphorus concentrations in Gigüela river draining to Las Tablas de Daimiel National Park. The river is temporary and hence there are many periods in which it is dry, thus transporting no pollutants.

It is also well known that stream waters usually reduce their organic matter content through degassing (Cole & Caraco, 2001), denitrification (Piña & Alvarez-Cobelas, 2006) and burial in sediments (Masiello, 2004). Very few biogeochemical processes have been studied in semiarid freshwater environments as related with waste water; this is what older researchers termed as “self-purification”. Our data indicate that, as a result of self purification, ranges of total phosphorus used as an index of waste water inputs decrease at the entrance of valuable freshwater ecosystems (compare Figs 3 and 5, Alcázar treatment plant-Las Tablas de Daimiel National Park, El Rocío treatment plant-Doñana National Park).

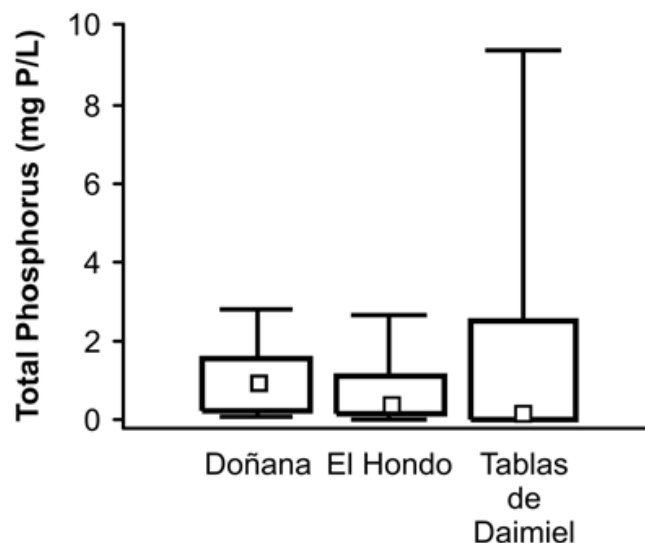


Fig. 5. Box-whisker plots of total phosphorus concentrations entering some Spanish freshwater ecosystems. Doñana wetland is in southwestern Spain, whereas El Hondo wetland is located in the SE. Las Tablas de Daimiel (central Spain) data is a much longer data set dating back to the eighties and hence its higher variability because waste water treatment was started in the nineties.

There are few data on biogeochemical effects of waste water discharge in semiarid freshwater environments. Some evidence reveals that it increases net heterotrophy of stream metabolism (Merseburger, 2006). Nitrogen-rich waste water appears to enhance both nitrification and denitrification downstream the point source of a treatment plant in semiarid streams (Merseburger, 2006; Fig. 6). Hotspots of chemoautotrophic activity may then appear as a result of waste water inputs (Merseburger et al., 2005). However, retention efficiency of nutrients has been demonstrated to be altered by the quantity and quality of waste water in Mediterranean semi-arid streams (Martí et al., 2004).

Once in the freshwater ecosystem, pollutant concentrations are strongly changed due to many biogeochemical processes (mineralization, burial, outgassing, uptake by organisms, even water abstraction for irrigation). This lead to high temporal variability of nutrient concentrations in rivers, lakes and wetlands, which is very important to understand its effects (Fig. 7). Because of the fluctuating nature of flow, the highest variability is perhaps experienced by stream systems (see the Arroyo de la Torre plot in Fig. 7), which cannot usually cope with waste water pollutants in episodes of low streamflow.

