Chungará Chronicles: Exploring mercury dynamics in Chile's highest lake

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Environmental **Fate→ Natural and anthropogenic sources**

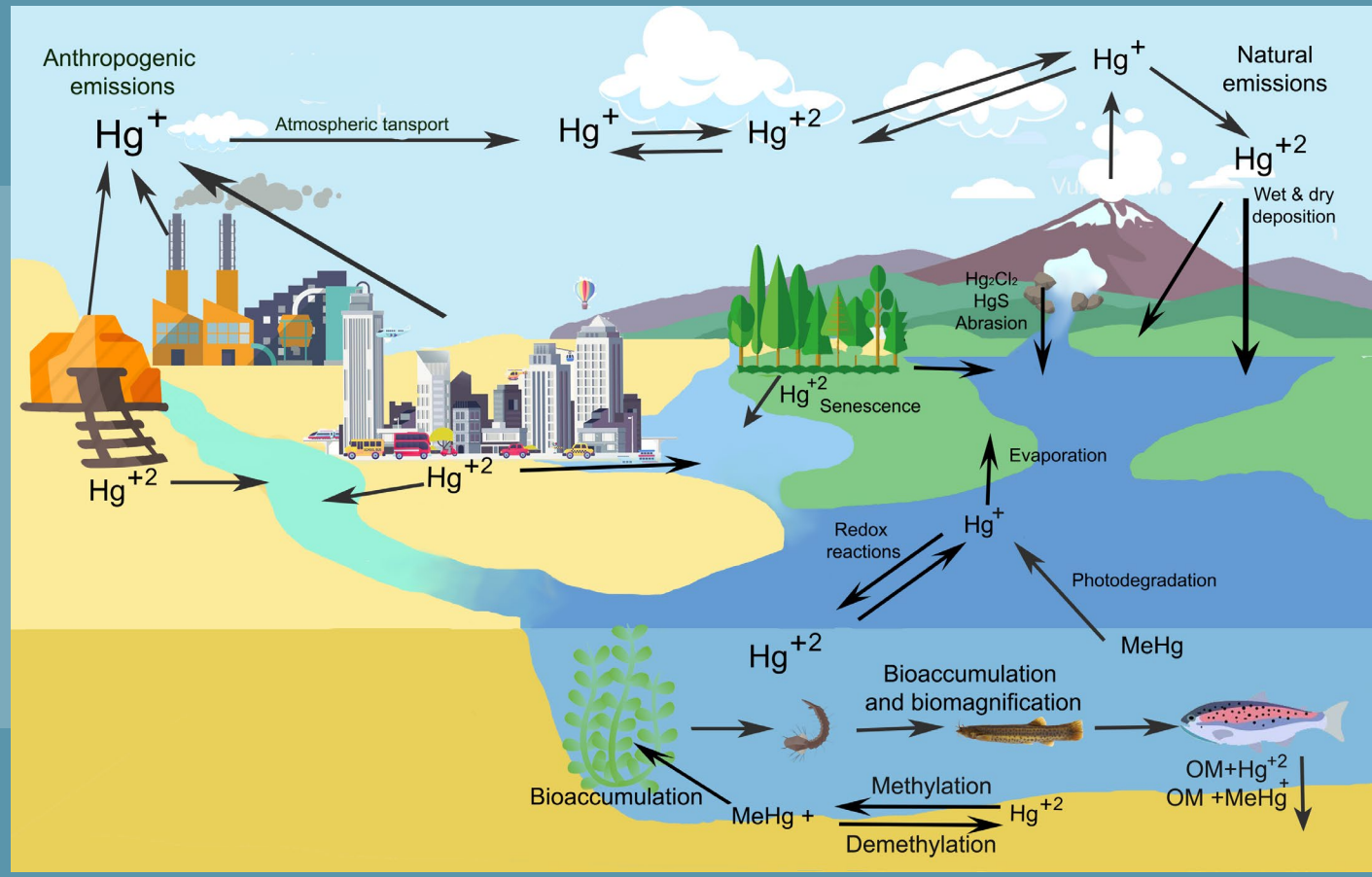
(Temme *et al.*, 2003; Streets *et al.*, 2011; Liu *et al.*, 2011; Amos *et al.*, 2013; Schneider *et al*, 2022).

Increase in emisión of Hg → ≈**150-180 years**

(Streets *et al.*, 2011)

Global pollutant → affects several aquatic **foodwebs**

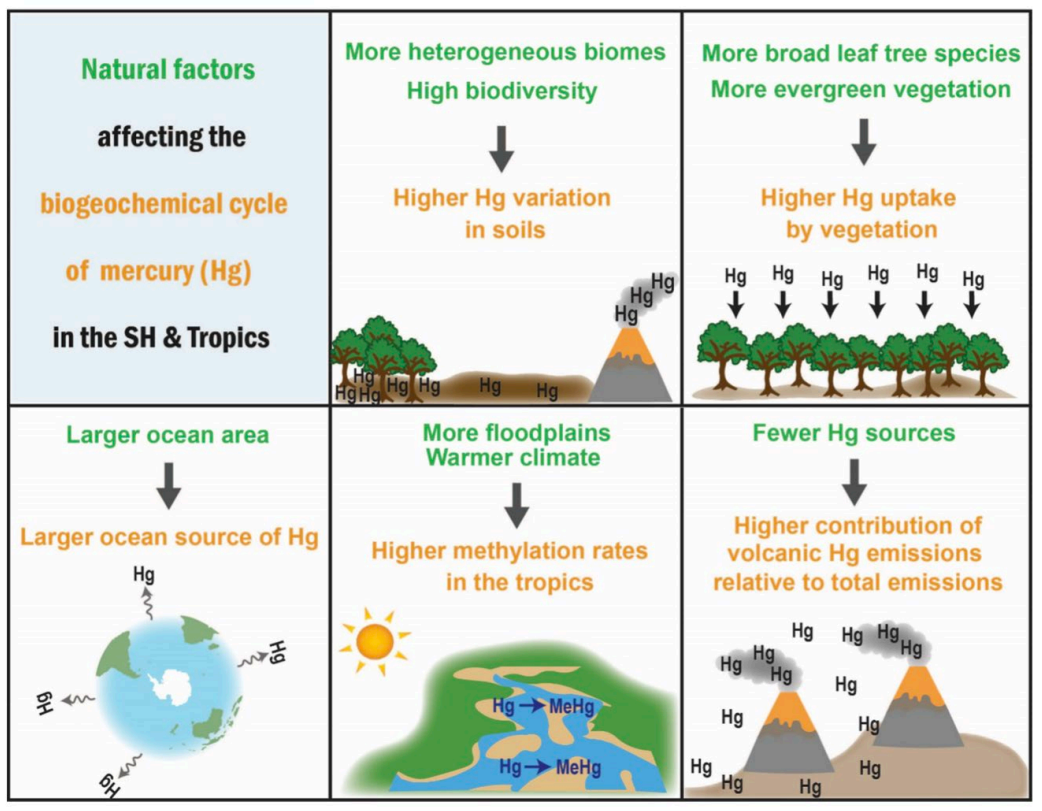
(DeForest *et al.*, 2007; Tong *et al.*, 2012; Lavoie *et al.*, 2013; Cipro *et al.*, 2016; Seco *et al.*, 2021; Chiang et al. 2021; Schneider *et al.*, 2023)



Mercury in aquatic ecosystems

Research in the Northern Hemisphere

(might) Not be extrapolable to the Southern Hemisphere (SH)
(Hempel, 1985; Schneider *et al.*, 2023)



Source: Schneider *et al.*, 2023.

