Technical Report with Roadmap: Developing Best Practices to Address Coastal Marine Oxygen Loss in APEC Economies for Improving the Management of Marine Living Resources

APEC Ocean and Fisheries Working Group

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APEC Project: OFWG 201 2023

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Executive summary

The OFWG 201 2023 - APEC project: "Developing best practices to address coastal marine oxygen loss in APEC economies for improving the management of marine living resources", was organized by the Peruvian Institute of Marine Research (IMARPE) and sponsored by the following APEC economies: Canada, Chile, China, Russia, Viet Nam, and Chinese Taipei.

The project aimed to promote the adoption of good and innovative practices for the collection, analysis, and data processing to assess coastal oxygen concentrations and to improve the collaboration to implement or sustain local environmental observatories of coastal oxygen loss. The specific objective of the workshop was to share and transfer good and innovative practices for improving the collection, analysis, quality control, and data processing of coastal dissolved oxygen in APEC economies to benefit fisheries and aquaculture management.

The workshop took place in Paracas, Peru, from September 30th to October 3rd and included i) a report of a pre-workshop survey, ii) keynote lecturers, iii) short presentations and discussion of case studies from the participant economies, iv) practical demonstrations of oxygen data collection and experimental setup for assessing biological responses to low-oxygen conditions, and v) roadmap discussions with recommendations to implement or improve sustained local environmental observatories to track or detect oxygen loss for fisheries and aquaculture applications.

To improve the management, adaptation, and sustainable practices in fisheries and marine aquaculture in coastal waters, affected by exposure to eutrophication-driven and climate change-driven deoxygenation, the building of a roadmap was started in the workshop. The challenges and opportunities to standardize, integrate, and manage oxygen data across APEC economies were recognized. The need for implementing best practices at different action levels was pointed out, such as oxygen data collection and management, monitoring design, and generating meaningful applications or metrics of coastal hypoxia for fisheries and aquaculture stakeholders.

The workshop successfully achieved its goal of enhancing theoretical and practical knowledge on hypoxia detection and monitoring in marine-coastal areas among the participant APEC economies representatives. It created opportunities to collaborate on dissolved oxygen monitoring, data analysis, and developing indices to assess hypoxia's impact on fisheries and aquaculture within the global context of coastal water deoxygenation. Contributions from nine APEC economies revealed varying capacities in

handling dissolved oxygen data while creating a collaborative roadmap that strengthened cooperation and knowledge sharing.

The proposed roadmap emphasizes fostering collaboration among APEC economies to address coastal oxygen loss through scientific partnerships and capacity building. Short-term goals include establishing partnerships and promoting ocean literacy, while medium- and long-term objectives focus on improving data management, conducting multidisciplinary research, and developing vulnerability metrics. A key initiative would be implementing early warning systems for deoxygenation events. Stakeholder engagement and securing international funding are central to these efforts, aiming to integrate local and global approaches for effective resource management and ecosystem preservation.

1. Introduction

The relevance of coastal deoxygenation for fisheries and aquaculture

Since the 1950s, more than 500 coastal areas have been identified to have persistent or seasonal oxygen concentrations below 1.4 mL/L (2 mg/L), a threshold that classifies them as hypoxic (Chan et al., 2019). The oxygen content decrease in the oceans can impact nutrient cycles and impair marine habitats, potentially harming ecosystems, the people (communities) that depend on them, and coastal economies. This problem may be even more widespread in coastal areas, particularly in developing economies where hypoxic conditions or increasing trends may go undocumented because oxygen monitoring data remains limited.

The oxygen loss in the coastal ocean can be attributed to two overlying causes: eutrophication resulting from nutrient runoff from land and nitrogen deposition from fossil fuel burning, and the warming of ocean waters due to climate change. Excess nutrients entering the coastal ocean through watershed and river runoff and atmospheric deposition fuel algal blooms that increase oxygen demand and further the development of hypoxic coastal zones; nutrient enrichment also intensifies hypoxic in areas that already have naturally-occurring low-oxygen conditions (Figure 1). Additionally, the ocean absorbs most of the excess heat the earth retains due to greenhouse gas-induced warming, primarily causing the decrease of oxygen solubility and changes in ventilation and ocean mixing that reduce the oxygen supply to deeper waters (Breitburg et al., 2018).

The global extent of eutrophication-induced hypoxia and its threats to ecosystem services is well-documented, but many of the long-term consequences for human health, social and economic systems and their combined effects with other ocean stressors remain unknown (Bassett et al., 2019; Breitburg et al., 2019). Vulnerable populations, particularly those in coastal urban and rural areas, poor households in developing economies, and marginalized groups- including women, children, and indigenous communities -are likely to be the most vulnerable to the effects of ocean deoxygenation.

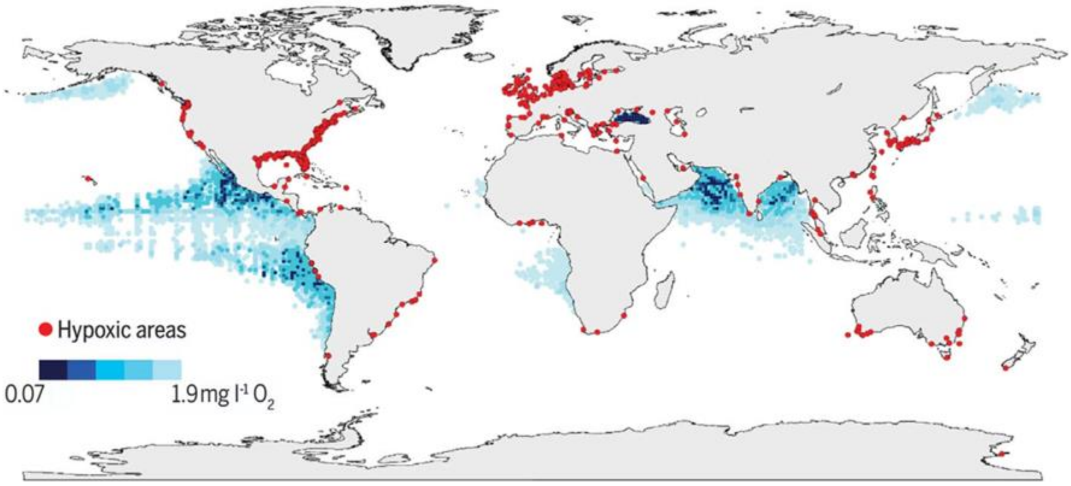

Figure 1. Distribution of low oxygen levels in the ocean waters and coastal hypoxic areas worldwide (Breitburg et al., 2018).

As naturally occurring low-oxygen areas, the Eastern Boundary Upwelling Systems (EBUS) appear particularly vulnerable to further deoxygenation and represent hot spots for ocean deoxygenation concerns (Deutsch et al., 2011). While oxygen minimum zones (OMZ) expand and become shallower towards the EBUS margin due to climate change (Stramma et al., 2010), hypoxia induced by eutrophication and amplified by global warming put further pressures on the oxygen conditions in these coastal areas (Breitburg et al., 2018). Thus, the quality and availability of suitable habitats for many organisms is reduced, with diminished habitat causing altered species distributions, decreased growth, reproduction, survival, disruption of life cycles, and altered behavior (Figure 2).

The deoxygenation effects on individuals in coastal waters significantly impact population productivity and have cascading effects on capture fisheries and aquaculture. These effects affect fisheries through negative effects on growth, survival, and reproduction, influencing biomass and harvestable yield, and the altered movement affects their availability to harvest. A predominant effect of deoxygenation is the shifts in fishing locations in response to small-scale distribution changes of target species due to their attempt to avoid exposure to hypoxia, which then impacts the catch capacity, efficiency, and bioeconomics of the fishery (Rose et al., 2019).

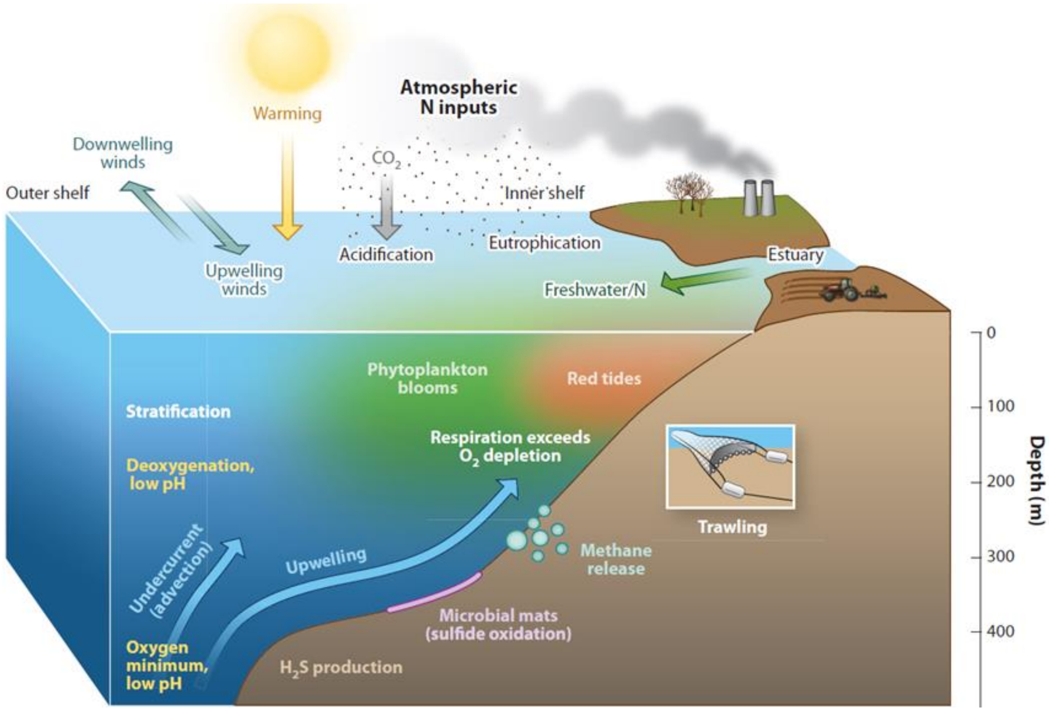

Figure 2. Interaction of climate change and eutrophication on deoxygenation in the EBUS coastal areas (Levin & Sibuet 2012).

Finfish and shellfish aquaculture are also especially vulnerable to deoxygenation, as the animals are confined within nets or structures that prevent them from escaping to areas with higher oxygen levels. Evidence for contained organisms' inability to avoid exposure is that arthropods and mollusks caught in traps face high mortality rates when oxygen concentrations drop (Grantham et al., 2004). However, aquaculture itself can also contribute to deoxygenation. Densely-stocked animals consume oxygen through respiration, while microbial decomposition of excess fish feed and waste further depletes oxygen. In areas with limited water circulation, these factors can lead to substantial drops in oxygen levels within the local zone of influence of the nets or structures (Rice, 2015; Sun et al., 2023).

2. The pre-workshop assessment

To assess the current capacities on coastal oxygen monitoring and hypoxia detection among APEC economies, an online survey was designed using Google Forms (link here) as part of a pre-workshop assessment and distributed throughout the Ocean Fisheries Working Group (OFWG). The main topics covered in this survey were the current situation and challenges involved in coastal oxygen monitoring, the kinds of storage and quality control applied to oxygen data, the availability of water quality standards on dissolved oxygen, and metrics developed to evaluate habitat conditions for living marine resources.

Representatives from eleven economies filled out the survey form and nine of them appointed their nominees for the workshop. The survey consisted of 28 questions (Annex 2) and the main results were:

i) Most economies reported events and/or increasing trends of low dissolved oxygen in their coastal waters (Figure 3).
ii) Oxygen loss represents a significant issue for fisheries, aquaculture, biodiversity, and water quality in APEC economies (Figure 4).
iii) Dissolved oxygen in the coastal waters of APEC economies is being monitored, but there are differences in data treatment, usage, and information management (Figures 5 and 6).
iv) About half of the participating economies use coastal hypoxia metrics to assess the living resources habitats (Figure 7).

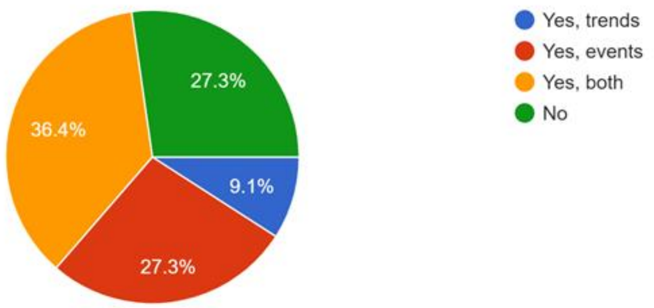

Figure 3. Percentages of 11 respondent economies to the question: have your coastal environments undergone trends (long-term changes) or events (episodes) of low dissolved oxygen?

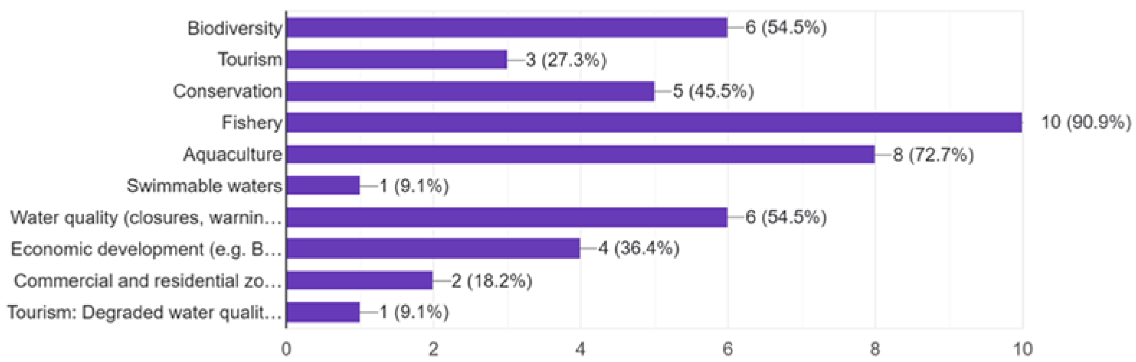

Figure 4. Percentages of 11 respondent economies to the question: to which of the following sectors is the oxygen loss issue relevant in your economy?

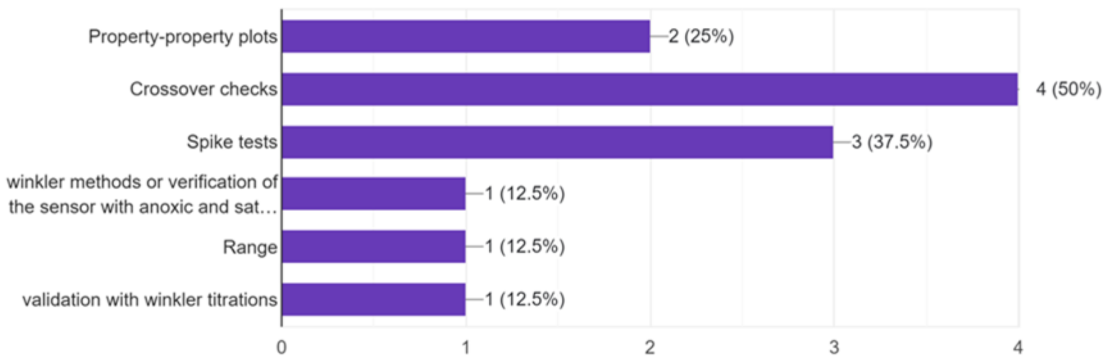

Figure 5. Percentages of 8 respondent economies to the question: which types of quality checks do you perform to oxygen data before storage?

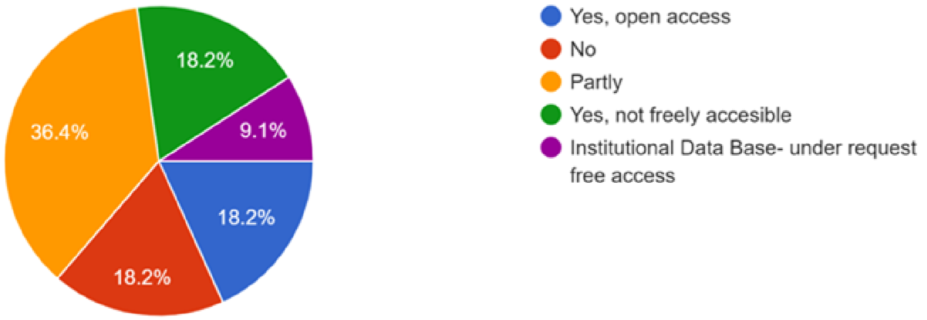

Figure 6. Percentages of 11 respondent economies to the question: Do you store your oxygen data in institutional or international databases?

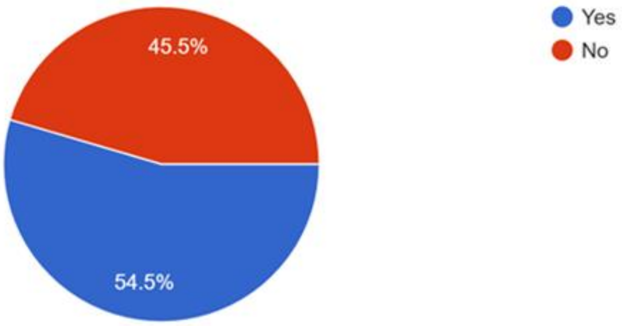

Figure 7. Percentages of 11 respondent economies to the question: Are there metrics related to coastal hypoxia, for supporting the assessment of habitat conditions of marine living resources, in your economy?

3. The workshop and activities within the project to promote best practices

The workshop of the OFWG 201 2023 project "Developing best practices to address coastal marine oxygen loss in APEC economies for improving the management of marine living resources", was organized by IMARPE and held in Paracas, Peru. The project was sponsored by the following APEC economies: Canada, Chile, China, Russia, Viet Nam, and Chinese Taipei; and the workshop welcomed participants with encouraged gender balance, from Chile, China, Malaysia, Mexico, Peru, Russia, Thailand, USA, and Viet Nam (Table 1, Figure 8).

Table 1. Summary table of workshop participation.

Participants	# male	# female	Total
Total of nominees	8	6	14
Total of experts/speakers	1	2	3
Total	9	8	17
Participants (excluding speakers and contractors)			14

Opening and keynote lectures

The workshop in Paracas was inaugurated on September 30th with opening remarks from Peru's OFWG focal point and IMARPE's Director of Research in Oceanography and Climate Change. The event covered the project's background, objectives, and expected outcomes, focusing on implementing and sustaining oxygen monitoring for fisheries and aquaculture. The workshop activities were outlined, and keynote speakers introduced (Figure 9).

The keynote lectures covered fisheries management in the context of ocean deoxygenation and climate change, emphasizing decision-making and regulation. They also explored water quality standards using the U.S. EPA as a case study, detailing oxygen thresholds for Chesapeake Bay aquaculture (Figure 10). Subsequent talks focused on oxygen data management, stressing monitoring trends, validation, and spatial mapping (Annex A2). The case of deoxygenation in the Gulf of Mexico was shown, highlighting biological indicators, oxygen thresholds, fisheries impacts, and the role of experiments and models in assessing hypoxia vulnerability under climate change (Annex A3).

An invited talk entitled “Initiative for a Global Ocean Oxygen Database and Atlas (GO_2DAT Project) to assess deoxygenation and ocean health in open and coastal waters” was delivered (Annex A4). The need for high-quality data to monitor ocean deoxygenation and the heterogeneous situation of procedures, such as data flagging and quality control in databases, were highlighted. In this talk, the first-level products of GO_2DAT were mentioned as integrating Winkler observations of dissolved oxygen from different databases, the second level includes CTD sensor data, while the third and fourth levels include oxygen data from Argo buoys and gliders, respectively.

In this way, these keynote lectures provided workshop participants not only with theoretical knowledge about the issue of coastal deoxygenation and its relationship with factors such as climate change and eutrophication but also with examples of the development of monitoring and management of oxygen data, indicators, water quality standards, impact thresholds, experiments, and models.

Figure 8. Workshop participants in the event opening.

Figure 9. Presentation of background and goals of the workshop.

Figure 10. Keynote lecture of the workshop.

Practical activities

Workshop participants visited IMARPE Pisco's coastal laboratory for a hands-on demonstration of oxygen data collection using sensors, profilers, and the Winkler titration method. They also observed an experimental setup for assessing the Peruvian scallop's respiration (*Argopecten purpuratus*) under low oxygen conditions (Figure 11).

Subsequently, and divided into groups, participants analyzed and visualized recorded data, comparing results from different methods of collecting samples. A discussion between the groups on the differences in the recorded dissolved oxygen was held, highlighting the different volumes and depth level of water in which measurements were made, using both sampling bottles and probes, as likely origins of data differences. The groups also explored basic quality control, processing and analysis of both the practical demonstration data and historical time series from Paracas Bay. Thus, they recognized the importance of applying simple control such as data range checks on raw oxygen data for identifying outliers and errors in collected data, as well as of processing oxygen time series through temporal decomposition—for exploring dissolved oxygen variability in diurnal and seasonal time scales—and analysis of data trends.

Figure 11. Practical demonstration at the IMARPE-Paracas facilities.

Discussion of case studies and roadmap

A roundtable discussion examined case studies on coastal oxygen monitoring and hypoxia in the Changjiang Estuary (China), the northern Gulf of Mexico (USA), and Paracas Bay (Peru) (Annex A6). The Changjiang Estuary case highlighted seasonal hypoxia, the role of monitoring and modeling nutrient reduction, and the impact of tropical cyclones on fisheries. The Gulf of Mexico case focused on Mississippi River-driven hypoxia, monitoring systems identifying affected zones, and data supporting nutrient reduction efforts. The Paracas Bay case emphasized natural hypoxia drivers, IMARPE's monitoring system, wind variability's role, and impact indices for local benthic resources like the scallop *Argopecten purpuratus* (Figure 12).

Subsequently, the workshop outlined expected outcomes and the motivation for drafting a roadmap to implement and sustain oxygen monitoring for fisheries and aquaculture in the APEC economies. Participants brainstormed challenges, opportunities, and best practices. Finally, roadmap ideas were presented, including its purpose and strategy. Participants discussed in groups about oxygen data—its quantity, quality, availability, and protocols—and case studies, focusing on fisheries, aquaculture, species affected by hypoxia, and aquaculture's future role in addressing hypoxia (Annex A7 and A8).

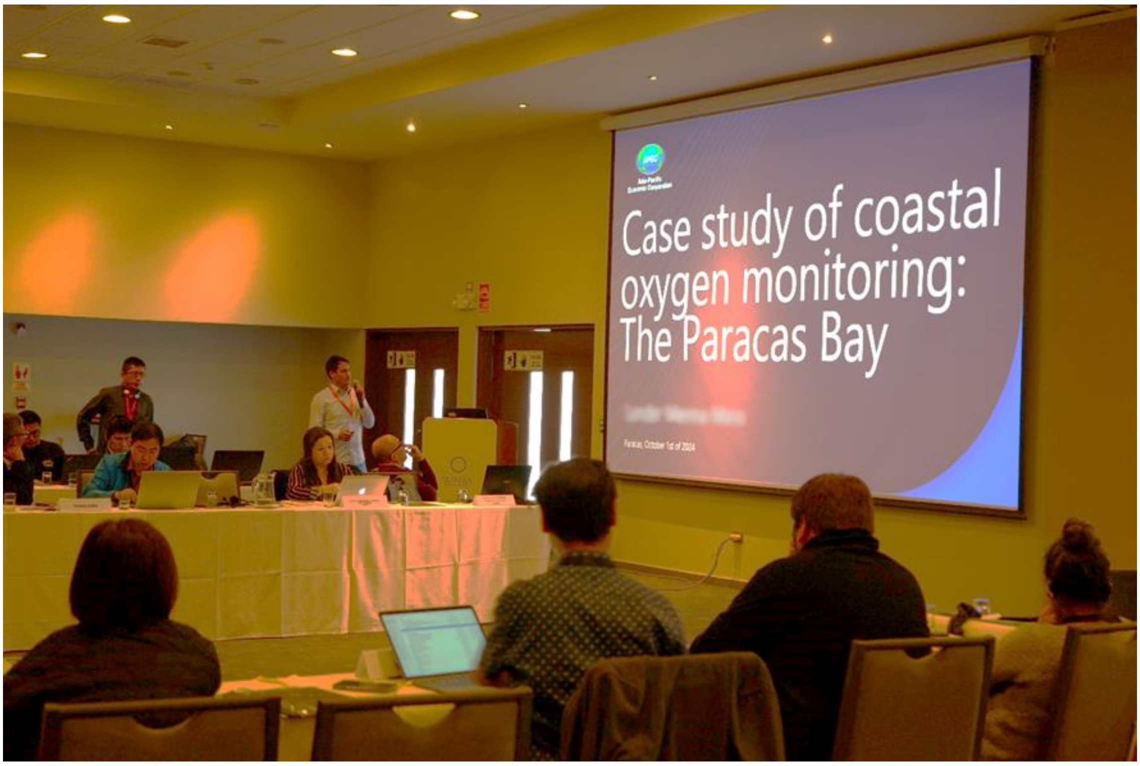

Figure 12. Presentation of the case study of Paracas Bay.

Complementary actions in the project

After the workshop, complementary actions to enhance the current state of oxygen monitoring and its applications to fisheries and aquaculture in APEC economies were considered during the project period. The following actions were proposed to contribute to the implementation of best practices in oxygen monitoring in coastal waters where fishing and aquaculture activities are held:

- Hosting an online webinar to improve data quality and consistency of oxygen determinations among APEC economies, focusing on training in data management, metadata preparation, standardization and documentation of protocols, and data quality control procedures.
- Organizing an online workshop for exchanging monitoring and research experiences, particularly for fishery and aquaculture applications, such as using the data to develop exposure metrics and considerations of hypoxia's spatial and temporal scales relative to fisheries and aquaculture activities.

4. Building the roadmap

Motivation and goal

The roadmap is motivated by the need to improve management, adaptation, and sustainable practices in marine fisheries and aquaculture in coastal waters by considering their vulnerability to deoxygenation driven by eutrophication and climate change. In this regard, the primary goal of this roadmap is to establish, optimize, and sustain robust oxygen monitoring systems for fisheries and aquaculture in the APEC economies.

Considering these, the roadmap focuses on developing and applying indices to assess exposure to low-oxygen conditions, hypoxia sensitivity, and adaptive capacity of coastal fisheries, aquaculture, and living resources.

The roadmap

This roadmap considers the APEC's basic principles of equality among its members and consensus-based decision-making. It can be divided into implementing actions in the short and medium/long term.

<u>In the short term (outcomes within 1 to 2 years):</u>

A. Establishing a partnership for Coastal Oxygen Loss and its impacts on Fisheries and Aquaculture

A scientific partnership among APEC economies would facilitate the articulation of efforts to implement and maintain best practices and capacities for oxygen monitoring and hypoxia detection, focusing on fisheries and aquaculture applications. Furthermore, efforts should be made to strategically link this partnership with UN Ocean Decade endorsed projects to leverage the experience of global and regional synergies.

Objective: Create a scientific partnership among APEC economies to address coastal oxygen depletion and its effects on fisheries and aquaculture.

Actions:

- Submit a letter of interest by the APEC economies to the Ocean and Fisheries Working Group to establish the partnership, involving a working group with scientists and policymakers, tasked with defining its goals and objectives.
- Develop a framework to share knowledge and data across APEC economies, focusing on the application of monitoring systems in areas with existing or possible future usage by fisheries and aquaculture.

Expected outcome:

A significant outcome of this partnership might be the joint proposal to international programs (e.g., GEF) under the UN Ocean Decade framework to raise funds for enhancing building capacities to improve oxygen data management and apply it to fisheries and aquaculture among APEC economies.

B. Scientific communication and ocean literacy

Because coastal deoxygenation threatens biodiversity and the productivity of fisheries and aquaculture, there is a need to deliver effective information to stakeholders within the coastal areas of APEC economies. While the scientific partnership would promote communication between experts (see above), the scientific information should be translated and delivered to managers and policymakers, enabling them to leverage knowledge in decision-making. Communication with stakeholders is also critical for effective management, and concepts from the co-production of knowledge would be considered.