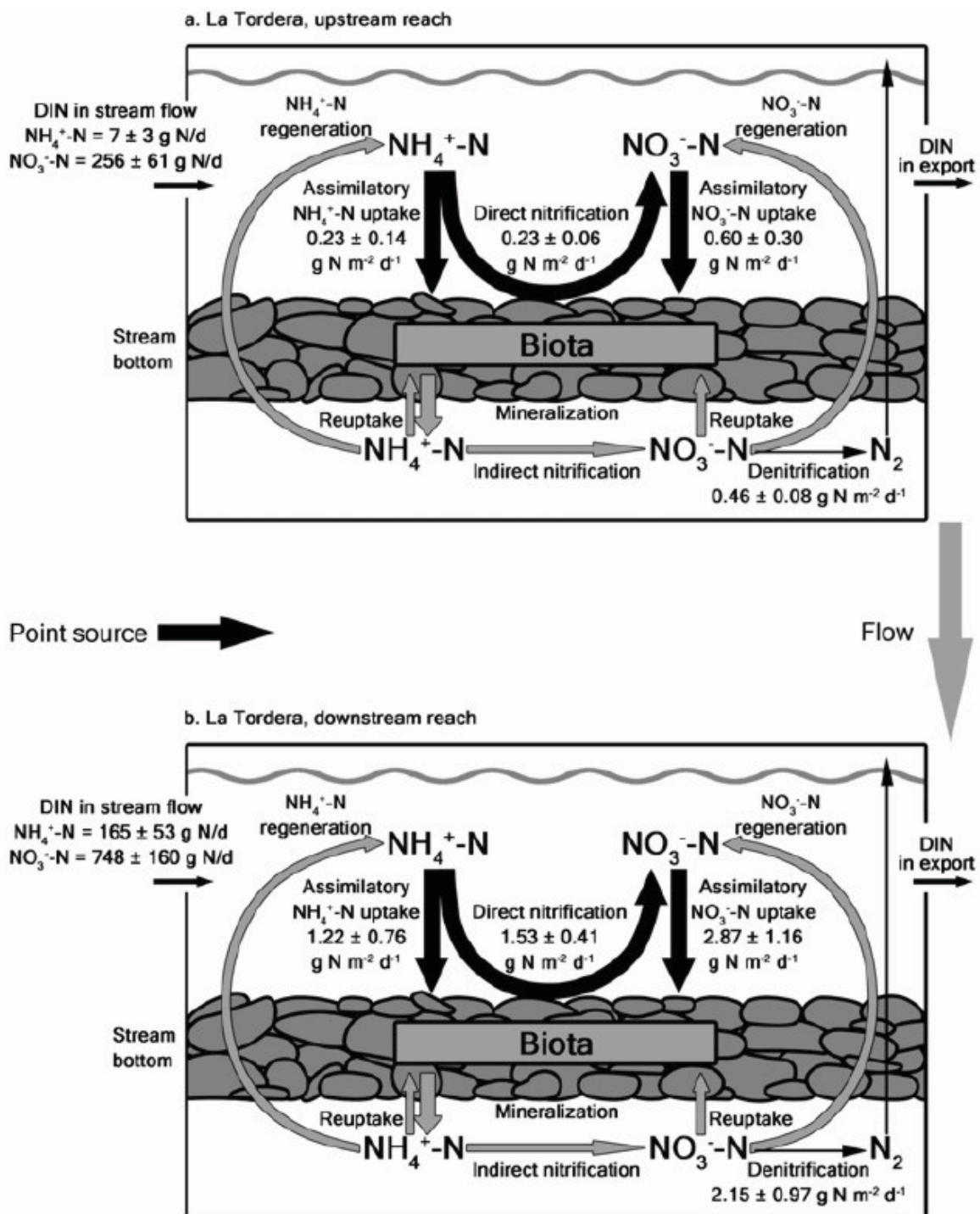


Fig. 6. Nitrogen processes in a forested catchment of NE Spain. The lower panel shows nitrogen dynamics downstream of the outlet of a waste water treatment plant (figure from Merseburger, 2006).

Phosphorus inputs of waste water promote primary production in freshwater ecosystems. The effects of phosphorus load has been the core of much research carried out in wetlands (Reddy & DeLaune, 2008), despite the fact that it rarely controls primary production (Sánchez-Carrillo et al. 2010). Our data for the hypertrophic wetland of Las Tablas de Daimiel National Park suggest that phosphorus is strongly retained in wetland

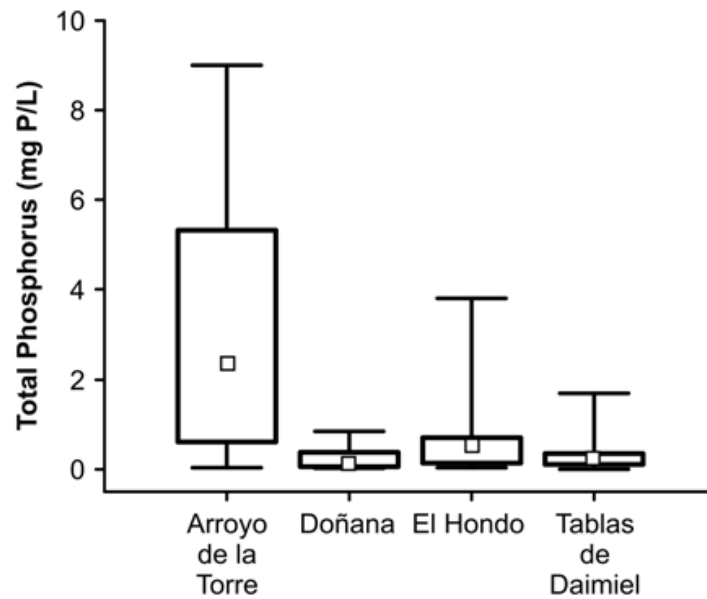


Fig. 7. Box-whisker plots of total phosphorus contents in some semiarid freshwater ecosystems of Spain. Arroyo de la Torre is an urban stream, whereas Doñana, El Hondo and Las Tablas de Daimiel are wetlands of varying salinity.

