



## Comment

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# Chronicle of an Environmental Disaster: Aculeo Lake, the Collapse of the Largest Natural Freshwater Ecosystem in Central Chile

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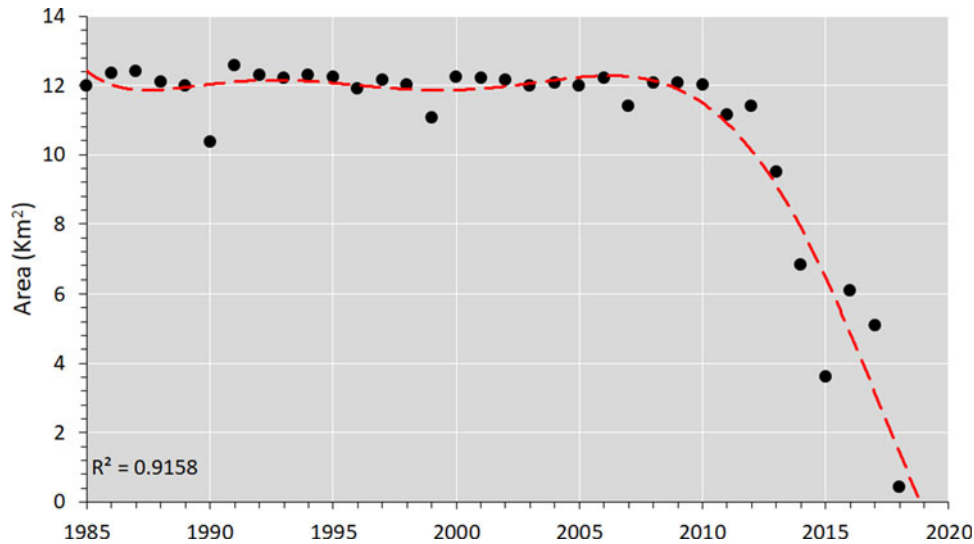
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The environmental destruction generated by human activities, driven mainly by changes in land use, has generated several extinctions around the world (Pimm et al. 2014). Collapses of whole ecosystems have been reported in 37 marine pelagic cases and 48 temperate forests, but not in freshwater (Bland et al. 2018). One of the most iconic is the case of the Aral Sea in Middle Asia (Keith et al. 2013). This ecosystem, which was the fourth largest water body in the world, was transformed into a desert due to the overuse of its water for cropland irrigation and human consumption (Keith et al. 2013). Ecosystem collapse changes both the biotic and abiotic original characteristics of the system (Bland et al. 2017, 2018). Here, we explore the political and environmental causes of the recent collapse of the largest natural freshwater body in the central metropolitan zone of Chile.

