HABs, ocean colour remote sensing, bio-optical monitoring in fjords and aquaculture activities

Prepare for:
IV Int. Ocean Colour Science meeting (IOCS-2019)

Busan, South Korea 10 April 2019

Hosted by **Korea Institute of Ocean Science and Technology** (KIOST)
iocs.ioccg.org/programme/schedule/

Prepare by:

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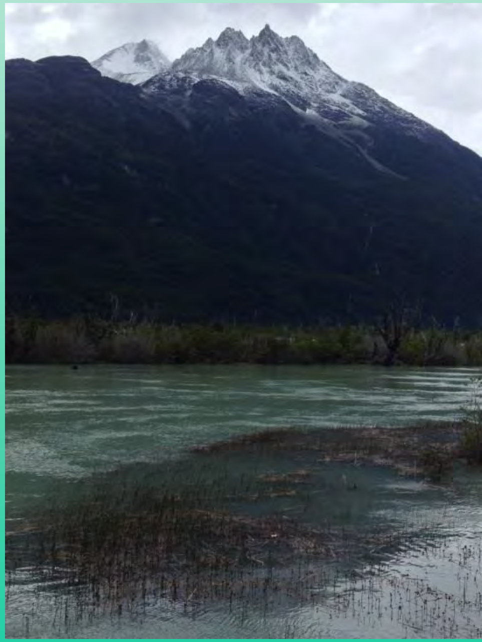


PLANCTON ANDINO

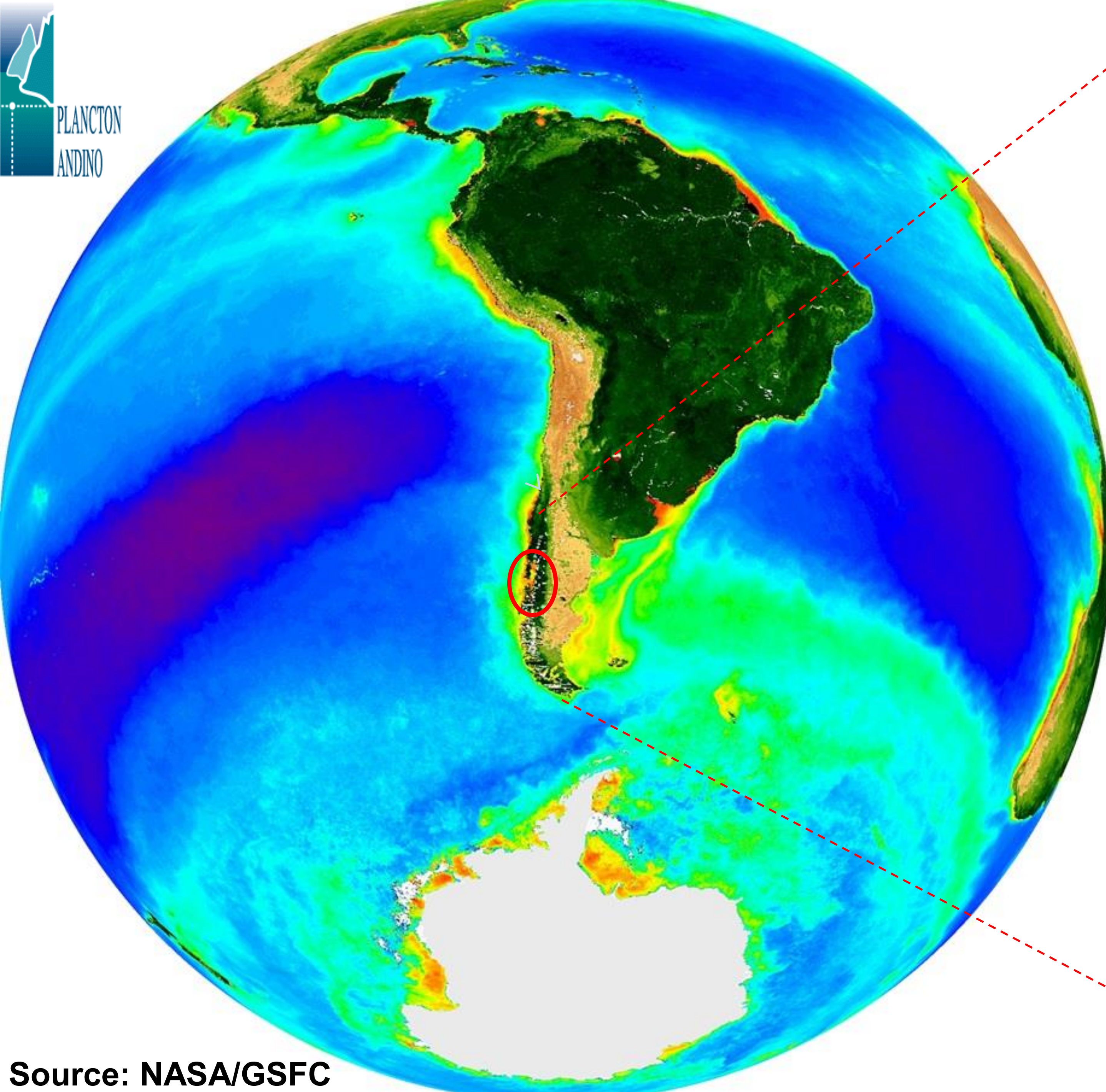
Since 1998: 21 years

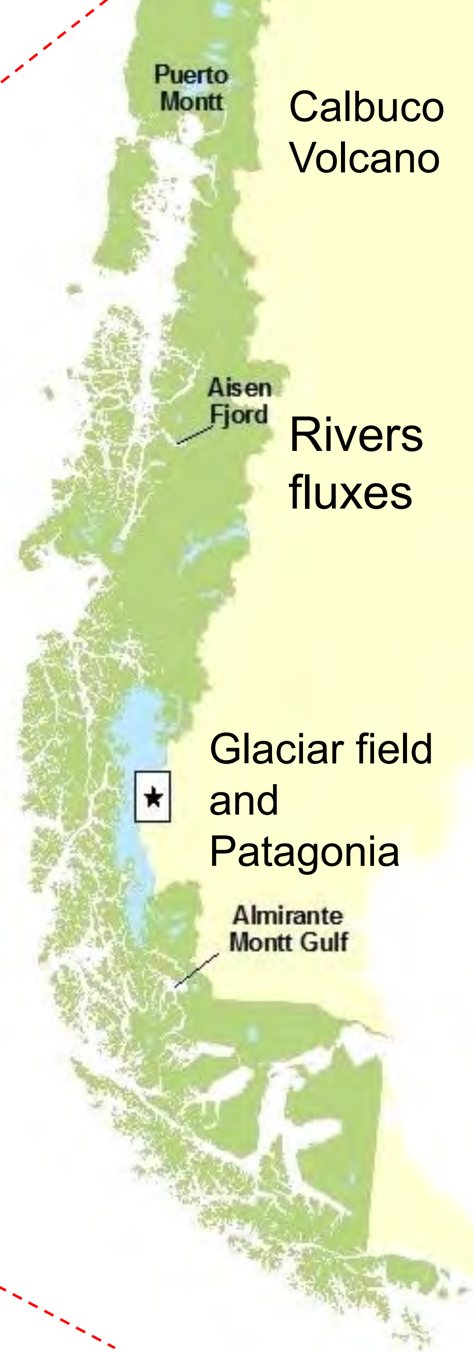
Plancton Andino is a local private company and our mayor focus of interest are environmental assessment and monitoring HABs for aquaculture and government.

OBJECTIVES

1. To study HAB events in **optically-complex waters** of Chile´s Patagonian fjords, and apply ocean color remote sensing and bio-optical methods.

2. To improve our understanding of HABs to give support and recommendations to people in the decision making process.





Source: NASA/GSFC

Post Last Glacial Environment and climatic anomalies

42°- 55 °S, Pacific margin of South America represents a 200–300 km wide shelf with thousands of islands and a fjord system across the Andes.

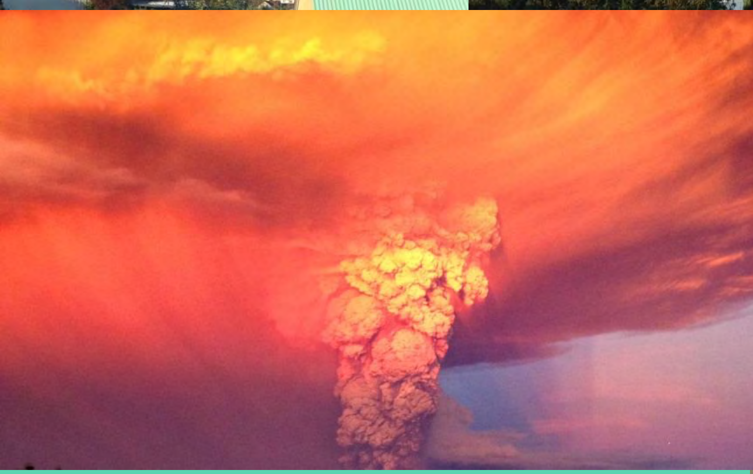
During Last Glacial, most of these fjords were proglacial lakes.

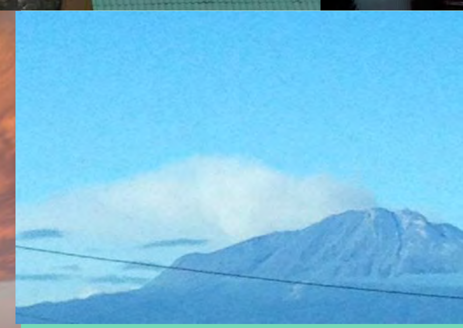
After the Last Glacial Maximum (LGM) global sea level rise led to marine transgression into the continental margin. (R. Kilian et al. 2007).

Extreme event:
Calbuco Volcano Eruption April 22, 2015 18:18










- **Recent Eruption:**
  - **Chaiten May 2, 2008**
  - **Cordon Caulle June 4, 2011**

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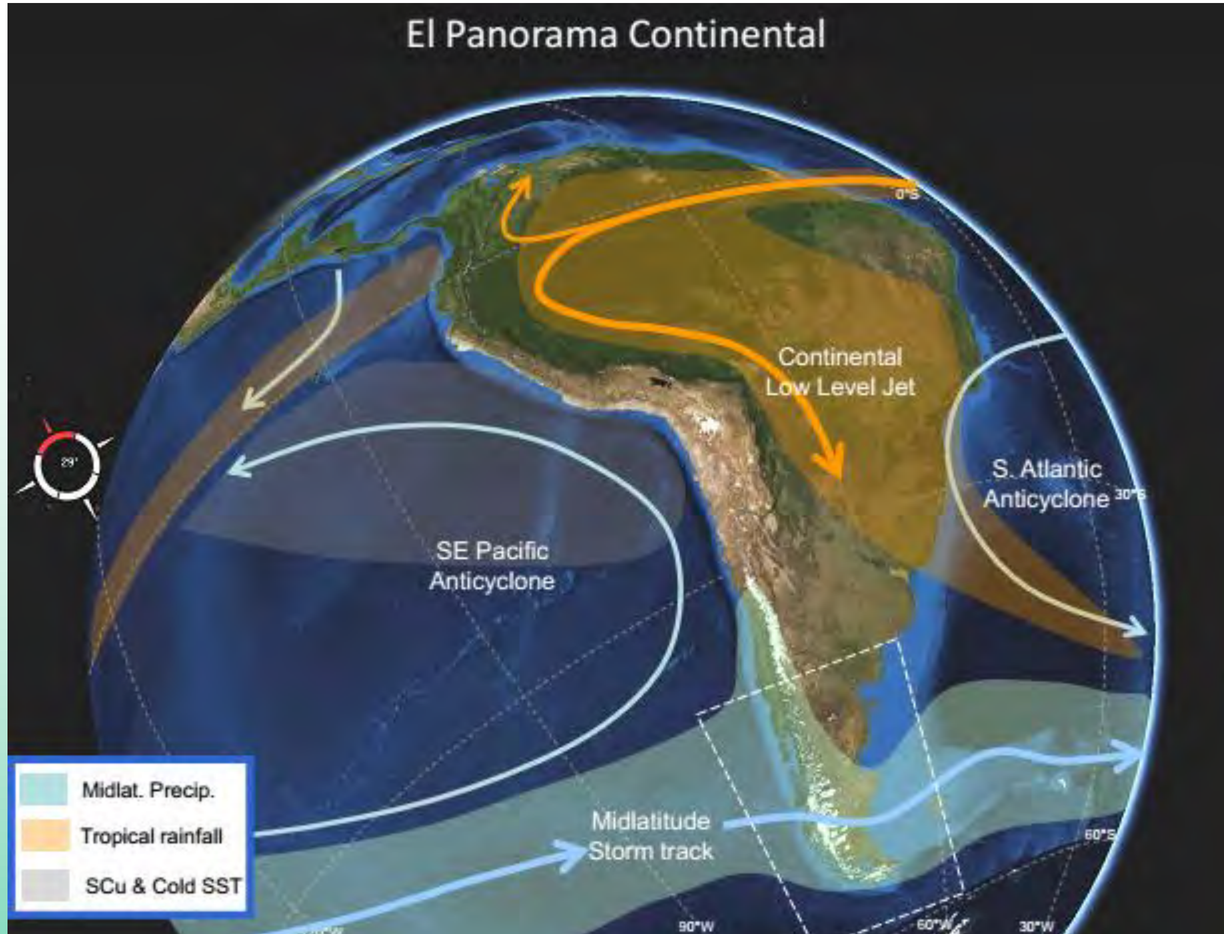


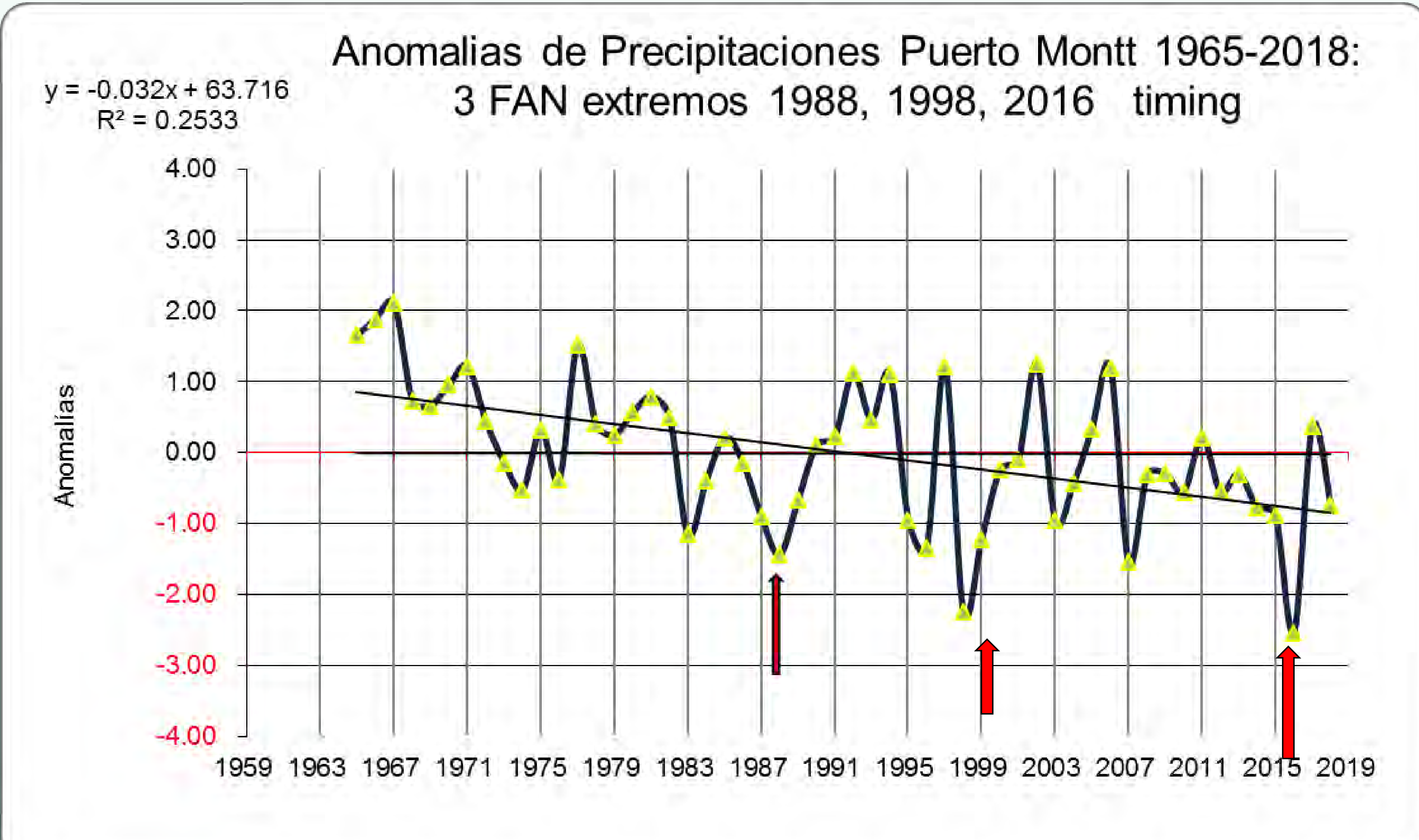
Source: Garreaud et al 2013

Photos from Germán Weil

March April 2019

Climatic anomalies, rain falls as an Example

Data Source www.meteochile.cl

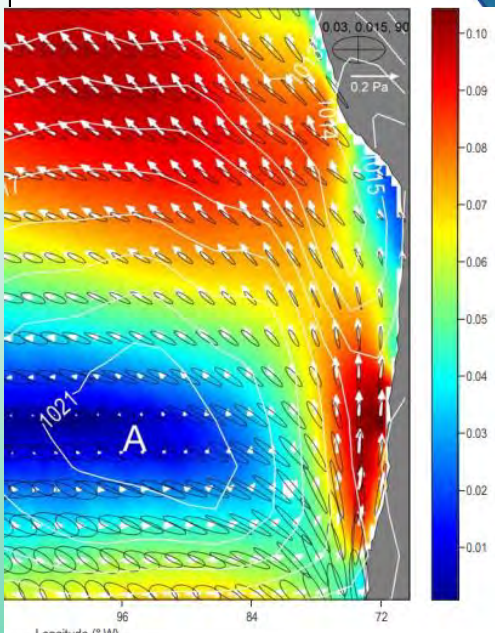


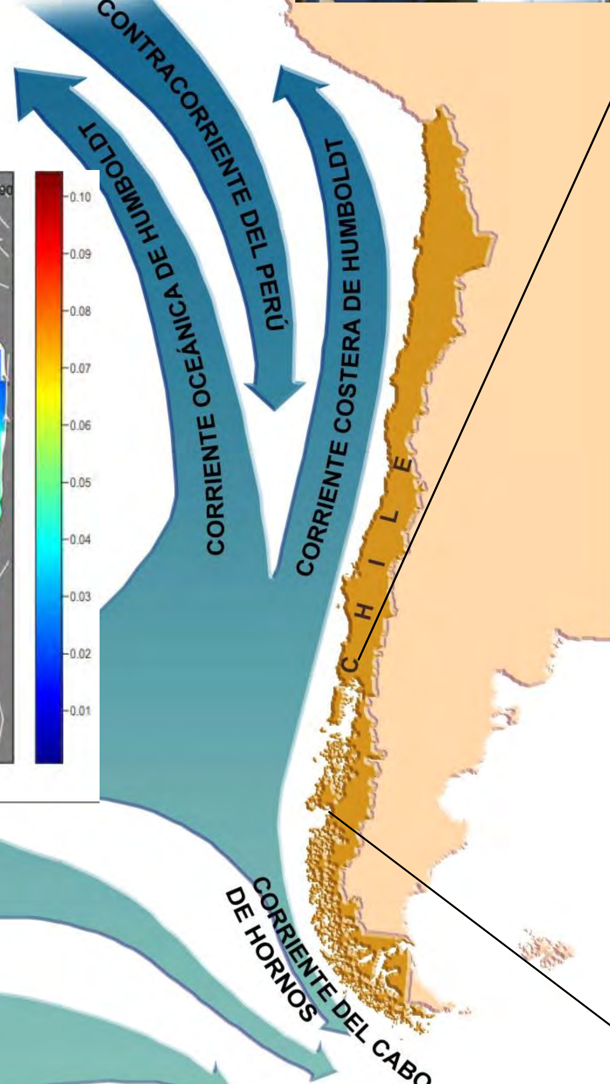
In honor to Dr. Steve Neshyba

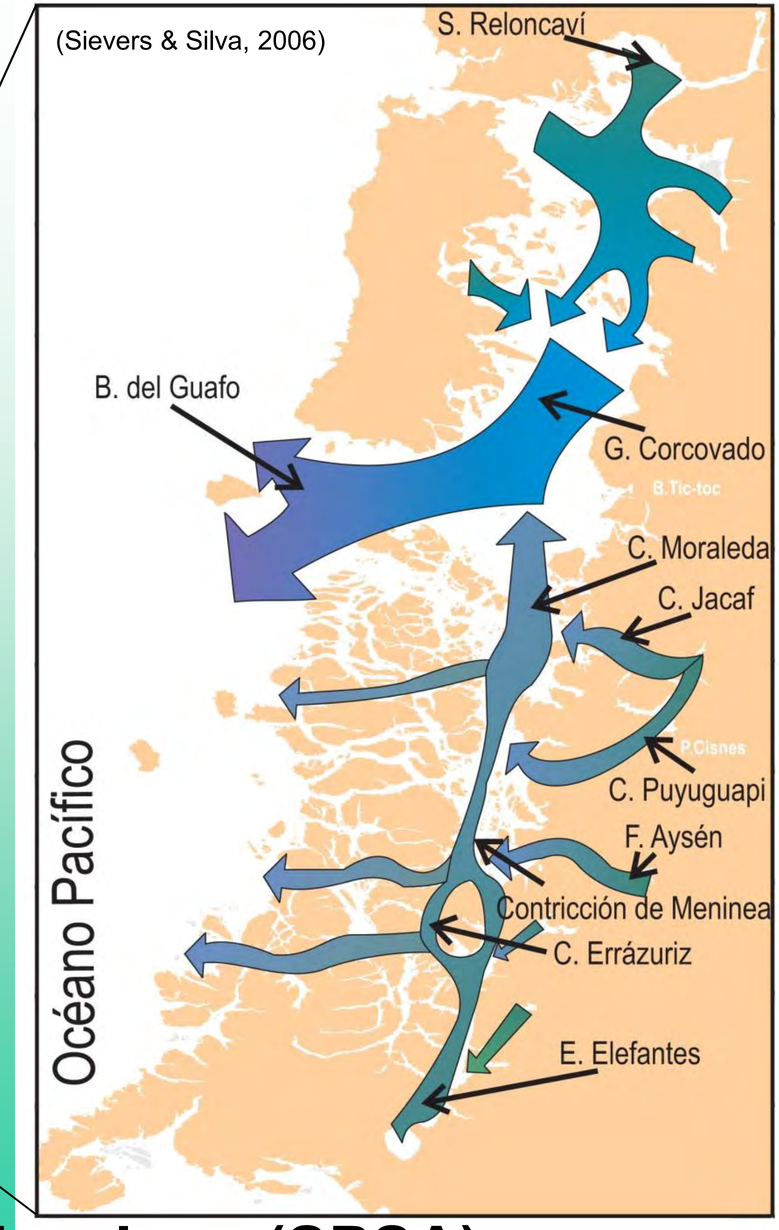
Warmer summer & flows of FW/Si during last decades in southern Chile, real time position using RS.

