Arabian Gulf Harmful Algal Blooms Workshop

DAY 1 (22 February, 12:00-15:00 UK time)

Understanding the susceptibility of the Arabian Gulf and adjoining sea areas to harmful algal blooms (HABs) and impacts on fish health and food safety

DAY 2 (23 February, 12:00-15:00 UK time)

Developing early warning systems (EWS) for HABs for mitigating impacts on fisheries and aquaculture

1) Welcome & aims of the workshop – *Qusaie Karam (Kuwait Institute for Scientific Research)*

The virtual workshop explores existing knowledge and data on Harmful Algal Blooms (HABs) and impacts on fisheries and finfish aquaculture in the Arabian Gulf. It is sponsored by the UK and Kuwait Governments and is endorsed by the Global Harmful Algal Blooms (GlobalHAB) Programme http://www.globalhab.info/.

Workshop aims:

1) Evaluate global trends and identify environmental factors driving the risk of HAB events and impacts on fisheries and finfish aquaculture in different regions of the world. This involves exploration of existing information from *in situ* monitoring networks (e.g. aquaculture production sites, desalination plants and commercial ports), satellite monitoring platforms (e.g. MODIS, Sentinel), physical, biogeochemical and empirical models.

2) Explore the potential effects of eutrophication and climate warming on HABs and consequent impacts of HABs on aquaculture and fisheries in the ROPME Sea Area (RSA) i.e. the Arabian Gulf and Sea of Oman. HAB occurrences have been linked in some areas to extreme climatic events, such as heatwaves. The regular occurrence of extreme high temperatures in the Arabian Gulf makes this region an obvious focal point for research on this topic.

3) Identify tools and opportunities to develop early warning systems for HABs and support the sustainable development of aquaculture in the Arabian Gulf and elsewhere, contributing to achievement of the objectives of the UN Oceans Decade (https://www.oceandecade.org/) and helping to tackle the ensuing climate emergency and biodiversity crisis. More integrated approaches to aquatic food production have the potential to meet Sustainable Development Goals to improve nutrition (Goal 2), ensure sustainable consumption and production (Goal 12), and sustainably use marine resources (Goal 14) (IUCN, 2017).

2) Opening address – *Sunny Ahmed (Deputy Ambassador for Kuwait)*

The UK and Kuwait governments are proud sponsors of this workshop which aims to better understand the susceptibility of the RSA to harmful algal blooms (HABs) and impacts on fish health and food safety.

Global aquaculture production from finfish, shellfish and seaweed is projected to grow by 32% from 2018-2030, helping to ensure food security and alleviate pressures on wild stocks from overharvesting and climate change (FAO, 2020). In the Arabian Gulf finfish aquaculture alone is projected to grow by over 7% between 2018 and 2024. However the growth of the aquaculture industry is threatened by HABs, which are being observed increasingly at aquaculture sites around the globe, with some HAB species causing mass fish mortalities. The recent global meta-analysis by Hallegraeff et al. highlighted the need for more data quantifying the occurrence and impacts on HABs in Arabian and Indian coastal waters. This workshop aims to identify and address these data needs, in order to provide early warning systems for HABs and to mitigate impacts on fisheries and aquaculture.

3) Global Perspective on HABs, Environmental Drivers & Impacts

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Abstract
Harmful Algal Blooms (HABs) are natural events that can also be fostered by human pressures on aquatic ecosystems. Some HABs are caused by species producing phycotoxins associated to human health problems due to bioaccumulation in seafood, direct contact with the water or inhalation of aerosolized chemical compounds. Other HABs affect wild and cultured fish and marine fauna and the ecosystems, with subsequent impacts on economy and human wellbeing. In particular, HABs constitute a special threat to aquaculture, a key activity for protein supply to humans and the economy of local populations in different areas, including the Arabian Gulf. Massive fish kills can be caused by high microalgal biomass that limit oxygen availability and/or produce ichthyotoxins. Contamination of seafood with HAB phycotoxins forbids extraction and commercialization.

To prevent impacts on aquaculture, *in situ* monitoring of the causative organisms (and their toxins) is essential (combined with satellite observations if possible) and should allow elaboration of detailed and accessible databases. This information, along with fundamental multidisciplinary research about the main HAB occurring species in the area can help producing models to predict the occurrence of some blooms. Time series analyses suggest that some HABs may increase and intensify with climate change. The efforts to minimize HABs occurrence and mitigate their impacts should be parallel to the implementation of a sustainable aquaculture, in coordination to stakeholders and policy makers, to guarantee a healthy and productive ocean for the future generations.

4) Environmental mechanisms associated with algal blooms in the Arabian Gulf

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Abstract
The formation of harmful algal blooms (HABs) is not thoroughly understood in the Arabian Gulf (AG). A wide spectrum of bloom events occurs in the AG, at the deep sea such as Strait of Hormuz and the Arabian Sea, and the shallow coastal zones. Most vents are considered to have an adverse impact on the environment, leading to fish kills. The HABs involves various environmental conditions associated with river runoffs, human nutrient loadings, inter-annual ocean cycles, and meteorological conditions. Kuwait Bay has experienced several HAB events over the 30-40 years at an increasing trend. Historical records have shown that the events occur in different seasons, yet summer is lethal to many species. Given the environmental variability associated with the Bay's HABs numerical models have provided insight into the low dynamic zones where hypoxia could be computed and predicted in some cases. The study shed light on the fields where HABs are initiated and the environmental mechanisms triggering the blooms in the Bay. The finding may well serve other locations within the AG, particularly at the shallow western coast where the hydrographical features and human activities are alike. In addition, the finding shall act as the first step towards forecasting HABs and early warning systems for coastal management purposes in the region.

5) Decision and Information System for the Coastal waters of Oman (DISCO)

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Abstract

Over the past decade, Oman has witnessed a massive outbreak of harmful algal blooms (HABs) that has been attributed to the trend of warming and the influx of hypoxic waters onshore. Field and satellite data from the past few years indicate that harmful algal blooms are becoming more widespread and intense in the Sea of Oman and Arabian Sea. What is particularly disconcerting being that these outbreaks are beginning to pose a significant threat to coastal resources, water quality, public health, tourism, and the operational capabilities of the many coastal industries that serve the energy, freshwater, and socio-economic needs of Oman, and of the countries bordering the Arabian Sea and Sea of Oman.

HABs monitoring programs have been implemented and developed since long time using modern technologies, in order to predict its occurrence and limit its harmful effects. Recently, an operational Early Warning System was developed called Decision and Information System for the Coastal waters of Oman (DISCO) for providing timely advisories to stakeholders, including coastal resource managers is needed. The main objectives of this system are:

- Provide information and future predictions about coastal fisheries resources, evaluate the effects of climate change and determine the ideal locations for fish farming activities on the Omani coasts.
- Provide real-time forecasts of atmospheric and sea state conditions using an outputs from an atmosphere/ocean/biogeochemical coupled model tailored for the coastal waters of Oman.
- Provide real-time forecasts of outbreaks of HABs based on a fusion of model outputs with satellite ocean color data.

In the future, DISCO could be used to serve the needs of a diverse range of infrastructure development activities in support of Oman's transition to a Blue Economy. It will be an effective monitoring and forecasting system that benefit various sectors such as desalination plants, fish farming and other relevant authorities. It also will create an integrated database that includes physical, biological and other environmental data. DISCO will contribute in several other applications such as: monitoring and prediction of hypoxia and fish kills. Tracking the path of harmful phytoplankton blooms, jellyfish multiplication, liquid waste, oil spills and hurricanes, and thus providing decision-makers with a comprehensive early warning system.

6) The status and trajectory of aquaculture in the Arabian Gulf and Sea of Oman

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Abstract

Fish captured from the sea have traditionally been favoured more than farm-raised fish in Arab countries, because of the former's perceived greater health and taste benefits. Yet, aquaculture has been gaining more acceptance, and even popularity, in the Middle East. Some wealthy Gulf nations, such as Saudi Arabia, UAE, and Oman, have stepped up their efforts to cultivate aquaculture to meet the demand for fish, to reduce imports of seafood, and to maintain food security. Although it is a relatively new and small sector in these

countries, they have been heavily investing in fish farming. The governments of Saudi Arabia, UAE, and Oman provide favourable policies and numerous incentives to attract investments into fish farming. This has encouraged the development of a number of aquaculture projects in these countries. Aquaculture is often seen as an important sector for supply of seafood from their coastal resources for revitalization of coastal areas and supporting complementary businesses.

The main commercial marine aquaculture systems are saltwater ponds used for shrimp farming and circular cages used for fish culture in exposed environments. Marine spatial planning and/or ICZM is used for the selection of aquaculture sites and avoid conflict with other users of the coastline. The establishment of Aquaculture Zones ensures the full integration of aquaculture with other coastal activities and thus prevent and minimize possible conflicts. Oman, UAE and Saudi Arabia have prepared an aquaculture atlas identifying potential areas for aquaculture development. Most countries have developed hatchery facilities for a range of species. The main culture species include Barramundi, Gilthead seabream, Meagre, Sobaity seabream and Shrimp. Fish culture usually depends on the use of artificial feed. However, not all the nutrients in the feed are utilized for fish growth. Approximately 45% of nitrogen, and 18% of phosphorous contained in feed are excreted as dissolved inorganic nutrients and enter the water column. The impacts on the environment are most apparent in flow-through systems and cages, whereas the impacts in ponds are more complex as there is uptake of nutrients by primary production.

The Arabian Gulf and Sea of Oman are prone to algal blooms which is a risk for fish cage culture. Blooms may kill fish in several ways. Densely concentrated algal bloom can deplete oxygen in the water due to the high respiration rate of the algae, or by bacterial respiration during their decay. Some algae cause damage to the gills of fish, with the result that they are unable to take in enough oxygen. There have been several bloom events that have affected aquaculture. In 1999 there was a red tide in Kuwait Bay that caused a fish kill due to elevated nutrient levelss, potentially from aquaculture activities as well as industrial and sewage inputs. In Oman the bloom of the marine ichthyotoxic dinoflagellate *Cochlodinium polykrikoides* from August 2008 to May 2009 caused mortalities of wild and farmed fish (Qurayat, Oman) as well as extensive coral reef damage and restricted fishing activities. The pattern of subsequent recurrence of blooms may become a persistent problem for aquaculture development in the region.

7) Shrimp aquaculture: an overview, challenges, and accomplishments in Kuwait

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Kuwaiti demand for seafood is rising rapidly, with high imports set to be the main source of supply, unless aquaculture expands greatly in Kuwait to ease fish and shrimp importation. A perusal of the world aquaculture industry reveals that the research efforts during the last few decades have been focused largely on the development of sustainable, biosecured and cost effective super-intensive production technology which resulted in developing re-circulating system (RAS) and Biofloc technology (BFT) for aquaculture system. These two systems have captured the attention of the investors and aquaculturists since it allows production at high stocking densities with limited energy, water and land use.

Worldwide shrimp culture is dominated by Pacific white leg shrimp, *Litopenaeus vannamei*, owing to the development of Specific Pathogen Free (SPF) stock and its large scale adoption in most of the shrimp producing countries. This species has excellent abilities to adapt to different salinities and temperature, and exhibits high growth and survival under high densities. Establishing shrimp aquaculture in KISR for farming this alien species is an urgent need to place Kuwait among the shrimp producing countries in the GCC. This species forms an ideal candidate for biofloc culture in land based facilities under controlled conditions.

Ion imbalance of the low salinity water is considered the biggest obstacle facing inland shrimp farming. Most of the underground water sources are deficient in magnesium and potassium, which cause reversed Mg/Ca or high/low Na/K compared to those in standard sea water. The ion imbalance of the brackish water has been extensively studied at KISR to develop sustainable production and culture of the non-native shrimp, *L. vannamei*, using brackish water.

8) Environmental extremes and additional pressures on marine ecosystems in the RSA

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Abstract
The Gulf is facing unprecedented pressures from multiple sources, including climate change, marine pollution, coastal modification and increasing coastal burdens of population and expansion. The Gulf is already a unique place, experiencing extremes of temperature and salinity not seen elsewhere, with these extreme ranges predicted to increase with higher temperatures and salinities. These changes are happening alongside an expanding coastal environment with associated increases in marine pollution. The local and regional changes need to be considered in the context of the larger climate shifts when planning mitigation and recovery programs at a local and regional level. This talk briefly describes these climate and pollution pressures, using Kuwait as a case study to demonstrate some of the longer term water quality issues that are occurring across the ROPME Sea Area. These shifts are influencing and driving water quality issues including increase in algal blooms, toxicity events and HABs. Both national and regional programs need to consider this complexity of issues and shifting baselines when developing long term solutions to HABs in the Gulf region.

9) Linking environmental factors, HAB events and impacts on finfish and shellfish

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Abstract
Around 300 HAB species have been identified globally. Some produce toxins that can accumulate in shellfish, and finfish and poison their consumers, while others cause harm to fish through gill clogging or via the production of fish toxins (ichthyotoxins) or via oxygen depletion affecting entire marine ecosystems. All these modes of action are represented in HAB species recorded in the Arabian Gulf. Different monitoring techniques are appropriate for different HAB species, depending on specific toxins/profiles and also algal bloom densities at which harmful effects are caused. Unbiased/catch-all techniques are required when effects

are unexpected (e.g. out of the normal seasonal and/or regional pattern) – here regular sampling and full characterisation of species assemblages is required and there is no substitute as yet for microscopic analysis, which provides anatomical and functional information as well as taxonomic data. Otherwise monitoring can be targeted on high risk species that are most likely to cause harmful effects, for example *Dinophysis* species that often form low biomass summer blooms in coastal waters of Europe, the Americas and Asia, and intoxicate wild and farmed shellfish with Diarrhetic Shellfish Toxins (DST). Safe thresholds for DST are often exceeded, even when *Dinophysis* cell counts are low, resulting in costly shellfish harvesting closures. Since these low biomass blooms are undetectable by satellite, predictive models are needed to reliably forecast *Dinophysis* blooms, in order to help target monitoring and shellfish testing, to avoid harvesting of intoxicated shellfish and to manage supply chains. Moving towards more "proactive" monitoring data collection to feed data-driven HAB models will be enabled by acquiring real-time data from *in situ* sensors capable of near real- time quantification of changing HAB toxin concentrations and HAB species abundance via automated algal cell imaging, cytometric or molecular-based methods.

10) Understanding impacts of HABs on fish farms based on lessons learned in Chile

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Abstract

The southern Chilean coast is widely known for suffering severe Harmful Algal Blooms (HABs) in the last decade, especially those related to fish kills (Fish Killing Algae -FKA). Recent studies and observations have shown that these ecosystems are highly vulnerable to the effects of climatic (i.e., ENOS, SAM) and anthropogenic stressors (i.e., aquaculture), leading to a dramatic increment in the intensity and distribution of harmful algal blooms (HABs) in southern Chile. For instance, two massive HABs in the Patagonian fjords in 2016, due to severe droughts, produced the worldwide known "Godzilla-Red tide events". First, the ichthyotoxic flagellate *Pseudochattonella verruculosa*, produced the most extensive fish farm mortality ever recorded worldwide (equivalent to an export loss of USD$800 M) evidenced that the Chilean salmon industry was not prepared for this unexpected bloom; and second, an intense bloom of the PSP producer *Alexandrium catenella* led to a vast socio-environmental impact for the local shellfish industry. After this massive bloom in 2016, *A. catenella* has been observed migrating equator-ward reaching northern areas and producing extreme PSP events (i.e., a world-record of 143,130 µg STXeq. 100 g –1 in 2018). The climatic anomalies have also recently triggered 'super blooms' of opportunistic cryptic toxic algal genera (i.e., *Karenia, Heterosigma*), especially affecting important aquaculture areas in southern Chile. Overall, HAB events in Chile have produced, for example, an estimated annual cost in microalgae and toxin monitoring of approximately 7M US$ in 2019 and 93,000 US$ due to hospitalizations in 2018.

Regular phytoplankton monitoring in southern Chile needs to be accompanied with new technology (i.e., molecular approaches, automated flow cytometry) to improve the detection of fragile FKA species (i.e. *Heterosigma, Pseudochattonella, Vicicitus*) and the quantification of ichthyotoxins (i.e., RTgill-W1 gill assay). Climate change is strongly affecting the southern Patagonian fjords. Further studies need to focus on how projected local-to-global scenarios will modulate scientific capabilities to monitor, model and mitigate future HAB events, and how HABs-environmental uncertainties would affect essential system functions and consequently ecosystems services and wellbeing of coastal communities.

11) Control of HABs in China using a modified clay approach

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Abstract

The concept "controlling Harmful algal blooms (HABs)" means the effective interruption to the matching relationship between biological factors representing its growth and environmental factors supporting its proliferation for a specific HAB occurrence. Clay flocculation is one of promising measures that has been used to control HABs in field but still has crucial bottlenecks for its popularizing in real-world cases, including insufficient efficiency for clay particles to flocculate HAB cells, great amount of clay in use and plenty deposit thereof. According to our research, surface modification is an effective way to increase the flocculation rate for natural clay, thus we proposed Modified Clay (MC) technology. By using MC in field, 70%-80% HAB organisms could be flocculated directly to the bottom while the growth of residual is inhibited and would be ultimately settled down by repetitive sprayings. There are 3 characteristics of such technology. Initially, it's safe and environment friendly. The row material is the major component of nature soil. In the meantime, MC is proved safe to use in field after careful and plenty evaluations for its ecological effects on typical aquaculture, water quality, benthic, planktonic organisms, and so on. Secondly, it's highly efficient to control HABs in field. The water clarity could be visibly improved in 30 minutes while the removal rate of MC to different HAB organisms could reach 90% averagely. Meanwhile, the dosage of MC used in the open water is only 4-10 tons/km2 averagely, which is adequately as 4-10 g/m2, with the purpose of effective control of HABs. Last but not least, it's such a technology being easy to use. The automatic specialized equipment for MC mixing and spraying has been developed in several types according to varied scale of waters. Since 2005, as a "fire extinguisher" for HAB emergencies, MC has been successfully applied in over 20 different waters of China, including cooling water of nuclear plants, typical aquaculture areas and waters for some important activities, such as Olympic sailing regatta, BRICs summit, etc. It has been listed in the National Standards of China for HAB control, and successfully introduced abroad. As a summary, MC technology is a reliable method to control HABs and has the potential to be widely used in ROPME sea area further.

12) Development of an Early Warning System for Harmful Algal Blooms, red tides, and fish kill incidents in Kuwait Territorial Waters

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Abstract

Kuwait's marine environment receives numerous pollutants from multiple pollutions sources such as point source pollution of treated and untreated sewage. Those sources can contribute to the adverse effects load on the aquatic ecosystem, endangering native marine resources like fisheries, and shrimp which are of economic value. Elevated nutrients load in wastewater along with increasing water temperature and salinity can trigger algal blooms in marine waters which can be a precursor for subsequent red time and fish kill incidents. Also, harmful algal bloom (HAB) species can be responsible for several marine mortality cases in Kuwait

Territorial waters, as it can consist of neurotoxic algal species. On these grounds, the Kuwait Environment Public Authority (KEPA) has requested from Kuwait Institute for Scientific Research (KISR) to submit a research proposal to assess marine crises like HAB, red tides, and fish kills frequently occurring in Kuwait territorial waters. Consequently, the idea was consolidated to propose an integrated system to predict, forecast, and understand the reoccurring events which triggered us to propose the development of an early warning system (EWS) for such environmental phenomena. The EWS will incorporate various analytical tools of ecologically indicator systems to analyze HAB, red tide, and fish kill events. Proper prediction, response, and management of environmental crises are essential to assist decision-makers. As a follow-up study to the establishment of the EWS, a comprehensive review of historical observations of HAB, red tide, and fish kill events in Kuwait marine waters was developed to support an effective prediction and forecasting of those events. Major outcomes of the study are: HAB events frequencies are elevated in the summer season, Kuwait Bay is a hotspot for HAB events, and wastewater is the confirmed triggering factor for HAB, events.

13) Existing HAB observation and EWS in the Persian Gulf and Sea of Oman

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Abstract
Since the Harmful Algae Blooms (HABs) catastrophe in 2008, HAB's research has become one of the most important types of research in the countries around Sea of Oman and the Persian Gulf (ROPME Sea Area's; RSA). This was because the occurrence of that bloom was remarkable in terms of the area it spread, intensity and duration, and its mortality rate. Harmful algae bloom research is also important from social, economic and environmental points of view in the region. In recent decades, HAB incidents reported from Iran, Kuwait, Qatar and Oman waters. Aaccording to various research works, only 6% are potentially HABs former species from the total phytoplankton reported from the Sea of Oman and the Persian Gulf. However, these species have had destructive effects on marine organisms. Among these species, the common HAB former species include: *Peridinium quinquecorne, Gonyaulax polygramma, Karenia selliformis, Pyrodinium bahamense, Levanderina fissa (=Gyrodinium instriatum), Margalefidinium polykrikoides(= Cochlodinium polykrikoides), Scrippsiella trochoidea Noctiluca scintillans, Karlodinium sp. and Amphidinium carterae*.

One of the key issues in HAB research is the identification of the HAB species life cycle, which includes vegetative cells and the cyst stage, which is an essential step in management and planning to predict and reduce destructive effects of HAB. As far as research is concerned, HABs prediction, identification of key area, marine biodiversity, environmental awareness, and marine sample bank are the significant goals of research in the Sea of Oman. As a result, some researches that have been conducted in recent years on the abundance, distribution and identification of dinoflagellate cysts, in the sediment, increased our knowledge on the existence of some species that may have missed from plankton samples due to their short life in the water column. Accordingly, they have resulted in a little promotion of our knowledge on marine biodiversity of phytoplankton in the Persian Gulf and the Sea of Oman.

14) Development and Operations of Harmful Algae Warning Systems in the United States

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Abstract
Harmful algal blooms (HABs) produce local impacts in nearly all freshwater and marine systems, resulting in ecological, economic, and human health damage. HABs are a global problem but generally require regional to local solutions tailored to the specific environment. Improved scientific understanding of HAB dynamics coupled with monitoring and ocean observations facilitates new prediction and prevention strategies. In the United States, several regional observing and forecasting systems have been developed, each with its own scope, methods, and application. Three examples of operational systems include the Pacific Northwest Harmful Algal Blooms Bulletin, the Lake Erie Harmful Algal Bloom Bulletin, and the California Harmful Algae Risk Mapping (C-HARM) System. While there are many similarities in these programs, no two systems are identical since each was built to be fit for purpose. Common themes leading to operational success include: (1) scientifically vetted underlying observational and modeling tools; (2) attentiveness to end-user needs; (3) operational capacity; (4) frequent review and adaptation of new or improved methodologies. Lessons learned from these programs identify several key needs for existing and proposed operational forecasts. First, operational forecasts require sustained, preferably automated, near real-time information from nearshore and offshore sites to validate predictions and provide improved, advanced HAB warnings. Second, ecological knowledge and models are necessary to move beyond short-term (days) forecasts to seasonal and interannual forecasts. Third, sustained operations requires buy-in from stakeholders, meaning that the monitoring and forecasting system must provide enough value to end-users to justify the cost.

15) Changes and complexity of HABs in Asia: Implications for early warning systems and future projections

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Abstract
Harmful algal blooms are affecting fisheries and aquaculture throughout Asia, but different HAB taxa are common in different parts of the region. Increases in both nitrogen and phosphorus over the past decades have contributed to the proliferation of these blooms, as recently documented for three regions of China. The number of HAB events and affected HAB area for China are also highest under elevated nitrogen:phosphorus (N:P). Since the 1970s, nutrient pollution has increased largely due to river export. The largest fraction of nutrients from rivers comes from agriculture-derived nutrients, but river export of aquaculture nutrient sources and export of nutrients from marine aquaculture have also increased.

Prediction of HABs is rapidly advancing. New data streams and new models, including statistical, mechanistic and machine learning approaches are all being developed. To advance beyond prediction of chlorophyll and to predict growth of individual species, several approaches are suggested. In mechanistic models with multiple phytoplankton groups represented, a rhomboid strategy may be used, parameterizing the HAB taxa individually while modeling other species in functional groups. Habitat models may be useful in defining

a species niche, and therefore in producing risk maps, but such an approach cannot predict cell density. To improve parameterization of growth of many HAB taxa in developing mechanistic models, inclusion of mixotrophic nutrition (the ability to consume particulate food and to carry out photosynthesis in the same cell) will be required. Mixotrophy can increase growth rates, can prolong periods of growth, and at least for some taxa, increases under increased N:P conditions. A suite of coupled physical-biogeochemical-HAB-multi-trophic level models will be needed to test how current and emerging stressors (warming, nutrient changes, acidification, etc.) interact to project future HAB growth spatially and temporally and to project future risks to aquaculture and other fishery resources.

16) HABreports: Online early warning of harmful algal and biotoxin risk for the Scottish shellfish and finfish aquaculture industries

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Abstract

Harmful algal blooms (HABs) of biotoxin producing phytoplankton are monitored by light microscopy in Scottish waters to ensure shellfish safety. However, while protecting human health, this regulatory system provides little early warning of HAB events to aquaculture operators. Here we present an on-line early warning system (www.HABreports.org) that has been developed for Scottish coastal waters that utilises HAB, biotoxin and other environmental data to provide risk assessments that minimize HAB the risk to humans and aquaculture businesses. The system includes both map and time-series based visualization tools. A “traffic light” index approach is used to highlight locations at elevated HAB/biotoxin risk. High resolution mathematical modelling of cell advection provides early warning of HAB transport by coastal water movements. Expert interpretation of HAB, biotoxin and environmental data in light of recent and historical trends is used to provide, on a weekly basis, a forecast of the risk from HABs and their biotoxins to allow mitigation measures to be put in place by aquaculture businesses, should a HAB event be imminent. Recently the UK’s first imaging FlowcytoBot (IFCB) has been deployed as part of the HABreports system and is currently being trained to identify and enumerate harmful species at a high temporal frequency to allow more rapid risk assessment of HAB development.

17) “HABs and Early Warning System (EWS) in Chile”

Alejandro Clément, Francisca Muñoz, Nicole Correa, Stephanie Saez, Carmen Tellez, Bárbara Ramirez, Gustavo Contreras, Osvaldo Egenau, Alvaro Jorquera, Pablo Riquelme & Andrea Colifef, Puerto Varas, Roberta Crescini, Carlos Flores y Marcela Cárdenas, Castro. Carmen G. Brito, Coyhaique. Martin Contreras, Puerto Montt-Chile (Plancton Andino, Chile). AClement@plancton.cl

Abstract

The main objective of this work is to share the southern Chile experience of our group on HABs monitoring, research, and progress in Early Warning System (EWS), with focus on fish aquaculture.

There are several examples of EWS around the world, in USA we observe many cases; prediction, and Early Warning of the National Office for HABs, and the Great Lakes EWS. In

UK there is an Online EWS of Harmful Algal and Biotoxin Risk for the Scottish Shellfish and Finfish Aquaculture Industries (Davidson et al 2021). Also, we observe researchers using molecular biology and meta-coding data for HAB as EWS. McKenzie, et al is preparing a paper in relation with EWS for high biomass bloom and fish kills and other impacts. Devred et al 2018, development of a conceptual warning system for toxic levels of *A. fundyense* in the Bay of Fundy based on remote sensing data.

Our focus is to improve and progress in an EWS with an intense phytoplankton monitoring program on space (x, y & z) and time (t) called POAS (fish aquaculture) and PSMB (for shellfish). We complement with ecophysiology of HABs & bio-optics studies, such as *in vivo* analysis of photosynthesis of PSII using Fast Rate Repetition fluorometry (FRRf3). February results of photosynthetic parameters and abundance of *P. micans* & *L. danicus*, show clearly that dinoflagellate cells represent more photosynthesis activity than diatoms during the bloom. Dissolved oxygen levels are distinctly influenced by *P. micas*, in Reloncavi Sound section. In addition, using a linear model, there is a very high correlation (R> 96%) between Fo, Fm and abundance of *P. micans*. Therefore, FRRf3 parameters is a proxy for HABs cells abundance and understanding ecophysiology conditions and improvement of decision-making process. On the analytic approach, we have developed of an algorithm for algal bloom risk for fish aquaculture, called the HABf INDEX (Clément et al 2020). In addition, we are analyzing FlowCam images, forecasting the HABf INDEX using data analytic and Machine Learning (see Link to YouTube in presentation). No doubt that smartphones are part of our lives, so we design an App for on-line visualization and automatic alerts messages after a critical threshold of an harmful algae (See in link to Youtube in presentation). Improving of SQL & Python codes, API, BI capabilities and data analytic is frequent work in the system. We are developing a system with Bio-Optical Aqua Sensors (BAS) to collect on real time water quality data. Remote Sensing, despite the limitation in Optically Complex Waters is used as tool. Climatic anomalies analysis, particularly radiation and rain fall is a part of our EWS.

As final remarks, a EWS is a practical and operational approximation to decrease the risk and mitigates HAB. However, bloom and cells conditions of *P. micans* (and probably most phototrophic flagellates) modulates the shape and fluxes of the oxygen and AOU layers in stratified waters. Local variability, patches, and vertical distribution (thin layers) complicate EWS and forecasting. The HAB of *Pseudochattonella* during January of 2022 in southern Chile was practically impossible to alert, due to a very small-scale distribution and occurred in an extreme short-term period (2 to 4 days). The message should be to increase frequency and the use several technologies to improved monitoring for early warning in isolated sites.

18) Discussion

Day 1 – Discussion points
Understanding the susceptibility of the RSA (Arabian Gulf and Sea of Oman) to harmful algal blooms and impacts on fish health and food safety

The status of the environment and sea food production in the RSA is under threat from multiple pressures e.g. pollution & disturbance from agriculture, urban & coastal development, shipping & climate change.

1. How are HABs responding to these pressures – what are the likely future trends?
   The data presented at the workshop indicate a series of major HAB events in the RSA from the 1990s to present day. There is evidence of increasing frequency and intensity of blooms in the last decade in some Gulf Countries, including Kuwait and Oman.
2. What are the biggest HAB impacts now and in the future?
   HABs present a significant threat to coastal resources, water quality, public health and tourism, Historical impacts include major fish kills, seafood poisoning, impairment of drinking water quality and operation of desalination plants.
3. How can we accelerate management of water quality issues to "buy" time for climate mitigation?
4. How else can Gulf Countries mitigate risks – e.g. through ROPME?
   It would be advantageous for Gulf Countries to share monitoring data, and coordinate monitoring and modelling programs and early warning systems to better inform mitigation actions for HABs (e.g. use of bubble curtains, elevating or lowering fish cages, modified clays).
   Additional monitoring data relevant to aquaculture development and fisheries conservation could be obtained from: desalination plant monitoring; mussel watch programme.
5. How can aquaculture be developed sustainably in the marine environment (and inland)?
   Integrated Coastal Zone Management (ICZM) and spatial planning – Several Gulf Countries including Oman, United Arab Emirates and Saudi Arabia have each produced an Aquaculture Atlas, which identifies favourable zones for aquaculture development.
6. Do we have enough data?
   The recent global meta-analysis by Hallegraeff et al. https://doi.org/10.1038/s43247-021-00178-8 highlighted the need for more data quantifying the occurrence and impacts on HABs in Arabian and Indian coastal waters. Data quantifying potential environmental drivers and HAB impacts, as well as HAB occurrences are needed.
7. What should a monitoring and forecasting system look like in the RSA?
   Integrated system, combining in situ and satellite monitoring data collection to feed HAB forecasting models. There are already examples of HAB early warning systems in Oman - Decision and Information System for the Coastal waters of Oman (DISCO). As well as monitoring and predicting of hypoxia and fish kill events, DISCO can track liquid waste, oil spills and hurricanes, and thus provide decision-makers with a broad spectrum early warning system.

Day 2 – Discussion points

Developing early warning systems (EWS) for HABs for mitigating impacts on fisheries and aquaculture

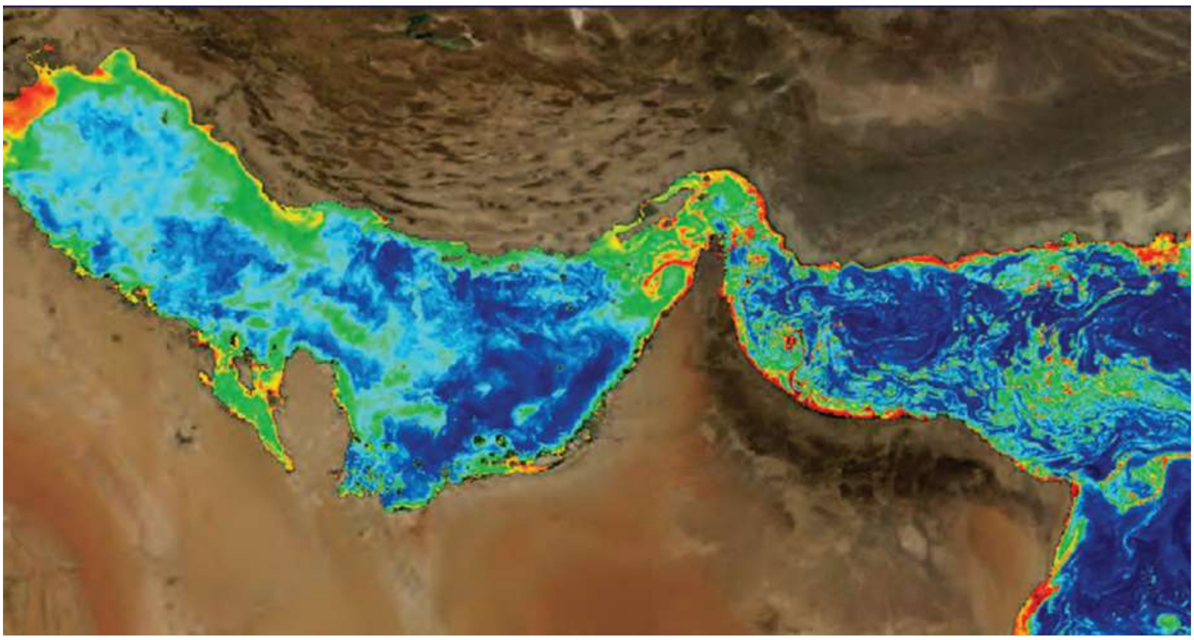
Predicting HABs in a complex, changing world is difficult – there is no one solution for every situation, *BUT all HAB monitoring & forecasting systems must be fit for purpose, sustainable, and useful to end-users*

1. How would we characterize the situation in the RSA both spatially and temporally?

HAB risk varies throughout the RSA. Coastal margins are threatened and risk is greatest in embayed areas and areas of intense coastal development with prolonged water exchange (flushing) times and increased nutrient inputs. Nutrient and sewage inputs also contribute to increased eutrophication and hypoxia risk. The Arabian Gulf is connected to the Sea of Oman via the narrow Straits of Hormuz and the oceanography of these sea areas are different. Nevertheless HABs often extend into the Arabian Gulf from the Sea of Oman and the Arabian Sea (Al-Alawi, 2018; Attaran-Fariman, 2018). Therefore it is necessary for circulation models for predicting HABs to include oceanographical forcing over this extended area (El Kharraz, 2018).

Typical phytoplankton bloom patterns in the Arabian Gulf and Sea of Oman include low chlorophyll (dark blue, Figure 1) away from the coasts and high chlorophyll (orange and red), particularly around the Arabian Peninsula. The patterns are caused by surface transport and concentration of blooms that can disperse widely in response to surface currents and eddies (Anderson et al., 2017). The general circulation of the Gulf is counter-clockwise, and is mainly driven by halocline forces caused by the high evaporation rates (Reynolds, 1993). The northwesterly or "shamal" wind plays an important role in the large-scale circulation of the Gulf (Perrone, 1979).

Figure 1: Chlorophyll concentrations captured by the MODIS Aqua sensor (NASA) representing a bloom of the harmful algae *Margalefidinium* (*Cochlodinium*) spp. (in Anderson et al., 2017; Courtesy of R. Kudela and NASA)



2. What could a monitoring and forecasting system look like in the RSA?

There are examples of advanced HAB early warning systems in North and South America, Europe and Asia. Components of these systems could be implemented in early warning systems in the RSA, including: real-time in situ observation of HAB cell counts using imaging flow cytobots and sensors for monitoring environmental conditions. Molecular meta-barcoding could also be used to supplement microscopic analysis of water samples obtained on a regular basis to map changes in plankton community composition over time. Monitoring of HAB cysts in sediments could also be undertaken on a regular basis.

3. Areas of method development highlighted in Day 2 presentations:

- *Monitoring data – moving beyond measuring algal blooms using chlorophyll to remote sensing of specific HAB forming species (via satellite imagery)*
- *Dinoflagellate cyst mapping*
- *Coupled physical-biogeochemical-HAB-multi-trophic level models*
- *Data and models quantifying HAB physiology and mixotrophy*
- *Cost/benefit of modelling versus high frequency sampling within early warning systems*

4. How can international efforts be best integrated?

In the first instance, RSA Countries could compile and share HAB monitoring data on a shared data platform. Suitable international platforms already in existence include Ocean Biodiversity Information System (OBIS) (https://www.obis.org) and Harmful Algae Event Database (HAEDAT) (http://haedat.iode.org). Other information and tools identified beyond this workshop could also be shared via GlobalHAB (http://www.globalhab.info/).

Knowledge concerning HAB events and environmental drivers (including finfish aquaculture) in the RSA, supported by information from other geographical areas (hotspots), are being collated in a workshop paper.

Ultimately the workshop paper will be used to develop a larger research proposal that will support the development of an integrated monitoring-modelling system for forecasting HABs and impacts in Kuwaiti waters and the wider Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area (RSA), including the Arabian Gulf and Sea of Oman. This early warning system will support sustainable aquatic food production and will benefit other sectors (e.g. desalination and tourism) in the region. Research in this area will be applicable to other regions facing climate warming.

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Reynolds RM (1993). Physical oceanography of the Gulf, Strait of Hormuz, and the Gulf of Oman Results from the Mt Mitchell expedition Mar. Pollut. Bull., 27:35–59.

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KISR Kuwait Institute for Scientific Research

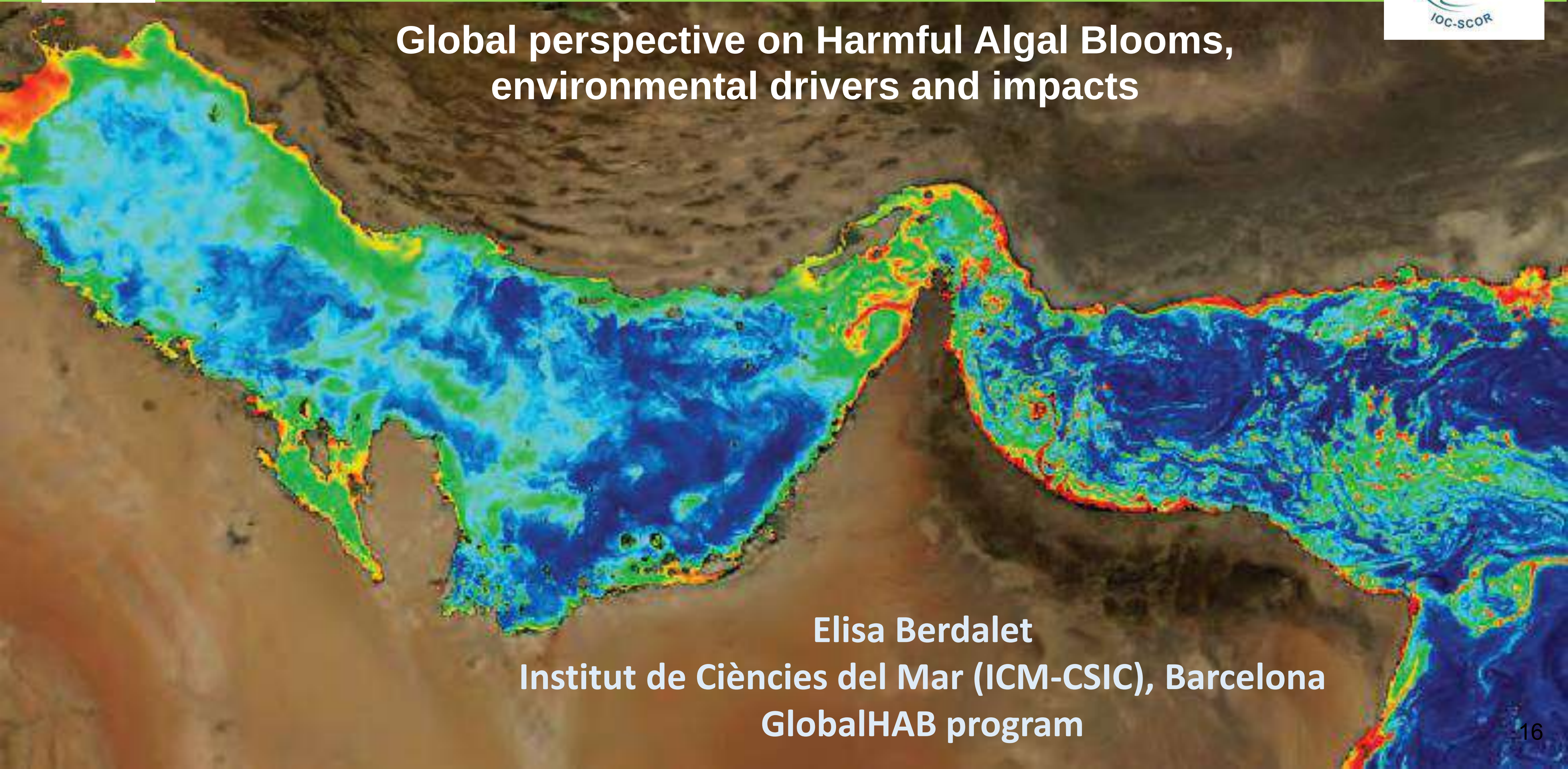
UNIVERSITY OF EXETER

Cefas

SUSTAINABLE AQUACULTURE FUTURES

GlobalHAB IOC-SCOR

Global perspective on Harmful Algal Blooms, environmental drivers and impacts



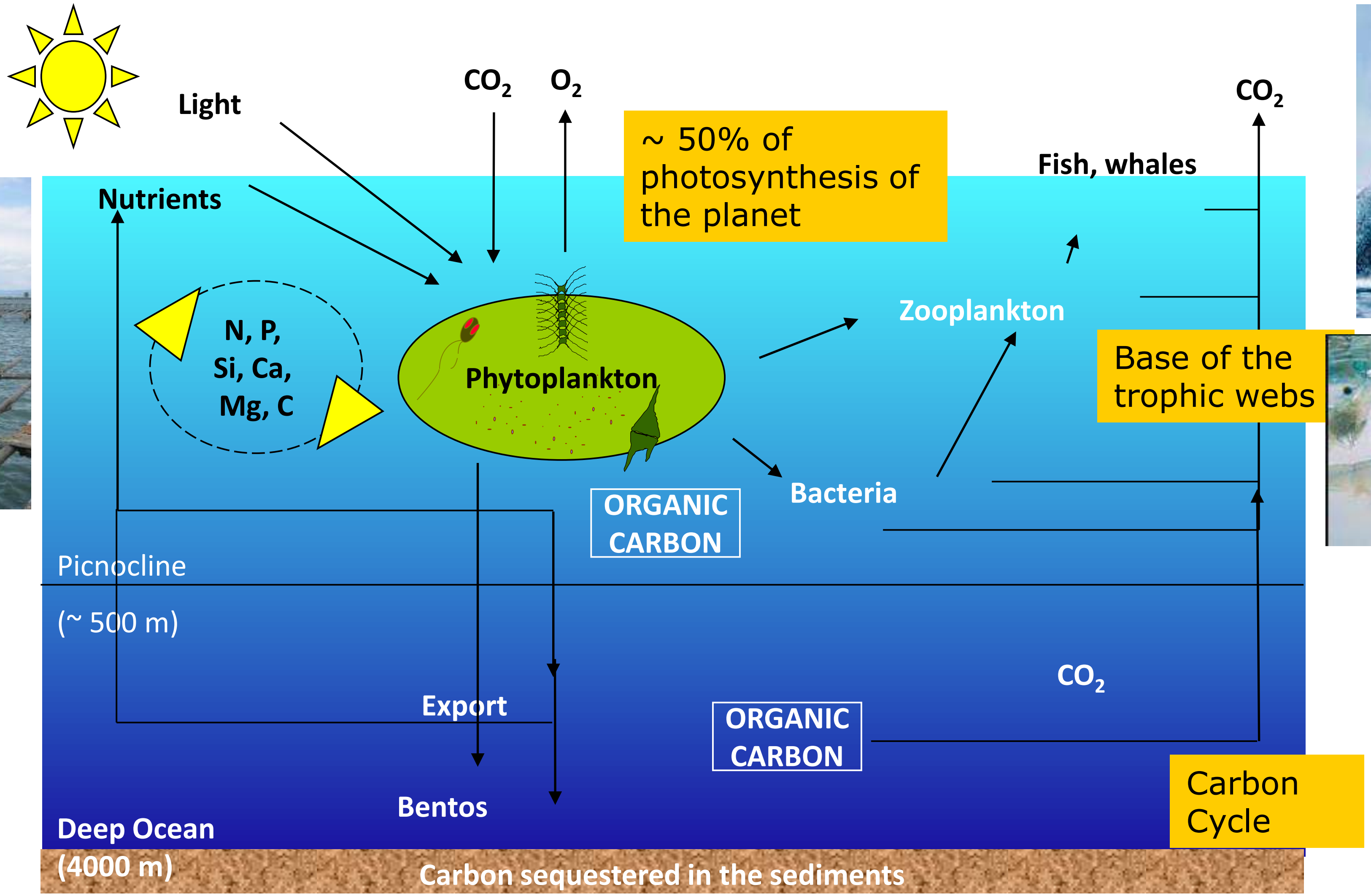
Elisa Berdalet

Institut de Ciències del Mar (ICM-CSIC), Barcelona

GlobalHAB program

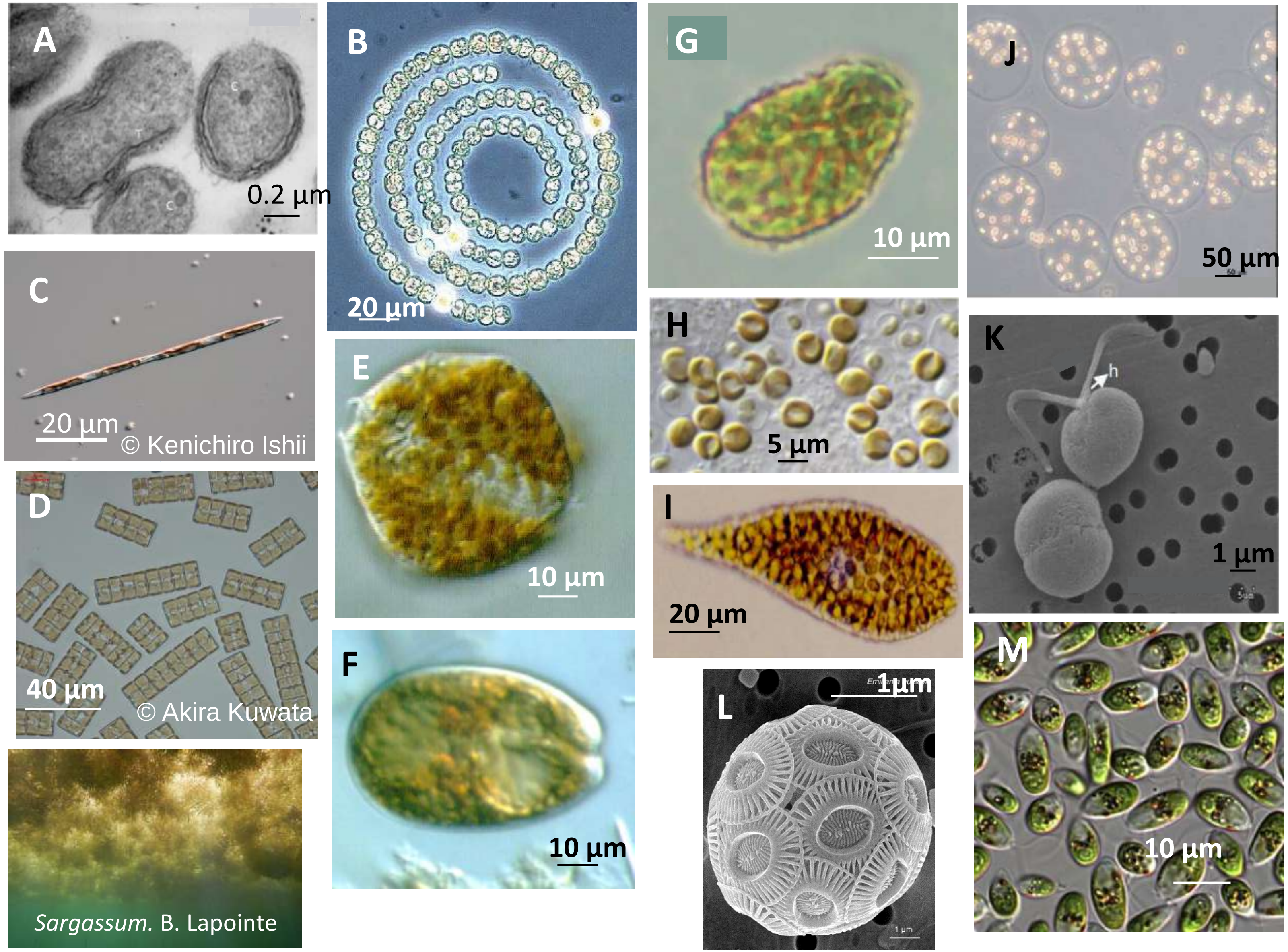
What are Harmful Algal Blooms (HABs)?

"Algae" (senso lato): - photosynthetic organisms that produce O_2, consume CO_2
- constitute the base of the food webs
- relevant role in the export of Carbon to the deep ocean

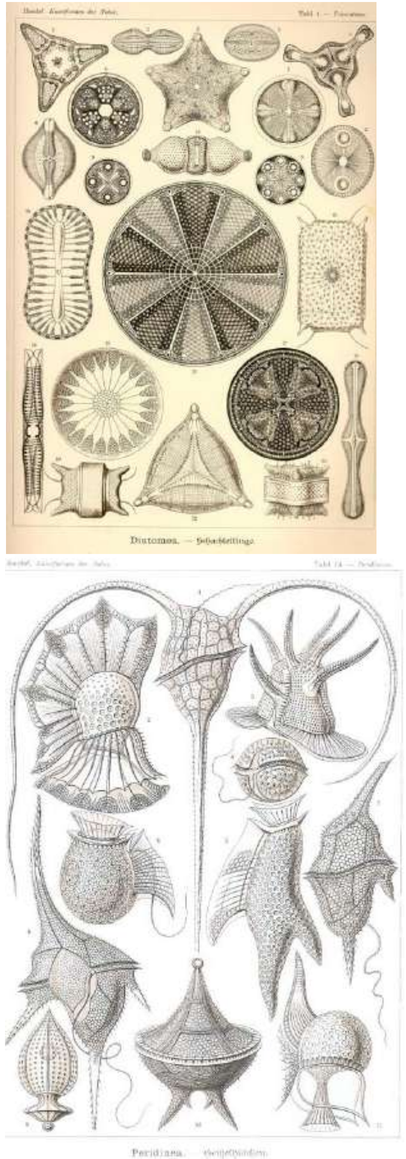


Examples of "Algae" including cyanobacteria and macroalgae

Plankton sample. Galician Rías.
Sonsoles González-Gil



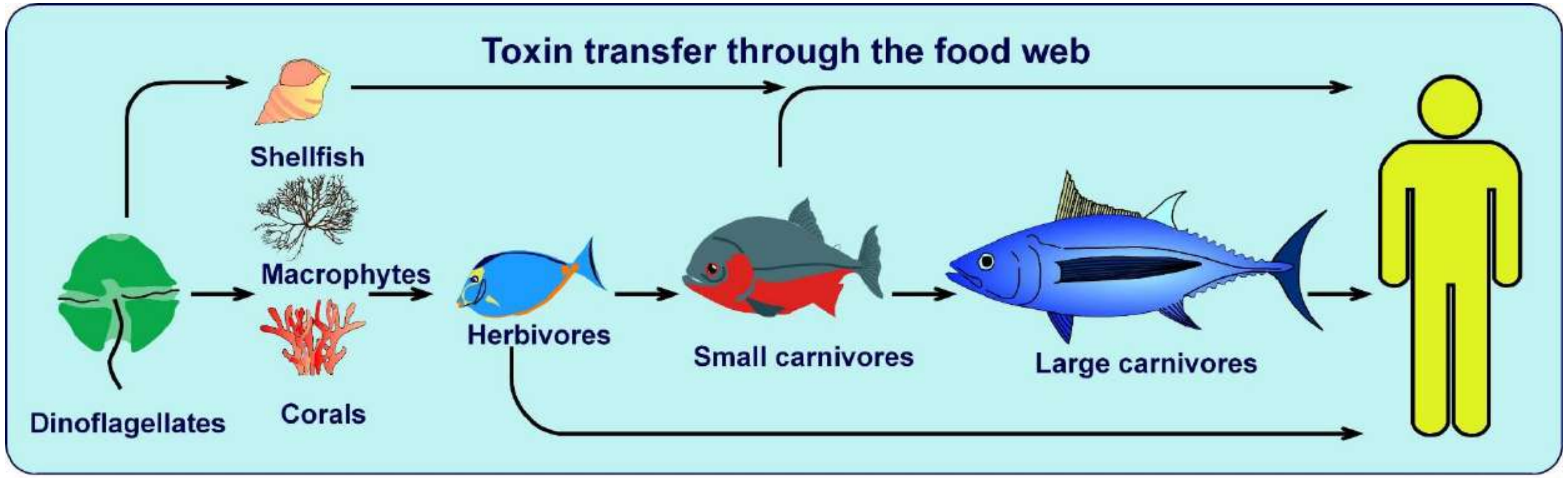
Berdalet (2020). TSC. 10.2436/20.1501.02.187



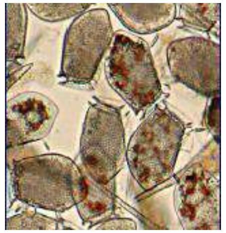
Haeckel, E. (1899-1904)
Kunstformen der Natur

Harmful Algal Blooms due to **impacts** on **human health** and **wellbeing**

Some microalgae produce toxic substances that are transferred through the foodwebs and ultimately affect humans and aquatic organisms, with associated socio-economic impacts

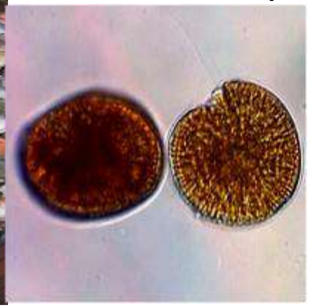


Institut de Ciències del Mar, CSIC



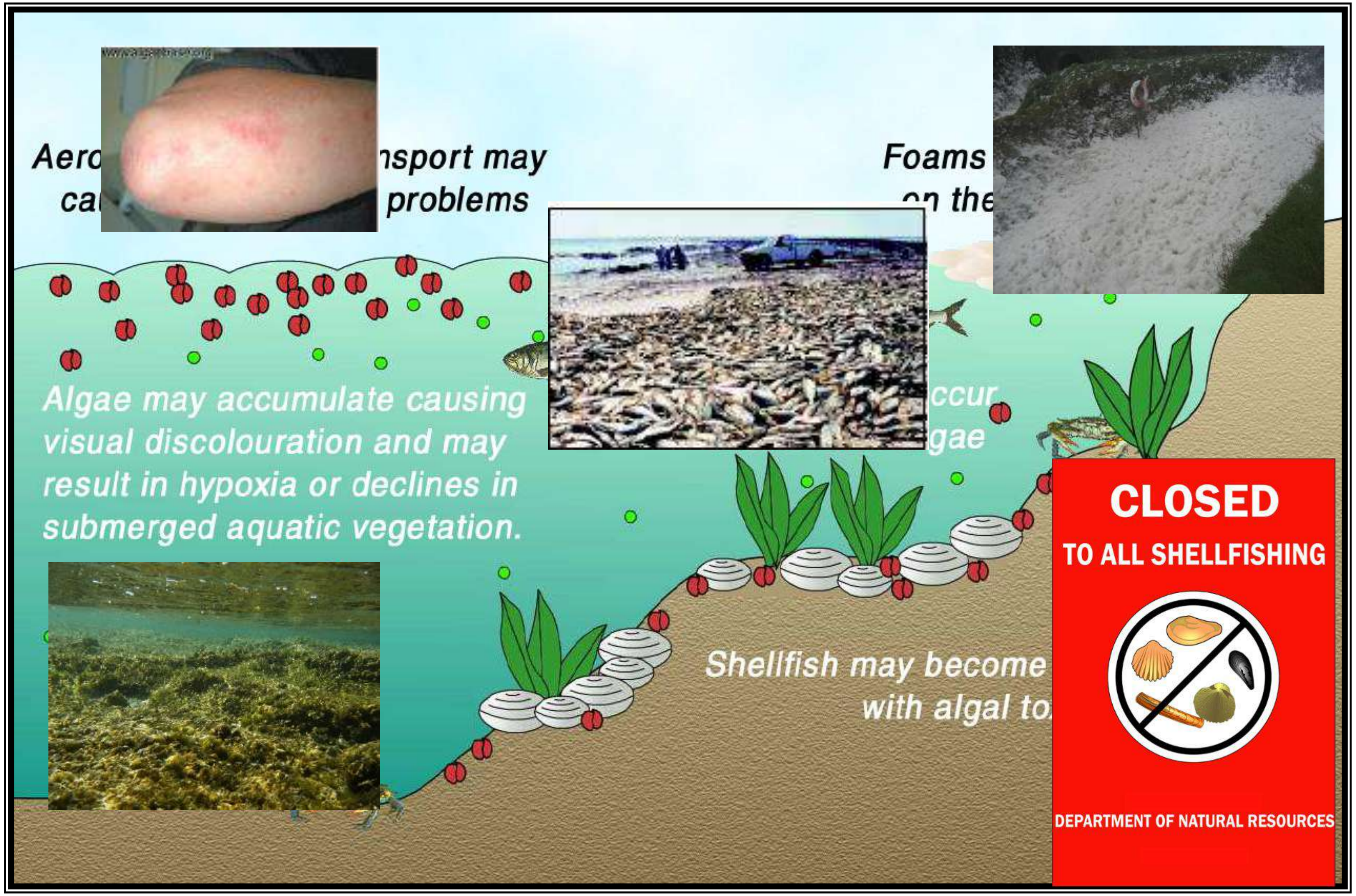
Dinophysis,
Diarrheic Shellfish Poisoning,
Closure of shellfish harvesting

Gambierdiscus,
Ciguatera fish poisoning
Endemic in the tropics
Incidence 1:4 people
$20 M loss p.a.



Some images of HABs, low or high biomass, toxic or not, with different impacts

The term "Harmful" is anthropocentric: defined due to the perceived impacts on human health and wellbeing



GEOHAB (2001)

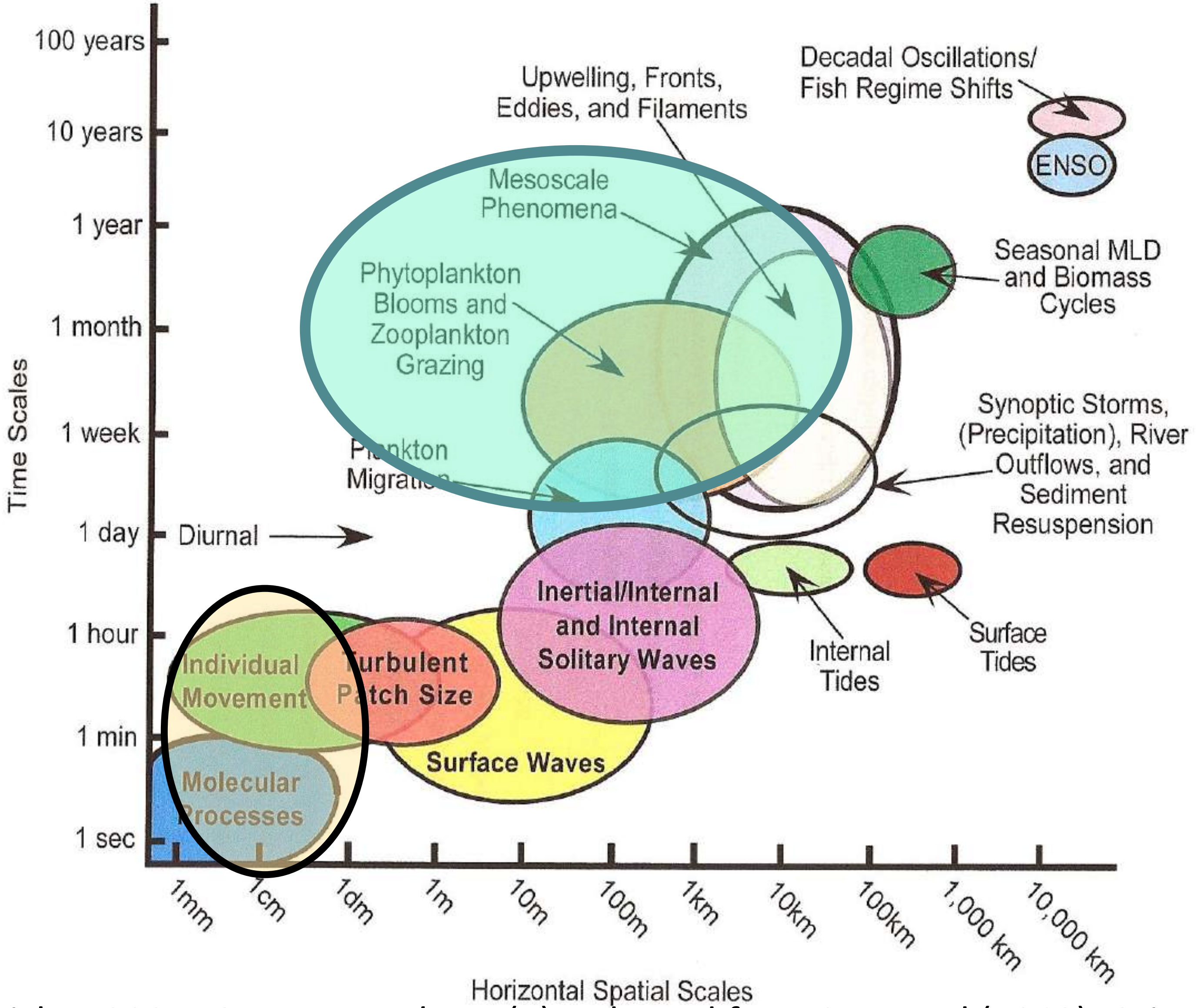
HABs known by native populations

Margalef, Ramon 1998. "Red tides and ciguatera as successful ways in the evolution and survival of an admirable old phylum." In *Proceedings of the VIII International Conference on Harmful Algae, Vigo, Spain, 25-29 June 1997*, edited by Reguera, Beatriz, Juan M. Blanco, Mª Luisa Fernández, and Timothy Wyatt, 3-7. Xunta de Galicia and Intergovernmental Oceanographic Commission of UNESCO.

"Alvar Núñez Cabeza de Vaca (1490?-1564), in his *Naufragios* (Ship-wrecks, Ferrando, 1984) composed between 1537 and 1549, referred to a place along the north coast of the Gulf of Mexico, probably not far from the present Apalachee Bay. He wrote that the indigenous people there did not know how to relate the passage of time to the movements of the Sun and the Moon, and used neither months nor years, but *they understand and know about the different periods in nature by observing when the fruits mature and when the fish die.* That is, **native populations took as witness of the passage of time the return of the seasons marked by the death of fish**, a mortality that could have been caused, then as nowadays, by the **action of *Gymnodinium breve (=Karenia brevis)*.**"

"To people making a living around the Galician Rías, red-tides ("purgas de mar") are familiar events, traditionally compared with menstruation, through which process the local waters would be cleansed from time to time, most notoriously in autumn. I**t was general knowledge that it is not safe to eat shellfish gathered when the water has the reddish-brownish hue**. I suppose that when mass cultivation of mussels in the Galician Rías came to be in the hands of relatively inexperienced developers, regrettable events of dispersal of mussels became more frequent, with one particular instance of autumn of 1976."

Factors controlling phytoplankton and HABs dynamics are the same



Dickey 2001. *Oceanography* 14(4). Adapted from Stommel (1963). *Science* 139: 572-6.

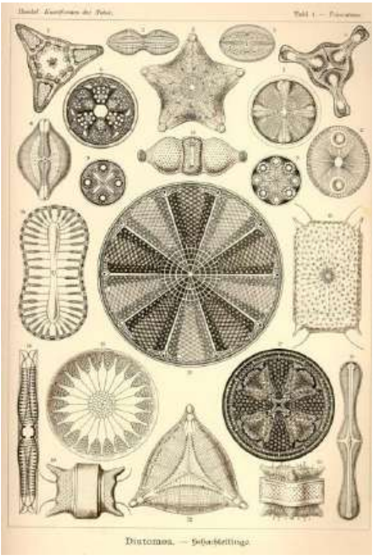
Phytoplankton blooms result from the interactions of physical, chemical, ecological and biological processes that occur at different scales

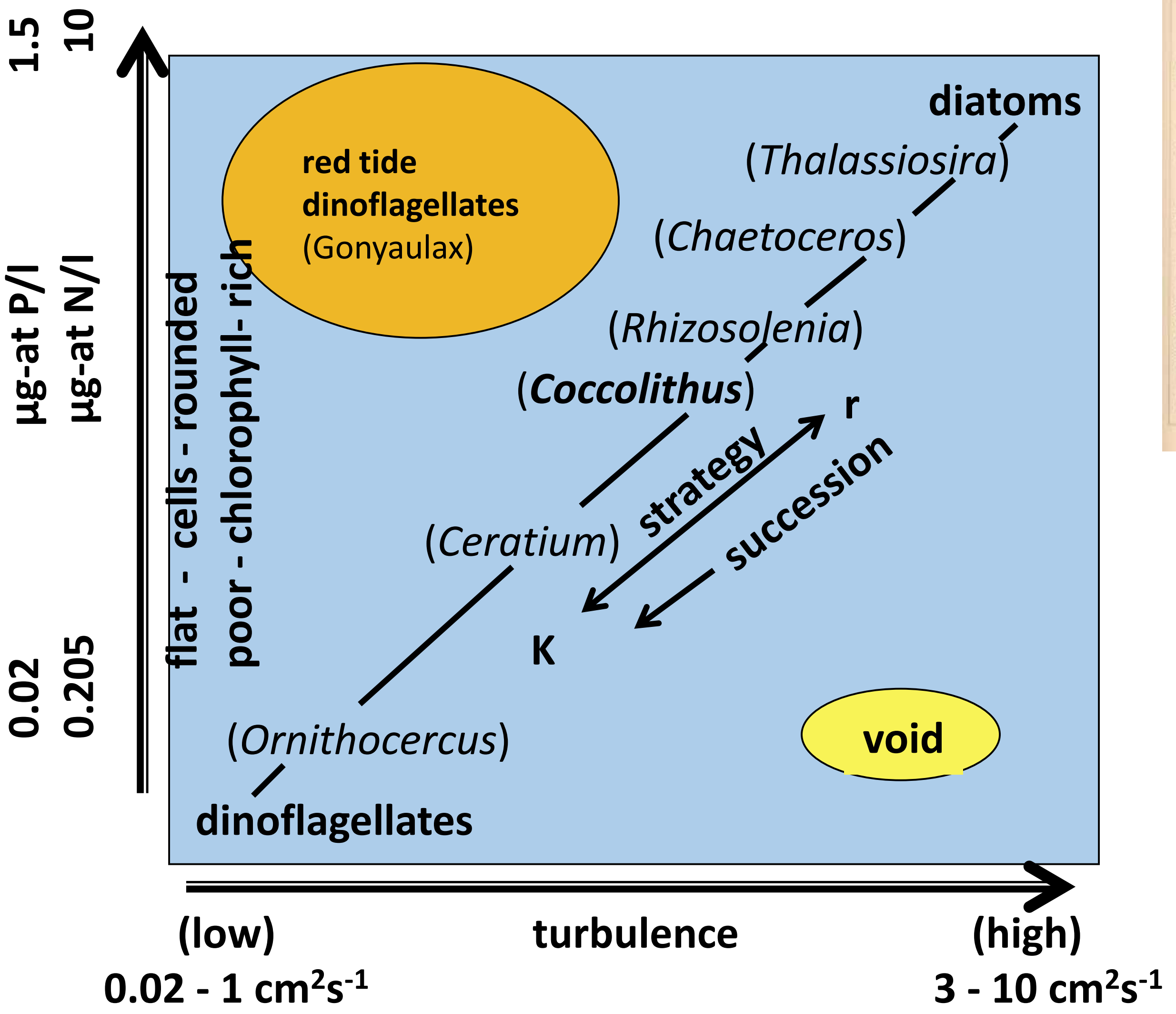
*** Light & nutrients**
*** Water stability**
*** Reproduction capacity**
*** Competition capacity**
*** Few losses (death, predation)**

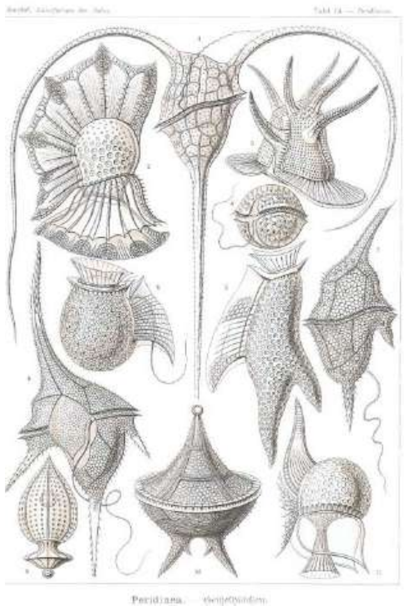
$$\frac{\partial n}{\partial t} = mn - mn - \nabla(n\bar{v}) - \nabla(n\bar{u})$$

HABs are a natural process occurring in all aquatic ecosystems

The phytoplankton mandala, Margalef 1978. *Oceanologica Acta 1(4):493-509* - A tentative plot …







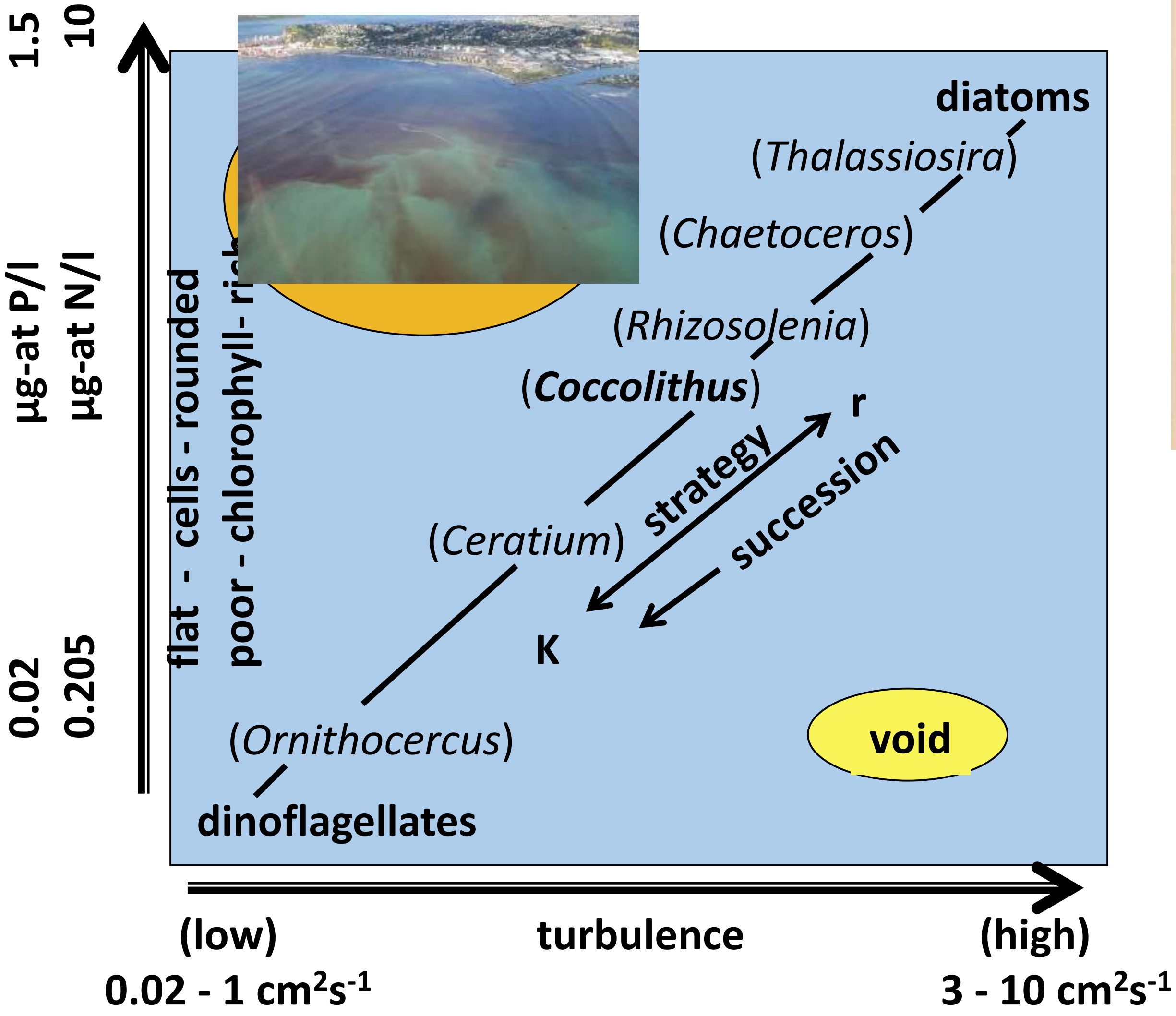
HABs are a natural process occurring in all aquatic ecosystems

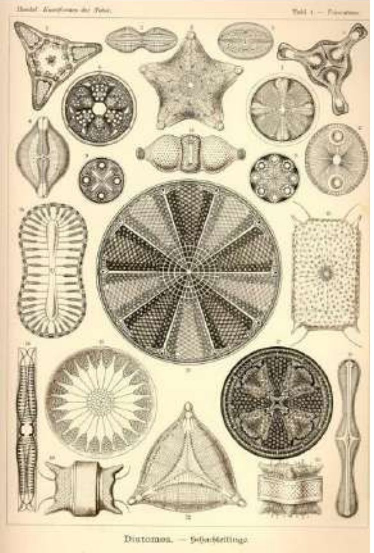
The phytoplankton mandala, Margalef 1978. *Oceanologica Acta 1(4):493-509* - A tentative plot …

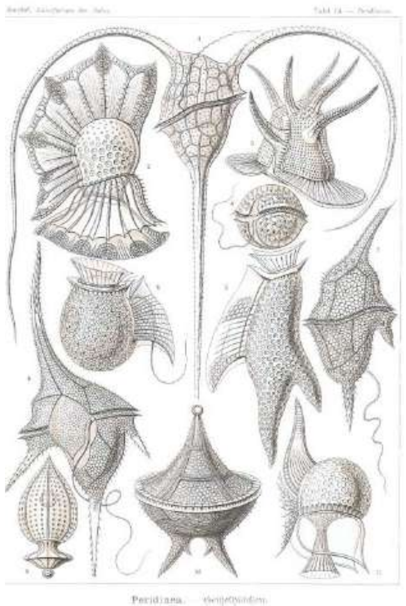
Harmful Algal Blooms

… are a particular situation within the phytoplankton succession …

… a sort of illness, not completely ironed by evolution …

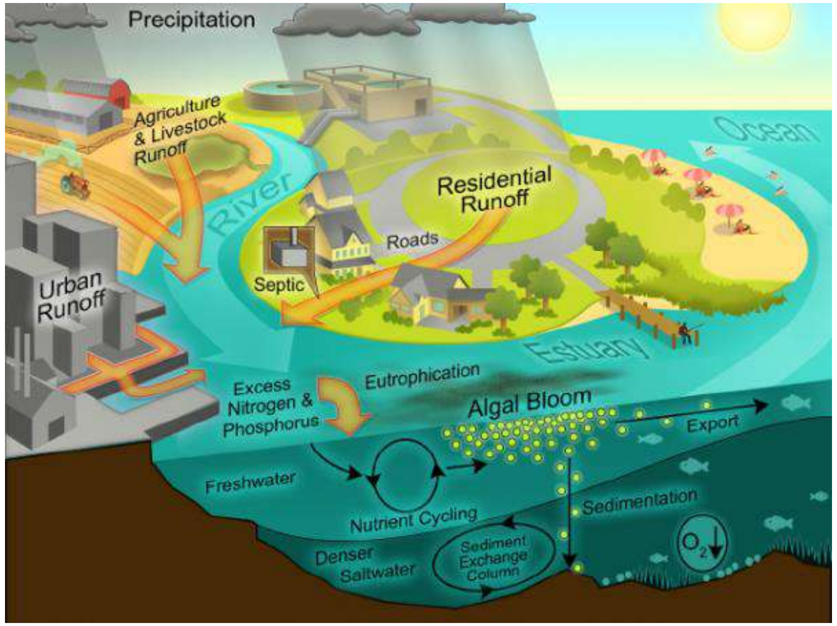






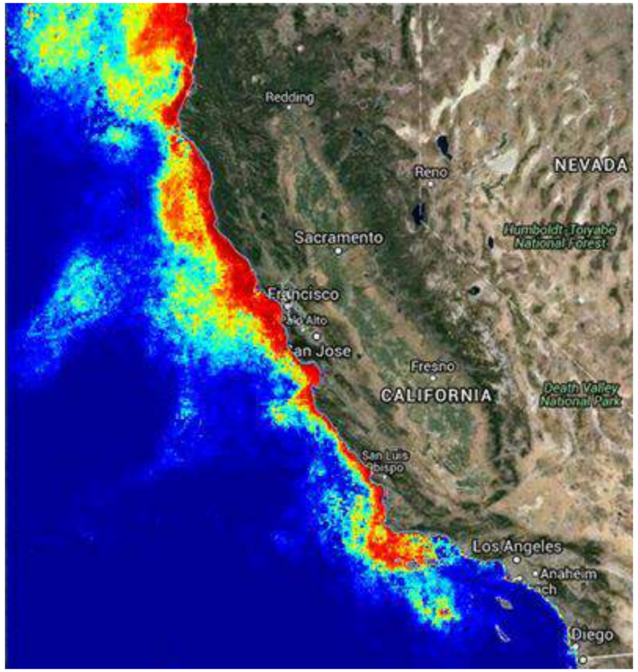
Some human activities favour HABs

- **Eutrophication: anthropogenic nutrient enrichment** leading to **excess phytoplankton production** that can result in **undesirable disturbance to water quality** and the **diversity of organisms**
- Alteration of **water circulation** patters by **harbors and aquaculture facilities:** retention areas that favor **accumulation** of **vegetative** and **resting** cell life forms
- **Spread of harmful organisms through ballast waters or transport of cultured organisms: blooms in areas not previously affected by** (certain) **HABs**



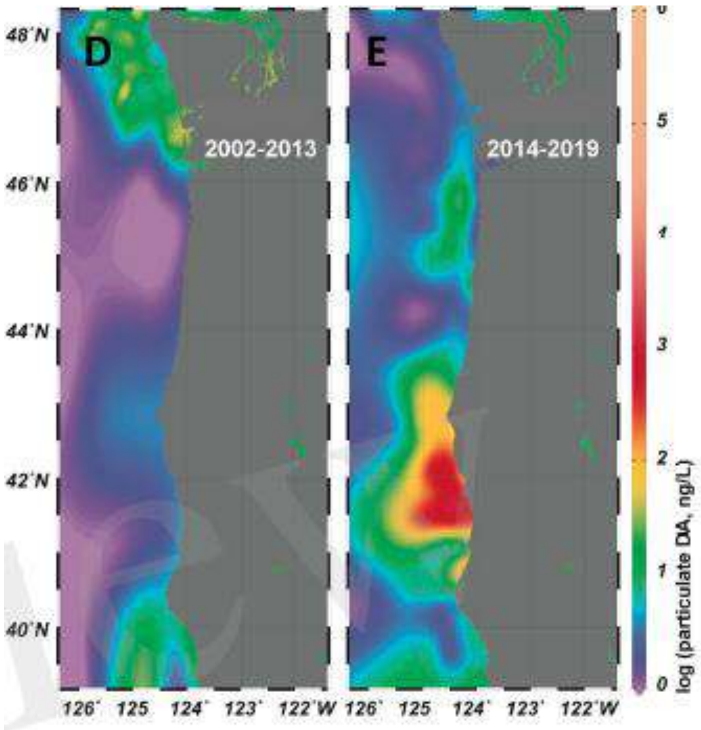
Alexandrium catenella
Images: M. Delgado/ M. Vila / JM Fortuño (ICM-CSIC)

2015. Exceptional *Pseudo-nitzschia* bloom in the Pacific coast of America



Amnesic Shellfish Poisoning (ASP) – domoic acid

Pseudo-nitzschia spp.
Photo: M. Montresor, SZN



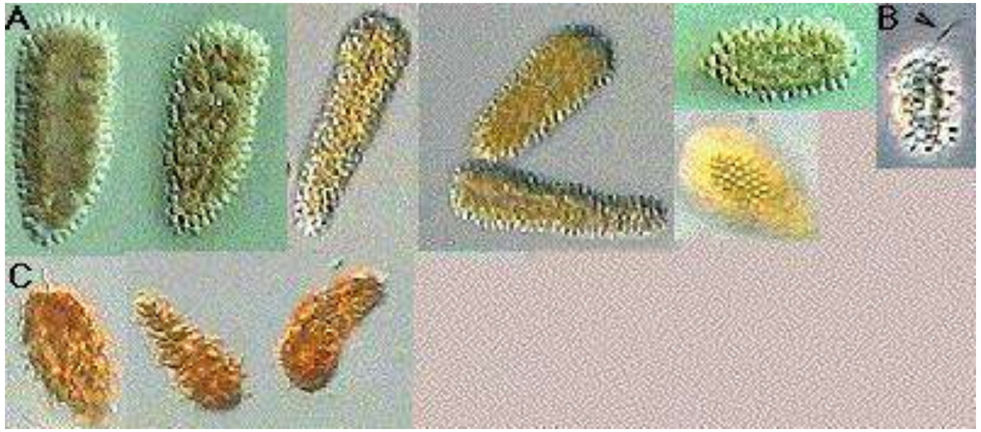
Trainer et al. 2020. Climate Extreme Seeds a New Domoic Acid Hospot on the US West Coast. Frontiers in Marine Science doi: 10.3389/fclim.2020.571836

2016. Exceptional *Pseudo-chattonella bloom* in Chile

Chile salmon farms lose 23 million fish due to toxic algae bloom

BY KAREN GRAHAM MAR 10, 2016 IN ENVIRONMENT

An ongoing and deadly toxic algae bloom off the coast of Chile, the world's second largest salmon exporter, has sent the country's salmon industry into a tailspin.



http://nordicmicroalgae.org/taxon/Pseudochattonella

Available tools for prevention and mitigation of HABs

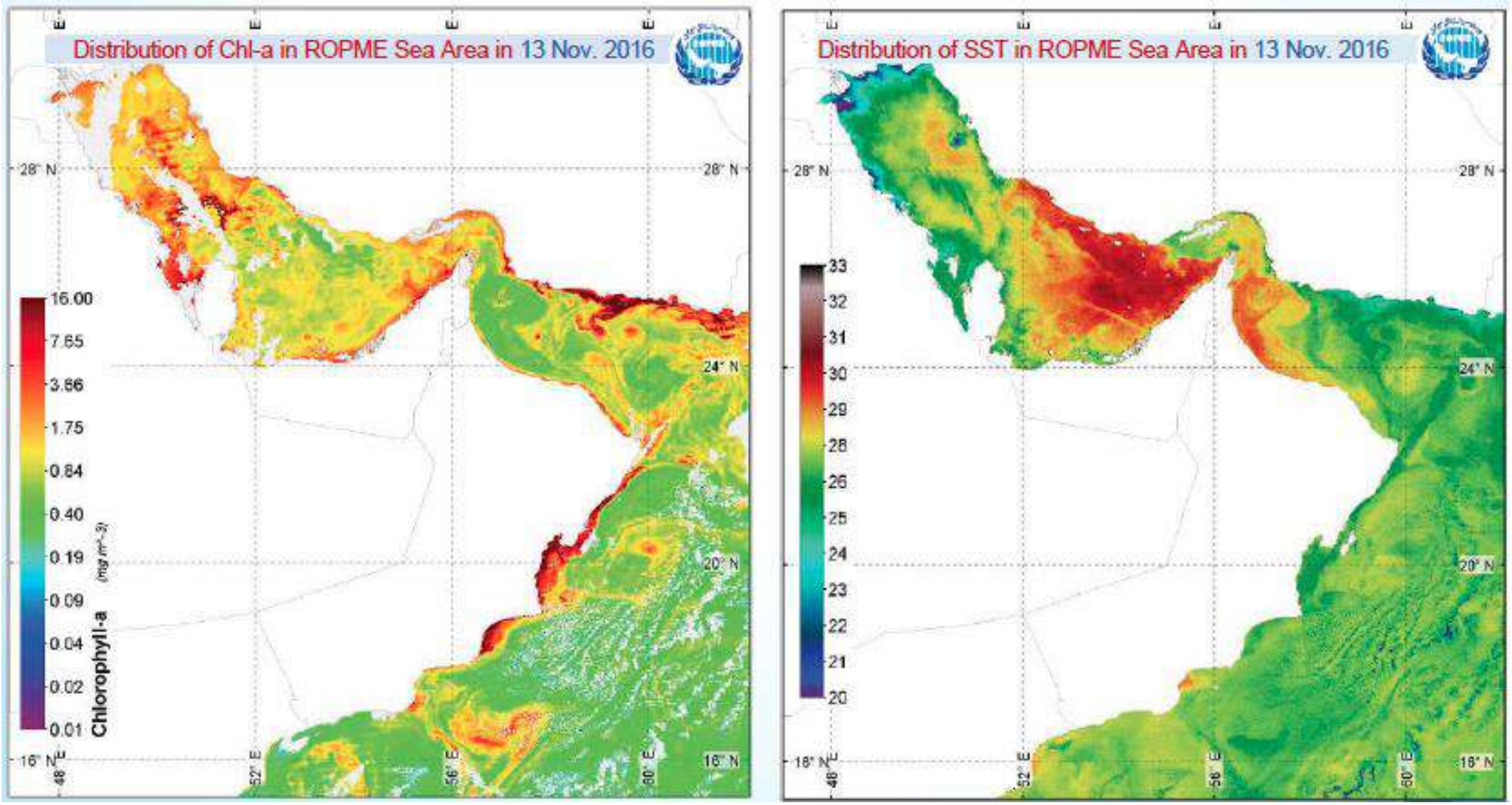
- **Multidisciplinary, fundamental research. Integrated understanding of the links between nutrientes, physiology of HABs/phytoplankton and physical dynamics**

- **MULTIPARAMETER TIME SERIES (basic MONITORING, in situ automated instruments) & DATA BASES**

Available tools for prevention and mitigation of HABs

- **Multidisciplinary, fundamental research. Integrated understanding of the links between nutrients, physiology of HABs/phytoplankton and physical dynamics**

- **MULTIPARAMETER TIME SERIES (MONITORING) & DATA BASES + KNOWLEDGE = EARLY WARNING SYSTEMS**



Wahid Moufaddal, 2018

Available tools for prevention and mitigation of HABs

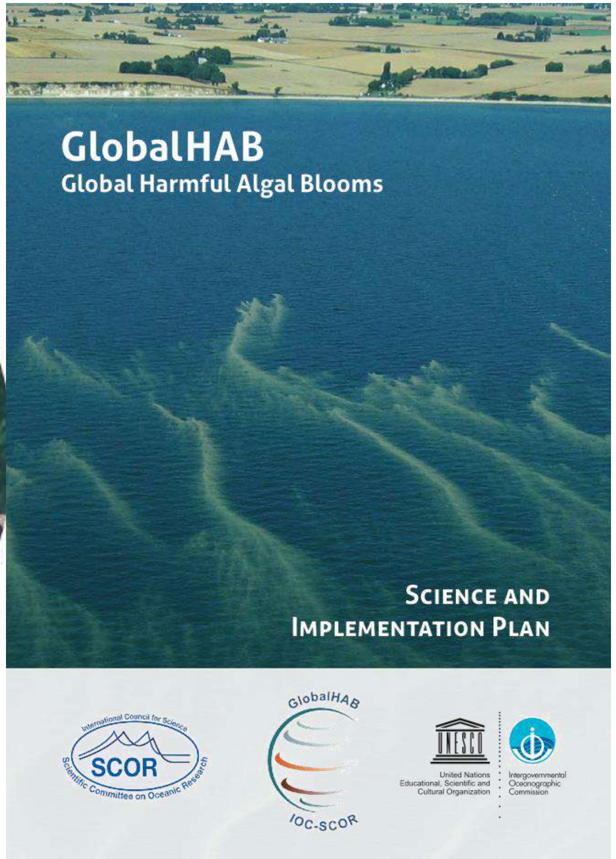
➢ **Sustainable aquaculture**

Tiger shrimp, *Penaeus monodon*, extensively cultured on the coast of Cam Ranh Bay, Vietnam. (Y. Fukuyo).

14 LIFE BELOW WATER

CONSERVE AND SUSTAINABLY USE THE OCEANS, SEA AND MARINE RESOURCES FOR SUSTAINABLE DEVELOPMENT

➢ **International coordination: sharing knowledge**



Questions for discussion

- **HABs events can not be realistically eliminated, but some causing factors can be controlled and their impacts can be alleviated**

➢ *Which are the factors related to aquaculture that can foster HABs?*

➢ *Which are the main impacts of HABs on the aquaculture sector?*

- **HABs are a global issue that requires international cooperation and local solutions**

➢ *What are the lessons learnt in the different parts of the planet?*

➢ *What can be implemented in the Arabian Gulf?*

- **HABs must be integrated with policy decisions**

➢ *What are the priority satregies to be coordinated among scientists, stakeholders and end users?*

EARLY WARNING SYSTEMS

THANKS FOR YOUR ATTENTION

14 LIFE BELOW WATER

CONSERVE AND SUSTAINABLY USE THE OCEANS, SEA AND MARINE RESOURCES FOR SUSTAINABLE DEVELOPMENT

Thanks for your attention
and be involved with GlobalHAB!!!
www.globalhab.info

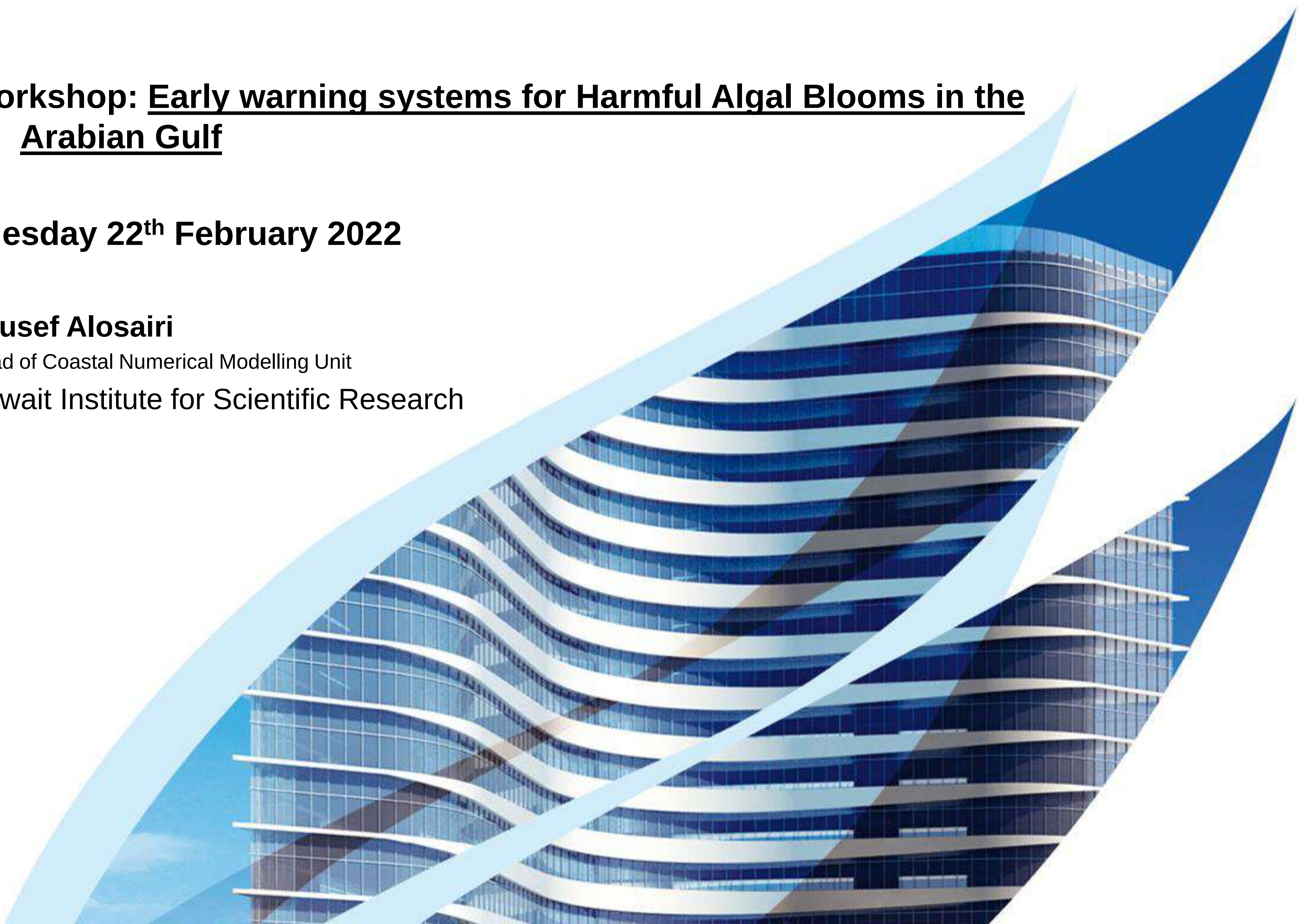
Environmental mechanisms associated with algal blooms in the Arabian Gulf: Kuwait Bay

KISR
Kuwait Institute for Scientific Research

Workshop: <u>Early warning systems for Harmful Algal Blooms in the Arabian Gulf</u>

Tuesday 22th February 2022

Yousef Alosairi
Head of Coastal Numerical Modelling Unit
Kuwait Institute for Scientific Research



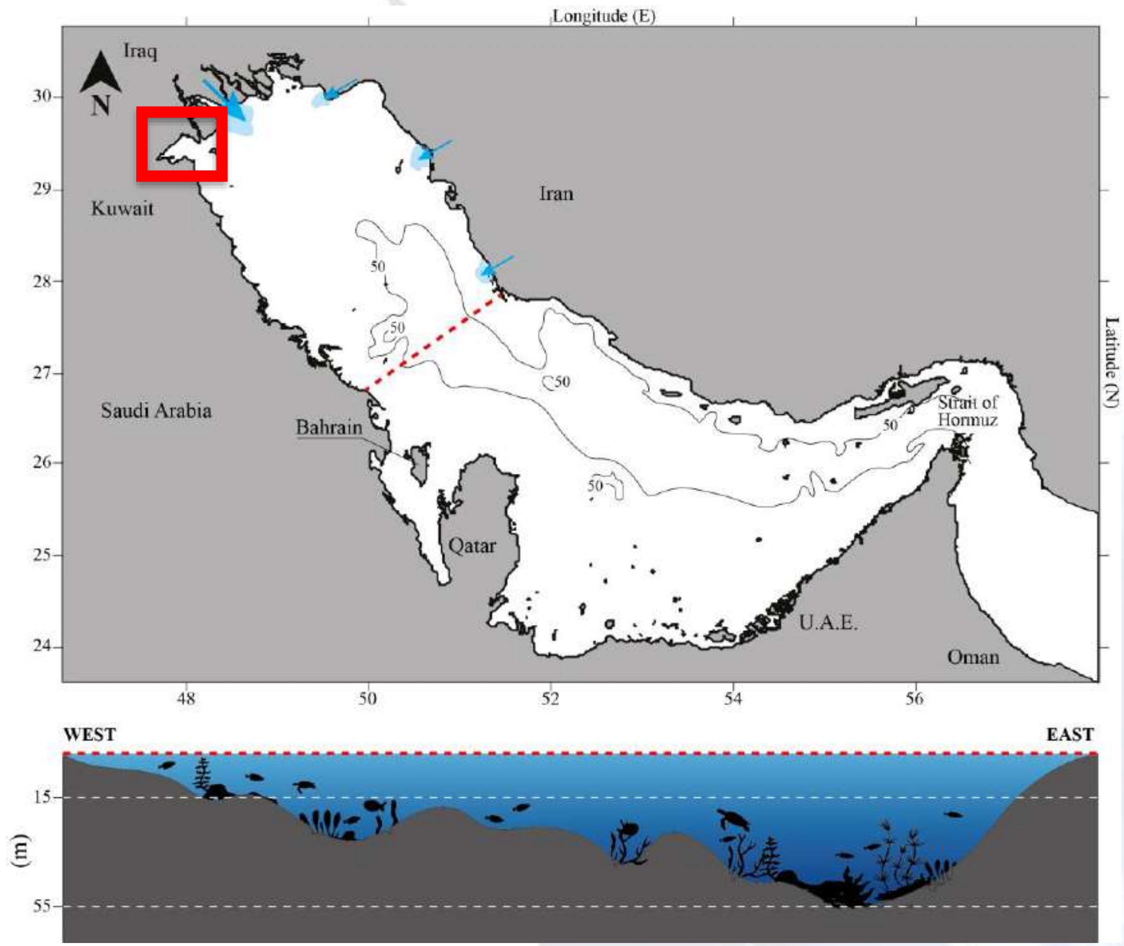
Presentation Outline

1. Arabian Gulf and Kuwait Bay characteristics
2. Environmental Impacts in relation to algal blooms
3. Understanding algal blooms using numerical models
4. Requirements to forecast algal blooms in Kuwait Bay

Introduction

Hydrographical characteristics of the Arabian Gulf

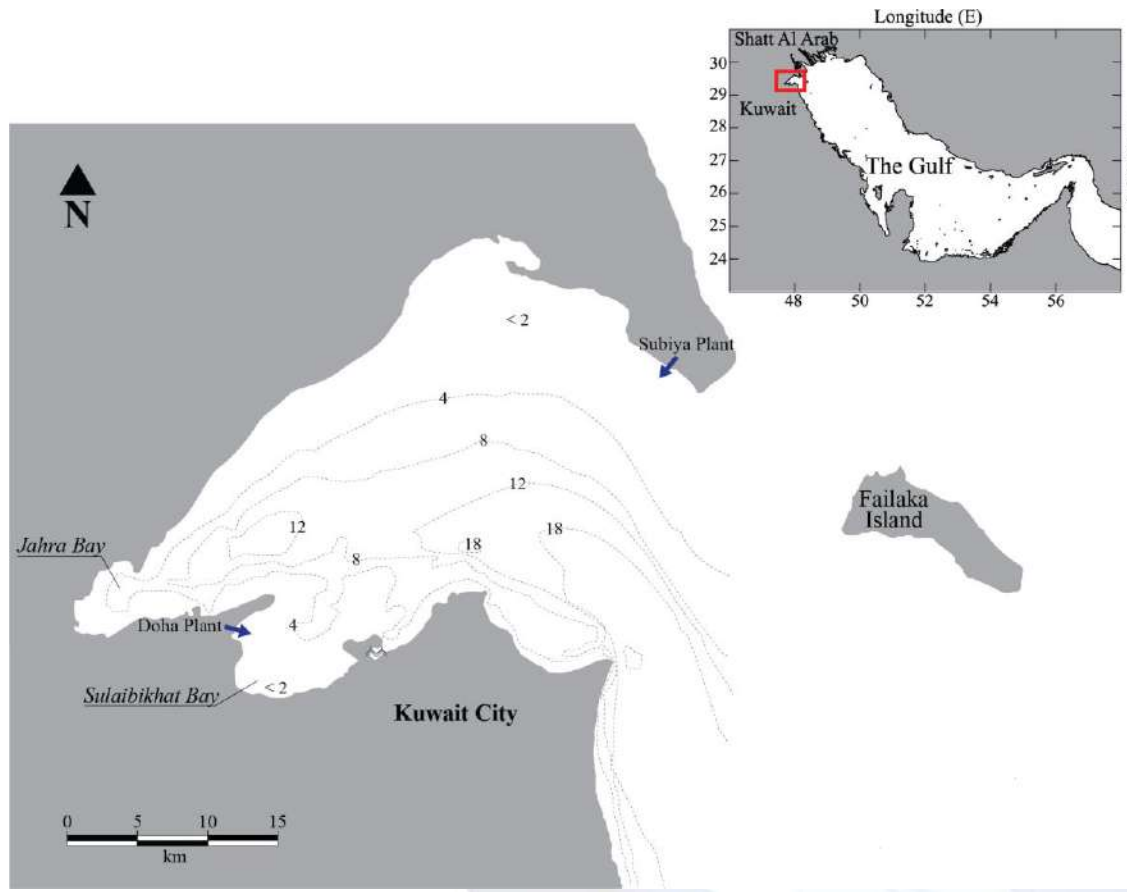
- 1,000 km along the main axis, 330 km in width.
- Limited river discharges (Shatt Al Arab being the highest)
- Relatively deeper water at the eastern coast. compared to the western coast.
- Horizontal scales (several km) are much larger than the vertical (several meters)
- Restricted by the Strait of Hormuz (56 km in width)
- High residence time (3-4 yrs)
- High evaporation
- Tides are mixed semi-diurnal
- Dominating winds blow from northwest.
- **Horizontal transport is much larger than the vertical**



Introduction

Hydrographical characteristics of Kuwait Bay

- 40 km along the main axis, 21 km in width.
- 2 desalination plants (3 discharges)
- Depth range 2-20 m
- Residence time 45-60 days
- High evaporation
- Tides are mixed semi-diurnal
- Tidal driven currents



Coastal Human Activities

Waterfront developments in the Arabian Gulf

- Increase in water turbidity
- Reduced water quality
- Human nutrient loading
- Macro and micro plastics input
- Shift in the dynamic behavior

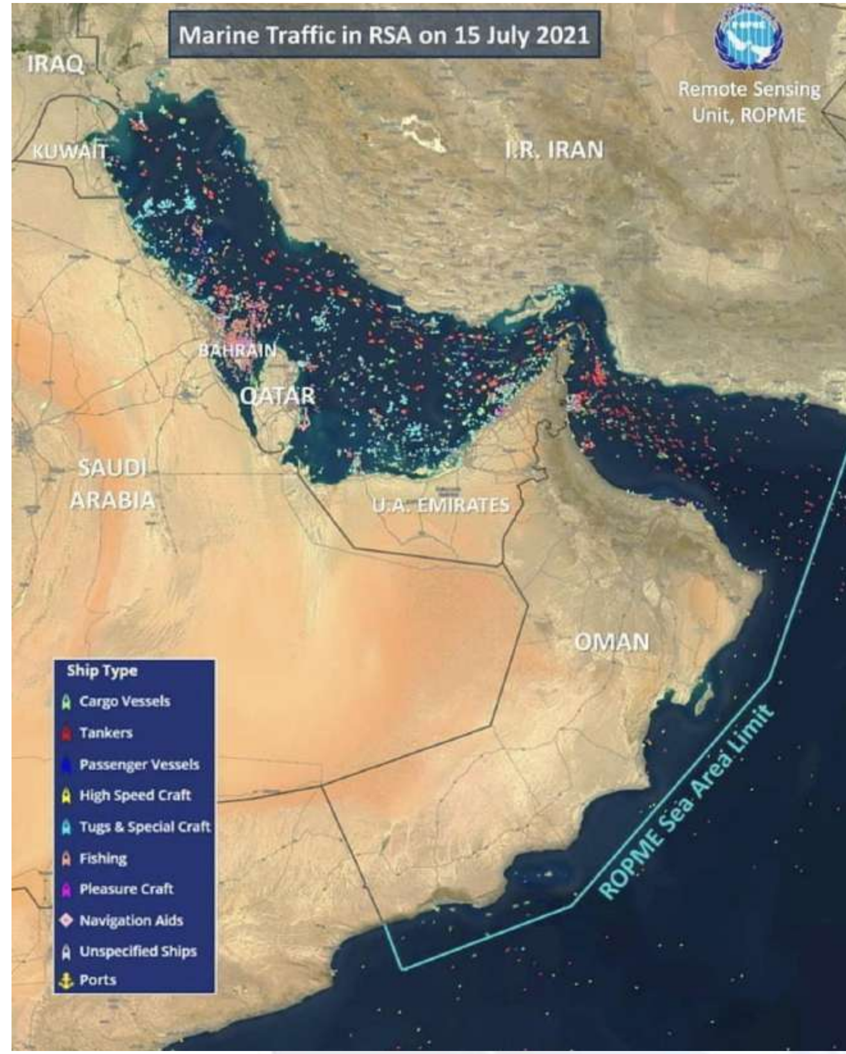
Source: www.arabianbusiness.com

Regional Environmental Impacts

Marine traffic on 15 July 2021

- **The Arabian Gulf receives more than 50 thousand vessels/boats:**
  - Oil related transport
  - Tourism
  - Commercial
  - Military
  - Fishing

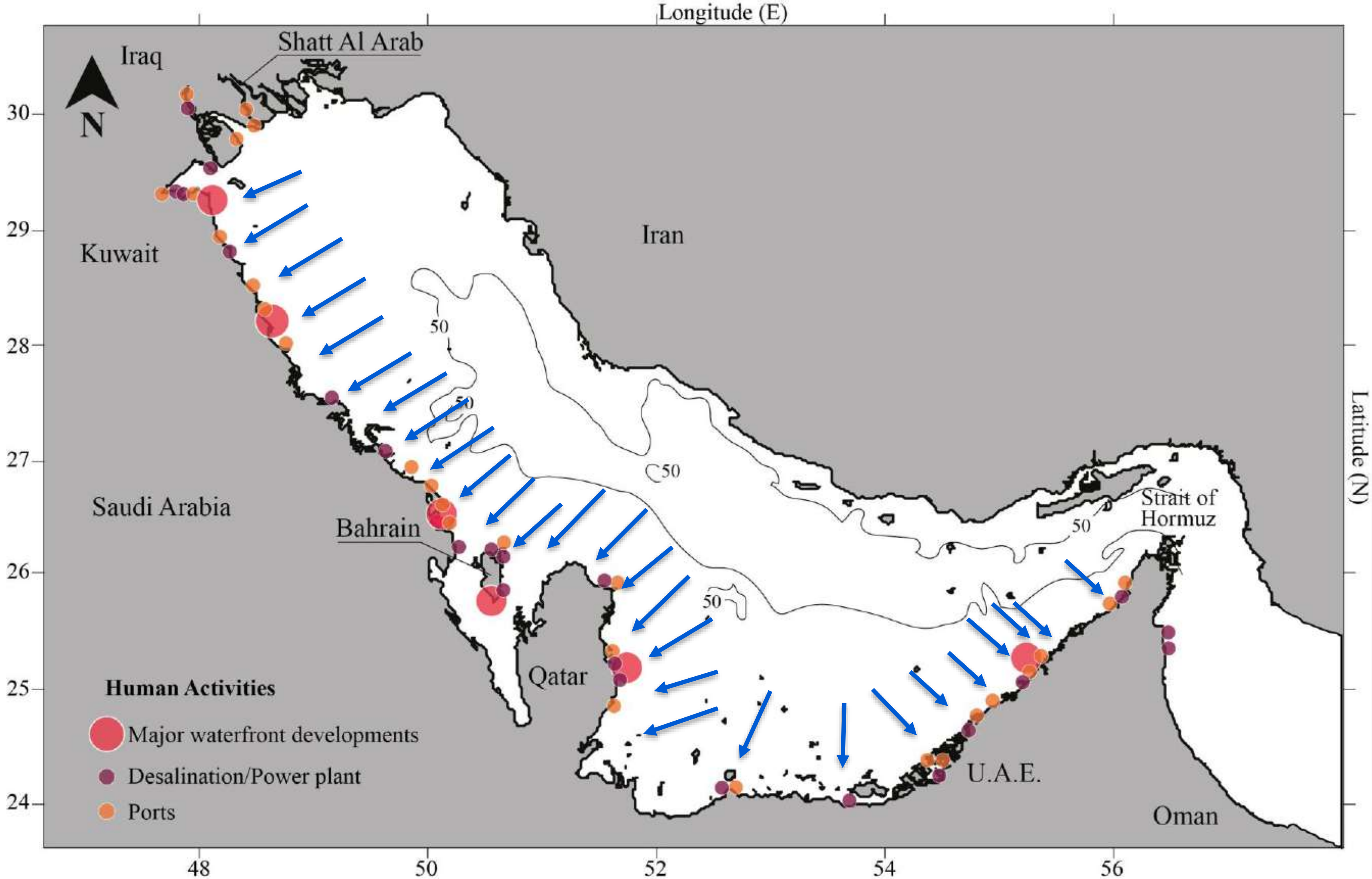
Invasive species !!