Objective: Increase public awareness of the effects of coastal deoxygenation on food security and well-being.

Actions:

- Launch targeted outreach programs.
- Conduct webinars and workshops, and consider co-production methods, engaging stakeholders.
- Develop flyers for managers and policymakers to create an ocean-literate community.

Expected outcome:

An outcome of this activity is the distribution of brochures and establishing guidelines with stakeholders and managers about explicit consideration of deoxygenation in fisheries and aquaculture management and policy.

In the medium and long term (outcomes within 2 to 3 years):

C. Data management

Objective: Improve data accessibility and integration to enable better management and responses to coastal deoxygenation.

Actions:

- Align local data collection with the FAIR principles (Findable, Accessible, Interoperable, and Reusable).
- Encourage sharing local databases with global platforms such as GO2DAT to support advanced research on coastal deoxygenation changes and trends and support management assessments.

Expected outcome:

An integrated database of coastal dissolved oxygen among APEC economies that follow international standards and FAIR principles.

D. Collaborative research

Objective: Promote multidisciplinary and transdisciplinary research to study the impact of deoxygenation on fisheries and aquaculture.

Actions:

- Implement collaborative studies of climate vulnerability and habitat suitability involving low-oxygen for the APEC economies' fishery and aquaculture living resources.
- Develop indices (metrics) to quantify hazards, exposure, and vulnerability of coastal fisheries, aquafarms, and the related socio-ecological systems with a transdisciplinary approach.

Expected outcomes:

A web portal with synthesized data, insights, and lessons learned on oxygen monitoring and its impacts on fisheries and aquaculture, as well as briefings and outlines for effective management strategies.

A workshop to develop and apply appropriate metrics to quantify hazards, exposure and vulnerability of coastal fisheries and aquafarms related to low-oxygen conditions or events.

E. Early warning and risk assessments

Objective: Develop, design, test, and implement risk assessments and early warning systems for coastal deoxygenation events and related extreme events (e.g. HABs).

Actions:

- Encourage and facilitate the development of early warning systems of low-oxygen, and other extreme events like harmful algal blooms, using in situ oxygen measurements, satellite data, and numerical modelling.
- Promote collaboration among scientists, government personnel, and stakeholders to design and test warning systems.
- Foster active collaboration with local managers and stakeholders to address low-oxygen hazards through tailored risk assessments, capacity-building initiatives, and the co-creation of adaptive management strategies that integrate scientific insights with local knowledge and priorities.

Expected outcome:

Implement a pilot program for testing early warning options for coastal deoxygenation events in selected sites of the APEC economies.

6. Conclusions

Regarding the project's first expected outcome:

With nine APEC economies contributing through surveys and domestic reports, the workshop highlighted differences in capacities for collecting, processing, and analyzing dissolved oxygen data across the Pacific basin's coastal waters.

The workshop successfully met its goal of providing both theoretical and practical knowledge on best practices for detecting and monitoring hypoxia in marine-coastal areas. This knowledge aims to enhance fisheries and aquaculture management, benefiting participants from APEC economies.

Regarding the project's second expected outcome:

The event opened opportunities to foster cooperation among APEC economies in the areas of dissolved oxygen monitoring, data analysis, and interpretation, and the development of indices to assess the impacts of hypoxia on fisheries and aquaculture within the broader global context of coastal water deoxygenation.

The collaborative development of a roadmap to optimize dissolved oxygen monitoring and data management underscores strengthened cooperation and knowledge transfer among participating economies.

The roadmap prioritizes collaboration among APEC economies to address coastal oxygen loss through scientific partnerships and capacity building. It outlines short-term goals like promoting ocean literacy, and long-term goals such as advancing research, data management, and early warning systems.

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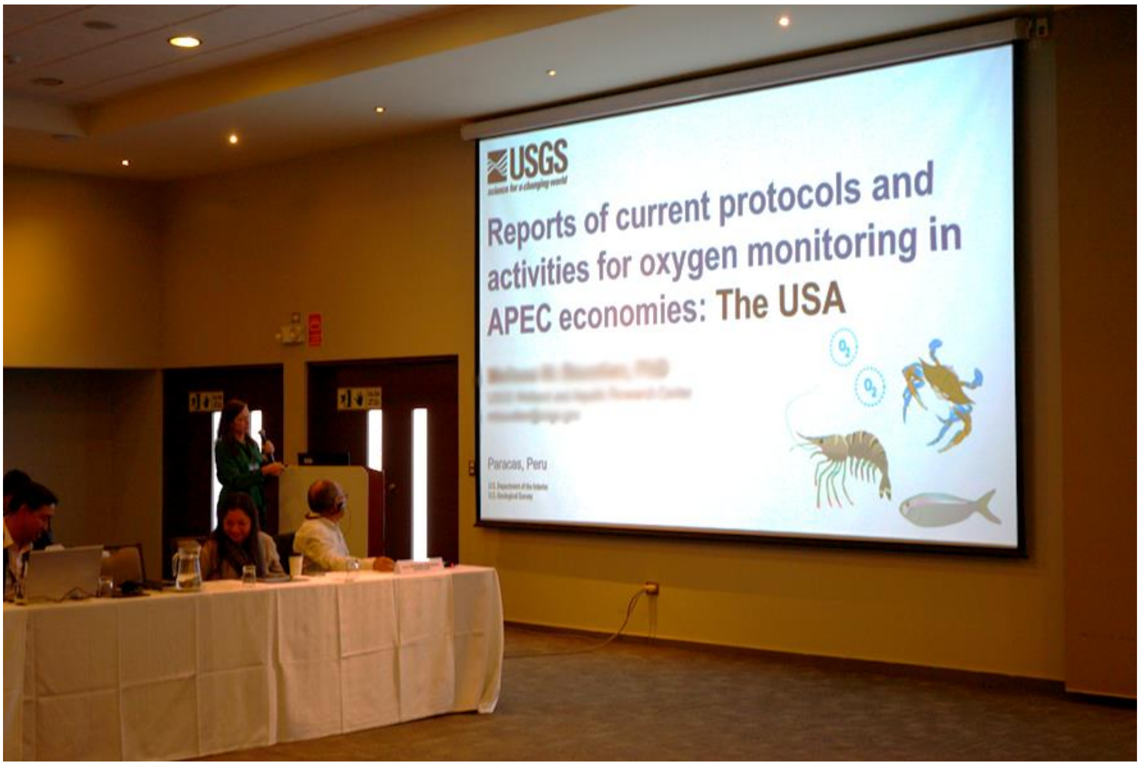
8. Annexes

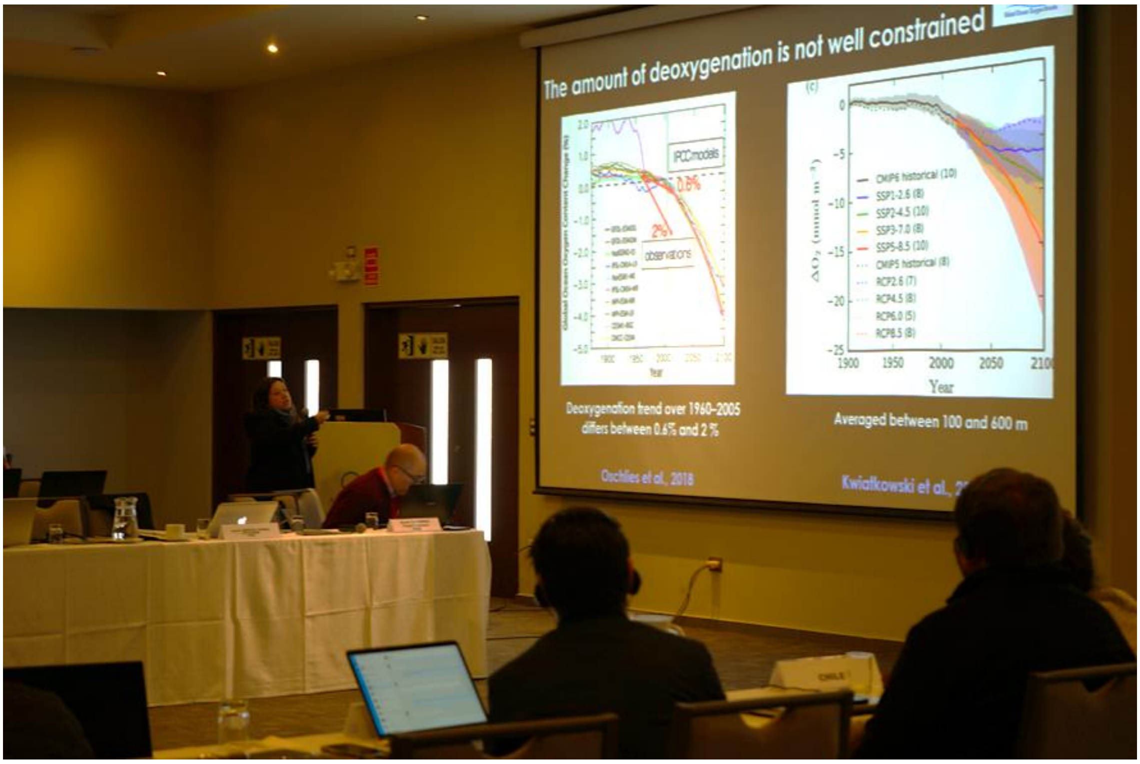
Annex 1. Pictures of the workshop

A1. Workshop opening outdoors.

A2. Keynote lecture on oxygen data management.



A3. Keynote lecture on biological indicators of deoxygenation.



A4. Invited talk from GO_2DAT.

A5. Presentation of the background of experimental studies of IMARPE.

A6. Discussion of case studies.

A7. Discussion to outline a roadmap.

A8. Roadmap discussion in groups.

Annex 2. The online survey form and responses

Survey of the Project “Best practices to address coastal marine oxygen loss in APEC economies”

11 responses

Publish analytics

1. Economy

11 responses

Hong Kong, China

Thailand

Viet Nam

USA

Chile

PERU

RUSSIA

Japan

MALAYSIA

México

CHINA

2. Full name of focal point / specialist

11 responses

3. E-mail:

11 responses

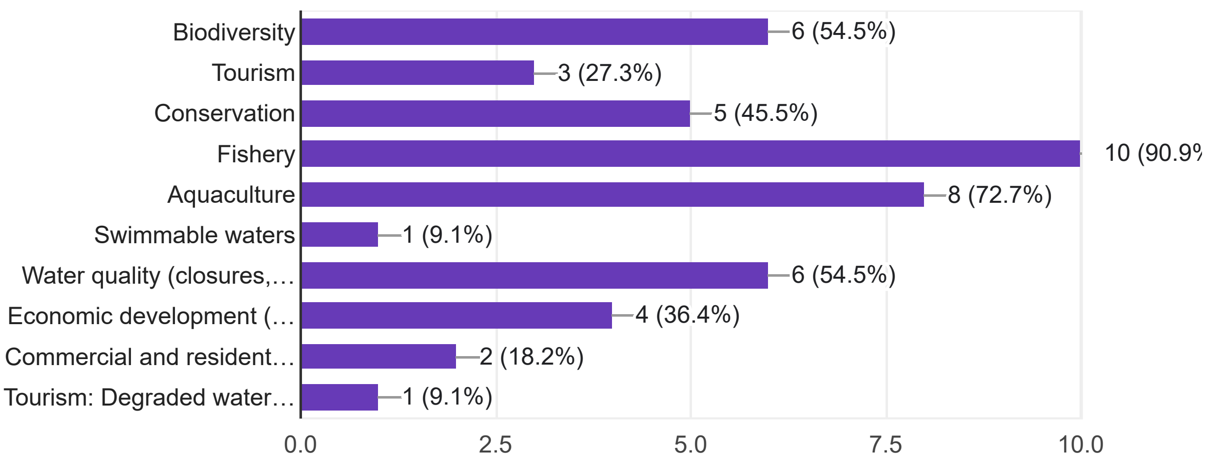
4. Institutional affiliation

11 responses

5. To which of the following is the oxygen loss issue relevant in your Economy?

Copy

11 responses



6. Are you currently measuring dissolved oxygen in open ocean and/or coastal waters?

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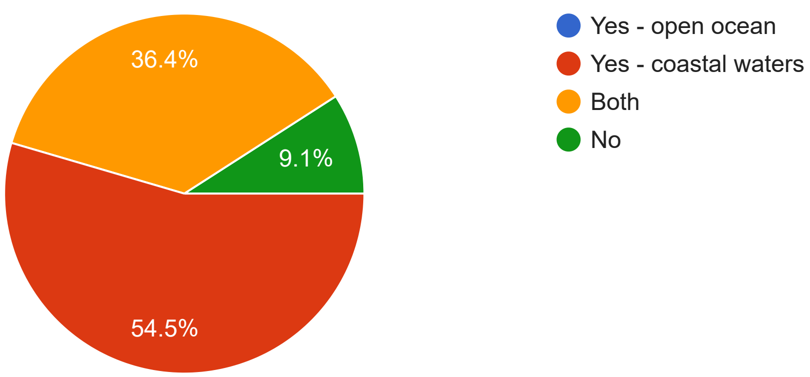
11 responses



7. In case of open ocean, indicate the ocean basin(s) and seas you are measuring dissolved oxygen in

6 responses

Gulf of Thailand, Andaman Sea

Pacific Ocean Basin: Specifically, the Western Pacific Ocean, which lies off the eastern coast of Viet Nam. South China Sea: This sea is a marginal sea of the Pacific Ocean and borders Viet Nam to the east. It is one of the key areas where Viet Nam might be measuring dissolved oxygen, especially in the context of coastal and nearshore waters.

Along the Peruvian Pacific Waters

Indian Ocean

NA

Northern Indian ocean, Northeastern Pacific Ocean

8. In case of coastal waters, indicate the coastal environment you are measuring dissolved oxygen in.

10 responses

Designated fish culture zones in Hong Kong waters

Gulf of Thailand, Andaman Sea

Mangroves: Viet Nam has extensive mangrove forests, particularly in the Mekong Delta region, where dissolved oxygen levels are important for maintaining the health of these ecosystems. Coral Reefs: Coastal waters around areas like Nha Trang and the Con Dao Islands contain coral reefs, which are sensitive to changes in oxygen levels. Estuaries and River Mouths: Locations where major rivers, such as the Mekong and the Red River, meet the sea are critical for monitoring dissolved oxygen due to the mixing of fresh and saltwater and the potential for nutrient loading and pollution. Lagoons: Coastal lagoons, like the Tam Giang-Cau Hai Lagoon in Central Viet Nam, are important for biodiversity and aquaculture and require monitoring of dissolved oxygen levels. Seagrass Beds: These are found in shallow coastal waters and play a vital role in carbon sequestration and supporting marine life. Monitoring oxygen levels here is essential. Coastal Bays: Areas such as Ha Long Bay and Cam Ranh Bay are significant for both ecological and economic reasons, including tourism and fisheries, making them key sites for monitoring dissolved oxygen.

northern Gulf of Mexico

Southern fjord and channel system

Coastal areas, as Callao, Paracas Bay and other coastal-marine systems

Japanese sea

Malacca Strait and South China Sea

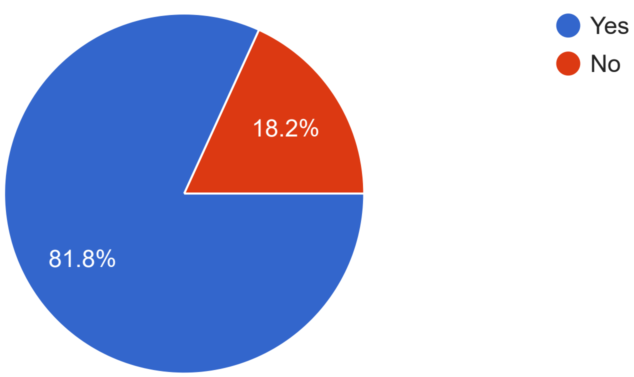
Bahía de Mazatlán and Estero de Urías, Sinaloa, México.

Coastal seas in China, including Bohai Sea, East China Sea and South China Sea

9. Is there any governmental institution in your Economy that performs dissolved oxygen measurements?

Copy

11 responses



If yes, provide a URL.

9 responses

https://www.afcd.gov.hk/english/fisheries/fish_aqu/fish_aqu_env/fish_aqu_env.html

https://www.pcd.go.th/water/

Viet Nam Environment Administration (VEA): Under the Ministry of Natural Resources and Environment (MONRE), the VEA is responsible for monitoring and managing environmental quality, including water quality assessments, which involve measuring dissolved oxygen levels in various water bodies. Institute of Oceanography (Nha Trang): This institute, under the Viet Nam Academy of Science and Technology (VAST), conducts extensive research on marine and coastal environments, including the monitoring of dissolved oxygen as part of its oceanographic studies. Domestic Center for Water Resources Planning and Investigation (NAWAPI): Also under MONRE, NAWAPI is involved in water resources management and monitoring, including the assessment of water quality parameters like dissolved oxygen in rivers, estuaries, and coastal waters. Research Institute for Marine Fisheries (RIMF): Operating under the Ministry of Agriculture and Rural Development (MARD), RIMF conducts research and monitoring related to marine resources, including dissolved oxygen measurements in areas relevant to fisheries. Provincial Departments of Natural Resources and Environment (DONREs): These local governmental agencies are responsible for environmental monitoring at the provincial level, including the assessment of water quality in coastal and inland waters, where dissolved oxygen is a key parameter.

https://chonos.ifop.cl/

IMARPE (Instituto del Mar del Perú) https://www.gob.pe/imarpe

http://tinro.vniro.ru/ru/

Sorry that I cannot check now, but at least JMA has been observing oxygen along 137E

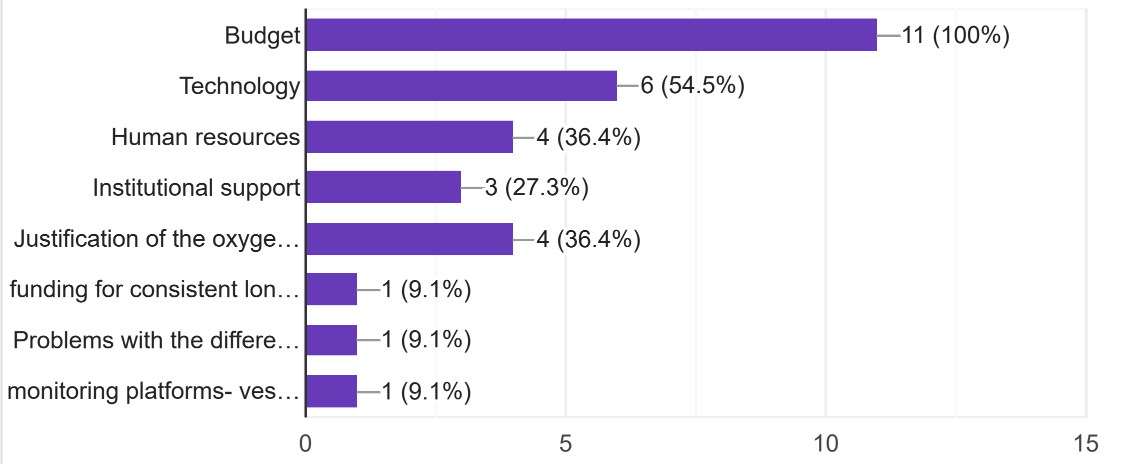
https://www.doe.gov.my/

Department of Early Warning and Monitoring, Ministry of Natural Resources, and relevant institutions. https://www.mnr.gov.cn/sj/sjfw/hy/gbgg/

10. What aspect of your current capacities makes it challenging to establish or sustain coastal oxygen monitoring?

Copy

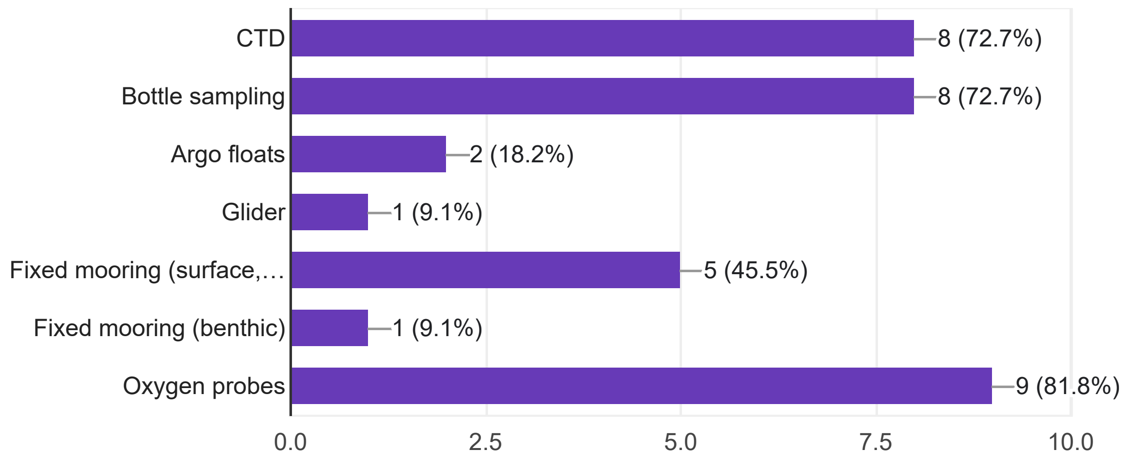
11 responses



11. Which kind of platform are you using to measure dissolved oxygen in coastal waters?

Copy

11 responses



12. Provide the reference(s) of the Standard Operating Procedure/ Protocol/ Best Practices that describe the methodology you use for ocean oxygen measurements.

11 responses

in-situ multiparameter instrument is used

Method of Seawater Analysis, A Practical Handbook of Seawater Analysis

The Global Ocean Observing System (GOOS) - Best Practices: GOOS provides best practices for ocean observations, including the measurement of dissolved oxygen. This includes detailed methodologies for using CTD sensors, oxygen probes, and other monitoring platforms. UNESCO’s Intergovernmental Oceanographic Commission (IOC) Manuals and Guides No. 56 - "Guide to Best Practices for Ocean CO2 Measurements": While focused on CO2, this guide includes methodologies for related parameters, including dissolved oxygen, and is a key reference for oceanographic research. American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater: This comprehensive manual includes methods for measuring dissolved oxygen in both freshwater and marine environments, using techniques such as Winkler titration and electrochemical probes. The World Ocean Circulation Experiment (WOCE) Operations Manual: This manual includes protocols for measuring dissolved oxygen in oceanographic research, including sampling methods and sensor calibration procedures. U.S. Environmental Protection Agency (EPA) - "Methods for the Determination of Dissolved Oxygen in Seawater": This provides standardized procedures for the determination of dissolved oxygen in marine environments, particularly in coastal waters.

https://gulfhypoxia.net/research/shelfwide-cruises/

Winkler method Bottle sampling

Protocol- Chemistry Laboratory from the Oceanographic and Climate Change DirectionResearch

Winkler method

JOS oceanographic measurement guideline

Standard Methods for the ExaAmerican Public Health Association (APHA)

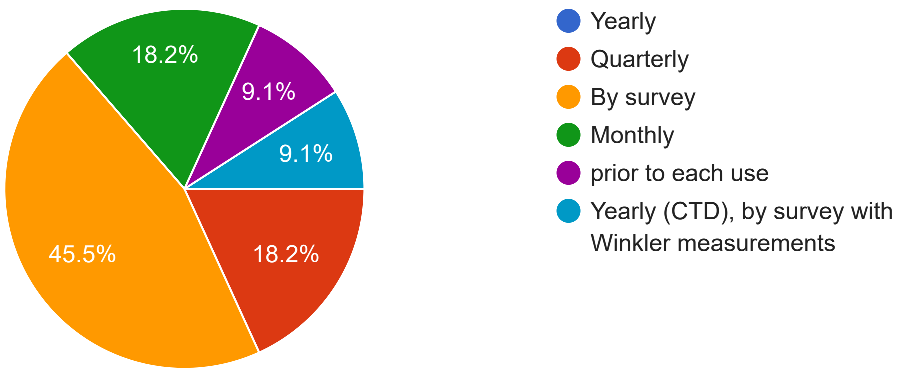
NA

1. Winkler, L.W. (1888). Die Bestimmung des in Wasser gelösten Sauerstoffen. Berichte der Deutschen Chemischen Gesellschaft, 21: 2843–2855. 2. Strickland, J.D.H., and Parsons, T.R. (1968). Determination of dissolved oxygen. in A Practical Handbook of Seawater Analysis. Fisheries Research Board of Canada, Bulletin, 167, 71–75. 3. Marine Survey Specification Part IV: Investigation of Seawater Chemical Elements GB/T 12763.4-2007. (In Chinese)

13. If you use an instrument to measure coastal dissolved oxygen, how often do you calibrate it?

Copy

11 responses



14. How long have you been monitoring dissolved oxygen in your coastal waters?

11 responses

over 20 years

Over 30 years

governmental institutions and research organizations have been monitoring dissolved oxygen in coastal waters for several decades. The monitoring efforts likely began in the late 20th century, coinciding with increasing environmental awareness and the need for data to support sustainable fisheries, aquaculture, and coastal management.

39 years by my colleagues

10 years

Several years (Callao from 1996, Paracas Bay 2004 and monitoring since 2013- Paita, Chicama2004)

More then 20 years

N/A

5 years

8 years

More than 40 years through scientific survey. In recent years, we established the routine monitoring system including spring, summer and autumn, supported by Department of Early Warning and Monitoring, Ministry of Natural Resources, and relevant institutions.

15. What frequency of dissolved oxygen measurements have you established on your current monitoring?

11 responses

monthly basis

monthly

capture real-time data. Monthly or Quarterly Measurements: Routine environmental monitoring programs might measure dissolved oxygen on a monthly or quarterly basis, allowing for the assessment of seasonal changes and long-term trends. Seasonal Surveys: In some regions, especially those impacted by seasonal changes like the monsoon, measurements might be conducted seasonally to capture variations related to these changes. By Survey: Specific research projects or environmental assessments might conduct measurements during targeted surveys, which could occur annually or more frequently depending on the study's goals.

annual summer shelf-wide cruises

seasonal and some data for six-month periods. Currently, we have some monitoring stations online, approximately 2 years.

Bimonthly in Callao, Paracas Bay oxygen probes, Paita Chicama monthly

Regularly, every week, from May to October

N/A

twice a year

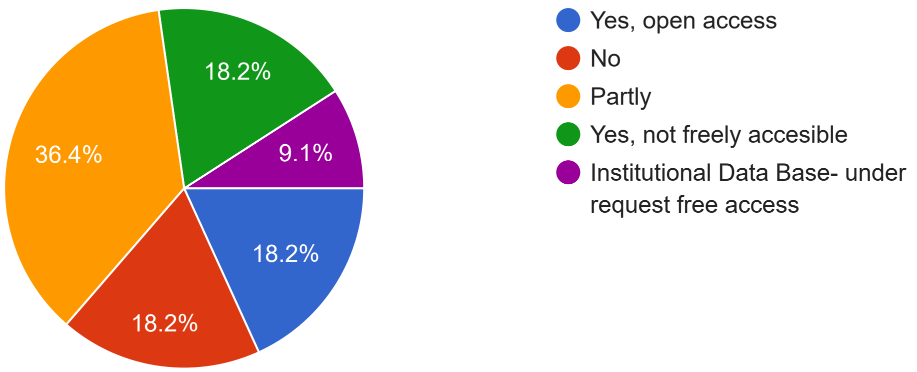
Monthly

Routine monitoring system covers three seasons, including spring, summer and autumn, For Changjiang Estuary and adjacent East China Sea, we carried out the additional summer monitoring, Including survey (ctd and bottle sampling) and mooring systems.

16. Are your ocean oxygen data stored in an institutional database, Domestic Oceanographic Data Centre, international or regional data center?

