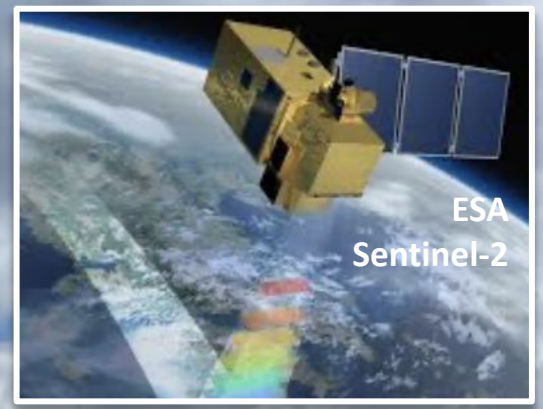
INBO 30th World General Assembly Program, October 06-10, 2024, Bordeaux, France

- the highest navigable lake (3,809 m a.s.l.)
- the largest (8,562 km^2) of the 253 Large Lakes (> 500 km^2)
- the largest freshwater lake in South America (23rd worldwide)



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Sistema Hídrico TDPS : Perú - Bolivia

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Assessing global changes and eutrophication with the permanent Lake Titicaca Observatory (OLT)

Observatorio Binacional LagoTiticaca

Instituto francés de Investigación para el Desarrollo
IRD Institut de Recherche pour le Développement FRANCE

gef

PNUD

https://sites.google.com/view/observatorylaketiticaca-olt/home

Lazzaro X.[1], **Núñez Villalba J.**[2], **Maldonado Alfaro J.**[2] & **Ocola Salazar J.**[1]

[1] **ALT** – Autoridad binacional del Lago Titicaca, Perú-Bolivia; [2] **IIGEO/UMSA** –Instituto de Geografía, Univ. Mayor de San Andrés, La Paz, Bolivia

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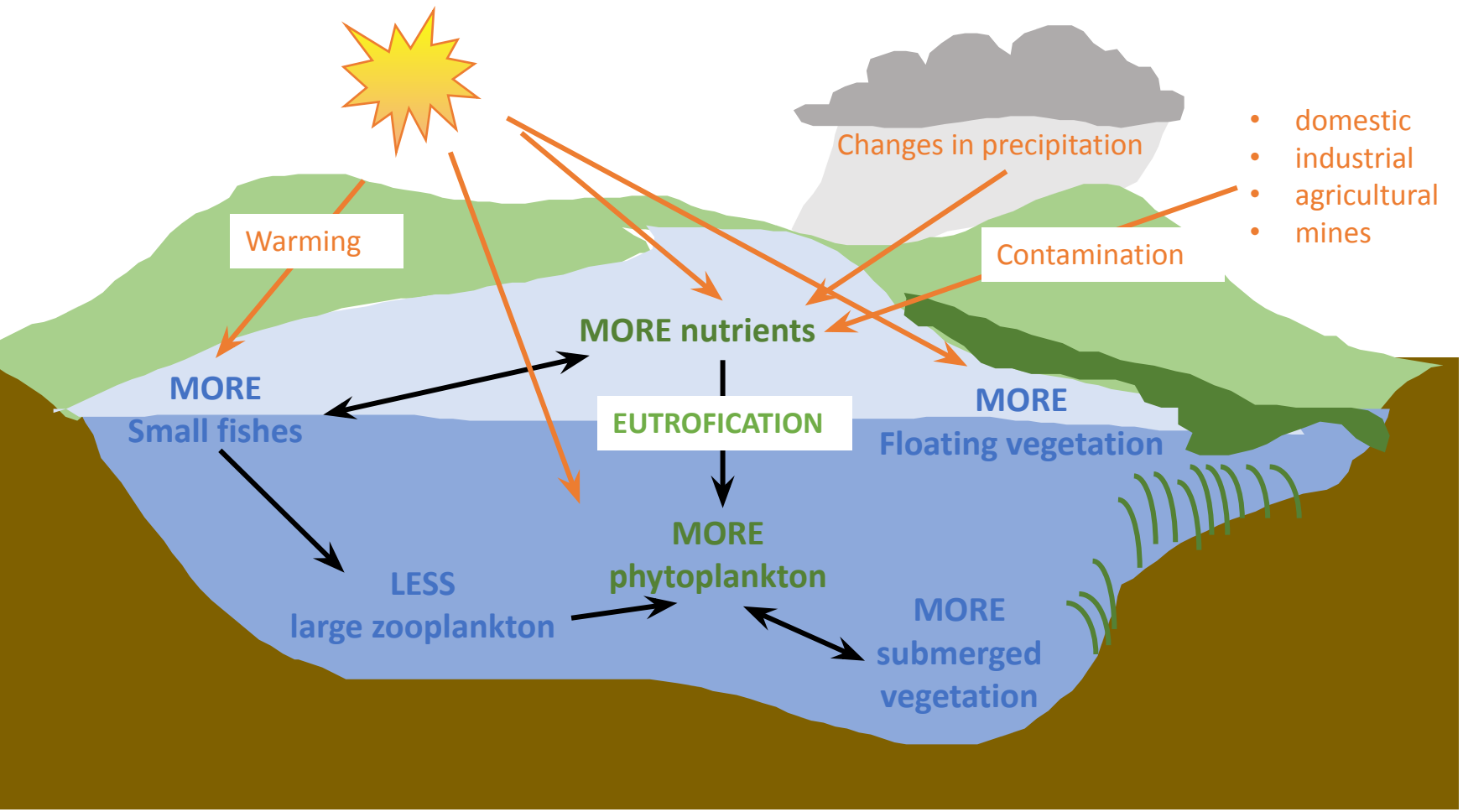
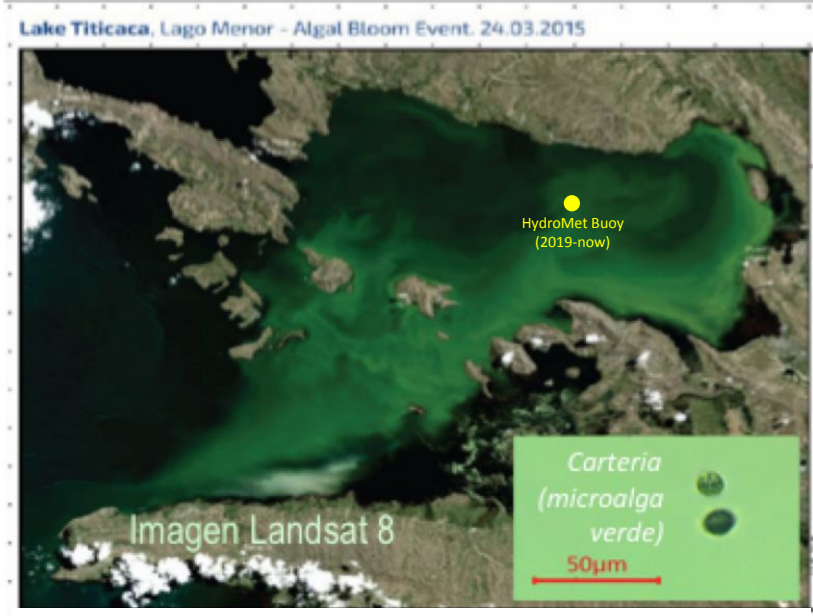
GLOBAL CHANGES (= warming + contamination)

