



THE LAKE TITICACA BINATIONAL OBSERVATORY (OBLT) ON UMR BOREA WEB PAGE

by Xavier LAZZARO (IRD/BOREA) – 13/10/2016

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<http://borea.mnhn.fr/en/OBLT-uk>

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Lake Titicaca characteristics

Located on the Altiplano, between the two Andean Cordilleras (Oriental and Occidental), Lake Titicaca is a transboundary (Peru-Bolivia) tropical (16° S, 69° W) mountain lake that has unique characteristics worldwide:

- The highest freshwater lake in South America: 893 km^3 , 8.300 km^2 , $170 \text{ km} \times 60 \text{ km}$
- The Highest of the World Great Lakes (3.810 m a.s.l.)

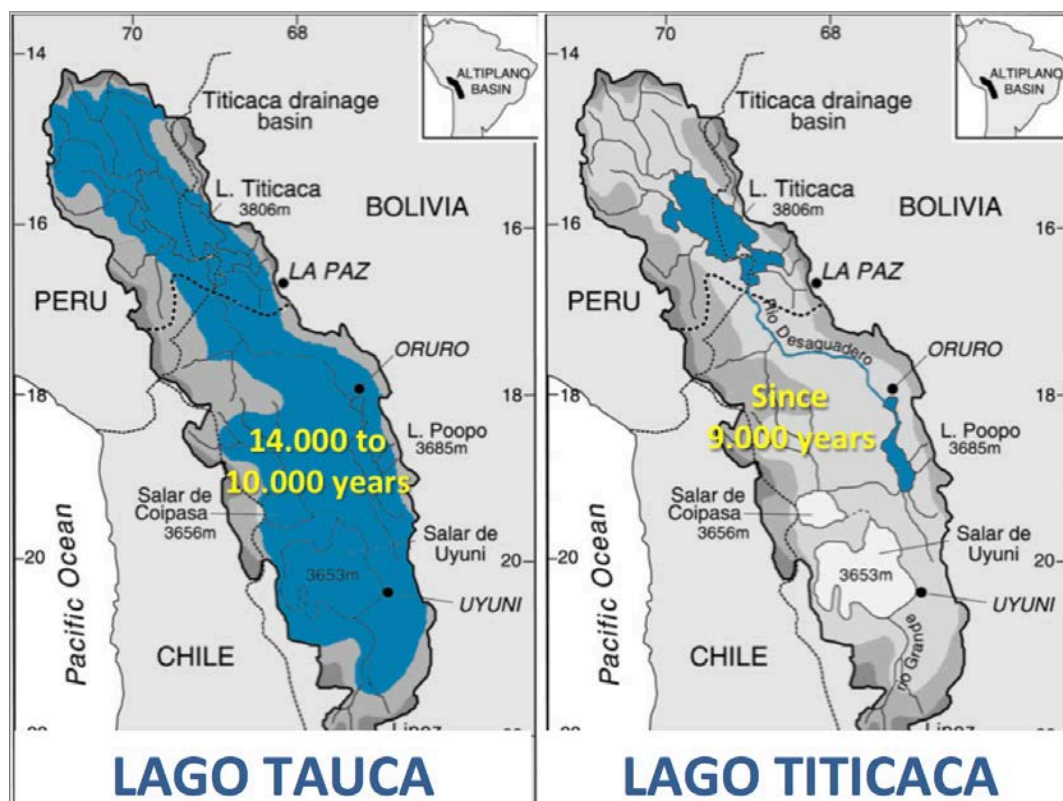


Fig. 1 – Lake Tauca (from 14,000 to 10,000 years) and Lake Titicaca (since 9,000 years)

- One of the 20 oldest lakes, formed as known today about 9,000 years ago following a succession of lakes after a 3-million year long geological history and quick climatic changes

- Comprising the deep (mean 180 m, maximum 280 m) Lago Mayor (Major Lake) and the shallow (9 m, maximum 40 m) Lago Menor (Minor Lake), connected by the Tiquina Strait (900-m wide, 40-m depth)

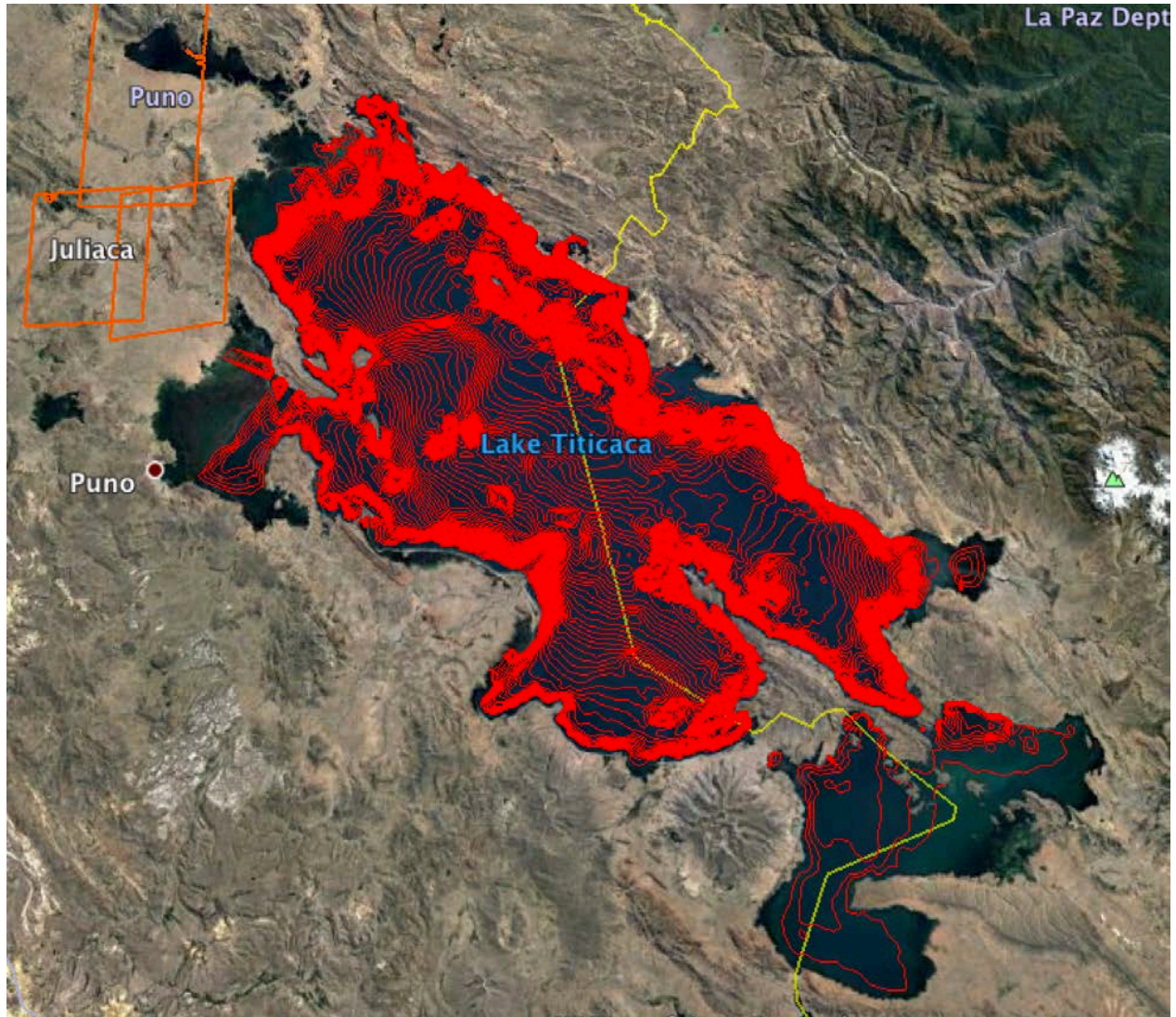


Fig. 2 – Bathymetric map of Lake Titicaca. Interval of 5 m between isolines. The yellow line indicates the border between Peru (west) and Bolivia (east). The deepest area (280 m) is located near the island Soto in the Major Lake.

