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The Lakes in Andean Protected Areas of Ecuador

Resumen

El Ecuador tiene varias lagunas en los páramos altoandinos y en los valles interandinos. La mayoría de las lagunas andinas son parte del Sistema Nacional de Areas Protegidas. El presente artículo describe las lagunas más importantes en cada una de las áreas. Pese a su relativamente pequeño tamaño, las lagunas son atributos hidrológicos muy importantes del paisaje tropandino, ya que regulan la disponibilidad del agua en la cuenca hidrográfica. Las lagunas también son importantes para el turismo, para la pesca de truchas y para la provisión de hábitat acuático y litoral, y de alimento a una gran diversidad de vida silvestre asociada al ecosistema léntico andino.

Introduction

Ecuador established in 1981 a National System of Protected Areas which is outlined in the "Law of Forestry and Conservation of Natural Areas and Wild Life." The law recognizes seven management categories: (1) National Parks, (2) Ecological Reserves, (3) Wildlife Refuges, (4) Biological Reserves, (5) National Recreation Areas, (6) Areas of Fauna Production, and (7) Areas for Hunting and Fishing. The criteria used to classify these areas include size of the area, nature and state of the natural resources, and the human activities that can or cannot be permitted in the area (EcoCiencia 1994).

Figure 1 and Table 1 show the 18 major protected areas of Ecuador. These areas include a most varied geography: rain forests, lowland deserts, the Galapagos Islands, cloud forests, páramo, highland deserts, tundra, etc. Twelve of the eighteen areas are entirely or partly in the Andes mountains, and in ten of these there are lakes. Because of their large number, variety and, often, easy access, the lakes of the Andes of Ecuador also provide opportunities for research and environmental education in the still relatively young field of tropical limnology.

I have been searching all parts of Ecuador for lakes and ponds since 1975. My research is directed not only to a regional limnology of Ecuador, but also to using the biota of lakes for testing ecological theories on species diversity, such as the theory of island biogeography (Colinvaux and Steinitz-Kannan 1980; Steinitz-Kannan 1979). In addition, I have assembled a large diatom database and diatom herbarium for Ecuadorian