Source: https://www.instagram.com/ropme/?hl=en

Activities along the shoreline of the western coast of the Gulf

KISR
Kuwait Institute for Scientific Research

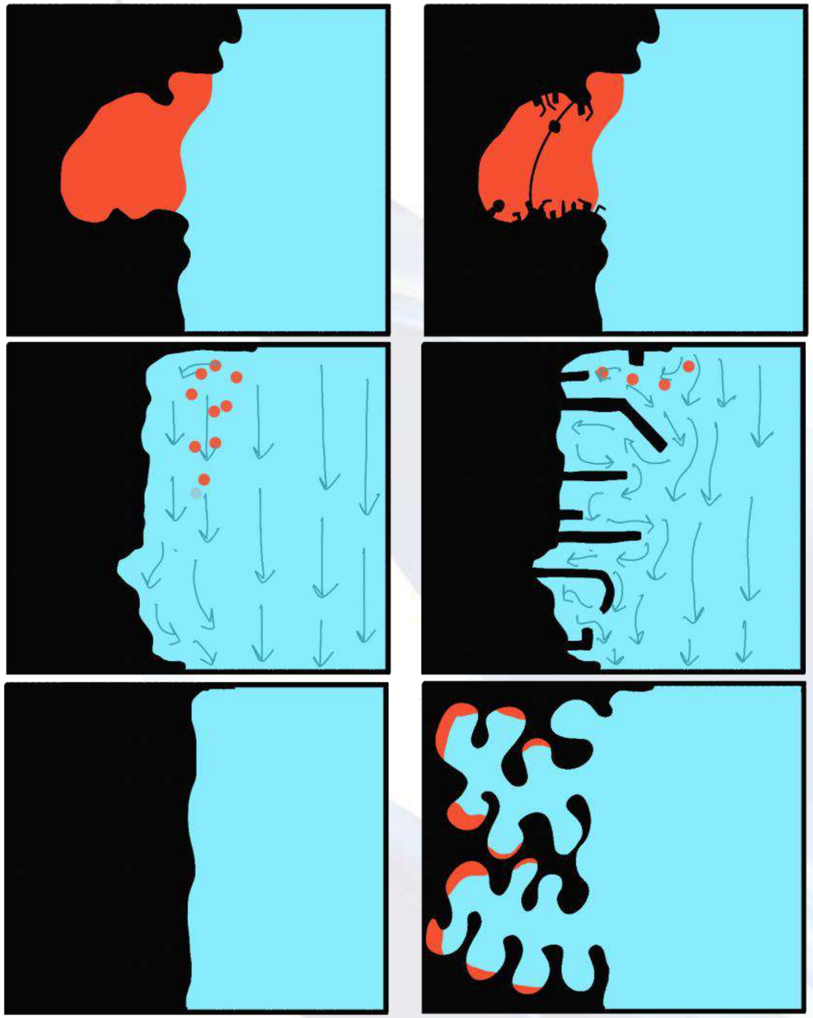


Source: Alosairi Y. 2021 (*in preparation*)

Local Environmental Impacts

Waterfront developments effects at the near fields

- High residence time
- Long transport time scales
- Entrapments and accumulation
- Low water exchange and renewal
- Shifts in mixing and dispersion regime
- **Sediment adsorption/desorption (nutrient fluxes)**



Climate Change Impacts

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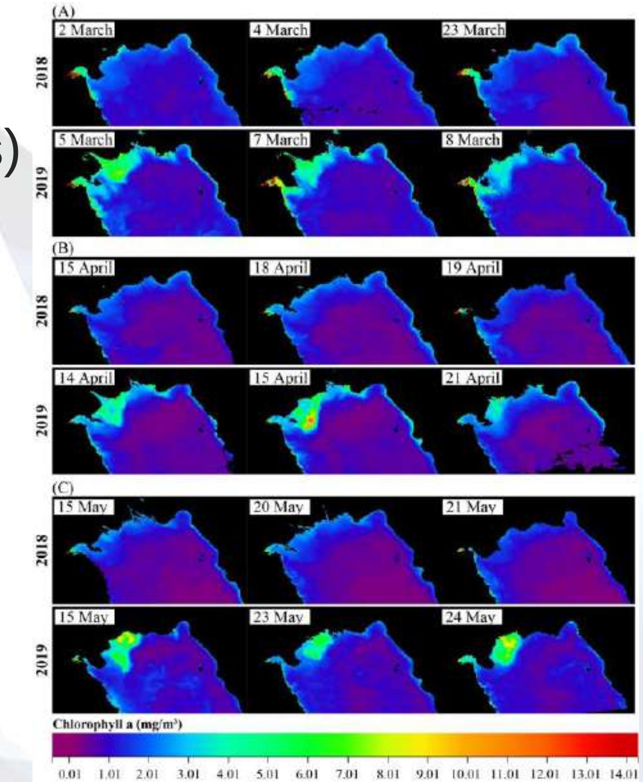
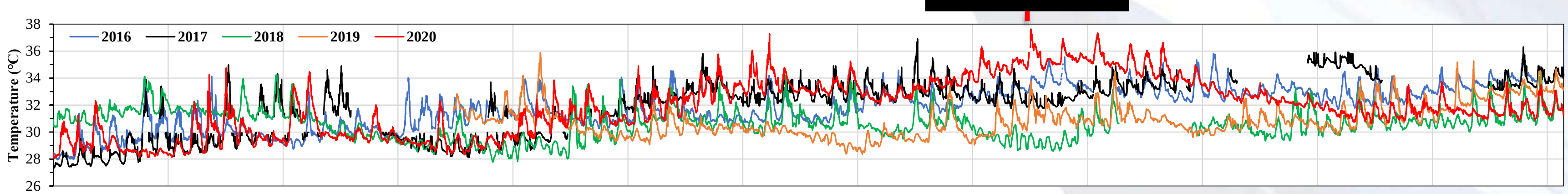
- Increase in sea-surface temperature
- Extreme winds
- Reduction/shifts in runoffs (loss of species)
- Frequent and extensive dust storms
- **Shift in species communities**

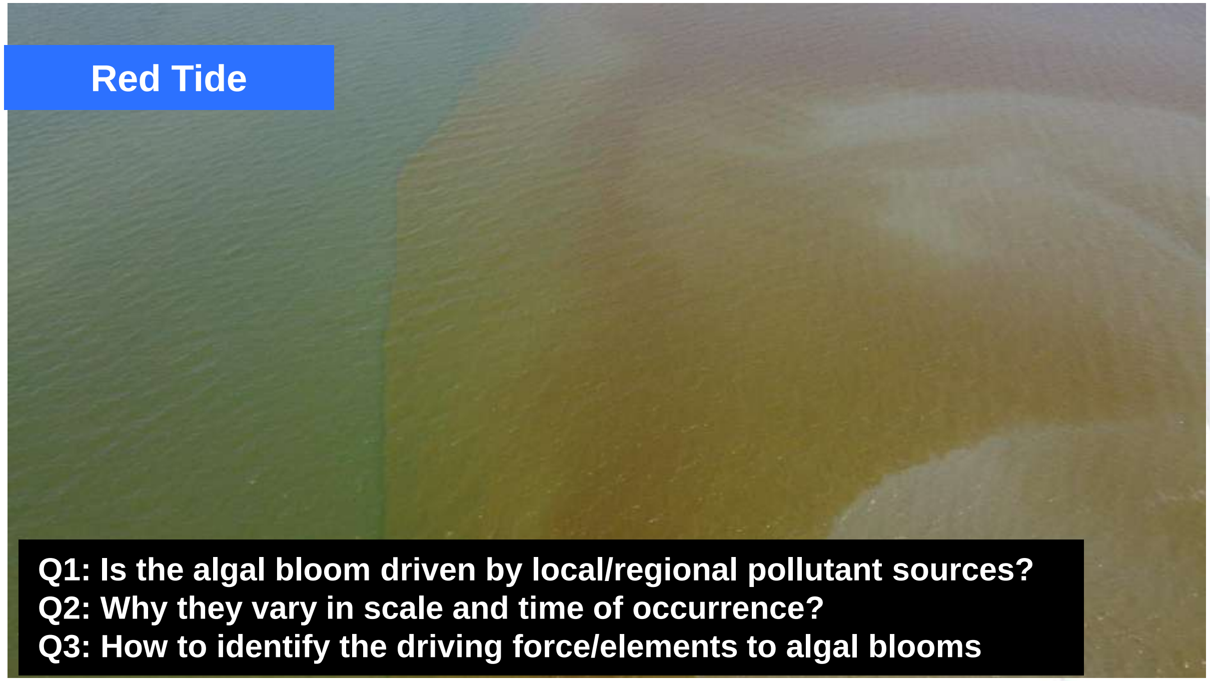
Northern Gulf





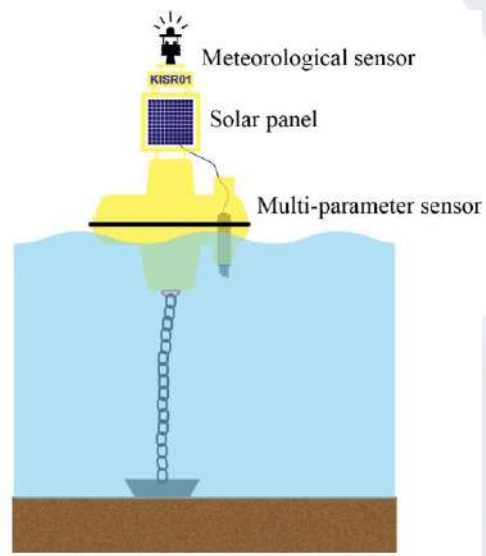
Source: Alosairi et al., 2020

Algal blooms and fish kill events



Understanding the Environment-Hydrodynamics

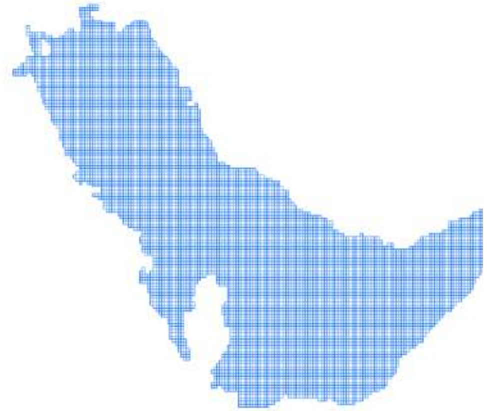
- Field measurements of the physical parameters using autonomous sensors
- Understanding the seasonal variations of the driving forces

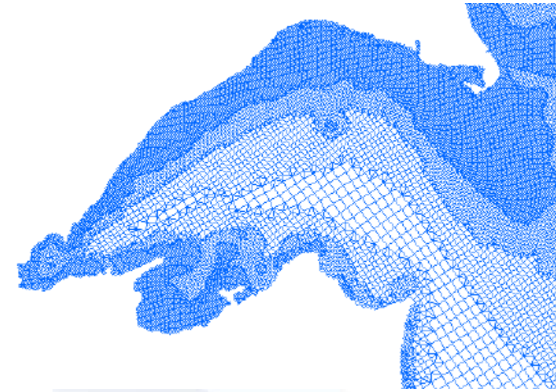


Numerical Modelling

Limitations and Challenges

- Computational time/capacity
- Numerical assumption
- Model calibration and validation
- Horizontal and vertical resolutio
- **Model schematization**





Challenging

Hydrodynamics

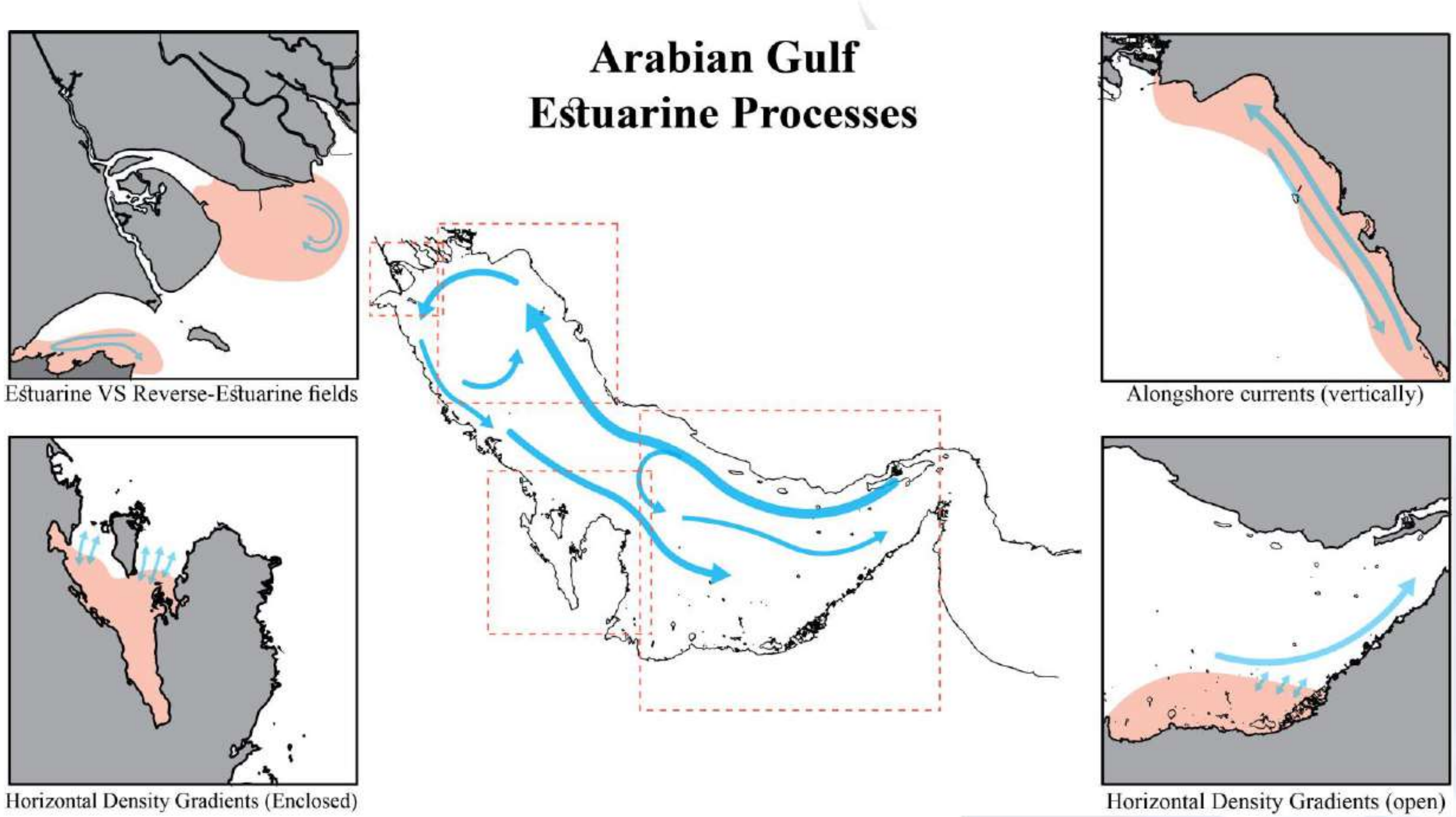
- Data availability
- Well defined mathematically
- Data available for boundary forcing (e.g. global models, satellite)
- Sensitivity assessments involve limited parameters

Water quality/algal blooms

- Data scarcity
- Complex kinematics
- Difficult to force boundary conditions (many unknown sources/sinks)
- Sensitivity assessment involve many parameters

Water Circulation

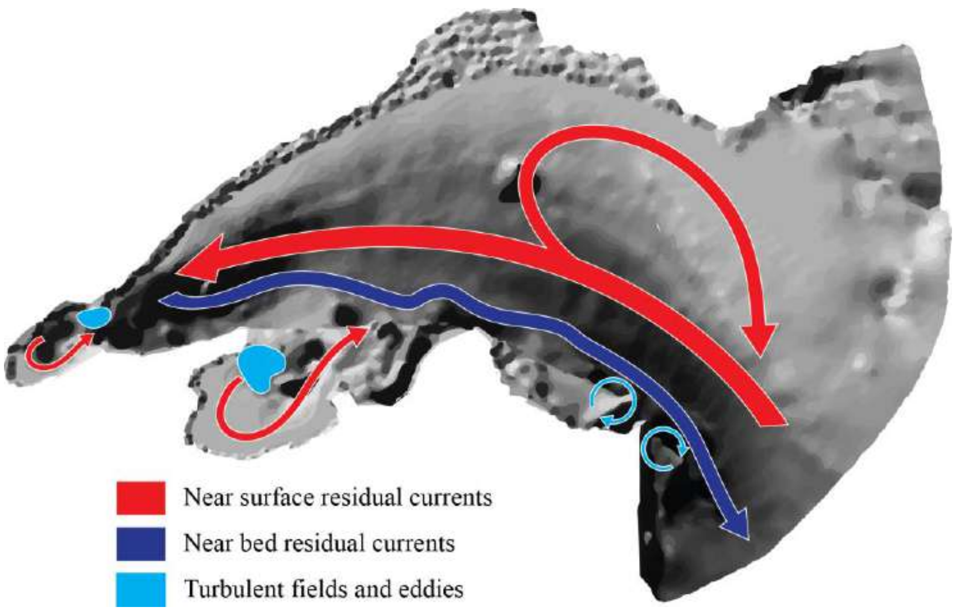
Numerical modelling and field survey

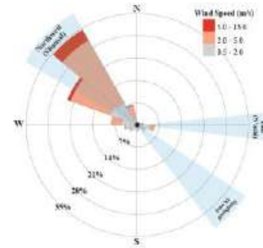


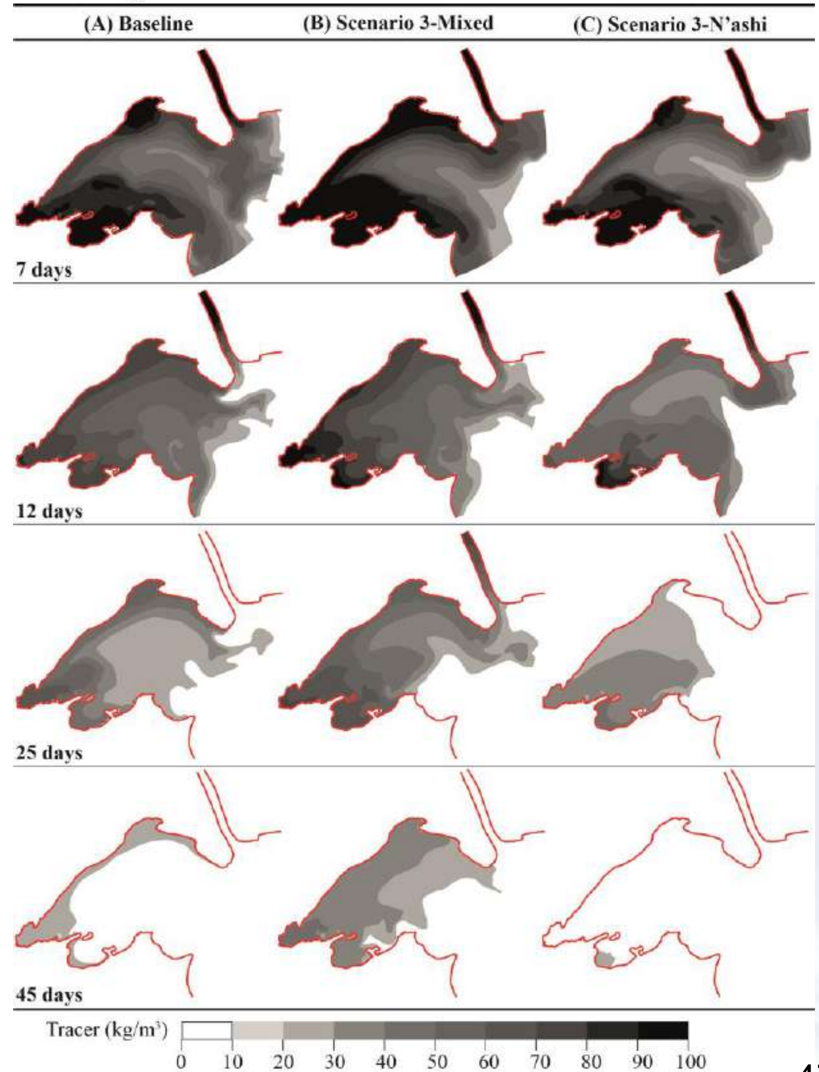
Understanding the mixing and transport regime

Kuwait Bay Hydrodynamics

Residual circulations and residence time







- Reverse estuarine circulations at the relatively deep areas
- Internal areas experience high residence time
- Winds play significant role in flushing the system

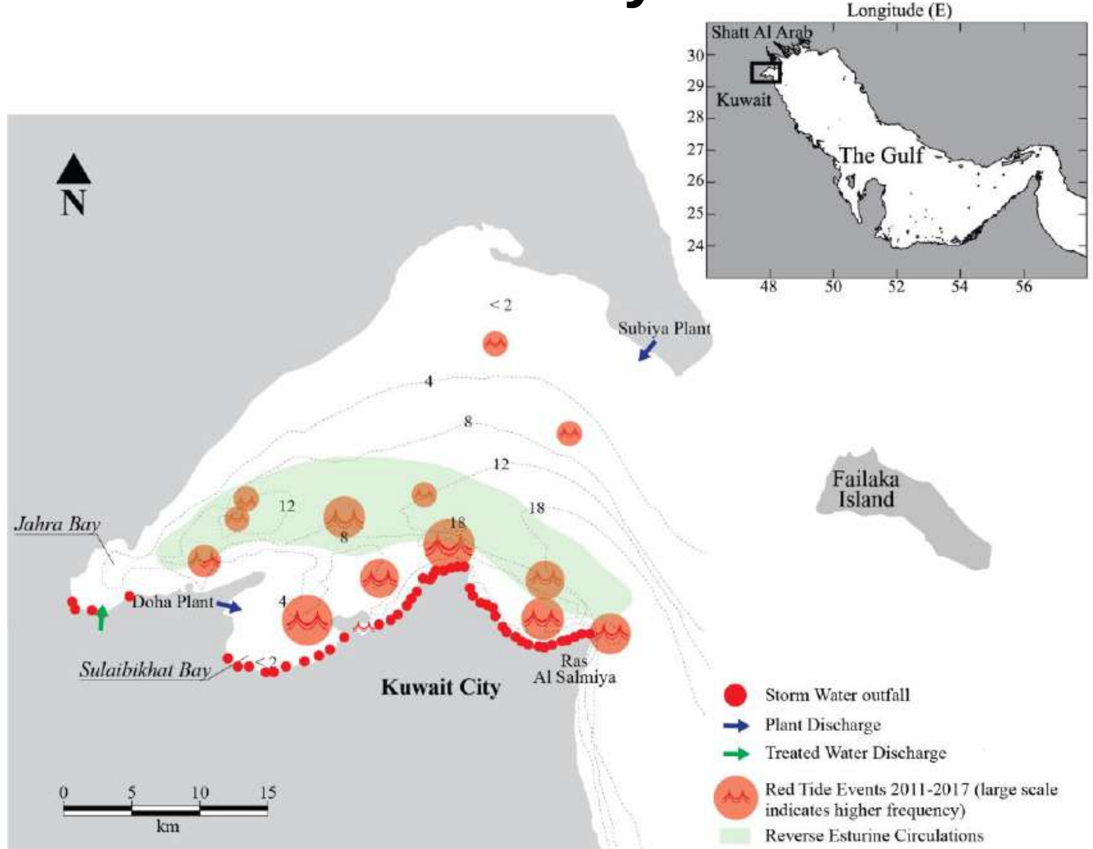
Algal blooms in Kuwait Bay
Residual circulations and residence time

- General patterns of the bloom follow the residual currents of the Bay
- Algal blooms occurs closer to the southern coast (lower dynamic zones)

Understanding Algal blooms in Kuwait Bay

<u>Nutrient loadings</u>

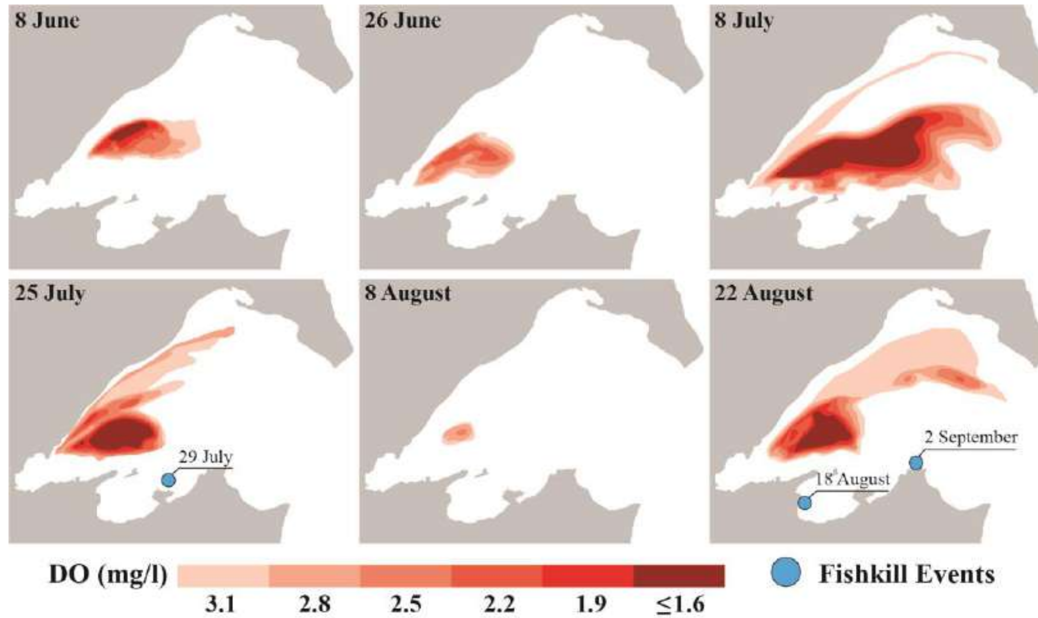
- Unsystematic discharges are continuous and increasing (74 outfalls from 1970s up to date)
- Algal blooms and fish kill events vary in scales but within the same vicinity
- Summer blooms are associated with fish kill events
- Hypoxic waters are found in the internal semi-enclosed zones

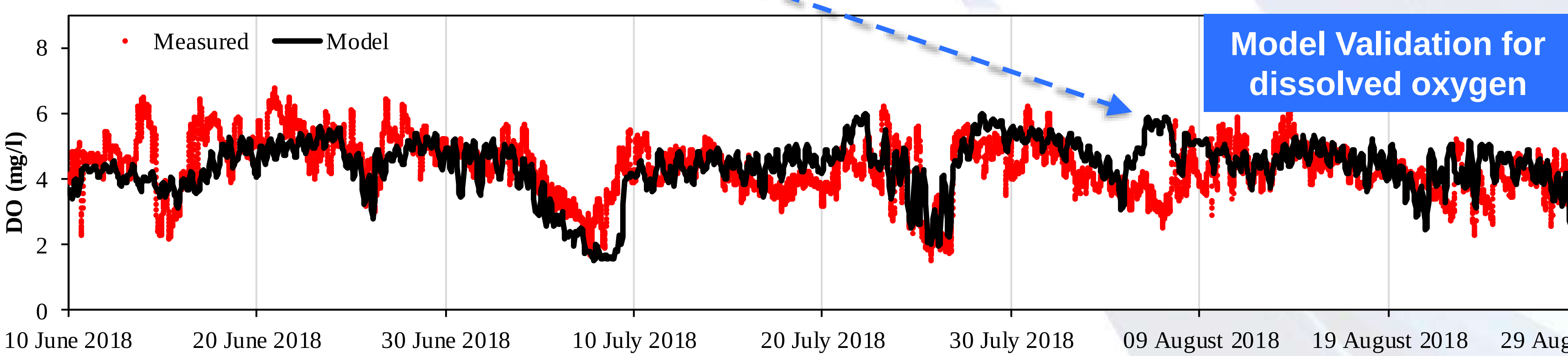


Kuwait Bay-Water quality modelling

Simple model configurations

- Modelling dissolve oxygen dynamics
- Validate with field measurements
- Identifying the hypoxic zones and relate them with algal blooms
- **Several incidents could not be captured**

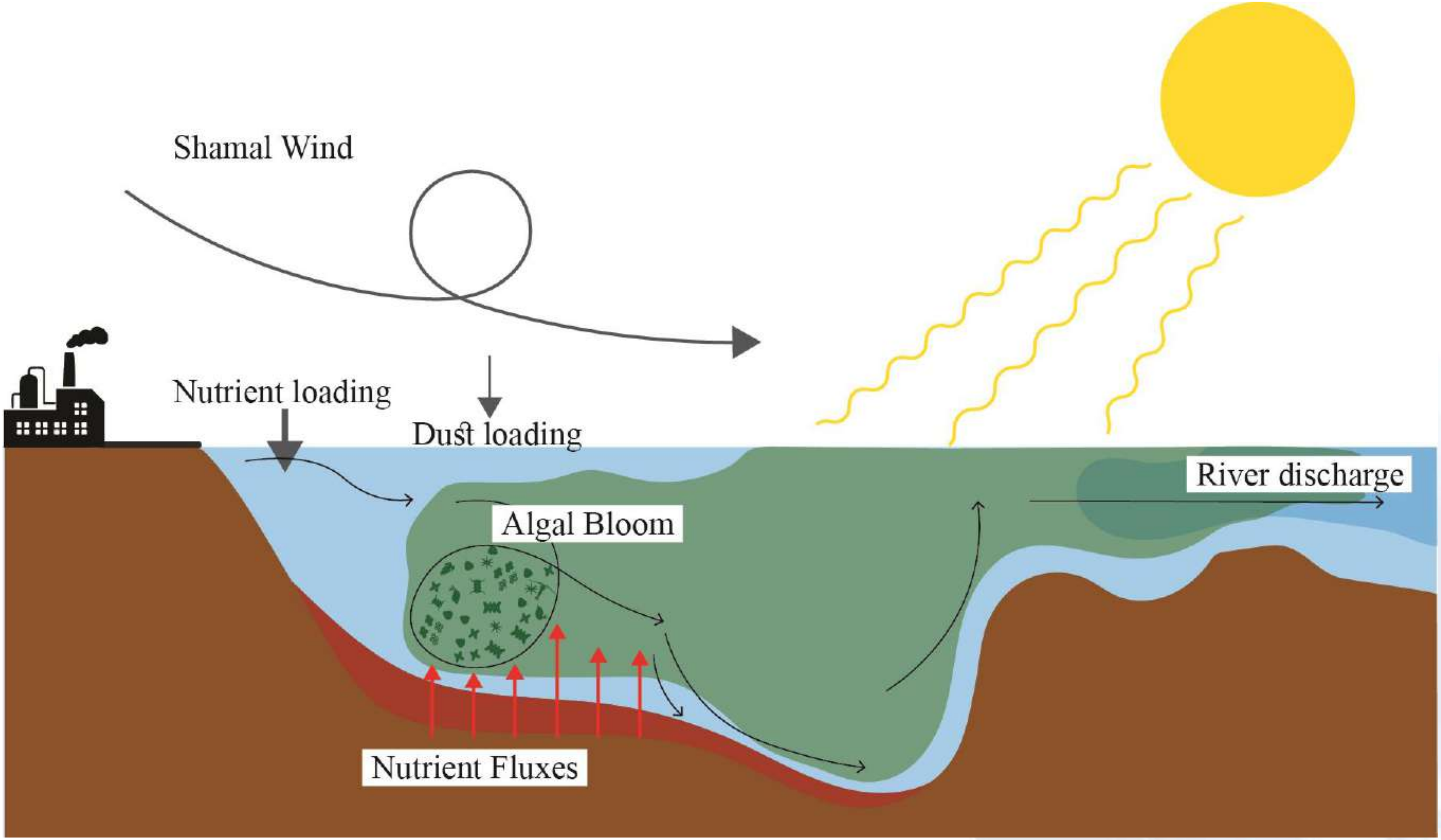




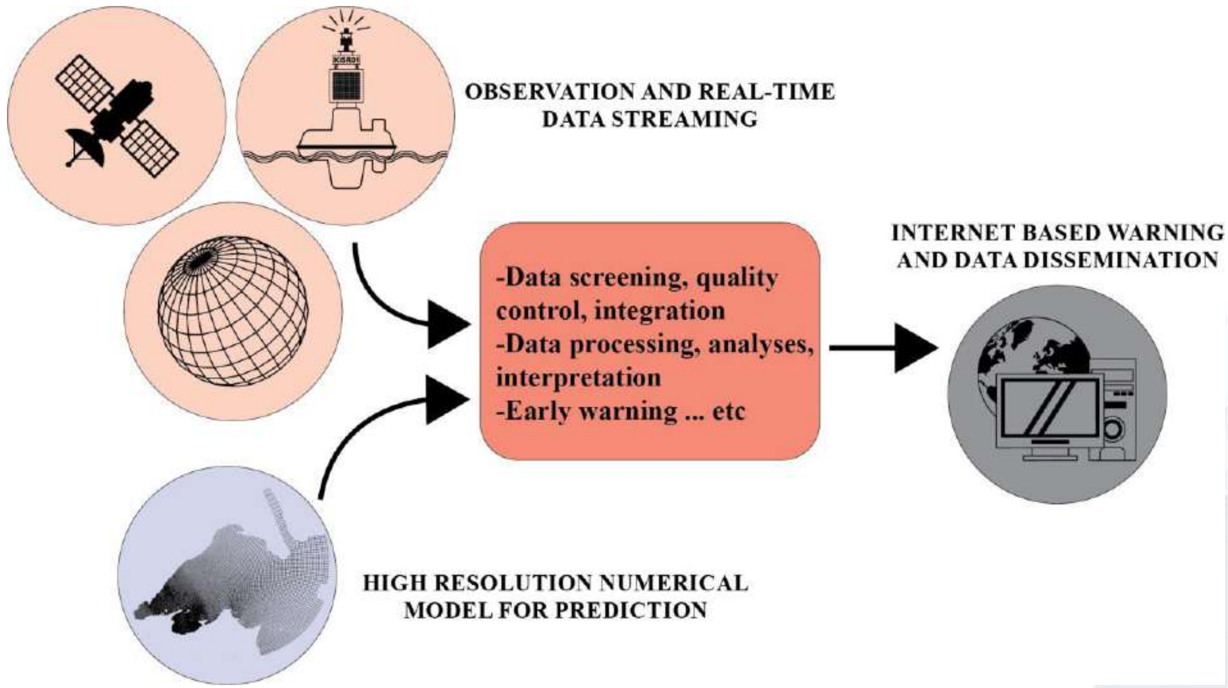
Model Validation for dissolved oxygen

Numerical Modelling Improvements

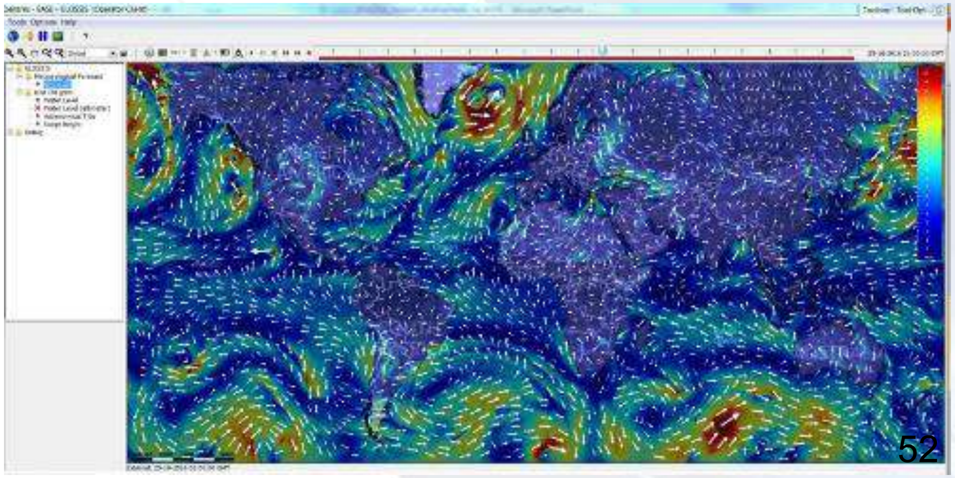
Sediment-water interactions



Developments of forecasting system



- What is the best configuration for an operational numerical system for Kuwait Bay?
- How could the knowledge of an operating system be utilized for coastal management purposes?
- What it requires, numerically, to develop a fully integrated system including water quality and sediment transport for algal bloom forecasting.
- Can an operational system assist in understanding the potential risks and challenges on the current and future waterfront development of the Bay?



Discussion Points

- Understanding and synchronizing the timescales of the algal blooms and the different hydrodynamics conditions.
- Continuous measurements of nutrients to facilitate for numerical modelling of algal blooms.
- Establishment for empirical formulations to express the nutrient sediment fluxes at the critical zones

References

- Alosairi, Y., Alsulaiman, N., Rashed, A., & Al-Houti, D. (2020). World record extreme sea surface temperatures in the northwestern Arabian/Persian Gulf verified by in situ measurements. *Mar Pollut Bull*, *161*(Pt B), 111766. https://doi.org/10.1016/j.marpolbul.2020.111766
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- Alosairi, Y., Alsulaiman, N., Rashed, A., & Al-Houti, D. (2020). World record extreme sea surface temperatures in the northwestern Arabian/Persian Gulf verified by in situ measurements. *Mar Pollut Bull*, *161*(Pt B), 111766. https://doi.org/10.1016/j.marpolbul.2020.111766

Thank You

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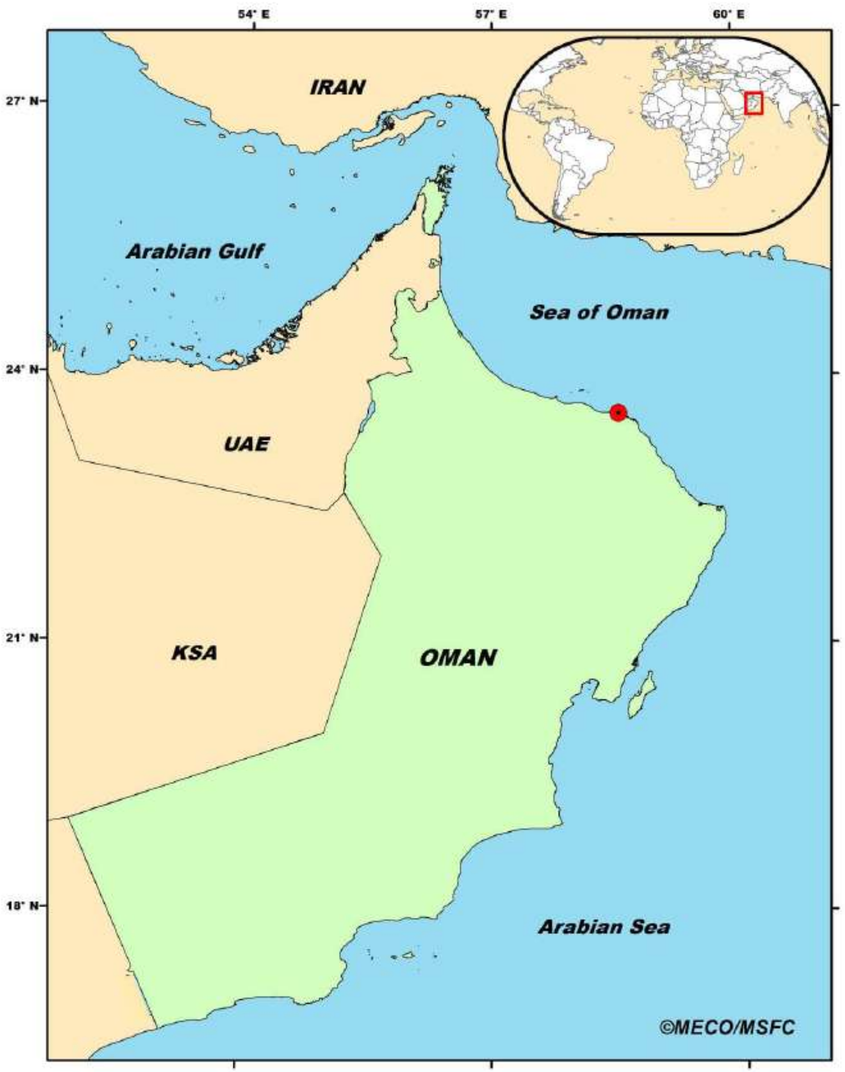
Ministry of Agricultural Wealth, Fisheries and Water Resources

Decision and Information System for the Coastal waters of Oman (DISCO)

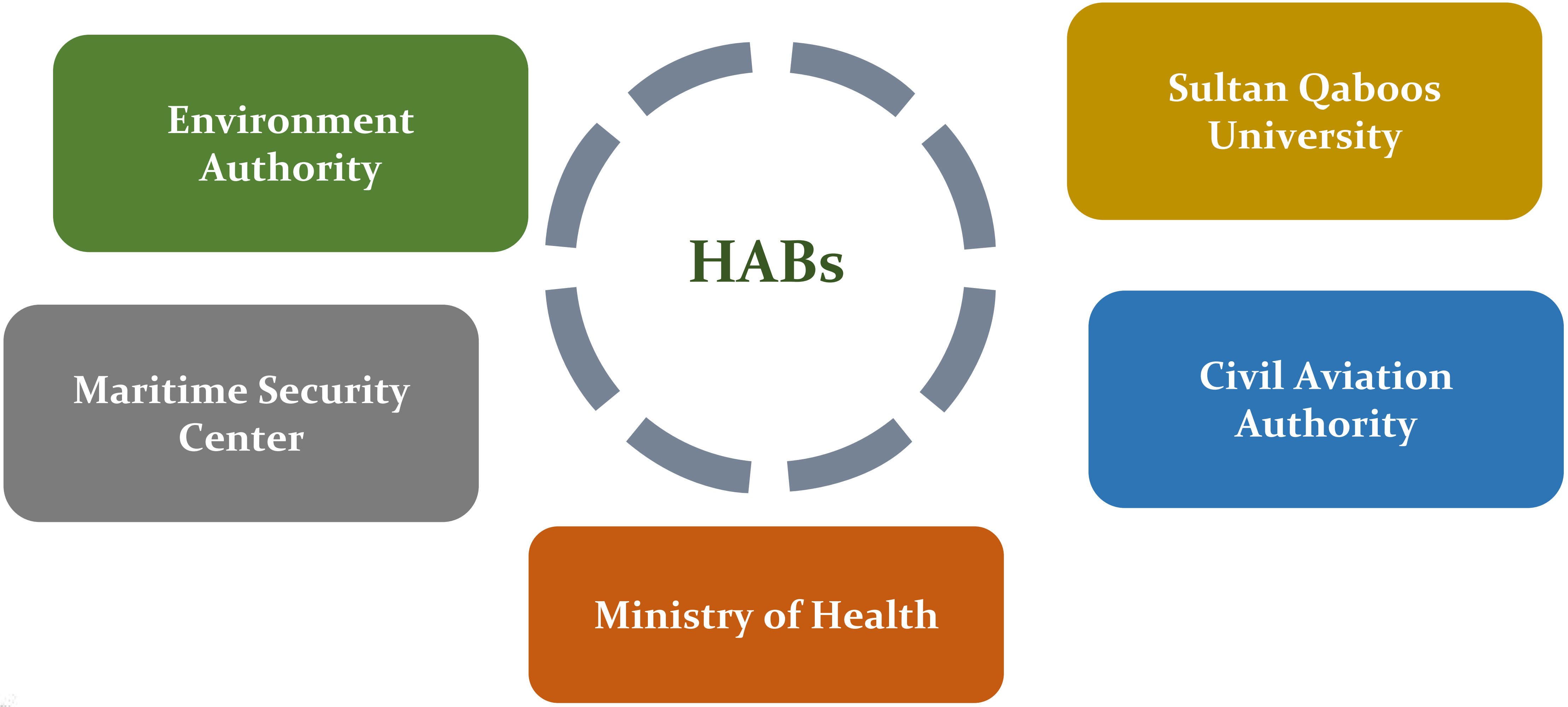
Suad Al Bimani
Marine Ecologist
Marine Science and Fisheries Center

General demographic country information

- 3165 km-long coastline
- Surrounded by the Arabian Sea, Sea of Oman, and Arabian Gulf.
- Extremely rich fishing grounds
- Fisheries play significant role of Oman Income
- Marine Science and Fisheries Center is a research center that belong to General Directorate of Fisheries Research/ Ministry of Agricultural Wealth, Fisheries and Water Resources.



Cooperation with the National institutions in HABs



Cooperation with the International organizations in HABs

HABs

Intergovernmental Oceanographic Commission of UNESCO (IOC),

International Atomic Energy Agency (IAEA)

National Aeronautics and Space Administration (NASA)

National Oceanic and Atmospheric Administration (NOAA)

Regional Organization for the Protection of the Marine Environment (ROPME)

Why Oman need an Early Warning System for Harmful Algal Blooms?

Why Oman need an Early Warning System for Harmful Algal Blooms?

- Over the past decade, the Sultanate of Oman has been experiencing massive outbreaks of Harmful Algal Blooms (HABs).

- Field and satellite data from the last few years indicate that HABs are becoming more widespread and intense in the northern Arabian Sea and Sea of Oman.

- These outbreaks are beginning to pose a significant threat to coastal resources, water quality, public health, tourism, and the operational capabilities of many coastal industries that serve the energy, freshwater, socio-economic needs of Oman, and of countries bordering the Arabian Sea.

- An operational Early Warning System for providing timely advisories to stakeholders, including coastal resource managers is needed.

How Harmful Algal Bloom is managed in Oman?

1. **Monitoring of Harmful Algal Blooms in Omani waters**

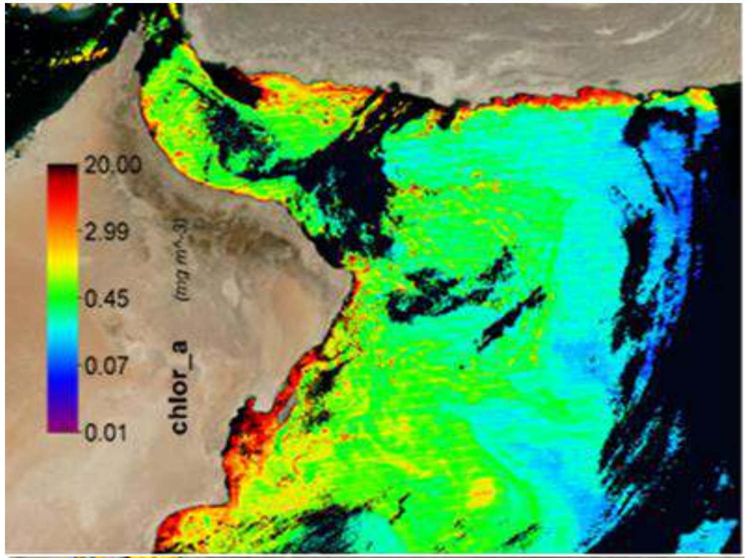
2. **Decision and Information System for the Coastal waters of Oman (DISCO)**

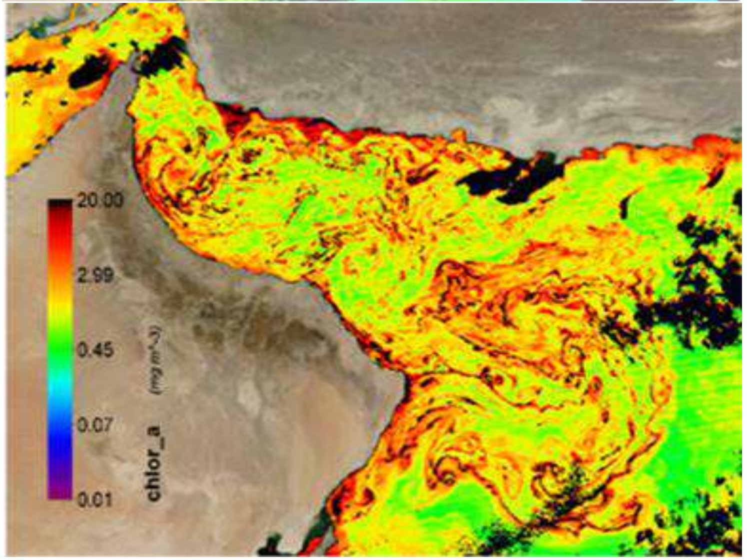
Monitoring of Harmful Algal Blooms in Omani waters

- The first record of Harmful Algal Blooms in the Arabian Sea was in August 1976 along the coast of Salalah and it caused the death of thousands of tons of fish.
- The events of this phenomenon in the Omani coasts have been regularly monitored and recorded at close intervals since 1988.
- Most of the species are non-toxic, and the recorded cases of marine organisms mortality are either due to a lack of dissolved oxygen levels, an excess of ammonia, or clogging of fish gills then suffocation.
- A huge bloom was recorded in late 2008 as it extended from Musandam on the east coast of Oman to the Arabian Sea in the west and lasted for about 8 months, and had strong effects on fisheries, aquaculture, tourism and the environment.

Monitoring of Harmful Algal Blooms in Omani waters

- Monitoring of this phenomenon continues until now, using the latest modern technologies, in order to predict its occurrence and limit its harmful effects.
- Preparing monitoring programs along the coasts of Oman in addition to awareness programs before, during and after HABs events.
- Creating a team to ensure rapid response to HABs event and to make the necessary procedures for the sampling and analysis.
- Tracking blooms using remote sensing, identifying affected locations and alerting affected communities and fishing villages.



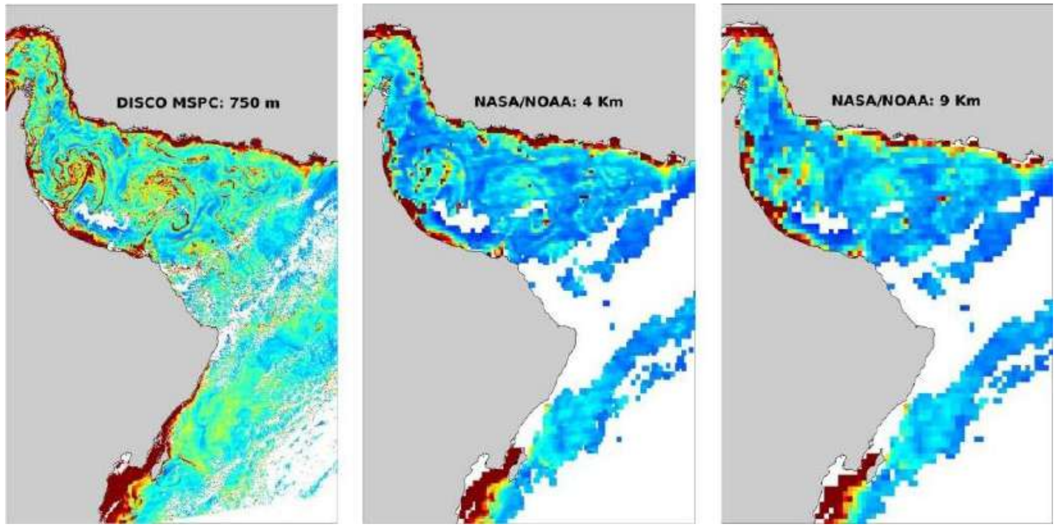


Decision and Information System for the Coastal waters of Oman (DISCO)

DISCO's background

- Decision and Information System for the Coastal waters of Oman (DISCO) is an operational HAB forecasting and decision support system.

- In 2016, the system was operated in Oman in collaboration with Columbia University with funding from NASA, USA. In 2022, the system will be developed as an Omani operational early warning system.



Decision and Information System for the Coastal waters of Oman (DISCO)

DISCO's aim

- Provide information and future predictions about coastal fisheries resources, evaluate the effects of climate change and determine the ideal locations for fish farming activities on the Omani coasts using modern technologies such as remote sensing systems and numerical modeling.

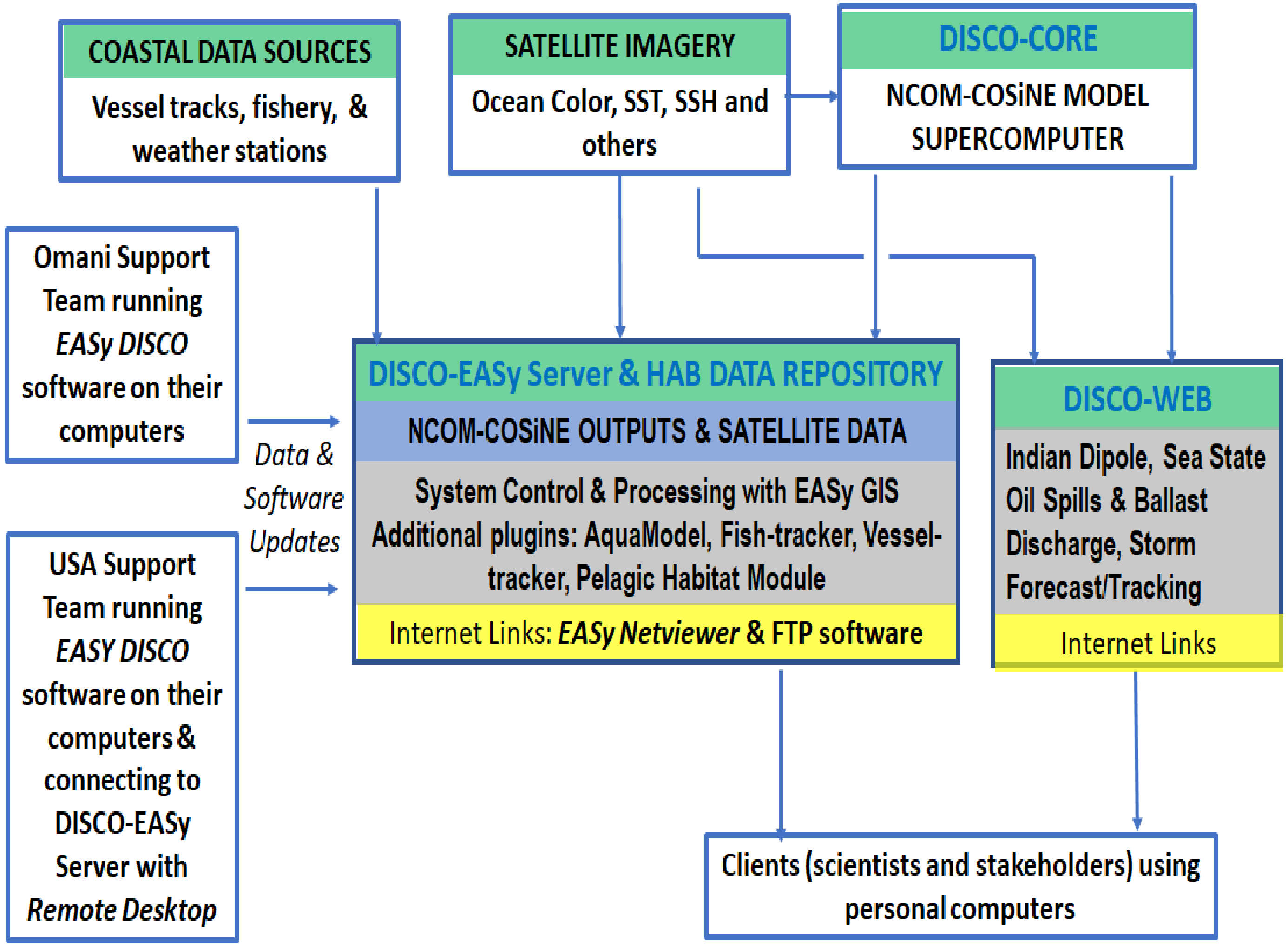
- Provide real-time forecasts of atmospheric and sea state conditions using an outputs from an atmosphere/ocean/biogeochemical coupled model tailored for the coastal waters of Oman.

- Provide real-time forecasts of outbreaks of HABs based on a fusion of model outputs with satellite ocean color data.

Decision and Information System for the Coastal waters of Oman (DISCO)

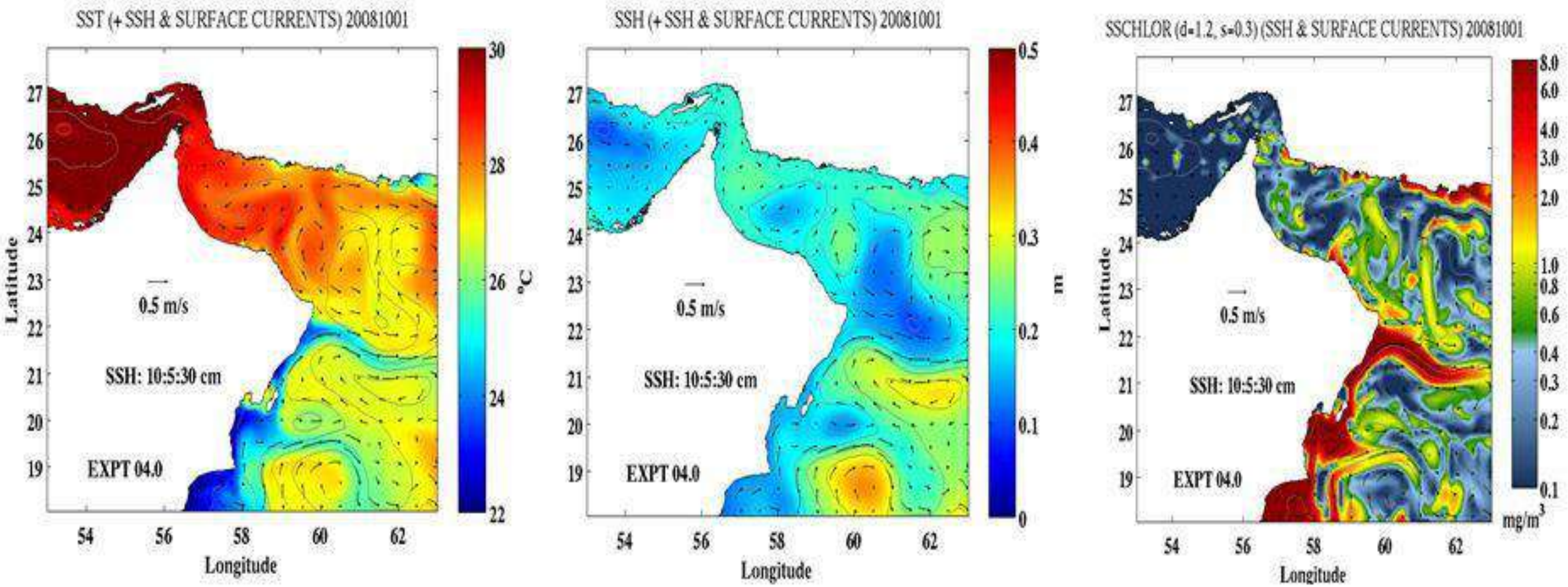
DISCO's architecture (Platforms)

1. DISCO-CORE, which is responsible for ingesting, producing, and archiving data.
2. DISCO-WEB, for web-page product delivery (front-end clients).
3. DISCO-EASy (Environmental Analysis System) for highly interactive and in-depth analysis via a sophisticated graphical user interface.

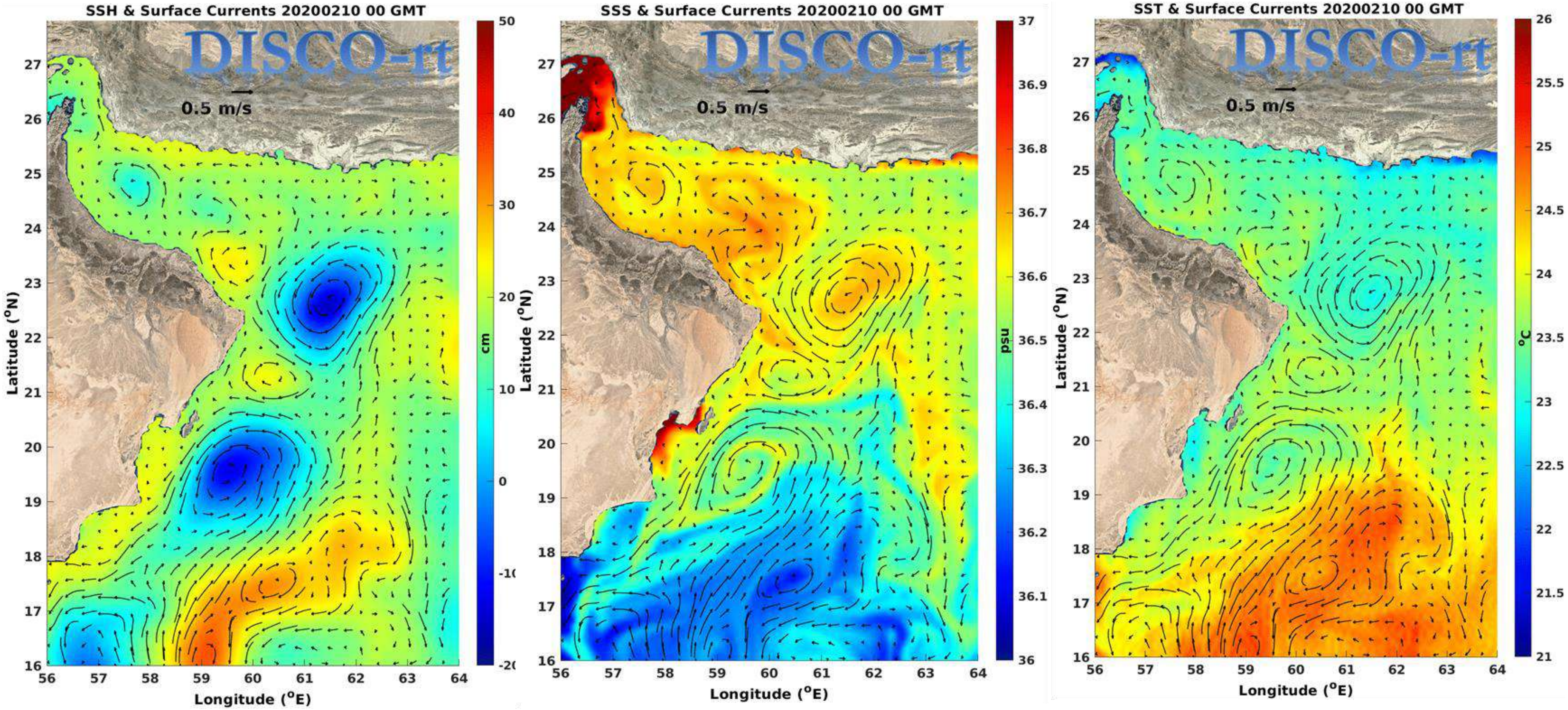


Decision and Information System for the Coastal waters of Oman (DISCO)

Real time outputs and forecasts generated every 12 hours by DISCO-CORE (Supercomputer)

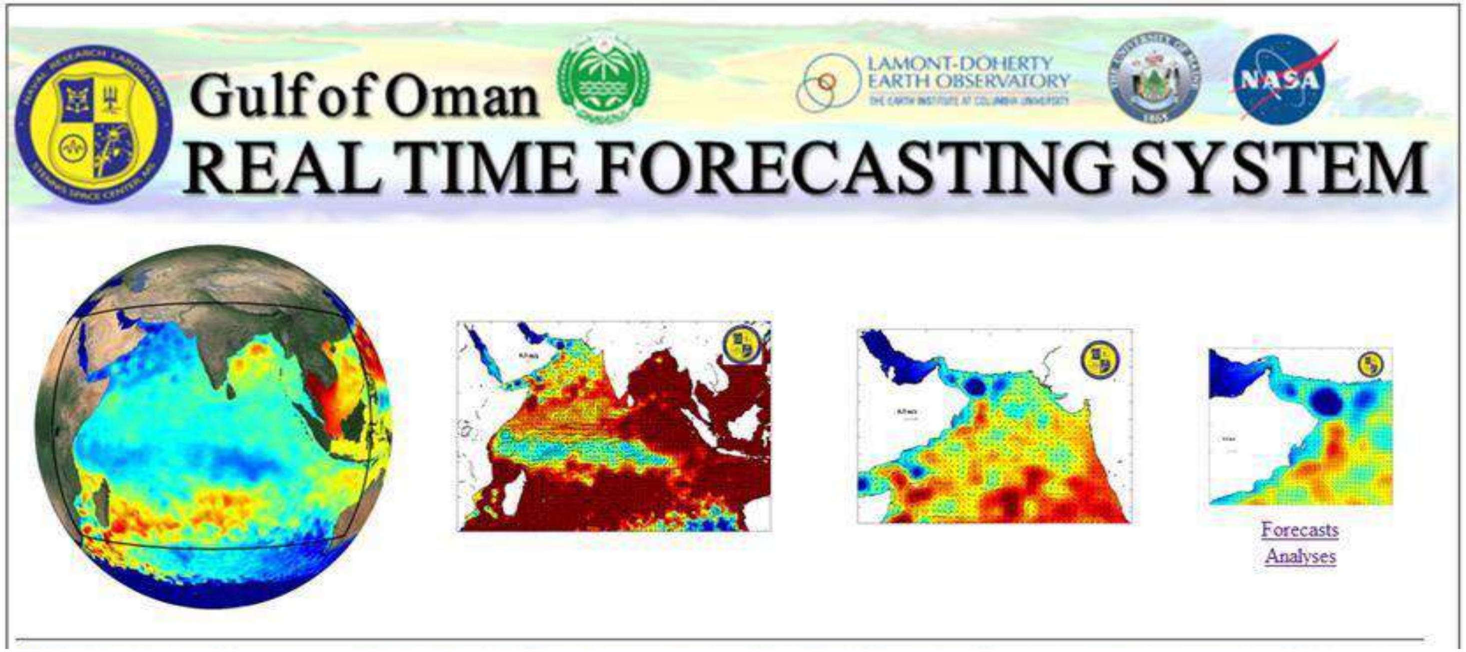


Decision and Information System for the Coastal waters of Oman (DISCO)



Decision and Information System for the Coastal waters of Oman (DISCO)

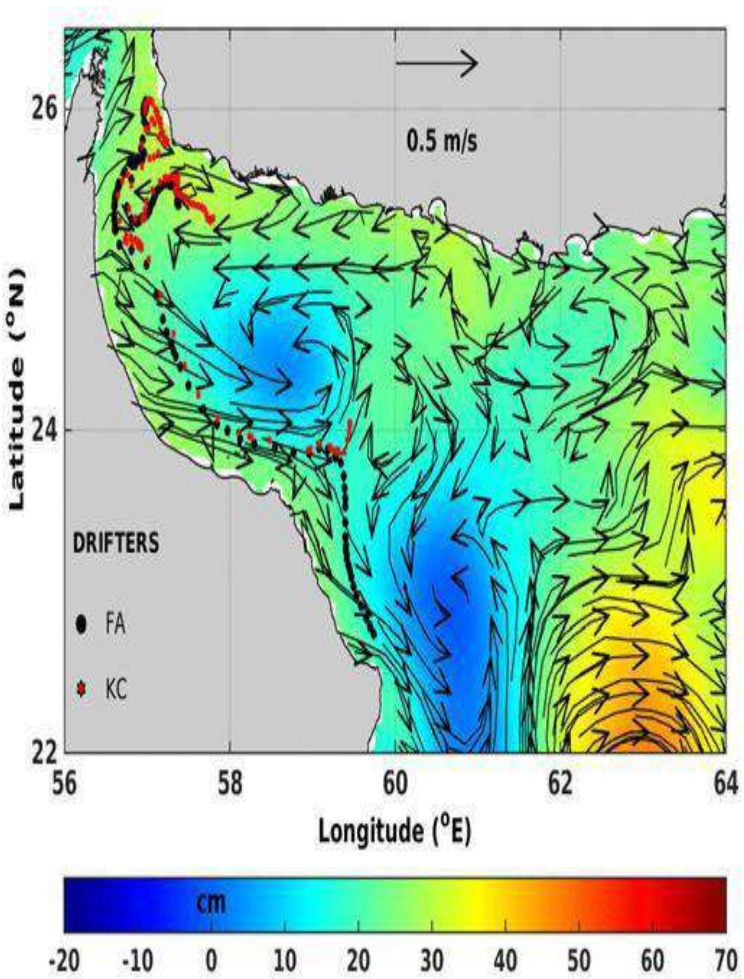
DISCO-WEB: gives users centralized access to automated near-real-time analysis products such as figures of sea-state, animations of forecasts, comparisons and validations of model simulations, historical time-series, up-to-date climate-index analyses, as well as direct access to all DISCO data.

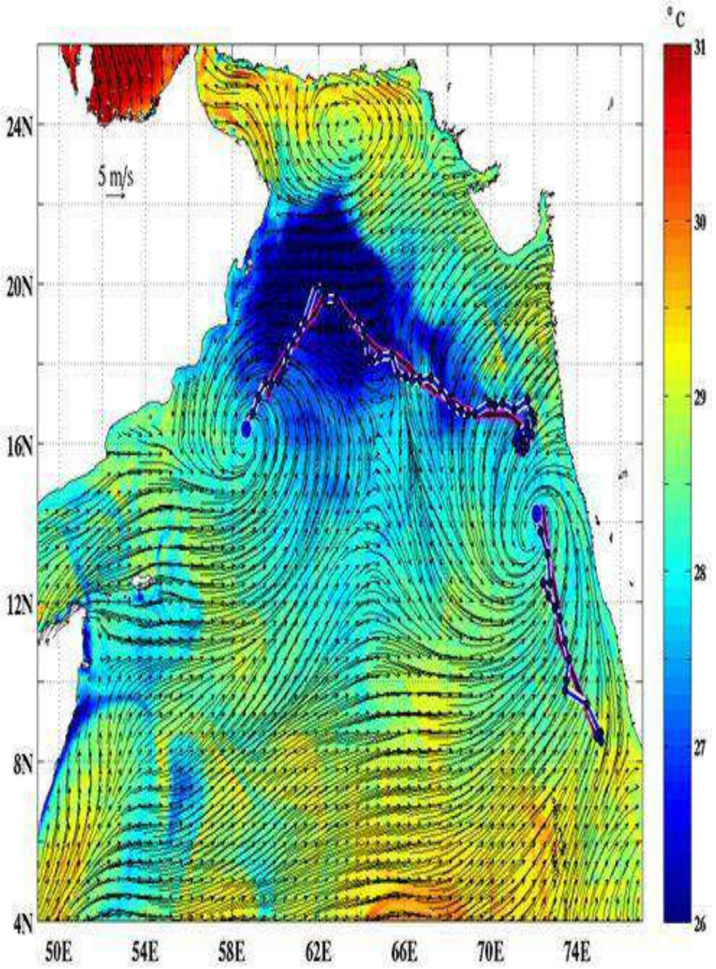


Decision and Information System for the Coastal waters of Oman (DISCO)

- Example of DISCO being used to: a) tracking the fate of the oil spill from the two tanker incidents (FA=Front Altair, KC=Kokuka Courageous) on June 13, 2019; and
- b) track the path and intensity of cyclone Kyarr, and the ocean-response (simulated SST) to cyclone Kyarr in late October 2019, followed by cyclone Maha.

- The forecasting model provided an early warning to Oman and predicted the strong south westerly turn Kyarr took, sparing the Omani coast of a direct hit.

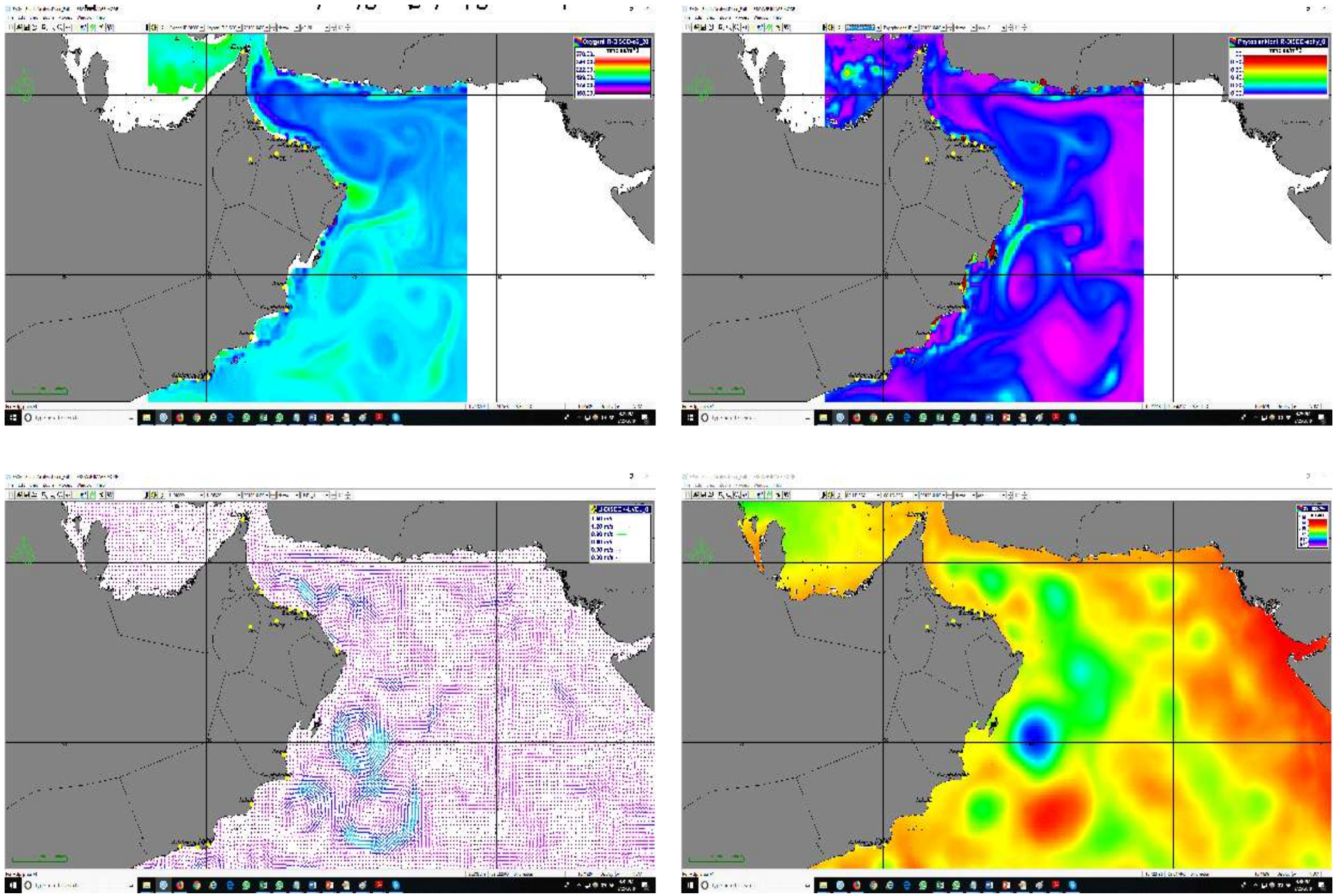




Decision and Information System for the Coastal waters of Oman (DISCO)

- **DISCO-EASy** is the third major component of the DISCO platform, providing a state-of-the-art hardware-software solution that combines a powerful server with customized GIS software.

- Four snapshots of output from the DISCO-MODEL for January 04, 2019. Upper left panel shows concentration of oxygen at 20 m depth; upper right shows the concentration of chlorophyll at the sea surface; lower left shows surface current vectors; lower right shows sea surface height.



Decision and Information System for the Coastal waters of Oman (DISCO)

Current Capabilities within DISCO

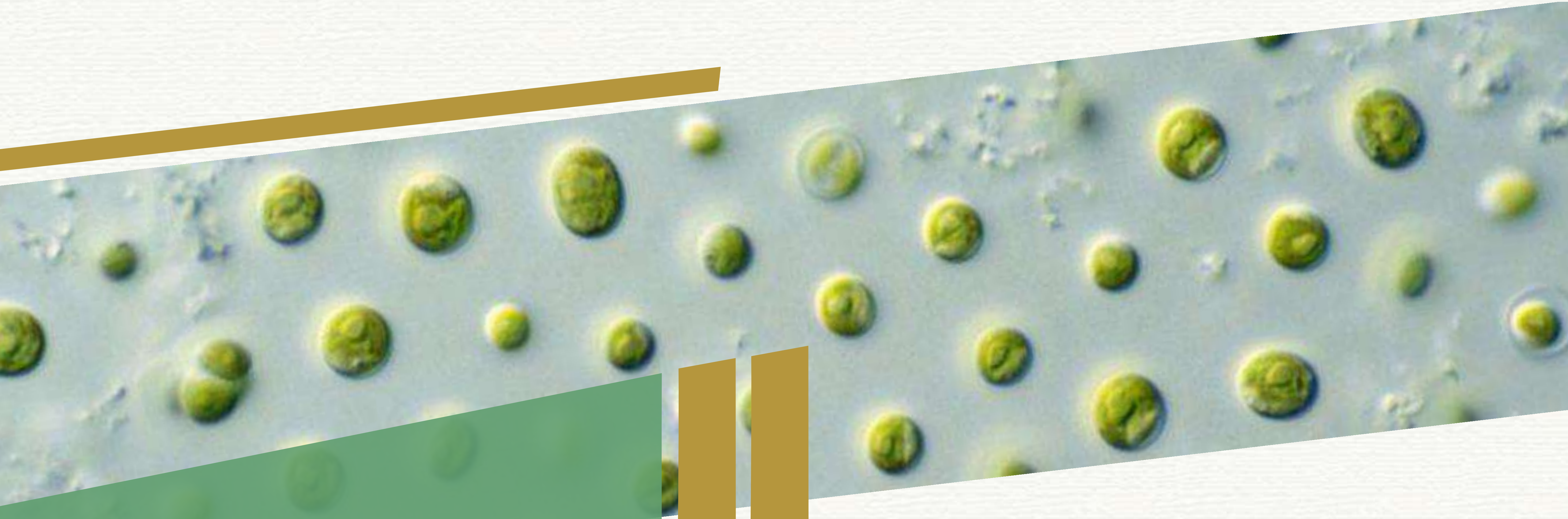
DISCO provides a continuous stream of products that rely on data from environmental sources (e.g. NOAA's World Ocean Atlas), operational global models (e.g. U.S. Navy Global Operational Forecasting System), satellites (e.g. MODIS-Aqua, NPP-VIIRS, AVISO+ altimetry products, etc.), and inputs to/outputs from the DISCO-MODEL that can be used for the following:

1. Historical (DISCO data-archive presently holds 7 years of historical environmental data), present-day, and up to 10-day advance forecasts of atmospheric and oceanic sea-state conditions, including information of approaching storms and cyclones.
2. Monitoring of HAB outbreaks in the coastal areas of Oman, including the evolution in space over time to guide realistic mitigation strategies that minimize risks to coastal marine resources and coastal activities.

Decision and Information System for the Coastal waters of Oman (DISCO)

Significant benefits

- DISCO could be used to serve the needs of a diverse range of infrastructure development activities in support of Oman's transition to a Blue Economy.
- DISCO has the capabilities for coastal aquaculture and fisheries management applications.
- The ability of DISCO to predict hypoxia and HABs opens up the possibility for not only forecasting fish kill events, but the ensued analysis of their cause.
- Existence of effective monitoring and forecasting systems that benefit various sectors such as desalination plants, fish farming and other relevant authorities.
- Create an integrated database that includes physical, biological and other environmental data.
- Using the system in several other applications:
    1) Monitoring and prediction of hypoxia and fish kills
    2) Tracking the path of harmful phytoplankton blooms, jellyfish multiplication, liquid waste, oil spills and hurricanes, and thus providing decision-makers early warning system.

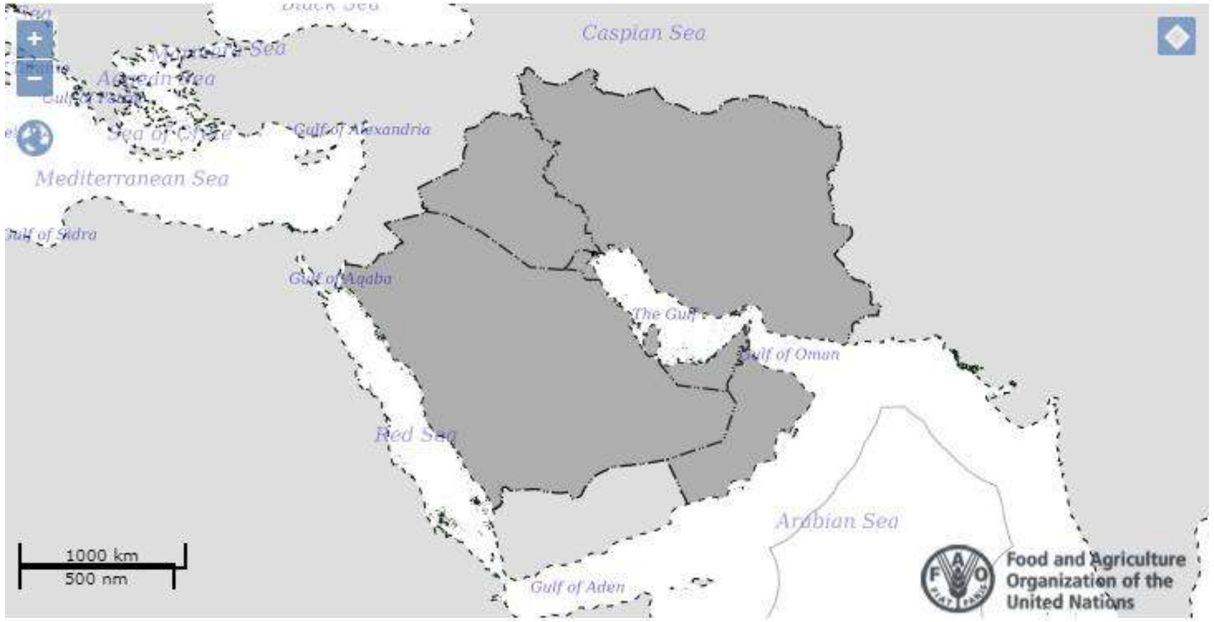


Thank You !

The status and trajectory of aquaculture in the Arabian Gulf and Sea of Oman

Patrick White

FAO Consultant

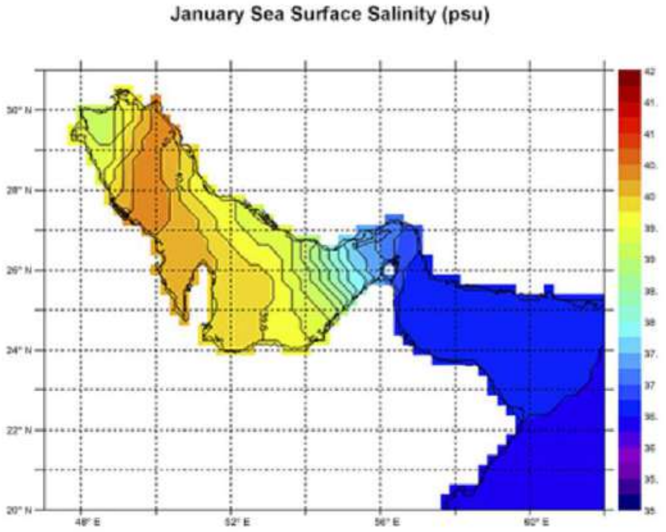


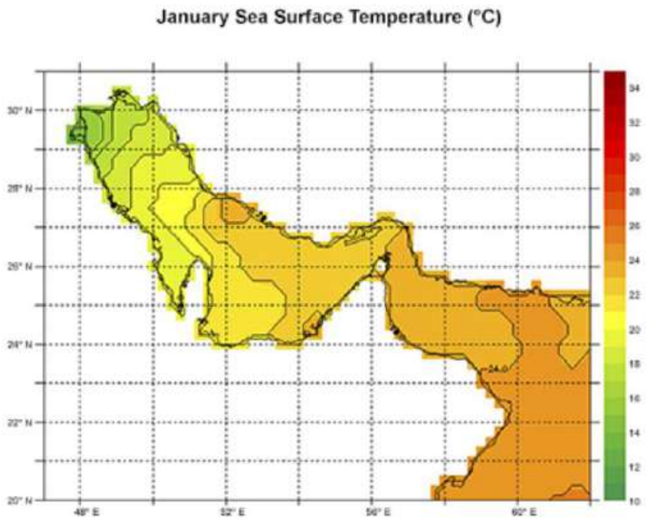
Suitability for aquaculture

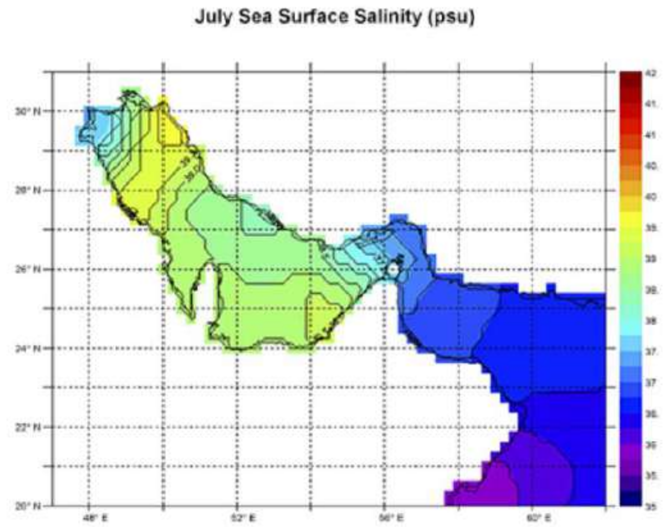
Salinity

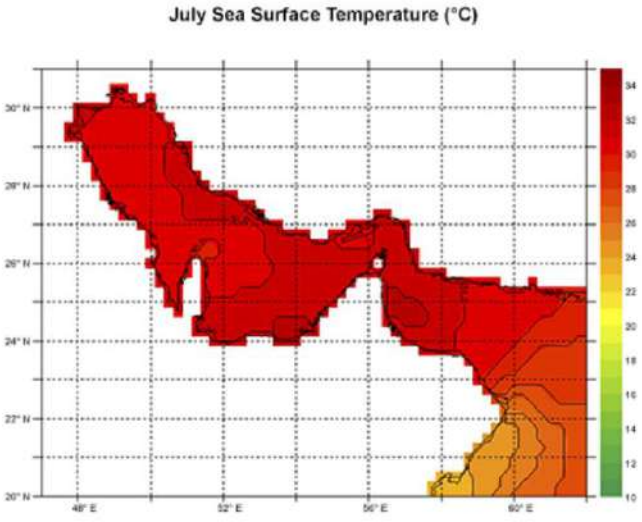
Temperature

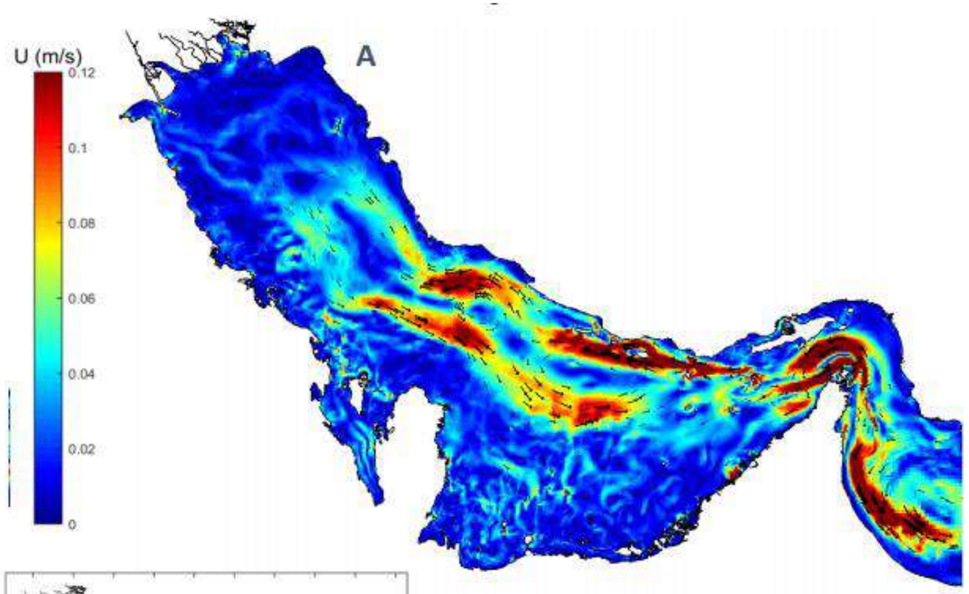
Residual currents











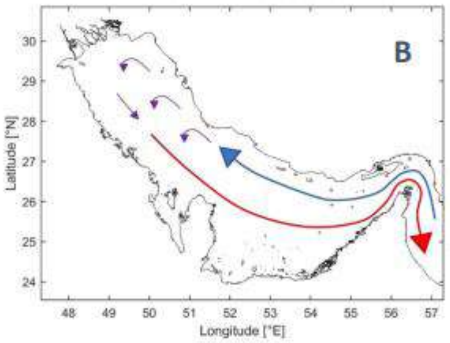
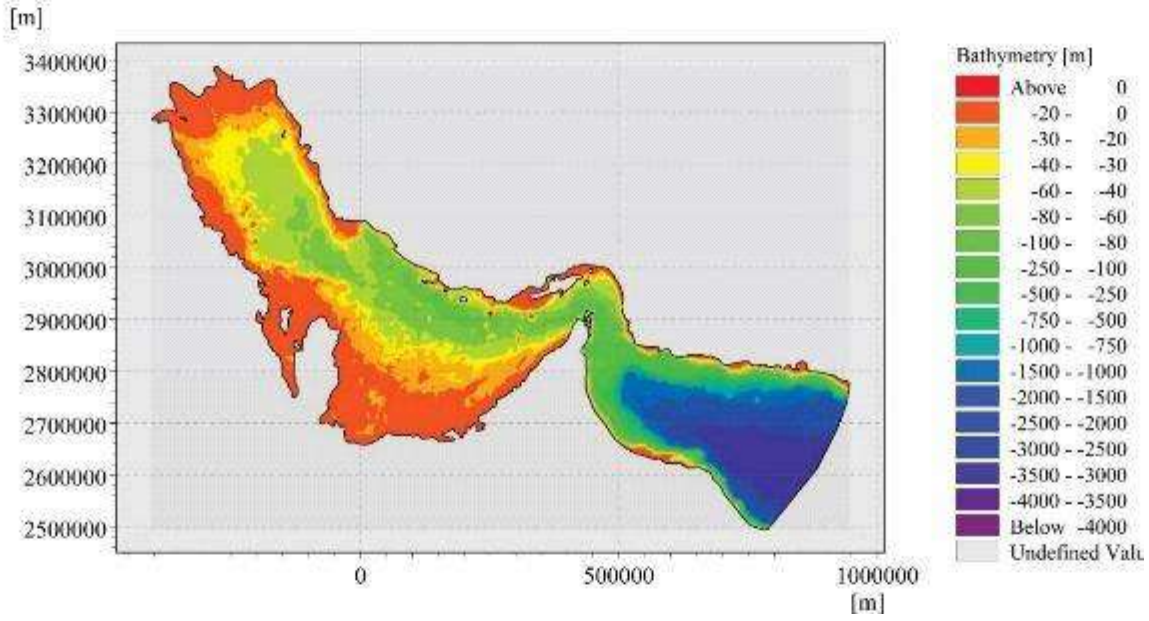
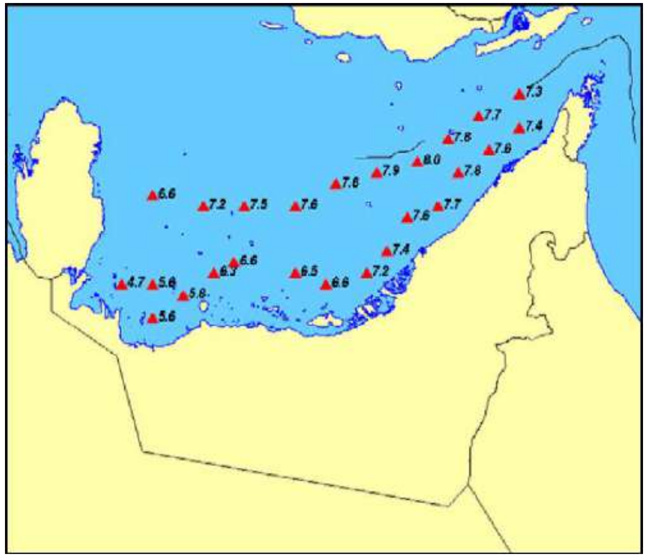


Figure 13: Top figure (A): Simulated yearly residual circulation of the reference case, gained with a Fourier analysis. The color scale describes the year averaged, depth averaged flow velocity and the black arrows indicate the local flow direction. Left bottom panel (B): the principle of the cyclonic flow in the Arabian Gulf with surface inflow (blue), the transition zone (purple arrows) and bottom outflow (red).

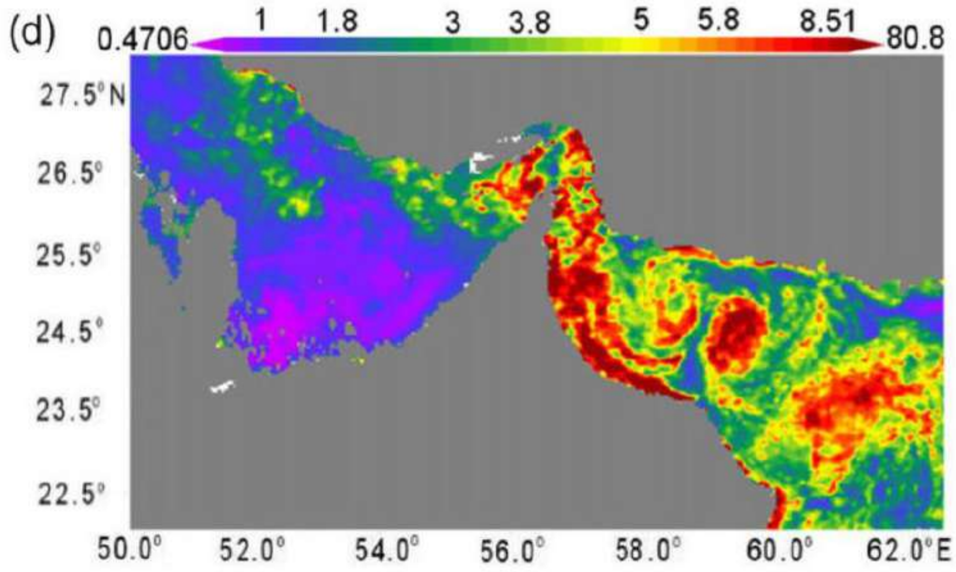
Constraints to aquaculture



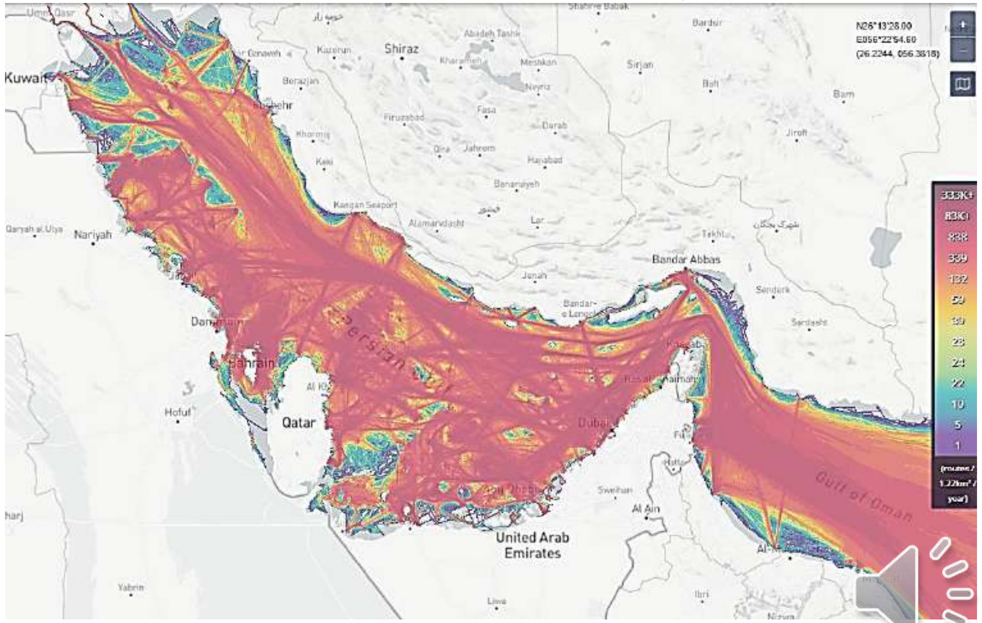
Significant wave height (m)



Chlorophyll levels



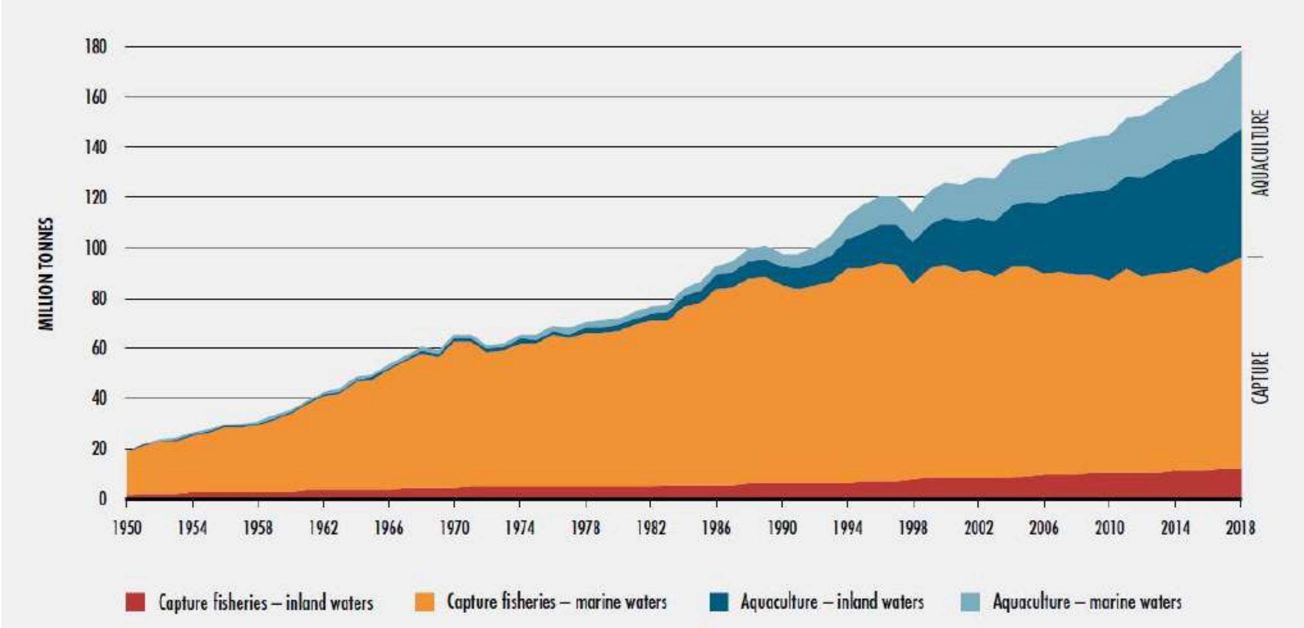
Marine traffic heat map



https://www.marinetraffic.com/

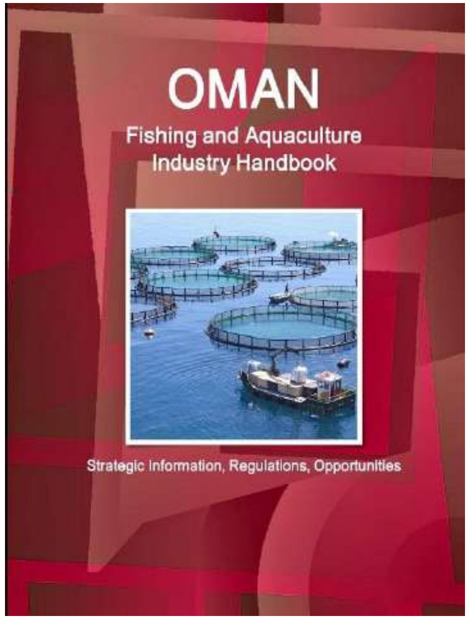
Importance of aquaculture

- Fish captured from the sea have traditionally been favoured more than farm-raised fish in Arab countries, because of the former's perceived greater health and taste benefits.
- Yet, aquaculture has been gaining more acceptance, and even popularity, in the Middle East.
- Some wealthy Gulf nations, such as Saudi Arabia, UAE, and Oman, have stepped up their efforts to cultivate aquaculture to meet the demand for fish, to reduce imports of seafood, and to maintain food security
- Although it is a relatively new and small sector in these countries, they have been heavily investing in fish farming.



Policy towards aquaculture development

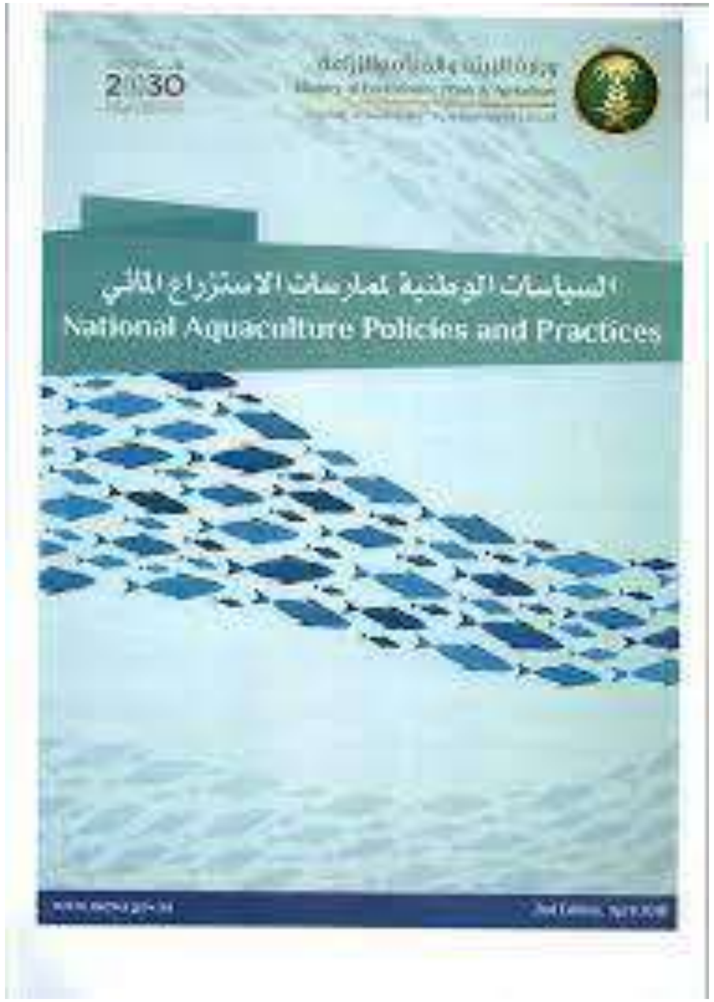
- The governments of Saudi Arabia, UAE, and Oman provide favorable policies and numerous incentives to attract investments into fish farming
- This has encouraged the development of a number of aquaculture projects in these countries.
- In 2018, the contribution of aquaculture towards total GDP was
  - 0.07 percent in Saudi Arabia,
  - 0.06 percent in Iraq,
  - less than 0.01 percent in the other countries.



Policy towards aquaculture development

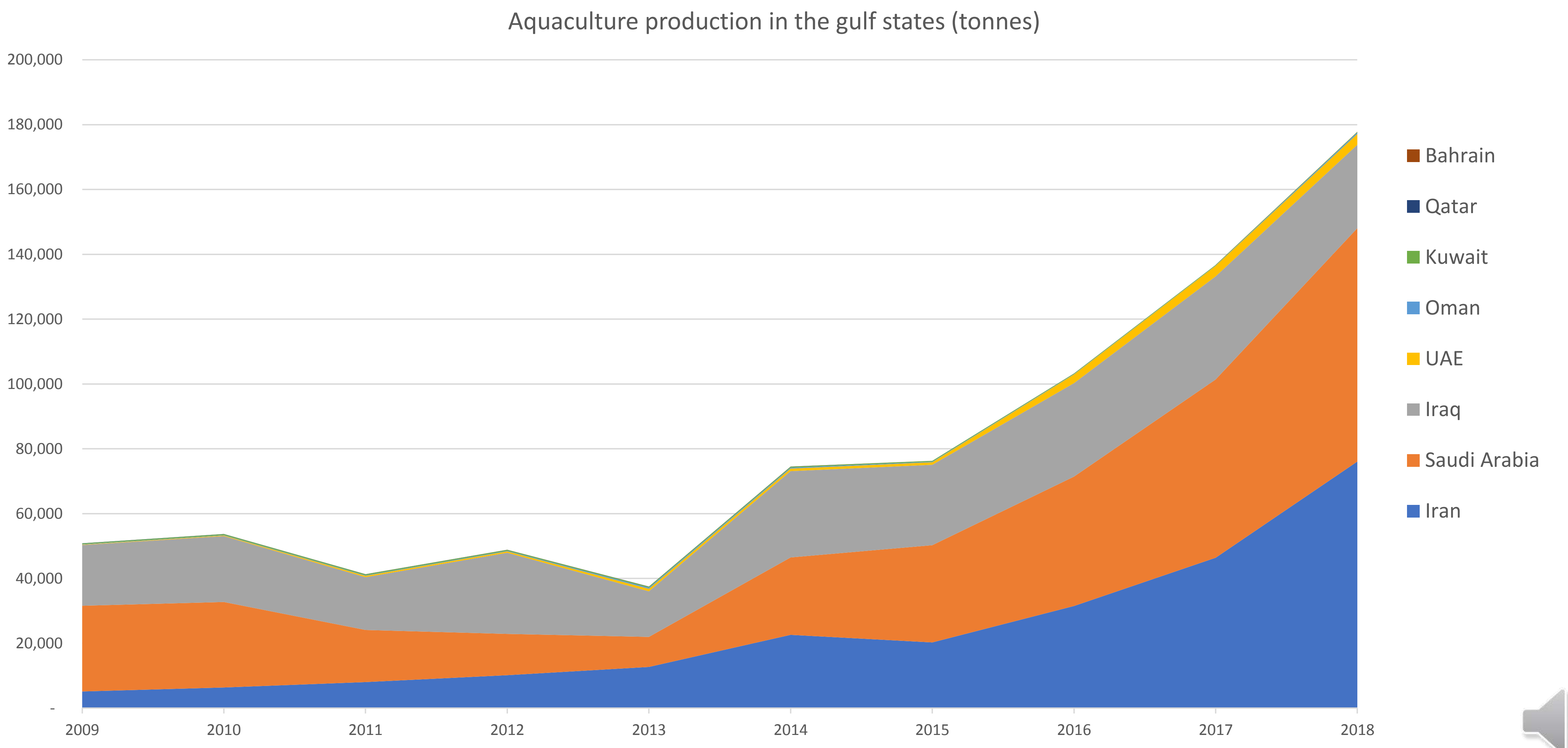
Aquaculture is often seen as an important sector for

- Supply of seafood from their coastal resources
- Revitalization of coastal areas
- Supporting complementary businesses
  - input supply (e.g. feed)
  - processing
  - transport
  - marketing
  - research, technological development and innovation
  - education and training.



Aquaculture production in the Gulf States

Freshwater, Brackish and Marine.



Present status of aquaculture (tonnes in 2018)

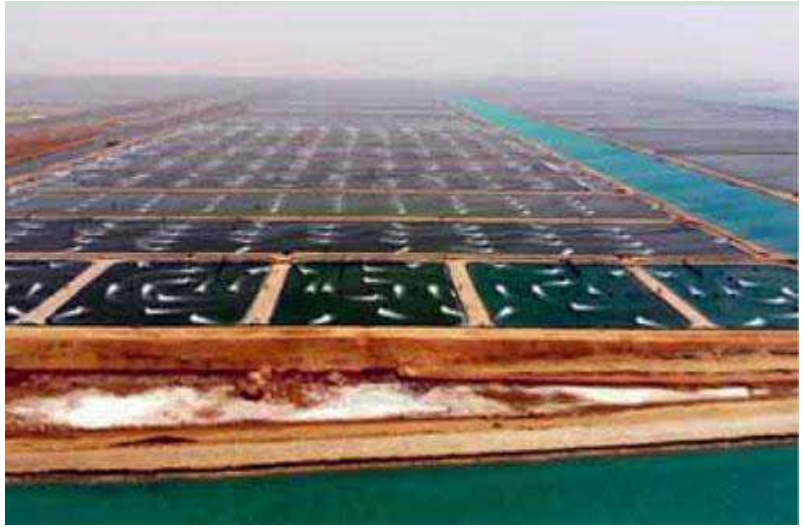
Country/Territory	Production environment		
	Freshwater (t)	Brackishwater (t)	Marine (t)
Bahrain	0	0	0
Iraq	25,737	0	0
Kuwait	0	187	11
Oman	101	0	350
Palestine	279	470	0
Qatar	10	0	0
Saudi Arabia	7,600	280	64,120 (Red Sea)
United Arab Emirates	258	0	3,092
Iran	3,636	54,159	21,900
TOTAL	37,621	55,096	89,473

25,000 tonnes)

Main culture systems

The main commercial marine aquaculture systems are;

- Saltwater ponds used for shrimp farming. Smaller units such as shrimp nursery ponds are normally lined makes them easier to clean, which can be important for biosecurity. Larger ponds are constructed in sabkha areas.
- Circular cages used for fish culture in exposed environments. These range in size from 20 m to 80 m diameter depending on the size of the farm, exposure and depth of the farm site.



Main culture systems - hatcheries

Hatchery facilities for fish and shrimp seed production and have developed or are developing for a range of species.

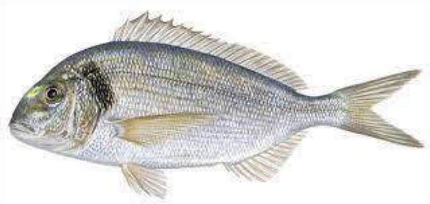
- Oman
- United Arab Emirates
- Qatar
- Bahrain
- Saudi Arabia (ARAMCO)
- Kuwait
- Iran

Culture species

Main species

- Barramundi

- Gilthead seabream



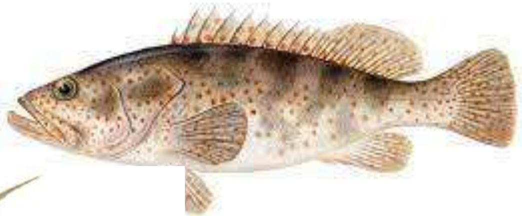
- Meagre

- Sobaity seabream

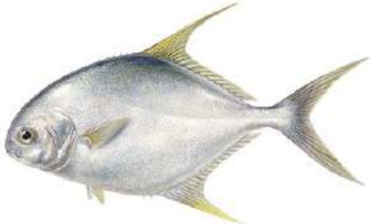
- Shrimp

Potential species

- Grouper

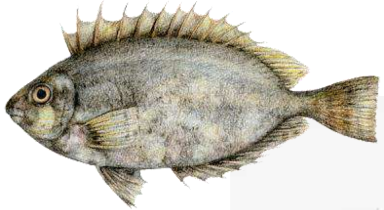


- Pompano



- Cobia

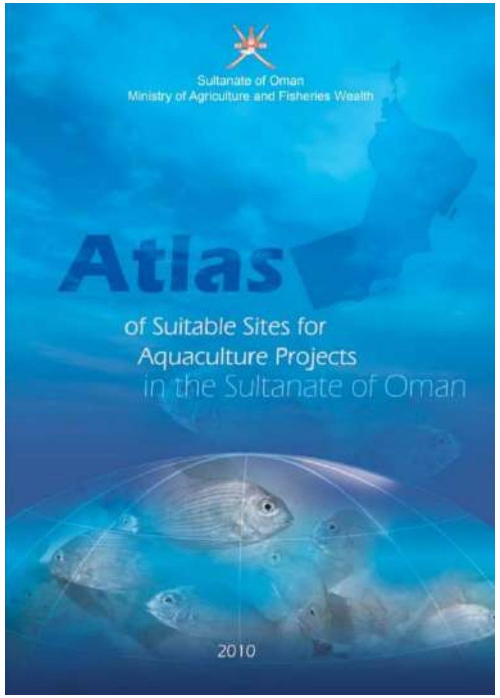
- Rabbitfish

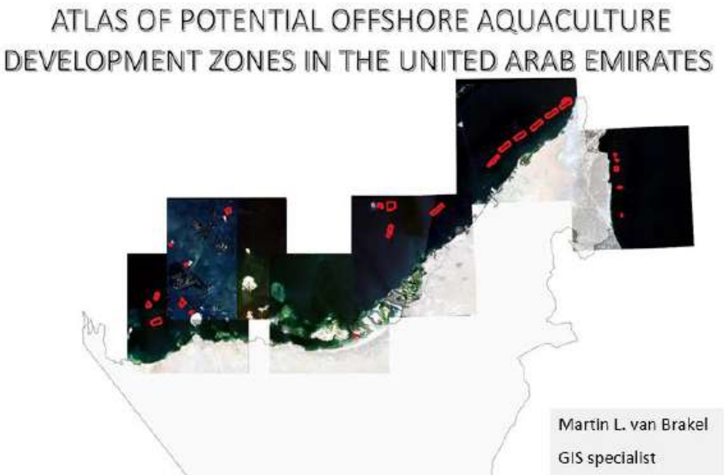


- Oyster

Aquaculture Planning

- Marine spatial planning and/or ICZM is used for the selection of aquaculture sites and avoid conflict with other users of the coastline
- The establishment of Aquaculture Zones to ensure the full integration of aquaculture with other coastal activities and thus prevent and minimize possible conflicts.
- Development of Aquaculture Atlas
    - Oman,
    - UAE
    - Saudi Arabia





Status of aquaculture development

Oman

- Since 2013, Oman’s Ministry of Agriculture and Fisheries has been creating essential infrastructure to boost aquaculture as wild fisheries began to decline.
- There are currently 23 tilapia farms, one shrimp farm and a marine cage farm producing European seabass and gilthead seabream.
- The country’s authorities hope to produce more than 200,000 tonnes of fish and create jobs for 11,000 people between 2030 and 2040.
- It pledged more than 1 billion USD to develop this sector and is providing nearly 15,000 hectares of land for that purpose.

United Arab Emirates

- Fish farming is important to the UAE because of strong seafood demand, increasing dietary preferences for fish, and a nearly 70 percent rate of importation for seafood
- There are five commercial farms (Abu Al Abyad, Al Jaraf Fisheries LLC, Fish Farm LLC, Emirates Fish Farms and Dibba Bay Farm) with a plans to build a specialized feed mill for aquaculture.
- The country’s Ministry of Climate Change and Environment is promoting local and foreign investments into aquaculture by easing the permitting process for fish farming projects and supporting scientific research to boost this industry.

Bahrain

- Bahrain also intends to develop its aquaculture sector.
- Commercial marine aquaculture began in 2014, when Asmak Bahrain Company started producing marine finfish.
- In 2015, the Ministry of Works, Municipalities Affairs and Urban Planning allocated six investment land plots.
- Each plot has a surface of 6,000 m2 with the aim of producing a minimum 250 to 300 tonnes of fish in recirculating aquaculture systems (RAS).
- The current priority is to modernize the National Mariculture Centre of Ras Hayan and upgrade its capacity to supply fry and fingerlings of local species to local and regional aquaculture farms.

Saudi Arabia

- Saudi Arabia has a more developed aquaculture industry as it has been investing in this sector since the 1980s.
- The Saudi Ministry of Environment ,Water and Agriculture plays a central role in establishing aquaculture across the country strategy.
- Fish and shrimp production reached 60,000 tons in 2017 and Saudi Arabia has an ambitious plan to produce 600,000 tons by 2030.
- Because growing demand for fish has pushed up Saudi Arabia’s imports of fish to 60 percent, the Kingdom aims to cut its dependence on imports by making farmed fish its main source of seafood.
- Saudi Aramco has built a large fish hatchery on the Gulf coast.

Kuwait

- Kuwait’s Aquaculture Program aims to develop feasible technologies to help Kuwait's aquaculture industry become more commercially viable and to improve food security.
- The Kuwait Institute of Scientific Research(KISR) aquaculture program is focused on research and development for breeding and fry production, improved feed formulation and disease control.

KISR
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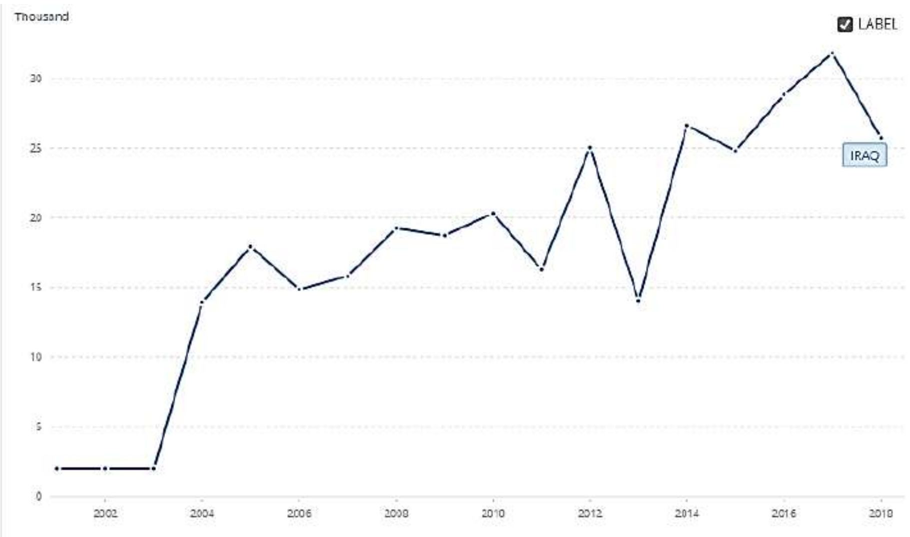
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

Iraq

- Iraq has a large freshwater aquaculture production but very little marine aquaculture production
- The main species cultured are freshwater species such as common carp, grass and silver carp and Barbus sp.
- There is hatchery production of common carp.
- The coastline is only 20.5 km and so there is limited scope for marine aquaculture production. However, there are studies to develop aquaculture in the marsh areas along the banks of the Euphrates.

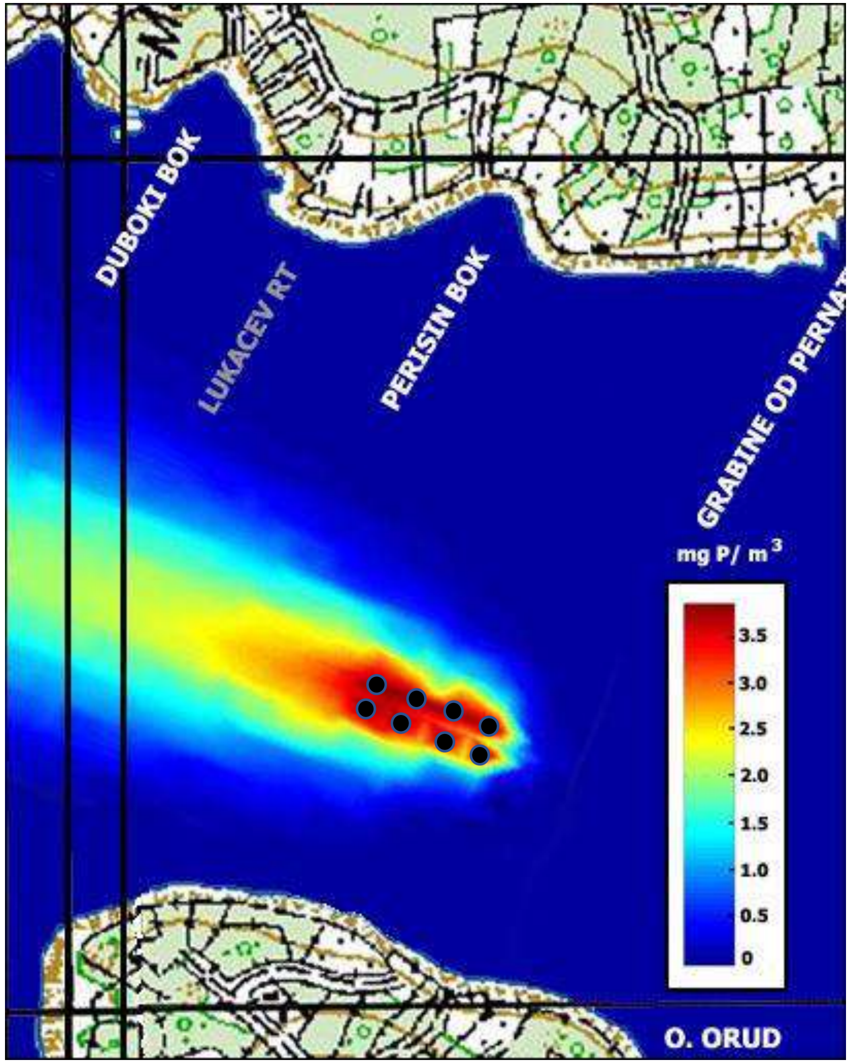


Iran

- Aquaculture in Iran is primarily Rainbow Trout in freshwater and shrimps grown in brackish and marine ponds.
- The total shrimp farming area covers 9,259 ha and produced 32,331 tonnes in 2017.
- Most of the production is taking place in the southern provinces, and shrimp are produced by around 680 small, family-owned farms.
- Production levels are yet to realize their full potential.

Environmental impact - nutrients

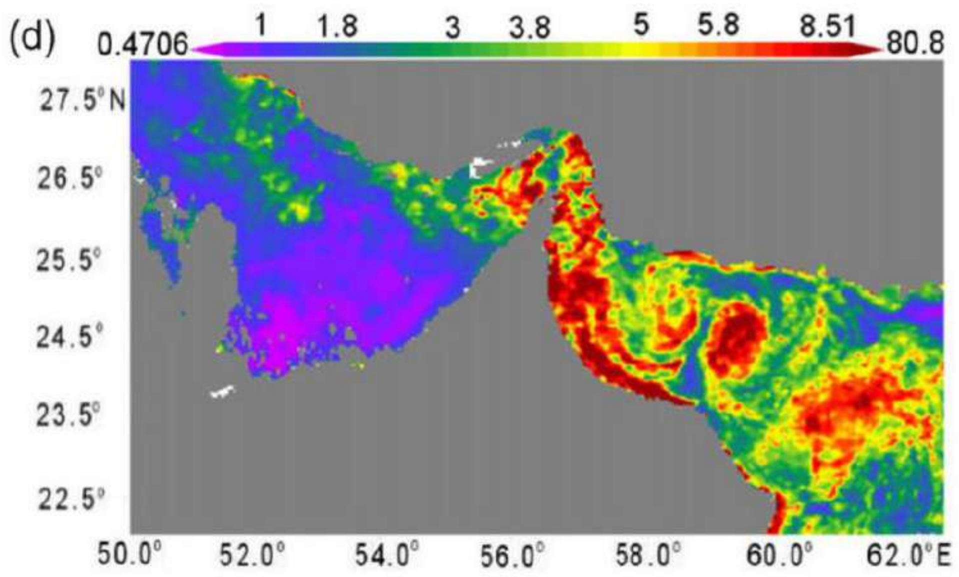
- Fish culture usually depends on the use of artificial feed. However, not all the nutrients in the feed are utilized for fish growth.
- Approximately 45% of nitrogen, and 18% of phosphorous contained in feed are excreted as dissolved inorganic nutrients and enter the water column.
- The impacts on the environment are most apparent in flow-through systems and cages, whereas the impacts in ponds are more complex as there is uptake of nutrients by primary production.



Algal blooms

- The Arabian Gulf and Sea of Oman are prone to algal blooms which is a risk for fish cage culture.
- Blooms may kill fish in several ways.
  - Densely concentrated algal bloom can deplete oxygen in the water due to the high respiration rate of the algae, or by bacterial respiration during their decay.
  - Some algae cause damage to the gills of fish, with the result that they are unable to take in enough oxygen.

Chlorophyll levels



Harmful Algal Blooms

- There have been several bloom events that have affected aquaculture.
  - 1999 red tide in Kuwait Bay indicated caused a fish kill due to elevated nutrient levelss, potentially from aquaculture activities as well as industrial and sewage inputs
  - The bloom of the marine ichthyotoxic dinoflagellate *Cochlodinium polykrikoides* from August 2008 to May 2009 caused mortalities of wild and farmed fish (Qurayat, Oman) as well as extensive coral reef damage and restricted fishing activities.
- The pattern of subsequent recurrence of blooms may become a persistent problem for aquaculture development in the region.