- *Endorheic* lake: 95% of water loss due to evaporation, against 5% from its outflow, the Desaguadero river that feeds the hypersaline Lake Poopó at the Southern end of Altiplano, being progressively dried out due to the excessive consumption of water for irrigation and mines
- Its essential contribution to the region microclimate allows the development of endemic animal and vegetal species, and ideal conditions for agriculture and farming

- These exceptional conditions lead to the development of several major prehispanic Andean civilizations (Pukara, Tiwanaku, Colla Lupaka and Inca). Currently, more than 2.5-million inhabitants directly or indirectly depend on its natural resources
- Its shoreline populations, under an extreme state of poverty (84% in Peru, and 98% in Bolivia), are exposed to the ongoing global change risks. The uncertainty is large because the previsions of the global models cannot be applied because of the extreme relief of the Andes and the complex climatic interactions (El Niño, La Niña, ITCZ)
- Paradoxically, the ecological and biogeochemical functioning of Lake Titicaca remain little studied. Since the research of IRD (ex- ORSTOM) in the 1970-1980s (Dejoux & Ittis' 1991 synthesis), no coordinated long-term monitoring program between Peruvian and Bolivian institutions has been implemented to document the effects of neither anthropogenic pressures nor the deregulated climate
- Lake Titicaca is a 'hotspot' of diversity and endemism, yet certain species are already at risk of extinction, such as the giant frog *Telmatobius culeus*, the fishes of the *Orestias* genus, and the grebe micropteer (zampullín) *Rollandia microptera*, among others
- Today, following the contamination from mines, industries and urban areas, the estuaries of the Ramis and Suhez rivers, as well as the Bays of Puno, Copacabana, and more particularly Cohana, the outflow of the El Alto city (1.2-million inhabitants), are contaminated and/or eutrophicated, as demonstrated by the recent IRD-IUCN synthesis (Pouilly et al. 2014)

Map of Lake Titicaca and monitoring stations

<https://www.google.fr/maps/place/Lac+Titicaca/@-15.9129113,-70.4260877,8z/data=!3m1!4b1!4m5!3m4!1s0x915d9b22f6af7c75:0xf682724d4df71dc!8m2!3d-15.9254!4d-69.3354?hl=fr>

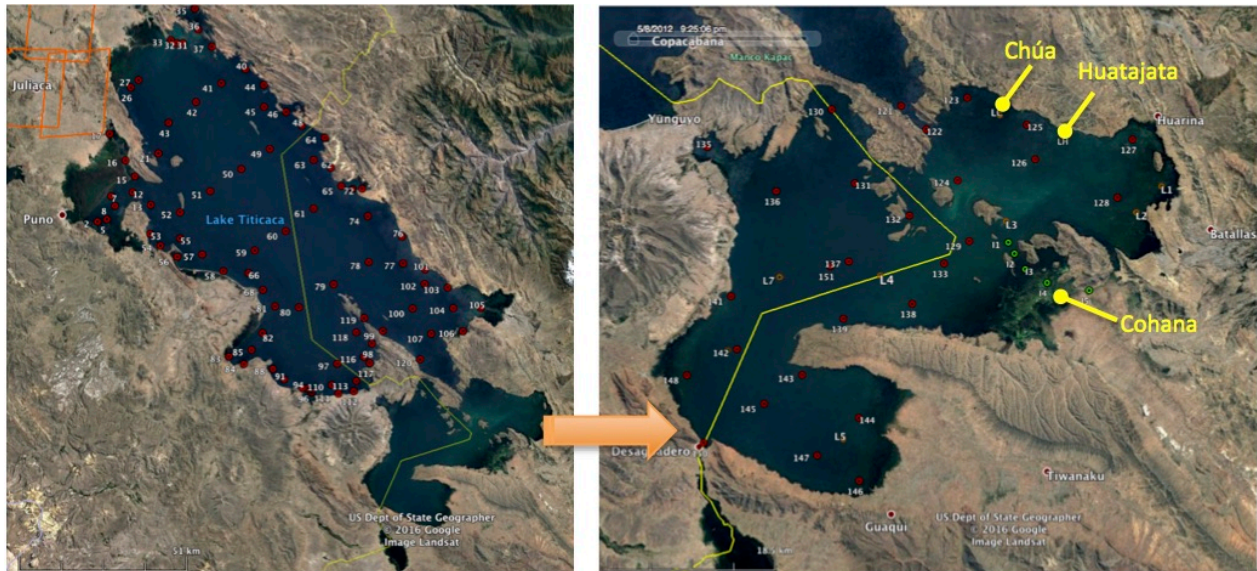


Fig. 3 – Location map of the main monitoring stations in Lake Titicaca: Major Lake (left side) and Minor Lake (right side).

Why to implement the OBLT?

Globally, Lake Titicaca has never been monitored continuously on the long-term so to predict its evolution or to prevent, or at least anticipate, the undesirable extreme events, such as *blooms*, fish mortality, biodiversity loss, drop of fisheries productivity. This is a paradox since Lake Titicaca rare characteristics related to the peculiar climatic conditions of the Altiplano make it a unique sentinel lake of the region global changes.

As such, compared to conditions at sea level, in Lake Titicaca, the dissolved oxygen concentration in the water is decreased of 30%, while the solar global and ultraviolet irradiance is increased by > 30%. The intense solar radiation induces a strong superficial inhibition of the phytoplankton photosynthesis, a deep chlorophyll-*a* maximum concentration, and prevents superficial waters to freeze in winter. The wide daily thermal amplitude of the air > 20 °C, with a water temperature ≥ 5 °C above the air temperature, generates (starting between 3 and 5 p.m.) a thermal daily wind regime responsible for the water column well mixing in the shallow regions.

Current knowledge is lacking on the lake trophic functioning and on the increasing amplitude of the effects of climate changes (glaciers regression in the Andes Cordillera, seasonal disruption) and anthropogenic changes (multiple contamination, eutrophication, overfishing), amplified since the last two decades.

The extreme biodiversity and endemism of Lake Titicaca has attracted the interest of the most famous naturalists, such as Alcide d'Orbigny (1826-1833), Alexander Agassiz (1876), Maurice Neveu-Lemaire (1906) and The Percy-Sladen-Trust Expedition de Cary Gilson (1937), prior to the multidisciplinary works of IRD (ex- ORSTOM) in the 1970-1990s. However, the Bolivian part of Minor Lake has been abandoned during the last two decades (see the video of Lazzaro & Aviles 2014) for the scientific research, essentially performed by UMSA, whereas in Peru since 2006

IMARPE has maintained annual expeditions over both two lakes. This abandon by Bolivian public authorities unfortunately has coincided with the uncontrolled exponential expansion of the urban area of El Alto-Viacha, the suburb of La Paz capital, initiated about 15 years ago.