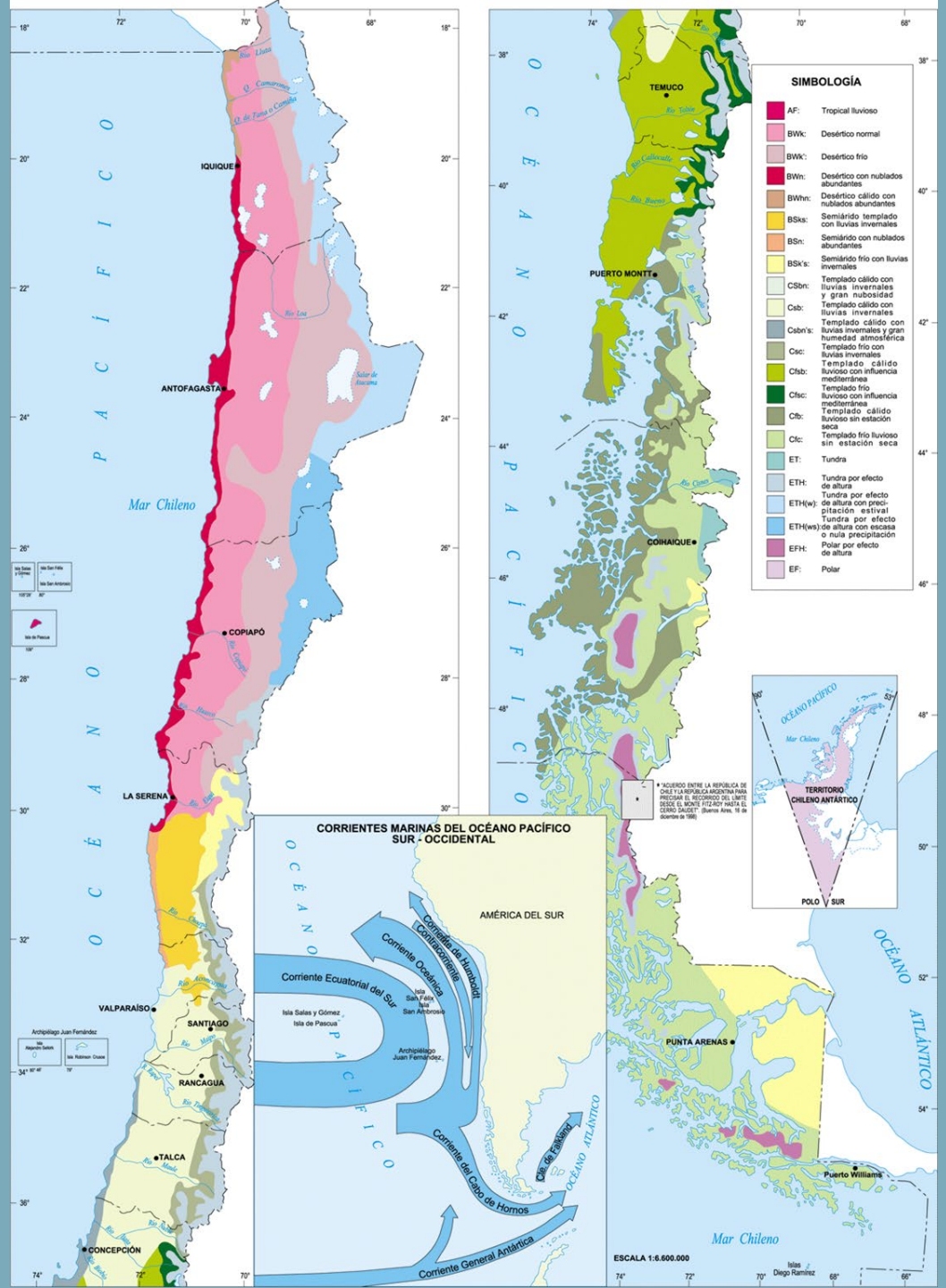
Interhemispheric differences

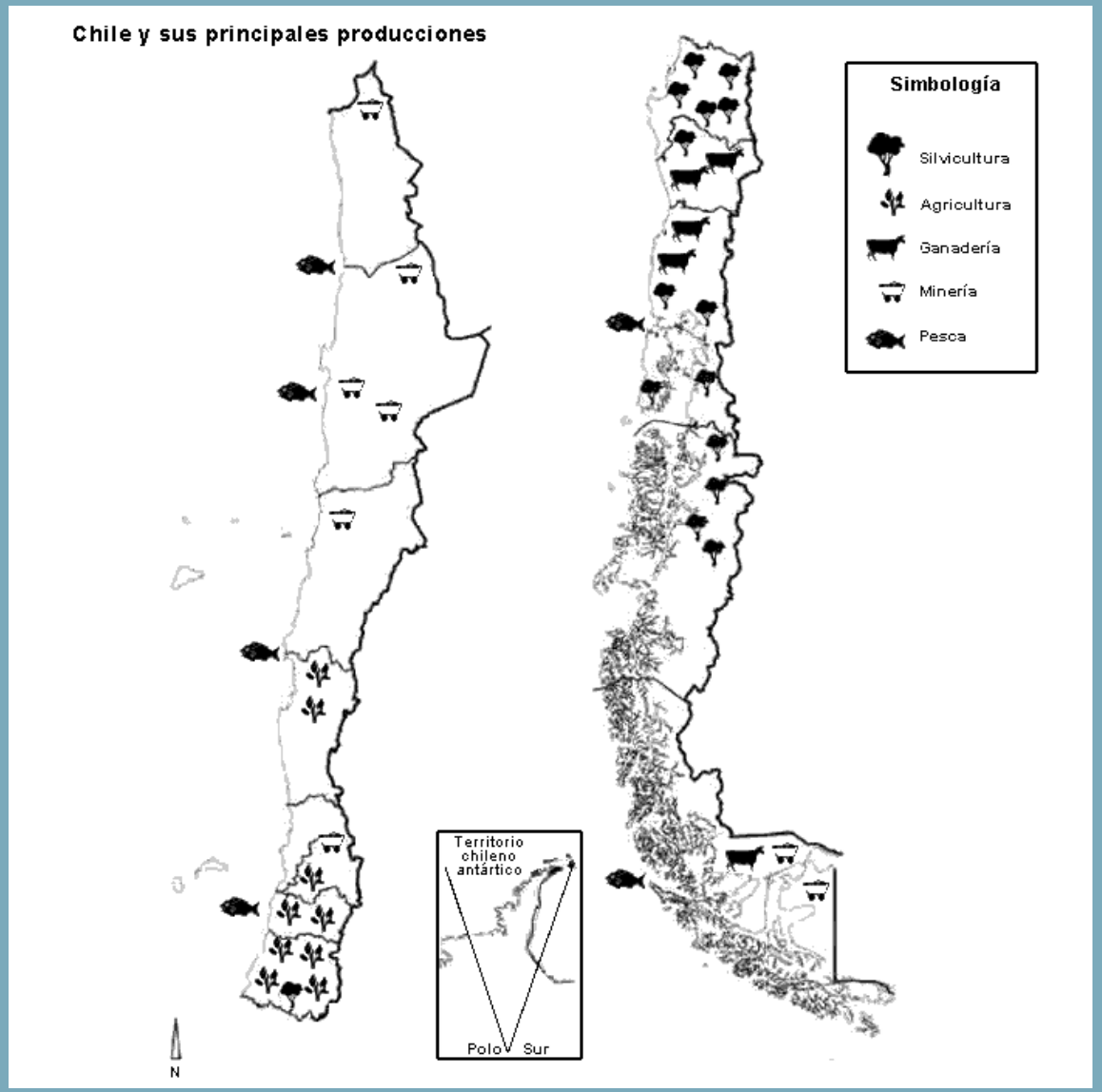
(Hempel, 1985; Horowitz *et al.*, 2017; Schneider *et al.*, 2023; Fisher *et al.*, 2023).