Shrimp Aquaculture: An Overview, Challenges and Accomplishments in Kuwait

Dr. Sherain Al-Subiai
Aquaculture Program/ELSRC
Kuwait

Date: 22/Feb/2022

- Kuwait Institute for Scientific Research (KISR) has initiated aquaculture research in 1983
- KISR has earlier studied the hatchery seed production and tank rearing of *P.semisulcatus* and achieved encouraging results
- 2015, Government Initiative on technology development and application of shrimp culture for commercial production
- Development of the seed production and culture of the second most common local species *M. affinis* using Biofloc system

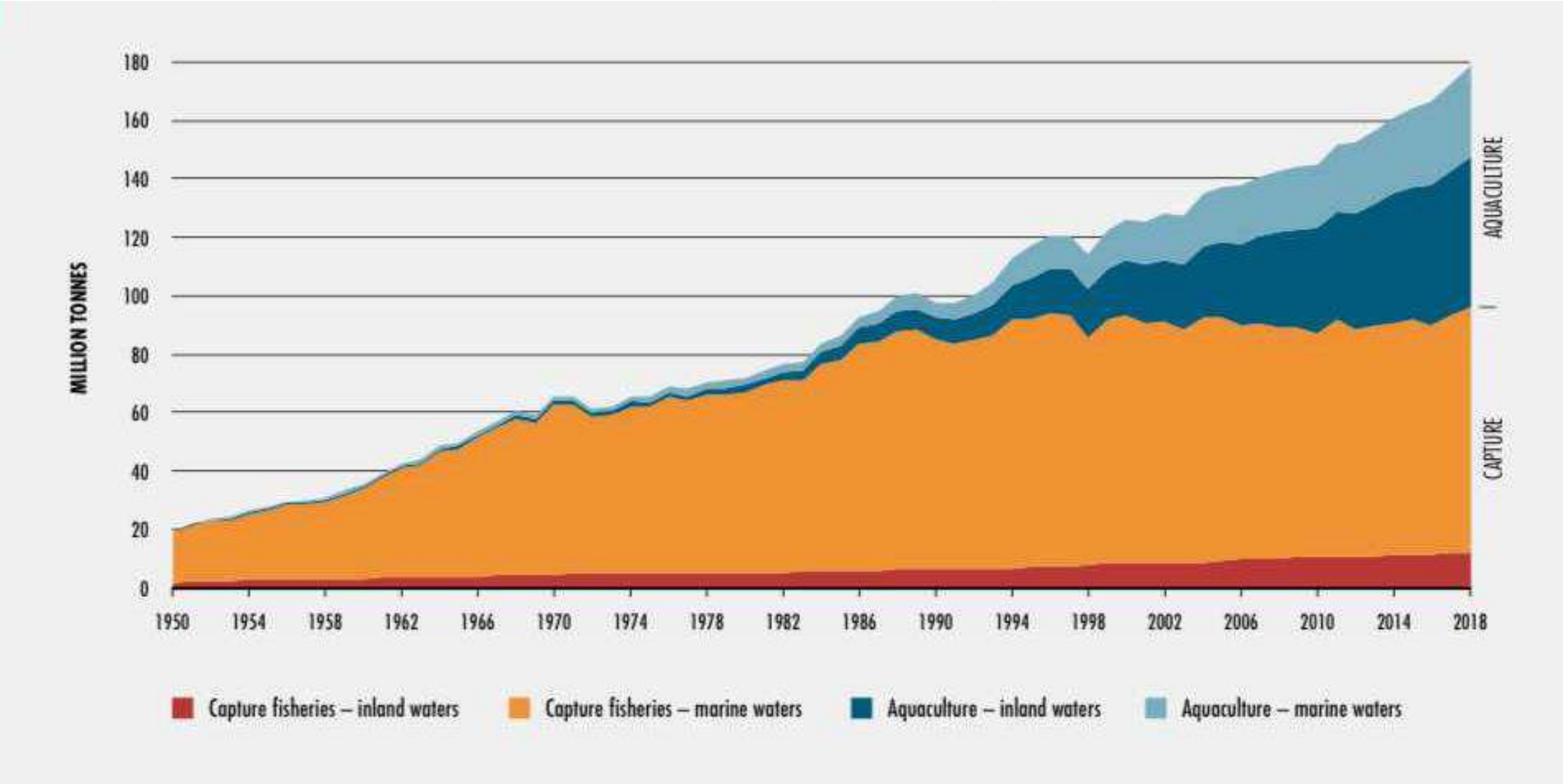
1,260 tonnes
Local Shrimp

1,588 tonnes
Imported Shrimp

0
Cultured shrimp

Shrimp Production in Kuwait

	Imported			Local Captured			Total		
Year	Value (KD)	Price(KD)	Quantity (Kg)	Value (KD)	Price(KD)	Quantity (Kg)	Value (KD)	Price(KD)	Quantity (Kg)
2005	2,175,922	1.588	1,370,080	3,531,471	1.868	1,890,255	5,707,396	1.751	3,260,335
2007	1,900,943	1.502	1,265,750	2,718,744	1.766	1,539,857	4,619,687	1.647	2,805,607
2009	1,846,289	1.447	1,275,715	3,272,483	1.871	1,749,307	5,118,773	1.692	3,025,022
2010	1,726,646	1.543	1,118,700	4,050,478	1.926	2,102,721	5,777,125	1.793	3,221,421
2011	1,697,312	1.807	939,360	3,453,970	2.4	1,439,142	5,151,282	2.166	2,378,502
2012	2,720,531	1.759	1,546,270	3,112,314	2.119	1,468,478	5,832,845	1.935	3,014,748
2013	2,701,744	2.073	1,303,550	3,650,223	2.417	1,510,080	6,351,966	2.258	2,813,630
2014	3,547,041	2.234	1,588,060	4,245,471	2.854	1,487,551	7,792,512	2.534	3,075,611
2015	4,497,361	2.119	2,122,200	4,088,554	2.831	1,444,309	8,584,587	2.407	3,566,509
2016	5,040,498	2.079	2,427,760	4,916,388	3.023	1,626,319	9,956,886	2.456	4,054,079


MILLION TONNES
180
160
140
120
100
80
60
40
20
0
1950
1954
1958
1962
1966
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006
2010
2014
2018
AQUACULTURE
CAPTURE
Capture fisheries – inland waters
Capture fisheries – marine waters
Aquaculture – inland waters
Aquaculture – marine waters

FAO, 2020

Shrimp Culture Systems

1. Traditional or extensive

Size: 3-20 hectare
Stocking density:3,000-5,000/ha

Yield is very low

2. Improved traditional or semi-intensive

Size: 1–3 hectares
Water depth: 0.80 - 1.2 meters
Stocking density: 20,000-50,000/ha

3. Intensive method

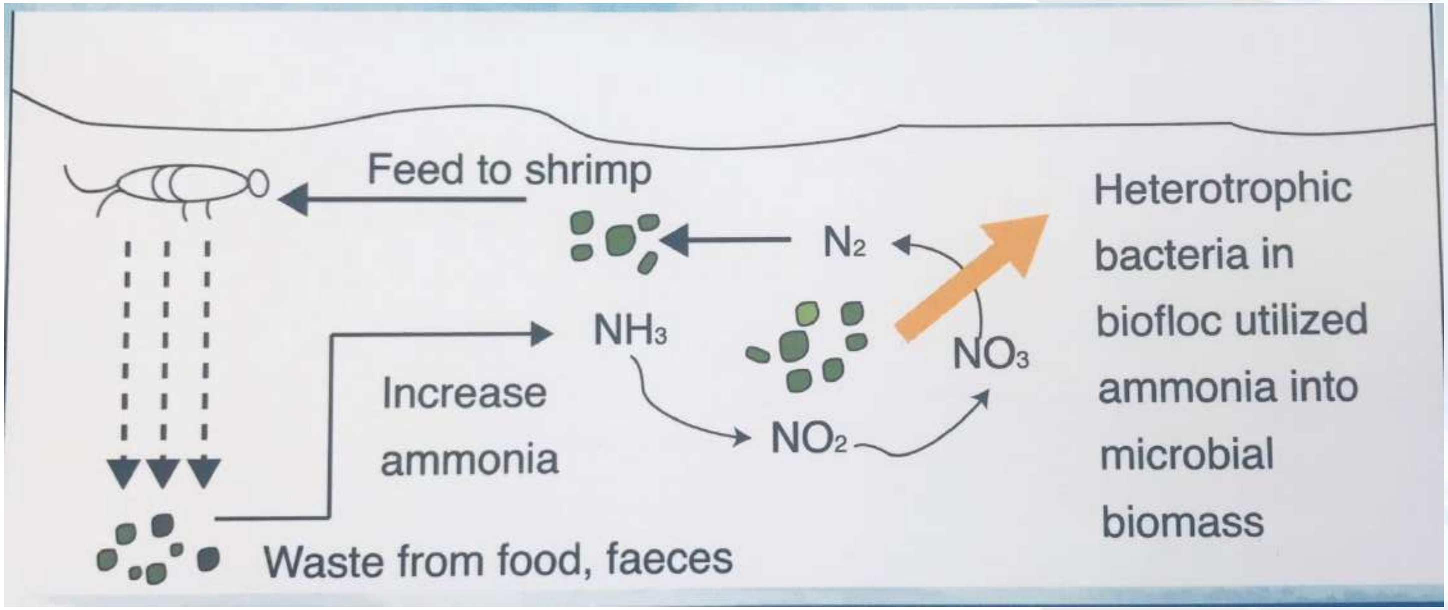
Earthen or concrete pond
Size: 500-5000 m^2
Stocking density: 200-250/m^2

Biofloc Raceway




Biofloc?

- The Biofloc system is a recent innovative aquaculture technology, very promising for stable and sustainable production as the system has self-nitrification process within culture ponds/tanks/raceways with zero water exchange



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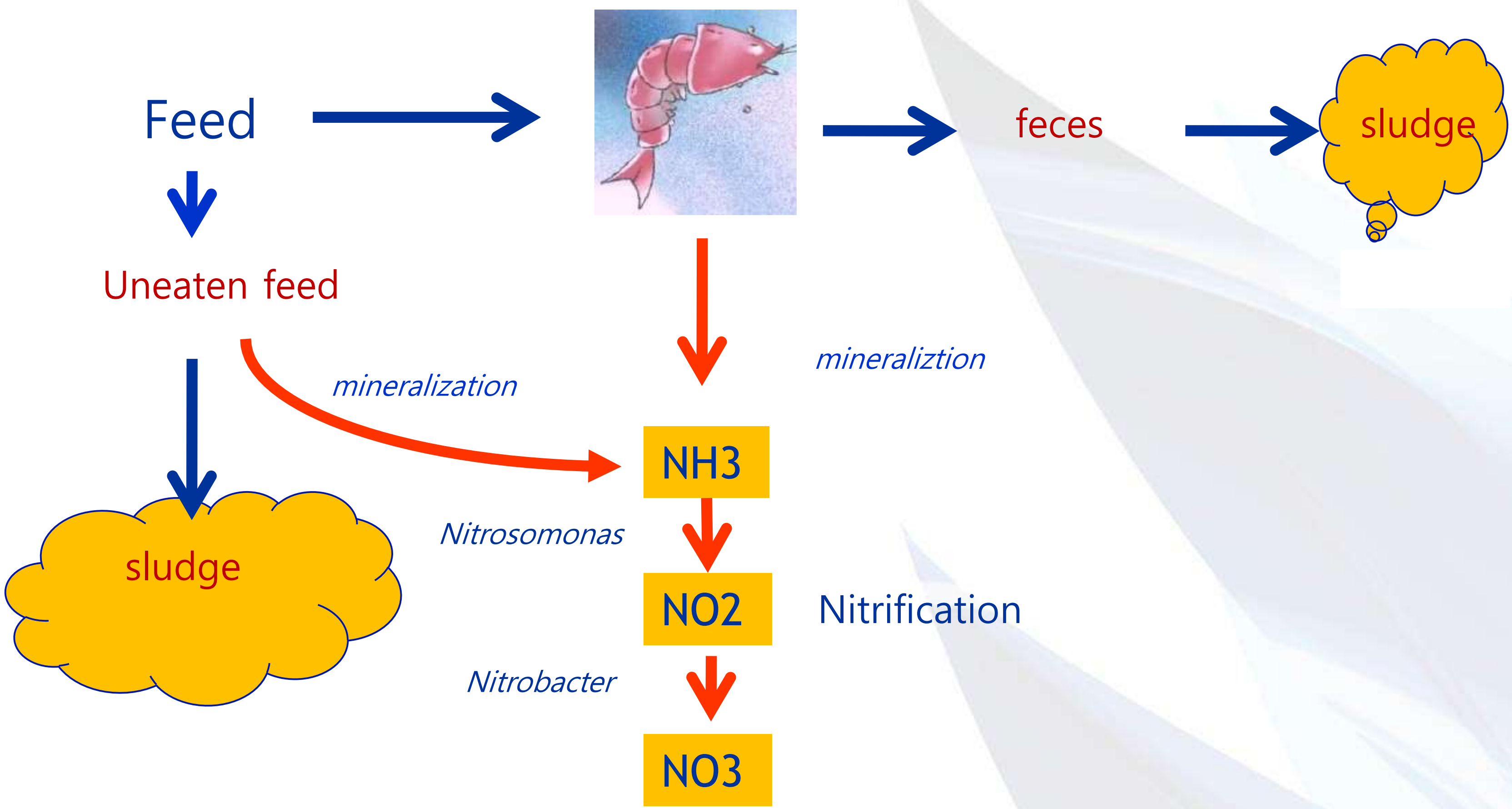
Nitrification cycle
(Chemoautotrophic pathway)



- Optimizing shrimp biofloc culture condition on SPF *L. vannamei* using seawater, diluted seawater and brackish water

Seawater
46 ppt

Diluted-seawater
30 ppt

Brackish
5 ppt

Corrected-brackish
8-10 ppt

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Kuwait Institute for Scientific Research

- Inland shrimp farming has relatively a short history, due to the fact that ground water is unsuitable for shrimp farming

- KISR has overcome this problem through scientific research at experimental scale

- The hard success of such a unique technology has raises the bar to test the production at semi-commercial scale at Kabd site

10 Kg for 60$ to make 333L of 30 ppt

300 Kg to make 10 tons of water to start up small raceway

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No.	Water	Salt	Amount	Salinity (ppt)	Price (KD/kg)
1	DW 500ml	Indian Artificial Sea Salt	5g	10	2.0
2	DW 500ml	KSA salt-1 (red pack)	5g	10	0.2
3	DW 500ml	KSA salt-2 (livestock)	5g	10	0.1
4	DW 500ml	KISR salt (desalination)	7g	11	0.0
5	DW 500ml	Vietnamese salt	6g	10	0.7

W.Q (mg/L) \ Source	1. Indian salt	2. KSA salt-1	3. KSA salt-2	4. KISR salt	5. Viet salt
pH	5.4	5.5	6.6	9.3	8.2
Sal (ppt)	10.5	10.1	10.3	11.2	11.4
Ec(25°C, us/cm)	16,670.0	16,330.0	16,420.0	17,430.0	18,080.0
Na	3,890.0	3,618.0	3,801.0	3,827.0	4,092.0
K	0.01	0.01	2.4	48.6	13.7
Mg	0.01	0.01	9.0	176.5	85.0
Ca	0.01	0.01	0.01	44.0	50.0
Cl^-	6,439.0	6,322.0	6,316.0	6,746.0	6,927.0
Na:K	389,000	361,800	1,590	79	299
Mg:Ca	1.0	1.0	900.0	4.0	1.7

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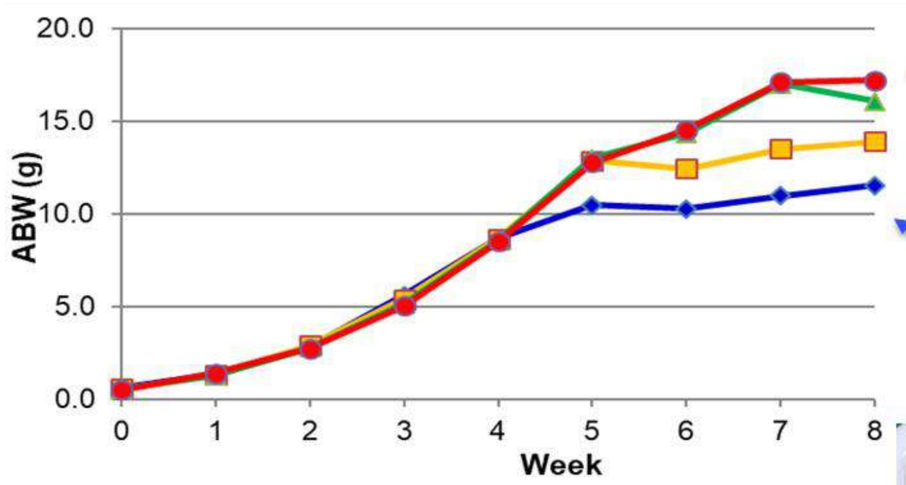
Shrimp weekly growth

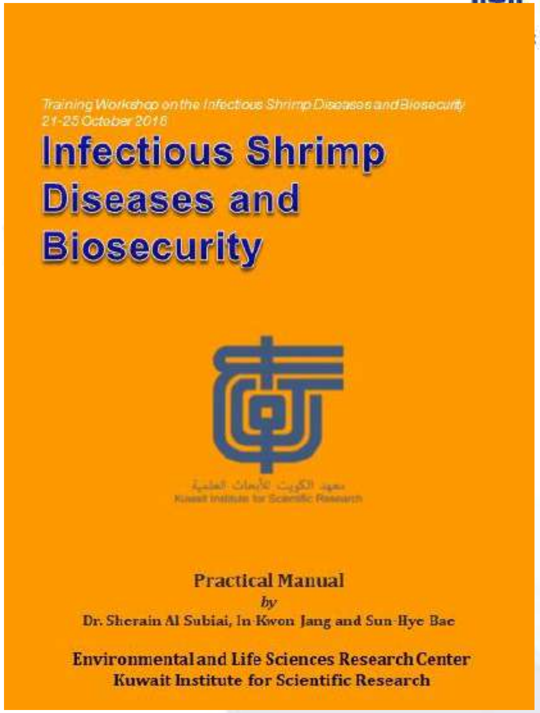


Addition of Mg-salt

Without Mg-salt

Tank		Tank Area (m²)	Water volume (m³)	Stocking Density (/m²)	Stocking Density (/m³)	Days	Initial ABW (g)	Fianl ABW (g)	Total Production (g)	Yield (g/m³)	Survived shrimp (INDS)	Survival Rate (%)	FCR	ADG (g/day)
GW 1	Mean	1	0.8	200	250	56	0.55	13.9	1,650	2,063	120	59.8	1.32	0.24
	STD						0.02	1.0	147	184	19	9.4	0.13	0.02
GW 2	Mean	1	0.8	200	250	56	0.53	16.1	1785	2231	111	55.5	1.24	0.28
	STD						0.06	0.3	68	84	6	3.04	0.05	0.01
GW 3	Mean	1	0.8	200	250	56	0.49	17.2	1608	2010	94	47.2	1.36	0.30
	STD						0.03	1.7	87	109	15	7.3	0.07	0.03

KISR
Institute for Scientific Research



Training Workshop on the Infectious Shrimp Diseases and Biosecurity
21-25 October 2018

Infectious Shrimp Diseases and Biosecurity

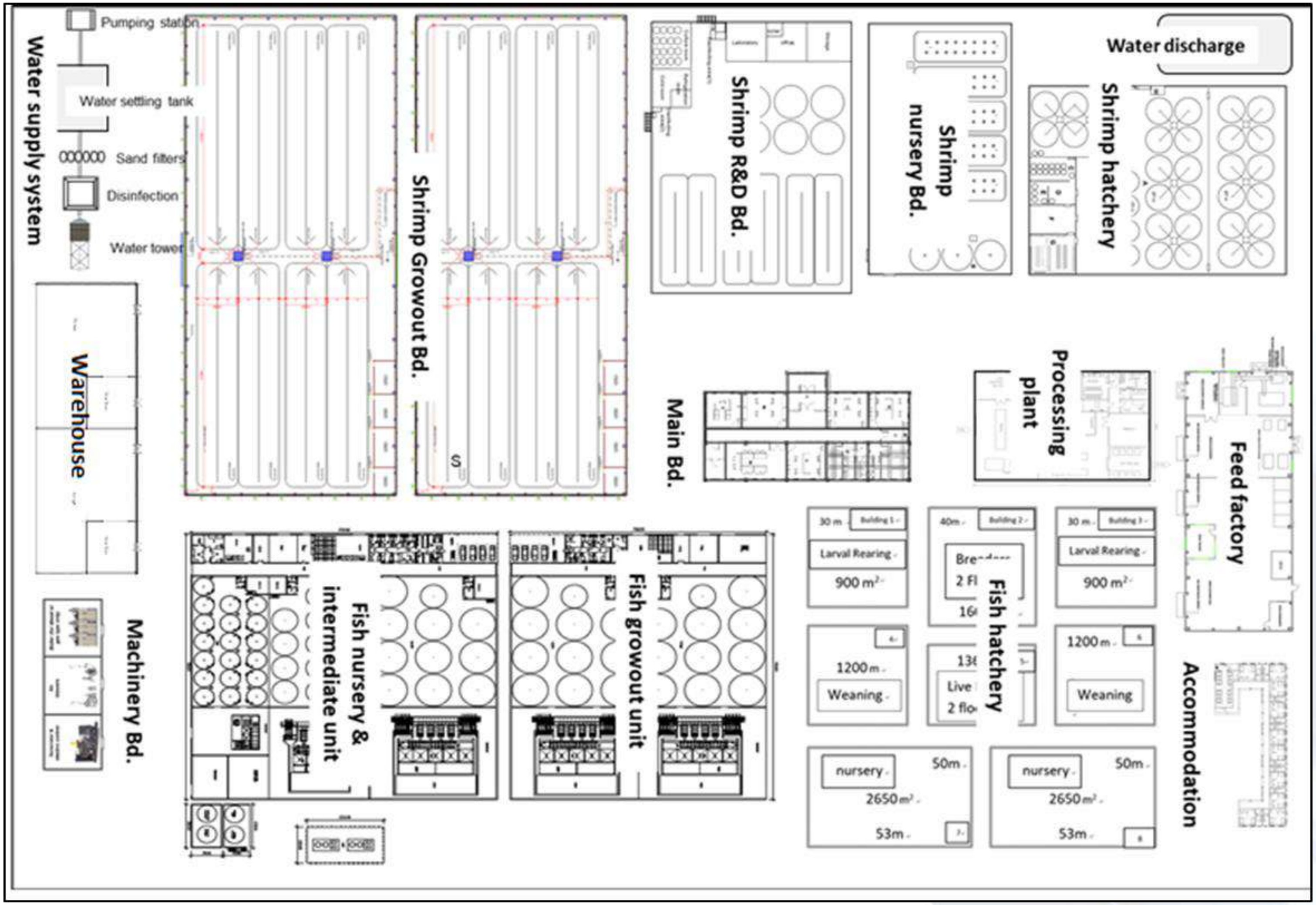
معهد الكويت للأبحاث العلمية
Kuwait Institute for Scientific Research

Practical Manual
by
Dr. Sherain Al Subiai, In-Kwon Jang and Sun-Hye Bae

Environmental and Life Sciences Research Center
Kuwait Institute for Scientific Research


حملة اطلاق المليون يرقه من الروبيان
الشحامي في المياه الكويتية
١٩ سبتمبر ٢٠١٨
KISR
مركز أبحاث البيئه والعلوم الحياتيه
معهد الكويت للأبحاث العلمية
ELSRC

Established Inland Shrimp Farm


Water supply system
Pumping station
Water settling tank
Sand filters
Disinfection
Water tower
Warehouse
Machinery Bd.
Shrimp Growout Bd.
Shrimp R&D Bd.
Shrimp nursery Bd.
Shrimp hatchery
Water discharge
Main Bd.
Processing plant
Feed factory
Fish nursery & intermediate unit
Fish growout unit
Fish hatchery
Accommodation
30 m
Larval Rearing
900 m²
40m
1200 m
Weaning
nursery
50m
2650 m²
53m

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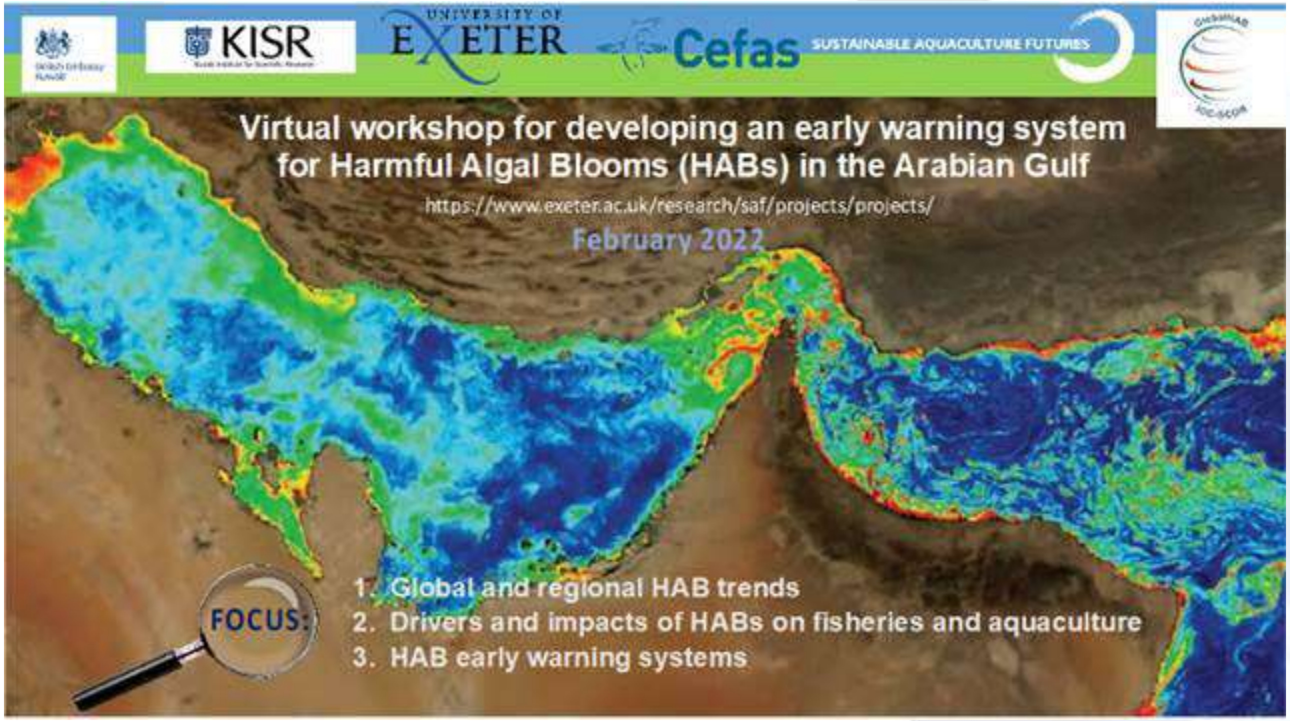
Key Discussion Points

- Hatchery seed production of local shrimp species was attempted in Kuwait
- In general, shrimp aquaculture industry is in nascent stages in Kuwait
- Mg/K-salt improve shrimp performance for inland shrimp farming but, was not enough to make satisfactory profits for commercial farms
- Shrimp still probably needs other trace metals from sea water
- Further advancement leading to commercial shrimp culture is wanting in Kuwait

• Thank You !



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UNIVERSITY OF EXETER
Cefas
SUSTAINABLE AQUACULTURE FUTURES
Virtual workshop for developing an early warning system for Harmful Algal Blooms (HABs) in the Arabian Gulf
https://www.exeter.ac.uk/research/saf/projects/projects/
February 2022
FOCUS:
1. Global and regional HAB trends
2. Drivers and impacts of HABs on fisheries and aquaculture
3. HAB early warning systems

Environmental extremes and additional pressures on marine ecosystems in the RSA

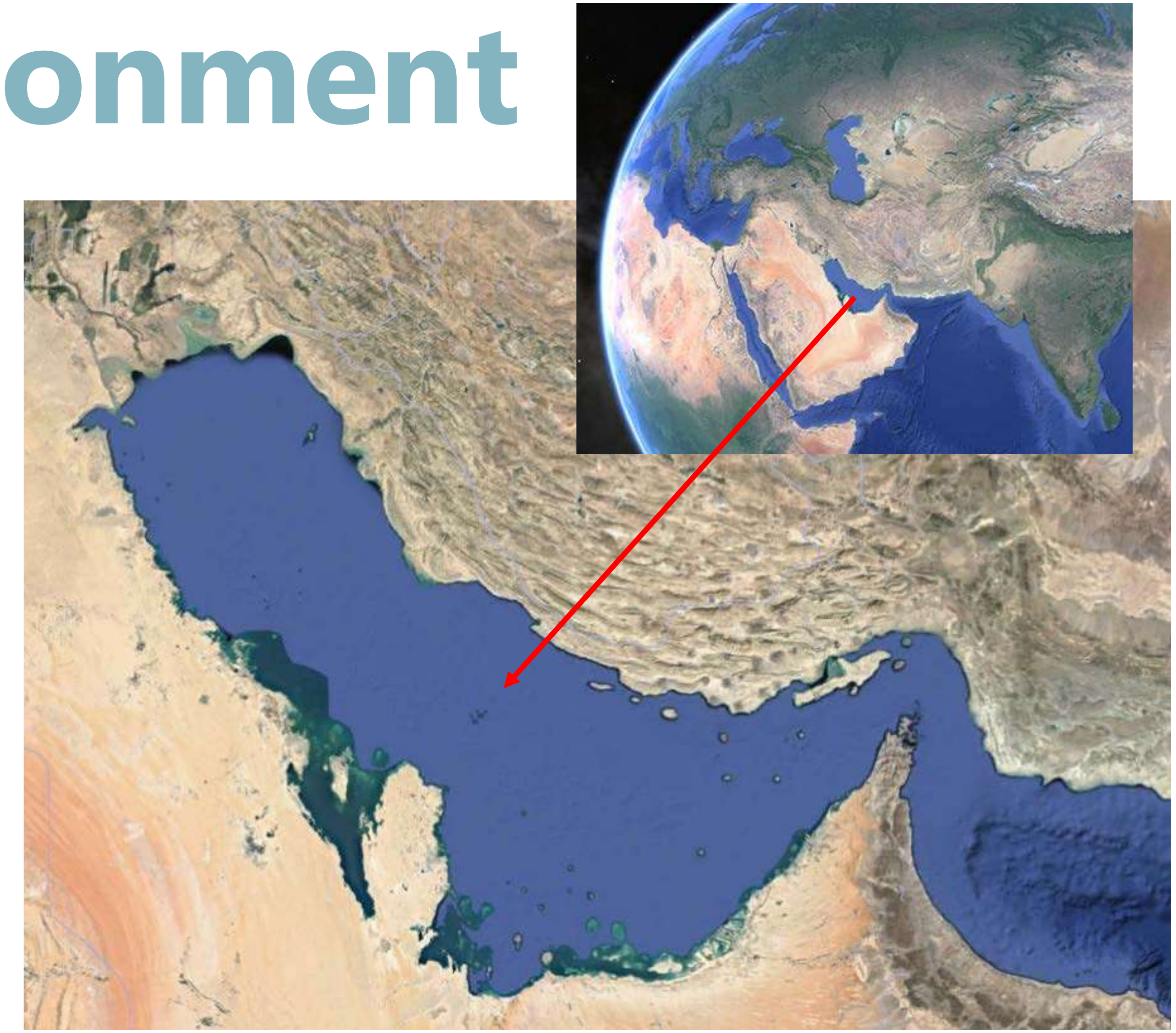
Michelle Devlin and Brett P. Lyons

Centre for Environment Fisheries & Aquaculture Science

Cefas

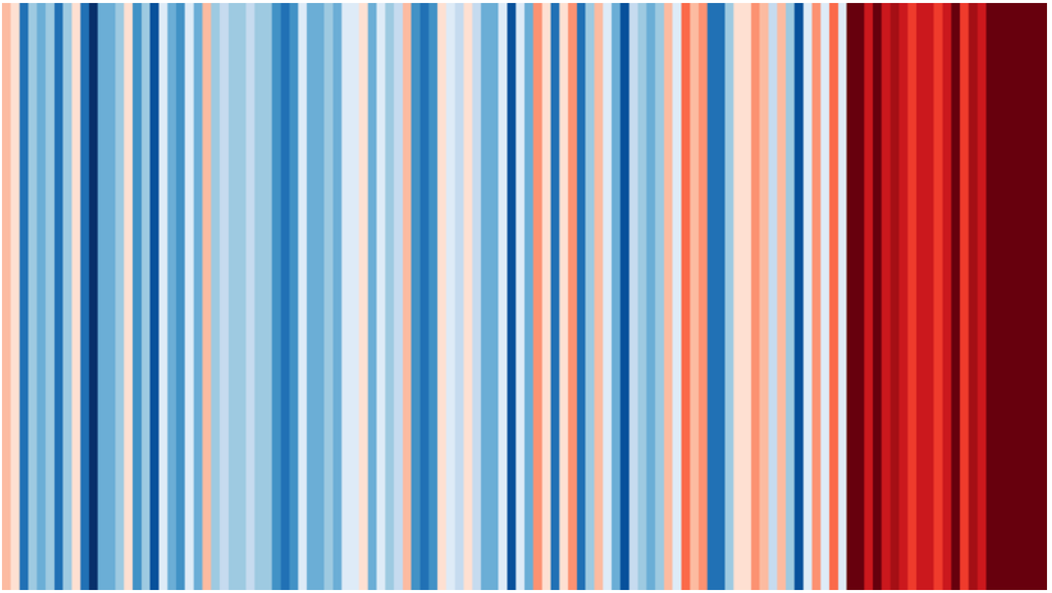
Gulf’s marine environment

- Maximum depth approx. 90m.
- Iranian side of Gulf tends to have steeper gradiant with more gradual slope along the Arabian shoreline.
- High temperatures and dry winds = 1-2 m equivalent of evaporation per year.
- Salinity >39psu across most Gulf waters.
- General circulation pattern via Strait of Hormuz, along Iranian coast in counter-clockwise direction.
- Low flushing rates lead to salinities > 70psu in embayments (e.g. Gulf Salwah, south of Bahrain).



The world's hottest sea…

- The Gulf has been identified as the warmest water body world-wide.
- Recent satellite imagery indicated that the Gulf frequently experiences the highest SST globally, exceeding 36.0 °C.
- Extreme sea surface temperatures reached 37.6 °C, on 30th July 2020 in Kuwait Bay (at an offshore station).



Bahrain air temperature (1901-2020)

Centre for Environment Fisheries & Aquaculture Science

Cefas

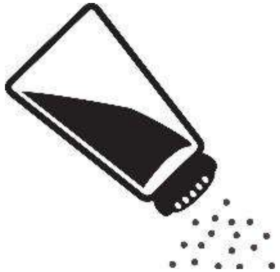
Hot, salty, sour and breathless!

Temperature

Gulf already one of warmest seas (>36°C)

SST could increase by 2.8–4.2 °C

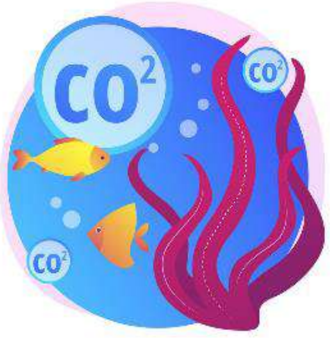
Salinity



High evaporation leads to very saline waters

Salinity increased by 0.5–1.0% over the past 60 years

Ocean acidification



pH in the Gulf could decrease by ~ 0.25 units by 2050

Low oxygen

Areas of low oxygen concentration (OMZs) are expected to become larger and more persistent

Cyclones & storms

The number of severe tropical cyclones in the may increase by the end of this century (Arabian Sea)

Monsoon

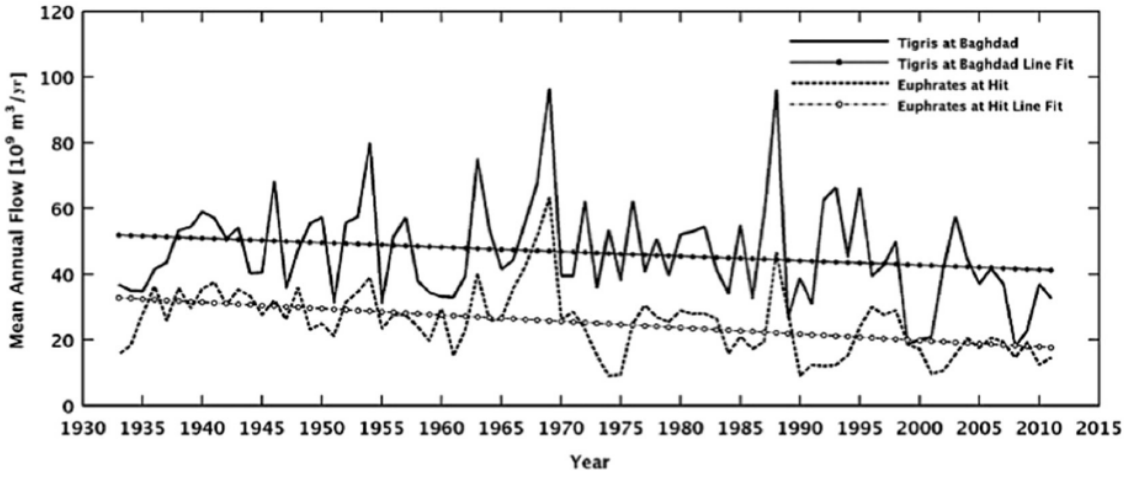
Projections for 2100 suggest a weakening of the Indian winter monsoon in the Arabian Sea

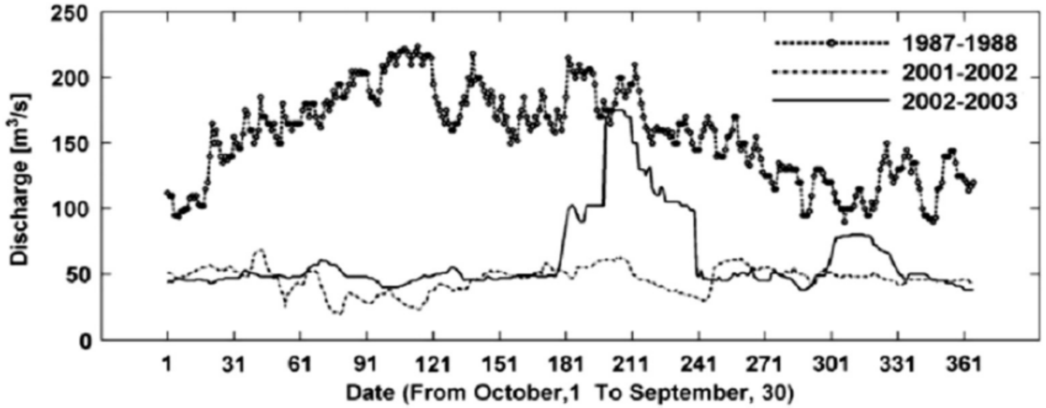
Sea level rise

Sea-level rise of 2.2 mm per year has been estimated for the Gulf

Other pressures are impacting the Gulf

- Fresh water flow from the North (Tigris, Euphrates and Karun estimated to be 35-133 km3 year -1.
- Net evaporation 350 – 800 km3 year -1.
- Inflow to the south from the Arabian Sea via the Strait of Hormuz.
- Discharge of brine from desalination plants.



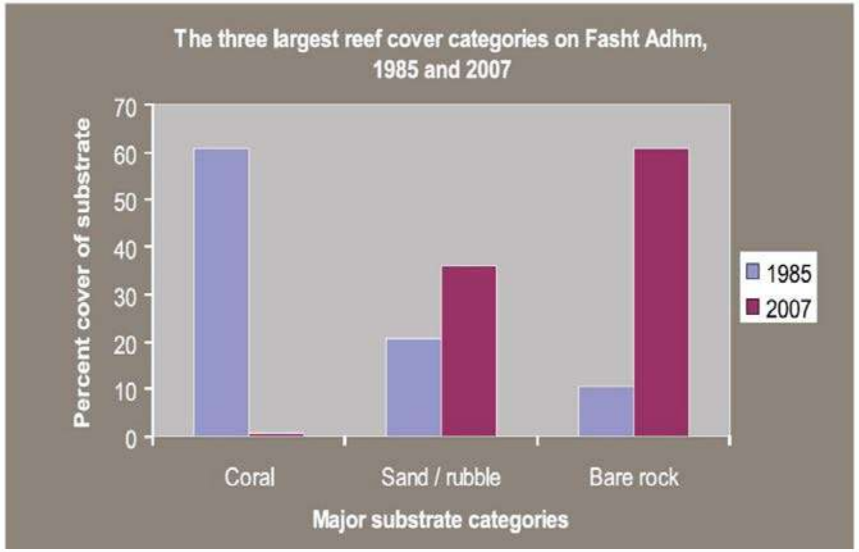


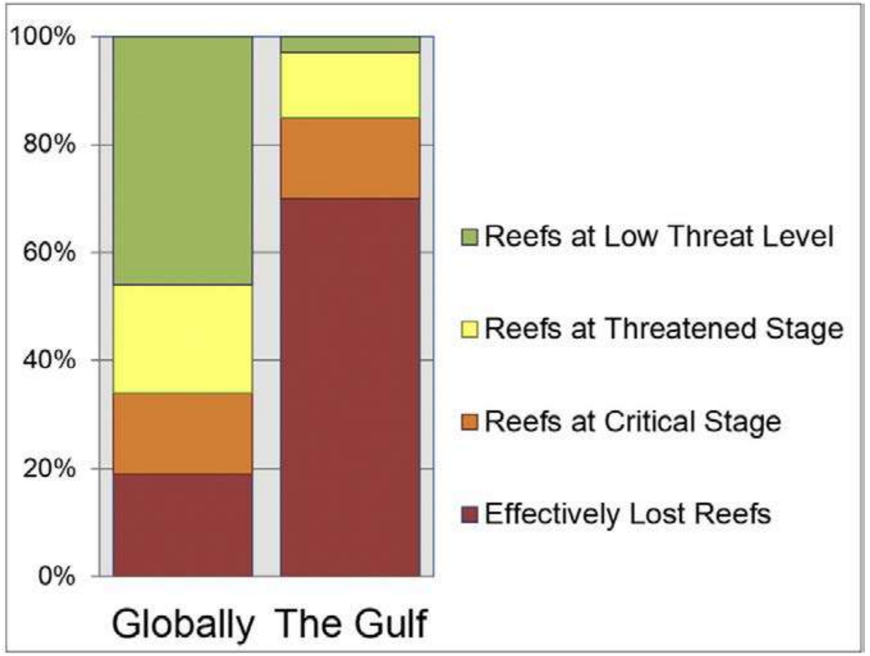
Alosairi and Pokavanich, Mar Pol Bul (2015)

Abdullah et al., (2015). Int. J. River Basin Manag. 13, 215–227.

The Gulf - a ecosystem in trouble

- Evidence to suggest that a significant decline is happening across all marine systems (coral reefs, sea grass beds, fisheries etc), to the extent its been termed a 'young sea in decline' (Sheppard et al., 2010).
- Estimated that 70% loss of coral reef cover from the historic 3800 km2 of cover.
- Economic impact associated with decline.
- Equates to an annual loss of $94 billion to the regional economy (Costanza et al., 2014; Burt et al., 2014; Sheppard et al., 2015).





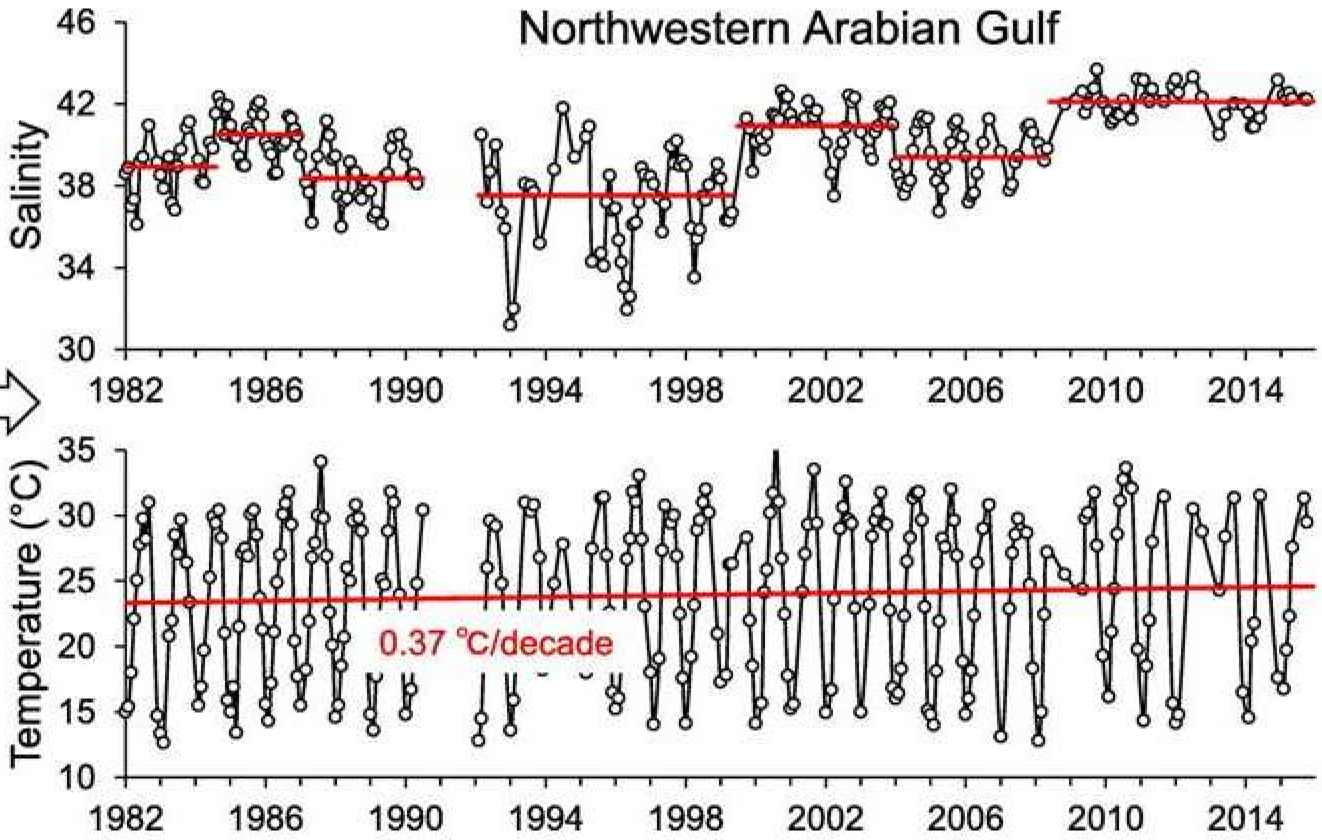
Burt et al., (2014). . Ocean Chall., 20, 49-56
Costanza et al., (2014). Glob. Environ. Chang., 26, 152-158
Sheppard et al., (2010). Mar. Pollut. Bull., 60, 13-18
Sheppard et al., (2015). Mar. Pollut. Bull., 105, 593-598

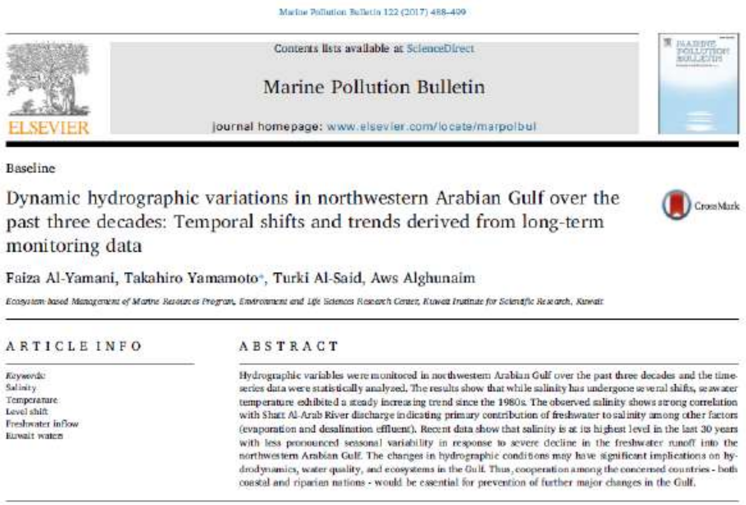
Water exchange

River discharge

Climate change

Wastewater (brine)





Marine Pollution Bulletin 122 (2017) 488-499

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Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Baseline

Dynamic hydrographic variations in northwestern Arabian Gulf over the past three decades: Temporal shifts and trends derived from long-term monitoring data

Faiza Al-Yamani, Takahiro Yamamoto*, Turki Al-Said, Aws Alghunaim

Ecosystem-based Management of Marine Resources Program, Environment and Life Sciences Research Center, Kuwait Institute for Scientific Research, Kuwait

ARTICLE INFO

Keywords:
Salinity
Temperature
Level shift
Freshwater inflow
Kuwait water

ABSTRACT

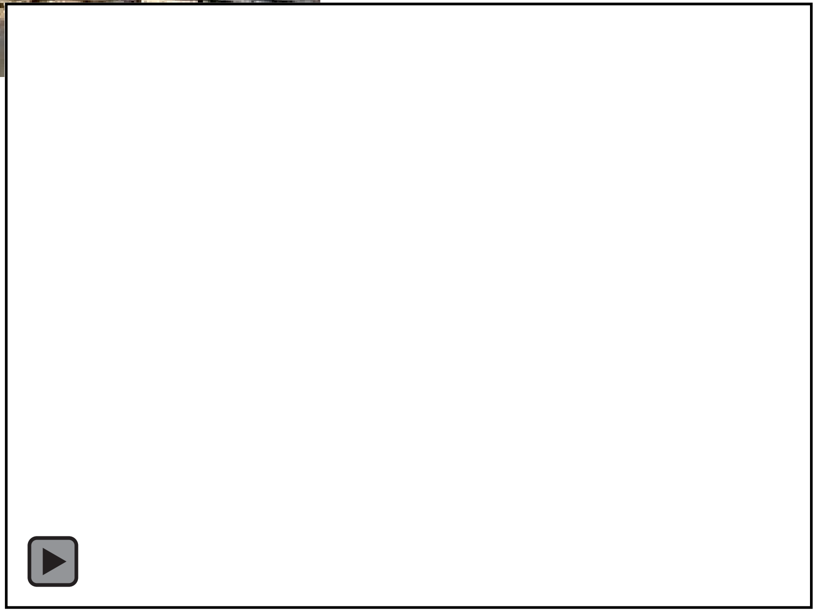
Hydrographic variables were monitored in northwestern Arabian Gulf over the past three decades and the time-series data were statistically analyzed. The results show that while salinity has undergone several shifts, seawater temperature exhibited a steady increasing trend since the 1980s. The observed salinity shows strong correlation with Shatt Al-Arab River discharge indicating primary contribution of freshwater to salinity among other factors (evaporation and desalination effluent). Recent data show that salinity is at its highest level in the last 30 years with less pronounced seasonal variability in response to severe decline in the freshwater runoff into the northwestern Arabian Gulf. The changes in hydrographic conditions may have significant implications on hydrodynamics, water quality, and ecosystems in the Gulf. Thus, cooperation among the concerned countries - both coastal and riparian nations - would be essential for prevention of further major changes in the Gulf.

Al Yamani et al., (2017). Mar. Pollut. Bull., 122, 488-499

Water Quality issues

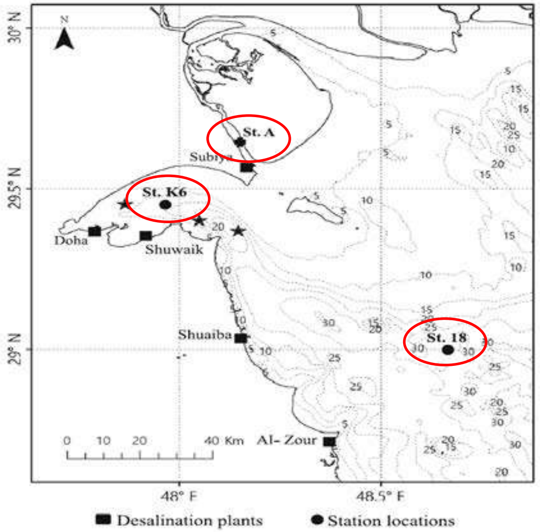
- Urbanisation, sewage outfalls
- Elevated nutrient concentrations
- Phytoplankton –shift in plankton community?
- Increase incidence of HABS?
- Increasing turbidity inshore
- Dissolved Oxygen sags
- Microbial (bathing water) issues
- Human health concerns

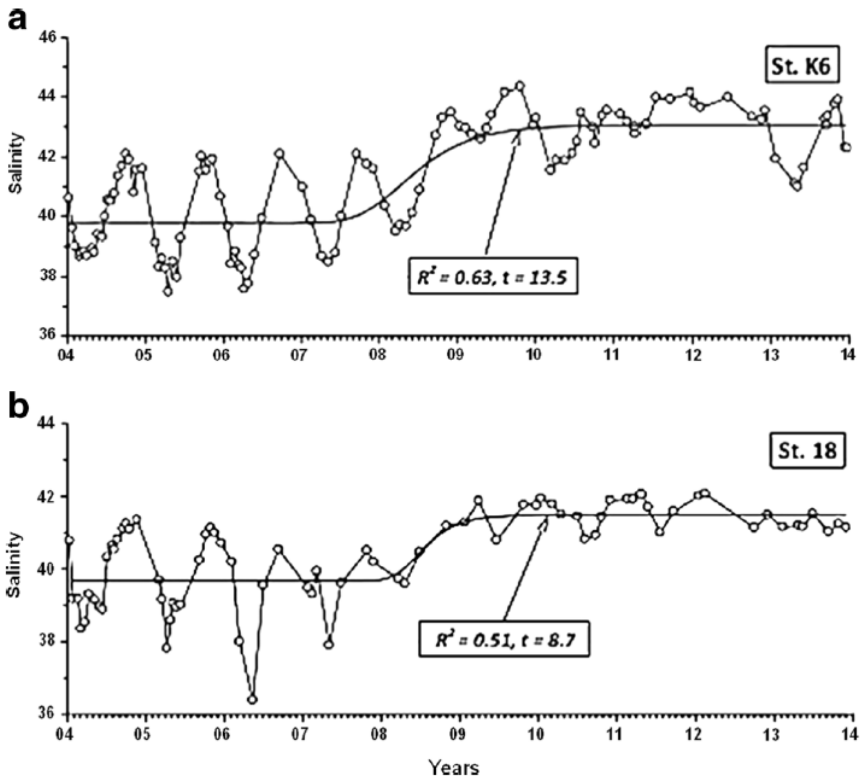
- Water quality issues can impact on resilience.



Case Study - Kuwait

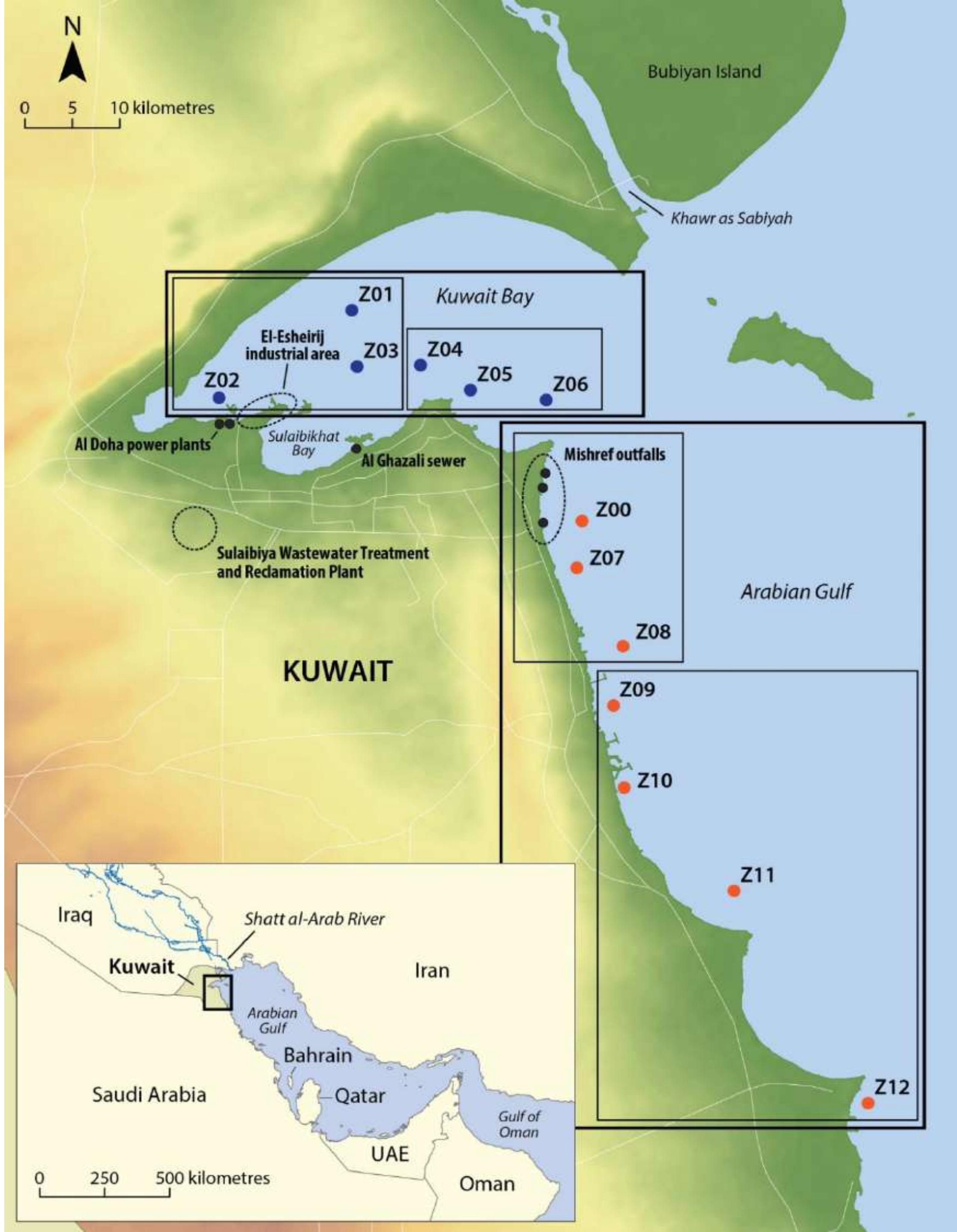
- The Shatt al-Arab River responsible for diffuse nutrient runoff from late 1980s
- Changing land use patterns – Shatt Al Arab River – higher salinity
- Human intervention (1970s) related to water mining, marsh drainage, damming policies and limited bilateral water management resulting in reductions in water flow and increased salinity levels in receiving waters – shifting baseline represents much of the Gulf

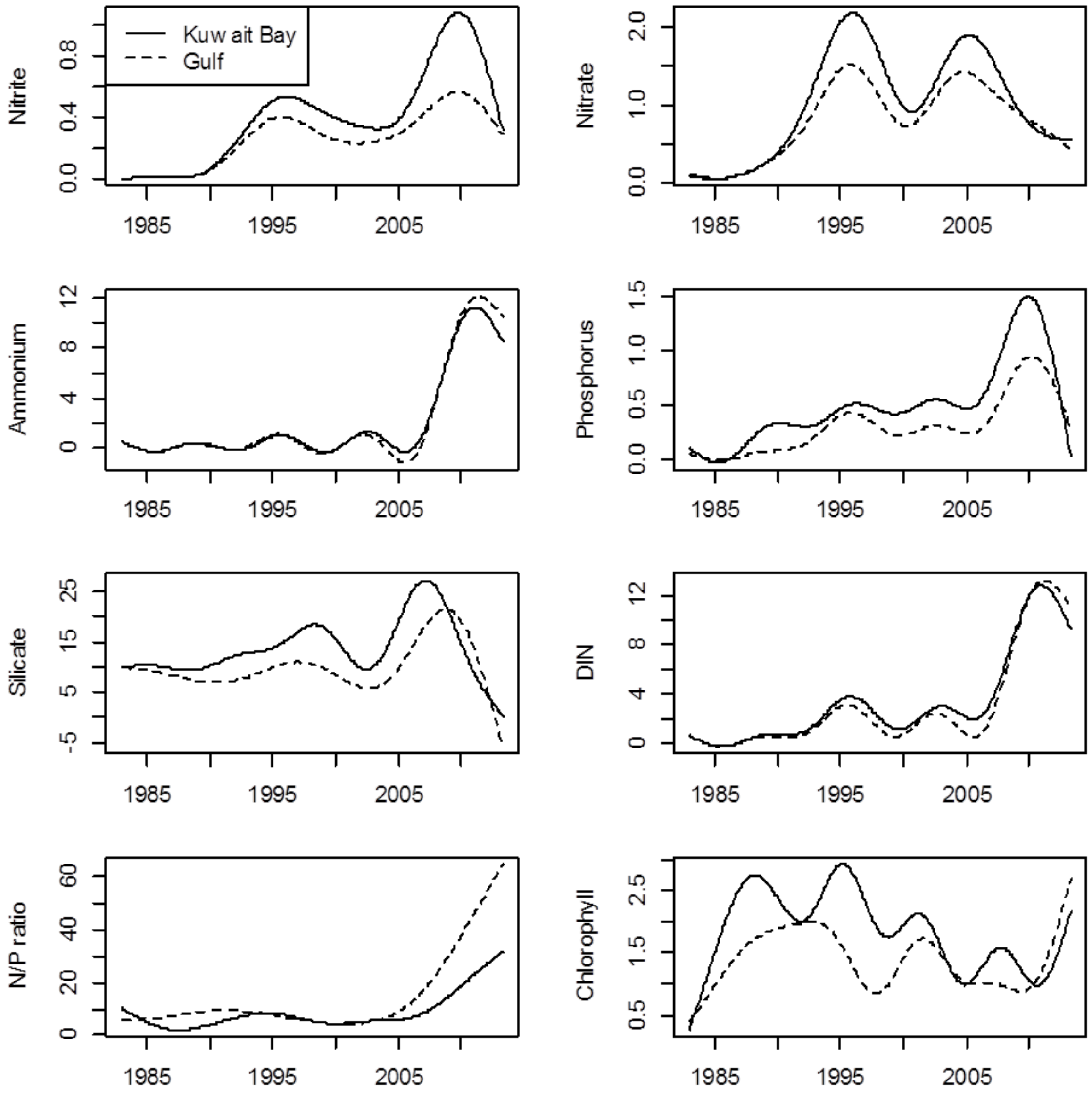




St A: % freshwater
1997 = 25.6 – 42.5 %;
2012-2013 = 0.8 – 4.6%

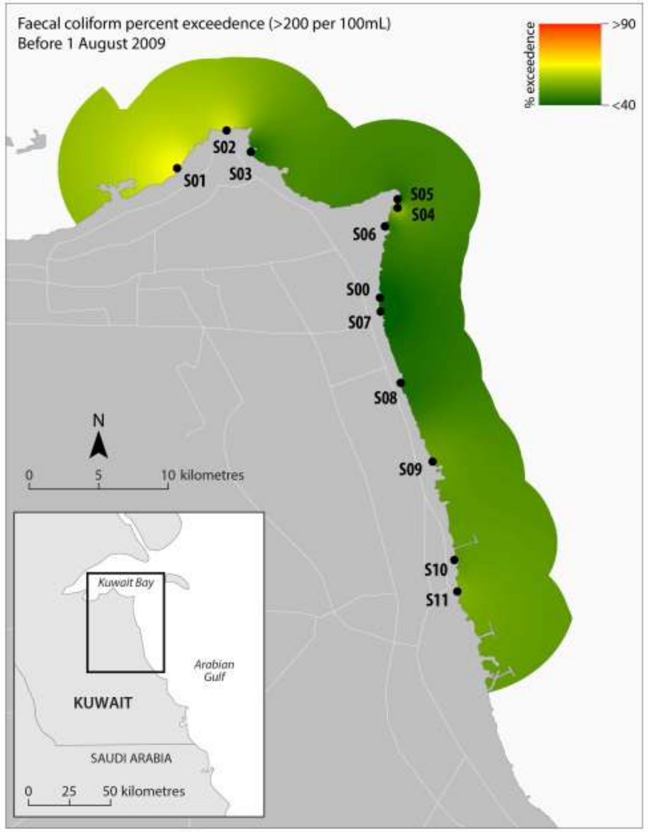
Abdullah et al., (2015). Int. J. River Basin Manag. 13, 215–227.


N
0 5 10 kilometres
Bubiyan Island
Khawr as Sabiyah
Kuwait Bay
Z01
El-Esheirij industrial area
Z03
Z04
Z05
Z06
Z02
Al Doha power plants
Sulaibikhat Bay
Al Ghazali sewer
Mishref outfalls
Z00
Z07
Z08
Sulaibiya Wastewater Treatment and Reclamation Plant
Arabian Gulf
KUWAIT
Z09
Z10
Z11
Z12
Iraq
Shatt al-Arab River
Kuwait
Iran
Arabian Gulf
Bahrain
Saudi Arabia
Qatar
Gulf of Oman
UAE
Oman
0 250 500 kilometres

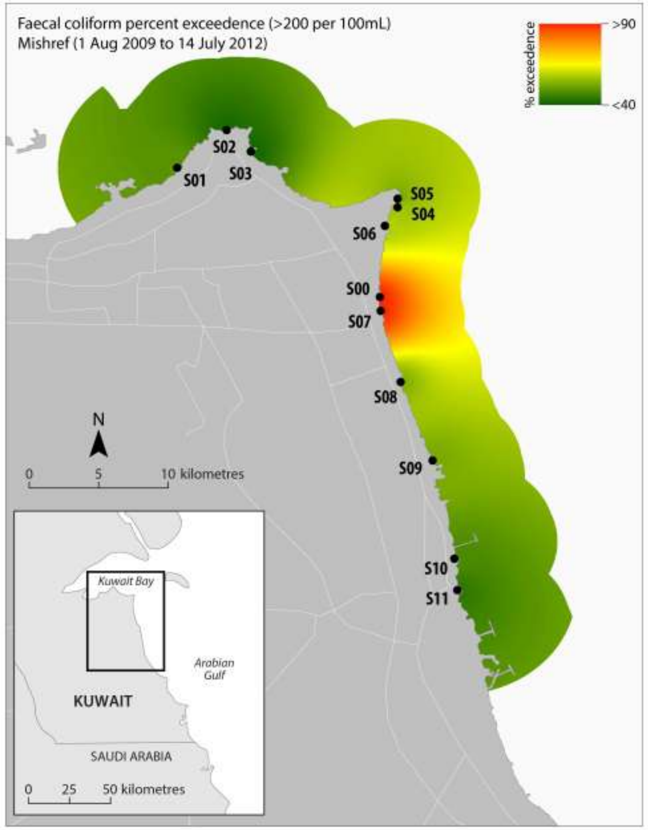

Kuw ait Bay
Gulf
Nitrite
Nitrate
Ammonium
Phosphorus
Silicate
DIN
N/P ratio
Chlorophyll
1985
1995
2005

Kuwait

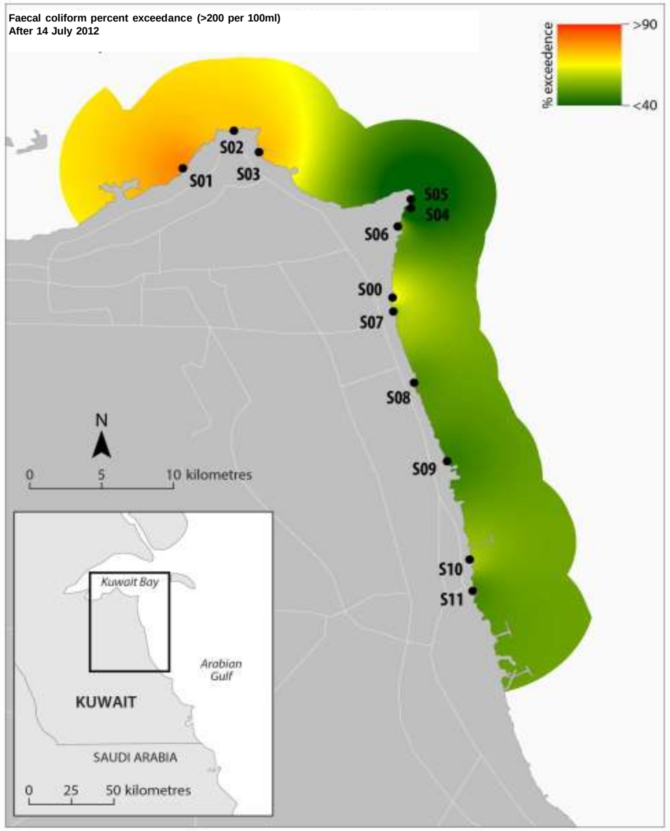
Pre – chronic event



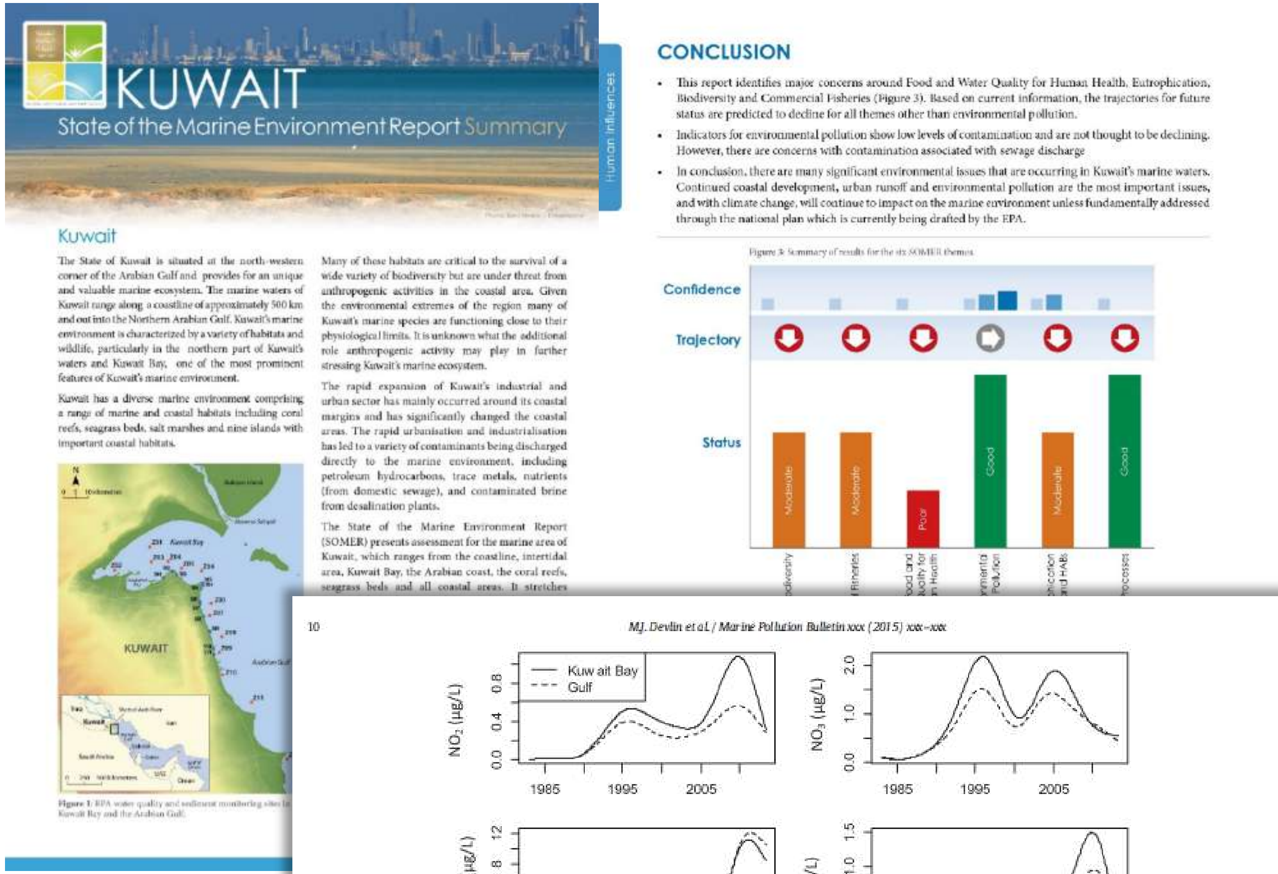
Chronic event



Post Chronic event (to late 2013)



- A combination of chronic and diffuse nutrient loads has had a major impact on the status of the water quality indicators – dissolved nutrients have increased over last 30 years
- Chlorophyll-a data shows a significant reduction in the phytoplankton biomass associated with seasonal blooms
- DO sags
- Increased turbidity in Kuwait Bay
- Analysis of phytoplankton lifeforms shows community shifts



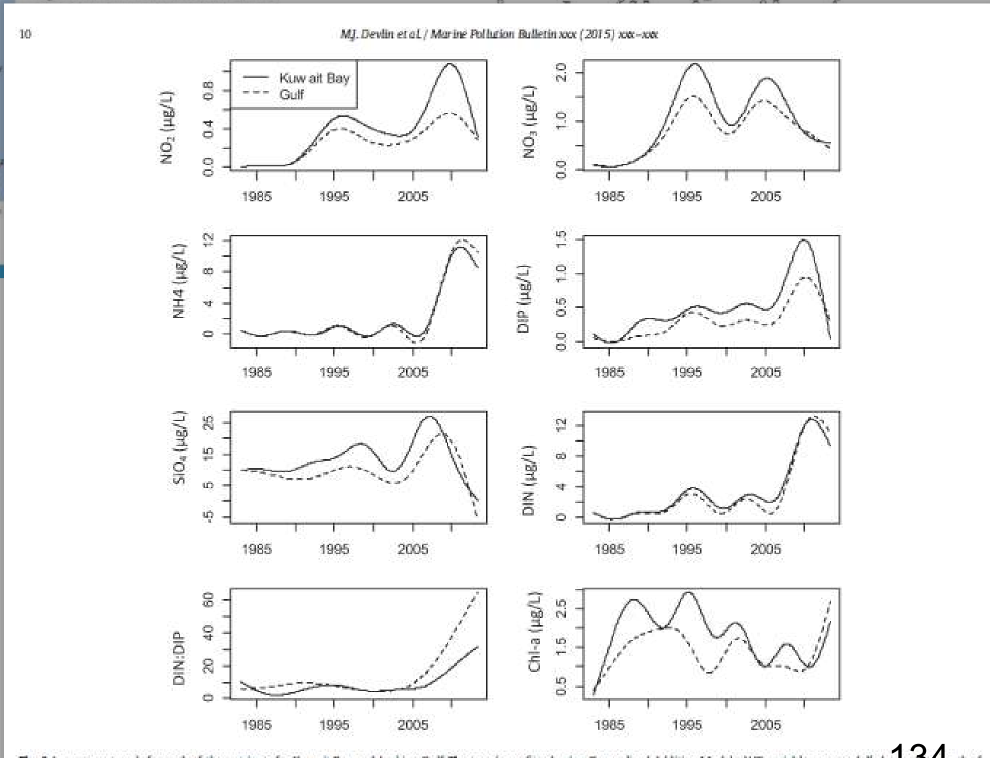
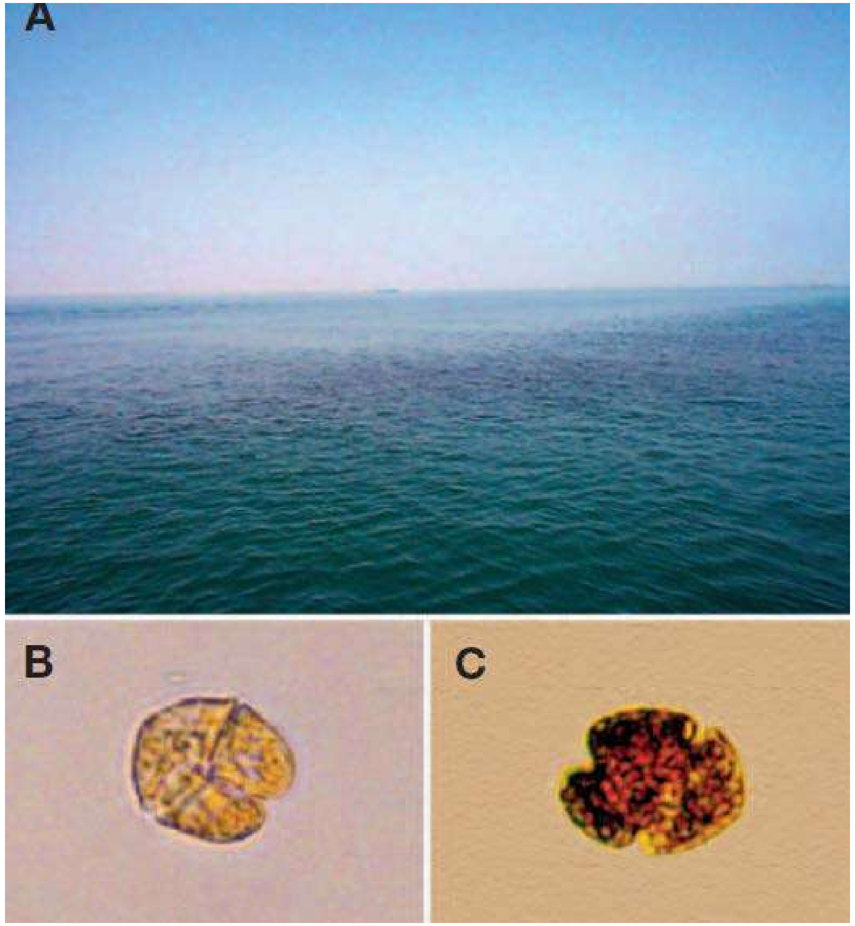


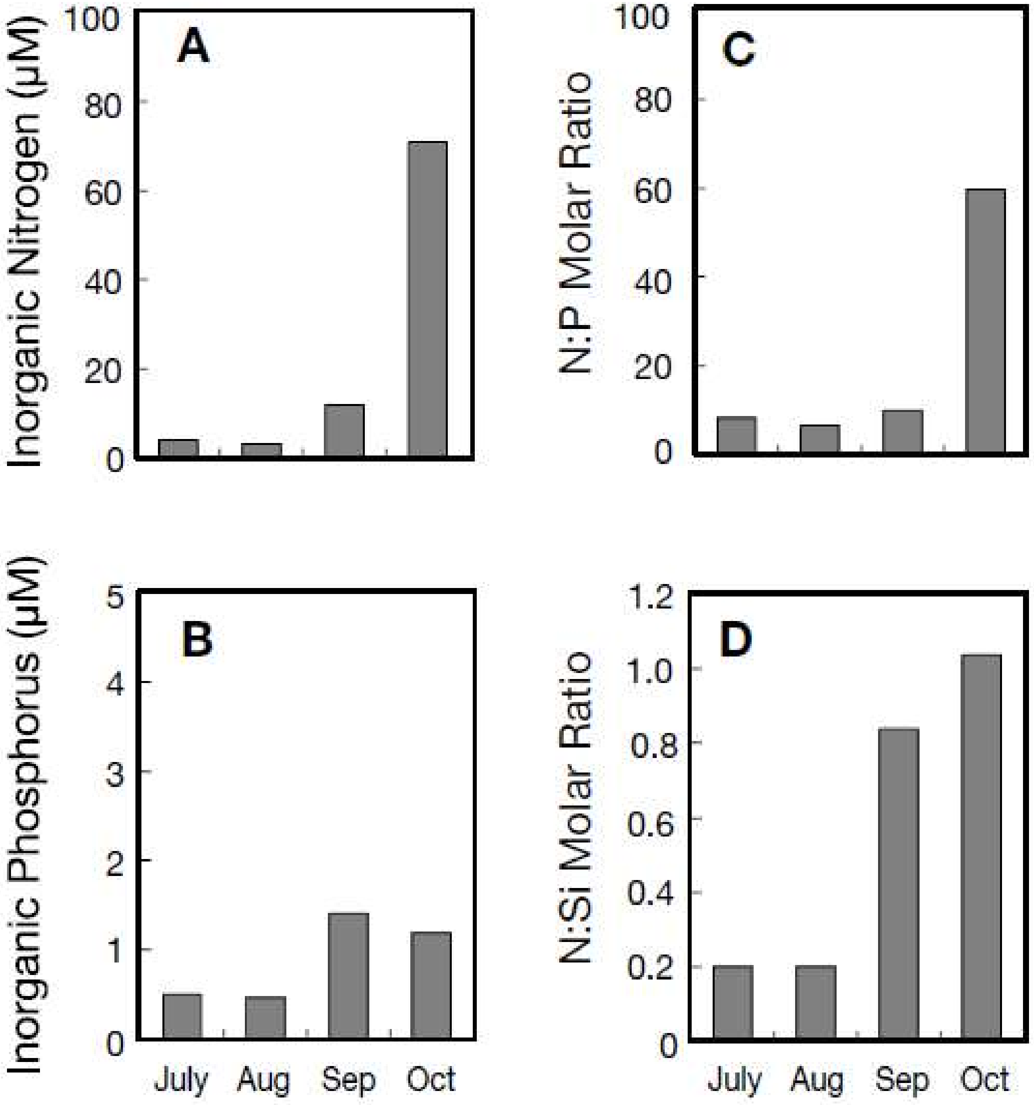
Fig. 6. Long-term trends for each of the nutrients for Kuwait Bay and Arabian Gulf. The trends are fitted using Generalised Additive Models. WQ variables are modelled over the length of the time series (1984–2012). Water quality parameters include NO3, NO2, NH4, PO4, silicate, DIN (NO3 + NO2 + NH4), DIN:DIP (DIN:DIP only) ratio and chlorophyll-a. Units of measure for all nutrient species and chlorophyll-a are µg/L.

Devlin et al., 2012, Devlin et al., 2012, Lyons et al., 2012
Al-Said et al. 2018

1999 HAB event Kuwait Bay



Heil et al., 2001



EUTROPHICATION AND HARMFUL ALGAL BLOOMS

Strategic goals

- To minimise human-induced eutrophication and its
- To reduce the frequency of human-induced harmf consequences of HABs.

Key findings

Status = MODERATE | Trajectory = DECLINE | Co

- Status assessment is MODERATE
- Future trajectory of status is predicted to continue to decline.

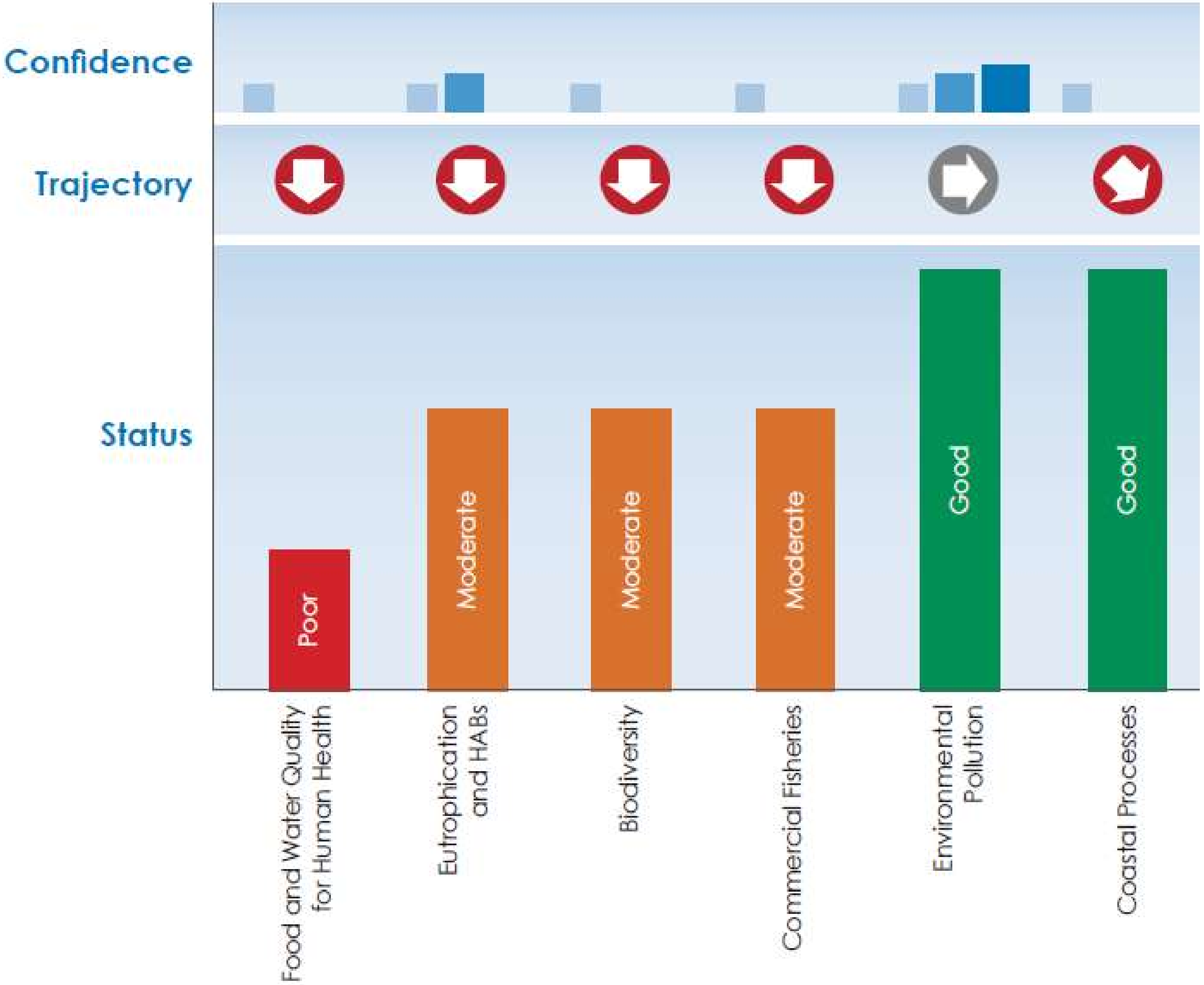
Indicator outcomes

Attribute	Component	OUTCOMES		
		Status	Future trajectory	Confidence of assessment
				Eutrophication and HABs
Eutrophication	Dissolved Inorganic Nitrogen (DIN)	●	⬇	■■■
	Dissolved Inorganic Phosphorus (DIP)	●	⬇	■■■
	Phytoplankton—Chlorophyll-a	●	⬇	■■
	Phytoplankton—Community composition	?	?	■
	Dissolved oxygen	●	➡	■
	Water quality index	●	⬇	■■
HABs	Harmful Algal Blooms	●	?	■

* Water Quality (WQ) index reports nutrients, phytoplankton, turbidity and dissolved oxygen as a single eutrophication index.

SOMER - Kuwait

- Major concerns around Food and Water Quality for Human Health, Eutrophication, Biodiversity and Commercial Fisheries
- Trajectories for future status are predicted to decline for all themes other than environmental pollution



Wider Gulf

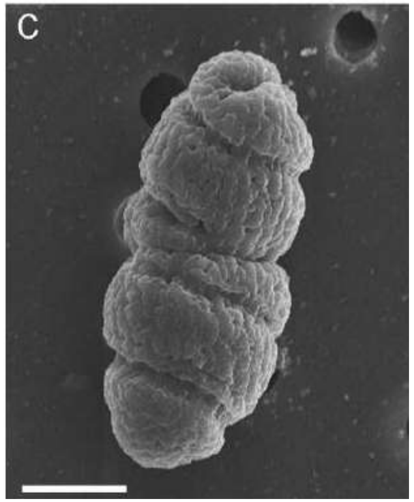
- Many similar issues
- Chronic coastal pollution related to urban expansion, unregulated infrastructure, unregulated, illegal discharges
- Reduce flow, increasing salinity having profound impact on plankton community in Northern Gulf
- Decline is happening across all marine systems (coral reefs, sea grass beds, fisheries etc),

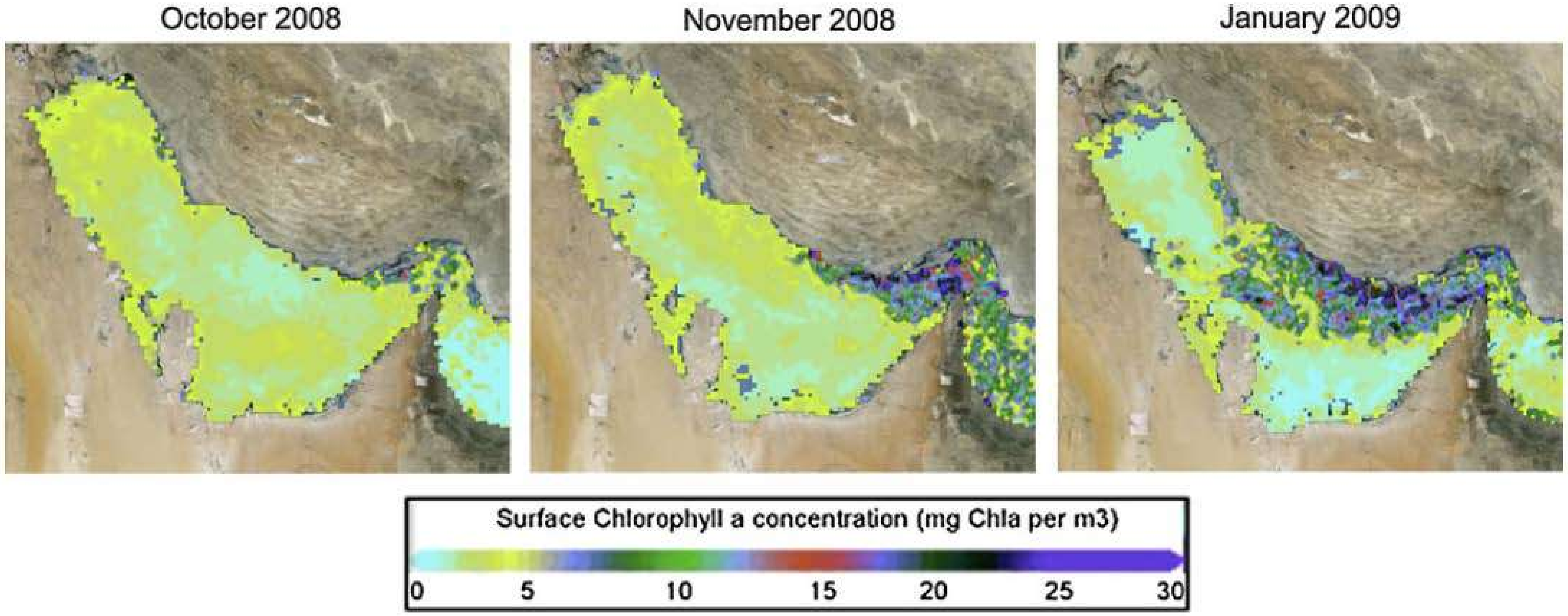
Ben-Hasen et al., 2018 MPB
Al0 Said et al., Env Mon Ass
Shepard et al.,2010 MPB

- Salinity-related environmental changes - coincidental decrease in species diversity and significant changes in phytoplankton community
- Corresponding decline in fish catch for commercial species
- Major concerns with HABS issues
- Significant declines in coral reefs
- Climate change interactions

HABS in the Gulf

- Low DO during algal blooms -primary causes of benthic mortality
- Smothering – coral mortality
- Death of large quantities of fishes and crustacean
- Impact on human health by causing respiratory irritation
- Impacts on desalination plants





Large-scale HAB event (> 500 km2) of the dinoflagellate Cochlodinium polykrikoides caused the complete loss of the branching corals, Pocillopora and Acropora spp., and substantial reductions in the abundance, richness and trophic diversity of the associated coral reef fish communities

Kuwait (Gilbert et al., 2002), Oman and UAE (Al-Azri et al., 2014, Al Gheilani et al., 2011, Al Shehhi et al., 2014, Claereboudt et al., 2001, Richlen et al., 2010) and UAE; (Guzmán et al., 1990), (Sellner et al., 2003, Tomlinson et al., 2009); Richen et al., 2010

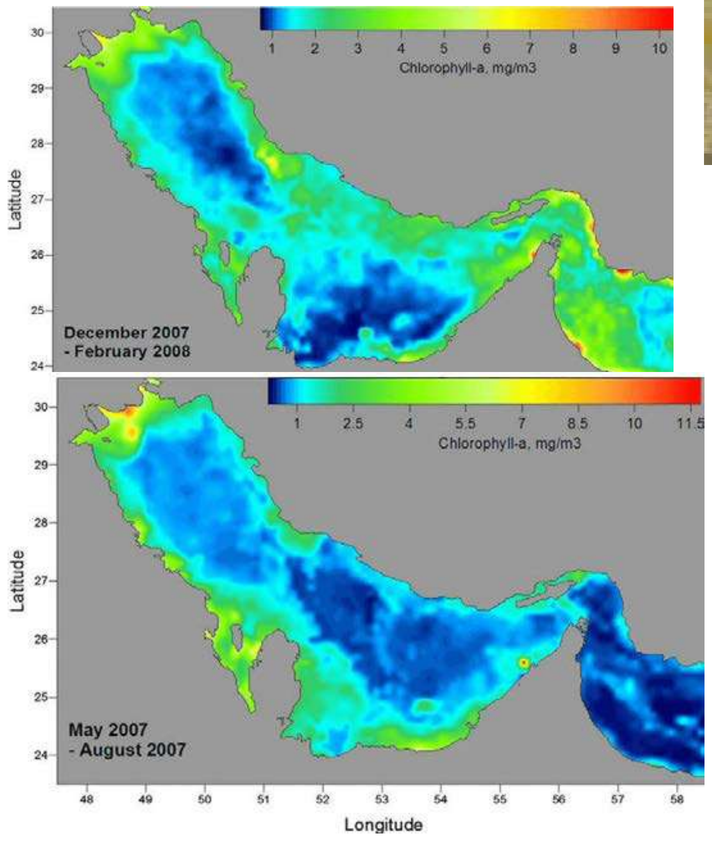
Sale et al., 2011

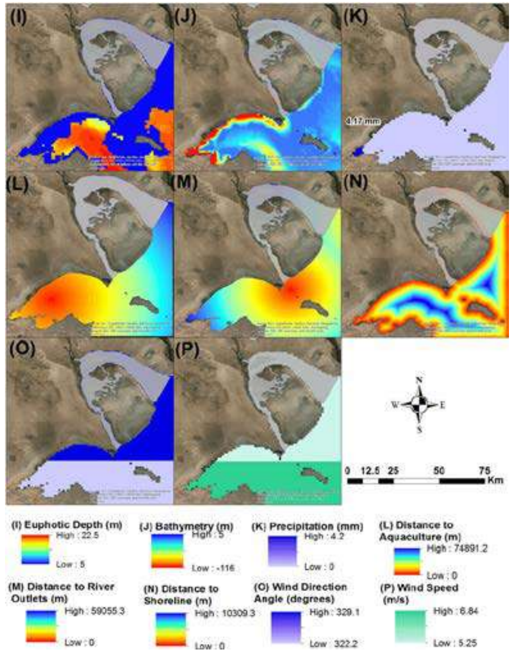
Gulf solutions

Positives

- Growing awareness of coastal water quality issues
- Development of strategic environmental goals via national ministries and regional bodies
- Organisations – such as ROPME – recognising the transboundary issues must be solved through a common approach.
- Many other national and regional programs underway
- Several Gulf countries developing national and regional frameworks – recognising the uniqueness of the Gulf environment and high biodiversity values.
- Move towards global frameworks (SDGs, Aichi targets)

Gulf scale





Al-Mudaffar Fawzi & Mahdi, 2015, Sheppard et al.,2015

Challenges

- Unique habitats – in decline.
- Coastal expansion continues – lack of coastal planning
- Climate change – multiple stressor framework required.
- No single driver or solution.
- HABS issues not resolved
- Human health concerns
- Complex relationships with changing river flows not resolved

Need for Gulf wide approach aligned with national priorities

- **Take home question**
- How to accelerate management of water quality issues to "buy" time for climate mitigation

Linking environmental factors, HAB events and impacts on fish and shellfish

Adam Lewis
Ross Brown

22nd & 23rd February 2022

Workshop: Early warning systems for Harmful Algal Blooms in the Arabian Gulf

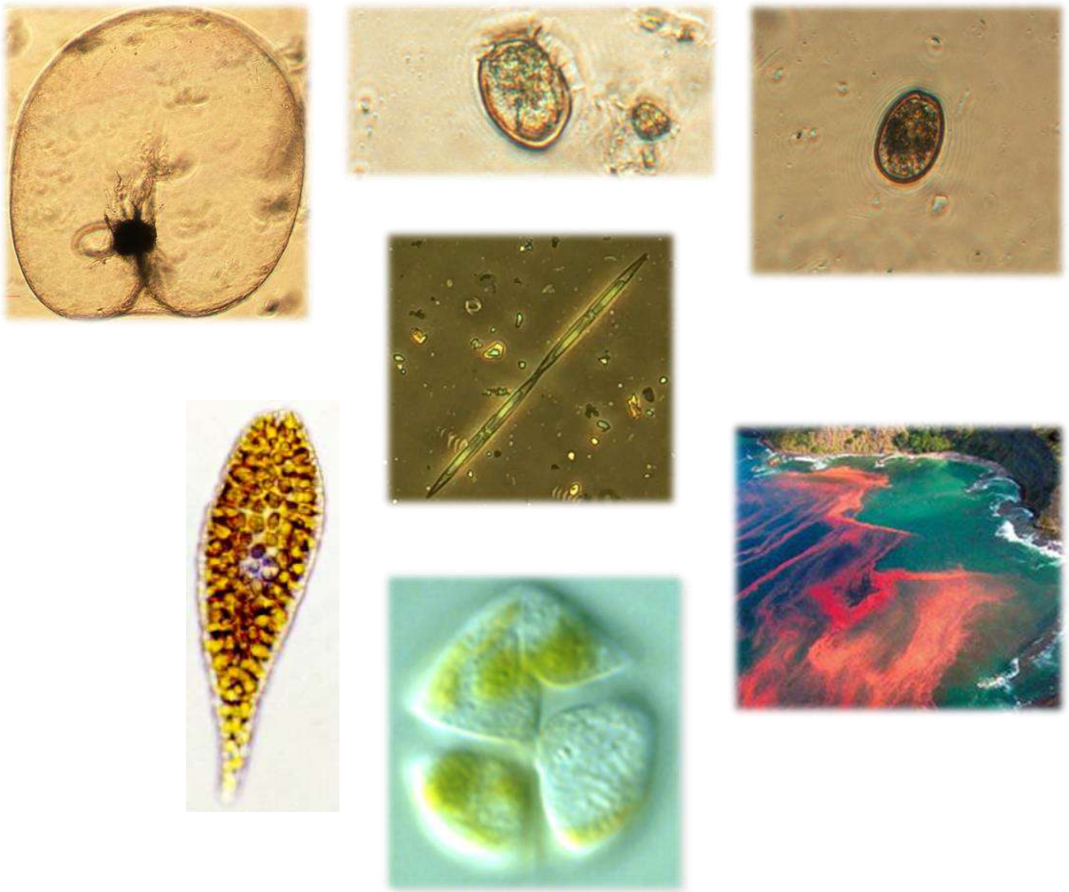
Centre for Environment Fisheries & Aquaculture Science

UNIVERSITY OF EXETER

Cefas

Harmful Algal Blooms and the Environment

- **~300 Harmful microalgal species**
    - **Dinoflagellates***
    - **Diatoms, Raphidophytes, Haptophytes**
- **Diverse impacts at diverse concentrations**
    - **Toxic**
    - **Mechanical**
    - **Hypoxia**
- **Local Environmental drivers vary**
    - **Recurrent Vs Transient**
    - **Physical & chemical**
    - **Anthropogenic**



HABS and One Health

Turner *et al.* 2021

HABs and the Arabian Gulf

<table>
<tr><th>Harmful species</th><th>Toxins</th><th>Impact</th></tr>
<tr><td>Alexandrium minutum</td><td>Paralytic shellfish toxins (PST)</td><td rowspan="5">• Shellfish intoxications.
• Can lead to human consumption and subsequent poisonings.
• Present in a wide range of marine organisms at different trophic levels.</td></tr>
<tr><td>Alexandrium tamarense*</td><td>PST</td></tr>
<tr><td>Alexandrium affine</td><td>PST</td></tr>
<tr><td>Gymnodinium catenatum</td><td>PST</td></tr>
<tr><td>Pyrodinium bahamense</td><td>PST</td></tr>
<tr><td>Protoceratium reticulatum</td><td>Yessotoxins (YTX)</td><td rowspan="2">• No human poisoning known.
• Has been implicated in mass marine mortalities.</td></tr>
<tr><td>Lingulodinium polyedra</td><td>YTX</td></tr>
<tr><td>Chatonella sp.</td><td>Ichthyotoxins</td><td rowspan="4">• Often poorly or undescribed.
• May impact finfish in a variety of ways depending on the nature of the toxin.
• Can be fast acting with high levels of mortality or cause longer term sublethal effects.</td></tr>
<tr><td>Polykrikos hartmani</td><td>Ichthyotoxins</td></tr>
<tr><td>Heterosigma akashiwo</td><td>Ichthyotoxins</td></tr>
<tr><td>Cochlodinium polykrikoides</td><td>Ichthyotoxins</td></tr>
<tr><td>Scripsiella trochoidea</td><td>Anoxia</td><td>• High biomass can result in mass marine mortalities.</td></tr>
<tr><td>Fukuyoa yasumotoi</td><td>-</td><td>• Related to Ciguatera producing species.</td></tr>
</table>

Identification of Bloom species & Toxins

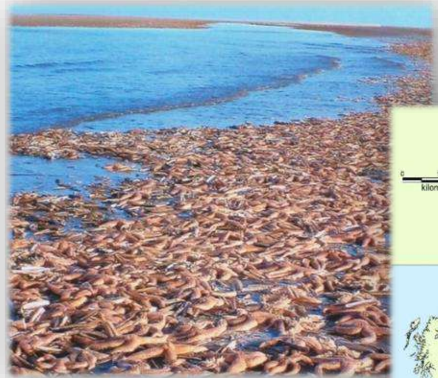
- **Range of techniques**
  - **In-situ or off site.**
- **Different techniques may be suited to different species**
  - **Preservation/detection issues**
- **Morphological and/or Molecular taxonomy**
- **Quantitative and Qualitative methods**
- **Targeted and untargeted methods**

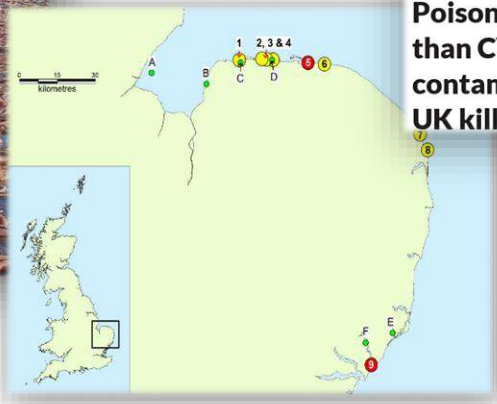





Ecological impacts in the UK

- **Winter storms 2017/18**
  - **Mass marine strandings.**
- **Dog sickness and death following consumption**
  - **Analysis of clinical material and stranded organisms revealed Paralytic Shellfish Toxins (PST) as the cause.**
- **Prevalence of PST in marine organisms**
  - **Two independent analytical techniques used.**
  - **Multiple trophic levels.**
  - **Unexpected region and season.**
  - **More questions than answers.**





Turner et al. 2018

Data-driven models for predicting HAB impacts on shellfish aquaculture

Ross Brown (University of Exeter)

Recording and accessing HAB monitoring data

Datasets	Records
Network Monitoring phytoplankton (France)	5,457
ICES Phytoplankton Community dataset	5,247
SHARK - Monitoring of phytoplankton (Sweden)	4,444
National Monitoring Programme Aquaculture Production Areas Netherlands	4,397

HAB monitoring programmes

HAB occurrence
cell abundance

HAB impacts
shellfish poisoning, fish kills

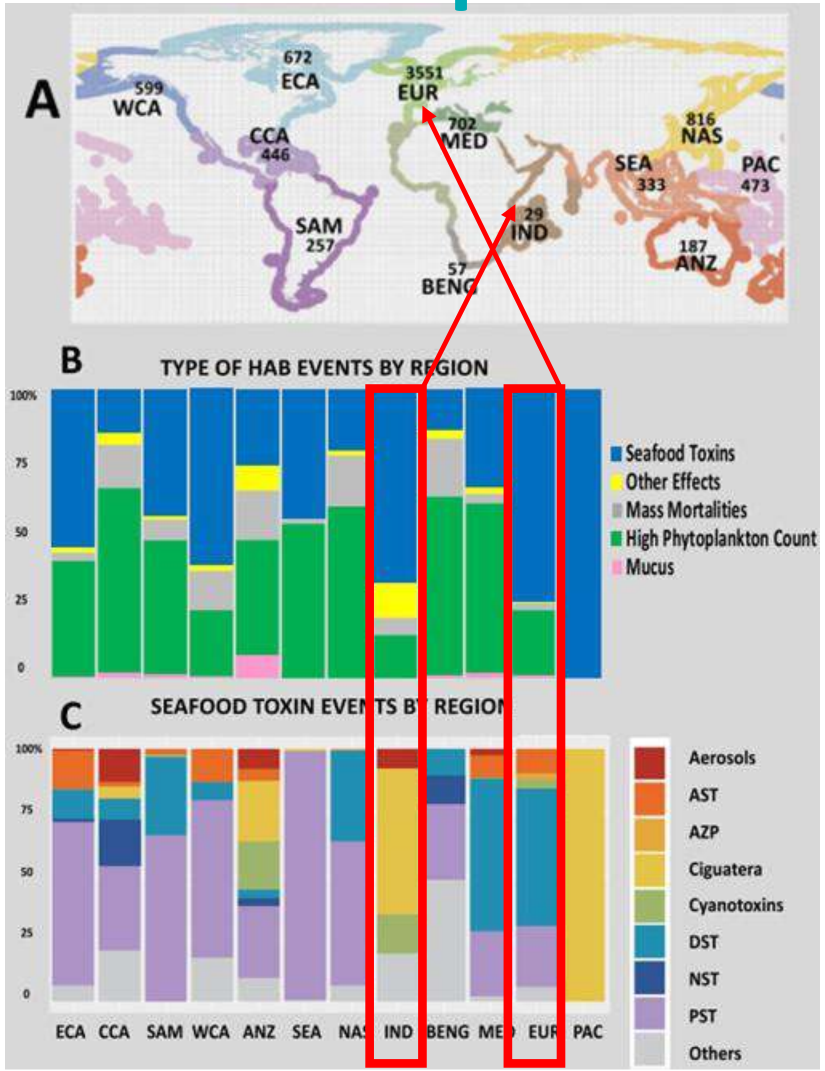
Ocean Biodiversity Information System (OBIS)
(https://www.obis.org)

Harmful Algae Event Database (HAEDAT)
(http://haedat.iode.org)

HAB monitoring has increased with aquaculture expansion

- Perceived increase in harmful algae events
- Increasing global trends not supported
- Indian Ocean (incl. Arabian Gulf) excluded from trend analysis
- **HAB trends should be analysed regionally at the species level**
- **HAB impacts are conspicuous in all regions**

Gustaaf M. Hallegraeff, Donald M. Anderson et al. (2021)



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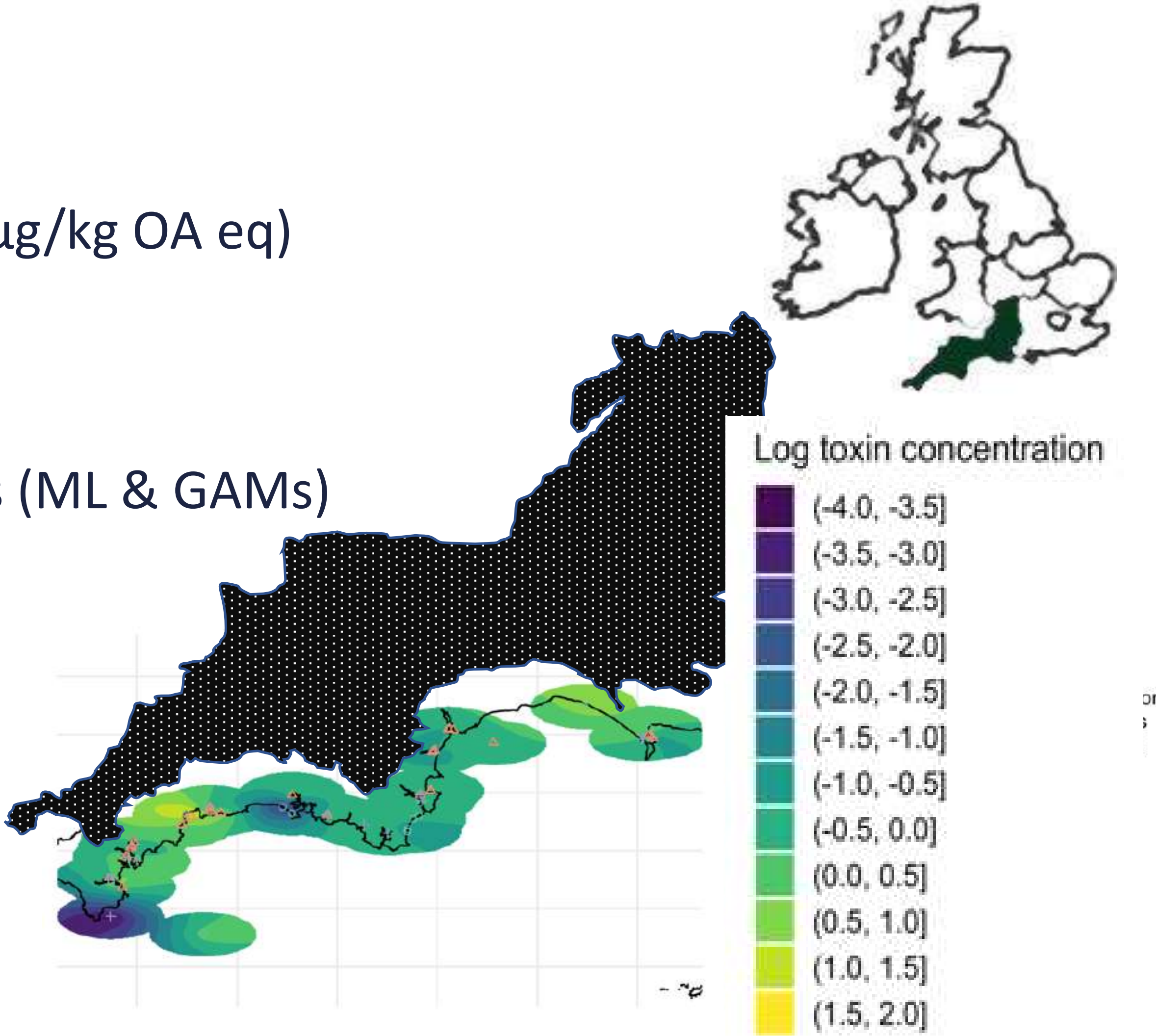
Interrogating HAB monitoring data for UK shellfish sites

- *Dinophysis* spp. abundance (≥100 cells/L)
- Dinophysis toxin concentrations in shellfish (≥160 µg/kg OA eq)
- Environmental data (e.g. sea surface temperature)
- Data-driven analysis of spatial and temporal trends (ML & GAMs)
- **Predict hotspots for *Dinophysis* spp.** 
- **Predict future impacts on shellfish farms**

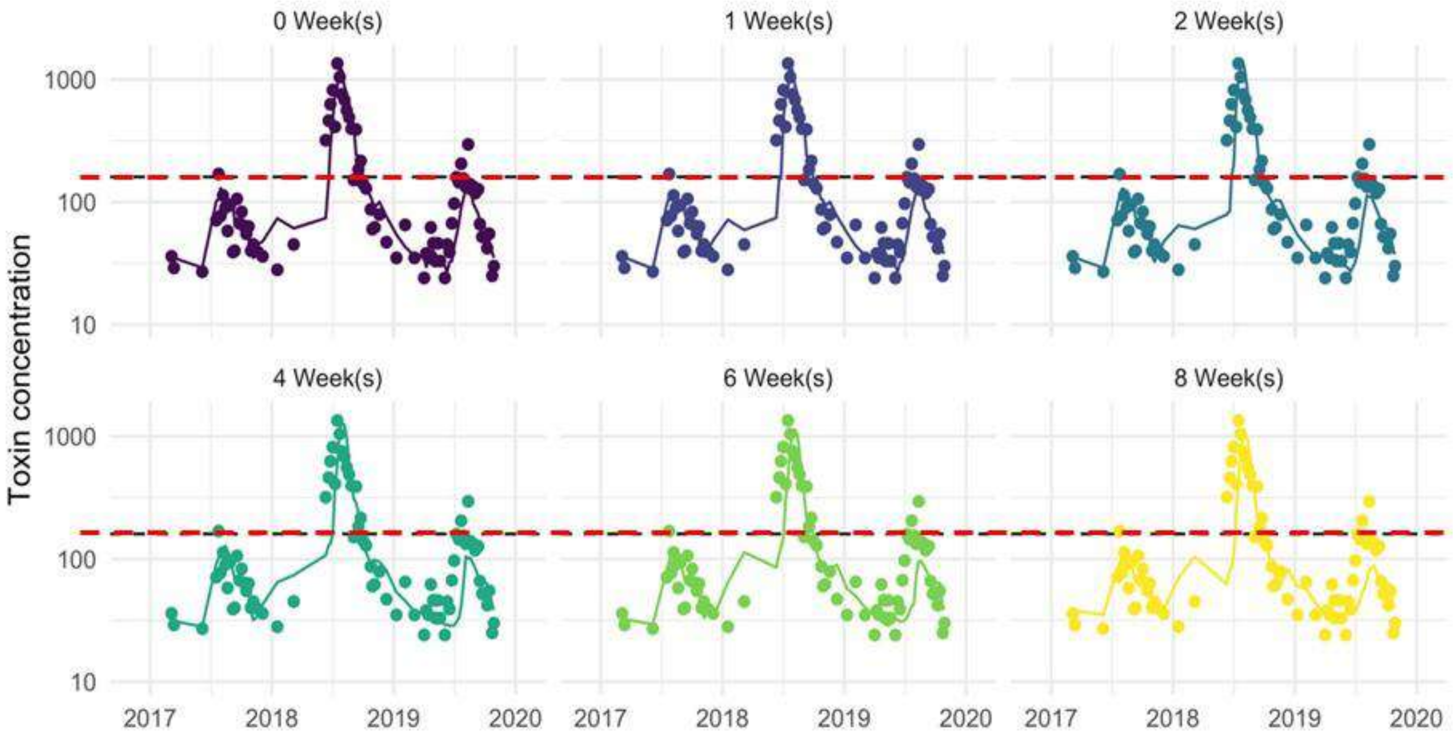
Oliver Stoner and Theo Economou et al. (2021).



Forecasting Dinophysis toxin concentrations

- Account for time-lagged temperature and abundance (26 variables)
- Account for different shellfish species
- Long-term seasonal smoothing
- Forecast exceedance of threshold up to **8 weeks ahead (87% accuracy)**
- **Inform design of future monitoring**

Oliver Stoner and Theo Economou et al. (2021).