Silva & Neshyba, 1977

Ancapichún, S Garcés-Vargas J 2015







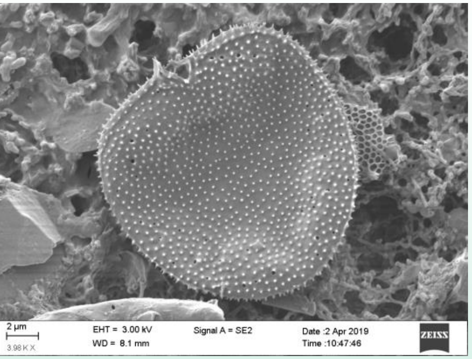
Southeast Pacific Subtropical Anticyclone (SPSA)

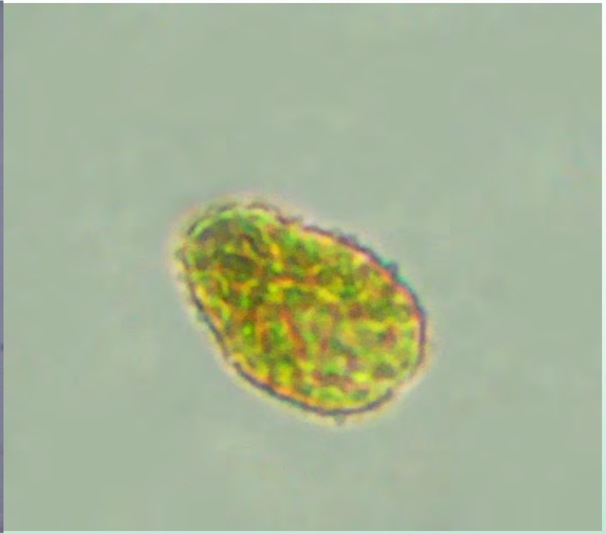
Trainer V *et al* in press Drawing from Jorge Mardones

HAB is……….

1. A scientific problem and ecological phenomema, but also…
2. An economic impact (> US $ 700M)
3. A social and fake news
4. After 2002 a political issue

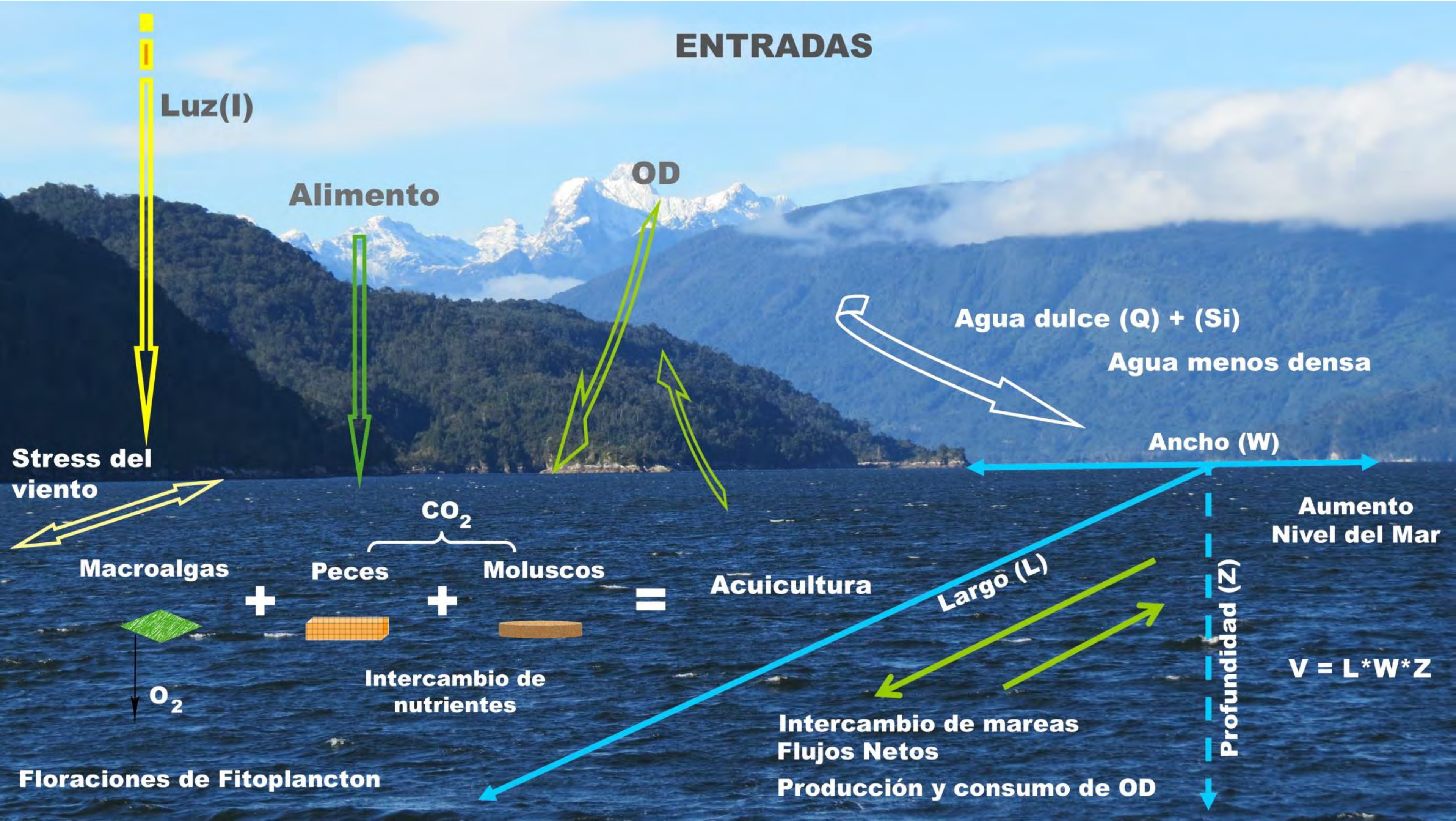
Photo-autotrophic cells: target





1. Phytoplankton Functional Types: bio-optical properties and remote sensing ocean color.
2. Do we observed a higher frequency of flagellates blooms? *A. catenella, Cochlodinium, Pseudochattonella, Karenia & Prorocentrum* spp*.*
3. What are the triggering factors for *A. catenella* blooms?

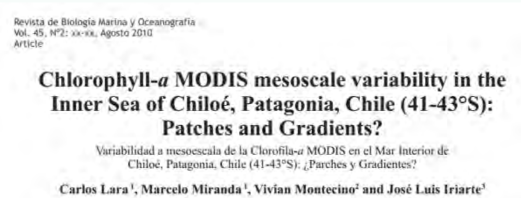
Basic Conceptual Model of Water Column interactions with aquacultures in fjords systems (Clément 2013)



Ecological basic questions

1. Are fjords and coastal ocean during summer/early fall a more competitive habitat and niche for flagellates blooms?
2. Implications in water column net **heat exchange**, **stratification and mixing**, pycnocline position and thin layers formation (Smyth et al 2014 Wyatt 1980 Sullivan et al).
3. **Nutrients** concentrations, ratios & freshwater flow [N/P/**Si**].
4. Underwater **Light** attenuation due to particles (Secchi < 2,5 m)
5. Interpretation & implications of climate change, warming, run off, glacial melting and impacts on fjords (Iriarte et al 2016).

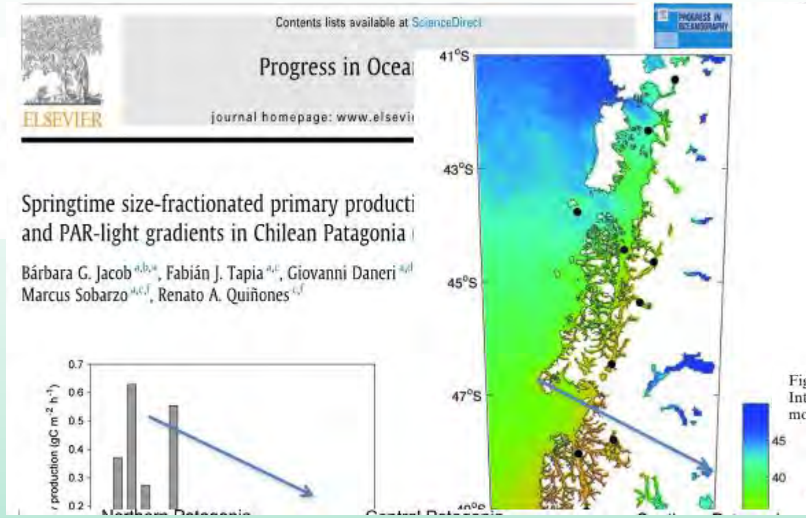
Remote Sensing and Ocean color data from Southeastern Pacific Ocean and the Inland sea.


Revista de Biología Marina y Oceanografía
Vol. 45, Nº2: xx-xx, Agosto 2010
Article

Chlorophyll-*a* MODIS mesoscale variability in the Inner Sea of Chiloé, Patagonia, Chile (41-43°S): Patches and Gradients?

Variabilidad a mesoescala de la Clorofila-*a* MODIS en el Mar Interior de Chiloé, Patagonia, Chile (41-43°S): ¿Parches y Gradientes?

Carlos Lara[1], Marcelo Miranda[1], Vivian Montecino[2] and José Luis Iriarte[3]



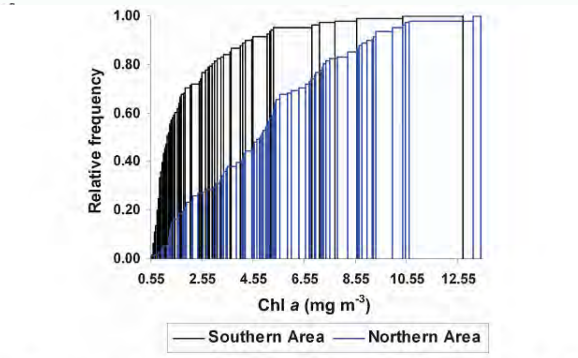


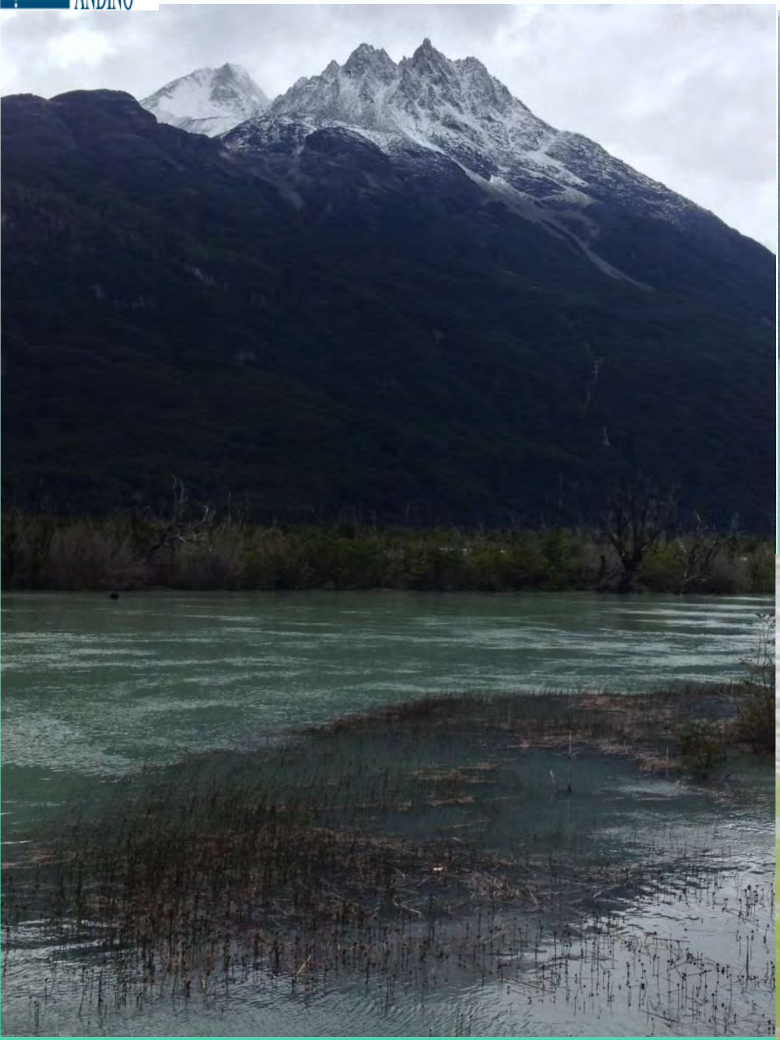
Figure 5. Cumulative distribution of Chl *a* concentrations in the southern area for the Interior Sea of Chiloe for the period January 1998 - December 2006. The data corresponds to monthly averaged Chl *a* values.

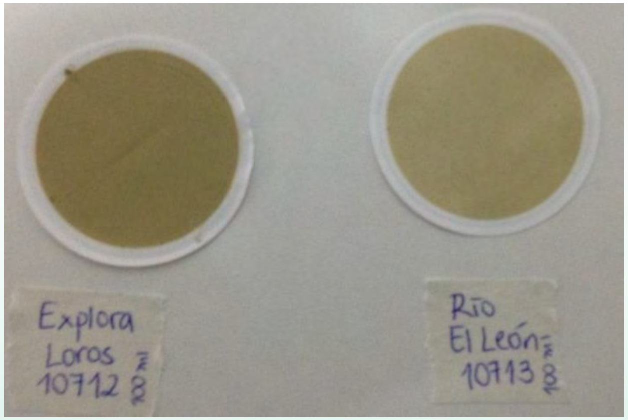
Uribe & Neshyba, 1983, Clément 1988, Thomas 1999, Montecinos et al 2006, Tello et al, Lara et 2010, Saldías et al 2019

Cochlodonium blooms in South Korea Ahn et al 2006

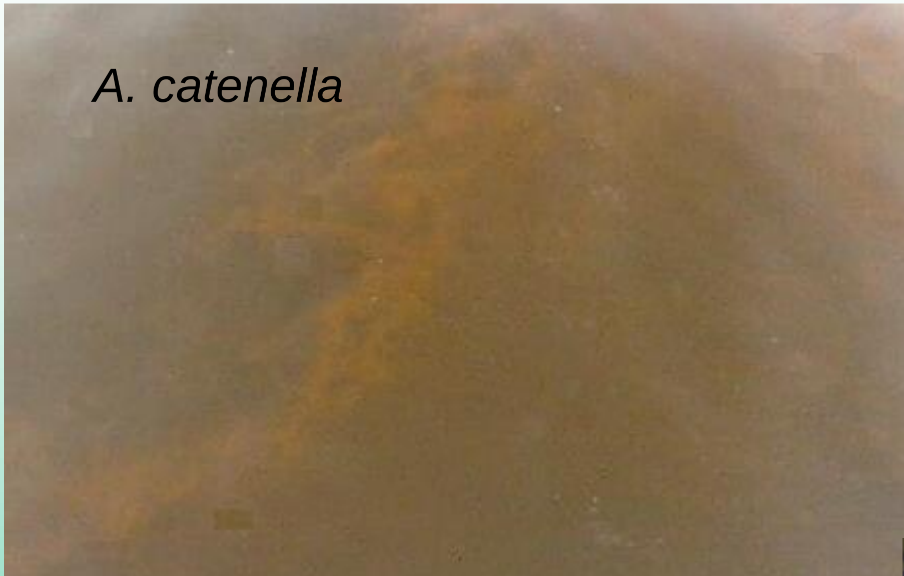
https://www.bigelow.org/news/articles/2016-04-21.html
American Geophysical Union's journal, Global Biogeochemical Cycles, Volume 30, Issue 2, February 2016, pages 268-292.

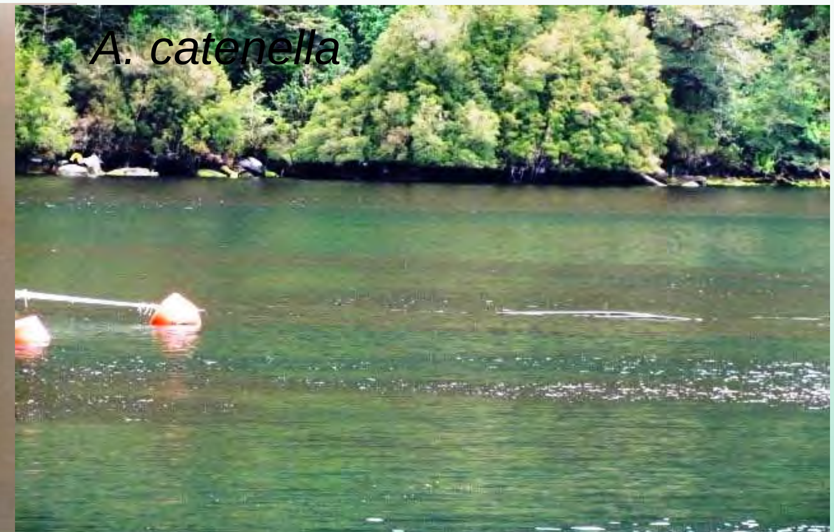
WATER COLOR AND BIO-OPTICS




Explora Loros 10712
Rio El León 10713

HABs, Patches and water color





Methodology, data management and visualization

Phytoplankton Monitoring Programs for Mussel (PSMB) and Salmon aquaculture industry (POAS).

- On line Data base and SQL server http://sispal.plancton.cl/PAL/index.asp
- **Bus. Intelligence & cloud computing data visualization Bime Analytics pdf**
- Biological, Optical & Physical variables.
  - Microscopy observations and flow cytomer (flow Cam) for celss ID and counting
  - User require and demand rapid time response after sampling < than 24-48 hours.

Complement activities of Photoautotrophic cells classification with optical techniques.