Currently, the shallowest regions, the most vulnerable, such as Puno Bay in the Major Lake (Peru) and above all Cohana Bay in the Minor Lake (Bolivia), are exposed to eutrophication accelerated by the development of the cities of Puno-Juliaca and El Alto-Viacha, respectively. Even if the deep central pelagic zone of the Major Lake and most part of the Minor Lake have not lost their spectacular beauty and magic, and seem always as transparent, the contamination being most often invisible, the littoral and shallow zones are the most vulnerable and impacted. Thus, in March-April 2015, the first large phytoplankton bloom comprised of *Carteria* sp., a unicellular flagellated harmless Chlorophyta micro-algae, propagated in most part of the Minor Lake shallower than 5 m, killing massively the native fish species (*Orestias* and *Trichomycterus*) and the giant frogs (*Telmatobius culeus*) already classified as in 'danger of extinction', in addition to aquatic birds. This mortality result from the anoxic conditions caused by the decomposition of the excessive load of organic matter and the release of H₂S, a powerful neurotoxic, generated from the mineralization by sulfate-reducing bacteria (Achá & Lazzaro 2015, Lazzaro & Achá 2015). The magnitude of this extreme event convinced the decision maker politicians that the loading capacity of the Minor Lake had been reached, the role of biological filter played by the aquatic macrophyte beds of Cohana Bay being insufficient.

The absence of water treatment plants, in Bolivia as well as in Peru, makes unmanageable the diffuse and punctual loads of nutrients, organic matter and contaminants coming from the untreated releases from agriculture (pesticides, artificial fertilizers), and farming, as well as from domestic, industrial and mining origin, as consequences of the demographic growth of shoreline populations and unplanned urban centers. Globally in the binational watershed, the population today reaches > 3 million inhabitants. This contamination by the activities of the shoreline villages, but above all of the 1.2-million inhabitants of El Alto (originally a suburb of La Paz, the Bolivian capital) towards Cohana Bay, contributes mainly to the organic eutrophication and degradation associated to the littoral zones. The punctual actions, essentially limited to harvesting *Lemna* sp., the floating macrophytes that invade the water surface, in particular in Puno Bay, produce only very mixed results (Northcote 1989, Beltrán et al. 2015).



Fig. 4- Course of the multiple contamination from the city of El Alto to Minor Lake: Milluni mines, El Alto, Puchucollo water treatment plant, Viacha cement plant, along the river Palina, then downstream river Katari towards Cohana Bay.

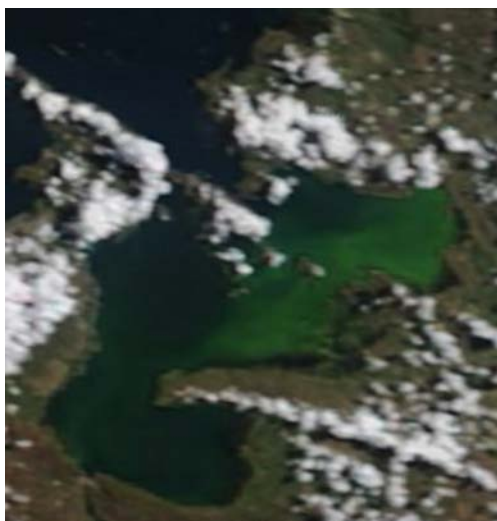


Fig. 5 – Evolution of the *Carteria sp.* Bloom (green zone) in Minor Lake after its paroxysm on April 14, 2015. MODIS images, Terra/ Aqua satellite, in natural colors.

The 1941-1942 introduction of exotic predatory species, such as the Californian rainbow trout (*Oncorhynchus mykiss*) and the Argentinean pejerrey (*Basilichthys bonariensis*), did not enhance as expected the productivity of small-scale fisheries. To the contrary, this introduction would have negatively impacted the native carachi (*Orestias spp.*) populations and even eradicated the

only piscivorous native *O. cuvieri* (Loubens & Osorio 1988, Loubens 1989, Ibañez et al. 2014). However, in the Bolivian part of Minor Lake, the harmful impact of indiscriminate fishing cannot be ignored.

During the 1st International Symposium of Lake Titicaca (Puno, 2011), the research on eutrophication and restoration actions coordinated between the Bolivian and Peruvian institutions were notoriously missing.

In response to this situation, from 2012 to 2015 several partner projects were implemented between various UMR of IRD (GET, BOREA, LTHE, ISTERRE, PRODIG), CNRS (IPREM), and IE/UMSA (coordinator D. Achá), so to better understand the ecological, trophic, and biogeochemical current functioning of Minor Lake, such as IDH EUTITICACA, TITICACA SENSORS, ANR LA PACHAMAMA, and IDH LATICO2, between others (see below).

Facing the degradation of the Bolivian northeastern part of Minor Lake, and the absence of mobilization of the relevant institutions, X. Lazzaro has prioritized the research on eutrophication processes (which also are the responses to global changes), and developed binational monitoring strategies. Thus, as scientific organizer of the 2nd International Symposium on Lake Titicaca (Puno, 2013), in the context of a dedicated workshop X. LAZZARO proposed to create the Binational Observatory of Lake Titicaca (OBLT), unanimously approved by the representatives of the main relevant technical and scientific institutions. In order to clarify the relevant actions, X. Lazzaro has imagined and organized the 1st International Conference – Observatories of Transboundary Lakes (La Paz, 2014). Its goal was to reinforce the scientific binational collaborations and the institutional governance so the implement a continuous long-term system of monitoring of water quality and management of hydrobiological resources coordinated between the two countries, based on reliable and updated knowledge. In order to internationally reveal this initiative, X. Lazzaro coordinated a *Side-event: Challenges of change for Lake Titicaca binational watershed (Peru-Bolivia)*, in the context of the COP20 (Lima, 2014). This drew the attention of the scientific community, the major international donors and the public attention on the accelerated eutrophication of certain parts of the Lake. ALT, IRD, and UMSA, and more institutions sponsored these events.

To enroll in the French strategy for environmental research infrastructures defined by AllEnvi – Alliance for the Environment (Food, Climate, Water, and Territories), X. Lazzaro presented to the DER Department of IRD a proposition to create the Binational Observatory of Lake Titicaca (OBLT). In July 2015, DER positively evaluated the OBLT, institutionally supporting this device now integrated within the Director Plan of ALT, and assigning it the IRD Label "South", yet still without any financial support.

The research projects at the origin of OBLT

- IDH EUTITICACA: eutrophication of Cohana Bay, with the search of bioindicators such as H₂S anticipating the appearance of symptoms represented by the spreading of phytoplankton blooms, and the expansion of (floating) aquatic macrophytes beds (Achá et al. 2013).

- TITICACA SENSORS: High frequency automatic monitoring (15-min, multiparameter and chlorophyll-*a* fluorescence probes) of the Huatajata shallow station (5 m), and routinely (20-day, probes and phyto- and zooplankton sampling) of the Huatajata and Chúa (40 m) (point et al. 2013).
- ANR LA PACHAMAMA: biotic/abiotic mechanisms of methylation/demethylation of Hg in the water column and at the interfaces (periphyton, phytobenthos, phytoplankton) (Amouroux et al. 2012).
- IDH LATICO2: carbon balance of Minor Lake (Achá et al. 2014).