sediments (in central and outlet sites of the wetland, Fig. 8), which is later released to the water column during flooding cycles, increasing eutrophication. Although most of this element arises from wetland plant decomposition, phosphorus retention can reach up to 85% of external inflows during humid periods (Sánchez-Carrillo & Álvarez-Cobelas, 2001). Spatial retention of phosphorus in semiarid wetlands is strongly linked to the kinetic energy of discharge, being lower at the inlet sites while increasing towards the outlet areas, following an exponential function (Sánchez-Carrillo et al., 2001).

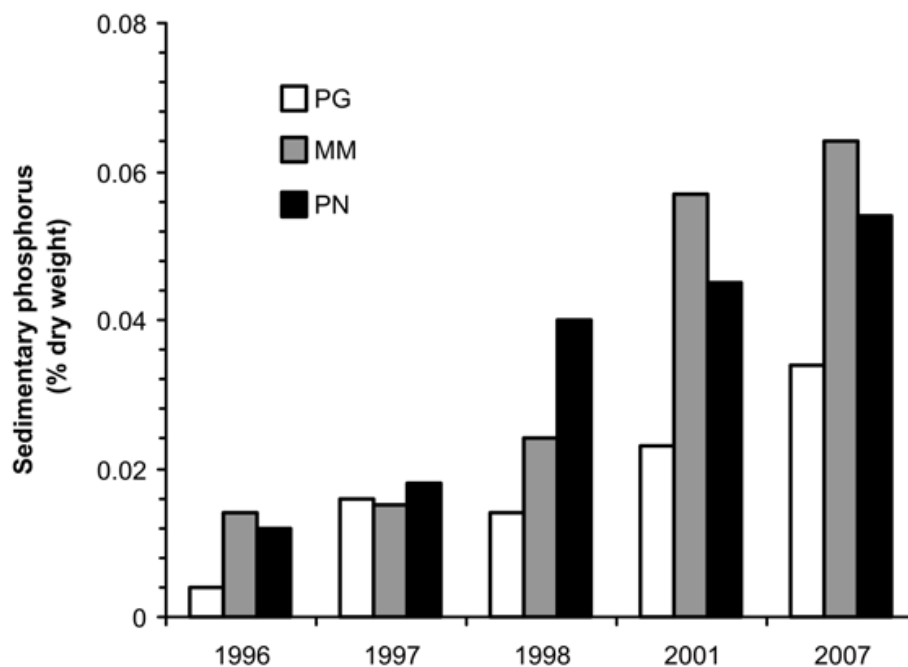


Fig. 8. Phosphorus content in sediments of Las Tablas de Daimiel National Park from 1996 onwards. PG is an inlet site, MM is a central site, whereas PN is an outlet site.

Very few data exist on stoichiometry of freshwaters as affected by waste water. Ours in the wetland of Las Tablas de Daimiel National Park reflect increasing N:P ratios towards the outlet (Fig. 9). What appears to be more interesting is that most areas show N:P ratios below 16 in less than half sampling dates, but the terminal site only shows these ratios in 15% of dates. This means that either nitrogen or phosphorus limitation of primary production might occur in many places of this wetland, except in the terminal area where phosphorus limitation may occur much more often, in spite of the pattern shown by phosphorus retention. Such a spatial distribution might reflect inputs of waste water whose N:P ratios are very fluctuating. Waste water inputs could often shift nutrient limitation of primary production from phosphorus to nitrogen in many areas of this wetland. Therefore, waste water may play an important, albeit poorly known, role in the stoichiometry of ecosystems that receive it.