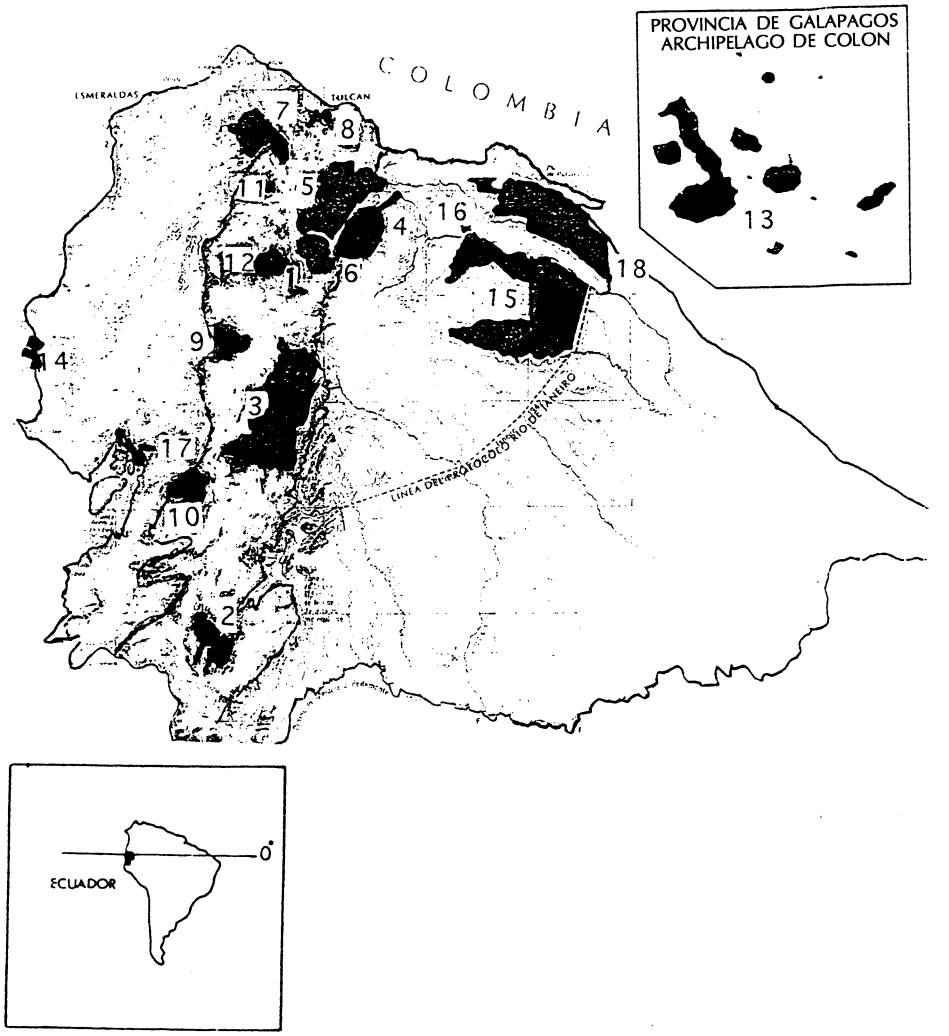

Figure 1. The major protected areas of Ecuador

lakes at Northern Kentucky University, with information that allows the use of the diatom communities as indicators of environmental conditions. Fossil diatoms and pollen from the sediments of many of these lakes are being used for reconstructing short-term and long-term climatic histories of the region (Steinitz-Kannan et al. 1993; Colinvaux et al. 1988; Colinvaux et al. in press; De Oliveira et al. 1986, 1988; De Oliveira and Steinitz-Kannan 1992). The physical and chemical limnology of Ecuador is described in Steinitz-Kannan et al. (1983). Information about individ-

Table 1. List of the major protected areas of Ecuador shown in Figure 1 (adapted from EcoCiencia 1994). The first 12 areas are entirely or partly in the Andes Mountains. Lakes in the first 10 areas are listed in Table 2.

No. in Fig.1	Protected Area	Provinces	Area (hectares)	Altitudinal range (m)
1	Cotopaxi National Park	Cotopaxi, Pichincha, Napo	33,393	3,400 - 5,897
2.	Podocarpus National Park	Loja, Zamora-Chinchipe	146,280	1,000 - 3,600
3.	Sangay National Park	Tugurahua, Chimborazo, Morona Satiago	517,725	900 - 5,230
4.	Sumaco-Galeras National Park	Napo	205,249	600 - 3,732
5.	Ecological Reserve Cayambe-Coca	Pichincha, Imbabura Napo, Sucumbíos	403,103	750 - 5,790
6.	Ecological Reserve Antisana	Pichincha, Napo	120,000	1,400 - 5,076
7.	Ecological Reserve Cotacachi-Cayapas	Imbabura, Esmeraldas	204,420	100 - 4,939
8.	Ecological Reserve El Angel	Carchi	15,715	3,600 - 4,218
9.	Chimborazo Reserve for Faunistic Product.	Chimborazo, Tunguraha Bolivar	58,560	3,800 - 6,310
10.	Cajas National Recreation Area	Azuay	28,808	3,000 - 4,300
11.	Geobotanical Reserve Pululahua	Pichincha	3,383	1,800 - 3,356
12.	Boliche National Recreation Area	Cotopaxi	1,077	3,000 - 3,600
13.	Galapagos National Park	Galapagos	693,700	0 - 1,707
14.	Machalilla National Park	Manabi	55,059	0 - 850
15.	Yasuni National Park	Napo	982,000	300 - 600
16.	Limoncocha Biological Reseve	Sucumbíos	4,613	230
17.	Manglares de Churute Ecological Reserve	Guayas	35,042	0 - 900
18.	Cuyabeno Reserve for Faunistic Production	Sucumbíos, Napo	655,781	200 - 280