OBLT objectives

- To develop research on the ecological and biogeochemical functioning of Lake Titicaca, in relation to global changes
- To implement an automatic-routinely monitoring in order to follow the environmental evolution and to check the effectiveness of the measures taken
- To generate quality databases, updated and validated, for the research of scientists, the decision making of politicians, at the service of the civil society (information, education, improvement of living conditions)
- To Identify the sources and sites of contamination, their effects on water quality, water balances, hydro-biological resources, and human activities
- To anticipate extreme events and to control eutrophication induced by climate and anthropogenic changes
- To design and test bio-restoration approaches using ecological engineering
- To become a model of monitoring, management, and governance for the lacustrine transboundary ecosystems

The operational structure of OBLT

The first step to implement the OBLT is to capitalize on scientific and technical knowledge acquired on Lake Titicaca during the last three decades. In addition to the scientific publications, this step is based on the digitizing to the pdf format of the last paper copies of about **300 historical institutional reports** before they could not be found anymore, over an agreement between IRD and IUCN that resulted into the synthesis book of Pouilly et al. (2014). The numerical content of these reports will progressively be integrated by IIGEO/UMSA into the databases made available in its GEOVISOR (see below).

The second step was to make operational the **university geographic portal GEOVISOR IIGEO**, which is a **Spatial Data Infrastructure (SDI)**:

- The **GEOVISOR IIGEO** (www.geovisorumsa.com) is dedicated to the spatial and historical analysis of the results of the multidisciplinary research conducted in collaboration

between UMSA and several UMR of IRD, among which BOREA, PRODIG, GET, ISTERRE and LEMAR. The IRD (ex- ORSTOM) framework agreement is more than four decades old.

Javier Nuñez, IIGEO Director, and X. Lazzaro submitted the project "Development of Web tools for the stability, control, and production of analysis and content for the three geographic viewfinders of the university portal GEOVISOR IIGEO of UMSA, La Paz, Bolivia" which was funded in 2015 by the SPIRAL program of IRD. For this project, a consortium was created between IIGEO/UMSA, ADSIB, and the GEOBOLIVIA project, ensuring the validation of the presented information, data and images, as well as the standards compliance (including the exclusive use of free software license, as such as GeOrchestra) established by the national authority constituted by ADSIB and GEOBOLIVIA, both grouped into the Vice-Presidency of the Plurinational State of Bolivia. The GEOVISOR IIGEO has become the academic platform of national and regional reference on Lake Titicaca in connection with its watershed, including the contamination from El Alto to Minor Lake (see below the video tutorial).

The third step initiated in 2016 seeks to develop **different observations and analyzes 'modules'** (see the operational flowchart of OBLT):

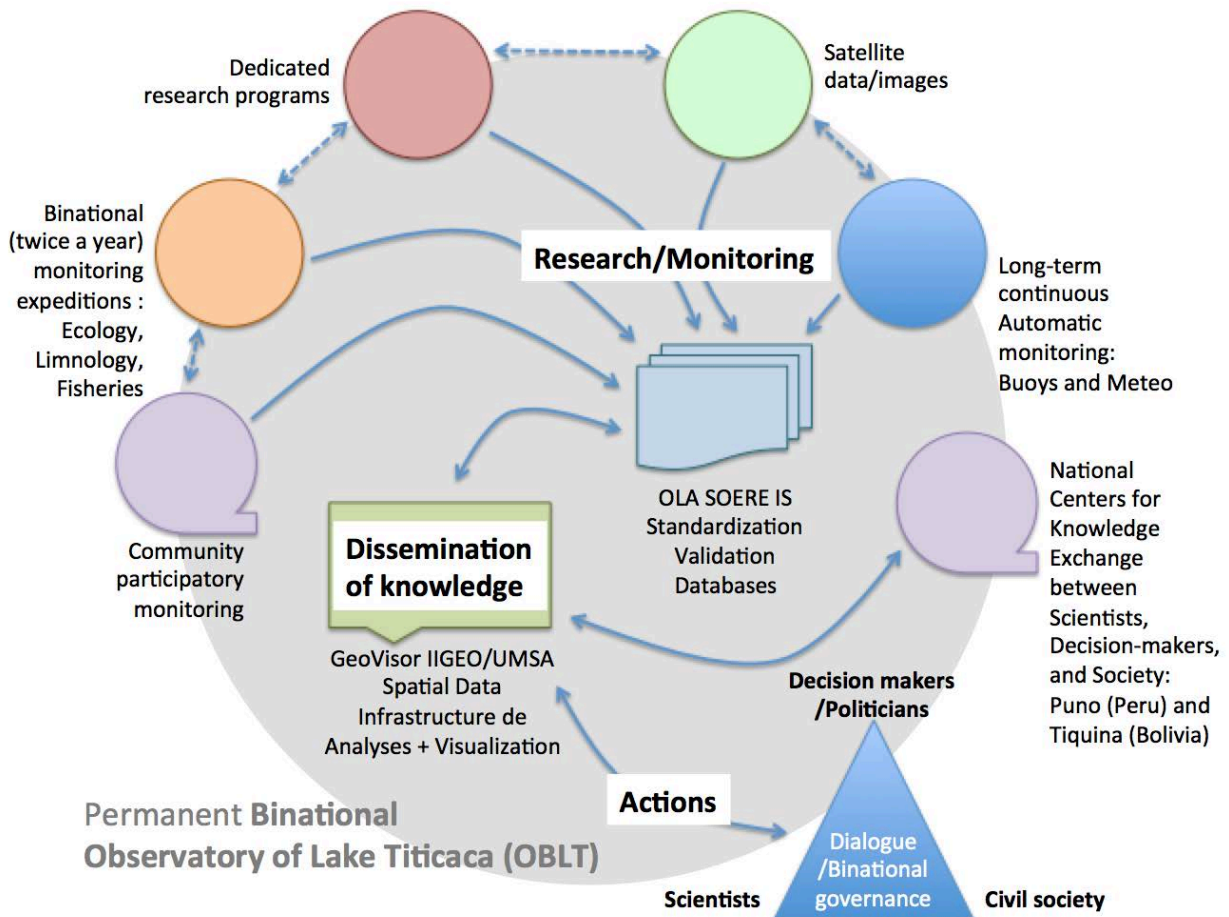


Fig. 6 – Operational flowchart of OBLT.

