16th international Living Lakes Conference "Biodiversity and Ecosystem Services in Lakes and Wetlands: Mitigation and Adaptation Strategies"
Puno, 06-08 December 2022

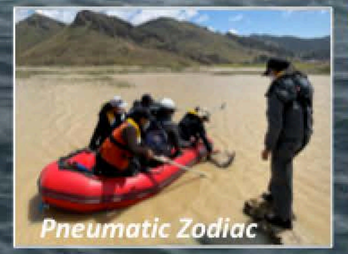
The 1st permanent Observatory of Lake Titicaca (OLT)

The 05B05 PNUD/GEF pilot project on Minor Lake (2019-2022)

Inti research boat

HydroMet buoy

Peque peque outboard



Pneumatic Zodiac

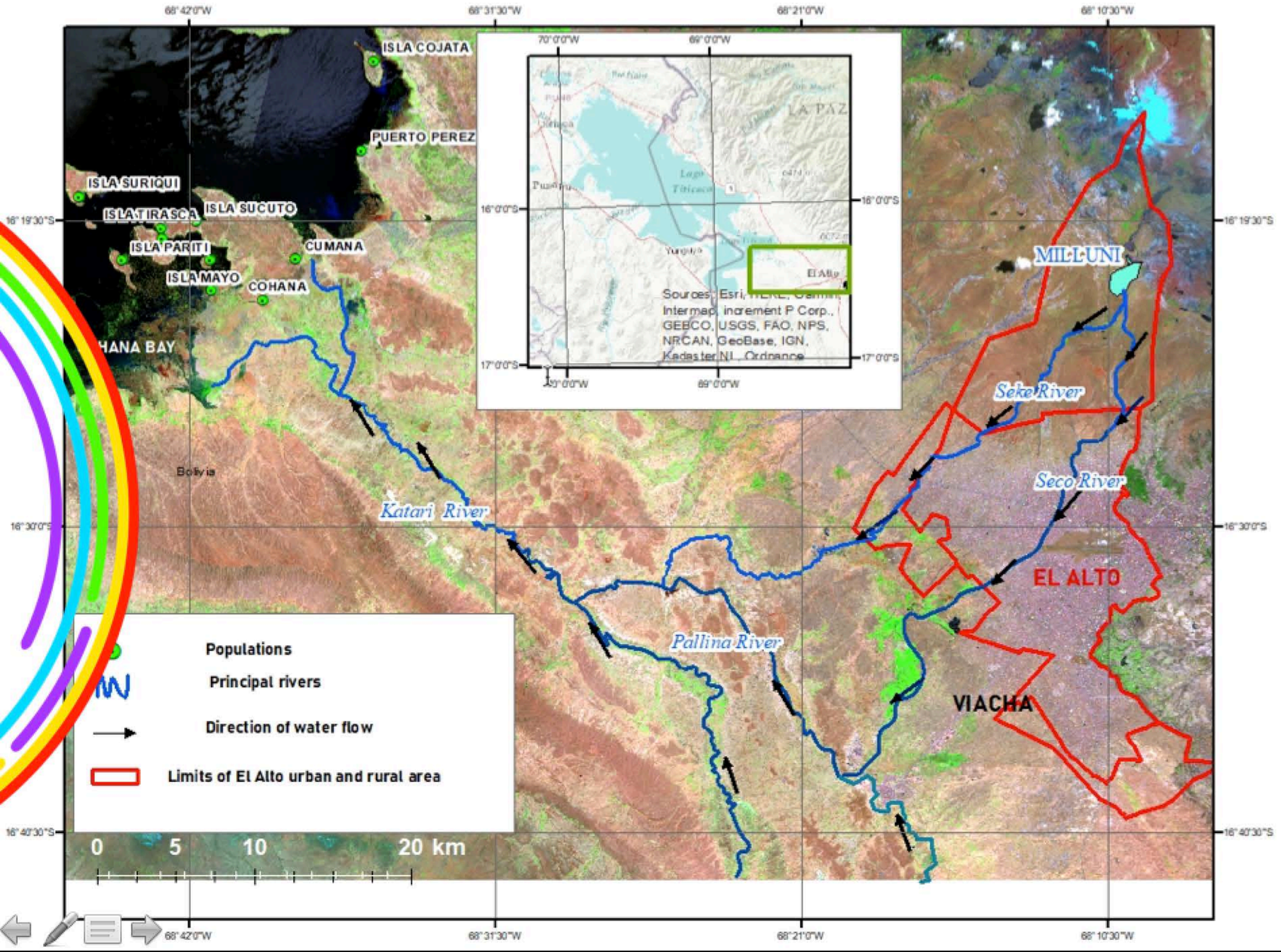
Solar catamaran

Xavier Lazzaro[1], **Viviana Cruz**[2], **Gustavo Lanza**[2], **Marcela Ormachea**[3], **Javier Maldonado**[3]

[1]IRD/BOREA, [2]UMSA/IE, [3]UMSA/IIGEO, La Paz, Bolivia

Local cooperators: **Máximo & Erik Catari**, Huatajata | **Oscar Limachi**, Quehuaya | **Isaac Callizaya**, Isla Pariti

DESCRIPTION and SCOPE OF INTERVENTION

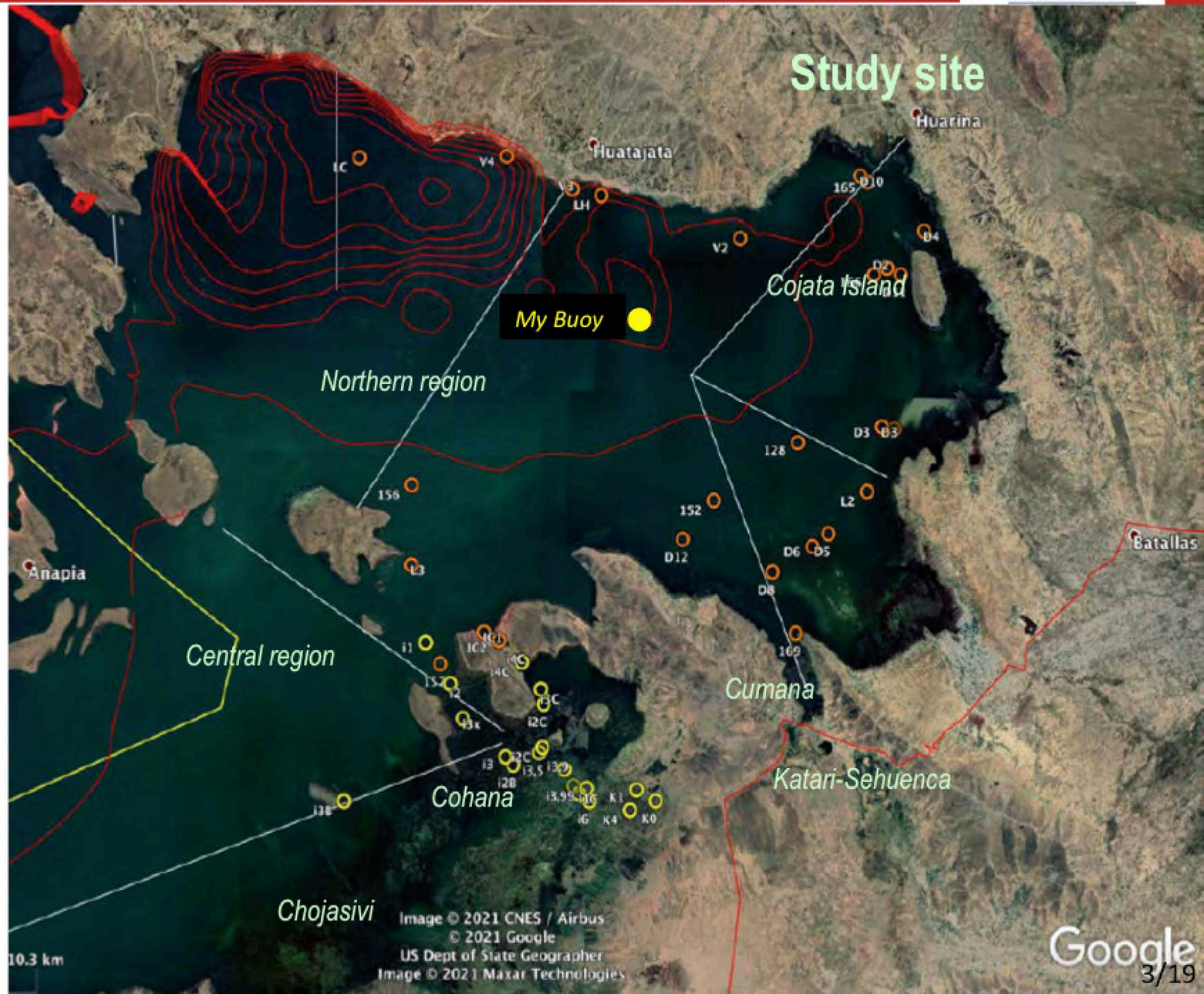


- **El Alto – Viacha (1.2 M inhab.) wastewater contamination through the Katari watershed**
  ➔ Eutrophication process in shallow **Cohana Bay** and Minor Lake
- Katari – Sehuenca river system
  ➔ Cohana and Cumana Bays
  ➔ Minor Lake Northern and Central regions
- 2015 bloom in Minor Lake
  ➔ *Carteria* sp. ➔ Recurrent blooms in the future?

DESCRIPTION and SCOPE OF INTERVENTION

1ST DOCUMENTED ALGAL BLOOM IN TITICACA MINOR LAKE – MARCH-APRIL 2015

Carteria sp.