- CTD-O and Chl a *in situ* profiles
- EcoTriplet Fluorometer, *in situ* chlor a, Backscattering Bb(460 & 660 nm)
- Total Absorption coefficient marine water a(λ) Future Colaboration Nagur Cherukuru CSIRO
- Discrete water column samples from above 20 m. more than **800 samples/month**
- Sampling frequency 5-20 days depending the season and risk.
- **Ocean color remote sensing (Rrs) as an intermediate users WINSOFT**
- **others**

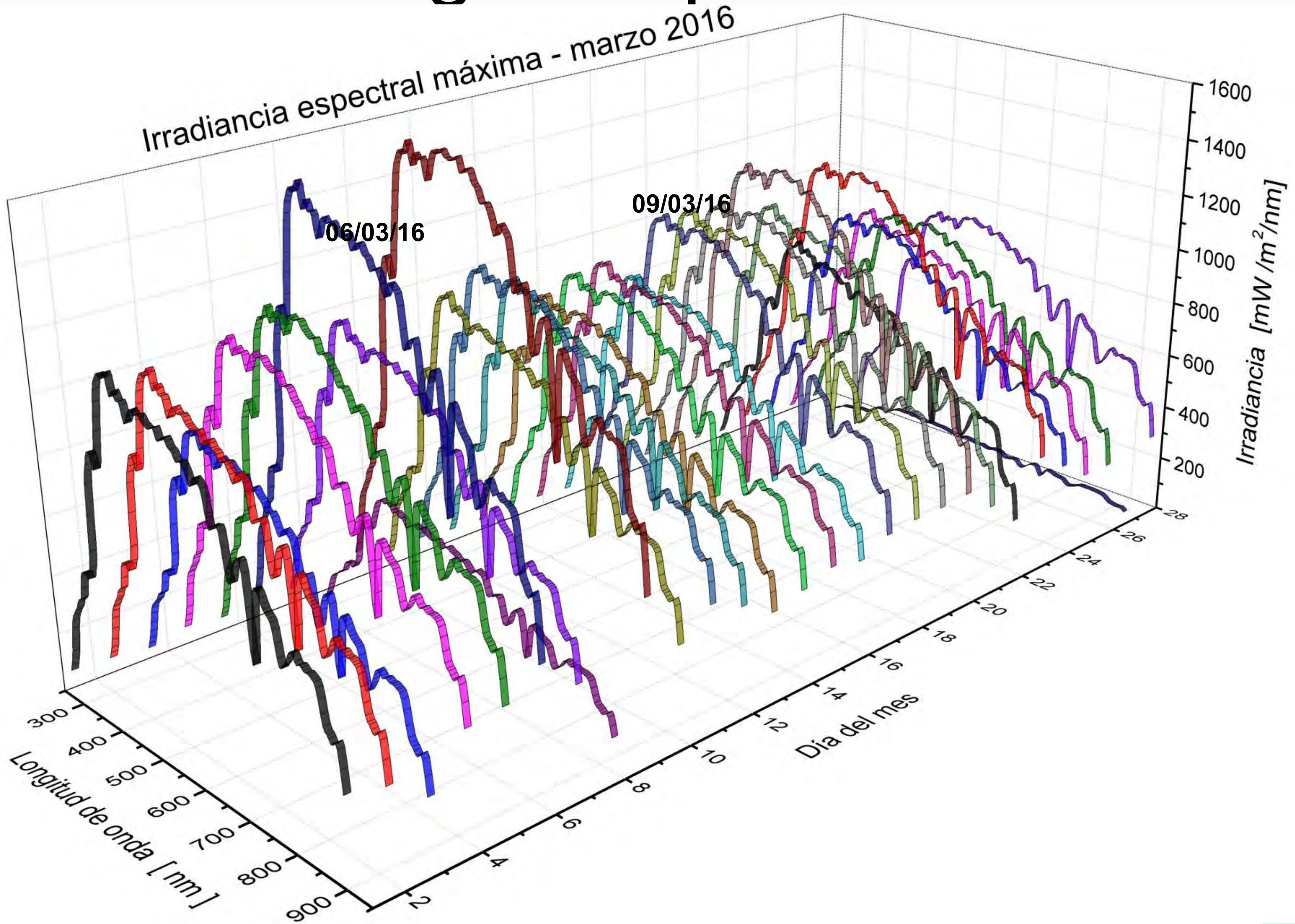
Applications of Bio-optics in optically complex o waters

1. **Absorption Coefficient** ($a$ph) QFT Greg Mitchell
2. **Backscattering** (bb 440 y 660 nm).

Appreciate inputs of Steward Bernard, Collin Roesler & V. Martinez.

1. Chlorophyll *a* **Chl**
   1. **Passive and *in situ and* In vitro**
   2. **FRRf3, Variable &Active chlor *a* fluorescence** Fo, Fm, Fv, Fv/Fm, Sigma **Kolber et al 1998** Oxborough et al Chelsea Technology Group, UK
2. Hyperspectral Irradiance I (λ,t)

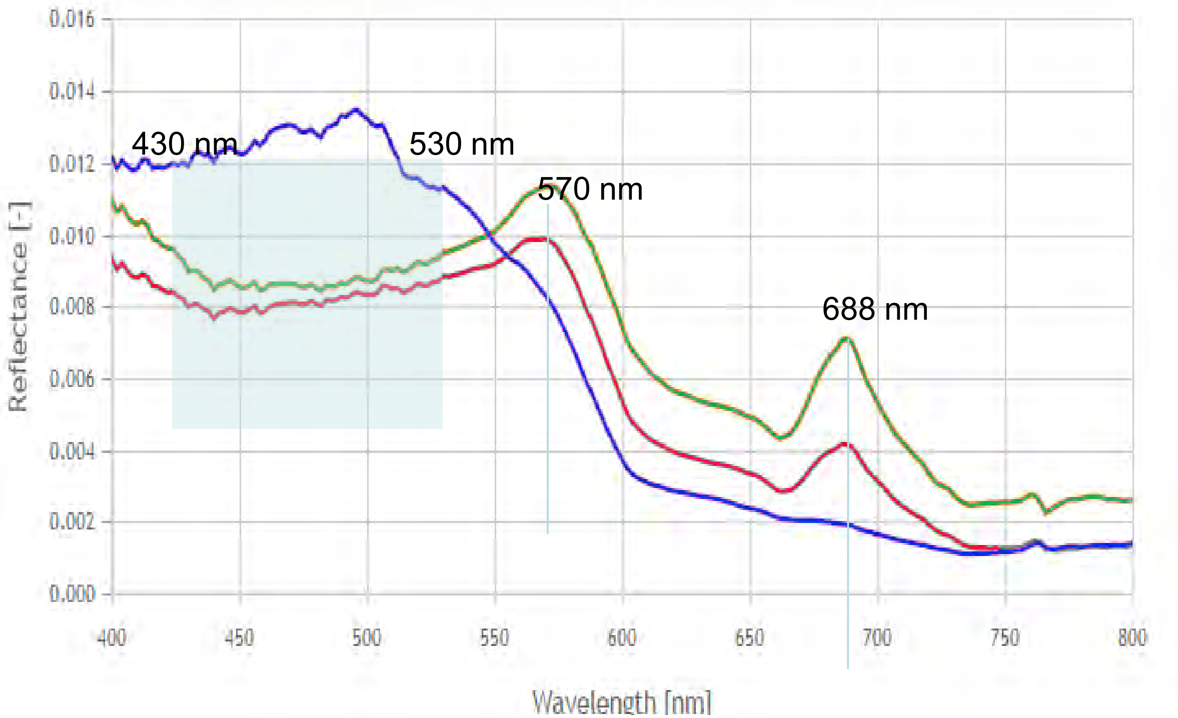
Hyper-spectral radiometry, before during max peak of HAB N° 122



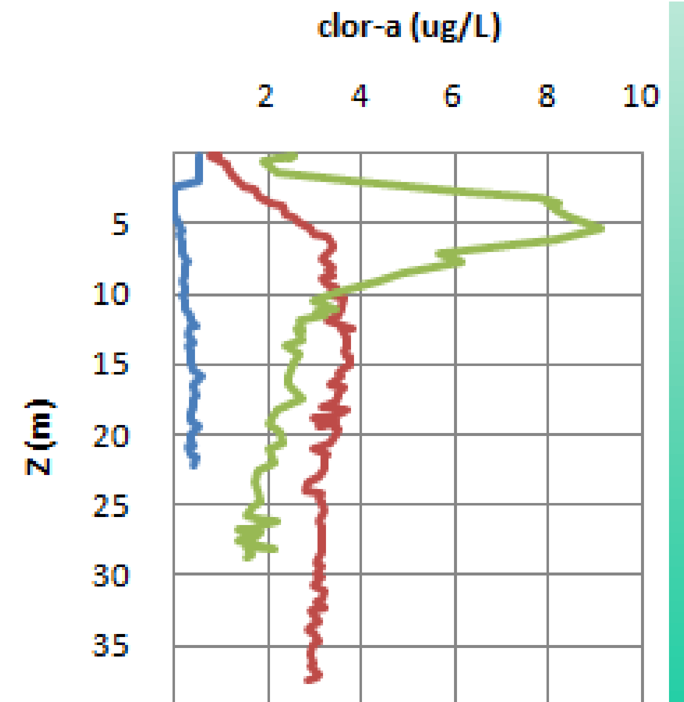
WISP-3 spectra & *IN SITU* CHL a

Different Reflectance spectra and Water Column Chl a *in situ*, phytoplankton abundance, and water color perception

simple algorithm base upon water column & spectral shape

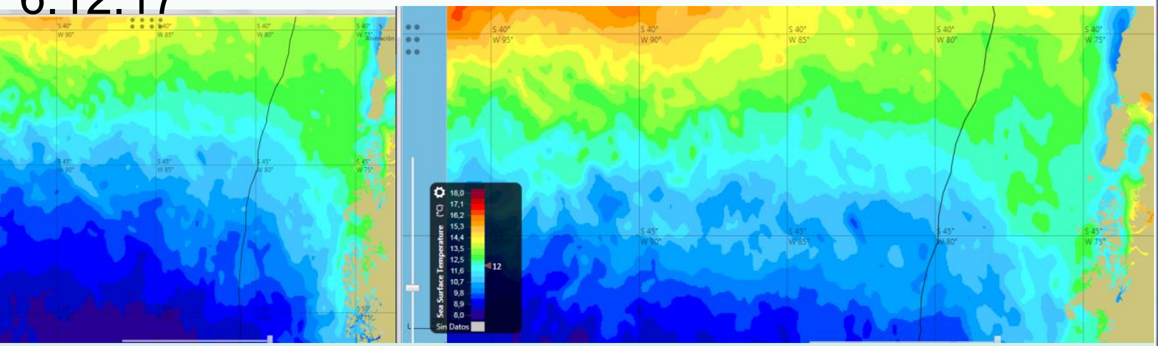


Fecha	Hora	Estación	secchi (m)	Color del agua	Cielo	Z (m)	cel/mL	clora (ug/L)	
								Spect	EcoTriplet
						0	9	0.30	0.50
27-oct	12:30	E1	14	azul	Despejado	5	16	0.80	0.10
						10	25	0.12	0.18
						0	1707	0.9	0.84
24-nov	13:45	E2	4	verde	Parcial	5	1478	2.2	2.65
						10	1695		3.36
						0			2.36
24-nov	15:00	E3	4	verde	Parcial	5			9.07
						10			3.4

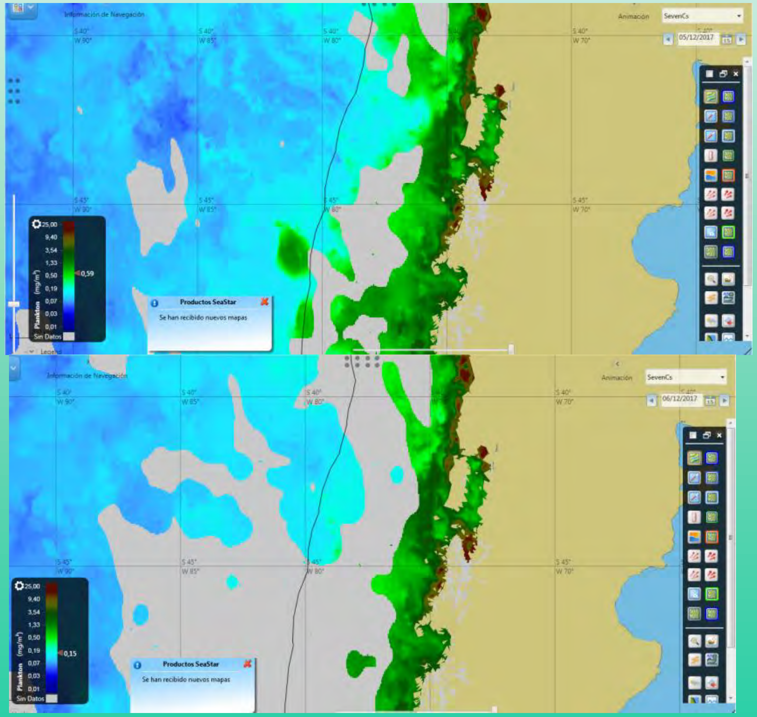


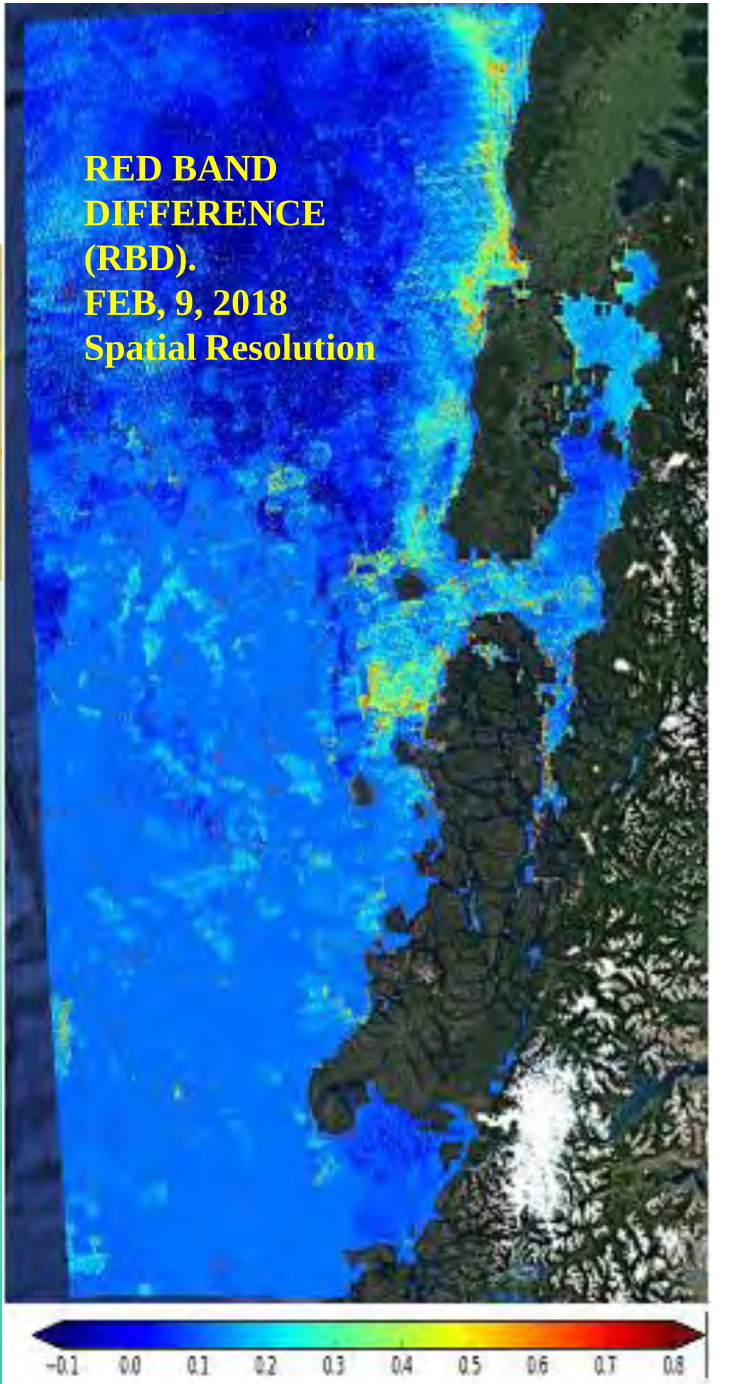
Chl,SST using InsightExplorer

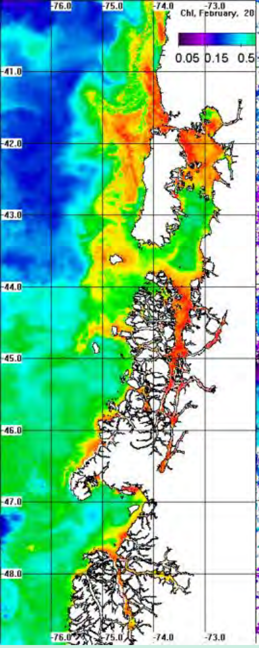
6.12.17 7.12.17

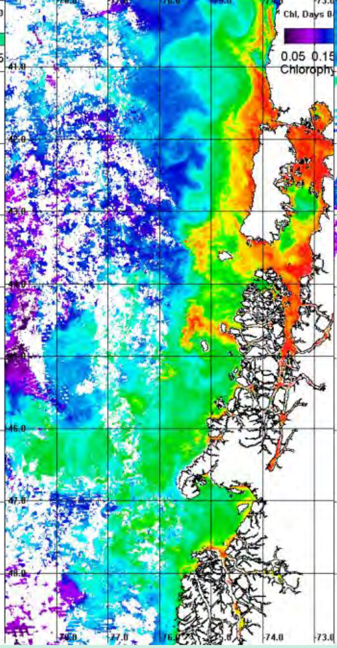


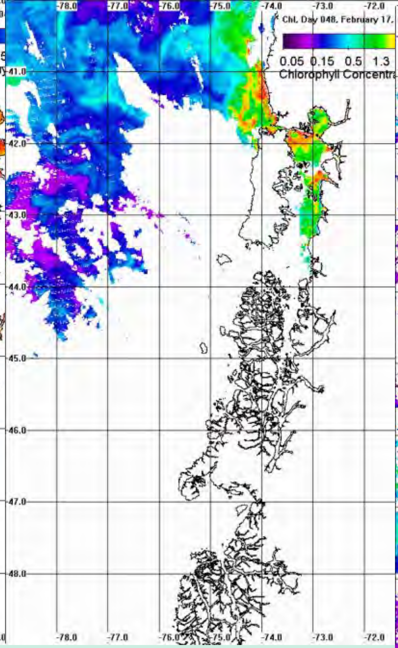
Chl *a* : 1 al 5 y 1 al 6 de diciembre del 2017