- The **dedicated research programs**: they are all the research programs and projects implemented by the various scientific and technical institutions of the two countries, especially the universities, on subjects concerning the hydrological, ecological, limnological, biogeochemical and climate functioning of Lake Titicaca, in relation to the impacts of socio-economic and cultural activities (agriculture, livestock, aquaculture, industry, mining, urbanization, tourism...). Some of this research are conducted in cooperation with French UMR of IRD (BOREA, GET, LTHE, ISTERRE, PRODIG) and CNRS (IPREM), but also with Swiss (SDC), Swedish (SIDA), Belgian (underwater archeology, ULB) and Spanish (AECID, UB, UVEG) cooperations, among others.
- The **binational (twice a year) monitoring expeditions** (ecology, limnology, fish biomass): such as the **Expeditions for the assessment of limnological and ecological characteristics** within the **ECERP program** (Scientific Expeditions of Fish Resources Assessment) of ALT and its institutional scientific partners of Peru (IMARPE, PELT) and Bolivia (IE/UMSA, VRHR/MMAyA, IPD PACU/MDRyT, UOB), and IRD. The team of young scientists associated with IE/UMSA has already participated in three binational expeditions, in collaboration with their Peruvian counterparts (IMARPE, PELT), within the Major and Minor Lakes from 14/07 to 09/08/15, and in Minor Lake from 21/11 to 05/12/15 and 02-15/08/16. They currently constitute the Bolivian national team funded by VRHR/MMAyA and IPD PACU/MDRyT: William Gustavo LANZA AGUILAR, phytoplankton (wilanz66@gmail.com); Magda Pamela ALCOREZA ORTIZ, phytoplankton (diatomeadiva@gmail.com); Ana Julia FLORES CHAMBI, zooplankton (anaflores94@hotmail.com); Adilen FERNÁNDEZ PAZ, benthic macroinvertebrates (adilenfp@hotmail.com); Pablo FERNÁNDEZ, H₂S as bioindicator of eutrophication (pablo86fernandez@hotmail.com); Erick Zender LOAYZA TORRICO, hydroacoustic and experimental fishing (erickz.loayzatorrico@gmail.com); under the coordination of Carla IBANEZ LUNA for ichthyology and fisheries (carla.lunallena@gmail.com) and X. LAZZARO for limnology and aquatic probes.
- **Satellite data and images**: This is a scientific and technological challenge for OBLT. Based on the use of remote sensing (LANDSAT8, MODIS, and SENTINEL2,3 satellites) for the monitoring of water quality parameters, it aims to develop tools (products) which, based on a calibration of field measurements, will estimate particularly the concentrations of phytoplankton chlorophyll-*a* (the main photosynthetic pigment) across the entire lake, but also the distribution, composition and biomass of aquatic macrophytes (floating: e.g. *Lemna*, *Azolla*; emerged: *Totora*; benthic: *Chara*, *Potamogeton*) in shallow areas of Minor Lake. Three teams contribute to this module at different levels: (a) the Functional Remote Sensing Unit of IMARPE, Lima, Peru (German Roberto VELAOCHAGA CARPIO, gvelaochaga@imarpe.gob.pe & Han XU, hxu@imarpe.gob.pe); (b) the CES Colors of continental waters (host Jean-Michel Martinez, IRD/GET, SORE HYBAM, jean-michel.martinez@ird.fr); (c) the Laboratory for Earth Observation of the University of Valencia, Spain (UVEG/LEO), for the Master of Remote Sensing of Marcela PEREIRA SANDOVAL (mps2806@hotmail.com) advised by Jesús DELEGIDO GOMEZ (Jesus.Delegido@uv.es) and Antonio RUIZ-VERDÚ (antonio.ruiz@uv.es) through a

collaboration with the Remote Sensing Laboratory of IIGEO/UMSA (Director Javier NUÑEZ VILLALBA).

- **Long-term automatic monitoring**, using buoys equipped with a weather station: we plan to install a network of automatic limno-meteorological buoys equipped with sensors (multiparameter, fluorescence) mounted on vertical profilers (for depths > 10 m), which will be deployed on 'critical' stations in the Peruvian and Bolivian parts of Major Lake and Minor Lake. Given the high cost of each unit and the technical feasibility/reliability to be checked, a pilot project will be developed starting in 2017 (see below).
- The **PILOT PROJECT "PERMANENT OBSERVATORY"**: The United Nations Program for Integrated Water Resources Management of the Titicaca System (IWRM UNDP-GEF) is financing this project during 2017-2020. Its model is the TITICACA SENSORS high-frequency monitoring project. It represents a full-scale feasibility test of the automatic buoys strategy (see above). It is lead by D. Achá CORDERO (UMSA/IE), Javier Nuñez VILLALBA (UMSA/IIGEO), Stéphane Guédron (IRD/ISTERRE, heavy metal contamination, paleolimnology stephane.guedron@ujf-grenoble.fr), Celine DUWIG (IRD/LTHE, coordinator of the Katari basin monitoring network for modeling contaminant transport, celine.duwig@ujf-grenoble.fr), X. LAZZARO (IRD/BOREA) and Alexis GROLEAU (IPGP/LGE, biogeochemistry, carbon balance, groleau@ipgp.fr). It consolidates a test program of high frequency continuous automatic environmental monitoring focused on Minor Lake eutrophication resulting from the Katari basin contamination by the city of El Alto through Cohana Bay. It must be accessible to key actors and technicians to develop an expertise in characterizing the ecological/limnological, forecasting/anticipating evolution of undesirable extreme events.
- The **OLA SOERE IS**: The information system (IS) of the LAkes Observatory (OLA) is led by Isabelle DOMAIZON (Head of SOERE, isabelle.domaizon@thonon.inra.fr) and Ghislaine MONET (SI Administrator, ghislaine.monet@thonon.inra.fr) INRA/CARRTEL of Thonon-les-bains (<https://si-ola.inra.fr/>). The inclusion of Lake Titicaca into the SOERE OLA was adopted at its general meeting in March 2016. The SOERE gather a dozen laboratories around an assessment approach of state-of-the-art, operation and long-term ecological trajectories of lake ecosystems. The observed lakes are historically large peripheral Alpine lakes (Geneva, Annecy, Bourget, and Aiguebelette), and Massif Central lakes (Aydut, Pavin), a Jura lake (Remoray), mountain lakes in the Alps, and an urban lake (Créteil). SOERE information is an important scientific heritage for studying the long-term evolution of the lake state and biodiversity, and the human and climate change impacts. The OLA databases (physico-chemistry, phytoplankton, zooplankton, fish) combine the *in situ* sensor data and analyses obtained from samples in the laboratory. A user agreement manages the rights/privileges based on the user profile and access rights defined by the authors. The drop of the Titicaca data onto the OLA IS requires previous formatting to the defined standard, making data compatible with those of other lakes. It guarantees the quality of the backup and access security. The IS represents an essential filter before displaying the information through the GEOVISOR IIGEO. It remains to put the projects database (see above) in IS format.