3 STRATEGIES with 7 ACTIVITIES

GIRH TDPS

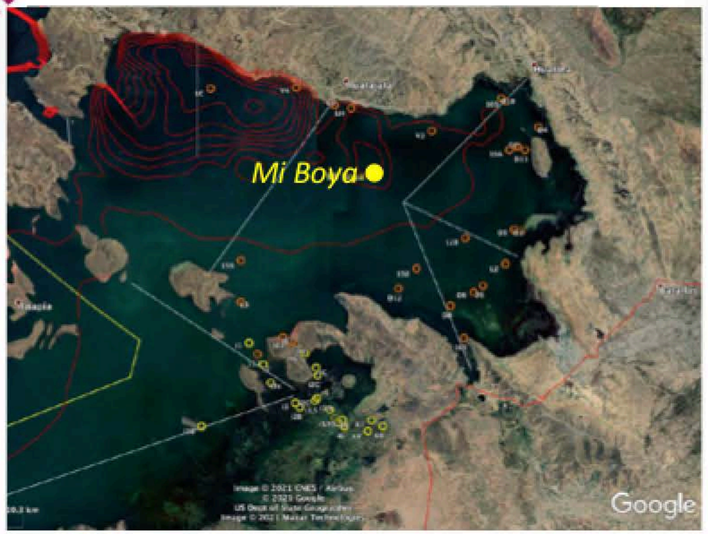
1. Implement **a Hydro-Meteorological Buoy** in the **Bolivian sector** of Titicaca Minor Lake

Store/validate/share **databases** in the **IIGEO/UMSA GeoVisor**

2. Conduct *in situ* ***limnological*** **campaigns** at a network of representative **limnological stations**, synchronized with **Sentinel-2** satellite pass (frequency 5 days)

3. Identify **key indicators** and mechanisms of **good ecological and biogeochemical functioning** of the lake.

3 LOGISTICAL STRATEGIES



5. Design an **Early Warning System** to anticipate **undesirable phenomena** of 'eutrophication'.

4. Use **satellite remote sensing** with ***in situ validation*** to generate a **chlorophyll-*a* algorithm** for Minor Lake

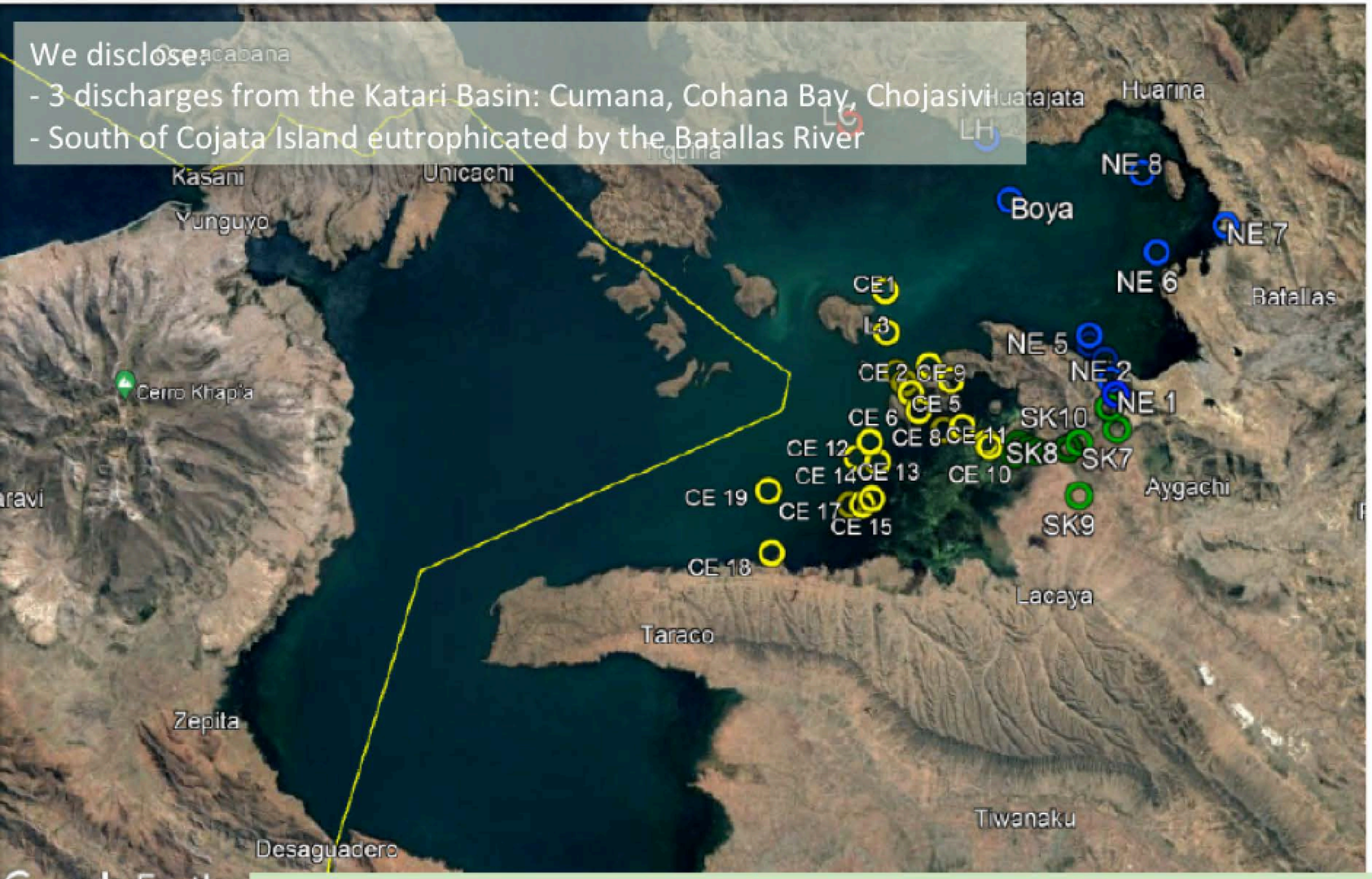
6. Train academic and technical personnel. Share experiences and technologies with Peruvian institutions

7. Share knowledge through technical-scientific publications, educational brochures, **web site**, **synthesis book**, **databases**

RESULTS

MONITORING OF A NETWORK OF 41 LIMNOLOGICAL STATIONS

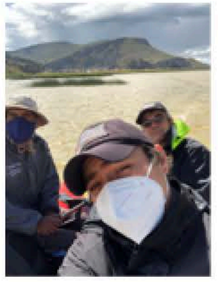
- PHYSICOCHEMICAL MEASUREMENTS AND PLANKTON SAMPLE COLLECTION

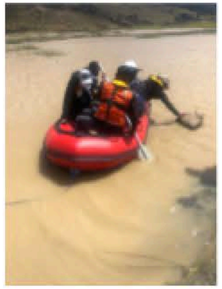


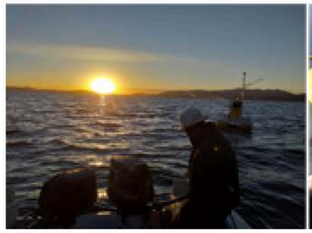
36 one-day campaigns (2019-2022), 119 samples, in 41 stations

Zone	Number of stations
Northeast	10
Katari-Sehuenca water system	10
Central	20
Northwest	1

- Samples: **119 phytoplankton** and **zooplankton**, **80 periphyton**
- **4 seasons** (wet, wet-dry transition, dry and dry-wet transition) during **2019-2022**