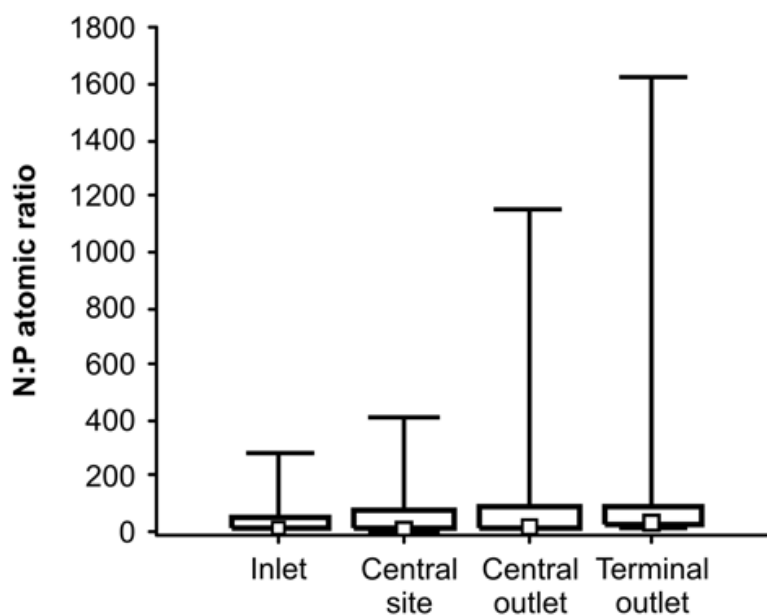


Fig. 9. Box-whisker plot of total nitrogen:phosphorus atomic ratio in some sites of Las Tablas de Daimiel wetland. Statistics have been calculated on monthly 1996-1998 data, a period when the wetland was continuously flooded, often receiving waste water. Distributions are not statistically different from each other, as judged by a Friedman test ($p > 0.05$).

Waste water also impairs the underwater light climate of freshwater ecosystems, strongly diminishing transparency, which in turn makes submerged plants disappear (Phillips et al., 1978). Long-term observations (> 30 years) in Las Tablas de Daimiel National Park by one of us (Cirujano-Bracamonte, unpublished observations) attest this statement; in the seventies and early eighties light penetration reached all depths in this otherwise shallow (< 4 m) wetland, but since early nineties most sites are turbid, with many suspended solids and dissolved organic carbon that turn water more turbid and brown-coloured.

The flowpath of waste water motion in semiarid freshwaters is another aspect that deserves mention, but has not been tackled as yet. This is particularly interesting in wetlands, where the patchy distribution of emergent vegetation enhances some directions of water motion, along with pollutants, and prevents others. One of us (S. Cirujano-Bracamonte) has often observed preferential flowpaths of waste water pollution in Las Tablas de Daimiel wetland,

but this event has not been explored further. Clearly this pattern can increase the spatial heterogeneity of ecological effects of waste water.

All in all, it is clear that waste water dynamics in freshwater environments also relies on the quantity of water available. The interplay between water amount and the nature and concentration of waste water compounds is still poorly known. For example, the length of water renewal time is certainly related to biogeochemical dynamics of waste water, including its effects on changes of biological populations, but to our knowledge no study has been undertaken to support this. Retention time is related to water availability and the discharge:ecosystem volume ratio, but these key factors are seldom measured in semiarid environments, because 1st) it is not a simple task to measure discharge accurately in semiarid streams, 2nd) it is not easy to estimate ecosystem volume in semiarid freshwater environments which are very fluctuating, and 3rd) funding is often lacking.

Until now, we have dealt with chronic inputs of waste water, which are mostly of urban origin. Another entirely different topic is that of infrequent, but sudden inputs of waste water, which are the case for accidental pollution events. Obviously, they can hardly be predictable and hence it is impossible to implement sampling procedures and designs for them to study their magnitude and ecological effects. It is likely that these impacts are very different depending upon magnitude and stoichiometry, but we still have no data to support this.

5. Biological effects

Inputs of waste water to freshwater ecosystems usually result in changing species composition and this is the more studied feature of this topic (Liebmann, 1960-1962; Fjerdingstad, 1965; Sladeczek, 1973). Diatoms and chrysophytes are usually substituted by green algae and cyanobacteria, most submerged macrophytes decline, many invertebrate groups (molluscs, copepods, cladocerans, water bugs, mayflies, caddisflies, most fish), disappear and others (oligochaetans, ciliates, rotifers, dipterans, carp, mosquitofish) colonize these impaired environments. Disappearances of many species have been reported in the long term study of Las Tablas de Daimiel National Park (Sánchez-Carrillo & Angeler, 2010).

Anyway, there are not many studies dealing with straightforward relationships between waste water and species richness of biological communities in freshwaters. It is often assumed that the effects of waste water are of complex nature, interacting with other environmental factors, and hence those relationships in semiarid ecosystems are seldomly reported. Our own work enables us to depict some of them. For example, it is a commonplace that the algal group of Euglenophytes is enhanced by organic matter (Sladeczek, 1973); our data for the inlet area of Las Tablas de Daimiel National Park, which receives waste water very often (see Fig. 4), suggest that this holds true, because chemical oxygen demand almost explains half of the whole variability in species richness of this algal group (Fig. 10).

Waste water can also have strong effects on aquatic productivity. Phytoplankton biomass at the inlet of Las Tablas de Daimiel National Park often exceeds 200 mg Chl-*a*/m³, with production values that can be close to the highest ever recorded (Alvarez-Cobelas et al., in press; Talling et al., 1973). Depending upon their ecological performance, the cover of emergent plants may reflect the impact of waste water. While reed (*Phragmites australis*) cover over the years is enhanced by phosphorus, cut-sedge (*Cladium mariscus*) cover is impaired (Fig. 13).