accelerate **EUTROFICATION** synergistically !



These mechanisms occur in all lakes, leading to the development of microalgal efflorescences (blooms) .....

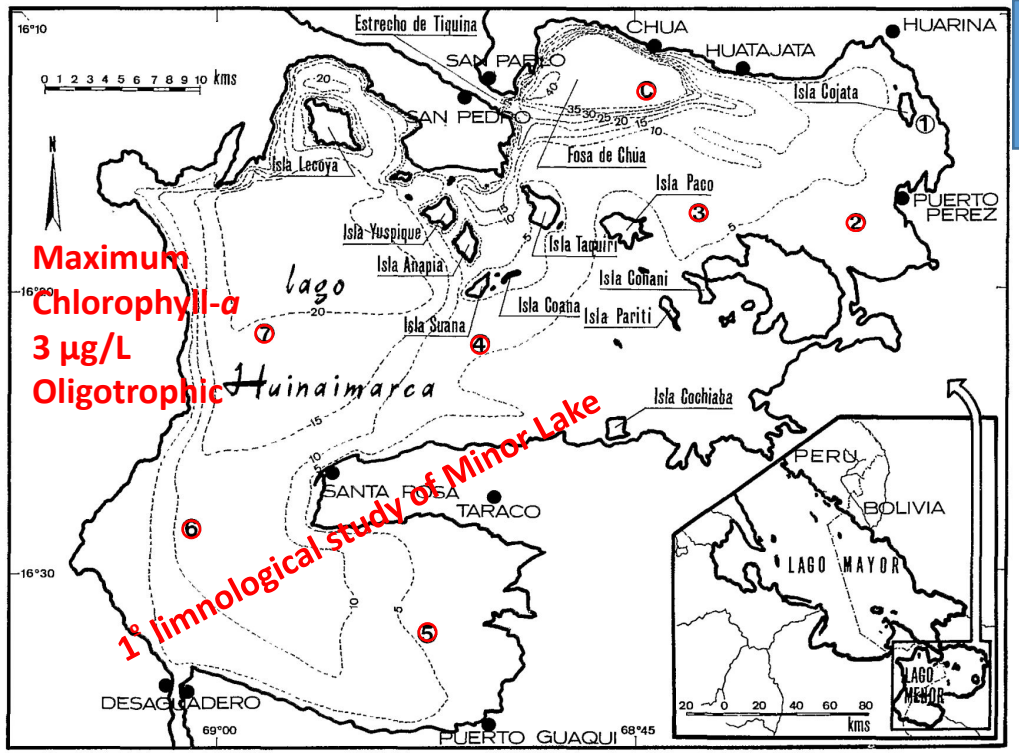


March 2015, 1st Algal bloom in Titicaca Minor Lake, produced massive die-offs of fish, frogs and waterfowl.

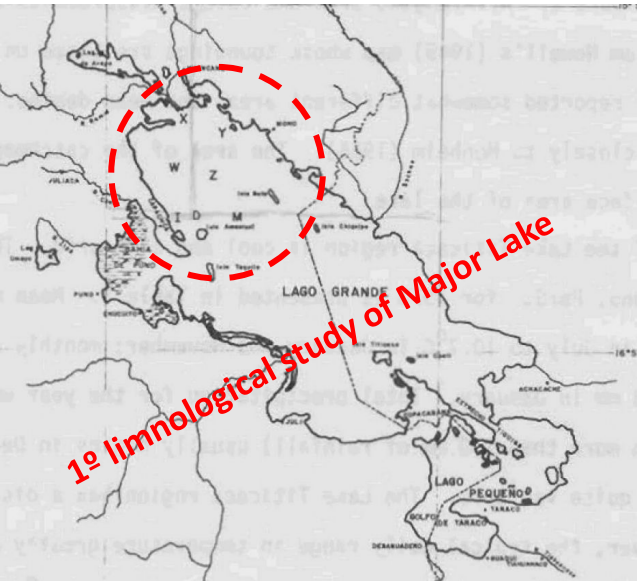
HydroMet Buoy site, Sept. 1st 2024

Selection of the study site impacted by the Katari watershed wastewater discharges from El Alto.

Current maximum Chlorophyll-*a* > 10 µg/L → Minor Lake became meso- to eutrophic !