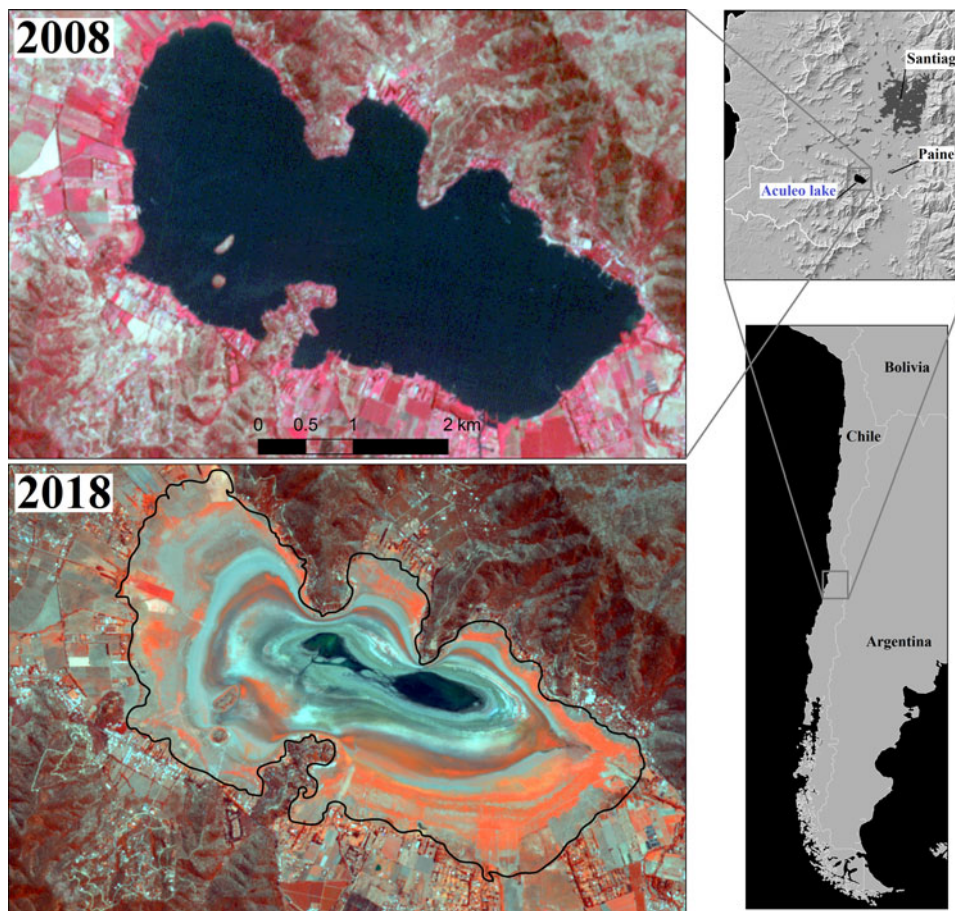
Aculeo Lake is located 50 km southeast of Santiago City in the locality of Paine, a commune that is part of a densely populated region in the country and containing more than 7 million people. It is located at 33°50'S and 70°54'W at an elevation of 350 m within the Chilean Mediterranean biodiversity hotspot (Alaniz et al. 2016). The lake has a Holocene origin from c. 11 000 ybp (Villa-Martínez et al. 2003); it was created by natural damming by sediments transported via the Pintué River and a series of ravines from the Altos de Cantillana range. Aculeo Lake is very important to the inhabitants of Paine, a small commune with a subsistence agricultural tradition that greatly depends on the availability of water for cropland irrigation (Valencia 2018).

The mean summer area of Aculeo Lake during 1985–2010 was c. 12 km<sup>2</sup>. However, since 2010, the water level has dropped until it reached its lowest ever recorded area in December 2018, with 96.4% of the lake being dry (Figs 1 and 2). This event caused alarm in the local population, which had no more water for their daily activities, generating serious social and economic problems. This is an additional problem facing the substantial number of endangered terrestrial ecosystems in this zone, mainly associated with the expansion of croplands and urban areas (Alaniz et al. 2016). We identified three main potential causes of the collapse of the lake ecosystem: (1) increased urbanization of the Paine district, mainly associated with the large population increase of recent years (45.4%), from 50 028 inhabitants in 2002 to 72 759 in 2017 (INE 2002, 2017); (2) increased illegal water extraction associated with the recent massive installation of agricultural monocultures (DGA 2015, Silva 2017); and (3) climate change implications, particularly the strong drought in the zone over the last 8 years (Garreaud et al. 2017). The ecological implications of the recent loss of Aculeo Lake are still being studied; however, it is highly probable that the collapse thresholds had already been exceeded (Fig. 3 and Supplementary Fig. S1, available online). The large decrease in lake area, which exceeds previously recorded normal fluctuations, makes the collapse of the aquatic biotic assemblage highly probable. Significant species losses occurred between 1976 and 1985, including a 67% decrease in phytoplankton species (ten species extirpated) and a 57% decrease in fish species (four species extirpated) (DGA 1987, Muhlhauser & Vila 1987).