Unique geographic and environmental conditions →

≠ biogepochemical cycles, TMS and anthropogenic impacts

PRODUCTIVE AND CLIMATIC LATITUDINAL GRADIENT

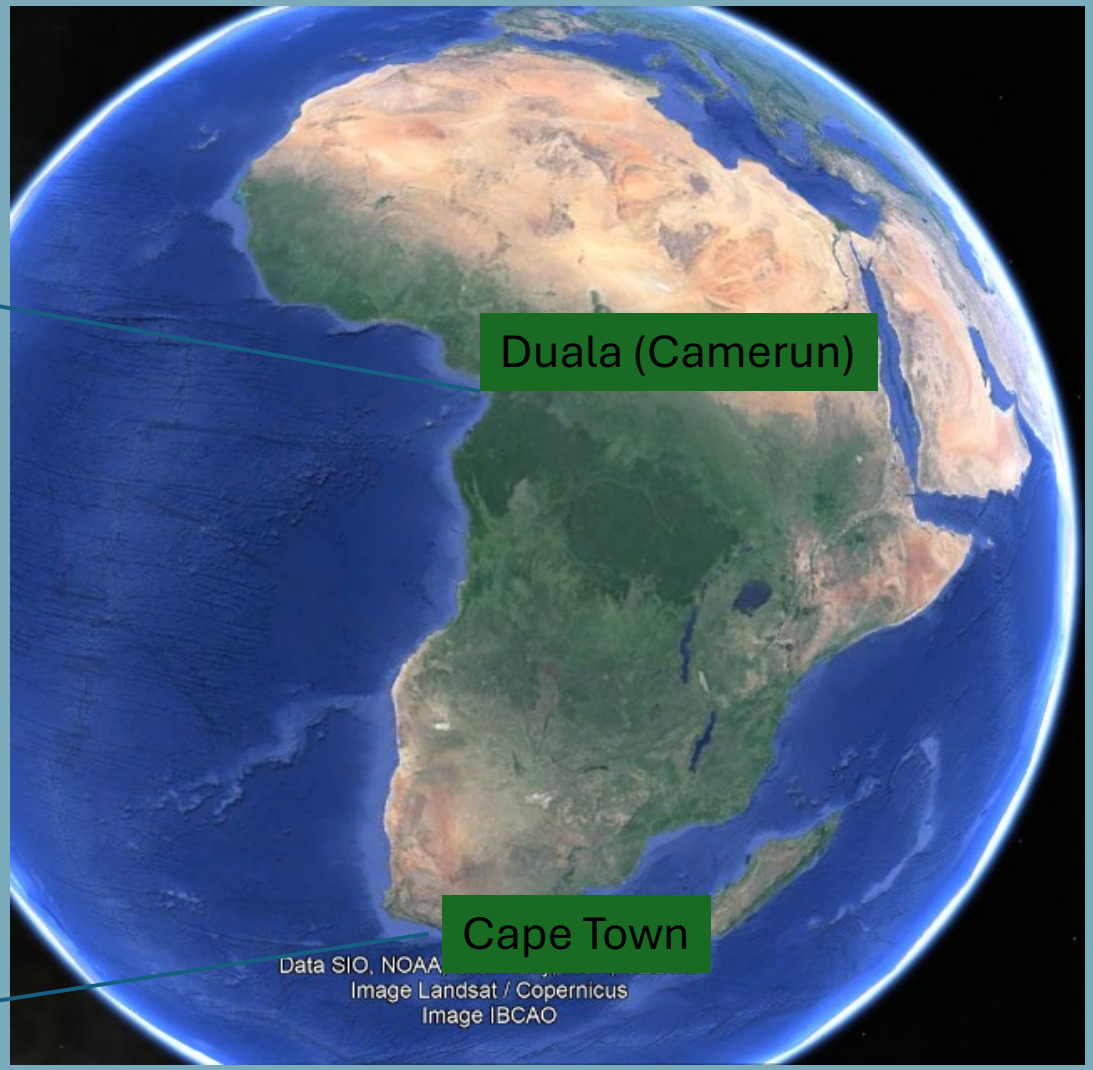




Source Silva, 2018

GEOGRAPHICAL DISTRIBUTION OF PRODUCTIVE AREAS IN CHILE


Chile
Santiago


Duala (Camerun)
Cape Town
Data SIO, NOAA
Image Landsat / Copernicus
Image IBCAO

Biomagnification of mercury in freshwater ecosystems

Food web

(DeForest *et al.,* 2007; Tong *et al.,* 2012; Lavoie *et al*., 2013)

- Structure
- Length
- Interactions

Species diversity

Ecosystem characteristics

(DeForest *et al.,* 2007; Tong *et al.,* 2012; Lavoie *et al*., 2013; Chiang *et al.,* 2021)

- Productivity
- pH
- Tº
- Among others

Bioavailability

Latitudinal gradients

(Fitzgerald *et al.,* 2007; Lavoie *et al*., 2013; Cipro *et al.,* 2016; Chiang *et al.,* 2021).

Correlation with Hg biomagnification values.

Higher latitud → **- Excretion + TMS**

lower latitud → **+ Excreción - TMS**

Latitude-Altitude?

Altiplano (High Plains) **Simpler** trophic webs (> diversity & > Hg excretion rates) → **+ TMS Hg**

And what if we add invasive species such as trout?

Biomagnification rates in southern SouthAmerica and Antarctica

Different functional groups, foodweb structures → Stables isotopes

(Bargagli *et al.,* 1998; Sanchez, 2000; Ribeiro *et al.,* 2009, 2010; Rizzo *et al.,* 2011; Díaz *et al.,* 2013; Soto *et al.,* 2014; Cipro *et al.,* 2017; Seco *et al.,* 2021; Matias *et al.,* 2022)

Patagonic Lakes

(Ribeiro *et al.,* 2009, 2010; Rizzo *et al.,* 2011; Soto *et al.,* 2014)

Patagonic coastal zones and rivers

(Chiang et al., 2021)

Coastal zones (Chile) with direct impact

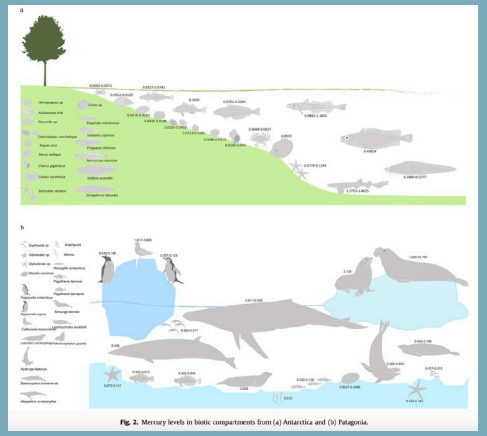
(Díaz *et al.,* 2013)

Antarctic costal zones

Terra Nova Bay (Bargagli *et al.,*1998)
King George Island (Cipro *et al.,* 2017)
Scotia Sea (Seco *et al.,* 2021)
Livingston Island (Chuang et al., 2021; Matias *et al.,* 2022)
Paradise Bay (Chuang et al., 2021)