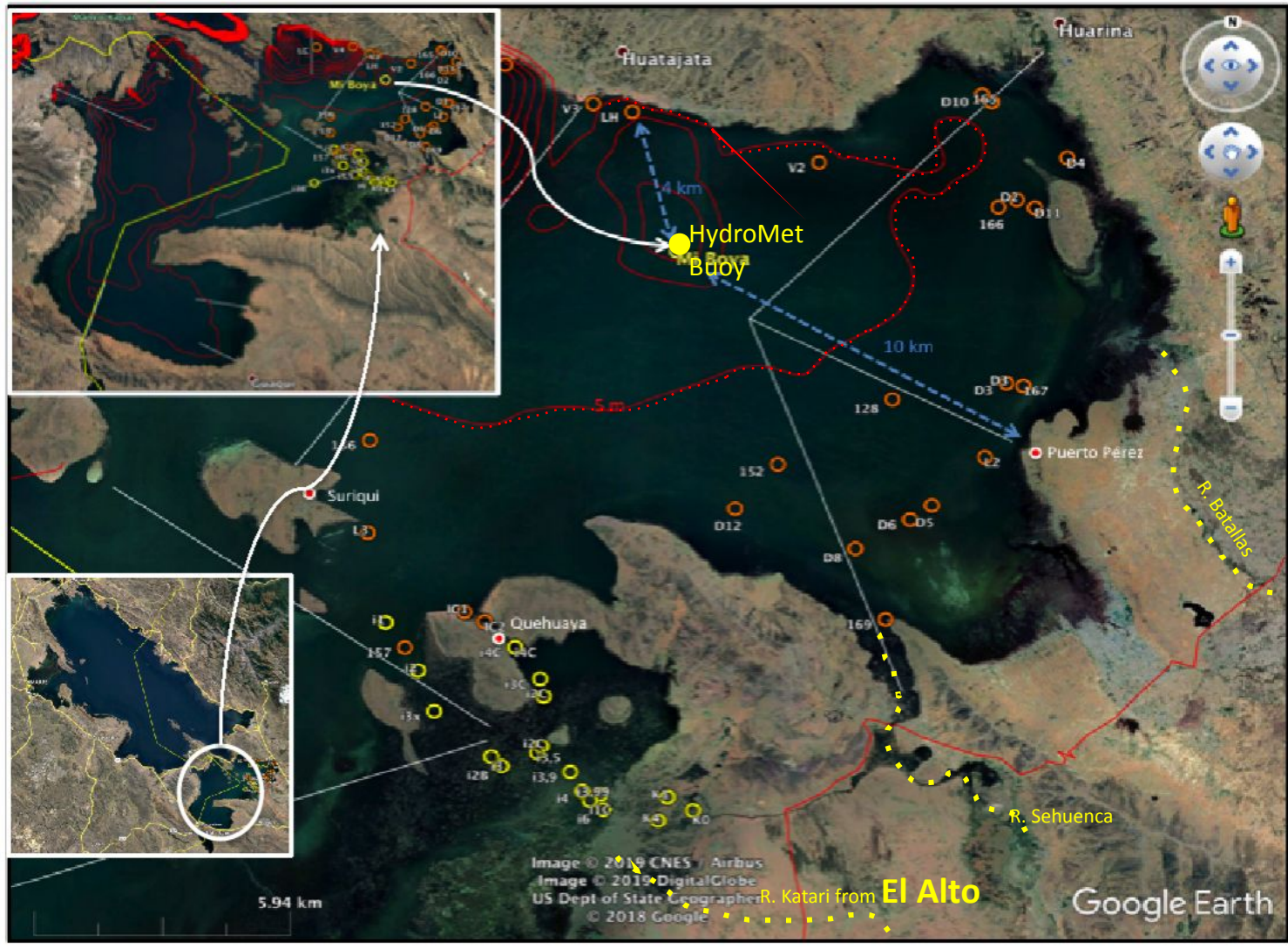


Lazzaro 1981. Rev. Hydrobiol, trop. 14: 319-380
VSNA **1979-1980**, ORSTOM-UMSA cooperation

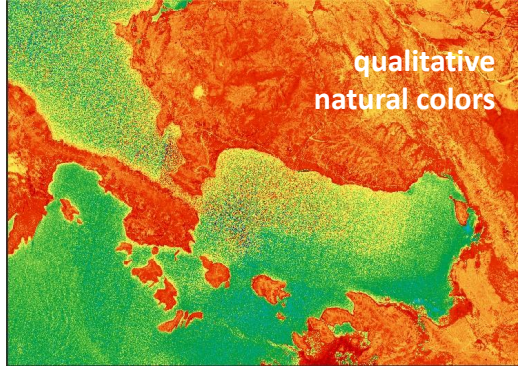


Richerson et al. 1977
Univ. of California - **1973**,
IMARPE - UNTA – NatGeo cooperation

Lazzaro et al. 2019-2022. Pilot Project Permanent Observatory (OLT) of Lake Titicaca, IRD-UMSA cooperation.