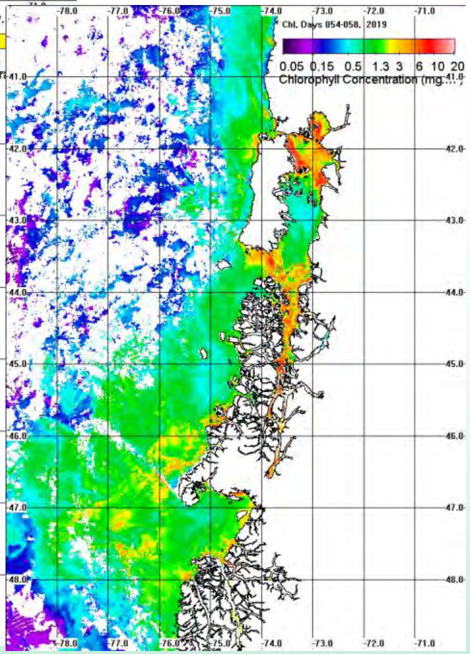


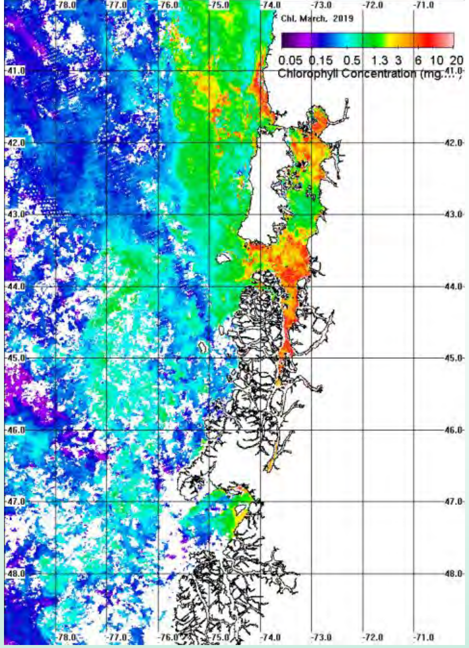


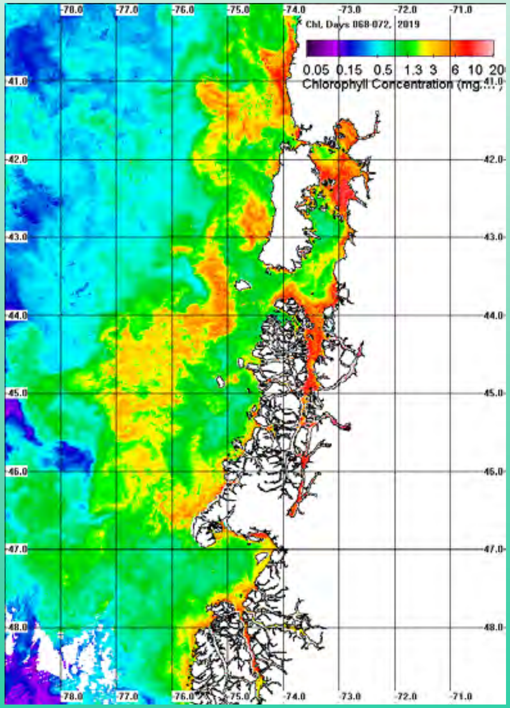

Chl, February, 20
0.05 0.15 0.5

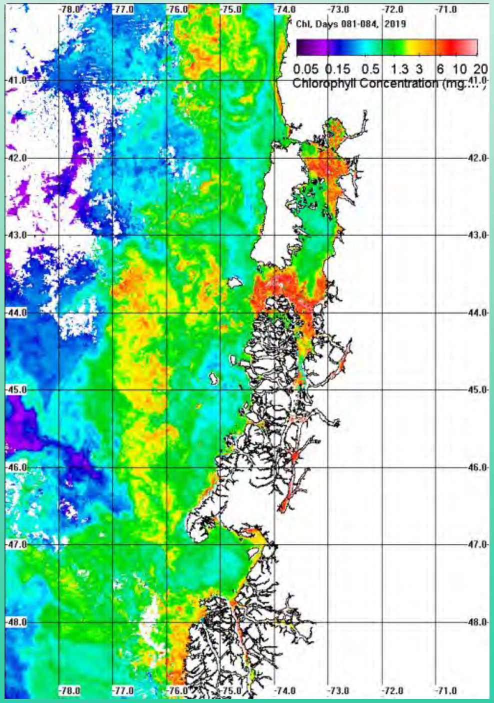

Chl, Days 0
0.05 0.15
Chlorophy

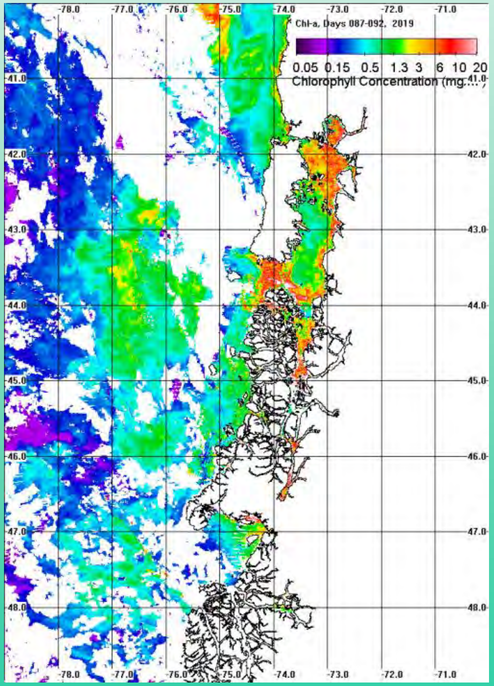

Chl, Day 048, February 17,
0.05 0.15 0.5 1.3
Chlorophyll Concentr

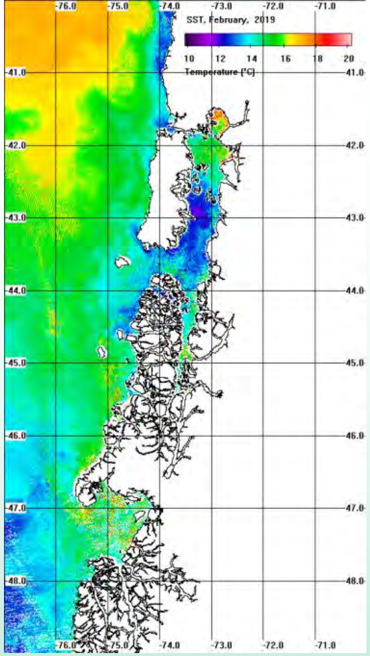

Chl, Days 054-058, 2019
0.05 0.15 0.5 1.3 3 6 10 20
Chlorophyll Concentration

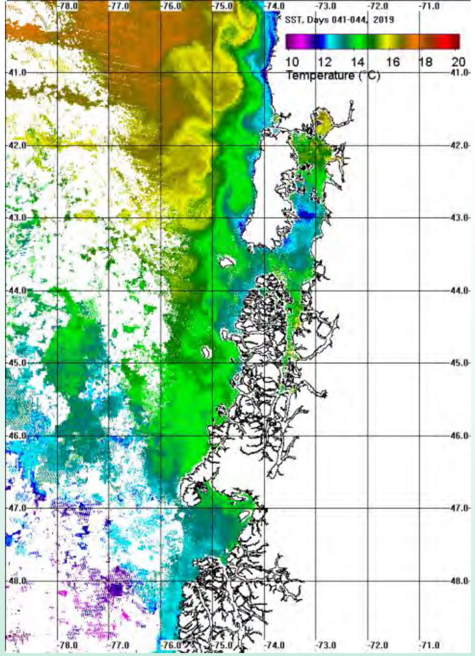

Chl, March, 2019
0.05 0.15 0.5 1.3 3 6 10 20
Chlorophyll Concentration

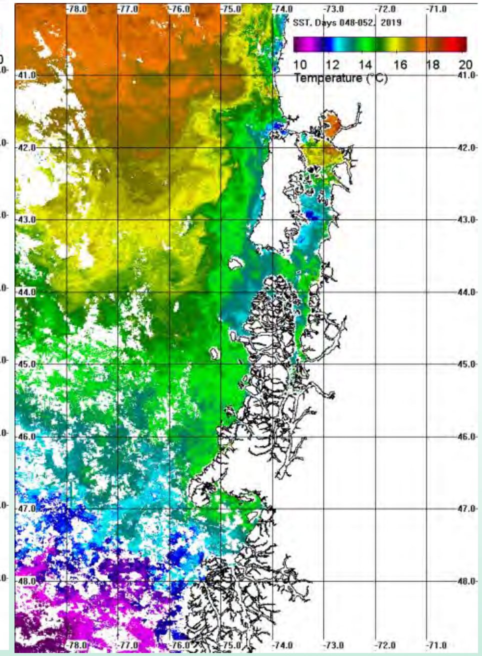

Chl, Days 068-072, 2019
0.05 0.15 0.5 1.3 3 6 10 20
Chlorophyll Concentration

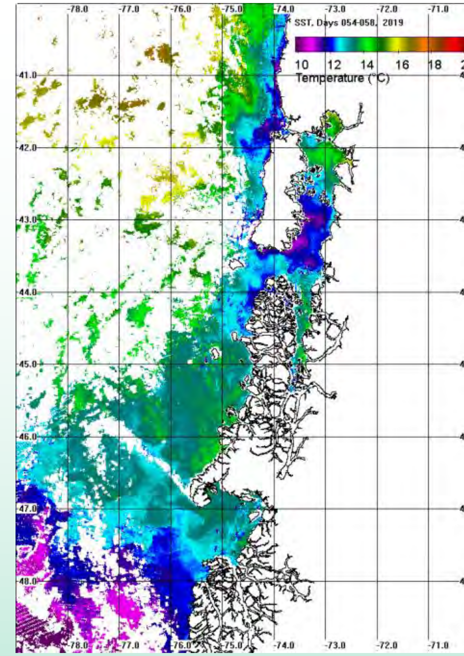

Chl, Days 081-084, 2019
0.05 0.15 0.5 1.3 3 6 10 20
Chlorophyll Concentration

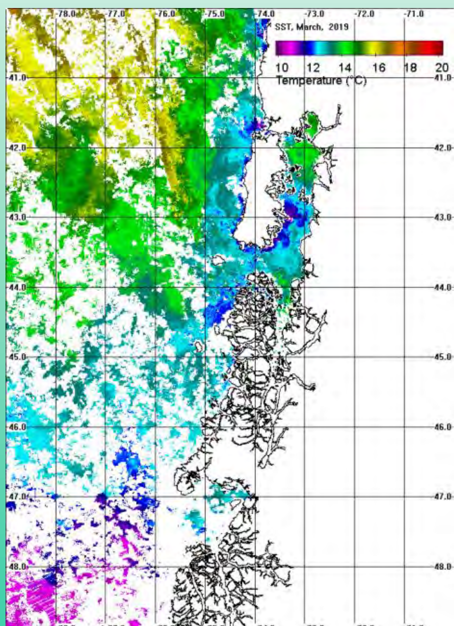

Chl-a, Days 087-092, 2019
0.05 0.15 0.5 1.3 3 6 10 20
Chlorophyll Concentration

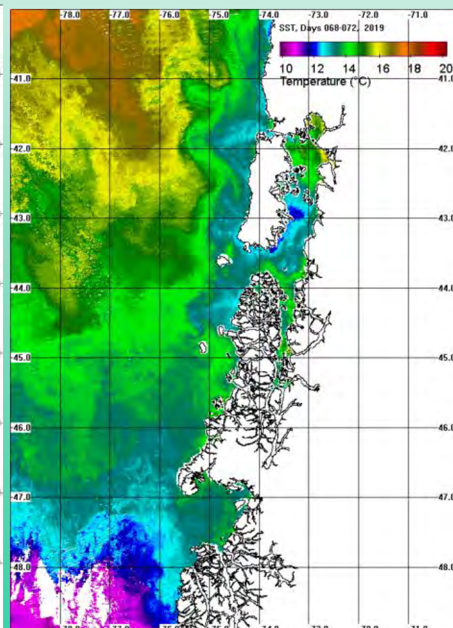

SST, February, 2019
10 12 14 16 18 20
Temperature (°C)

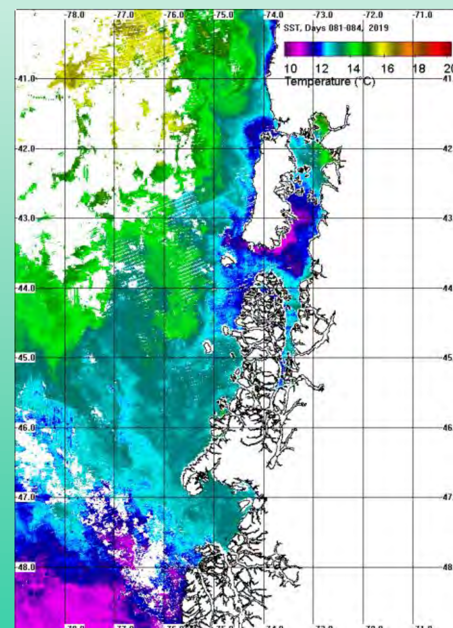

SST, Days 041-044, 2019
10 12 14 16 18 20
Temperature (°C)

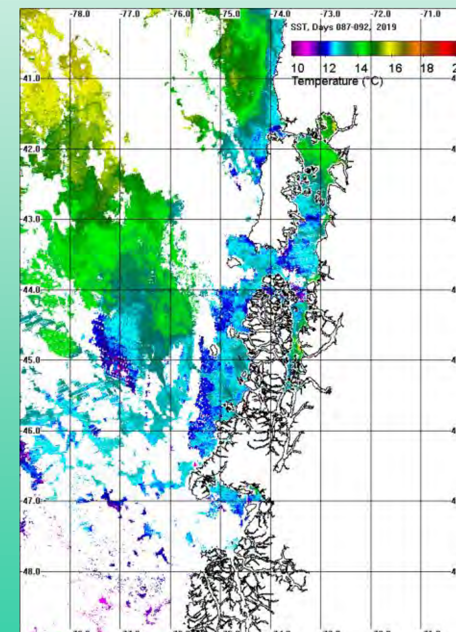

SST, Days 048-052, 2019
10 12 14 16 18 20
Temperature (°C)


SST, Days 054-058, 2019
10 12 14 16 18 20
Temperature (°C)


SST, March, 2019
10 12 14 16 18 20
Temperature (°C)


SST, Days 068-072, 2019
10 12 14 16 18 20
Temperature (°C)


SST, Days 081-084, 2019
10 12 14 16 18 20
Temperature (°C)


SST, Days 087-092, 2019
10 12 14 16 18 20
Temperature (°C)

41-44

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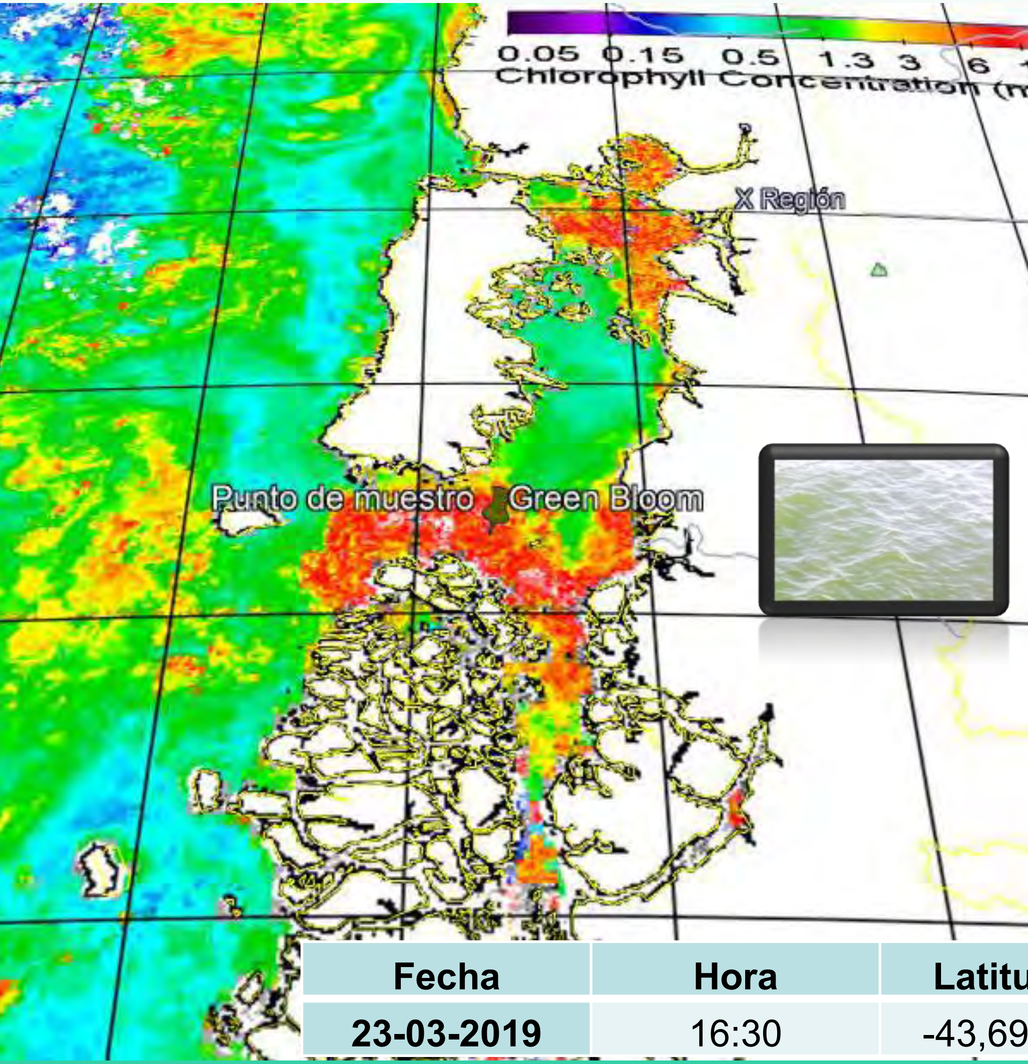
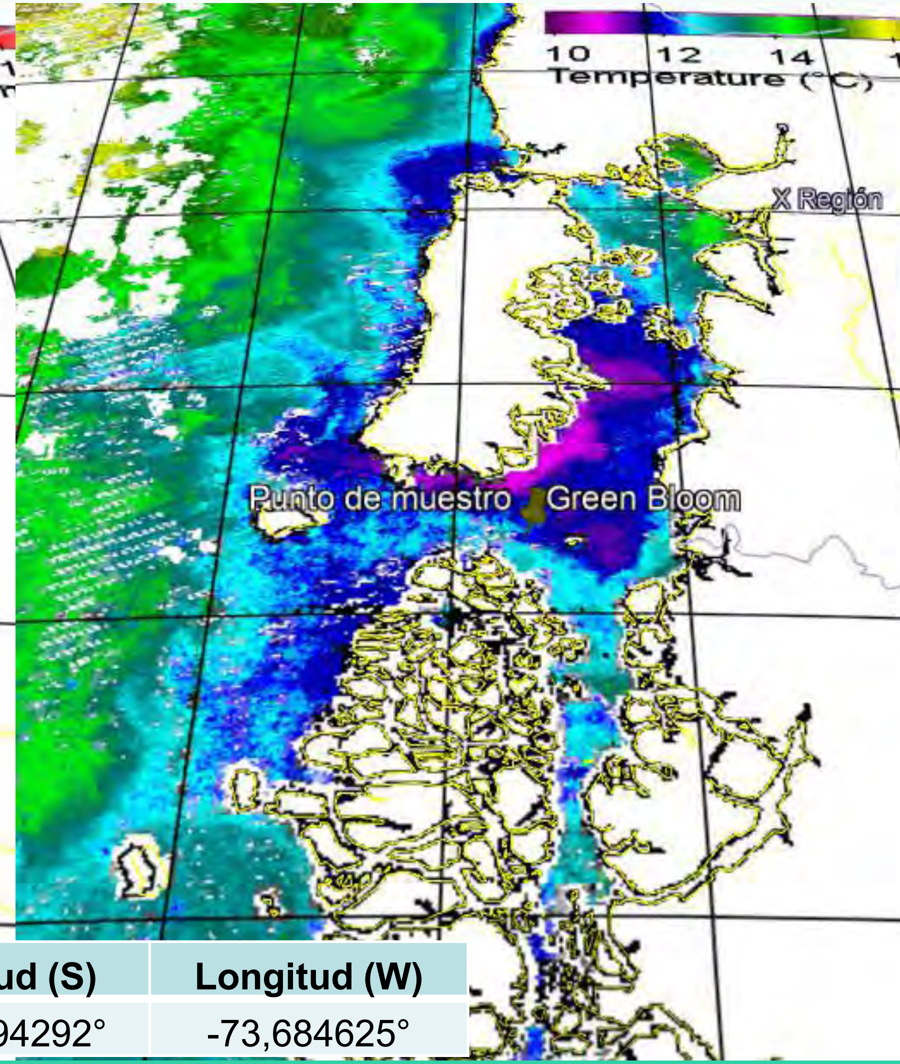
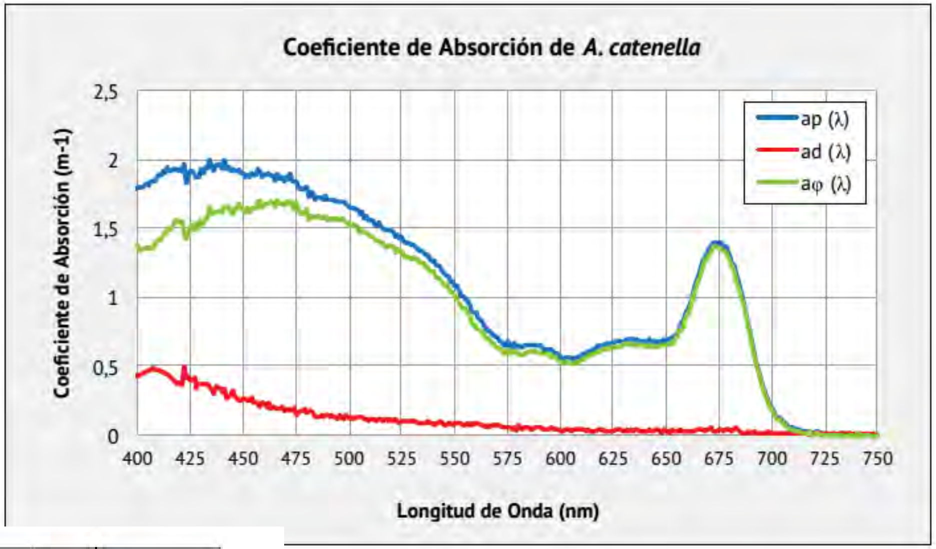
Lepidodium chlorophorum a green dino producing blooms, Remote Sensing Chl and SST Using WINDATA/WINSOFT from M. Kahru & Google maps *.kmz dates 81-84

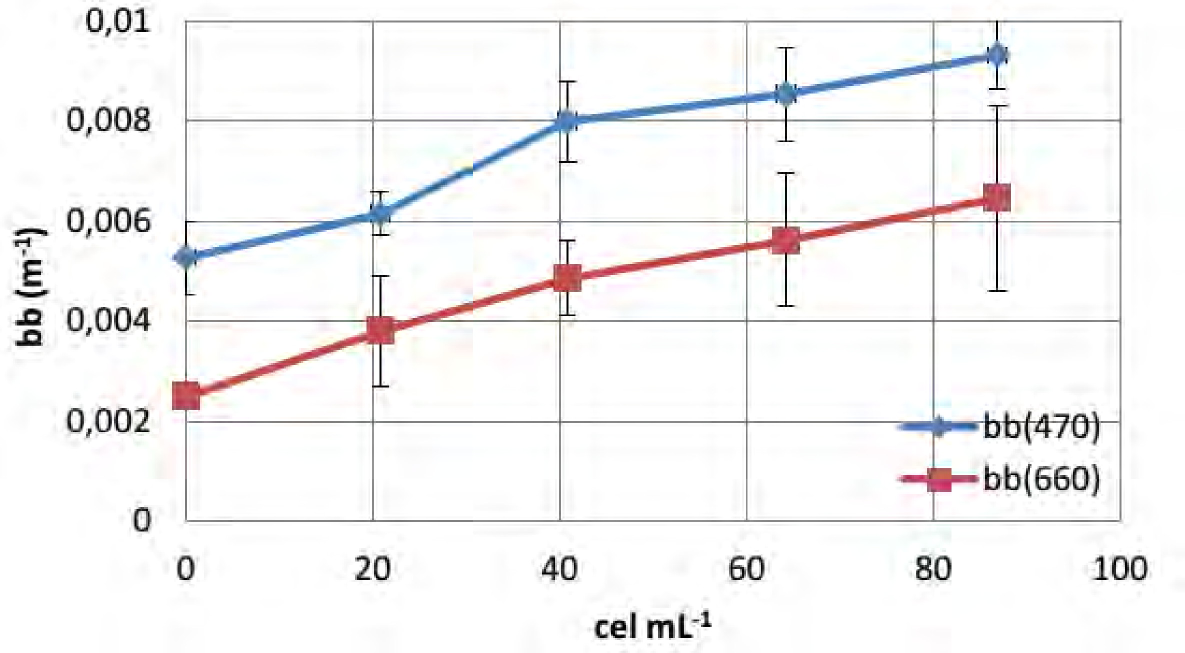




Fecha	Hora	Latitud (S)	Longitud (W)
23-03-2019	16:30	-43,694292°	-73,684625°

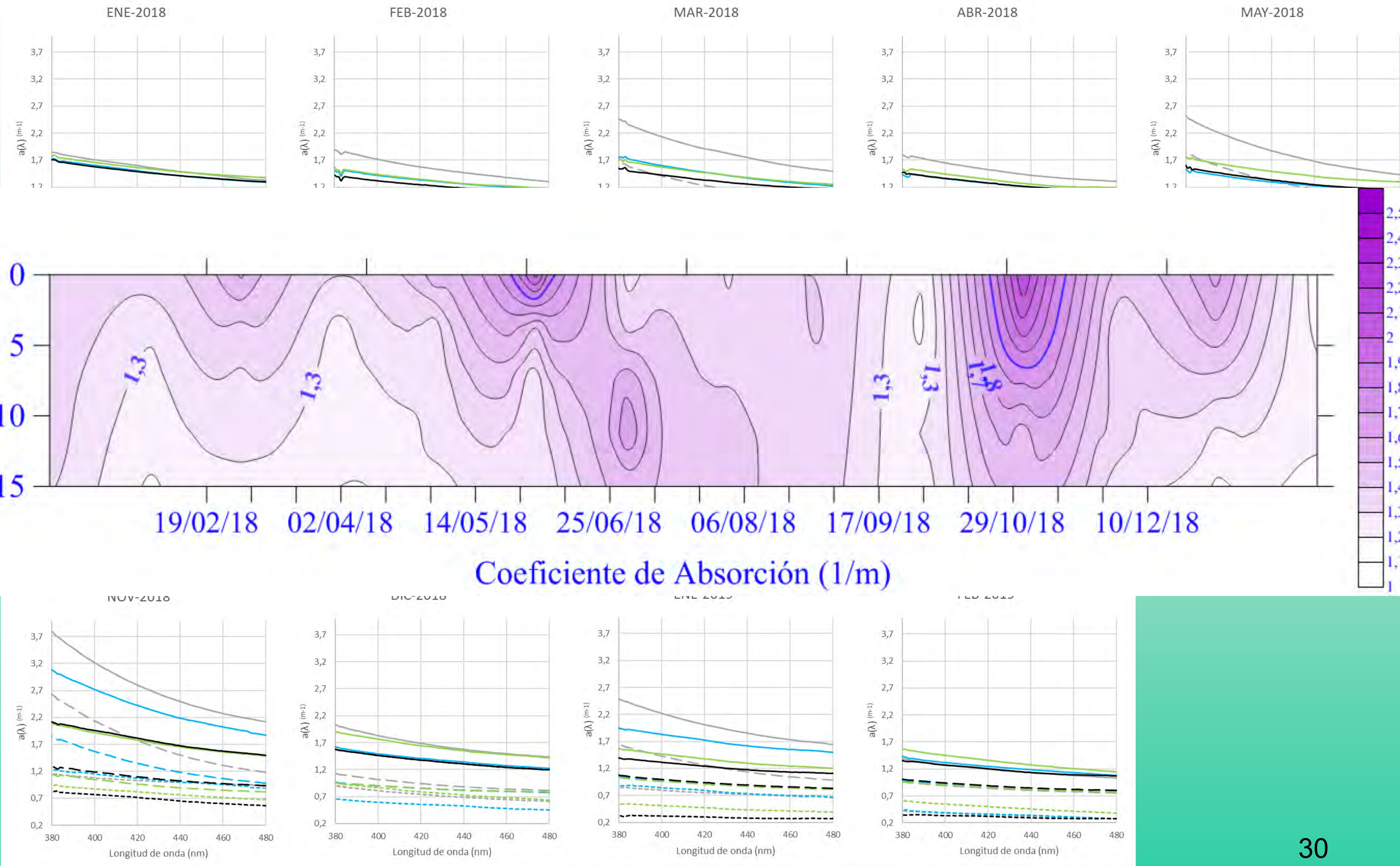
Bb (λ) and Absorption Coefficients of *Alexandrium catenella* motile culture cells