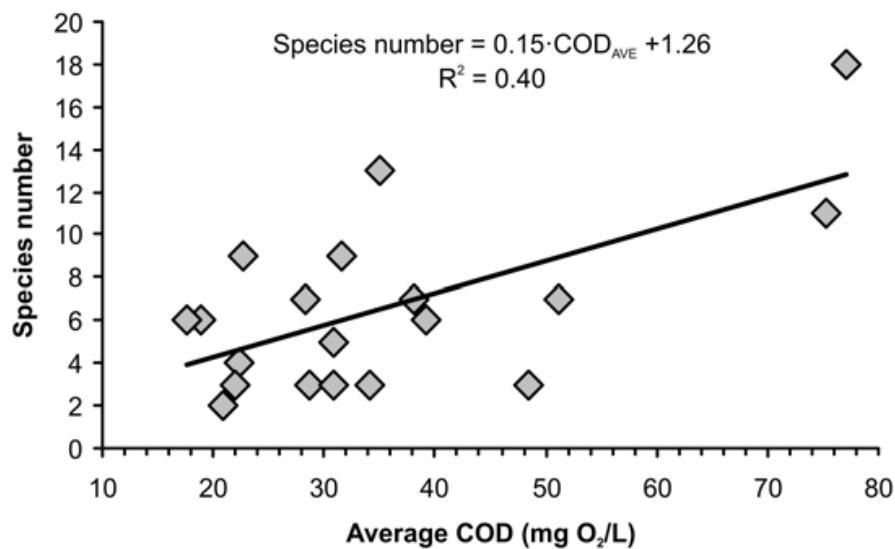


Fig. 10. Species numbers of Euglenophytes as related with average Chemical Oxygen Demand (COD) at the main inlet of Las Tablas de Daimiel National Park. Data from 1996-2002, reported in Conforti et al. (2003). The relationship is statistically significant at $p < 0.05$.

If the whole community of riverine benthic algae and macroinvertebrates is considered, the higher the chemical oxygen demand the lower the species richness of these biological groups (Figs. 11-12).

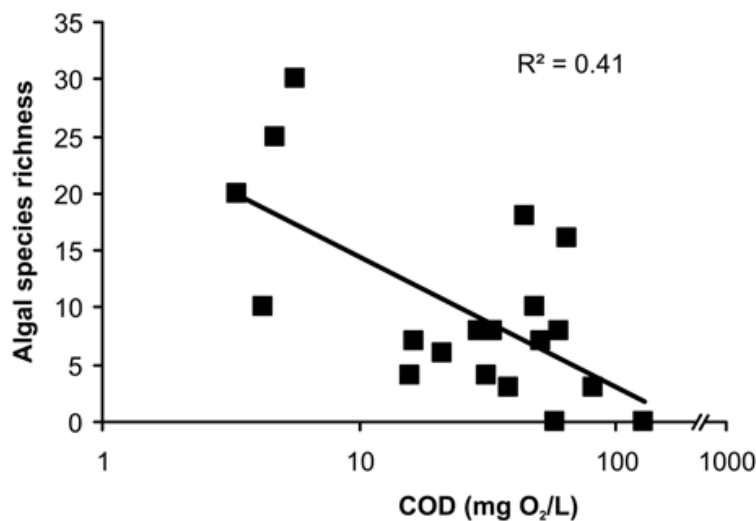


Fig. 11. Species richness of benthic algae in streams of Las Rozas de Madrid (central Spain) watershed as related with chemical oxygen demand (COD) in a semilogarithmic plot. Data from 2004-2006.

Plants living on the surface of lakes and wetlands, such as the aquatic fern *Azolla* and the water lentil *Lemna*, are enhanced by total phosphorus concentrations in water. Our study of this invasive fern in Doñana National Park has demonstrated a strong relationship between phosphorus and the biomass that it can attain, though other less known factors may be important for *Azolla* growth at times (Fig. 14).

Lemna (Fig. 15) has often occupied big surface areas in Las Tablas de Daimiel National Park over the years, often attaining large covers, as flooding water and high phosphorus concentrations have enhanced its development.