Remote sensing by
Sentinel-2 ESA
Copernicus 10 m
5 days

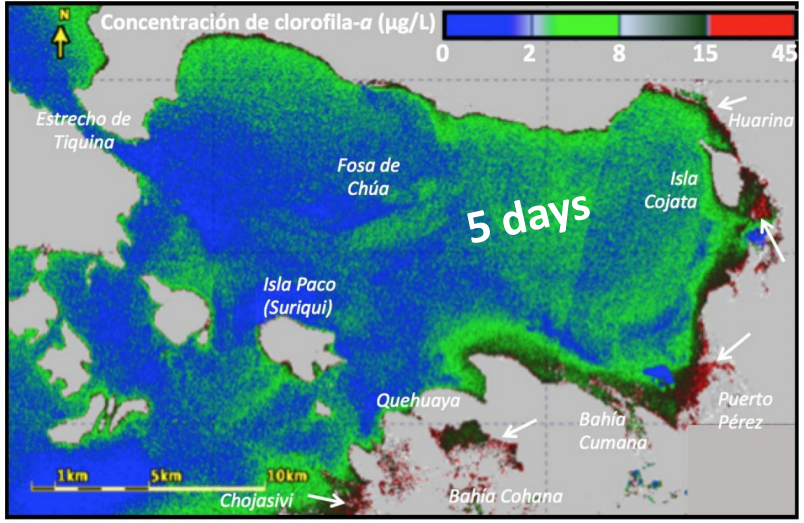


Atmospheric correction

Validation of *Javier Maldonado's algorithm*

in situ Chl-*a*

in situ Chl-*a*

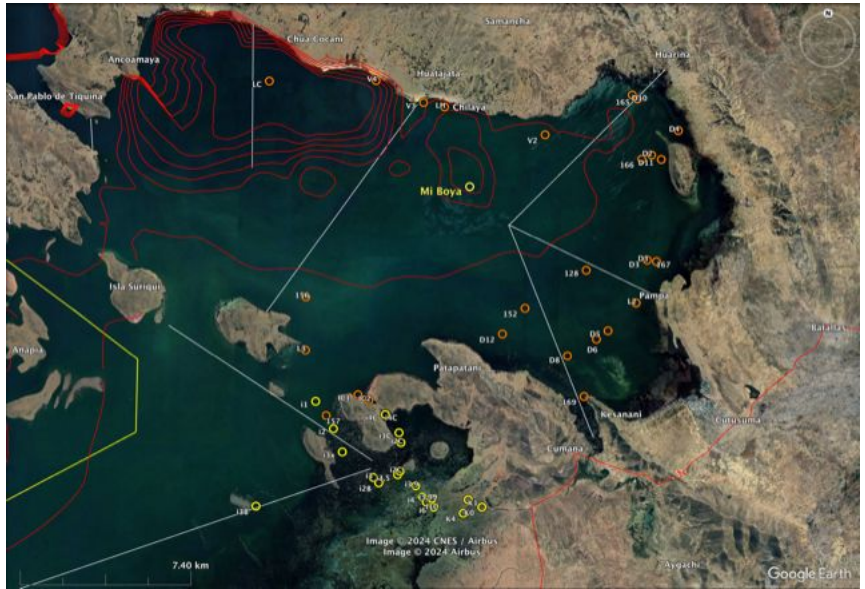


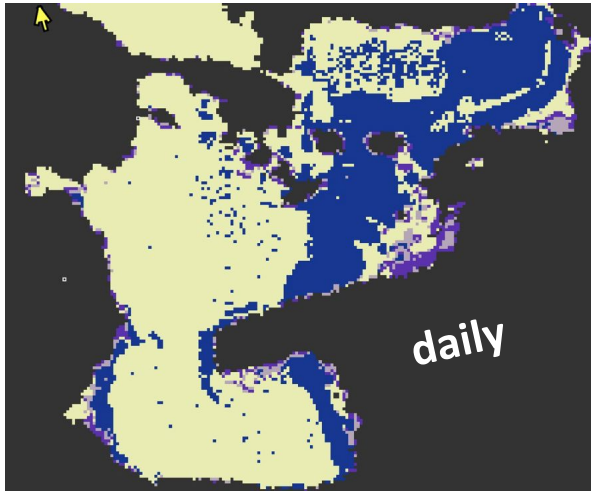
Quantitative Chl-*a* (µg/L) algorithm specific to Minor Lake

Deployed on June 27, 2019.... to present
HydroMet XYLEM solar profiling buoy (1-10 m) high-frequency (5 min, 30 min, 2 hrs.) GSM data transmission