- The **Community participatory monitoring** of water quality: Bolivian ministries (MMAyA, MDRyT), the Universidad Indígena Aymara Boliviana "Tupak Katari" (UNIBOL A-T/K, <http://www.utupakkatari.edu.bo>) and the private initiative of IMTD – Institute for Multi-Track Diplomacy (Director for Latin America, Adam R. Zemans azemans@imtd.org), modeled on the volunteer program on the lakes of Maine in USA (VLMP), will take the local coordination. Simple daily measures may be implemented, such as of dissolved oxygen, transparency (Secchi disk), temperature at representative impacted vs. reference sites. This will expand the network of observations and raise awareness among local residents and the general public about the importance of monitoring for ecosystem conservation.
- The **National Centers for Knowledge Exchange**: For scientists, policy makers and civil society to share their knowledge about Lake Titicaca, socialize projects/programs, compare opinions, and combine traditional knowledge and scientific approaches, it is necessary to have at least two reference centers, one per country, where organizing workshops and having access to information. This will raise the level of education, understanding, and thus make each actor category more responsible and proactive. The Puno Center (Peru), with the presence of IMARPE, PELT, ALT, and ANA, and the Tiquina Center (Bolivia), with the Trout Farming Center of IPD PACU (MDRyT) near UNIBOL A-T/K, all two located on the lakeshore, are appropriate candidates. La Paz, where coexist UMSA, MMAyA, and IPD PACU, and many other institutions, is another good option, but far from the Lake and the local populations.
- The PILOT PROJECT "RESTORATION USING ECOLOGICAL ENGINEERING" (IWRM UNDP-GEF): This project tests the efficiency of phytoremediation by aquatic macrophytes as a complement to the conventional sanitary wastewater approach using sewage treatment plants. It is coordinated by Susana CISNEROS ARZA (UMSA/IE-CIDES sussycisnerosarza@gmail.com), Susana M. DEL GRANADO (UMSA/IE-INASP, smdelgra@gmail.com), Cristina Ruiz (UMSA/IE-FCPN, cristinaruiz547@gmail.com), Darío Achá (UMSA/IE), Jorge QUEZADA (UMSA/IBMB-FCPN, jorgequezada@yahoo.com), Geraldine SARRET (IRD/ISTERRE, geraldine.sarret@univ-grenoble-alpes.fr) Stéphane Guédron (IRD/ISTERRE), David POINT (IRD/GET, david.point@ird.fr), Celine DUWIG (IRD/LTHE) and X. LAZZARO (IRD/ OREA) for the characterization of biogeochemical and ecological improvements of the Minor Lake water column. This project will determine the capacity of heavy metal (Hg, MeHg, Zn, Cu) bioaccumulation by the tissues of Totora (*Schoenoplectus californicus* spp.) or the groups of colonizing algae (periphyton). It will evaluate the H₂S production of the superficial sediment of three zones. It will serve to optimize the design and construction of artificial wetlands and handling of natural wetlands to make them more efficient and sustainable. It will help to develop water treatment systems appropriate to ecosystems and economic conditions of the Bolivian Altiplano.

Today, the network of monitoring stations of Minor Lake, defined by the binational program of expeditions, coupled with the network of monitoring stations of the Katari River Basin (path of contamination from El Alto to the Cohana Bay, within the project 'Critical Zone of the Bolivian

Altiplano' of the consortium VRHR/MMAyA-IIQ/UMSA-LTHE/ISTERRE/IRD-SENAMHI-BO) represent the **Master Plan for the Management and Restoration of the Katari River Basin** managed by the Bolivian government (VRHR/MMAyA). Similarly the Binational Observatory of Lake Titicaca is part of the **ALT Master Plan**.

Some references

1st International Symposium of Lake Titicaca – Challenges for an ecosystem-based management, Puno, 19-21 October 2011, 60 participants:

http://rnia.produce.gob.pe/index.php?option=com_content&view=article&id=118:simposio-internacional-el-estado-del-lago-titicaca&catid=7:eventos-y-actividades&Itemid=75

2nd International Symposium of Lake Titicaca, scientific coordinator X. Lazzaro (IRD), Puno, 7-9 March 2013, 500 participants: www.simposiotiticaca.org

1st International Conference – Observatories of Transboundary Lakes, developer and scientific coordinator X. Lazzaro, La Paz, 16-18 June 2014, 150 participants:

www.lagossinfronteras.org , www.pieb.com.bo/lagos.php

Side-event: Challenges of climate change for Lake Titicaca binational watershed (Peru-Bolivia), COP20, Lima, Peru, 12 December 2014:

www.youtube.com/watch?feature=player_detailpage&v=Vy5QLxoSN-8

<http://climatechange.mtnforum.org/sites/default/files/1COP20%20Titicaca%20%26%20Video.pdf>

Achá Cordero D., Alvarez Aliaga M.T., Nuñez Villalba J., Point D. & Lazzaro X. (2013) Enfoque socio-ambiental de la eutrofización, los causantes y los potenciales de biorremediación en el continuo entre el Lago Titicaca y la Ciudad de El Alto. Proyecto IDH EUTITICACA, UMSA, IRD, 2013-2014, 32 p.

Achá D. & Lazzaro X. (2015) Comunicado: Análisis y recomendaciones acerca de la muerte de peces, anfibios y aves ocurrida en la zona Norte del Lago Menor durante el mes de Abril 2015, IRD-Bolivia: http://www.bolivia.ird.fr/toda-la-actualidad/la-actualidad/comunicado-analisis-y-recomendaciones-acerca-de-la-muerte-de-peces-anfibios-y-aves-ocurrida-en-la-zona-norte-del-lago-menor-durante-el-mes-de-abril-2015#eztoc3326304_1

Achá Cordero D., Nuñez Villalba J., Point D., Lazzaro X. & Groleau A. (2013) Estudio de la biogeodinámica del dióxido de carbono y el oxígeno en el contexto de cambio climático en la cuenca menor del Lago Titicaca. Proyecto LATICO2 : Dinámica del CO₂ en el Lago Titicaca. IDH 2013-2014, IE-UMSA, IRD/GET-BOREA, IPGP, 18 p.

Amouroux D. et al. (2012) Lacs de l'Altiplano (Bolivie) : exploration in situ des Processus (A)biotiques contrôlant la biogéochimie Aquatique du Mercure A l'échelle Moléculaire et isotopique. ANR LA PACHAMAMA 2014-2016, CNRS/IPREM, IRD/GET-BOREA-LEMAR, IE/UMSA, 40 p.

Arfi R. (2015) Avis de l'Institut de Recherche pour le Développement sur l'observatoire OBLT animé par X. Lazzaro. 15 juillet 2015. 1 p.

- Beltrán Farfán D.F., Palomino Calli R.P., Moreno Terrazas E.G., Peralta C.G. & Montesinos-Tubée D.B. (2015) Calidad de agua de la bahía interior de Puno, lago Titicaca durante el verano del 2011. *Revista peruana de biología* 22: 335 – 340.
- Dejoux C. & Iltis A. (Eds.) (1991) *Lake Titicaca – A synthesis of limnological knowledge*. Kluwer Academic Publishers. *Monographiae Biologicae*, Vol. 68, 626 p.
- Ibanez Luna C., Hugueny B., Esquer Garrigos Y., Zepita C. & Gutierrez R. (2014) Biodiversidad ictica en el Lago Titicaca. In : Pouilly M., Lazzaro X. Point D. & Aguirre M. (Eds.) *Linea base de conocimientos sobre los recursos hidrológicos e hidrobiológicos en el sistema TDPS con enfoque en la cuenca del Lago Titicaca*. UICN – IRD: 135-153. ISBN 9789997441843.
- Jiménez-Muñoz J.C., Llinares Llorens M., Ruíz-Verdú A., Tenjo Gil C., Delegido Gomez J., Sobrino Rodriguez J.A. & Moreno Méndez J. (2015) Propiedades ópticas y térmicas del Lago Titicaca a partir de imágenes Landsat-8 y MODIS. XVII SBSR Brazilian Symposium on Remote Sensing. 25-29 April. Joao Pessoa, Brazil.
- Lanza Aguilar W.G., Loayza Torrico E.Z., Fernández Paz L.A., Alcoreza Ortiz M.P., Flores Chambi A.J., Fernández P., Ibañez Luna C., La Cruz Aparco L., Morales S. & Lazzaro X. (2016) Expedición Científica Binacional de Evaluación de las Características Limnológicas y Ecológicas del Lago Menor del Titicaca. Informe Técnico de los equipos Boliviano (IE/UMSA), Peruano (IMARPE, PELT) y Francés (IRD/BOREA) detallando el Plan de Trabajo de la Expedición. Programa ECERP – Evaluación Científica de Recursos Pesqueros, 02-15 de Agosto de 2016, 30 p.
- Lazzaro X., Alcoreza P., Lanza Aguilar G., Flores Chambi A.J., Fernández P., Fernández Paz A., Zepita Quispe C., Loayza Torrico E. & Ibañez Luna C. (2016) Expedición binacional de evaluación de recursos pesqueros y condiciones limnológicas del Lago Titicaca – CR.1507-08 – Jul-Ago 2015 – Informe Técnico del Equipo Boliviano. IE/UMSA & BOREA/IRD, versión final, 01/07/2016, 95 p.
- Lazzaro X. (2015a) Informe técnico sobre el crucero binacional en el Lago Menor del Titicaca por el equipo Boliviano-Francés. 21 nov.-05 dic. 2015. 11 p.
- Lazzaro X. (2015b) Observatoire Binational du Lac Titicaca / OBLT (Observatorio Binacional del Lago Titicaca). Dossier IRD à remplir pour le bilan et la labellisation 2015-2019 d'un Service National d'Observation. 87 p.
- Lazzaro X. (2015c) El Lago Menor verde, evento meteorológico extremo o cambio climático en marcha? IRD-Bolivia: <http://www.bolivia.ird.fr/toda-la-actualidad/la-actualidad/el-lago-menor-verde-evento-meteorologico-extremo-o-cambio-climatico-en-marcha>
- Loubens G. (1989) VI.5b Especies introducidas - 1. *Salmo gairdneri (trucha arco iris)*. *Rev. Hydrobiol. trop.*, 22 : 157-177.
- Loubens G. & Osorio F. (1988) Observations sur les poissons de la partie bolivienne du lac Titicaca - III. *Basilichthys bonariensis* (Valenciennes, 1835) (Pisces, Atherinidae). *Rev. Hydrobiol. trop.* 21 : 153-177.

