Science of the Total Environment 613–614 (2018) 866–876

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Disentangling natural and anthropogenic influences on Patagonian pond water quality

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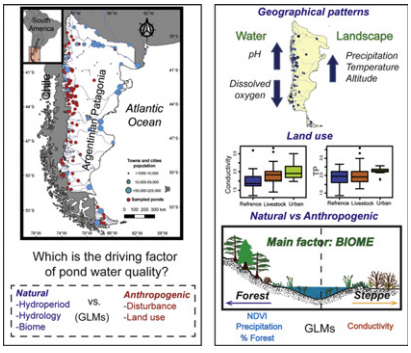
HIGHLIGHTS

- West-east variability of pond water status was mainly determined by rainfall gradient.
- Dissolved oxygen and pH showed a variation pattern from the north to the south.
- Livestock used ponds exhibited higher wet-grasses cover and total suspended solids.
- Natural variability plays a major role on Patagonian ponds ecosystems.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 24 June 2017
Received in revised form 13 September 2017
Accepted 14 September 2017
Available online 21 September 2017

Editor: D. Barcelo

Keywords:
Eutrophication
Land use
Land cover
Hydrology
Wetlands
Mallines

ABSTRACT

The water quality of wetlands is governed not only by natural variability in hydrology and other factors, but also by anthropogenic activities. Patagonia is a vast sparsely-populated in which ponds are a key component of rural and urban landscapes because they provide several ecosystem services such as habitat for wildlife and watering for livestock. Integrating field-based and geospatial data of 109 ponds sampled across the region, we identified spatial trends and assessed the effects of anthropogenic and natural factors in pond water quality. The studied ponds were generally shallow, well oxygenated, with maximum nutrient values reported in sites used for livestock breeding. TN:TP ratio values were lower than 14 in >90% of the ponds, indicating nitrogen limitation. Water conductivity decreased from de east to the west, meanwhile pH and dissolved oxygen varied associated with the latitude. To assess Patagonian ponds water status we recommend the measure of total suspended solids and total nitrogen in the water, and evaluate the mallín (wetland vegetation) coverage in a 100 m radius from the pond, since those features were significantly influenced by livestock land use. To evaluate the relative importance of natural variability and anthropogenic influences as driving factors of water quality we performed three generalized linear models (GLM) that encompassed the hydrology, hydroperiod and biome (to represent natural influences), and land use (to represent anthropogenic influences) as fixed effects. Our results revealed that at the Patagonian scale, ponds water quality would be strongly dependent on natural gradients. We synthetized spatial patterns of Patagonian pond water quality, and disentangled natural and anthropic factors finding that the dominant environmental influence is rainfall gradient.

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http://dx.doi.org/10.1016/j.scitotenv.2017.09.147
0048-9697/

1. Introduction

Ecosystems water quality is dependent on many factors, including land use, climate, geomorphology and soil conditions. Worldwide, the impacts of different land uses on water bodies and their relative importance compared to the effects of natural environments variability are yet to be ascertained and quantified. Landscape scale approaches are useful for exploring fundamental ecological patterns across a region and for improving our comprehension about the influence of the surrounding matrix in the ecosystems. These approaches are also useful, among others, for studying how climatic and geomorphological variation determine pond features, and for describing land use patterns to distinguish between impacted and reference areas (Céréghino et al., 2014). By studying small, isolated water bodies (ponds) it is possible to recognize the spatial variation and the main environmental controls across broad regional scales (Hefting et al., 2013).

Argentinian Patagonia is a region located at the southern end of the South American continent. This remote region shows a remarkable environmental heterogeneity, mainly determined by an exponential west-east decrease in precipitation. Thus, most of the territory is characterized by semiarid and arid conditions, supporting shrub-grass vegetation, typical of the steppe (del Valle, 1998; Paruelo et al., 1998). Patagonian wetlands, colloquially known as "*mallines*", develop in association with particular conditions of the landscape where an unusual amount of water is available (Movia et al., 1987), and are characterized by isolated small patches of hydrophytes included in a terrestrial matrix (Kandus et al., 2008). These azonal freshwater ecosystems provide the most productive soils for livestock breeding, which is the most important source of income for farmers in certain arid or heavily grazed areas (Ayesa et al., 1999).

Ecological processes in ponds play a major role in global cycles (Downing, 2010). Patagonian ponds are a key component of urban and rural landscapes because they provide several ecosystem services such as habitat for wildlife, watering for livestock, suitable environments for fish production, and recreational amenities (Jeffries et al., 2016). Patagonian ecosystems had not been grazed by domestic herbivores prior to European colonization so that the introduction of large herds of horses, cattle and sheep had a significant impact on soils, landscape processes, vegetation and fauna. It is known that decreases in vegetative cover promote the increase of evaporation rates and loss of soils by water and wind erosion (Kepner et al., 2000). These effects are inducing a desertification process, one of the main environmental problems affecting Patagonia (del Valle et al., 1998). Livestock grazing, conducted for more than a century (~130 years), has become so widespread that ungrazed areas are practically nonexistent (Golluscio et al., 1998) and most Patagonian mallines are currently threatened.