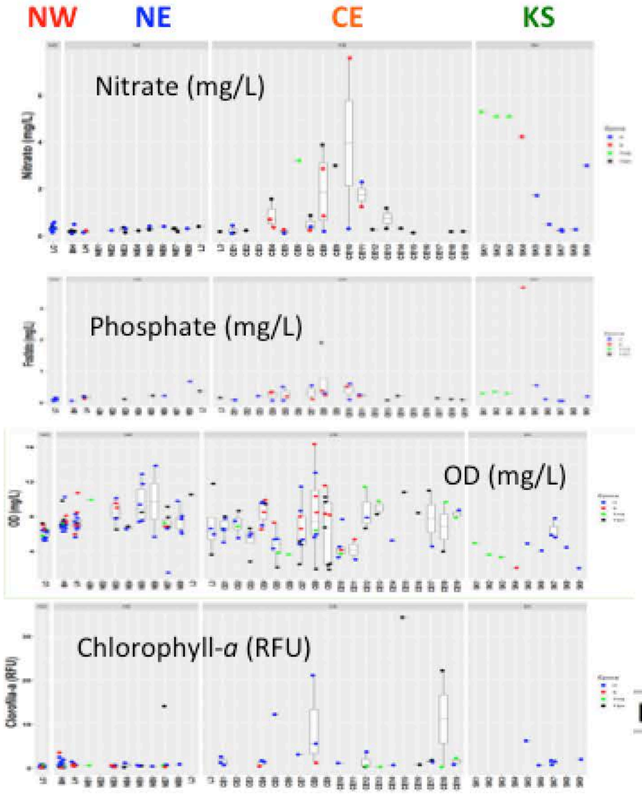


MONITORING PARAMETERS AND PLANKTON IN THE 41 LIMNOLOGICAL STATIONS

RESULTS

GIRH TDPS

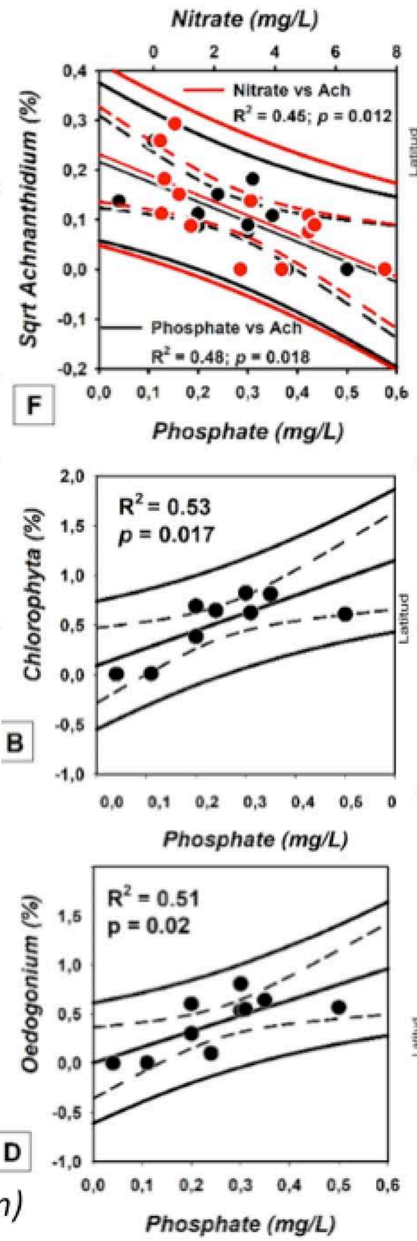
Physico-chemistry



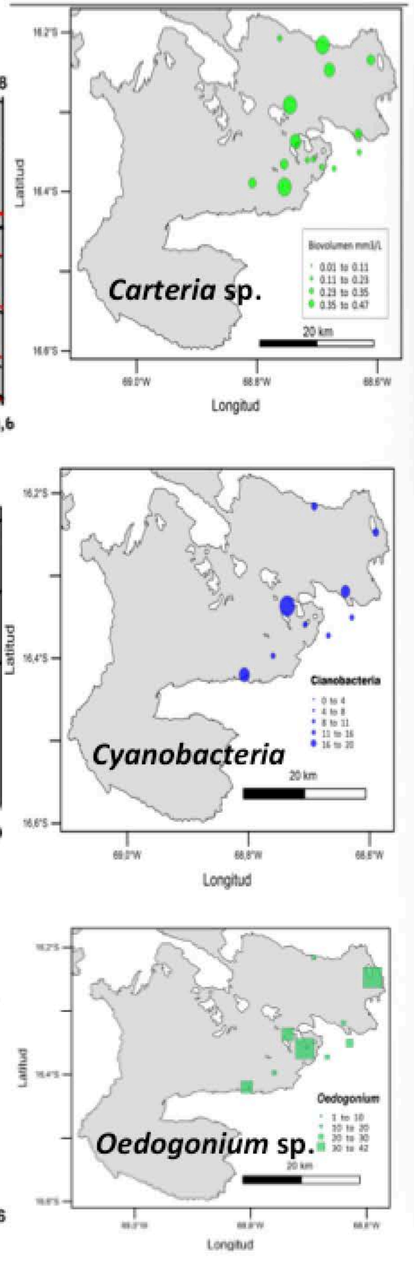
Seasons: Wet, Dry, Wet-Dry transition, Dry-Wet Transition

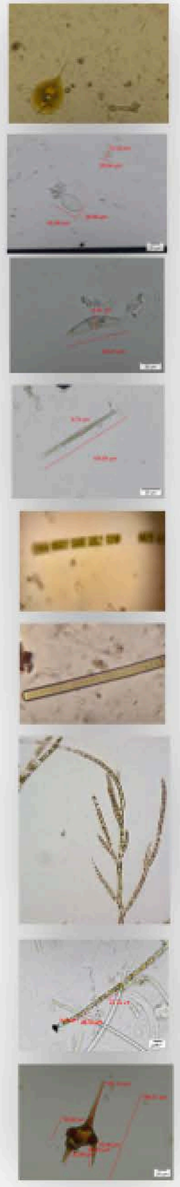
Parameters: pH, **Conductivity** (µS/cm), **DO** (mg/L), **Turbidity** (RFU), **Nitrate** (mg/L), **Nitrite** (mg/L), **Amonium** (mg/L) and **Fosfatos** (mg/L), **Fluorescent Dissolved Organic Matter** (fDOM) (RFU), **Chlorophyll-*a*** (Chla-*a*) (RFU) and **Phycocyanin** (RFU)

Algae : Nutrients

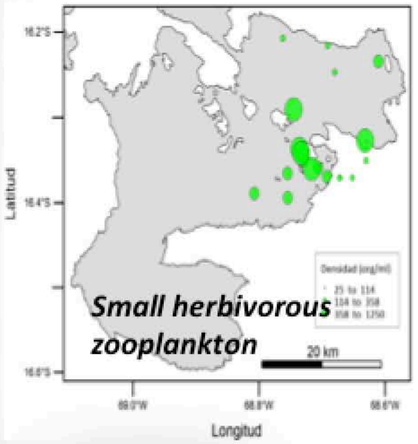


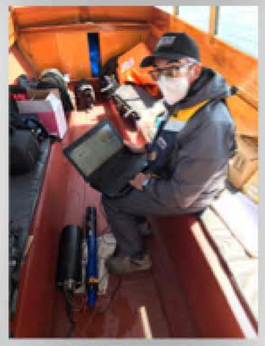
Phytoplankton & Periphyton

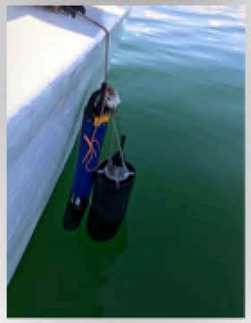




Zooplankton





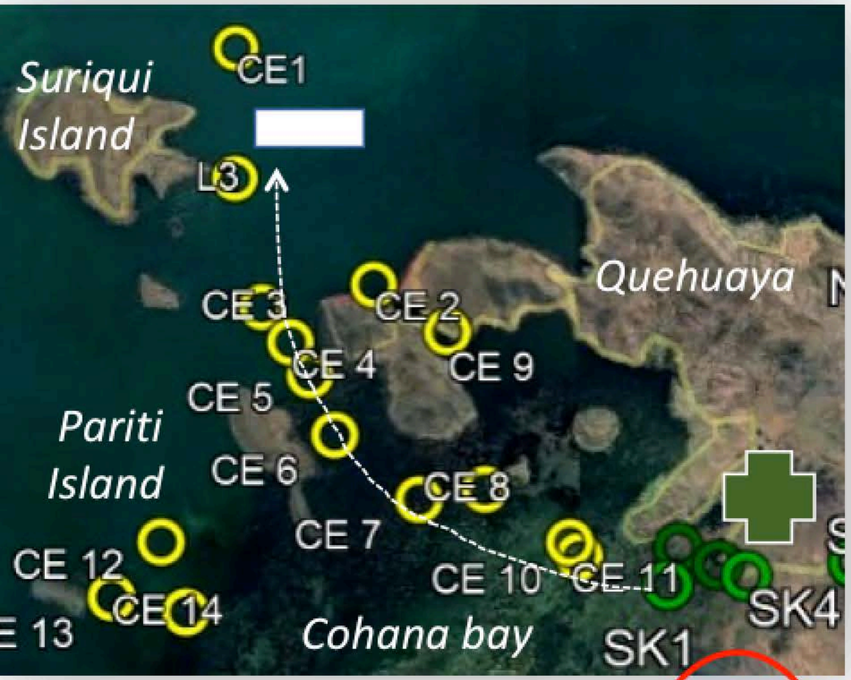


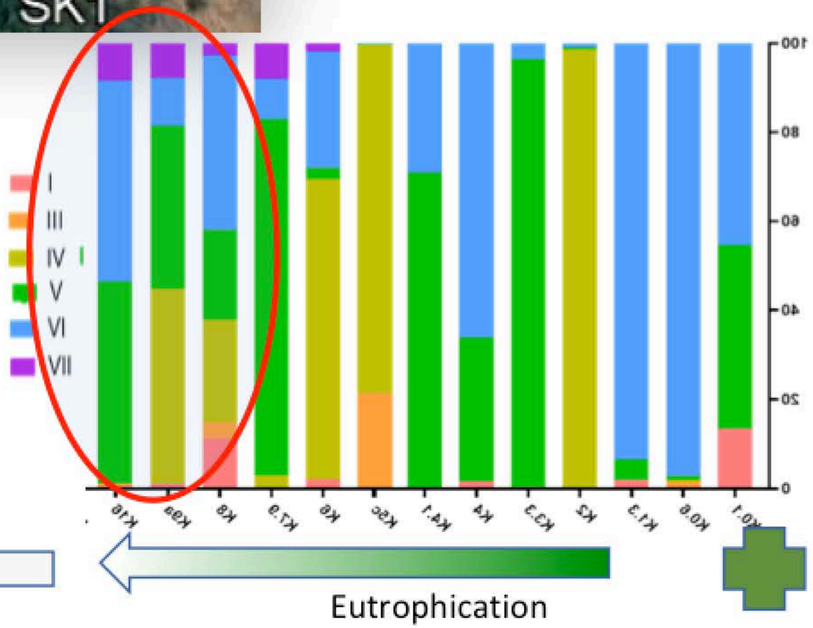
(Vivian Cruz & Gustavo Lanza elaboration)

(Ana Julia Flores elaboration)

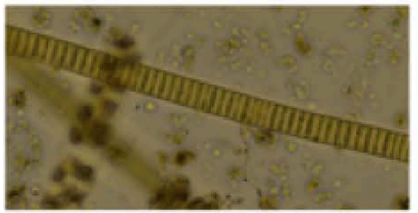
RESULTS

KRUK et al.'s (2010) PHYTOPLANKTON MORPHOLOGY-BASED FUNCTIONAL GROUPS (I TO VII), ALONG A DECREASING EUTROPHICATION GRADIENT





Cohana bay Outlet -> Minor Lake



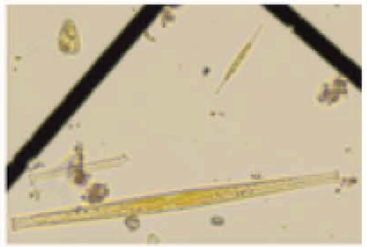
Oscillatoria (G-III)