- Northcote T., Morales P., Levy D. & Greaven M. (Eds.) (1989) Pollution in Lake Titicaca, Peru: Training, Research and Management. West-water Research Center, Univ. of British Columbia, Canada.
- Peireira Sandoval M. (2015) Estudio multitemporal mediante teledetección de la eutrofización de la Bahía de Cohana, Lago Titicaca – Bolivia. Máster Oficial de Teledetección, Departamento de Física de la Tierra y Termodinámica, Universidad de Valencia, Valencia, España. Director: Jesús Delegido Gómez ; collaboration avec X. Lazzaro pour les vérités terrain 49 p.
- Pereira M.A., Tenjo C., Ruíz-Verdú A., Lazzaro X., Delegido J. & Moreno J. (2016) Multitemporal remote sensing study of eutrophication of Cohana Bay, Lake Titicaca (Bolivia). Submitted to Limnetica.
- Point D., Lazzaro X. & Groleau A. (2013) *In situ* biogeochemical and ecological sensing of Lake Titicaca. TITICACA SENSORS : A joint IRD-IPGP research initiative 2013-2014. February 2013, IRD/GET-BOREA, IPGP, 17 p.
- Pouilly M., Lazzaro X., Point D. & Aguirre M. (2014) Línea base de conocimientos sobre los recursos hidrológicos en el sistema TDPS con enfoque en la cuenca del Lago Titicaca. IRD – UICN/Bridge, Quito, Ecuador. 320 p. : <http://www.bolivia.ird.fr/mediatheque/les-editions-et-co-editions-en-bolivia/linea-de-base-de-conocimientos-sobre-los-recursos-hidrologicos-e-hidrobiologicos-en-el-sistema-tdps-con-enfoque-en-la-cuenca-del-lago-titicaca> , <https://portals.iucn.org/library/sites/library/files/documents/2014-015.pdf>
- Ruiz-Verdú A., Jiménez J.C., Lazzaro X., Tenjo C., Delegido J., Pereira M., Sobrino J.A. & Moreno J. (2016) Comparison of MODIS and LANDSAT-8 retrievals of chlorophyll-a and water temperature over Lake Titicaca. IGARSS-IEEE International GeoScience and Remote Sensing Symposium, Beijing, China, 10-15 July 2016: http://borea.mnhn.fr/sites/default/files/pdfs/RuizVerdu_Titicaca_wq_fv_IGARSS%202016.pdf

The movies

- Video « **Testimony on climate change in the binational watershed of Lake Titicaca** » (12 min in Spanish), realized by Xavier Lazzaro & Simón Avilés, for the COP20 in Lima, December 2014: <https://www.youtube.com/watch?v=Vy5QLxoSN-8>
- Video « **Xavier Lazzaro – Don Ramon Catari, about Lake Titicaca** » (9min16, original version French – Spanish, French subtitles). Film presenting the work of IRD researchers in Bolivia, directed by Antoine Deprez Segobia, trainee, supervised by IRD Audiovisual Service, November 2015. A long history of friendship but also science binds the two men working for more than 3 decades on Lake Titicaca. Today, the balance of the Lake is threatened by the expansion of large cities. The signals are strong: few months ago the Lake changed color, became green. This double portrait of the lake and researchers who study it poses in the background the question of the impact of man on his environment:

<http://www.bolivie.ird.fr/mediatheque/selection-de-media/films-documentaires/films-de-presentation-du-travail-des-chercheurs-de-l-ird-en-bolivie>

- Documentary « **Titicaca – The fever of the Sacred Lake** » (20 min in Italian), coproduction ELANDRA-IRD, scientific advisors: Xavier Lazzaro & Jacques Gardon, filmmakers: Francesca Massa & Jacopo Tofani; presented (at the 53th min) during the program SCALA MERCALLI at TV RAI on Saturday 12 March 2016:
<http://www.rai.tv/dl/RaiTV/programmi/media/ContentItem-b747e353-58d3-471f-b999-228429b0a6a7.html>
- Video Tutorial of the Spatial Data Infrastructure, the GeoVisor IIGEO/UMSA « **Contamination from El Alto to Lake Titicaca** » (17 min in Spanish), directed by Javier Nuñez & Xavier Villaba Lazzaro, co-production IIGEO/UMSA-IRD/DSI, produced by Fermin Cruz (CONTRAPLANO), March 2016:
<https://www.youtube.com/watch?v=4JlkfRT1Lfo&feature=youtu.be>

The glossary

Bloom = proliferation of phytoplankton microalgae, often a single species, due to an excessive load of organic matter and nutrients, under strong photosynthetic sunlight radiation

Endorheic lake = whose waters are not connected to the sea, but are lost in the land and/or by evaporation

Acronyms of the institutions

- ADSIB – Agency for Development of the Society of Information in Bolivia:
www.adsib.gob.bo
- AECID – Technical Office of the Spanish Cooperation, in Bolivia:
<http://www.aecid.bo/portal/agua/>
- AllEnvi – Alliance for the Environment (Food, Climate, Water, Territories):
<http://www.allenvi.fr>
- ALT – Binational Authority of Lake Titicaca: <http://www.alt-perubolivia.org/web/>
- ASDI – Swedish Cooperation for Development:
<http://www.sida.se/English/About-us/Our-mission/>
- CES – Scientific Expertise Centers of THEIA (laboratories or groups of national laboratories conducting research and developing innovative methods of mobilization of satellite data on the "land surface" thematic):
<https://www.theia-land.com/en/presentation/centers-of-expertise-scientific-these>
- CES color of inland waters, host Jean-Michel Martinez (IRD/GET): https://www.theia-land.fr/sites/default/files/imce/theia/CES_couleur-eaux-continentales.pdf