Table 2. Lakes of Ecuador's Andean national parks and other protected areas shown in Figure 1.
(* = lakes studied by the author's research team; + = important lakes, not part of protected areas)

No. in Fig. 1	Names of lakes	Province	Latitute	Longitude	Altitude (m)
1	*Lake of Limpiopungo	Cotopaxi	0°36' S	78°28' W	3970
2	Lagunas del Compadre	Loja	4°10'S`	79°09'W	>3000
	Lacustrine complex La Campana	Loja-Zamora	4°20'S	79°10'W	>3400
3	Lacustrine complex Ozogoche:				
	Ozogoche or Cubillín, Laguna de Mactayán	Chimborazo	2°18'S	79°45'W	>4000
	Atillo or Colay-Cocha, L. Azul, L. Verdecocha,	Chimborazo	2°10'S	78°25'W	>4000
	L. Boazo,L. Pichahuiña, L. Jactán, L. Tintillón,				
	L. Cochapunga and others				
4.	Laguna de Sumaco	Napo	0°36'S	77°35'W	2400
5.	Puruantac	Imbabura	0° 12' N	77° 57'W	3471
	*San Marcos	Pichincha	0° 07'N	78°25'W	3414
	*L. de Papallacta, L. Tumiguina	Pichincha	0°24'S	76°37'W	3920
6.	Micacocha, Muerte Pungo	Pichincha	0°36'S	78°12'W	3980
	>25 lakes in Oyacachi paramo: Yanacocha,	Pichincha	0°15'S	78°10'W	>3800
	Nunaluiro, Encantada etc.				
7.	*Cuicocha Lake	Imbabura	0°,17'N	78°21'W	3010
	Mojanda Lakes: *Caricocha (Mojanda Grande)	Imbabura	0°08'N	78°15'W	3716
	*Huarmicocha (M. Chicha),*Yanacocha (M. Negra)	Imbabura	0°07'N	78°15'W	3696-3700
	Lakes of Piñán: Cristococha, La Cocha, Parcacocha,	Imbabura	0°20'N	78°25'W	>3500
	Yambarro, L. de Cubilche, L. Donoso	Imbabura	0°30N	78°24'W	>3500
	*+Laguna de San Pablo	Imbabura	0°13'N	78°14'W	2585
	*+Laguna de Yaguarcocha	Imbabura	0°23'N	78°05'W	2380
8.	Lagunas de Páramo de El Angel, L. El Voladero	Carchi	1°40'N	77°50'W	3700
9.	*L. Pucacocha,*L. Plateriacocha, *L. Cochabamba	Chimborazo	1°29'S	78°42' W	3600 - 3720
	*+Laguna de Cota	Chimborazo	1°45'S	78° 44'W	3420
10.	Cajas Lake district: > 230 glacial lakes:				
	*Toreadora, *Illincocha, *Apicocha	Azuay	2°46'S	79°13'W	3900
	*Surocucho (Llaviucu or Zorrocucho)	Azuay	2°50'S	79°08'W	3260
	*Culebrillas	Cañar	2°25'S	78°51'W	3985
	Osohuayco, Ventana, Mamamag,	Azuay	2°55'S	79°20'W	>3500
	Lluspa, Sunincocha, Lagartococha	Azuay	2°55'S	79°20'W	>3500

ual lakes and their biota is given in Steinitz-Kannan (1983), Steinitz-Kannan et. al (1982, 1986), Miller et al. (1984), De Oliveira and Steinitz-Kannan (1992), and Sarmiento (1988). In addition there are brief references to lakes in books on geography, geology or ecology of Ecuador (Wolf 1934; Sauer 1971; Terán 1975; Sarmiento 1987).

