CONTRIBUTION OF THE HAB_f INDEX FOR FISH FARM'S RISK ANALYSIS

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Abstract

In recent years in Chile, numerous HAB events have been observed, particularly photo-autotrophic flagellate species, which have caused problems in fisheries and aquaculture. The Chilean fjord ecosystem has been intensely monitored and studied for key phytoplankton species, including characterization of cells using FlowCam analysis, photosynthesis and ocean color remote sensing.
The results provide valuable information as they contribute to understanding the oceanographic and ecological significance of such HABs. Here, we developed an *on-line* biological indicator such as a HAB_f INDEX **(=HABFIX)** that provides fish farmers, authorities and general users an integrated and comparable variable for a risk information system.
HABFIX is based on an algorithm that considers different weighting factors and risk coefficients of various parameters. Specifically, the structure of the algorithm is based on the sum of the water-column-weighted average of each harmful algal abundance and their ratios. With this novel algorithm we attempt to include the synergies of harmful algal effects on fish farms.
In hindsight we are able to run HABFIX, checking a large dataseries from phytoplankton monitoring through e-cloud computing using business intelligence software. While the results of HABFIX show a direct relation with harmful algae bloom effects on fish farmsthere are , however, a few challenges to overcome.

Keywords: HAB_f INDEX, monitoring, phytoplankton, algorithm.

Introduction

Southern Chile is an marine ecosystem providing numerous benefits for society, most importantly sustainable economic development, including aquaculture and fisheries, maritime activities, tourism, fjord bio-diversity and conservation.
Most scientists believe HABs are increasing in frequency, magnitude, and duration worldwide (Wells et al., 2015). Locally, we have observed an increase in duration and intensity of HABs depending on the species. These outbreaks have significant economic and social impacts, and climatic anomalies are playing important role triggering extreme events (Clément et al., 2017; Trainer et al., 2019). Our major focus of interest is to apply several techniques, such as, bio-optics, cell imaging, harmful algal algorithms for monitoring and forecasting HABs.
Phytoplankton monitoring has been carried out in Southern Chile for more than 29 years (Clément & Guzmán 1989; Montes et al., 2018) but since the 2000s more air-sea complexities have been observed (León-Muñoz et al., 2018). Until now, the main species of concern are photosynthetic flagellates; *A. catenella*, *Pseudochattonella* spp., and *Karenia* spp. From a practical point of view, the risk of occurrence of HABs can be estimated as a function, influenced by harmful algae ratios and weight factors. Under this complex biological environment, we have developed and tested a novel **HAB_f INDEX = (HABFIX)** to ease, and improve decision making process for officials authorities and fish farmers. In Europe the Plankton

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Community Index is a quantitative method for evaluating changes in the community structure of phytoplankton using a state-space perspective (Tett et al., 2008). Several phytoplankton indices have been used, but very few focus on HABs. Anderson et al., 2014 developed the HAB INDEX, for shellfish poisoning toxicity in the Gulf of Maine. There also exists the *K. brevis* Bloom Index (KBBI) that is based on remote sensing optical techniques for detecting and classifying the toxic dinoflagellate *Karenia* spp., (Amin et al., 2009).
The main objective of this study was to develop an algorithm that measures the risk of several harmful algal species in the marine coastal ecosystem, with emphasis on fish farms areas.

Material and Methods

The phytoplankton dataset comes from the monitoring program of the Chilean salmon farming industry, called POAS (Programa Oceanografico Ambiental en Salmonidos; Clément, 2016). This program runs since 1998 and has over 40 sites, and provides weekly samples with no chemical fixatives, and at 4 depth levels (0, 5, 10 and 15 m). The program covers a large area of 80,000 km^2 (Fig. 1). For water and cells analysis we use several phytoplankton techniques, including inverted microscopy of fresh cells, imaging flow cytometer (FlowCam), FRRf3 measuring active and variable chlorophyll fluorescence (Fo, Fm & Fv) to obtain an eco-physiological approach of the cells (Oxborough et al., 2012). The phytoplankton data is archived in a local database (http://sispal.plancton.cl/clientes/) and we apply business intelligence software for data visualization for fish farmers and other users.