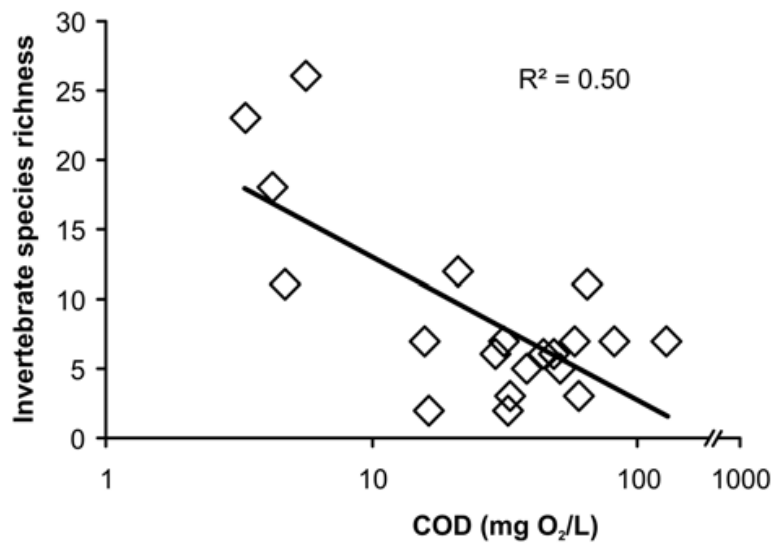


Fig. 12. Species richness of benthic macroinvertebrates in streams of Las Rozas de Madrid (central Spain) watershed as related with chemical oxygen demand (COD) in a semilogarithmic plot. Data from 2004-2006.

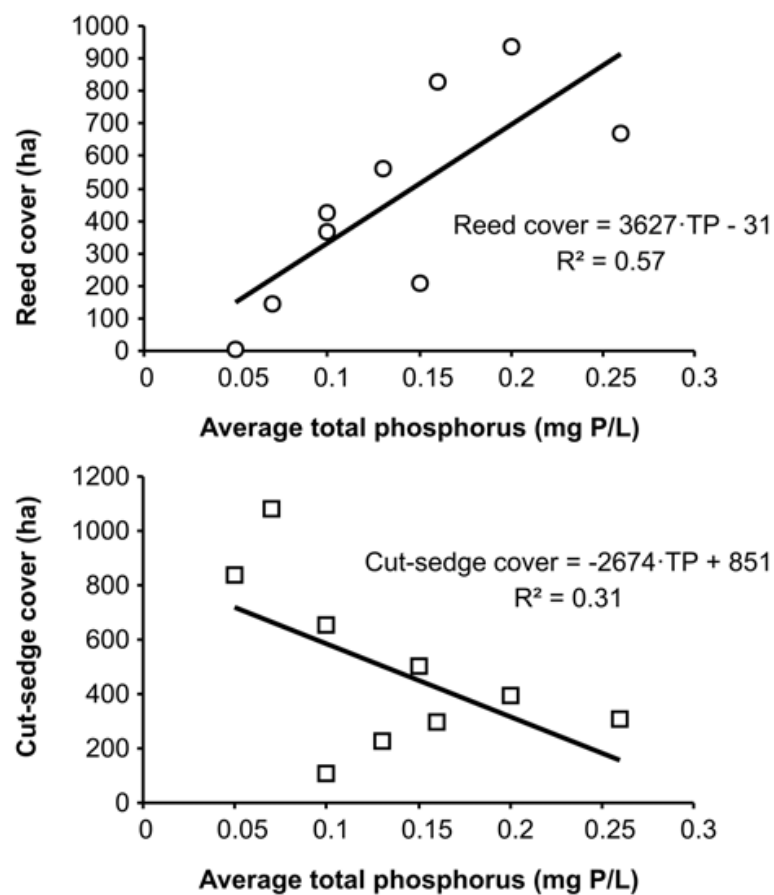


Fig. 13. Cover of dominant emergent helophytes in Las Tablas de Daimiel National Park over the years as related with average total phosphorus concentrations in the wetland. Data recorded in scattered years from 1956 until 2007. Both relationships are statistically significant at $p < 0.05$.