Dynamic maps of the lake trophic states → early warning system of Blooms!

Network of limnological stations and transects





Sentinel-3 ESA Copernicus remote sensing 200 m daily - OWT GLaSS_6C classification. In blue the most eutrophic mean Class 4: Chl-*a* 107 µg/L; CDOM 4.2 RFU; TSM 37.7 g/m^3

Pilot Project 2019-2022

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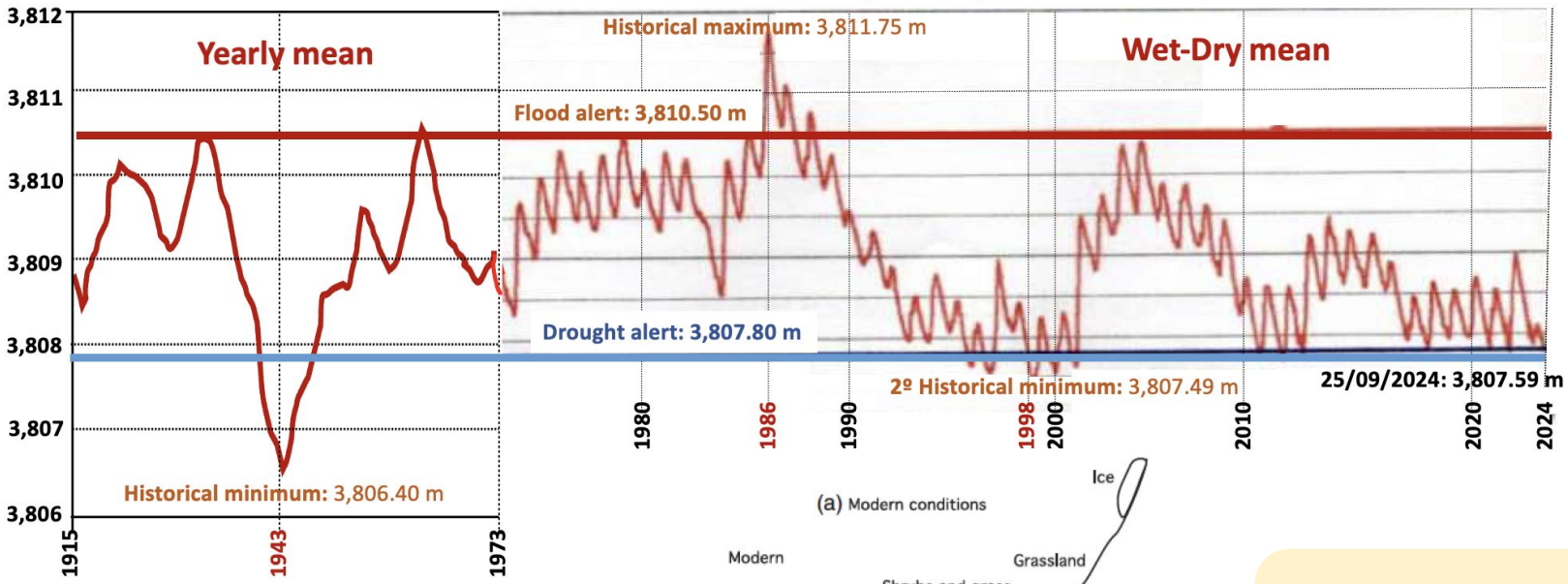
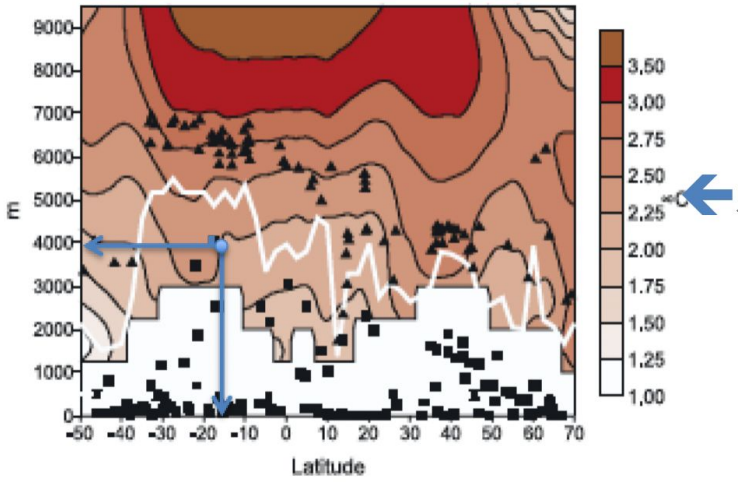
Lake Titicaca water level (m a.s.l.)