Copy

11 responses



17. If you answered yes or partly to the question above, please provide the URL(s) to the respective data center(s)

6 responses

https://www.dmcr.go.th/detailLib/6015

https://data.griidc.org/data/R4.x264.000:0033

https://chonos.ifop.cl/ and https://www.ifop.cl/en/busqueda-de-informes/

JODC

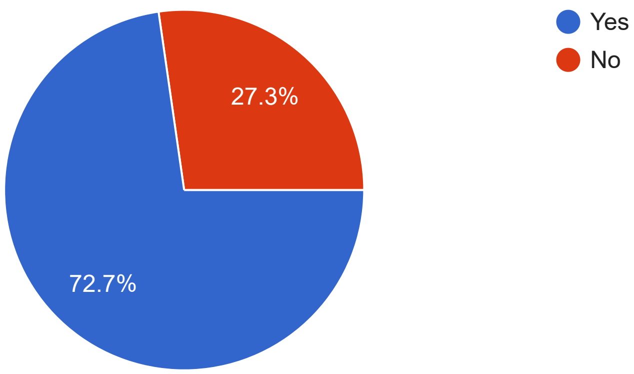
http://uninmar.icmyl.unam.mx/tulum

Domestic Marine Data Center https://mds.nmdis.org.cn/pages/home.html

18. Do you conduct any quality checks before submitting the data to a data center?

Copy

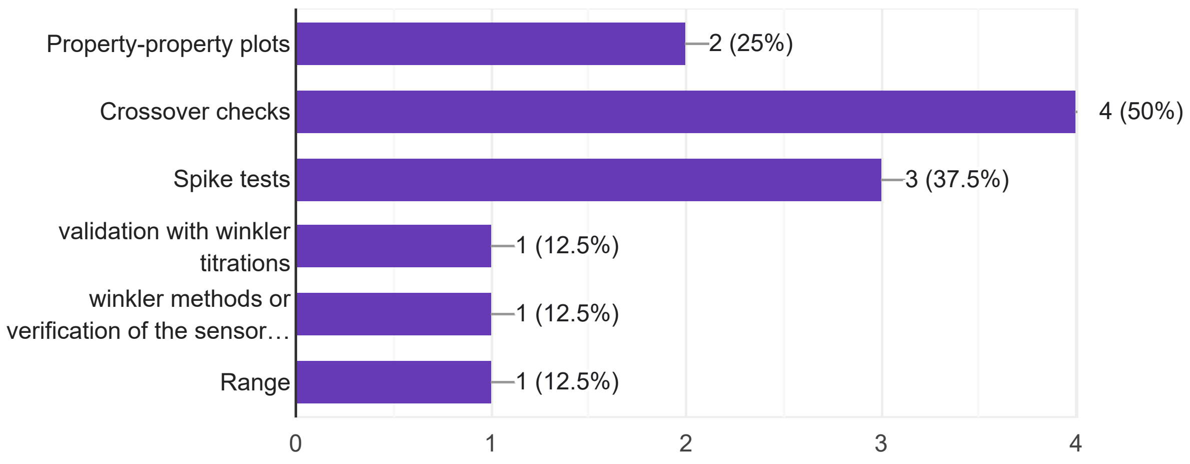
11 responses



19. If you answered yes to the previous question, which quality checks do you conduct?

Copy

8 responses



20. Please provide the reference(s) for the applied quality checks

11 responses

N/A

Standard methods for examination of water and waste-water

In Viet Nam, specific references for quality checks like spike tests might not always be available as publicly accessible documents, particularly if they are internal protocols of certain institutions. However, general references for conducting spike tests as part of data quality control in oceanographic and environmental monitoring include: UNESCO/IOC Manuals and Guides No. 54, "The GO-SHIP Repeat Hydrography Manual: A Collection of Expert Reports and Guidelines": This manual outlines various quality control procedures, including spike tests, for hydrographic data, which can be applied to dissolved oxygen measurements. The World Ocean Circulation Experiment (WOCE) Operations Manual: This manual provides detailed procedures for conducting quality checks, including spike tests, on oceanographic data. Global Ocean Observing System (GOOS) Best Practices: GOOS guidelines and best practices include recommendations for quality control procedures, including the use of spike tests to ensure data accuracy.

https://data.griidc.org/data/R4.x264.000:0033

In order to make corrections to possible drifts or deviations that the CTD or the multiparameter probe may present, seawater samples are taken simultaneously at standard depths, which are analyzed by the Winkler method, and then corrections are made to the measurements.

CDO protocols

Not available

JOS oceanographic measurement guideline

American Public Health Association, American Water Works Association, & Water Environment Federation. (2017). Standard Methods for the Examination of Water and Wastewater (23rd ed.). APHA Press.

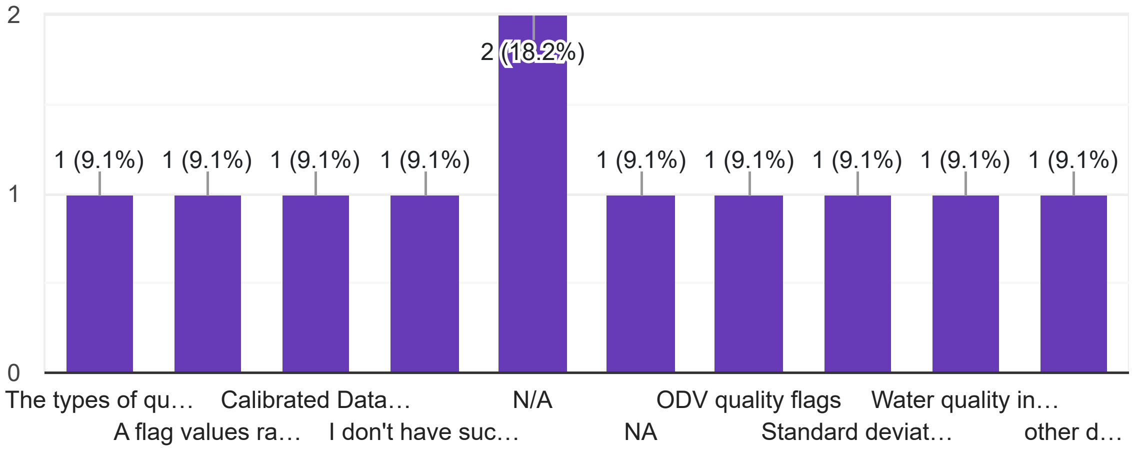
NA

1. Strickland, J.D.H., and Parsons, T.R. (1968). Determination of dissolved oxygen. in A Practical Handbook of Seawater Analysis. Fisheries Research Board of Canada, Bulletin, 167, 71–75. 2. Marine Survey Specification Part IV: Investigation of Seawater Chemical Elements GB/T 12763.4-2007. (In Chinese)

21. In case relevant, please let us know which type of quality flags do you use?

Copy

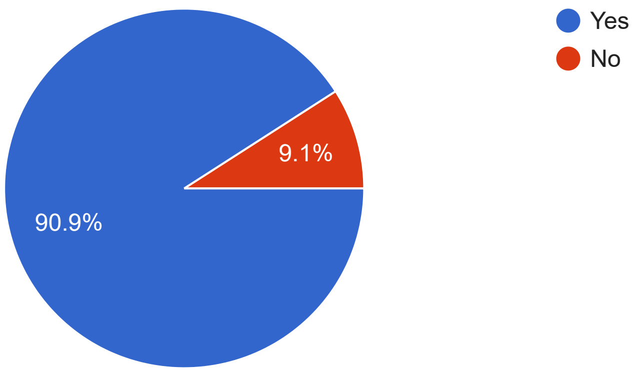
11 responses



22. Are there water quality standards on dissolved oxygen concentrations in your Economy?

Copy

11 responses



If yes, provide a reference.

10 responses

Water Quality Objectives

https://www.pcd.go.th/laws/15123/

Viet Nam has established water quality standards that include dissolved oxygen (DO) concentrations. These standards are set by the Vietnamese government to ensure the protection of aquatic ecosystems, human health, and the sustainability of fisheries and aquaculture.

The key regulations that outline these standards include:

QCVN 08-MT:2015/BTNMT - Domestic Technical Regulation on Surface Water Quality: This regulation specifies the allowable concentrations of dissolved oxygen in surface waters, which vary depending on the water use classification (e.g., drinking water supply, aquatic life protection, recreation).

For example, for Class A1 (surface water used for domestic water supply with simple treatment), the standard for dissolved oxygen is generally ≥ 6 mg/L.
For Class A2 (water used for domestic supply but with more advanced treatment), the standard is ≥ 5 mg/L.
QCVN 10-MT:2015/BTNMT - Domestic Technical Regulation on Coastal Water Quality: This regulation sets standards for dissolved oxygen in coastal waters, which are critical for maintaining healthy marine ecosystems and supporting aquaculture.

Typically, the required dissolved oxygen concentration for coastal waters is ≥ 5 mg/L.
These standards are enforced by the Ministry of Natural Resources and Environment (MONRE) and are part of Viet Nam's broader efforts to manage and protect its water resources. Compliance with these standards is mandatory for various industries and activities that impact water quality, including wastewater discharge, aquaculture, and industrial operations.

Hypoxia Task Force has a goal to reduce the area of low dissolved oxygen.
https://www.epa.gov/ms-htf/hypoxia-task-force-action-plans-and-goal-framework

Oxígeno disuelto (OD) % saturación 90

ECAS (from Canada) for environmental- poluttion monitoring

more than 4 mg/l

https://doe.gov.my/wp-content/uploads/2021/11/Standard-Kualiti-Air-Kebangsaan.pdf

NA

The seawater quality evaluation adopts the "Seawater Quality Standard" (GB3097-1997) (in Chinese).

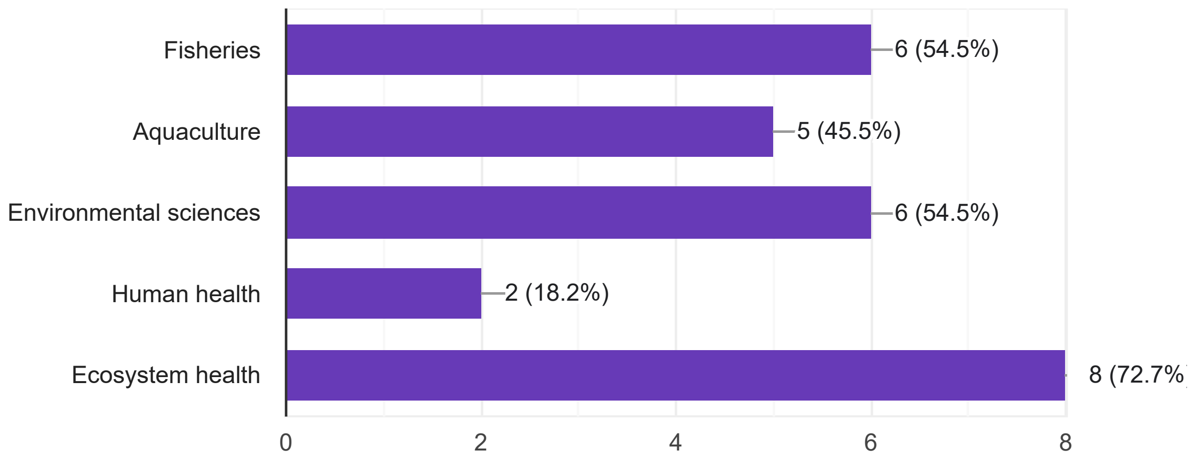
For Dissolved Oxygen(DO) more than 6 mg/L, it is evaluated as the Grade I for seawater. And 5, 4, 3 for grade II,
Grade III and Grade IV.

Classification of seawater quality in China is as follows:
According to the different use functions and protection objectives of the sea area, the water quality is divided into four categories:
The first category(Grade I) applies to marine fishery waters, marine nature reserves and protected areas for rare and endangered marine life.
The second category (Grade II) applies to aquaculture areas, bathing beaches, marine sports or recreation areas where the human body is in direct contact with seawater, and industrial water areas directly related to human consumption.
The third category(Grade III) is suitable for general industrial water use areas and coastal scenic tourism areas.
The fourth category(VI) is applicable to marine port waters and marine development operation areas.

23. What is the main field area for which you use the coastal oxygen data?

Copy

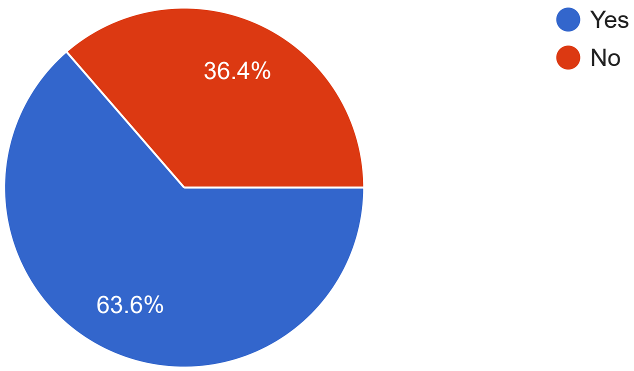
11 responses



24. Have you carried out studies about the impact of hypoxia (low dissolved oxygen) on the abundance, spatial distribution, or productivity of the living resources (algae, zooplankton, benthos, fish, shellfish) in your coastal area?

Copy

11 responses



If yes, provide the references.

8 responses

Eutrophication in Songkhla Lake

In Viet Nam, various studies have been conducted on the impact of hypoxia (low dissolved oxygen) on the abundance, spatial distribution, and productivity of living resources in coastal areas. These studies are typically carried out by research institutions, universities, and governmental agencies. The research focuses on understanding how hypoxia affects marine ecosystems, including:
Fish and Shellfish: Investigating how low oxygen levels impact the survival, growth, and distribution of commercially important fish and shellfish species.

Benthos: Assessing the effects of hypoxia on benthic organisms, which are crucial for nutrient cycling and as a food source for higher trophic levels.

Algae and Zooplankton: Studying how low oxygen conditions influence the composition and productivity of algae and zooplankton communities, which form the base of the marine food web.

https://link.springer.com/article/10.1007/s12237-009-9187-3

https://www.subpesca.cl/fipa/613/articles-92064_informe_final.pdf / https://link.springer.com/chapter/10.1007/978-3-031-39408-9_12

Ej. Gutiérrez et al., 2008, Graco et al., 2017, Merma et al., 2024, Aguirre-Velarde, Arturo, et al.2016

https://www.elibrary.ru/item.asp?id=49485247

NA

Chen, J. Li, D., Jin, H., Jiang, Z., Wang, B.,et al. (2020). Changing Nutrients, Oxygen and Phytoplankton in the East China Sea. In: Chen, CT., Guo, X. (eds) Changing Asia-Pacific Marginal Seas. Atmosphere, Earth, Ocean & Space. Springer, Singapore. https://doi.org/10.1007/978-981-15-4886-4_10.

Wang, B., Chen, J., Jin, H., Li, H., Huang, D., Cai.W. (2017). Diatom bloom−derived bottom water hypoxia off the Changjiang estuary: with and without typhoon influence [J]. Limnology and Oceanography, 62,1552-1569.

Li, D. W., Chen, J. F., Wang, B., Jin, H. Y., Shou, L., Lin, H., et al. (2024). Hypoxia triggered by expanding river plume on the East China Sea inner shelf during flood years. Journal of Geophysical Research: Oceans, 129, e2024JC021299. https://doi.org/10.1029/2024JC021299

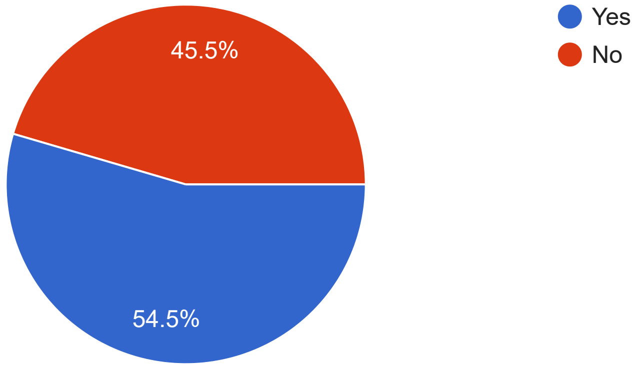
Wang, K; Cai, W; Chen, J; Kirchman, D; Wang, B; Fan, W; Huang, D. (2021). Climate and Human-Driven Variability of Summer Hypoxia on a Large River-Dominated Shelf as Revealed by a Hypoxia Index.

FRONTIERS IN MARINE SCIENCE, 8,
https://doi.org/10.3389/fmars.2021.634184

25. Do you use metrics related to coastal hypoxia for supporting the assessment of habitat conditions of marine living resources?

Copy

11 responses



If yes, provide the reference.

6 responses

in Viet Nam, metrics related to coastal hypoxia are used to support the assessment of habitat conditions for marine living resources. These metrics typically include:

Dissolved Oxygen Concentrations: The primary metric used to assess the severity and extent of hypoxia in coastal waters. Low oxygen levels are a key indicator of poor habitat conditions, which can affect the survival and distribution of marine species.

Hypoxic Area Extent: Measuring the spatial extent of areas affected by hypoxia helps in understanding the impact on different habitats, such as benthic zones, which are crucial for many marine species.

Frequency and Duration of Hypoxic Events: Monitoring how often and for how long hypoxic conditions occur provides insights into the resilience of marine ecosystems and their ability to recover from these stressors.

Biological Indicators: The abundance and diversity of species sensitive to oxygen levels, such as certain fish, shellfish, and benthic organisms, are monitored as biological indicators of habitat quality.

These metrics are used by environmental agencies, research institutions, and fisheries management bodies in Viet Nam to evaluate the health of marine habitats, assess the risks to living resources, and develop strategies for conservation and sustainable use of marine resources.

Area of coastal hypoxia. https://www.epa.gov/ms-htf/hypoxia-task-force-action-plans-and-goal-framework

https://www.subpesca.cl/portal/615/articles-10517_documento.pdf

Ej. Igarza et al., 2024, Aguirre et al., 2019

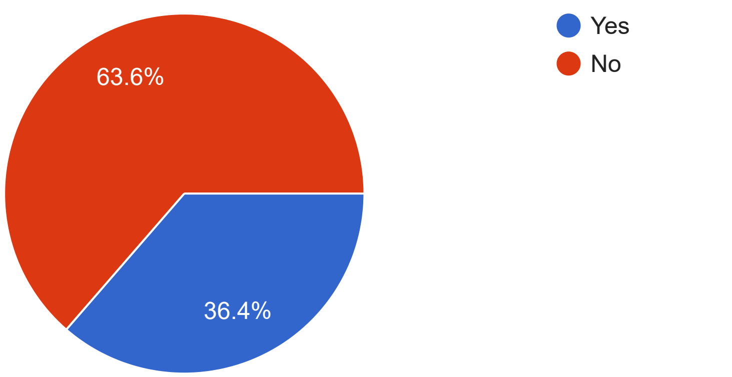
NA

Communiqué on the State of China's Marine Ecological Environment

26. Have you developed an early warning system for fisheries and aquaculture using these metrics?

Copy

11 responses



27. Have your coastal environments undergone trends (long-term changes) or events (episodes) of low dissolved oxygen?

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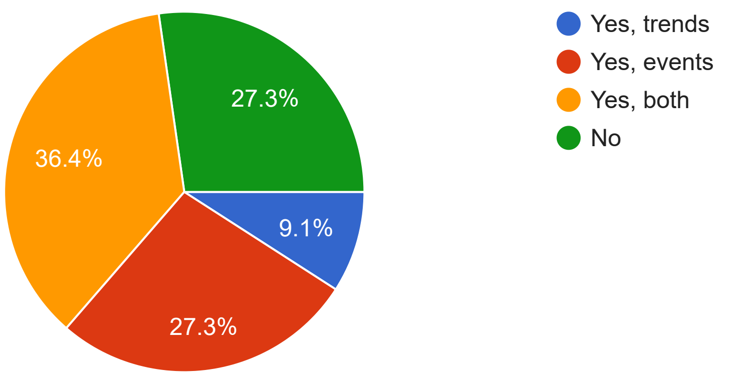
11 responses



If yes, Provide the reference of the recorded trends or events

8 responses

Variability and Trend of Some Water Quality at the Vicinity of Fish-Cage Culture, Outer Songkhla Lake in Two Decades (1992 – 2011)

Vietnam's coastal environments have experienced both long-term trends and episodic events of low dissolved oxygen (hypoxia). Long-term trends may be associated with broader environmental changes, such as nutrient loading from agriculture and urbanization, while episodic events often result from seasonal factors, such as monsoons or specific environmental disturbances, including algal blooms or extreme weather events. These occurrences have significant implications for marine ecosystems, fisheries, and aquaculture in the region.

https://gulfhypoxia.net/research/shelfwide-cruises/#Size

https://www.subpesca.cl/portal/616/articles-120345_documento.pdf;
https://www.subpesca.cl/portal/617/w3-article-109981.html

Espinoza et al., 2017,Schmidtko, S., Stramma, L., & Visbeck, M. (2017),Oschlies, A., Schulz, K. G., Riebesell, U., & Schmittner, A. (2008).

https://www.elibrary.ru/item.asp?id=44426040
https://www.mdpi.com/2077-1312/9/9/953?trk=organization_guest_main-feed-card-text
https://link.springer.com/article/10.1134/S0001437017050071

Herrera-Becerril, C. A., Sanchez-Cabeza, J. A., Sánchez, L. F. Á., Lara-Cera, A. R., Ruiz-Fernández, A. C., Cardoso-Mohedano, J. G., Machain-Castillo, M.L., Colas, F. (2022). Statistical identification of coastal hypoxia events controlled by wind-induced upwelling. Continental Shelf Research 233, 104634.
https://doi.org/10.1016/j.csr.2021.104634

Chen, J. Li, D., Jin, H., Jiang, Z., Wang, B.,et al. (2020). Changing Nutrients, Oxygen and Phytoplankton in the East China Sea. In: Chen, CT., Guo, X. (eds) Changing Asia-Pacific Marginal Seas. Atmosphere, Earth, Ocean & Space. Springer, Singapore.
https://doi.org/10.1007/978-981-15-4886-4_10.

28. What are your expectations regarding the project workshop?

11 responses

to improve knowledge on data processing and analysis

We would like to learn about new methodologies for water quality analysis used in other economies.

Knowledge Sharing: Expecting to gain new insights and knowledge about dissolved oxygen monitoring techniques, data management, and the latest research findings.

Capacity Building: Looking forward to training and skill development in using advanced tools and methodologies for coastal monitoring.

Networking: Anticipating opportunities to connect with other professionals, researchers, and stakeholders to exchange experiences and collaborate on future projects.

Project Planning: Hoping to refine the project objectives, timelines, and methodologies through discussions and feedback from experts.

Solution Development: Expecting to identify and develop solutions to current challenges in dissolved oxygen monitoring and data usage in Vietnam's coastal areas.

Policy and Decision-Making Support: Looking forward to gaining insights that could inform better policies or practices related to environmental management and fisheries/aquaculture in Viet Nam.

To learn from other researchers about 1) their ecosystem that is experiencing low dissolved oxygen, 2) how they are monitoring hypoxia, 3) the type of biological responses to hypoxia they have documented, and 4) future research ideas.

Best practices for data management and data quality assessment practices. In addition, to be able to know updated measurement protocols so that the data obtained in the Pacific Basin are comparable. Finally, to share our experience and learn about the experiences of other economies in these areas.

Share experiences, lessons learned, and to establish a roadmap for implementing harmonized oxygen measurements with quality standards

To become familiar with the methods used to assess hypoxia in the economies of the APEC region. To compare data obtained by various scientific institutes on hypoxia of sea waters in the regions of the Asia-Pacific region. To establish scientific links with scientists from other economies engaged in research on oxygen content in marine ecosystems

exchange of information on data quality

The workshop aims to facilitate knowledge exchange between experienced professionals and promote collaborative approaches to addressing the challenges posed by coastal hypoxia. By gathering experts from a variety of relevant fields, the workshop seeks to develop comprehensive strategies for monitoring, managing, and mitigating the impacts of hypoxia on marine ecosystems and associated industries.

Adopt better practices for collecting, analyzing, processing data, and assessing the quality of coastal oxygen concentrations.
Start collaboration with fisheries and aquaculture to sustain the Mazatlan observatory of coastal hypoxia.

China has relatively systematic research results and scientific achievement in the fields of formation mechanism and prediction of marine hypoxia, the impact of hypoxia on marine biodiversity and ecosystems, and the environmental monitoring and assessment of marine hypoxia areas, especially for the response strategies of marine hypoxia under the influence of climate change, and the policy formulation under the sustainable development of coastal waters. In this project workshop, we would like to share the advances in oxygen deoxygenation research and experiences in dealing with coastal hypoxia, and enhance China's international influence, together with the other APEC economy in coping with the problem of coastal hypoxia and improving the management level of marine living resources.

