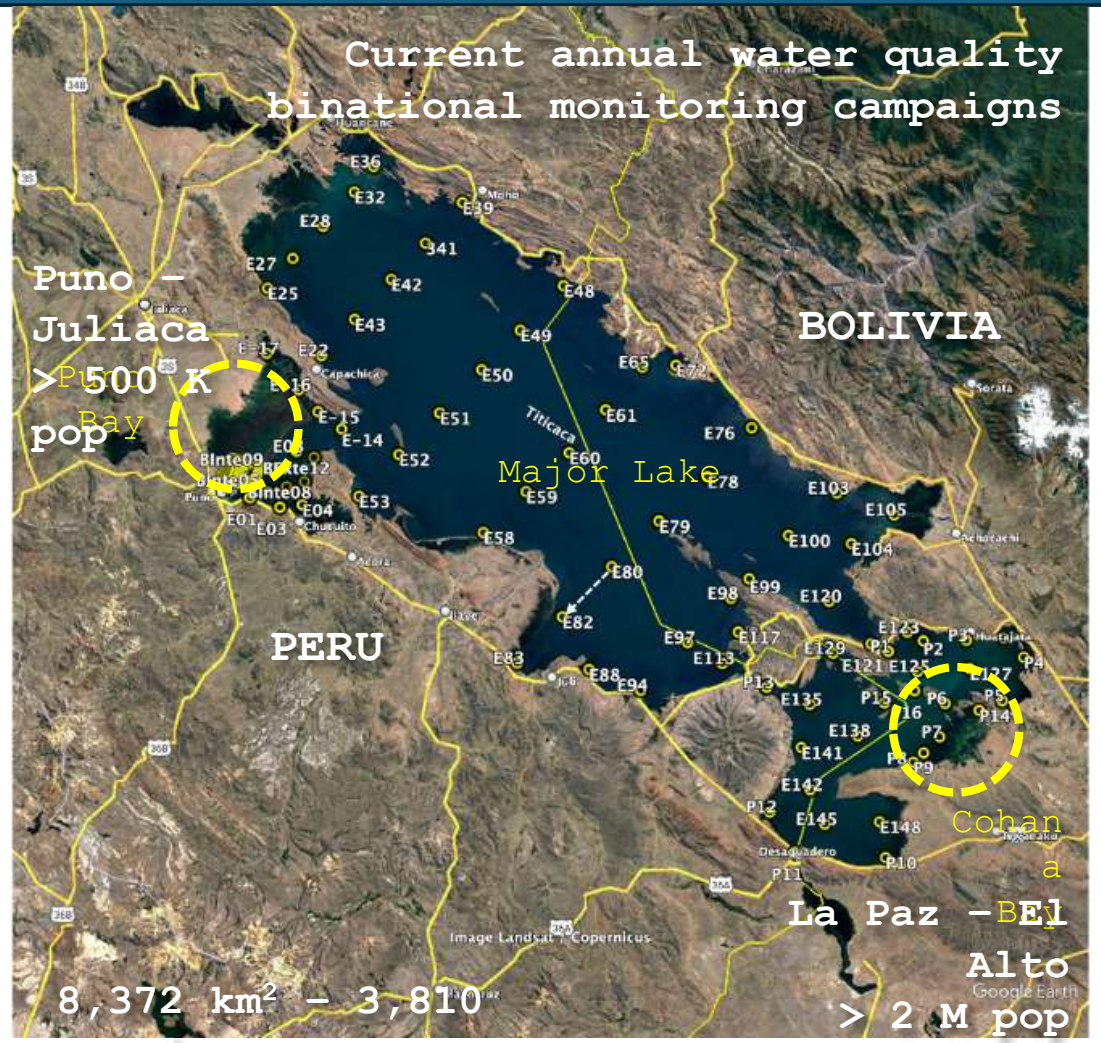
Limnológical Monitoring of Lake Titicaca – Puno Bay Case Study

Trophic States (OCDE 1982) vs. Optical States (OWT 2017), Algal Blooms Early Warnings & Urgent Management Recommendations

Uros floating islands – Willy river



Ph.D. Xavier Lazzaro
xlazzaro
@alt-perubolivia.org

MSc. Javier Maldonado Alfaro
javier.maldonado.alfaro
@gmail.com

INBO World Basin Summit 17/06/2026 - Session 1 - DATA: From data to action: modernizing water resources monitoring for resilient basin management

Current Limitations

Annual water quality binational monitoring campaigns (2014+)

- Spot sampling ~70 points, 2-week campaigns, 2 scientific boats, tens of specialists, >2 months data analysis and interpretation (reactive)
- **High costs: fossil fuel (diesel) + logistics**
- **Surface measurements 20-30 cm**
- Mostly pelagic zones, not shallow littoral
- **GOAL: permissible thresholds respected based on water quality standards (Peruvian ECA)**
- 20 physicochemical parameters + 2 coliforms + >21 trace metals: not major limnological variables
- **Ecological health not evaluable**
- **Impossible forecasts and early warnings**
- Management recommendations by parameter