HABFIX is an algorithm using a series of variables and coefficients, which include: water column weighted average concentration of total phytoplankton, ratio of specific harmful algae concentration divided by the critical or threshold value to damage fish tissue (Mardones & Clément 2016; Montes et al., 2018).
The synergistic effects, i.e., presence of 2 or more harmful algae are calculated using different ratios, applying specific empirical constants and coefficients factors. The HABFIX is dimensionless, and its numerical range varies from 0 to practically 560, though it could be larger. The maximum value of 560 was observed for the *Pseudochattonella* cf. *verruculosa* 2016 bloom.

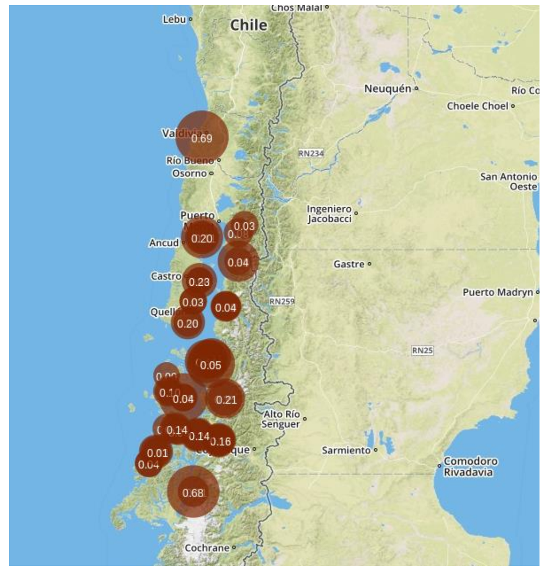

Fig. 1. Study area and POAS phytoplankton monitoring stations at fish farm and weekly average of HABFIX.

Mathematical formulations

The first term, [Harmful], is the sum of several ratios of harmful algae species that produce damage and/or mortality to farmed-fish. The second term, [Phyto], represents the ratio of total phytoplankton averaged concentration (**C_T**), divided by the Critical Total Concentration (**Cx_T**) defined as 25,000 cell/mL (See Eq. 3). Waters at high phytoplankton concentration are very turbid (Secchi Disk < 2 m) and produce organic exopolymeric substances (EPS) generated mainly from phytoplankton (Jenkinson & Arzul 1998).

$$\text{Eq. (1)} \quad HAB_f = [\text{Harmful}] + [\text{Phyto}]$$

The main formula of the algorithm is Eq. 2 which include a series of summation of harmful algae ratios, averaged in the water column, multiplied by the amplification factor $(2 + 0.5 * \lambda_i)$, by α_i, and *d*. In addition, both variables $\overline{\overline{C_i}}$ and Cx_i are raised to exponents < 1, to modulate the resulting values of the HABFIX, as high phytoplankton abundance (e.g. > 5000 cell/mL) can lead to significant differences.

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Eq. (2)

$$[\text{Harmful}] = \sum_{i}^{M}\left((2 + 0.5\cdot\lambda_i)\cdot\frac{\overline{C_i}^{0.75}}{Cx_i^{0.6}}\cdot\alpha_i\cdot d\right)$$

Description of main parameter, coefficients and terms of the algorithm

$\overline{\overline{C}}_i$	**Enhanced Mean** is an integrated water column average concentration of each harmful algae (*i)* species (cell/mL).
Cx_i	**Critical Concentration** of harmful algae*(i).* Tabulated values [1-50000 cell/ mL], which are captured directly from database. Empirical value obtained from POAS, historical HABs, & Montes et al., 2018.
λ_i	**Amplification Factor:** Amplifies the effect of each harmful species *i* in case: $\overline{\overline{C}}_i \geq Cx_i \rightarrow \lambda_i = 1$; $\overline{\overline{C}}_i < Cx_i \rightarrow \lambda_i = 0$
α_i	**Harmful species** (*i)* **risk coefficient.** Weights the noxious effect of each harmful algae, according to the degree of damage in fish aquaculture. Tabulated values [0 - 1].
d	**Type of damage.** 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 and concentration of harmful algae species in water samples.
N	**Number** of layers or depths sampled in water column.
$C_{i,z}$	**Concentration** of species *i* at depth *z*.