Annex 3. Keynote lectures

Developing best practices to address coastal marine deoxygenation in APEC economies for improving the management of marine living resources

Horn Point Laboratory
University of Maryland Center for Environmental Science

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

APEC
Asia-Pacific Economic Cooperation

PAUL HORN / Inside Climate News

Session 1 (Seminar)

An overview on the relevance of oxygen loss for fisheries and marine aquaculture

Topic-1 – Fisheries

and

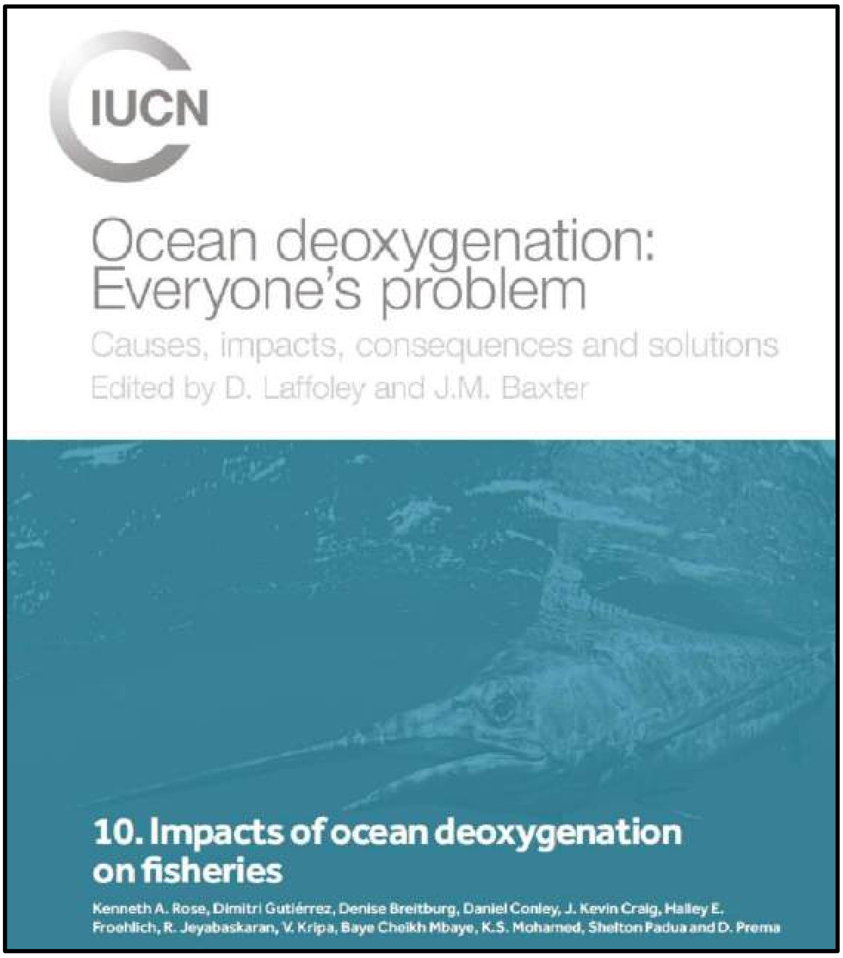
Topic-2 – Aquaculture

Session 2 (Seminar)

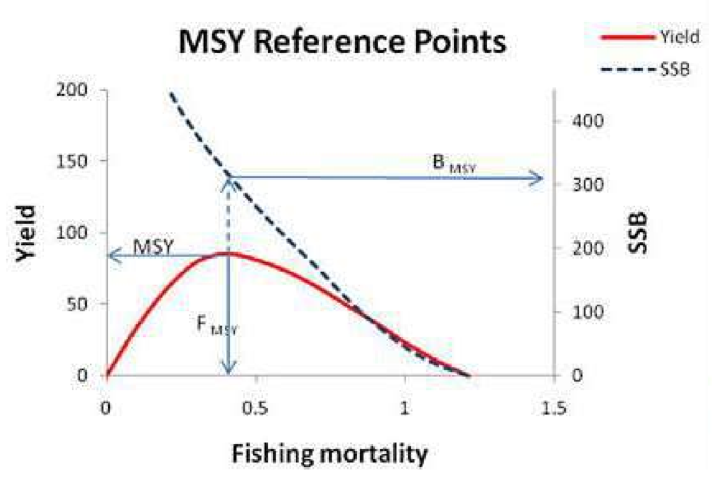
Regulatory Framework of Water Quality

Session 1, Topic 1

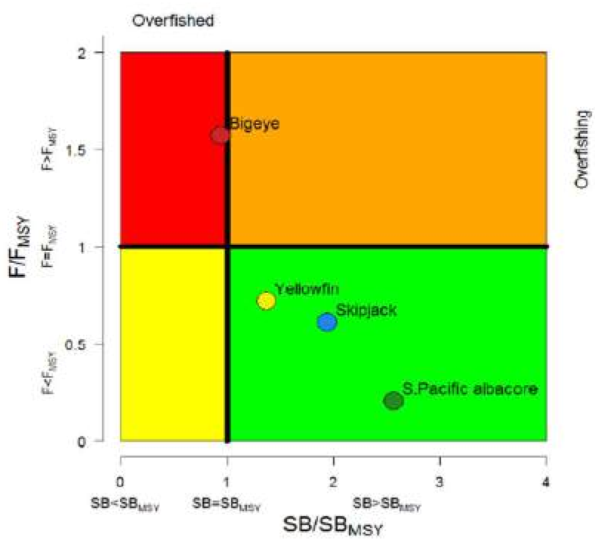
Fisheries



Fisheries Management

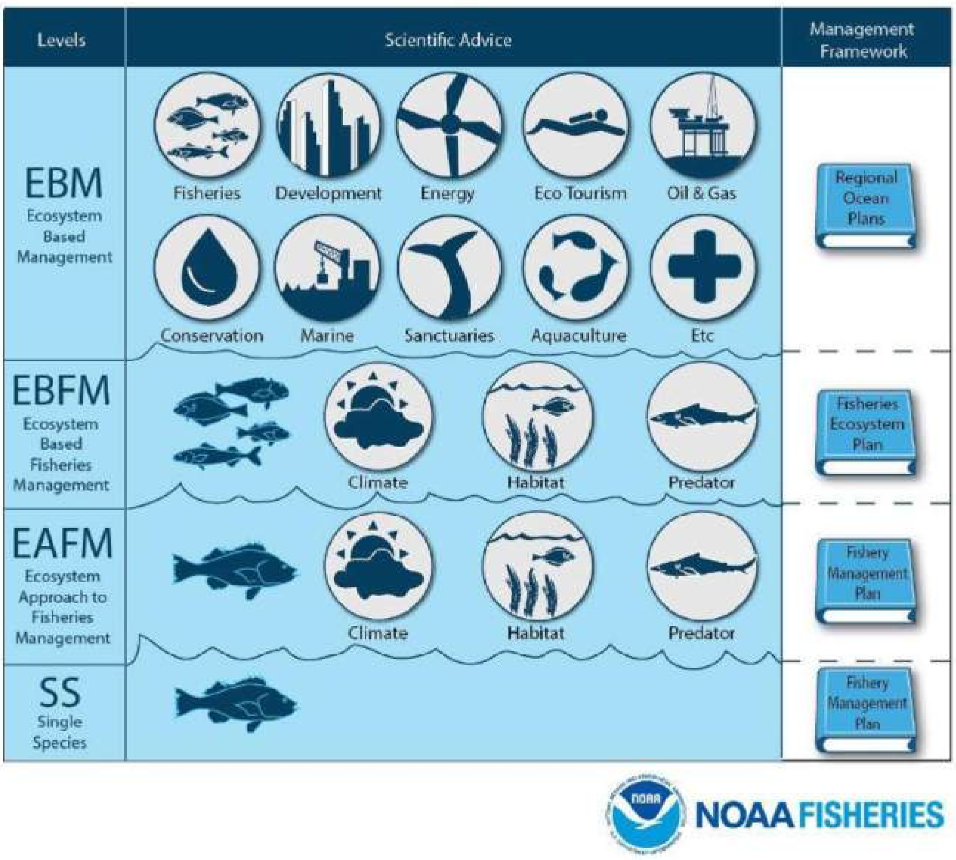


ICES 2011



Kirchner et al. 2014.

Fisheries Management



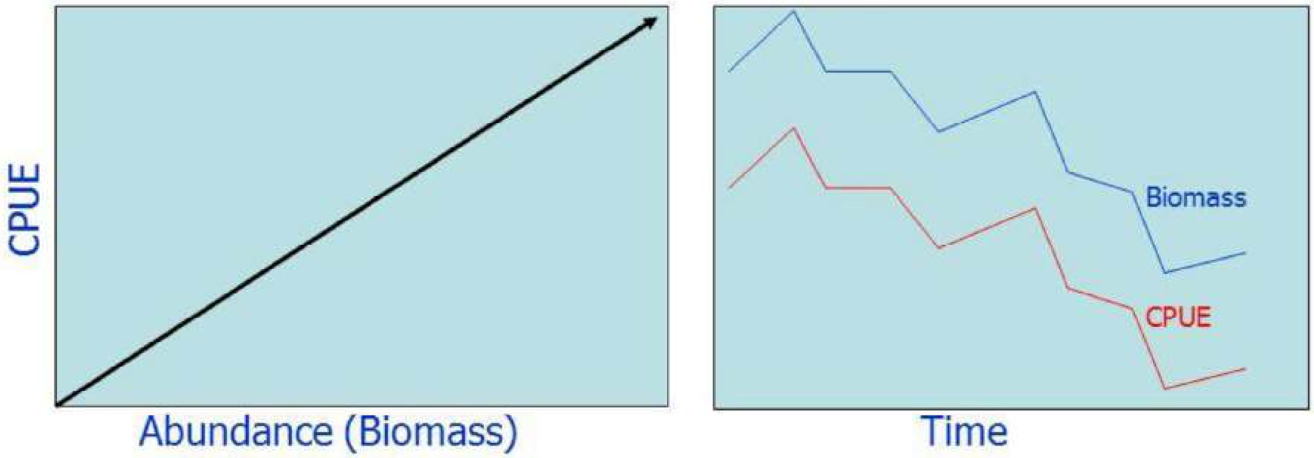
CPUE as an abundance index

Its use as an index of abundance is based on the assumption that the amount of fish caught per unit fishing effort will be proportional to the abundance of the fish:

Oceanic Fisheries Programme April 2017

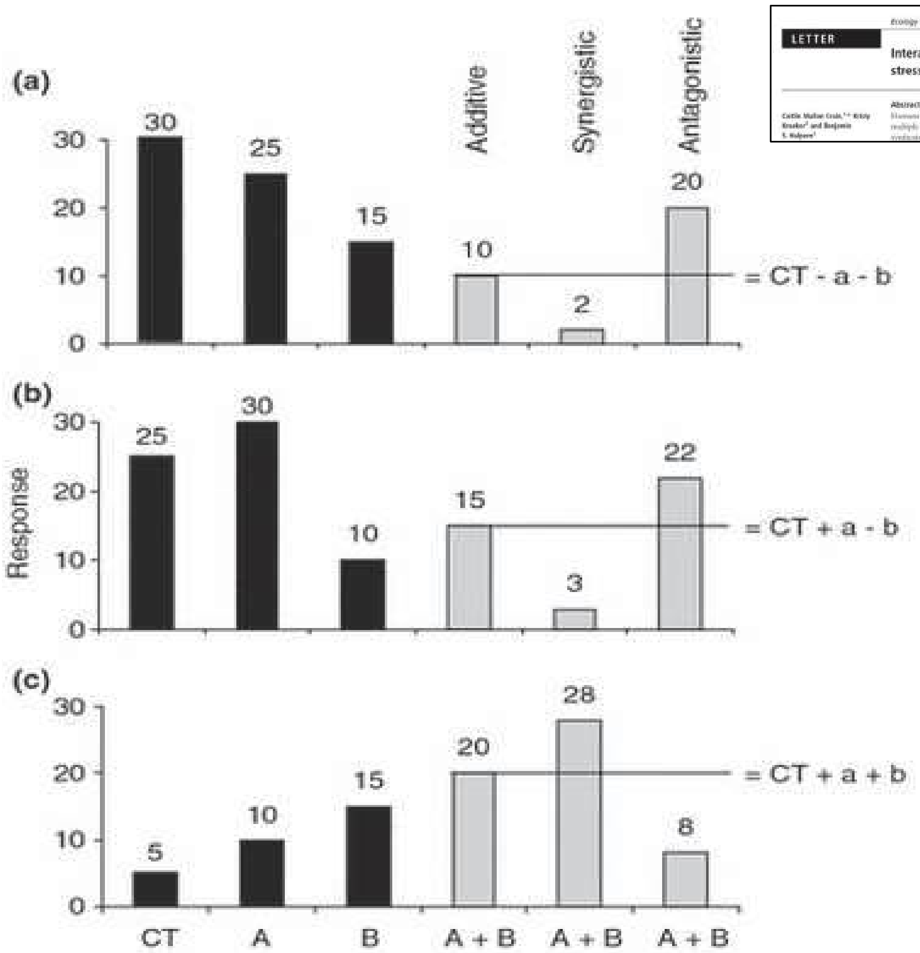
$$C/E = qB$$

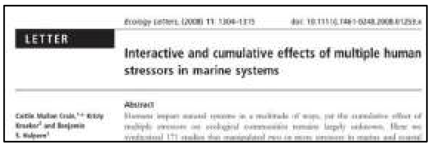
Catch/Effort = Catchability x Biomass



Multiple Stressors

- Deoxygenation covaries with other factors
  - Temperature
  - Nutrient loadings
  - OA
- Global climate change
  - Many fishery species are mobile
  - Sensitive to temperature

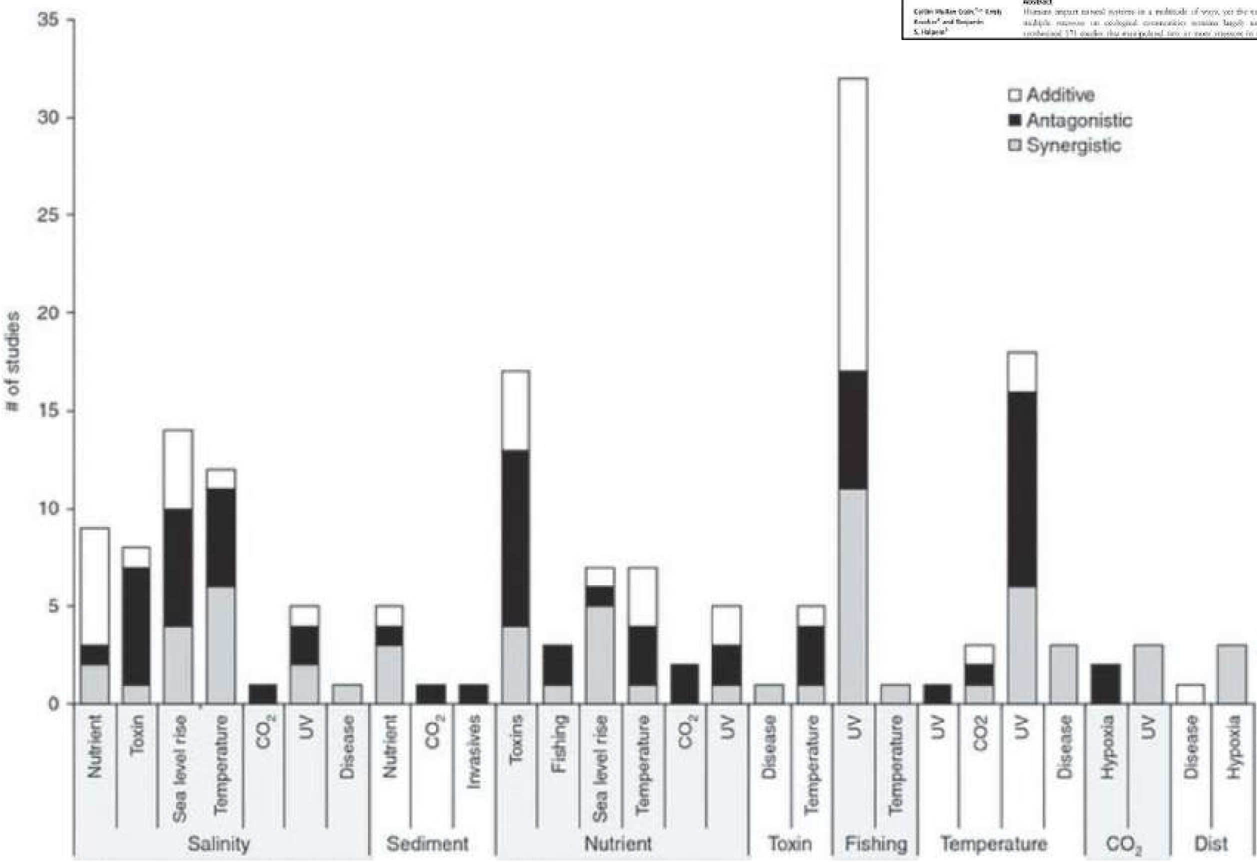


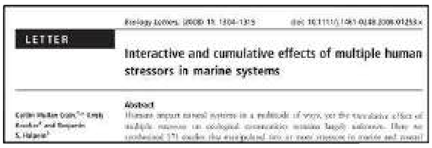

Ecology Letters, (2008) 11: 1304–1315

LETTER

Interactive and cumulative effects of multiple human stressors in marine systems

Abstract




Ecology Letters, (2008) 11: 1304–1315

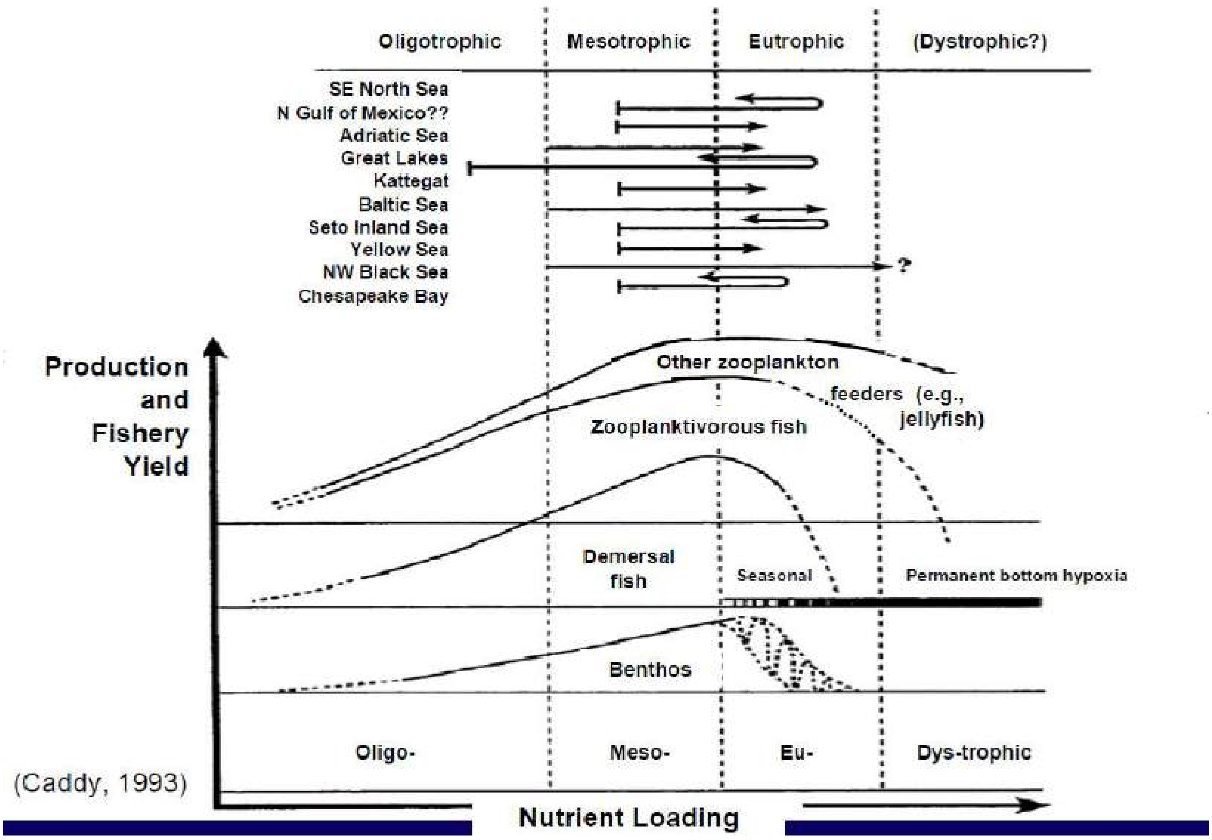
LETTER

Interactive and cumulative effects of multiple human stressors in marine systems

Abstract

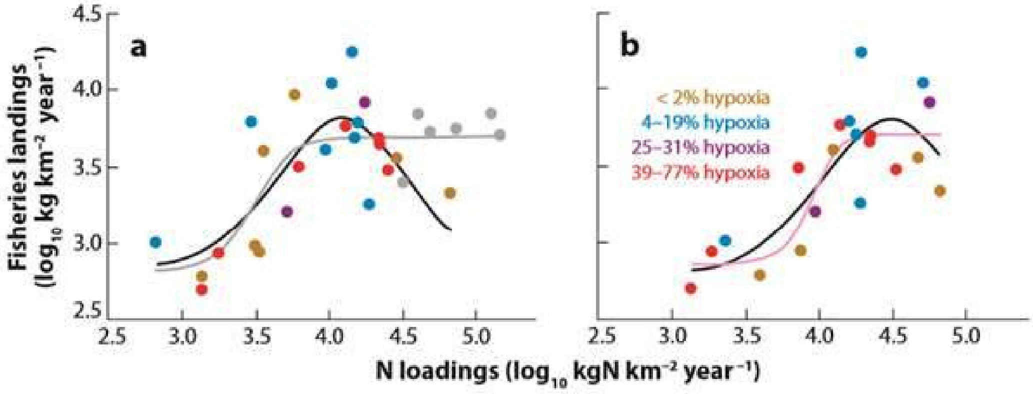
Ecosystem Services

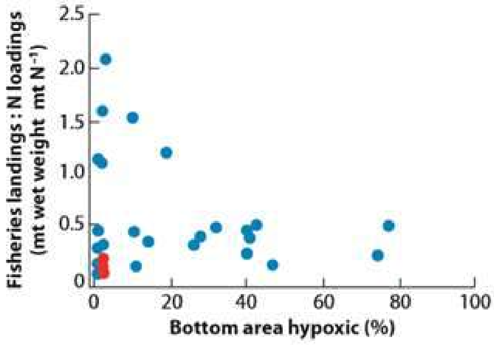
- Harvest is an ecosystem service
- Over harvest and ecosystem impacts are stressors

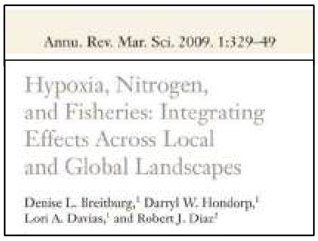


From a Nancy Rabalais presentation

Correlation





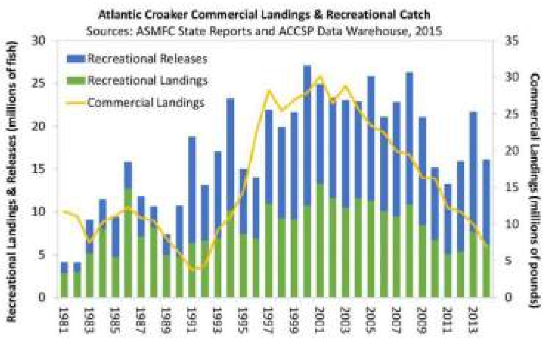

Annu. Rev. Mar. Sci. 2009. 1:329–49

Hypoxia, Nitrogen, and Fisheries: Integrating Effects Across Local and Global Landscapes

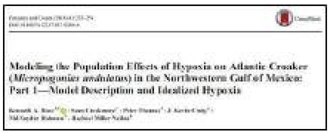
Denise L. Breitburg,[1] Darryl W. Hondorp,[1] Lori A. Davias,[1] and Robert J. Diaz[2]

Case Study 1: Croaker in Gulf of Mexico

- Individual-based population model
- Quantifies hypoxia versus food effects
- Note: not a fishery now in GOM
  - 120 Million pounds in the 1950's
  - Fisheries in other systems

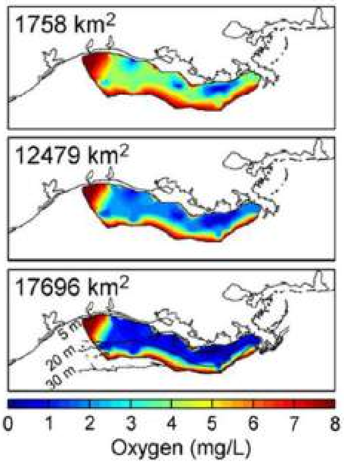


http://texasaquaticscience.org/wp-content/uploads/2013/08/C12_fig_12.1-aquatic-science-texas.jpg

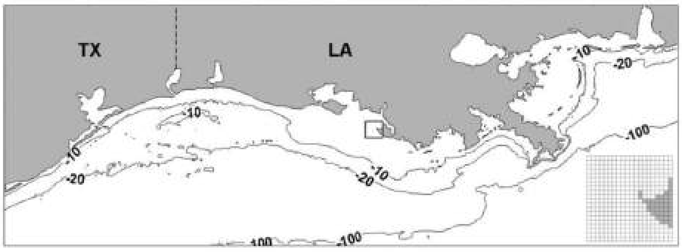


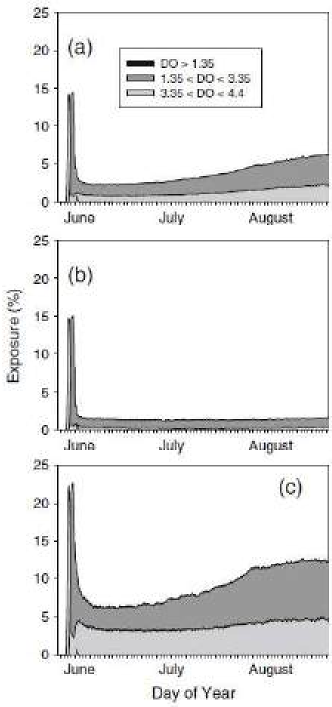
Model Overview

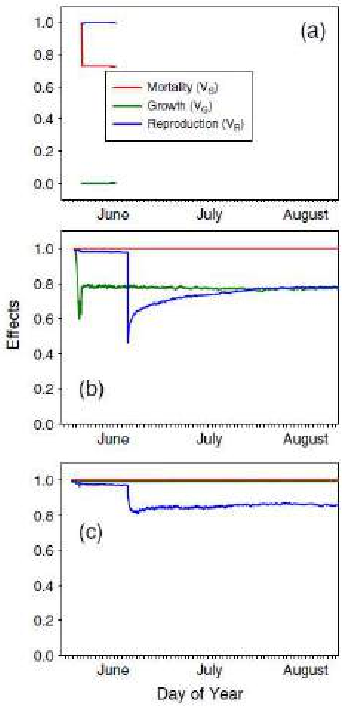
- Individual-based
  - Follows 7 stages to age 8
  - DO from 3-D FVCOM
  - Severe, intermediate, mild
  - 140 synthetic years

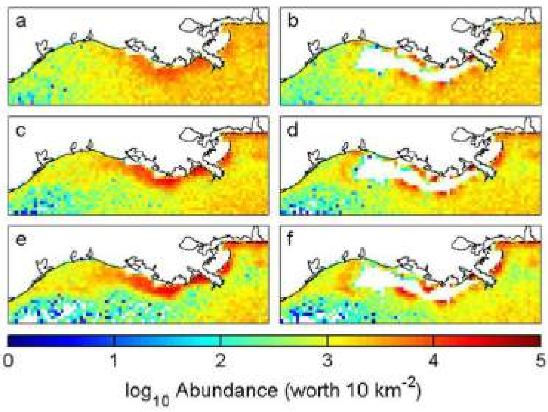


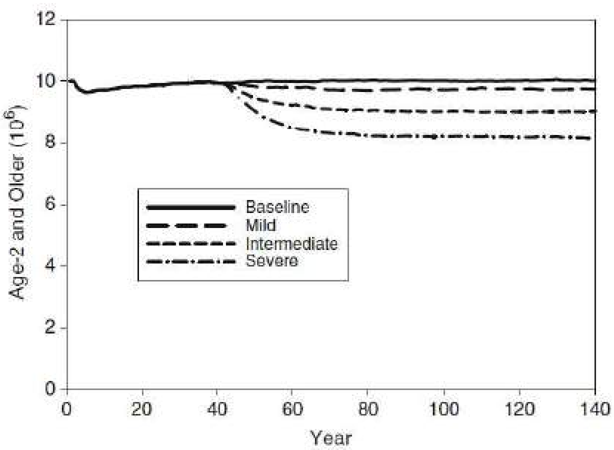
- Hourly processes
  - Growth
  - Mortality
  - Reproduction
  - Movement
  - DO effects

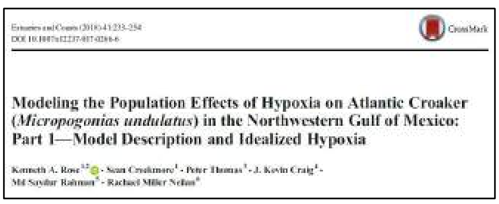










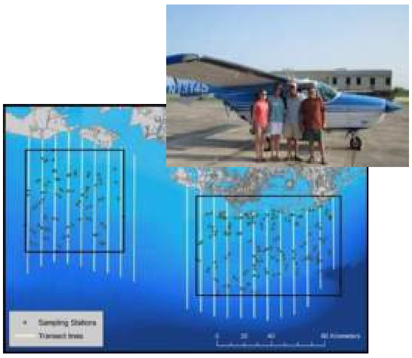

Estuaries and Coasts (2018) 41:233–254
DOI 10.1007/s12237-017-0266-6

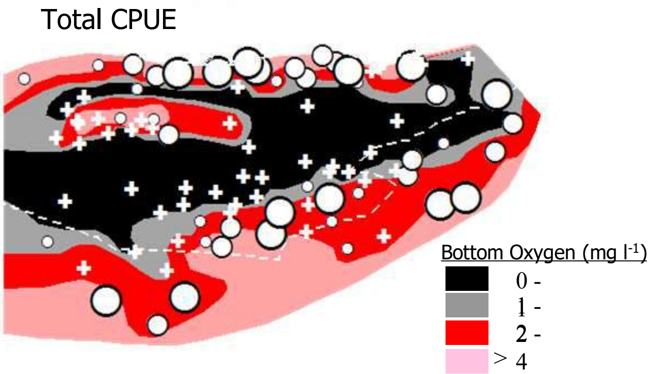
CrossMark

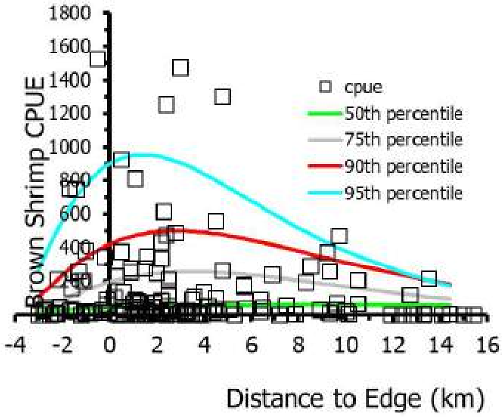
Modeling the Population Effects of Hypoxia on Atlantic Croaker (*Micropogonias undulatus*) in the Northwestern Gulf of Mexico: Part 1—Model Description and Idealized Hypoxia