GCM SIMULATIONS

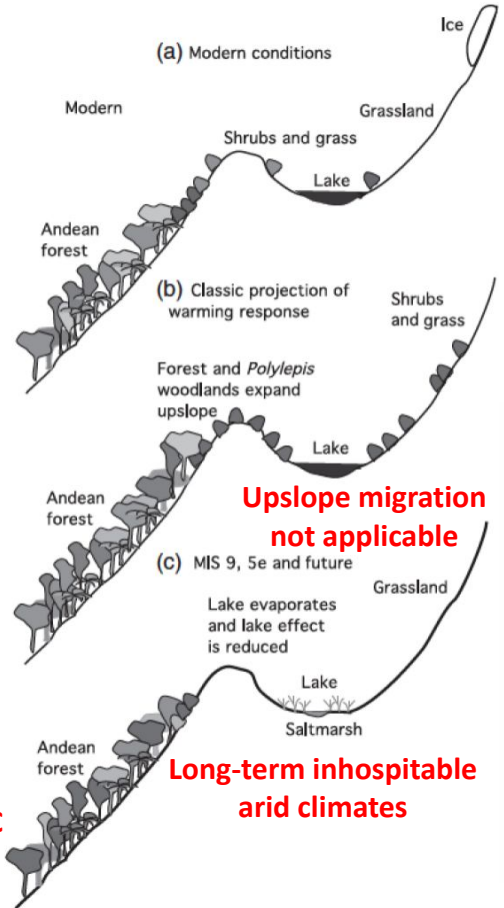
Bradley et al., Geophysical Research Letters 2004



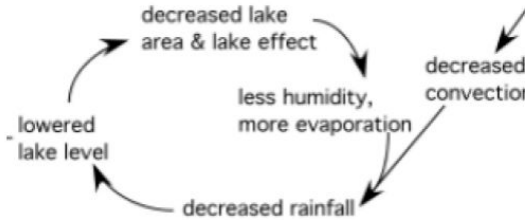
Sever climate warming harms Lake Titicaca resilience, shifts towards aridity!

INTERGLACIAL PALEOECOLOGICAL RECORD

Bush et al., Global Change Biology 2010



Positive feedback loop



Upslope migration not applicable

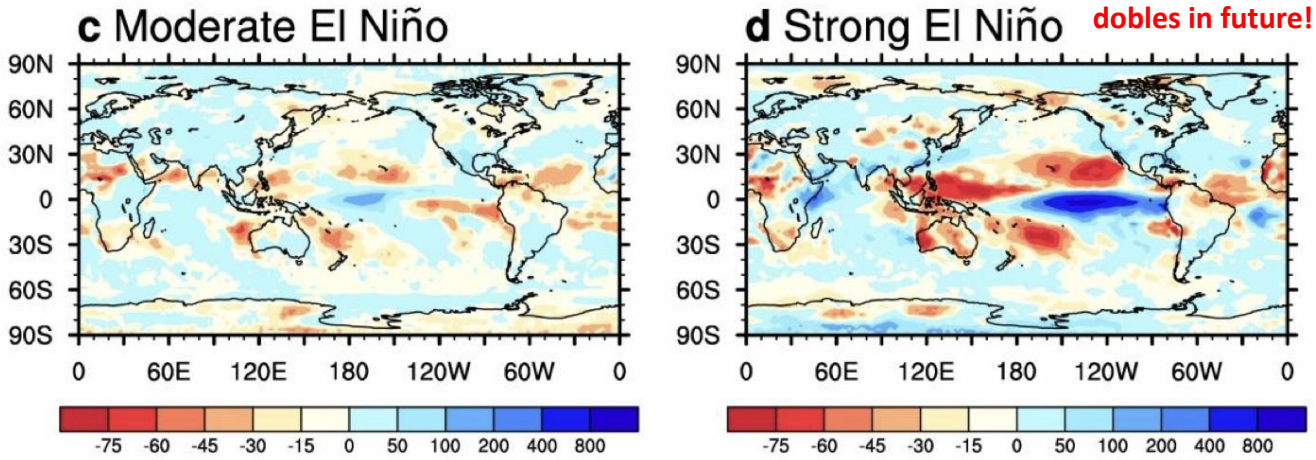
Tipping point at +1-2 ºC current temperature