Anabaena (G-III)

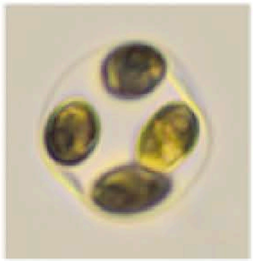
Euglena (G-V)

Cryptomonas (G-V)

Carteria (G-V)



Synedra (G-VI)



Oocystis (G-VII)

Spirogyra (G-IV)

Tetraedron (G-I)

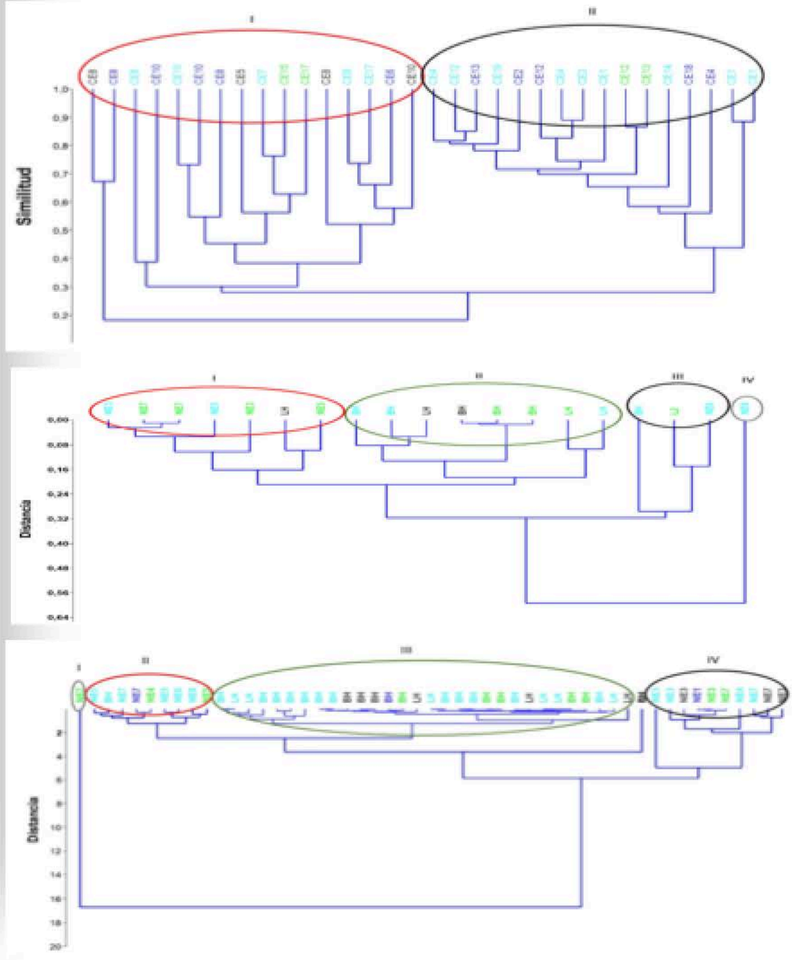
(Viviana Cruz elaboration)

RESULTS

SIMPLIFYING TO A MINIMUM NETWORK OF 17 LIMNOLOGICAL MONITORING STATIONS

(Gustavo Lanza elaboration)

Cluster Analysis for physico-chemical and Biological data: UPGMA method - Euclidean distances - Bray Curtis Index



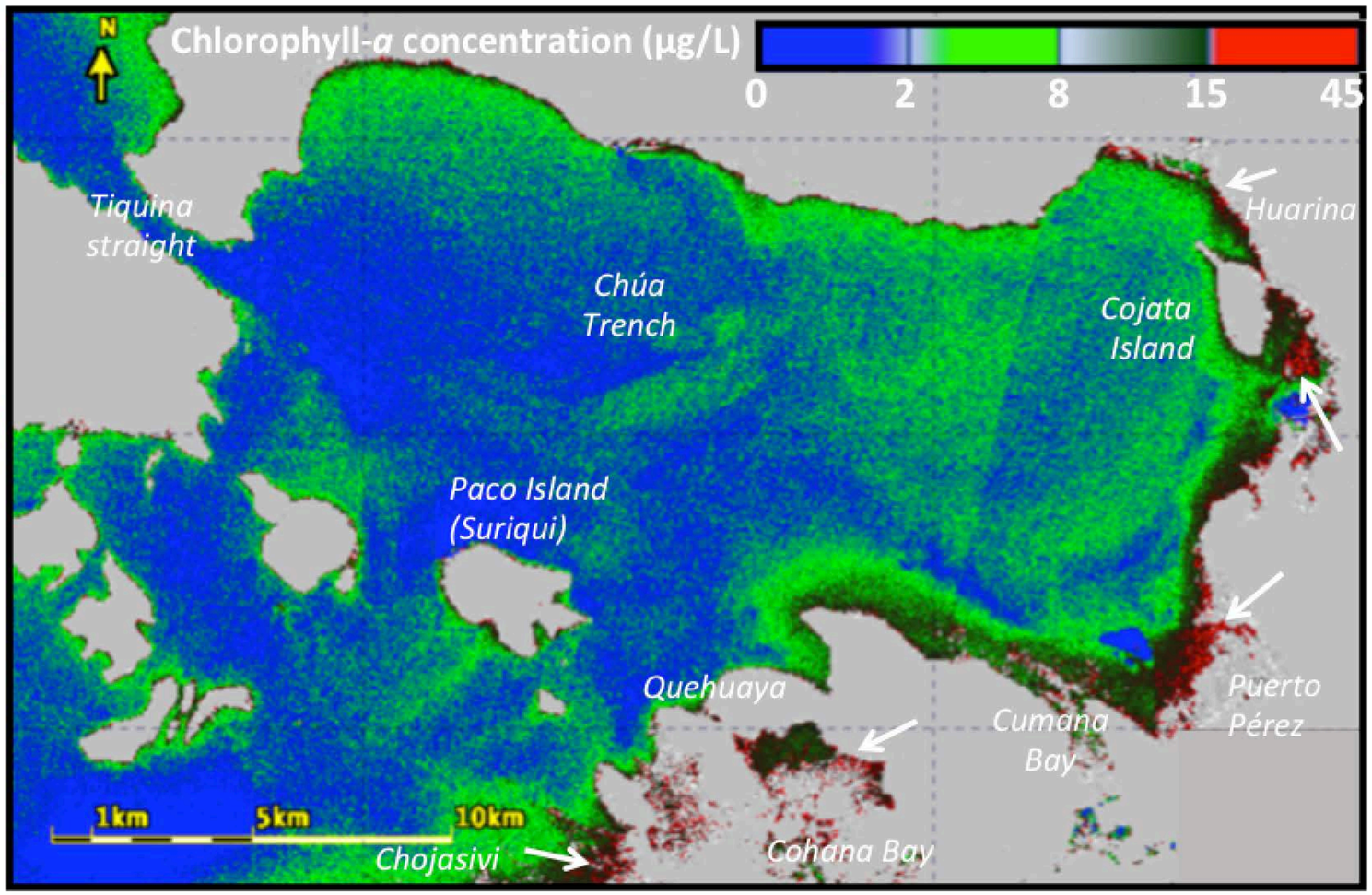
RESULTS

CHLOROPHYLL-*a* SATELLITE REMOTE SENSING: ATMOSPHERIC CORRECTION PLUS VALIDATION WITH *IN SITU* MEASUREMENTS (YSI EXO2 MULTIPARAMETRIC PROBE)

26/04/22, Sentinel 2 image (spatial resolution 10 m), natural color (RGB, B4-B3-B2 bands), iCOR 10 m atmospheric correction, spatial resolution 10 m/pixel *(Javier Maldonado elaboration)*

Chlorophyll-a (Chl-a) = principal photosynthetic pigment of microalgae = proxy for phytoplankton biomass

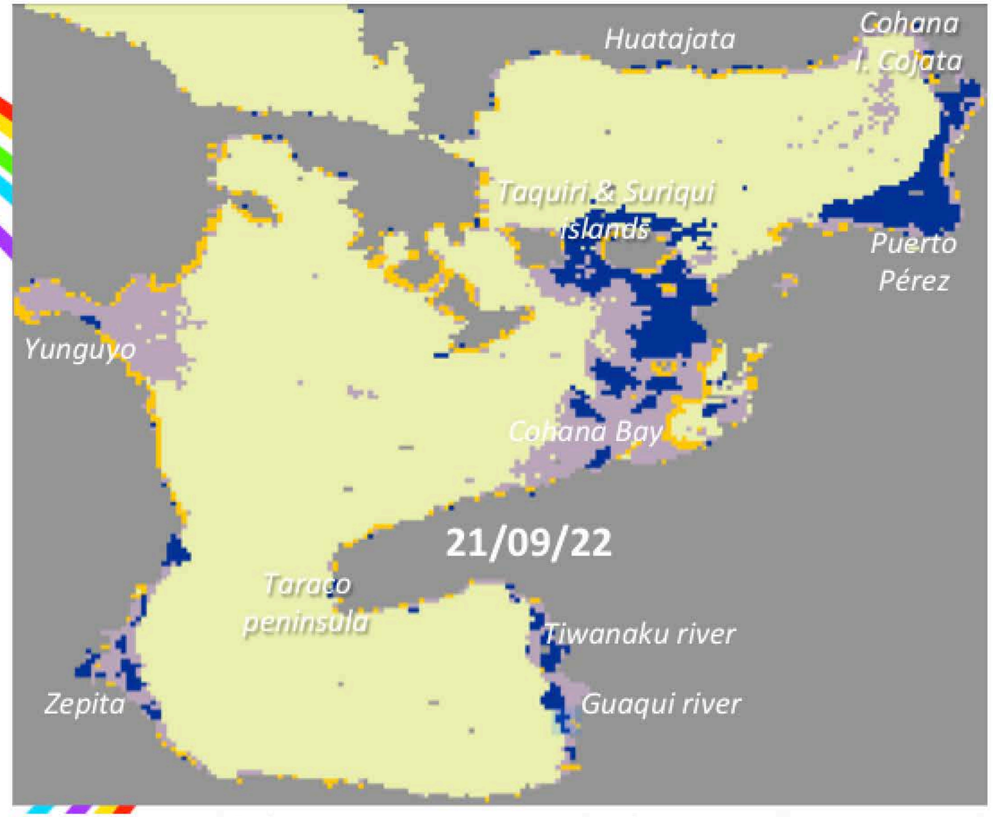
This is the only way to get values for chlorophyll-a concentrations →