General Characteristics of Mountain Lakes of Ecuador

The majority of mountain lakes in Ecuador are located at altitudes above 3,000 m. Most have basins that are clearly of glacial origin, being kettles, depressions in till, or behind moraine dams or small fjords. A few occupy volcanic explosion craters (maars) or collapsed calderas. A few have formed by lava dams blocking the flow of rivers. The páramo lakes are cold year-round with maximum temperatures seldom reaching 12°C, and minimum temperatures close to freezing (1-2° C). Since there is no winter, they do not freeze. Most are deficient in dissolved ions, the water being in consequence poorly buffered so the pH fluctuates with photosynthesis from a very acidic pH of 4 at sunrise to neutral or even slightly alkaline by afternoon on sunny days. Such fluctuations are more dramatic in the more productive lakes that receive organic matter, whether from animals grazing near their shore, agricultural runoff, or trout hatcheries. The many blackwater lakes in the region have the lowest pH because of the high concentrations of humic acids. The lakes in general are polymictic, with only brief periods of thermal stratification, if any. Oxygen levels are generally high, except in the bottom most waters. In contrast to the páramo lakes, lakes of the Interandean Plateau, between 2,000 and 3,000 m in altitude, are usually nutrient-rich, of high pH, and eutrophic. The average water temperature is around 17°C. Exotic fish, mainly trout (*Salmo trutta, S. gairdnerii,* and others) have been introduced to every accessible lake in the Ecuadorian Andes and, with few exceptions, have today healthy populations. Most of the lakes occupy closed basins so that they probably had no fish before the introductions.

There is a very high diversity of microscopic algae in these lakes. We have identified up to 106 species of diatoms coexisting in one lake *(Surucucho)* alone, and have 750 different diatom taxa in our herbarium from this region. In addition there is an interesting diversity of microscopic invertebrates (ostracods, cladocerans, rotifers {Koste & Böttger 1992}; Boeckellid copepods, endemic in páramo lakes {Loeffler, 1963}; water bears {Tartigrades}; nematodes; water mites; and insect larva). The shallow areas of most of these lakes have macrophytes such as *Scirpus totora, Myriophyllum, Ceratophyllum, Potamogaeton* and, in a few, *Chara*. The lakes attract a great variety of birds and mammals, many of which depend on them for water, food or nesting sites, as is the case of

the Andean lapwing, or *ligle (Vanellus resplendens),* the lacustrine avian guardian of the páramos.

Mountain Protected Lakes

The names and location of lakes of the protected areas of the Ecuadorian Andes are given in Table 2. Below is a brief description of lakes in specific protected areas.

1—Cotopaxi National Park. The lake of *Limpiopungo* is one of the main attractions of the park. It is easily accessible by a 6-km gravel road that branches off the Pan-American Highway. It occupies a very shallow basin in flat land at the intersection of a system of valleys immediately below the snow-capped, 5,897-m peak of the Cotopaxi volcano. Both the depth (13-65 cm) and the area of the lake vary dramatically with rainfall and amount of snow-melt. The bottom is carpeted with gelatinous masses of blue-green algae (Cyanobacteria) of the genus *Phormidium*, forming mats with 48 other species of benthic algae (Steinitz-Kannan et. al. 1983). In addition to Limpiopungo, there are several very small glacial basins around the Cotopaxi volcano. Most are of difficult access and are yet to be studied.

2—Podocarpus National Park. The lakes in this park are accessible through a hiking trail that branches off the main administration building of the park, goes over a luscious cloud forest to the páramo, where the lakes are. There are several basins of glacial origin. The most accessible set of lakes are known collectively as *Lagunas del Compadre.* There is another set known as the lacustrine complex of *La Campana.*

3—Sangay National Park. The lakes in this park are formed from melting glaciers of three volcanoes: the Altar, the Sangay, and the Tungurahua. The lacustrine complex of Ozogoche is one of the most spectacular and largest group of lakes of glacial origin in the Andes of Ecuador. The largest lake in the complex is *Ozogoche* or *Cubillín* which is 12 km long in its south-to-east direction. Just north of Ozogoche is *Laguna Mactayán,* and south of Ozogoche are at least 11 smaller lakes. All these lakes are connected by streams, forming a typical "paternoster" chain. About 12 km north of Mactayán are the lakes of *Atillo* or *Colay-Cocha,* famous as the place used by the ancient Puruhaes to punish condemned criminals to death by freezing or drowning. A series of paternoster lakes also come out of Laguna de Atillo.