Long-term inhospitable arid climates

SIMULATIONS FROM THE 1982/83 AND 1997/98 EXTREME EL NIÑO EVENT DATASETS

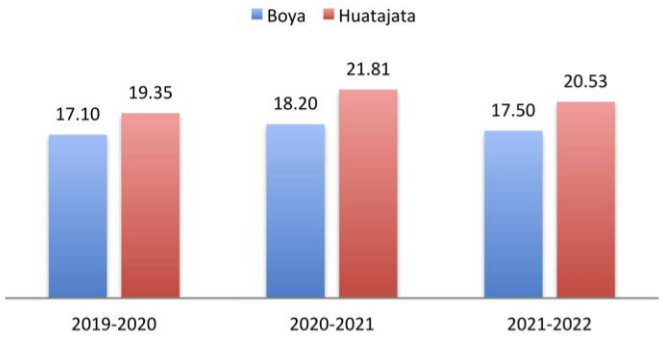
Cai et al., Nature Climate Change 2014

Frequency dobles in future!

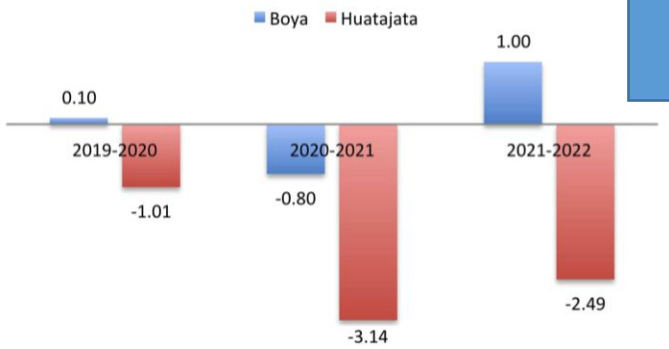


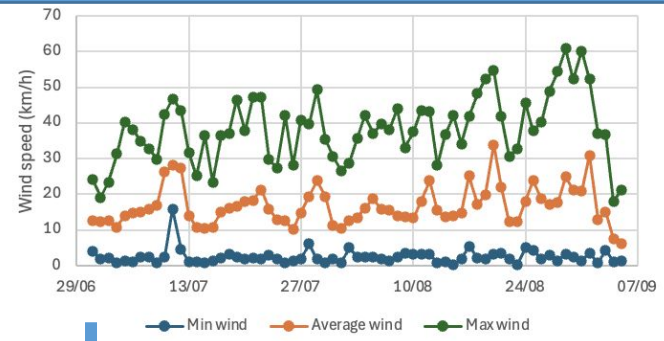
Meteorological results from OLT HydroMet buoy (*in blue*) reveal global changes

Yearly maximum air temperature (ºC)



Yearly minimum air temperature (ºC)





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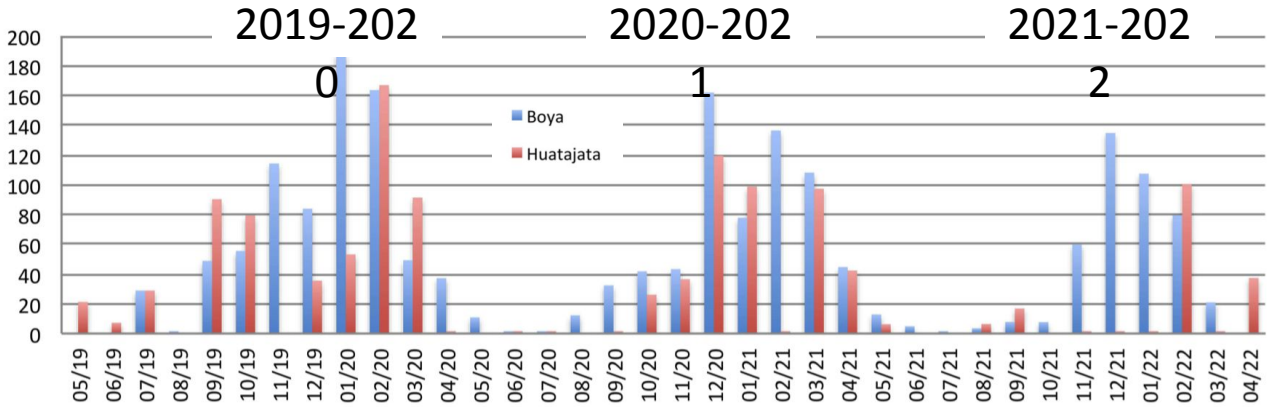
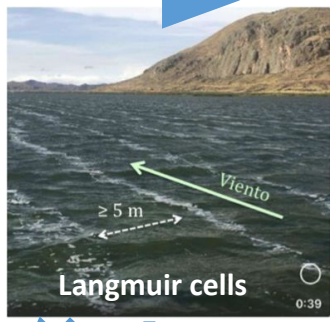
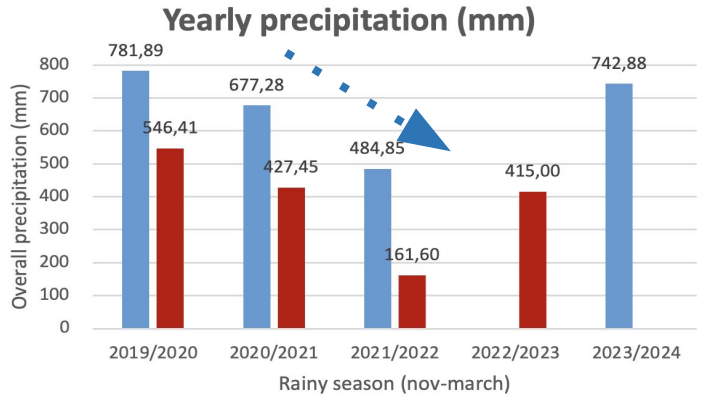
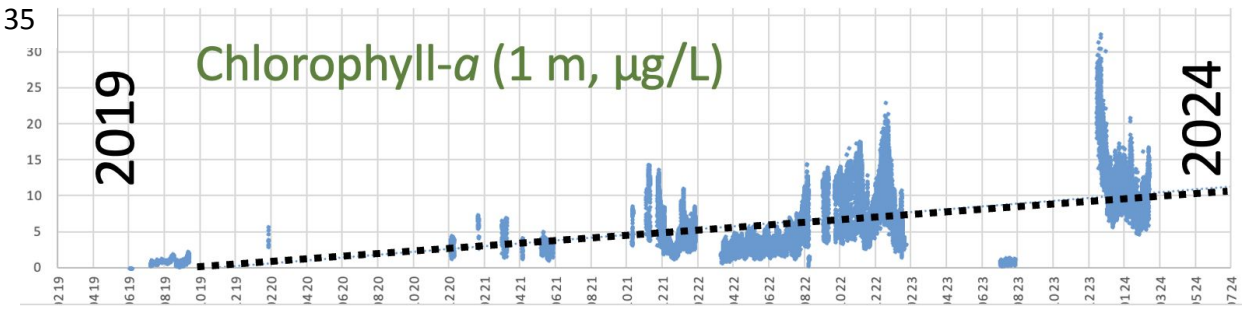
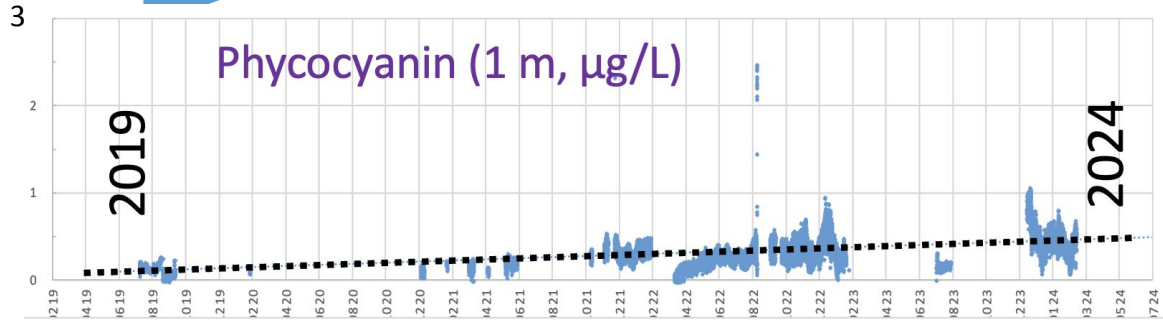
Buoy - monthly rain (mm; in blue; frecuency 5 min)