26/04/22, Sentinel 2 image of **chlorophyll-*a* concentration (µg/L)**, with iCOR 10 m atmospheric correction and algorithm generated from a validation synchronized to the satellite pass with *in situ* measurements using the YSI EXO2 probe *(Javier Maldonado elaboration)*

RESULTS

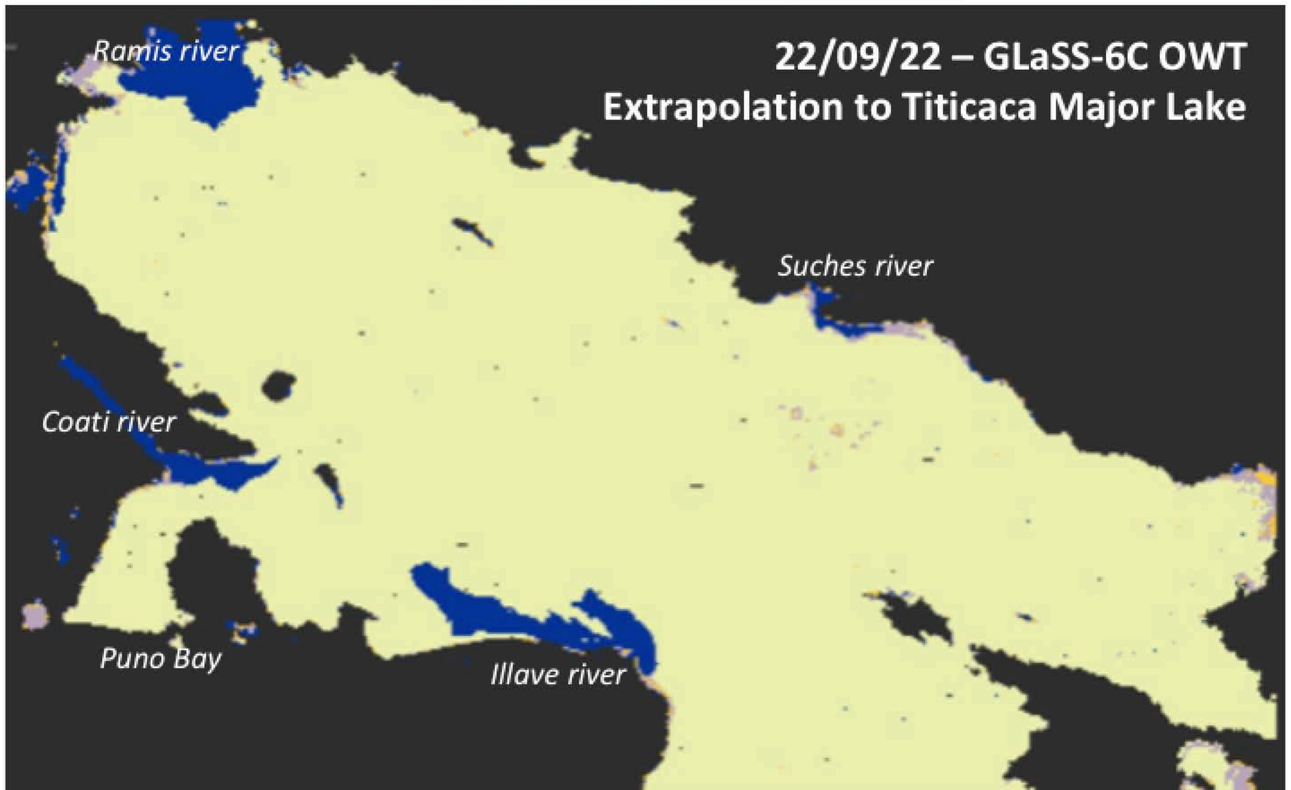
4. Satellite remote sensing of eutrophication status with the Global Lakes Sentinel 3 Services (GLaSS-6C OWT) algorithm
(spatial resolution 300 m; prepared by Javier Maldonado)



Label	Colour	Value	Frequency
class_1		1	78.546%
class_2		2	3.500%
class_3		3	11.049%
class_4		4	6.905%
class_5		5	0.000%
class_6		6	0.000%

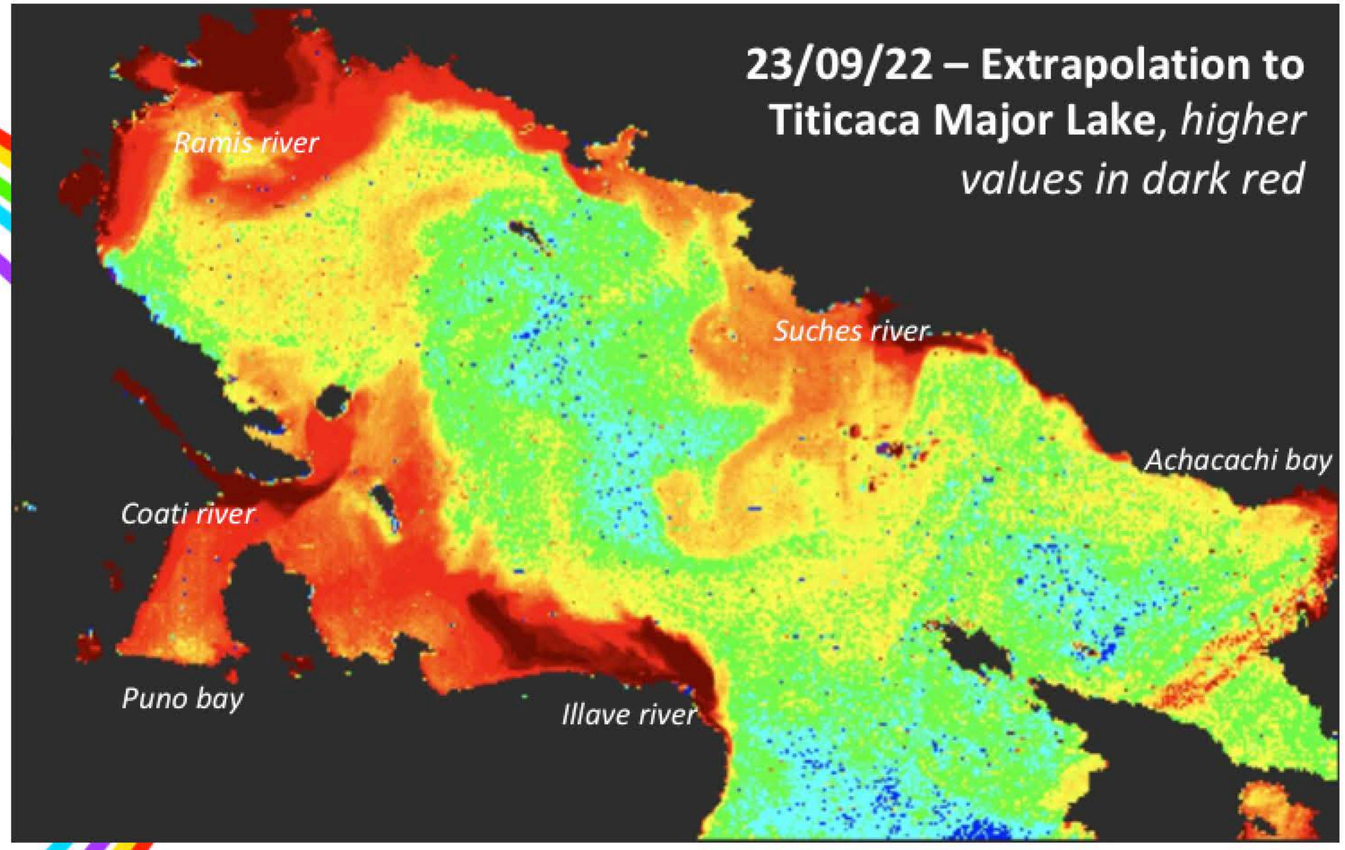
OWT	Chl min	Chl median	Chl max	CDOM min	CDOM median	CDOM max	TSM min	TSM median	TSM max
1	0.1	1.6	12.3	0.04	0.17	1.03	0.15	1.34	14.70
2	0.8	7.2	69.6	0.9	4.8	20.43	0.87	27.18	52.28
3	1.3	24.0	33.0	0.05	2.6	8.0	0.28	16.76	208.9
4	0.9	107.0	705.0	0.27	4.2	18.67	1.70	37.65	190.07
5	0.8	27.0	86.1	0.2	1.17	17.0	3.10	54.03	285.6
6	7.5	22.5	450.0	0.32	0.76	1.03	1.4	67.27	250.36

Class 1 = clear water, low chlorophyll-*a*. **Classes 1, 3, a 4** = increased chlorophyll-*a*. **Classes 5 y 6** = waters with sediments. **Class 2** = dark waters throughout with high humic absorption (CDOM). *Eleveld et al. 2017. An Optical Classification Tool for Global Lake Waters,* https://doi.org/10.3390/rs9050420