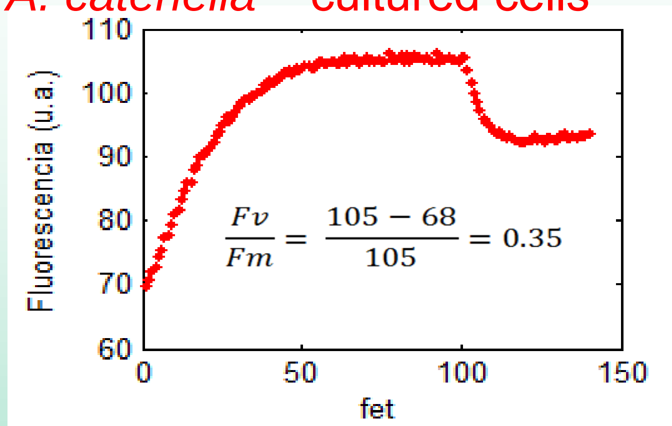
Stuart et al 2004

Absorption (λ,t, z) near a fish farm in a fjord 440

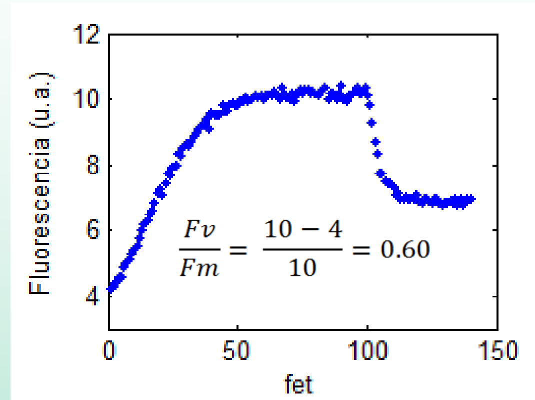


FRRf3 Induction Curves of PSII
Dinoflagellates from culture, *Pseudochattonella*, *S. costatum*, from Marine Inland Sea

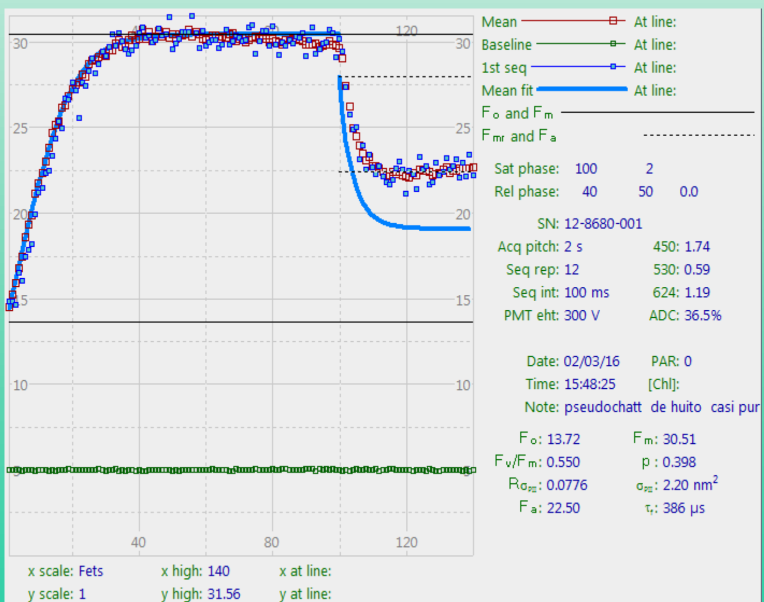
A. catenella cultured cells



Skeletonema field cells



Pseudochattonella cells from 2016 bloom

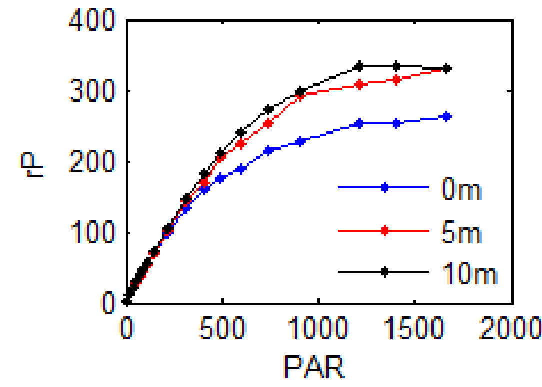


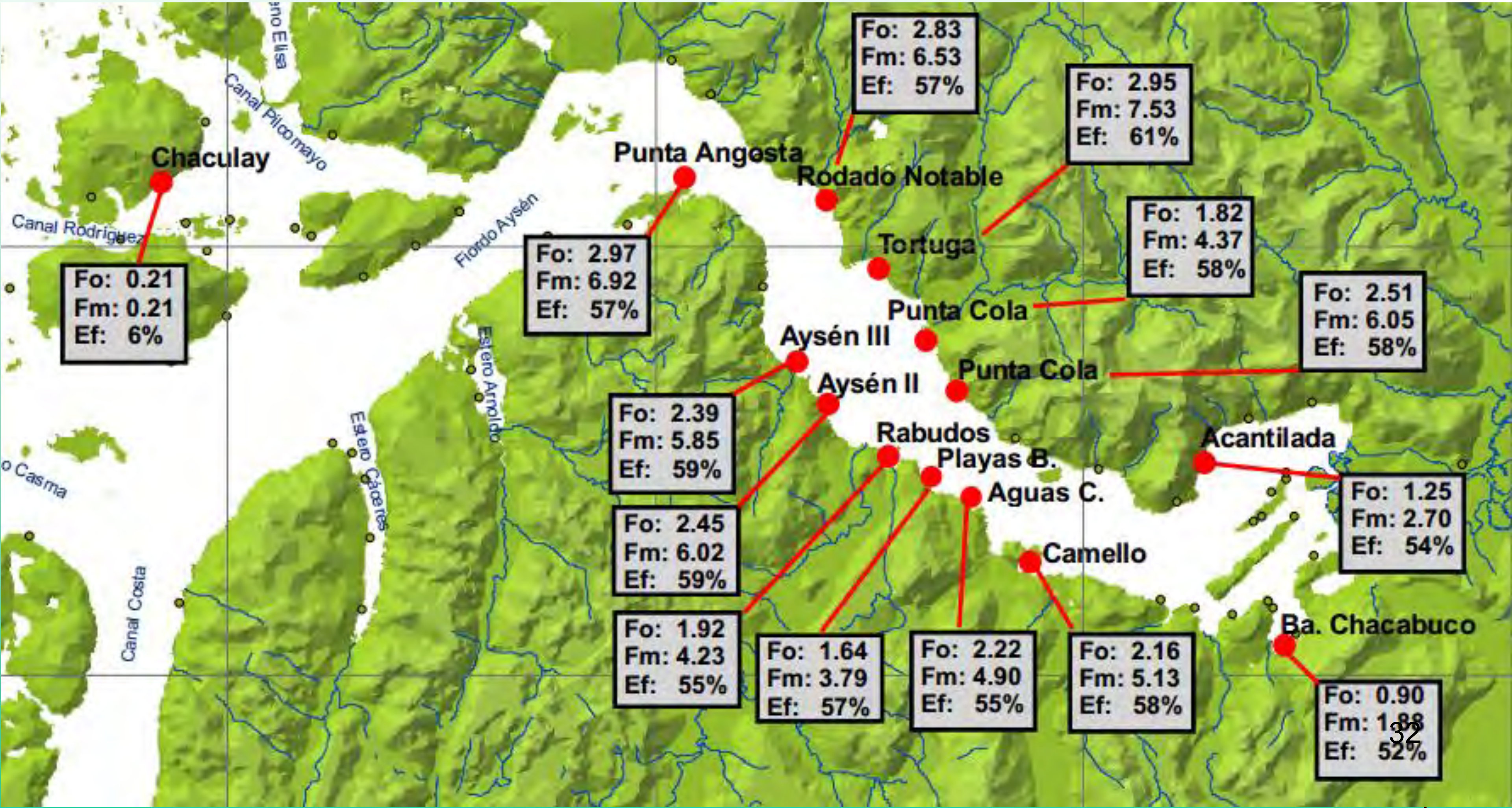
***Pseudochattonella*, among others, all the high biomass Harmful blooms studied with FRRf have really high Fo (13) & Fm (30) values.**

Light and Phothosynthesis

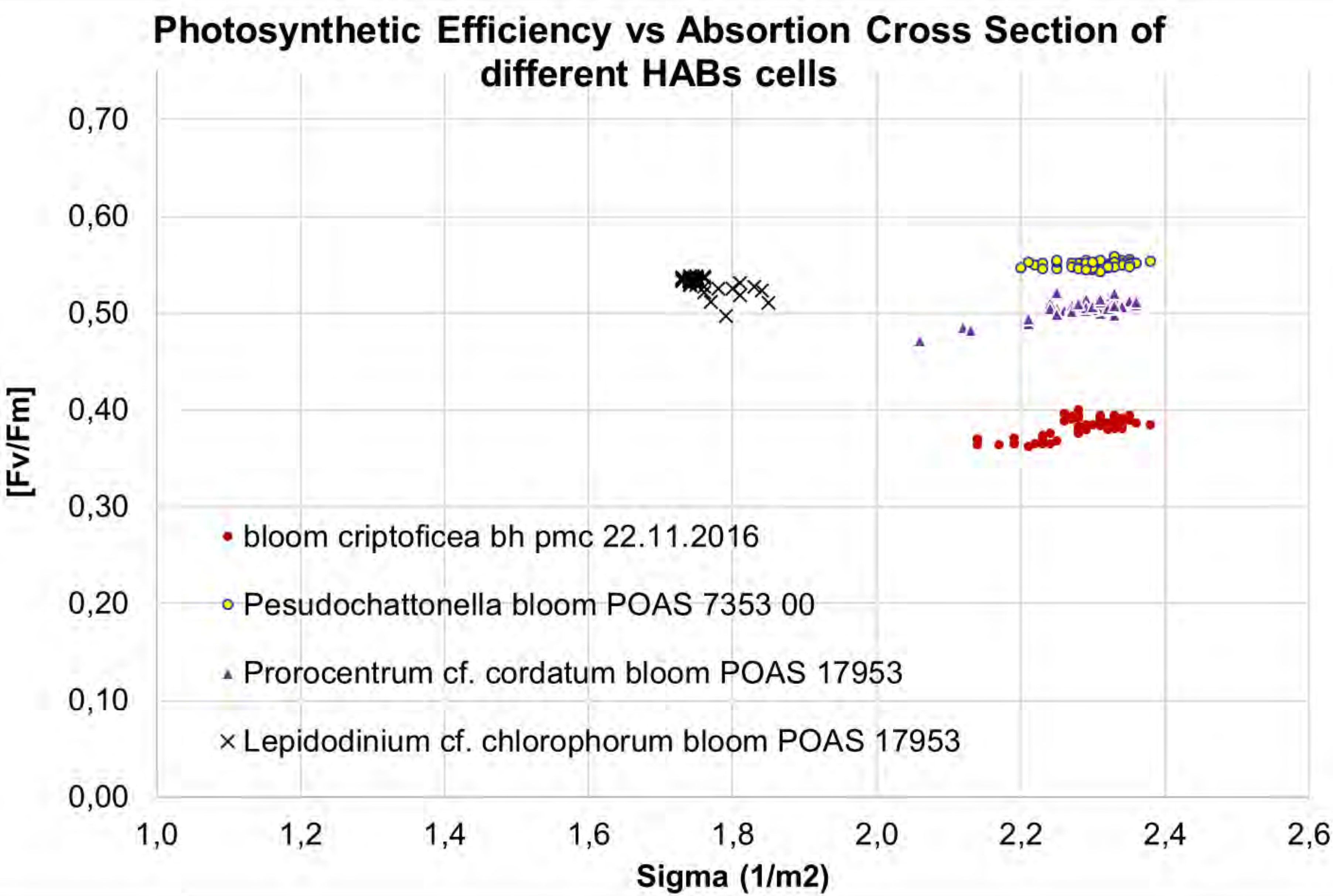
7353-0 huito bloom.

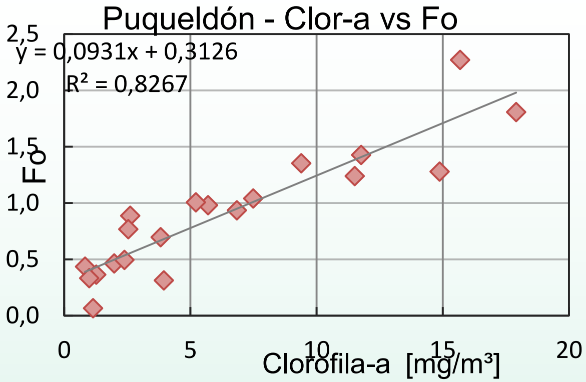
Harmful diatom bloom in
Aysen Fjord
T. seudonanna (5 um)
Photosynthetic parameters with FRRf3 (RLC)



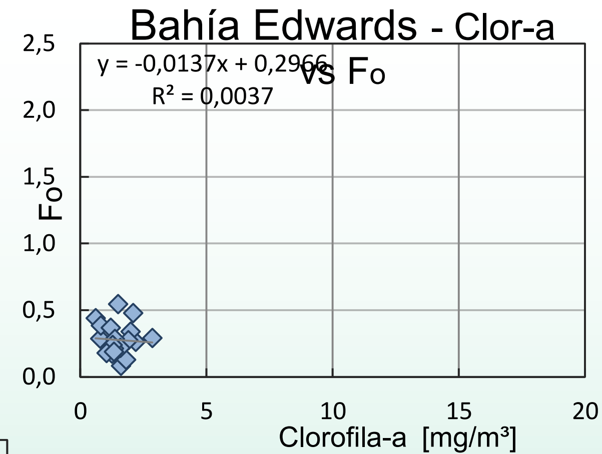


QUANTUM EFFICIENCY OF PSII (Fv/Fm) vs. CROSS SECTION OF PSII
Data from natural assemblages

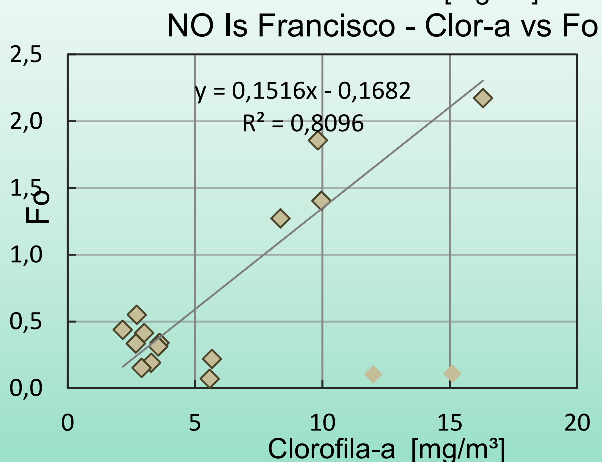




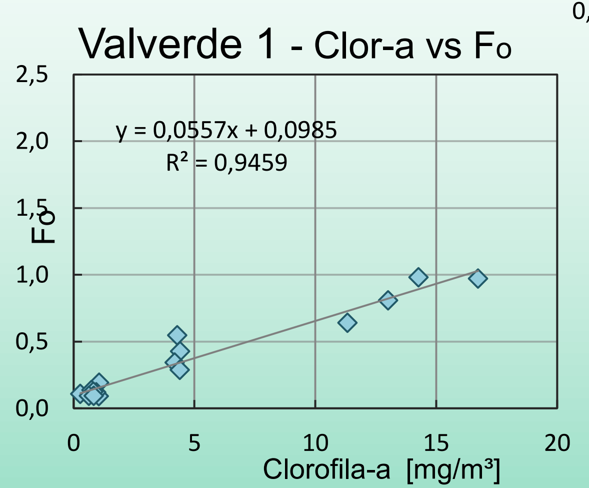
Puqueldón - Clor-a vs Fo
y = 0,0931x + 0,3126
R² = 0,8267
Fo
Clorofila-a [mg/m³]



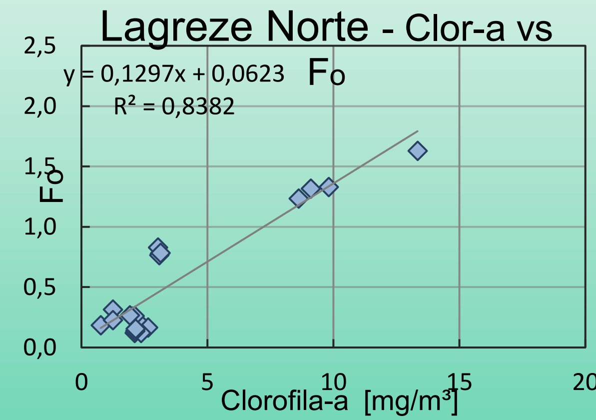
Bahía Edwards - Clor-a vs Fo
y = -0,0137x + 0,2966
R² = 0,0037
Fo
Clorofila-a [mg/m³]



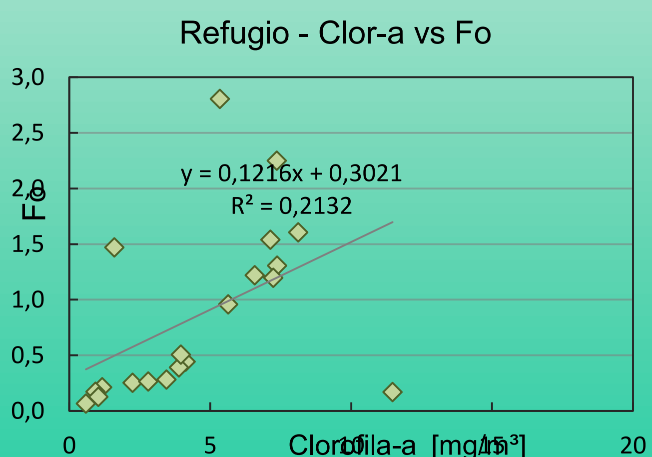
NO Is Francisco - Clor-a vs Fo
y = 0,1516x - 0,1682
R² = 0,8096
Fo
Clorofila-a [mg/m³]



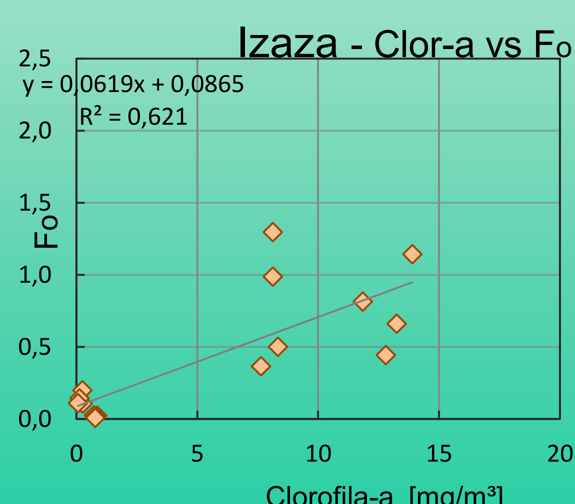
Valverde 1 - Clor-a vs Fo
y = 0,0557x + 0,0985
R² = 0,9459
Fo
Clorofila-a [mg/m³]