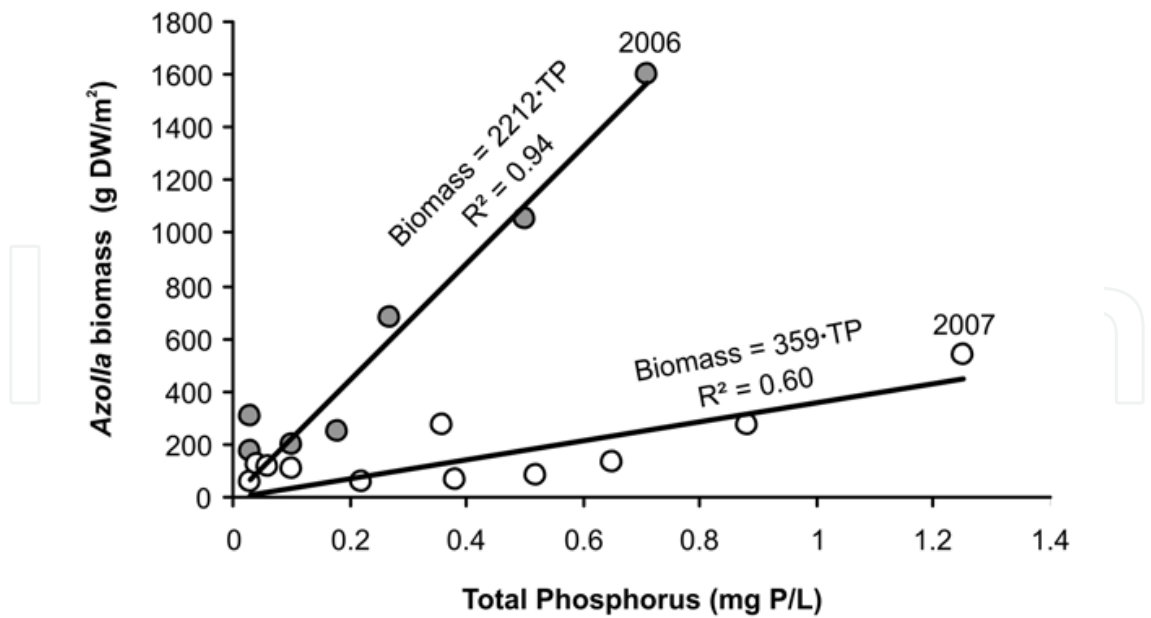


Fig. 14. Biplots of total phosphorus concentration and *Azolla* (an aquatic fern) dry biomass in the wetland of Doñana National Park in two years of contrasting flooding. All relationships are statistically significant ($p < 0.01$).



Fig. 15. Surface occupation of Las Tablas de Daimiel National Park by *Lemna gibba*, the water lentil, in 1996 (photograph by S. Cirujano-Bracamonte).

The synergistic impact of factor interactions is often more important than the impact of a single factor, such as phosphorus for example. In this context, semiarid environments are also impacted by unevenness of water availability, sometimes an outcome of anthropogenic nature. This can be worsened if water renewal is lowered by smaller discharge, and decomposing organic matter of primary producers remains in the ecosystem. Our studies have identified such an interplay for many species in Las Tablas de Daimiel National Park, which has caused many species disappear because of strong water shortage and impaired water quality of autochthonous origin (Table 3; Alvarez-Cobelas et al., 2001). Freshwater mussels and the fairy shrimp have also been extinguished in that marshland by such an interplay of factors.

	1956	1973	2007
Emergent macrophytes	18	18	11
Submerged macrophytes	22	20	5
Fish		16	3
Ducks and herons		21	16

Table 3. Species richness of the most conspicuous biological groups in Las Tablas de Daimiel National Park over time. From the seventies, the combined action of shorter water availability, arisen from unsustainable irrigation, and impaired water quality has resulted in diminishing species richness. Data source: Alvarez-Cobelas et al. (2001) and Sánchez-Carrillo & Angeler (2010).

6. Remedial actions

Semiarid environments are mostly located in areas of moderate economic development. In addition, the ongoing, and unfortunately occurring on a long-term basis, world economic crisis will threaten funding for environmental management and ecosystem restoration. This crisis is worsened in many Mediterranean countries, such as Spain and Greece, as a result of the decay of the building industry and the adaptation measures of their governments that intend to save public investments that enable payments of the extraordinarily high debt rates owed to international banks. Otherwise, there would be a risk of national bankruptcy for these countries. Therefore, it is likely that less and less money will be devoted to environmental protection of these nations in the years to come, which will make environmental restoration of waste water-impacted ecosystems very doubtful.

On the other hand and with a low degree of uncertainty, water will be more scarce as a result of global warming in semiarid climates (Parry et al., 2007). It is thus likely that waste water will often be the single water source for many freshwater environments as time goes by. All these conditions, *i.e.* less water available and of lower quality and lower funding for environmental management, must make us think of simple, green and money-saving environmental technologies to confront these challenges. Raw waste water cannot enter as such in rivers, wetlands and lakes of semiarid countries, because if so they will be either impaired very soon or hardly restored. Treated waste water is unfortunately the only solution to secure water availability enough for ecosystem performance. It is then urgent to develop treatment systems adapted to the peculiarities of the semiarid regions. Probably, treatment wetlands upstream of valuable freshwater ecosystems to diminish the impact of

nutrient-rich streamwater, is the best option and the more economically feasible in the short term. The technology for such wetlands is now widely available; they are not expensive and can be operated by native, non-experienced workers (Kadlec & Knight, 1996), and probably the only one that can cope with the strong fluctuating hydrology of semiarid climate.

Other measures to cope with these problems, such as water saving, water reuse and lower consumption of commodities that decrease pollutants exported to river courses, seem unrealistic, given the culture of luxury consumption of goods and resources installed in many developed semiarid societies (Davis, 1977).