RESULTS

SATELLITE REMOTE SENSING OF THE CHLOROPHYLL-*A* RANGE USING THE ULYSSYS TOOL (Javier Maldonado elaboration)

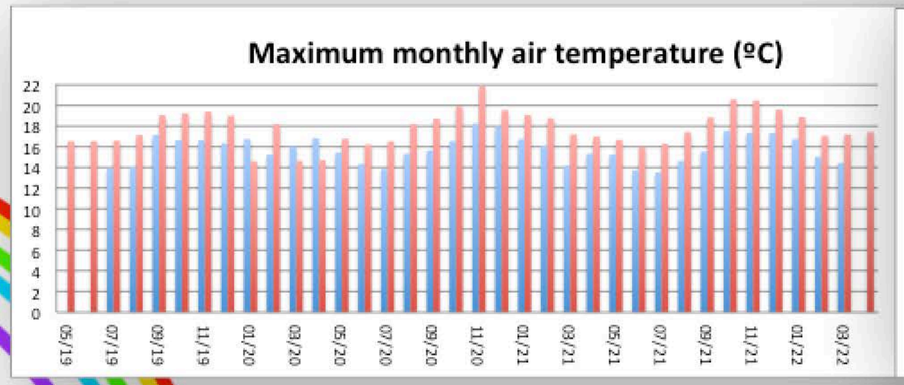


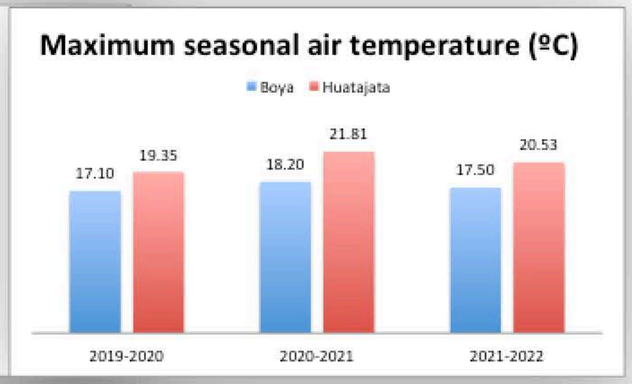
January-May 2022, Northern and Central regions of Minor Lake: Timelapse of the chlorophyll-*a* range (qualitative) using the Ulyssys tool = Water quality visualization script for Sentinel-2 imagery data *(Javier Maldonado elaboration)*

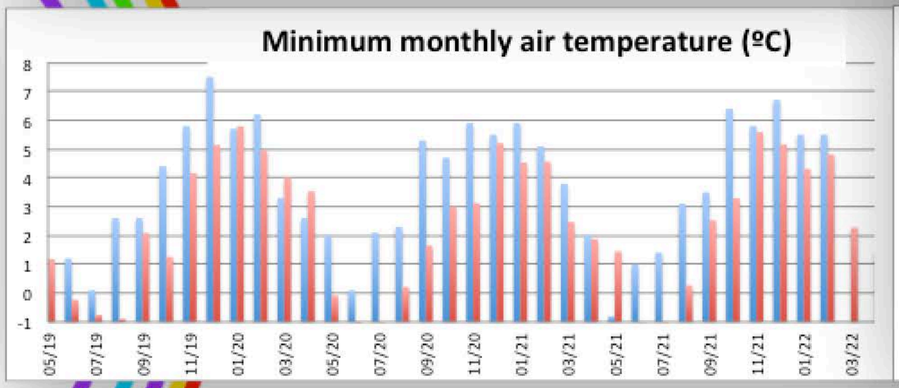
RESULTS

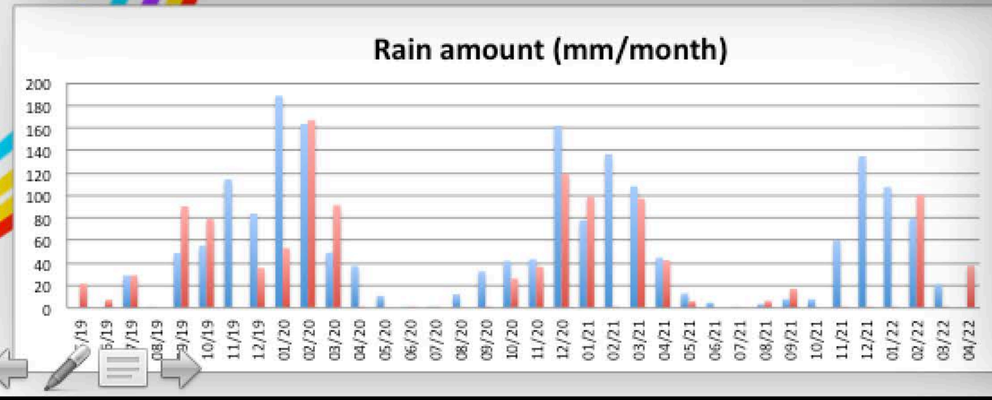
In the lake…

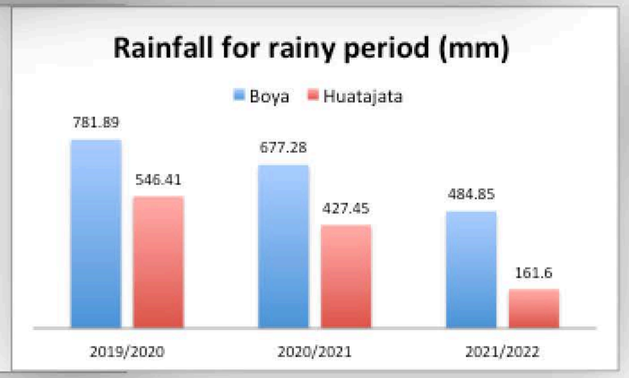
HYDROMET BUOY: 3 YEARS OF HIGH-FREQUENCY MONITORING, CLIMATE CHANGE/WARMING INTENSIFICATION











Increase average air temperature:
+0,2 ºC/966 days ➔ **+0,76 ºC/decade**

Annual rainfall reduction:
-105 mm to -192 mm/year

Reduction of rainfall intensity and duration of the rainy season (July 2019-May 2020, to November 2021-March 2022)

Less intense hailstorms (0.9 impacts/cm² in 2021; 0.2 impacts/cm² in 2022) and fewer hailstorms

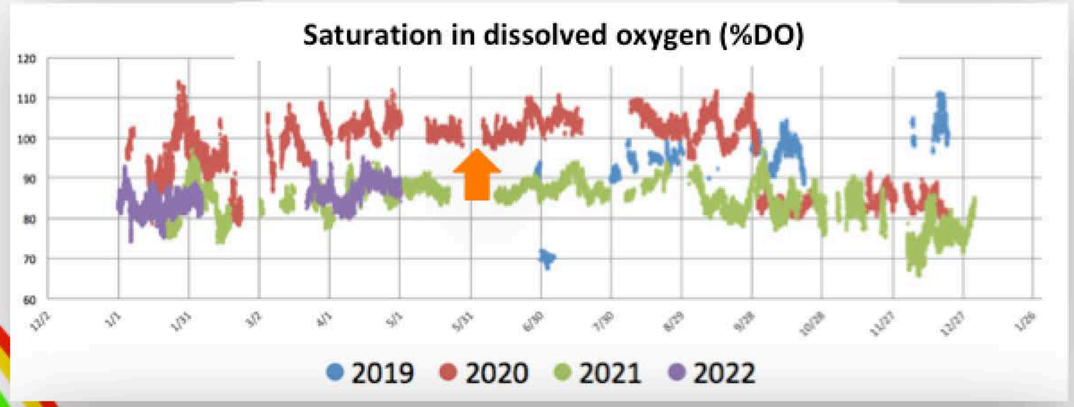
More frequent wind gusts, up to maximum speeds > 16 m/s (> 58 km/h)

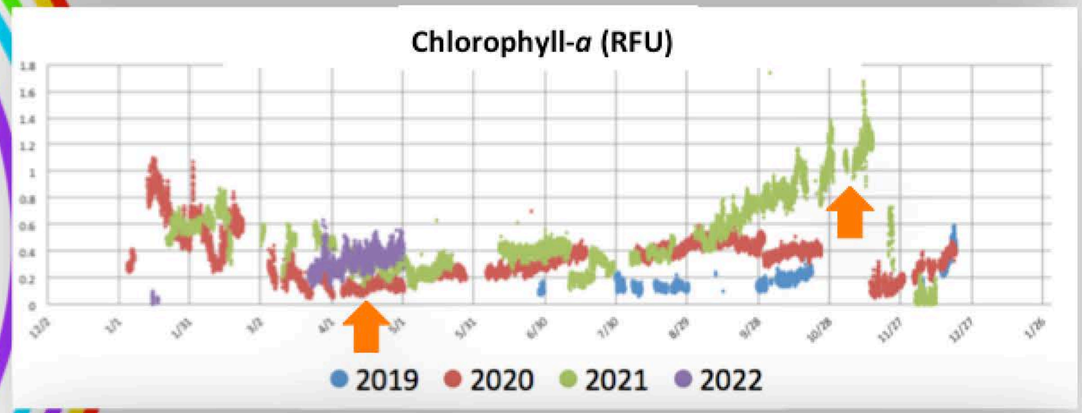
Frequency 5 min: 278.111 records x 7 parameters = **1.946.777 data**