Lagreze Norte - Clor-a vs Fo
y = 0,1297x + 0,0623
R² = 0,8382
Fo
Clorofila-a [mg/m³]

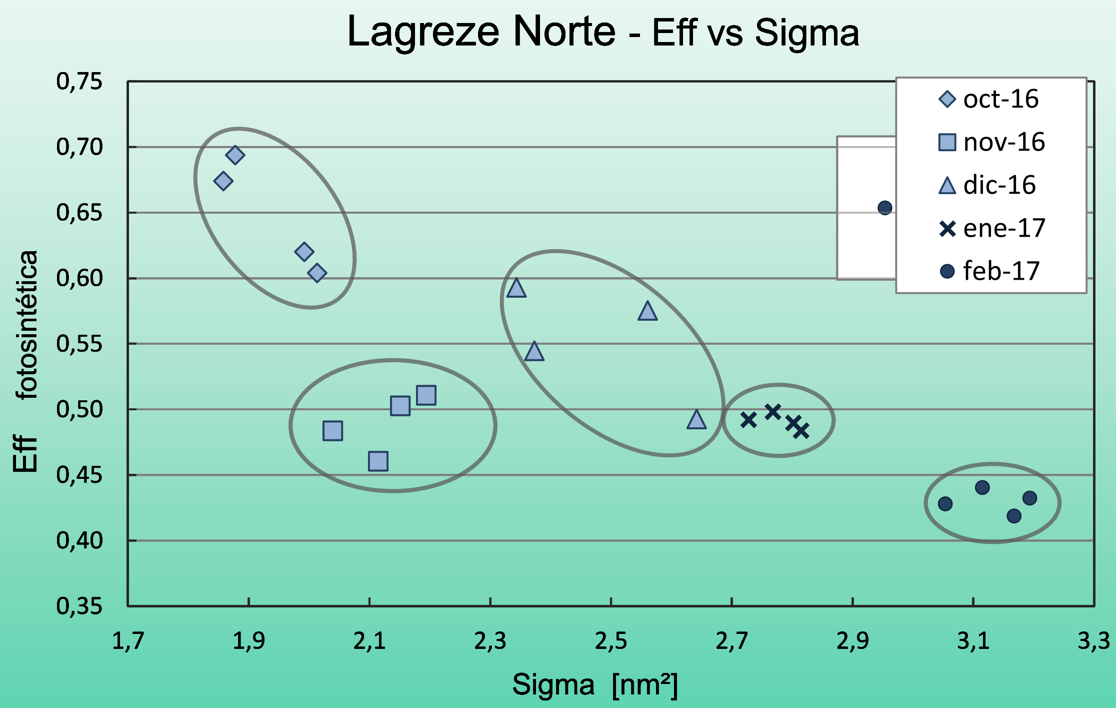


Refugio - Clor-a vs Fo
y = 0,1216x + 0,3021
R² = 0,2132
Fo
Clorofila-a [mg/m³]

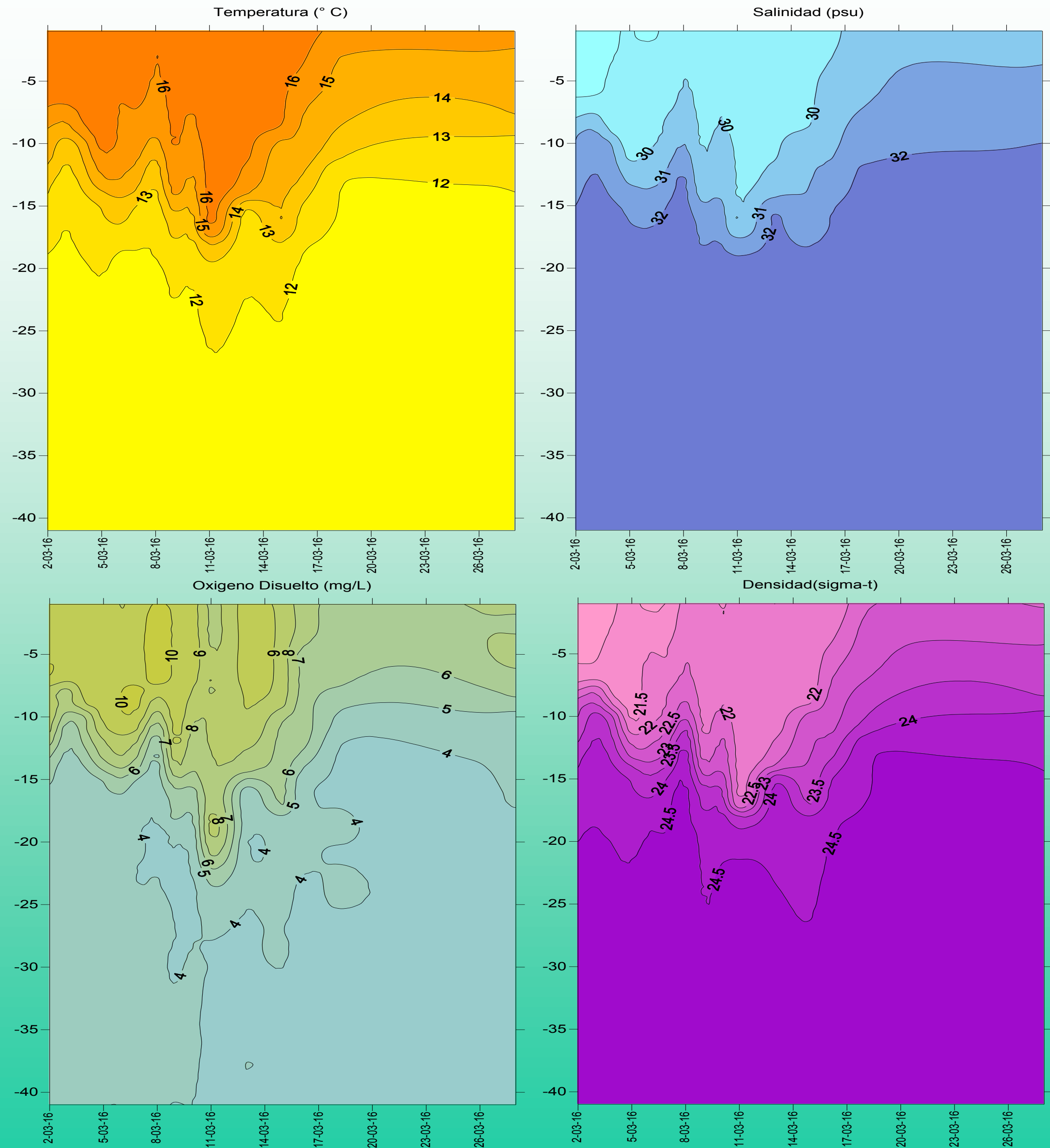


Izaza - Clor-a vs Fo
y = 0,0619x + 0,0865
R² = 0,621
Fo
Clorofila-a [mg/m³]

QUANTUM EFFICIENCY OF PSII (Fv/Fm) vs. CROSS SECTION OF PSII
Data from natural assemblages



Extreme Event of HAB 2016



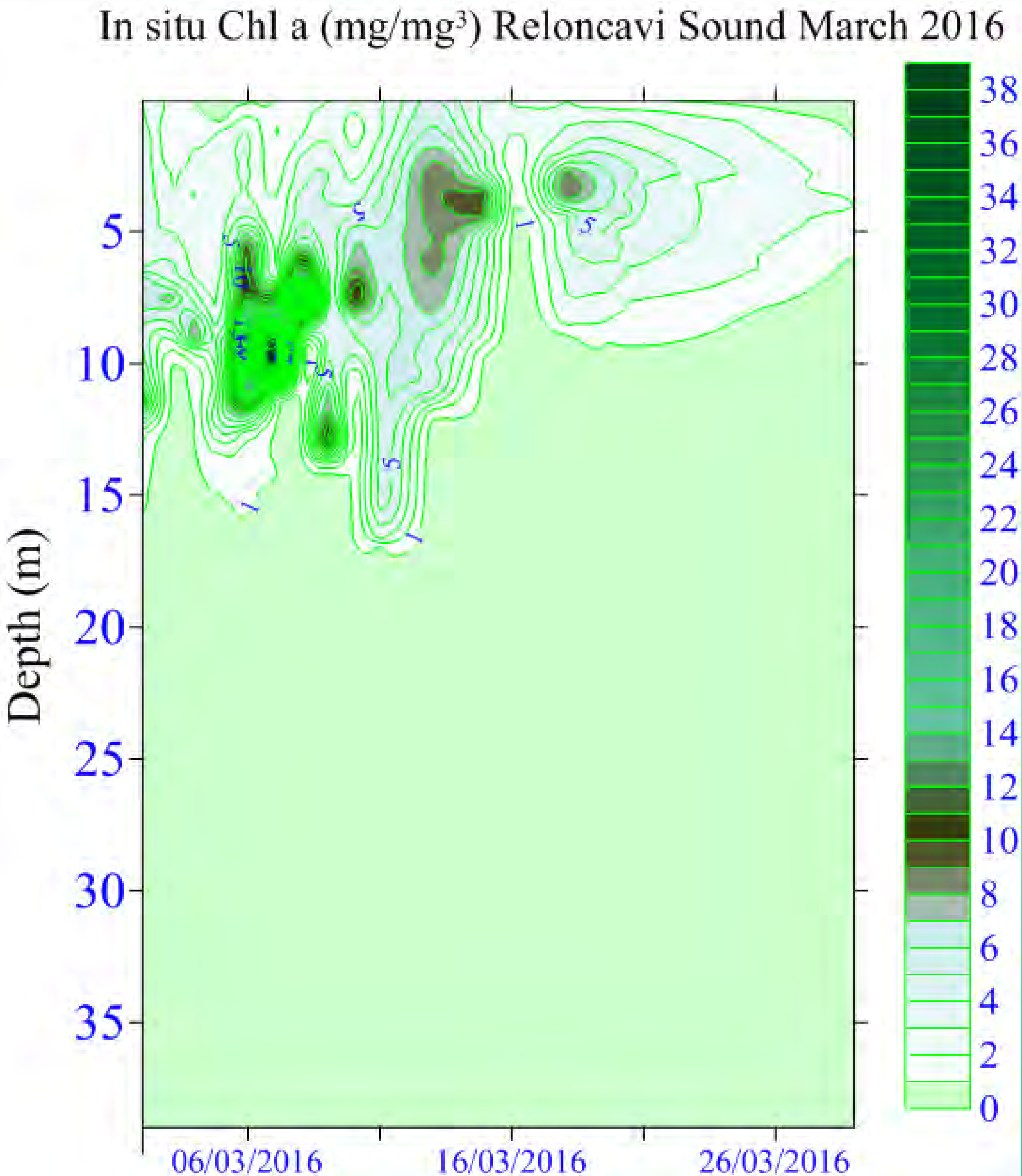
The "Godzila 2016" HAB of *Pseudochattonella*, *in situ* Chl a Fluorescent, Bbp (470 and 660) 7-3-16, 14:51

1. At the max subsurface chl a value it is observed a minimum variability of particles backscattering coefficient ratio (Bb440/Bb660 ratio), and a very consistent relationship between BB and Chl a.

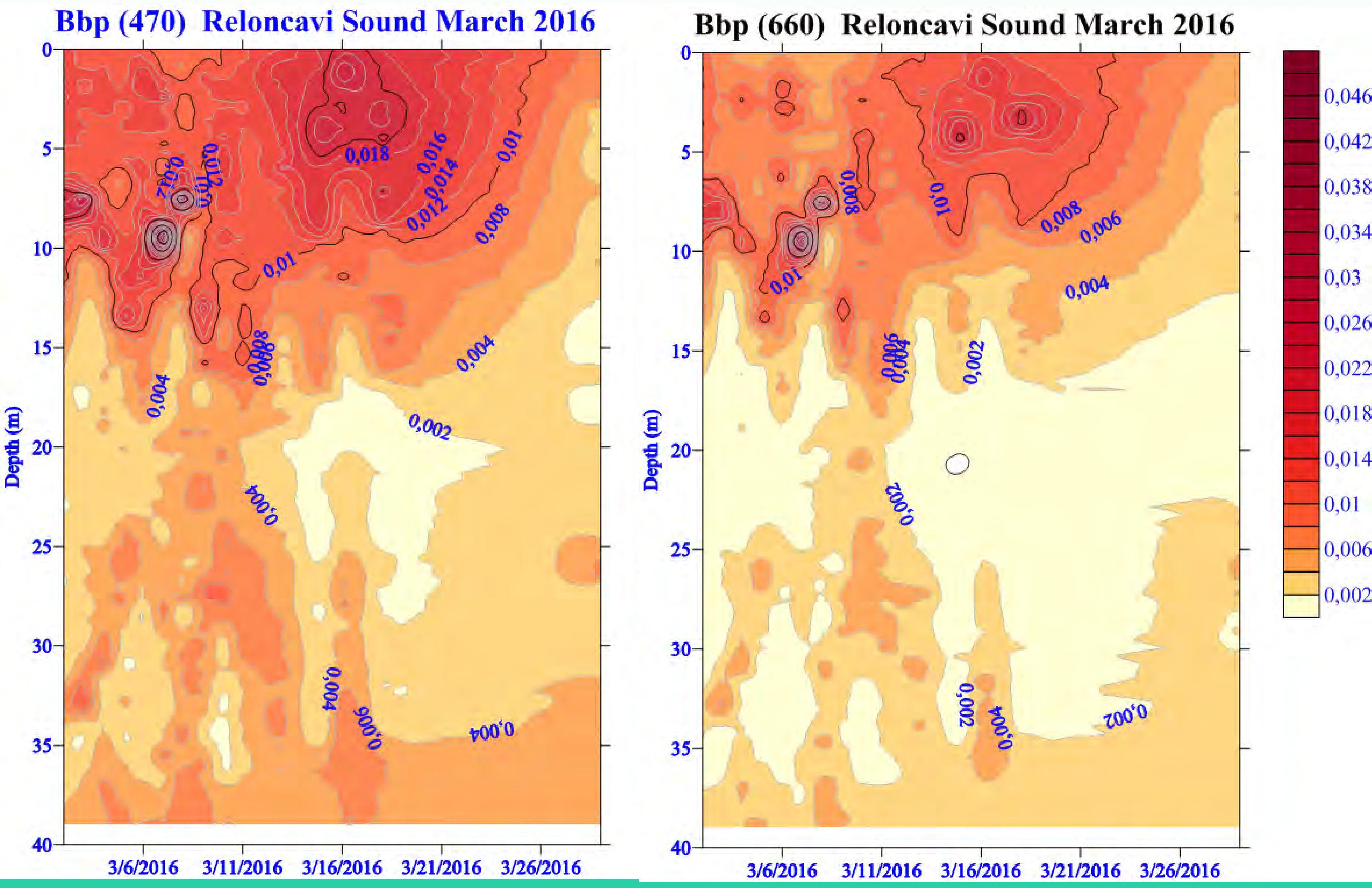
2. Dominant cells in thin layer maximum belong to *Pseudochattonella* (max 4000 cells/mL).

3. Bb distributions at 470 and 660 nm, and ratios could be used as a proxi for Pseudochattonella blooms

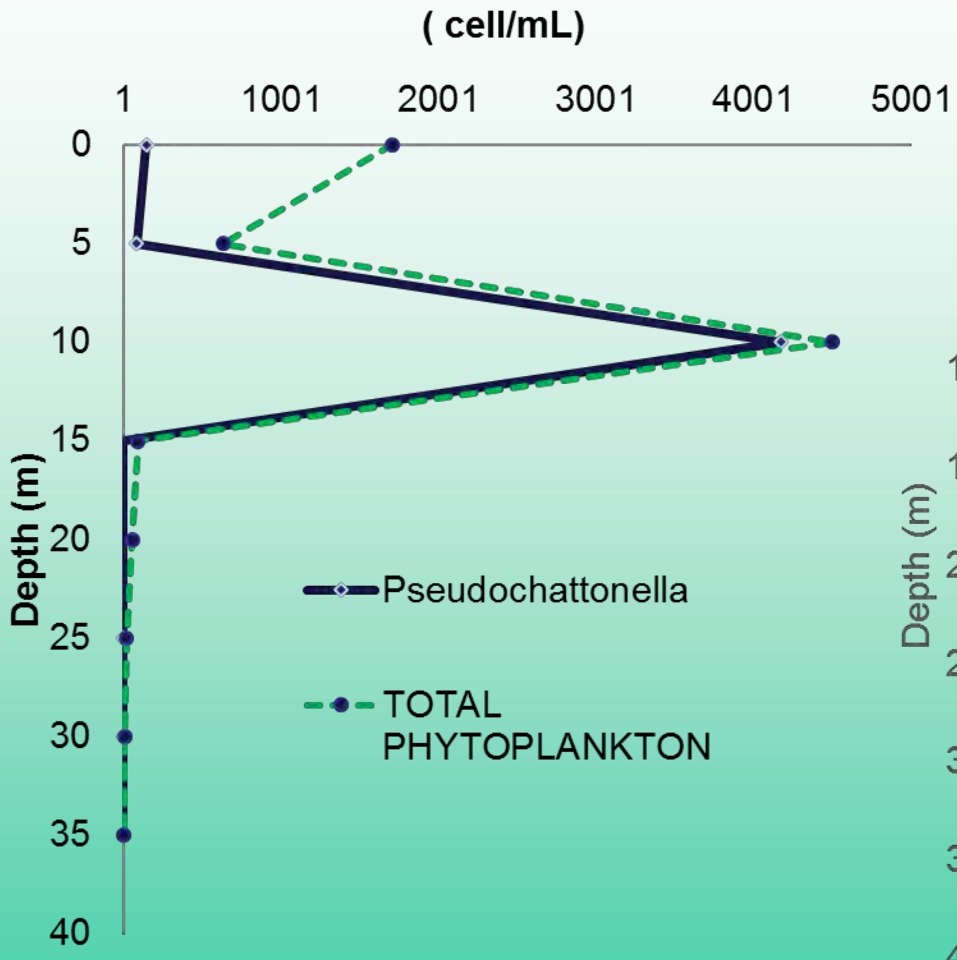
Clément et al 2017

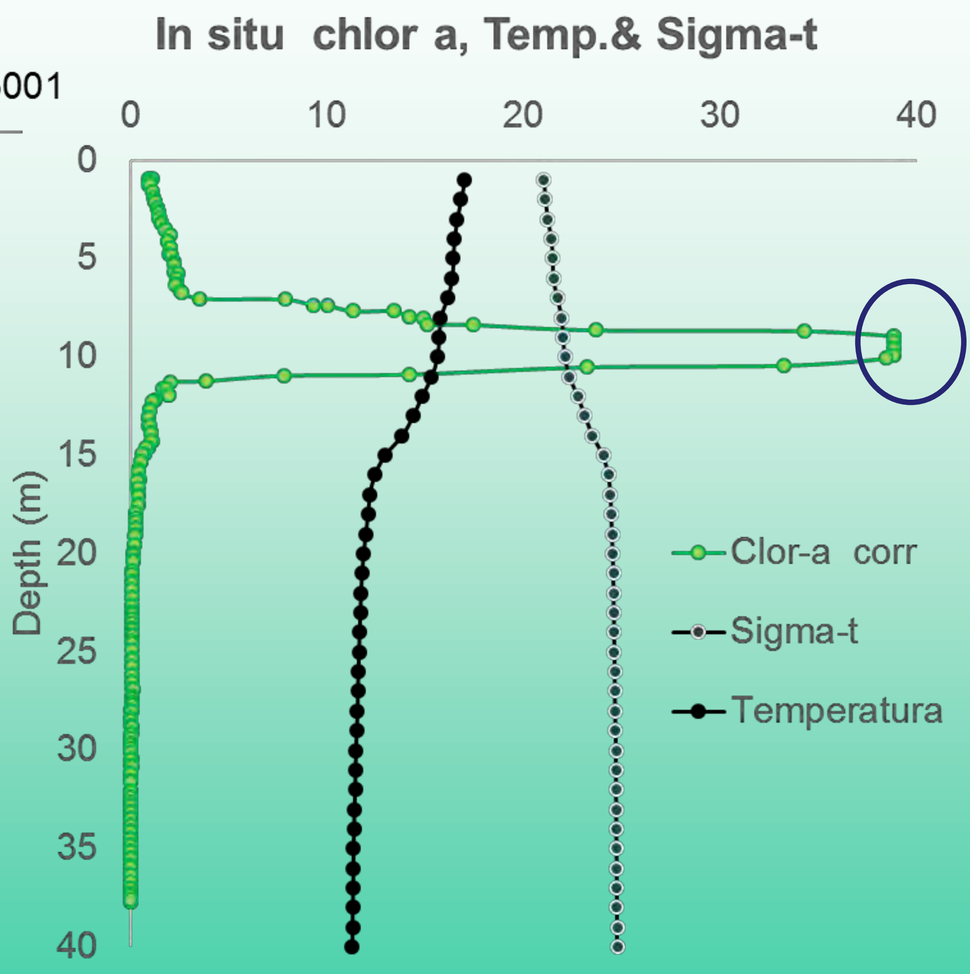


HABs of *Pseudochattonella*, *in situ* Chl a Fluorescent, Bbp (470 and 660) 7-3-16, 14:51



Phytoplankton Abundance, *Pseudochattonella*, *in situ* Chl <u>*a*</u> Fluorescent, Temperature, & Sigma-t. 7-march-2016, 14:51
(Clément et al 2017)