4—Sumaco-Galeras National Park. There are only a few lakes in this park; most are small glacial ponds at altitudes above 3,000 m. There is one lake in a maar (explosion crater), at an altitude of 2,400 m on the eastern flanks of the Sumaco volcano of potential interest for paleoecological studies.

5—Cayambe-Coca Ecological Reserve. There are a very large number of lakes in this reserve. The following have been studied: *Laguna de Puruhanta* (Sarmiento 1988), also known as *Laguna de Chique*, is in the southeastern Imbabura province.

Laguna de San Marcos (Steinitz-Kannan et. al. 1982, 1983) is located on the southern slope of the Cayambe. Both lakes occupy long, deep, U-shaped valleys surrounded by glacial end and lateral moraines, and appear to be true fjord lakes. The lacustrine complex of *Papallacta* (Steinitz-Kannan et. al. 1983) contains the closest lakes to the capital city of Quito. *Laguna de Rumicocha* is located directly off the road from Quito to Baeza. It occupies a channel of the river Papallacta, 1300 m long by 200 m wide, that was dammed by a lava flow from the Antisana volcano. Not far from Rumicocha and not as accessible, is *Laguna Tumiguina,* a lake somewhat smaller than Rumicocha (Papallacta). The páramo in this region is saturated with water and there are innumerable *Sphagnum* bogs and small ponds.

6—Antisana Ecological Reserve. From a hydrological standpoint this reserve could be considered an extension of the Papallacta lacustrine system. The páramo in this region is also saturated with water and there are numberless *Sphagnum* bogs and small ponds. Two notable lakes are *Laguna La Mica* or *Micacocha* and *Laguna Muerte Pungo*, both formed by damming of rivers by lava flows on the foothills of Antisana volcano.

7—Cotacachi-Cayapas Ecological Reserve. The predominant feature of this reserve is *Lake Cuicocha* in a spectacular caldera (collapsed crater), roughly 4 km by 2.5 km and 180 m deep on the flank of Cotacachi volcano. Two islands near the center of the lake are separated by a sill only 15 m deep and are apparently the remains of an old volcanic cone rising from the crater floor. Mountain forests cover both islands. The lake is highly oligotrophic, with a transparency of 18 m. Attempts to plant trout in this lake have failed due to the lack of shallow habitats for spawning, and to the low productivity of the system. The chemistry of Cuicocha (Steinitz-Kannan et. al. 1983), is that of a marl lake, with very hard water high in Ca and Mg. The margins support populations of the macro-algae *Chara,* characteristic of marl lakes and noted for its ability to inhibit the reproduction of mosquito larvae. Although not as spectacular as Cuicocha, several small crater lakes (mainly maars) can be found in this reserve. The Lakes of Piñan—*La Cocha, Cristococha, Parcacocha,* and *Yambaro*—are in the páramo of the eastern cordillera, north of Cuicocha. They are rather inaccessible. *Laguna Donoso*, and *Laguna de Cubilche* are on the western side of the park. In this region are also the Lakes of Mojanda. *Mojanda* is a broad volcanic chain which separates the basin of Quito from that of Ibarra, and forms the geographic and legal limit between the provinces of Imbabura and Pichincha. There are three lakes in this chain: *Caricocha* or *Laguna Mojanda Grande, Huarmicocha* or *Laguna Mojanda Chica,* and *Yanacocha* or *Laguna Mojanda Negra.* The lakes occupy the floor of a very large collapsed caldera. Caricocha, the largest, is 2 km across and highly

oligotrophic, with a transparency of 21.5 m. It has the lowest content of dissolved ions of any lake studied in Ecuador (Steinitz-Kannan et. al. 1983). Huarmicocha occupies a shallow oval depression about 400 m across. Its level is maintained only by rain water and can fluctuate dramatically. Yanacocha has a more permanent basin that appears to have been separated from Caricocha by a volcanic dam. Close to this reserve, although not in it, are *Lago San Pablo* and *Laguna de Yaguarcocha,* two well-known large eutrophic lakes that have earned the province of Imbabura the name of *Provincia de los Lagos,* also known as "the Switzerland of Ecuador."