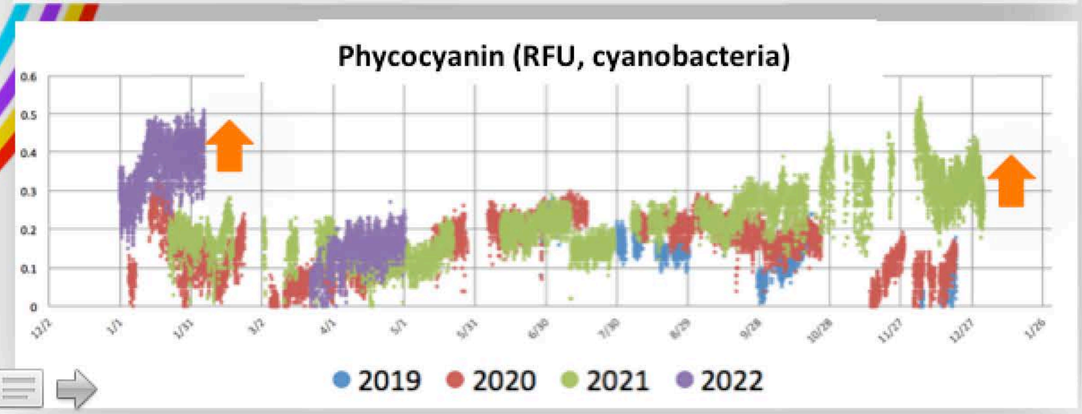
(Xavier Lazzaro elaboration)

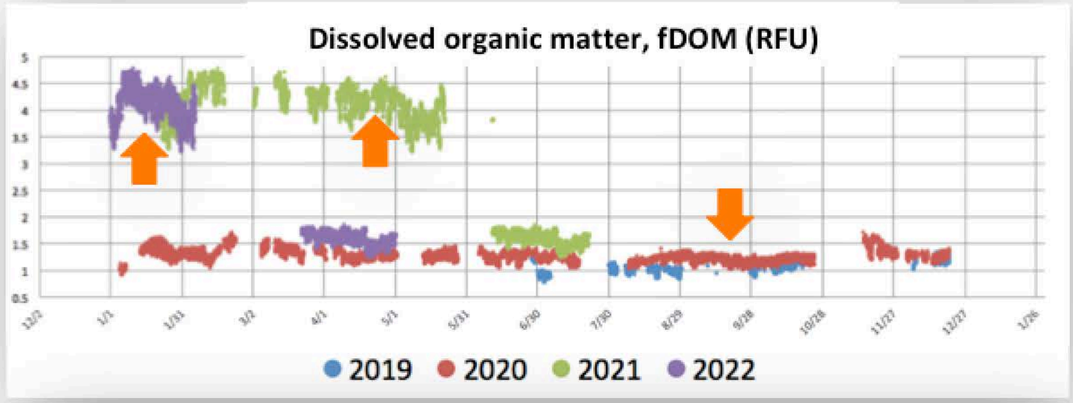
RESULTS

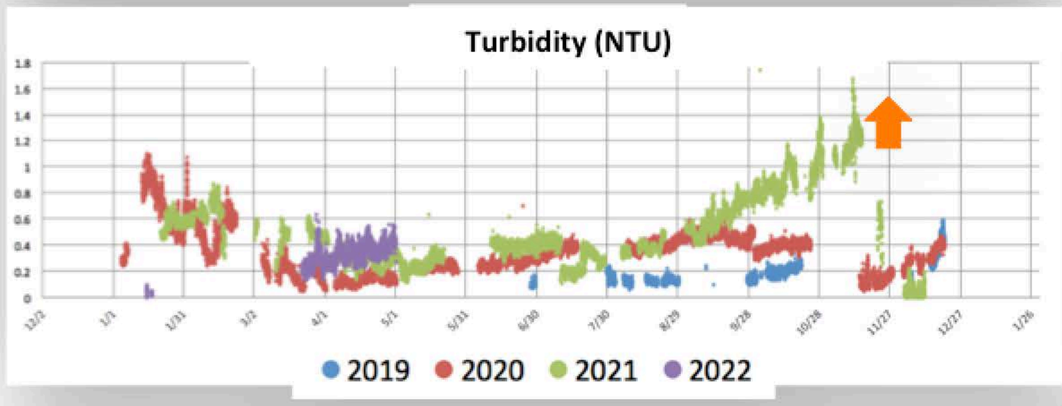
HYDROMET BUOY: 3 YEARS OF HIGH-FREQUENCY MONITORING, CLIMATE CHANGE/WARMING INTENSIFICATION











Frequency 30 min: 29.544 records x 12 parameters = **354.528 data**

(Xavier Lazzaro elaboration)

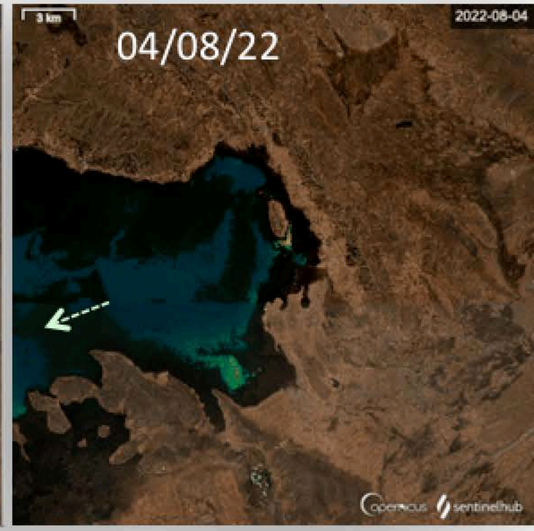
Significant increase in eutrophication level in Center of Northern region where the HydroMet buoy is located

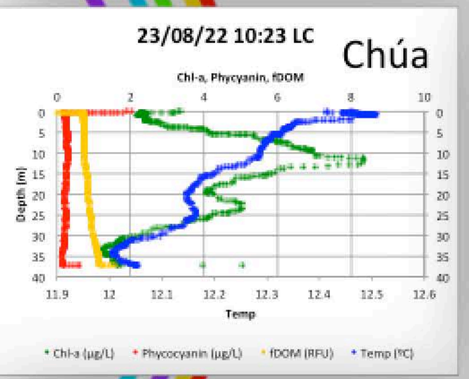
Slight improvement of conditions during confinement illustrates the important effects of human activities in stimulating the eutrophication process

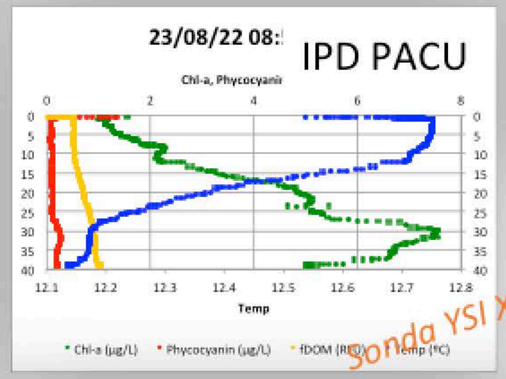
RESULTS

DESIGN AN EARLY WARNING SYSTEM TO ANTICIPATE HARMFUL EUTROPHICATION EVENTS (MICROALGAL BLOOMS)

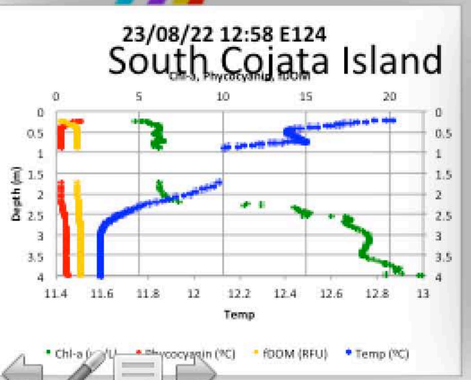
Sentinel-2 images

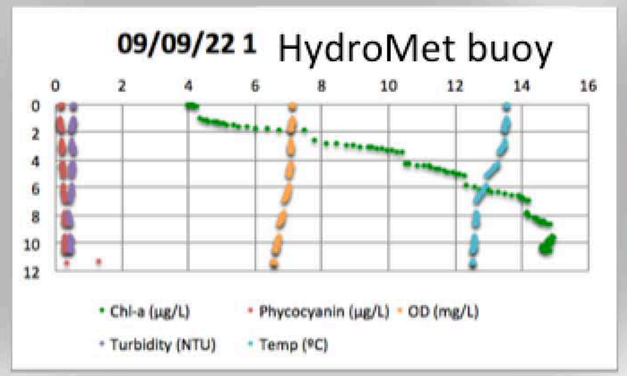




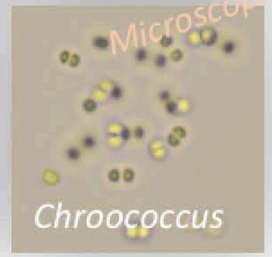


Sonda YSI XO2





55-87%

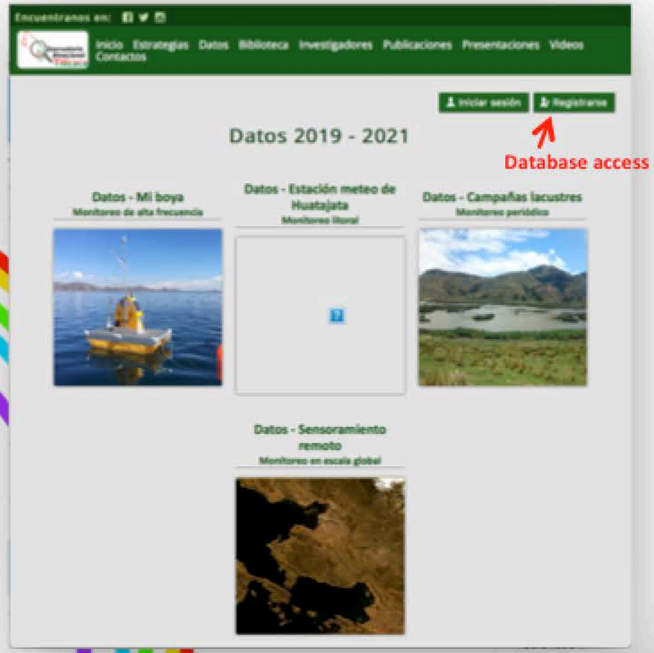


(Xavier Lazzaro elaboration)