- Length and structure of the trophic web
- Physical-chemical characteristics

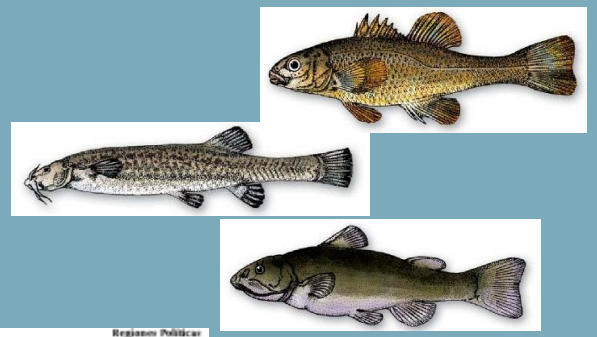
Biomagnification of Hg

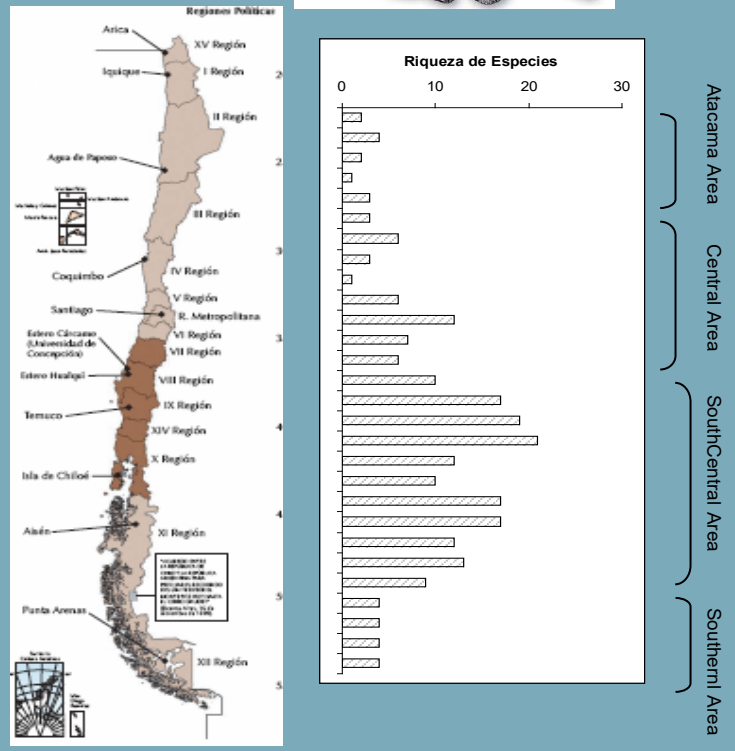


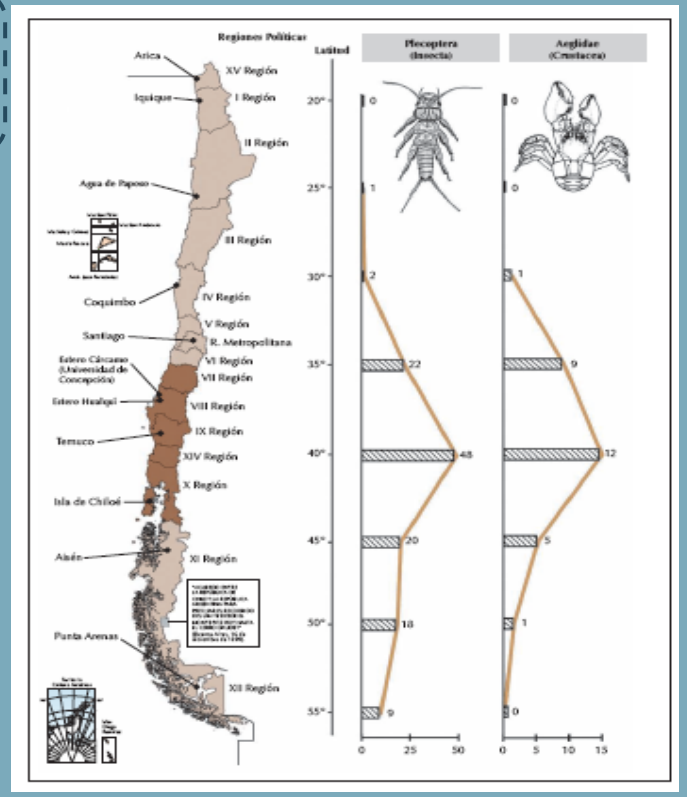
Hemispheric and latitudinal difference →Hg TMS

Chilean fish diversity in low (48 species)
Hihlgy endemic (>80%)

(Habit et al 2006, Rojas et al, 2019)



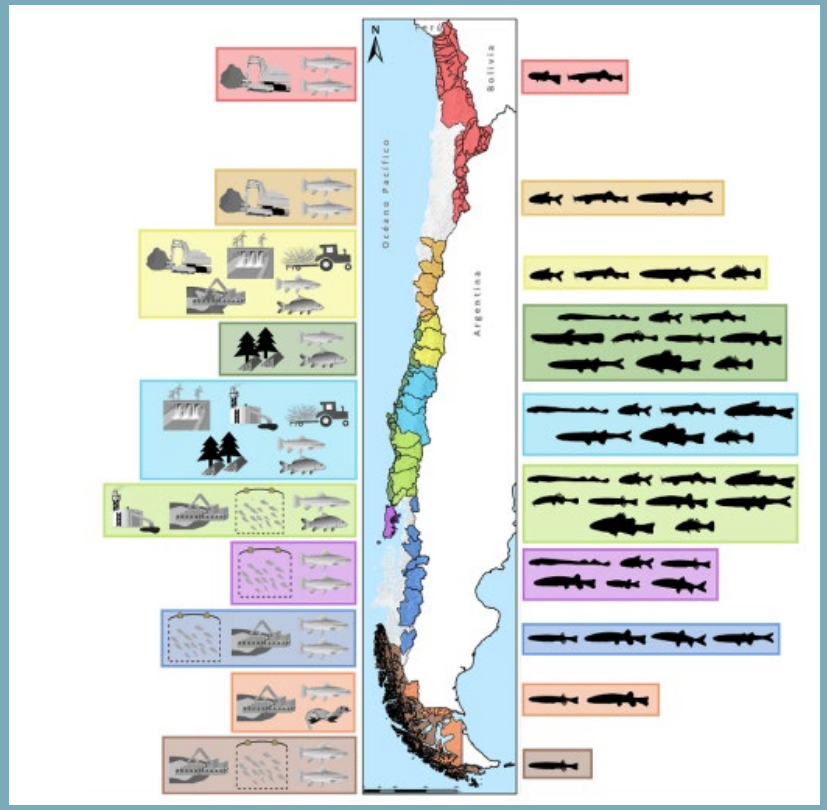




Valdovinos (2008)

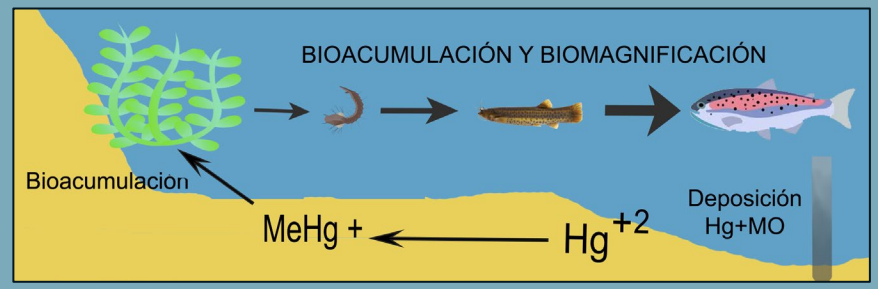
Impacted and modified by several other stressors

Chiang et al, 2011, Ali et al, 2020; Habit et al, 2024



Salmonids as bioindicators

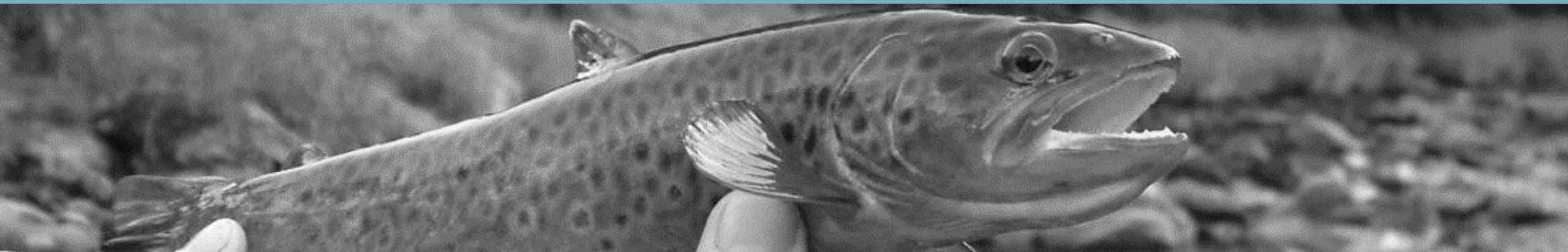
- Wide range of distribution, Arica to Punta Arenas (Cárcamo et al., 2015; Soto et al., 2006).
- High trophic level
- High-fat fish
- Larger than endemic fish
- No conservation problem
- Commercial and consumer interest
- They require good water quality to survive.