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Summary

- Linking cause and impact can be difficult
- Differences between aquaculture and wild capture
    - Motile Vs Sessile
- Disparate nature of blooms
- Monitoring to inform data driven models
- Emergency response capacity

Take home message

- Holistic monitoring, broad, consistent

References

- Hallegraeff GM., Anderson DM. et al. (2021). https://doi.org/10.1038/s43247-021-00178-8
- Stoner O., Economou T. et al (2021). https://doi.org/10.21203/rs.3.rs-668820/v1
- Turner et al. (2021). https://doi.org/10.1016/j.jip.2021.107555
- Turner et al. (2018). **https://doi.org/10.3390/toxins10030094**

Understanding impacts of HABs on fish farms based on lessons learned in Chile

INSTITUTO DE FOMENTO PESQUERO

CREAN

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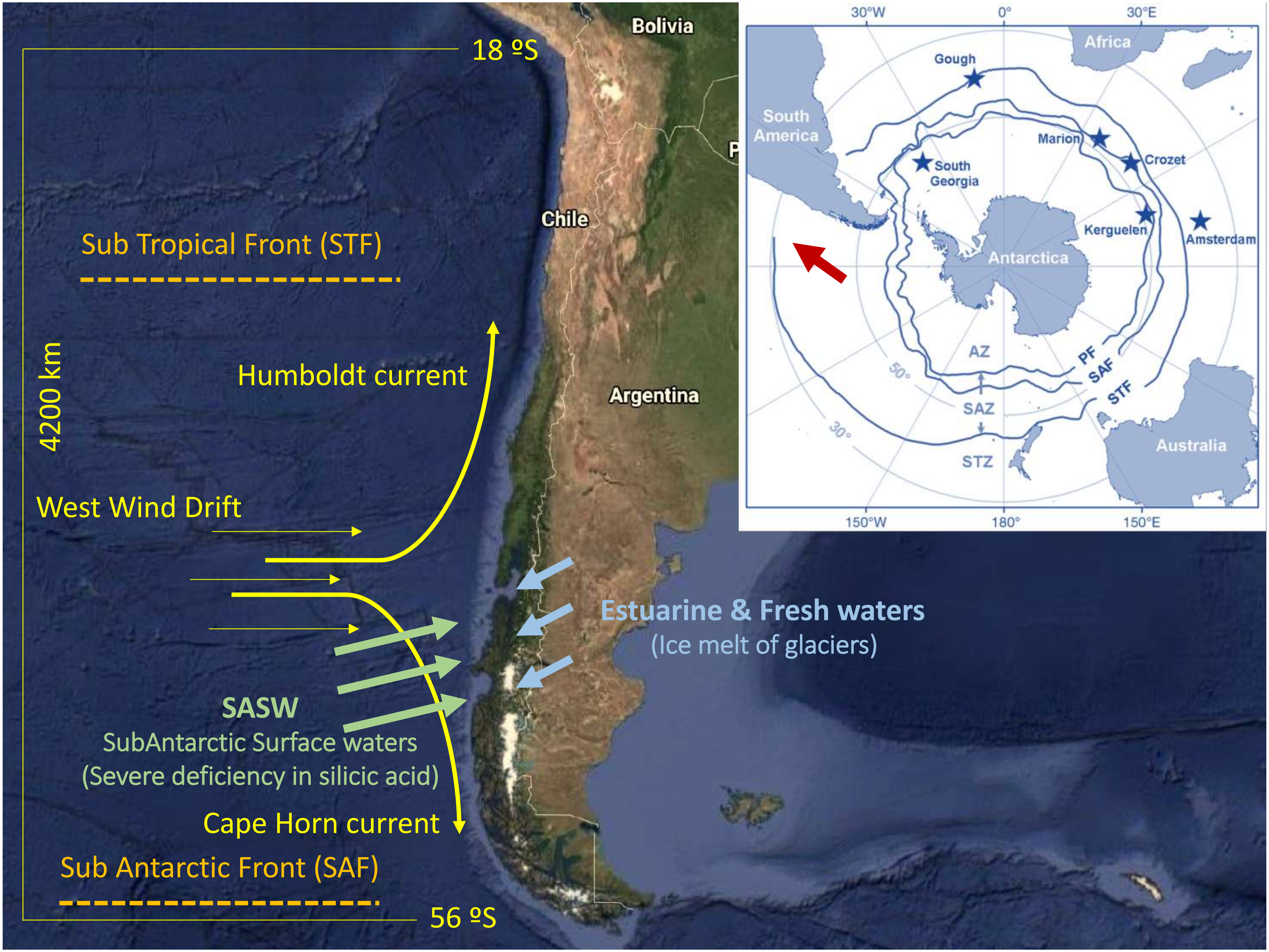


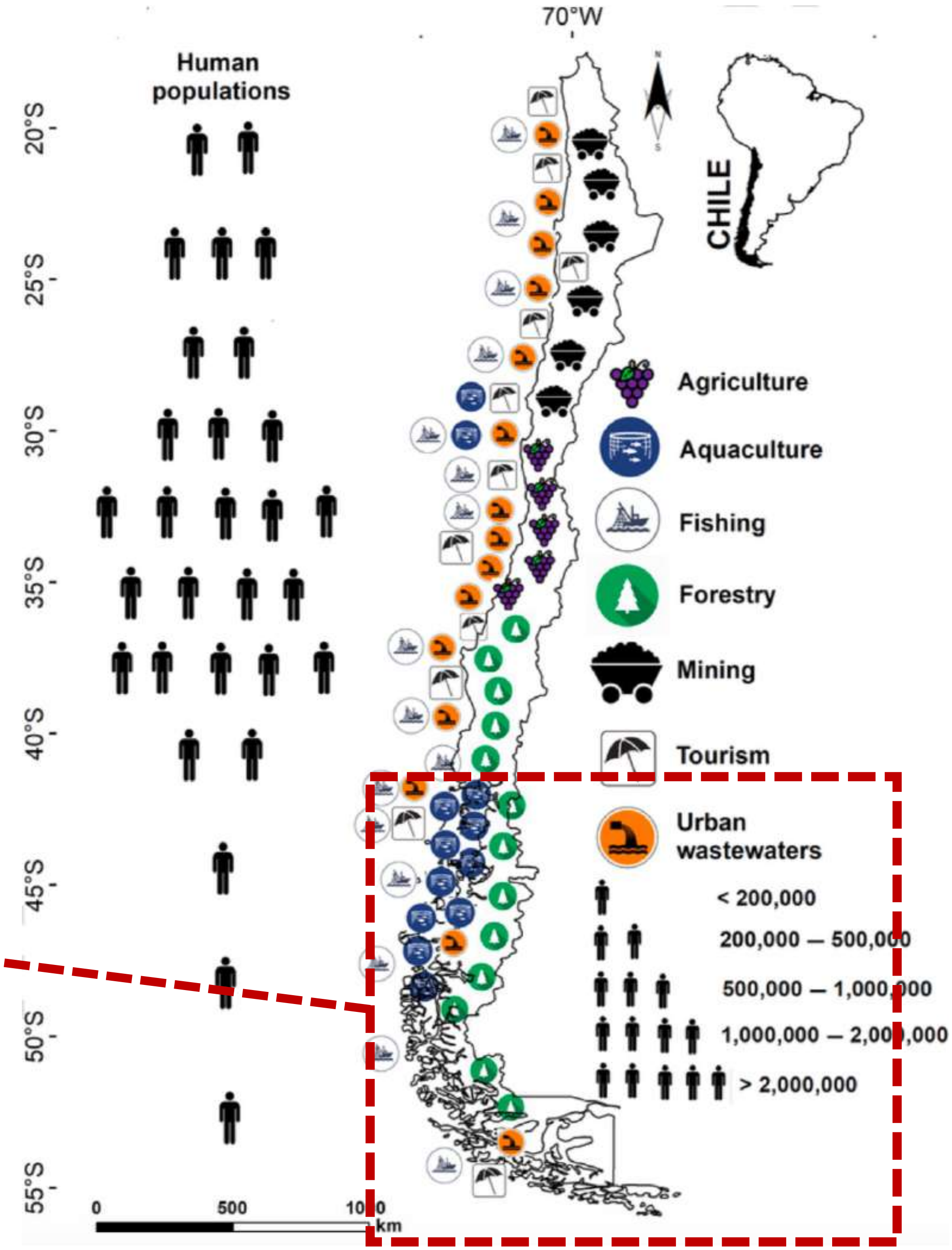
Bolivia
18 ºS
Chile
Sub Tropical Front (STF)
4200 km
Humboldt current
Argentina
West Wind Drift
Estuarine & Fresh waters
(Ice melt of glaciers)
SASW
SubAntarctic Surface waters
(Severe deficiency in silicic acid)
Cape Horn current
Sub Antarctic Front (SAF)
56 ºS
30°W
0°
30°E
Africa
Gough
South America
Marion
Crozet
South Georgia
Kerguelen
Amsterdam
Antarctica
AZ
PF
SAF
STF
SAZ
STZ
Australia
50°
30°
150°W
180°
150°E

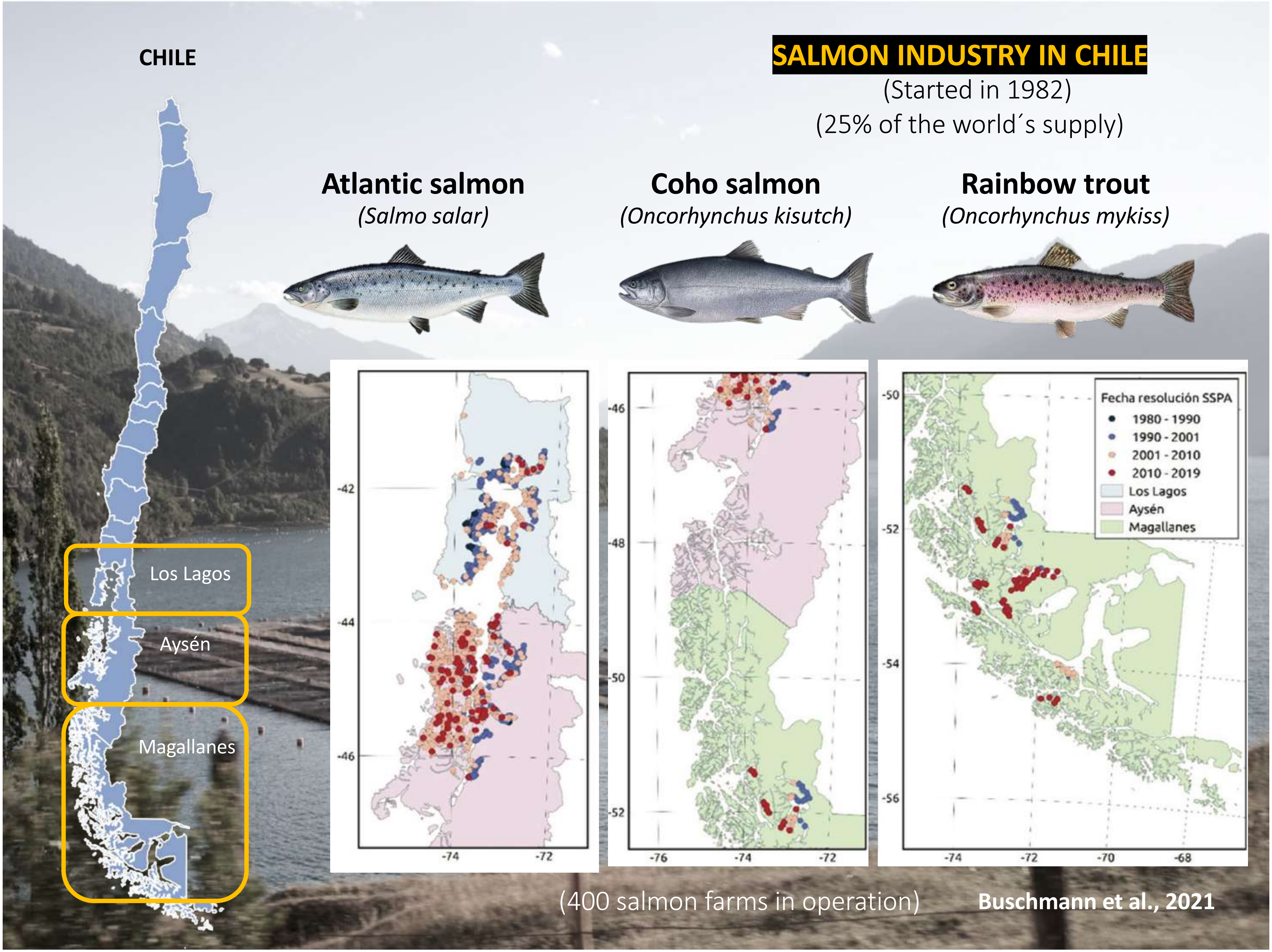
Overview of socio-economic activities along the Chilean coast.

(Aguilera et al., 2018)

Shellfish

Salmon

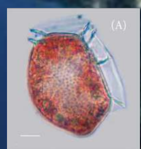



CHILE
SALMON INDUSTRY IN CHILE
(Started in 1982)
(25% of the world´s supply)
Atlantic salmon
(Salmo salar)
Coho salmon
(Oncorhynchus kisutch)
Rainbow trout
(Oncorhynchus mykiss)
Los Lagos
Aysén
Magallanes
Fecha resolución SSPA
1980 - 1990
1990 - 2001
2001 - 2010
2010 - 2019
Los Lagos
Aysén
Magallanes
(400 salmon farms in operation)
Buschmann et al., 2021

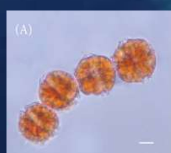
Harmful Algal Blooms in Chile

SOME WORLD RECORDS

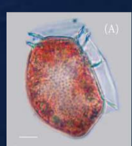
Blooms that affect Human heath
(true phycotoxins)



1970
First massive intoxication with DST (>250 people)



2018
Highest worldwide PST concentration ever recorded 143,130 ug STXeq. /100g of product

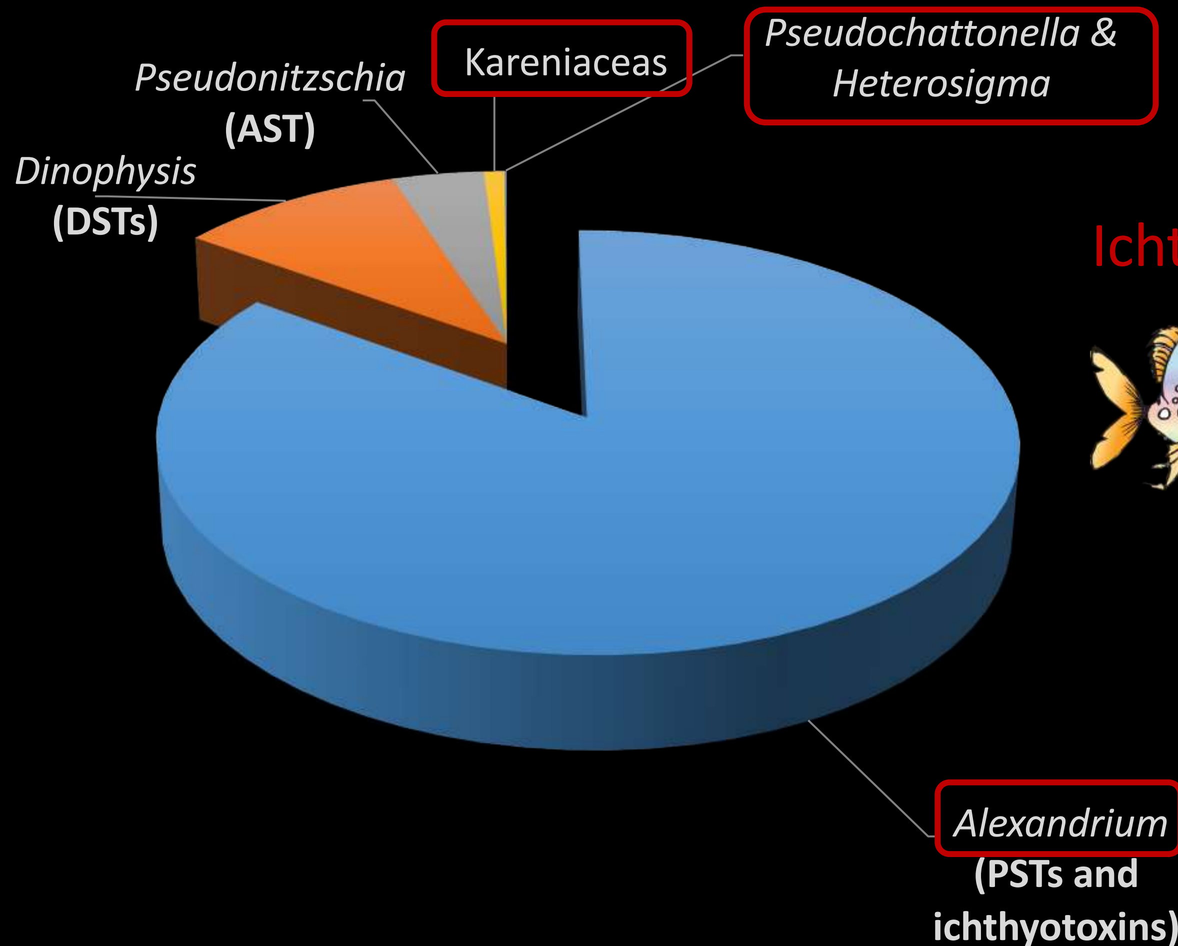


2018
Highest worldwide *Dinophysis acuta* cell conc. ever recorded (Aysén 118,700 cell L^{-1})

Fish killing Algal Blooms
(ichthyotoxins)

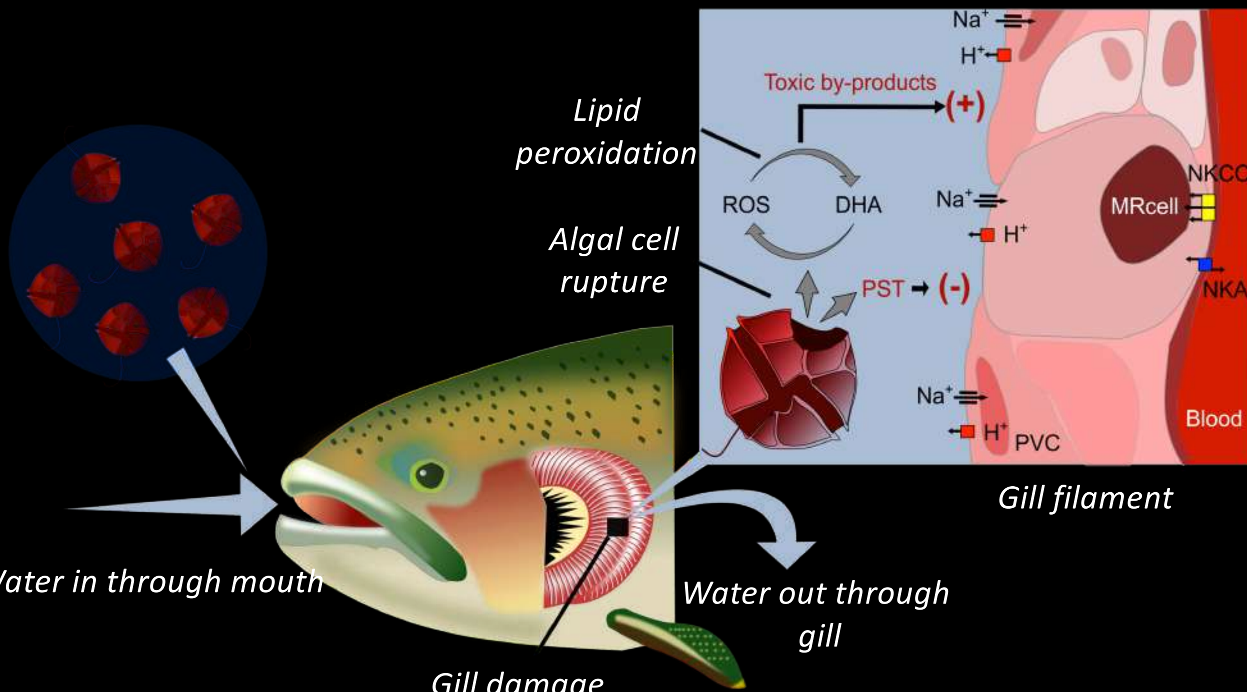
2016
US$800 M losses for the salmon industry

RESEARCH IN CHILE



Ichthyotoxic

“Microalgae species that produce true phycotoxins (PSTs, DSTs, ASTs) are not the same species reported to produce fish- kills due to gill damage”



Management


Harmful Algae 49 (2015) 40–49

Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

Fish gill damage by the dinoflagellate *Alexandrium catenella* from Chilean fjords: Synergistic action of ROS and PUFA

Jorge I. Mardones [a,*], Juan José Dorantes-Aranda [a], Peter D. Nichols [a,b], Gustaaf M. Hallegraeff [a]

(Mardones et al., 2015)


Harmful Algae 80 (2018) 55–63

Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

Fish gill damage by harmful microalgae newly explored by microelectrode ion flux estimation techniques

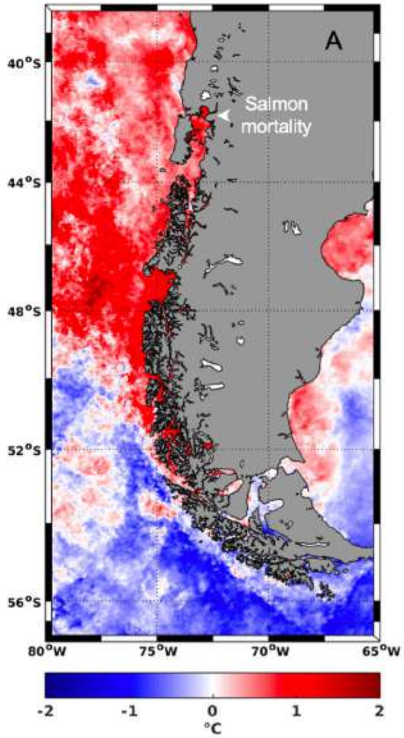
Jorge I. Mardones [a,b,*], Lana Shabala [c], Sergey Shabala [c], Juan José Dorantes-Aranda [a], Andreas Seger [a], Gustaaf M. Hallegraeff [a]

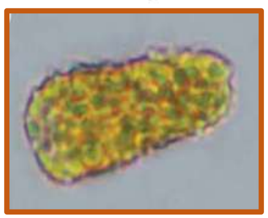
(Mardones et al., 2018)

- **PSTs do not produce gill damage but rather this damage is (in part) attributed to the synergistic reaction between ROS and PUFAs**
- **Ichthyotoxic activity may increase after cell lysis (mitigation strategies)**

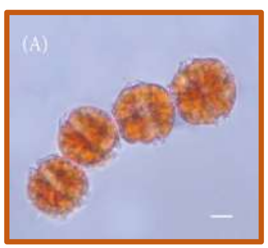

Fish Killing Algal Blooms in Chile
Causes
Impacts
Management
Climate change
High temperature &
Low precipitations
Fjord´s
Flushing capacity
Intensive
aquaculture
Eutrophication
Socio-economic
Ecosystem
Mitigation strategies
Monitoring
Analytical methods for
ichthyotoxin detection

Mardones et al., 2021





Pseudochattonella

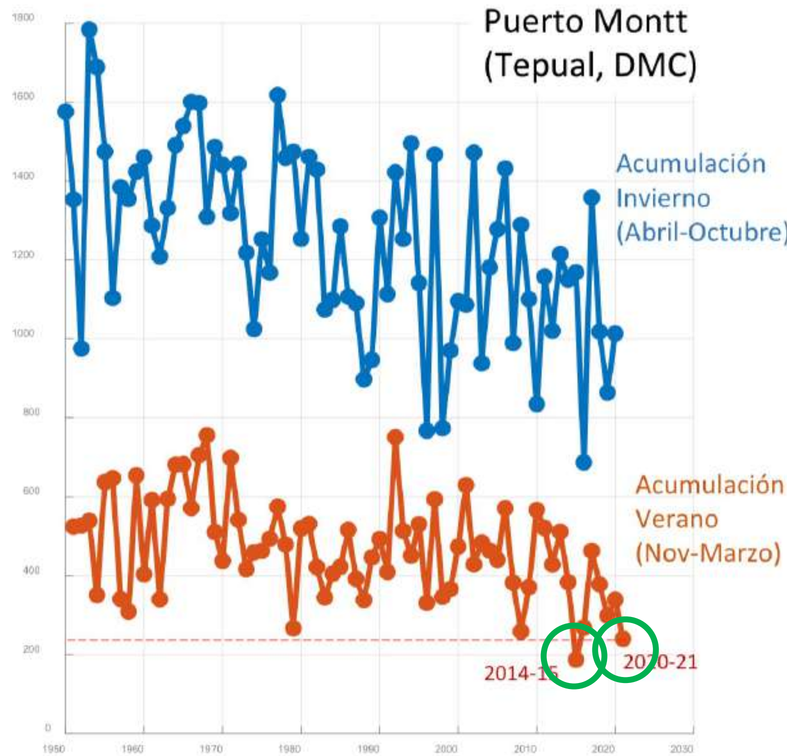


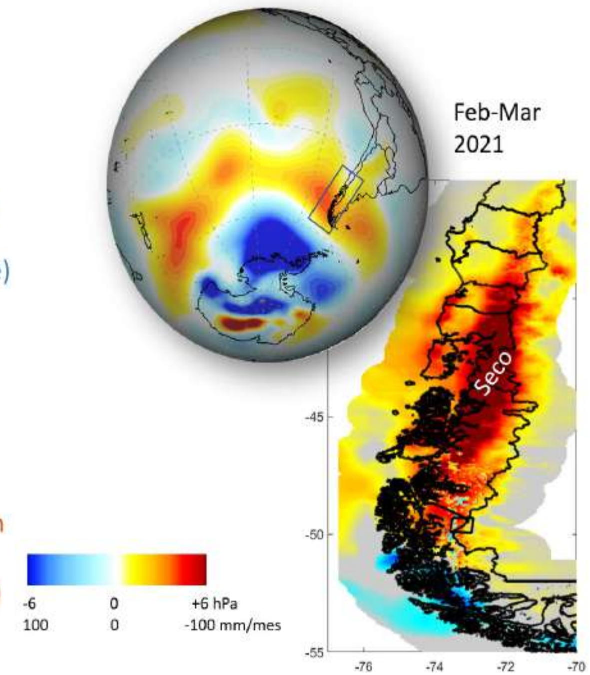
Alexandrium

Causes

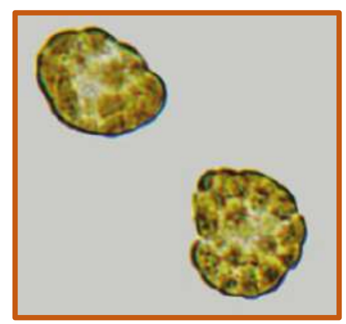
Climate change

Garraud, 2021

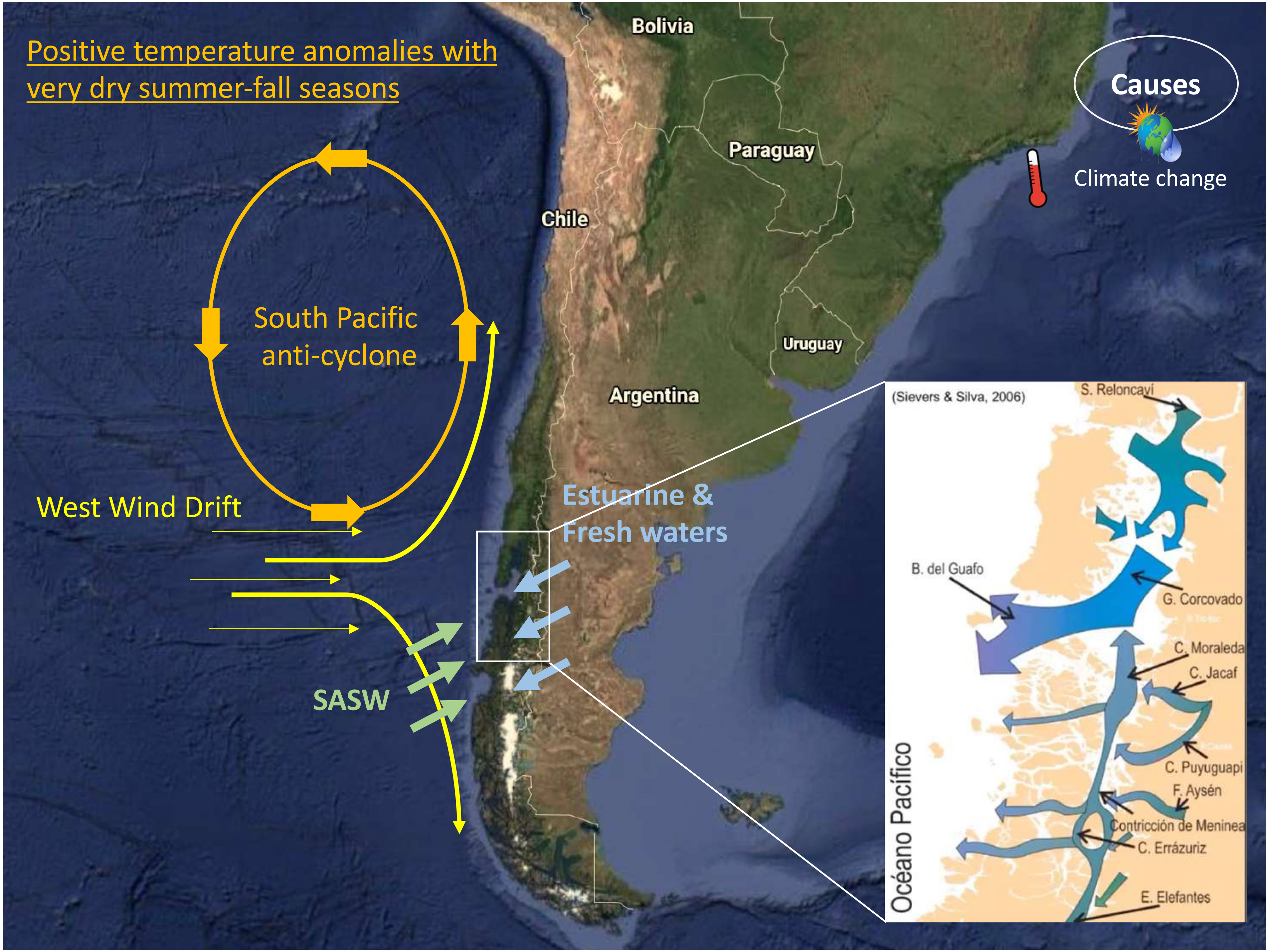




Mardones et al., 2022, *in press*



Heterosigma



Positive temperature anomalies with very dry summer-fall seasons
Bolivia
Paraguay
Chile
Uruguay
Argentina
Causes
Climate change
South Pacific anti-cyclone
West Wind Drift
Estuarine & Fresh waters
SASW
(Sievers & Silva, 2006)
S. Reloncaví
B. del Guafo
G. Corcovado
C. Moraleda
C. Jacaf
C. Puyuguapi
F. Aysén
Contricción de Meninea
C. Errázuriz
E. Elefantes
Océano Pacífico

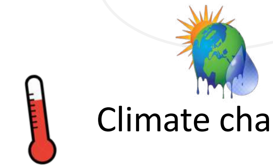
npj | Climate and Atmospheric Science
www.nature.com/npjclimatsci

ARTICLE OPEN

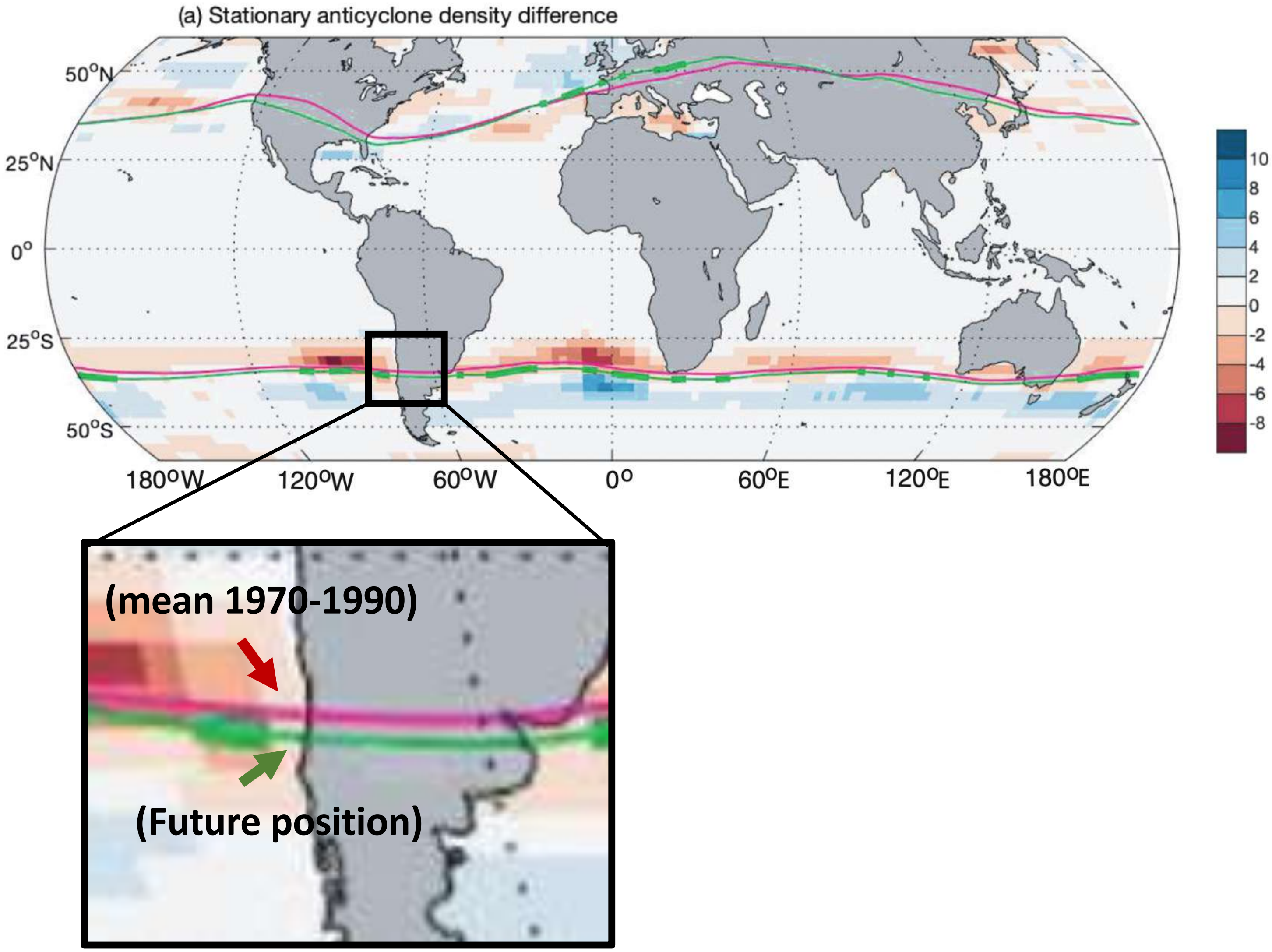
Role of synoptic activity on projected changes in upwelling-favourable winds at the ocean's eastern boundaries

Catalina Aguirre[1,2,3*], Maisa Rojas[1,4], René D. Garreaud[1,4] and David A. Rahn[5]

Causes



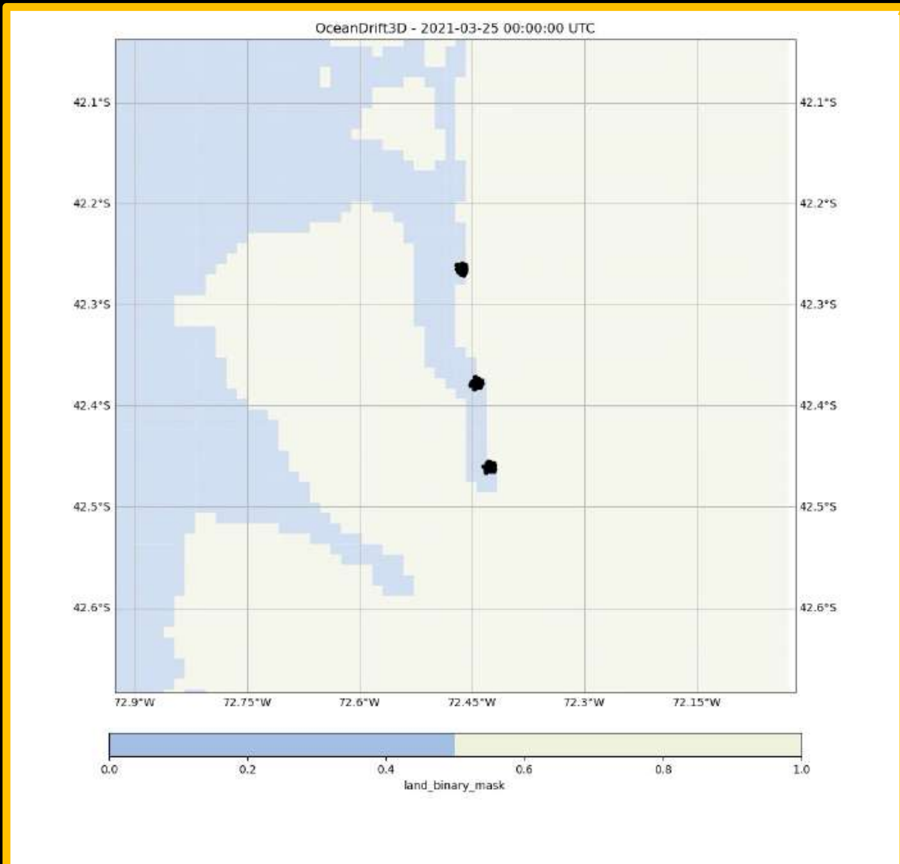
Climate change

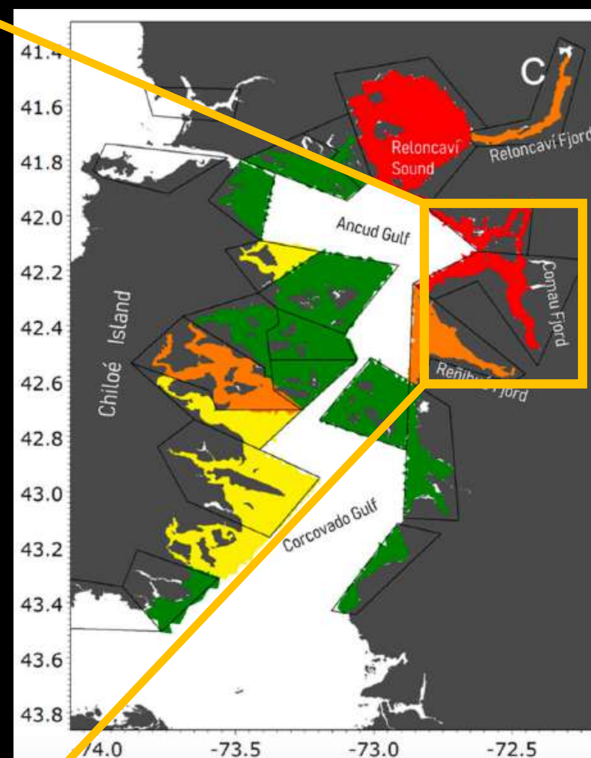


Modeling particle dispersion using Parti-MOSA

Causes

Flushing capacity





H. akashiwo

Mardones et al., 2020

Heterosigma akashiwo

Impacts

Socio-economic

Heterosigma akashiwo

Impacts

Socio-economic

Salmon mortality
> 6 tons

Mardones et al., *in press*

Marine Policy 132 (2021) 104705

Contents lists available at ScienceDirect

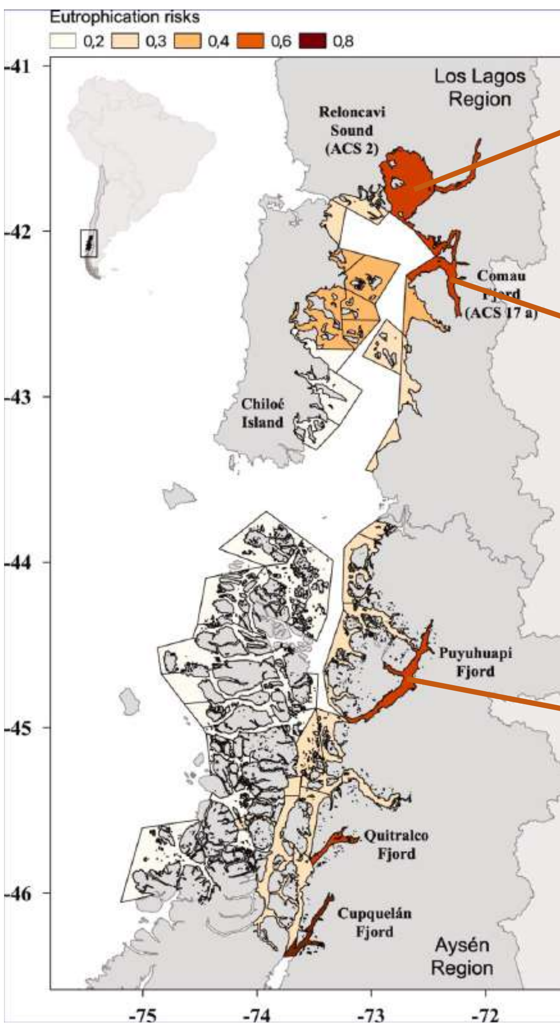
Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Short communication

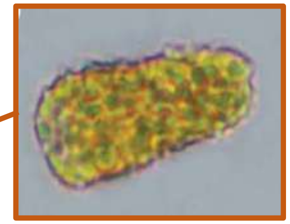
Scientific warnings could help to reduce farmed salmon mortality due to harmful algal blooms

Doris Soto[a,*], Jorge León-Muñoz[a,b], René Garreaud[c,d], Renato A. Quiñones[a,e], Francisco Morey[f]

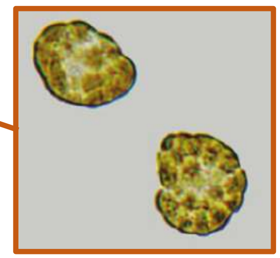


Causes

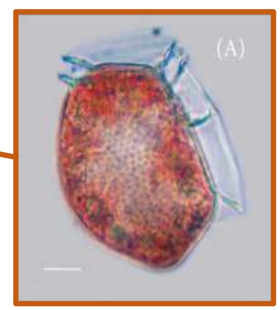
Eutrophication



P. verruculosa
2016



H. akashiwo
2021



D. acuta
2018

Southern Chile

Impacts

Ecosystem

Lepidodinium chlorophorum
(Mardones & Clément, 2016)

Tetraselmis sp
Summer 2022

Prorocentrum micans
Summer 2022

2017

Southern Chile (Kareniaceae)

Impacts

Ecosystem

´Godzilla-red tide event´

P. verruculosa

A. catenella

Impacts

Socio-economic

Science of the Total Environment 766 (2021) 144383

Contents lists available at ScienceDirect

Science of the Total Environment

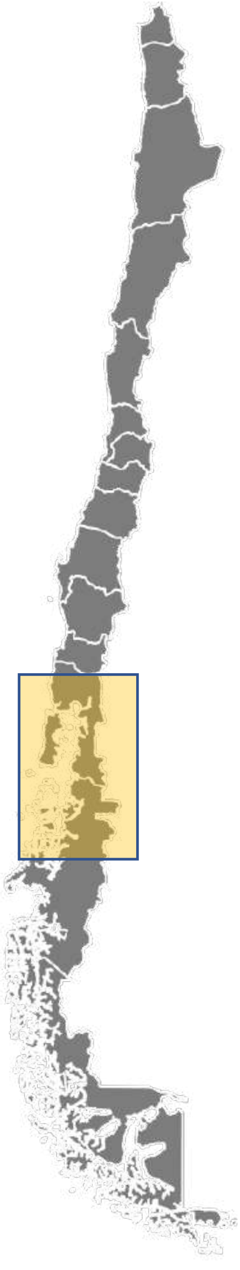
journal homepage: www.elsevier.com/locate/scitotenv

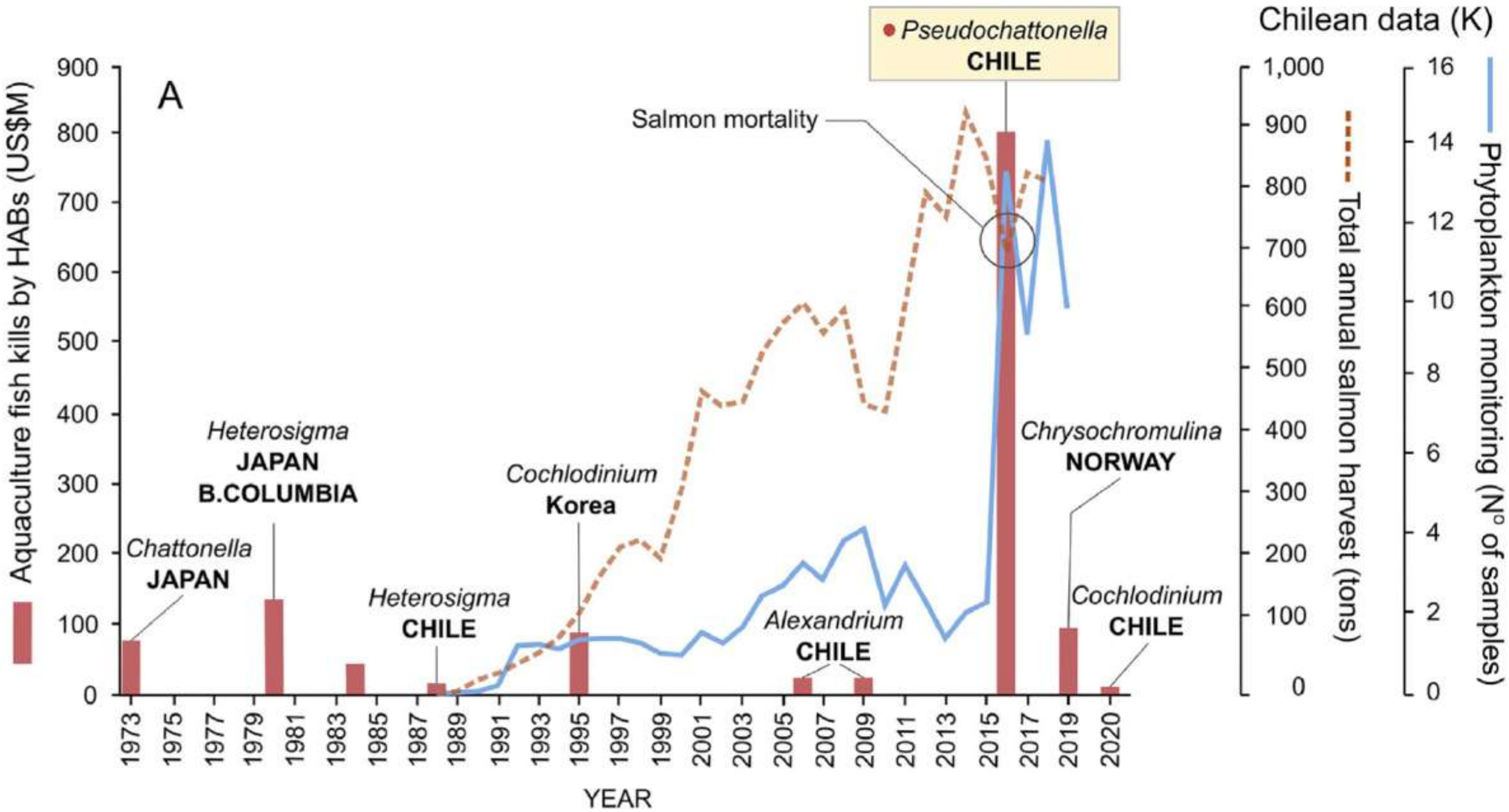
Impacts

Socio-economic

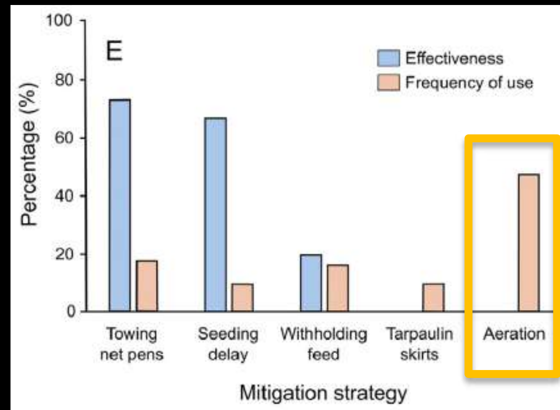
Disentangling the environmental processes responsible for the world's largest farmed fish-killing harmful algal bloom: Chile, 2016

Jorge I. Mardones [a,b,*], Javier Paredes [a], Marcos Godoy [c,d,e], Rudy Suarez [c,d,f], Luis Norambuena [a], Valentina Vargas [a], Gonzalo Fuenzalida [a], Elias Pinilla [g], Osvaldo Artal [g], Ximena Rojas [h], Juan José Dorantes-Aranda [i], Kim J. Lee Chang [j], Donald M. Anderson [k], Gustaaf M. Hallegraeff [i]





Mardones et al.,, 2021

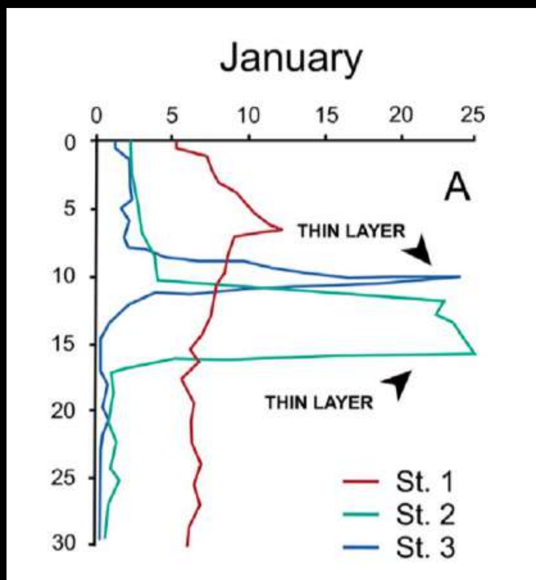


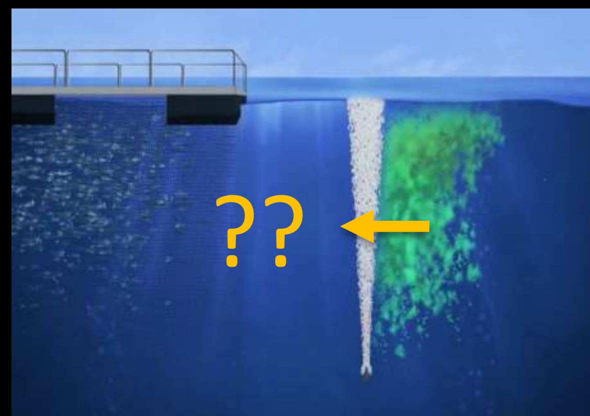
Management

Upwelling systems

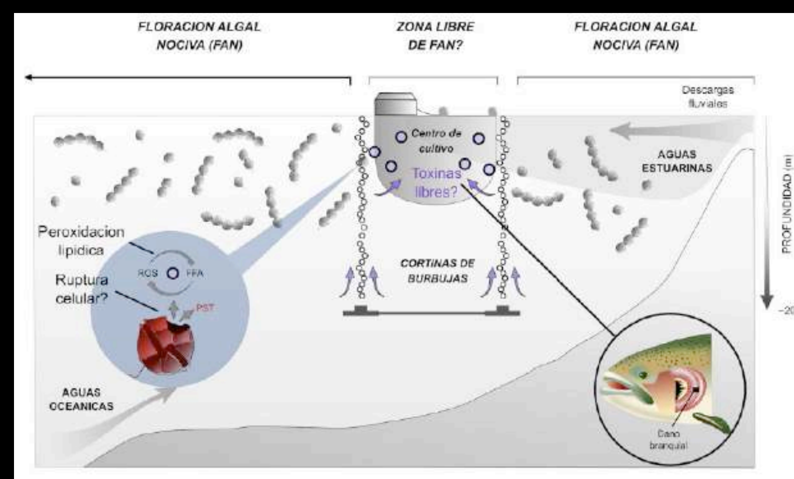
Bubble curtains

Mitigation strategies





Can these systems prevent ichthytoxic cells from entering salmon culture cages?



Can these systems prevent cell distruction due to mechanical action?

Mardones et al.,, *unpublished*

Complex life cycles, Pleiomorfism, fragile cells

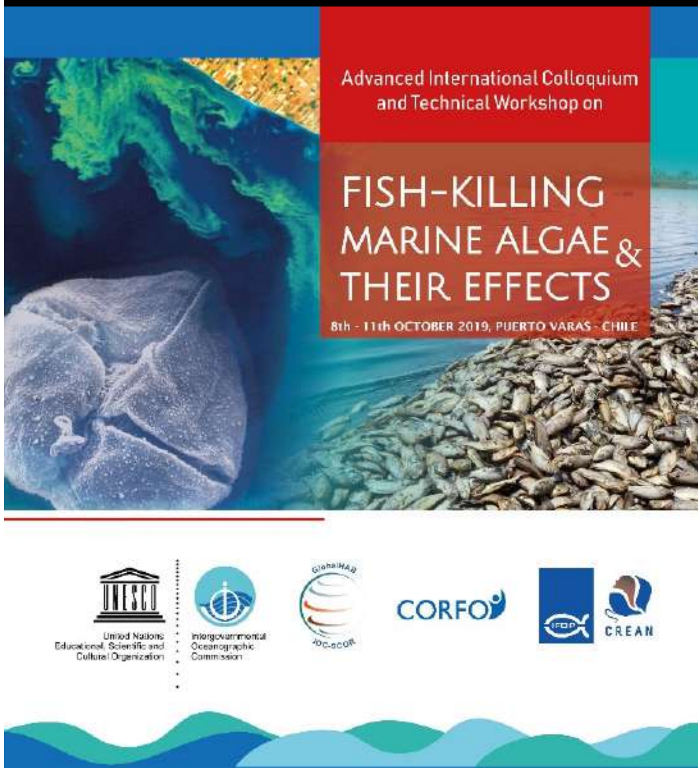
Management

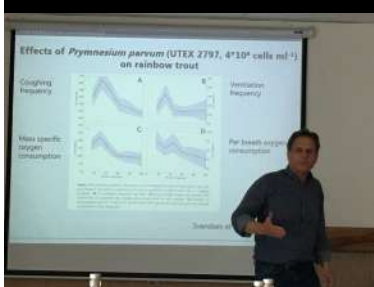
Monitoring

	Live	Lugol	Formalin
Vicicitus globosus			
Pseudochattonella verruculosa			
Karenia selliformis			

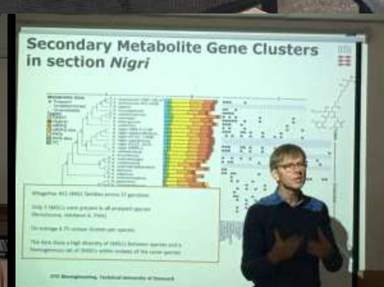
New technology is needed for fish killing algae:

- Molecular approaches
- Automated flow cytometry (allows analysis of live samples)


Advanced International Colloquium
and Technical Workshop on
FISH-KILLING
MARINE ALGAE &
THEIR EFFECTS
8th - 11th OCTOBER 2019, PUERTO VARAS - CHILE
United Nations
Educational, Scientific and
Cultural Organization
Intergovernmental
Oceanographic
Commission
CORFO
CREAN


Effects of Prymnesium parvum
on rainbow trout


Phylogeny and taxa


Secondary Metabolite Gene Clusters
in section Nigri

Management

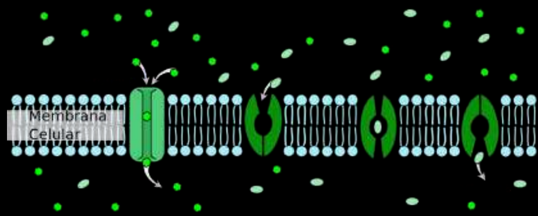
PST

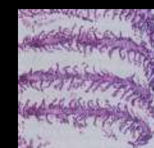
(Paralytic Shellfish Toxins)

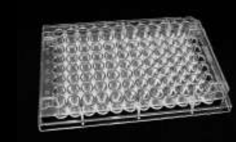
RTgill-W1

Gill cell lines

Management

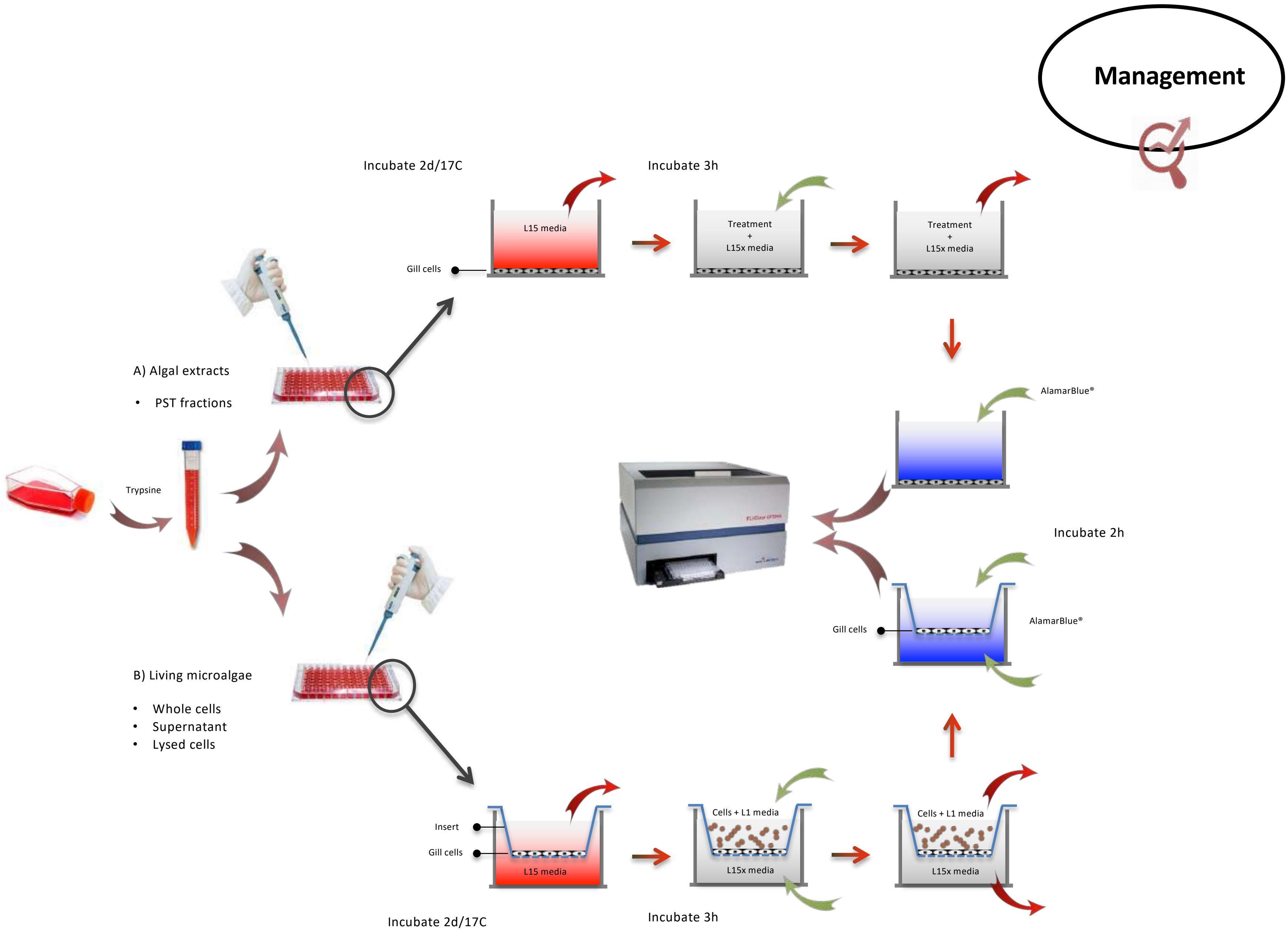






Ventajas:

- Menor volumen de muestra
- Más replicas
- No uso de animales
- Ahorro de tiempo



Mardones et al., 2022

Take home messages

The use of existing HABs mitigation strategies currently used at salmon farms need to be reassessed based on new studies.

Regular monitoring of FKA needs to be accompanied with new technologies to improve detection resolution (real biogeography).

It is necessary to standardize a common method for the detection of ichthyotoxins (I.e., Gill cell assay)

Finally, climate change is strongly affecting the southern Patagonia fjords in recent years and is adding much uncertainty about future HABs events.

Understanding impacts of HABs on fish farms based on lessons learned in Chile

INSTITUTO DE FOMENTO PESQUERO
CREAN

Jorge I. Mardones, PhD

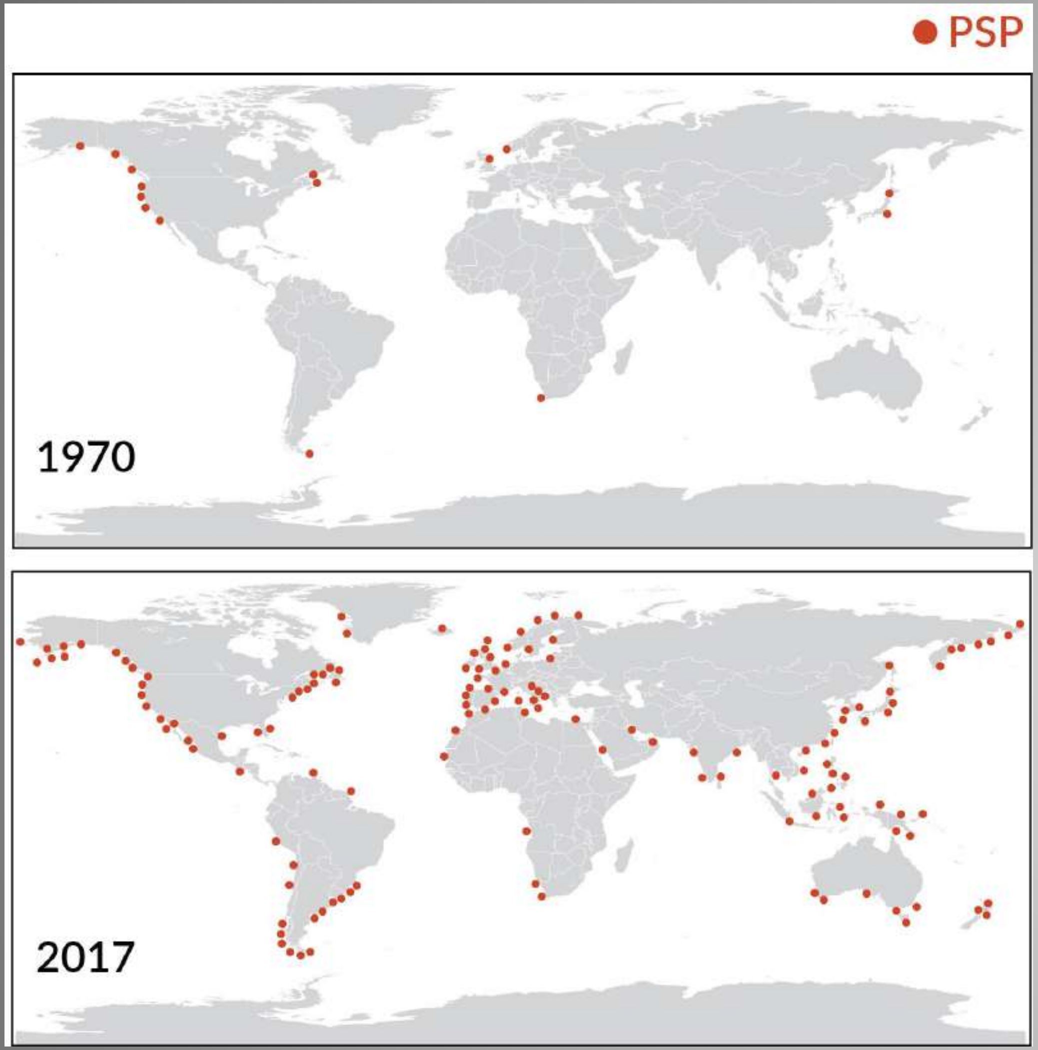
Center for the Study of Harmful Algal Blooms (CREAN)
Chilean Fisheries Development Institute (IFOP)

jorge.mardones@ifop.cl

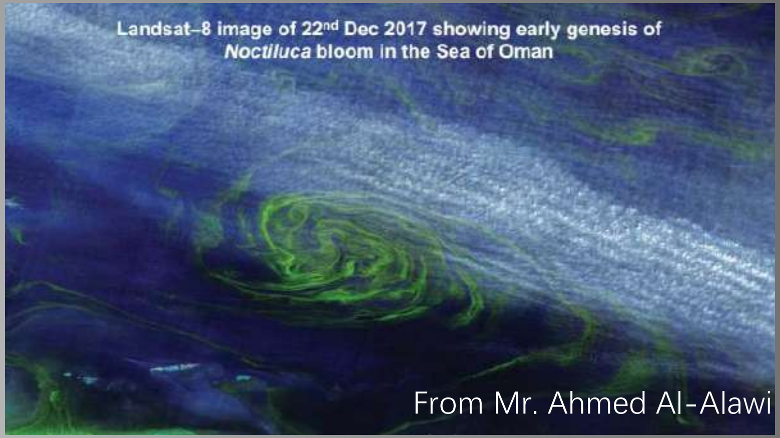
Control of Harmful Algal Blooms in China: a Modified Clay approach

Isaac Y. Yuan, Xiuxian Song, Xihua Cao, Zhiming Yu

Institute of Oceanology, CAS



Global distribution of PSP toxins recorded in 2017 compared with 1970, downloaded from website of U. S. National office for HABs.



Beyond a global ecological disaster, the HAB has become a regional challenge to ROPME countries that attentions should be paid necessarily.

As a disaster like a fire, HABs need to be controlled in emergency by a "Fire Extinguisher".

Physical Measures

e.g. ultrasonic

Difficulty — **In Open Sea**

Chemical Measures

e.g. algaecide

Prohibit — **2^{nd} pollution**

Biological Measures

e.g. bacterium

Slow — **No emergency**

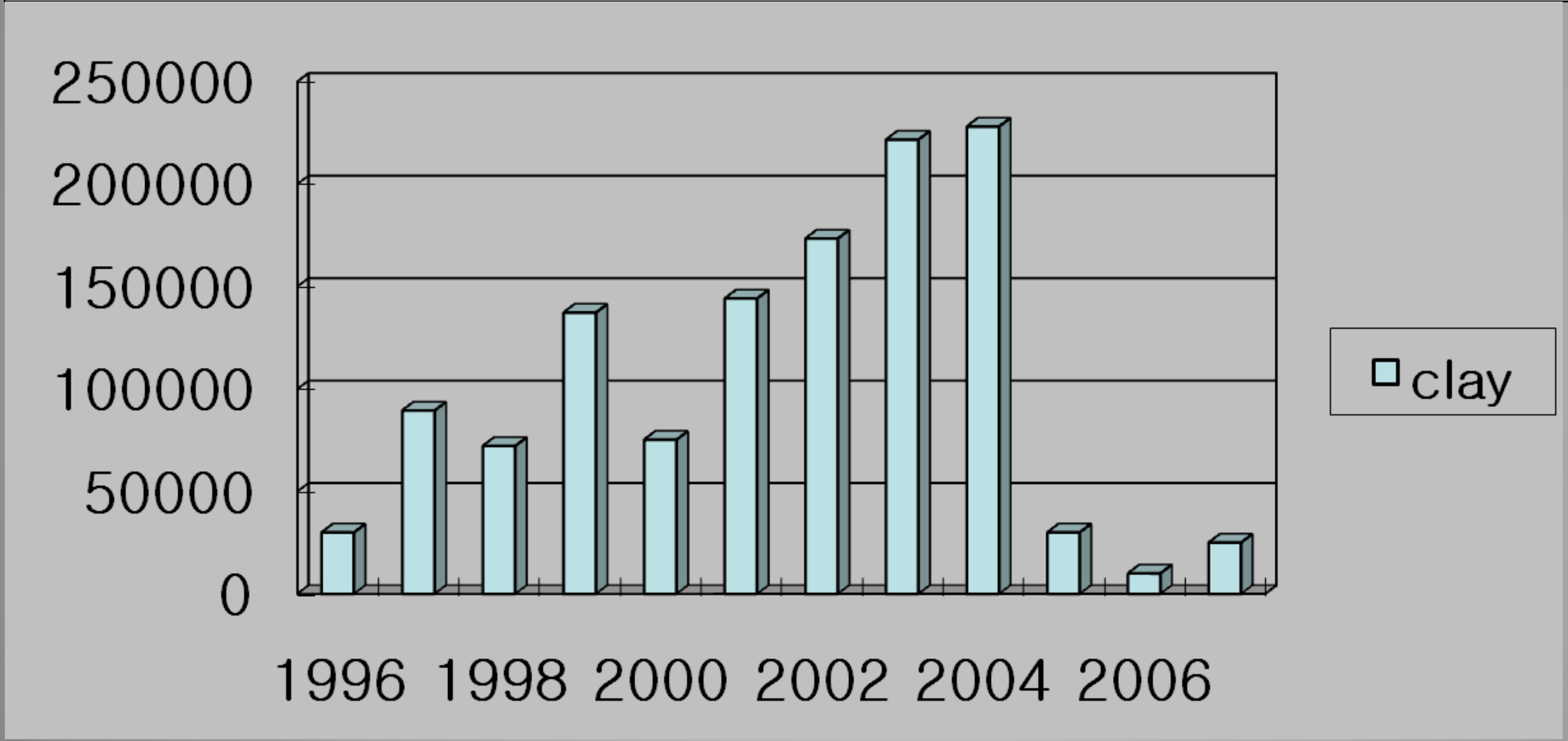
Flocculating control

- Removal of cells using clay dispersal

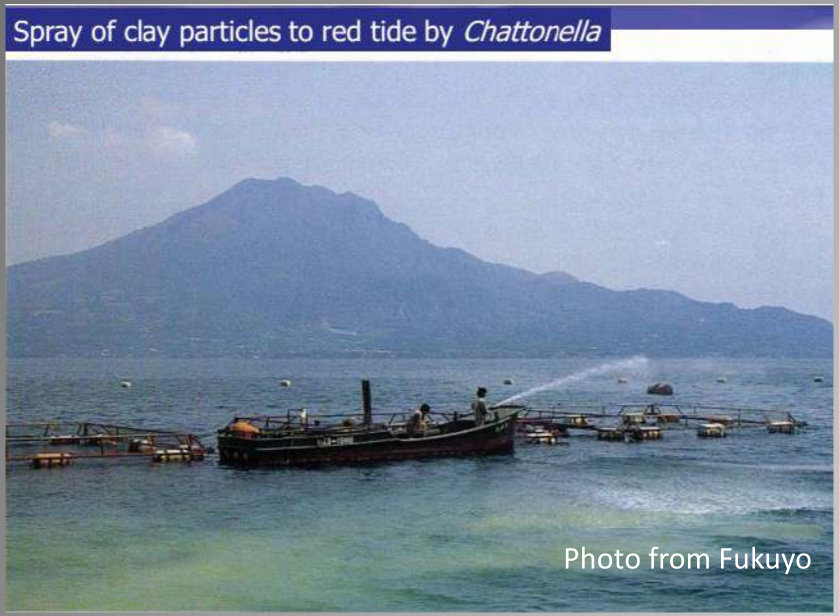
- This remains the most practical and acceptable large-scale bloom control strategy to date.

South Korea - clay dispersal now routine as a HAB mitigation strategy at fish farms

The amount of clay dispersed (tons) to fight *Cochlodinium* blooms in Korean waters since 1996.



"Numerous HAB mitigation methods have been examined in Korea, including yellow clay, marine bacteria, microscreen filtration and ozone, ultraviolet radiation, parasitic dinoflagellates, and microzooplankton predators of bloom species. Nevertheless, no other control methods have been used extensively in the sea except clay. " Park et al. 2013.



Japan

U. S.

Iran

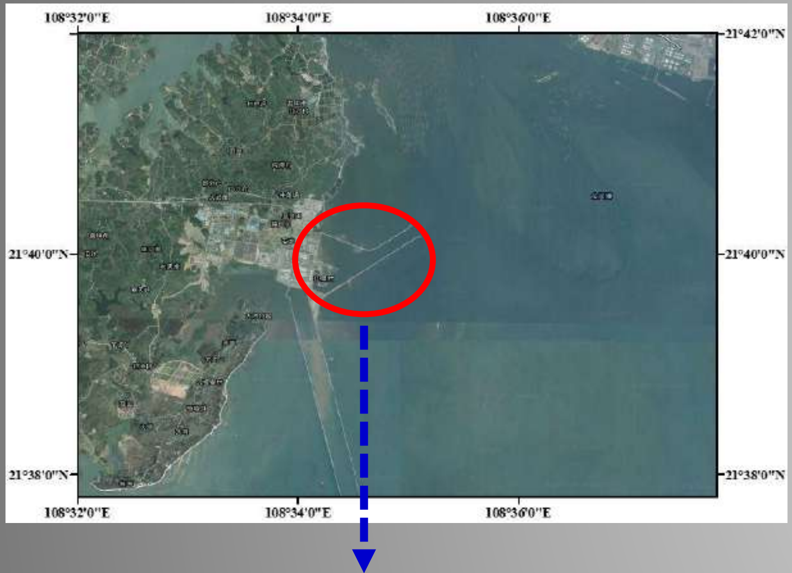
Application of modified clays in open waters - the Chinese approach

Application of modified clays in aquaculture area - the Chinese approach

Shrimp culture ponds

Abalone culture sites

Application of modified clays in cooling pond of NPP - the Chinese approach



Why can MC technology control HABs?

- Direct function

Settling HAB cells to sediment by flocculation

Resulting in mortality of HAB cells and the decrease of HAB biomass.

- Only 70%-80% HAB cells could be settled down to sediment once, but no blooms any more

For the residual cells

Normal cells

The residual cell

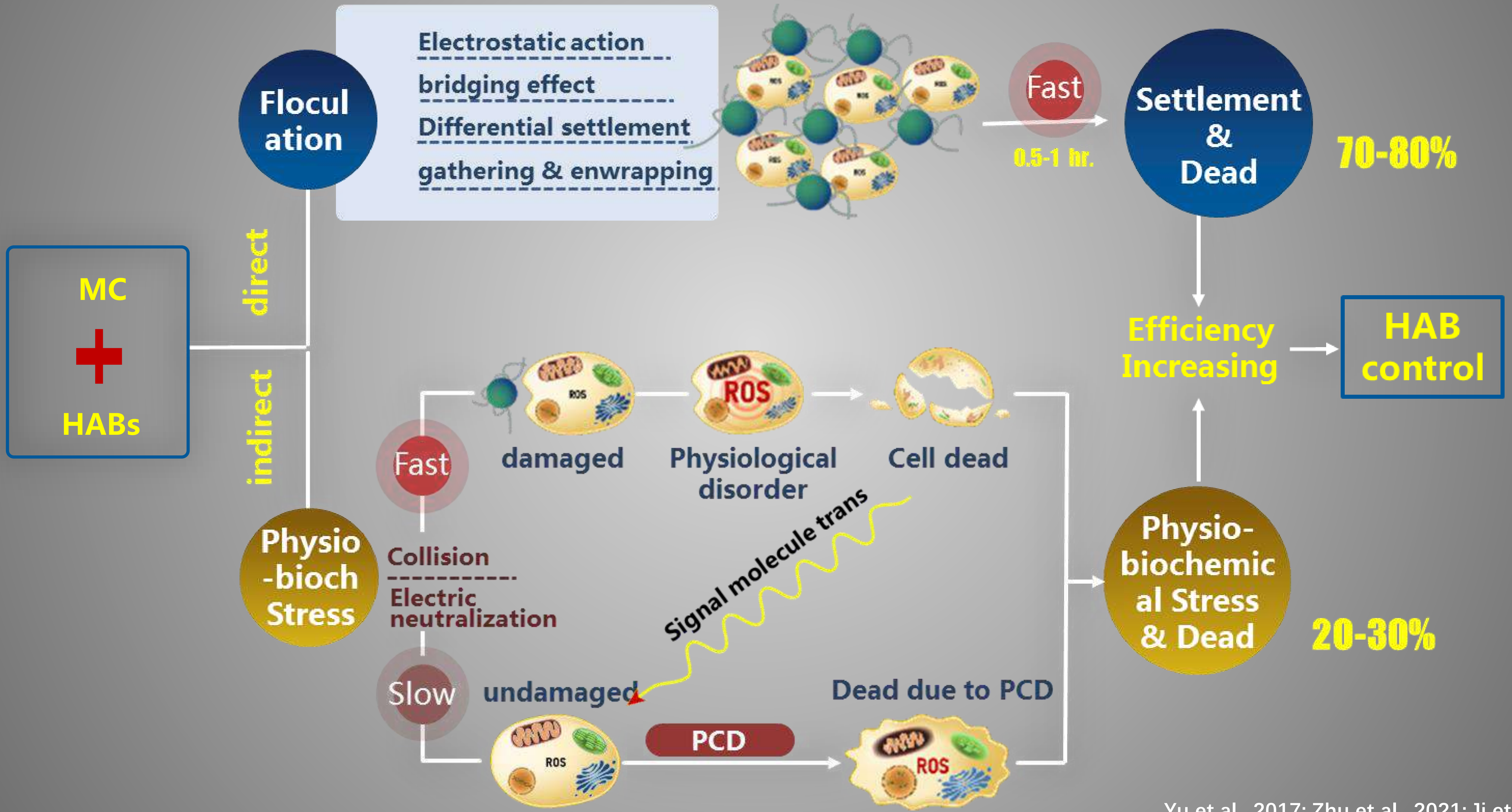
A broken cell

SEM examination of *Aureococcus anophagefferens* that was not flocculated

- The physiological & biochemical characteristics of the residual cell (unfloculated) are impacted by collision & electric neutralization. Physio-biochemical stresses result in cellular growth and division arrest.

Zhu et al., 2018

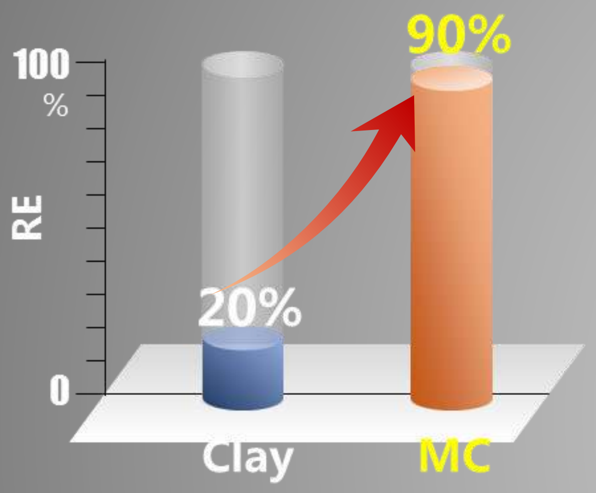
Mechanism of MC controlling HABs



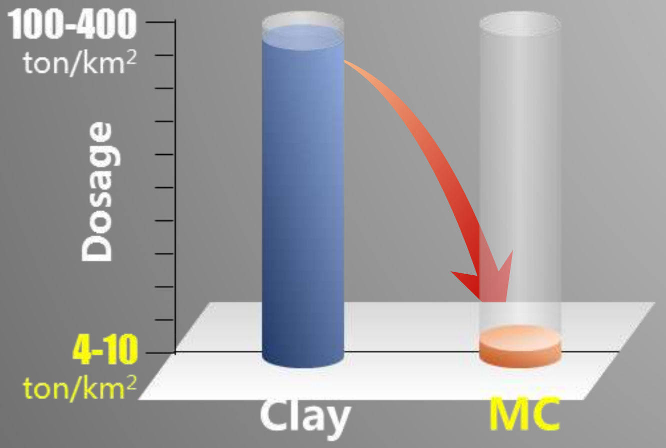
Yu et al., 2017; Zhu et al., 2021; Ji et al., 2021

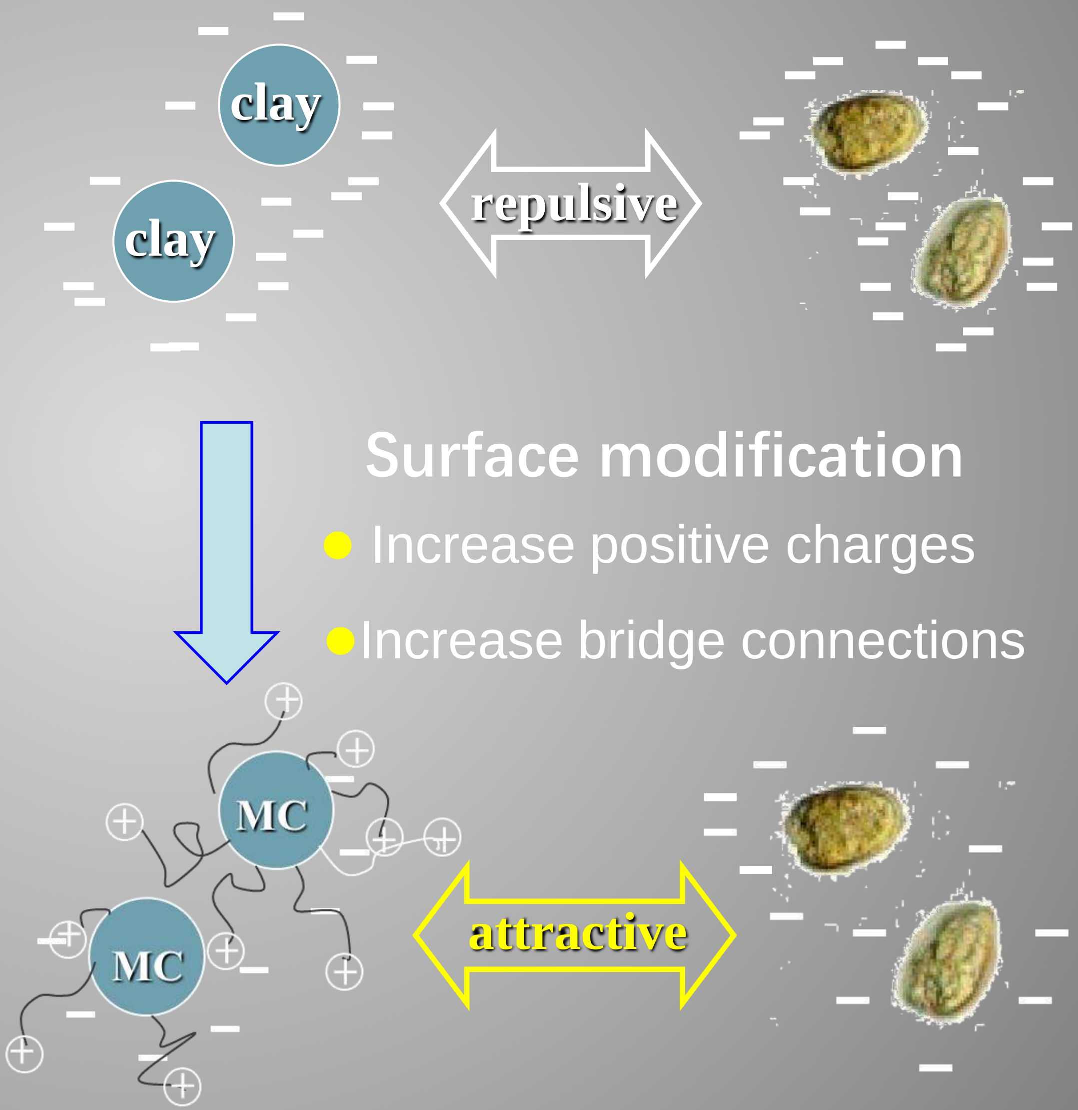
MC: A highly efficient technology

Control efficiency increasing



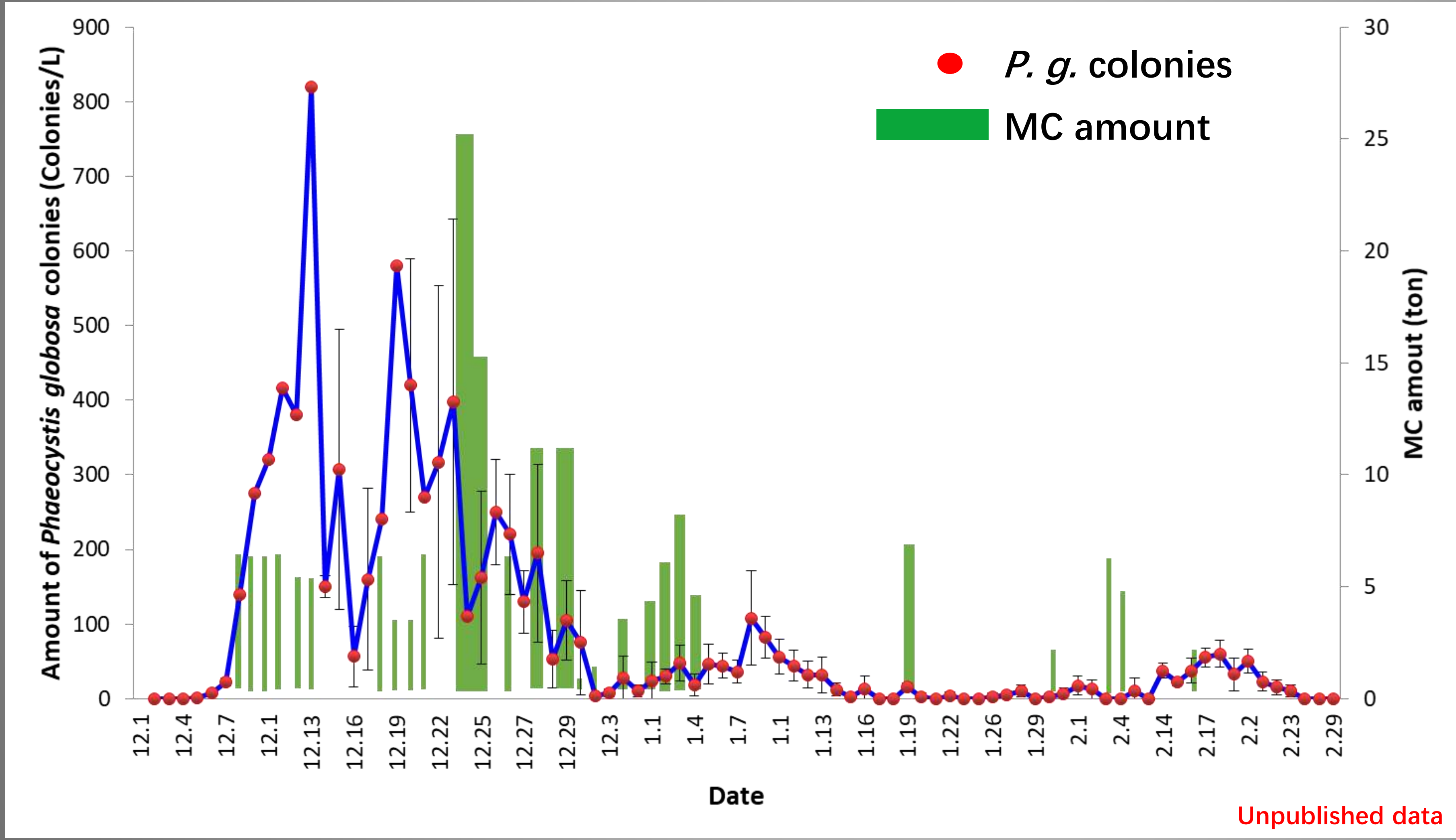
Dosage decreasing





Yu & Zou, 1994; Yu et al., 1999

Effective control of *P. g.* bloom in NPP

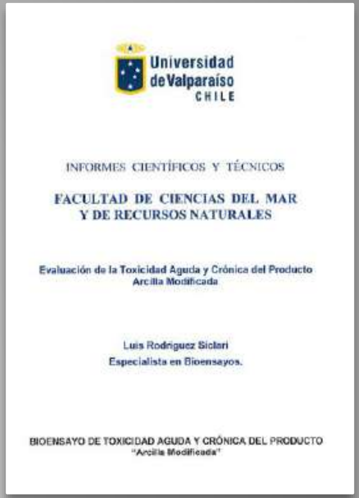


- The P. g. bloomed several times, peaked as 8 millions/m^3 in the mid-Dec.
- By using MC, the density declined to less than 0.5 millions and was kept till Mar.

MC: An environment-friendly technology

Water quality	Prevent POM back to the water, Absorb P & ammonia, Decrease COD	**Improve**
Aquaculture	Fish, Shrimp, Sea Cucumber, Shellfish (Scallop, Abalone, etc.)	**Harmless**
Toxins	Decrease toxin, Mitigate toxicity, Decrease toxin acceleration	**Decline**
Cysts (Seeds)	Inhibit germination of cysts (*A. pacificum, S. trochoidea, etc.*)	**Inhibit**
Ecosystem	Adjust the community structure, Improve biodiversity	**Optimize**

Evaluated by third parties


Universidad de Valparaíso
CHILE

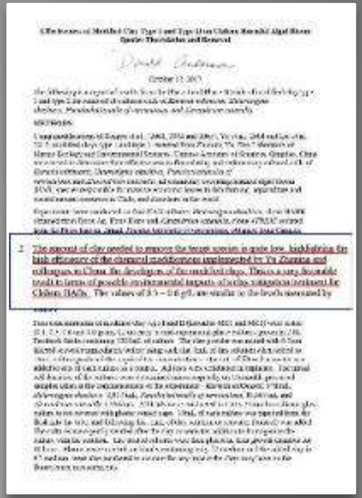
INFORMES CIENTÍFICOS Y TÉCNICOS

FACULTAD DE CIENCIAS DEL MAR
Y DE RECURSOS NATURALES

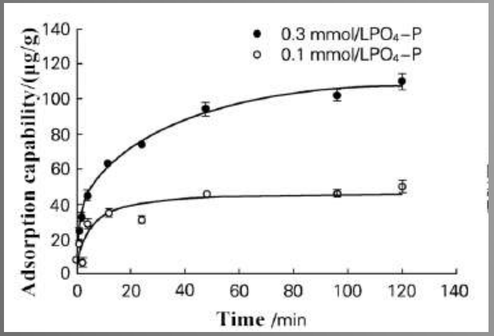
Evaluación de la Toxicidad Aguda y Crónica del Producto
Arcilla Modificada

Luis Rodríguez Siclari
Especialista en Bioensayos.

BIOENSAYO DE TOXICIDAD AGUDA Y CRÓNICA DEL PRODUCTO
"Arcilla Modificada"

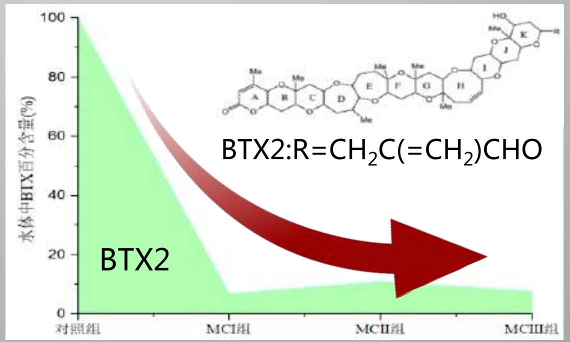


Absorb PO_4-P over 80%



No harm to cultured organisms

Decline toxins up to 80%



"No harm to other organisms"

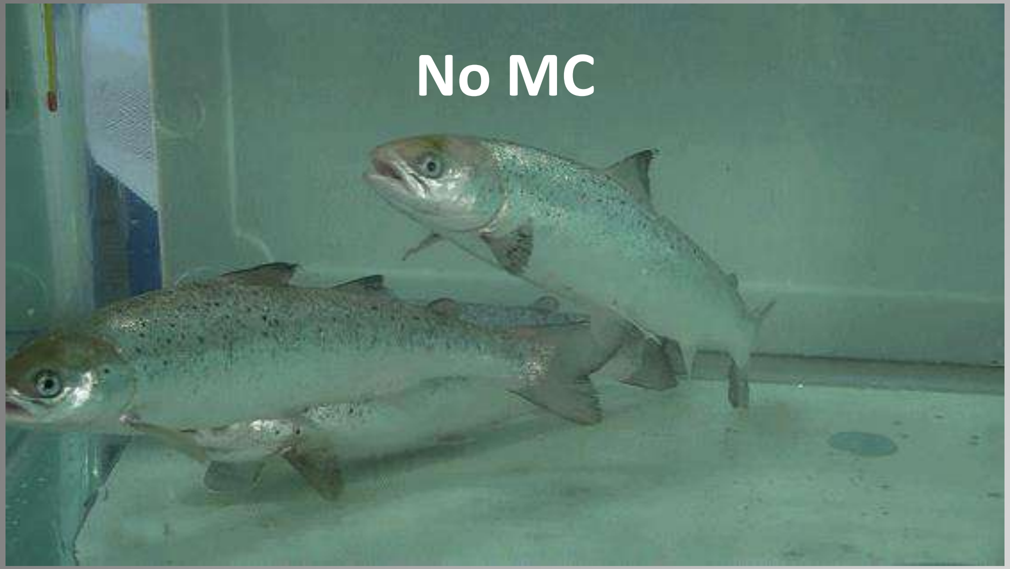
"Favorable impacts to the environment"

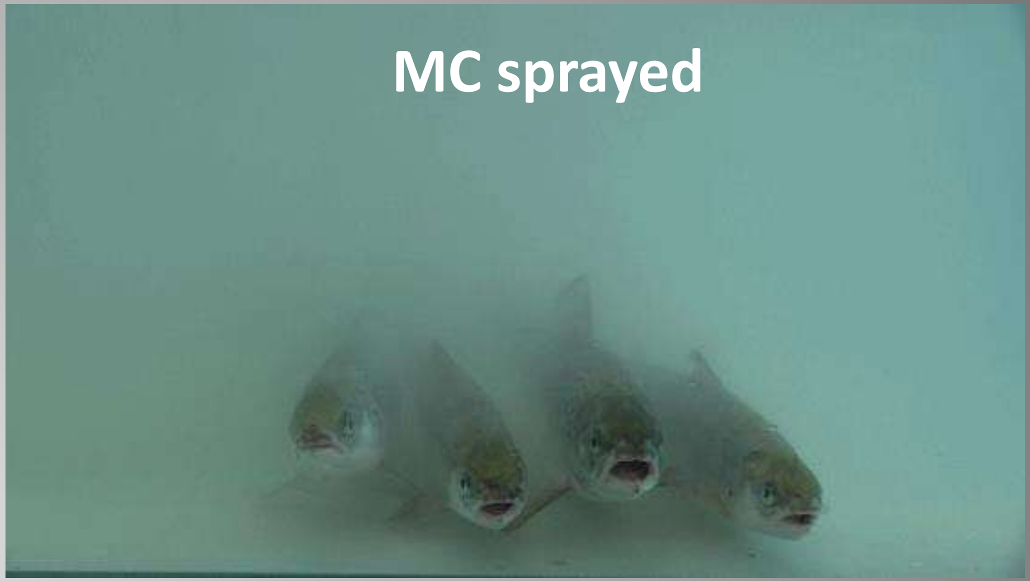
Yu et al., 2017; Song et al., 2021

Effect of MC on different typical aquatic organisms

MC Types	MC (g/L)	Experimental organisms	Co-culture with HAB organisms	The response of the experimental organism	Reference
Inorganic-MC	1.0	*Penaeus japonicus* (shrimp, 1~1.5 cm)	——	MR decreased from 80% (in control) to 40% in 96 h	(Song et al., 2003)
Organic-MC	0.03	*Penaeus japonicus* (shrimp, ~1 cm)	*P. donghaiense*	SR kept 100% in 48 h	(Cao et al., 2004)
	0.09		*H.akashiwo*		
Organic-MC	0.05	*Neomysis awatschensis* (shrimp)	*A. carterae Hulburt*	MR decreased from 33.3% (in control) to 16.7% in 48 h	(Wu and Yu, 2007)
			P.donghaiense	SR kept 100% in 48 h	
Complex-MC	0.1	*Crassostrea gigas* (oyster, ~0.2 cm)	——	No negative effects on gill and digestive gland super microstructure in 56 d	(Gao et al., 2007a)
			P.donghaiense;	SR increased 16%-26% compared with control in 12 d	
Inorganic-MC	0-0.5	*Patinopecten yessoensis* (scallop, 0.5 mm)	——	No impact on SR, shell length and height within 8 weeks	(Wang et al., 2014a)
			P. donghaiense	SR increased from 22% (in control) to 38% in 10 d	
Inorganic-MC	0-0.5	*Apostichopus japonicas* Selenka (sea cucumber, 1~2 cm)	——	No significant changes on GR, SR, in 60 d	(Wang et al., 2014b)
			P. donghaiense	MR decreased from100% (in control) to 3.33%-6.67% in 10 d	

Effects of MC on *Atlantic salmon*





Behavior

- Respiratory rate: ***Normal***
- Swimming ability: ***Normal***
- Cough: ***Normal***

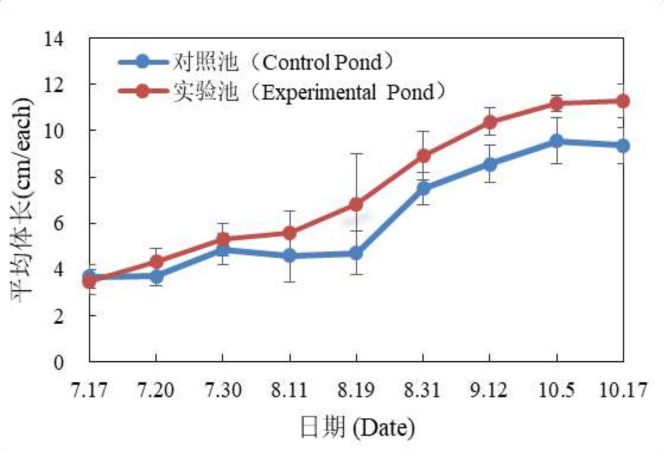
Survival

- ***No fish died*** **in MC spray group, but *died fish were found* in no MC spray group.**

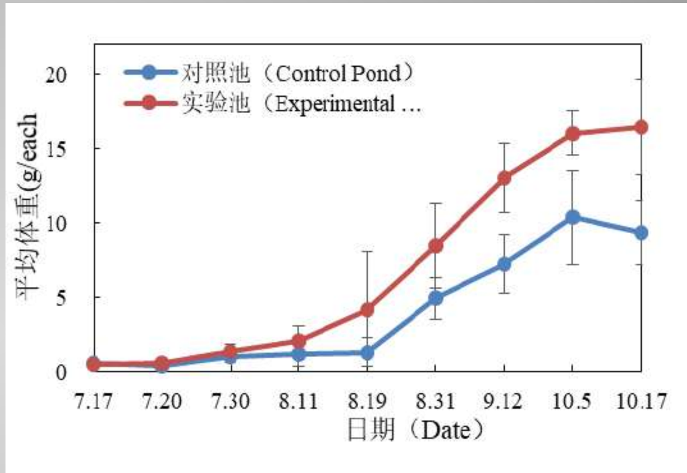
Unpublished data

Amazing Results used in the shrimp culture ponds

MC was used to improve the water quality for shrimp culture in ponds in 2020. Shrimp production increased by **2-3 times** and greatly improved in **nutritional quality and taste** of the shrimp.



Body length increased by 21%



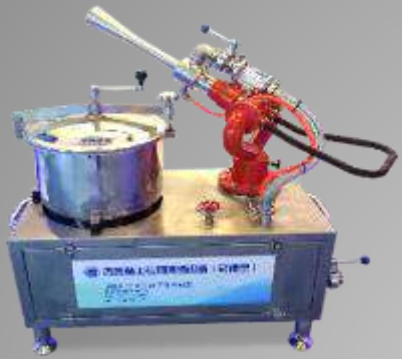
Body weight increased by 76%

Control group MC group

Unpublished data

MC: Easy to use

Portable model



small movable type

medium movable type

Movable type used in culture ponds

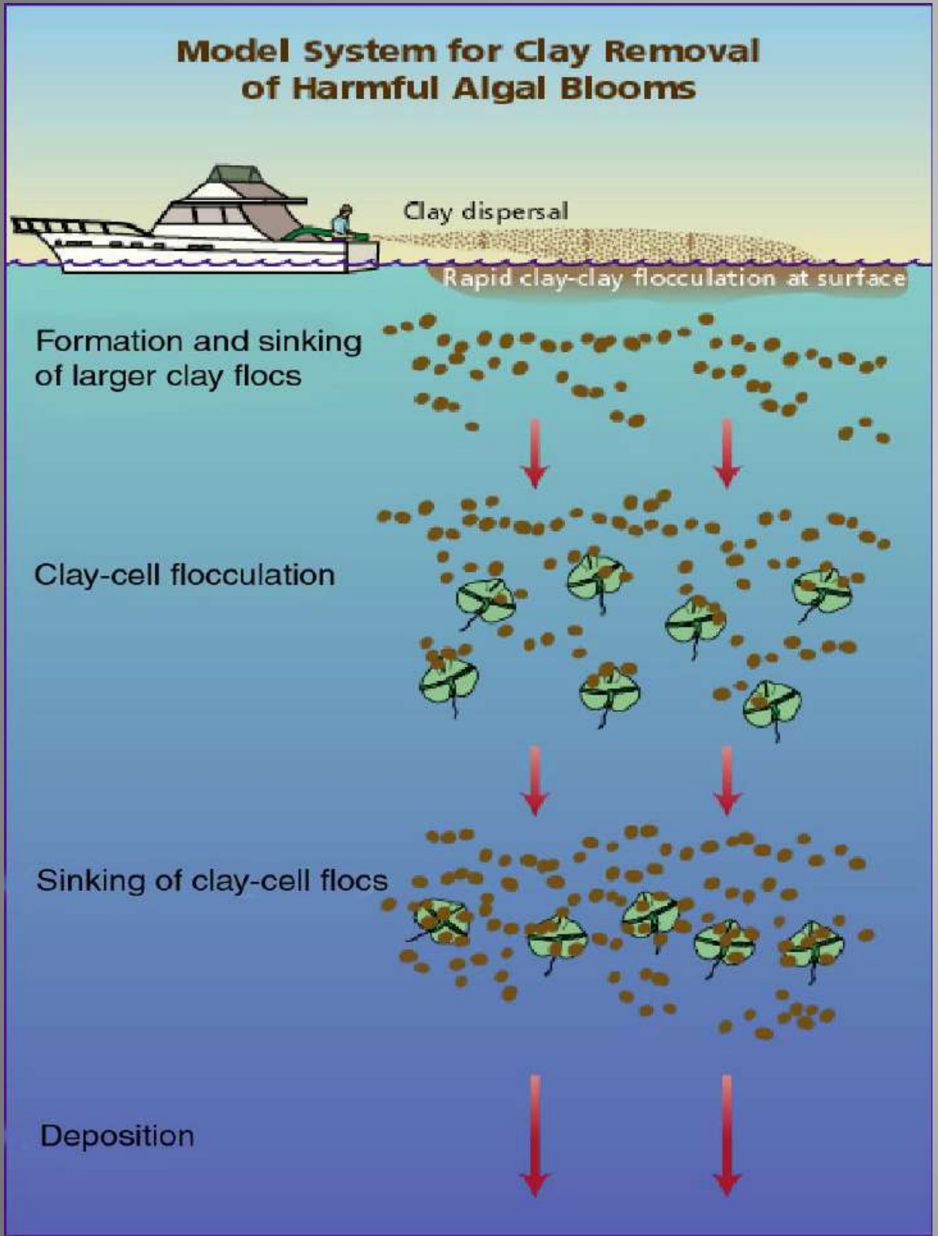
medium automatic model

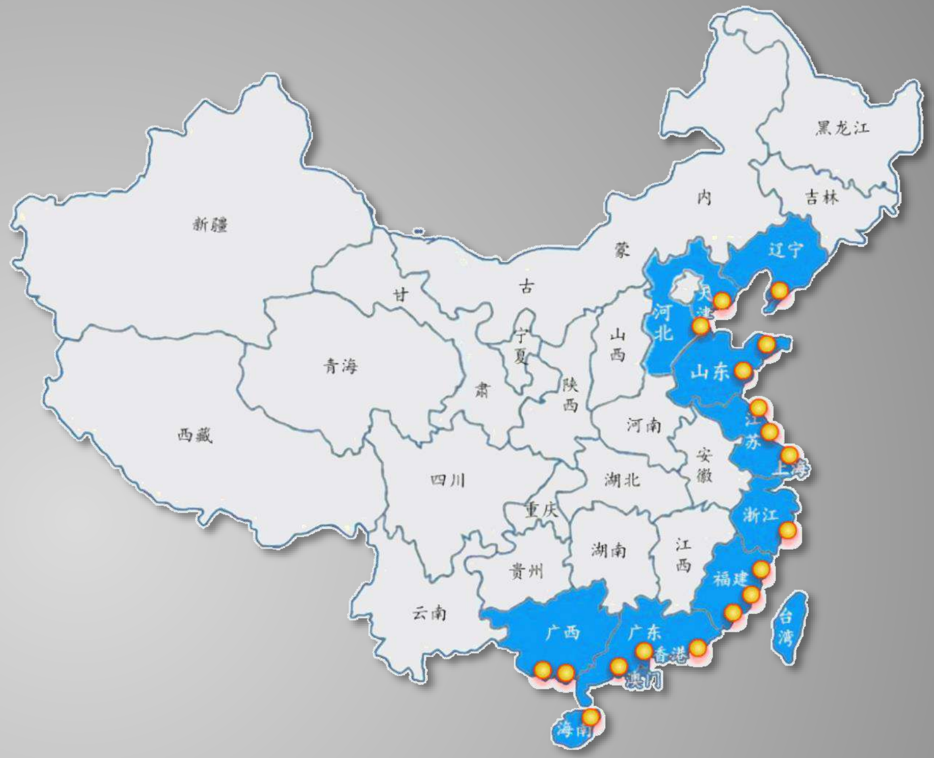
MC vessel for HAB control

Developed special equipments for MC spraying in the field.

MC vessel for HABs control

Modified Clay (MC), a reliable approach developed by IOCAS for HABs control





Beidaihe, 2012

Qingdao, 2008

Shenzhen, 2011

Culture pond, 2021

Nuclear plant, 2020

Xiamen, 2017

As the "First Aid" to HABs, MC has been used over 20 waters along China coast.

Final thoughts

- Many HABs are disasters and should be treated as such.
- The public, authorities, and the aquaculture industry in most countries want some level of HAB control.
- There are promising bloom control strategies that are in use in other countries, one of which is clay dispersal.
- MC is widely used for bloom control in China and has the potential to be used in RSA (Take home message).

Dr. Isaac Y. Yuan
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Thanks for your attention！

Dr. Isaac Y. Yuan

E-mail: yqyuan@qdio.ac.cn

Government of Kuwait

Development of Early Warning System for Harmful Algal Blooms, Red Tide, and Fish Kills Incidents in Kuwait Territorial Waters

Dr. Qusaie Karam

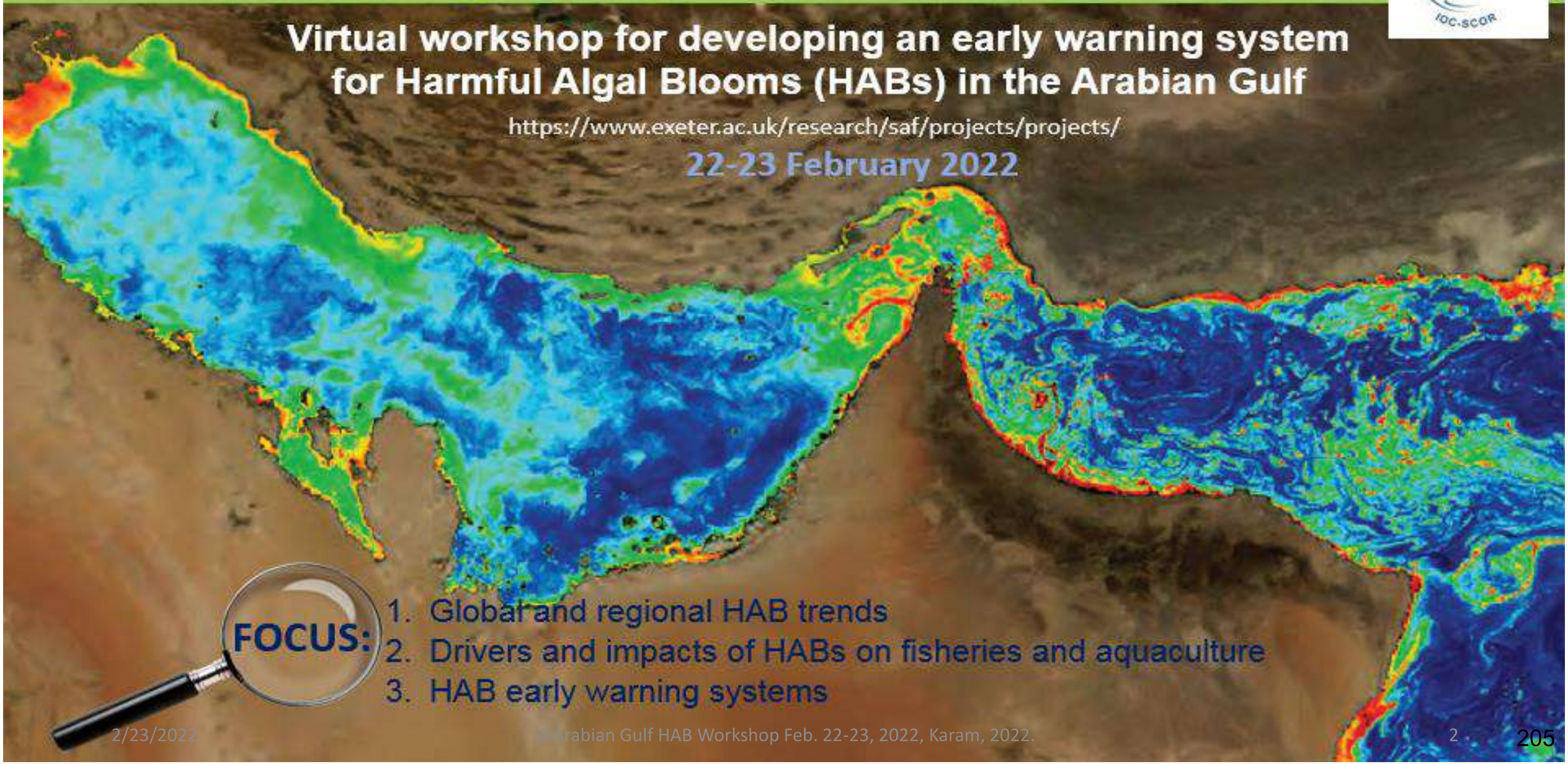
Co-Chair

Associate Research Scientist

Crises Management & Decision Support Program

Environment & Life Science Research Center

Kuwait Institute for Scientific Research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Kuwait Institute for Scientific Research
UNIVERSITY OF EXETER
Cefas
SUSTAINABLE AQUACULTURE FUTURES
GlobalHAB
IOC-SCOR
Virtual workshop for developing an early warning system for Harmful Algal Blooms (HABs) in the Arabian Gulf
https://www.exeter.ac.uk/research/saf/projects/projects/
22-23 February 2022
FOCUS:
1. Global and regional HAB trends
2. Drivers and impacts of HABs on fisheries and aquaculture
3. HAB early warning systems
2/23/2022
@Arabian Gulf HAB Workshop Feb. 22-23, 2022, Karam, 2022.
2

Introduction

- Multiple pollution sources impact Kuwait marine environment.
- Point source pollution of treated and untreated sewage can contribute to the adverse effects load on the marine ecosystem.
- Elevated nutrients load in wastewater along with increasing water temperature and salinity can trigger algal blooms in marine waters which can be a precursor for subsequent red time and fish kill incidents.
- Also, harmful algal bloom (HAB) species can responsible for selected marine mortality in Kuwait Territorial waters.
- On these grounds, the Kuwait Environment Public Authority (KEPA) has requested from Kuwait Institute for Scientific Research (KISR) to submit a research proposal to assess marine crises like HAB, red tides, and fish kills frequently occurring in Kuwait territorial waters with possible funding opportunities.

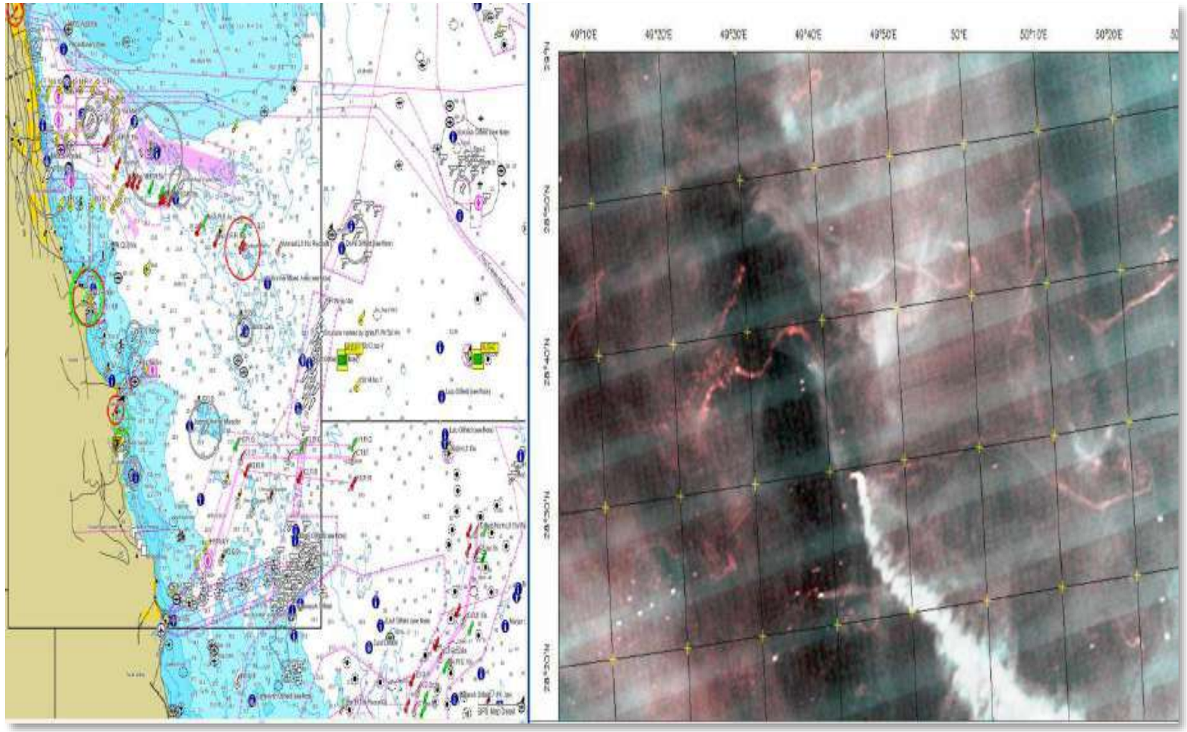
- Consequently, the idea emerged for an integrated system to predict, forecast, & understand the reoccurring events which triggered us to propose the development of an Early Warning System (EWS) for such environmental phenomena.

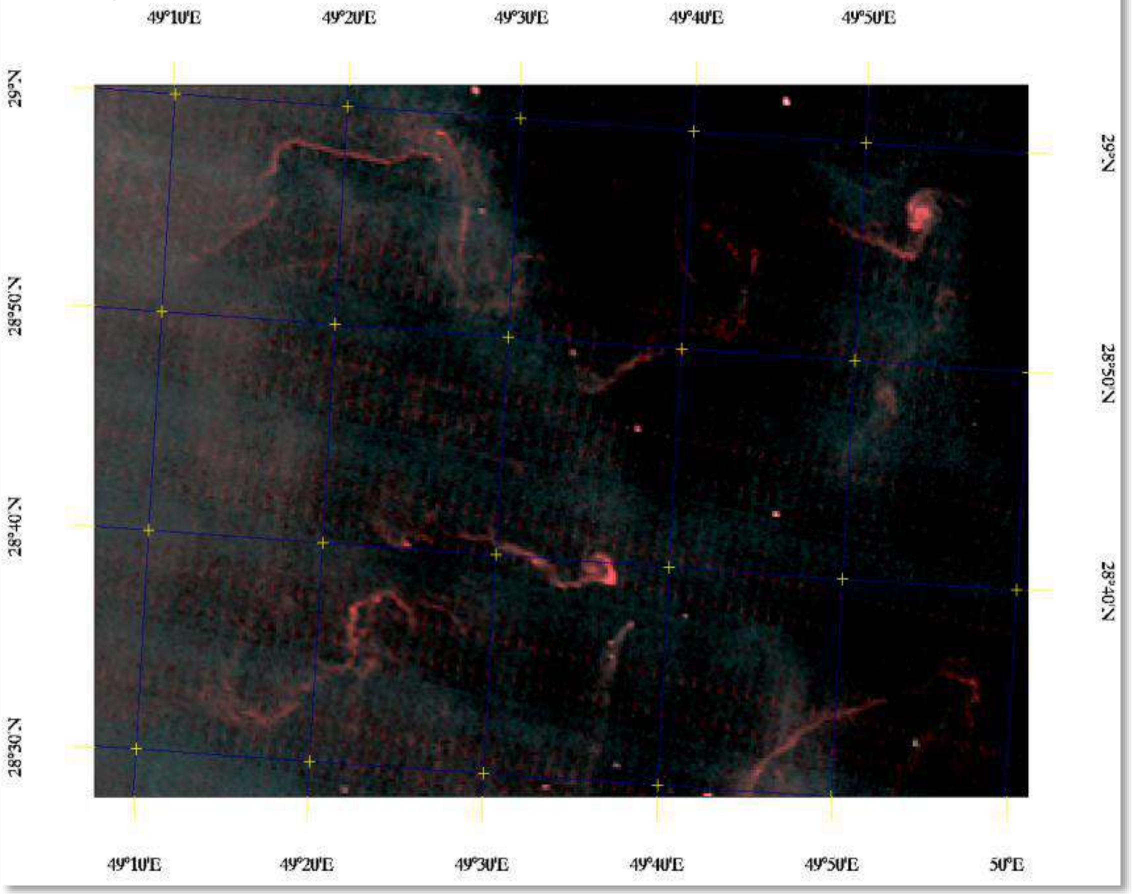
- The EWS will incorporate various analytical tools of ecologically indicator systems to analyze HAB, red tide, & fish kill events.

- Proper prediction, response, & management of environmental crises are essential to assist decision-makers.

- The suggested duration of the project will be 12 months.

Algal bloom.
Floating algal patches near Kuwaiti waters.
Terra MODIS (*Images by P. Petrov*).





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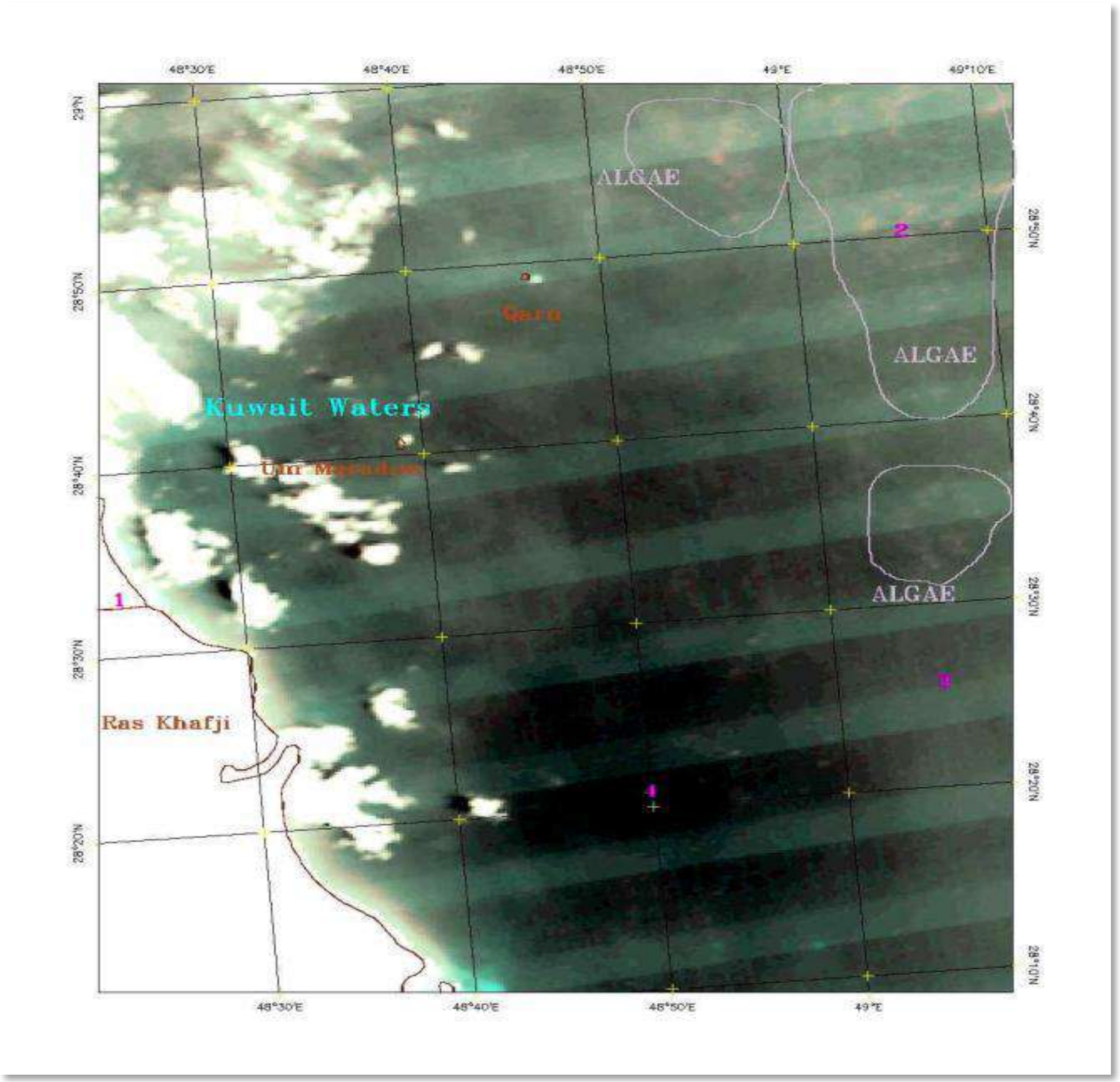
Algal bloom

Floating filaments as reddish patches in Northern Gulf near Kuwait waters, Terra MODIS (*Images by P. Petrov*).