Urban development increases production of runoff, one of the largest uncontrolled sources of pollution to receiving waters (Novotny, 2003), and while discharging nutrients (such as nitrogen (N) and phosphorus (P)) accelerates the eutrophication process (Carey et al., 2013). Despite being a sparsely populated region (<3 inhabitants per km^2), the Patagonian population is concentrated in urban areas modifying the water quality of the aquatic ecosystems that surround them (e.g., Miserendino et al., 2011), and using wetland areas for disposal or treatment of domestic effluents.

Since ponds are relatively small in both size and water volume, they may be sensitive to environmental changes due to land use pressures and climate change (Declerck et al., 2006). Moreover, predictions for the Patagonia region indicate that areas suitable for mallines are likely to decrease by the middle of the century (Crego et al., 2014), accelerating the degradation processes derived from livestock overgrazing (Brinson and Malvárez, 2002). To understand the interaction between land use patterns, climate, and other changes, reliable information on land cover configurations around Patagonian ponds is needed. The effects of anthropogenic impacts are also recognized through increased transfer of nutrients from one environment to another, and alterations in the rates of transformations of nutrients within environments (Depetris et al., 2005). Previous studies, conducted at Patagonian ponds, have demonstrated that nutrient concentrations are good predictors of water quality and status conditions (Epele and Miserendino, 2015). Thus, ponds affected by urban effluents or livestock are expected to show higher levels of nutrients in the water compartment than pristine or less impacted ones.

Some recent research in Patagonian pond ecology shows greater interest in fundamental aspects of these environments and suggests some actions and conservation strategies, e.g. the fencing of some wetlands of special interest (Crego et al., 2014; Kutschker et al., 2014; Epele and Miserendino, 2016). Despite their socioeconomic value and the possible environmental vulnerability, there is a general lack of knowledge about their structure, functioning and relationships with features of the surrounding landscape (Perotti et al., 2005). Our research attempted to use a comprehensive approach to assess the effects of land use (livestock and urban) on water quality, and compare them with the effects of climatic or natural variability across the Patagonian region. Using georeferenced field data from >100 ponds sampled across the Patagonian region we: (1) identify spatial variability in Patagonian pond water quality (e.g. N-S or W-E variations); (2) determine relationships between landscape characteristics and pond water features; and (3) evaluate the relative importance of natural variability and anthropogenic influences as driving factors of water quality.

2. Material and methods

2.1. Study area

The study region, Patagonia Argentina (~800,000 km^2) is located in southern South America (Fig. 1A), extending from 36° to 55° S, ranging from the Andes Mountains on the west to the Atlantic Ocean on the east, and including five political provinces (from the north to the south: Neuquén, Río Negro, Chubut, Santa Cruz and Tierra del Fuego). The region is sparsely populated (<3 inhabitants per km^2), with 87% of the people living in cities or towns that are less populated to the south (National Government of Argentina, 2010).

The climate of Patagonia is strongly determined by the Andes Mountains, which impose a significant barrier for humid air masses coming from the Pacific Ocean. Most of the water in these maritime air masses is released on the Chilean side, and the air becomes hotter and drier through adiabatic warming as it descends on the Argentine side of the Andes (Paruelo et al., 1998). From the Andes eastward, total annual precipitation decreases exponentially, from >1000 mm to <150 mm at the eastern arid extreme. Precipitation is mainly concentrated in winter. Precipitation maximum in winter results in a strong summer deficit, excepting at the NE region. Most of the central portion of Patagonia receives <200 mm per year (Fig. 1B).

Patagonia can be defined as a temperate or cool-temperate region. A distinctive feature of the temperature pattern is the NW-SE distribution of the isotherms (Fig. 1C). Mean annual temperature ranges from 12 °C in the north-eastern part to 3 °C toward the south. The mean temperature of the coldest month (July) is >0 °C in all the extra-Andean Patagonia. However, toward the mountain parts of the southwest Patagonia, absolute minimum temperatures are lower than −20 °C (Paruelo et al., 1998). The annual range of monthly temperature is lower in Patagonia than in similar latitudes of the Northern Hemisphere.

A characteristic of the Patagonian climate is the predominance of winds from the west. In the center-west of the region, westerly winds represent between 65 and 75% of the daily observations in the year (Paruelo et al., 1998). Because of the seasonal displacement of the pressure systems, winter has a more uniform distribution of winds from the west, whereas in summer a southerly component is evident (Beltrán, 1997). Westerly winds are characterized not only by their persistence during the year but also by their intensity, with mean annual speed values that varied between 15 and 22 km h^{-1}. Low humidity content