Kenneth A. Rose[1,2] · Sean Creekmore[1] · Peter Thomas[3] · J. Kevin Craig[4] · Md Saydur Rahman[3] · Rachael Miller Neilan[5]

Case Study 2: Shrimp in Gulf of Mexico



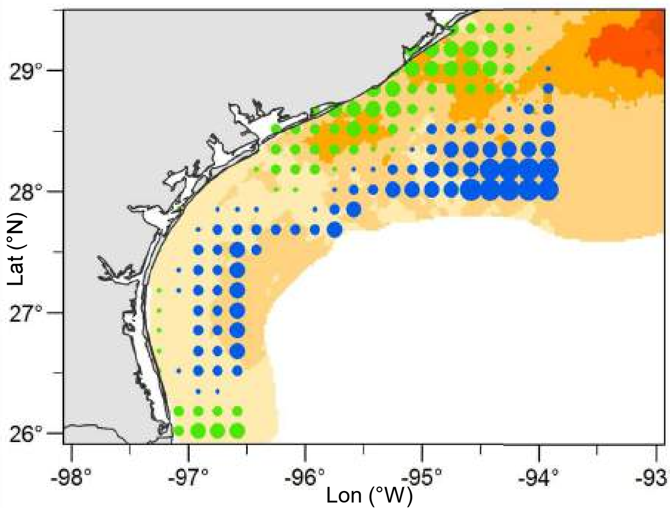




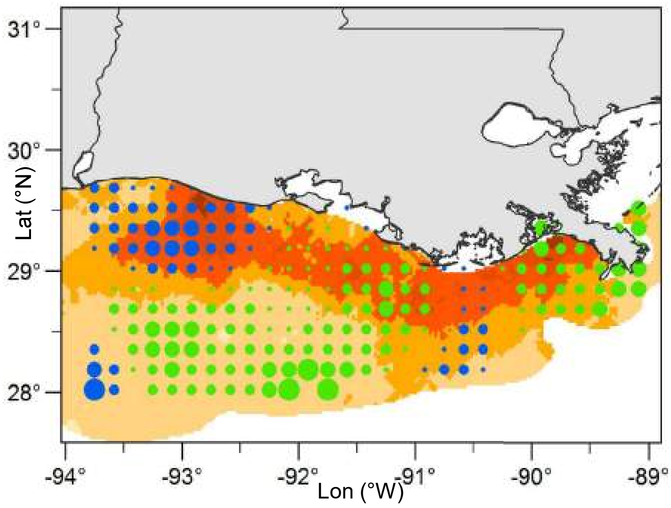
IUCN: Craig 2012, Craig and Crowder 2005, Craig et al. 2005, Purcell et al. 2017, Smith et al. 2014, 2017

Case 2: Shrimp

Texas Shelf



Louisiana Shelf



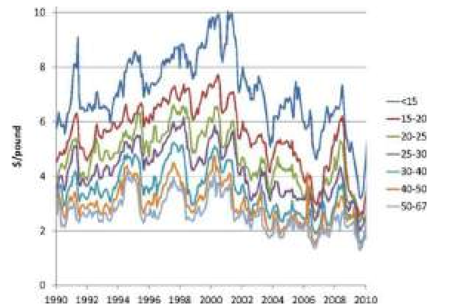
Slope of Spatially Varying DO Effect

Green: Decrease in effort when DO is low (positive slope)

Blue: Increase in effort when DO is low (negative slope)

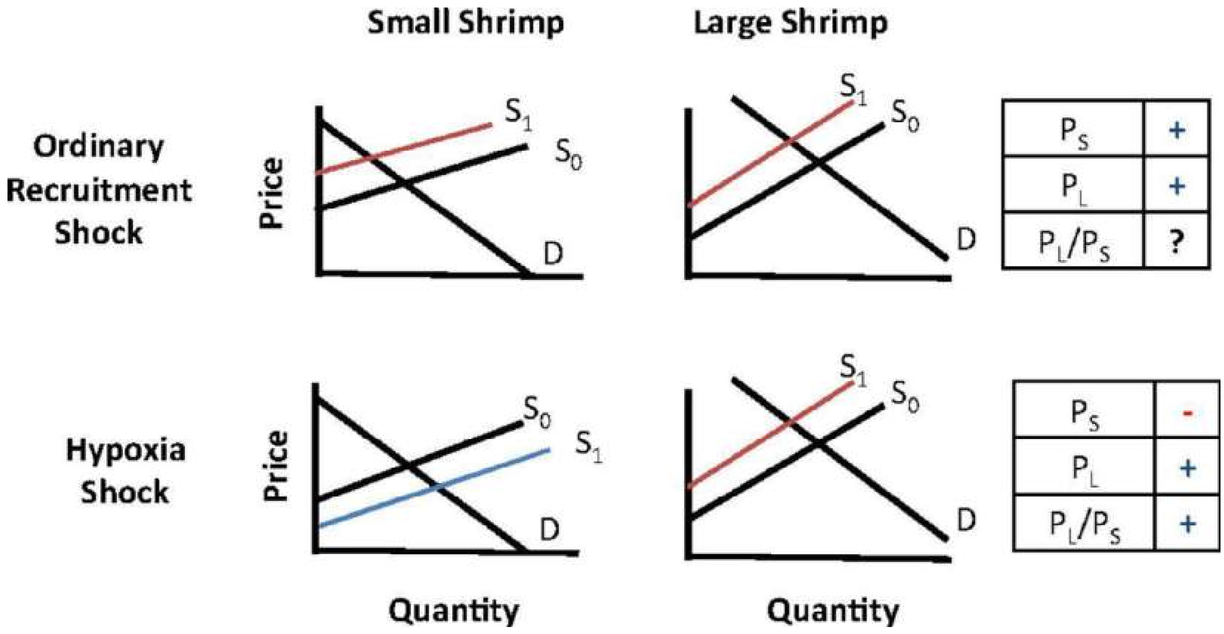
Case Study 2: Shrimp in Gulf of Mexico

- Smith et al. (2017) used 20 years monthly prices
  - Higher price for larger shrimp



- Severe hypoxia years results in fewer small shrimp
  - Aggregation, growth, mortality
  - Fewer shrimp lead to fewer large later in the season

Case Study 2



Seafood prices reveal impacts of a major ecological disturbance

Martin D. Smith, Atle Oglend, A. Justin Kirkpatrick, Frank Asche, Lori S. Bennear, J. Kevin Craig, and James M. Nance

1512–1517 | PNAS | February 14, 2017 | vol. 114 | no. 7

Case Study 3: Dungeness Crab in Hood Canal

- Highly valued species on west coast of USA
- Management is size, sex, and season
- Hood canal is seasonally hypoxic fjord
- Crabs shoal to avoid low oxygen

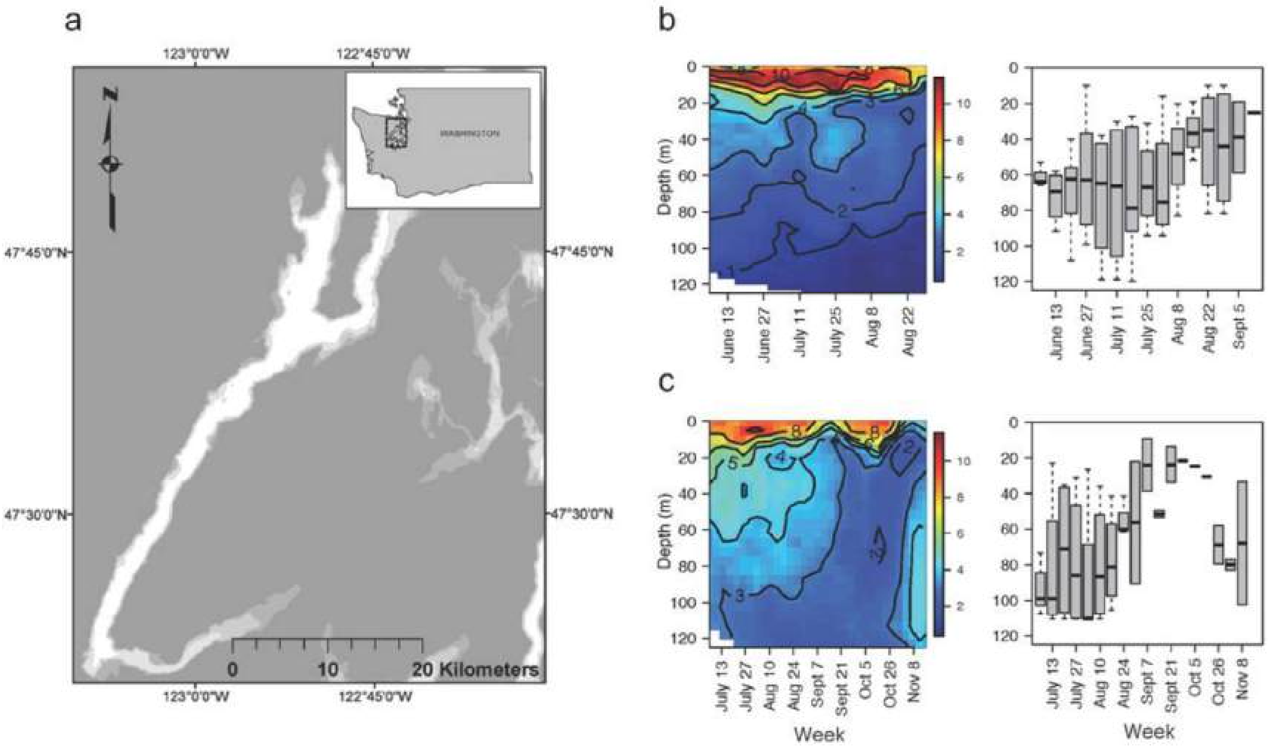
ARTICLE

When does hypoxia affect management performance of a fishery? A management strategy evaluation of Dungeness crab (*Metacarcinus magister*) fisheries in Hood Canal, Washington, USA

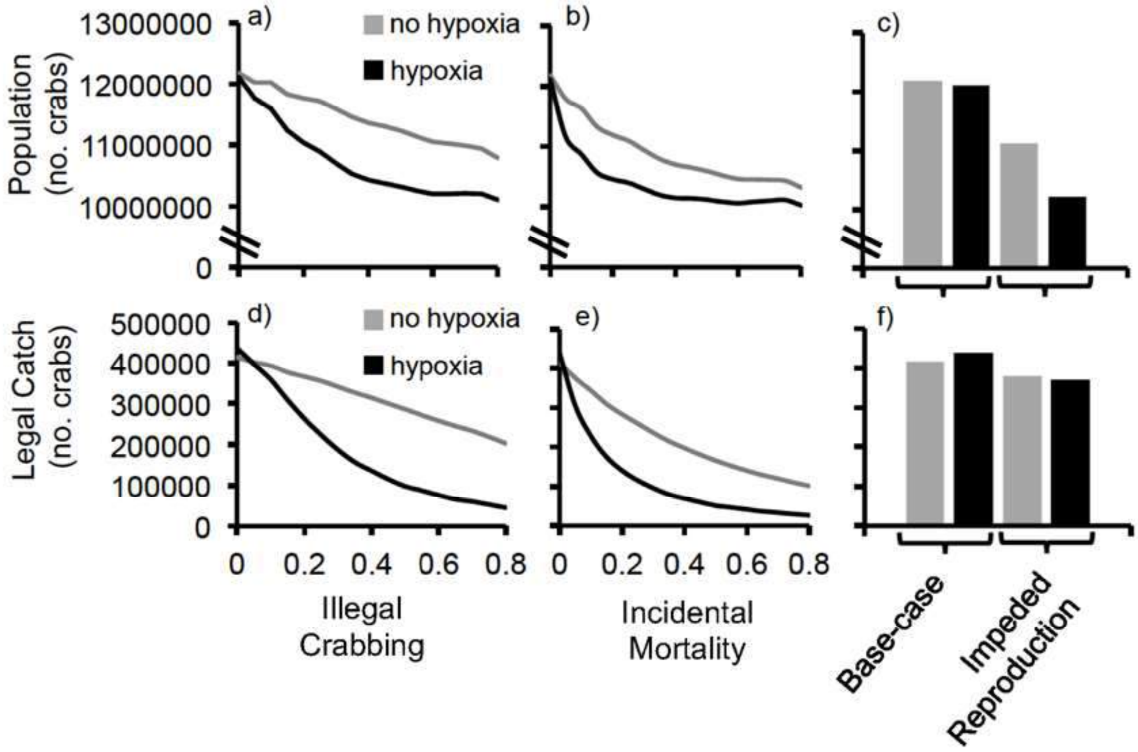
Halley E. Froehlich, Timothy E. Essington, and P. Sean McDonald

Can. J. Fish. Aquat. Sci. 74: 922–932 (2017) dx.doi.org/10.1139/cjfas-2016-0269

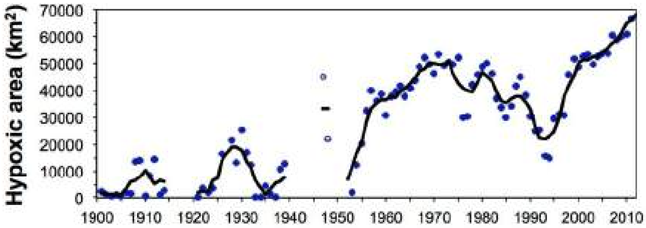
Case Study 3

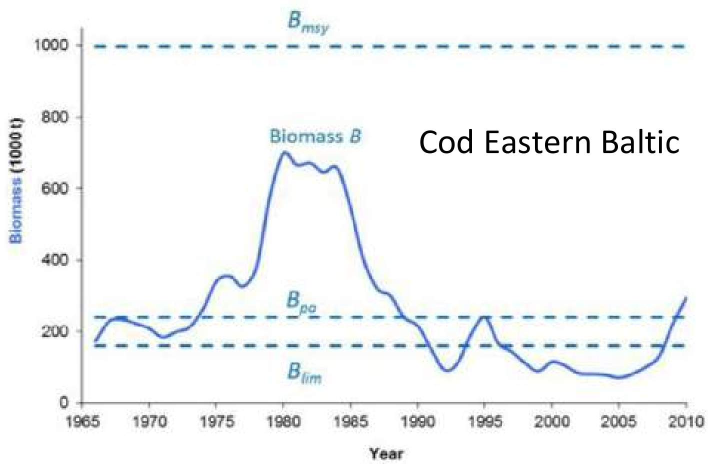


Case Study 3 MSE



Case Study 4: Cod in Baltic Sea

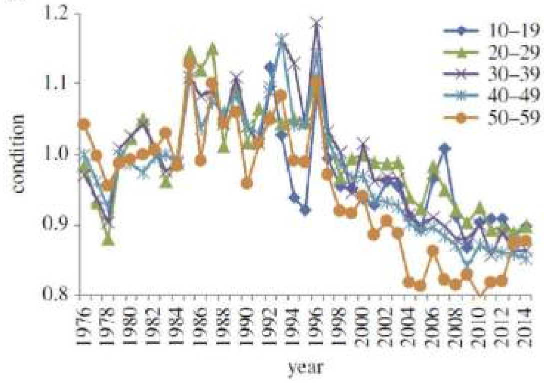




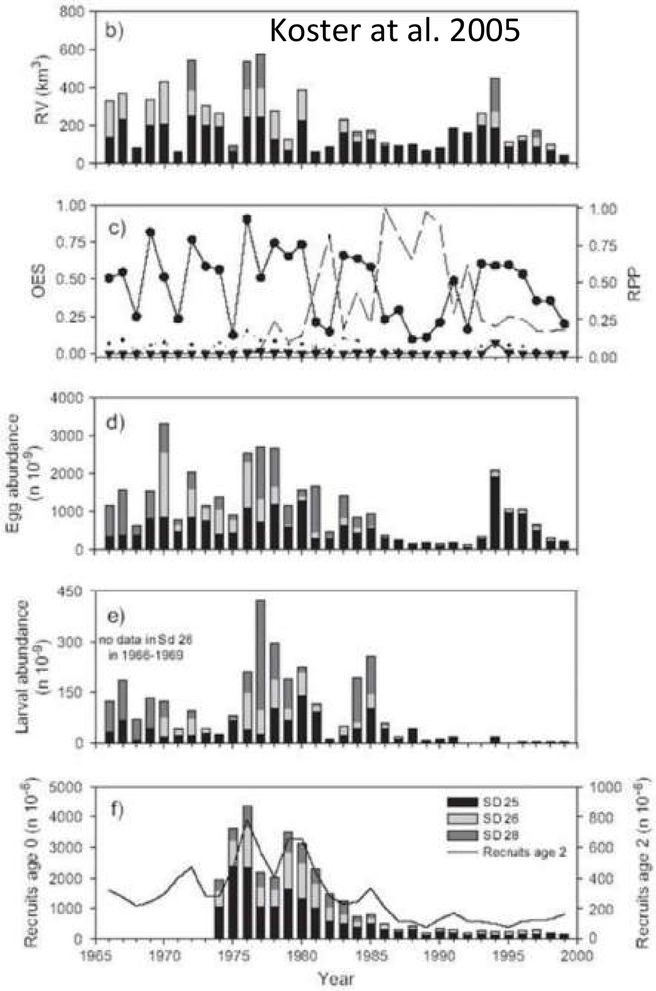
Rainer Froese, Towards Healthy Stocks and Healthy Profits in Baltic Fisheries, Presentation at European Maritime Day Conference, Gdansk, 20 May 2011

Case Study 4: Cod in Baltic Sea

Casini et al. 2016



Koster at al. 2005



(b) reproductive volume (RV)
(c) oxygen-related egg survival (OES) and relative egg predation pressure in SD 25
(d) egg abundance
(e) larval abundance
(f) recruitment at age-0 in Subdivisions 25, 26, and 28 and at age-2 in the entire central Baltic

Case Study 5: Peruvian Fisheries in the EEZ

- Fisheries in Peruvian EZZ are ~10% of world’s marine fish landings

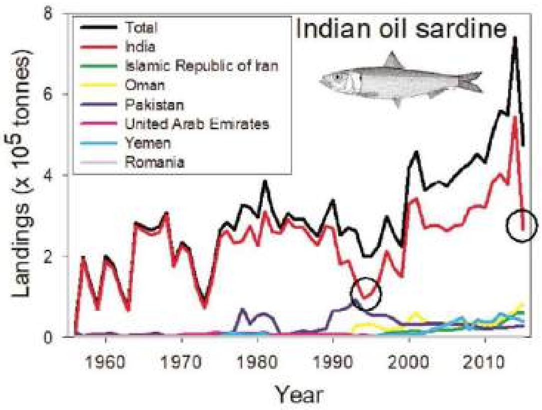
- Species distributions
  - Anchovy is more coastal
  - Sardine, jack mackerel, and giant squid are offshore

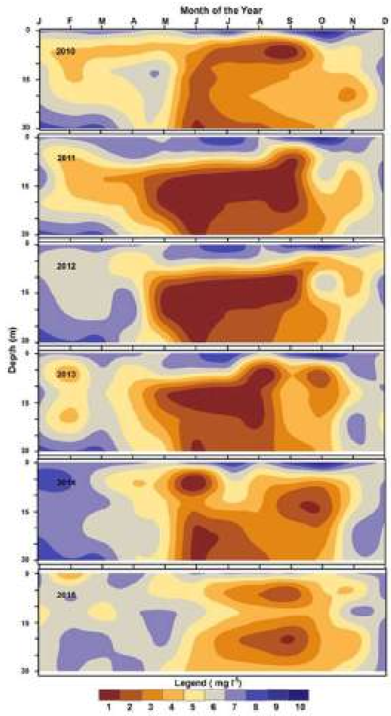
- Positive phase of PDO (1970’s - 1990’s)
  - reduced upwelling
  - high oxygen waters approached onshore
  - oxycline deepened
  - Higher predation on anchovy

- General pattern
  - Warm SST, high PP, shallow oxycline → more fishing
  - Cold, low PP, deep oxycline, few/deeper anchovy → less fishing

See references in IUCN chapter

Case Study 6: Indian Oil Sardine off Southwest Coast of India



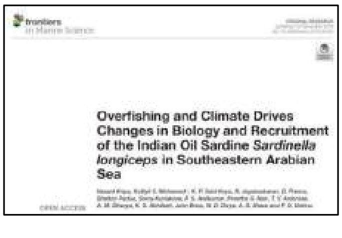


Dissolved Oxygen

Case Study 6

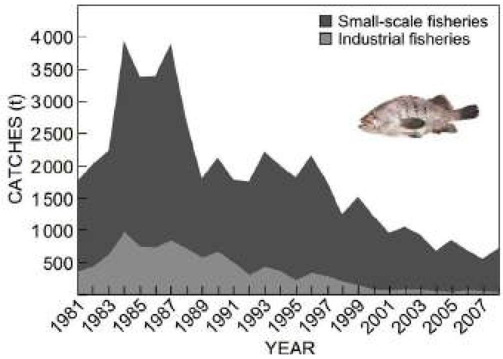
- Fishery harvests spawners born the previous year and new juveniles
- Negative effects on recruitment
  - pre-monsoon: early upwelling and low oxygen
  - Post-monsoon: low oxygen very near shore
  - Sardines cannot move near shore to spawn
- Monthly catch rates showed low oxygen
  - Reduced spawning and overall catch
  - Increased catch rates of larger fish

Published after IUCN


frontiers in Marine Science

Overfishing and Climate Drives Changes in Biology and Recruitment of the Indian Oil Sardine *Sardinella longiceps* in Southeastern Arabian Sea

Case Study 7: “Thiof” off NW Africa



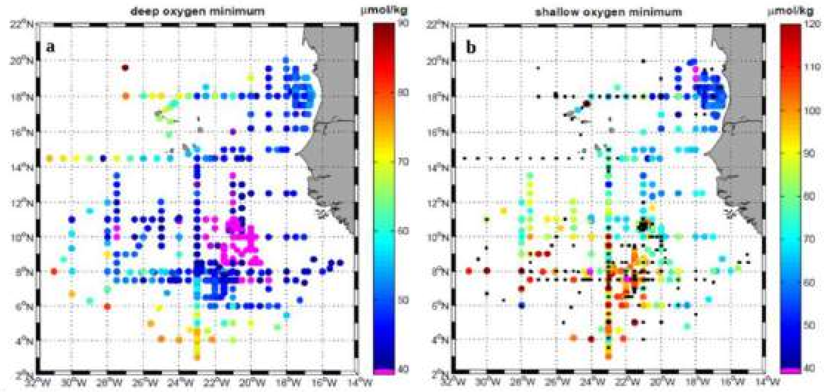
Eastern Tropical North Atlantic (ETNA)

Localization of:
(a) Deep oxygen minimum (>200m depth) zones
(b) shallow oxygen minimum (<200m depth) zones

Overexploited - Senegalese

Higher mortality with low oxygen

Distended abdomens

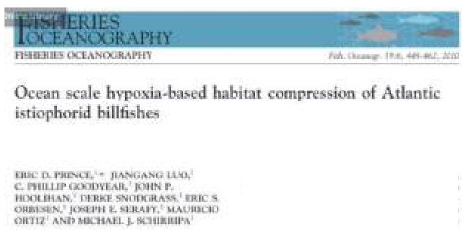


Source: Brandt et al. 2015

31

Case Study 8: Tropical Pelagic Billfishes

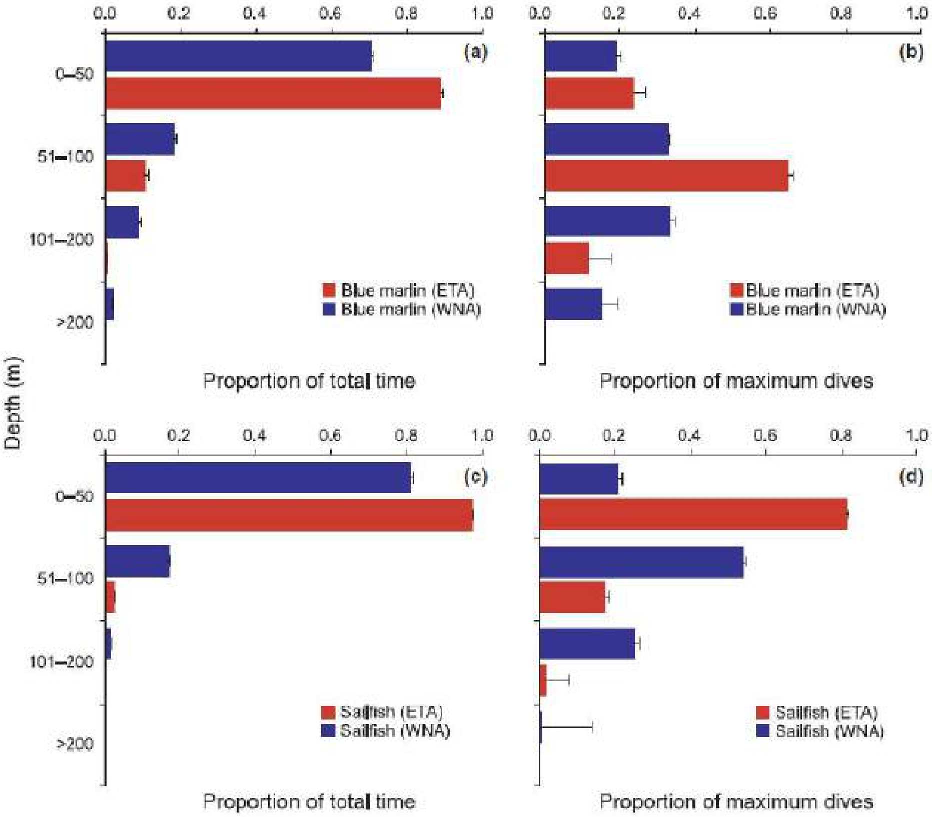
- Surface waters above 3.5 mg/L is decreasing
  - Loss of about 15% in NE Atlantic since 1960’s
  - Western (no OMZ) versus Eastern (OMZ) NA
- Pop-up satellite archival tags


FISHERIES OCEANOGRAPHY

Ocean scale hypoxia-based habitat compression of Atlantic istiophorid billfishes

ERIC D. PRINCE, JIANGANG LUO, C. PHILLIP GOODYEAR, JOHN P. HOOLIHAN, DERKE SNODGRASS, ERIC S. ORBESEN, JOSEPH E. SERAFY, MAURICIO ORTIZ AND MICHAEL J. SCHIRRIPA

Case study 8



Conclusions

- Recruitment
  - Croaker
  - Cod
  - Likely “thiof”
  - Maybe Indian oil sardine

- Spatial redistribution
  - Habitat compression of Billfishes affects availability (“q”)
  - Predator-prey overlap of sardine and jack mackerel on anchovy

- Body size
  - shift to smaller shrimp (“q”)

- Management performance and risk
  - Dungeness crab (“q”)

Conclusions

- Deoxygenation has complicated effects on fisheries
- Highly species-species and localized
- Deoxygenation co-varies with other stressors making isolation challenging
- Many fisheries with data are also at least partially managed
- Fisheries management has no room for mistakes and will be squeezed into the future

Developing best practices to address coastal marine deoxygenation in APEC economies for improving the management of marine living resources

Horn Point Laboratory
University of Maryland Center for Environmental Science

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

Session 1 (Seminar)

An overview on the relevance of oxygen loss for fisheries and marine aquaculture

Topic-1 – Fisheries
and
Topic-2 – Aquaculture

Session 1, Topic 2

Aquaculture

WHAT WE DO ABOUT US GET INVOLVED MEMBERSHIP & GIVING

PERSPECTIVES

The Aquaculture Opportunity

Can the sector grow to provide seafood and jobs in harmony with the ocean?