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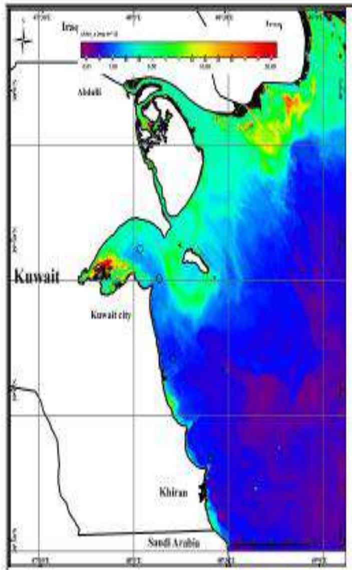
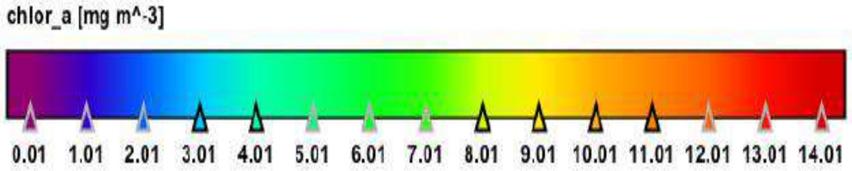
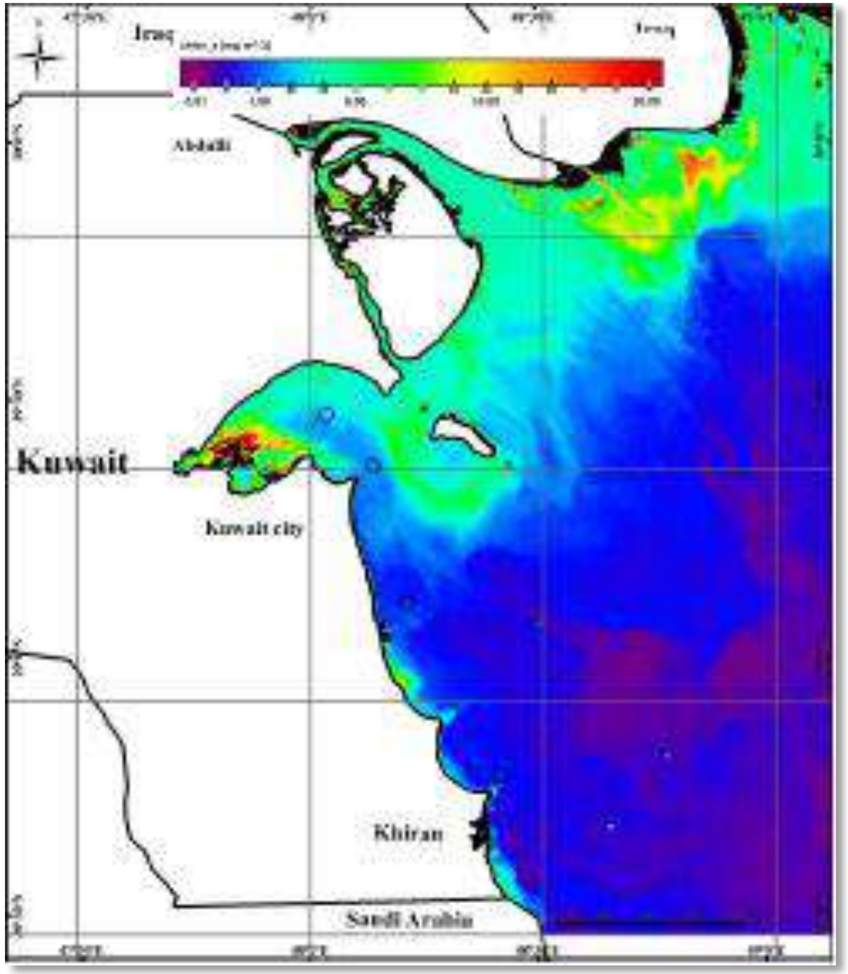
Kuwait Institute for Scientific Research
Crisis Decision Support Program

Remote Sensing Bulk Report for chlorophyl concentration (mg.m-3)

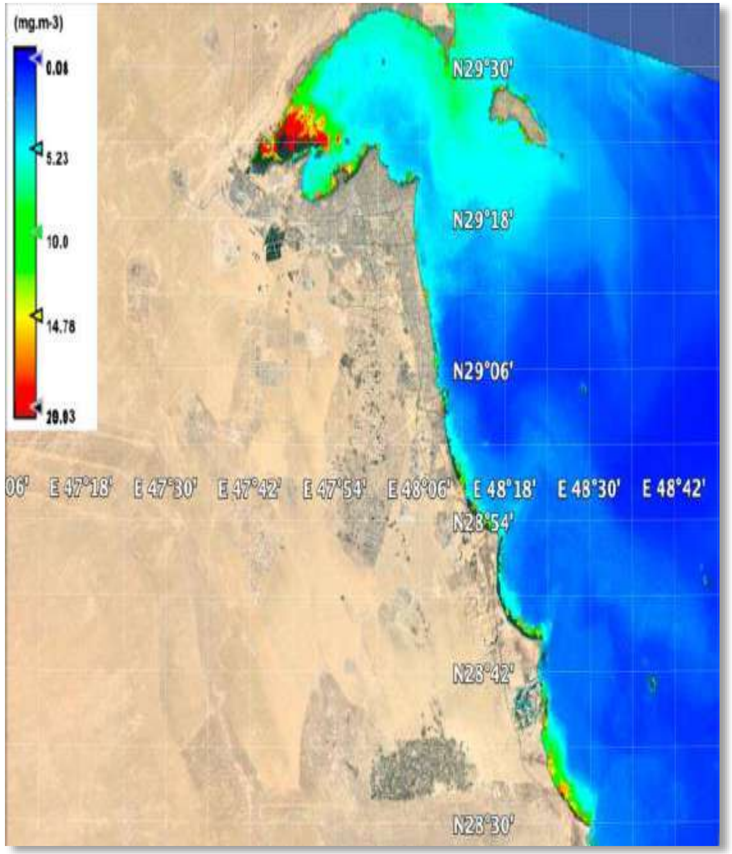


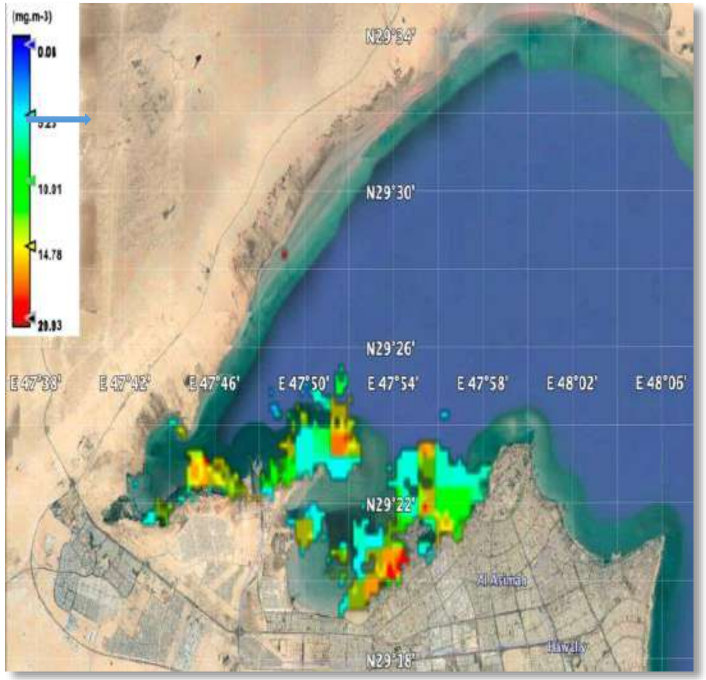
2022-01-09 (S3B)

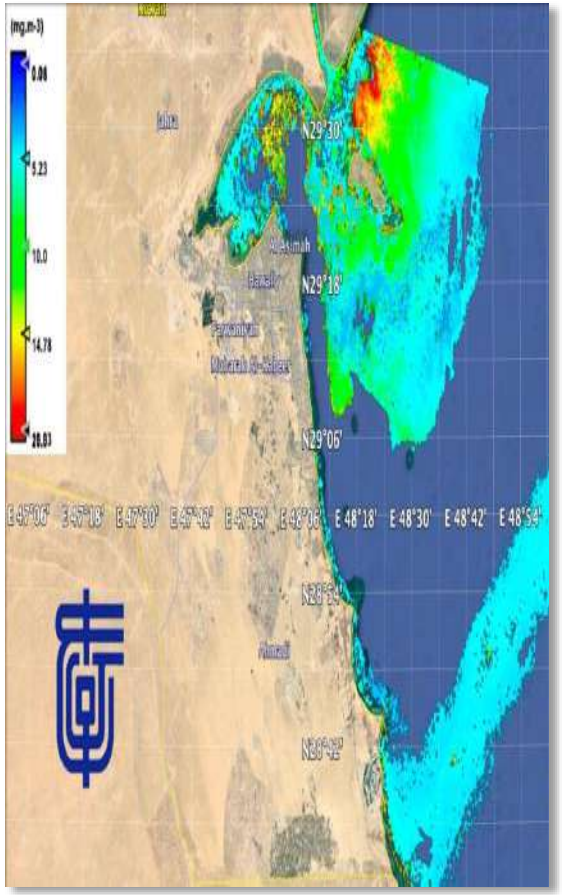




Algae Blooming







@Arabian Gulf HAB Workshop Feb. 22-23, 2022, Karam, 2022.

HABs, Red Tides, & Fish Kills in Kuwait:

- Discharges of untreated sewage to Kuwaiti waters can increase nutrients load in the water column triggering the eutrophication process leading to harmful algal blooms (HABs).

- As a consequence, red tides form which can cause major fish kill events devastating marine life.

- The outbreak of HAB in 1999 & 2001 lead to a fish kill event of mullet *Liza macrolepis* locally named meid; in Kuwait Bay and discoloration of seawater.

- It was estimated that in 1999, 25-30 tonnes of mullet fish were lost, and 2,500 tonnes in 2001

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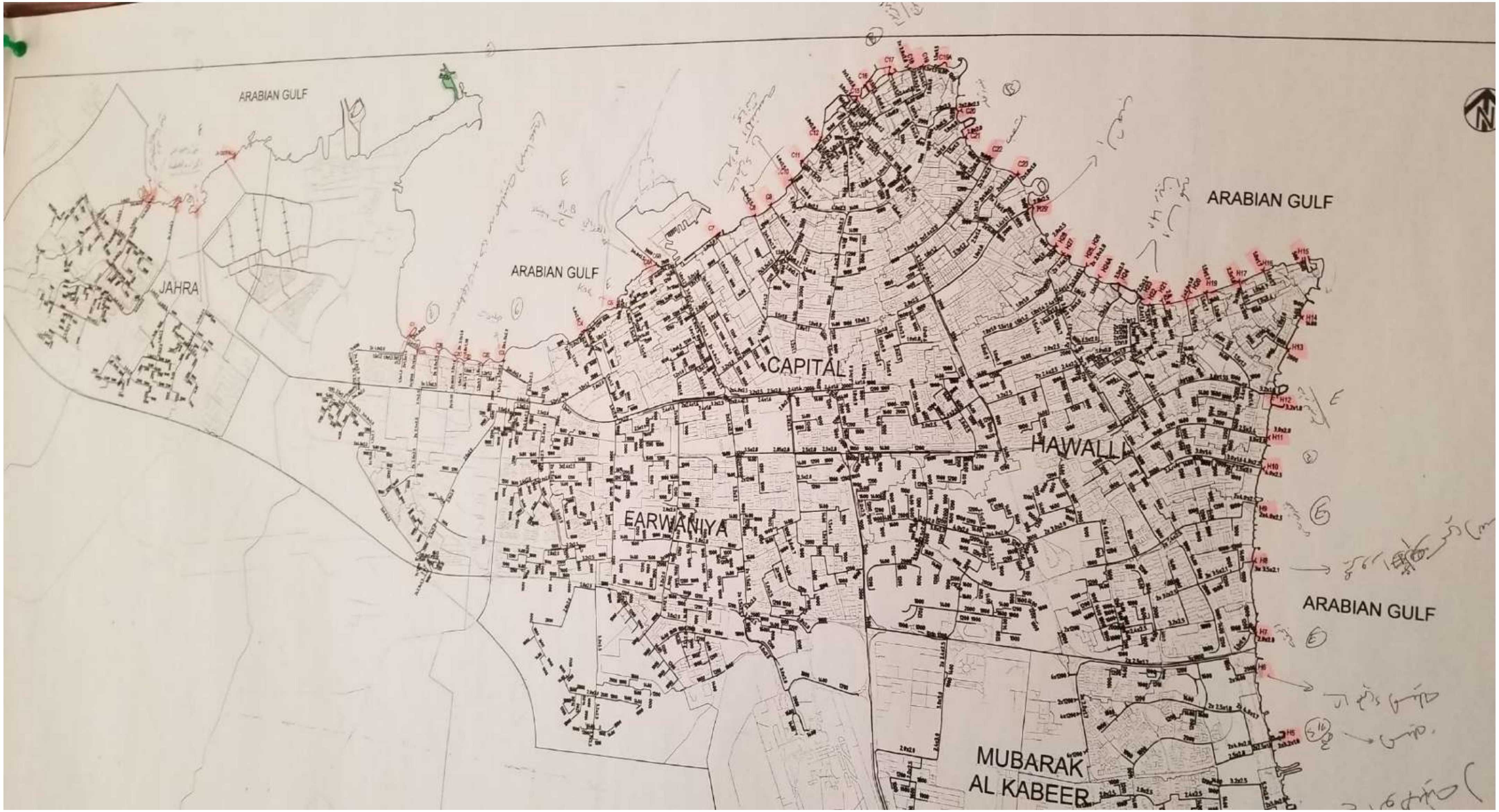
KUWAIT INSTITUTE FOR SCIENTIFIC RESEARCH

9 May, 2017

Fish Kill
Incident

Kuwait



Source: Al-Osairi, Y.

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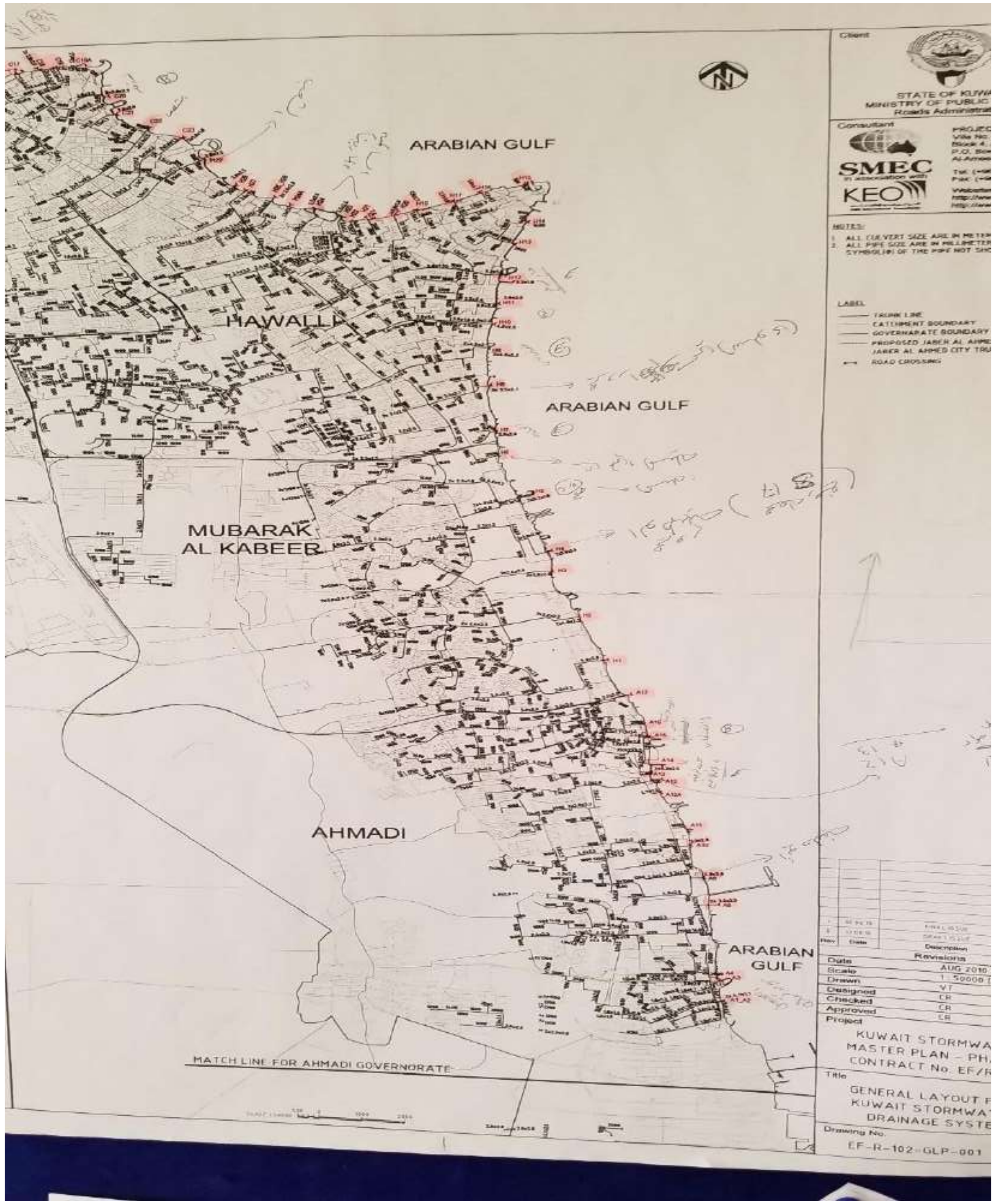

Source: Al-Osairi, Y.

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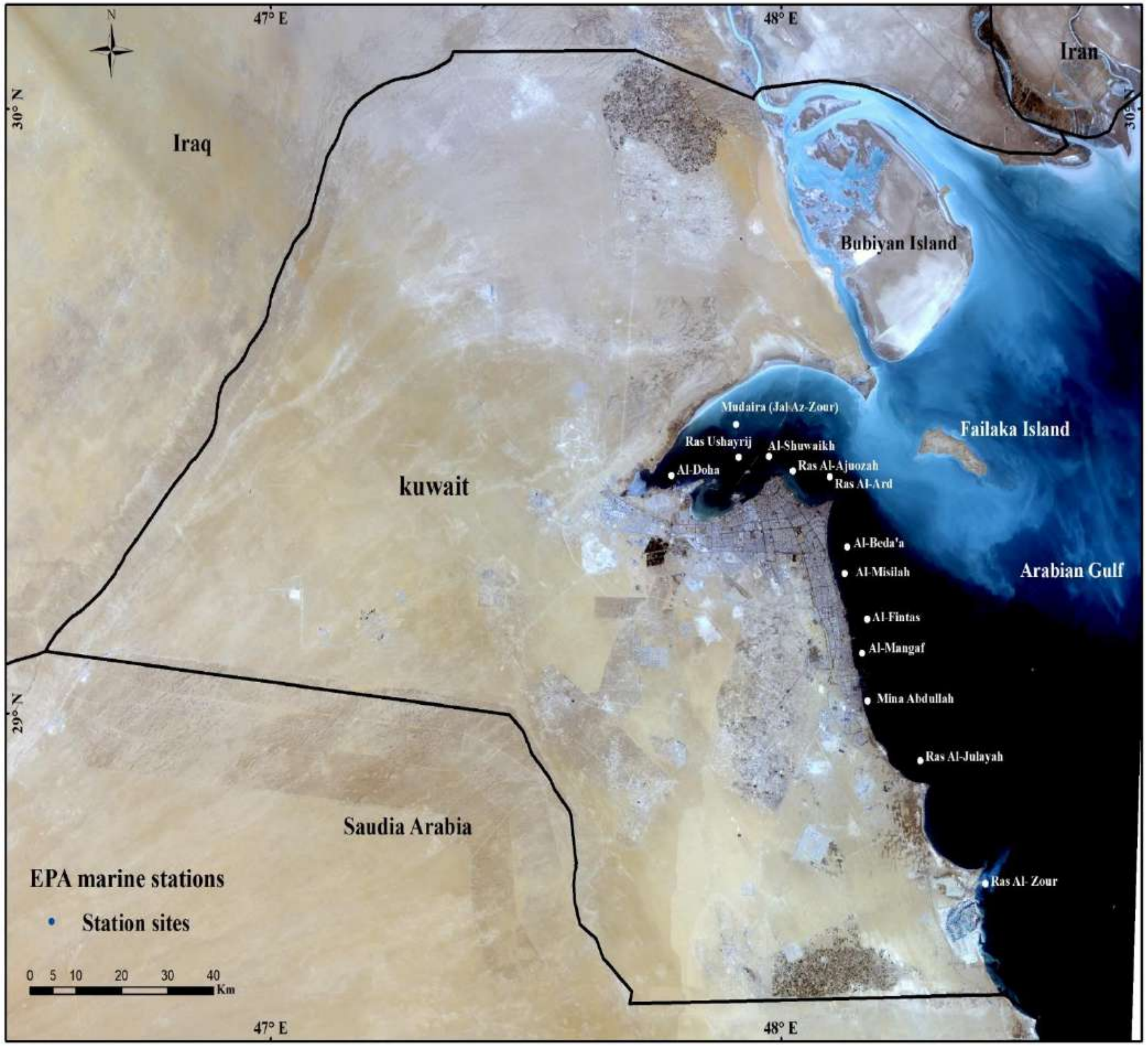
KEPA Monitoring Stations



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Historical Observations of Changes in Water Quality, Harmful Algal Blooms, and Fish Kills Incidents in North-Western Arabian Gulf Sea Area: A Review Study

	Chlorophyll (µg/L)	Nutrients	Biological Species	Sample Type	Year
HAB Events	14.3 µg/L- bloom site 1.4 µg/L - non-bloom sites		Dinoflagellate *Karenia selliformis* *Prorocentrum rhathymum* *Scripsiella spinifera*	Water & sediment (mudflats)	1999 2001 2007 2008 2020
Fish Kill Events	14.3 µg/L- bloom site 1.4 µg/L - non-bloom sites	Nitrogen, Phosphorous, Orthosilicic acid	Dinoflagellate		1999 2001
					Covid-19 Period-2020 Kuwait Bay

Table 1. List of potentially harmful species in Kuwait's marine environment and known harmful effects described for these species.

CLASS/*Taxon*†
DINOPHYCEAE
Akashiwo sanguinea (K. Hirasaka) G. Hansen & Ø. Moestrup [surfactant-producing]
Alexandrium catenella (Whedon & Kofoid) Balech [PSP]
A. leei Balech [PSP]
A. minutum Halim [PSP]
A. pseudogonyaulax (Biecheler) Horiguchi ex Kita & Fukuyo [PSP?]
A. tamarense (Lebour) Balech [PSP]
A. tamiyavanichii Balech [PSP]
Amphidinium carterae Hulburt [Haemolysins]*
A. gibbosum (L. Maranda & Y. Shimizu) M. Flø Jørgensen & S. Murray [Cytotoxins]
A. operculatum Claparède & Lachmann [Haemolysins]
Ceratium furca (Ehrenberg) Claparède & Lachmann
C. fusus (Ehrenberg) Dujardin
Cochlodinium fulvescens Iwataki, Kawami & Matsuoka [Ichthyotoxicity]
Dinophysis acuminata Claparède & Lachmann [DSP]
D. acuta Ehrenberg [DSP]
D. caudata Saville-Kent [DSP]
D. miles Cleve [DSP]
D. norvegica Claparède & Lachmann (DSP]
D. tripos Gourret [DSP]
Gonyaulax polygramma Stein
G. spinifera (Claparède & Lachmann) Diesing [Yessotoxin]
Gymnodinium catenatum H.W. Graham [PSP]
Karenia mikimotoi (Miyake & Kominami ex Oda) G.Hansen & Ø.Moestrup [Ichthyotoxicity]
K. papilionacea A. Haywood & K. Steidinger [NSP]
K. selliformis A. Haywood, K. Steidinger & L. MacKenzie [NSP]*
Lingulodinium polyedrum (F. Stein) J.D. Dodge [Yessotoxin]
Noctiluca scintillans (Macartney) Kofoid & Swezy
Ostreopsis ovata Fukuyo [CFP]
O. cf siamensis Schmidt [CFP]
Peridinium quinquecorne Abé*
Phalacroma mitra F. Schütt [DSP]
P. rapa Jorgensen [DSP]
P. rotundatum (Claparède & Lachmann) Kofoid & Michener [DSP]
Prorocentrum concavum Fukuyo [OA, DTX-1, CFP]
P. emarginatum Fukuyo [Haemolytic activity]
P. lima (Ehrenberg) F. Stein [DSP]
P. micans Ehrenberg
P. minimum (Pavillard) J. Schiller [NT]
P. rhathymum Loeblich, Shirley & Schmidt [Haemolytic activity]*
Protoceratium reticulatum (Claparède & Lachmann) Butschli [Yessotoxin]
Pyrodinium bahamense* var. *compressum (Böhm) Steidinger, Tester & Taylor [PSP]
Scrippsiella trochoidea (Stein) Balech ex Loeblich III
Takayama cf pulchella (Larsen) de Salas, Bolch & Hallegraeff [Ichthyotoxicity]

(Continued on next page)

Al-Yamani & Polikarpov, 2012.

Table 1. List of potentially harmful species in Kuwait's marine environment and known harmful effects described for these species. *(Continued).*

CLASS/*Taxon*†
BACILLARIOPHYCEAE
Amphora coffeaeformis (C. Agardh) Kütz [DA, ASP?]
Chaetoceros curvisetum Cleve*
C. pseudocurvisetus Mangin*
C. socialis H.S.Lauder*
Cyclotella sp.*
Cylindrotheca closterium (Ehrenberg) Reimann & J.C.Lewin*
Eucampia zodiacus Ehrenberg*
Guinardia flaccida (Castracane) H.Peragallo*
Nitzschia laevis Hustedt*
Pseudo-nitzschia pungens (Grunow ex Cleve) G.R.Hasle [ASP]
***Pseudo-nitzschia delicatissima* group** [ASP]
DICTYOCHOPHYCEAE
Dictyocha fibula Ehrenberg
D. speculum Ehrenberg
CRYPTOPHYCEAE
Teleaulax sp.*
RAPHYDOPHYCEAE
Chattonella marina* var. *antiqua (Y.Hada) M.Demura & F.Kawachi [Superoxides, NT]
Heterosigma akashiwo (Y.Hada) Y.Hada ex Y.Hara & M.Chihara [NT]*
PRYMNESIOPHYCEAE
Phaeocyctis cf globosa Scherffel (Haemolysins)*
CYANOPHYCEAE
Trichodesmium erythraeum Ehrenberg ex Gomont (NT, HT)*
Phylum CILIOPHORA
Myrionecta rubra Lohmann*

†species names were verified using the AlgaeBase website (Guiry and Guiry, 2012).

Harmful effect is indicated as above: 1 – *Toxic species* [Toxin, Syndrome]: **PSF** – Paralytic Shellfish Poisoning; **NT** – Neurotoxic; **HT** – Hepatotoxic; **ASP** – Amnesic Shellfish Poisoning; **DSP** – Diarrhetic Shellfish Poisoning; **NSP** – Neurotoxic Shellfish Poisoning; **CFP** – Ciguatera Fish Poisoning; **OA** – okadaic acid; **DTX** – dinophysistoxin; **DA** – domoic acid; 2 – *Harmful species*: those species that are known to produce blooms associated with fish mortality elsewhere; 3 – *Bloom-forming species**: bloom or close to bloom abundance (10^5–10^6 cells l^{-1}) was detected in Kuwait.

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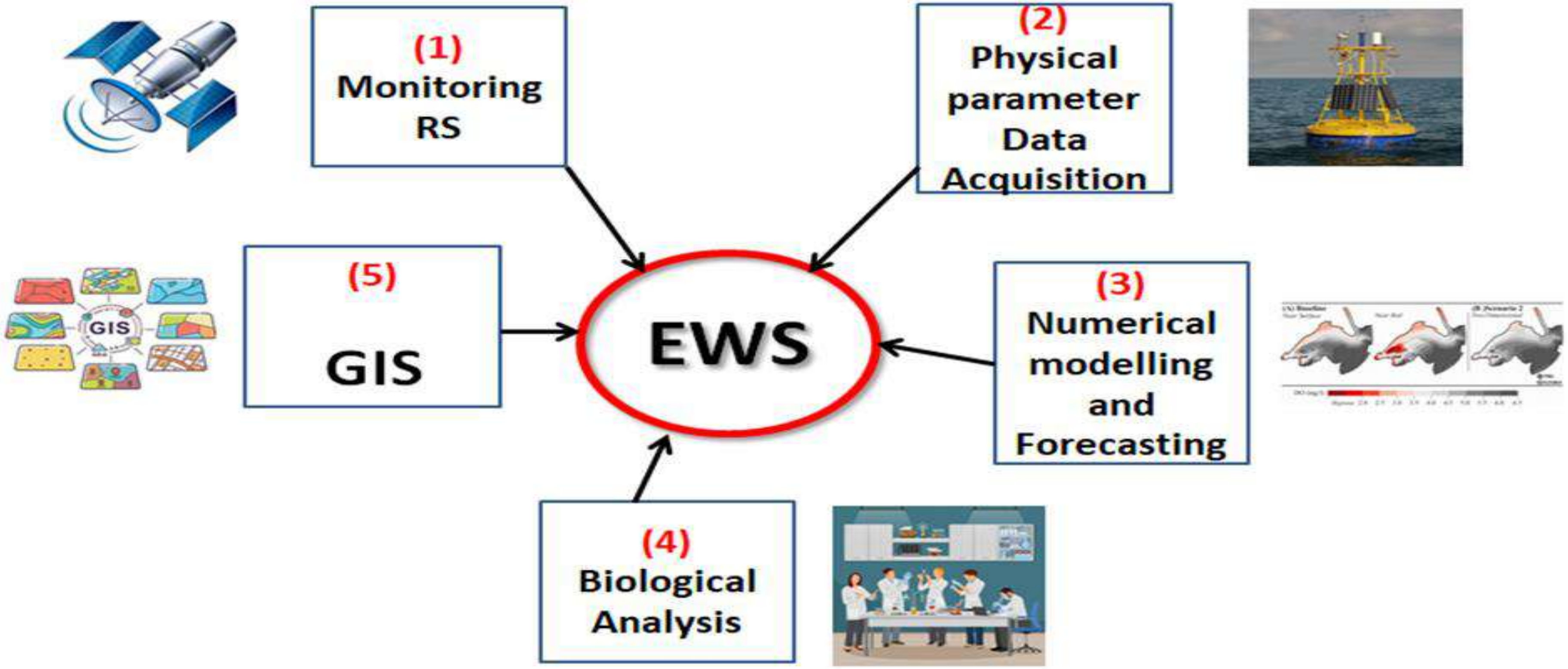
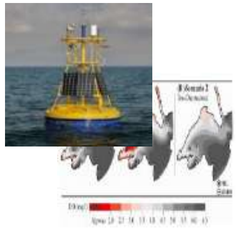


EWS: Early Warning System.
RS: Remote sensing.
GIS: Geographic Information System.

(1)
Monitoring Remote Sensing

Spectral reflectance of various plankton species, harmful algal blooms (HAB), and red tide events will be assessed. A hyperspectral camera will be used to measure the spectral signatures of the features within fieldwork measurements. Chlorophyll-a concentration will be estimated through MODIS-Aqua (Moderate Resolution Imaging Spectroradiometer) sensor.



(2)
Numerical modelling and Forecasting

Numerical model Delft3D will be used based on field measurements like salinity, water levels, temperature, and dissolved oxygen (DO). Also, meteorological aspects will be evaluated to support the hydrodynamic Delft3D-FLOW Model. The model will be coupled with a water quality model, Delft3D-WAQ.

(3)
Biological Analysis

Seawater samples will be carried out by team in the biodiversity department, KEPA. HAB species taxonomical identification, and classification into harmful/ non-harmful will be done. Common HAB species amongst others which will be identified as toxic or non-toxic in this study like *Cochlodinium polykrikoides*, toxic dinoflagellate *Gymonodinium* sp., and the non-toxic ciliate *Mesodinium rubrum.*

(5)
GIS

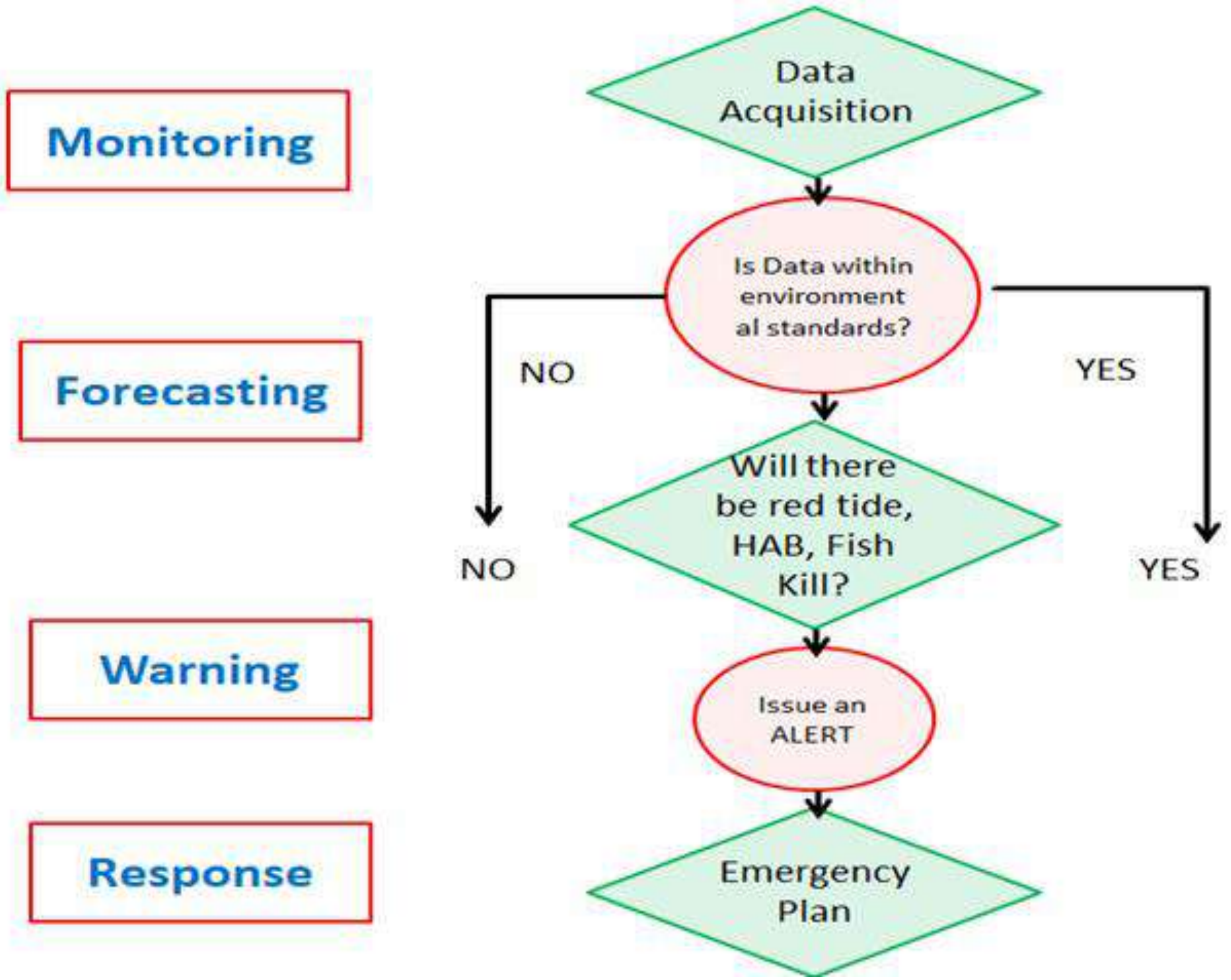
several analyses will be performed on the obtained data from Remote Sensing, field observations, HAB species, water quality parameters, numerical modelling, and others. For instance, water quality range, red tides spatial distribution, red tides intensity range will be produced. Also, a thematic map of red tide hazard degree assessment will be developed using the interpolation method, and the spatial distribution of hazard degree grades as indicated in previous studies

Early Warning System (EWS) for HAB, Red Tides, and Fish Kill Incidents in Kuwait Territorial Waters

OPERATION CENTER

(1) Remote Sensing → (2) Numerical Modeling → (3) Biological Assessment → (4) GIS → (5) Data Analysis

→ (6) Reporting


Monitoring
Forecasting
Warning
Response
Data Acquisition
Is Data within environment al standards?
NO
YES
Will there be red tide, HAB, Fish Kill?
NO
YES
Issue an ALERT
Emergency Plan

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Kuwait Institute for Scientific Research

Marine Buoy

"KISR-01"

Key Discussion Points

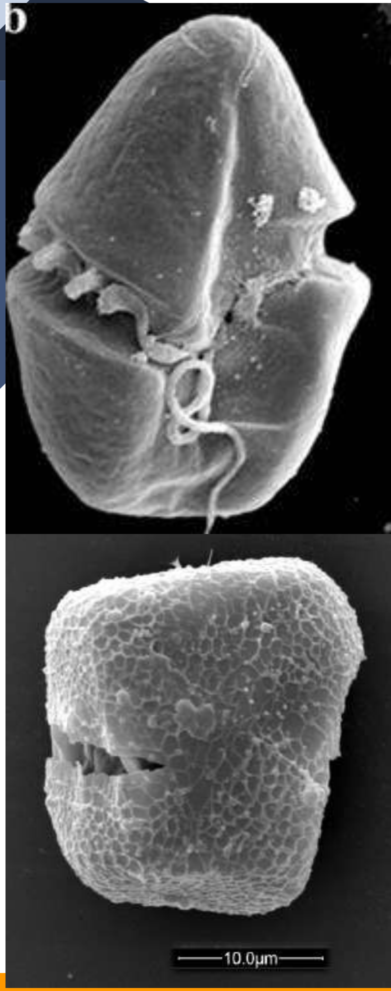
- HAB incidents in Kuwaiti waters consist of toxic and non-toxic species.
- Reoccurrence of specific neurotoxic HAB species over the years.
- Emergence of new species in RSA.
- HAB events frequencies are elevated in the summer season.
- Kuwait Bay in the northern Arabian gulf is a hotspot for HAB, and red tide events.
- Wastewater is the confirmed causative agent, and triggering factor for HAB, red tide, and fish kills events.

THANK YOU

Harmful Algal Blooms Workshop

Sponsor by UK and Kuwait Governments endorsed by the Global Harmful Algal Blooms (GlobalHAB) Programme

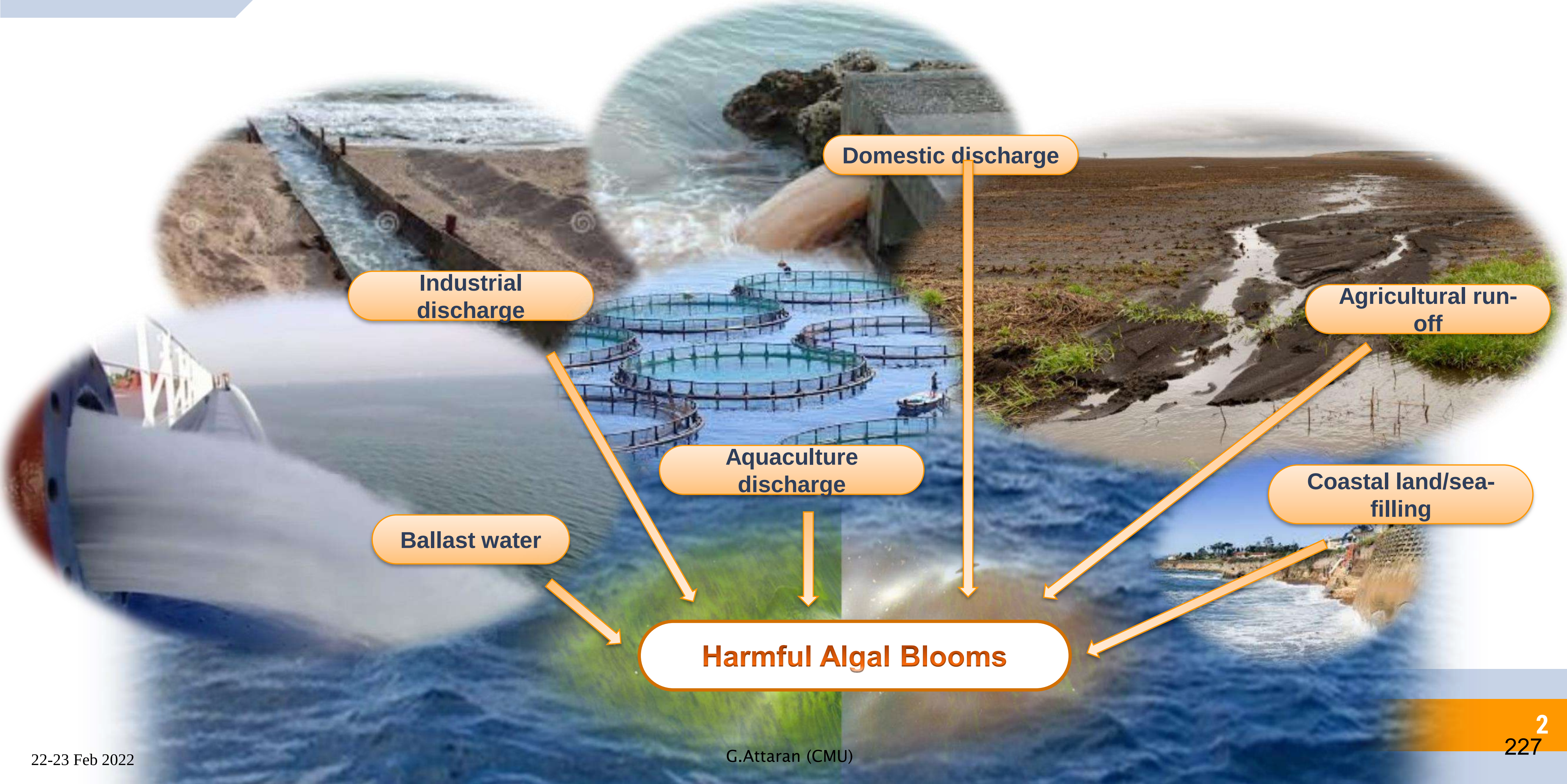
Existing HAB observation and EWS in the Persian Gulf and the Sea of Oman



Gilan Attaran-Fariman
(Chabahar Maritime University, Iran)

22-23 Februray 2022

ANTHROPOGENIC SOURCES INDUCING HABs



HAB species recorded in the Sea of Oman and the Persian Gulf

HAB species:

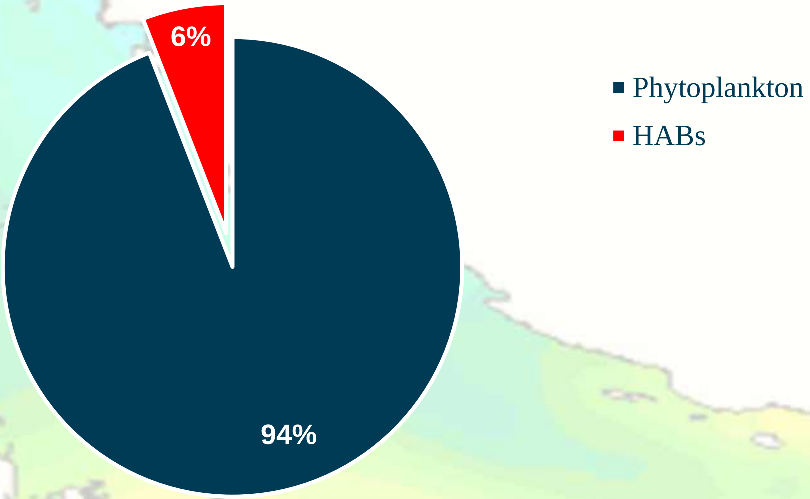
a) Toxin producer contaminant sea food and kill marine organism

b) High biomass producer

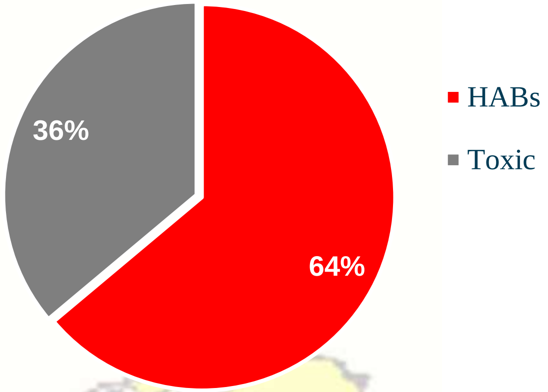
Hypoxia, anoxia, unselective mortality of marine organism

c) Some HAB species have characteristic of both

HABs in total phytoplanton



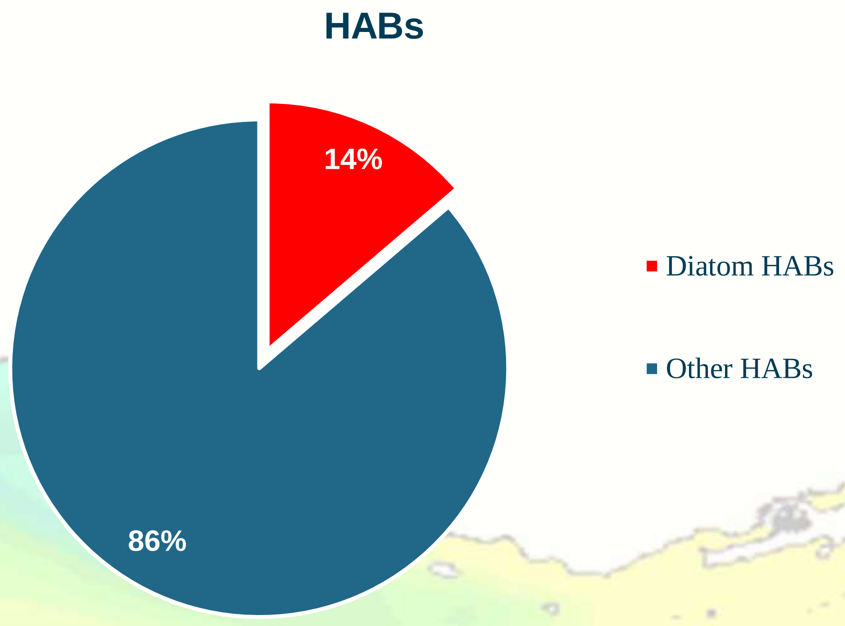
Toxic species in HABs



Source :Attaran Fariman and Asefi (2022)

HAB species recorded in the Sea of Oman and the Persian Gulf

Source :Attaran Fariman and Asefi (2022)



Diatoms HAB’s

Halamphora coffeaeformis
Nitzschia delicatissima
Pseudo-nitzschia spp

HAB species recorded in the Sea of Oman and the Persian Gulf

Dinoflagellates HAB’s
52 species

Source :Attaran Fariman and Asefi (2022)

Karlodinium gentienii

Karlodinium veneficum

Lingulodinium polyedra

Margalefidinium polykrikoides

Ostreopsis lenticularis

Ostreopsis ovata

Protoceratium reticulatum

Pyrodinium bahamense

Pyrodinium bahamense* var. *compressum

Ggonyaulax polygramma

Gymnodinium catenatum

Karenia brevis

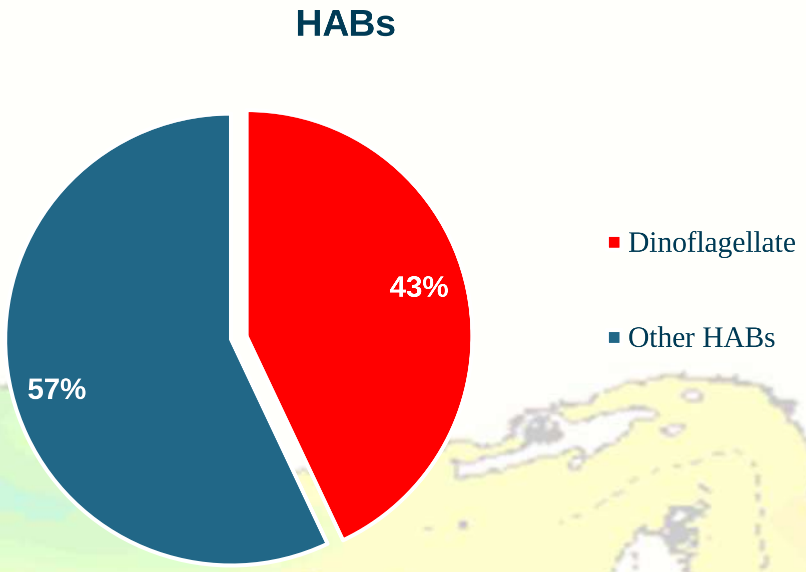
Karenia longicanalis

Karenia mikimotoi

Karenia papilionacea

Karenia selliformis

lavendaria fissa (Gyrodinium instriatum)



HAB species recorded in the Sea of Oman and the Persian Gulf

Other Group HAB's
6 species

Source :Attaran Fariman and Asefi (2022)

Chattonella antiqua

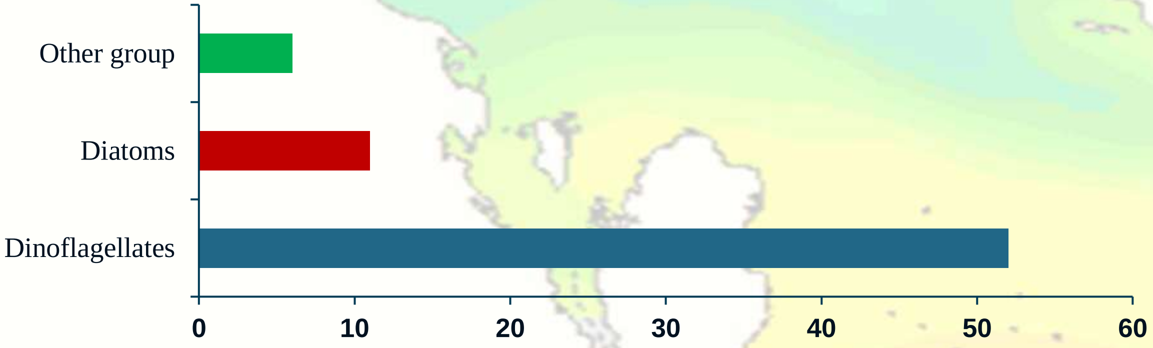
Chattonella marina

Chattonella subsalsa

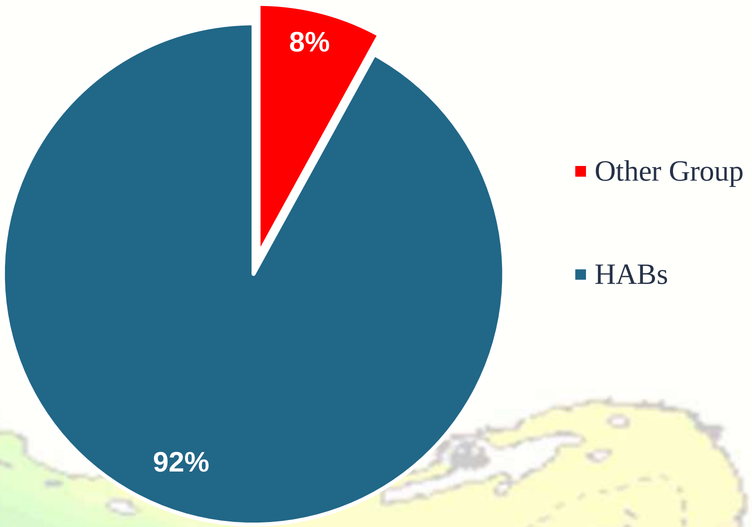
Heterosigma akashiwo

Phaeocystis globosa

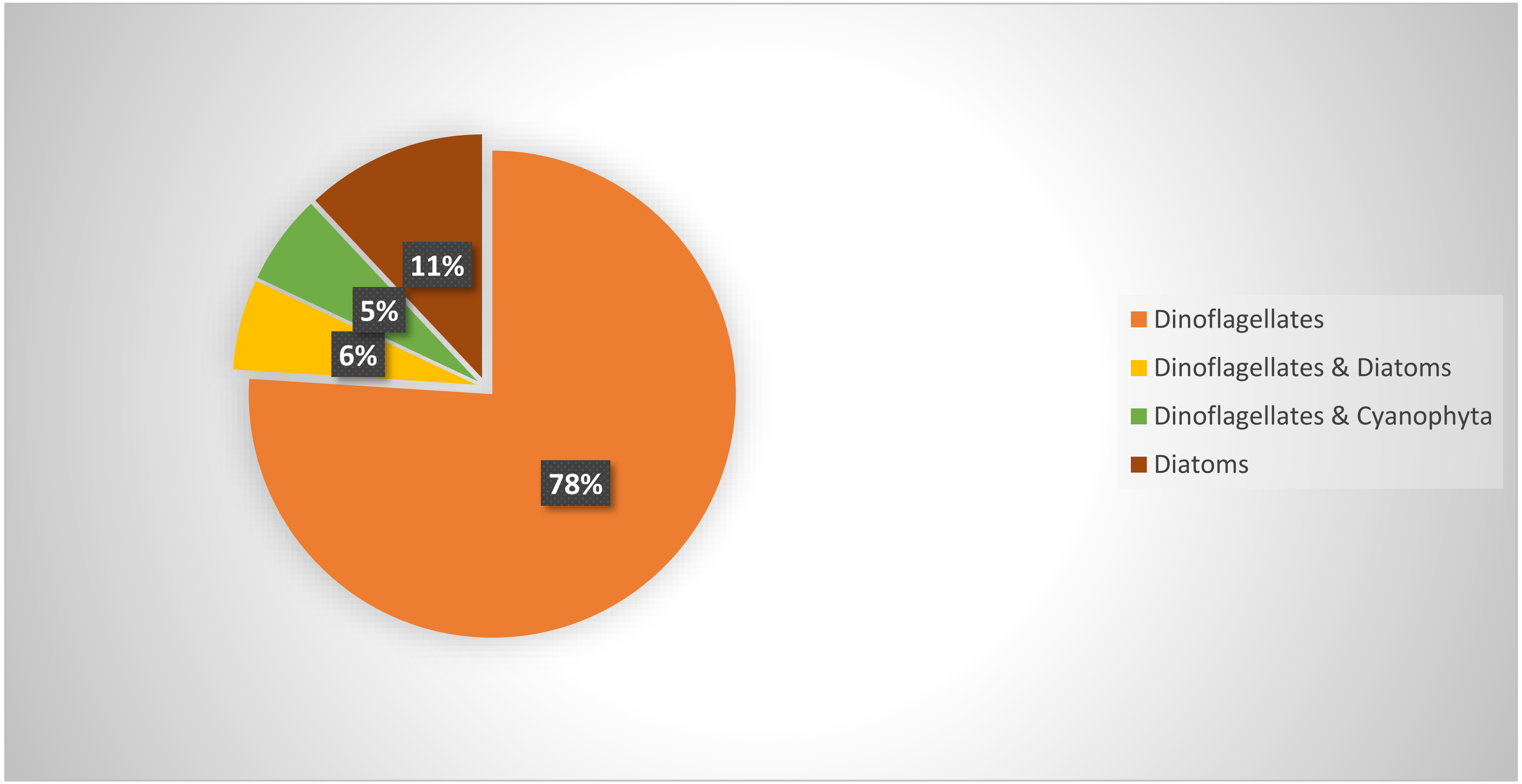
Phaeocystis pouchetii



Other Group HABs



Marine Mortality due to different groups of Algal Blooms in Persian Gulf and Sea of Oman (ROPME: 1988-2020)



Key points

Dinoflagellate are most important HAB former species in the Area

Most dinoflagellate HAB former species produce resting cyst

It estimates species in the water column

Cysts act as seed population

Cysts, as the seed bank, play an important role in the onset of plankton blooms that may occur, and therefore provide early warnings of the presence of toxic species in a particular area.

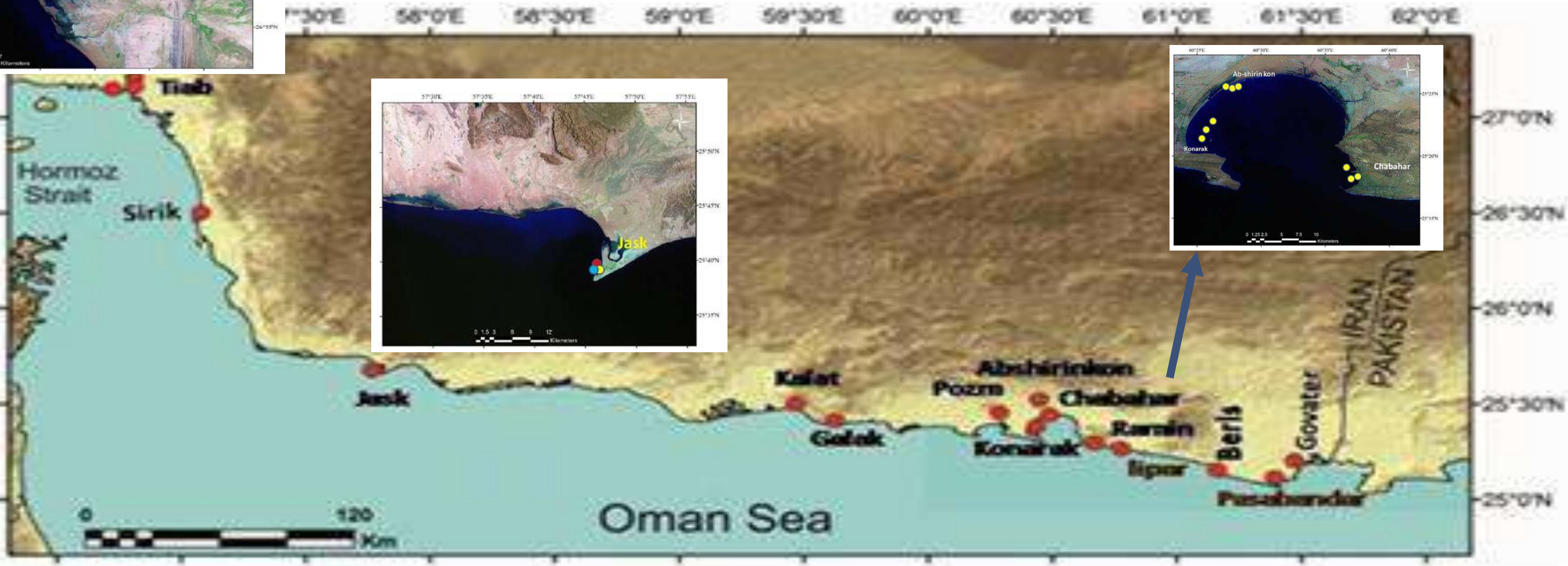
Dispersion and Abundance Assessment of different Species of Phytoplankton Cysts in Sediments of the Oman Sea (Attaran Fariman, 2016)

Division of Marine Environment

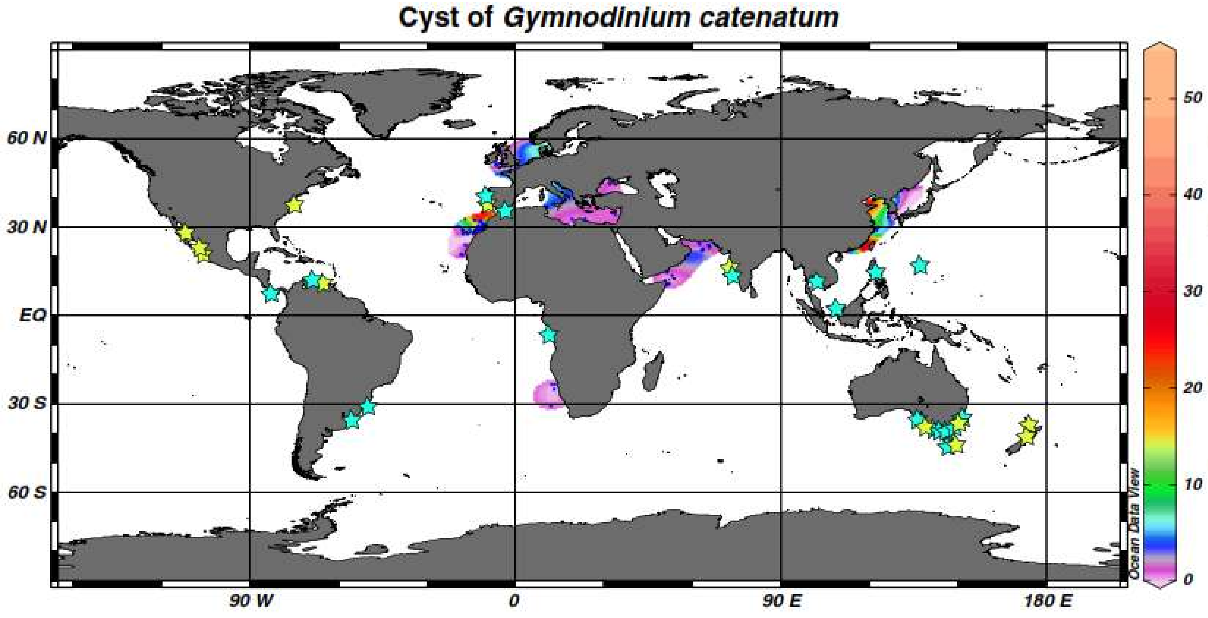
Dispersion and Abundance Assessment of different Species of Phytoplankton Cysts in Sediments of the Oman Sea

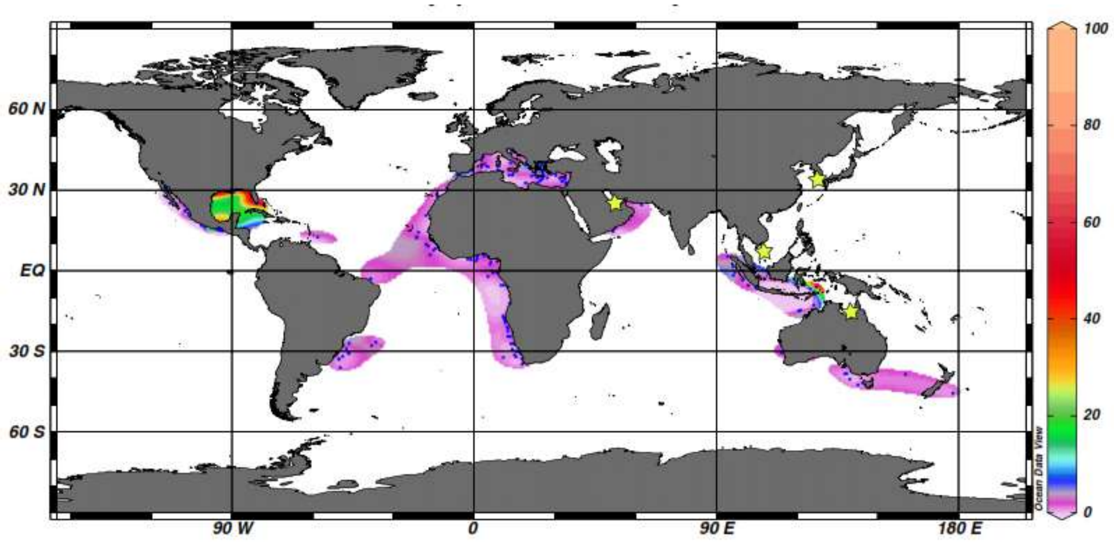
This Research Project Has Been Financially Supported by the Office of Marine Environment

47 stations in 16 area– 4 season: 83 dinocysts



HABs Cyst distribution in the area





Source: Zonneveld et al., 2013

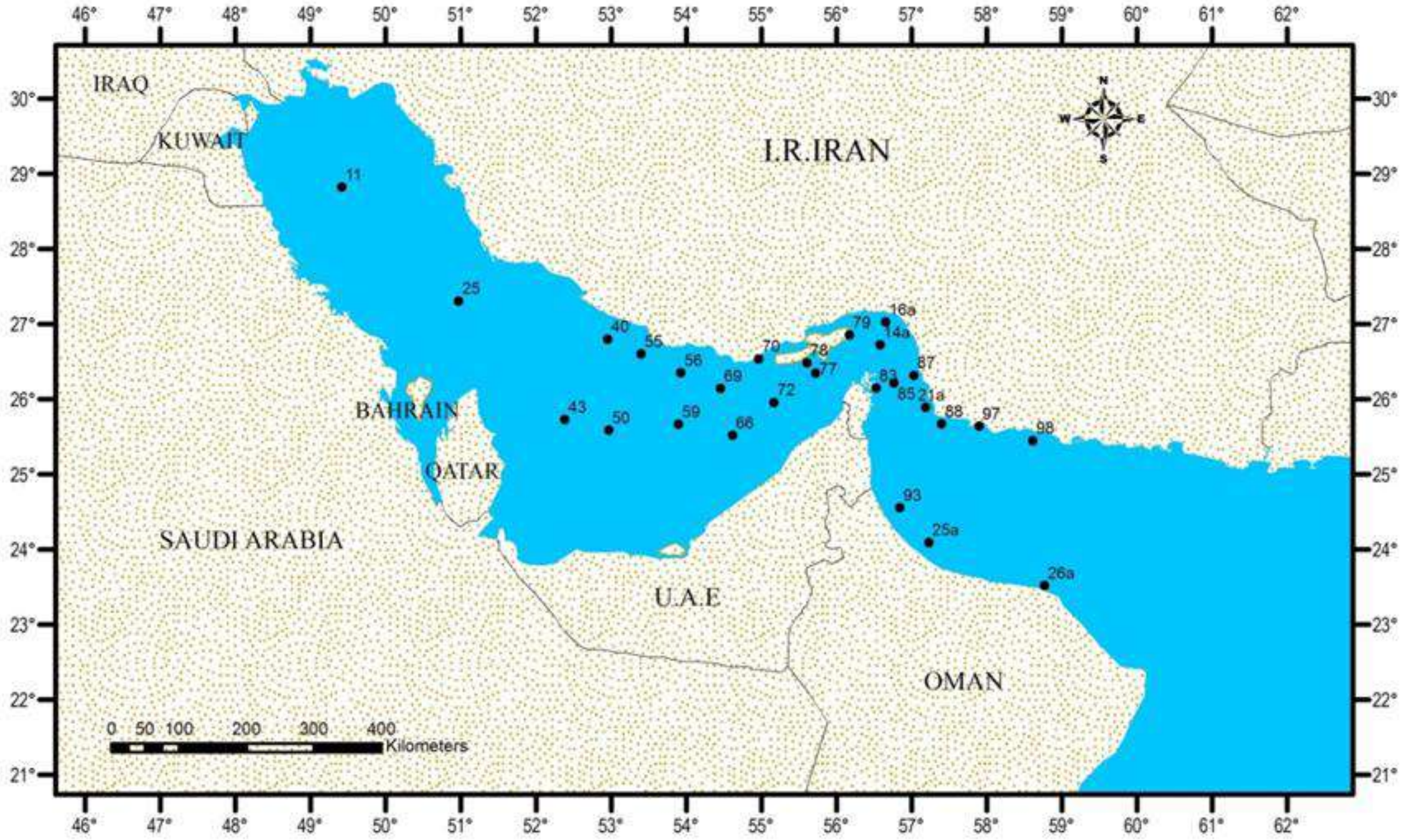
G. catenatum 2.3%

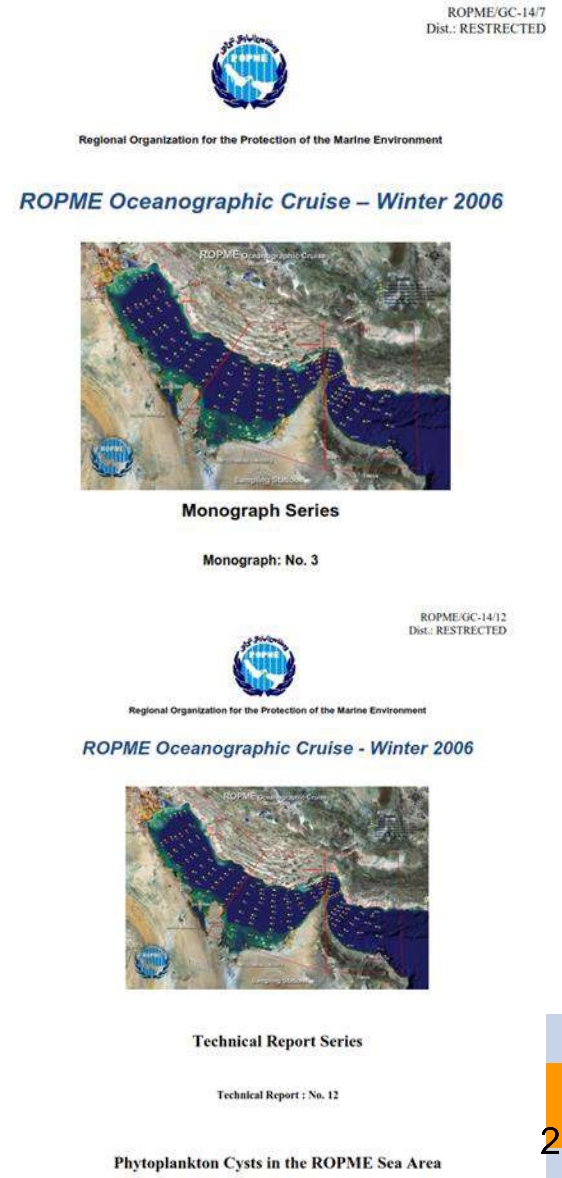
P. bahamense 2.7 %

M. polykrikoides 1.3%

(Attaran Fariman, 2016)

Identification and Distribution of Phytoplankton Cysts in Sediments from ROPME Winter 2006 Oceanographic Cruise(Attaran Fariman 2020)




ROPME/GC-14/7
Dist.: RESTRECTED

Regional Organization for the Protection of the Marine Environment

ROPME Oceanographic Cruise – Winter 2006

Monograph Series

Monograph: No. 3

ROPME/GC-14/12
Dist.: RESTRECTED

Regional Organization for the Protection of the Marine Environment

ROPME Oceanographic Cruise - Winter 2006

Technical Report Series

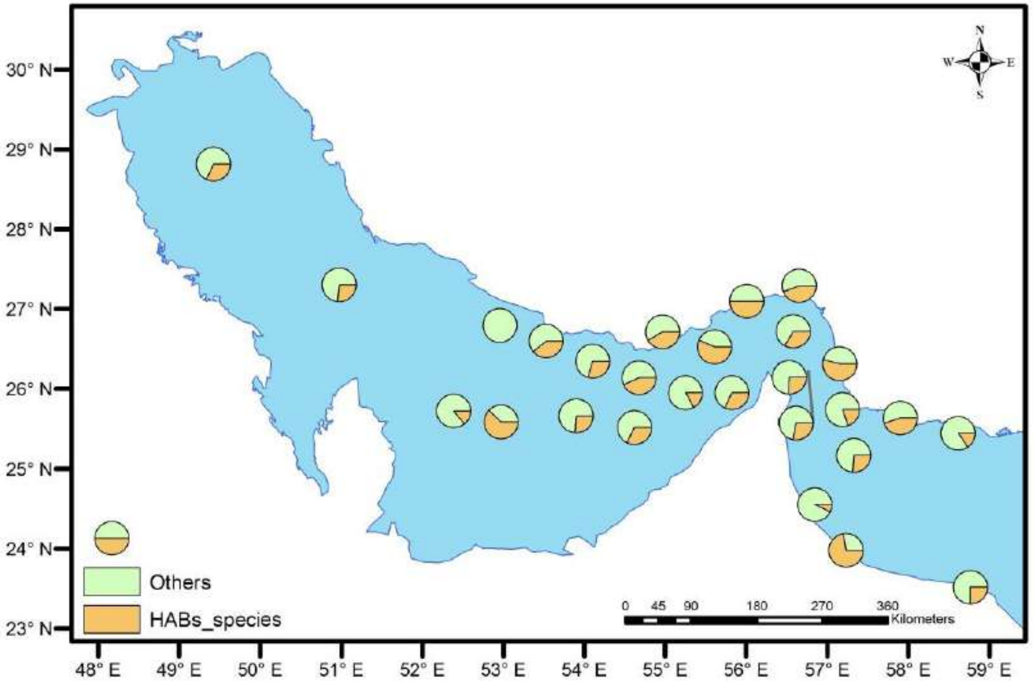
Technical Report : No. 12

Phytoplankton Cysts in the ROPME Sea Area

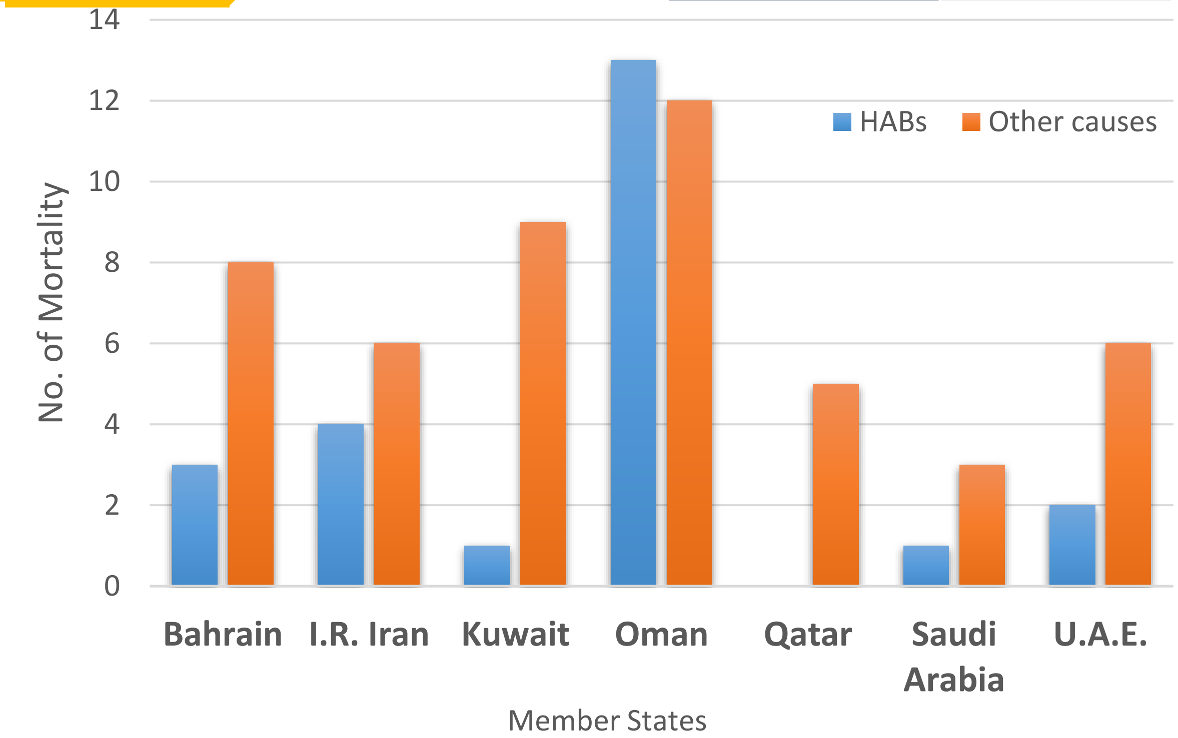
(Source; Attaran Fariman2020)

Phytoplankton cyst	Abundance (%)
Diatom	0.64
Dinoflagellate	99.06
Raphidophyte	0.39

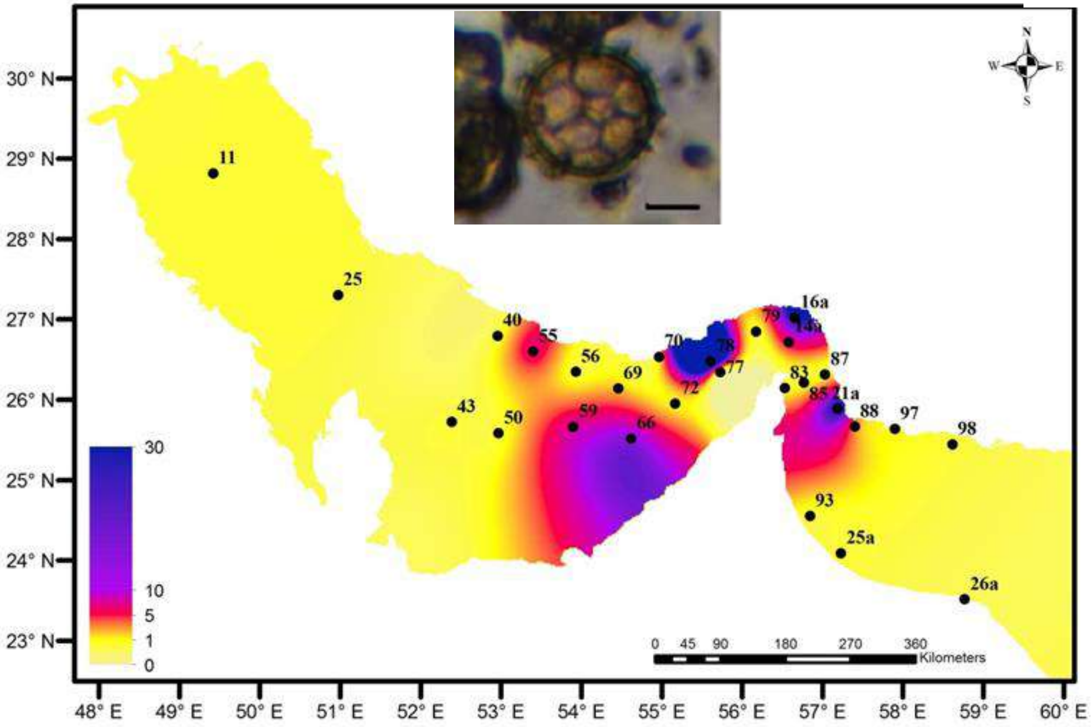
The highest abundance with 73% was recorded in station in the southern part of the Oman Sea along Oman coast



Distribution of HABs former cyst stage to others in different stations, winter 2006 (Source; Attaran Fariman2020)



Number of Marine Mortality incidents in coastal waters of Member States (Source ROPME;1988-2008)



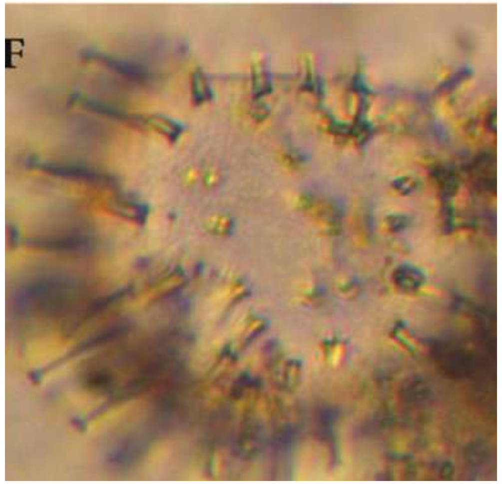
M. Polykrikoides **cyst concentration (Cyst g^{-1} dws)**

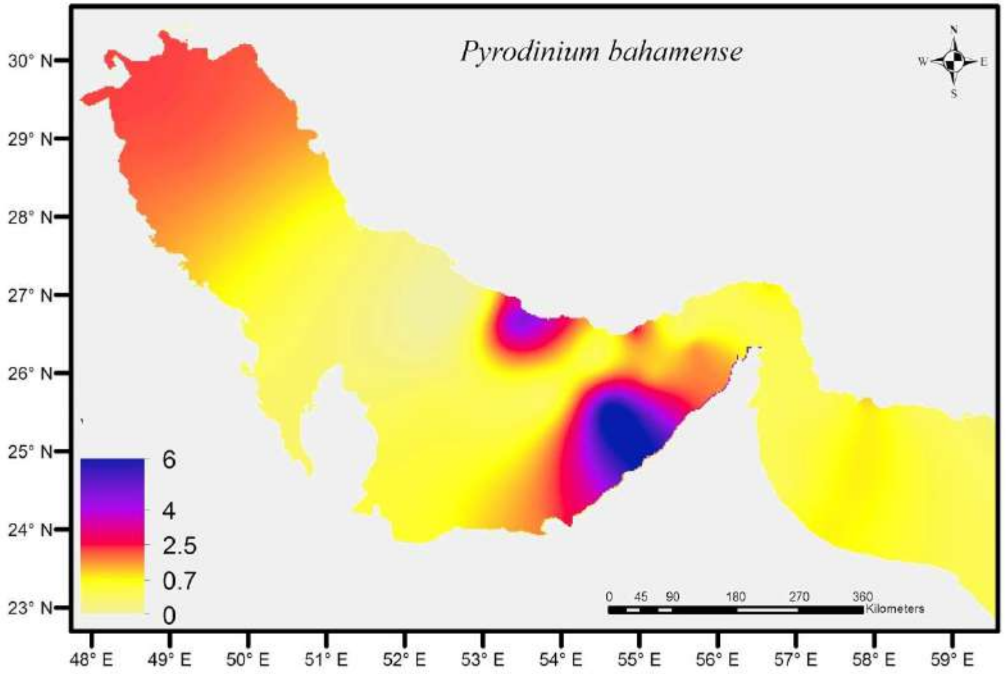
- **2008 incident of HABs: *Margalefidinium polykrikoides=Cochlodinium polykrikoides* coastal waters of UAE and Iran**

High cyst abundance in stations located in U.A.E and Strait of Hormuz

(Source; Attaran Fariman2020)

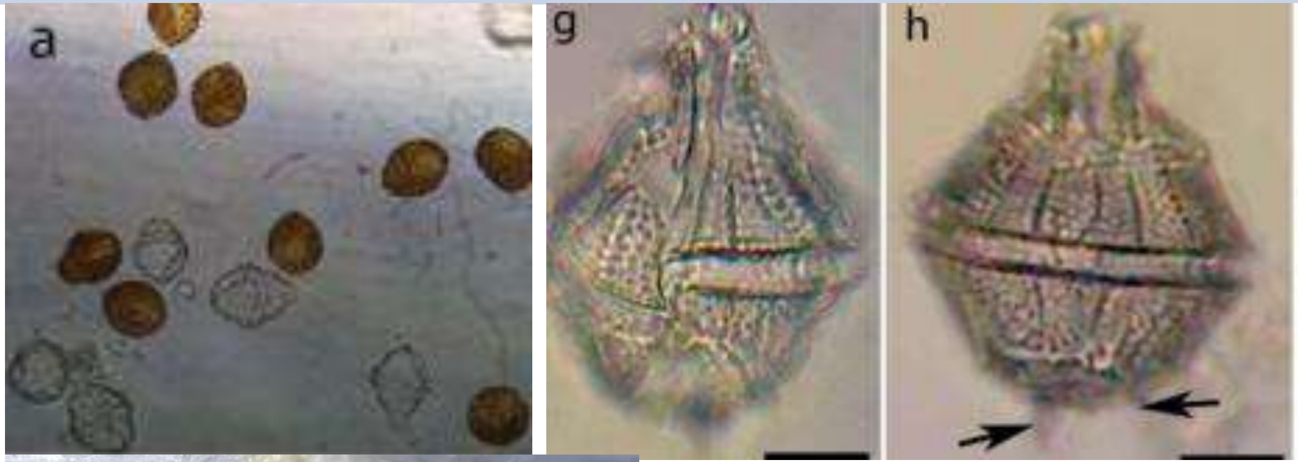
Bloom former and a typical warm water species (previously dominant) distributed in the tropical and subtropical regions from Indian Ocean to Pacific





P. bahamense **cyst concentration (Cyst g^{-1} dws)**
(Source; Attaran Fariman2020)

Algae bloom observation In the Sea of Oman (2017)



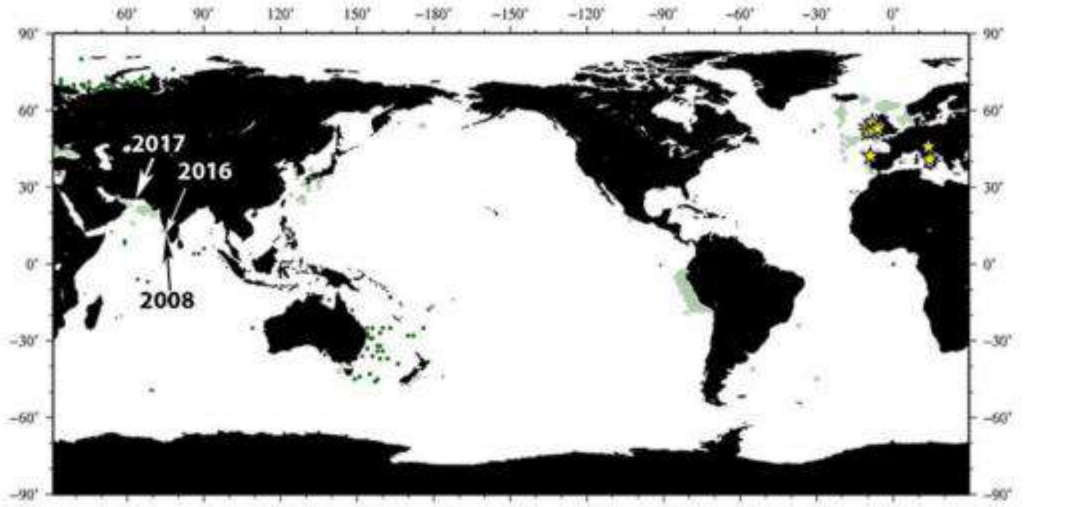
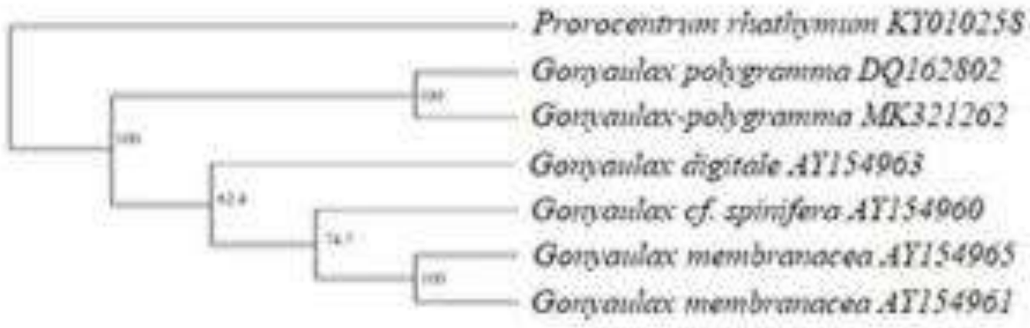


Figure 6: Global distribution of *G. polygramma* (in green) with years of red tide events in the

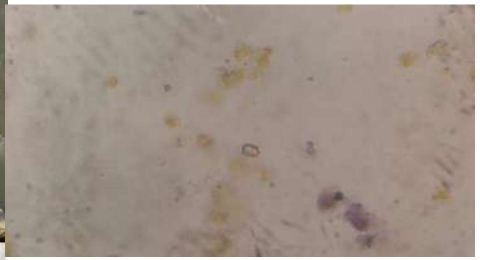


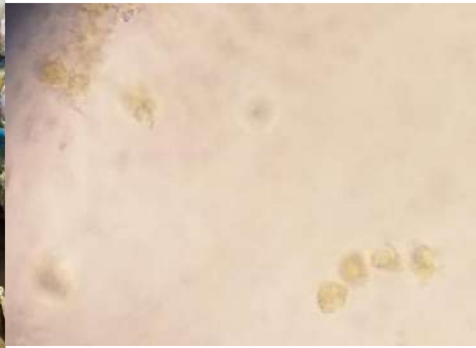
(Source: Dolatabadi et al. 2021)

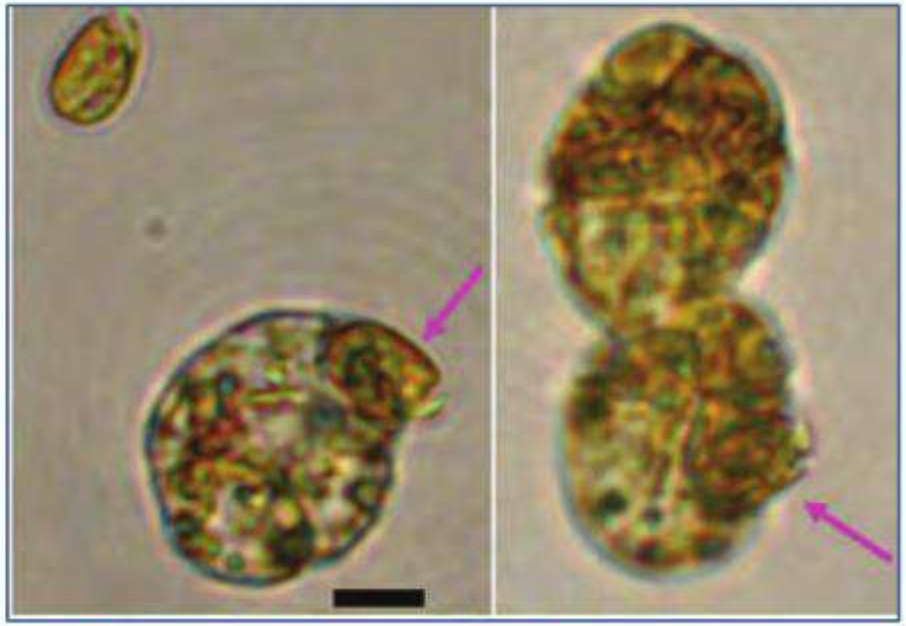
Macroalgae bloom (2018)

Algal Blooms North part of Sea of Oman, Iran, March 2018
(Source; Asefi and Attaran Fariman, 2022)

Algae bloom observation In the Sea of Oman(2019)



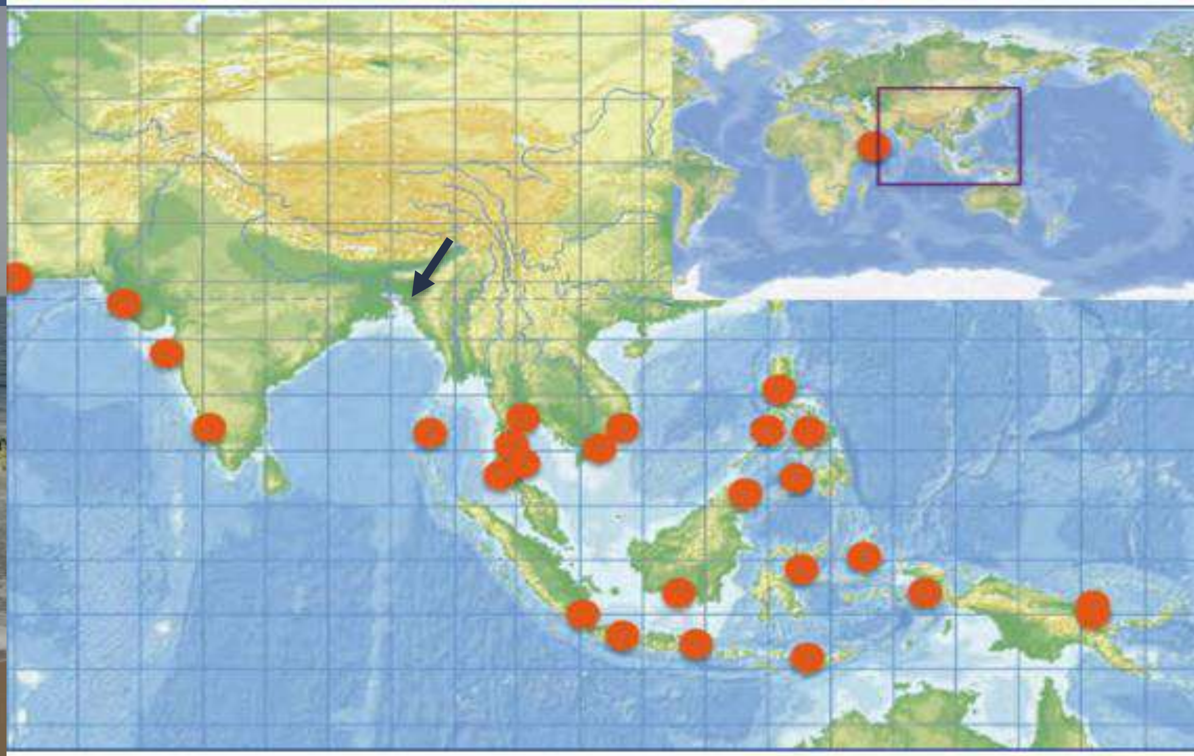




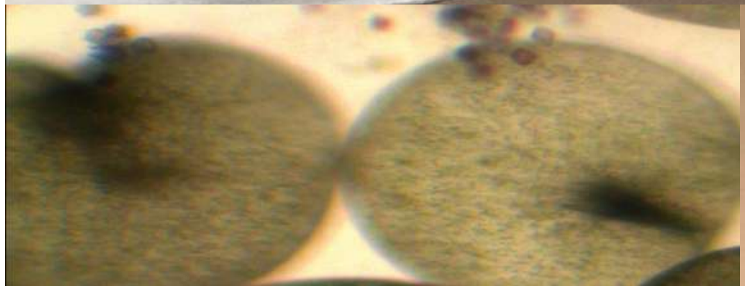
Feeding by *Cochlodinium polykrikoides* on the dinoflagellate *Amphidinium carterae* (arrows). Scale bar = 5 mm. From H.J. Jeong.

Many HAB species appear to grow faster when prey is available rather than in organic nutrient (Jeong et al, 2005)

Algae bloom observation In the Sea of Oman



Green *Noctiluca* is distributed in tropical coastal waters of the western Pacific and the Indian Oceans. Modified from Saito and Furuya (2006).



Algae bloom observation In the Kish Island, Persian Gulf (2021-22)

The photos were taken using a GoPro camera by Dr. Bargahi and pilot Etemadfar (2021-2022)

Pigment as a Chemical marker in HAB's research

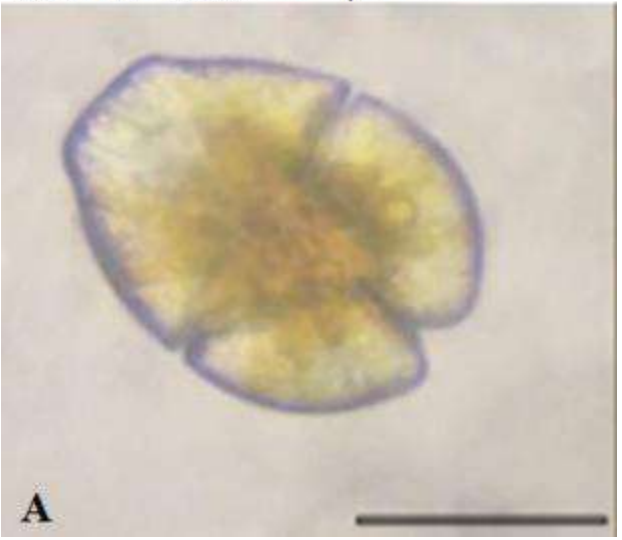
Journal of Applied Phycology
https://doi.org/10.1007/s10811-020-02331-w

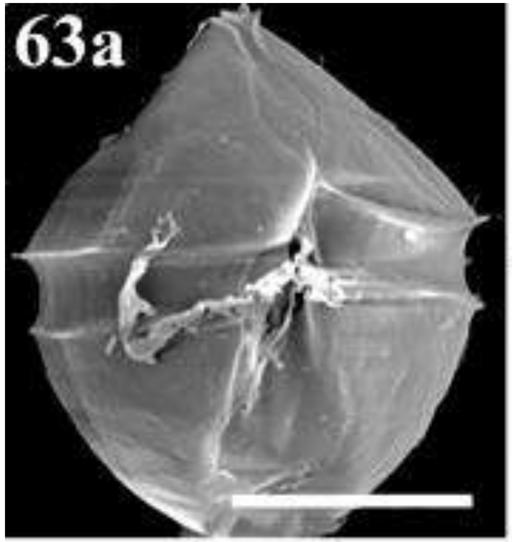
Check for updates

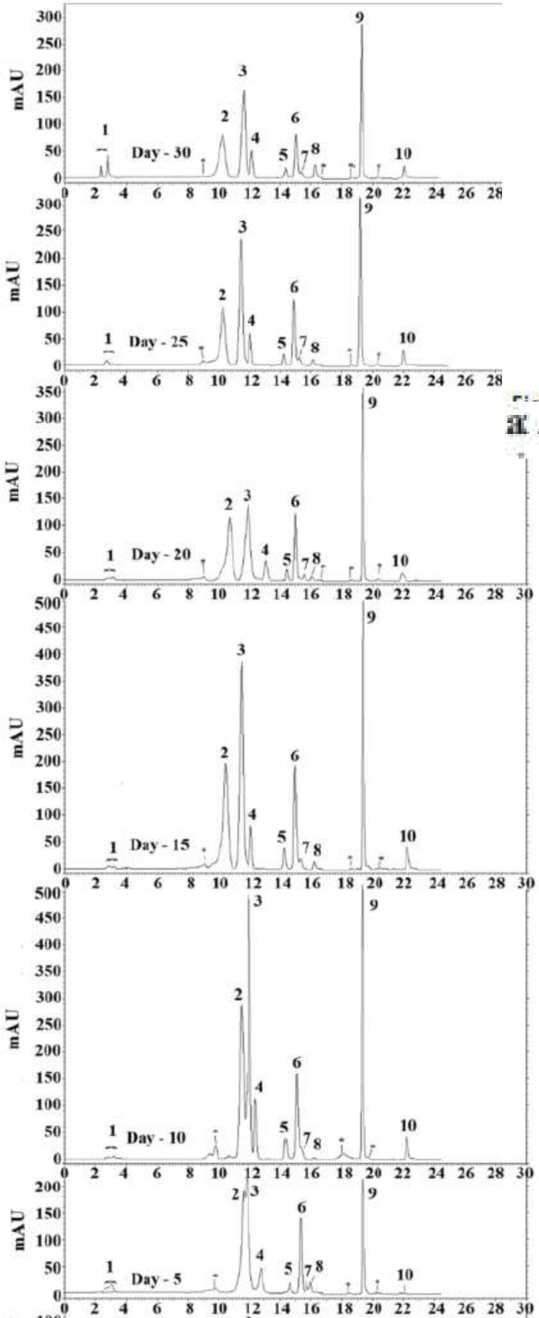
Pigment content analysis in two HAB forming dinoflagellate species during the growth period

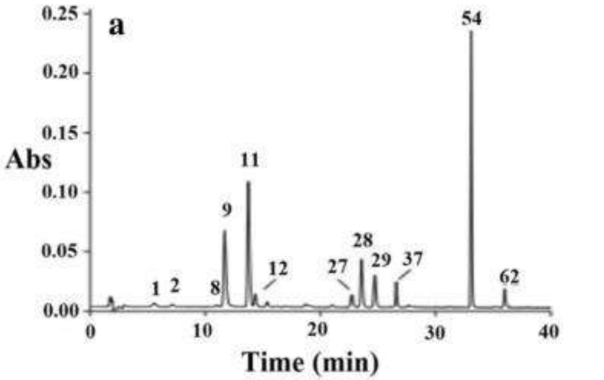
Somayeh Zahedi Dizaji[1] · Gilan Attaran Fariman[1] · Mir Mahdi Zahedi[2]

Received: 17 June 2020 / Revised and accepted: 8 November 2020









a *Alexandrium margalef* (Zapata et al. 2012)

Recommendation and key discussion point

- **Dinoflagellate cyst mapping in the ROPME Sea Area Provides Evidence of the Global Spreading or Recession of HABs Species**
- **Characterisation of HAB species in the region**
  - **“phylogenetically describe all major HAB species by conventional molecular technique”**
- **To integrate and adopt selected methods for detection, identification, enumeration and monitoring of HABs**
- **Taking international cooperation seriously and carrying out a joint project and integrate techniques in sampling and data analysis**

References

- Attaran Fariman G. Asefi Mohamd Ali (2022) Checklist of Phytoplankton of the Tropical Persian Gulf and Sea of Oman" accepted paper in "NovaHedwigia". DOI: 10.1127/nova_hedwigia/2022/0687
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- Zahedi Dizaji, S., Attaran Fariman, G. & Zahedi, M. Pigment content analysis in two HAB forming dinoflagellate species during the growth period. J Appl Phycol 33, 807–817 (2021). https://doi.org/10.1007/s10811-020-02331
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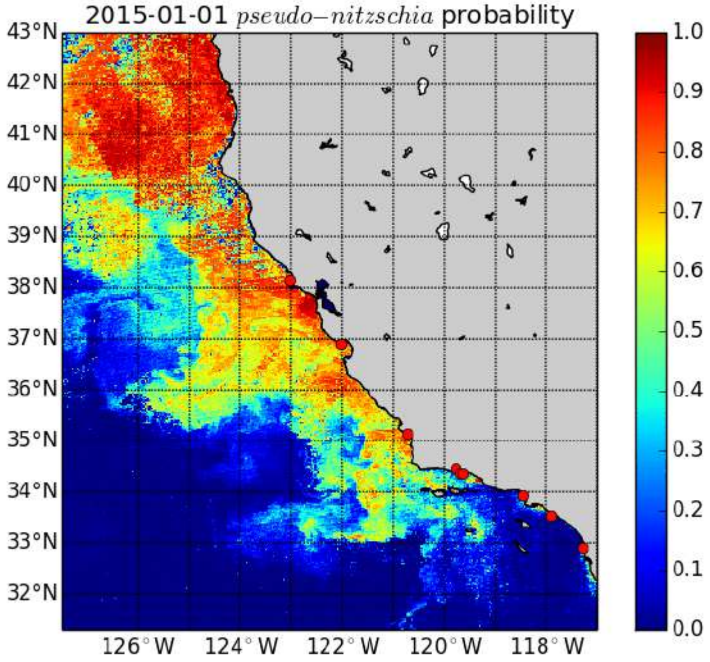
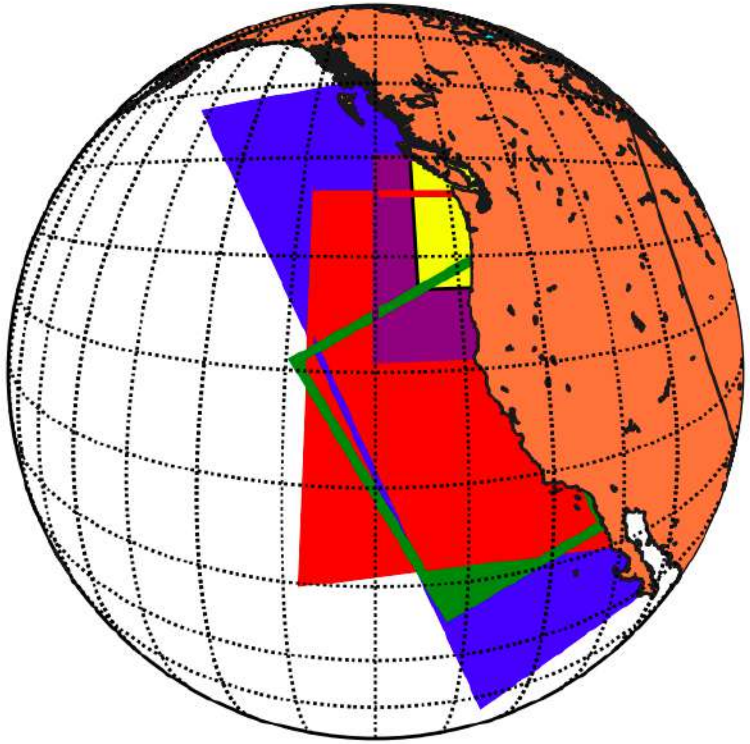
- Attaran-Fariman, G. (2016). Project "Dispersion and abundance assessment of different species of phytoplankton cysts in sediment of the Sea of Oman." *final report, division of the marine environment/Chabahar Maritime University*, 126pp.
- Attaran Fariman G(2020). Project "Phytoplankton Cysts in the ROPME Sea Area, ***Monograph: No. 3;*** Regional Organization for the Protection of the Marine Environment, 250pp
- Attaran Fariman G(2020). Project: "Phytoplankton Cysts in the ROPME Sea Area, ***Technical Report : No. 12***; Regional Organization for the Protection of the Marine Environment ,100pp
- Zonneveld, K. A., Marret, F., Versteegh, G. J., Bogus, K., Bonnet, S., Bouimetarhan, I., ... & Esper, O. (2013). Atlas of modern dinoflagellate cyst distribution based on 2405 data points. Review of Palaeobotany and Palynology, 191, 1-197.

Thanks for your attention

Gilan.Attaran@gmail.com

Development and Operations of Harmful Algae Warning Systems in the United States





Raphael Kudela

University of California Santa Cruz

With Credit to Clarissa Anderson, Don Anderson, Daniele Bianchi, Ryan McCabe, Rick Stumpf, Rubao Ji, CeNCOOS, SCCOOS

From Research to Operations

Three case studies from the US:

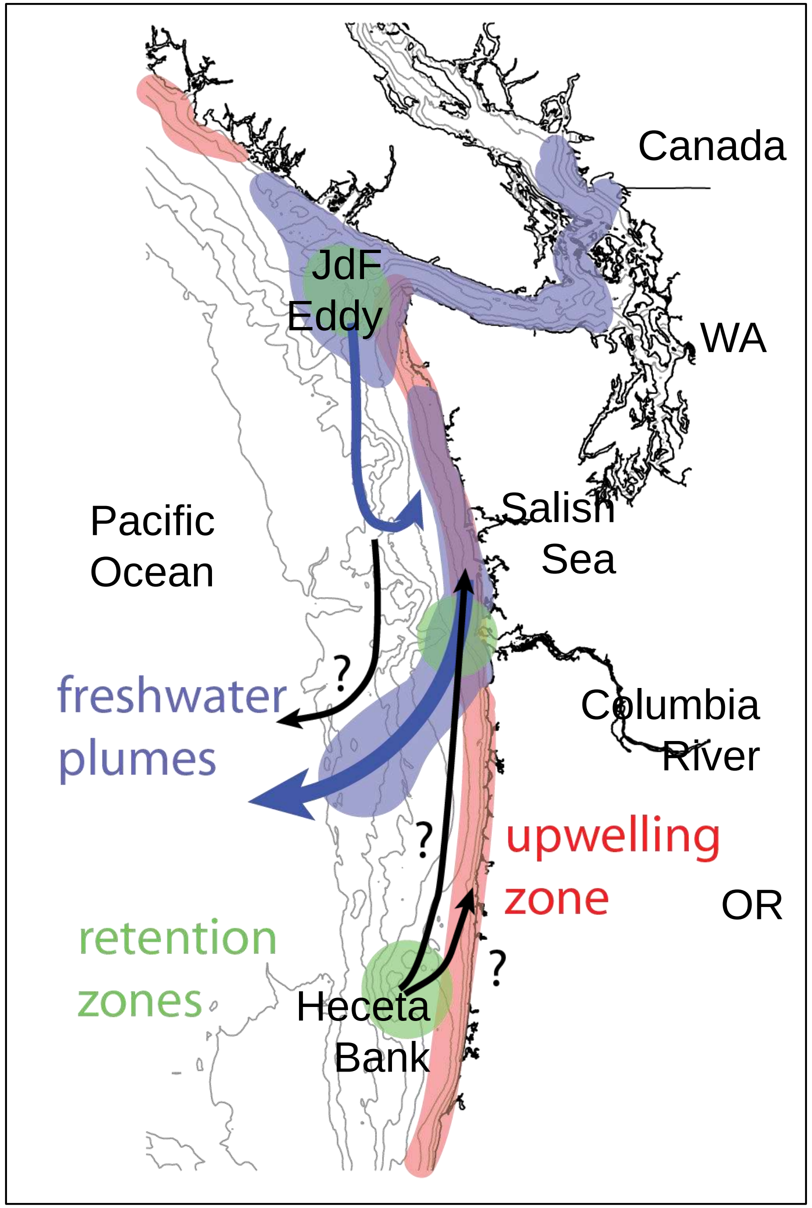
- Pacific Northwest
- California
- Lake Erie

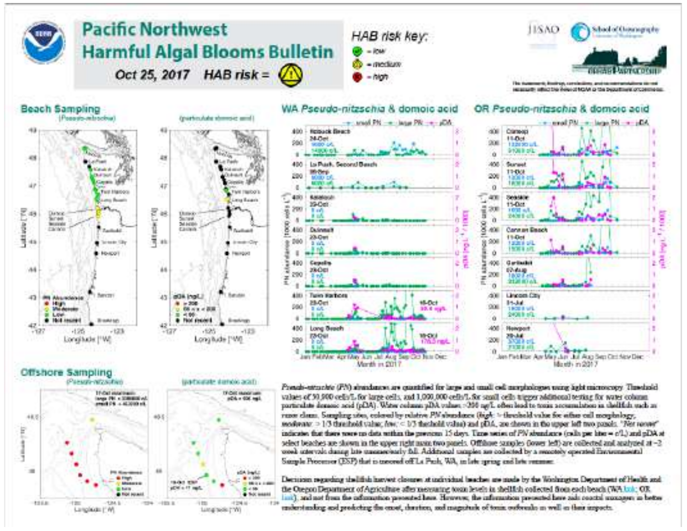
YSI Water Quality Monitoring buoy on Dubai Creek.

GOALS

To develop a mechanistic basis for forecasting toxic *Pseudo-nitzschia* bloom development and movement here and in similar coastal regions in Eastern Boundary upwelling systems

The role of the buoyant plume from the Columbia River in bloom development and transport was a central focus of the project




Pacific Northwest Harmful Algal Blooms Bulletin

Oct 25, 2017 HAB risk =

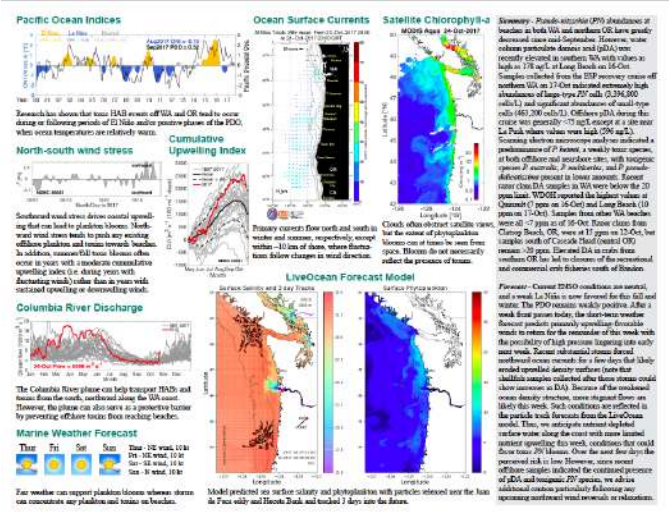
HAB risk key:

Beach Sampling

WA Pseudo-nitzschia & domoic acid

OR Pseudo-nitzschia & domoic acid

Offshore Sampling


Pacific Ocean Indices

Ocean Surface Currents

Satellite Chlorophyll-a

North-south wind stress

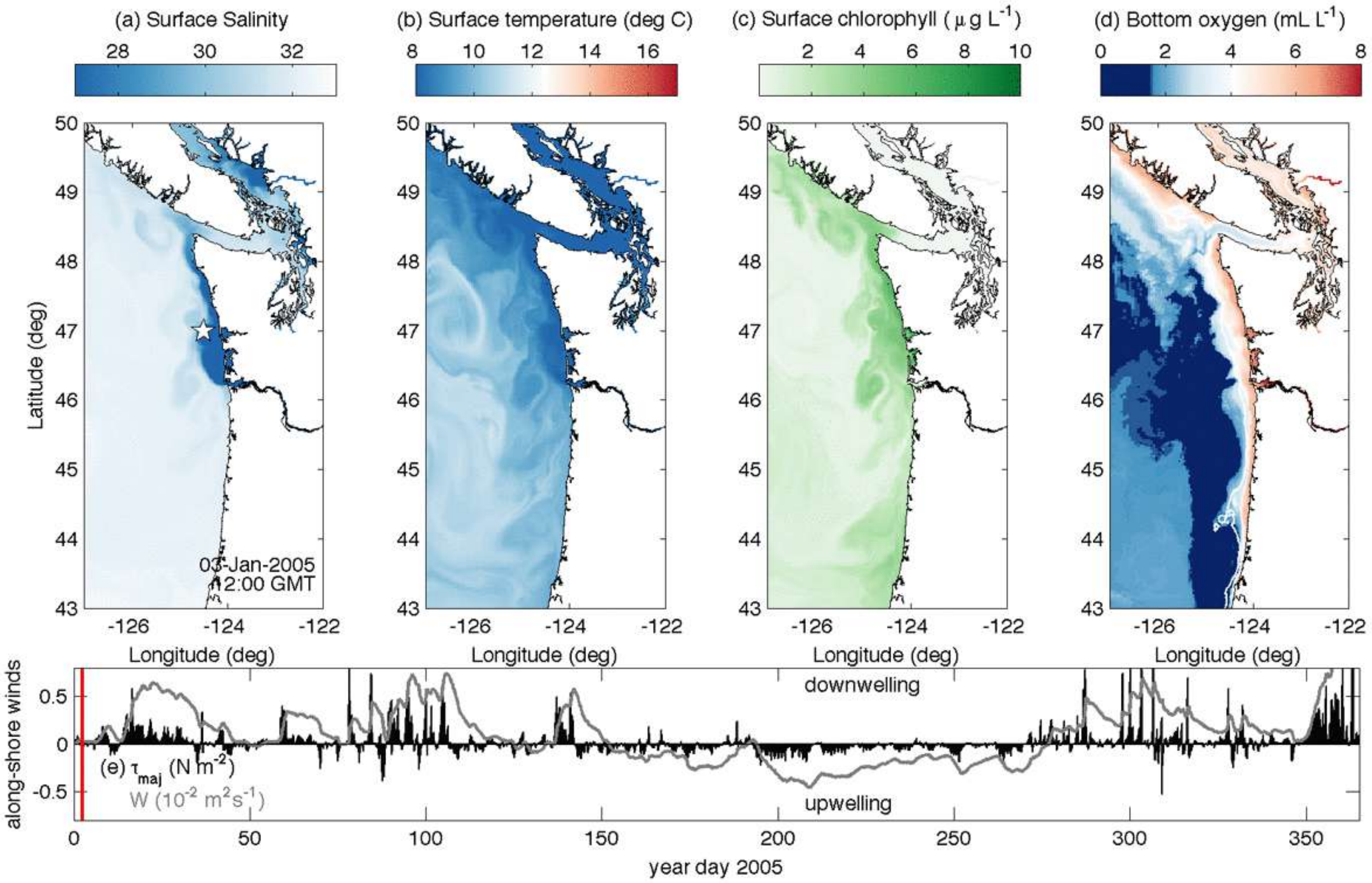
Cumulative Upwelling Index

LiveOcean Forecast Model

Columbia River Discharge

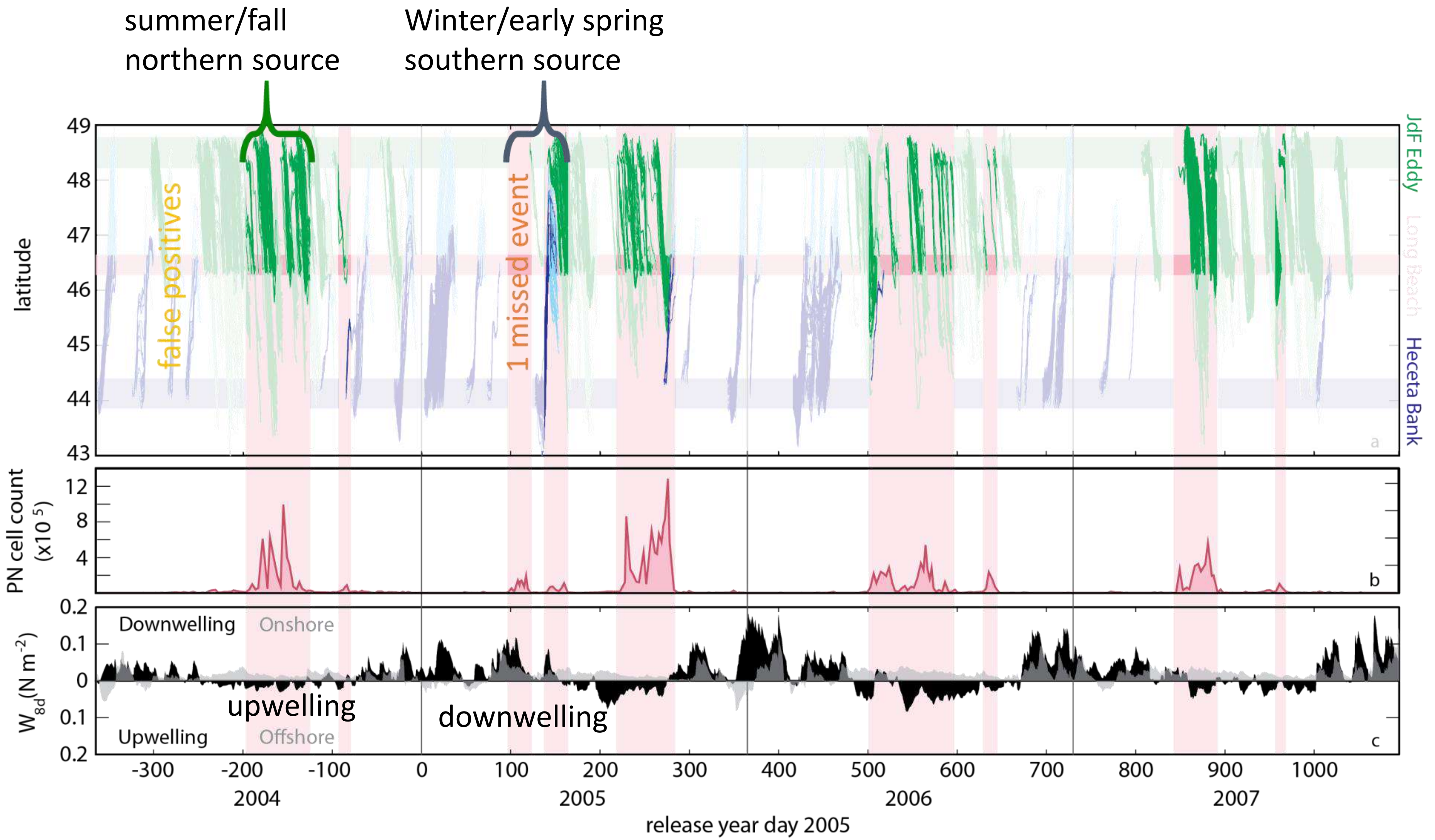
Marine Weather Forecast

Physical-biogeochemical Simulations



Davis, Giddings et al., 2013

How well does the model predict HAB transport?