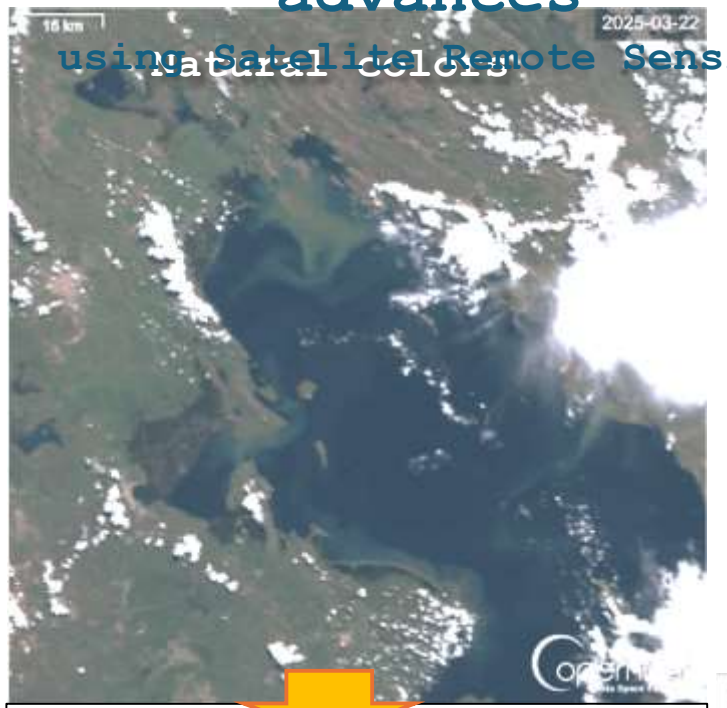
(1) Technological advances

Submersible multivariate YSI EXO2 probe

- Surface-bottom profiles (100 m)
- High frequency (1 Hz)
- Real-time
- Variables: Cond, Temp, ODO% CB, pH, ORP, Turb, Chl-*a*, Phycocyanin,

(2) Technological advances

using Satellite Remote Sensing



Lake responses to climate changes and human pressures?

Proposed innovative monitoring

In high frequency and real time

- Determine trophic states (OECD 1982) spatial distribution
- Disrciminate zones using Cluster Analysis
- Identify key variables using PCA
- Determine optical water types (OWT 2017)
- Validate satelite Chlorophyll-*a* data using *in situ* data
- Locate eutrophication zones
- Generate Blooms early warnings
- Suggest protection and restauration measures

Contribute to public policies

In Limnology, Trophic States = a scientific basis for understanding eutrophication processes (response to nutrient enrichment); a practical tool for management, monitoring, and regulation; an early indicator of environmental degradation (algal blooms).