First, the use of fertilizers has been reported in the basin since 1980, which has induced an increase in nutrient availability (nitrogen and phosphorus), generating eutrophication and degradation of the chemical water quality of the lake (Fig. 3 and Supplementary Fig. S1) (Cabrera & Montecino 1982, Muhlhauser & Vila 1987). Eutrophication is one of the main negative impacts on the food web and ecosystem functions of lentic systems (Teurlinckx et al. 2019). In Aculeo Lake, the rise of *Microcystis* spp. from 1987 to 1990 had serious impacts on species due to an increase in toxicity levels (Supplementary Fig. S1) (Vila & Muhlhauser 1984, Peñaloza et al. 1990). In addition, the invasive species *Cyprinus carpio* reached Aculeo Lake. The collapse of this ecosystem could have a severe impact on the quality of life of people due to the loss of ecosystem services such as climate regulation, implying a potential increase of temperature (Moor et al. 2015), impacting water provision and quality, affecting water flow and its chemical properties



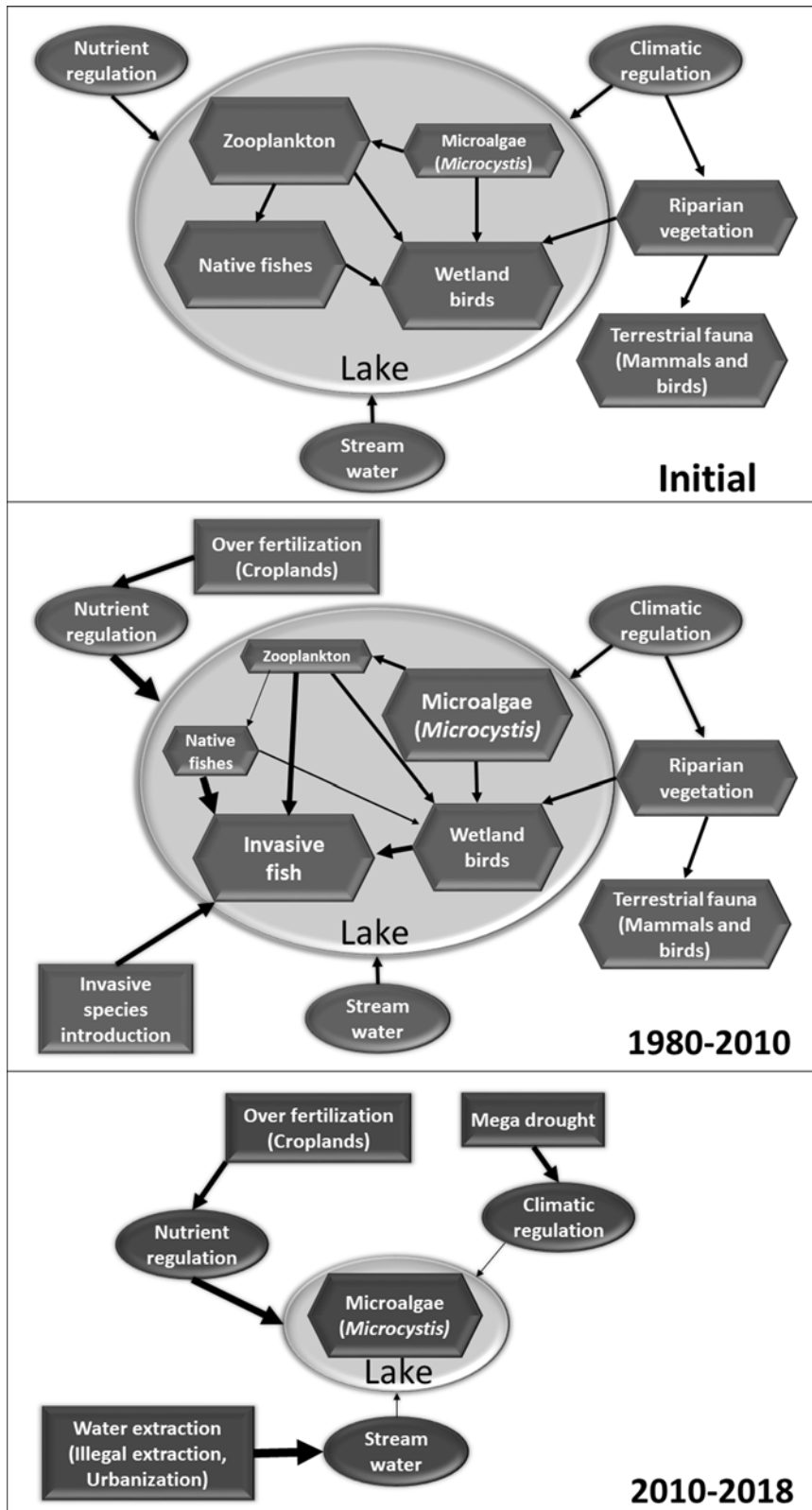
**Fig. 1.** Area of Aculeo Lake in summer over the last 33 years, estimated using the sensors Landsat-5 TM, Aster, Landsat-8 OLI and Sentinel-2 in the Google Earth Engine platform.