8—Ecological Reserve of El Angel. The very wet páramo in this park is characterized by the presence of *Espeletia hartwegiana* (commonly known as *Freilejón).* The super-saturated soil gives rise to a large number of bogs and small lakes; all are yet to be studied. The largest is *Laguna el Voladero.* These lakes are an important hydrological reserve that provides water for the settlements located just below the reserve.

9—Chimborazo Reserve for Faunistic Production. Unlike the páramo in the Reserve of El Angel, the páramo in this reserve is very dry, a semi-desert. We have studied three small basins. Lake *Pucacocha* and Lake *Plateriacocha* are less than 1 km apart, and Lake *Cochabamba* is a vernal pond located 3 km south of Lake Pucacocha in a shallow depression. These lakes occupy a plateau between Mount Chimborazo and Loma Grande, not far from the Pan-American Highway. The terrain appears to have been glaciated, and the lakes collect melt-water from Chimborazo. All three are very shallow and abandoned shore-lines indicate the lake levels fluctuate. Pucacocha and Plateriacocha probably never dry out completely since they support dense stands of *Potamogeton* and *Myriophyllum.* Cochabamba certainly dries out periodically. These very shallow basins lack fish, and have water of high mineral content. Cochabamba is the only high-altitude lake where we have collected fairy shrimps (*Eubrachipus* spp.). These ponds provide an important source of water for the vicuña that has been introduced into this park. Just south of the reserve is the biggest lake of the province of Chimborazo, *Laguna de Colta.*

10—Cajas National Recreation Area. By far the most interesting region of Ecuador from the point of view of lakes is the Cajas National Recreation Area, also known as the "Cajas Lake District." It is only about 34 km from the city of Cuenca. The terrain has a peculiar knob and depression surface reminiscent of the "kame and kettle" topography of glacial landscapes. Over 230 glacial lakes dot the landscape. The largest and best-known ones are *Surucucho* (or *Llaviucu), La Toreadora, Lagartococha, Osohuayco, Mamamag* (or *Taita Chugo), Lluspa, Sunincocha, Ventana, Apicocha, Culebrillas* and *Illincocha.* Many of these lakes form

chains connected by small streams, being classic examples of a paternoster formation. Others are kettles (such as Toreadora) or cirque lakes (such as Lluspa and Surucucho). From these lakes originate the rivers Tomebamba and Yanuncay that supply the city of Cuenca with water. Trout has been introduced into most of these lakes, and one of them, Surucucho, has a trout hatchery. Because of their proximity to Cuenca, some of these lakes have been studied extensively. Surucucho is surveyed on a regular basis by the province's water quality laboratories (ETAPA) and faculty and students from the Department of Environmental Biology of the Universidad del Azuay. A detailed record of chemical and physical parameters and chlorophyll values are available from all months of the year for this lake since 1995. Sediment cores raised in June 1988 from Surucucho have yielded a detailed history of the region from full glacial times to the present (Colinvaux et. al., in press).

Conclusion

The above-described lakes are among the most important features of the landscape in all the mountain protected areas of Ecuador. They attract tourism because of their beauty and their trout fisheries. They play a major hydrological function, regulating both water flow and water availability. They attract wildlife from the surrounding area, and themselves contain a large biological diversity, particularly at the microbial level. Many of the lakes in the Andes of Ecuador are of historical, cultural, and archeological importance. Many pre-Inca people settled around lakes, and some of the lakes are still considered sacred by native people of the Andes, with the god *Catequil* as a limnic inhabitant.

Even though the lakes are in protected areas, they are under continuous threat from an expanding human population that may divert the water for irrigation or other uses, or may contaminate it with agricultural runoff or other pollutants. It is essential that all regulations and management efforts to protect the national parks and reserves of Ecuador consider lakes as an integral part of the landscape worth preserving for future generations to enjoy.

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