OECD = Organisation for Economic Cooperation and Development

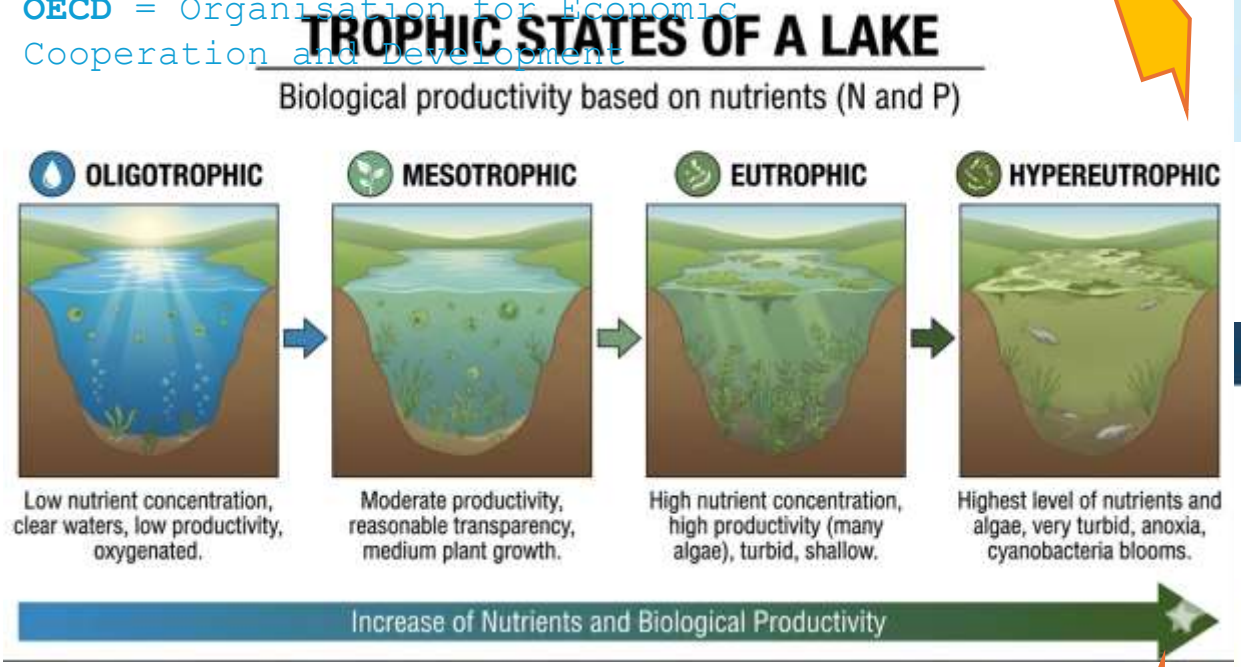
YSI EXO2

OECD (1982) Trophic State Classification Criteria

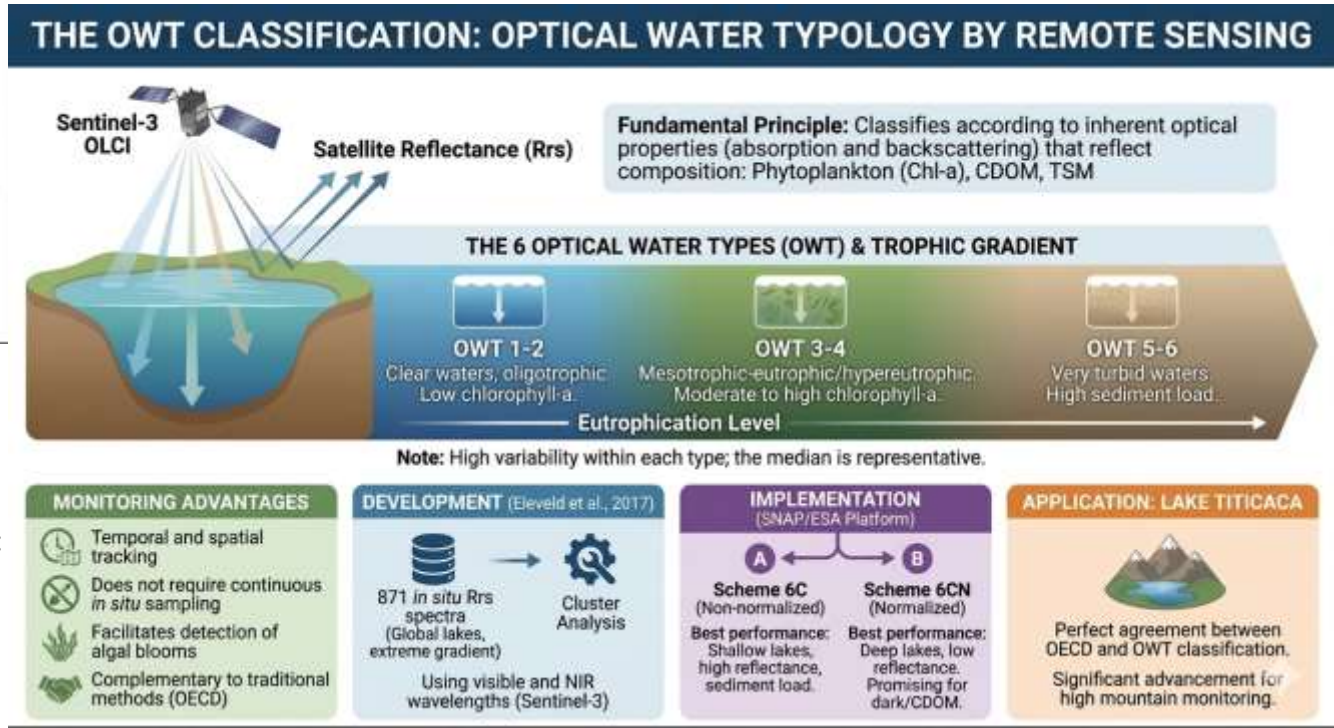
Source: OECD (1982)

Parameter (Unit)	→ INCREASING NUTRIENT LOADING / DECREASING CLARITY → Oligotrophic	Mesotrophic	Eutrophic	Hyper-eutrophic
Total Phosphorus (µg P/L)	3.0 – 17.7	10.9 – 95.6	16.2 – 386	750 – 1200
Total Nitrogen (µg N/L)	307 – 1630	361 – 1387	393 – 6100	
Chlorophyll-*a* (µg Chl-*a*/L)	0.3 – 4.5	3.0 – 11	2.7 – 78[2]	100 – 150
Secchi depth (m)	5.4 – 28.3	1.5 – 8.1	0.8 – 7.0	0.4 – 0.5

*Values indicate range of OECD (1982) criteria.



Eleveld et al.