**Fig. 2.** Satellite images in infrared false colour showing the change in the area of Aculeo Lake between 2008 (Aster) and 2018 (Sentinel-2) (maps on the left). The outline in the 2018 image shows the lake area in 2008. The maps on the right show the location of the lake within the region.

(Smith et al. 2013), and impacting recreational uses. A significant proportion of the Paine population who live near the lake depends on activities such as subsistence agriculture, as well as tourist activities that have also been lost (Castro & Lardiés 2002). This population is mainly composed of older, low-income people who have low economic, cultural and social resilience capacities (Castro & Lardiés 2002), hindering their response in the face of the ecosystem's collapse.

To date, previous cases of lakes drying up in Chile were reported mainly in Patagonia; however, the causes of these are quite different from that impacting Aculeo Lake, being associated with meteorological phenomena intensified by climate change (Lake Cachet II, Patagonia) or precipitation deficit (Riesco Lake, Patagonia) (Marín et al. 2013). In Aculeo Lake, the main cause of drying is associated with poor urban land-use planning and a lack of regulation of water extraction for agriculture



**Fig. 3.** Simplified scheme of the collapse process experienced by Aculeo Lake based on Bland et al. (2018) through time. The ovals correspond to environmental or abiotic ecological processes, squares represent collapse drivers and hexagons represent biotic elements of the ecosystem. The arrows show the directionality and intensity (arrow size) of the influences between the elements in the ecosystem.


(DGA 2014, Silva 2017, Valencia 2018). The poor regulation regarding illegal water extraction affects small farmers who cannot extract water from deep wells (DGA 2015). Another policy driver is the scarcity of efficient contingency plans regarding the intense drought in central Chile (40% precipitation deficit) (Garreaud

et al. 2017), which has led to the abandonment of small farmers and traditional production systems by the government.

Although ecosystem restoration could lead to the recovery of some ecological functions, this process is difficult and expensive, especially if key species from the original biotic assemblage have

gone extinct (Bland et al. 2017, 2018). Governmental institutions should take rapid action aiming to reduce the social vulnerability caused by this environmental disaster by providing economic assistance to the affected farmers and small-scale tourism operators. On the other hand, it is necessary to ensure the generation of policy instruments that regulate illegal water extraction through fines and taxes or even legal actions against the guilty. A modification of the local land-use plan is needed, regulating land-use change, urbanization and monoculture expansion. The collapse of Aculeo Lake should be considered an example of how poor planning and inadequate policy can lead to irrevocable damage in ecological and sociocultural dimensions.

**Supplementary Material.** For supplementary material accompanying this paper, visit [www.cambridge.org/core/journals/environmental-conservation](http://www.cambridge.org/core/journals/environmental-conservation)

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**Conflict of Interest.** None.

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