➔ **Anticipation of microalgae flowering, not yet a bloom!**

RESULTS

SHARING KNOWLEDGE FROM TECHNICAL-SCIENTIFIC PUBLICATIONS AND THE OLT WEB SITE



- **13 Quarterly reports** and technical reports (+ scientific attachments)
- **OLT Web Site** design and creation
- **3 Information brochures** accessible to the general public
- **Guide & Tutorials** on methods, equipment
- **Synthesis book** of results and perspectives
- **Scientific articles** (2 published and 4+ in preparation)
- **Academic training** (3 Master's Degrees and 1 Engineering Degree to be completed)

OLT website: olt.geovisorumsa.com

(Marcela Ormachea webmaster)

Cartillas educativas


Ecología en Bolivia

Editorial

HydroMet: La primera boya automática perfiladora con alta-frecuencia en el Lago Titicaca, el más alto de los Grandes Lagos del mundo

HydroMet: The first automatic high-frequency profiling buoy on Titicaca Lake, the highest of the Large Lakes of the world


REVIGEO – Revista del Instituto de Investigaciones Geográficas
UNIVERSIDAD MAYOR DE SAN ANDRÉS
CARRERA DE INGENIERÍA GEOGRÁFICA
INSTITUTO DE INVESTIGACIONES GEOGRÁFICAS
REVIGEO – UMSA - ISSN: 2708-3101

COBERTURA DE LA TOTORA A LO LARGO DEL LITORAL BOLIVIANO DEL LAGO MENOR DEL TITICACA EN AÑOS CON EVENTOS EXTREMOS, ENTRE 1986 Y 2019 MEDIANTE SENSORAMIENTO REMOTO

Jhasmin Duarte Tejerina [1*], Mishel Justiniano Ayllón [1*], Javier Alberto Maldonado Alfaro [1] Javier Nuñez Villalba [1] & Xavier Lazzaro [2]

Published scientific articles + four in prep.

PERSPECTIVES

- To sustain the **OLT Observatory** as a **Long Term Program** towards a **Binational Observatory - OBLT**, as the automatic **Real Time Monitoring System** of the global ecological state of the lake
- Operate the **Early Warning System** based on **Satellite Remote Sensing of [chlorophyll-*a*]** validated *in situ* by sampling/measurements and **high frequency monitoring** of the HydroMet Buoy
- Deploy **new buoys** to monitor river discharges ➔ Create a **Binational Buoy Network**
- Develop **biotic and abiotic indices** of ecological quality according to the **European Water Framework Directive (WFD-EU) approach**, which can be agreed upon and considered in environmental regulations at the binational level
- On the **website**, view **data in real time** using the **RTMC Pro application** (Campbell Scientific)
- Use the OLT Observatory to validate the **efficiency of the phytoremediation system with cattail** (totora floating islands, artificial wetlands with aquatic macrophytes, Pilot 03-B-03, *PI Darío Achá*): experiment at full scale

Restoration: Because of **weak trophic cascades** (no piscivores, small herbivorous zooplankton), **remediation using aquatic macrophytes** probably best ecological engineering approach. Else, could test the **OXY PLUS™ system in Mobile Unit** (Dellepere Enterprises) to purify tributary rivers, prior entering lake, by injection of **ozone, oxygen and UV light**

OLT is a **promoter of state-of-the-art technology, interdisciplinarity, binational collaborations,** in transboundary Lake Titicaca, the highest Great Lake, and largest freshwater lake in South America.

➔ **STILL UNSTUDIED: Climate change x eutrophication synergistic effects! River wastewater discharges!**

PERSPECTIVES

MAKING THE LAKE TITICACA OBSERVATORY SUSTAINABLE !

What is the value of Lake Titicaca? *(*answer below)*

OLT PNUD pilot (equipment excluded): 100 K U$/3 years (almost 4), 4 contracts ½ time 6 months/year, - 37% (taxes + AFP)

Proposal for the long-term sustainability of the OLT Observatory:

a) ➔ **Financing** by Bolivia via **ALT** (+ Peru for the binational OBLT)

Annual monitoring activities	Amount (K U$)	%
4 ½ time contracts (academic specialists)	36.6	63
Missions 6x1 day, 1x2 days, 2x3 days	5.2	9
Consumables (maintenance)	4.6	8
Training	0.8	1
Contingency reserve	10.8	19
TOTAL CONSERVATIVE COSTS	**58.0**	

In 2023: Acquisition of INTI Boat for Scientific Research: 20 K U$ essential for logistics

b) ➔**Monitoring (1/2 time) by UMSA researchers and students:** guarantees the quality of data acquisition, analysis, interpretations, conclusions, recommendations for public policy

c) ➔**Ecological/biogeochemical research** (1/2 time) by UMSA and other Univ.: through Master's and PhD training programs in Bolivia, and abroad

Lake Titicaca is of inestimable value! => monitoring cost is inexpensive !

GIRH TDPS

PARTNERS and BENEFICIARIES

Beneficiaries:

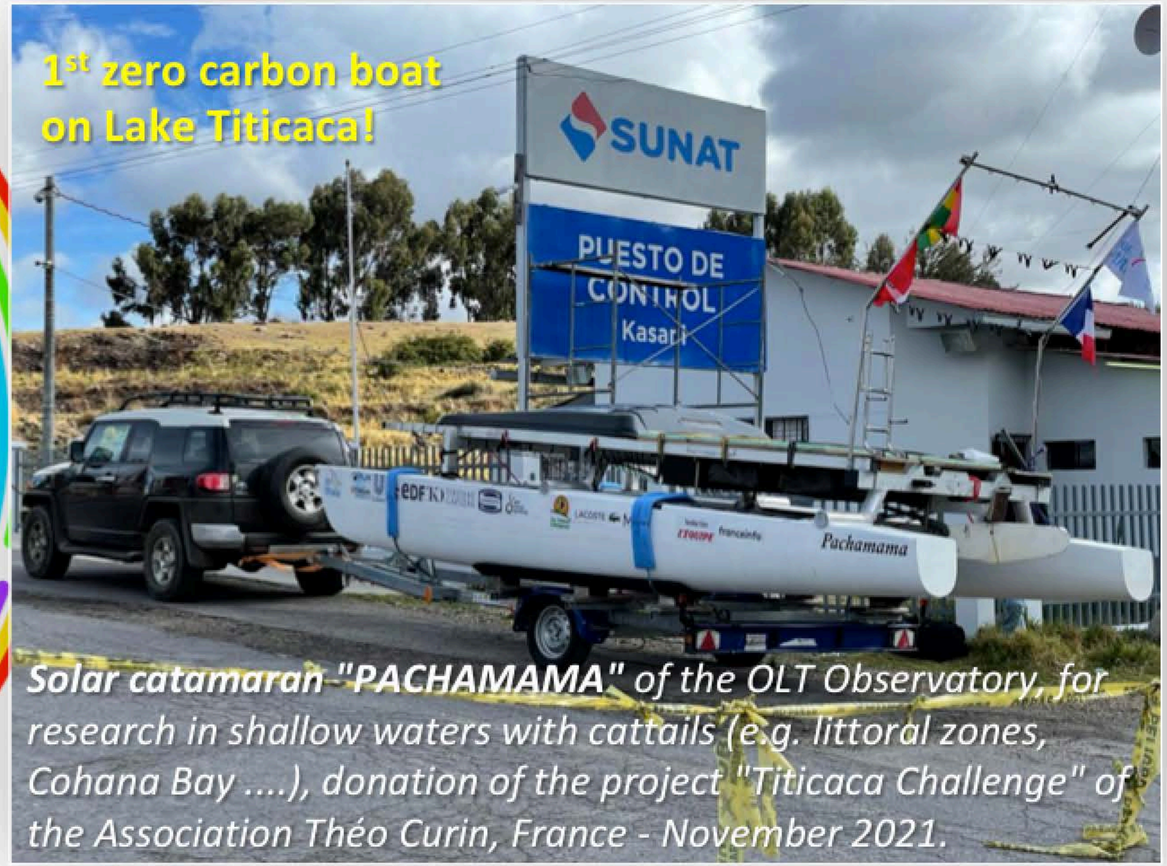
- **Municipalities** of Puerto Pérez, Huarina, Huatajata, Batallas, Chúa, Copacabana
- **Communities** of Quehuaya, Suriqui, Pariti, Pariti, Taquiri, Sicuya, Kalauta, Cohana, Cumana, Chojasivi, Taraco
- **Society in general**

CONTACTS

Síguenos como: @girhtdps

OLT website: olt.geovisorumsa.com
Web master: andremar985@gmail.com

Coordinator: xavier.lazzaro@ird.fr
WhatsApp: +591 7202 6879



Solar catamaran "PACHAMAMA" *of the OLT Observatory, for research in shallow waters with cattails (e.g. littoral zones, Cohana Bay ....), donation of the project "Titicaca Challenge" of the Association Théo Curin, France - November 2021.*

Viviana Cruz, vchrz11@gmail.com
Marcela Ormachea, andremar985@gmail.com
Gustavo Lanza, wilanz66@gmail.com
Javier Maldonado, javier.maldonado.alfaro@gmail.com
Javier Nuñez, jnunezvillalba@gmail.com
Pierre Sterling, pierre.sterling@xyleminc.com
Erik & Máximo Catari, erikcatarig@gmail.com
Isaac Callizaya, islapariti21@gmail.com
Oscar Limachi, +591 71279345

https://dipgis.umsa.bo/index.php/2022/04/06/embajada-de-francia-dona-un-catamaran-a-la-umsa-para-el-proyecto-observatorio-permanente-del-lago-titicaca/

Thank you!