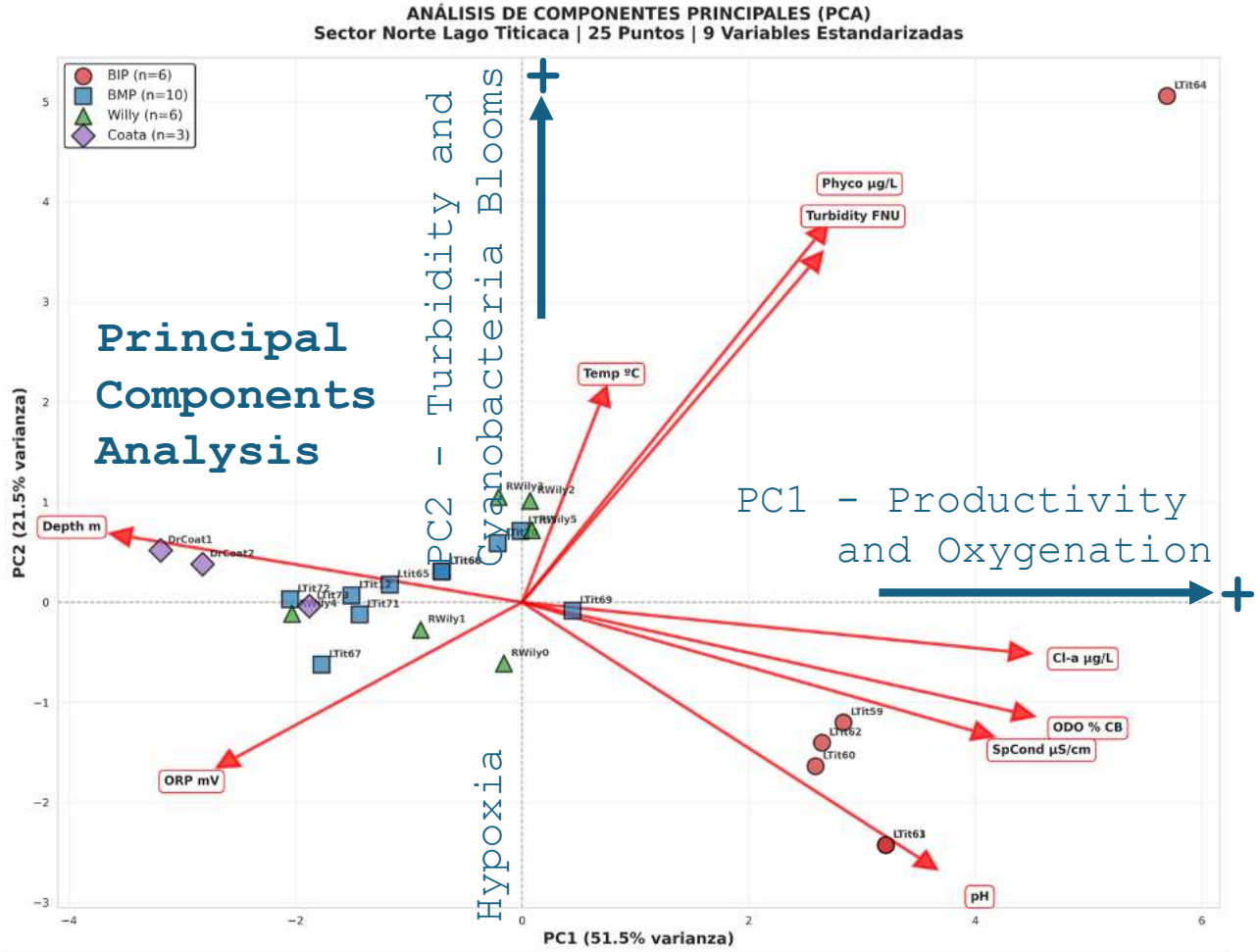


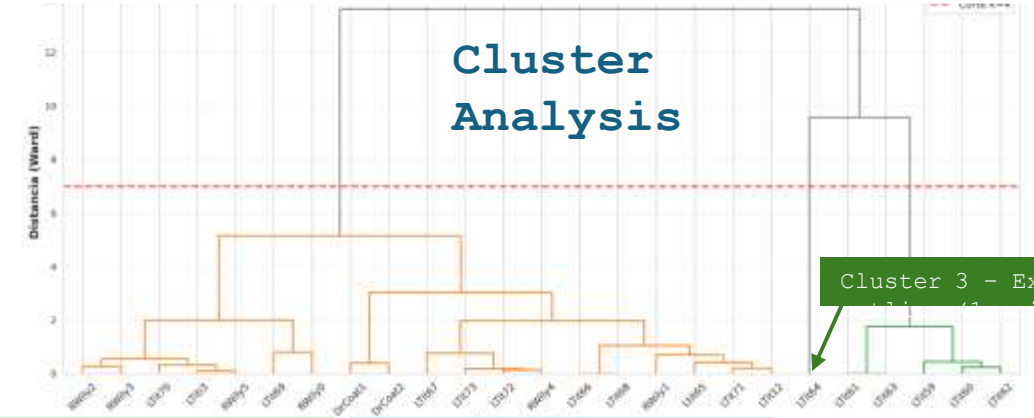
OWT	*Cl-a* (µg/L) min-max	CDOM (g/m³) min-max	TSM (g/m³) min-max
1	0.1 - 12.3	0.04 - 1.03	0.15-14.70
2	0.8 - 69.6	0.9 - 20.43	0.87-52.28
3	1.3 - 33.0	0.05 - 8.0	0.28-208.9
4	0.9 - 705.0	0.27 - 18.67	1.70-190.07

C2RCC / SNAP:
ophyll-*a* (µg/L)
CDOM (g/m³)
TSM (g/m³)