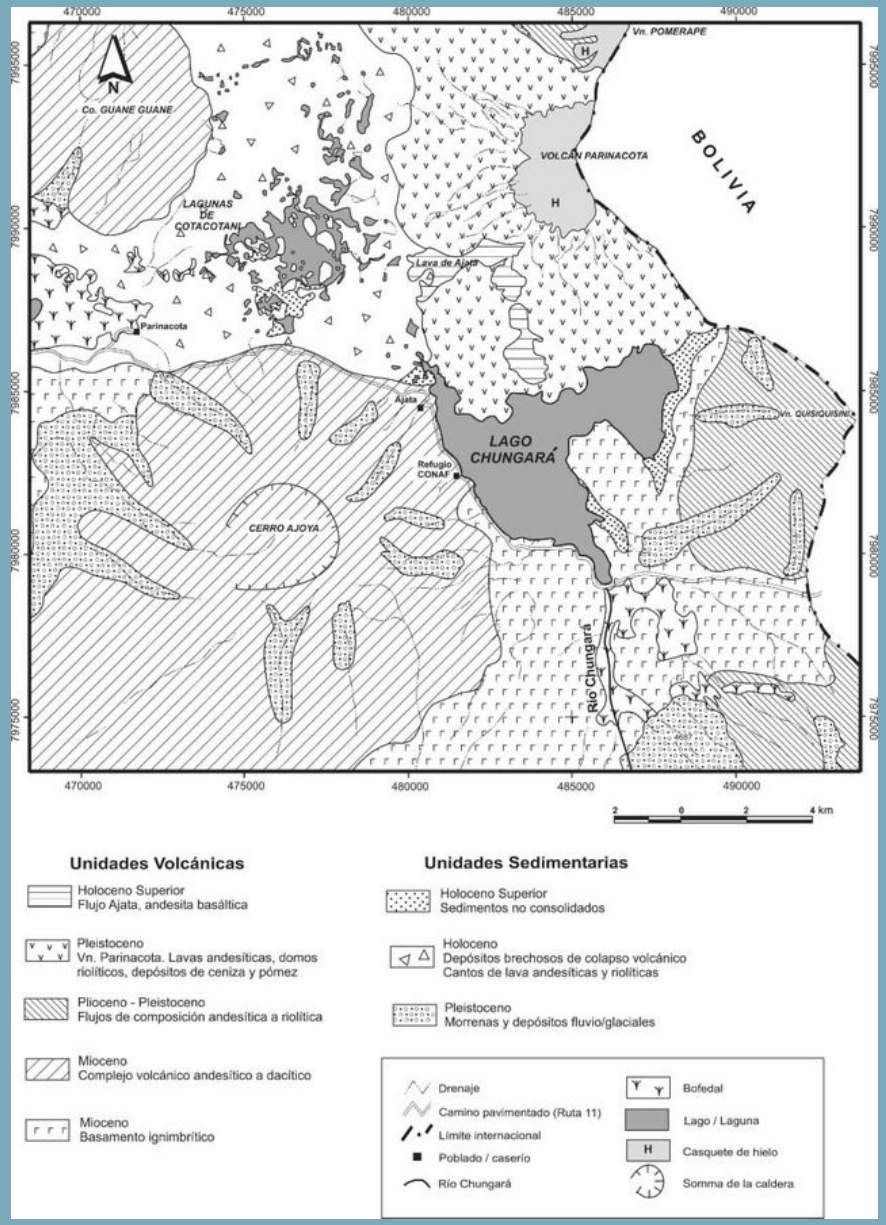
Natural laboratory

Ecosystem health

Risk to human health



Lago Chungará (Chungará Lake)



(Source: Herrera et al., 2006)

World's highest and southernmost non-navigable lake (**4.520 m.a.s.l.**)

(Dorador et al., 2003)

Polymictic lake, of volcanic origin and with a maximum depth of 34 m.

(Urrutia et al., 2002)

Lake contributions: 25% comes from the Chungará River, 75% from diluted waters on its shore or from similar subway sources.

(Gaona, 2004; Herrera et al., 2006)

Lago Chungará history (really short!)

About **20-10 thousand years ago**, the Parinacota volcano experienced a **collapse**.

(Ríos et al., 2016)

In Arica and Parinacota Region → **35 mining tailings deposits.**

Arica and Parinacota Region with the problem of contamination by **polymetals** (lead, cadmium, mercury, etc.) **and other pollutants.**

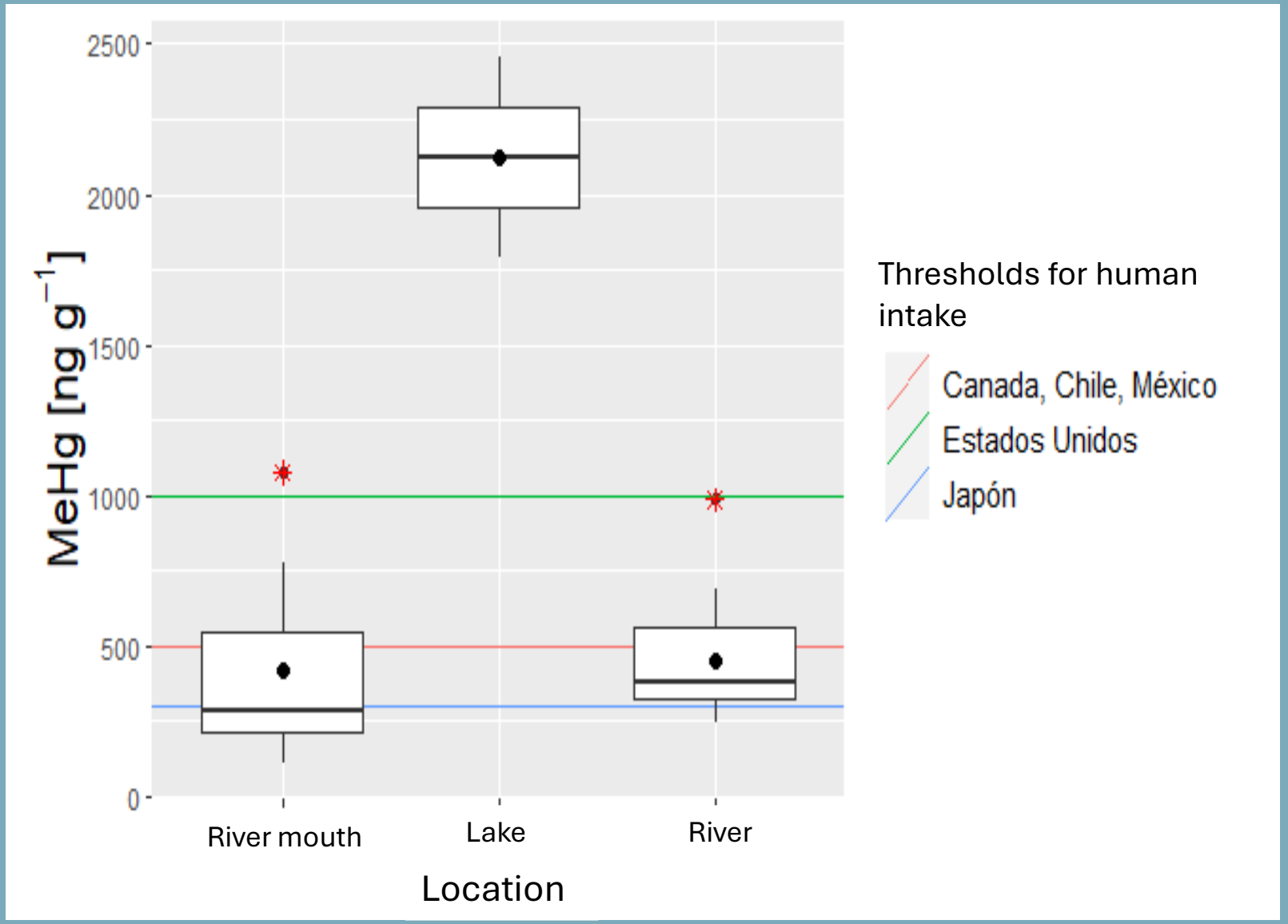
(Ríos et al., 2016)

Biodiversity **Hotspot**.

(Dorador et al., 2003)

Salmonids introduced as an alternative source of **protein**.

Trichomycterus chungaraensis. Source: Aqua, 2020.Critically endangered.


2500
2000
1500
1000
500
0
MeHg [ng g^{-1}]
River mouth
Lake
River
Location
Thresholds for human intake
Canada, Chile, México
Estados Unidos
Japón

INVASAL
MILLENNIUM NUCLEUS
INVASIVE SALMONIDS

Chungará Lake

Vertiente Mal Paso

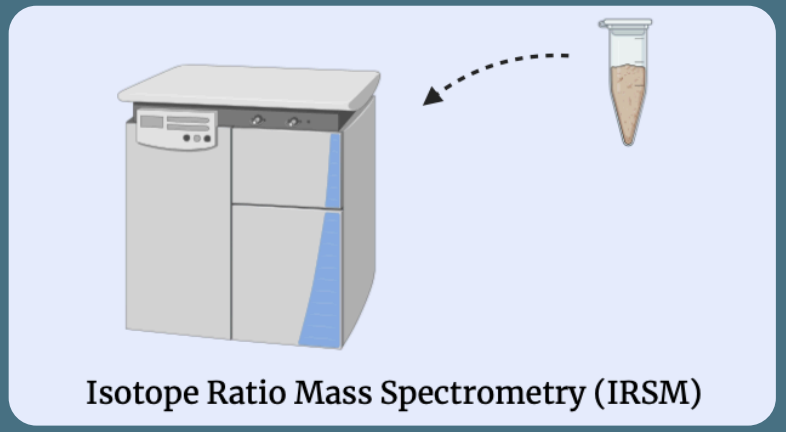
Chungará River

Photos: https://invasal.cl/lago-chungara/

Stable Isotopes

UA stable Isotope Facility (UASIF) – IA - Instituto Antofagasta

Isotope Ratio Mass Spectrometry (IRMS)



Isotope Ratio Mass Spectrometry (IRSM)

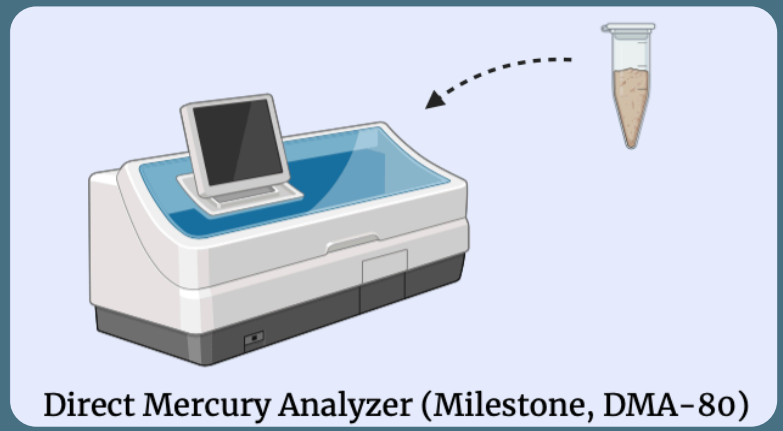
Biorender, 2024.