September 24, 2017

Aquaculture, done well, offers a huge potential not just for producing food for a growing planet, but to provide livelihoods to coastal communities and, in the case of shellfish or seaweed culture, help recover lost ecosystem services.

If we get it right, aquaculture could be our best hope to sustainably feed the planet.

https://www.nature.org/en-us/what-we-do/our-insights/perspectives/the-aquaculture-opportunity/
https://www.cartoonstock.com/cartoon?searchID=CS431395

Concepts from fisheries that apply

- Nutrients and eutrophication
- Individual effects of DO on development, physiology, and behavior
- Multiple stressors

Differences from fisheries

- Two-way effects
- Management/regulatory
- Stakeholders

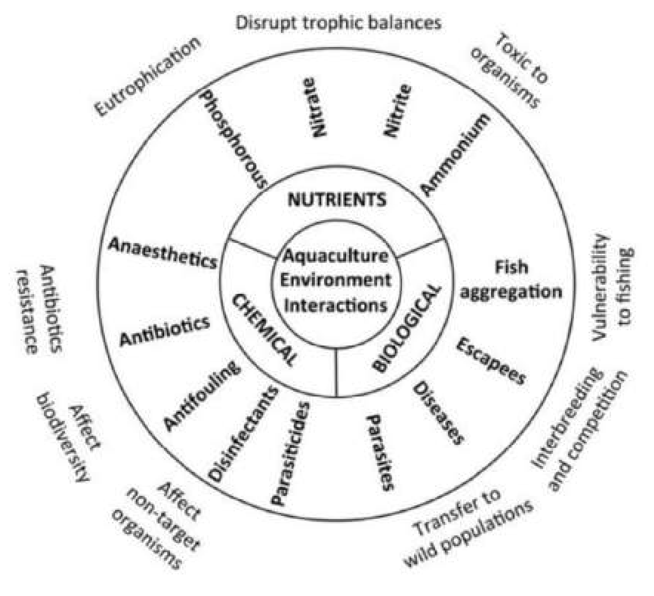


FIGURE 1 | The main pollution sources from marine finfish aquaculture and their related effects on the environment.

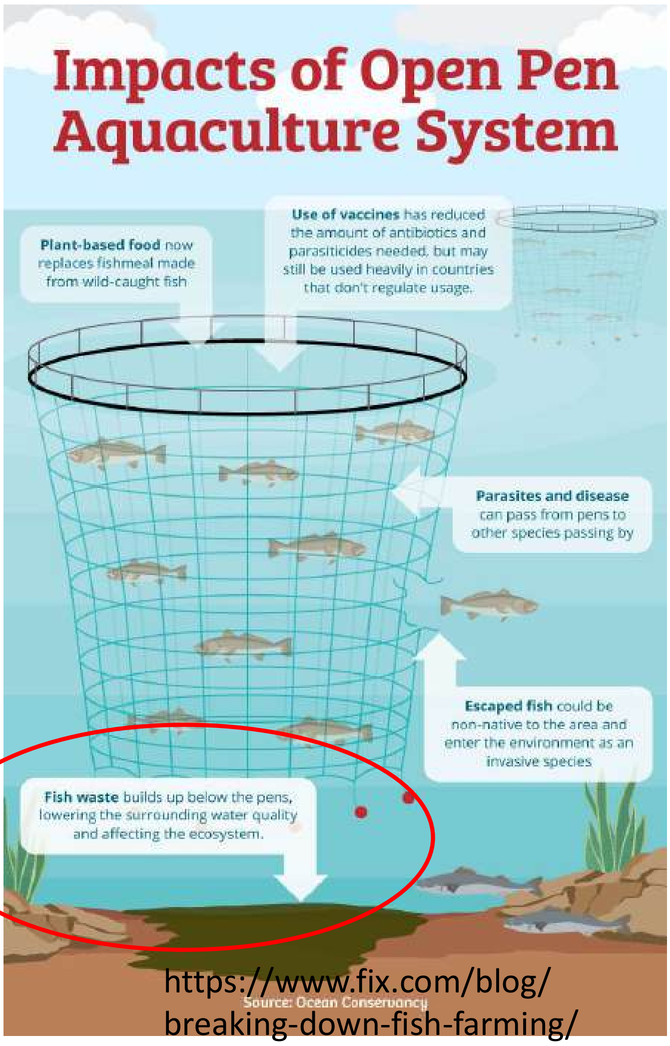
- Site selection
- Env Monitoring Plans
- Env Impact Assessment
- BACI/Gradient designs
- Indicator species
- Biotic indices


frontiers in Marine Science

REVIEW

Towards Environmental Sustainability in Marine Finfish Aquaculture

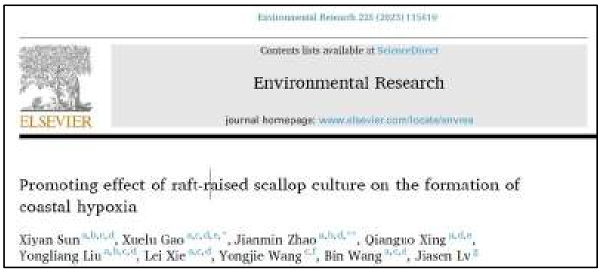
Carlos Brais Carballeira Braña, Kristine Cerbule, Paula Senff and Insa Kristina Stolz



https://www.fix.com/blog/breaking-down-fish-farming/

✚

Other Effects


Contents lists available at ScienceDirect

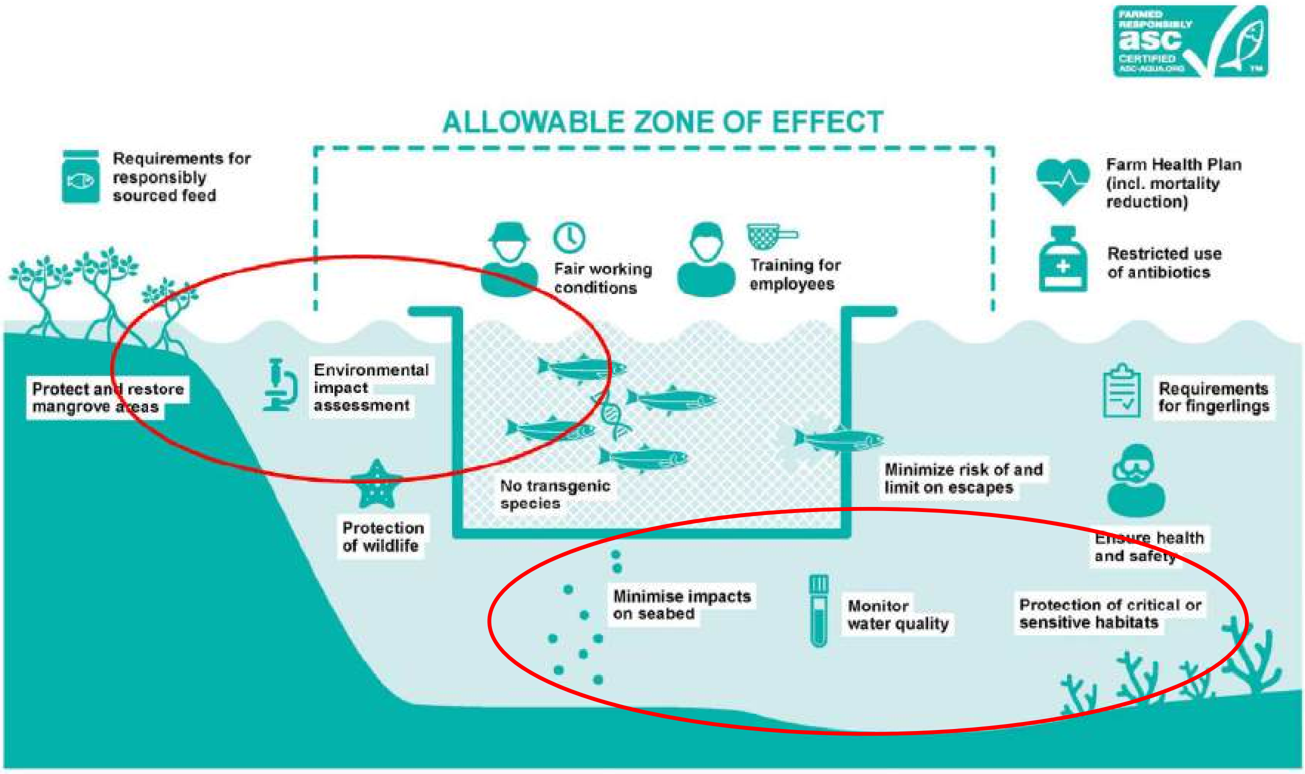
Environmental Research

ELSEVIER

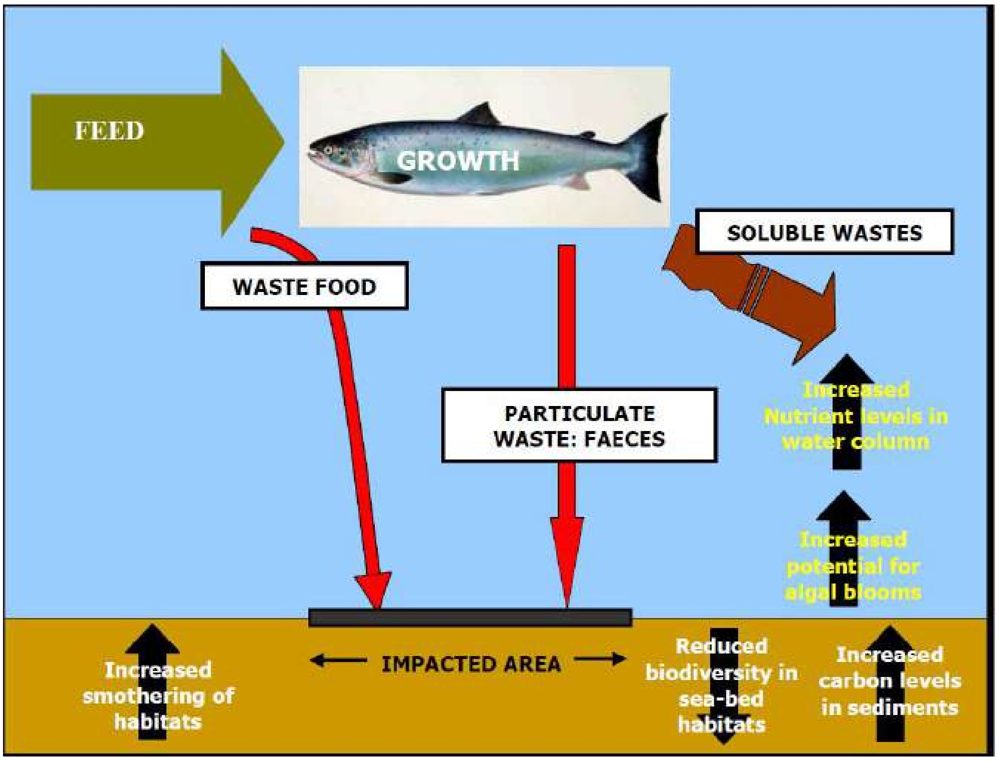
Promoting effect of raft-raised scallop culture on the formation of coastal hypoxia

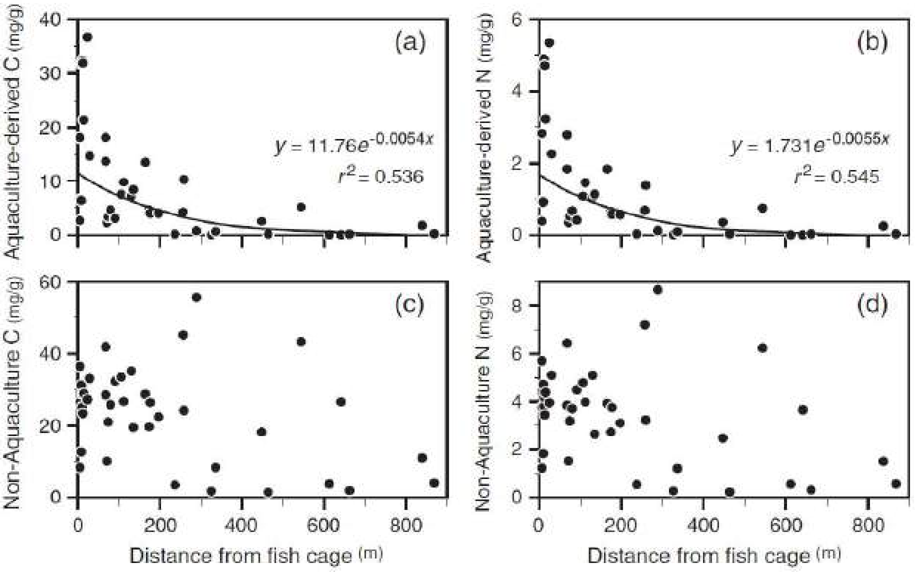
Xiyan Sun, Xuelu Gao, Jianmin Zhao, Qianguo Xing, Yongliang Liu, Lei Xie, Yongjie Wang, Bin Wang, Jiasen Lv

Rafts promoted hypoxia by adding nutrients AND altering circulation such as increased stratification.

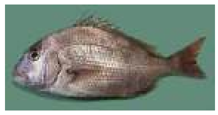


https://asc-aqua.org/learn-about-seafood-farming/aquaculture-environmental-impact/





Japanese amberjack
Seriola quinqueradiata
www.fishbase.org

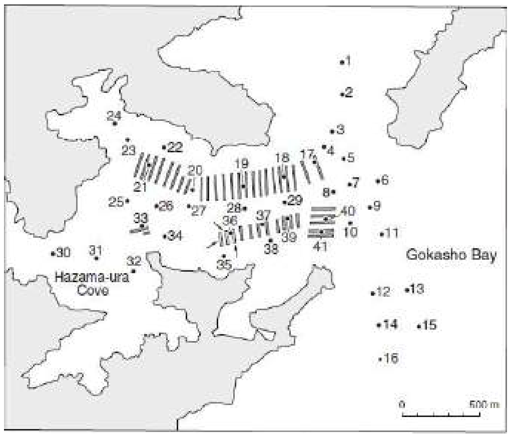


Red seabream
Pagrus major
www.Wikipedia.org

Available online at www.sciencedirect.com
SCIENCE DIRECT
Aquaculture
Aquaculture 254 (2006) 411–425
www.elsevier.com/locate/aqua-online
ELSEVIER

Quantifying aquaculture-derived organic matter in the sediment in and around a coastal fish farm using stable carbon and nitrogen isotope ratios

Hisashi Yokoyama *, Katsuyuki Abo, Yuka Ishihi
National Research Institute of Aquaculture, Fisheries Research Agency, Minami-Ise, Mie 516-0193, Japan



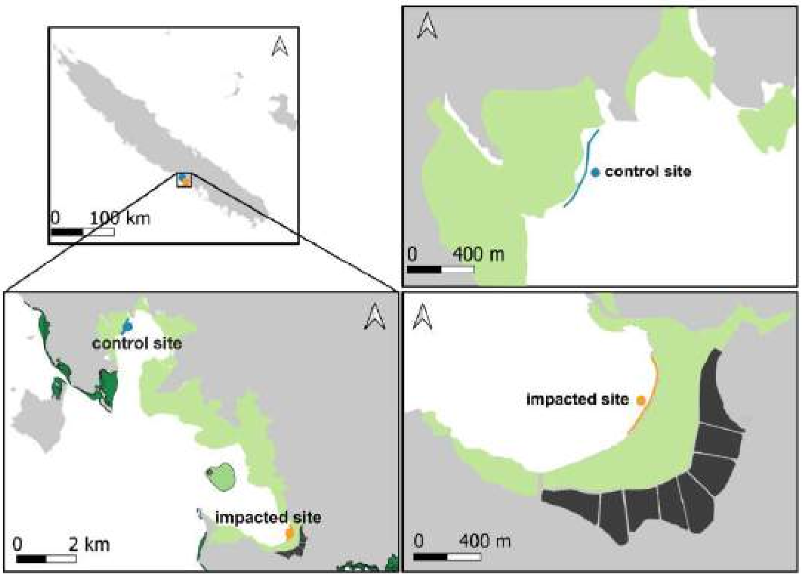


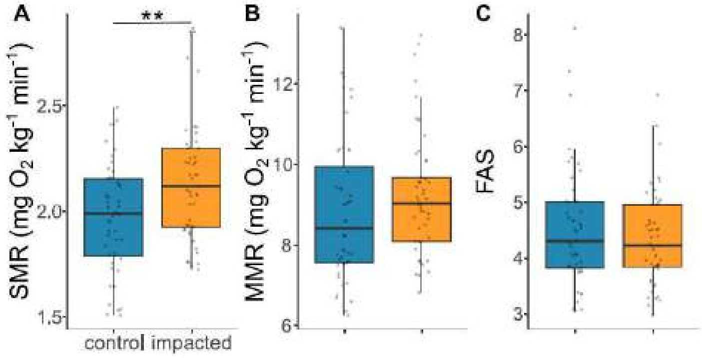
Fig. 1. Location of the two study sites on the west coast of New Caledonia (South Pacific). The coloured lines represent the 500 m transects followed during each sampling campaign at each corresponding site to account for spatial variability in environmental conditions. Black areas represent the 8 aquaculture ponds of the shrimp farm, light green areas are mangrove-lined bay and dark green areas are coastal mangroves following classification from Virly (2007). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Golden-lined spinefoot (*Siganus lineatus*)

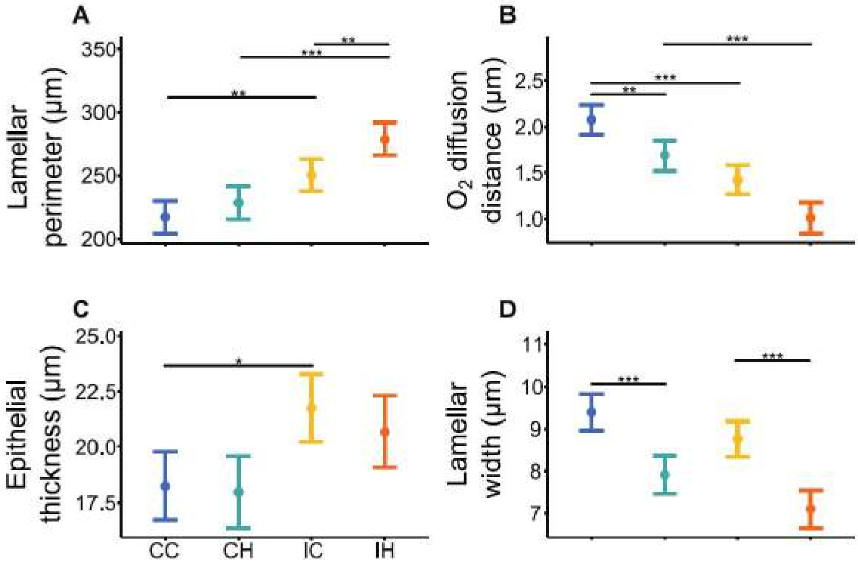
Contents lists available at ScienceDirect
Marine Pollution Bulletin
journal homepage: www.elsevier.com/locate/marpolbul
ELSEVIER

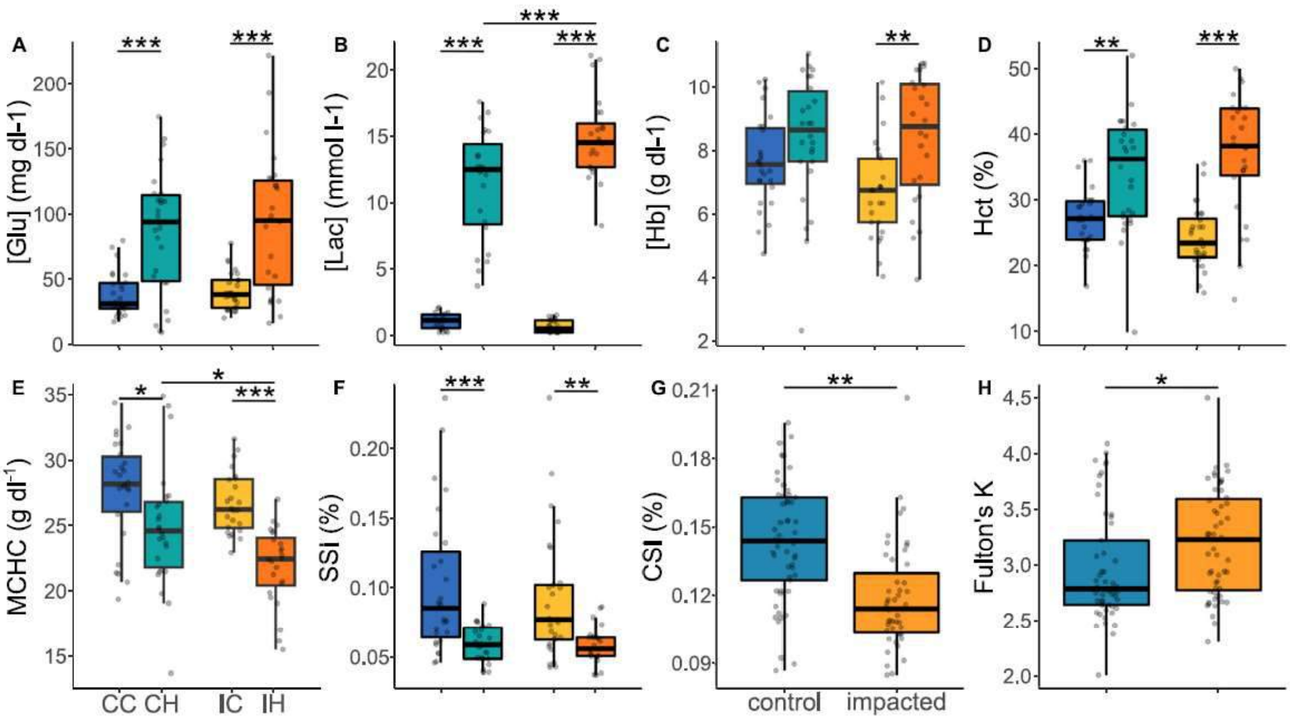
Coping with environmental degradation: Physiological and morphological adjustments of wild mangrove fish to decades of aquaculture-induced nutrient enrichment

A. Dubuc, J.L. Rummer, L. Vigliola, H. Lemonnier



Marine Pollution Bulletin
Coping with environmental degradation: Physiological and morphological adjustments of wild mangrove fish to decades of aquaculture-induced nutrient enrichment
A. Dubuc, J.L. Rummer, L. Vigliola, H. Lemonnier





Dubuc et al. 2024. Marine Pollution Bulletin


Marine Pollution Bulletin 194 (2023) 115207

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Review

Living in a hypoxic world: A review of the impacts of hypoxia on aquaculture

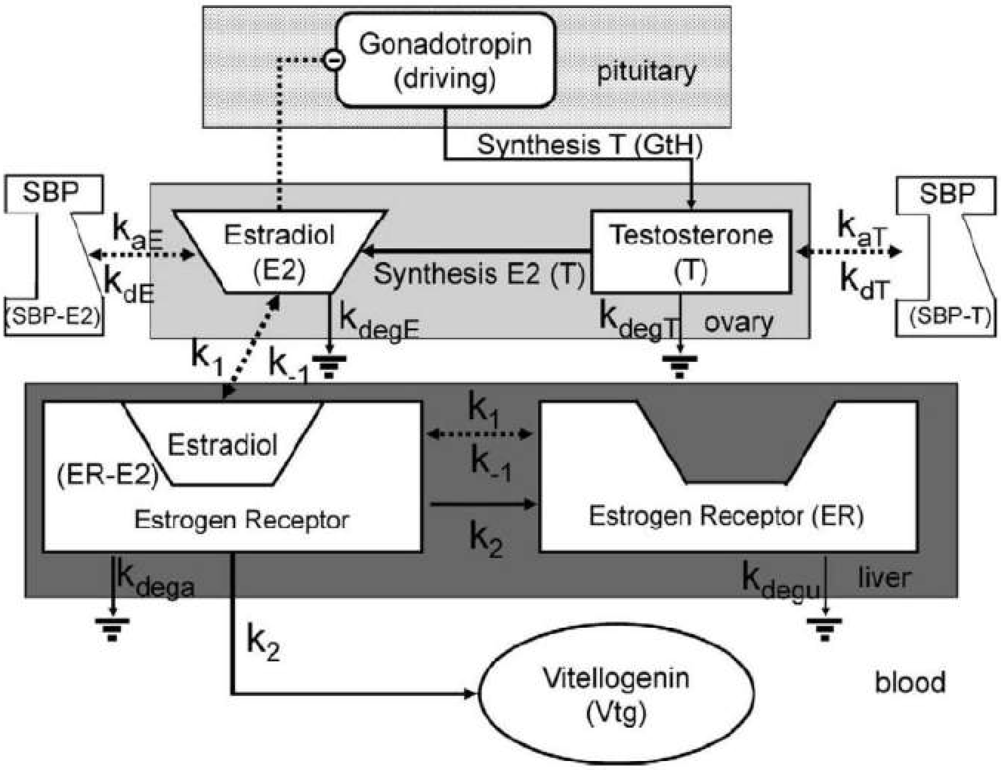
Yaoyao Zhan[a,1], Bingyu Ning[a,1], Jingxian Sun[a,b], Yaqing Chang[a,b,*]

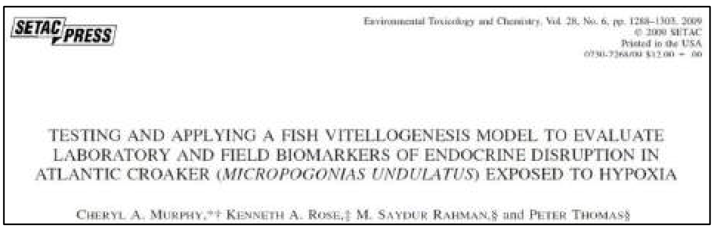
- Reproduction
  - Hypothalamus-pituitary-gonadal (HPG)
  - Gonadal development
  - Fecundity
  - Fertilization success

- Early stage development
  - Morphology (e.g., gills, heart)
  - Duration
  - Malformations
  - Mortality

- Metabolism and growth

- Behavior
  - Swim speed
  - ASR
  - Loss of equilibrium
  - Avoidance

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Environmental Toxicology and Chemistry, Vol. 28, No. 6, pp. 1288–1303, 2009
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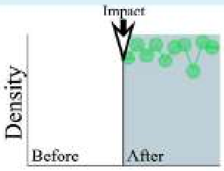
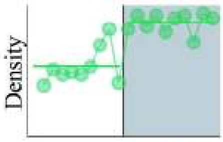
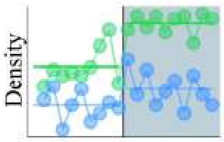
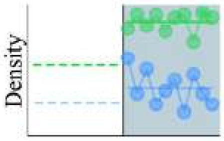
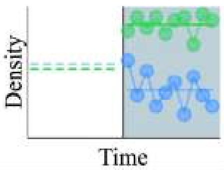
TESTING AND APPLYING A FISH VITELLOGENESIS MODEL TO EVALUATE LABORATORY AND FIELD BIOMARKERS OF ENDOCRINE DISRUPTION IN ATLANTIC CROAKER (*MICROPOGONIAS UNDULATUS*) EXPOSED TO HYPOXIA

Cheryl A. Murphy,*† Kenneth A. Rose,‡ M. Saydur Rahman,§ and Peter Thomas§

Design	Sampling regime	Relative cost	Relative difficulty in ecology	Suitability	Ecological examples of use
After		Very low	Very low	Most systems Where control unfeasible Unpredictable impacts	Pond creation
Before-After (BA)		Moderate	Moderate	Predictable impacts Where control unfeasible Availability of pre-impact data	Wildlife tunnels under roads
Before-After Control-Impact (BACI) (BARI, MBACI, BACIPS)		High	High	Predictable impacts Appropriate control Availability of pre-impact data	MPA effectiveness, renewable energy infrastructure
Control-Impact (CI) (Space-for-Time, Impact versus Reference Sites)		Low	Moderate	Unpredictable impacts Large-scale replicates that cannot be truly randomised	Oil spill or other pollution event
Randomised Controlled Trial (RCT)		Low	Very high	Unpredictable impacts Small-scale replicates appropriate for randomisation	Peatland restoration, field margins