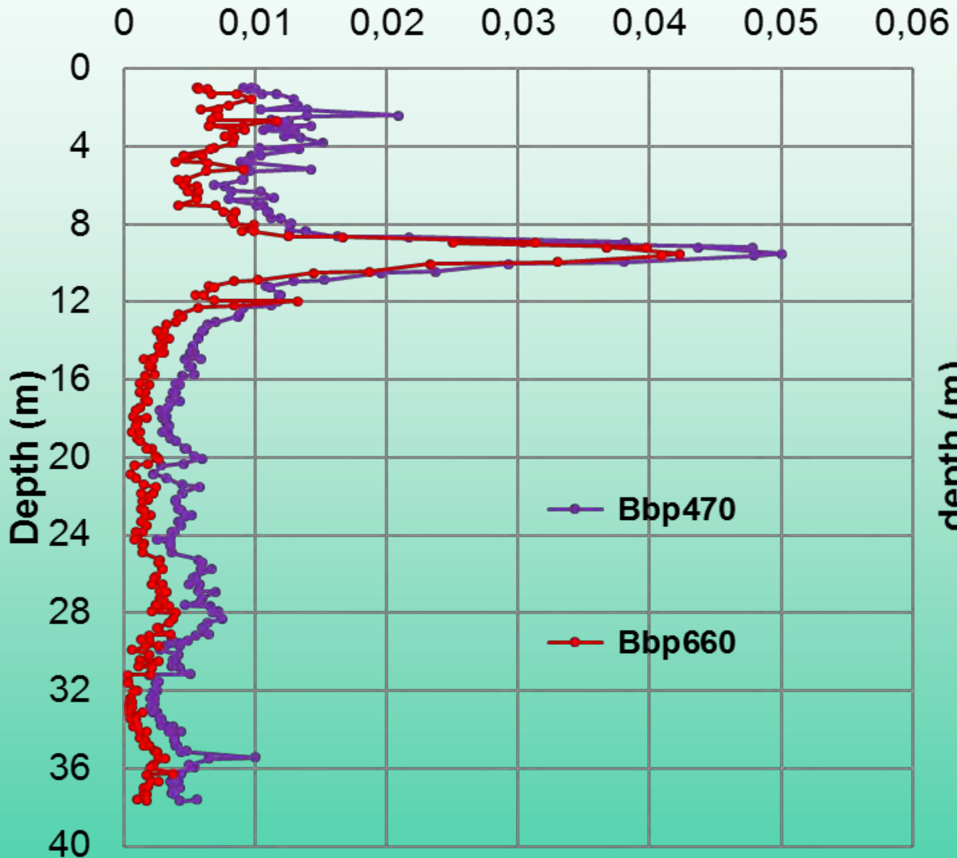


Clément et al 1994. McManus, M. A., et al 2003 Sullivan, J. M., Donaghay, P. L., & Rines, J. E. B. 2010. Alves-de-Souza, C.et al 2014, Clément et al 2017

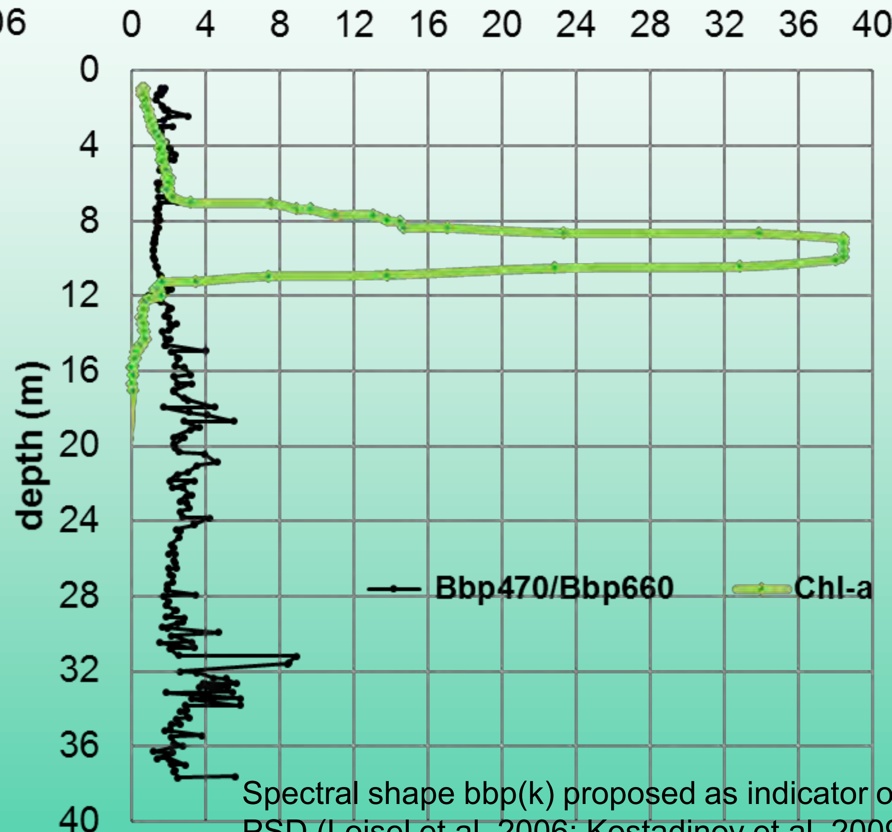
Thin layer, bio-optics and HABs of *Pseudochattonella*, *in situ* Chl a Fluorescent, Bbp (440 and 660 nm) 7-march-16, 14:51

Bb and cells size

Particulate Backscattering 470 and 660 nm



In situ Chlor a (mg/m3) and Backscattering ratio (470/660)

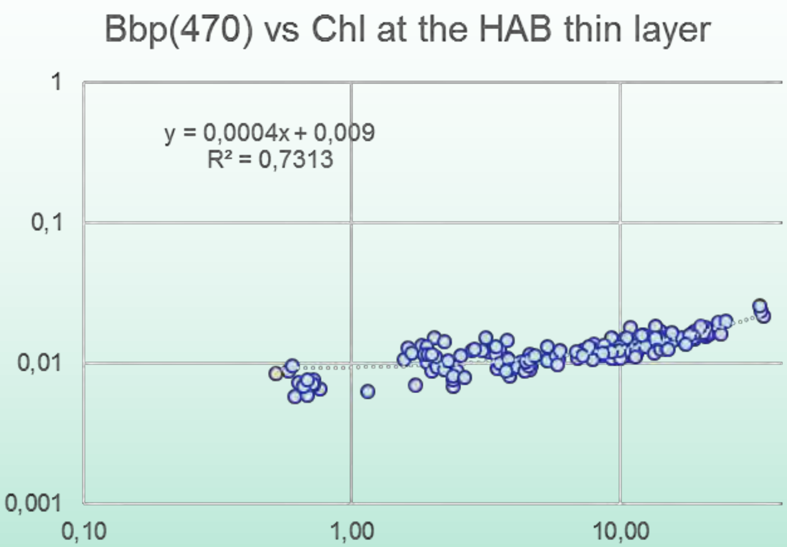


At Sub Surface Max chlor is observed minimum variability of backscattering Bb440/Bb660 ratio, & consistent relationssship between BB and Chl a. A this thin layer we observed max Pseudochattonella abundance 4000 cell/ml

Spectral shape bbp(k) proposed as indicator of PSD (Loisel et al. 2006; Kostadinov et al. 2009) and to characterize phytoplankton community structure (Kostadinov et al. 2010; Fujiwara et al. 2011).

Twardowski, M., Sullivan, J. and Dalgleish, F., 2016.

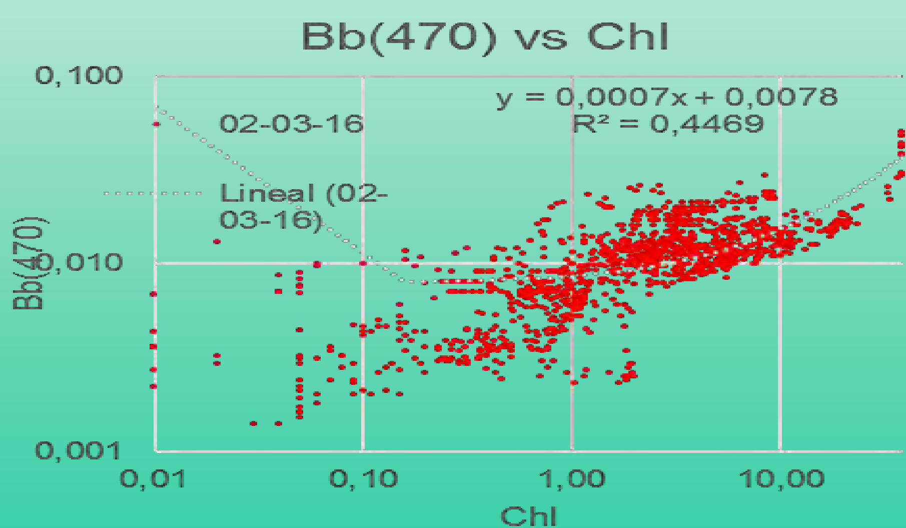
Bbp(470 nm) vs Chl in Fjords waters during HAB events

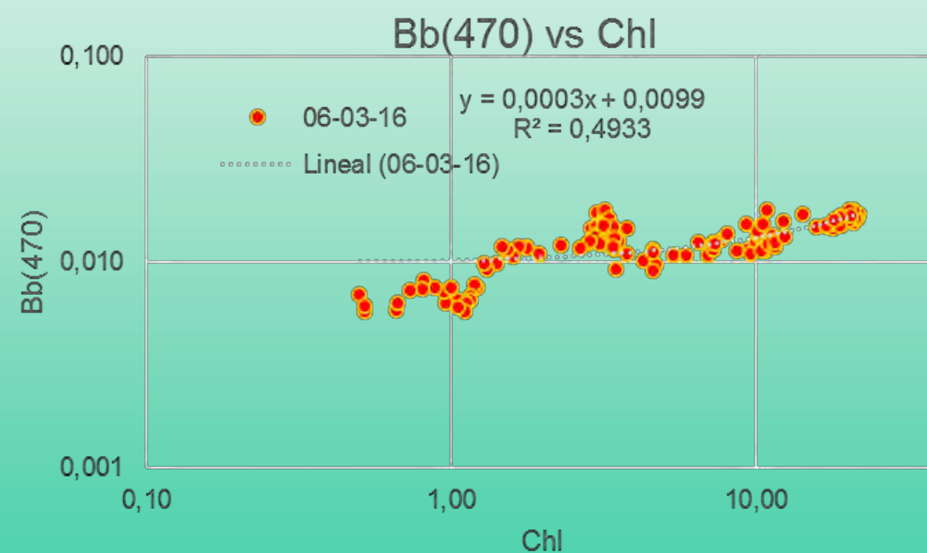


Hout et al 2008 Case 1 waters $R^2 > 0,8$

Complexities but best fit is precisely at thin layer, i,e., optically and biologically active layer.

Chl and uniform cells sizes and almost single specie niche.





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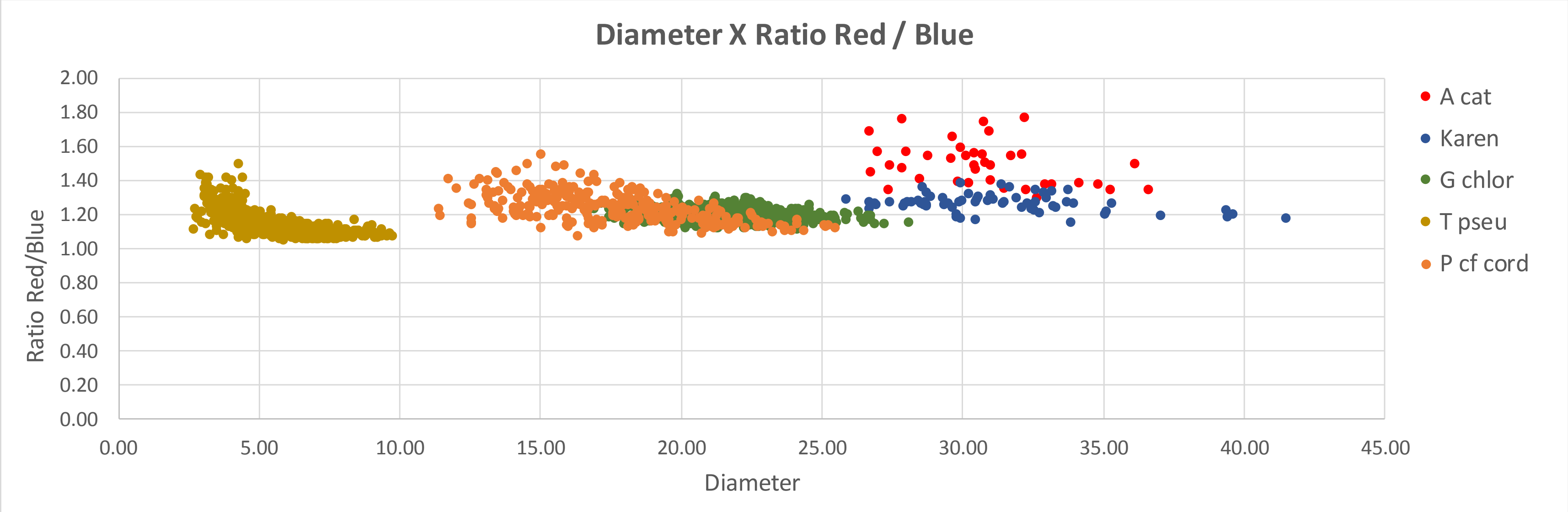
PHYTOPLANKTON TYPES,

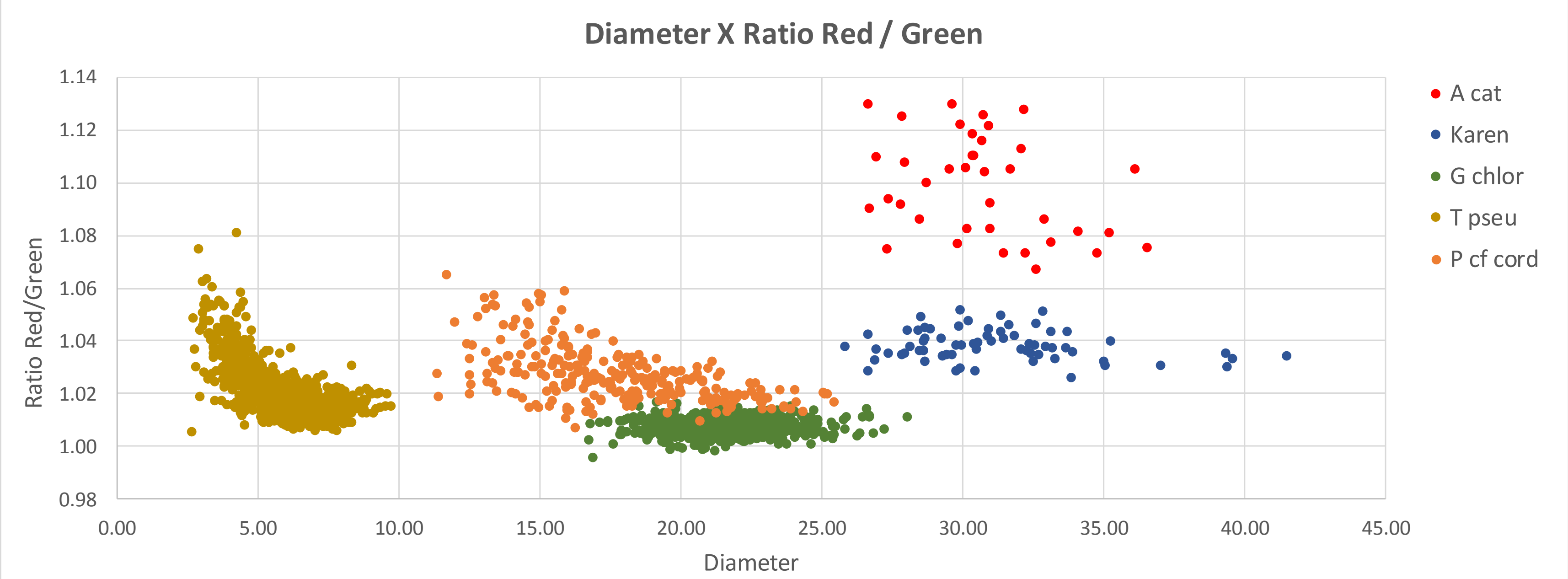
HABs cells,

Separated by FLOW CYTOMETER (FLOWCAM)

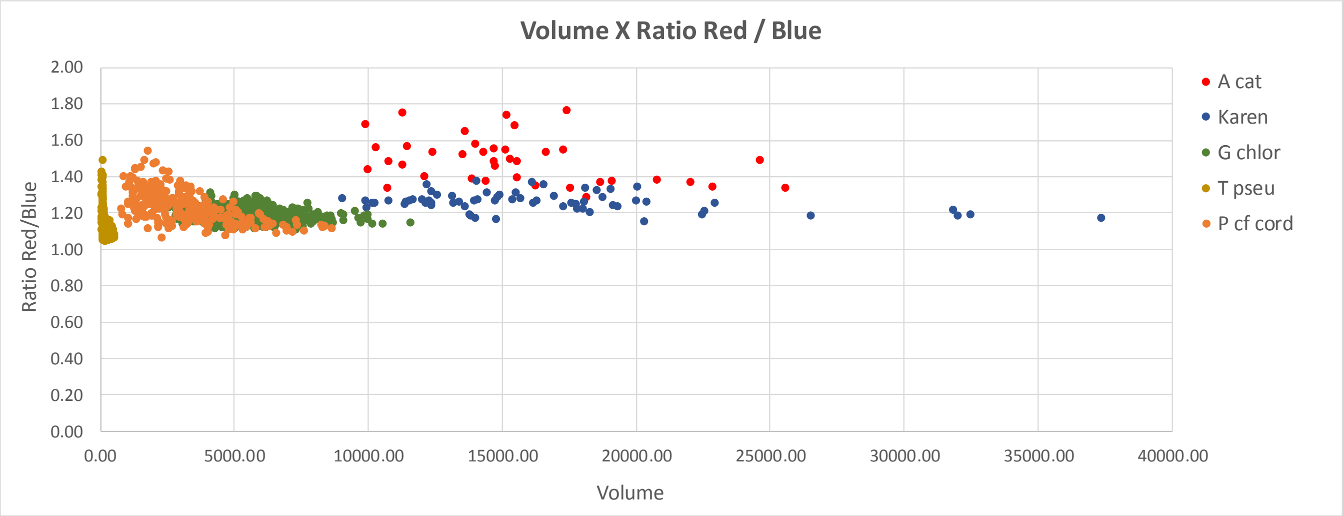
POPULATIONS OF DIFFERENT SPECIES, FORMING HABs, SEPARATED BY FlowCam PARAMETERS

Ratio [Red/Blue] vs cell Diameter

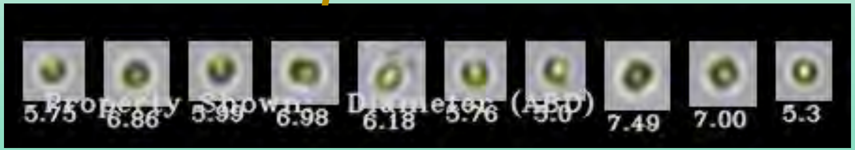




POPULATIONS OF DIFFERENT SPECIES, FORMING HABs, SEPARATED BY FLOWCAM PARAMETERS



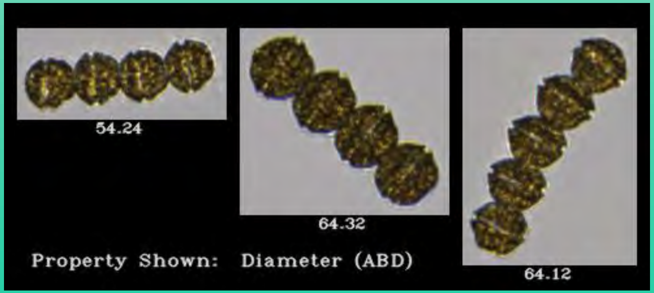
Thalassiosira pseudonana



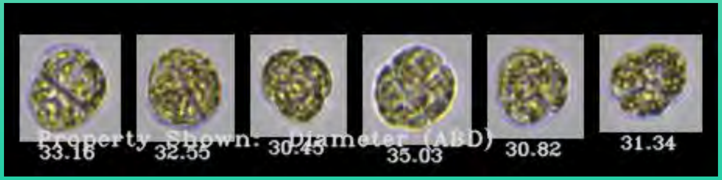
Prorocentrum cf cordatum

L chlorophorum

Alexandrium catenella



Karenia spp.