Fish (Rainbow trout, Orestias and Trichomycterus)
Invertebrates (Amphipods)

(Pel *et al.,* 2004; Muccio & Jackson, 2008)

Total mercury (THg)

Direct Mercury Analyzer (DMA-80evo)



Direct Mercury Analyzer (Milestone, DMA-80)

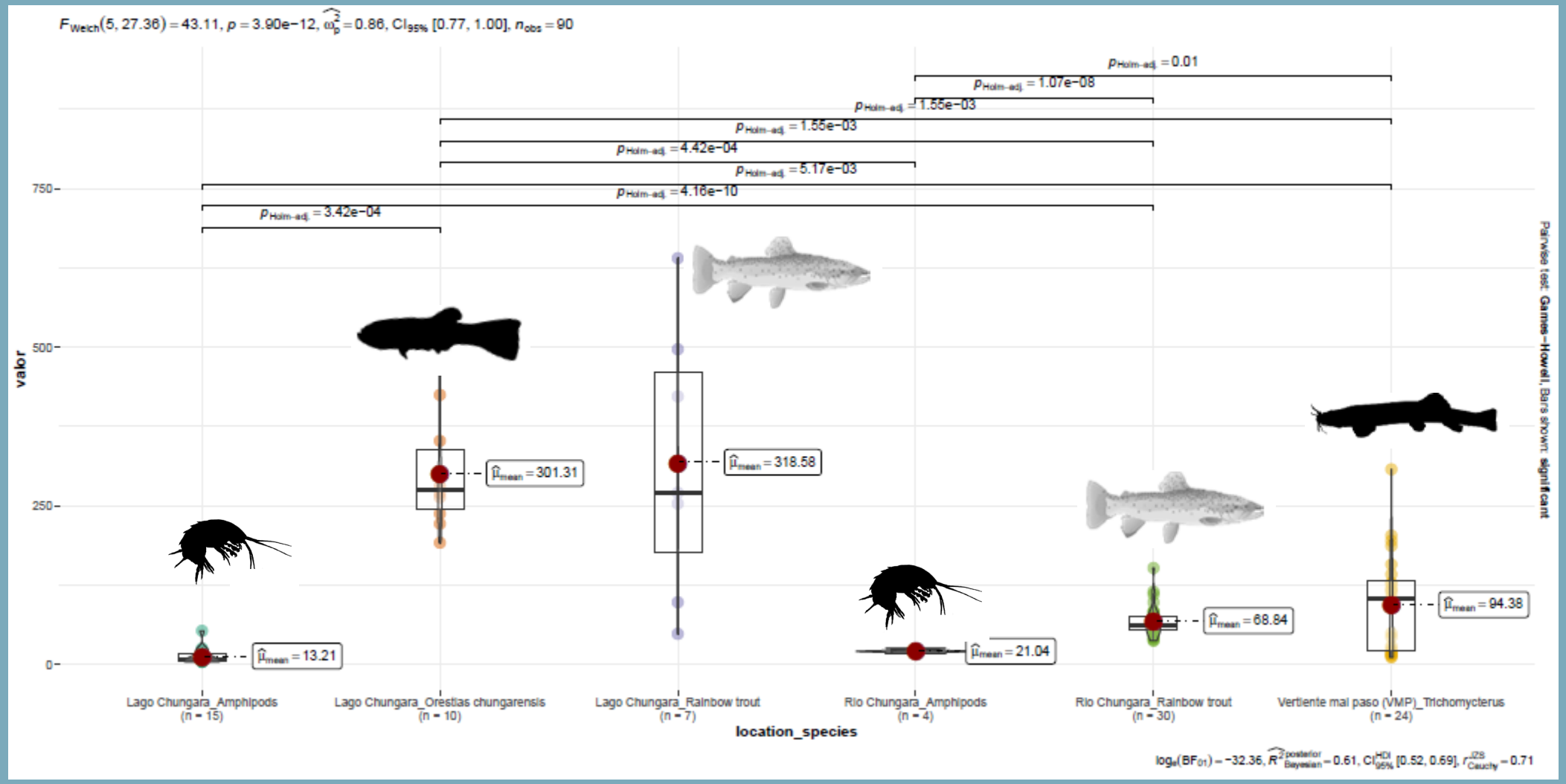
Biorender, 2024.

Laboratorio de biogeoquímica y Ecotoxicologia Acuatica (LabBEA), UNAB

Fish (Rainbow trout, Orestias and Trichomycterus)
Invertebrates (Amphipods)

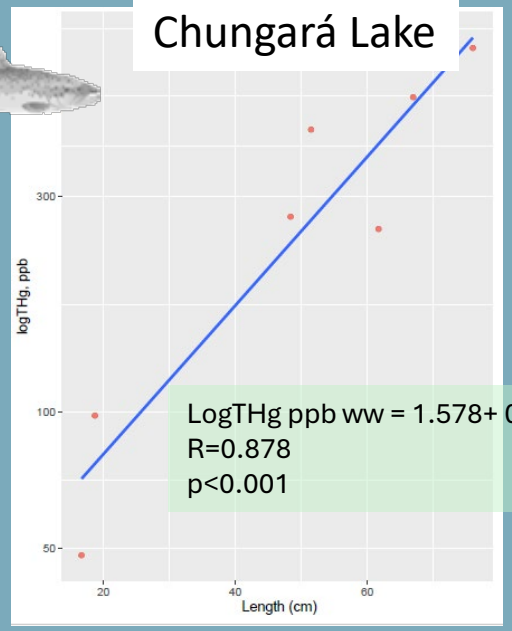
(Lichtenberg, 2006; Bolaños *et al.,* 2016; Vega & Pisconte, 2020)