7. Future research

There are still many aspects that deserve attention because they have hardly been tackled as yet. As a general recommendation, we suggest specifically designed studies on the relationship between waste- and freshwaters. Up to date, waste water is studied by waste water treatment engineers and freshwater is studied by ecologists, without much exchange of knowledge among both groups of people. Joint studies have to be carefully designed if our knowledge on this topic is to be expanded, increased and improved. This is particularly important in water shortage scenarios such as those of semiarid countries where a culture of collaboration among scientists and technicians is almost lacking.

Another suggestion is to pay more attention to the synergistic features of interplaying factors. Waste water effects are complicated by climate patterns and hence by water availability and renewal effects, but this is rarely considered in semiarid countries, where quantity and quality management offices do not perform collaborative work.

More specifically, effects of waste water on freshwaters have always been searched from the statistical viewpoint, mostly relying on the correlation approach. It is now time to focus on another approach, the cause-effect approach planning carefully designed experiments to fully address and describe those effects.

The biogeochemistry of interacting waste- and freshwater has scarcely been explored. Not only stoichiometry issues have to be studied, but also many processes that have been studied in climatic areas other than the semiarid one deserve attention. Among these, there are the effects of uneven patterns of wet-dry cycles in nutrient enriched sediments exposed to waste water discharges, the resilience of nutrients and other toxic substances in the aquatic environments, the methane, carbon dioxide and nitrogen gas emissions (which can be enhanced by waste water inputs), the sulphate reduction process and many more. Even the anammox process, which has originally been described from waste water treatment plants (Mulder et al., 1995), is likely occurring in freshwaters impacted by nitrogen-rich waste water (Zhu et al., 2010), but has not been searched for as yet.

Trophic cascades have not been considered as related to waste water inputs, and they should be because waste water usually kills most fish faunas, but when diluted, enhance carp occurrence. Carps also increase internal loading by bioturbation of sediments (King et al., 1997), thus affecting the survival of many benthic invertebrates and plants.

Concerning novel tools, there are some whose use must be rewarding. Microbial communities are very important mediating chemical transformations of waste water, and restriction enzymes of nucleic acids can be profitably used for a thorough description of bacterial communities, which otherwise is almost lacking in semiarid freshwaters. Stable

isotopes, which have been used to trace the origin of waste water (Cole et al., 2004), could also improve our knowledge of carbon, nitrogen and phosphorus cycling in freshwaters impacted by raw or treated waste water. Specifically, the study of O^{18} signature within the PO_4 ion will aid in outlining the flow path and transformations in freshwater of waste water-derived phosphorus, following the studies pioneered by McLaughlin et al. (2006).

8. Conclusion

Raw or treated waste water is very often discharged to freshwaters and results in changing ecological performance and biological diversity of these systems. The problem is particularly acute in semiarid regions where the beneficial effect of dilution is impaired by longer water retention time that arises from reduced rainfall and more water requirement for irrigation as compared with those of freshwaters in other latitudes. Some data suggest that waste water might change stoichiometry of freshwater ecosystems. Waste water inputs have been shown to be straightforwardly related with species richness of some algae (Euglenophytes), protozoa (Ciliates) and insects (Diptera), and inversely with species richness of most biological assemblages. Phytoplankton biomass and productivity and the biomass of some higher plants, such as *Lemna* and *Azolla*, are also enhanced by waste water. The cover of some species of emergent vegetation in semiarid wetlands, such as *Phragmites*, benefits from waste water inputs. Despite these findings, our knowledge on effects of waste water on freshwater ecosystems in semiarid regions is still very limited and hence must increase to prevent noxious and/or unwanted changes in these ecosystems.

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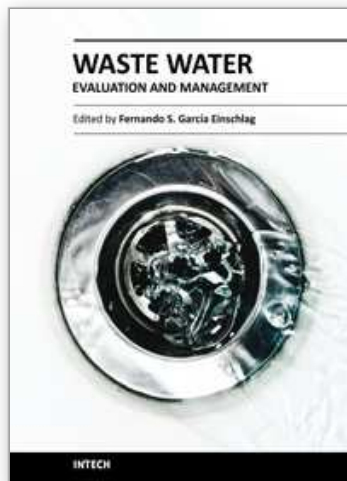
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Fresh water resources are under serious stress throughout the globe. Water supply and water quality degradation are global concerns. Many natural water bodies receive a varied range of waste water from point and/or non point sources. Hence, there is an increasing need for better tools to assess the effects of pollution sources and prevent the contamination of aquatic ecosystems. The book covers a wide spectrum of issues related to waste water monitoring, the evaluation of waste water effect on different natural environments and the management of water resources.

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