Journal of Applied Ecology, Volume: 56, Issue: 12, Pages: 2742-2754, First published: 31 August 2019, DOI: (10.1111/1365-2664.13499)

Deoxygenation affecting aquaculture

- Effects individuals
  - We know a lot
  - Lethal
  - Sublethal
  - Lab to field: Exposure
- Part of water quality
- Interacts with temperature, salinity
- Multiple stressors
- Growth (O2 or food), mortality, disease
- Density

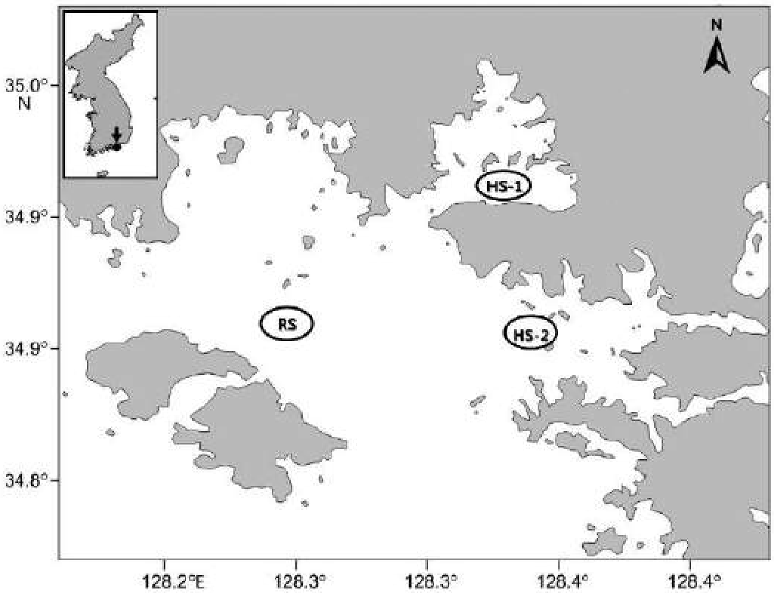
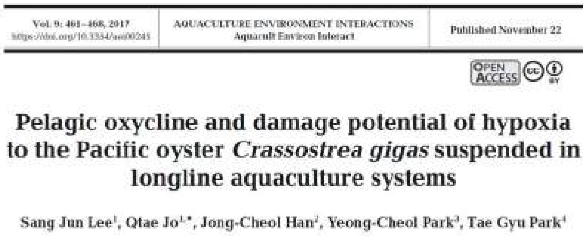


Fig. 1. Location of the study sites at the southern Korean coast. Two hypoxic sites (HS) in highly sheltered bays (HS-1 in Goseong Bay, HS-2 in Buksin Bay) and 1 normoxic reference site (RS) in a nearby area



Vol. 9: 461–468, 2017
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AQUACULTURE ENVIRONMENT INTERACTIONS
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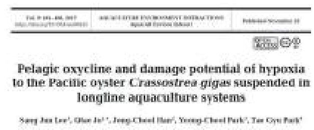
Pelagic oxycline and damage potential of hypoxia to the Pacific oyster *Crassostrea gigas* suspended in longline aquaculture systems

Sang Jun Lee[1], Qtae Jo[1,*], Jong-Cheol Han[2], Yeong-Cheol Park[3], Tae Gyu Park[4]


Pelagic oxycline and damage potential of hypoxia to the Pacific oyster *Crassostrea gigas* suspended in longline aquaculture systems

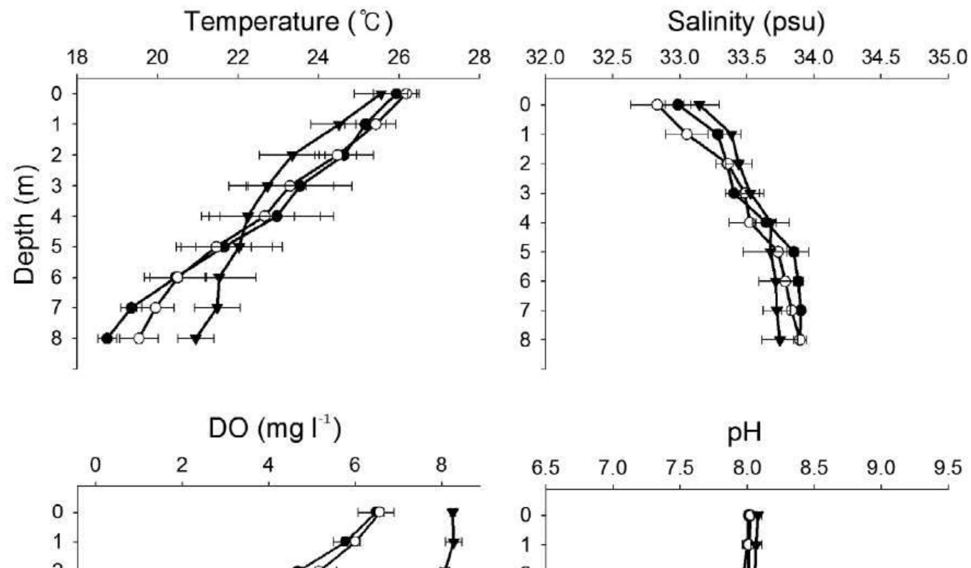


Fig. 2. Vertical profiles of the major environmental variables examined at the study sites during oxycline persistence. Solid circle: hypoxic site 1 (HS-1); empty circle: hypoxic site 2 (HS-2); solid triangle: reference site (RS). Data are means ± SD

Pelagic oxycline and damage potential of hypoxia to the Pacific oyster *Crassostrea gigas* suspended in longline aquaculture systems

Sang Jun Lee[1], Qiao Jo[1,*], Jong-Cheol Han[2], Yeong-Cheol Park[3], Tae Gyu Park[4]

Table 4. Mean (±SD) depth-dependent dissolved oxygen (DO) level (mg l^{-1}) and percentage mortality (in parentheses) of *Crassostrea gigas* during oxycline persistence. HS-1: hypoxic site 1; HS-2: hypoxic site 2; RS: reference site

Site	Depth (m)					
	1	2	3	4	5	6
HS-1	5.78 ± 0.29 (16.3 ± 3.7)	4.68 ± 0.09 (57.7 ± 6.4)	1.83 ± 0.24 (88.9 ± 2.1)	0.90 ± 0.25 (100)	0.88 ± 0.26 (100)	0.84 ± 0.27 (100)
HS-2	6.01 ± 0.10 (21.8 ± 5.7)	5.17 ± 0.41 (37.0 ± 7.2)	4.00 ± 0.08 (61.7 ± 11.3)	2.12 ± 0.56 (100)	0.51 ± 0.26 (100)	0.40 ± 0.19 (100)
RS	8.28 ± 0.19 (4.5 ± 0.3)	8.07 ± 0.09 (5.3 ± 1.8)	7.75 ± 0.10 (3.95 ± 1.0)	7.23 ± 0.35 (7.7 ± 1.6)	6.05 ± 0.26 (15.0 ± 3.5)	5.84 ± 0.14 (14.8 ± 4.2)

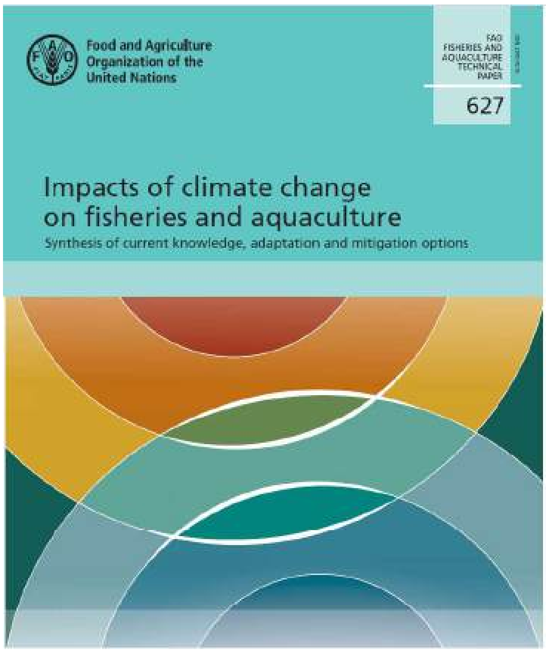
Table 5. Mean (±SD) depth-dependent percentage survival of *Crassostrea gigas* in reoxygenated water. HS-1: hypoxic site 1; HS-2: hypoxic site 2; RS: reference site

Site		Oyster bag position by depth (m)							
	Average	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
HS-1	53.7	86.6 ± 5.8	78.0 ± 7.3	67.1 ± 3.9	32.3 ± 6.0	45.9 ± 7.4	47.4 ± 9.4	35.3 ± 4.9	37.1 ± 6.0
HS-2	79.9	87.2 ± 7.3	86.5 ± 5.2	85.3 ± 3.6	88.1 ± 5.2	78.0 ± 9.3	83.5 ± 6.8	65.2 ± 6.1	65.4 ± 8.7
RS	93.9	94.4 ± 2.7	98.5 ± 3.0	92.8 ± 2.1	95.7 ± 3.4	93.4 ± 2.9	87.0 ± 4.1	92.8 ± 2.5	96.6 ± 2.1

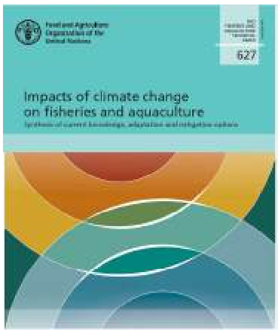
Impacts on Aquaculture & Adaptations

- Organisms, People, Farming system, Land-Seascape/ AMA, Global

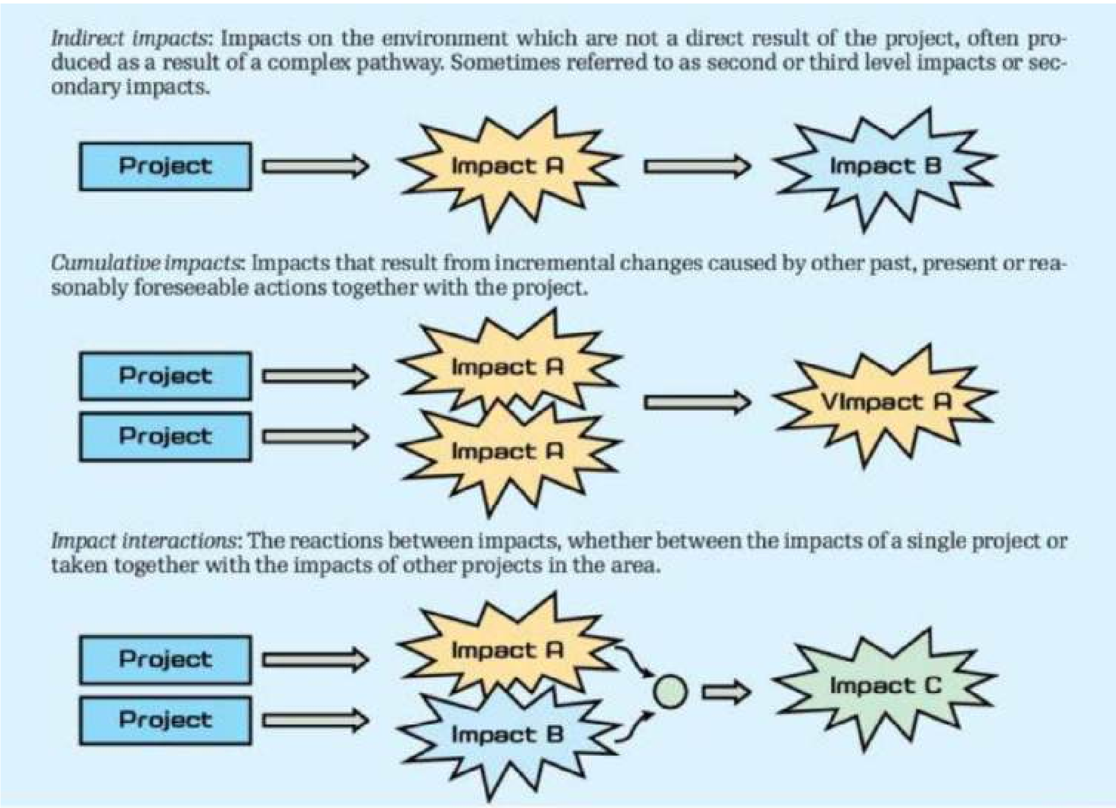
- Warming
- Acidification
- Distributional shifts
- Sea level rise
- Circulation/winds
- Extreme events
- HABs
- Water shortage
- Distal drivers



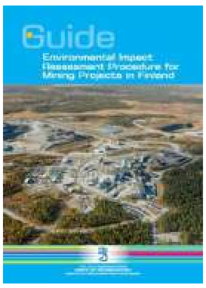
Drivers		Aquatic organisms	People	Farming system
Hypoxia	Potential impacts	• Species and/or strains with higher tolerance should be less affected • Increased mortality • Reduced growth • Higher sensitivity to other drivers (e.g. pathogens)	• Relocation of some farming facilities to better oxygenated areas may create new safety risks • Moving facilities may affect livelihoods and add to costs	• Lower carrying capacity of ecosystems • Increased aeration costs • Reduction in the number of annual crops when hypoxia is seasonal (e.g. stratification cycles in lakes)
	Adaptation measures	• Shift to more tolerant farmed species or strains	• Follow guidelines on decent work in aquaculture (e.g. FAO, 2016c)	• Relocate farming facilities to new areas offshore or inland



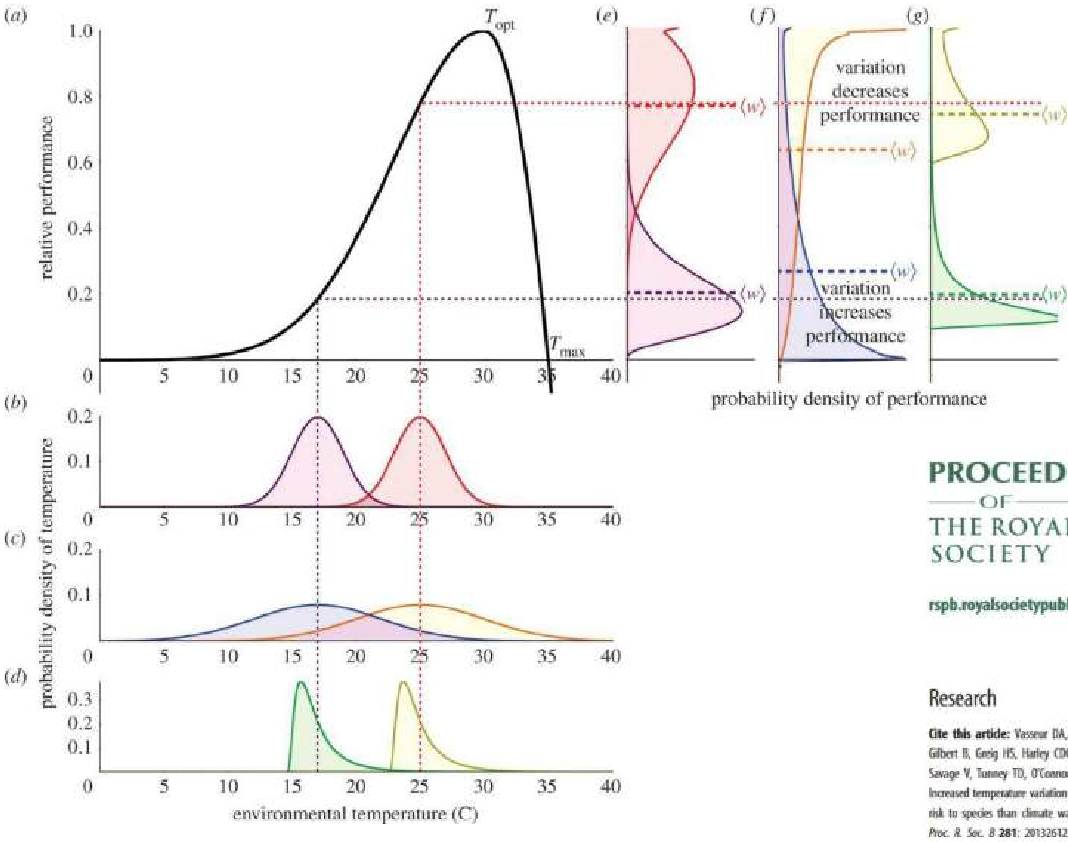
Land-Seascape/AMA[3]	Country	Global
• Lower carrying capacity of ecosystems • Some aquaculture areas may become unfavourable • Changes in ecological services to aquaculture	• Lower production resulting from lower carrying capacity	• New areas become favourable to aquaculture, others become unfavourable
• Move farming facilities to new areas offshore or inland • Mainstream spatial planning and ecosystem approach	• Mainstream spatial planning and ecosystem approach	• Mainstream spatial planning and ecosystem approach



European Commission's EIA guidelines (2001)
Modified by Jorma Jantunen, Finnish Environment Institute.



Variance and Nonlinear



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Research

Cite this article: Vasseur DA, DeLong JP, Gilbert B, Greig HS, Harley CDG, McCann KS, Savage V, Tunney TD, O'Connor MI. 2014 Increased temperature variation poses a greater risk to species than climate warming. *Proc. R. Soc. B* **281**: 20132612. http://dx.doi.org/10.1098/rspb.2013.2612

Developing best practices to address coastal marine deoxygenation in APEC economies for improving the management of marine living resources

Horn Point Laboratory
University of Maryland Center for Environmental Science

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

Session 2 (Seminar)

Regulatory Framework of Water Quality

PERSPECTIVE NATURE FOOD

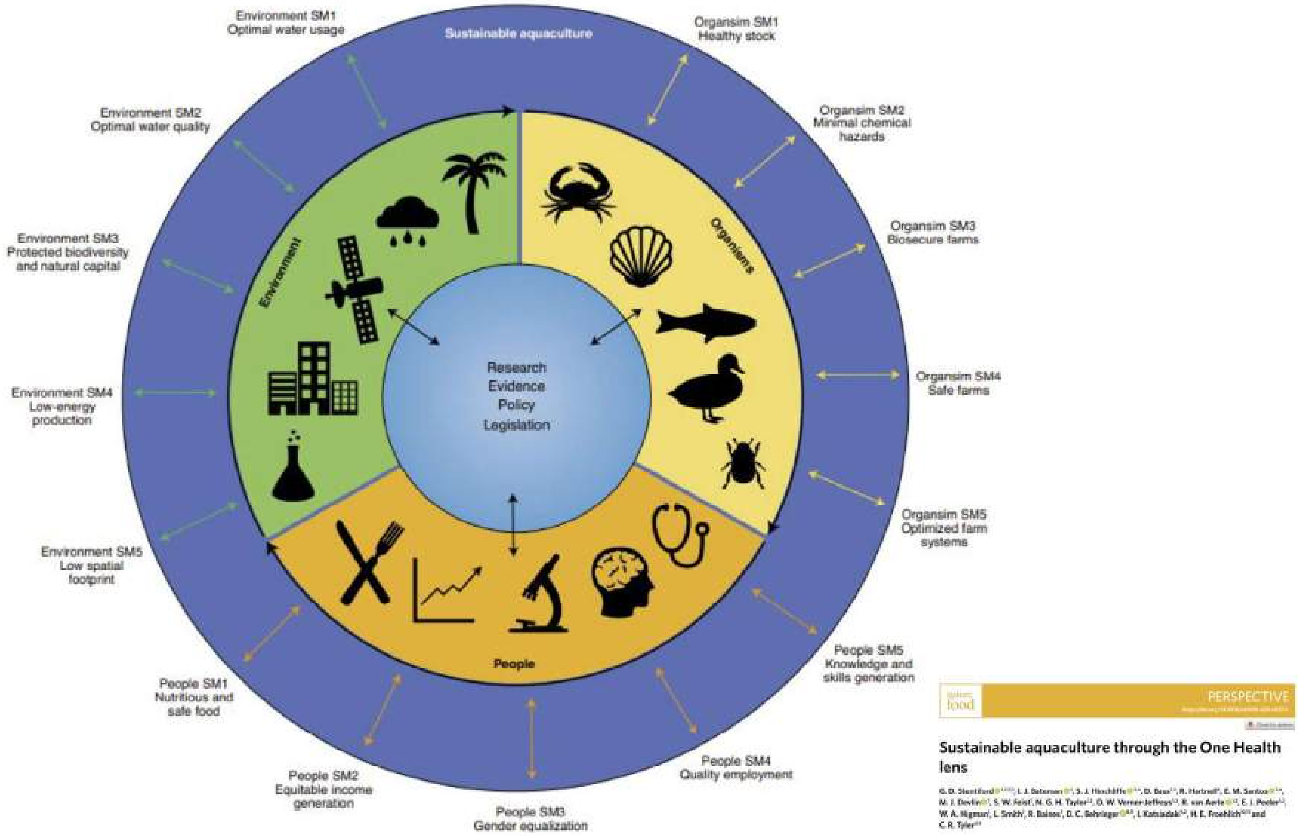
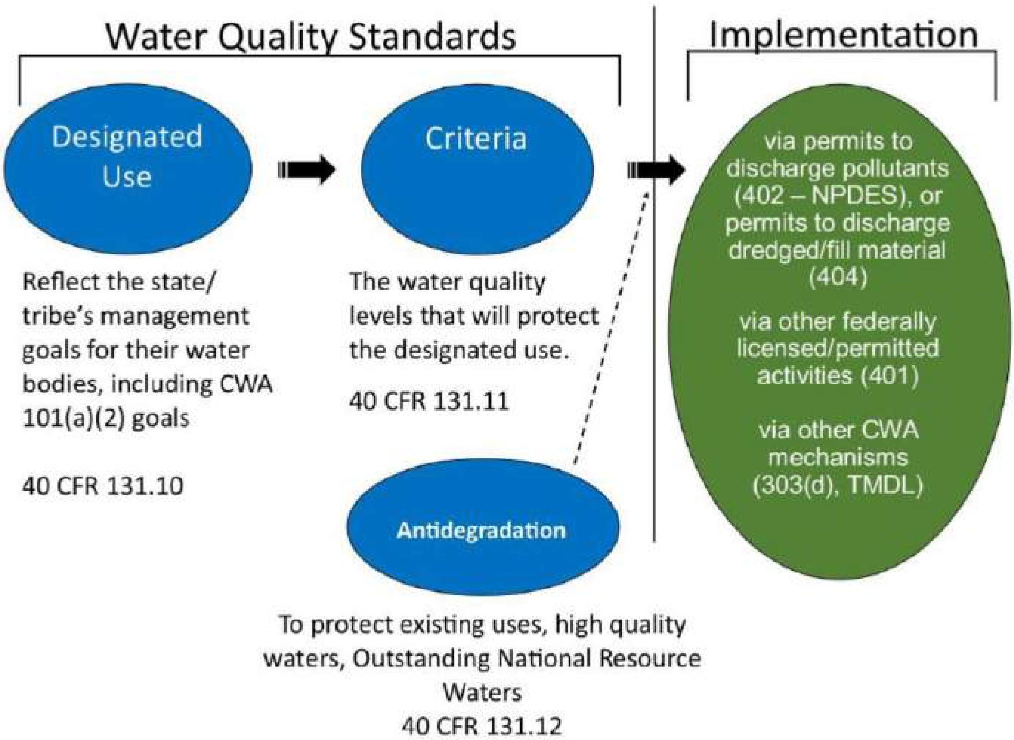


Fig. 2 | One Health success metrics for sustainable aquaculture. A One Health approach (Fig. 1) to the design and assessment of ESP in aquaculture and related sub-sectors requires success metrics (SMs) spanning environment, organism and human health. Descriptors for SMs (Table 1) are applied to hypothetical sub-sectors of the aquaculture industry in Fig. 3.

USA EPA: Water Quality Standards



https://www.epa.gov/sites/default/files/2021-04/documents/intro_to_wqs.pdf

Designated Uses

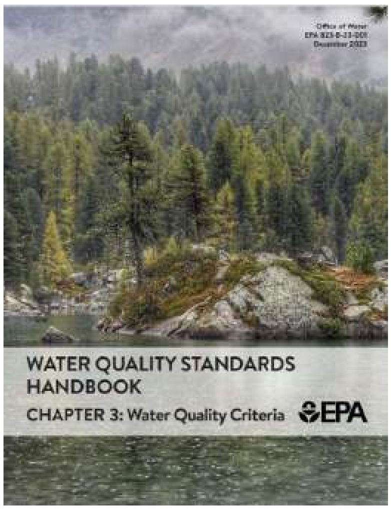
- Public water supplies
- Protection and propagation of fish, shellfish, and wildlife
- Recreation
- Agriculture
- Industry
- Navigation
- Coral reef preservation
- Marinas
- Groundwater recharge
- Aquifer protection
- Hydroelectric power

Criteria

- Magnitude
- Duration
- Maximum allowable frequency of exceedance

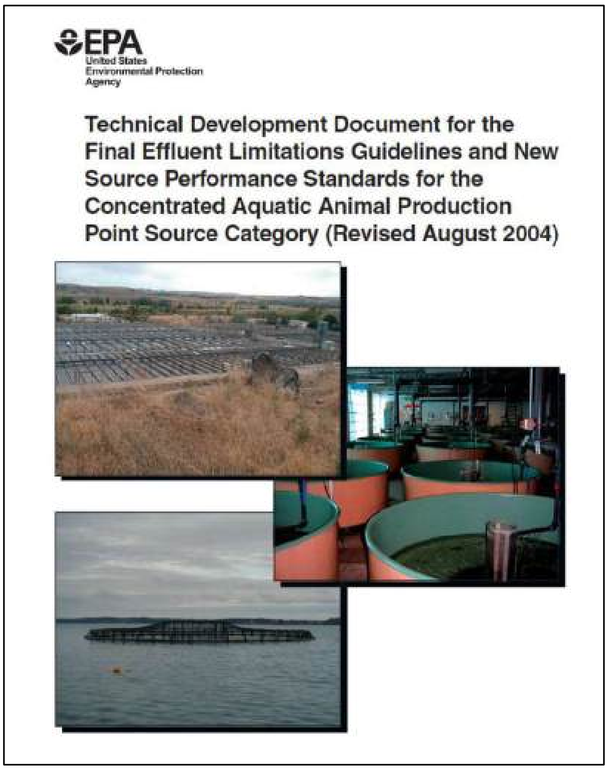
- Acute and chronic

- Nutrients
- Sediments
- Temperature
- Biocriteria



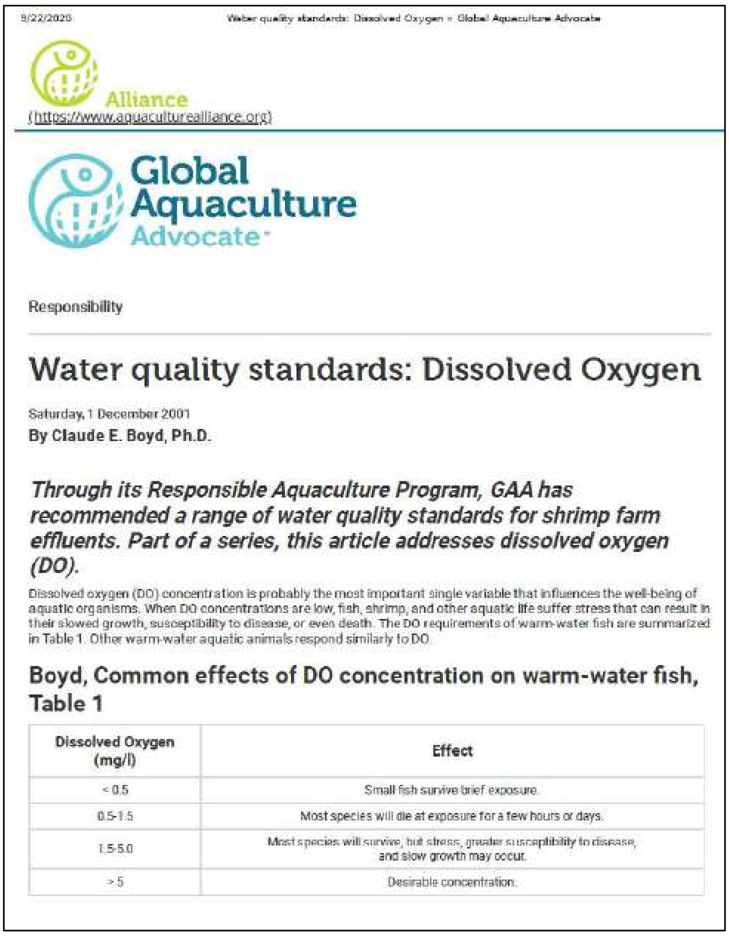
Fisheries and Aquaculture

- Dissolved oxygen to protect fish and shellfish
- None for fisheries (catch is involved)
- Some for aquaculture
- Chesapeake Bay as a an example



EPA
United States Environmental Protection Agency

Technical Development Document for the Final Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category (Revised August 2004)



9/22/2020 Water quality standards: Dissolved Oxygen « Global Aquaculture Advocate

Alliance
(https://www.aquaculturealliance.org)

Global Aquaculture Advocate

Responsibility

Water quality standards: Dissolved Oxygen

Saturday, 1 December 2001

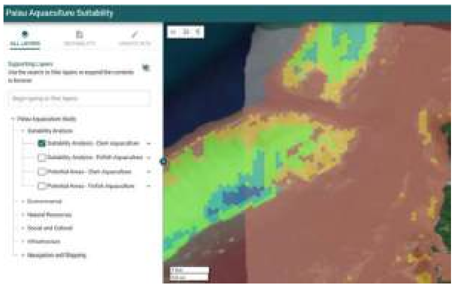
By Claude E. Boyd, Ph.D.