Total mercury in biota



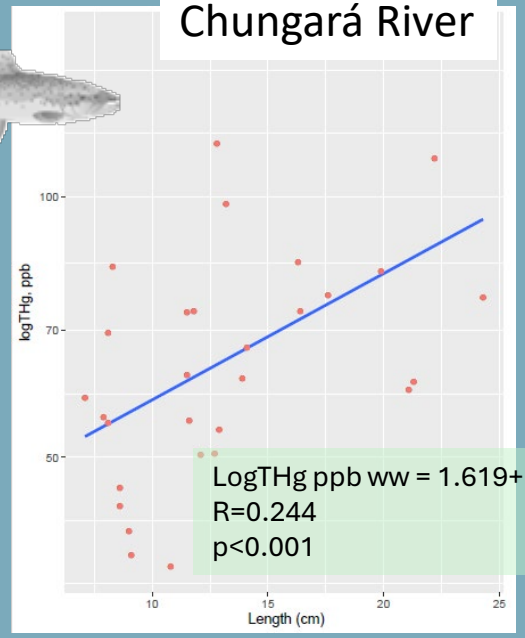
Mercury bioaccumulation

Chungará Lake

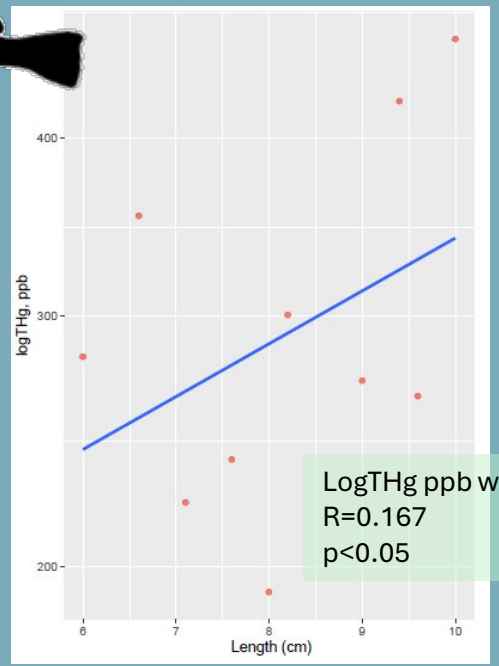


LogTHg ppb ww = 1.578+ 0.0164*Length (cm)
R=0.878
p<0.001

Chungará River

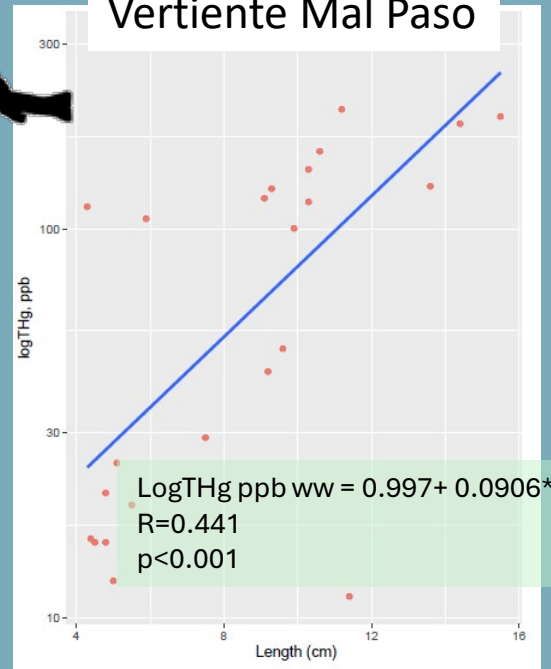


LogTHg ppb ww = 1.619+ 0.0146*Length (cm)
R=0.244
p<0.001



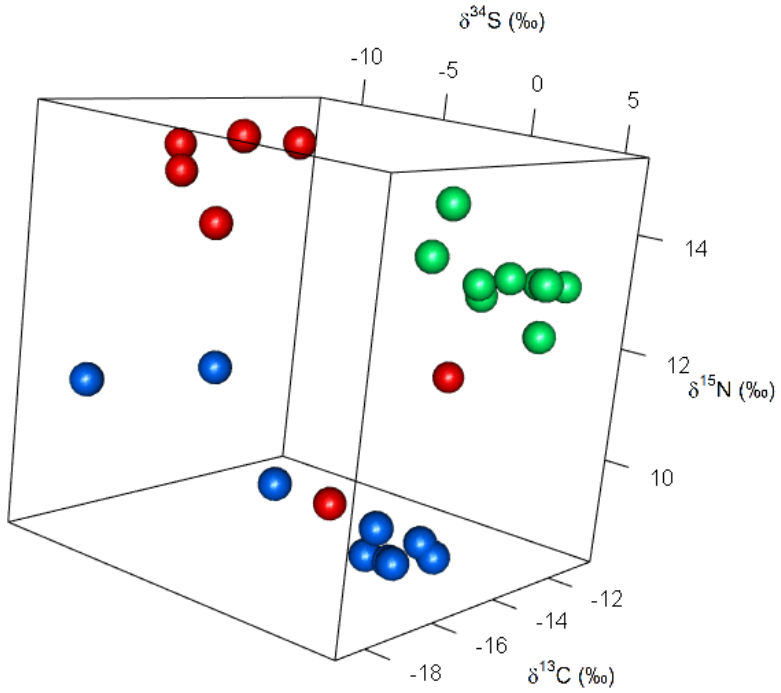
LogTHg ppb ww = 2.160+ 0.0372*Length (cm)
R=0.167
p<0.05

Vertiente Mal Paso



LogTHg ppb ww = 0.997+ 0.0906*Length (cm)
R=0.441
p<0.001

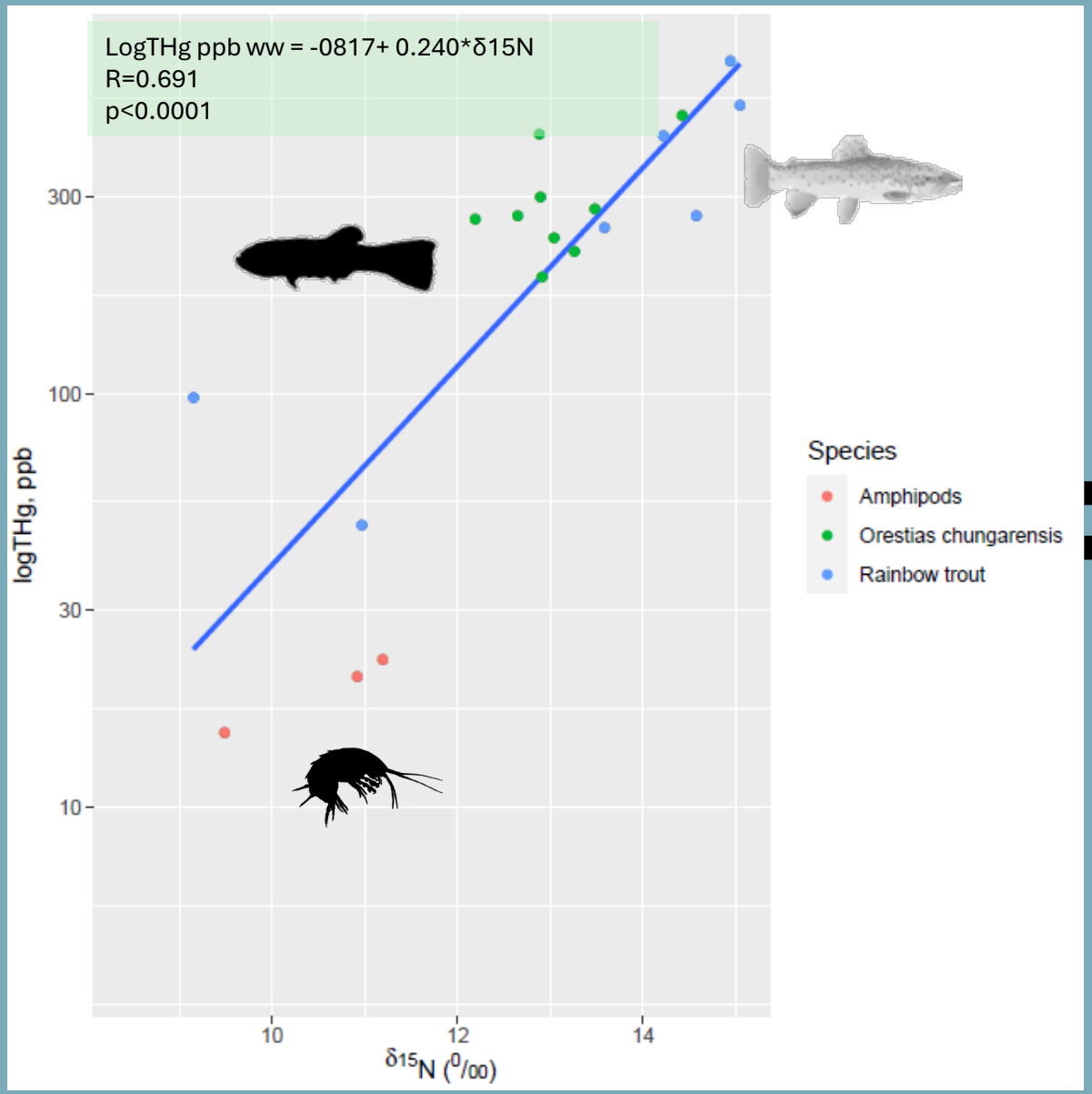
Foodweb structure and mercury biomagnification in Chungara Lake