Lake Titicaca warms the local Altiplano, increases rainfall! It is a reference global change sentinel of the Large Lakes. Shallow Minor Lake has shifted to the eutrophic state!

Some relevant results, anticipation and restoration proposals

From the HydroMet buoy and satellite remote sensing, worrying results (accelerated eutrophication):

- **Air warming +0,76 º C/decade → > +5 ºC in 2100**
- **reduction in precipitation:** 782 mm (2020), 677 mm (2021), 485 mm (2022)... **=> ~ONE rainy season lost during the last 5 years !**
- Occurrence of **microalgal blooms (*Carteria* sp.):** August 2022 (14 µg Chl-*a*/L), November 2023 (145 µg Chl-*a*/L), increase in the proportion of **cyanobacteria**, from north to south of Minor Lake
- **Specific Chl-*a* algorithm** + Sentinel-2 Ulyssys script + Sentinel-3 GLaSS-6C OWT classification

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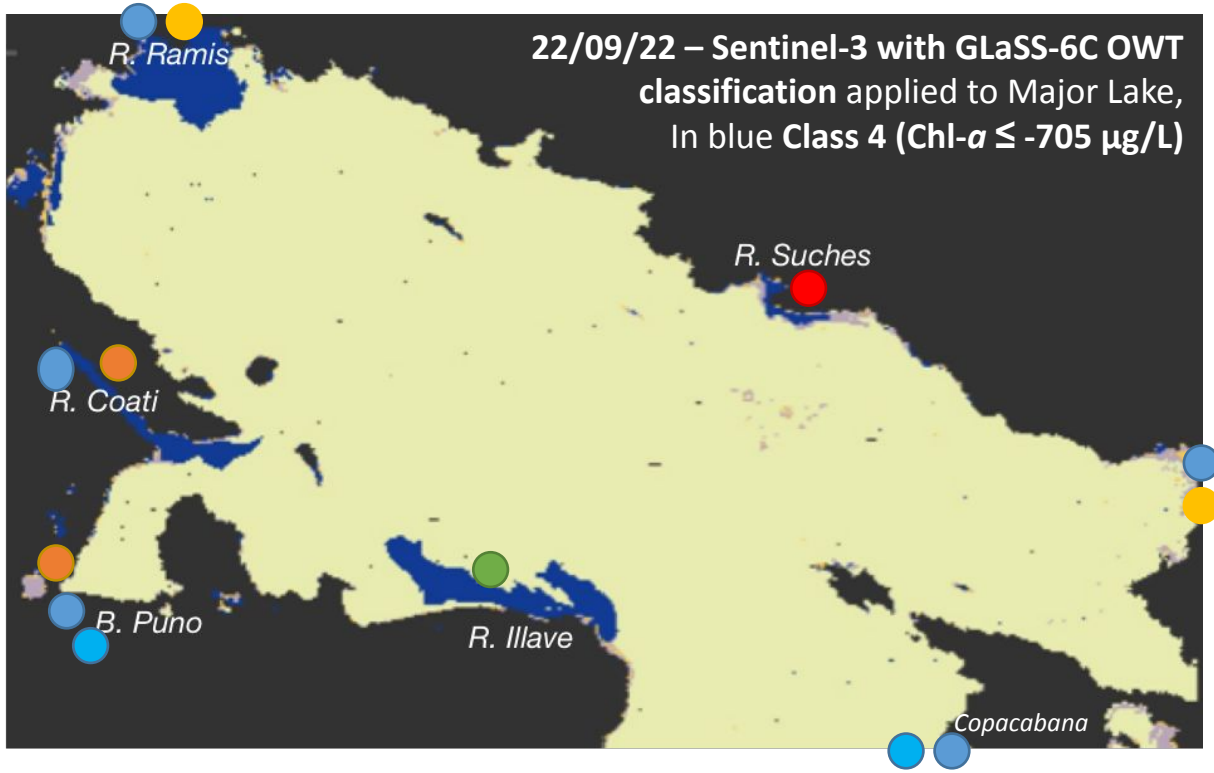
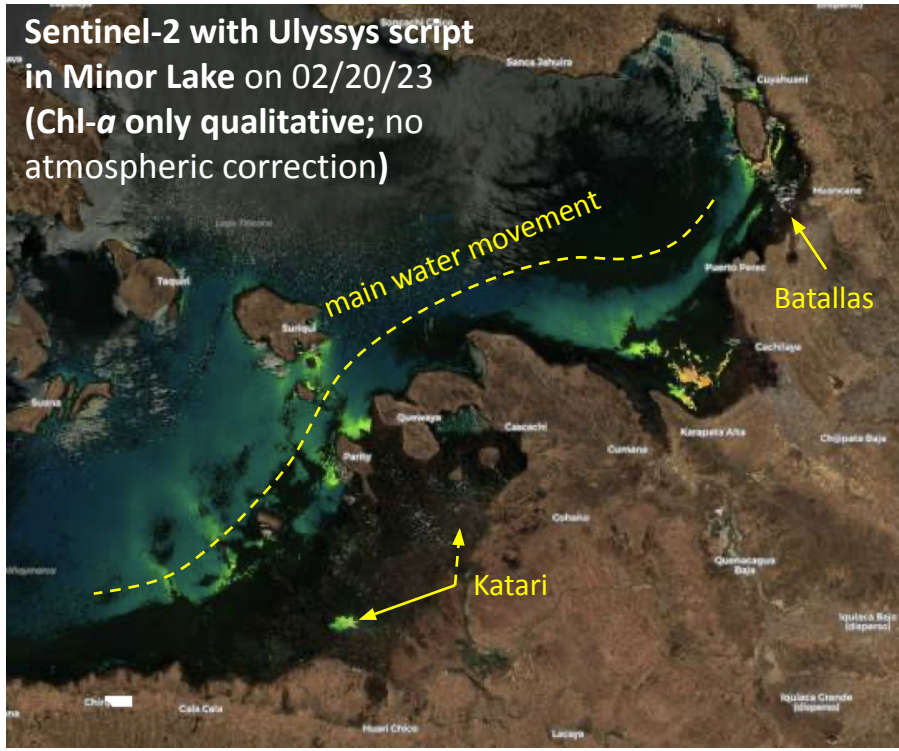
Using high-frequency *in situ* validated Chl-*a* satellite images improve monitoring confidence and Blooms early warning !



22/09/22 – Sentinel-3 with GLaSS-6C OWT classification applied to Major Lake, In blue **Class 4 (Chl-*a* ≤ -705 µg/L)**

The eutrophicated litoral areas mainly result from human activities ←

The Chl-*a* hotspots (yellow-green) result of wastewater discharges from Katari y Batallas tributaries →



Sentinel-2 with Ulyssys script in Minor Lake on 02/20/23 **(Chl-*a* only qualitative;** no atmospheric correction**)**

Contaminations: Domestic; Recreational boating; Industrial; Pisciculture; Agriculture; Mines

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Lake Titicaca Binational Observatory (OBLT) perspectives

Research

- **Eutrophication** mechanisms
- **Blooms** early warning
- **Remote sensing** vs *in situ*
- Effects of **meteorological events**
- Climate changes vs **anthropic** effects, …
- Adaptation to the **European Water Framework Directive**

Lake restauration proposals

- **Ecological Engineering:** divert tributaries into **constructed wetlands** for natural filtration by **aquatic macrophytes**, before returning to the lake
- **Compact sewage treatment plants** (STEP) in maritime containers installed in towns and river courses: **ultrafiltration, activated carbon, sterilization (UV), oxygenation (O_2), ozonification (O_3)** **+ Aquadelle water decontamination technology** (Puno inner bay)

pdf version available on the ALT website:
https://alt-perubolivia.org/?wpdmpro=el-libro-del-observatorio-permanente-del-lago-titicaca

Major Lake

Minor Lake

Peru

Bolivia

2021 HydroMet Buoy

2019 HydroMet Buoy

Thank you

xlazzaro@alt-perubolivia.org

For more information download the OLT book →

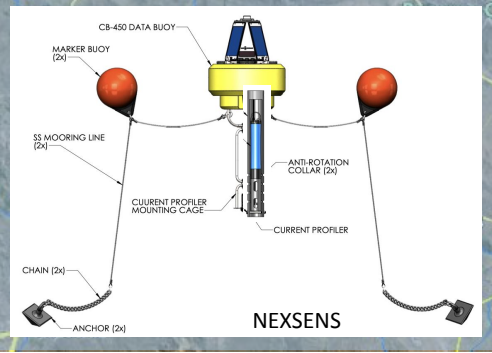
Future monitoring

Satellites

- **2030 Landsat Next** (pixel 10 m): early warnings about harmful algal blooms (bands 6-7)
- **ESA Sentinel-5p** – Solar Induced Chlorophyll-*a* Fluorescence (SIF)

Buoys

At tributary mouths



OLT observatory new website in English:
https://sites.google.com/view/observatorylaketiticaca-olt/home

Open Data available to registered users !