- COSUDE – Swiss Agency for Development and Cooperation, in Bolivia: <https://www.dfae.admin.ch/countries/bolivia/es/home/representaciones/oficina-de-cooperación.html>
- DER – Department of Environment and Resources at IRD
- EFPU – Photobiology Station Playa Union, Chubut, Argentina: <http://www.efpu.org.ar>
- GEOBOLIVIA – spatial data infrastructure project of the Plurinational State of Bolivia: <http://geo.gob.bo>
- IWRM UNDP/GEF – Integrated Water Resources Management of the United Nations Development Program/Global Environment Fund: <https://info.undp.org/docs/pdc/Documents/BOL/PRODOC%20-%20IP%20TDPS.pdf>
- IE – Institute of Ecology at UMSA: <https://www.facebook.com/Institutedeecologiaumsa/>
- IIGEO – Research Institute of Geography at UMSA: <http://geografiaumsa.blogspot.fr>
- IMTD – Institute for Multi-Track Diplomacy: www.imtd.org
- IPGP/LGE – Earth Physics Institute in Paris / Geochemistry Laboratory of waters: <http://www.fire.upmc.fr/?q=node/158>
- IUCN – International Union for Conservation of Nature; BRIDGE - Building River Dialogue and Governance: <https://www.iucn.org/theme/water/our-work/bridge>
- IMARPE – Sea Institute of Peru: <http://www.imarpe.pe/imarpe/>
- LCP - Continental Laboratory Puno: http://www.imarpe.pe/imarpe/index.php?id_seccion=I0171100000000000000000
- LEO – Laboratory of Earth Observation, University of Valencia, Spain: <http://ipl.uv.es/leo/>
- LTHE – Study Laboratory of Transfers in Hydrology and Environment (UMR5564): <http://www.lthe.fr/LTHE/?lang=fr>
- MMAyA – Bolivian Ministry of Environment and Water: <http://www.mmaya.gob.bo>
- HYBAM ORE – Observation service for monitoring geodynamic, hydrological and biogeochemical erosion/alteration and material transport in the Amazon: <http://www.ore-hybam.org/index.php/eng/Data/Station-Access-Maps/HYBAM-ORE-South-America>
- PELT – Special Program of Lake Titicaca: <http://www.pelt.gob.pe/pelt/>
- LTSP – Sanitation Program of Lake Titicaca: http://www.mmaya.gob.bo/index.php/informacion_institucional/content,1610.html
- IS SOERE OLA - Information System of the LAkes Observatory: <https://si-ola.inra.fr/>
- SPIRAL – Support for IT Project with Scientific Teams of IRD:

- THEIA (daughter of Uranus – the Sky – and of Gaia – the Earth) – Cluster of data and services and continental surfaces (created by 9 French public institutions involved in the observation of the earth and environmental sciences; scientific and technical structure aims to facilitate the use of images from the observation of land surface from space): <https://www.theia-land.fr/fr/presentation/theia>
- UB – University of Barcelona: <http://www.ub.edu/web/ub/ca/>
- UMSA – Major University of San Andrés: <http://www.umsa.bo/web/guest>
- ULB – Free University of Brussels: <http://philoscsoc.ulb.be/fr/users/cdelaere>
- UOB – Bolivian Operational Unit:
- UVEG – University of Valencia, Spain: <http://www.ub.edu/web/ub/ca/>
- VEPB – Vice Presidency of the Plurinational State of Bolivia: www.vicepresidencia.gob.bo
- VLMP – Maine Volunteer Lake Monitoring Program: <http://www.mainevlmp.org>
<http://www.highlandlakemaine.org/home/water-monitoring-committee-videos>
- AHR – Vice Ministry of Water Resources and Irrigation: <http://www.riegobolivia.org>

Valuation and scientific communication about Lake Titicaca (May 2013 - May 2015)

2 Releases, IRD-Bolivia Representation Web page/News:

Achá D. & Lazzaro X (2015) Análisis y recomendaciones acerca de la mortandad ocurrida en la zona Norte del Lago Menor durante el mes de Abril 2015; May 2015:

<http://www.bolivia.ird.fr/toda-la-actualidad/la-actualidad/comunicado-analisis-y-recomendaciones-acerca-de-la-muerte-de-peces-anfibios-y-aves-ocurrida-en-la-zona-norte-del-lago-menor-durante-el-mes-de-abril-2015>

Lazzaro X. (2015) El Lago Menor verde, evento meteorológico extremo o cambio climático en marcha? May 2015: <http://www.bolivie.ird.fr/toute-l-actualite/l-actualite/el-lago-menor-verde-evento-meteorologico-extremo-o-cambio-climatico-en-marcha>

2 Interviews in the Bolivian press on the ANR LA PACHAMAMA:

« Mercurio una alerta en el Titicaca »; Escape / La Razón, La Paz, May 2014 : http://www.la-razon.com/suplementos/escape/Mercurio-alerta-Titicaca_0_2048795180.html

« La Bahía de Cohana es la mas contaminada del Lago - Se consolida el observatorio ambiental binacional del Lago Titicaca »; Oxígeno, La Paz, May 2014:

1 animated slideshow in the CNRS Journal on the ANR LA PACHAMAMA:

« Les chasseurs de mercure du Lac Titicaca »: <https://lejournal.cnrs.fr/videos/les-chasseurs-de-mercure-du-lac-titicaca>

1 Interview in the Swiss press:

« Joyau d'Amérique, le lac Titicaca est en péril » - LeTemps.ch ; Frédéric Faux, 25 August 2015 : <http://www.letemps.ch/sciences/2015/08/24/joyau-amerique-lac-titicaca-peril>

4 TV Articles and 3 Radio Interviews:

Interview « Polución y eutrofización del Lago Titicaca »; Programa Nuevo Mundo, Canal Universitario TVU, La Paz, May 2013, in studio, 1hr

Reportage « Contaminación de la Bahía de Cohana »; Los Chapacas, Canal Universitario TVU, La Paz, May 2015, sur le terrain, 3 x 30 min

Documentary « Pérou: Planète extrême »; French Connection Films, Codex Now, Futura-Sciences and IRD, broadcast on Ushuaïa TV and TV5 Monde, 3 episodes, scientific advisors Olivier Dangles (Andes) and X. Lazzaro (Lake Titicaca):

http://www.terraeco.net/spip.php?page=imprimer&id_article=60166

<http://www.frenchcx.com/fr/portfolio/perou-planete-extreme/>

Documentary « Expédition Nouveau Monde »; Les Frères La Tullaye, Agence Biglo, broadcast on France 5 during the COP21 in Paris, Dic. 2015: <http://www.lesfrereslatullaye.fr>

Interview « Pollution: Le Lac Titicaca en danger », broadcast on France Inter, RTBF y France Info, Frédéric Faux, June 2015: <http://www.franceinter.fr/emission-ailleurs-pollution-le-lac-titicaca-en-danger>

Audio reportage « Bolivie : l'asphyxie du lac Titicaca », Frédéric Faux, RFI, Sept. 2015: <http://www.rfi.fr/emission/20151003-2-bolivie-lac-titicaca-asphyxie>

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To know more

Research and work of IRD and its partners on the Web page of IRD Representation in Bolivia:
<http://www.bolivie.ird.fr/content/advancedsearch?SearchText=titicaca+&SubTreeArray%5B%5D=19147>

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