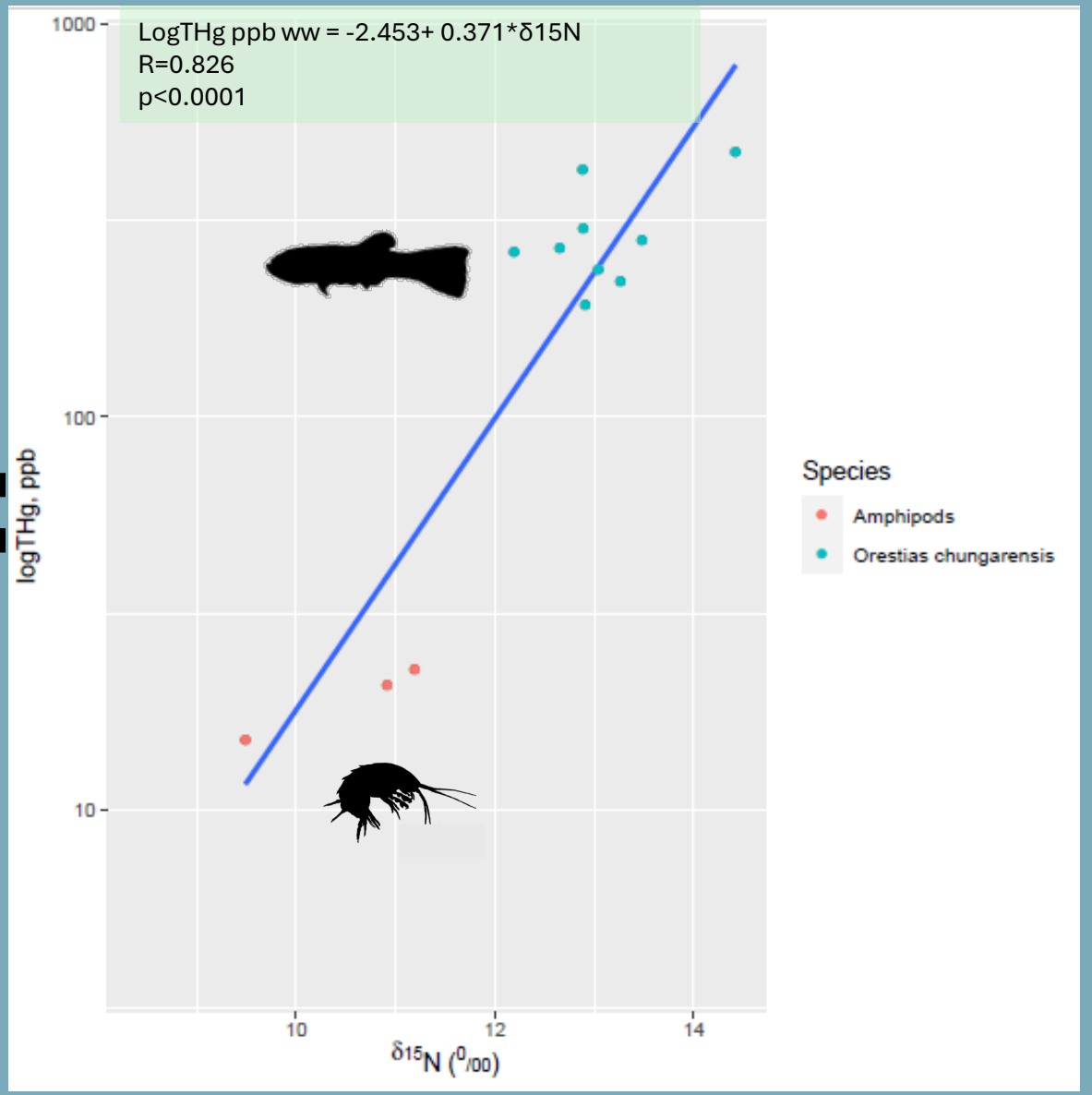
$d^{13}C$ = >

$d^{34}S$ = >

$d^{15}N$ < =


LogTHg ppb ww = -0817+ 0.240*δ15N
R=0.691
p<0.0001
300
100
30
10
logTHg, ppb
10
12
14
δ15N (0/00)
Species
Amphipods
Orestias chungarensis
Rainbow trout

≠

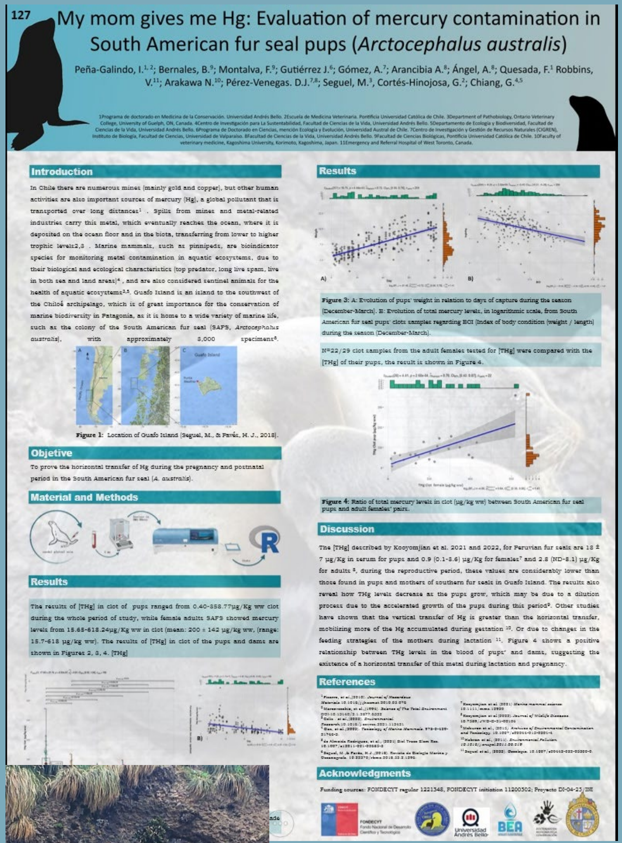

LogTHg ppb ww = -2.453+ 0.371*δ15N
R=0.826
p<0.0001
1000
100
10
logTHg, ppb
10
12
14
δ15N (0/00)
Species
Amphipods
Orestias chungarensis

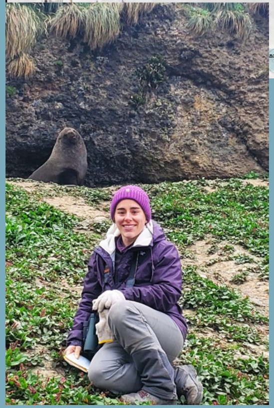
Remarks

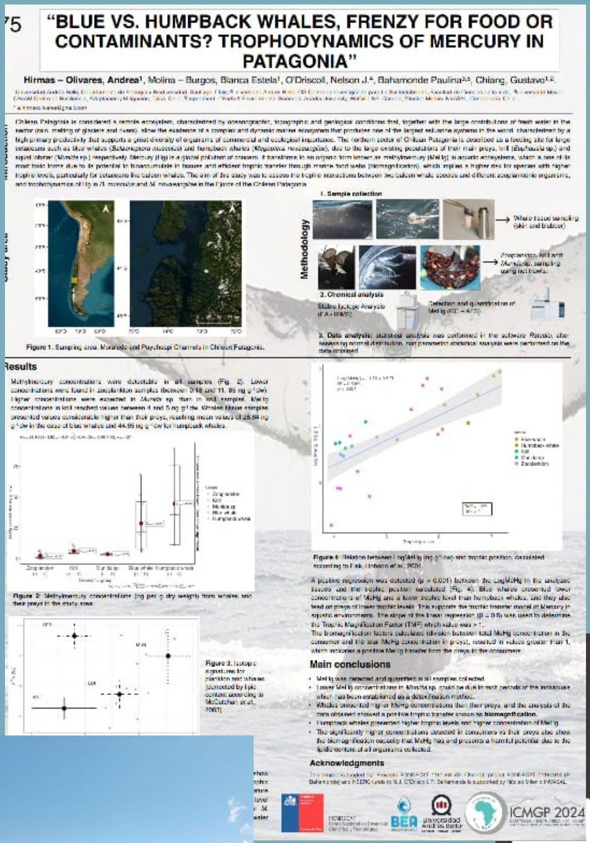
- Mercury bioaccumulation changes among freshwater systems <200 meters
- Small bodied fish accumulate ≠ raiboiw trout within lake→ age related?
- Small pencil catfish accumulates ≈ bigger rainbow trout in riverine systems.
- Amphipods showed ≈ [THg] no matter if they are in the lake or in the river

- Despite similar trophic position, Orestias chungaresis and raibow trout (in the lake) showed differences in sources of organic matter (≠ $d^{13}C$; ≠$d^{34}S$)
- Rainbow trout modifies trophic transfer of mercury → TMS(with trout)<TMS(without trout) → Biodilution?


Gracias!







Hg research in the SH: thursday 2:45