Multivariate statistical analyses

Ultra-oligo | Oligo | Meso | Eutro-Hypereutro





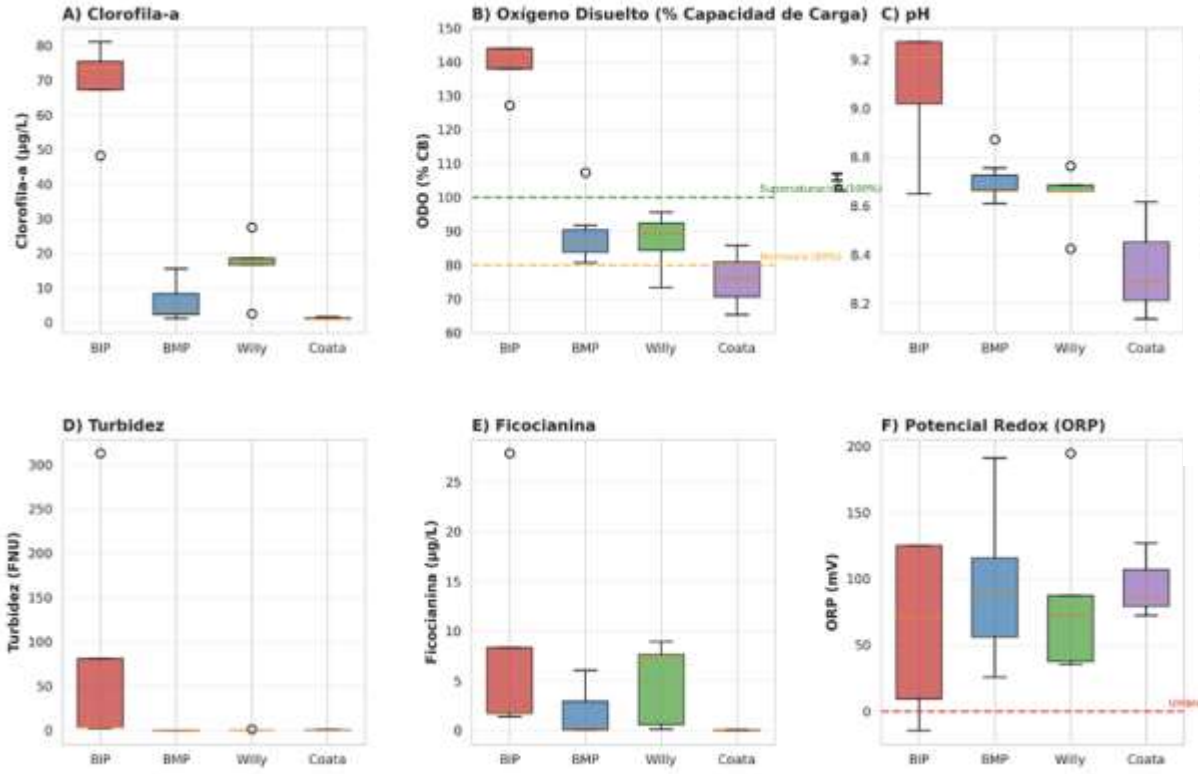
Cluster 3 - Extreme BIP

Cluster 2 - Mixed normoxic (7 points)
BMP - Willy

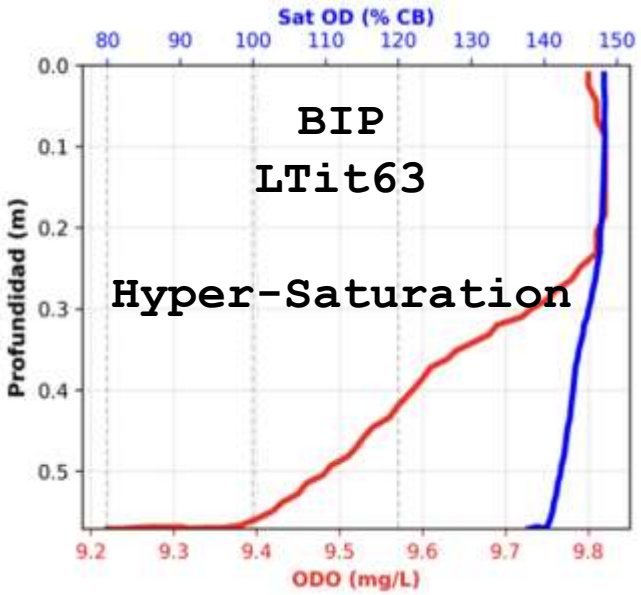
Cluster 1 - Deep oligotrophic (12 points)
BMP - Coata - Willy

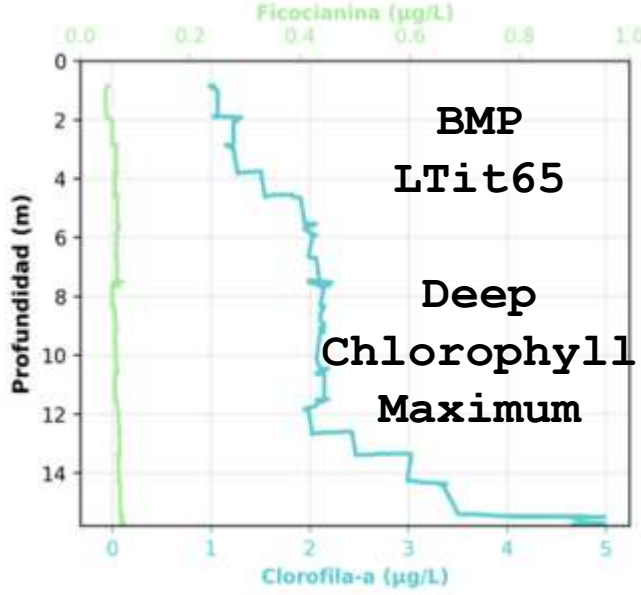
Cluster 4 - Hyper-eutrophic

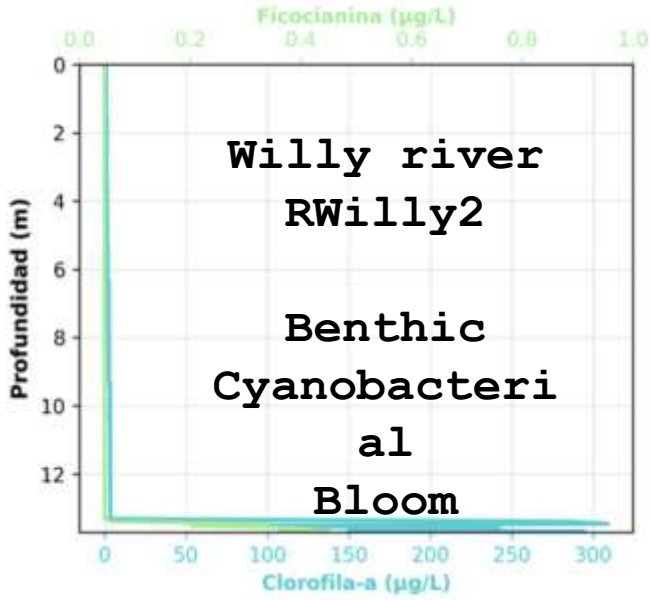
omparative limnological variables by zones