PN data from ORHAB, V. Trainer and A. Odell

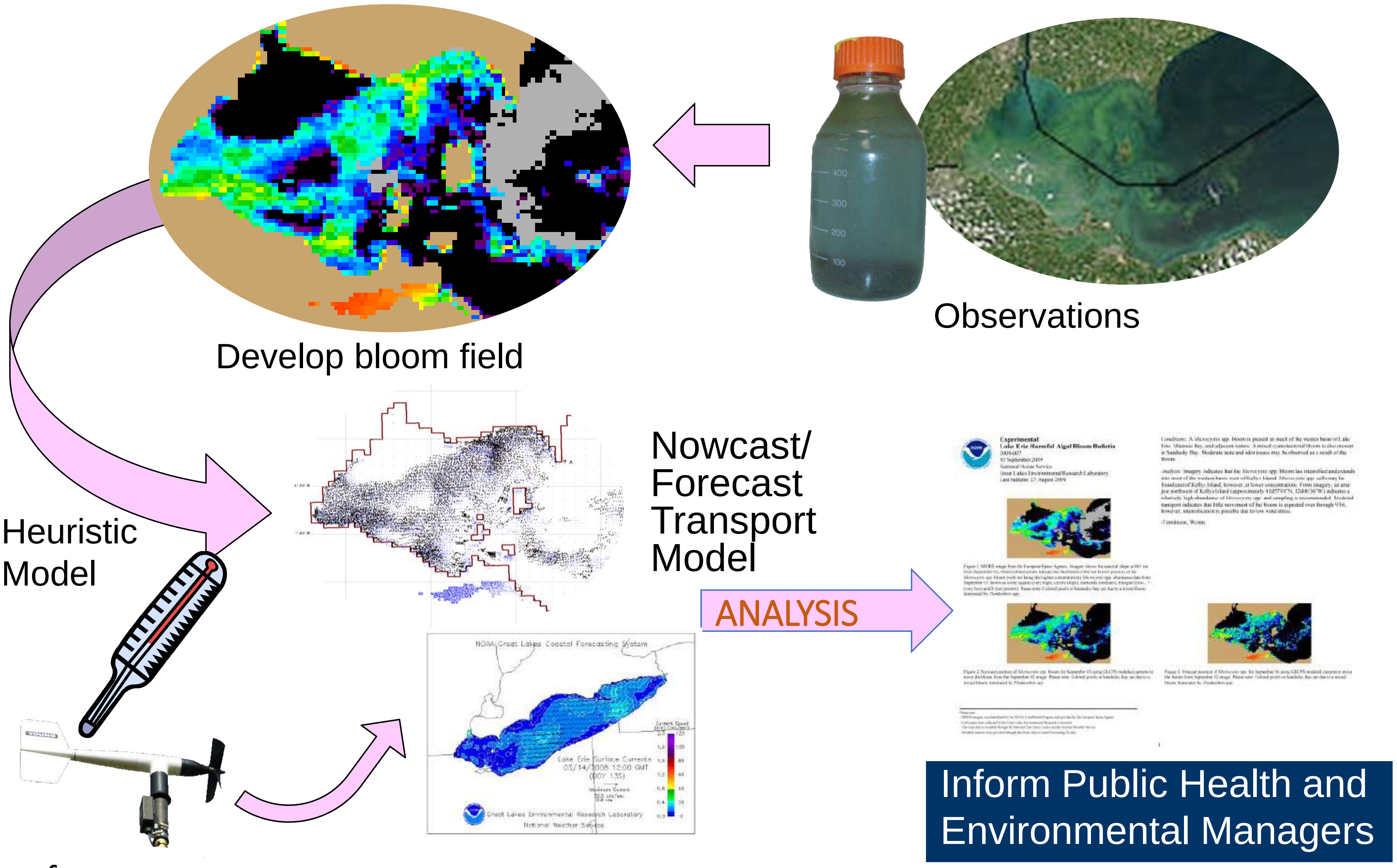
Davis et al., 2013

2011, the worst bloom in decades

Forecasting cyanobacteria in Lake Erie

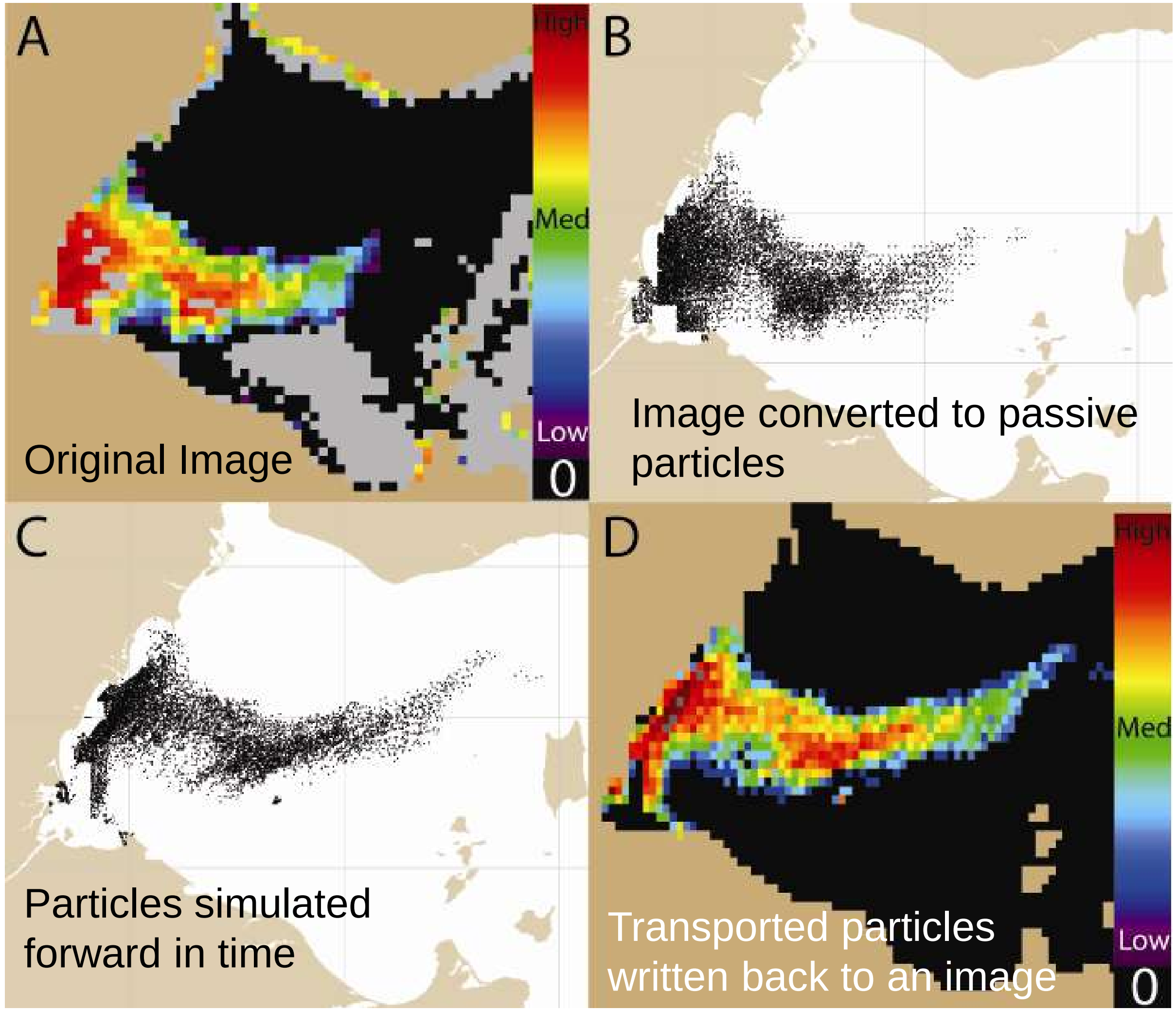
Source: Rick Stumpf

forecast



Source: Rick Stumpf

Image edited and formed to particles; modeled, and reformed to concentration



Product is an interpreted dataset providing guidance

Experimental
Lake Erie Harmful Algal Bloom Bulletin
2011-014
08 September 2011
National Ocean Service
Great Lakes Environmental Research Laboratory
Last bulletin: 01 September 2011

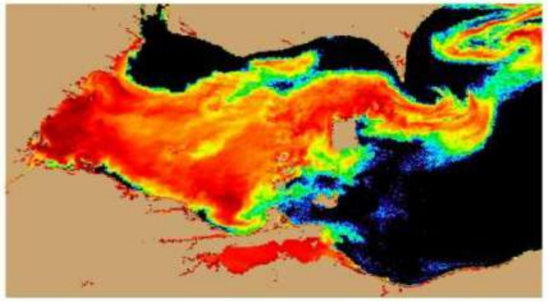


Figure 1. MERIS image from the European Space Agency. Imagery shows the spectral shape at 681 nm from September 03, where colored pixels indicate the likelihood of the last known position of the *Microcystis* spp. bloom (with red being the highest concentration). *Microcystis* spp. abundance data from shown as white squares (very high), circles (high), diamonds (medium), triangles (low), + (very low) and X (not present).

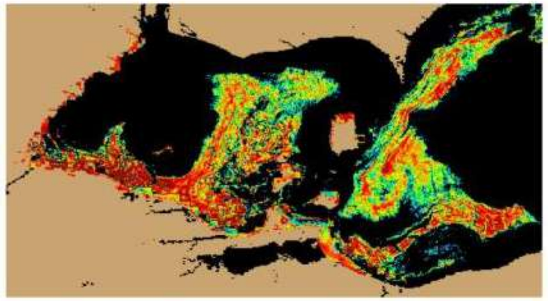
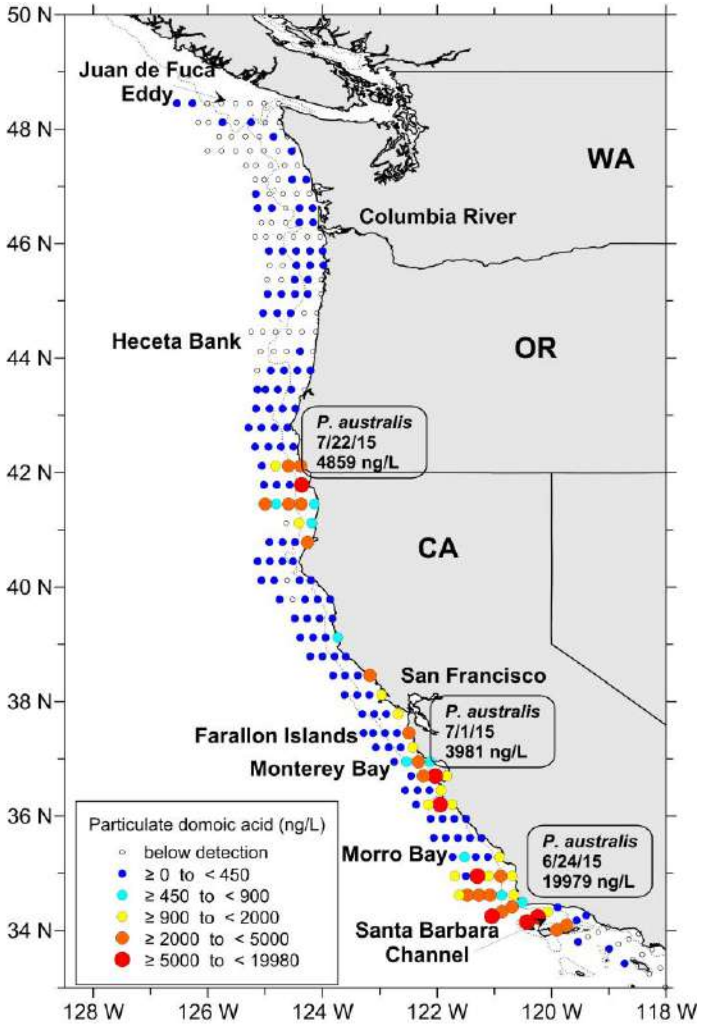
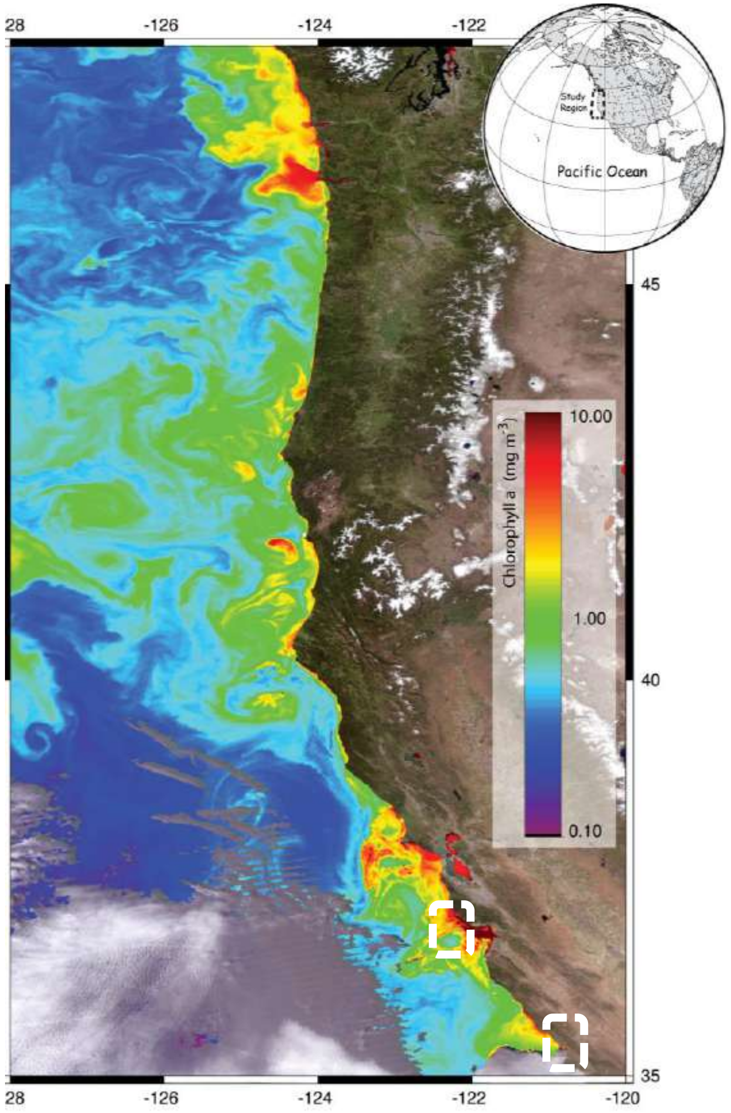


Figure 2. Nowcast position of *Microcystis* spp. bloom for September 08 using GLCFS modeled currents to move the bloom from the September 03 image.

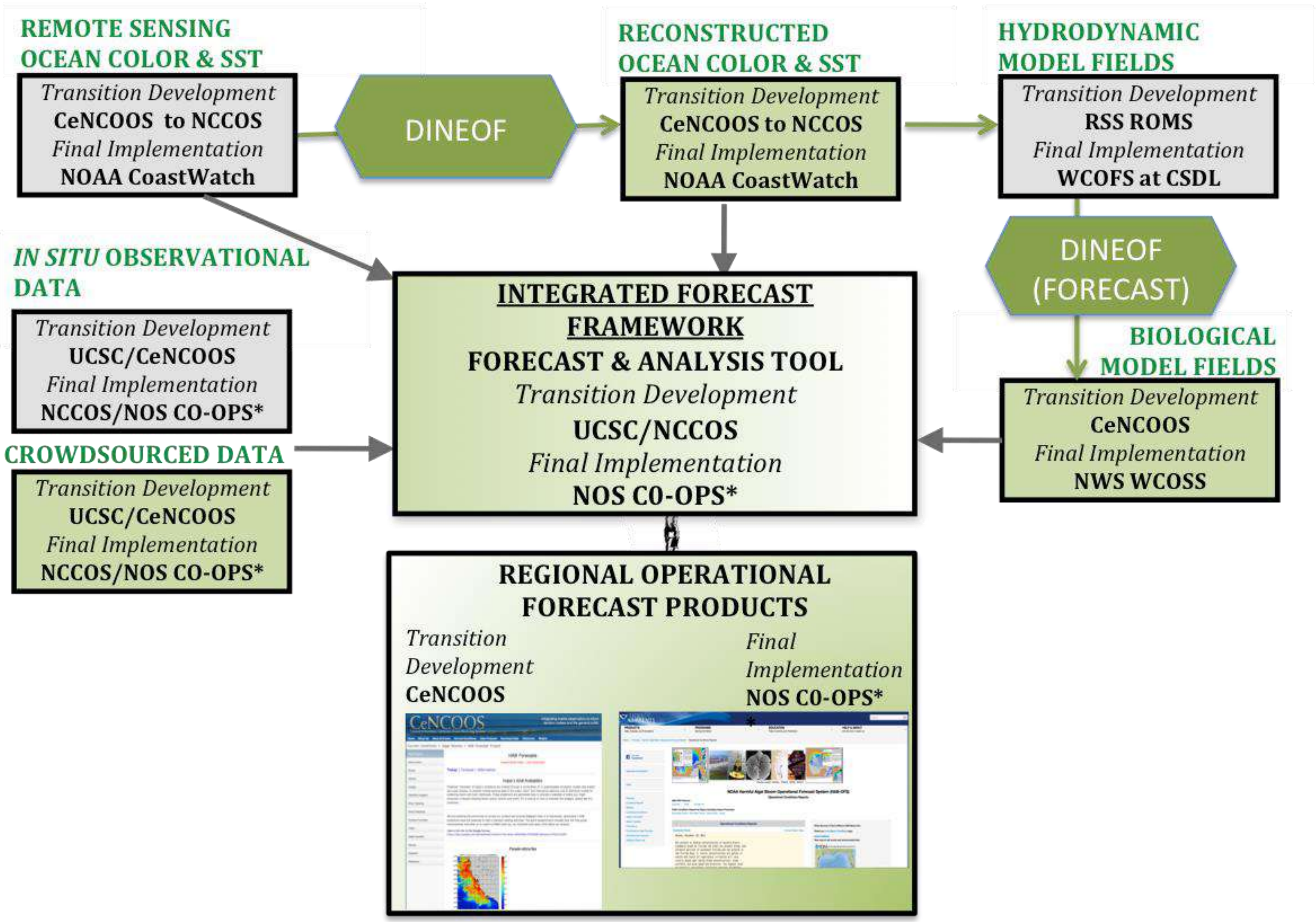
Source: Rick Stumpf

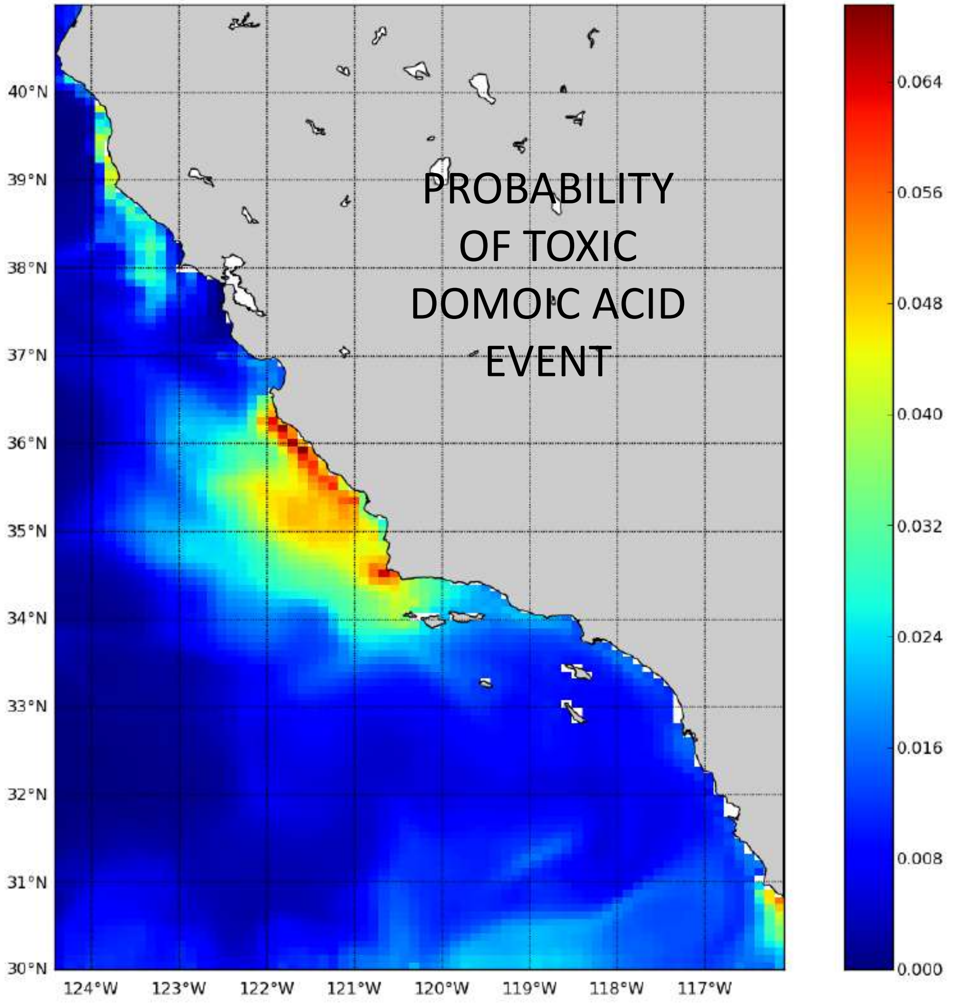
California Harmful Algae Risk Mapping System (C-HARM)





Operational Model Structure





Nowcast, 3-day forecast, seasonal hindcast

California HAB Bulletin

What is the CA HAB Bulletin?

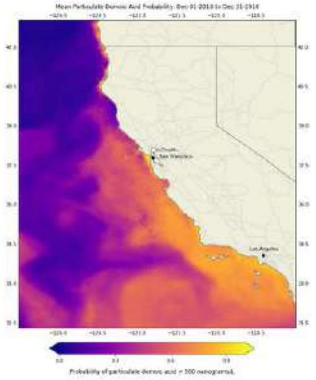
The purpose of this *experimental* product is to give the public and resource managers a quick outlook of recent toxic (marine) algal blooms in coastal California from models and aggregate data sets. **Monthly reports synthesize model output, near real-time observations, animal strandings, and public health alerts** to provide a more complete picture of the regional variability in harmful algal blooms for stakeholders.

Overview Data Products News Documents Projects

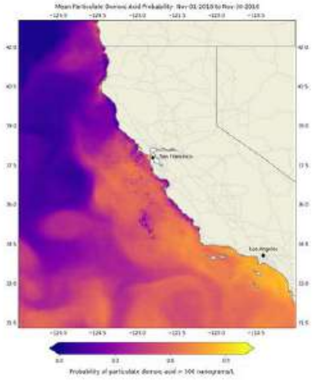
CA HAB Bulletin Archives

Please subscribe to CA HAB Bulletin listserv to receive the monthly CA HAB Bulletin.

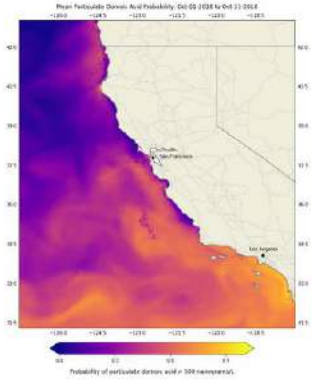
December 2018



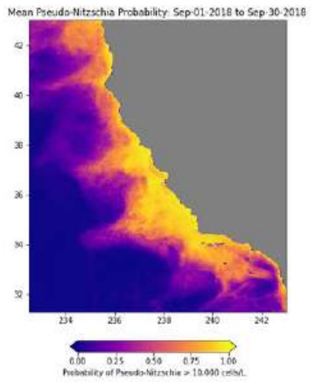
November 2018



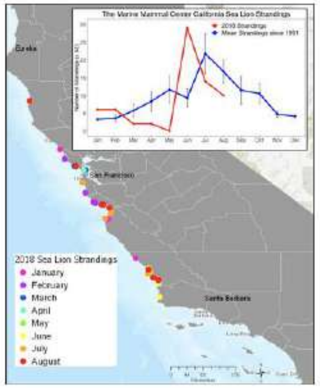
October 2018



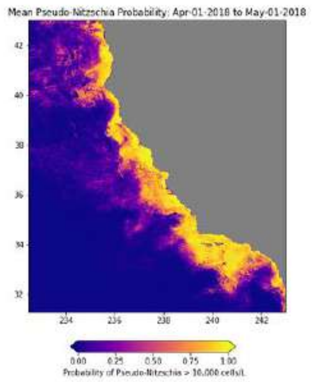
September 2018



August 2018



July 2018



June 2018

May 2018

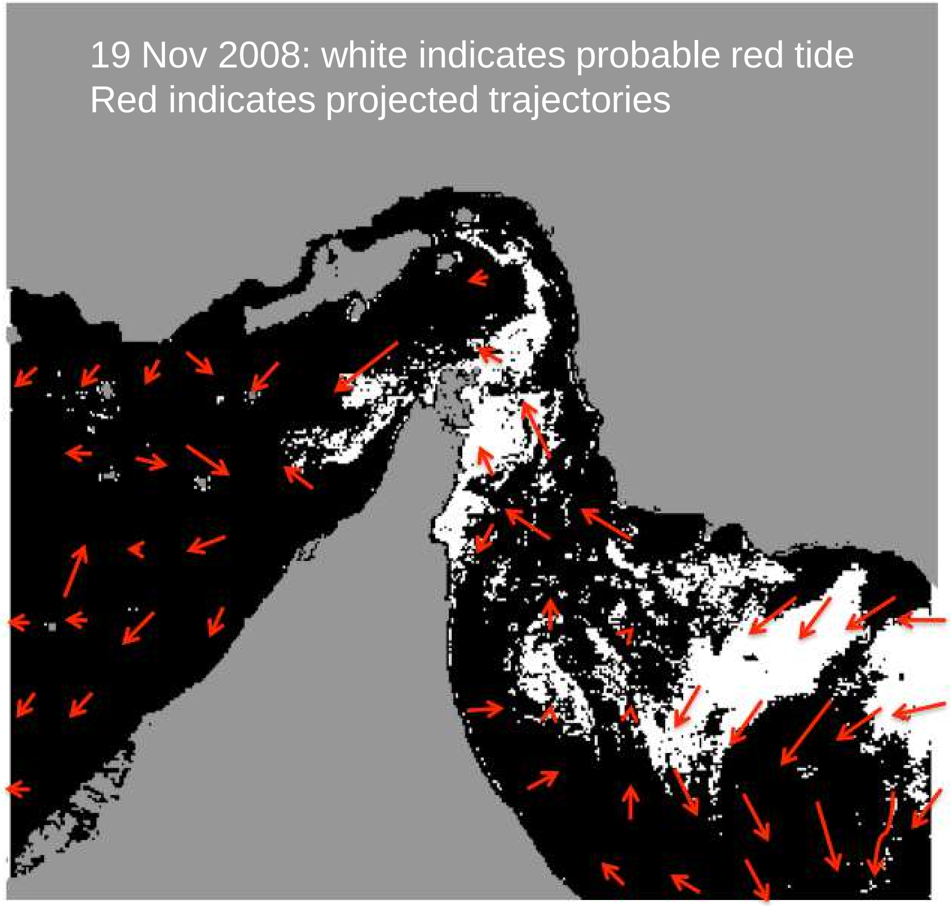
April 2018

SCCOOS SOUTHERN CALIFORNIA COASTAL OCEAN OBSERVING SYSTEM

CeNCOOS CENTRAL & NORTHERN CALIFORNIA OCEAN OBSERVING SYSTEM

sccoos.org/california-hab-bulletin/

What Would A Red Tide Prediction Look Like?



ALERT: satellite imagery indicates formation of a red tide associated with a cyclonic eddy in the Gulf of Oman. It will likely be carried onshore in northern Oman, and is being transported through the Strait of Hormuz where it is staying offshore of the UAE coastline. Based on satellite spectra, the bloom is not *Trichodesmium* or *Noctiluca*.

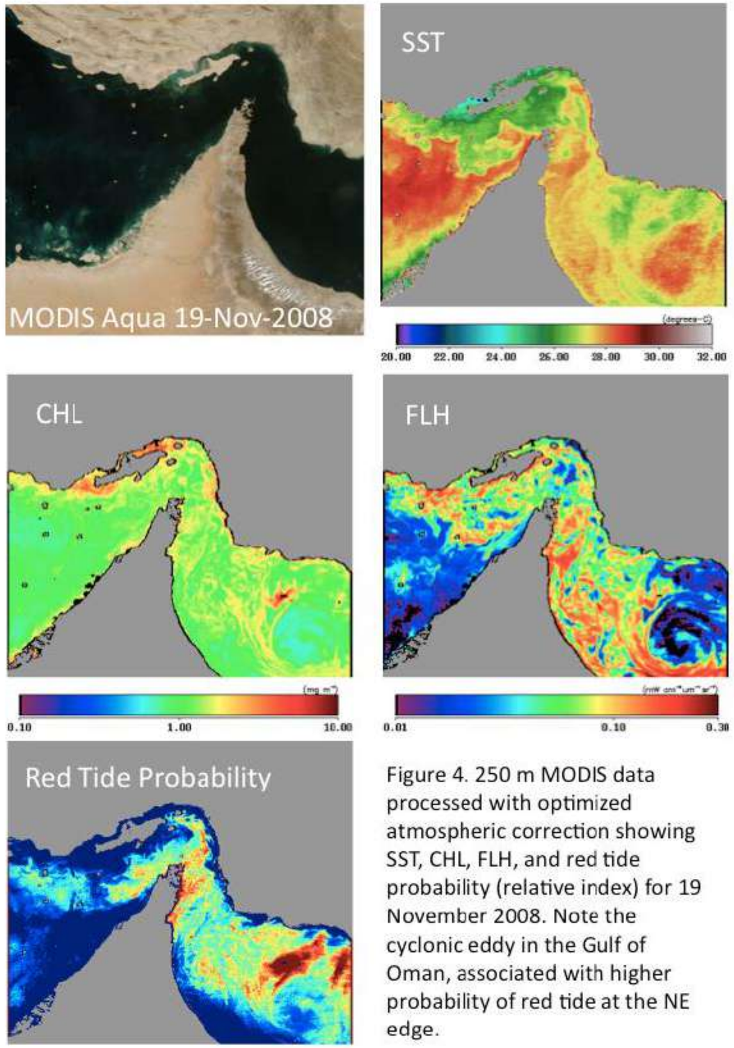
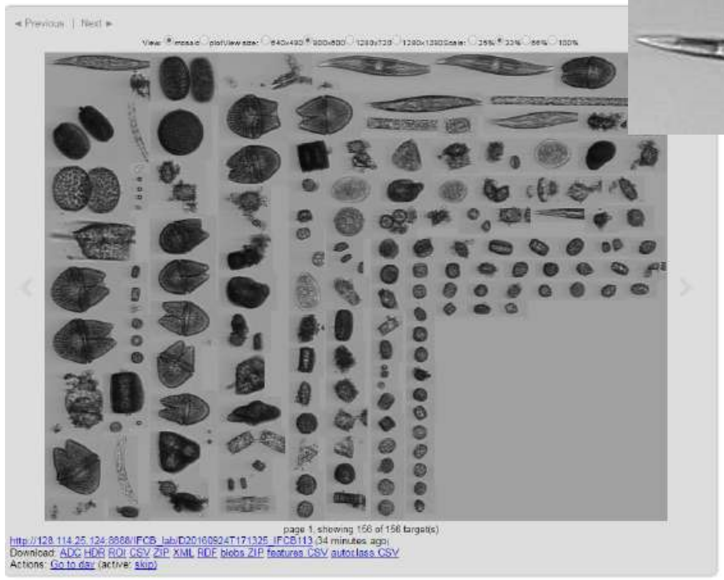
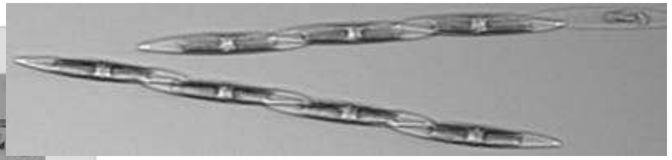


Figure 4. 250 m MODIS data processed with optimized atmospheric correction showing SST, CHL, FLH, and red tide probability (relative index) for 19 November 2008. Note the cyclonic eddy in the Gulf of Oman, associated with higher probability of red tide at the NE edge.

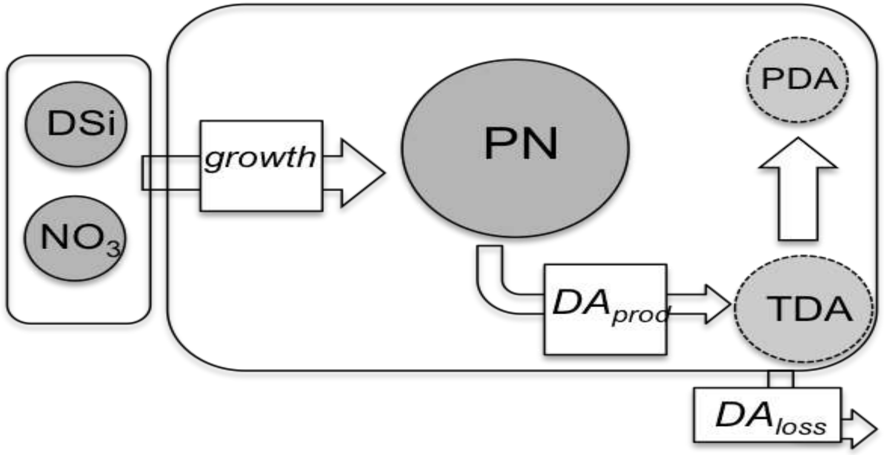
End Users need an interpreted product that provides useful information, NOT a science product.

Operational Does *Not* Mean Static

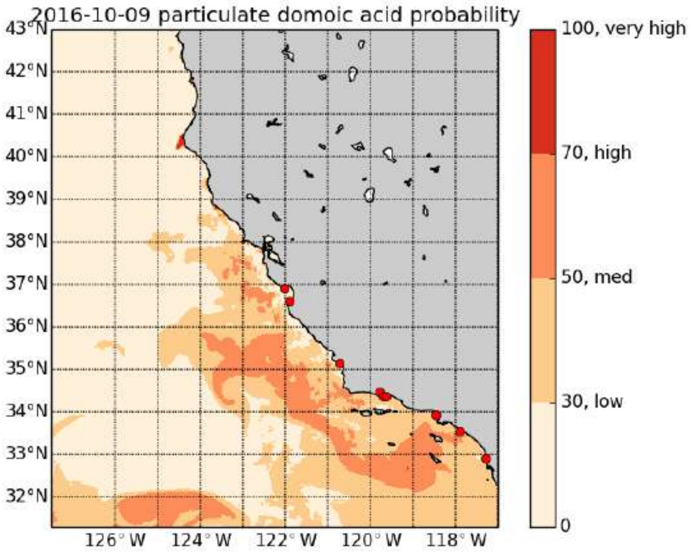


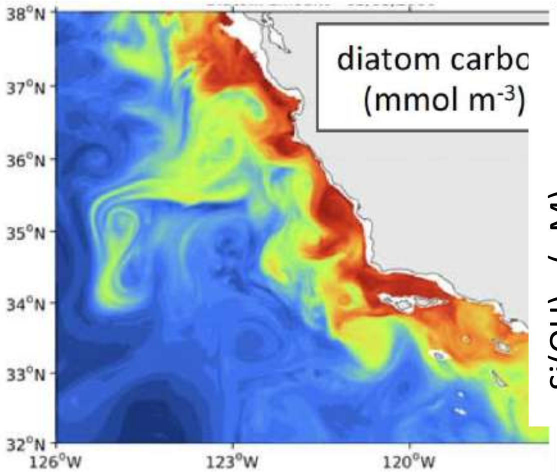


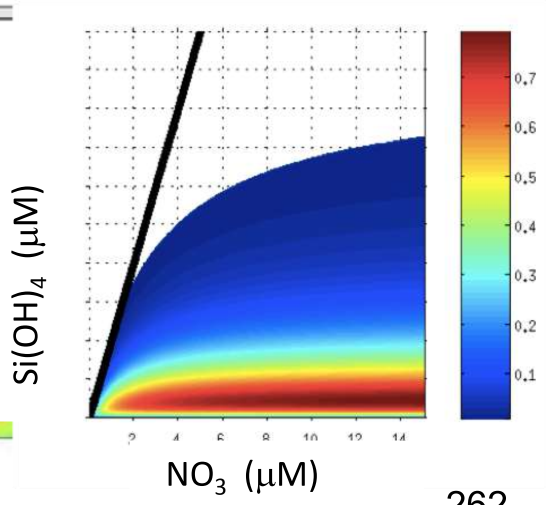
ALERT!



Mechanistic Model Embedded in ROMS-BEC

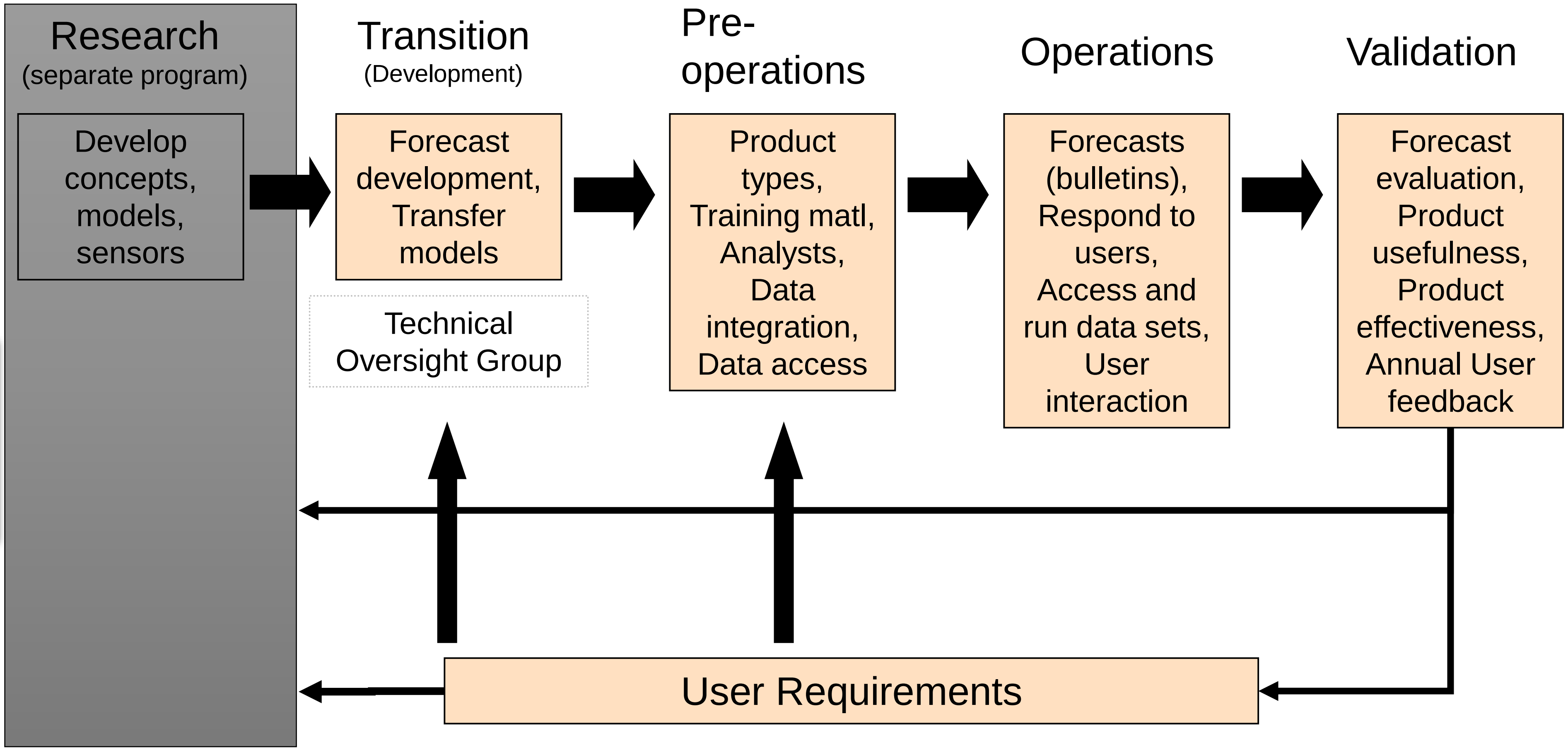






Bianchi et al., NOAA ECOHAB

Harmful Algal Bloom Forecast System: Concept of Operations

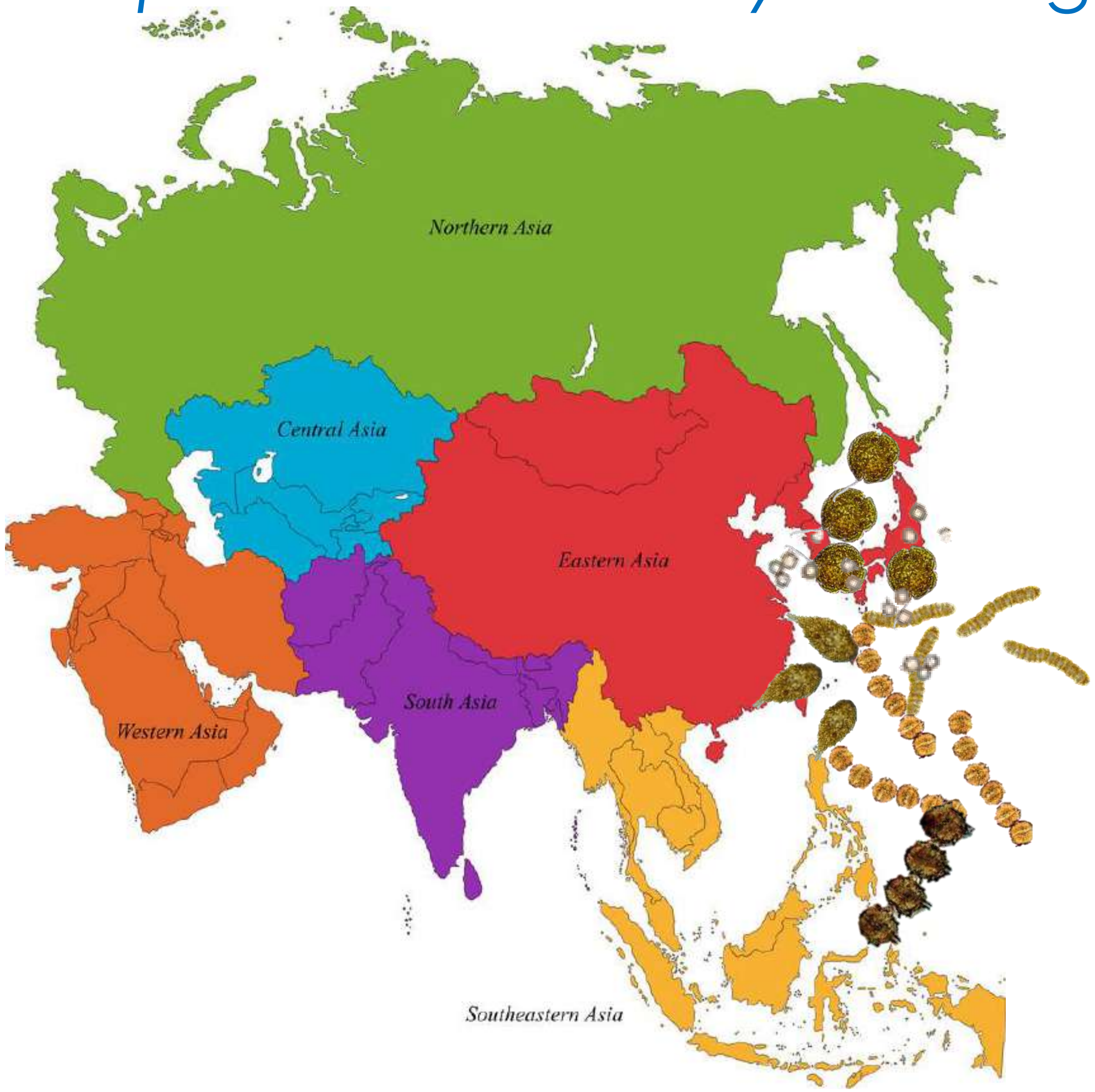


Take-Home Message:

An HAB Monitoring and Forecast system must be fit for purpose, sustainable, and useful to end-users. A successful system will be:

- ***Scientifically vetted***
- ***User vetted***
- ***Not reliant on a single entity or person***
- ***Adaptive to user needs***

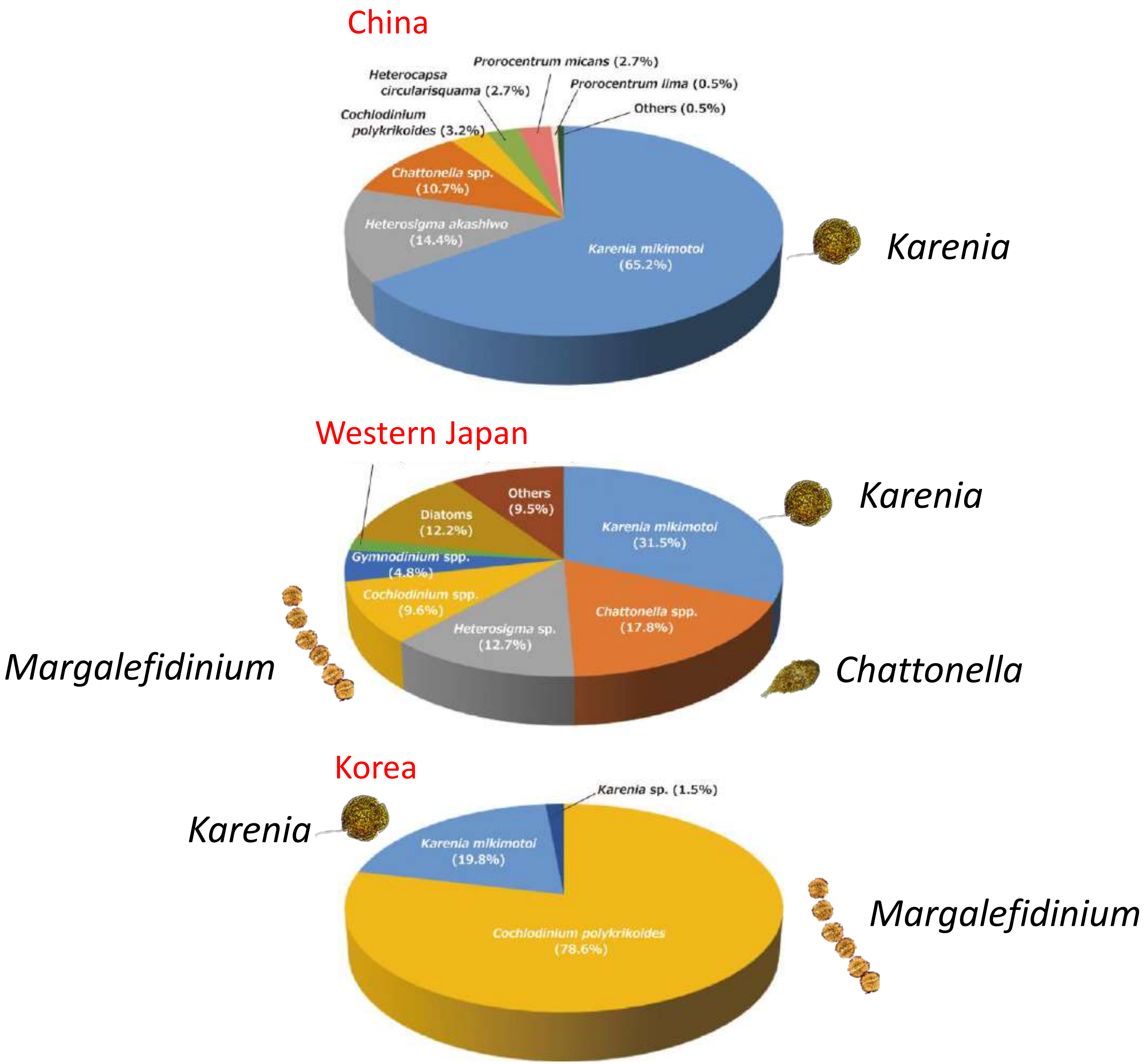
Changes and complexity of HABs in Asia:
Implications for early warning systems and future projections



Patricia M. Glibert

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE
HORN POINT LABORATORY
Cambridge, MD, USA

Harmful algal bloom species associated with fisheries damages.



ELSEVIER

Harmful Algae
Volume 102, February 2021, 101787

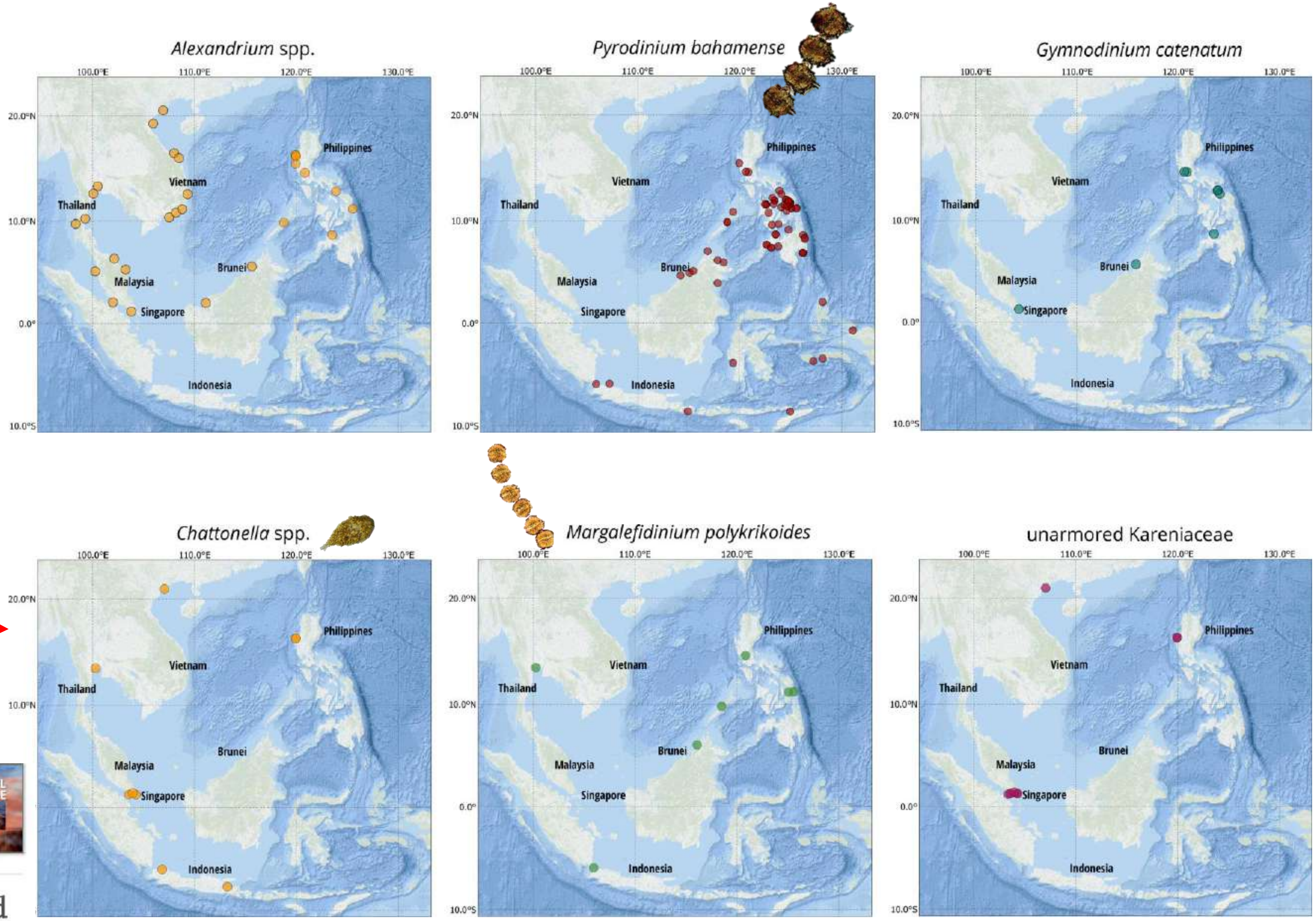
Harmful algal blooms and associated fisheries damage in East Asia: Current status and trends in China, Japan, Korea and Russia

Setsuko Sakamoto [a], Weol Ae Lim [b], Douding Lu [c], Xinfeng Dai [c], Tatiana Orlova [d], Mitsunori Iwataki [e]

Distributions of toxic HAB PSP species

and

fish killing species around Southeast Asia.



ELSEVIER

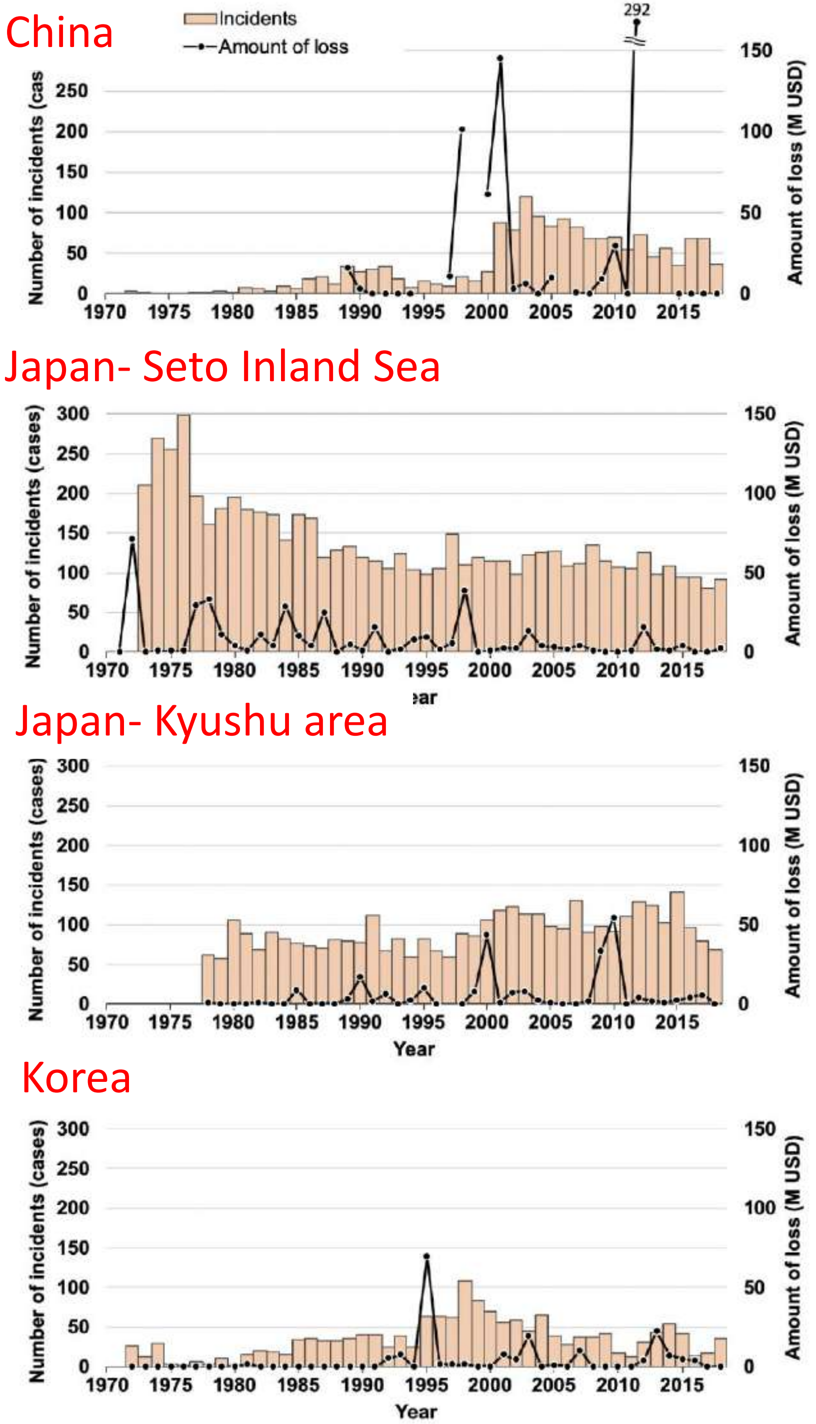
Harmful Algae

Volume 102, February 2021, 101776

Over 30 years of HABs in the Philippines and Malaysia: What have we learned?

Aletta T. Yñiguez [a], Po Teen Lim [b], Chui Pin Leaw [b], Steffiana J. Jipanin [c], Mitsunori Iwataki [d], Garry Benico [d], Rhodora V. Azanza [a]

Recorded red tide incident numbers and amount of economic losses



Harmful Algae
Volume 102, February 2021, 101787

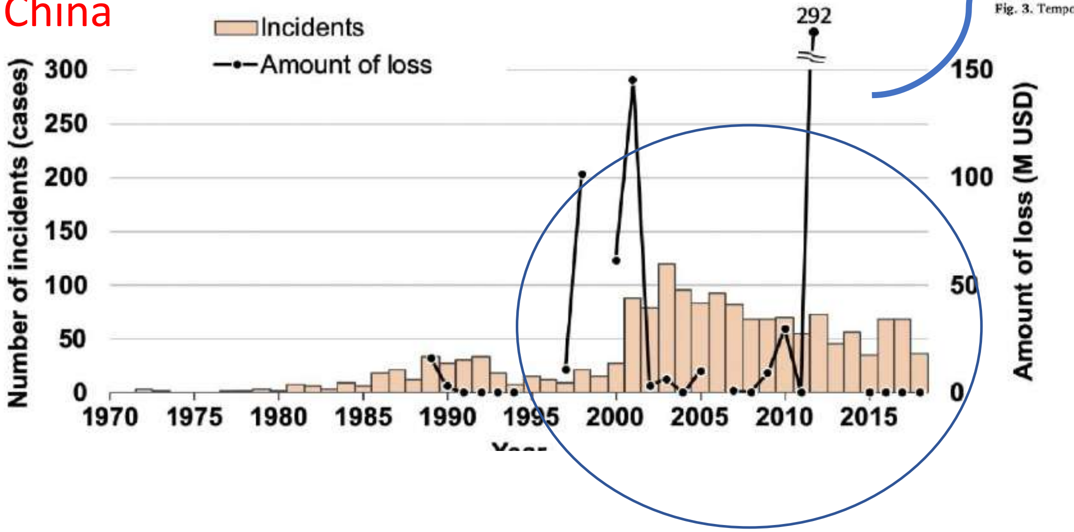
Harmful algal blooms and associated fisheries damage in East Asia: Current status and trends in China, Japan, Korea and Russia

Setsuko Sakamoto [a], Weol Ae Lim [b], Douding Lu [c], Xinfeng Dai [c], Tatiana Orlova [d], Mitsunori Iwataki [e]

Some potentially good news

Recorded red tide incident numbers and amount of economic losses:

China



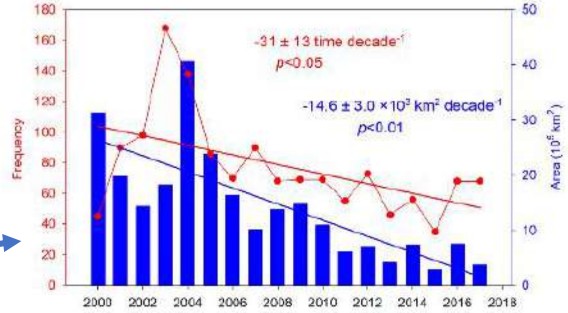


Fig. 3. Temporal changes in the annual frequency and coverage area of HAB events in China Seas from 2000 to 2017.

ELSEVIER
Harmful Algae
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Harmful algal blooms and associated fisheries damage in East Asia: Current status and trends in China, Japan, Korea and Russia

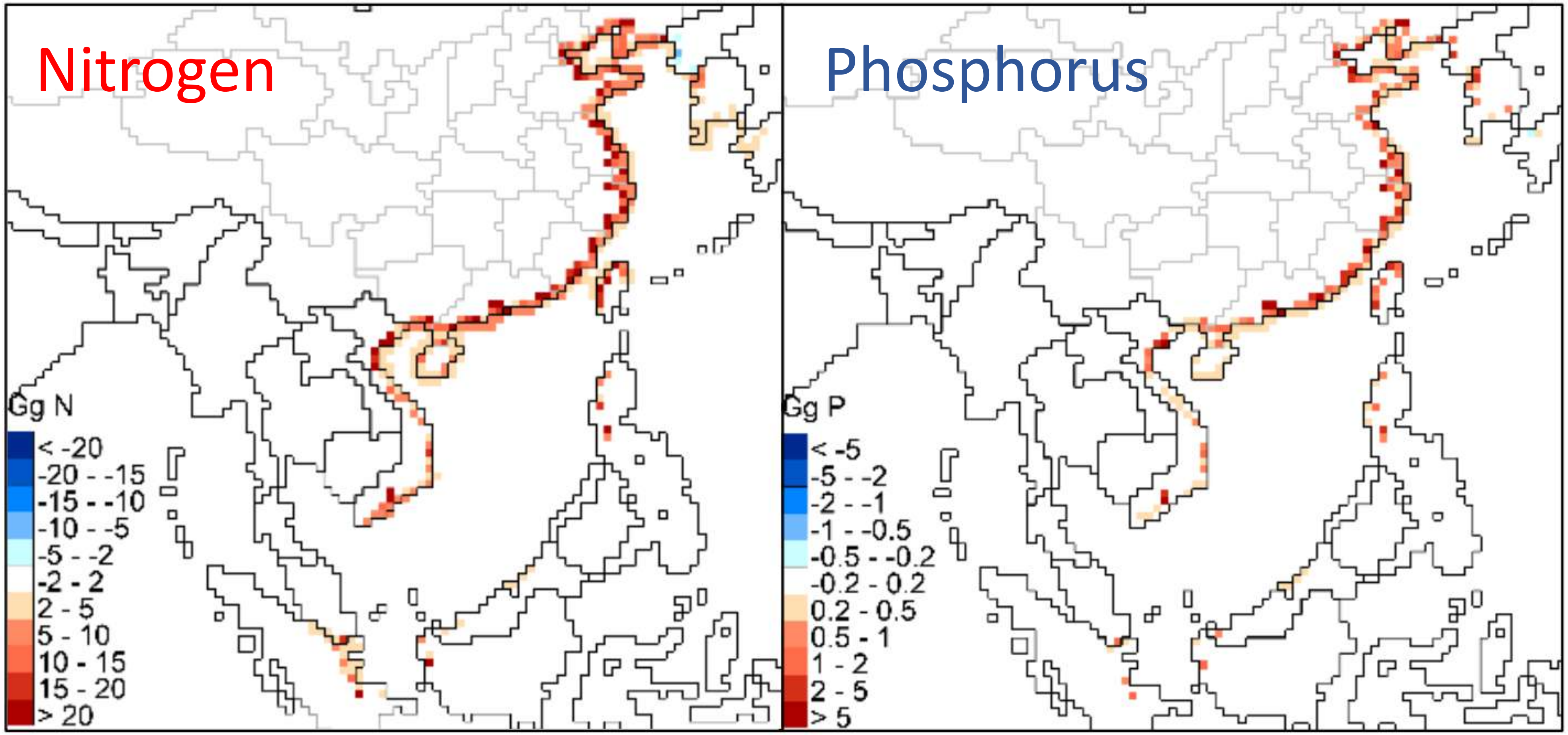
Setsuko Sakamoto [a], Weol Ae Lim [b], Douding Lu [c], Xinfeng Dai [c], Tatiana Orlova [d], Mitsunori Iwataki [e]

Contents lists available at ScienceDirect
Marine Pollution Bulletin
journal homepage: www.elsevier.com/locate/marpolbul
ELSEVIER
2019. doi: 10.1016/j. marpolbul.2019.01.002

Significantly decreasing harmful algal blooms in China seas in the early 21st century

Jing Zeng[a,b], Baoling Yin[a], Yetang Wang[a,*], Baojuan Huai[a]

Changes in **nitrogen** and **phosphorus** inputs 1970-2010



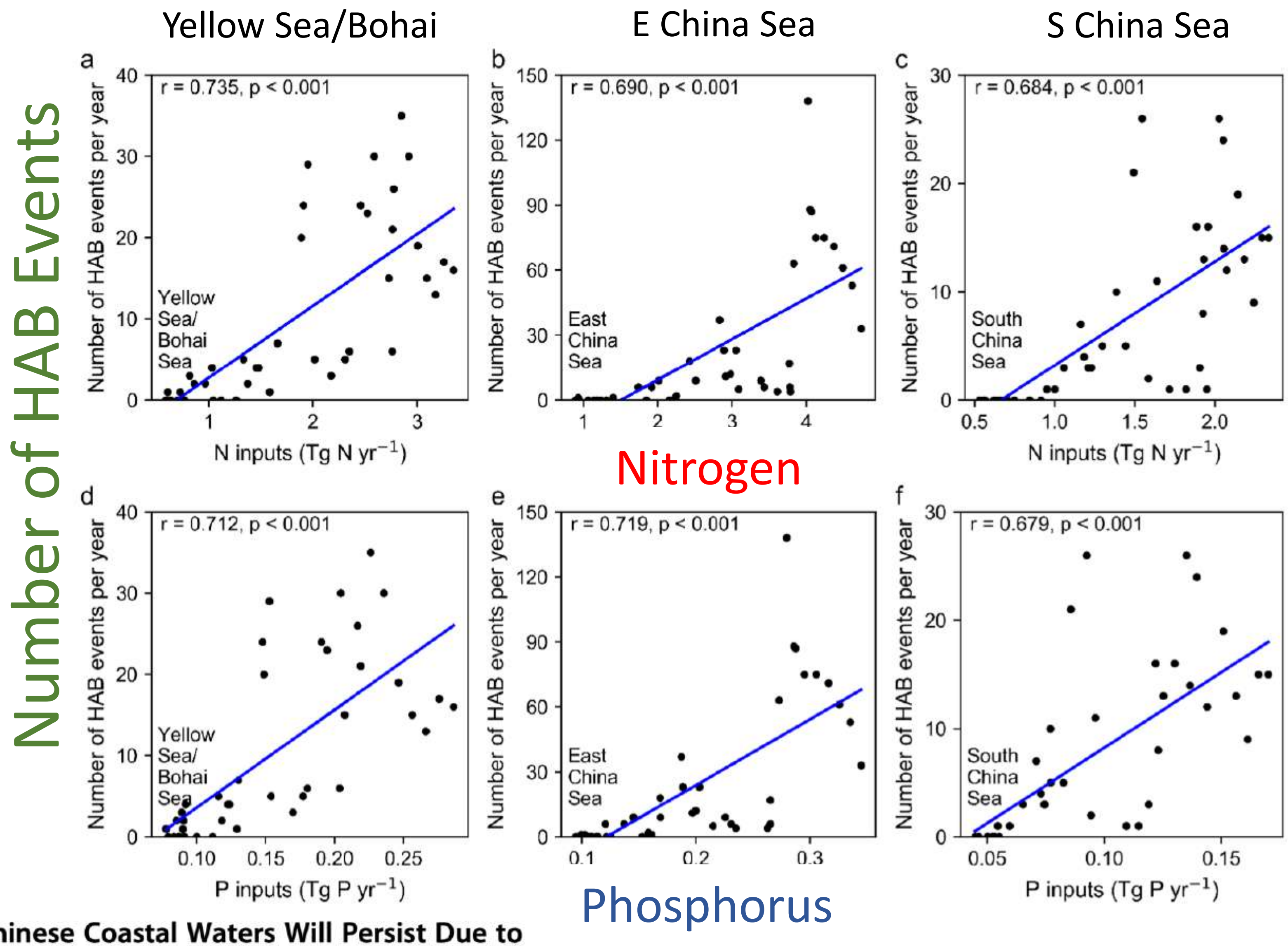
Environmental Science & Technology Letters

pubs.acs.org/journal/estlcu 2021 8:276-284. Letter

Harmful Algal Blooms in Chinese Coastal Waters Will Persist Due to Perturbed Nutrient Ratios

Junjie Wang, Alexander F. Bouwman,* Xiaochen Liu, Arthur H.W. Beusen, Rita Van Dingenen, Frank Dentener, Yulong Yao, Patricia M. Glibert, Xiangbin Ran, Qingzhen Yao, Bochao Xu, Rencheng Yu, Jack J. Middelburg, and Zhigang Yu

Relationship between HAB events and nutrient inputs 1970-2010



Environmental Science & Technology Letters
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2021 8:276-284.

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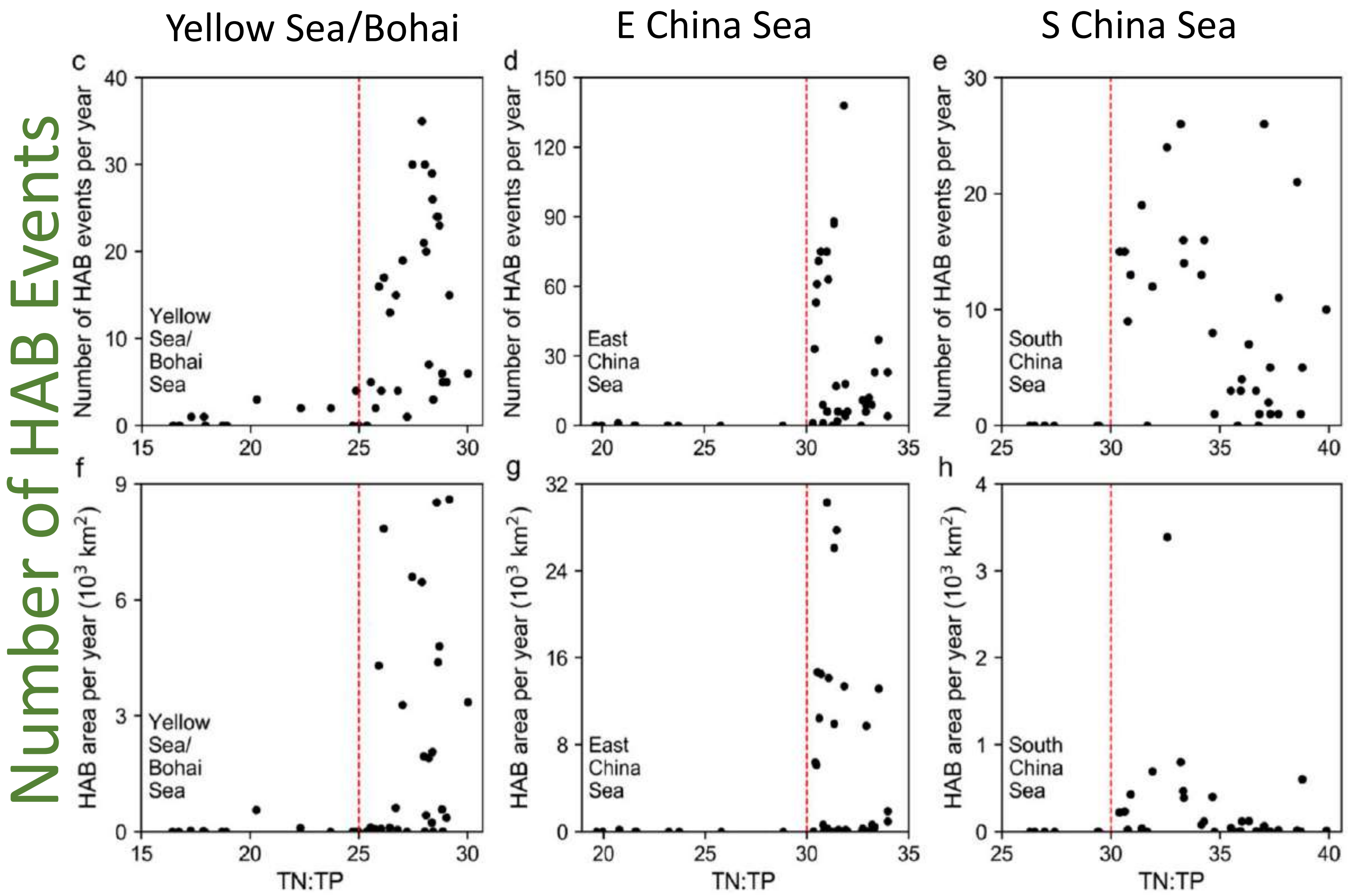
Relationship between HAB events and N:P inputs 1970-2010



Nitrogen: Phosphorus

pubs.acs.org/journal/estlcu 2021 8:276-284.

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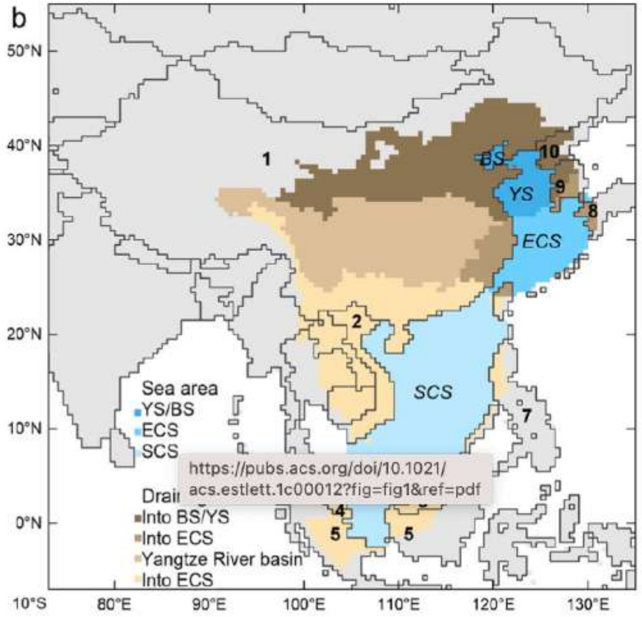
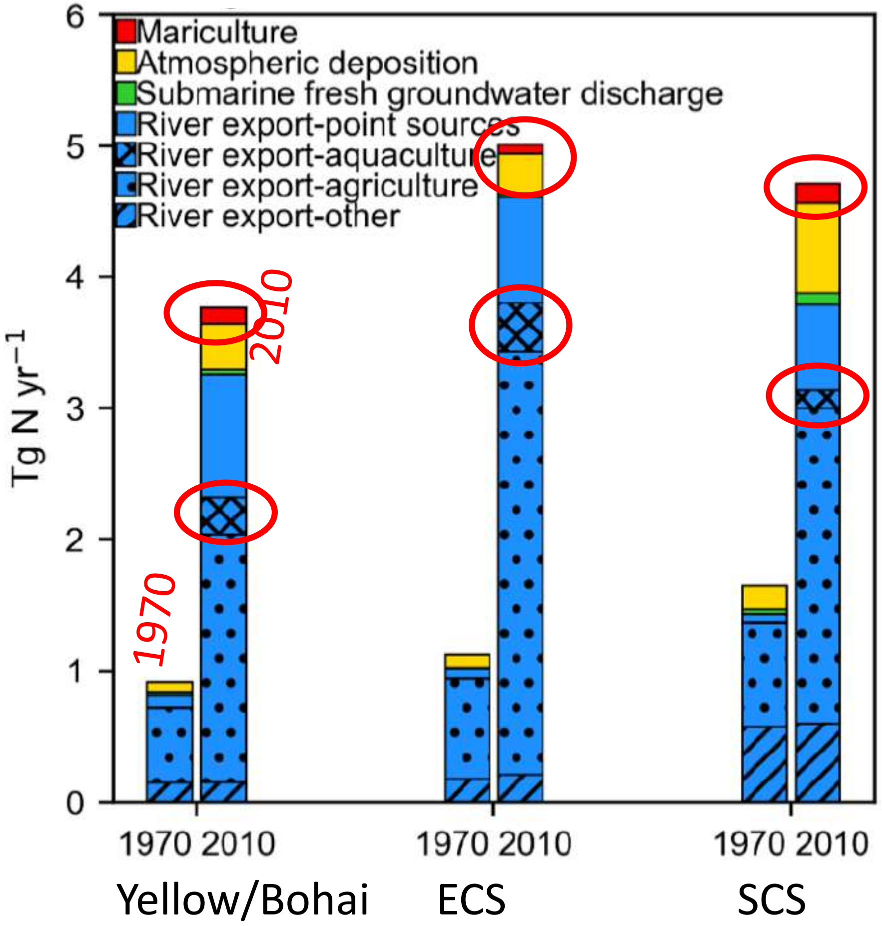
Nutrient ratios matter!

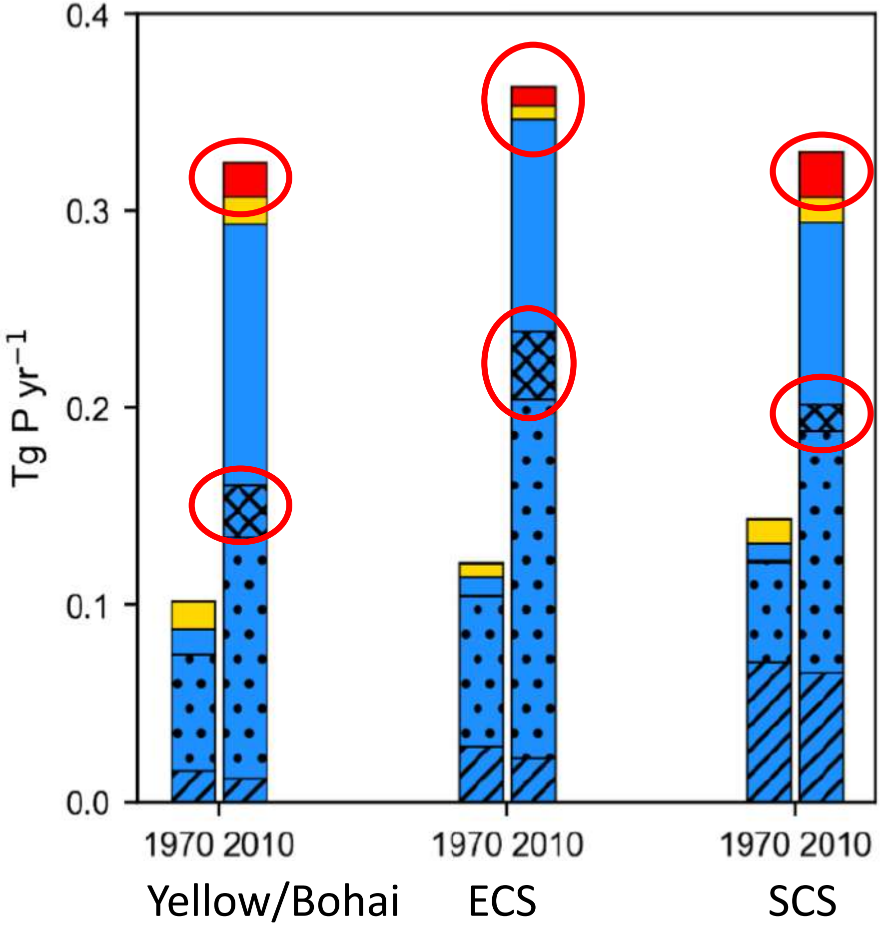
Sources of N and P to Yellow Sea/Bohai, E. China Sea and S. China Sea



Nitrogen



Phosphorus



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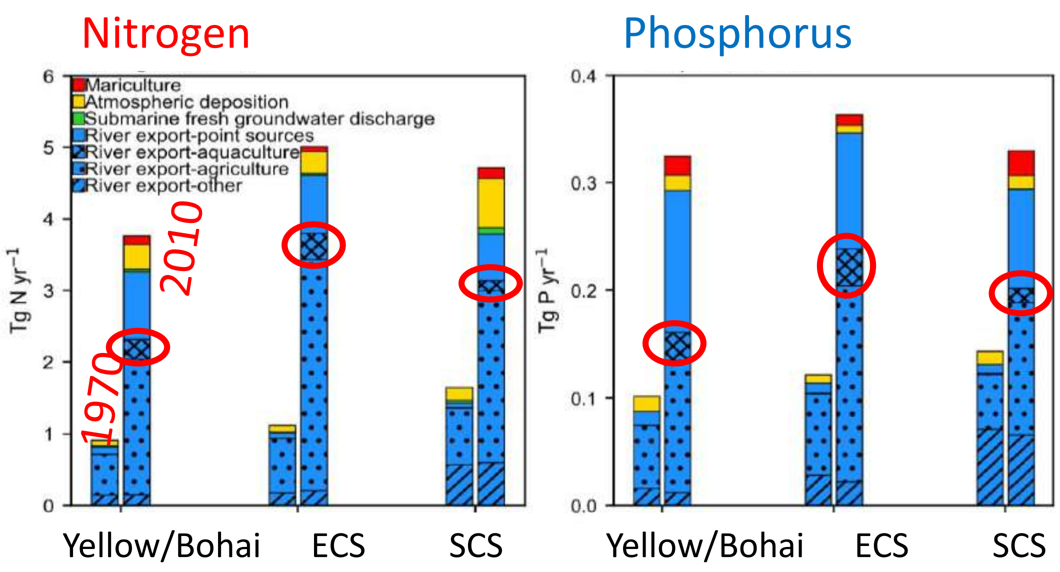

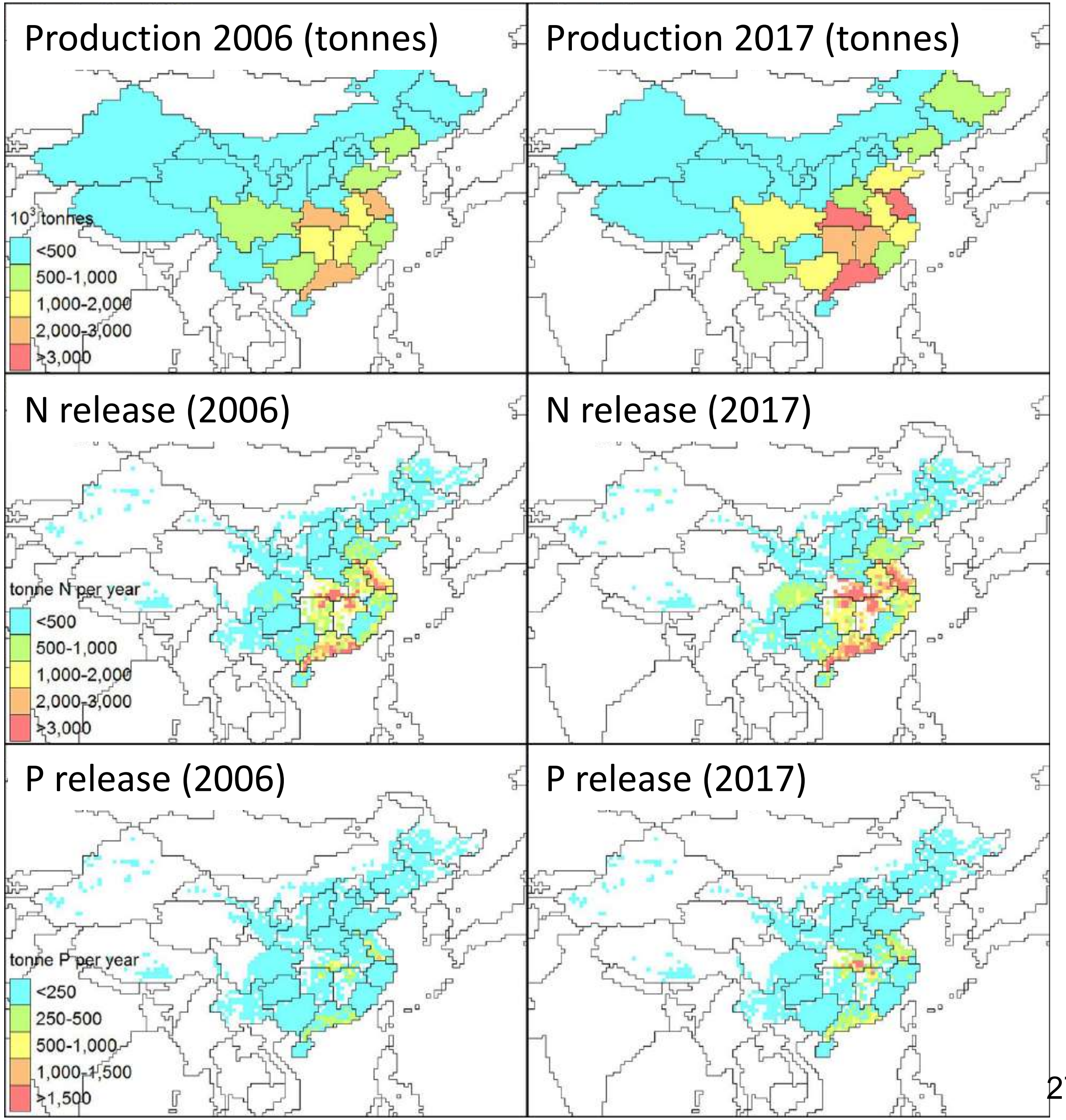

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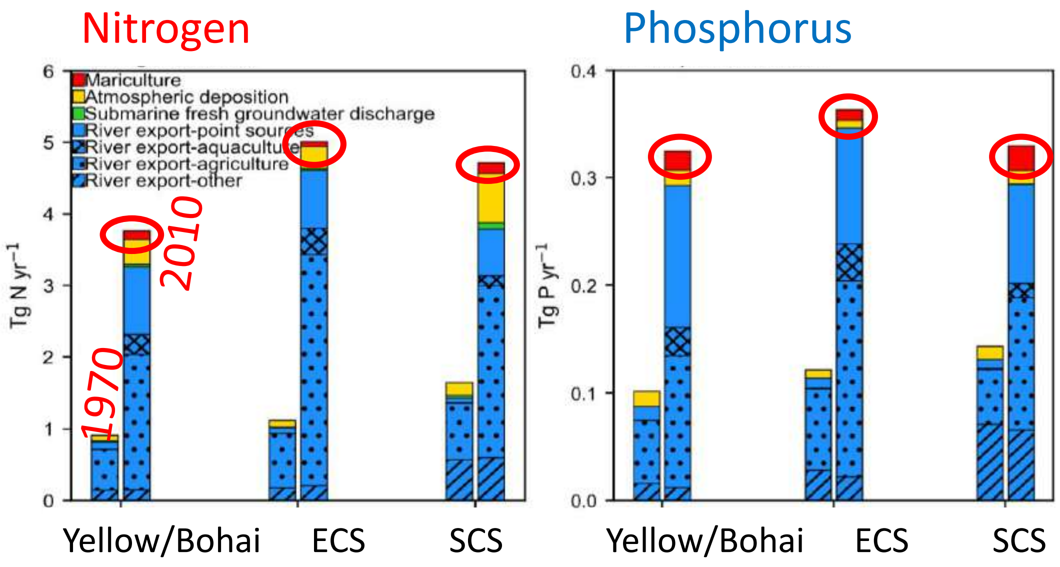

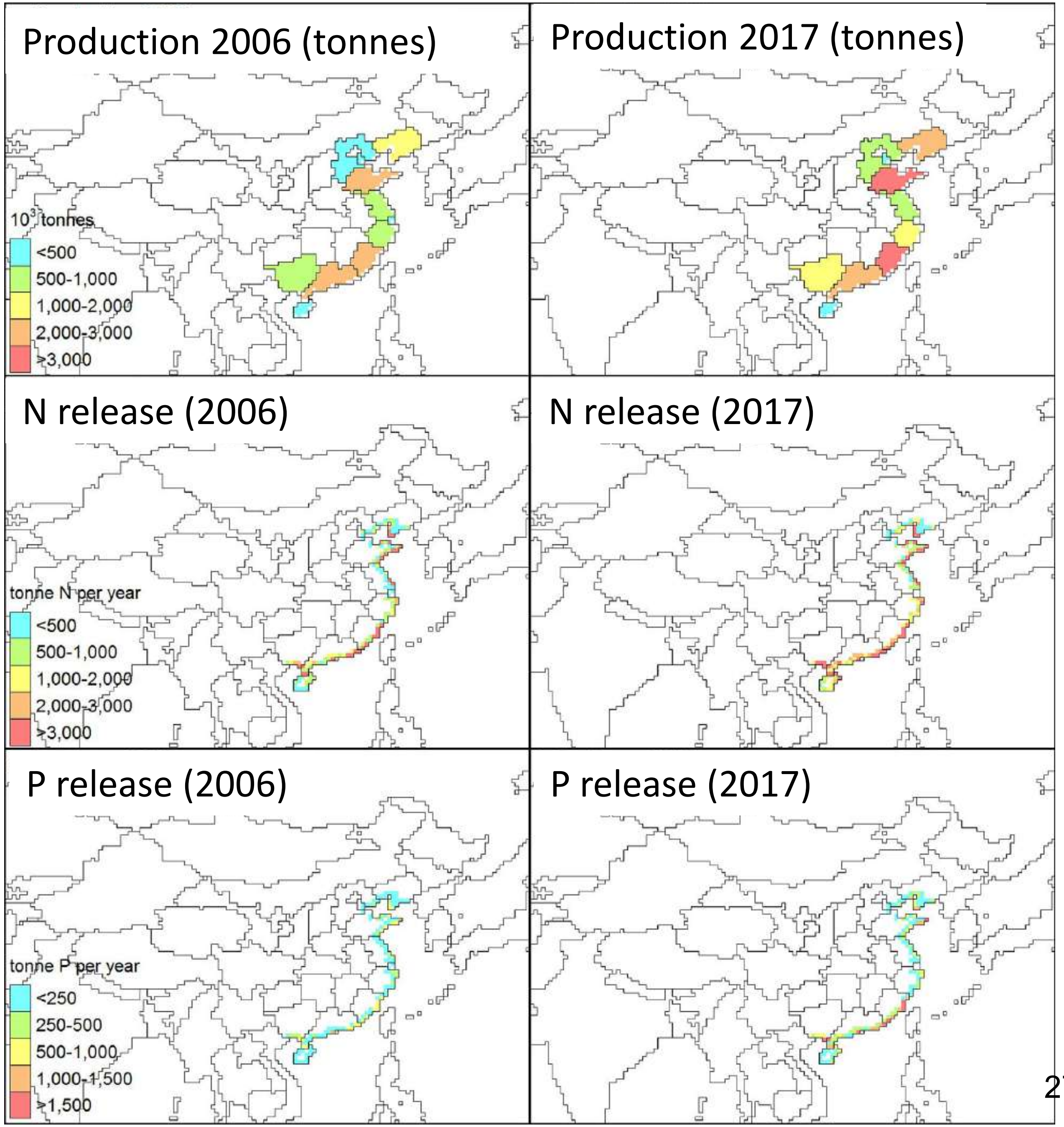

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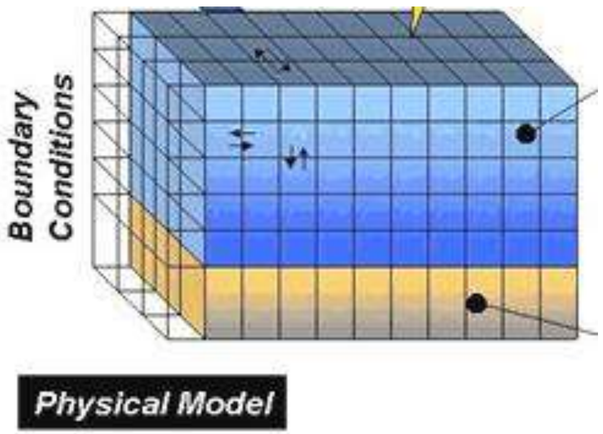
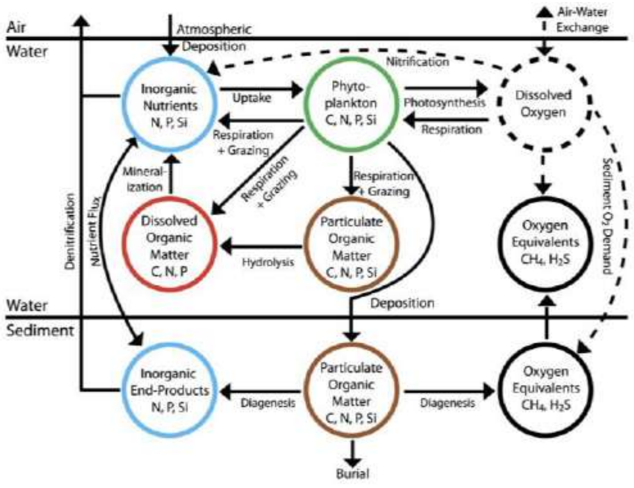
Advancing prediction

Advancing data acquisition
Advancing models

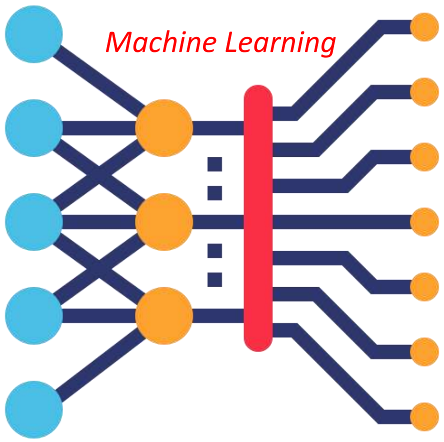
Data

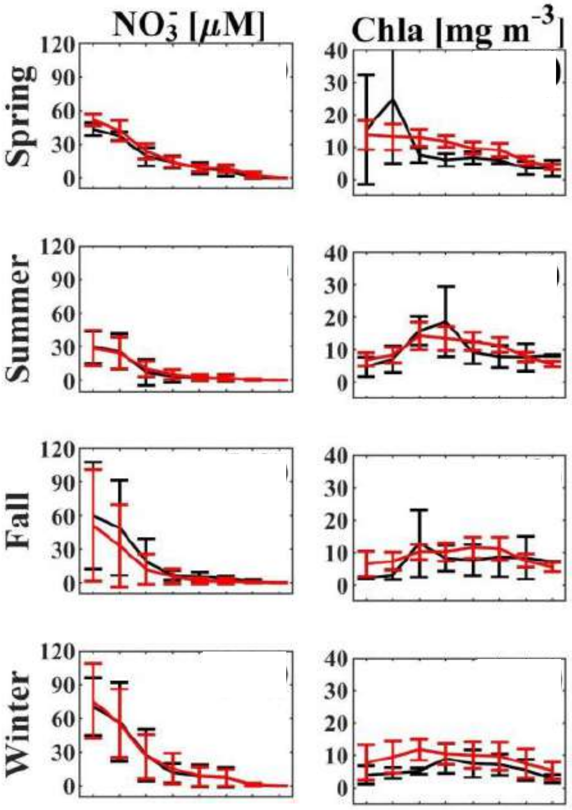


Mechanistic models



Machine Learning





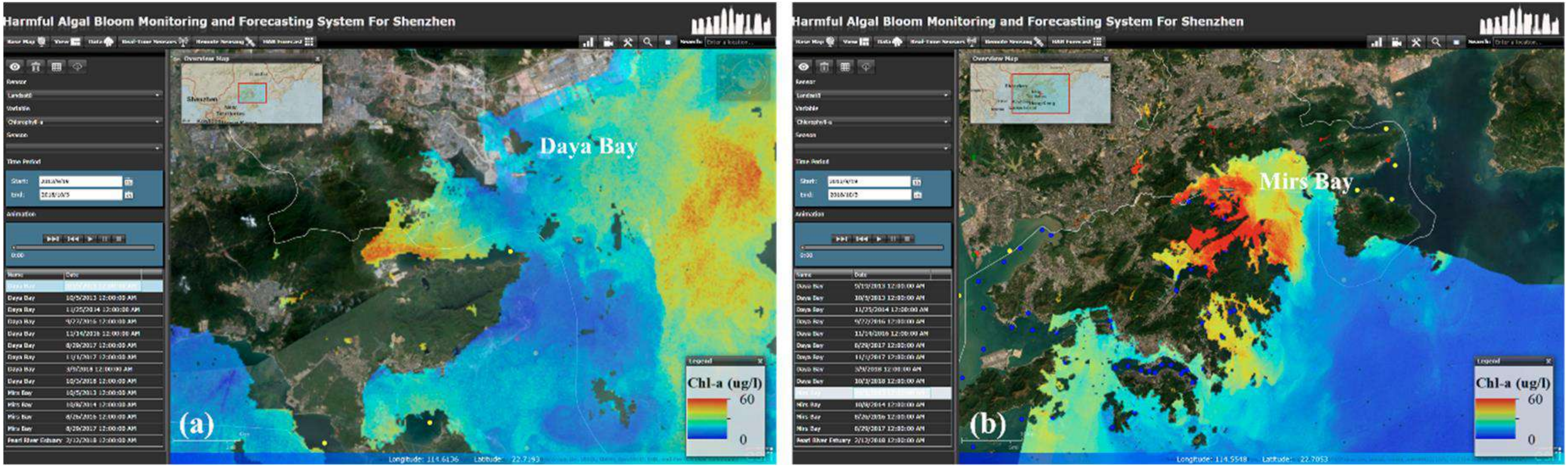
Models are rapidly advancing and predicting chlorophyll with high fidelity

Journal of
Marine Science and Engineering
2019 7:314

Forecasting HABs as **Chlorophyll** is advancing

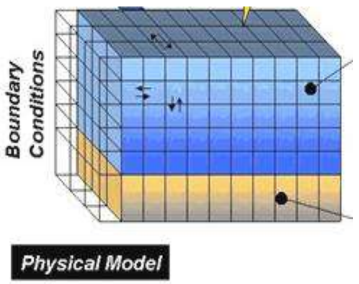
An Integrated Web-Based System for the Monitoring and Forecasting of Coastal Harmful Algae Blooms: Application to Shenzhen City, China

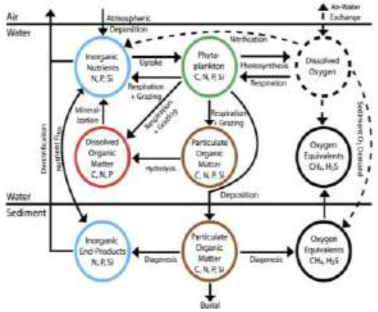
by Yong Tian [1,2] and Mutao Huang [3,*]

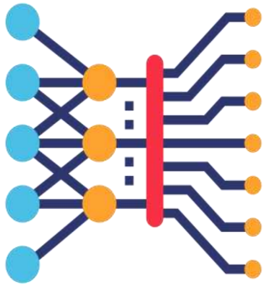


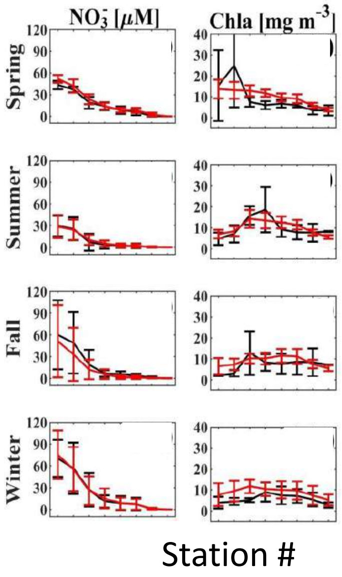
Chl-a concentration map of the harmful algal bloom (HAB)-affected areas using the support vector regression model: (a) HAB occurred on 25 November 2014 in the Daya Bay; and (b) HAB occurred on 29 August 2017 in the Mirs

Predicting **species** is more challenging



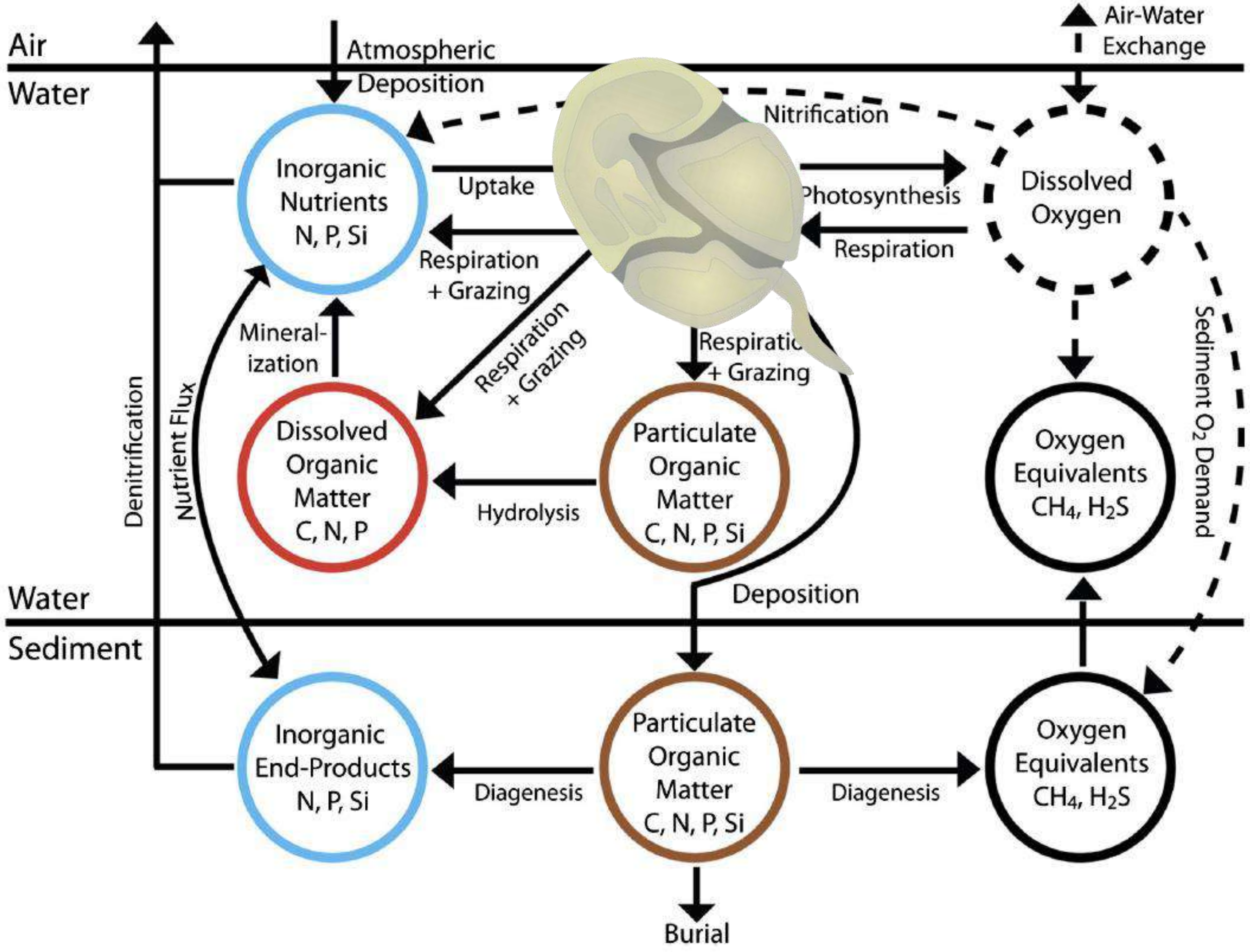






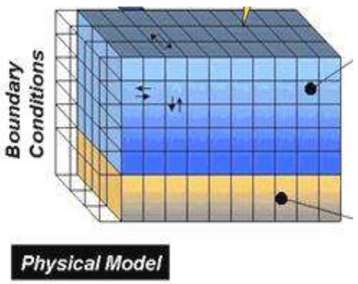
Rhomboid strategy (characterize one species against a background of functional groups)

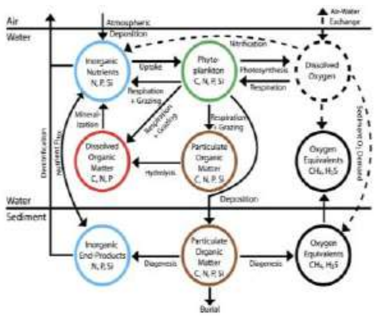
Biogeochemical model with 3 phytoplankton groups

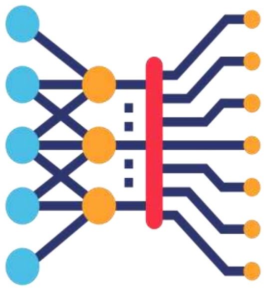


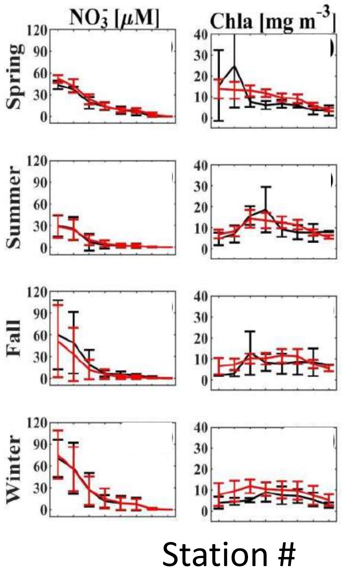
HAB taxa is modeled "on top of" generic phytoplankton functional groups (e.g., diatom group and nanoflagellate group)

Predicting **species** is more challenging







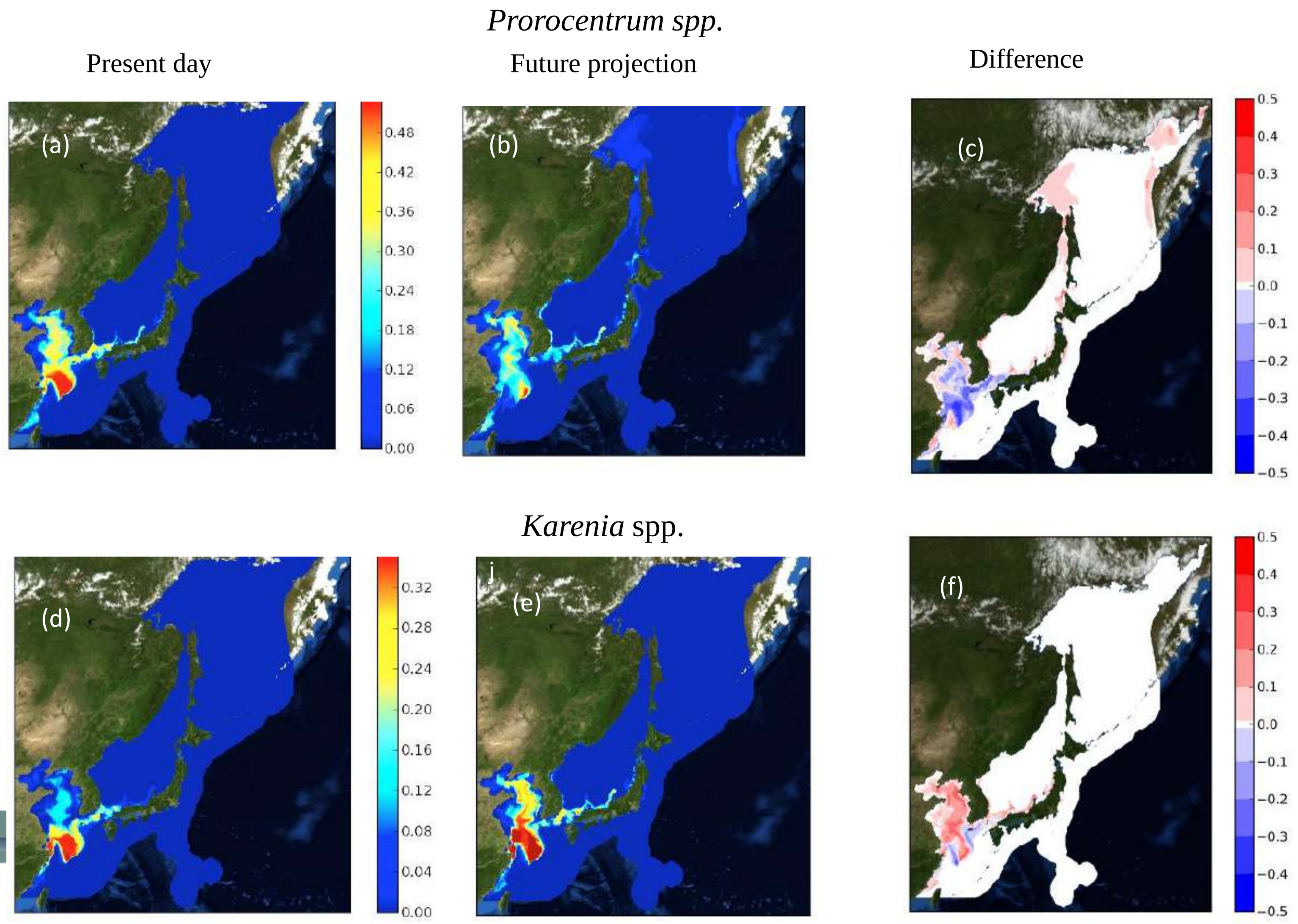


Rhomboid strategy
(characterize one species
against a background of
functional groups)

Habitat modeling-
Define a species niche
(not abundance of species)

Example of habitat modeling for *Prorocentrum* and *Karenia* spp.

(future is end of century)



Global Change Biology

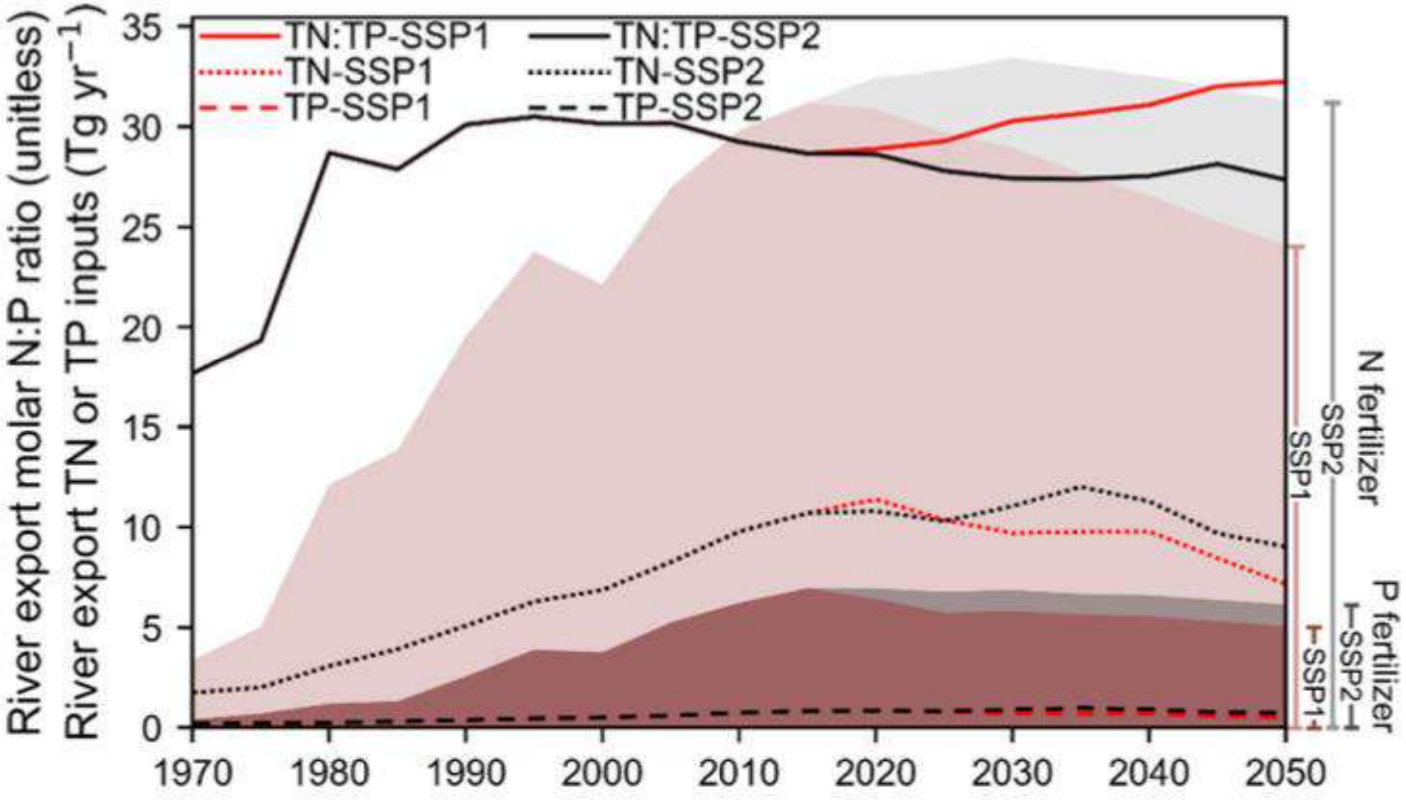
Global Change Biology (2014), doi: 10.1111/gcb.12662

Vulnerability of coastal ecosystems to changes algal bloom distribution in response to climate change: projections based on model analysis

PATRICIA M. GLIBERT[1], J. ICARUS ALLEN[2], YURI ARTIOLI[2], ARTHUR BEUSEN[3], LEX BOUWMAN[3,4], JAMES HARLE[5], ROBERT HOLMES[2] and JASON HOLT[5]

A habitat model only defines the available niche-
It does not project frequency or cell density
(risk map)

Projecting HABs will persist based on predicting scenario changes in TN:TP



ENVIRONMENTAL Science & Technology LETTERS

pubs.acs.org/journal/estlcu 2021 8:276-284. Letter

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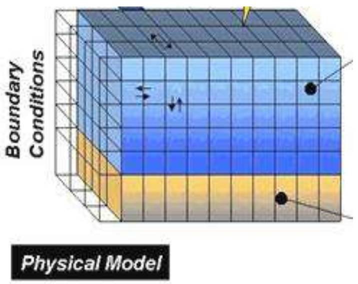
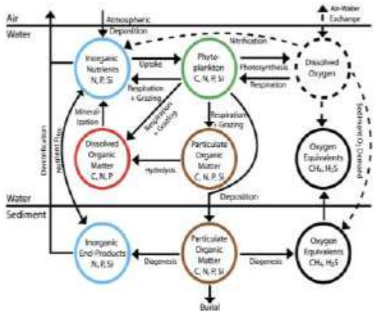
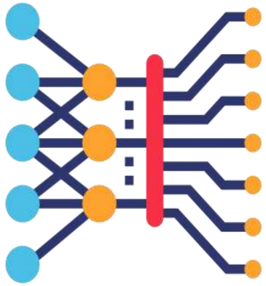
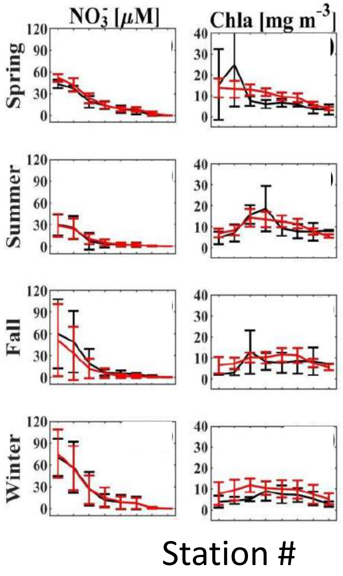
Predicting **species** is more challenging







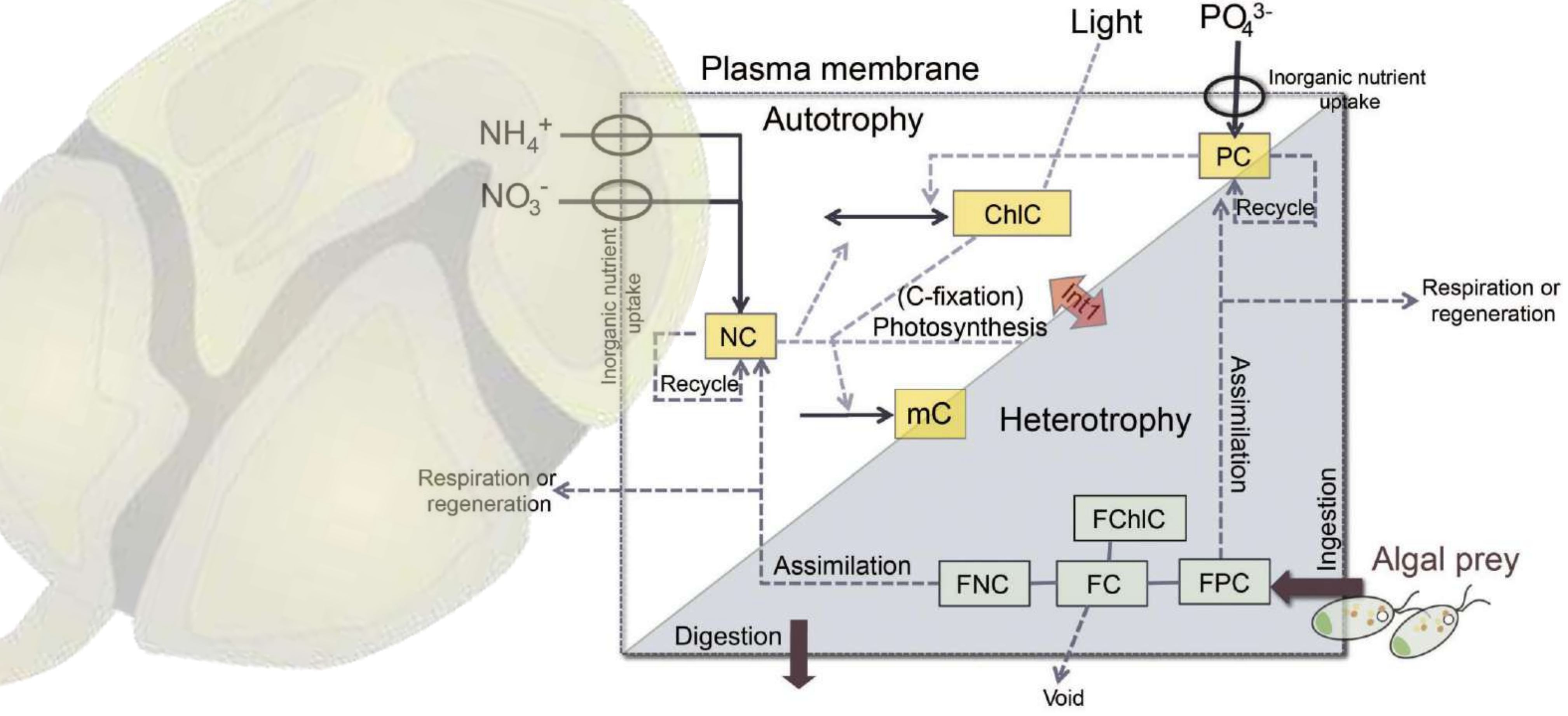


Rhomboid strategy (characterize one species against a background of functional groups)

Habitat modeling- Define a species niche (not abundance of species)

Improving mechanistic characterization of species- include mixotrophic nutrition

MIXOtrophic HAB model: the “perfect beast”

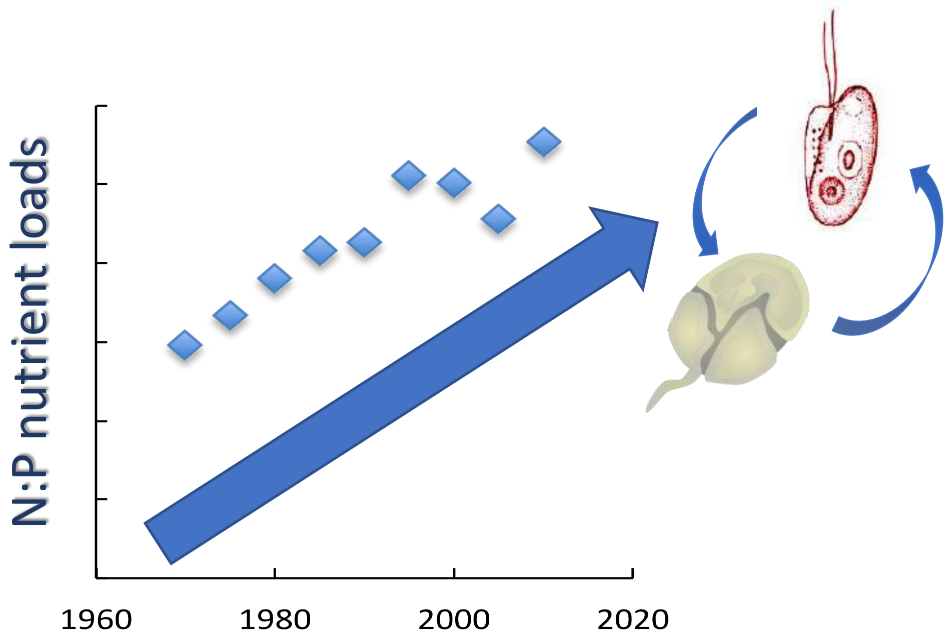


MIXO has 8 state variables describing C, N and P and chlorophyll (Chl) associated with the core mixotroph (m) biomass and those associated with the contents of the food (F) vacuole after the mixotroph has fed on algal prey.