Eq**.** 3 represent averaged water column phytoplankton ratio, but risk coefficients and type of damage are not included. The associate multiplicative amplification factor and exponent have less weight that those from the [Harmful] term. Therefore, [Phyto] term have low impact in total value of **HABFIX**, particularly with phytoplankton concentration lower than 25,000 cells/mL.

Eq. (3)

$$[\text{Phyto}] = (0.4 + 0.5\cdot\lambda)\cdot\left(\frac{\overline{C_T}}{Cx_T}\right)^{0.6}$$

HABFIX is an integrate value in the water column: Enhanced Mean, $\overline{\overline{C}}_i$, is slightly > than simple arithmetic average, especially when number of layers analyzed in water column is > 1 (N > 1). This factor is applied to avoid bias values resulting from highly heterogeneous cells distributions, such as those found in thin layers and bloom situations (Clément et al., 2017).

Eq. (4)

$$\overline{\overline{C}}_i = \frac{\sum_{z}^{N} C_{i,z}}{N^{0,9}}$$

Results and Discussion

We checked and hindcast the algorithm on the SQL database to evaluate different harmful algae concentrations, species risk coefficients (α), and compared the damage to a fish farm. We present **HABFIX** spatial and temporal data on a daily basis, to follow the risk of HABs for the fish aquaculture industry. Different harmful algae species and abundance apparently produce distinct a mechanism of mortality to fish (Mardones et al., 2015). Therefore, we weight the risk in the algorithm at several harmful algal concentrations (Fig. 2). **HABFIX** is based upon an algorithm that takes into account different weighting factors and risk coefficients. Basically, the weighted average ratio of each harmful algae and abundance determines the **HABFIX** magnitude (Eq. 2). The algorithm includes the sum of different harmful algae and concentrations in the same mathematical term, and in doing so, intrinsically takes into account synergist effects, e.g., we have observed several HABs of *L. danicus* and *Pseudochattonella* cf. *verruculosa* practically co-existing in time and space.

Results of **HABFIX** show a close relation with harmful algal distribution and its impacts on salmon farms, particularly with fish mortality rates.

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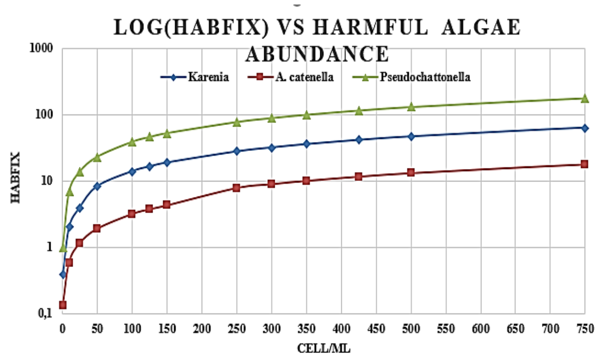

Fig. 2. The log of [HABFIX] in function of abundance of 3 different harmful algae. *Karenia* spp., *Pseudochattonella* spp., and *A. catenella*

New published data of critical concentration of weighting factors and coefficients are essential (Montes et al., 2018). After phytoplankton dataset is entered and saved to the server database, **HABFIX** is automatically calculated and shared *on line* for users; fish farmer, or official authorities, among others. Therefore, within a large fish farms network, is available through *e-cloud* as useful indicator of HAB risk, because describes spatial-temporal dynamics and synergistic effects of several harmful algae in the monitoring area, alerting the potential damage for marine fish culture zones.

The *P.* cf. *verruculosa* summer 2019 bloom in Chiloé Archipelago reached a **HABFIX** maximum of 59.5, increasining exponentially over a few days. During summer of 2018 a bloom of *Karenia* spp. in Chile´s Patagonian Fjords showed an increased rate lower than *P.* cf. *verruculosa*. Within a week **HABFIX** can increase from 1 to 9 indicating an early warning situation for fish farmers, managers and authorities.
HABFIX is a novel algorithm as it provides a summary of several parameters in one integrated and comparable variable estimating the risk of several harmful phytoplankton species and concentration in fish farm area. Fish farmers, official authorities and others users can use **HABFIX** > 2, as early warning limit, regardless the species of harmful algae in the water. Fish farmers can decrease feeding rates and set up HABs mitigations techniques under the scope of an empirical algorithm. The next step and challenge will be to forecast the **HABFIX** index.

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