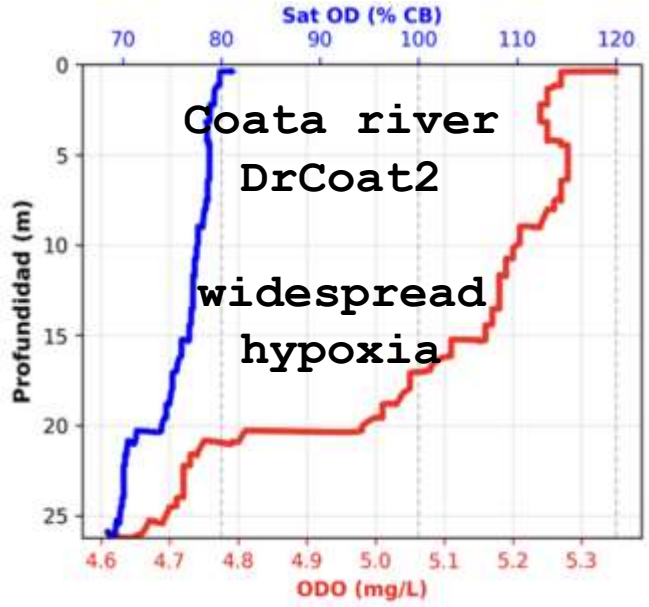


Peculiarities by zones

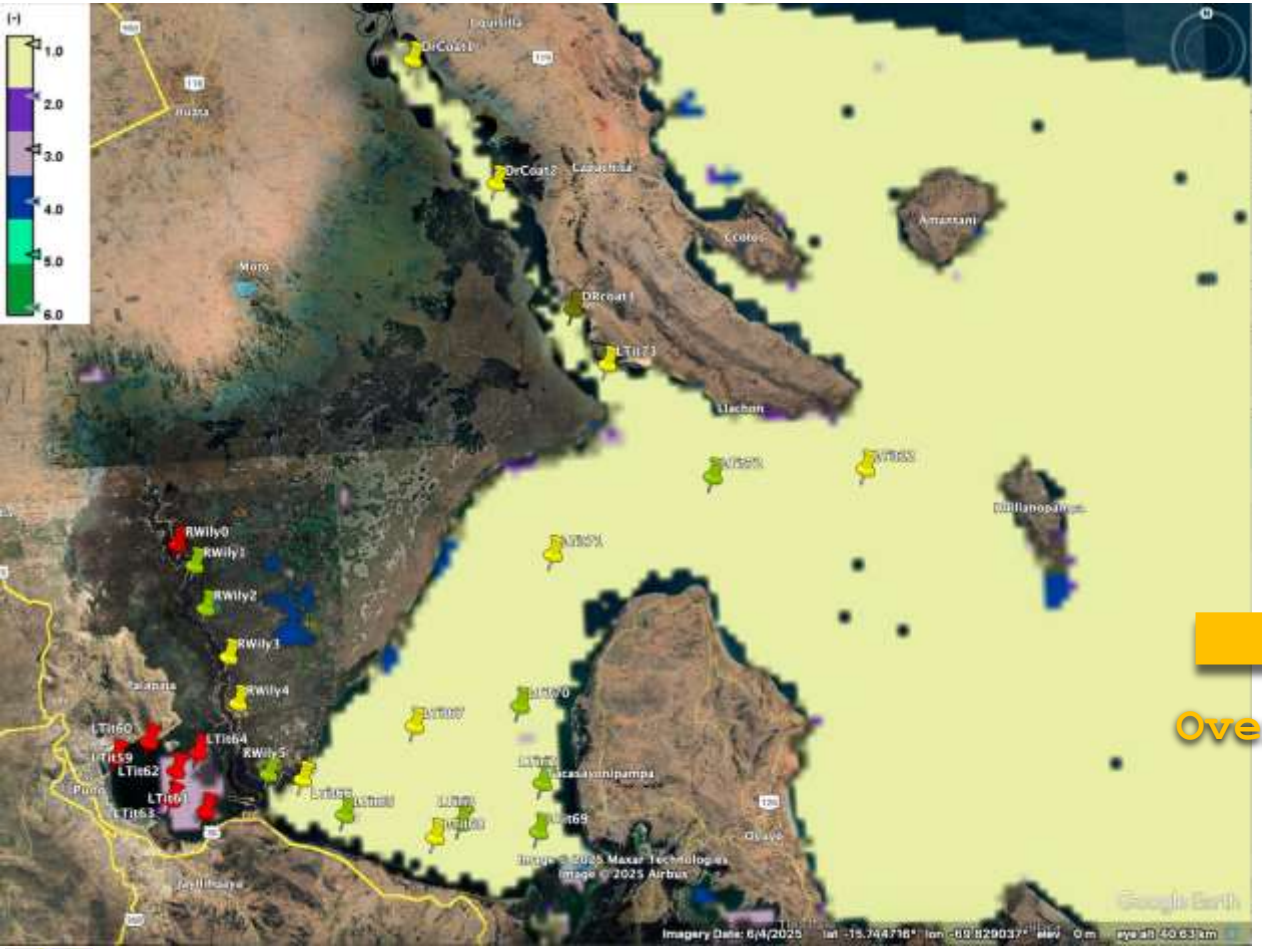


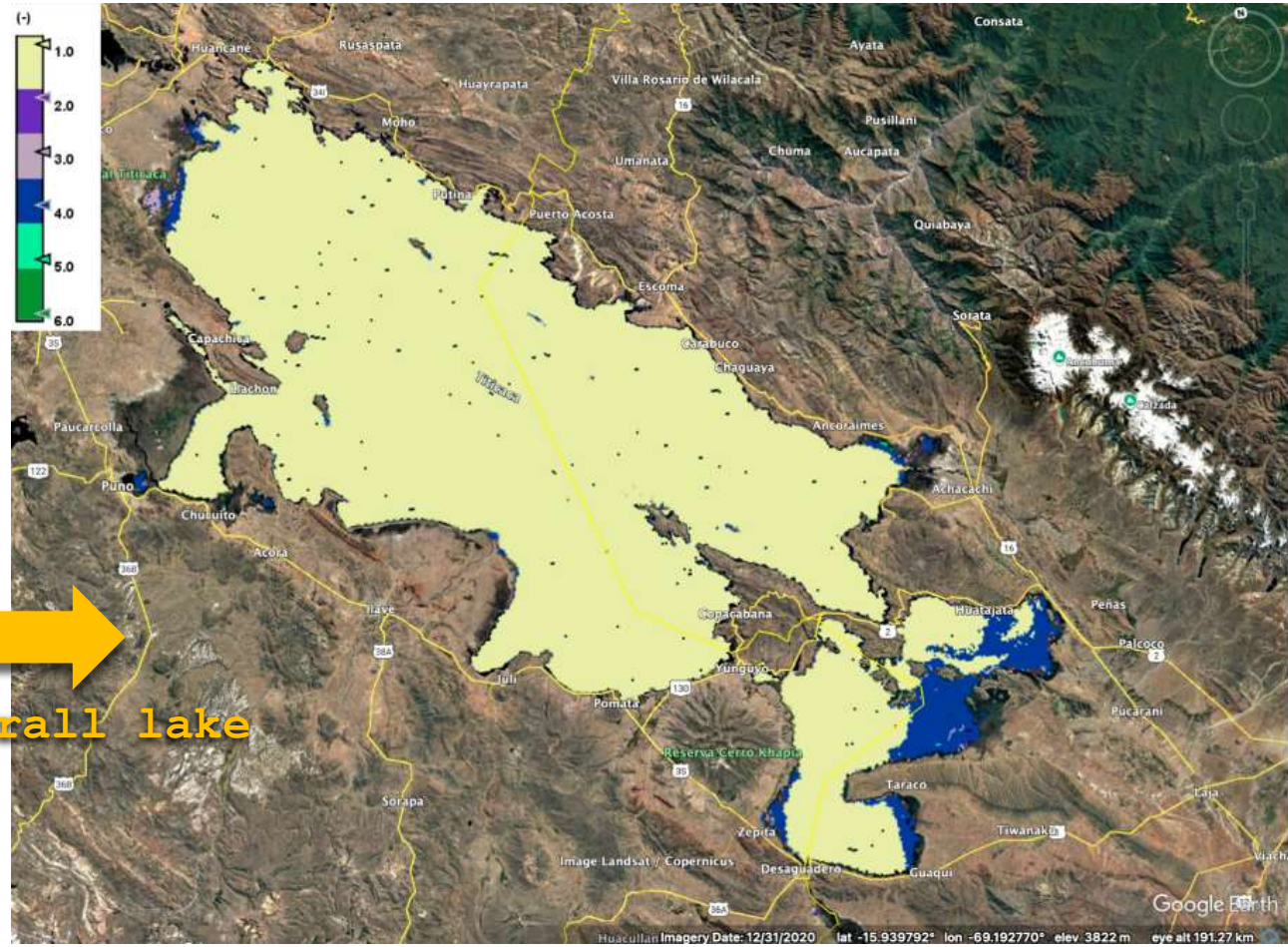