ORIGINAL RESEARCH
published: 10 September 2018
doi: 10.3389/fmars.2018.00320
frontiers in Marine Science

Simulating Effects of Variable Stoichiometry and Temperature on Mixotrophy in the Harmful Dinoflagellate *Karlodinium veneficum*

Chih-Hsien Lin[1], Kevin J. Flynn[2]*, Aditee Mitra[2] and Patricia M. Glibert[1]

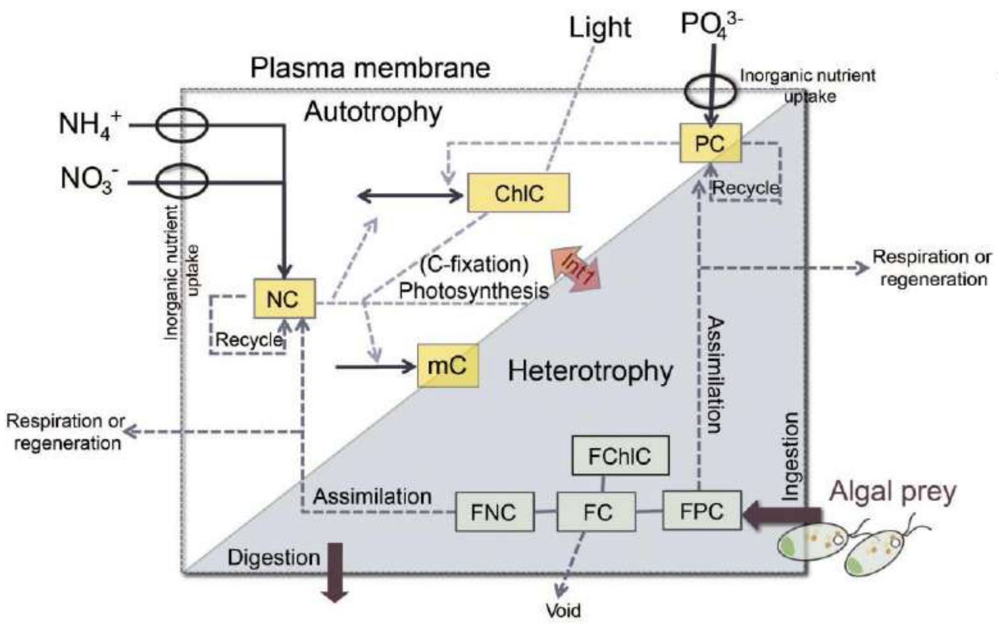


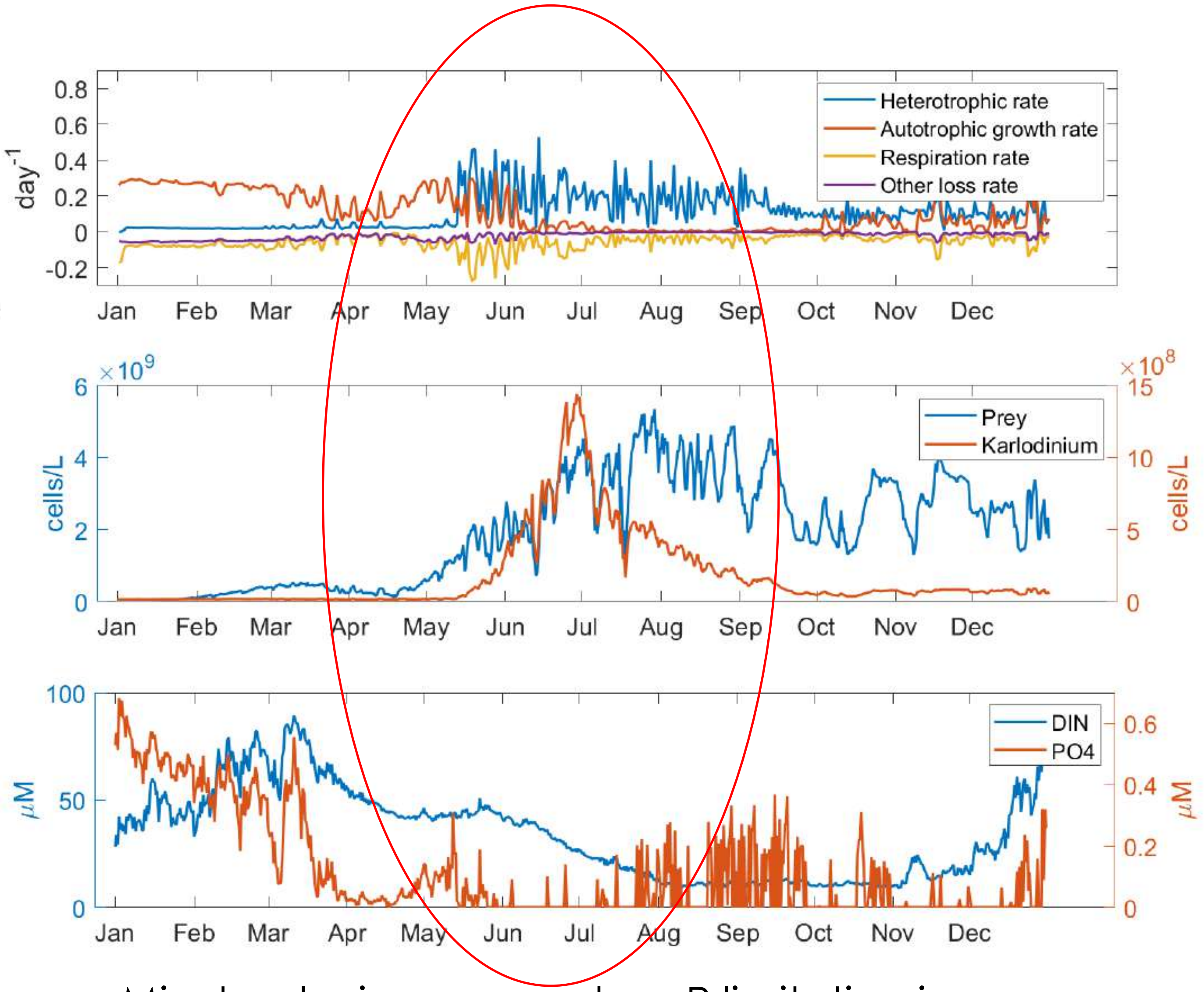
Mixotrophy increases growth rate and sustain growth longer

Mixotrophy often increases with increasing N:P

Mixotrophy and toxicity may be synergistic; Release of toxins harms prey, releasing dissolved nutrients or makes the prey easier to capture

Modeling mixotophy by *Karlodinium* in Chesapeake Bay, USA





Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

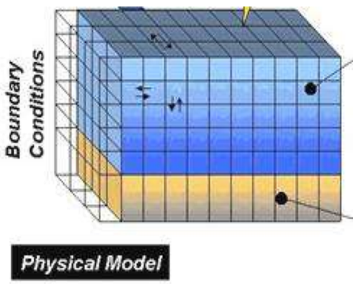
2022: in press

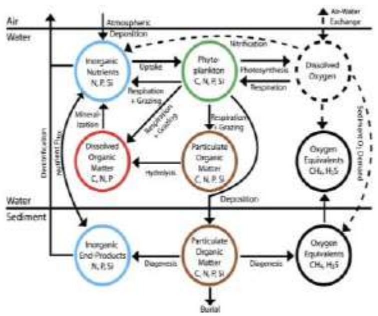
A Three-Dimensional Mixotrophic Model of *Karlodinium veneficum* Blooms for a Eutrophic Estuary

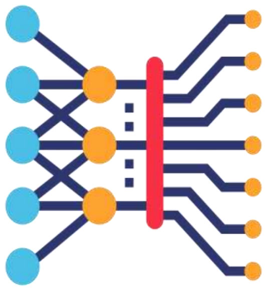
Ming Li*, Yuren Chen, Fan Zhang, Yang Song, Patricia M. Glibert, Diane K. Stoecker

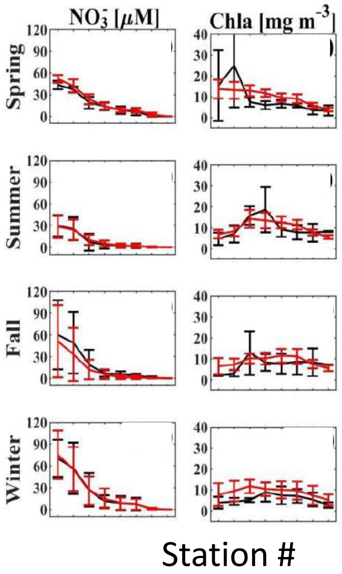
Mixotrophy increases when P limitation increases as waters warm and when prey increases

Predicting **species** is more challenging









Rhomboid strategy (characterize one species against a background of functional groups)

Habitat modeling- Define a species niche (not abundance of species)

Improved mechanistic characterization of species- include mixotrophic nutrition

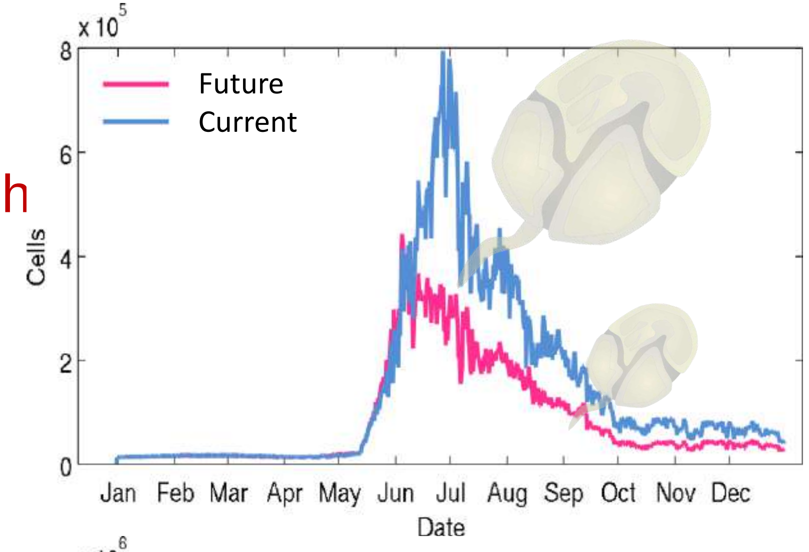
In silico experiments with multiple stressors (warming, nutrients, CO_2, pH, hypoxia, etc)

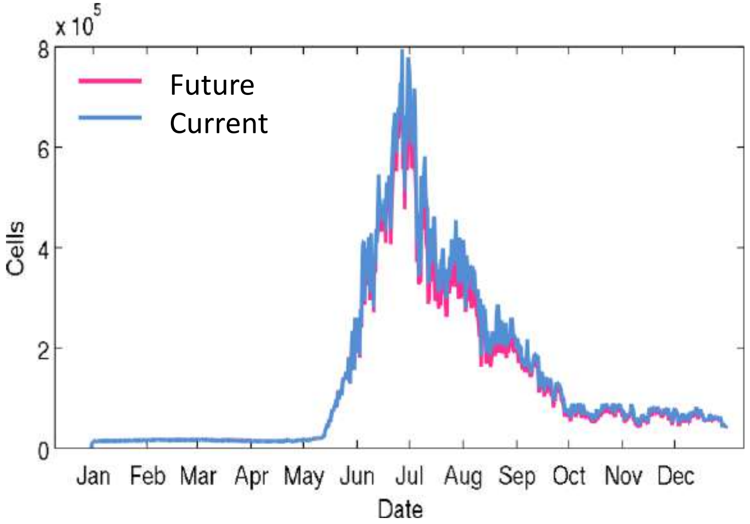
Testing future effects in silico

Effects of Warming

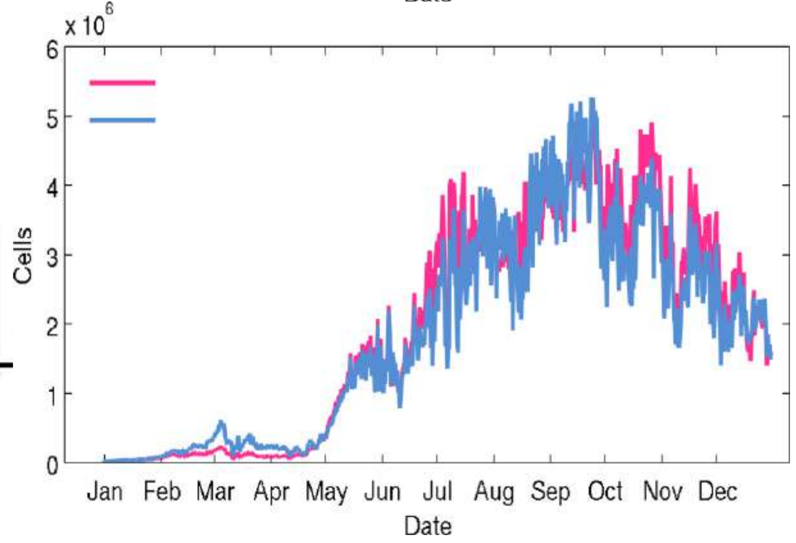
Effects of climate-induced changes in riverine NO_3 and PO_4 loading

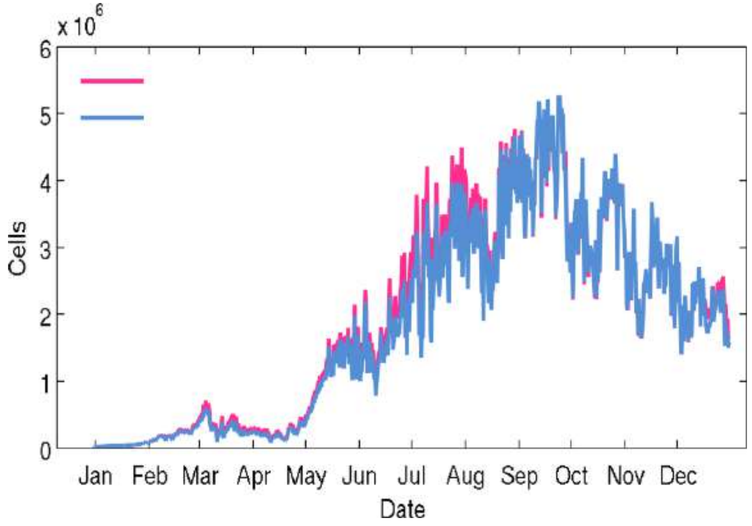
Mixotroph





Prey





Contents lists available at ScienceDirect

Harmful Algae

journal homepage: www.elsevier.com/locate/hal

ELSEVIER

2022: in press

A Three-Dimensional Mixotrophic Model of *Karlodinium veneficum* Blooms for a Eutrophic Estuary

Ming Li *, Yuren Chen, Fan Zhang, Yang Song, Patricia M. Glibert, Diane K. Stoecker

Take Home Lessons and Grand Challenges:

- ✓ Nutrient pollution remains a grand challenge. Some regional progress and potentially good news- but more reductions needed, especially N

- ✓ Aquaculture continues to be threatened by HABs, but also contributes to the nutrients supporting them

- ✓ Regional and early warning models are advancing but largely based on chlorophyll

- ✓ In order to predict HAB changes in a complex changing world, more attention to HAB physiology and mixotrophy is needed (which will require new data in many cases)

- ✓ A suite of coupled physical-biogeochemical-HAB-multi-trophic level models will be needed to test how stressors interact to project
    - o future HAB growth spatially and temporally
    - o future risks to aquaculture and other fishery resources

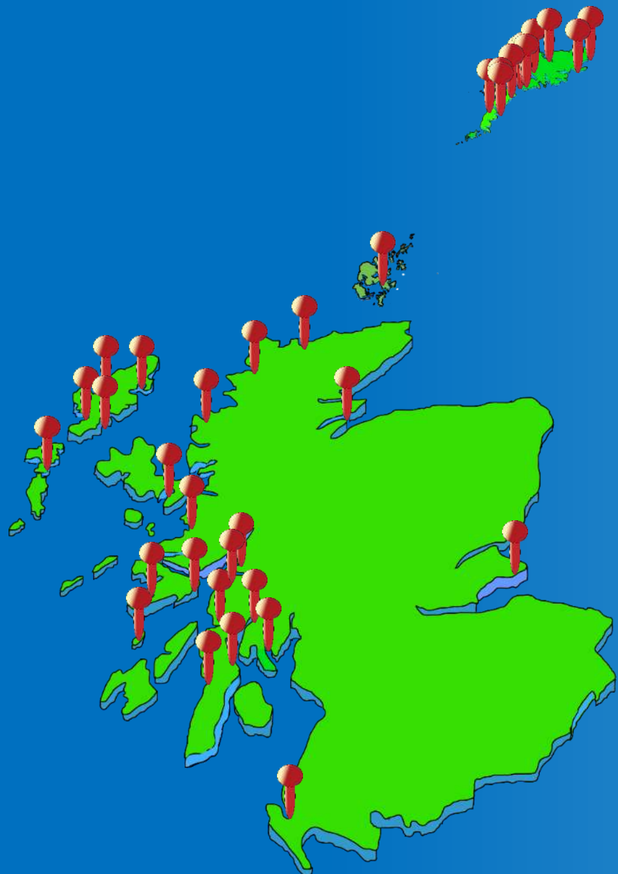
Thank you!
To the organizers,
and my co-authors
and other researchers
credited above

HABreports: Online early warning of harmful algal and biotoxin risk for the Scottish shellfish and finfish aquaculture industries

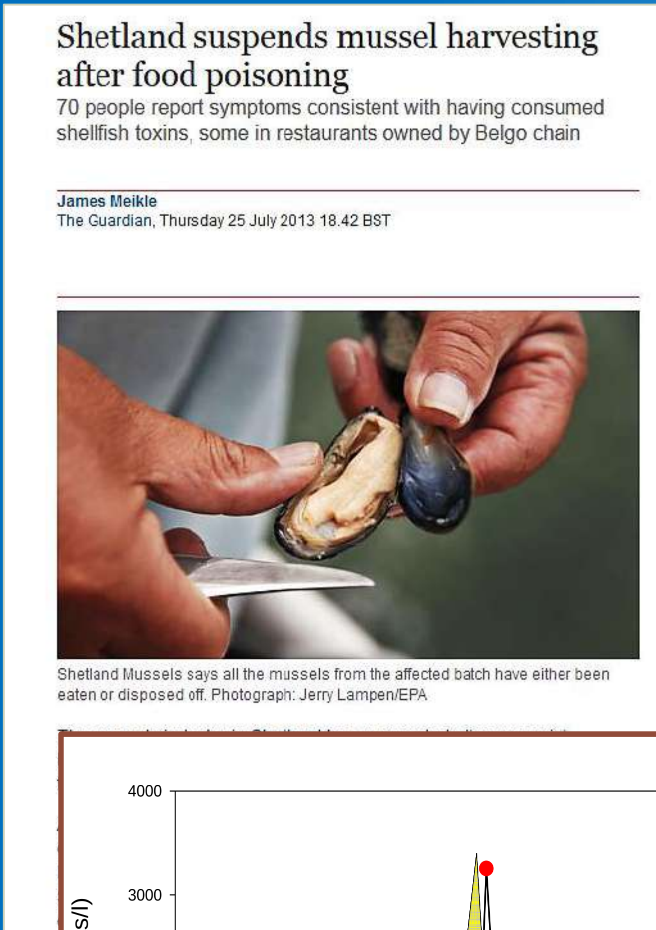
Keith Davidson,
Dmitry Aleynik, Gregg Arthur,
Solene Giraudeau-Potel, Steve Gontarek,
Callum Whyte

Keith.davidson@sams.ac.uk

Regulatory Monitoring for Toxin Producing Microplankton in Scottish Waters



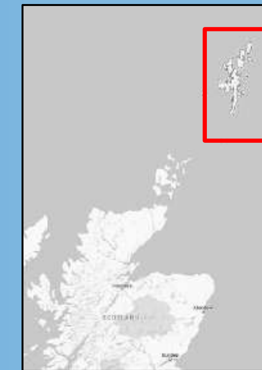
Since 2005 SAMS Enterprise has monitored **40 active** shellfish growing sites **weekly** – analysing approximately **1250 samples** during the year


Shetland suspends mussel harvesting after food poisoning

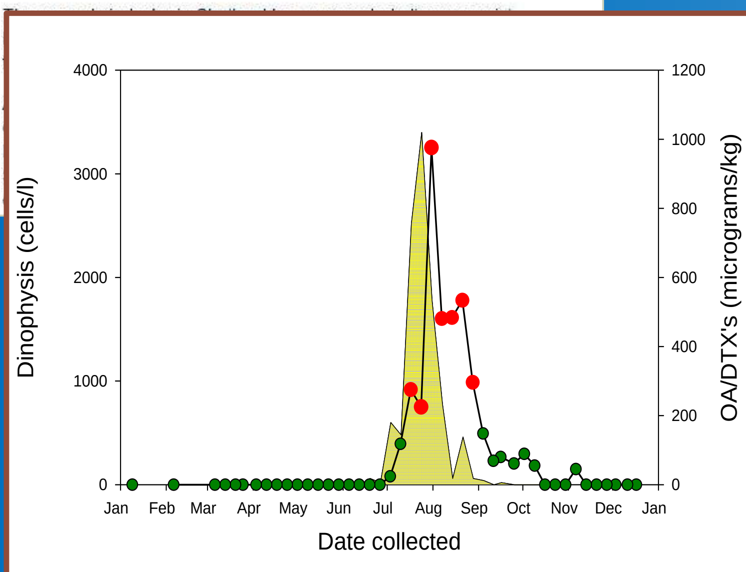
70 people report symptoms consistent with having consumed shellfish toxins, some in restaurants owned by Belgo chain

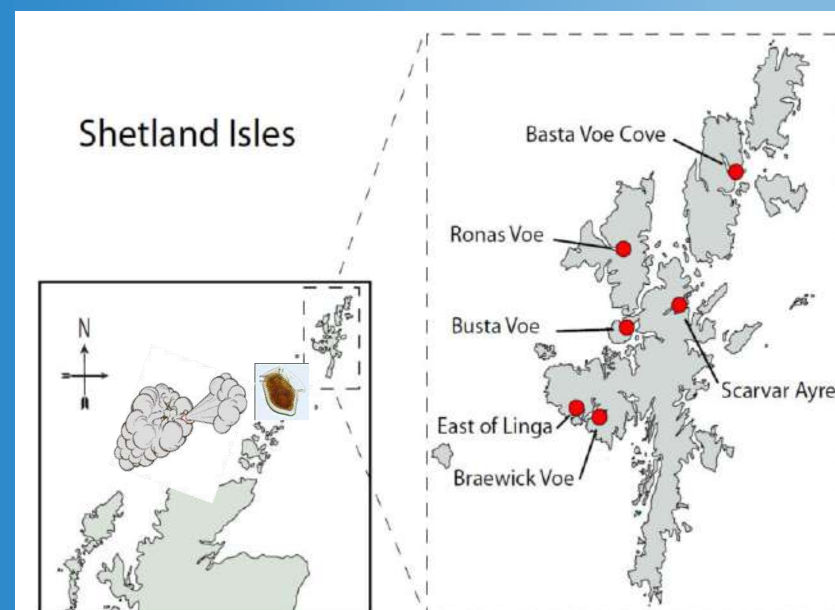
James Meikle
The Guardian, Thursday 25 July 2013 18.42 BST

Shetland Mussels says all the mussels from the affected batch have either been eaten or disposed off. Photograph: Jerry Lampen/EPA



UK has a **robust monitoring** scheme however in **2013** 70 people reported symptoms of **Diarrhetic Shellfish Poisoning** after eating in the Belgo chain of **restaurants** in London and South East England





Whyte et al. (2014) Harmful Algae 39: 365-373

SeafoodShetland
incorporating Shetland Fish Processors and Shellfish Growers


FSA in UK | FSA in Scotland | FSA in Wales | FSA in Northern Ireland

siness & ustry | Enforcement & regulation | Science & policy | About us

Centre ▸ Shellfish poisoning outbreak

Shellfish poisoning outbreak

Last updated: 25 July 2013

Following detection by the FSA of unusually high levels of toxins, various shellfish harvesting sites in Scotland have been closed. These toxins, which occur naturally, especially during the summer months, can cause acute food poisoning.

In addition, the FSA has been informed that approximately 70 people in south east England have reported symptoms consistent with diarrhetic shellfish poisoning (see 'Science behind the story' below). The vast majority of cases occurred between 13 and 15 July.

The cases have been linked to the consumption of mussels originating from a particular harvesting area in Shetland, Scotland. After these mussels were harvested, an unusually high toxin level was detected by the FSA's weekly monitoring programme. The area has been closed, and as a precautionary measure the industry has voluntarily suspended all commercial harvesting from the waters around Shetland until toxin levels subside.

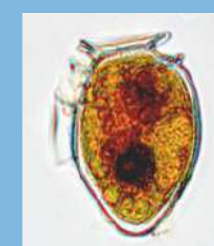
The business that supplied the shellfish, Shetland Mussels, has contacted its customers and advised the FSA that all of the mussels from this batch have either been consumed or disposed of. The local authority is investigating and liaising closely with the FSA.

The mussels had been supplied to a number of restaurants, some through a number of intermediary suppliers. Customers reported illness after eating at: Belgo in Covent Garden, Holborn, Clapham and Bromley; Zero Degrees in Blackheath and Reading; The Phoenix near Hook, Hampshire; Boulevard Brasserie in Covent Garden; and Pig's Ears in Richmond. These premises acted appropriately by notifying the relevant authorities when the cases of illness were identified.

Business responsibilities

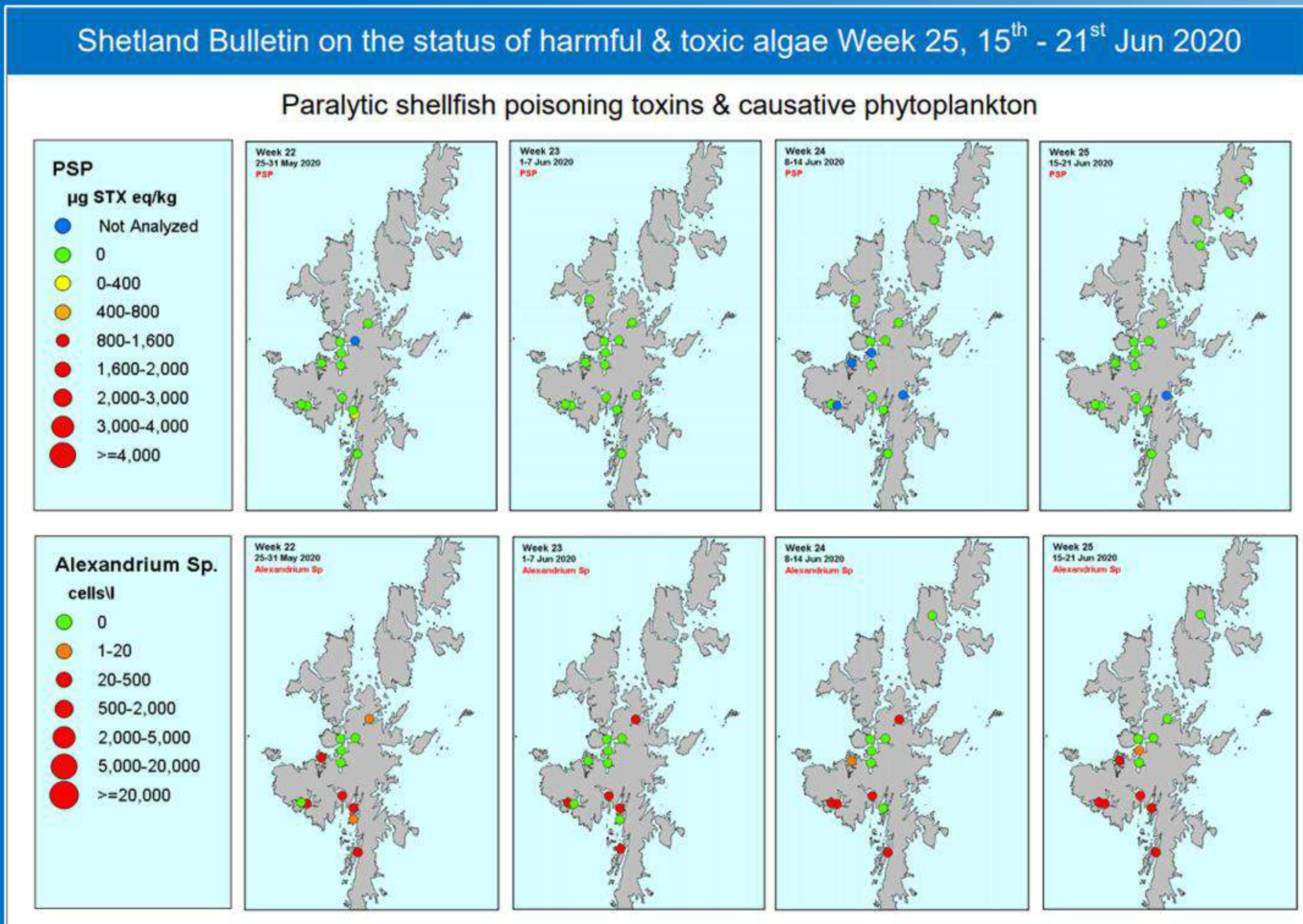
It is the legal responsibility of all food businesses to put in place appropriate controls to ensure that only food safe for consumption is placed on the market. The FSA is reminding all UK companies involved in the sale of shellfish to ensure that biotoxin

Annual losses due to Dinophysis toxicity events alone to the Scottish shellfish industry are estimated at 15% of total production (equivalent to £1.37m/year)



Martino et al. (2020) Harmful Algae 99 101912

Costs to the finfish aquaculture industry can run into £/million



PSP

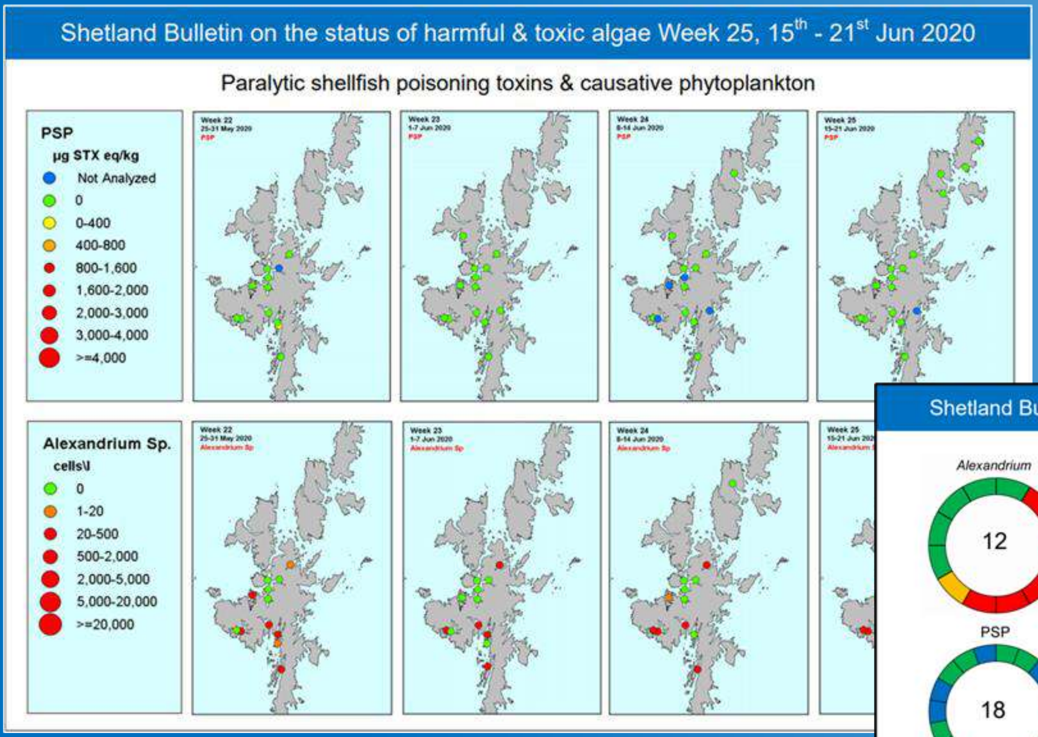
Maps of Sites with toxin and phytoplankton concentrations in this example the toxin is Saxitoxin and the causative species is *Alexandrium.*

Alexandrium

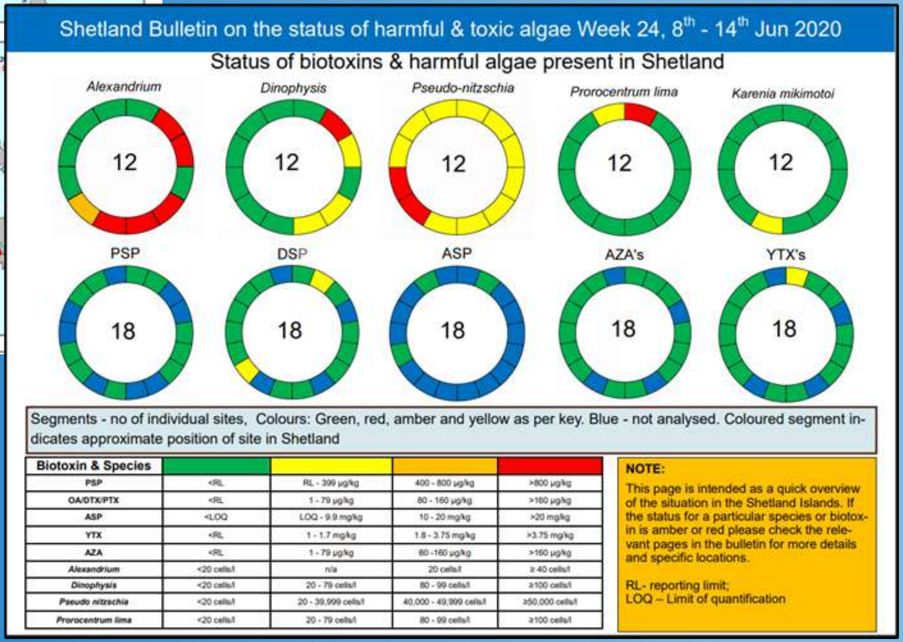
Preceding three weeks

Current week

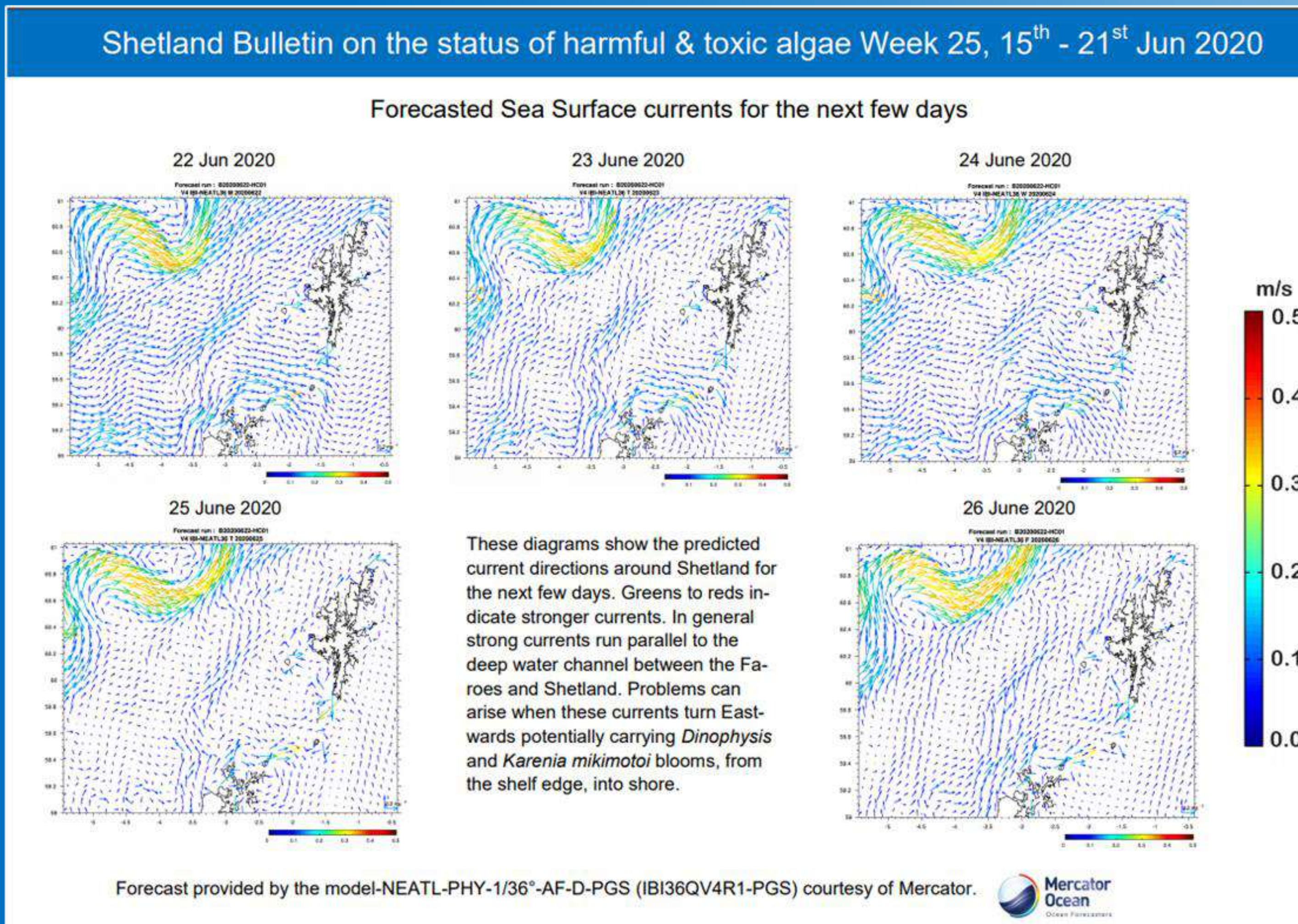
Initial pdf based weekly report for Seafood Shetland



Blended approach: Same information but presented as an infographic

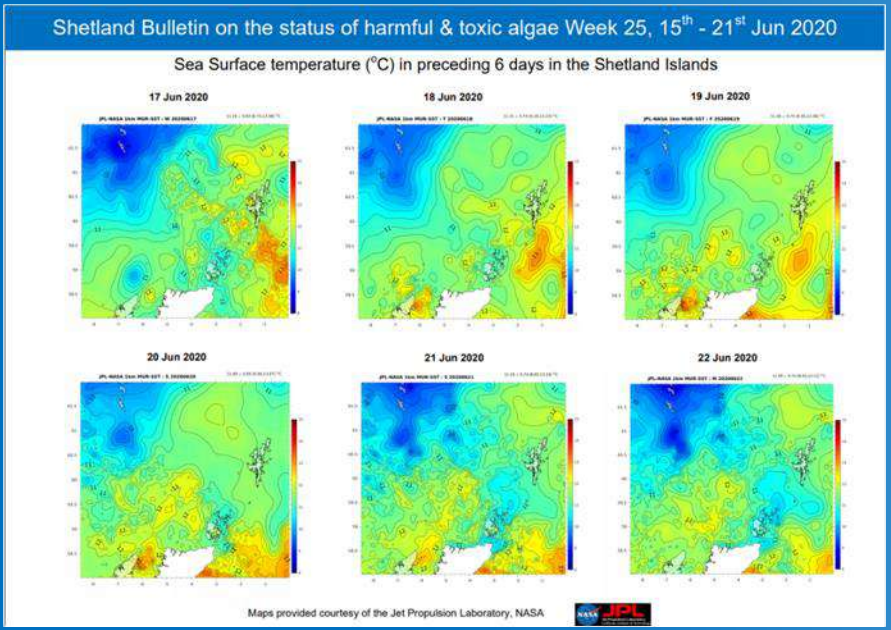


Biotoxin & Species				
PSP	<RL	RL - 399 µg/kg	400 - 800 µg/kg	>800 µg/kg
OA/DTX/PTX	<RL	1 - 79 µg/kg	80 - 160 µg/kg	>160 µg/kg
ASP	<LOQ	LOQ - 9.9 mg/kg	10 - 20 mg/kg	>20 mg/kg
YTX	<RL	1 - 1.7 mg/kg	1.8 - 3.75 mg/kg	>3.75 mg/kg
AZA	<RL	1 - 79 µg/kg	80 -160 µg/kg	>160 µg/kg
Alexandrium	<20 cells/l	n/a	20 cells/l	≥ 40 cells/l
Dinophysis	<20 cells/l	20 - 79 cells/l	80 - 99 cells/l	≥100 cells/l
Pseudo nitzschia	<20 cells/l	20 - 39,999 cells/l	40,000 - 49,999 cells/l	≥50,000 cells/l
Prorocentrum lima	<20 cells/l	20 - 79 cells/l	80 - 99 cells/l	≥100 cells/l

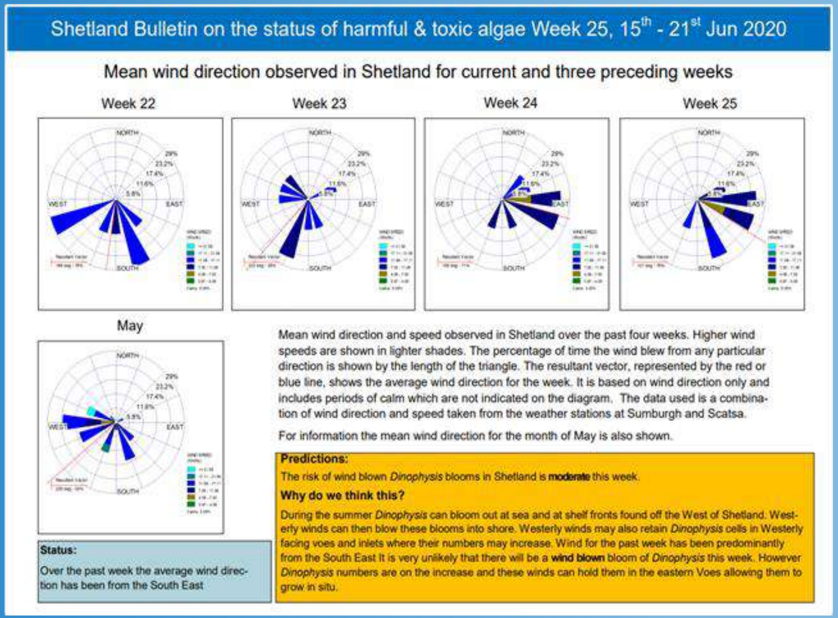


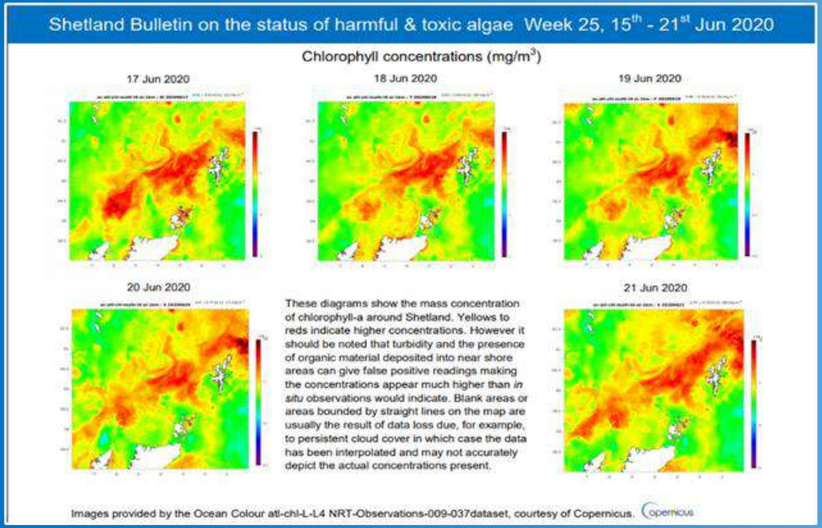
Forecasted sea surface currents for 3 - 4 days

Sea surface temperatures



Wind direction and speed





Chlorophyll concentrations

Summary Page: Toxins, Phytoplankton Trends, Risk assessment

Shetland Bulletin on the status of harmful & toxic algae Week 24, 8th - 14th Jun 2020

Biotoxin report:

PSP toxins: Ten sites were tested this week. Toxins were not detected.

DSP toxins: Fourteen sites were tested this week. Toxins were detected in low concentrations in Braewick Voe and Scarvar Ayre.

ASP toxins: Three sites were tested this week. No toxins were detected.

YTX toxins: Fourteen sites were tested this week. Toxins were detected in low concentrations in Inner Site 1—Thomason.

AZA toxins: Fourteen sites were tested this week. No toxins were detected.

Harmful algae report:

Alexandrium: Twelve samples were analysed this week. *Alexandrium* was detected at/above trigger in Stream Sound, Scarvar Ayre, Sandsound Voe, East of Linga and Braewick Voe and at warning level in Seggi Bight.

Dinophysis: Twelve samples were analysed this week. *Dinophysis* was detected at/above trigger level in Scarvar Ayre. It was found in low numbers in Stream Sound, Braewick Voe and Sandsound Voe.

Pseudo-nitzschia: Twelve samples were analysed this week. *Pseudo-nitzschia* was found above trigger level in Seggi Bight and Slyde. It was found in low numbers in all other sites.

Prorocentrum lima: Twelve samples were analysed this week. *P. lima* was detected above trigger level in Inner Site 1—Thomason and in low numbers in Parkgate.

Karenia mikimotoi; Twelve samples were analysed this week. *Karenia* was detected in low numbers in East of Linga.

Shetland: trends and forecast

***Alexandrium*/PSP:** *Alexandrium* is at/above trigger levels in many sites and while toxins have not been detected, care should be taken in those sites.

***Dinophysis*/DSP:** We are coming into the season for *Dinophysis* and they are beginning to appear in our samples. Low levels of toxins are also being detected and we would advise caution.

***Pseudo-nitzschia*/ASP:** While *Pseudo-nitzschia* numbers are high in two sites, it is unlikely that there will be a toxic bloom of *Pseudo-nitzschia* this week.

AZA and **YTX:** It is highly unlikely that these toxins will exceed threshold levels this week. However, large numbers of *Protoceratium reticulatum* have resulted in low concentrations of Yessotoxins in one site.

Risk for **PSP: Moderate**

Risk for **DSP: Moderate**

Risk for **YTX: Low**

Risk for **ASP: Low**

Risk for **AZA: Low**

Toxin concentrations provided courtesy of the Centre for Environment, Fisheries and Aquaculture Science

Funding for these bulletins is kindly provided by EMFF

Primary data for biotoxins and biotoxin producing phytoplankton available at: http://www.food.gov.uk/enforcement/monitoring/shellfish/algaltoxin/#.UY0TkcqTQ6O

Warning/Threshold Levels

Alexandrium (PSP causative)	Warning 20 cells/l Threshold 40 cells/l
Pseudo nitzschia (ASP causative)	Warning: 40,000 cells/l Threshold: 50,000 cells/l
Dinophysis (DSP causative)	Warning : 80 cells/l Threshold:100 cells/l
Prorocentrum lima (DSP causative)	Warning: 80 cells/l Threshold: 100 cells/l

The maximum permitted levels of biotoxins in shellfish are:

PSP: 800 µg/kg

ASP: 20 mg/kg

Lipophilic toxins (tested by LC-MS):

OA/DTXs/PTXs: 160 ug/kg of Okadaic acid equivalents

YTXs: 3.75 milligram of yessotoxin equivalent/kilogram

AZAs: 160 micrograms of azaspiracids equivalents/kilogram

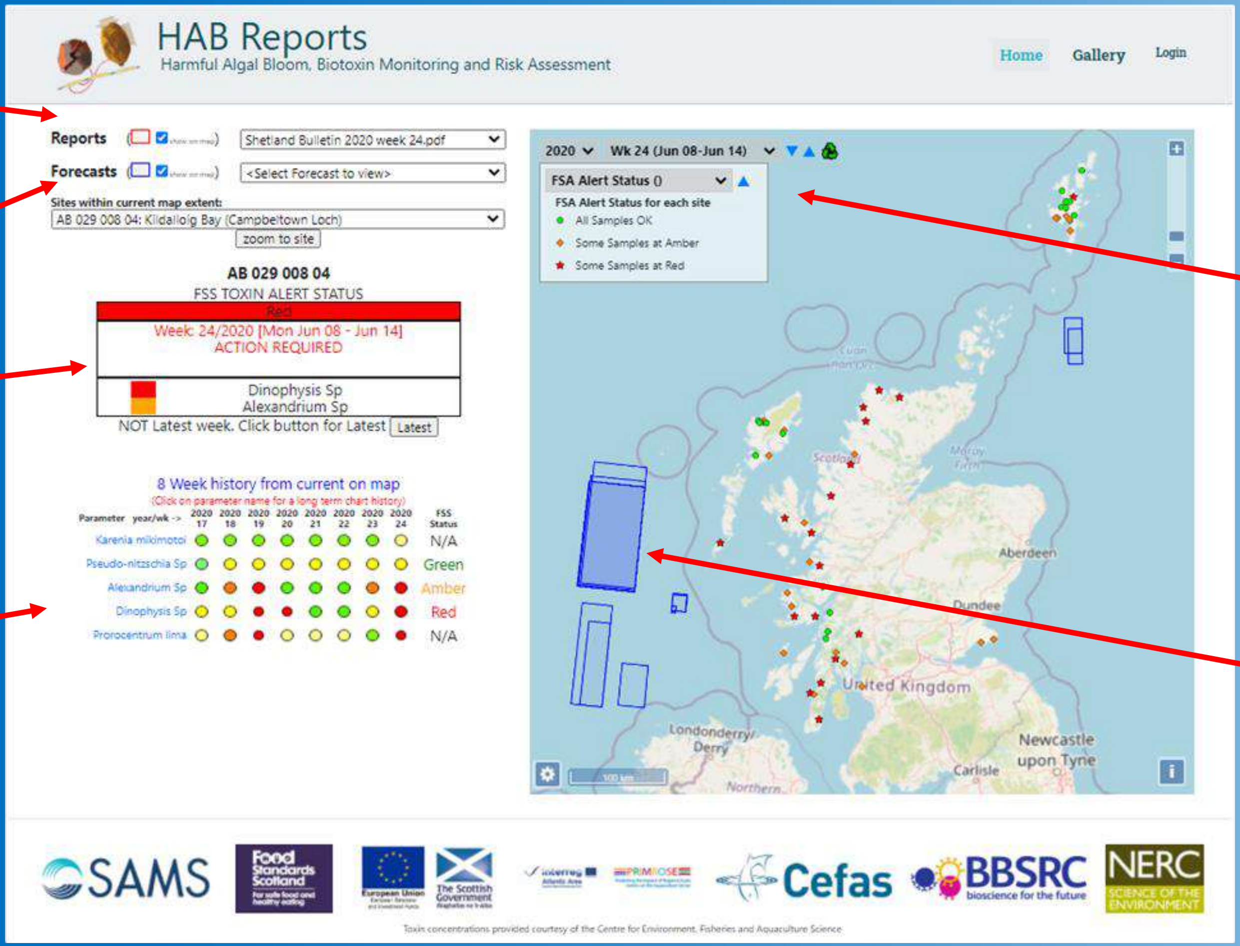
Available online at: www.HABreports.org

Select Reports

Select Models

Alert level For site

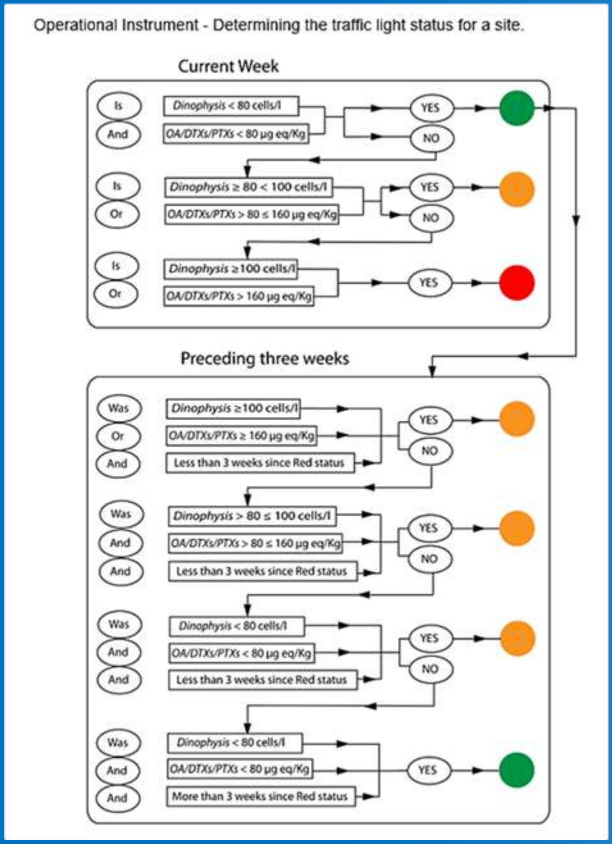
Select phytoplankton or toxin For plot of historic events

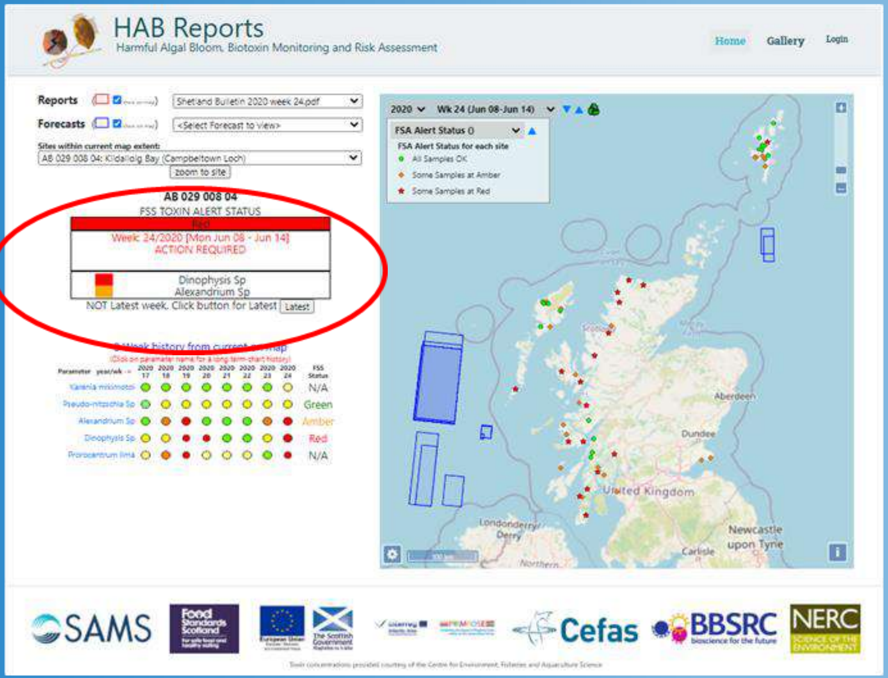


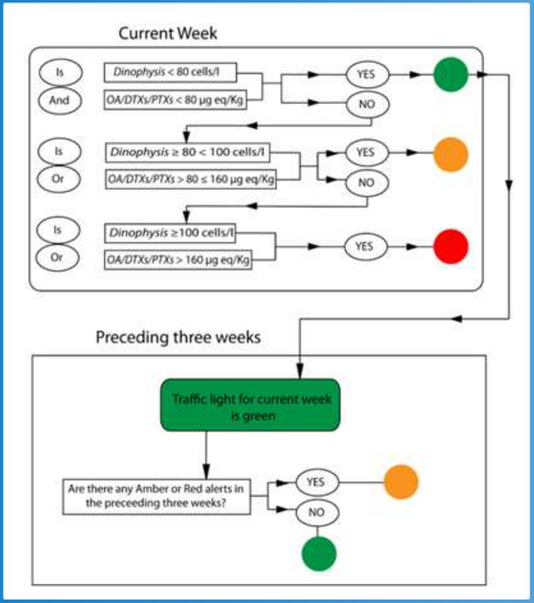
Interactive map with several layers selected from drop down menus

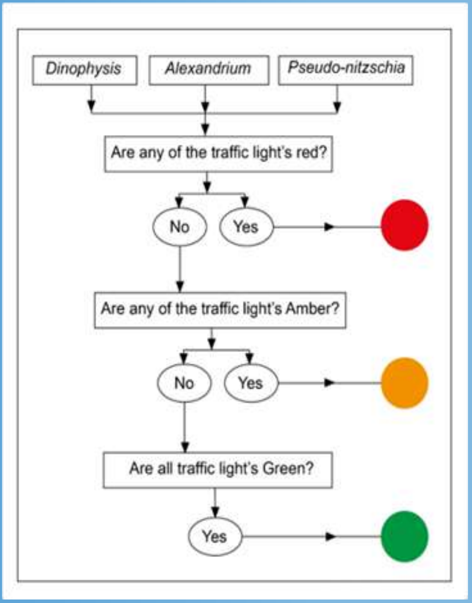
Available Model boundaries

Traffic Light Alert System

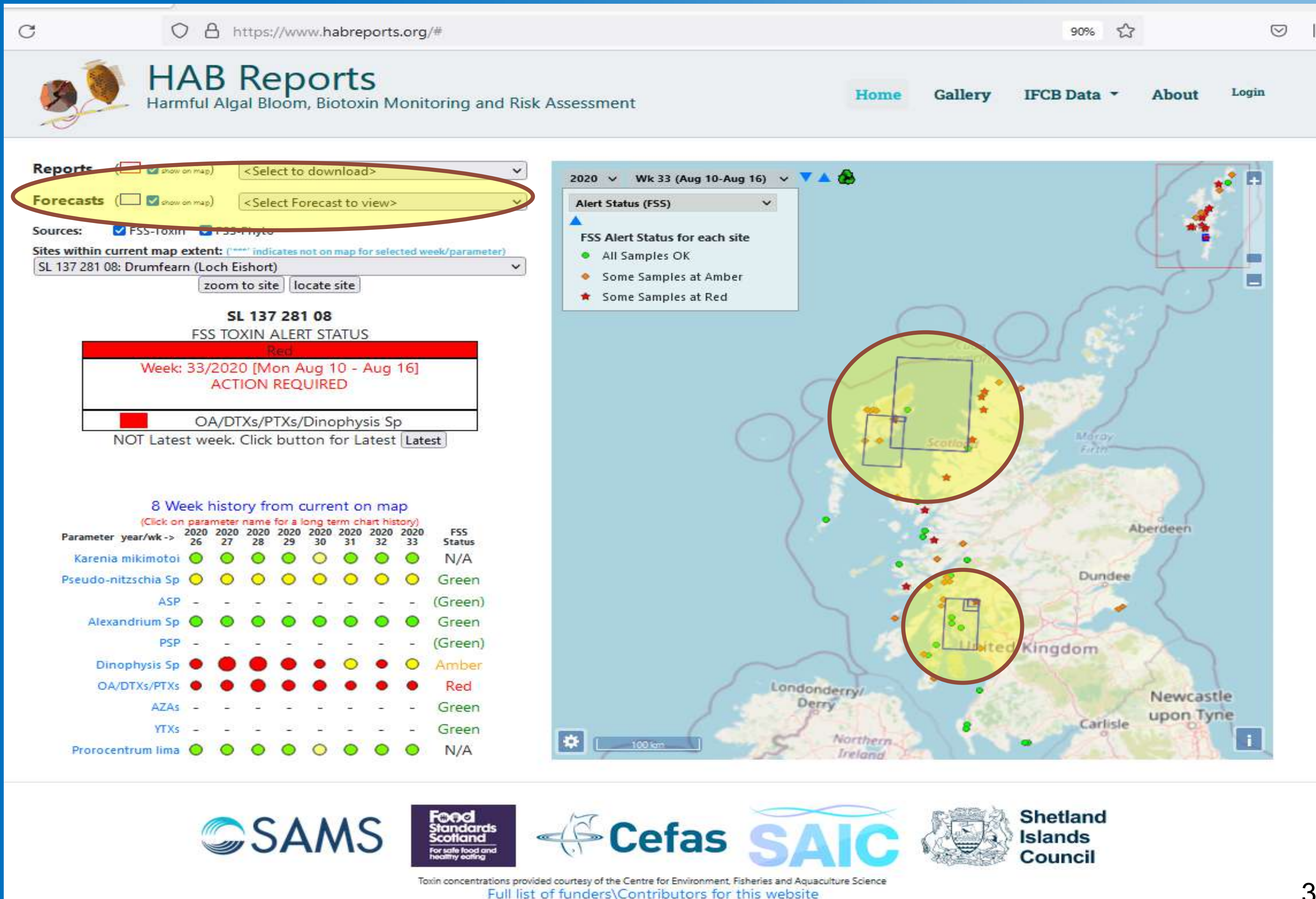






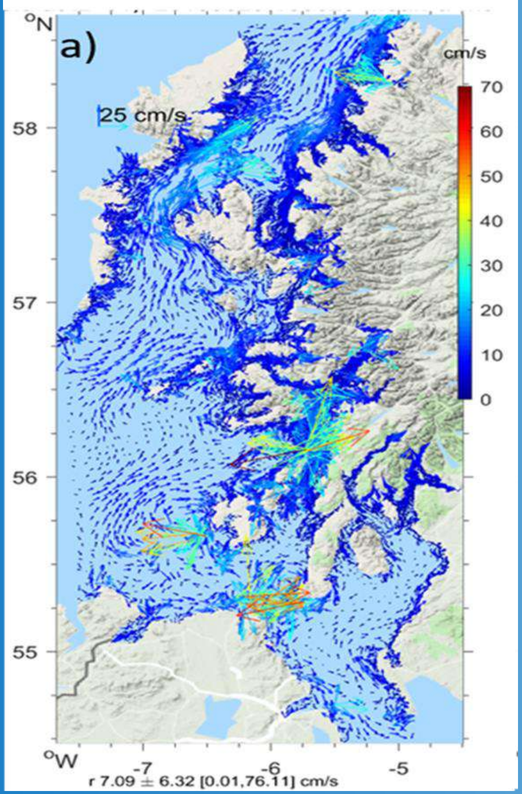


www.HABreports.org



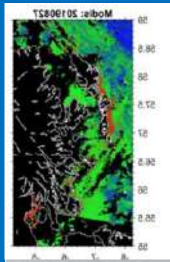
The model “WESTCOMS” developed at SAMS is a finite volume community ocean model (FVCOM) unstructured grid, hydrostatic model.

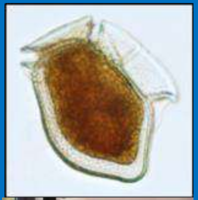
Modelled parameters include surface elevation, temperature, salinity, velocity and turbulence intensity.

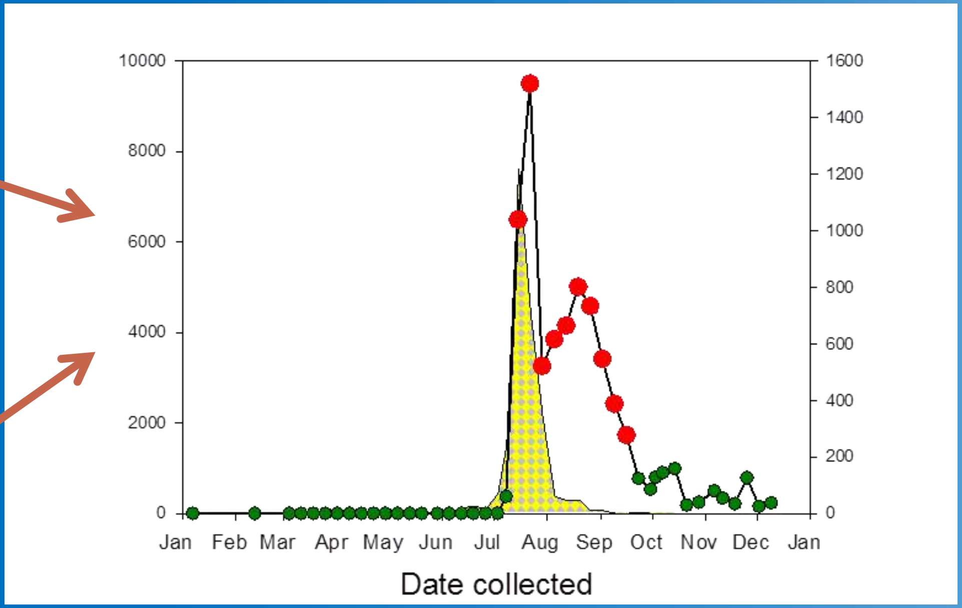


Aleynik et al. (2016)
Harmful Algae 53:102-117

Integrating model alerts into HABreport.org

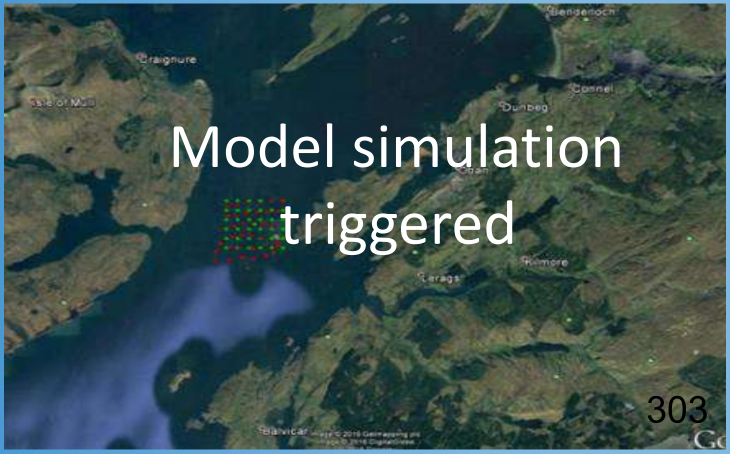




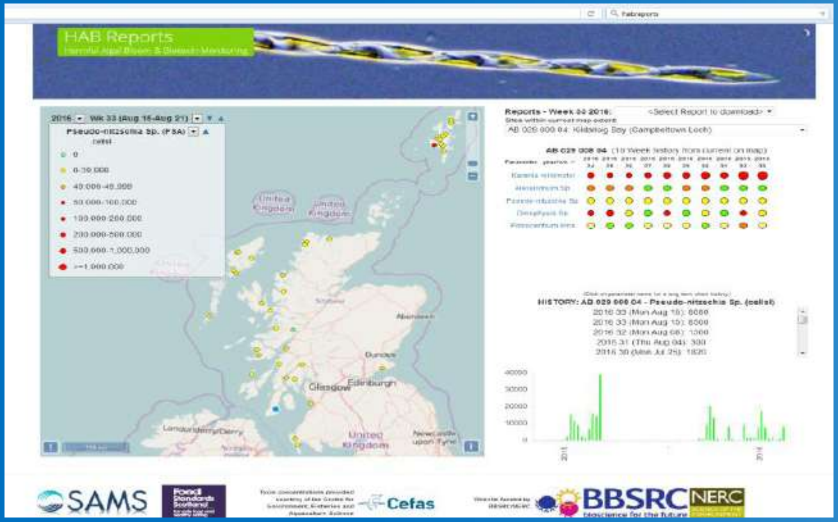


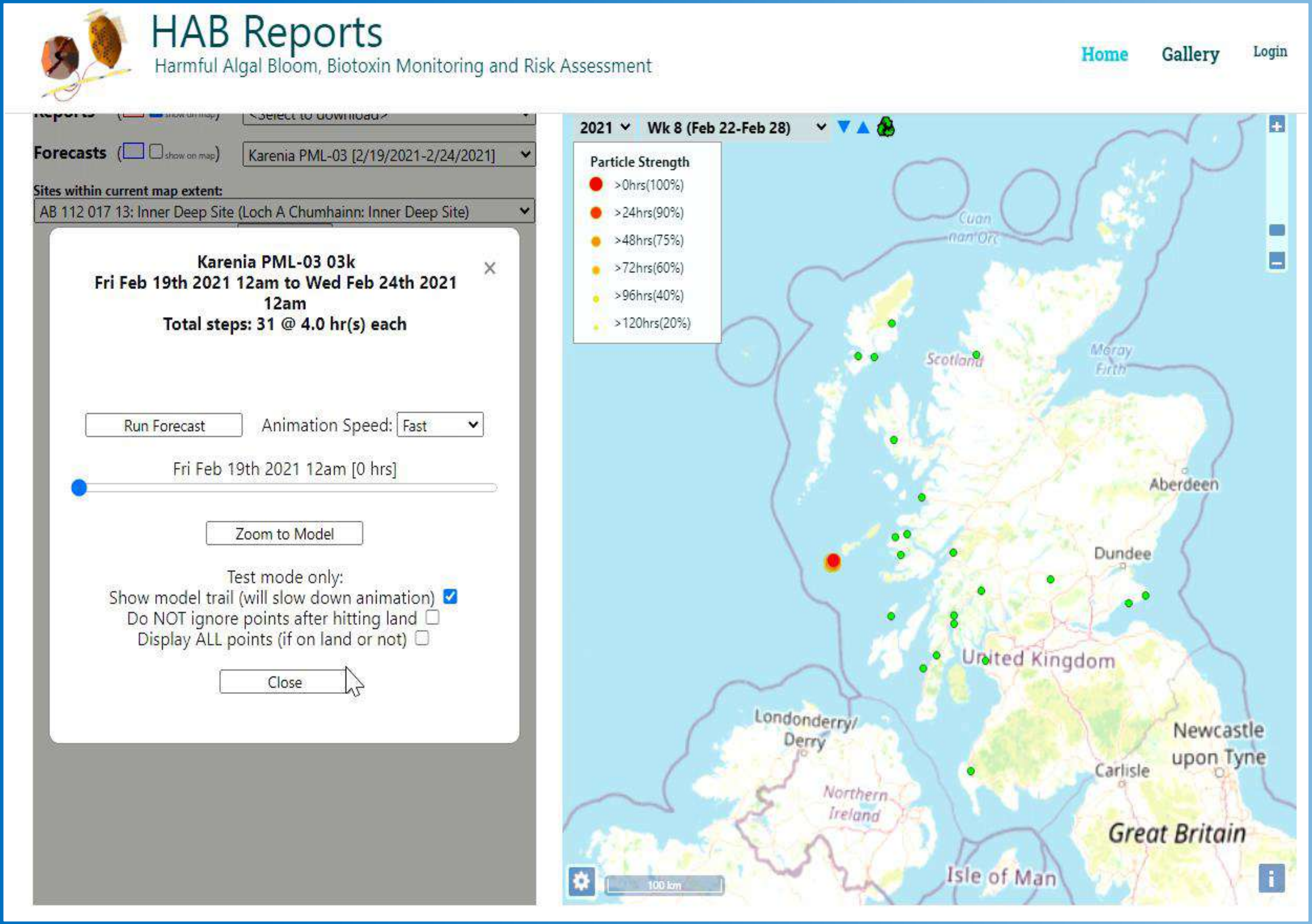
HAB alert

Location, date, species, density



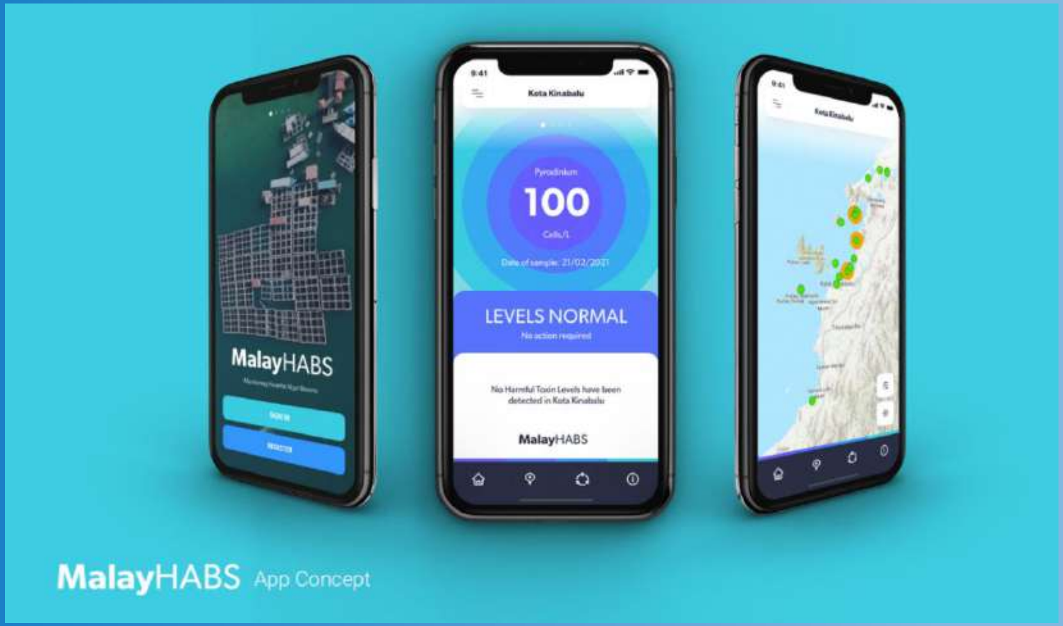
Model simulation triggered





Colours change and size of points diminish with time

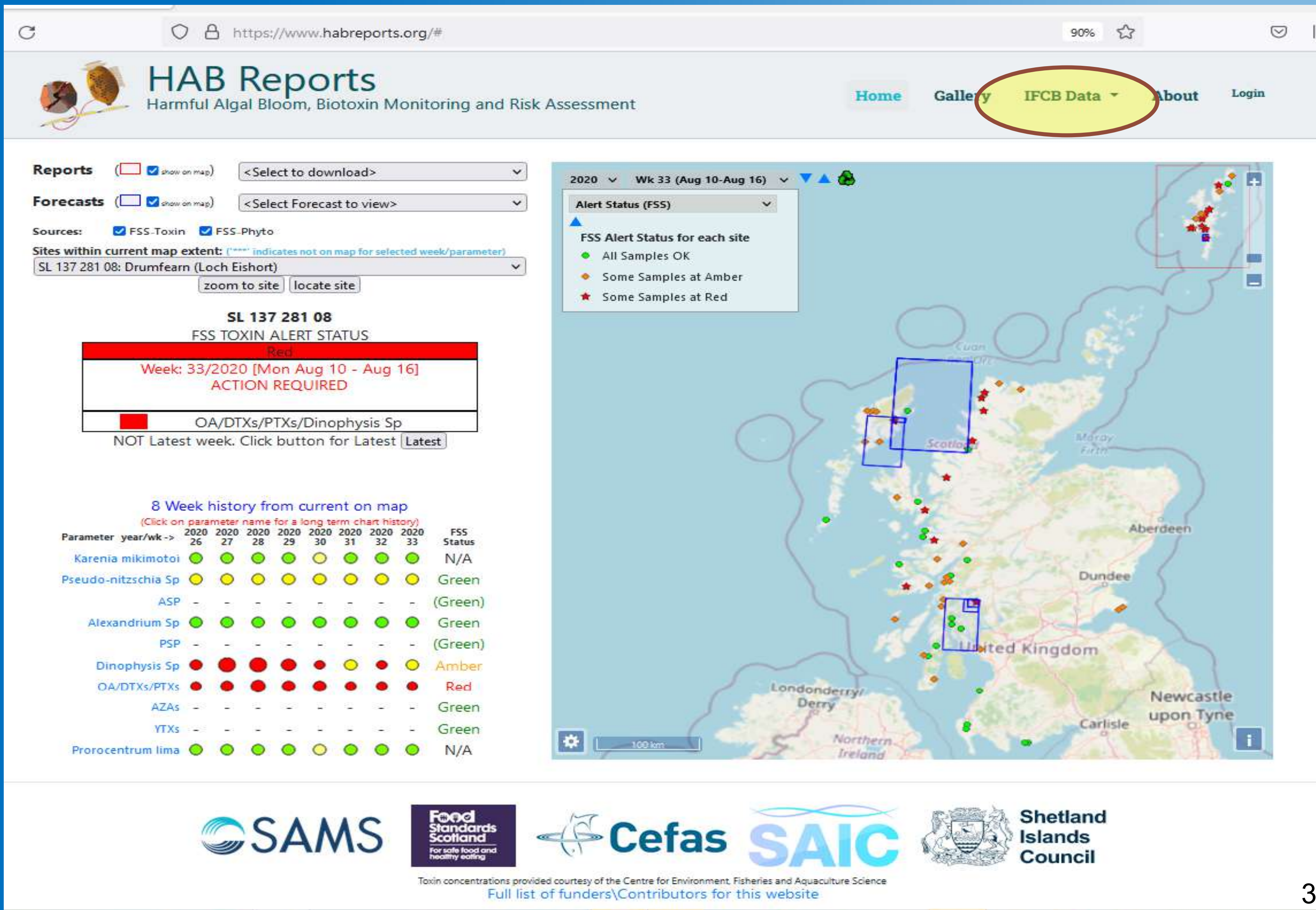
Work under way - Mobile Phone App



SAMS

UNIVERSITI MALAYA

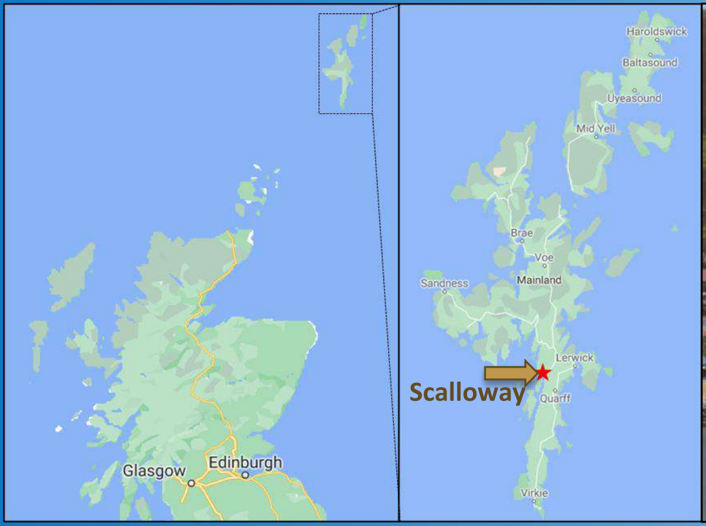
www.HABreports.org

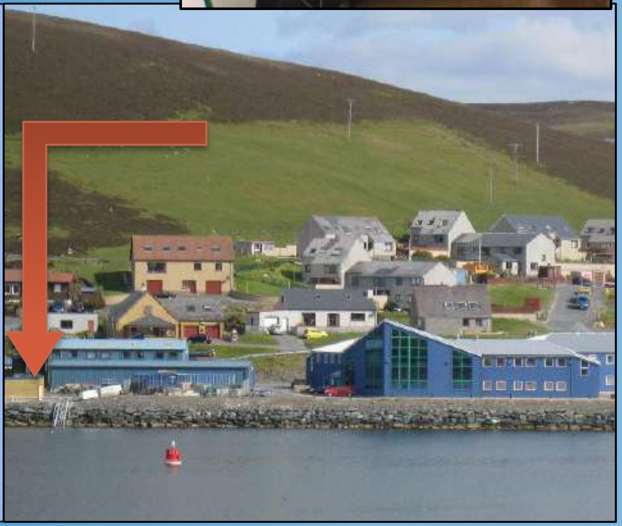


First Imaging FlowCytoBot (IFCB) in UK

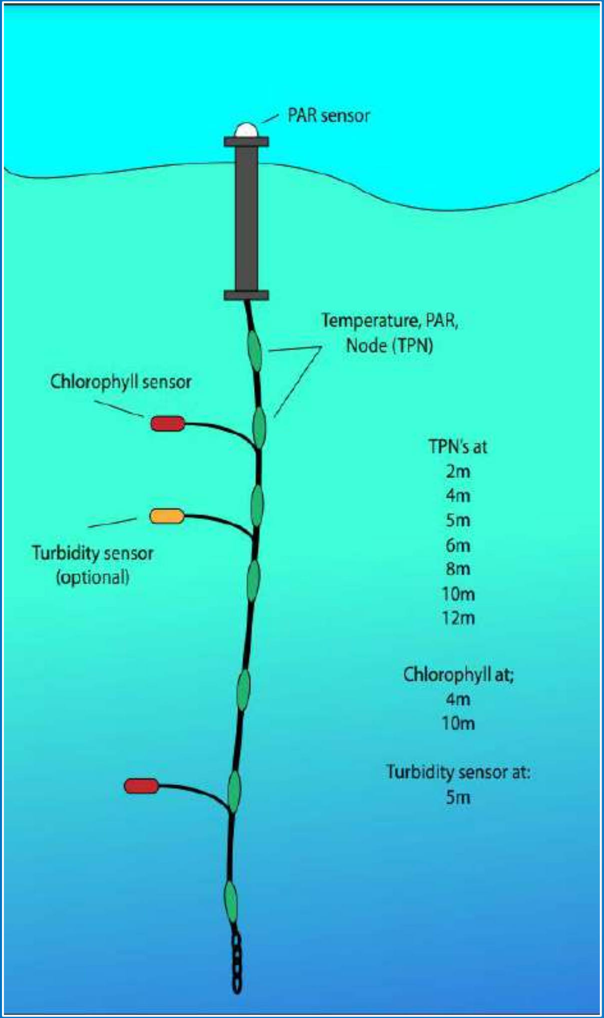
- 2 samples per hours (5ml)
- 10 to 150µm particles

- Scalloway – Shetland
- Land based – along peristaltic pump

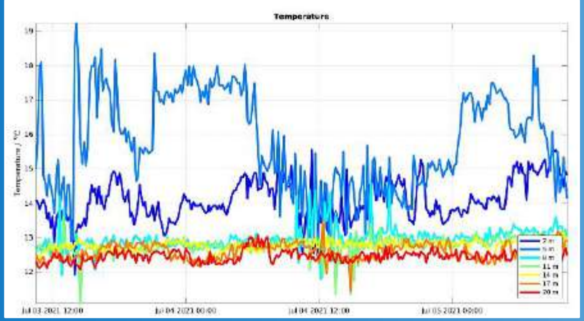




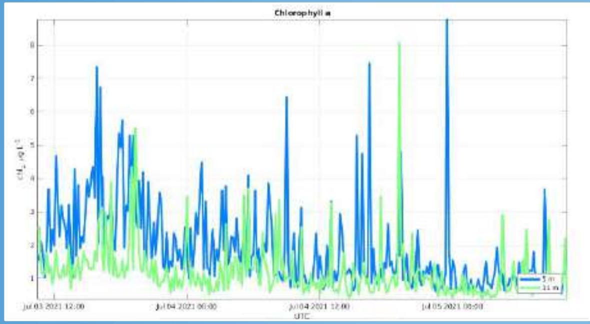
THE DATA LAB value from data
Scottish Government Riaghaltas na h-Alba gov.scot marine scotland
SAMS
University of the Highlands and Islands Oilthigh na Gàidhealtachd agus nan Eilean



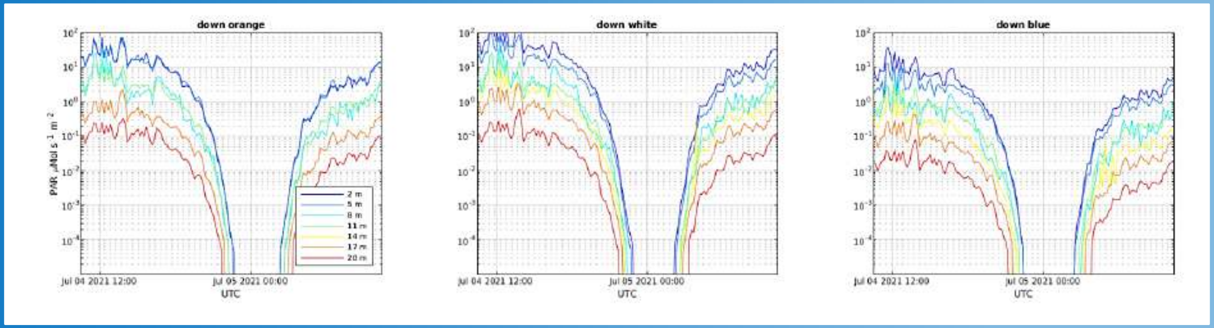
OptiCAL sensor chains relaying real-time Temperature, Chlorophyll a and PAR at 6 different depths



Temperature



Chlorophyll a



PAR

frontiers in Marine Science

ORIGINAL RESEARCH
published: 09 April 2021
doi: 10.3389/fmars.2021.631732

HABreports: Online Early Warning of Harmful Algal and Biotoxin Risk for the Scottish Shellfish and Finfish Aquaculture Industries

Keith Davidson[1*], *Callum Whyte*[1], *Dmitry Aleynik*[1], *Andrew Dale*[1], *Steven Gontarek*[1], *Andrey A. Kurekin*[2], *Sharon McNeill*[1], *Peter I. Miller*[2], *Marie Porter*[1], *Rachel Saxon*[1] and *Sarah Swan*[1]

[1] *Scottish Association for Marine Science, Oban, United Kingdom,* [2] *Plymouth Marine Laboratory, Plymouth, United Kingdom*

OPEN ACCESS

We present an on-line early warning system that is operational in Scottish coastal waters to minimize the risk to humans and aquaculture businesses in terms of the human health

Discussion point: cost/benefit to high frequency sampling
Within early warning systems

“HABs and Early Warning System in Chile”

Alejandro Clément aclement@plancton.cl
Roberta Crescini, Carlos Flores y Marcela Cárdenas, Castro
Carmen Gloria Brito, Coyhaique
Francisca Muñoz, Nicole Correa, Stefi Saez, Carmen Tellez, Barbara Ramirez, Gustavo Contreras, Osvaldo Egenau, Alvaro Jorquera, Pablo Riquelme& Andrea Colifef, Puerto Varas-Chile.
Martin Contreras, Puerto Montt

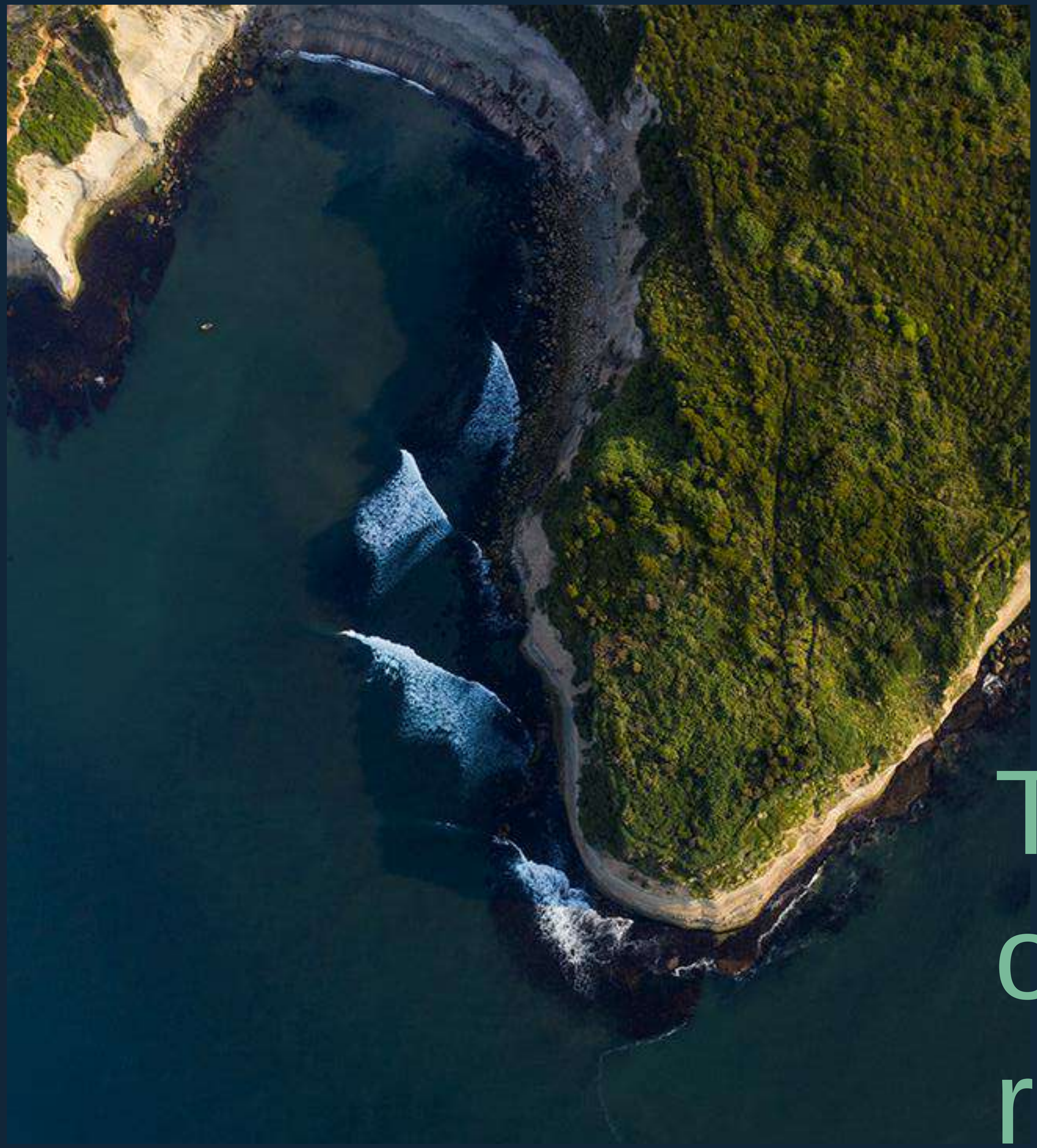
23-feb-2022

POAS

Proyecto apoyado por CORFO
Gobierno de Chile

www.plancton.cl


British Embassy Kuwait
KISR
Kuwait Institute for Scientific Research
UNIVERSITY OF EXETER
Cefas
SUSTAINABLE AQUACULTURE FUTURES
GlobalHAB
IOC-SCOR
Virtual workshop for developing an early warning system for Harmful Algal Blooms (HABs) in the Arabian Gulf
https://www.exeter.ac.uk/research/saf/projects/projects/
February 2022
FOCUS:
1. Global and regional HAB trends
2. Drivers and impacts of HABs on fisheries and aquaculture
3. HAB early warning systems
Virtual Arabian Gulf HABs workshop,
22 and 23 February 2022.



General Objective:

To share the southern Chile experience of our group on HABs monitoring, research and progress in Early Warning System, with focus on fish aquaculture.

Few examples of EWS:

Prediction and Early Warning. U.S. National Office for Harmful Algal Blooms

Great Lakes Early Warning system https://glos.org/priorities/projects/habs/

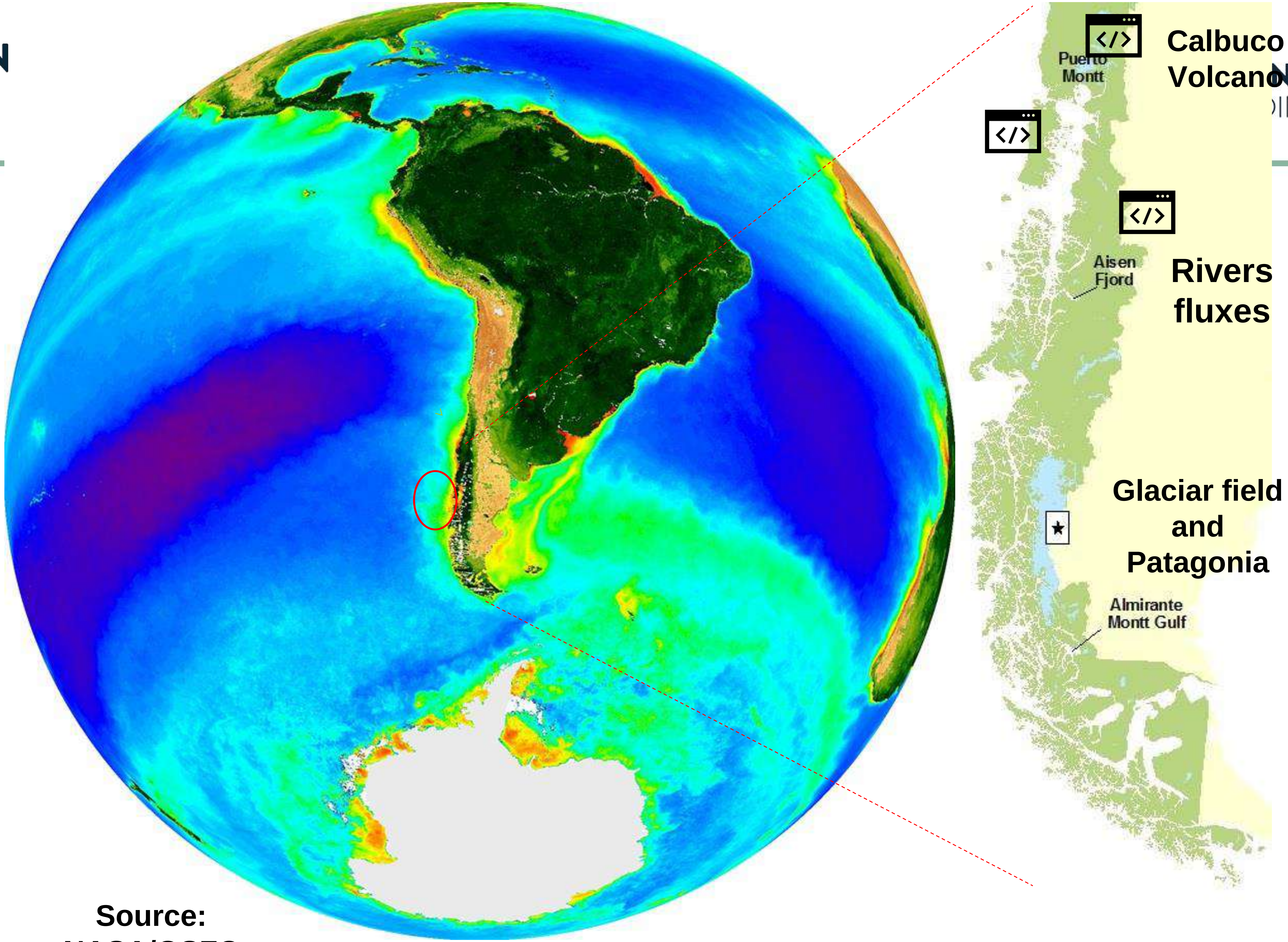
Online Early Warning of Harmful Algal and Biotoxin Risk for the Scottish Shellfish and Finfish Aquaculture Industries. Davidson K et al 202. https://www.frontiersin.org/article/10.3389/fmars.2021.631732

Researchers Use Genes as HAB Early Warning System

C.H. McKenzie, et al In prep. High biomass bloom and fish kills and other impacts.

Devred, E., et al 2018. Development of a conceptual warning system for toxic levels of *A. fundyense* in the Bay of Fundy based on remote sensing data. https://doi.org/10.1016/j.rse.2018.04.022

PLANCTON ANDINO



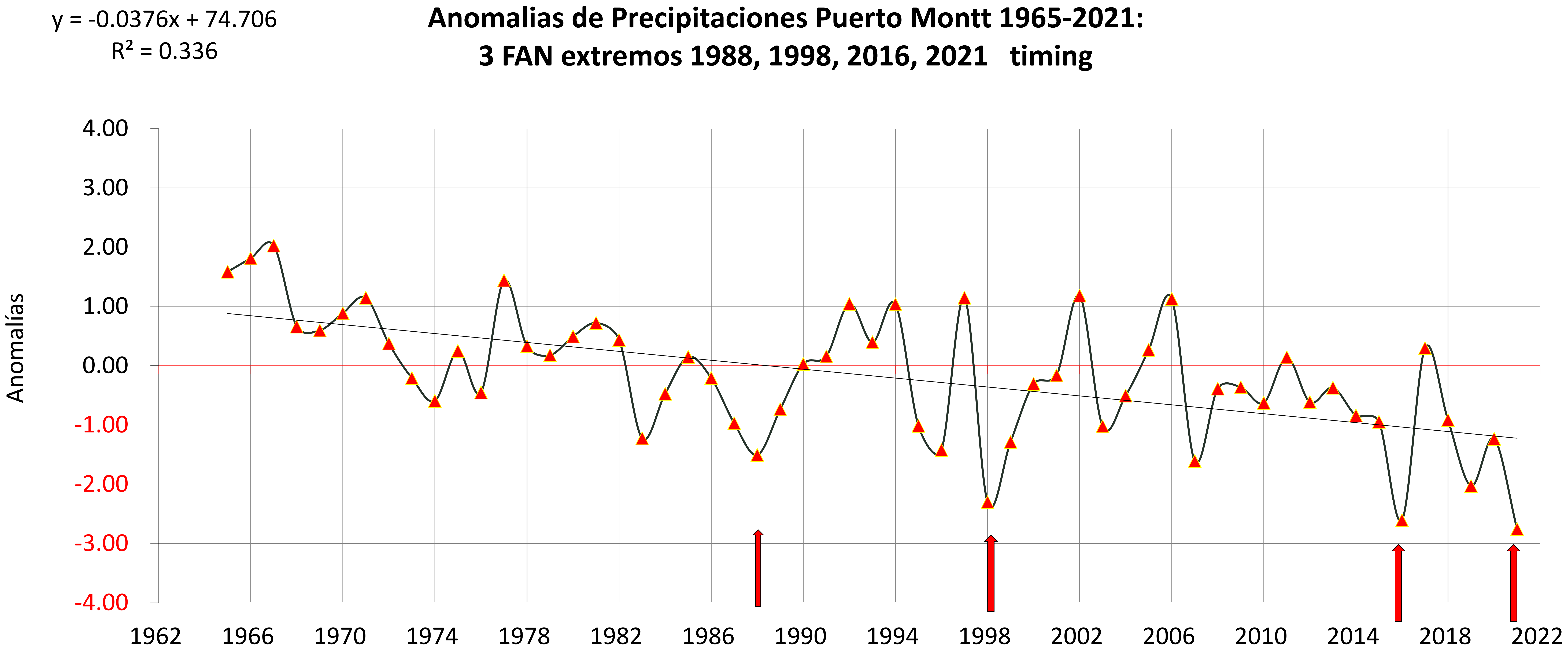
Source: NASA/GSFC

Introduction and Progress of EWS

PLANCTON ANDINO

1) Intense monitoring on space (x , y & z) and time (t). See POAS, PSMB IFOP, Health service.
2) Molecular biology and Ecophysiology of HABs & Bio-optics, Photosynthesis of PSII . FRRf3
3) Development of an Algorithm of algal bloom for fish aquaculture, called the HABf INDEX (Clément et al 2020)
   Table of Critical values
   Modelling and forecast the HABf INDEX using data analytic, and Machine Learning see Link in YouTube
4) App on-line and automatic text or email message. See description in link in Youtube
5) Improving server, SQL & Python codes, API, BI capabilities and data analytic
6) Developing the Bio-Optical Aqua Sensors (BAS) connect to the app
7) Biogeochemical and nutrients on-line indicators. Future work.
8) Remote Sensing, Limitation in Optically-Complex Waters see link (Clément et al 2019)
9) Climatic anomalies analysis.
10) Final Remark

Precipitation Anomalies at Puerto Montt. 1965-2022 see extreme cases and HABs occurrence



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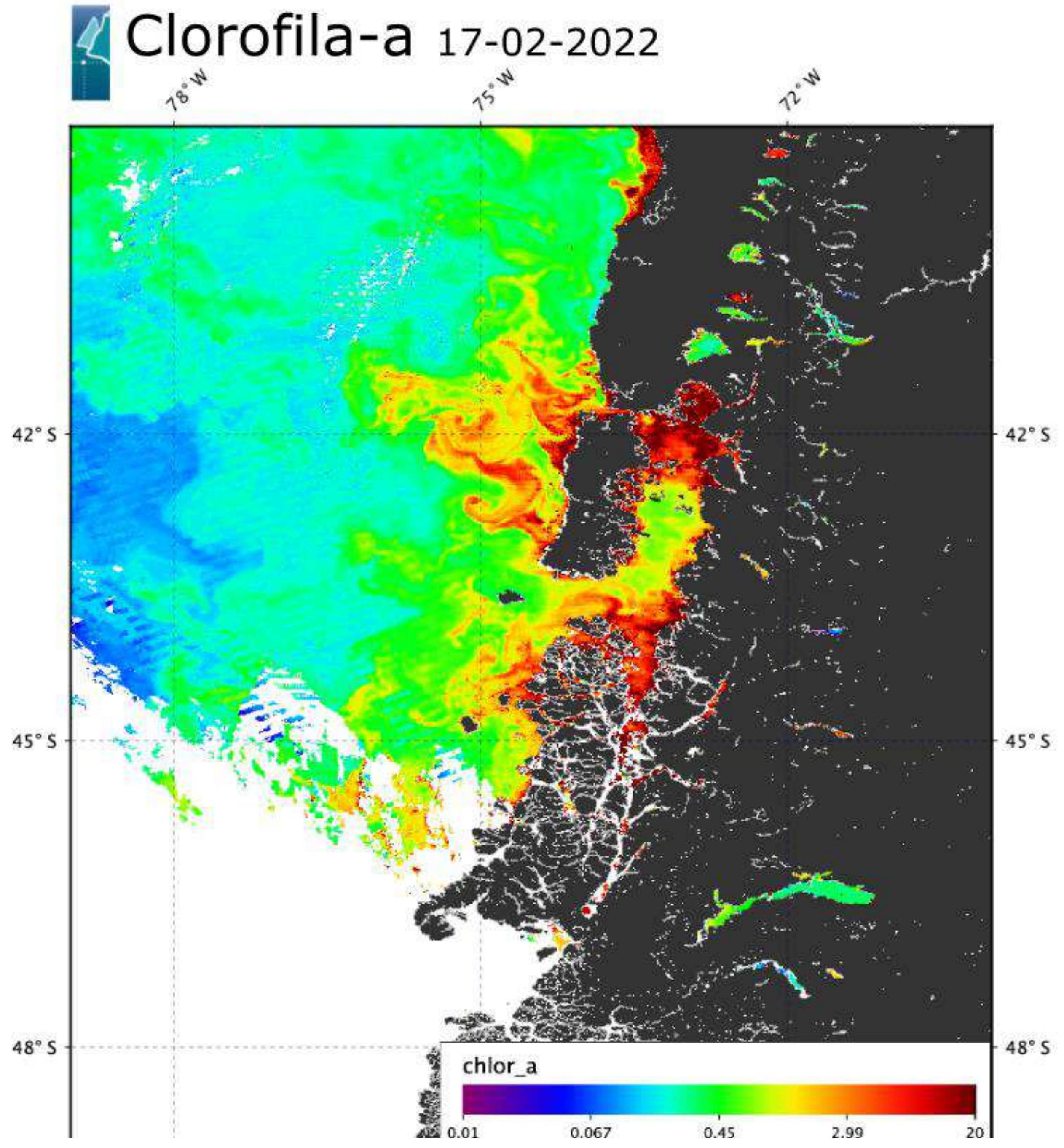
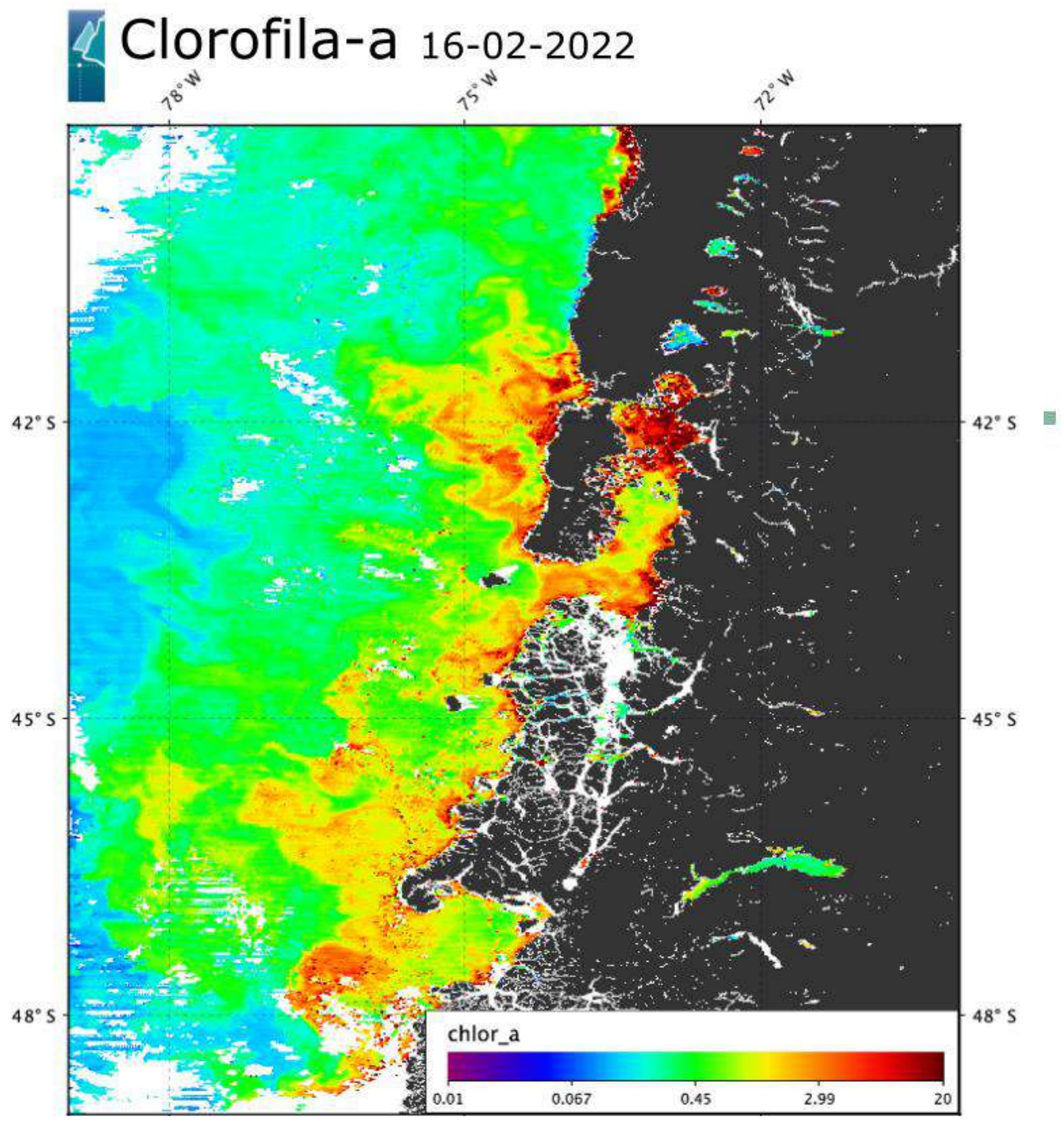
Remote Sensing and Ocean Color

Satellites images from NASA.

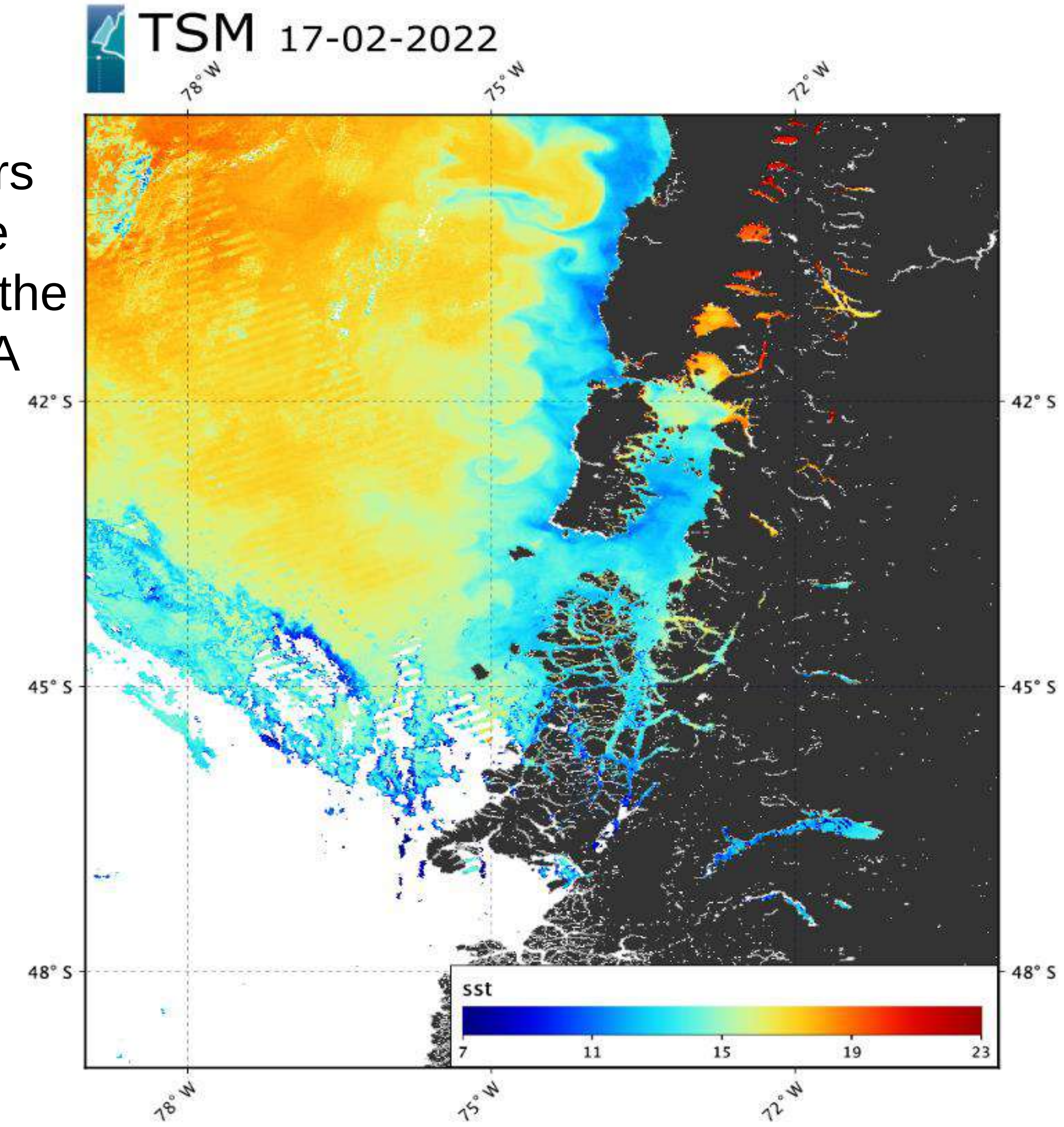
Chlor a (mg/m3): High biomass in the north and south of the inland sea. Reloncavi Sound, Ancud Gulf & Canal Moraleda.

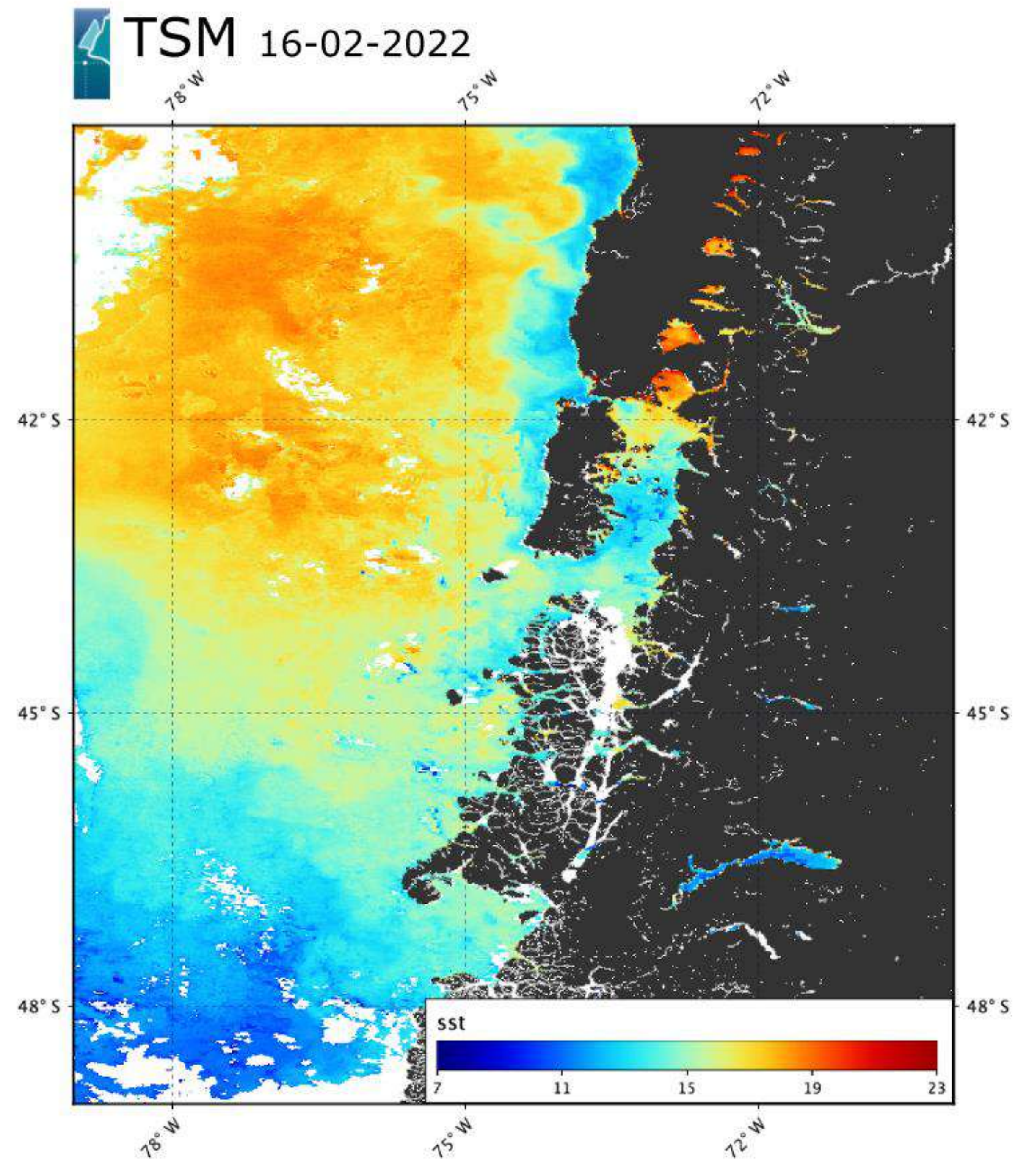
Sea Surface Temperature SST °C: Oceanic colder waters in the eastern boundary coast due to upwelling.



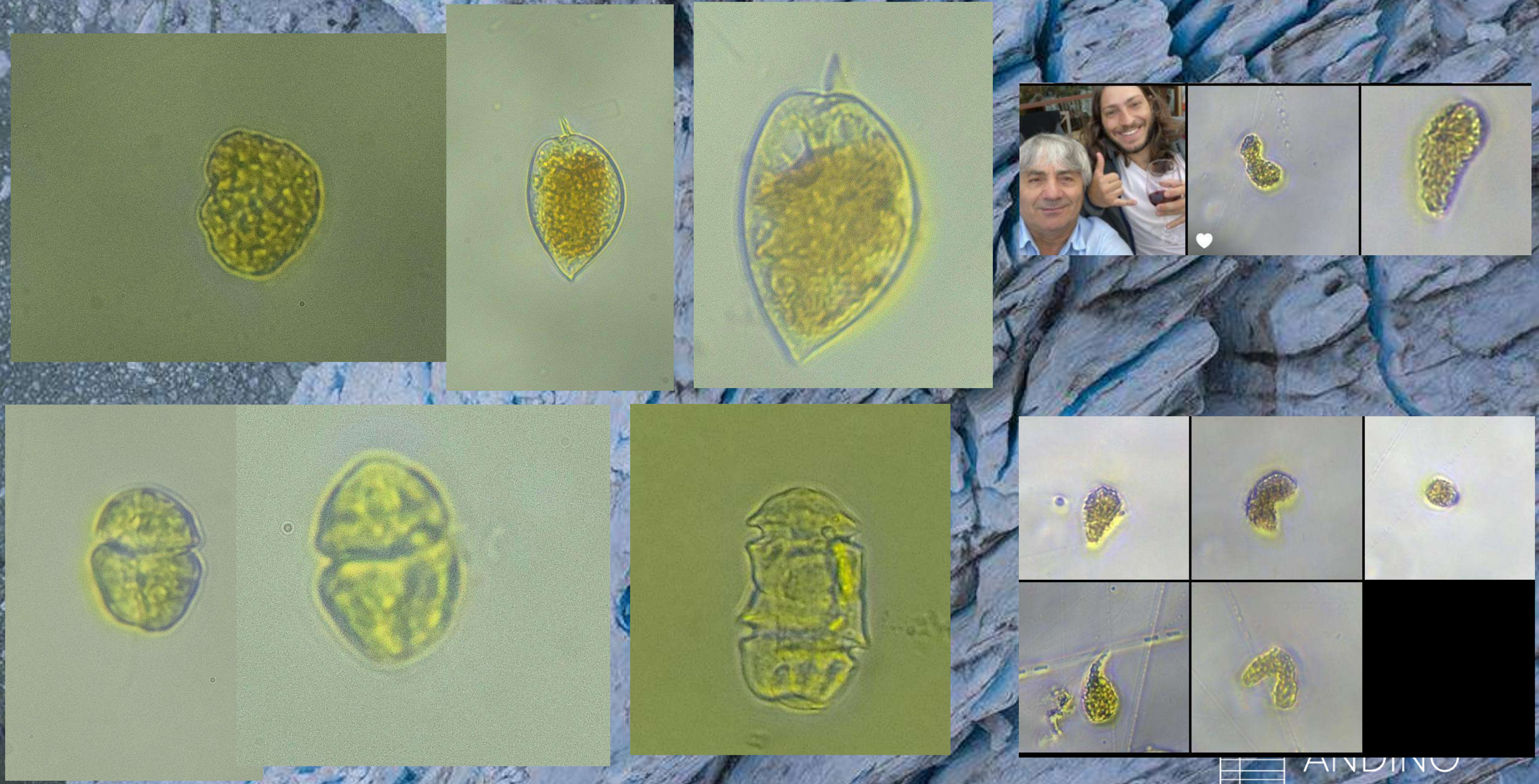


Satellite images obtained with the MODIS and VIIRS sensors (Moderate Resolution Imaging Spectroradiometer & Visible Infrared Imaging Radiometer Suite respectively) mounted on the Aqua, Terra, Suomi-NPP & NOAA-20 satellites of the NASA Ocean Color project.

