Dynamics of Declining Lake Habitats in a Changing Climate: From the Andes to Early Mars. N. A. Cabrol[1], E. A. Grin[1], G. Chong-Diaz[2], C. Demergasso[2], and the HLP Team, [1] NASA Ames/SETI CSC, Space Science Division, MS 245-3, Moffett Field, CA 94035-1000. Emails: Nathalie.A.Cabrol@nasa.gov and Edmond.A.Grin@nasa.gov; Email; [2] Universidad Católica del Norte, Antofagasta, Chile. Emails: gchong@ucn.cl and cdemerga@ucn.cl.

Introduction: We illustrate the impact of climate variability on lake habitat at high altitude on Earth as a proxy to the evolution of declining lakes on Mars. The physico-chemical and biological environment of high altitude lakes (4,500-6,000 m) in the Central Andes of Chile and Bolivia is being monitored by the the High Lakes Project (HLP). HLP [1] was funded in 2002-2003 as a reconnaissance project by a NASA Ames Directorate Discretionary Funds (DDF) reconnaissance grant and between 2003-2008 through the NASA Astrobiology Institute (NAI).

The environment of the Altiplano and high Andes presents analogies with Mars at a time when the planet was transitioning from a wetter to a drier, colder climate: thin atmosphere, high solar irradiance, low ozone, high daily and yearly temperature fluctuations with low averages, ice, reduced yearly precipitation, and volcanic geology. This region is also among the three areas of the world most impacted by climate change, which results in enhanced evaporation and strong negative water balance that modifies lake habitat rapidly. Data show that although the decline is not monotical [2], interannual fluctuations in precipitation, water balance, major ion concentration, and pH are well marked. Microorganisms dwelling near or at the water/atmosphere interface are exposed to a UV flux 170% that of sea level, and yearly UVB levels ranging from 1.5 to 4W/m2 equivalent to ~3 times that of Antarctica during ozone hole events. The thin and cold atmosphere generates sudden and significant inverse relationship between UV and temperatures. In this cold, unstable environment lake habitats host abundant life. In addition to adaptation strategies, data suggest that the timing of key cycles is a critical factor in life' survival.

Early Mars Environment Analogy: The environmental analogy of the region with early Mars is multifold [3]. The aridification of the Central Andes coincided with the end of the last deglaciation and the beginning of the Holocene and is accelerating today with Global Warming [4]. As a result, the water level of the lakes has fluctuated over the past 20 years. In an environment of aridity and evaporation, their geographical location (latitude and altitude) results in intense solar irradiance with UV-flux double that of present-day Mars at the equator and UV-B only half that of the red planet [*Hock* 2008], low average total ozone, and a low (480 mb) atmospheric pressure [2, 5-6]. The yearly temperature extremes range from -40^{o}C to +9 ^{o}C with daily averages of -12 ^{o}C in winter and -5 ^{o}C in summer. Ice covers the surface of the lakes starting April (austral fall), reaching maximum thickness by August. Typically, thawing occurs in September (austral spring), but negative night temperatures regularly result in the formation of a thin film of ice (2-5 mm) that thaws by mid-morning in spring and summer. Low average relative humidity (16-33% depending on the area) from April through December, scarce snow precipitation (30-120 mm/yr), and high evaporation (500-1,000 mm/yr) generate a strong negative water balance. Because of its extreme geophysical environment, rapid climate change, isolation, and a mostly uncharted ecosystem at the start of the study in 2002, these lakes are representative of an end-member class of terrestrial lakes [1] and meaningful analogs to early martian lakes.

Clues to the Decline of Martian Lakes: With differences inherent to the study of terrestrial analogs, i.e. the presence of zooplankton, the overall environmental similarity of altiplanic and Andean lakes with Mars at the Noachian/Hesperian transition period makes them unique analog to early martian lakes and a window into the likely transformation they experienced during the transition period from a wet to a dry Mars as liquid water completely disappeared from the surface.

From a climate standpoint, the demonstrated interannual variability in water input, related water level fluctuations, and the resulting changes in physico-chemical properties of the water column show that the decline was unlikely to be monotonical over time on Mars, and therefore probably challenging for putative life to adapt to. For instance, in 2005, a particularly dry year with only 30 mm precipitation in some of the study areas, lakes lost up to 55% of their total volume. One of them, lake Licancabur, lost about 2 meters of water column for an average depth of 5 meters. In 2006, its level was back to the highest in all years surveyed as a result of an exceptional wet season that brought the equivalent of two years of precipitation.

The interannual survey demonstrates that physico-chemical changes associated with such variability are significant. There is currently no data to show how this environmental roller coaster impacts biodiversity at the level of the overall population's density or that of the species. However, the relatively low diversity found in the samples of the microbial community is consistent with biodiversity loss and selection of specific species capable of mutating and adapting rapidly as shown by the compactness of their cladograms [1, 7-8].

The low atmospheric pressure and low cloud cover combine to generate strong daily and yearly temperature variations. Cloud passage results in rapid and severe fluctuations of both temperature and UV flux. Inverse relationships between UV and temperature are observed during those fluctuations, with summer daily average temperature gradients between 3.75-6.3^{o}C per hour, and significant dip and recovery patterns. This specific set of stresses would have been common on Mars as the atmosphere was thinning. Previous studies have documented that it impairs life's ability to repair DNA and, as a response, organisms were observed using the water column to shelter themselves [e.g., 9-10]. This survival strategy is efficient as long as the water column is deep enough (e.g., deeper than the UVB cutoff region) but becomes a dead-end as soon as the water level becomes shallower than this limit. While this behavior was also noted at Licancabur for some of the zooplankton species, other pigmented species were observed in 2006 swimming at the surface for extended periods of time at solar noon.

Habitability is also impacted by water chemistry and interannual variability may increase stress on microorganisms. However, partial loss of water column does not appear to always translate into more exposure for organisms. In some cases, significant interannual variations in Total Dissolved Solids (TDS) were noted, with shallow waters showing higher TDS, which results in UV being stopped higher in the water column. How this evolution and rapid interannual fluctuations impact microbial populations (e.g., diversity) has yet to be quantified.

From a physical perspective, data suggests that the timing of key cycles could be critical to the ecosystem's survival. For instance, minimum ozone occurs at the end of austral fall (May-June) when typical daily UV flux peak nears its lowest values. This is also the time when the lake freezes. The ice cover mitigates UV radiation and water temperature fluctuations, making the lake a safer and a more stable habitat. Thawing occurs in September when ozone concentration reaches its maximum yearly value.

These observations suggest that the combination of extreme atmospheric and environmental factors here is what governs habitability and life rather than their sum. Yet even minimum UV radiation and maximum ozone concentration in the Andes must be regarded as some of the most severe on our planet. They are further combined with low, yearly average temperatures including high daily variability and sharp fluctuations due to the thin atmosphere, ice, a rapidly changing climate, and fast chemical changes making Licancabur an end-member environment, possibly one of the closest terrestrial lake habitats to those of early Mars.

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