OECD Trophic States vs. OWT States concordance





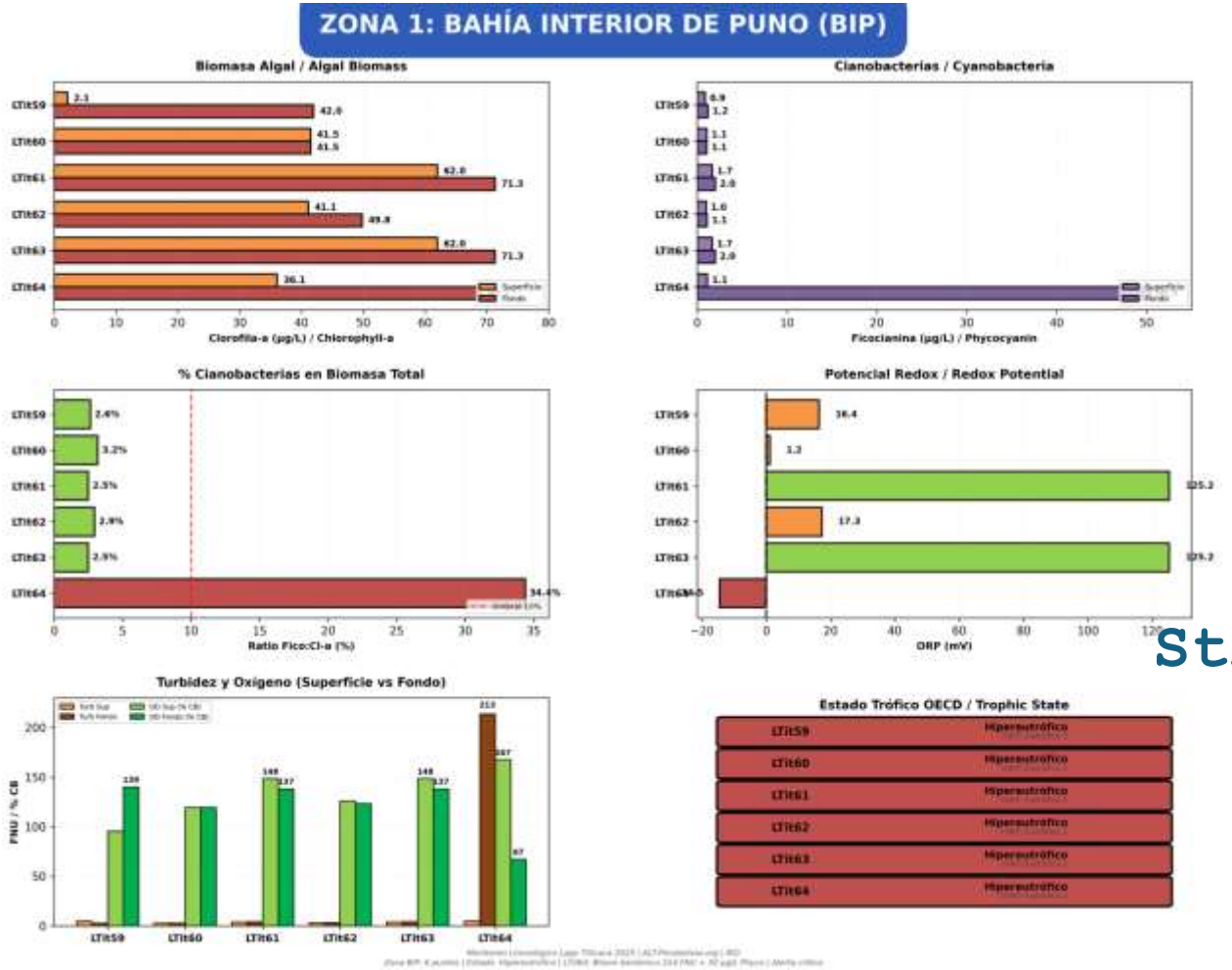
oligotrophic - OWT-1 (10)

mesotrophic - OWT-2 (9)

hyper-eutrophic - OWT-4 (7)