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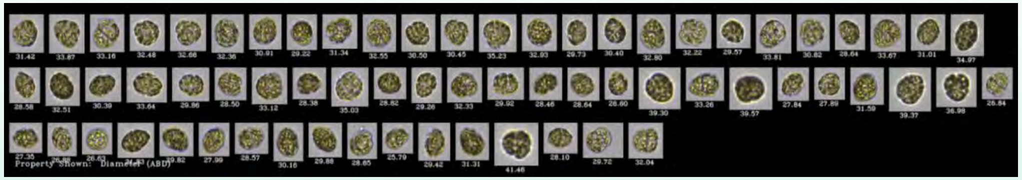
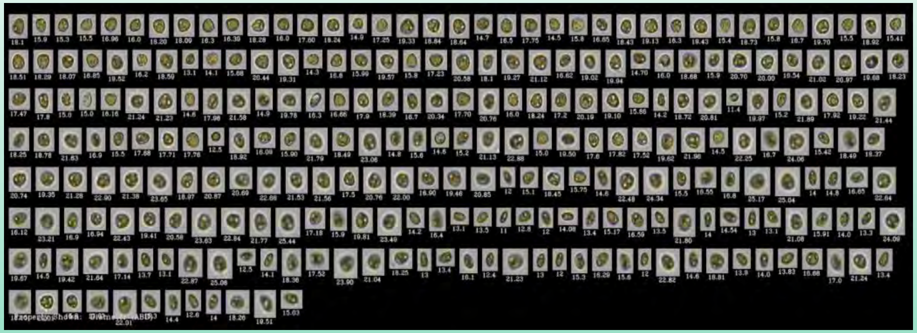
POPULATIONS OF DIFFERENT SPECIES, FORMING HABs, SEPARATED BY FLOWCAM PARAMETERS

Alexandrium catenella

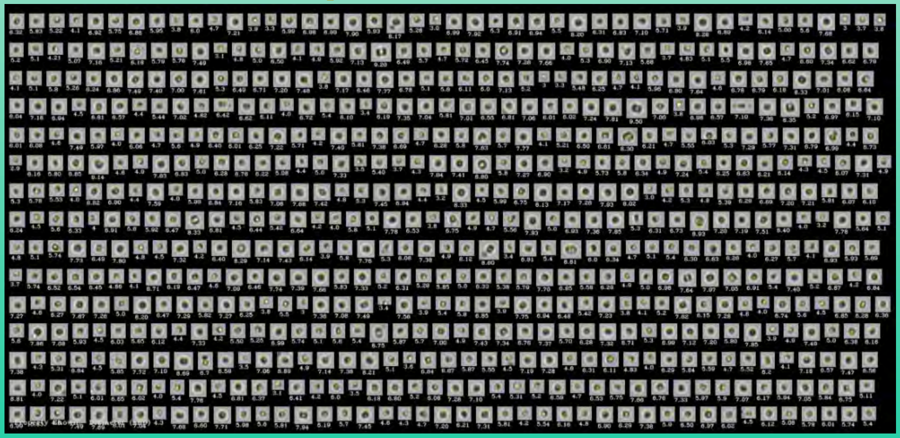
Karenia spp.



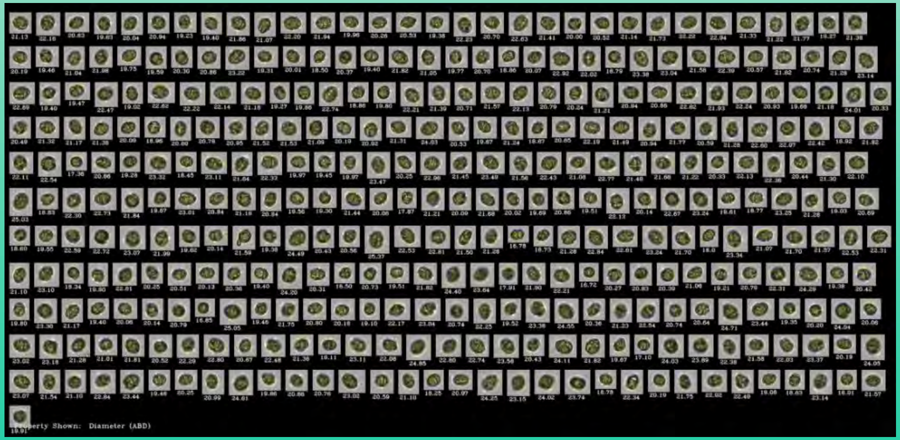
Prorocentrum cf cordatum



Thalassiosira pseudonana



Lepidonium chlorophorum



Characterization and digital libraries of dinoflagellates using FlowCam from Chilean fjords

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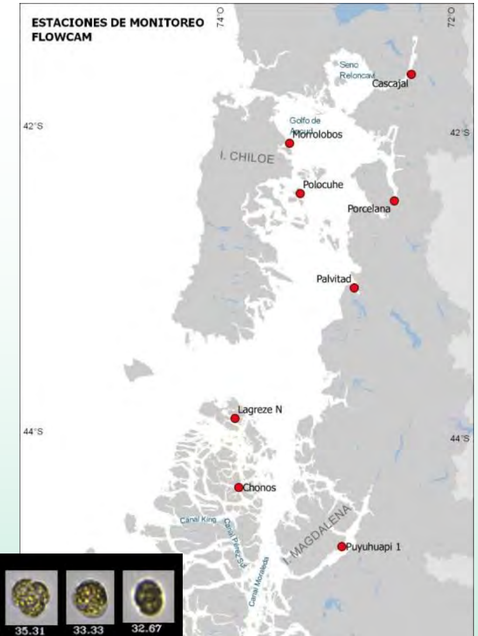
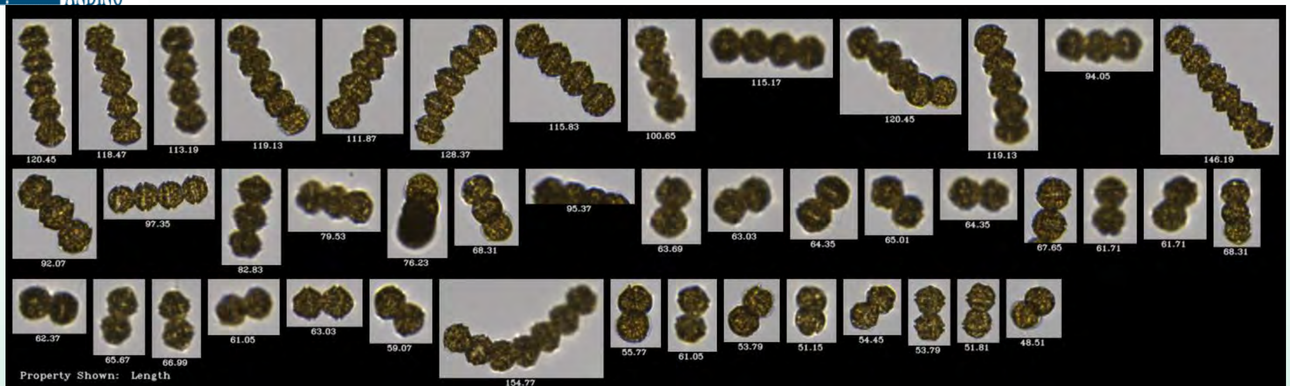
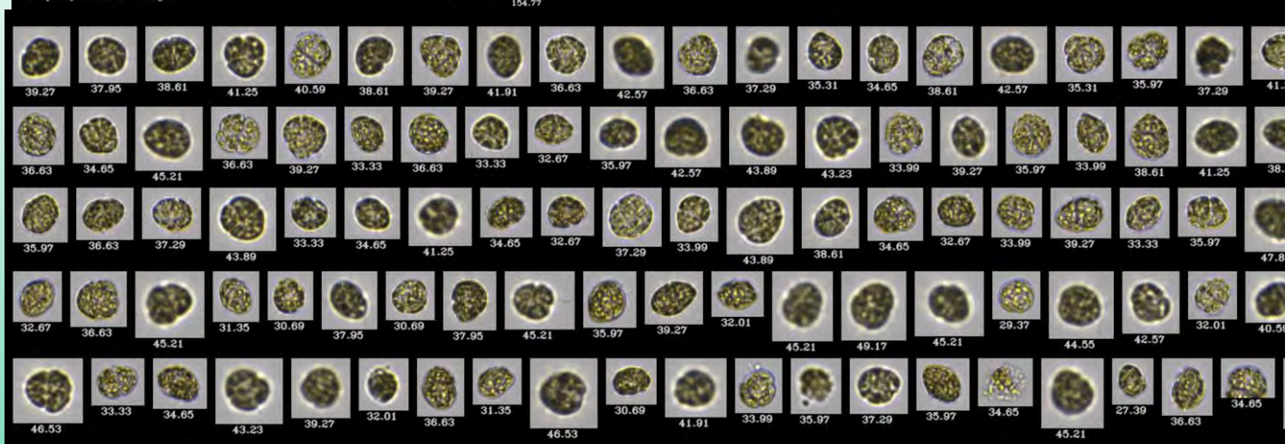
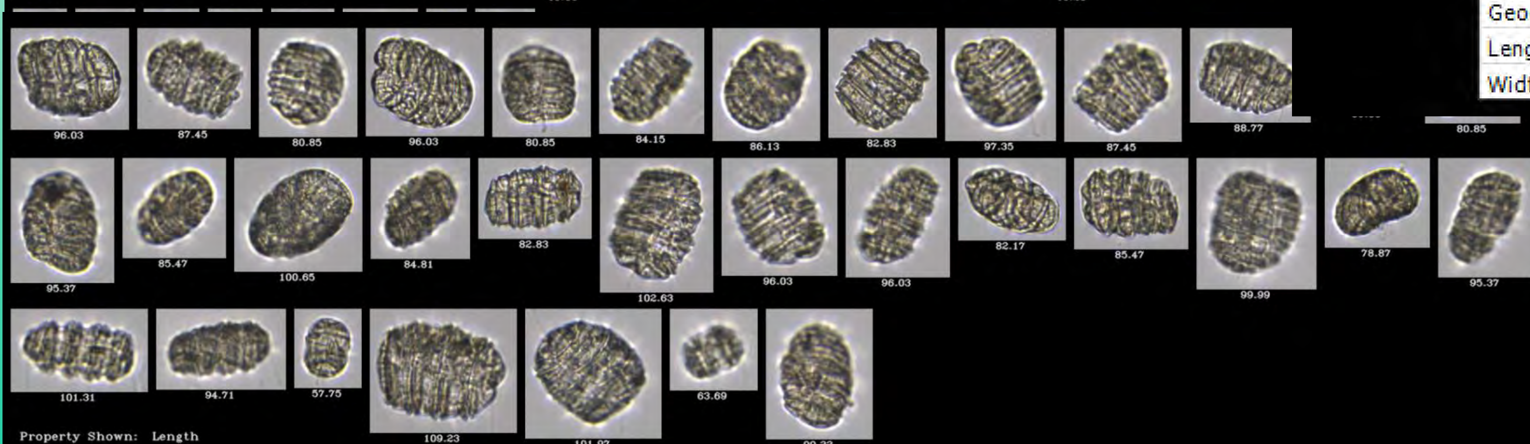
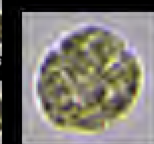






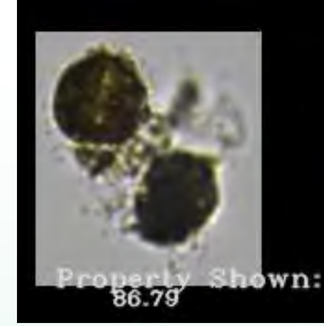


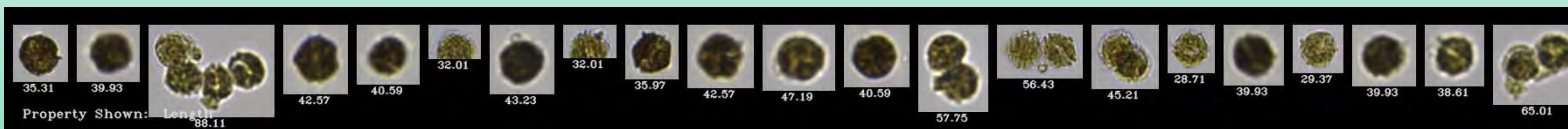

481

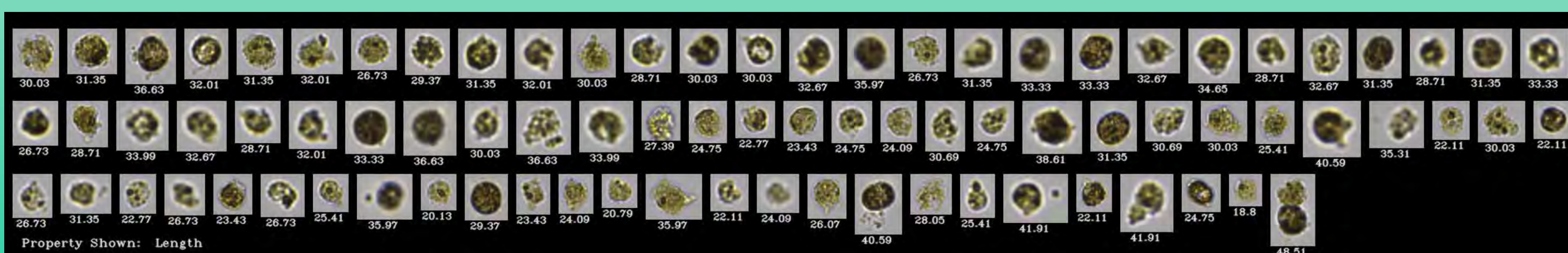
View Particle Properties

Particle ID	481
Area (ABD)	963.53
Aspect Ratio	0.93
Biovolume (Sphere)	22499
Ch1 Peak	5.47
Diameter (ABD)	35.03
Geodesic Length	45.71
Geodesic Thickness	24.81
Length	37.29
Width	35.31

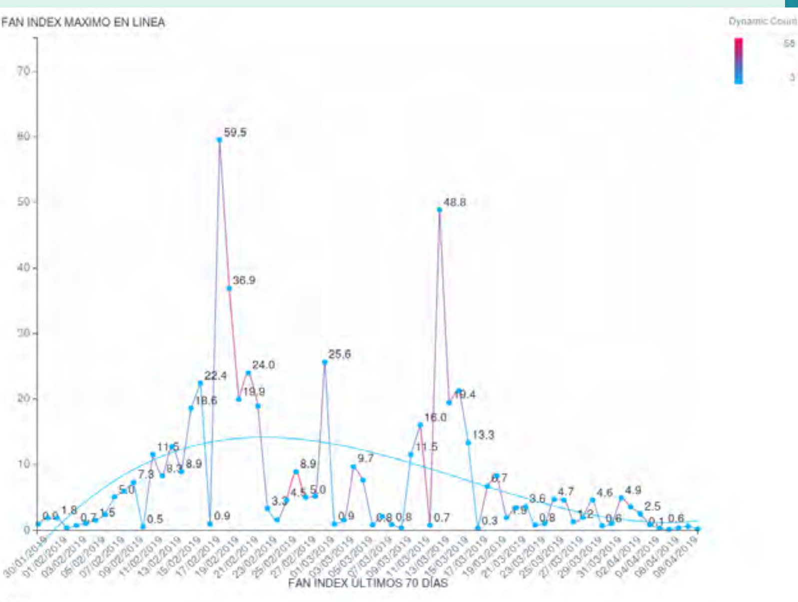
Damaged cells of *A. catenella* after decline of summer 2018 bloom in Archipelago of Chonos







#icha2018 Nantes France. HABf INDEX



CONTRIBUTION OF THE HAB$_f$ INDEX FOR FISH FARMS RISK ANALYSIS

Alejandro Clément [1], Thomas Husak [2], Sofía Clément [1], Francisca Muñoz [1], Marcela Saldivia [3], Carmen Brito [4], Roberta Crescini [3], Nicole Correa [1], Karenina Teiguel [1], Stephanie Saez [1] - Note: most are women

Plancton Andino, Puerto Varas[1], Castro[3], Coyhaique[4], Chile

OXZO Puerto Montt[2] Chile

Proud to celebrate 20 years creating service value and human capital

PLANCTON ANDINO

ABSTRACT

In recent years in southern Chile we observed numerous HABs event - particularly with flagellate species - which have been causing problem in fisheries and aquaculture. We have been monitoring and studying intensively the Chilean fjord ecosystem with emphasis on key phytoplankton species, their photosynthesis, and cell characterization and distribution with FlowCam, and remote sensing water color.

All the above results are valuable information as we develop an understanding of the oceanographic and ecological significance of the HAB events. However, we need in addition an on-line indicator such as **HAB$_f$ INDEX (= HABFIX)** for the fish farmers, authorities and general users.

The **HABFIX** is based upon a relatively simple algorithm that considers different weighting factors and risk coefficients of each harmful algae abundance divided by its critical or threshold value for fish.

We have tested the **HABFIX** retrospectively, checking large data set connected directly to a server and a business intelligence software (BIME).

While the preliminary results of the **HABFIX** show a close correlation with harmful algae bloom impacts on salmon farms, there are few challenges to solve.

INTRODUCTION

Southern Chile is an important marine ecosystem that offers multiple services for society and economic development. HABs are increasing in frequency, magnitude, and duration worldwide (Gilbert et al 2014), but it seems that climatic anomalies are playing important role as one of the triggering factor (Clément et al 2017 León-Muñoz, J. et al 2018).

Our mayor focus is to use pollution-free technology for monitoring HABs. The local ecosystem has been monitoring for more than 29 years (Clément & Guzmán 1989, Clément & Lembeye, 1993, Guzmán et al 2010, Seguel M, et al 2005), being *A. catenella*, *Pseudochattonella* spp., and *Karenia* spp., the main species of concern.

Under this biological environment we have developed an **HABFIX** to improved monitoring data visualization for authorities and fish farmer.

Anderson DM et al 2014 develop an interesting HAB Index for shellfish toxicity for the coastal environment of Maine. Also exists the *K. brevis* Bloom Index (KBBI), based upon remote sensing for detecting and classifying the toxic dinoflallete *Karenia* (Amin R A et al 2009).

OBJECTIVE

The goal is to explore, develop and evaluate an algorithm that measure the occurrence of HABs in the marine coastal ecosystem, with emphasis on fish culture areas.

$$HAB_f = [Harmful] + [Phyto]_{Total}$$

$$\overline{C_i} = \frac{\sum^{N} C_{i,z}}{N^{0,9}}$$

$$[Harmful] = \sum_i^M \left((2 + 0,5 \cdot \lambda_i) \cdot \frac{\overline{C_i}^{0,75}}{Cx_i^{0,6}} \cdot \alpha_i \cdot d \right)$$

$$[Phyto]_{Total} = (0,4 + 0,5 \cdot \lambda) \cdot \left(\frac{C_{Tot}}{Cx_{Tot}} \right)^{0,6}$$

METHODOLOGY & RESULTS

HABFIX is a simple algorithm of as a series of variables and coefficientes, such as; water column weighted average concentrations of phytoplankton and a specific harmful algae in relation with the critical or threshold value from a water sample from a marine fish farm.

After year 2002, in at least two cases, it has been observe blooms of *Leptocylindrus danicus* during several weeks in Southern Chile and then blooms of *Pseudochattonella*.

The synergistic effects, more than one harmful algae in ...

Several coefficients, Critical values and Risk factors used in the HABFIX algorithm

Genus	Species	Cx
Chaetoceros	*criophilus*	40
Chaetoceros	*convolutus*	5
Eucampia	*zodiacus*	1000
Eucampia	spp.	1000
Rhizosolenia	aff. *setigera*	1000
Skeletonema	*costatum*	50000
Leptocylindrus	*danicus*	4000
Leptocylindrus	*minimus*	3000
Thalassiosira	*pseudonana*	25000
Protoperidinium	sp1.	5
Cochlodinium	spp.	10
Cochlodinium	sp.	10
Alexandrium	*catenella*	50

[Harmful] is the main part of the algorithm of **HAB$_f$ INDEX**

$$[Harmful] = \sum_i^M \left((2 + 0,5 \cdot \lambda_i) \cdot \frac{\overline{C_i}^{0,75}}{Cx_i^{0,6}} \cdot \alpha_i \cdot d \right)$$

- Summation that depends on the number and concentration of harmful algae species
- Signal amplification factors
- Amplification factor: $\overline{C_i} \geq Cx_i \rightarrow \lambda_i = 1$; $\overline{C_i} < Cx_i \rightarrow \lambda_i = 0$
- Average in water column or Enhanced mean
- Critical concentration of harmful algae i
- Harmful species risk coefficient i
- Type of damage

Description of factor, coefficients and terms

C_i	Water column Average of each harmful algae concentration or Enhanced mean in units of cell/mL.
Cx	Critical concentration of harmful algae. Tabulated values [5 - 50000 cel / mL], which are capture directly from database and server. Empirical data obtain from POAS and historical HAB.
λ_i	Amplification Factor; potentiates the effect of each harmful species in the equation.
α_i	Harmful species risk coefficient. Ponders or weights the negative effect of each harmful algae, according to the degree of damage in fish aquaculture. Tabulated values [0 - 1].
d	Type of damage. It discriminates the contribution of each harmful species, in order to differentiate mathematically the effect of ichthyotoxic species (d = 2) and those that cause physical damage (d = 1,1).
M	Summation that depends on the number of harmful algae species in the water samples. This is an important issue because include the synergistic effect.
C_{iz}	Concentration of species i at depth z
N	Number of layers or depths sampled in water column

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FINAL REMARKS

1. Thin layers formation, sub-surface max, above pycnocline based on cells counts, *in situ* Chl, Bb(λ), Fv are essential features of *P. verruculosa* bloom, in addition ichthyo-toxicity. More info Andersen et al Hansen, Hallegraeff, Ishimatsu
2. FRRF3 is very useful tool for HAB monitoring, particularly during high Chl values (> 5 mg/M3) and **small sizes cells**. Aysén Fjrod case.
3. It is feasible as a proxi *in situ* and/or *in vitro* bio-optical/physical techniques to monitor HABs but demand a lot of data processing.
4. Phytoplankton OC-Rrs & bio-optical techniques have been studied for more than 35 years, however, is hard to predict Phytoplankton Functional Types (PFT) in o**ptically complex waters**, (IOCCG 2014, Bracher et al 2017).
5. The combination of standard microcopy, molecular biology, active Fluorescent (Fv/Sigma), cell imaging, IOP and RS OC are useful technique for monitoring optically complex waters. The challenge is data management, integration, modelling and **forecasting HABs**

This study was support by POAS, Fondef, CORFO, Plancton Andino