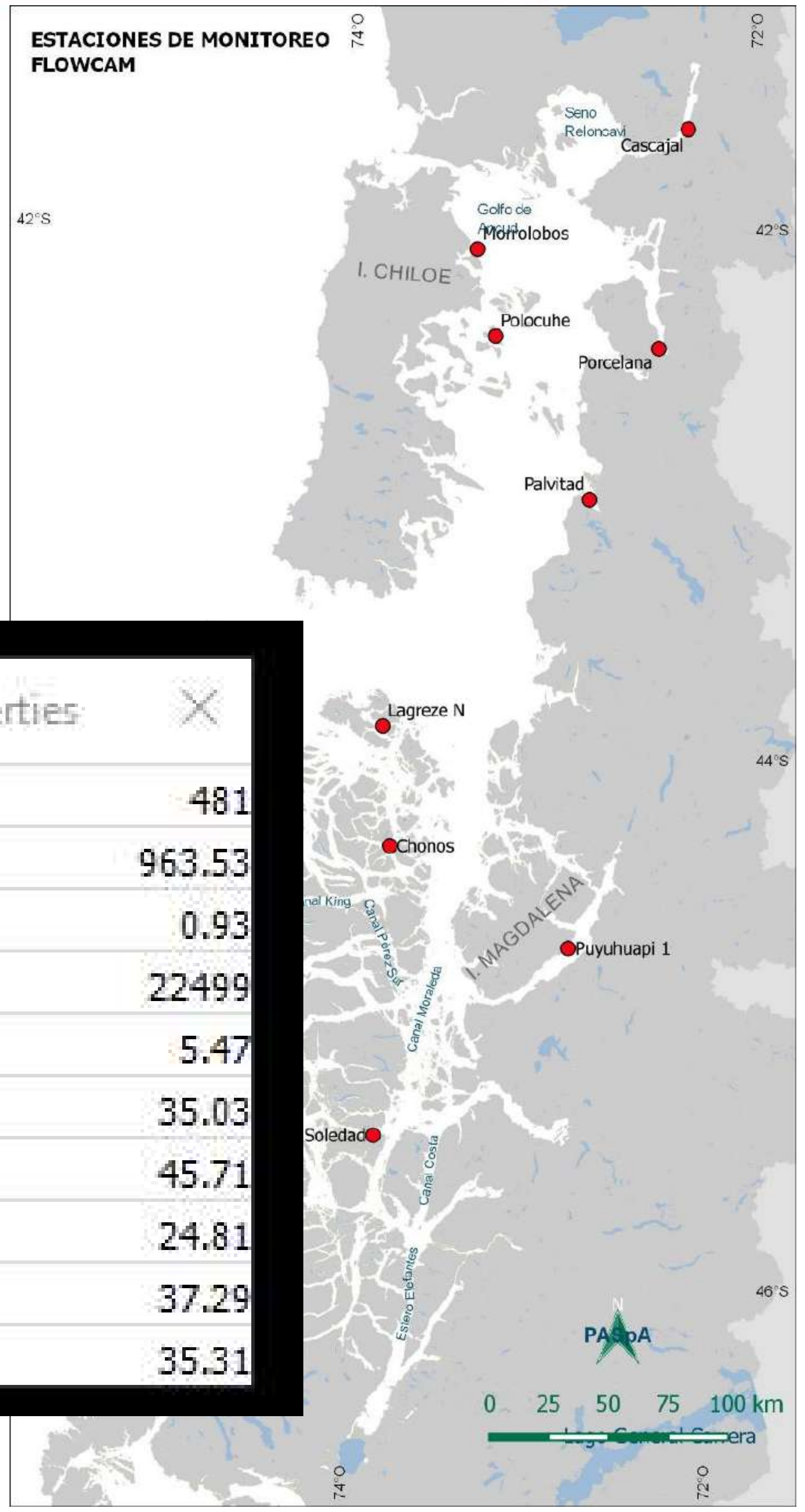




https://oceancolor.gsfc.nasa.gov/



Characterization and digital libraries of dinoflagellates cells using FlowCam from Chilean fjords



HAB$_f$ INDEX FOR RISK ANALYSIS

#icha2018
Nantes France

HAB$_f$ INDEX as indicator of RISK

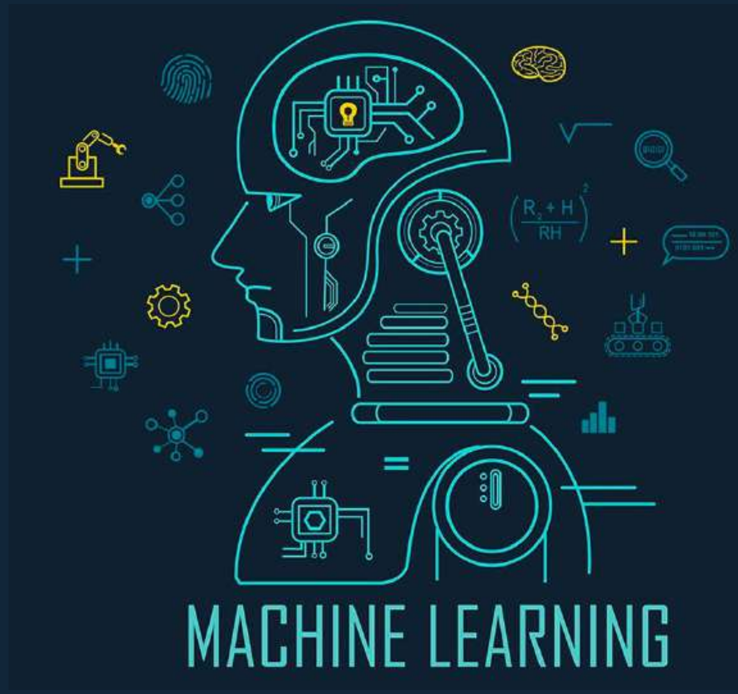
FAN*f* INDEX = [FITO]Harmful + [FITO]Total

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

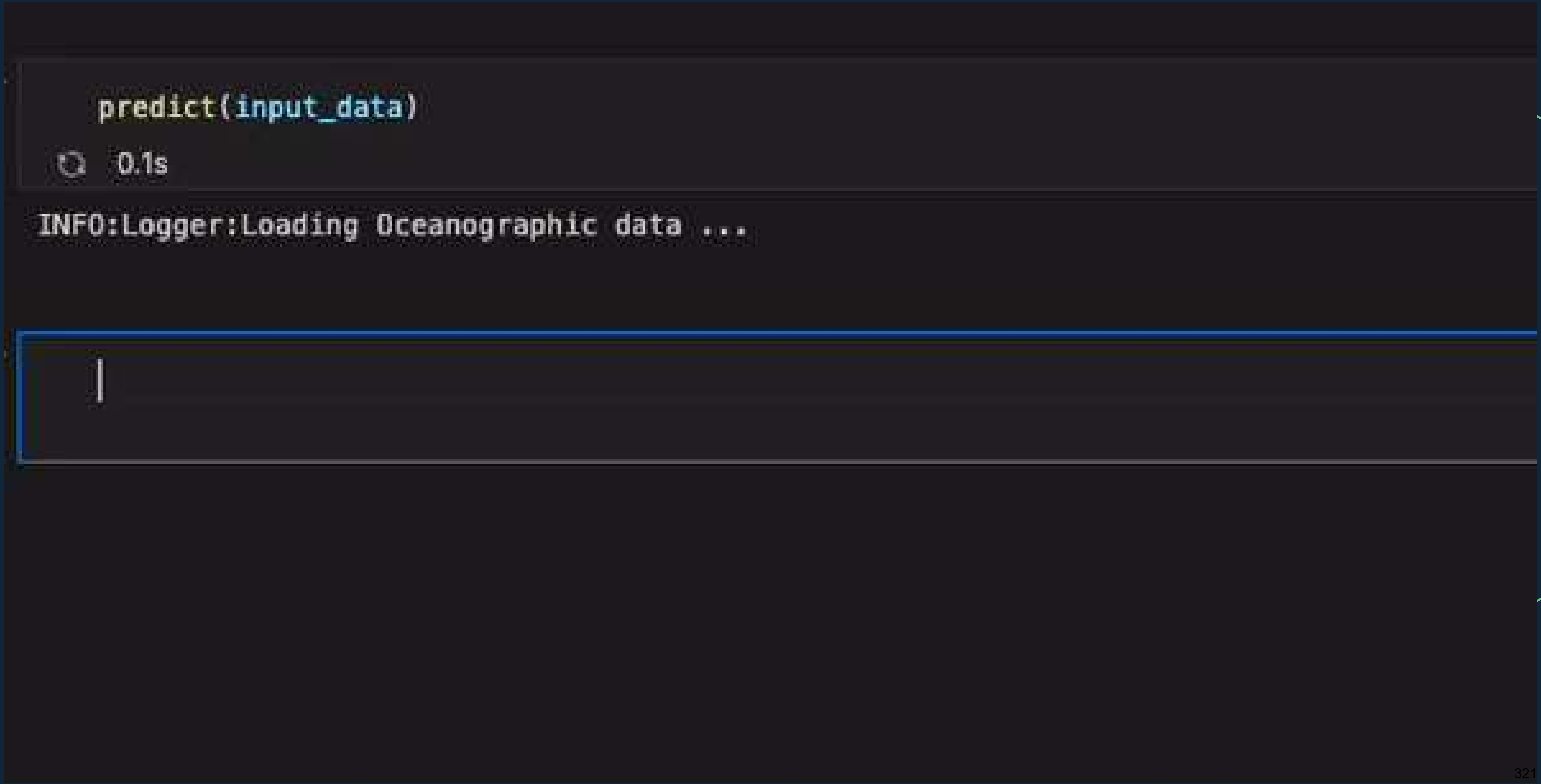
$$[Fito]_{Harmful} = \sum_i^N \left((2+0,5\cdot\lambda_i)\cdot\frac{\overline{\overline{C}}_i^{\,0,75}}{Cx_i^{\,0,6}}\cdot\alpha_i\cdot t \right)$$

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

HAB$_f$ INDEX MEETS MACHINE LEARNING AND FORECAST



> 90% of the project onsists of analytics and data transformation. Once transformed, it is iterated in Machine Learning algorithms, tested and finally implemented.



HAB$_f$ INDEX Rank for Early Warning

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Rango del FAN ÍNDEX y Alerta Temprana V1

CÓDIGO	COLOR	RANGO	RIESGO
1	VERDE	0,00 - 1,00	NULO
2	AMARILLO	1,01 - 3,00	LEVE
3	NARANJO	3,01 - 25,00	MEDIO ALTO
4	ROJO	> 25,01	ALTO

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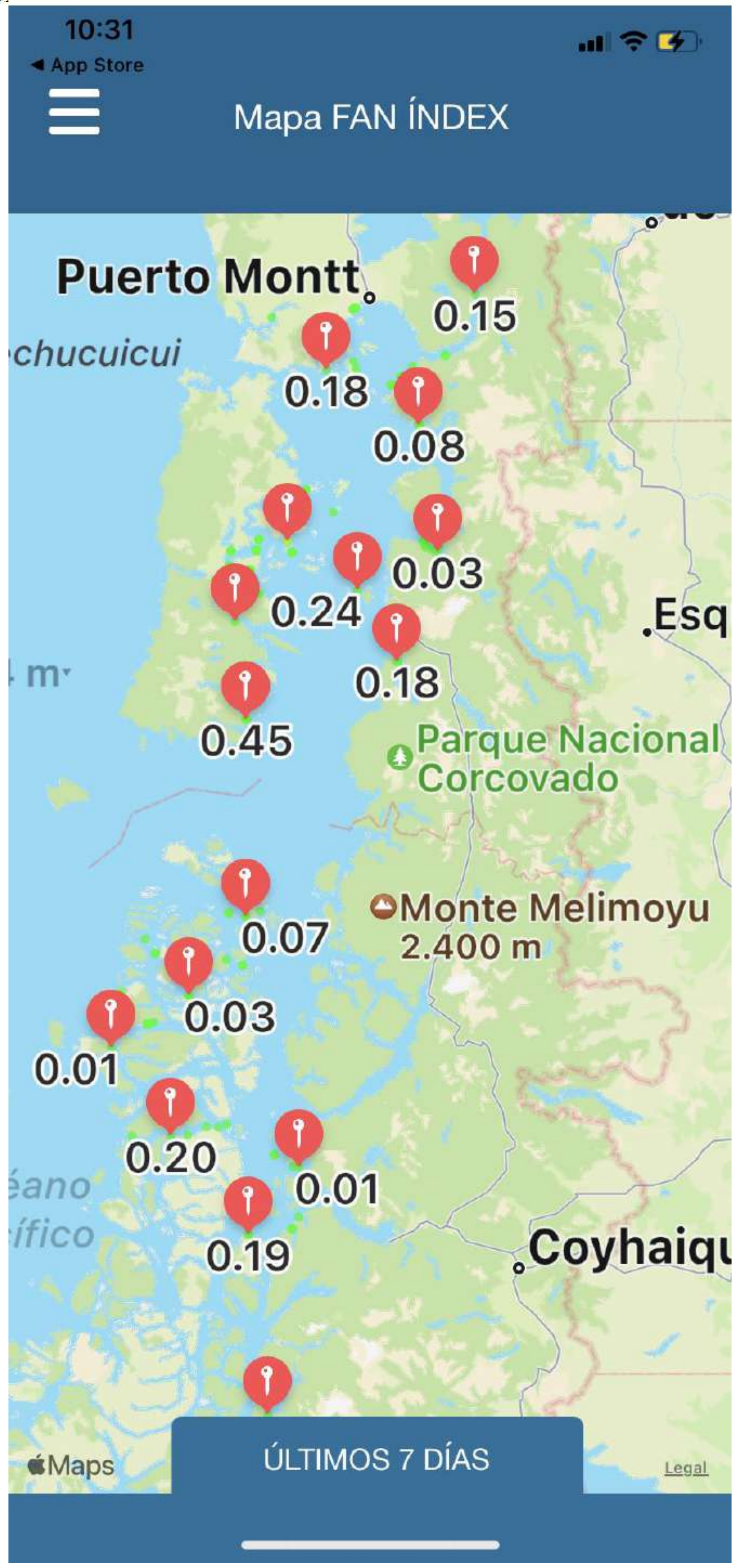
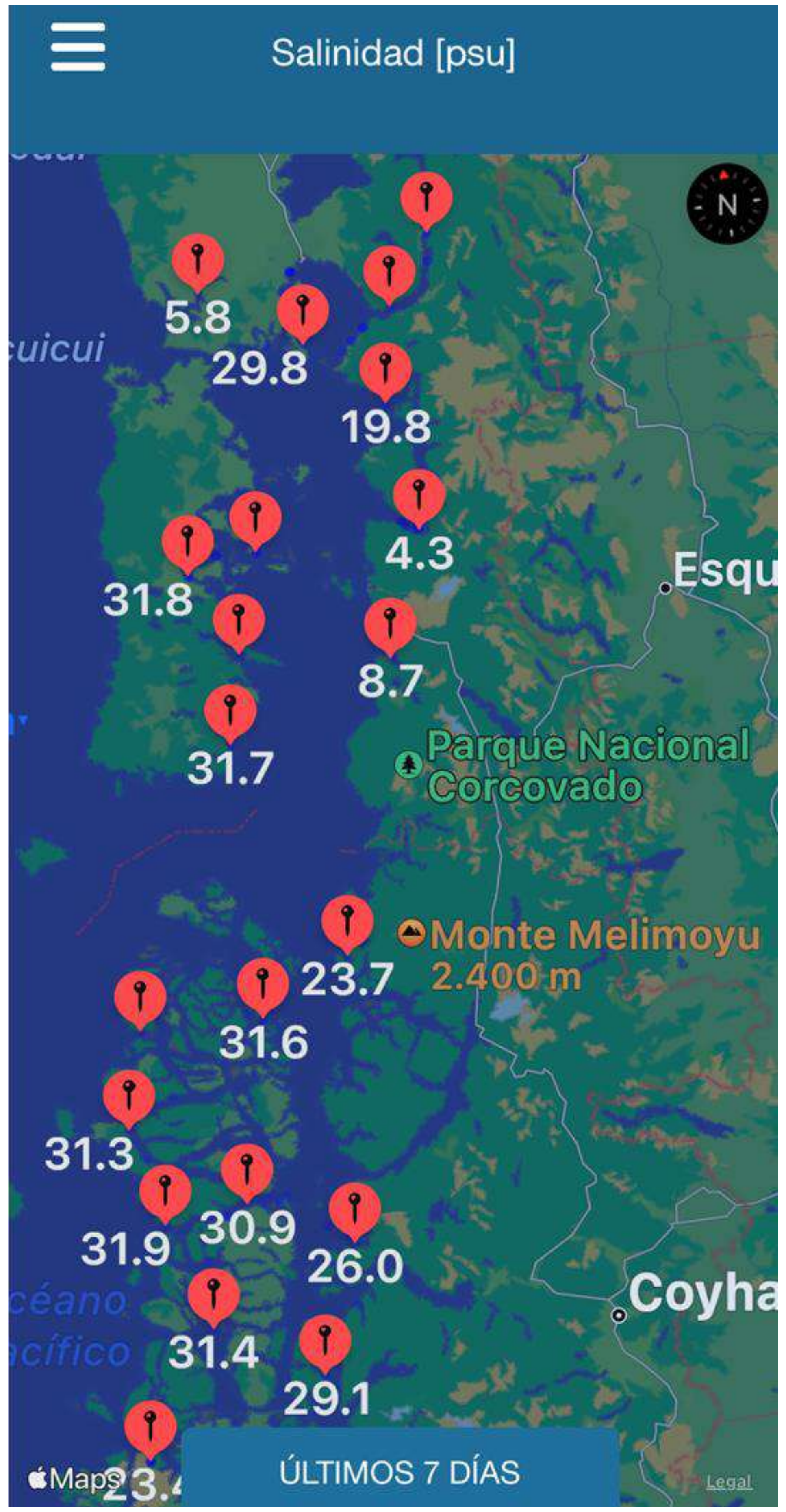
App on-line and database system with automatic text or emails as tool for an early warning message

Manual de la *APP* de Plancton Andino para usuarios PSMB y POAS.
Puerto Varas, diciembre 9, 2020

1. Ir a AppleStore para iPhone/iOS o Google Play Store, para Android del Smartphone:
   Buscar: **Plancton Andino**

Download on the App Store | DISPONIBLE EN Google Play





Ecophysiology of HABs as tool for EWS

1. Thin layer and water column distribution of cells is a key issue in stratified water columns and niches
2. Data collection and interpretation of photosynthetic parameters has been an import tool for following of algae conditions during a bloom
3. Data analytic and modelling biological parameters (in vitro growth rate, photosynthesis, apoptosis, etc.
4. Ecological parameters; competition, niche occupation, among others

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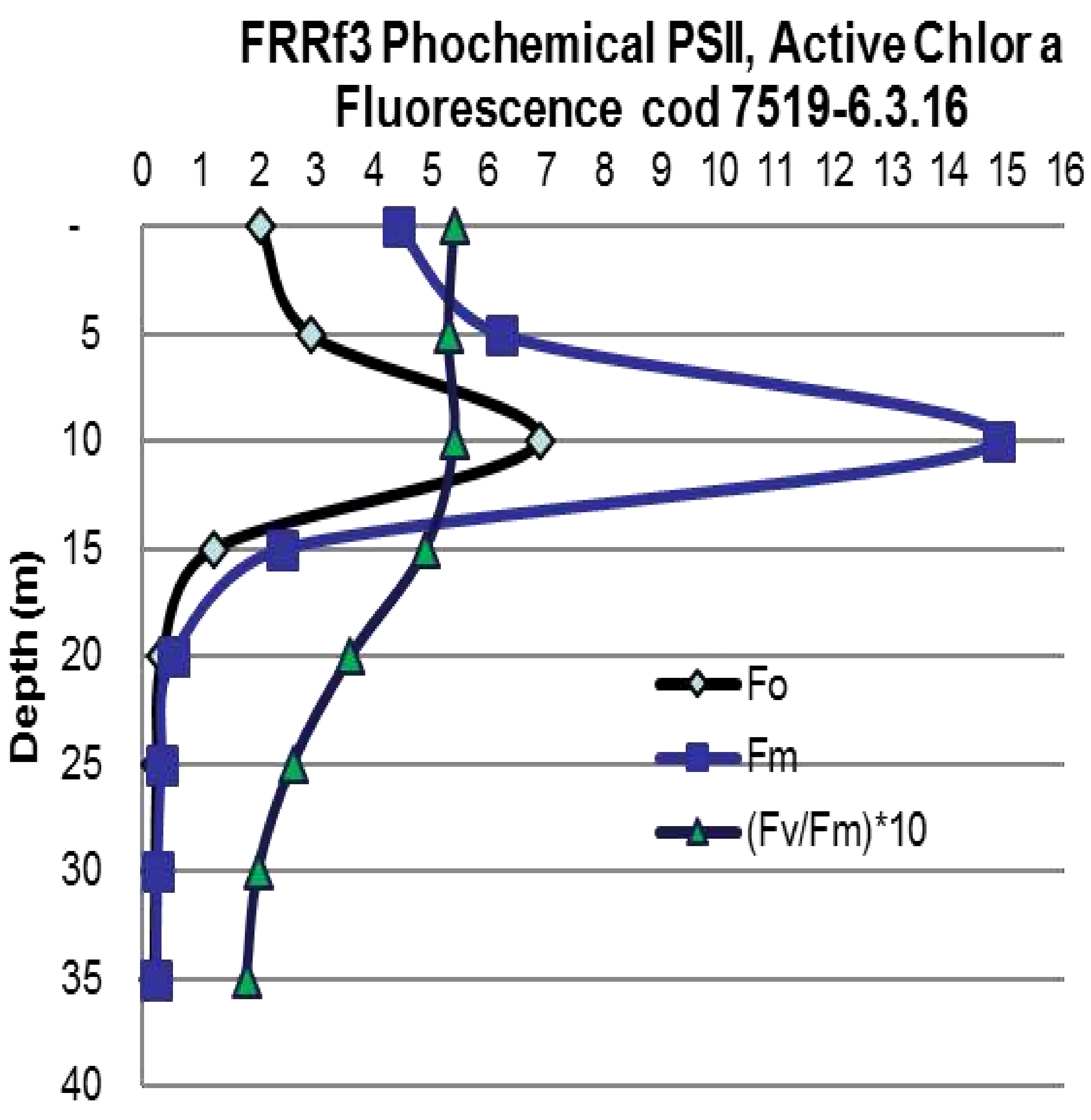
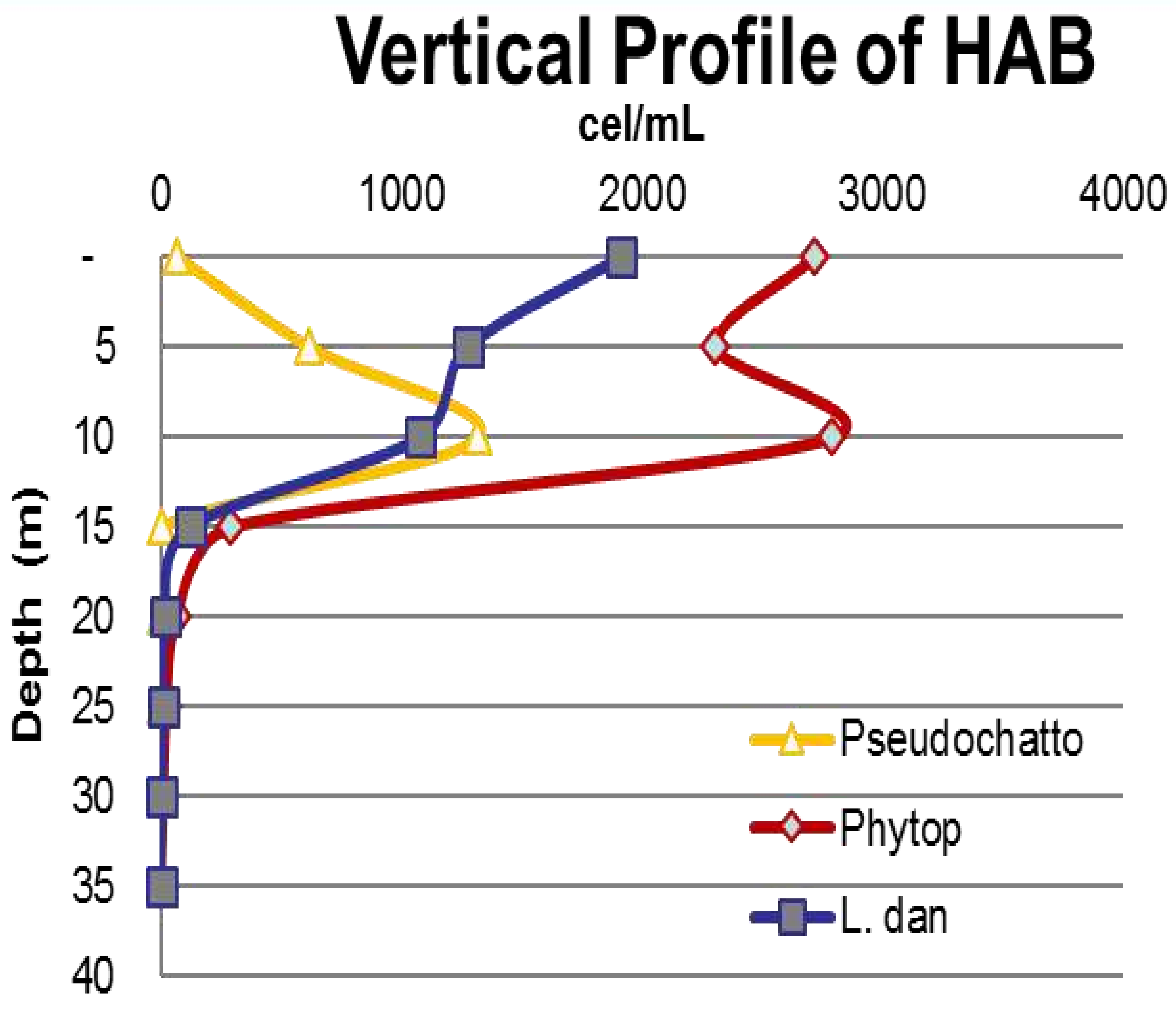
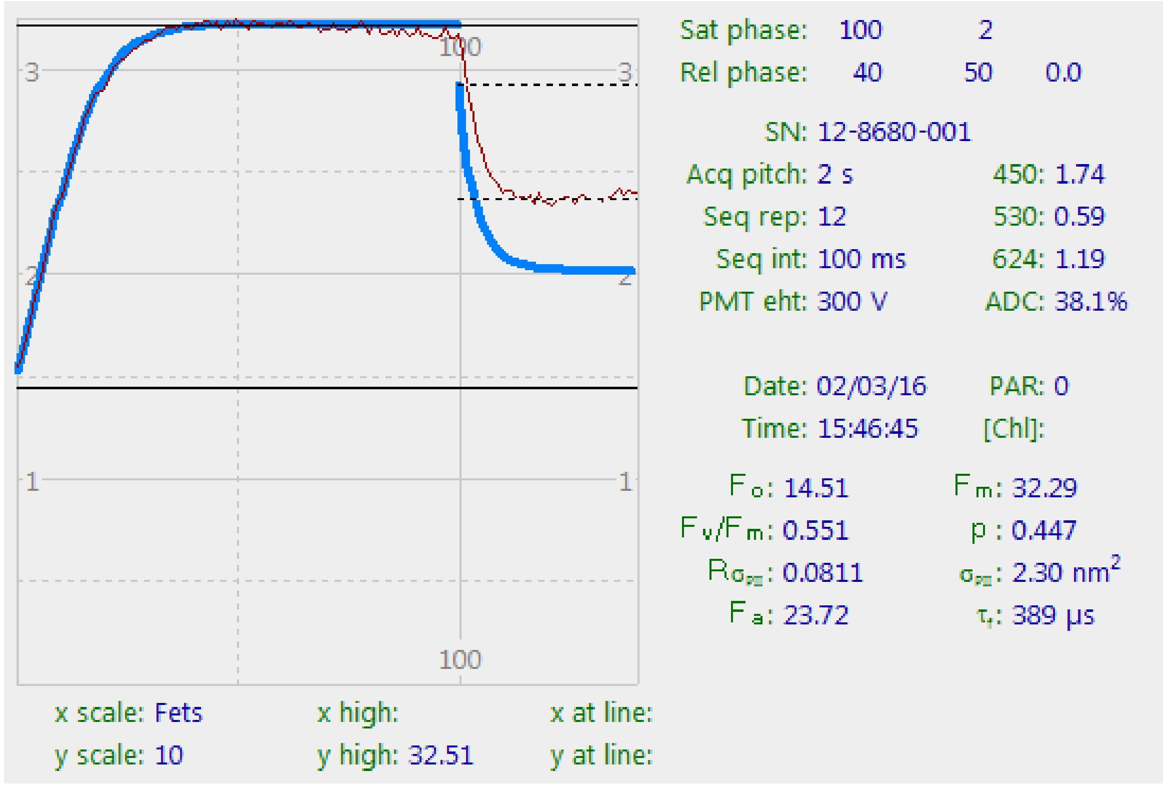
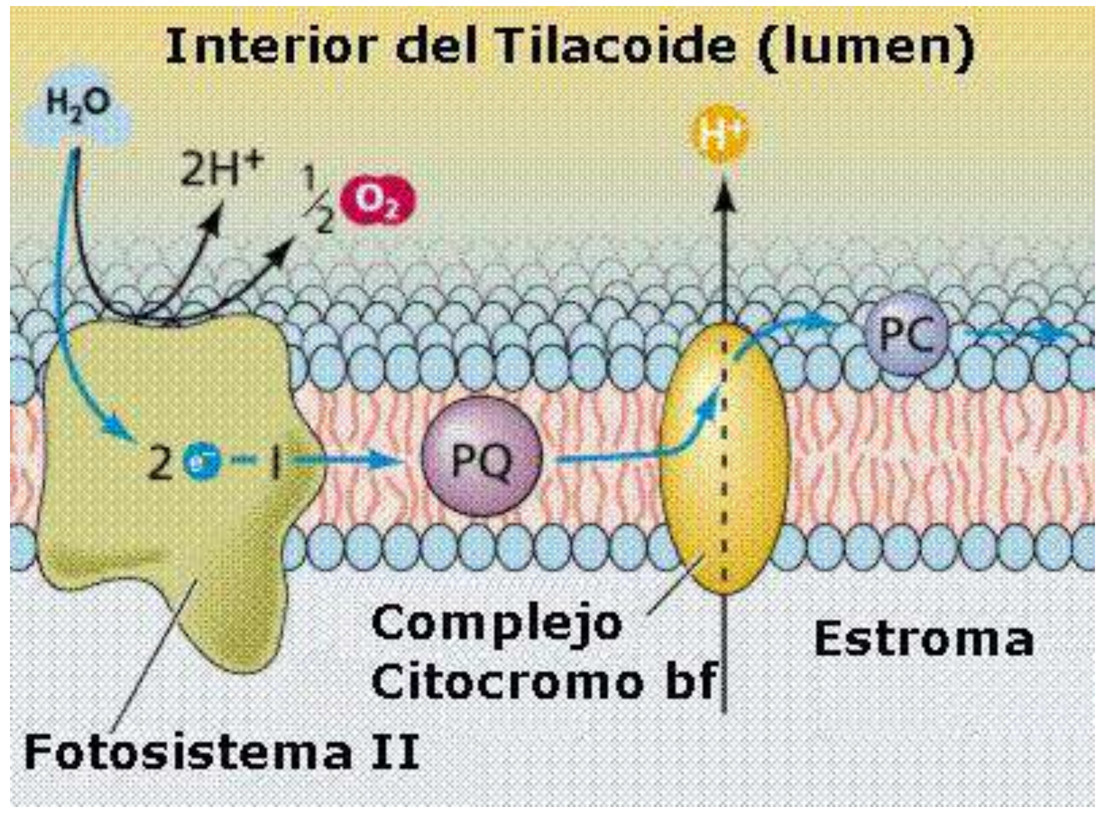
Líderes en la columna de agua

Fast Repetition Rate Fluorometry Induction Curve. Photochemical parameters (PSII) during *Pseudochattonella* HAB of 2016









Oceanographic results of a bloom of *Procentrum micans*. We apply Fluorometry (FRRf3) in vitro technology as a tool. Mouth of Reloncavi Fjord on 17.2.22. Fo and Fm are Initial and Maximum Fluorescence,

See profiles in the link

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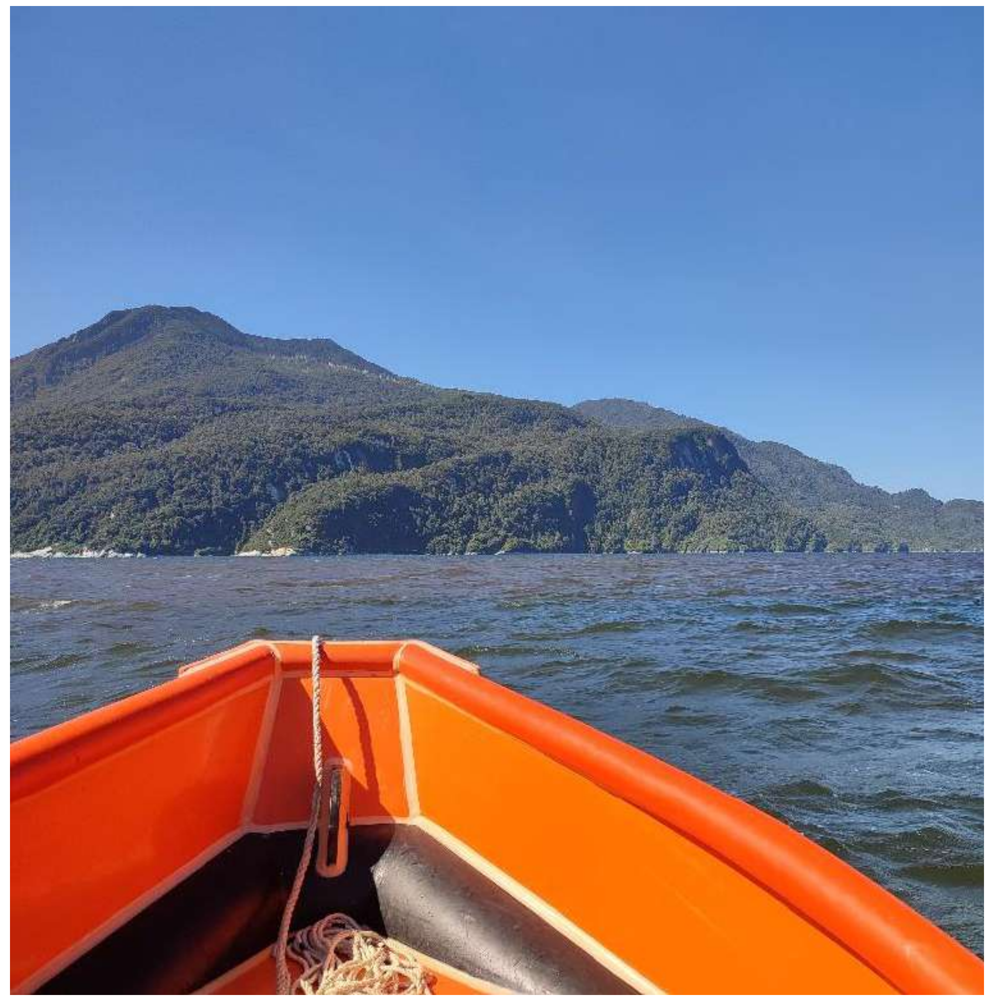
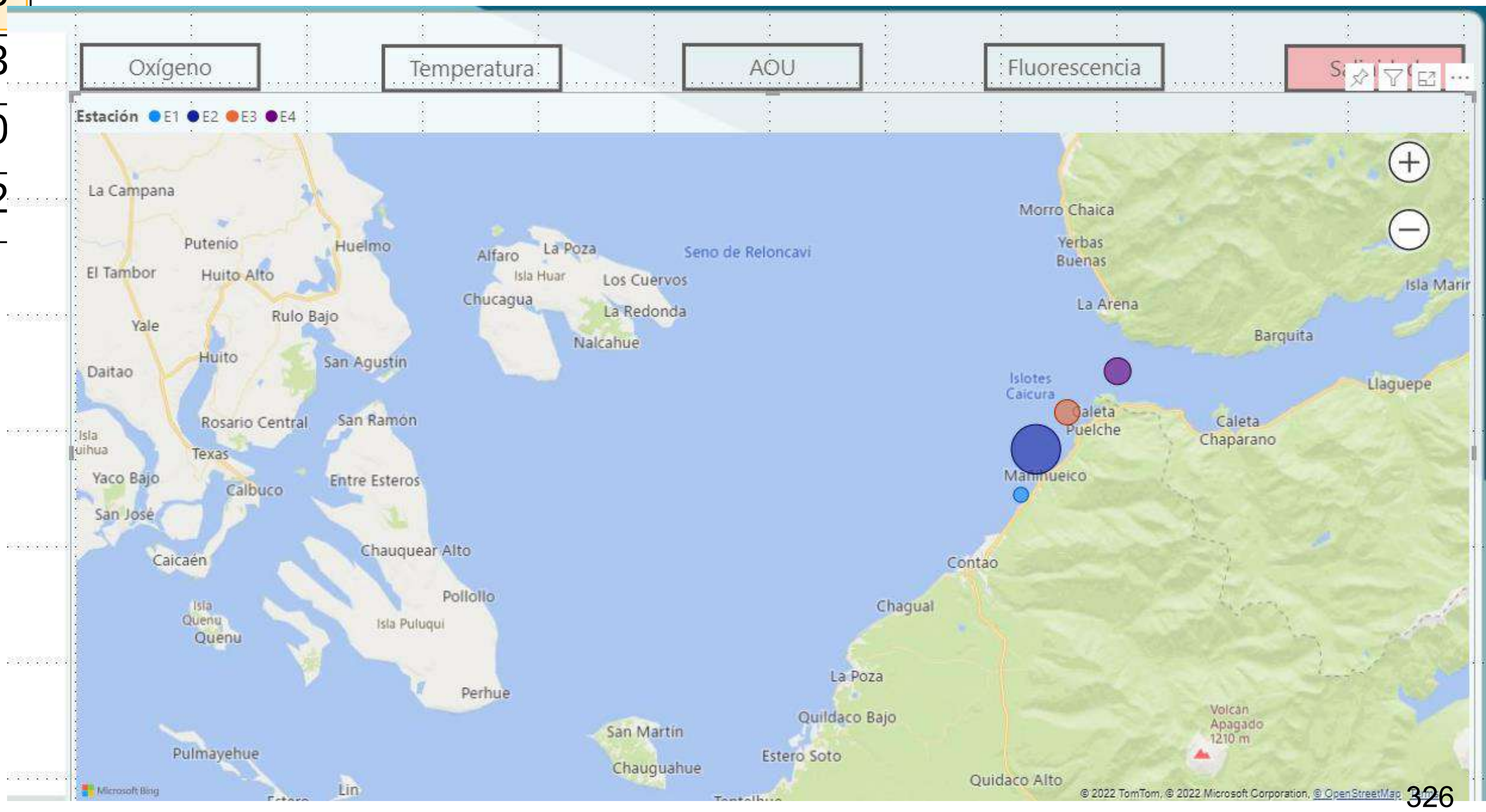
ESTACION	PROF (m)	Fo	Fm	P.micas/ mL	L.danicus/ mL	Fito total / mL	%
E1	0	**2.16**	3.69	25	76	**142**	17.6
E1	5	**8.67**	15.59	774	483	**1319**	58.7
E1	10	**7.74**	11.78	422	980	**1560**	27.1
E1	20	**5.70**	10.19	634	13	**672**	94.3
E2	0	**4.37**	6.58	304	226	**577**	52.7
E2	5	**28.88**	42.11	2726	685	**3657**	74.5
E2	10	**6.95**	11.51	398	349	**851**	46.8
E2	20	**3.36**	5.91	187	43	**253**	73.9
E3	0	**2.44**	4.04	114	254	**435**	26.2
E3	5	**19.53**	29.70	1743	448	**2268**	76.9
E3	10	**7.40**	12.81	814	116	**1032**	78.9
E3	20	**3.07**	5.35	542	20	**571**	94.9
E4	0	**28.95**	40.80	3141	98	**3285**	95.6
E4	5	**6.87**	10.42	848	490	**1384**	61.3
E4	10	**3.79**	6.47	463	362	**1363**	34.0
E4	20	**3.37**	6.08	46	40	**885**	5.2





In vitro photosynthetic parameters vs. Abundance of *P. micans* & *L. danicus*. Dinoflagellate cells represent more photosynthesis than diatoms during the bloom. DO fluxes are influenced by *P. micas*. In addition, using linear model, there is a very high correlation (R> 96%) between Fo, Fm and Abundance of *P. micas*. Therefore, we can be used FRRf3 as a proxi for HAB cell abundance and ecophysiology.

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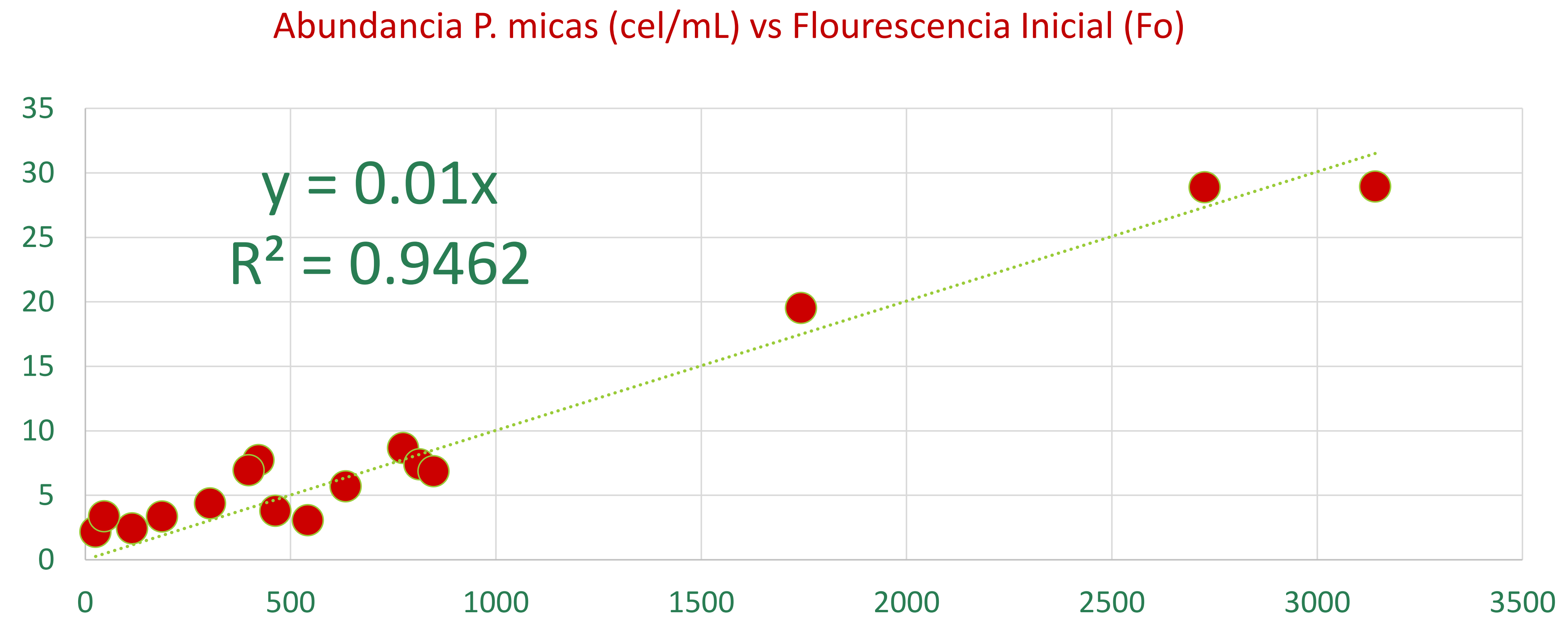

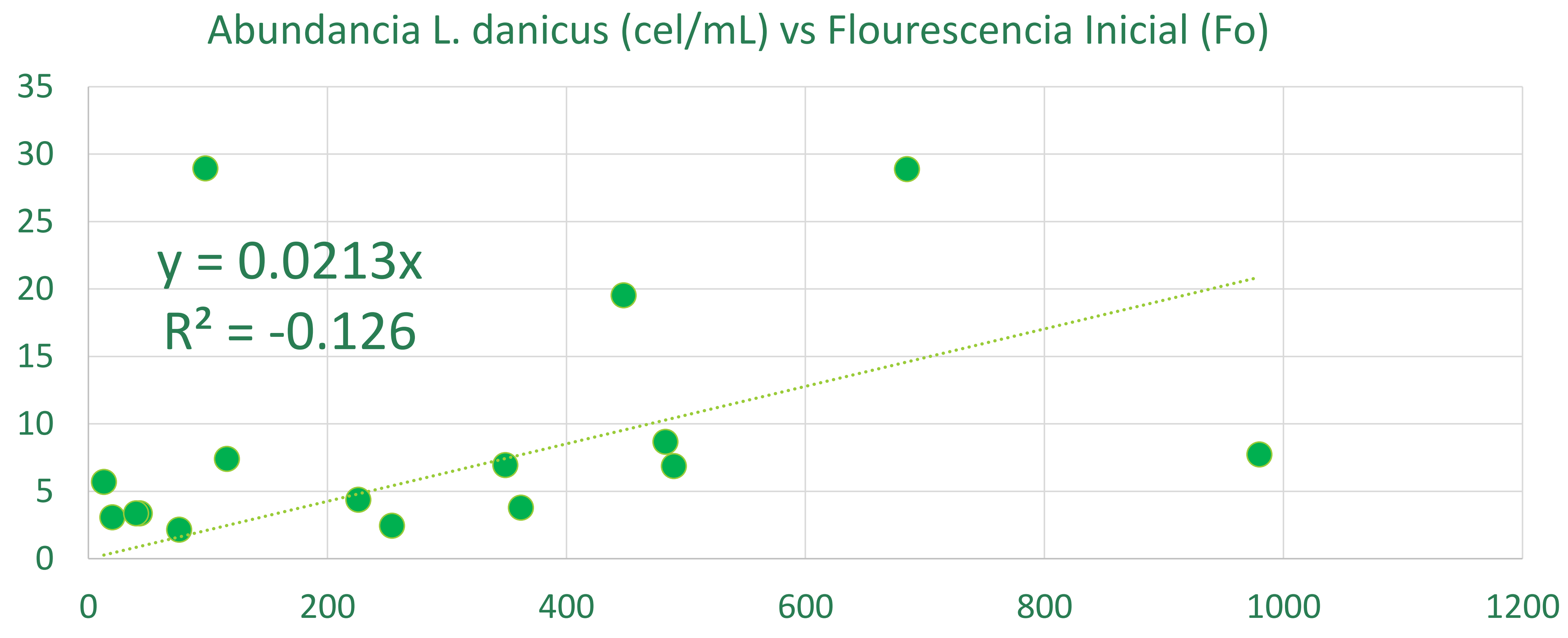

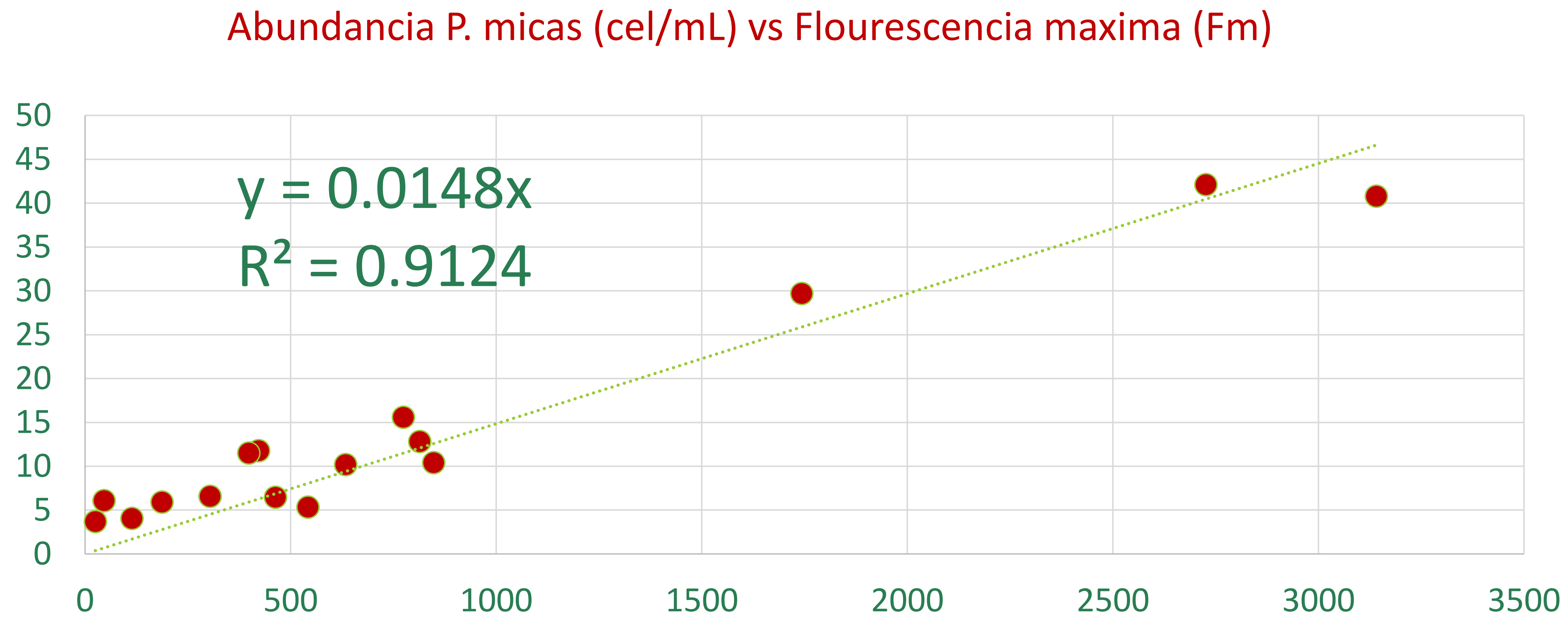

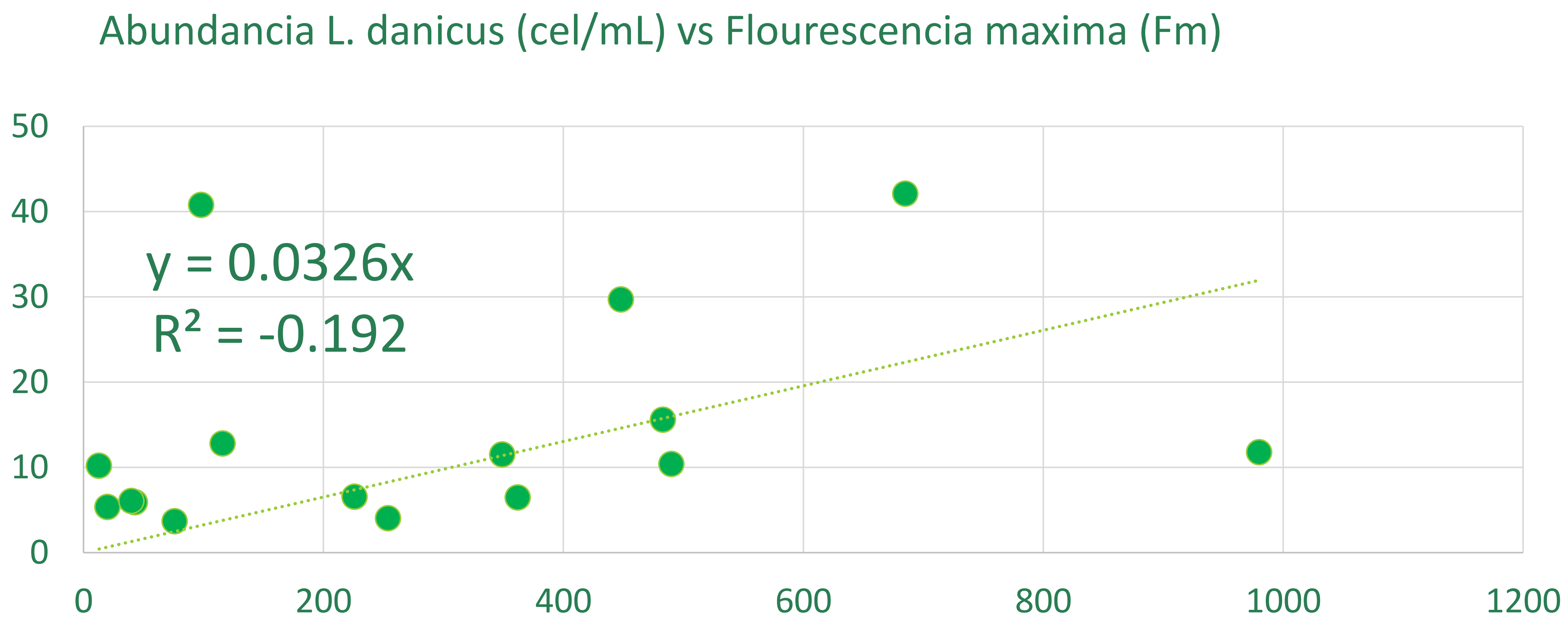

Recent Large biomass bloom during the season of 2021 and 2022, cause it by extreme climatic anomaly: Heterosigma, , Lepidodinium and Prorocentrum Pseudochattonella

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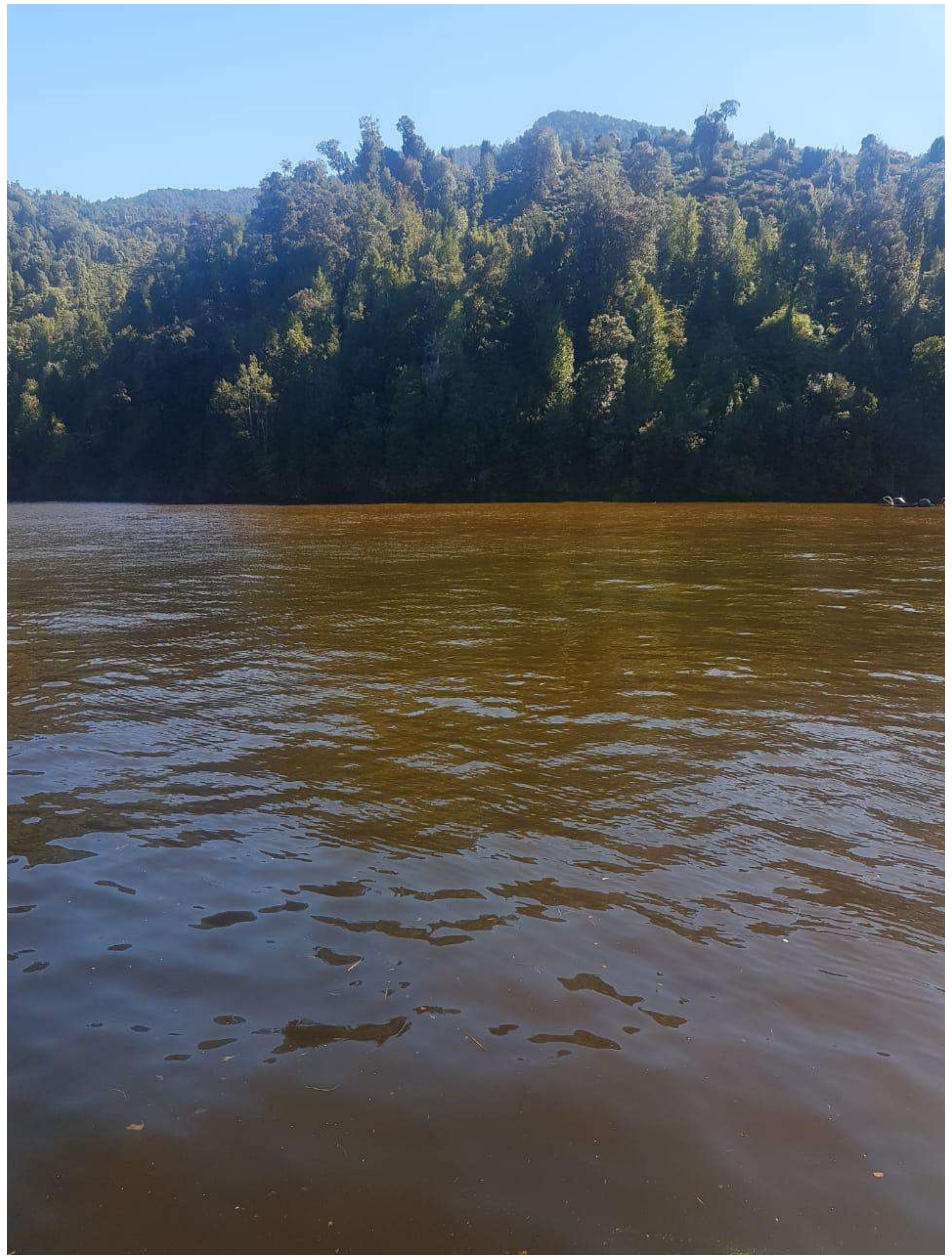
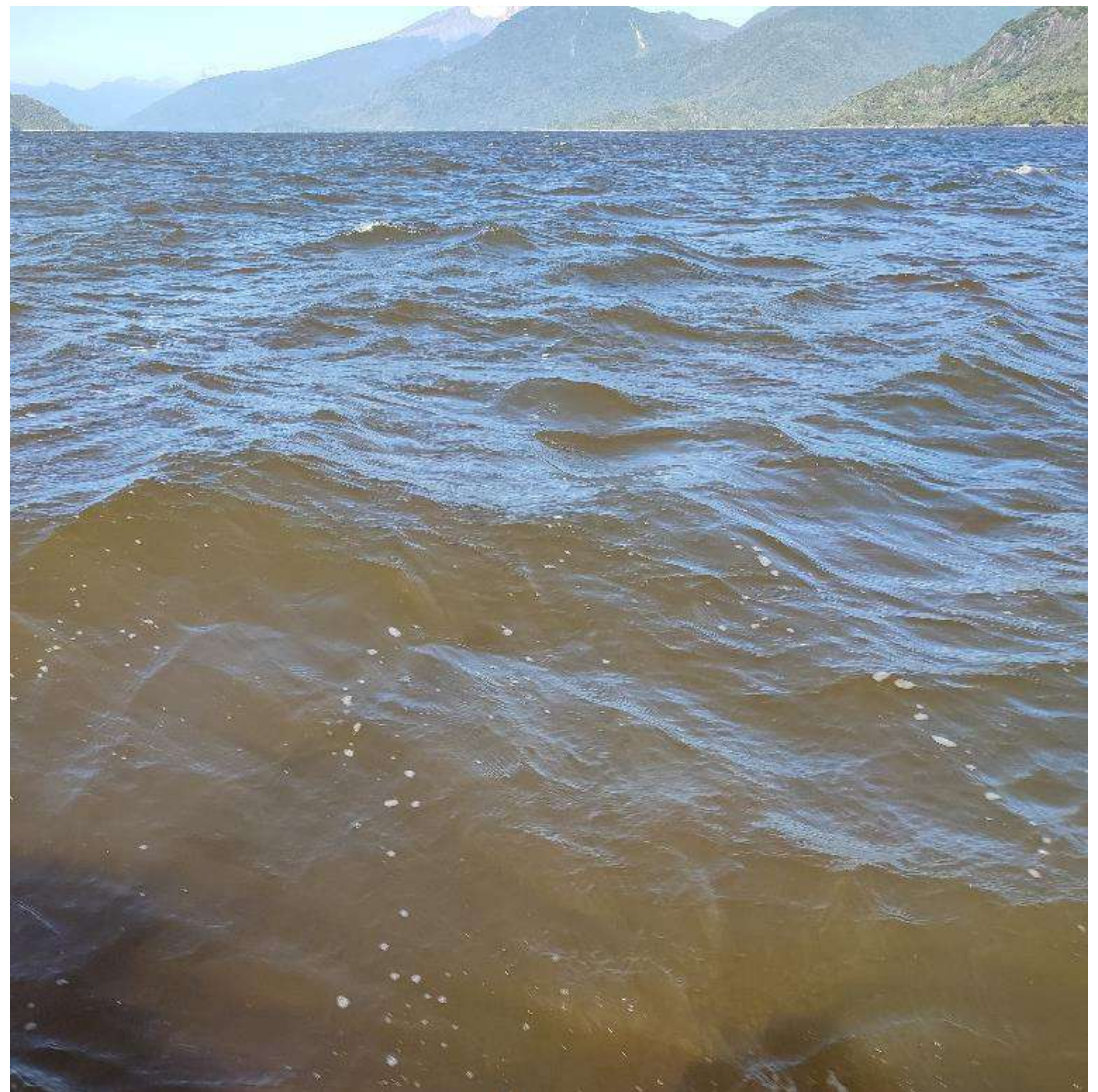


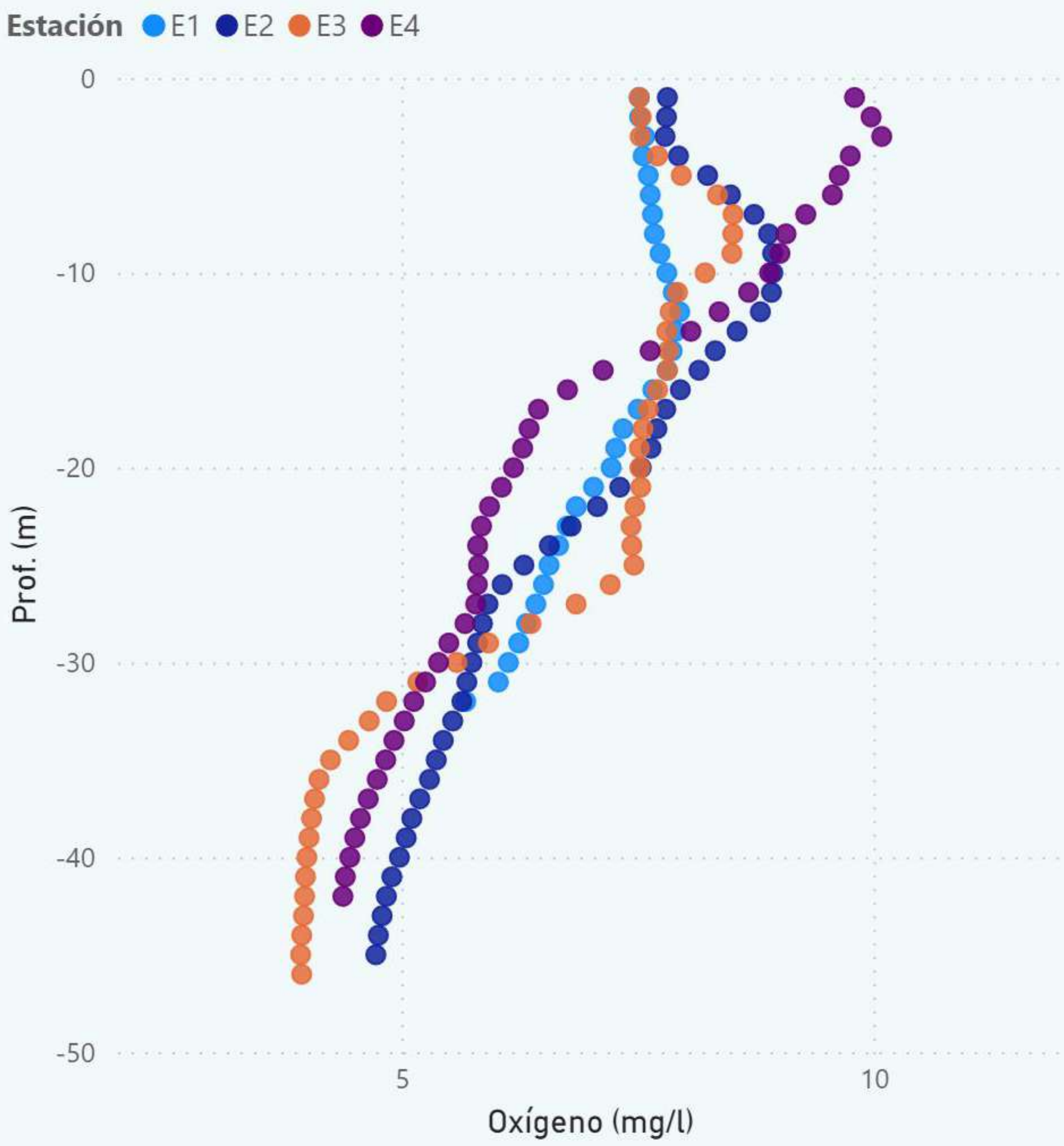


Features of Blooms of Flagellates during this season; *P. micas, Pseudochattonella & L. chlorophorum*

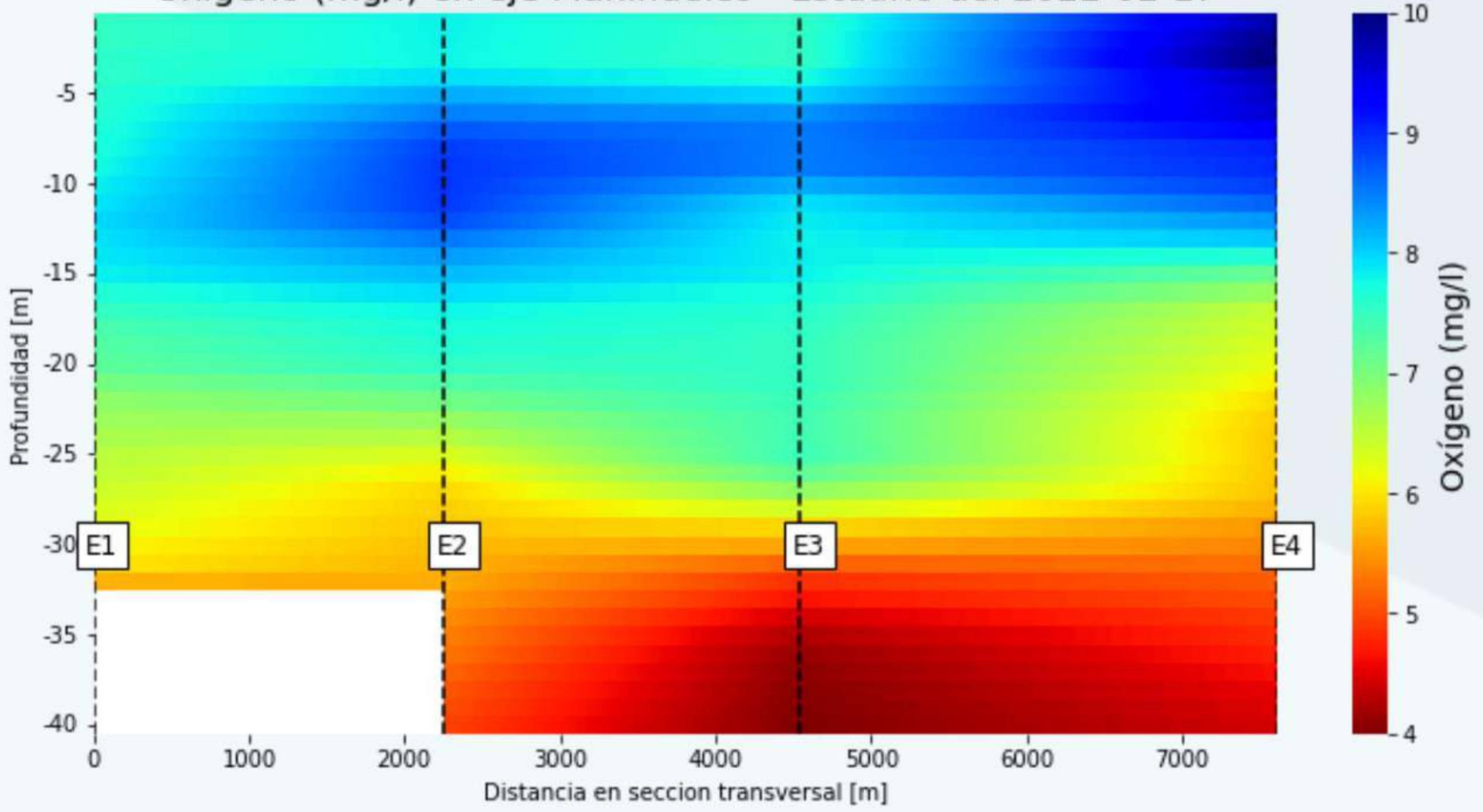
	Pseudochattonella	***L. chlorophorum***	***P. micas***
DATES	8/1/2022	19/12022	17/2/2022
PLACES	DEVIA CHANNEL, 11	MARINE INLAND SEA, 10 Reñihue Fjord	RELONCAVI SOUND, 10
Cells max/mL	163	15255	3141
Impact on fish aquaculture	3000-ton aprox	none	None yet
CELLS CONDITIONS	Different cells forms, highly ichthyotoxic Low Abundance	Massive bloom large biomass and highly photosynthetic Nontoxic but probable decrease DO	large biomass, local .and highly photosynthetic Modulates Oxygen distribution on photic water column
Environmental conditions	WARM WEATHER AFTER RAIN	WARM WEATHER	WARM WEATHER
HABf INDEX MAX	39.58	0.35	1.75
EW	Unpredictable	It has frequent bloom in summer	Interannual Low frecuency

Oxígeno | Temperatura | AOU | Fluorescencia | Salinidad

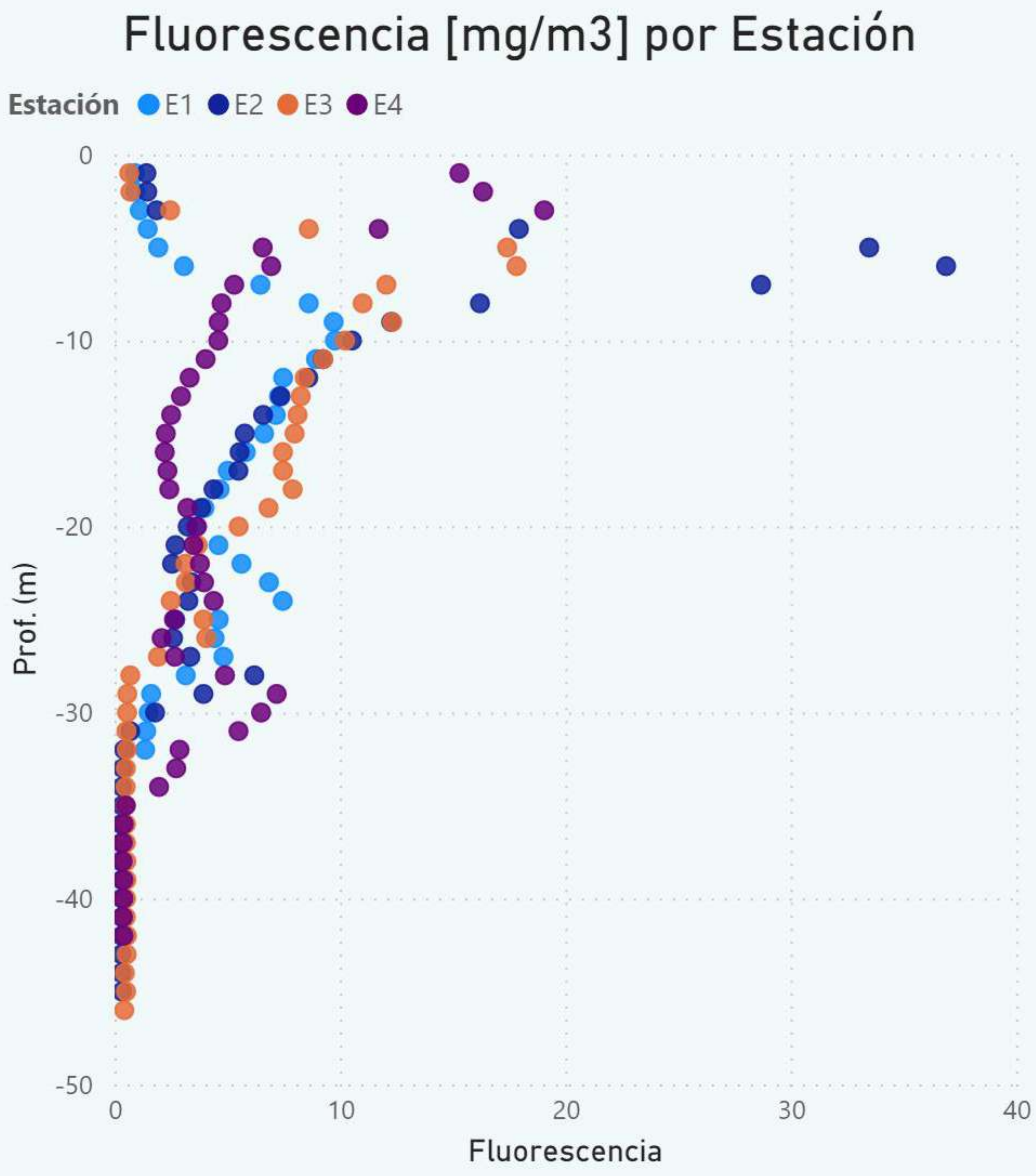
Oxigeno [mg/l] por Estación

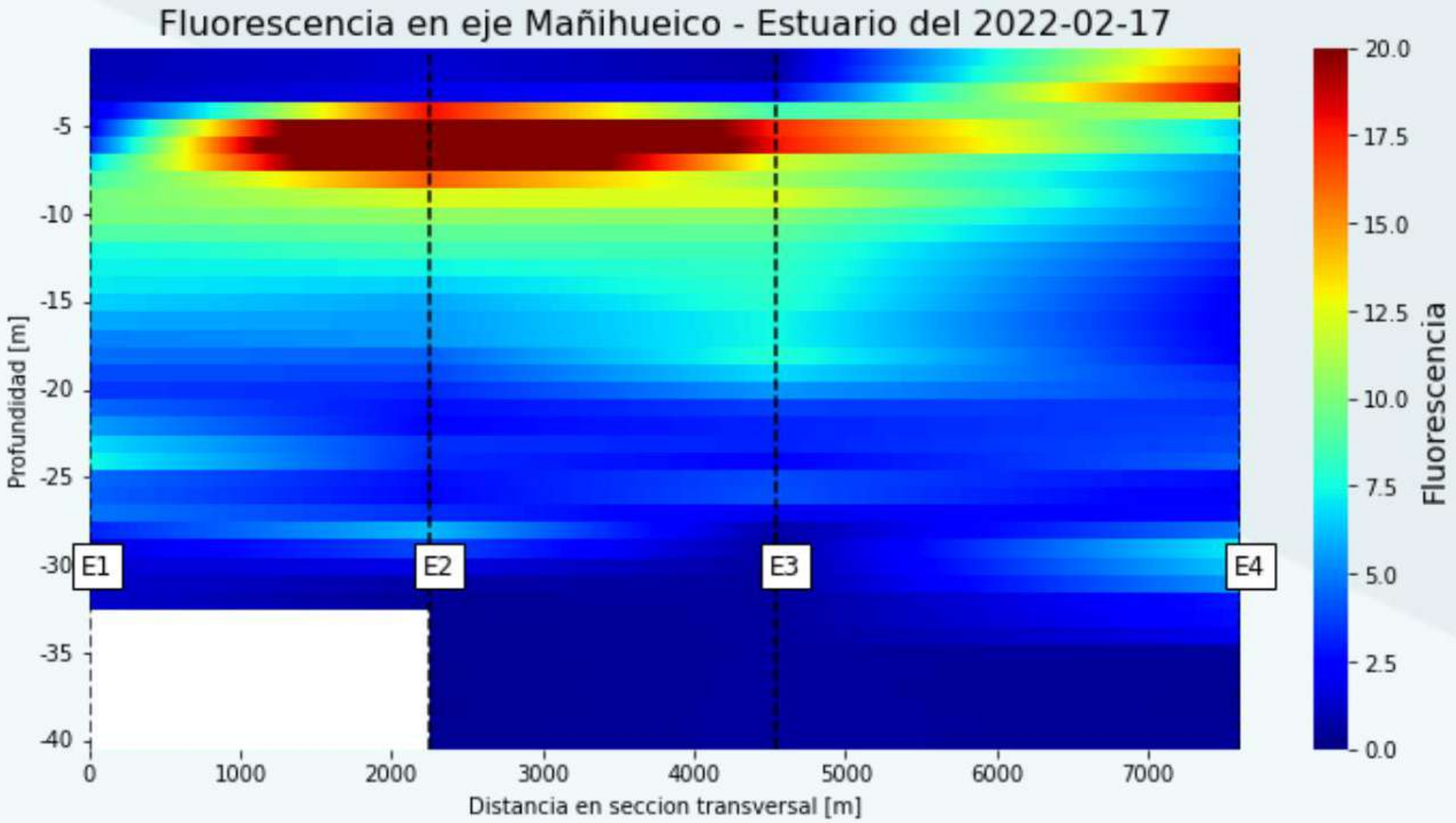


Oxígeno (mg/l) en eje Mañihueico - Estuario del 2022-02-17



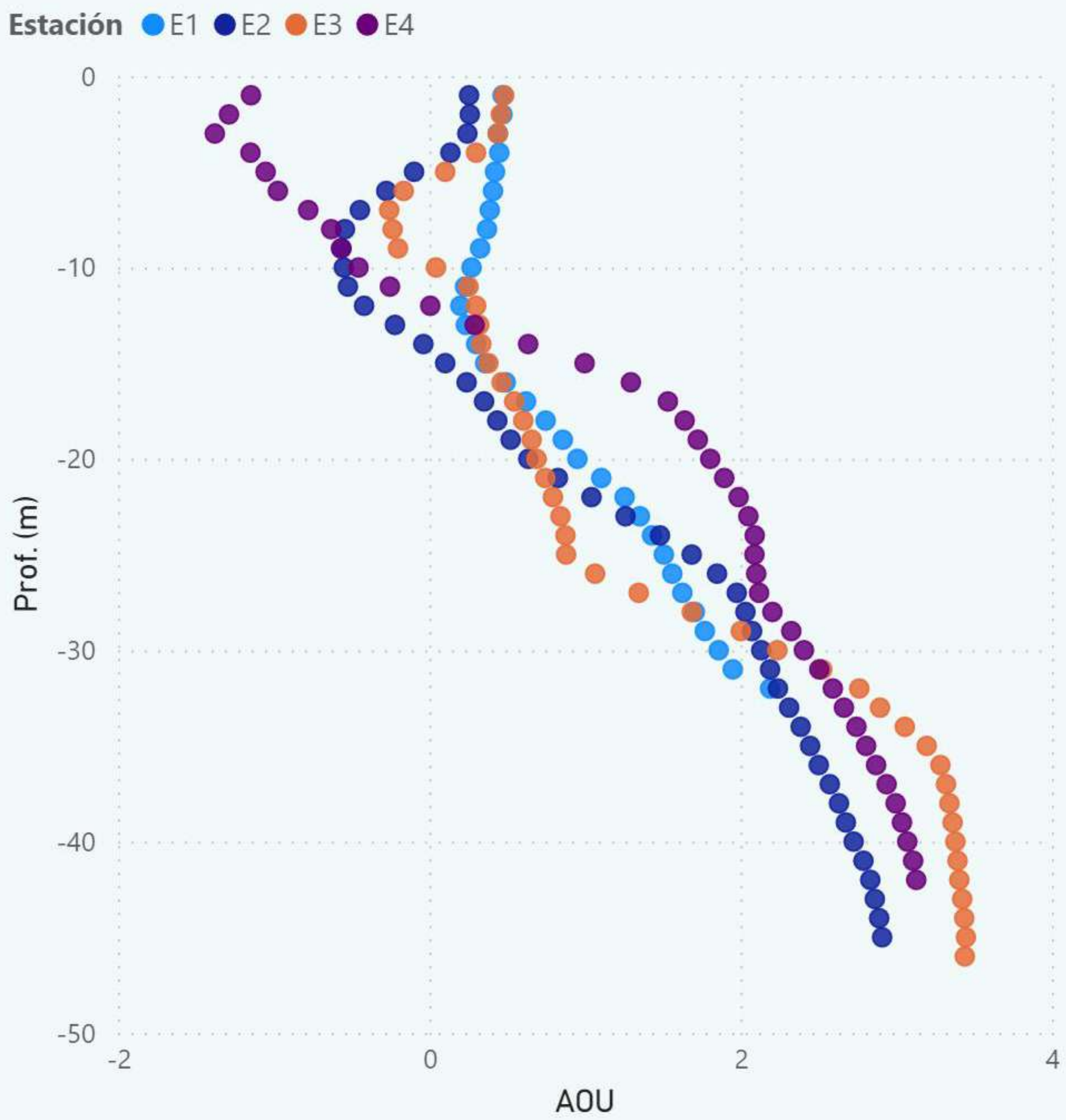
Oxígeno | Temperatura | AOU | Fluorescencia | Salinidad



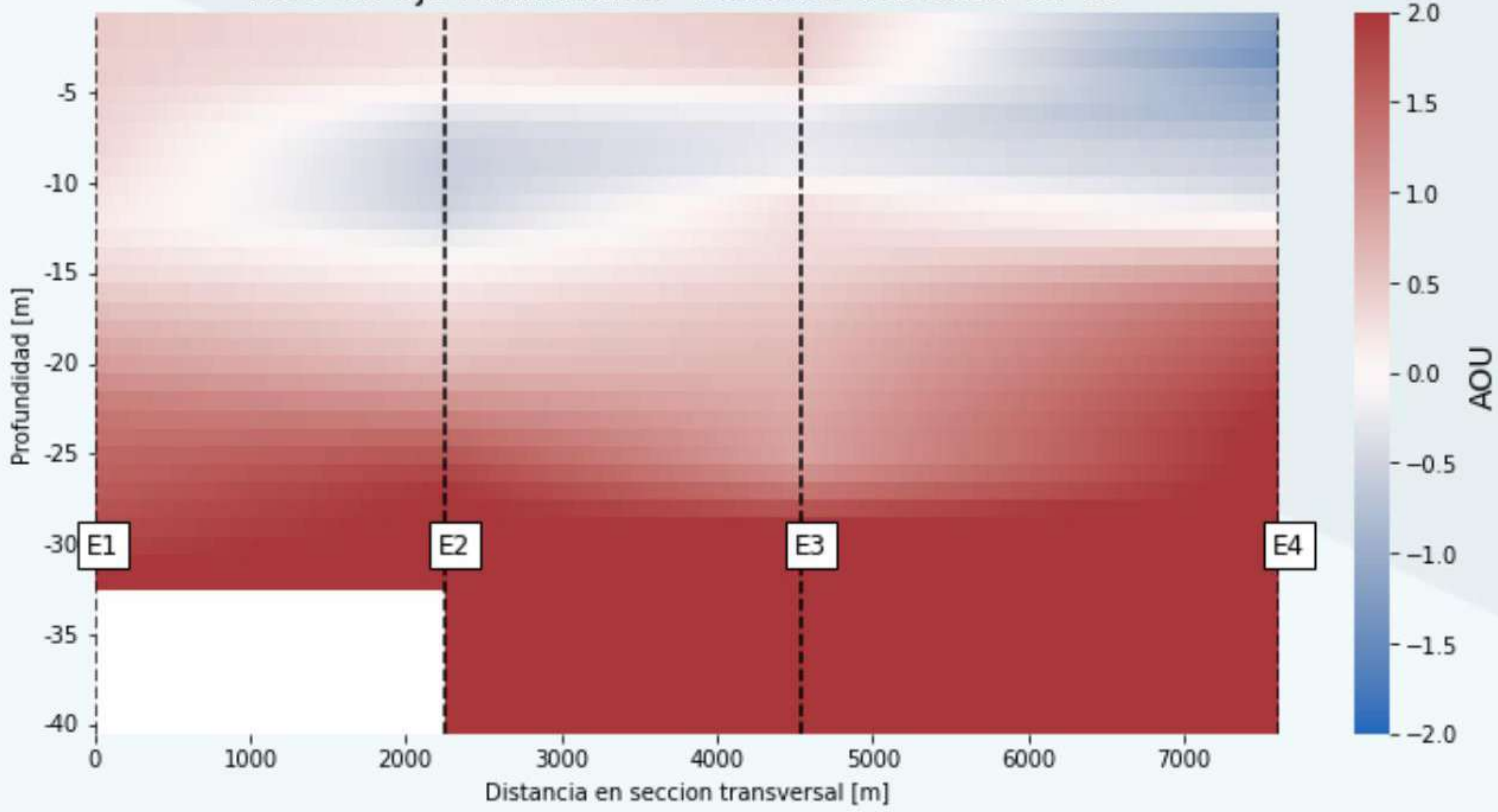


Oxígeno | Temperatura | AOU | Fluorescencia | Salinidad

AOU por Estación

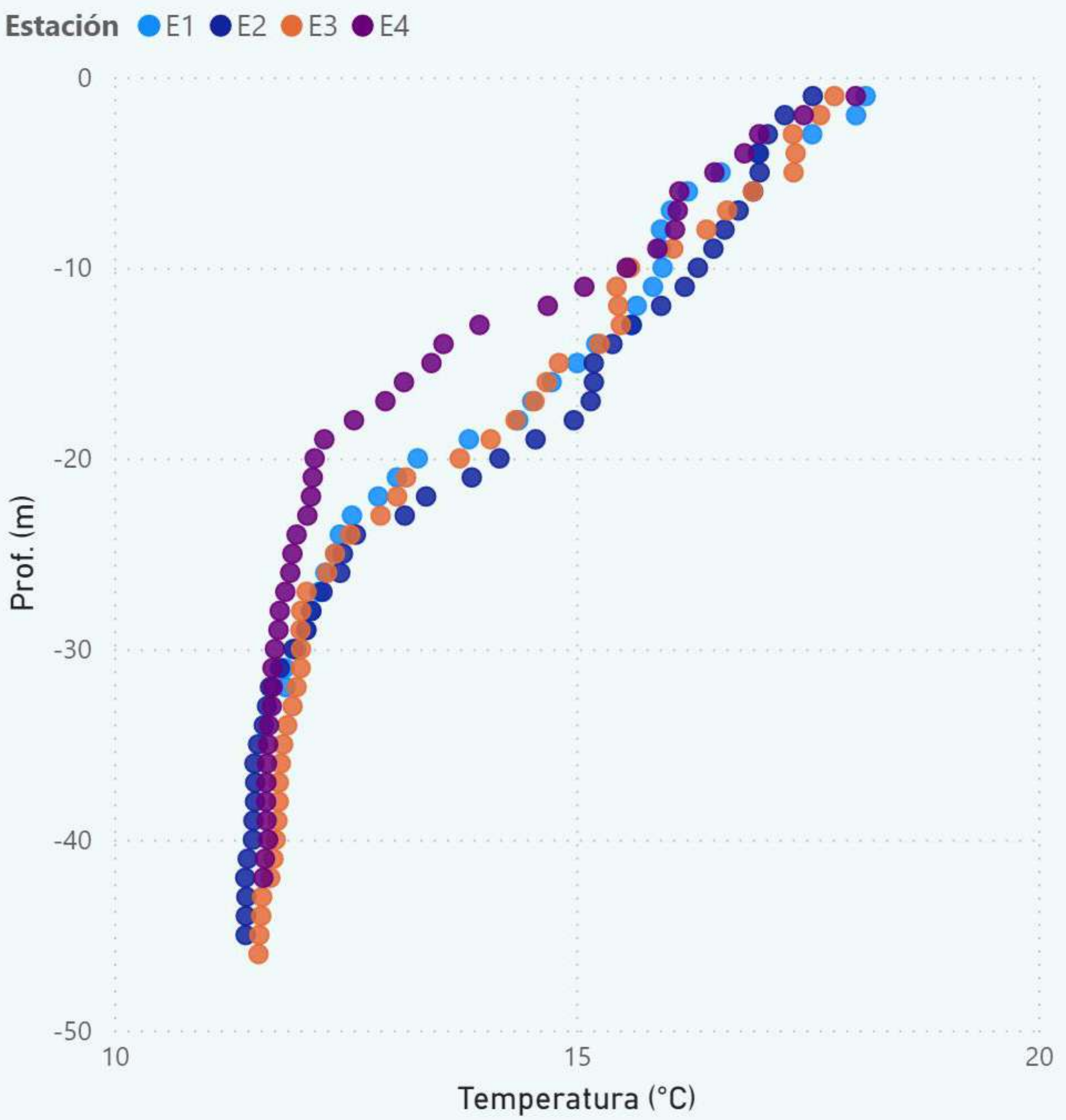


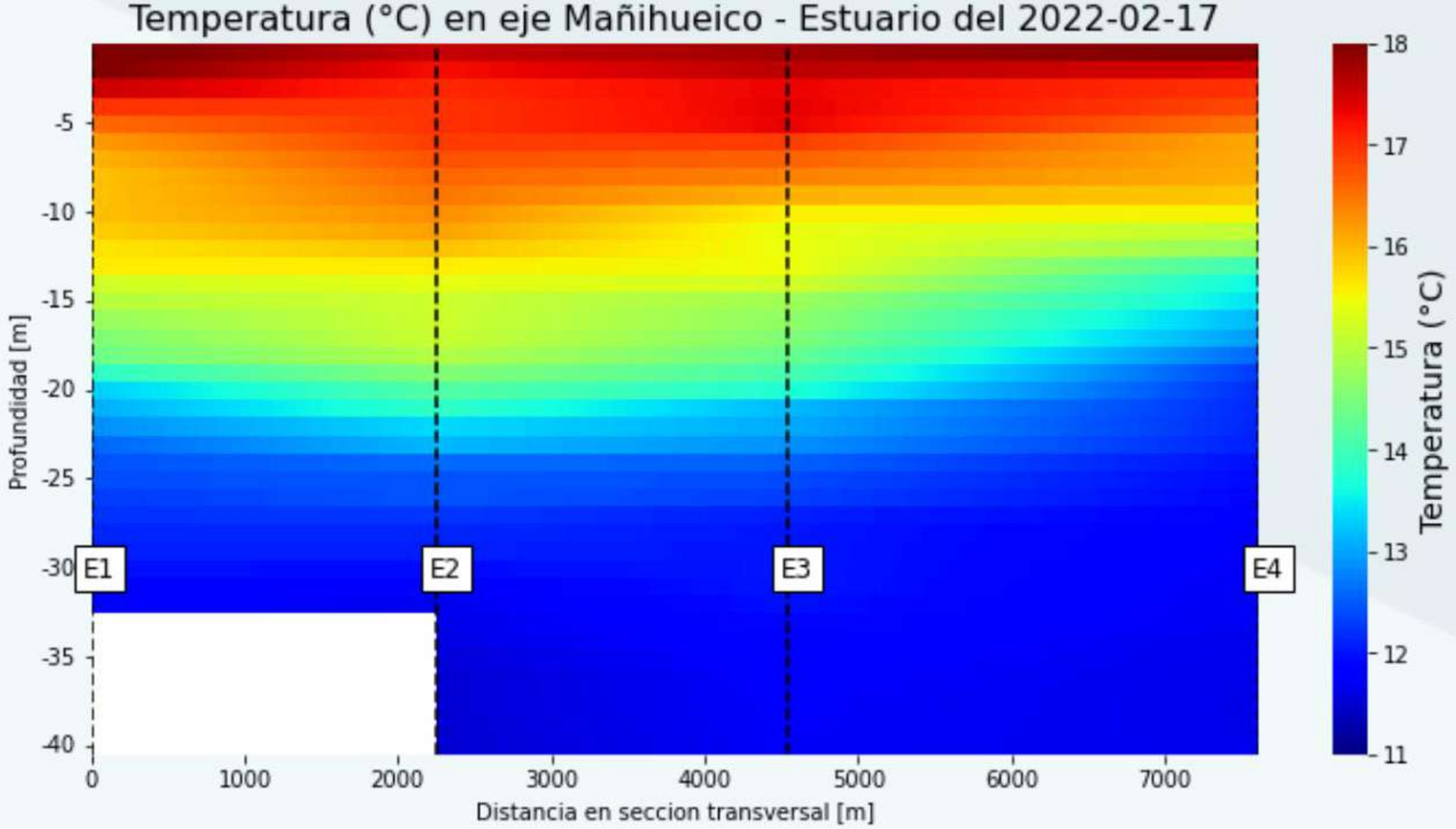
AOU en eje Mañihueico - Estuario del 2022-02-17



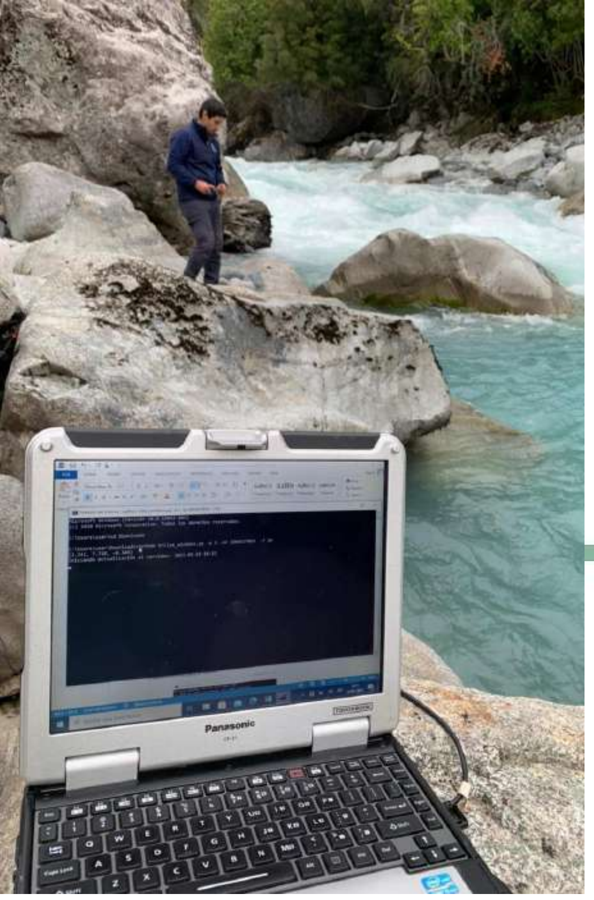
Oxígeno | **Temperatura** | AOU | Fluorescencia | Salinidad

Temperatura[°C] por Estación





BIO-OPTICAL AQUA SENSORS (BAS)



A

B

C

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BAS ¿QUÉ ES?

BAS = Bio-optical Aqua Sensors, corresponde a una solución desarrollada por Plancton Andino para la medición de variables bio-ópticas *in situ*, en tiempo real y libres de reactivos químicos (pollution-free). El BAS considera una aplicación IOT para el envío de datos actualizados en tiempo real disponibles en la aplicación móvil de Plancton Andino, utilizando herramientas de Business Intelligence.

¿DE QUE SE TRATA EL SERVICIO?

El BAS mide señales ópticas de clorofila *a*, turbidez, ficocianina e hidrocarburos. Las variables pueden ser capturadas *in situ* y en tiempo real o para aplicaciones a largo plazo (estaciones de monitoreo).

El servicio e implementación del BAS incluye la creación de alertas tempranas automáticas frente a posibles episodios de FAN, derrames de hidrocarburos, alteraciones de calidad de agua potables, entre otros, avisando en línea a clientes y/o usuarios.

BENEFICIOS DEL SERVICIO BAS

1. Obtener datos en línea y tiempo real.
2. Tomar decisiones oportunas frente a anomalías en la columna de agua.
3. Generar alertas tempranas para Floraciones de Algas Nocivas (FAN).
4. Sensores *in situ*, pollution-free.

Los sensores utilizados han sido corregidos y validados para las aguas chilenas mediante ensayos de laboratorio y experimentos en terreno. Además, el BAS considera el uso de modelos de detección de "outliers" para remover y corregir automáticamente datos y señales erróneas.

El monitoreo de variables bio-ópticas permite conocer en tiempo real el estado de las FAN en el agua, generando alertas tempranas para una rápida toma de decisiones, generando valor agregado a los servicios de Plancton Andino.

BIO-OPTICAL AQUA SENSORS (BAS) IS A USEFUL SYSTEM FOR EARLY WARNING including *IN SITU* Hydrocarbons ON REAL TIME

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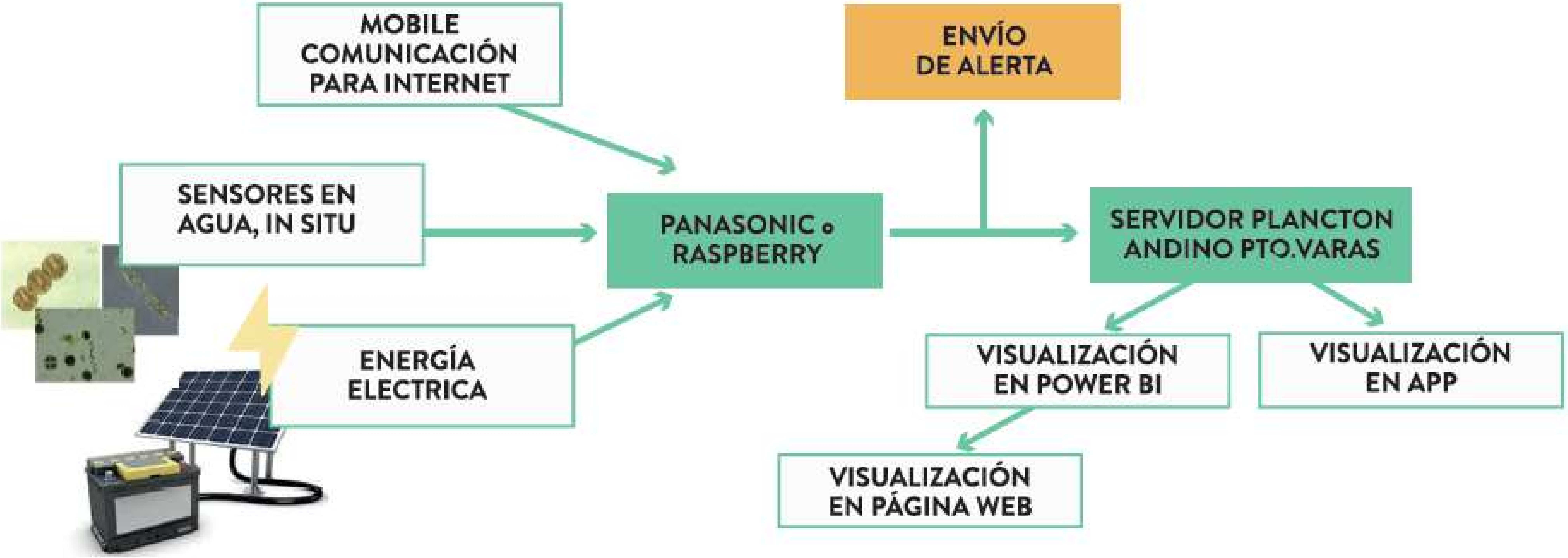

DATA PROCESSING AND QUALITY CONTROL OF THE BIO-OPTICAL AQUA SENSORS (BAS)

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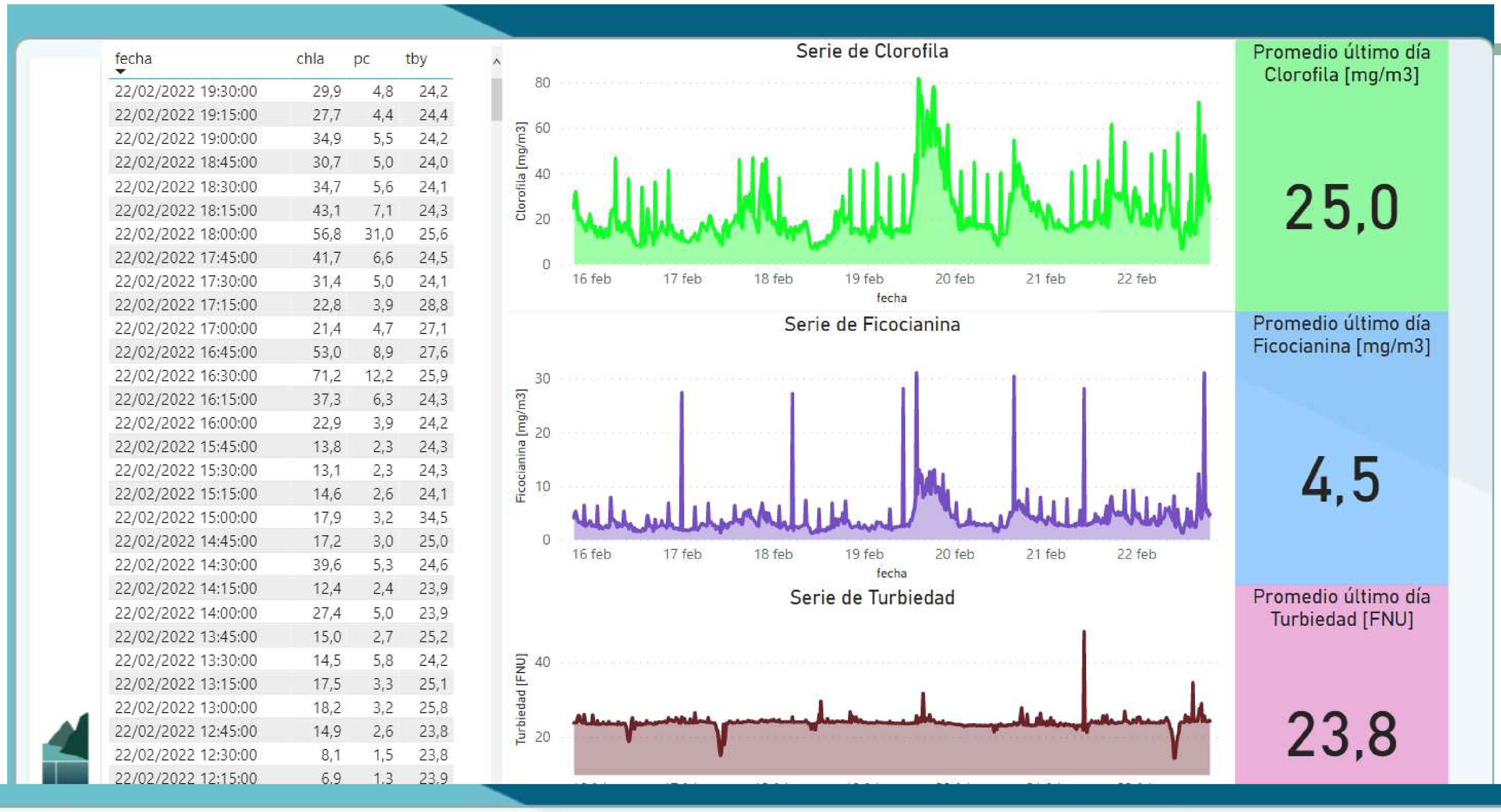
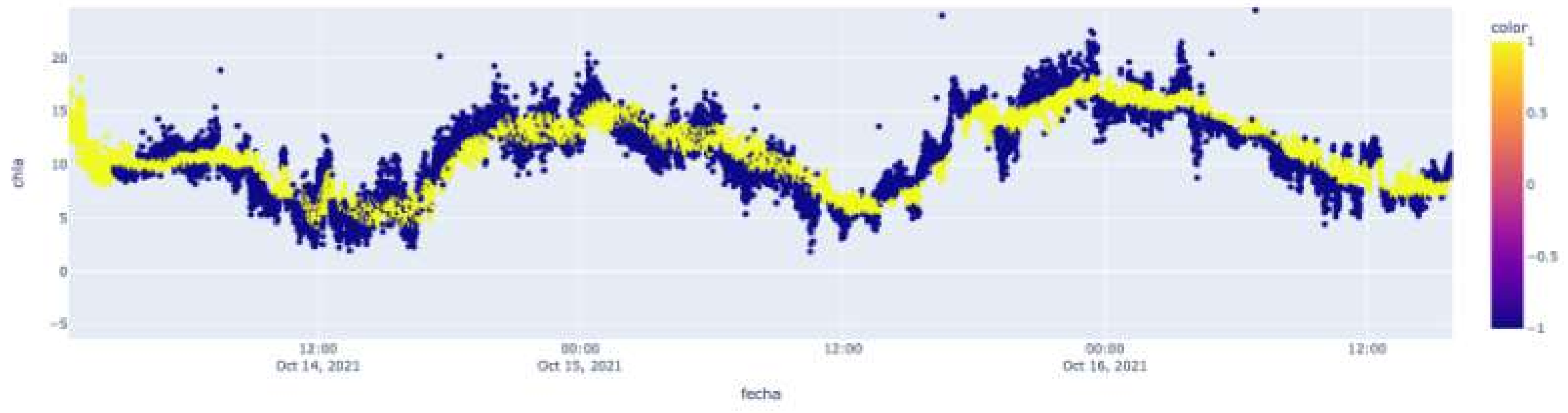
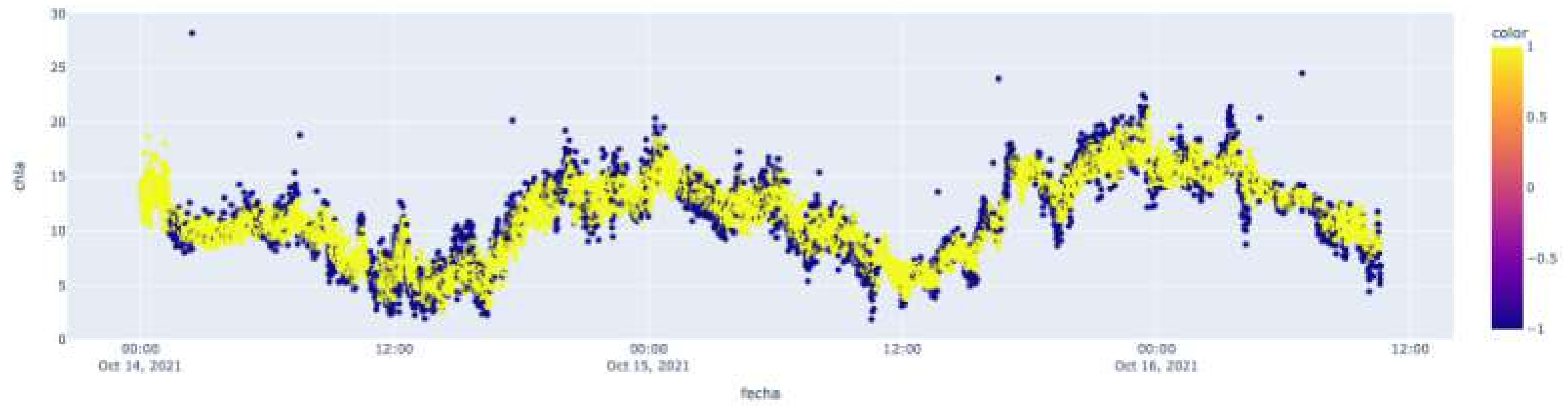


Data Processing outliers:

De los métodos descritos en la sección 2, los algoritmos que mejor resultado tuvieron fueron One Class SVM y Isolation Forest, siendo el primero más estricto para detectar outliers, mientras que el segundo más flexible.



One Class SVM. Robusto y estricto.



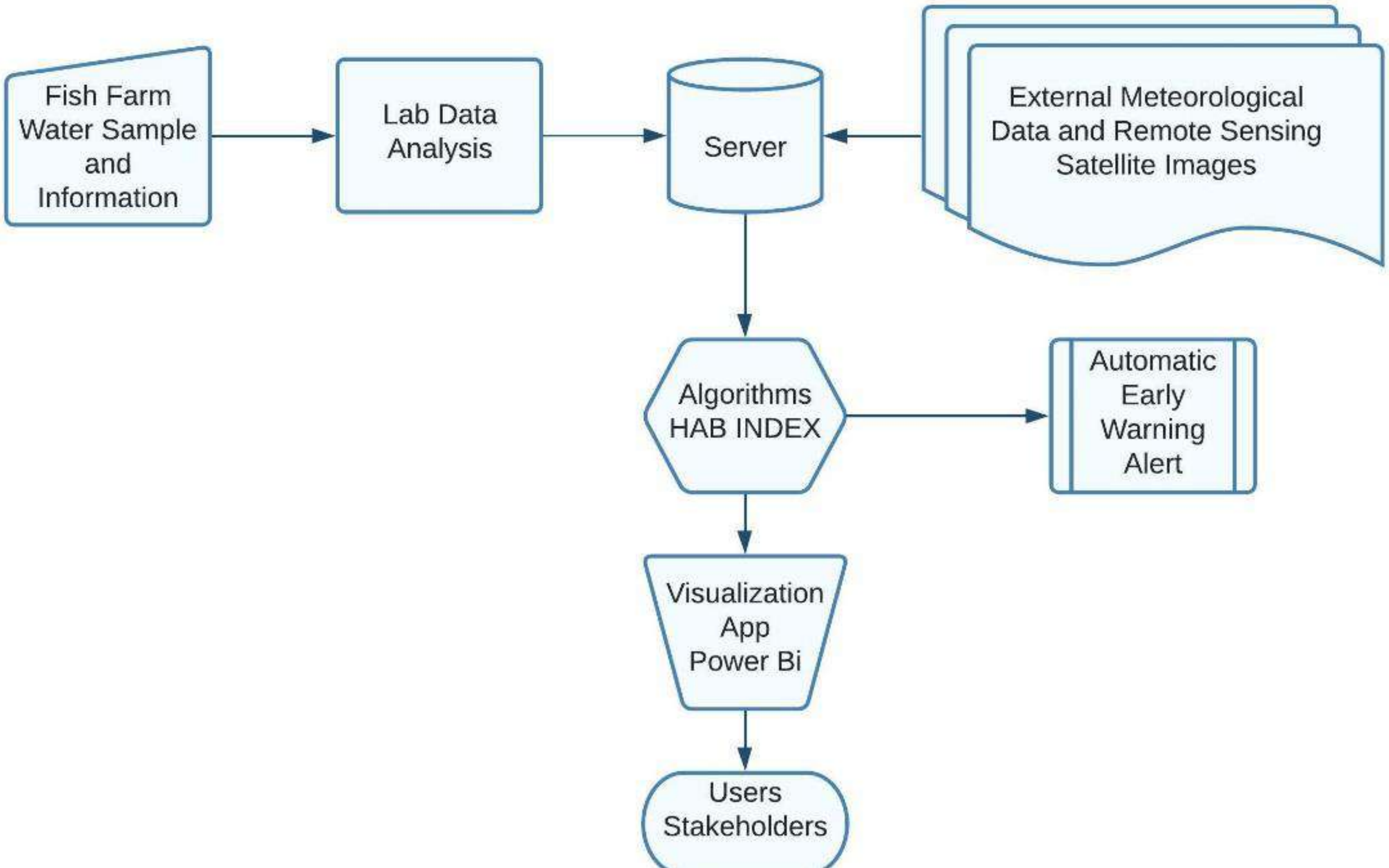
Isolation Forest. Algoritmo más flexible para detectar outliers

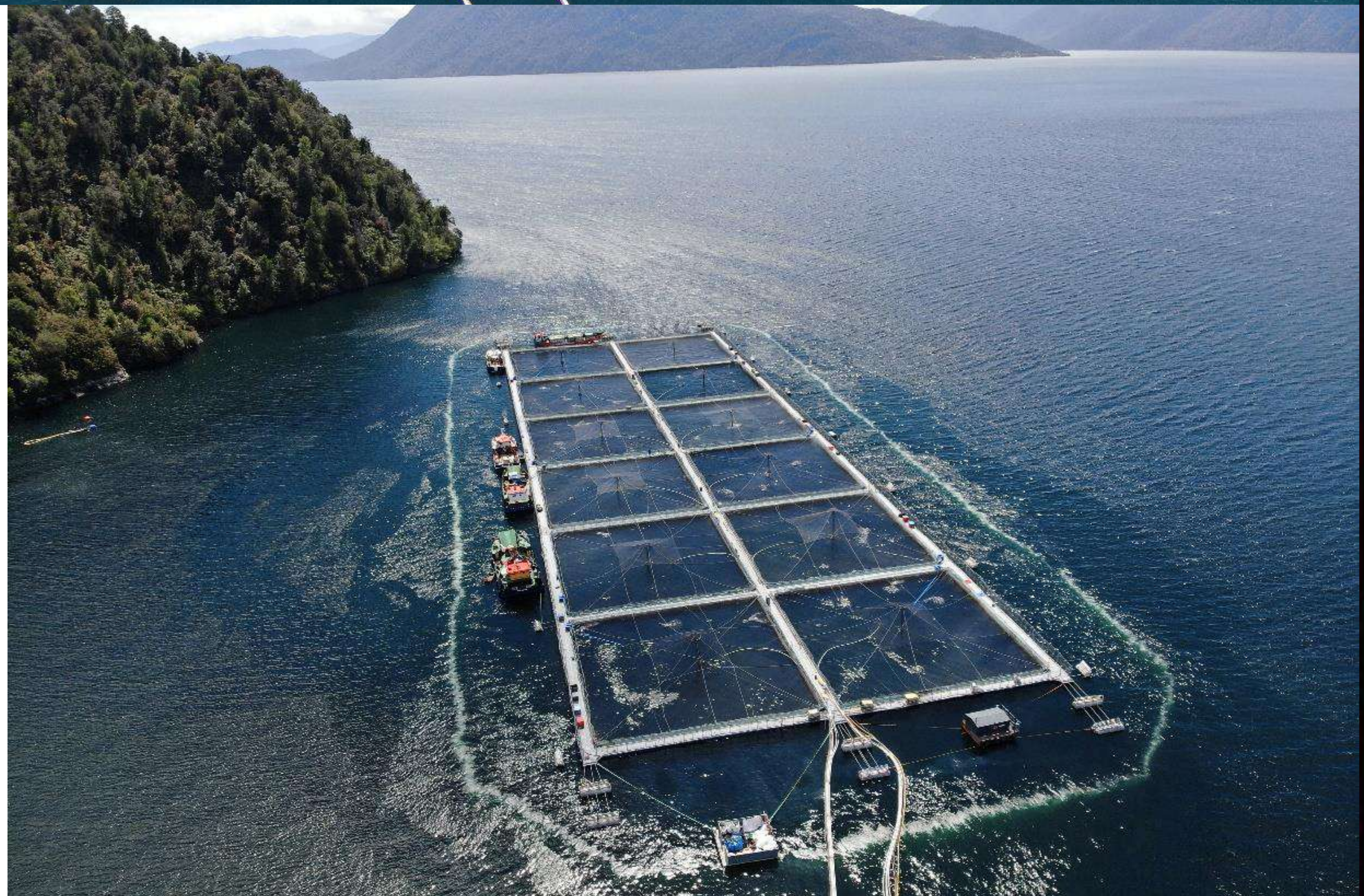
Ambos algoritmos son bastante rápidos en cuanto a procesamiento, lo que los hace buenos candidatos para usarlos en tiempo real.

Clément A, Jorquera A, Muñoz F, Ramirez B, Colilef A. Saez S, Clément S, Tellez C, & Contreras M. 2022. Manual y Protocolos de Mediciones de propiedades bio-ópticas del agua; énfasis en control de calidad. Proyecto Corfo Código: 19CV-119268. Plancton Andino SpA., Puerto Varas-Chile.

Early Warning System and Alert

PLANCTON ANDINO





lo2w
water aeration solutions

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FINAL REMARKS

1. EWS is a practical and operational approximation to decrease the risk of HAB.
2. The bloom and cells conditions of *P. micas (and probably most phototrophic flagellates)* modulates the shape and fluxes of the oxygen and OAU layers in stratified waters.
3. Local variability, patches and vertical distribution (thin layers) complicate EWS and forecasting.
4. The HAB of *Pseudochattonella* during January of 2022 in southern Chile was practically impossible to alert due to a very small-scale distribution and an extreme short-term period (2 to 3 days). The message should be; increase frequency or to use several technologies to improved monitoring in isolated sites. Difficult to forecasts

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References

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2. **Alejandro Clément, Thomas Husak, Sofia Clément, Francisca Muñoz, Marcela Saldivia, Carmen G. Brito, Roberta Crescini, Nicole Correa, Karenina Teiguel, César Fernández, Gustavo Contreras, S. S. (2020). Contribution of the HABf INDEX for fish farm's risk analysis. Ph. Hess [Ed]. Harmful Algae 2018 – from Ecosystems to Socioecosystems. Proceedings of the 18th Intl. Conf. on Harmful Algae. Nantes, International Society for the Study of Harmful Algae. 214 Pages. ISBN: 978-87-990827-7-3., 149–153.**
3. **Devred, E., Martin, J., Sathyendranath, S., Stuart, V., Horne, E., Platt, T., Forget, M. H., & Smith, P. (2018). Development of a conceptual warning system for toxic levels of Alexandrium fundyense in the Bay of Fundy based on remote sensing data. Remote Sensing of Environment. https://doi.org/10.1016/j.rse.2018.04.022**
4. **Great Lakes Early Warning system https://glos.org/priorities/projects/habs/**
5. **C.H. McKenzie, A. Cembella, J. I. Goes, D. A. Kiefer, A. Sulieman, A. Al Mawali, A. Clément, R. Stumpf, Q Dortch, M. Suddleson, S. Ud din, B. Karlson. In prep. High biomass bloom and fish kills and other impacts.**
6. **Davidson, K., Whyte, C., Aleynik, D., Dale, A., Gontarek, S., Kurekin, A. A., McNeill, S., Miller, P. I., Porter, M., Saxon, R., & Swan, S. (2021). HABreports: Online Early Warning of Harmful Algal and Biotoxin Risk for the Scottish Shellfish and Finfish Aquaculture Industries . In *Frontiers in Marine Science* (Vol. 8). https://www.frontiersin.org/article/10.3389/fmars.2021.631732**
7. **Researchers Use Genes as HAB Early Warning System**

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¡Muchas Gracias!