25 *in situ* OWT points overlaid on **Sentinel-3 OWT classification image** (300 m resolution, daily coverage, Aug 22, 2025)

Sentinel-3 OWT clasificación image overlaid on **Google Earth map** (Oct 24, 2024)



Infographics of key characteristi by zone

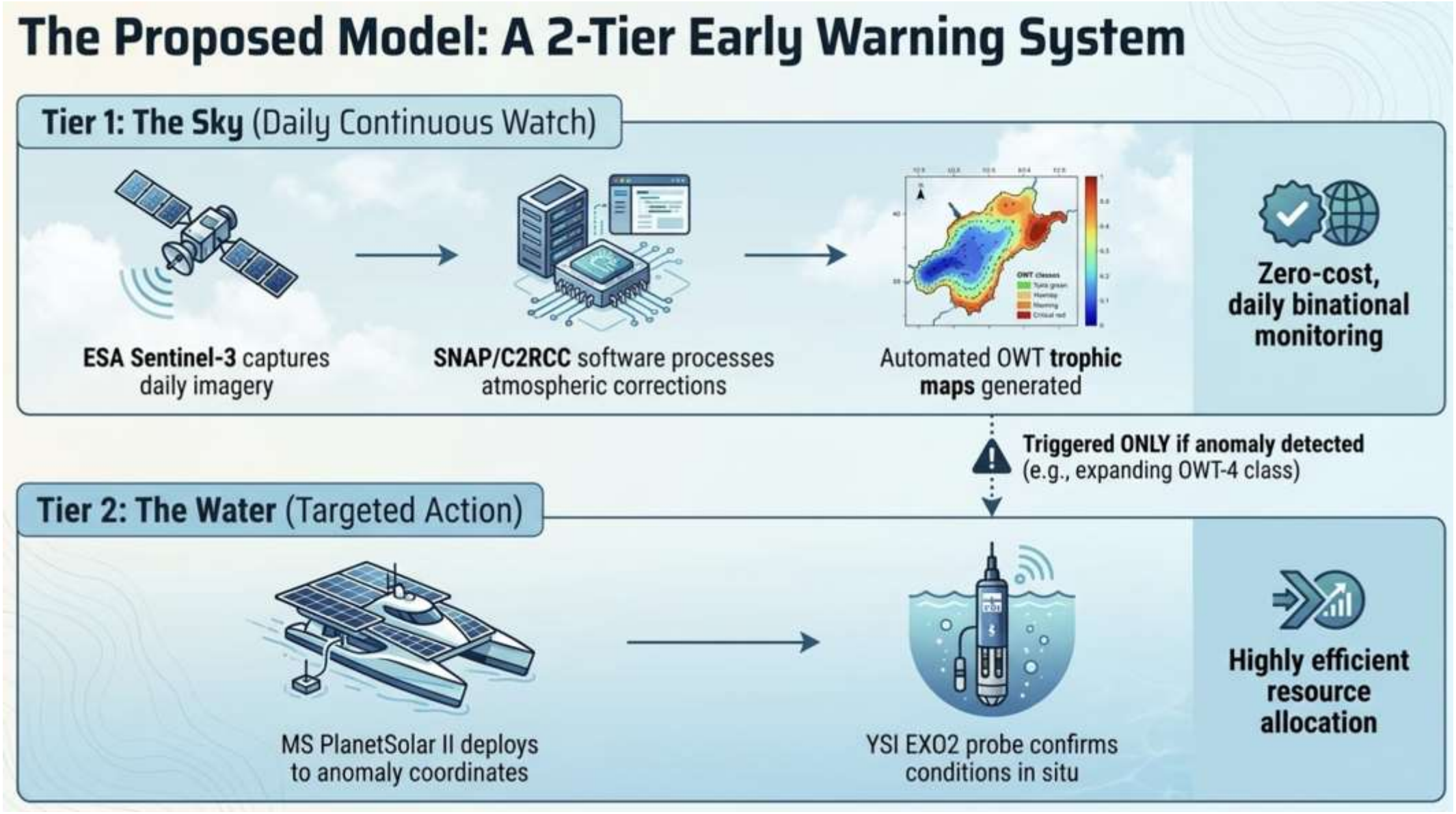
- **Fulfills ALT binational mandate:** protect ecosystem and population
- **Scarce resources:** Maximize dual impact (ecosystem + health)
- **Interdisciplinary:** Brings together limnologists, public health experts, and managers

Strategic management recommendations for public policy

PRIORITIZATION MATRIX

BALANCED Scenery: 50% ECOLOGY + 50% PUBLIC HEALTH

- TOP PRIORITY (2 points): LTit64 (BIP), RWilly2 (Willy)
- HIGH PRIORITY (6 points): RWilly5 (**Willy**), LTit62-LTiti2-LTit60 (**BIP**), LTit70 (**BMP**), RWilly3 (**Willy**)
- MEDIUM PRIORITY (2 points): LTIt66-LTit68 (**BMP**)
- LOW PRIORITY (15 points): RWilly1 (**Willy**), LTit59 (**BIP**), DrCoat1 (**Coata**), RWilly4 (**Willy**), DrCoat2 (**Coata**), Ltit61-LTit63 (**BIP**), RWilly0 (**Willy**), LTit72-Ltiti3-LTit69-LTit67-LTit71-LTit12-LTit73 (**BMP**)



Protecting the Ancestral Heritage of Lake Titicaca

- Science has identified the problem and outlined a solution