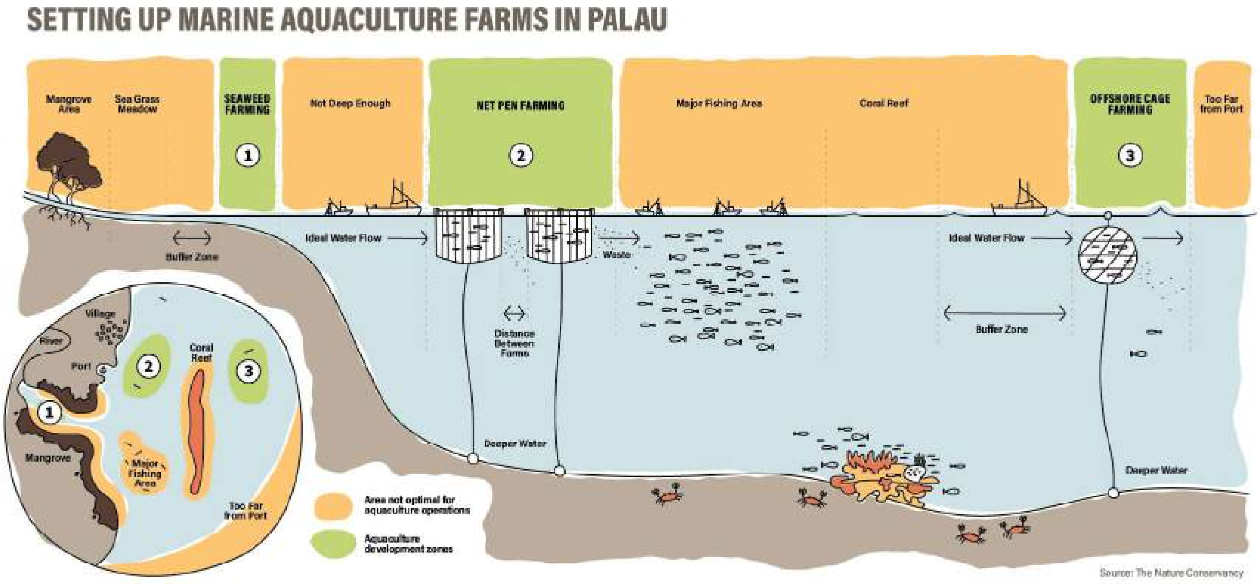
Through its Responsible Aquaculture Program, GAA has recommended a range of water quality standards for shrimp farm effluents. Part of a series, this article addresses dissolved oxygen (DO).

Dissolved oxygen (DO) concentration is probably the most important single variable that influences the well-being of aquatic organisms. When DO concentrations are low, fish, shrimp, and other aquatic life suffer stress that can result in their slowed growth, susceptibility to disease, or even death. The DO requirements of warm-water fish are summarized in Table 1. Other warm-water aquatic animals respond similarly to DO.

Boyd, Common effects of DO concentration on warm-water fish, Table 1

Dissolved Oxygen (mg/l)	Effect
< 0.5	Small fish survive brief exposure.
0.5-1.5	Most species will die at exposure for a few hours or days.
1.5-5.0	Most species will survive, but stress, greater susceptibility to disease, and slow growth may occur.
> 5	Desirable concentration.





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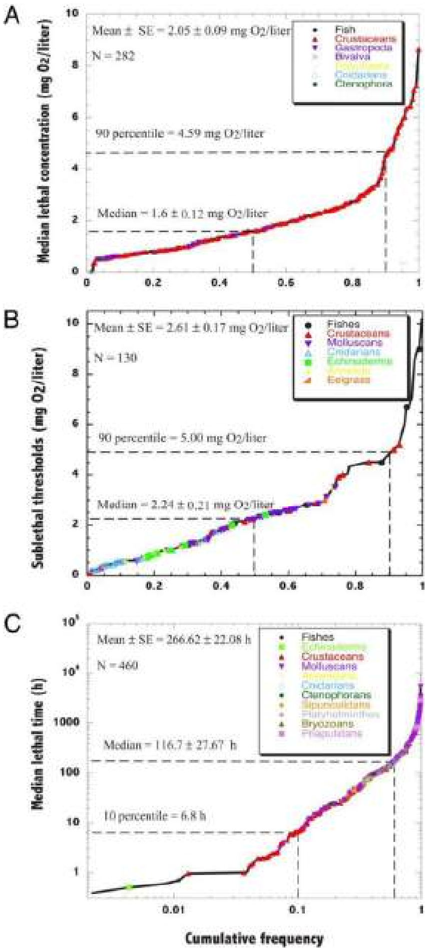
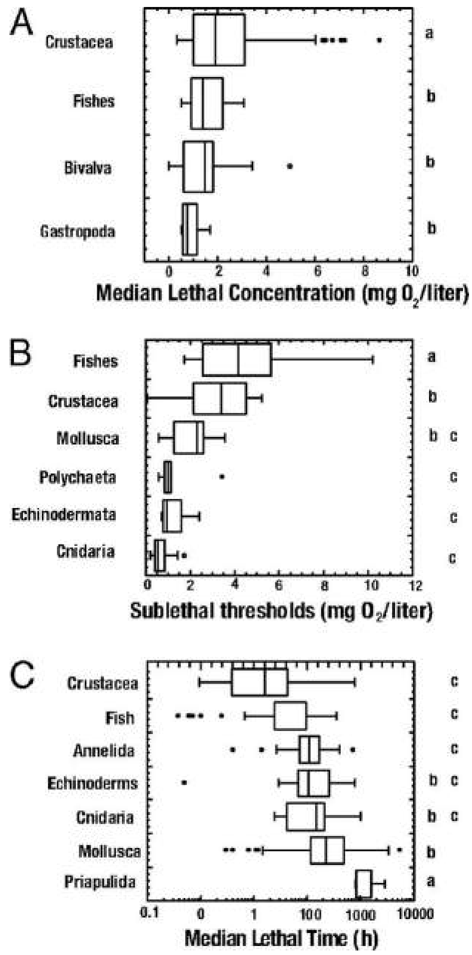
https://www.nature.org/en-us/what-we-do/our-insights/agriculture/aquaculture-siting-palau/

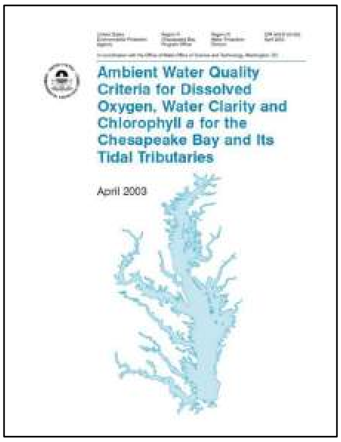




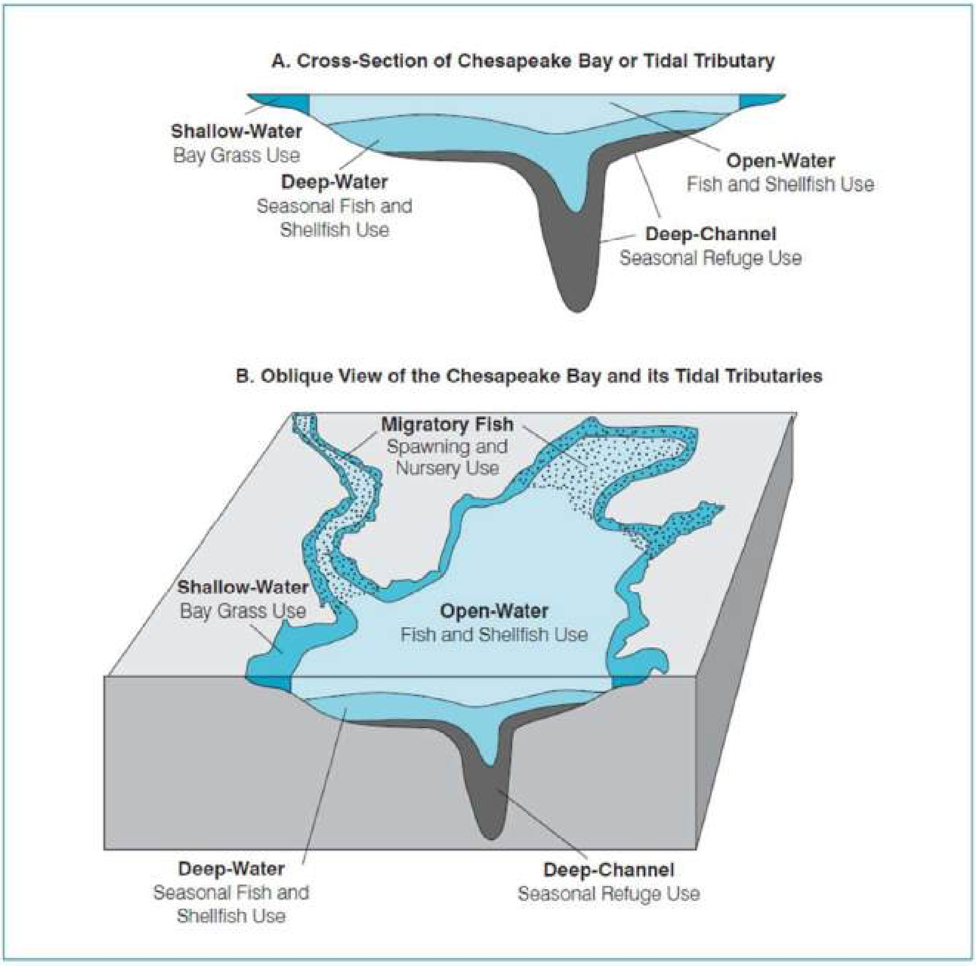
Thresholds of hypoxia for marine biodiversity

Raquel Vaquer-Sunyer* and Carlos M. Duarte

15452–15457 | PNAS | October 7, 2008 | vol. 105 | no. 40


Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a* for the Chesapeake Bay and Its Tidal Tributaries

April 2003



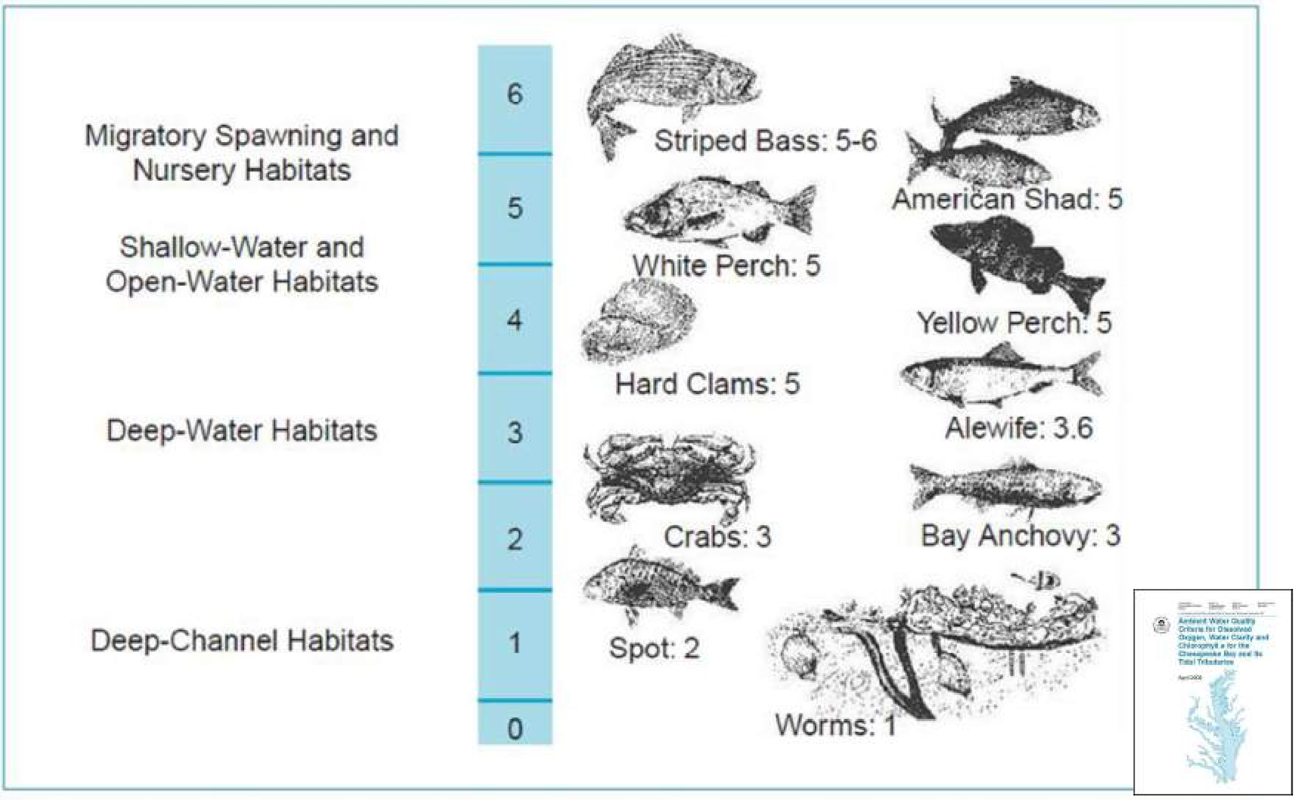


Figure 2. Dissolved oxygen (mg liter^{-1}) concentrations required by different Chesapeake Bay species and communities.

Table 1. Chesapeake Bay dissolved oxygen criteria.

Designated Use	Criteria Concentration/Duration	Protection Provided	Temporal Application
Migratory fish spawning and nursery use	7-day mean ≥ 6 mg liter^{-1} (tidal habitats with 0-0.5 ppt salinity)	Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species.	February 1 - May 31
	Instantaneous minimum ≥ 5 mg liter^{-1}	Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species.	
	Open-water fish and shellfish designated use criteria apply		June 1 - January 31
Shallow-water bay grass use	Open-water fish and shellfish designated use criteria apply		Year-round
Open-water fish and shellfish use	30-day mean ≥ 5.5 mg liter^{-1} (tidal habitats with 0-0.5 ppt salinity)	Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species.	Year-round
	30-day mean ≥ 5 mg liter^{-1} (tidal habitats with >0.5 ppt salinity)	Growth of larval, juvenile and adult fish and shellfish; protective of threatened/endangered species.	
	7-day mean ≥ 4 mg liter^{-1}	Survi-al of open-water fish larvae.	
	Instantaneous minimum ≥ 3.2 mg liter^{-1}	Survival of threatened/endangered sturgeon species.[1]	
Deep-water seasonal fish and shellfish use	30-day mean ≥ 3 mg liter^{-1}	Survival and recruitment of bay anchovy eggs and larvae.	June 1 - September 30
	1-day mean ≥ 2.3 mg liter^{-1}	Survival of open-water juvenile and adult fish.	
	Instantaneous minimum ≥ 1.7 mg liter^{-1}	Survival of bay anchovy eggs and larvae.	
	Open-water fish and shellfish designated-use criteria apply		October 1 - May 31
Deep-channel seasonal refuge use	Instantaneous minimum ≥ 1 mg liter^{-1}	Survival of bottom-dwelling worms and clams.	June 1 - September 30
	Open-water fish and shellfish designated use criteria apply		October 1 - May 31

[1] At temperatures considered stressful to shortnose sturgeon (>29°C), dissolved oxygen concentrations above an instantaneous minimum of 4.3 mg liter^{-1} will protect survival of this listed sturgeon species.

Ambient Water Quality…. Chesapeake Bay, EPA 903-R-03-002

Table III-1. 1992 Chesapeake Bay dissolved oxygen goal for restoration of living resource habitats.

The Chesapeake Bay dissolved oxygen goal for the restoration of living resource habitats is to provide for sufficient dissolved oxygen to support the survival, growth and reproduction of anadromous, estuarine and marine fish and invertebrates in the Chesapeake Bay and its tidal tributaries by achieving, to the greatest spatial and temporal extent possible, the following target concentrations of dissolved oxygen, and by maintaining the existing minimum concentration of dissolved oxygen in areas of the Chesapeake Bay and its tidal tributaries where dissolved oxygen concentrations fall above the recommended targets.

Target Dissolved Oxygen Concentrations	Time and Location
Dissolved oxygen ≥ 1 mg liter $^{-1}$	All times, everywhere.
1.0 mg liter $^{-1}$ ≥ dissolved oxygen ≤ 3 mg liter $^{-1}$	For no more than 12 hours, interval between excursions at least 48 hours, everywhere.
Monthly mean dissolved oxygen ≥ 5 mg liter $^{-1}$	All times, throughout above-pycnocline[1] waters.
Dissolved oxygen ≥ 5 mg liter $^{-1}$	All times, throughout above-pycnocline waters in spawning reaches, spawning rivers, and nursery areas.

[1]The pycnocline is the portion of water column where density changes rapidly becaue of salinity and temperature.
Source: Jordan et al. 1992

Ambient Water Quality…. Chesapeake Bay, EPA 903-R-03-002

Table III-6. Open-water fish and shellfish designated use dissolved oxygen criteria components.

Criteria Components	Concentration	Duration	Source
Protection against larval recruitment effects	> 4.6-4.8 mg liter $^{-1}$ > 3.4-3.6 mg liter $^{-1}$ > 2.7-2.9 mg liter $^{-1}$	30 to 40 days 7 days < 24 hours	U.S. EPA 2000
Protection against growth effects	> 4.8 mg liter $^{-1}$	-	U.S. EPA 2000
Protection of juvenile/adult survival	> 2.3 mg liter $^{-1}$	24 hours	U.S. EPA 2000
Protection for resident tidal freshwater species	> 5.5 mg liter $^{-1}$ > 4 mg liter $^{-1}$ > 3 mg liter $^{-1}$	30 days 7 days instantaneous minimum	U.S. EPA 1986
Protection against effects on threatened/endangered species (shortnose sturgeon)	> 5 mg liter $^{-1}$ > 3.5 mg liter $^{-1}$ > 3.2 mg liter $^{-1}$ [1] >4.3 mg liter $^{-1}$ [2]	30 days 6 hours 2 hours 2 hours	Secor and Niklitschek 2003; Niklitschek 2001; Secor and Gunderson 1998; Jenkins et al. 1994; Campbell and Goodman 2003
Additional published findings			
– Preferred striped bass juvenile habitat	> 5 mg liter $^{-1}$	-	Kramer 1987; Breitburg et al. 1994
– Juvenile striped bass growth, feeding effects	< 4 mg liter $^{-1}$	-	Kramer 1987; Breitburg et al. 1994
– Juvenile striped bass mortality	< 3 mg liter $^{-1}$	-	Chittenden 1972; Coutant 1985; Krouse 1968
– Total fish biomass declining	< 3.7 mg liter $^{-1}$	-	Simpson 1995
– Total fish species richness	< 3.5 mg liter $^{-1}$	-	Simpson 1995

[1] Protective of survival at nonstressful temperatures.
[2] Protective of shortnose sturgeon at stress temperatures (> 29°C).

Ambient Water Quality…. Chesapeake Bay, EPA 903-R-03-002

Table III-9. Response patterns of Chesapeake Bay benthic organisms to declining dissolved oxygen concentrations (mg $liter^{-1}$).

Response	Dissolved Oxygen	Species	Reference
Avoidance			
Infaunal swimming	1.1	*Paraprionospio pinnata*	Diaz et al. 1992
	0.5	*Nereis succinea*	Sagasti et al. 2001
Epifaunal off bottom	0.5	*Neopanope sayi*	Sagasti et al. 2001
	0.5	*Callinectes sapidus*	Sagasti et al. 2001
	1	*Stylochus ellipticus*	Sagasti et al. 2001
	1	*Mitrella lunata*	Sagasti et al. 2001
	0.5	*Dirodella obscura*	Sagasti et al. 2001
	1	*Cratena kaoruae*	Sagasti et al. 2001
Fauna, unable to leave or escape, initiate a series of sublethal responses			
Cessation of feeding	0.5	*Balanus improvisus*	Sagasti et al. 2001
	0.6	*Streblospio benedicti*	Llanso 1991
	1	*Loimia medusa*	Llanso and Diaz 1994
	1.1	*Capitella* sp.	Warren 1977; Forbes and Lopez 1990
Decreased activities not related to respiration	0.5	*Balanus improvisus*	Sagasti et al. 2001
	0.5	*Conopeum tenuissimum*	Sagasti et al. 2001
	0.5	*Membranipora tenuis*	Sagasti et al. 2001
	1	*Cratena kaoruae*	Sagasti et al. 2001
	1	*Stylochus ellipticus*	Sagasti et al. 2001
	1	*Streblospio benedicti*	Llanso 1991
Cessation of burrowing	1.1	*Capitella* sp.	Warren 1977

continued

Table III-9. Response patterns of Chesapeake Bay benthic organisms to declining dissolved oxygen concentrations (mg $liter^{-1}$) *(continued).*

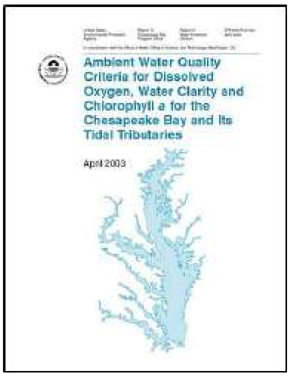
Response	Dissolved Oxygen	Species	Reference
Emergence from tubes or burrows	0.1-1.3	*Ceriathiopis americanus*	Diaz, unpublished data
	0.5	*Sabellaria vulgaris*	Sagasti et al. 2001
	0.5	*Polydora cornuta*	Sagasti et al. 2001
	0.7	*Micropholis atra*	Diaz et al. 1992
	1	*Hydroides dianthus*	Sagasti et al. 2001
	10% saturation	*Nereis diversicolor*	Vismann 1990
Siphon stretching into water column	0.1-1.0	*Mya arenaria, Abra alba*	Jorgensen 1980
Siphon or body stretching	0.5	*Molgula manhattensis*	Sagasti et al. 2001
	0.5	*Diadumene leucolena*	Sagasti et al. 2001
Floating on surface of water	0.5	*Diadumene leucolena*	Sagasti et al. 2001
Formation of resting stage	0.5	*Membranipora tenuis*	Sagasti et al. 2001
	0.5	*Conopeum tenuissimum*	Sagasti et al. 2001

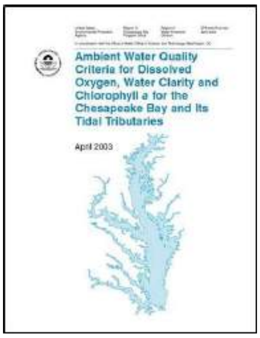
Sources: Diaz and Rosenberg 1995; Sagasti et al. 2001.

Ambient Water Quality…. Chesapeake Bay, EPA 903-R-03-002

Chesapeake Bay

- Monitoring for dissolved oxygen criteria attainment should address all four frequencies of dissolved oxygen criteria:
  - 30-day mean
  - 7-day mean
  - 1-day mean
  - instantaneous minimum
- 10% exceedance is allowed
- Temperature, salinity
- Natural (background) exceedance





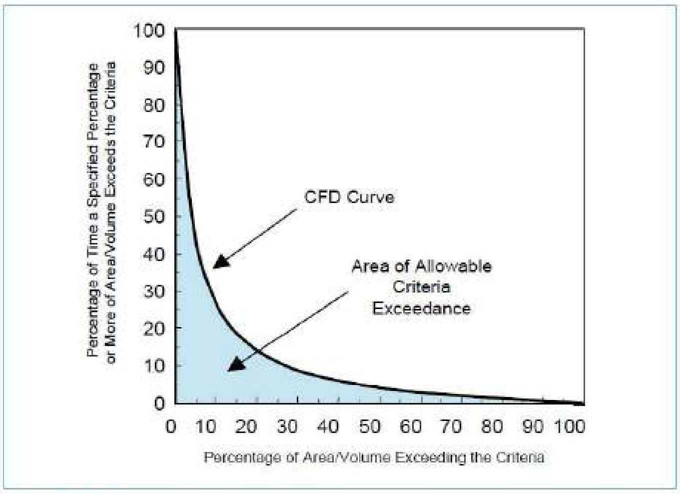


Figure VI-18. Cumulative frequency distribution curve in the shape of a hyperbolic curve that represents approximately 10 percent allowable exceedances equally distributed between time and space.

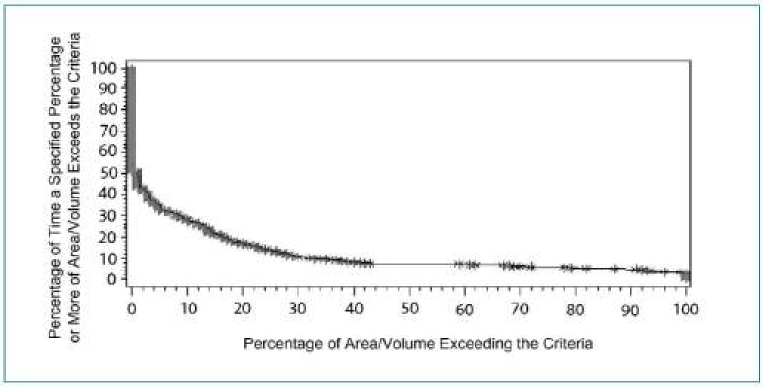
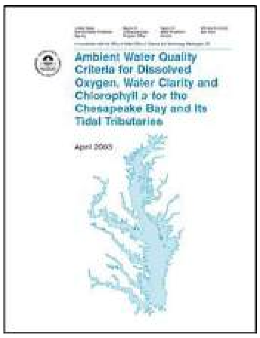


Figure VI-16. Dissolved oxygen criteria reference curve for defining criteria attainment in open-water designated use habitats.



Remarks

- Monitoring of DO based on biology
- Analyses
- Links to causes
- Concepts apply, specifics are economy and location specific

APEC Project OFWG 201 2023 workshop

Best practices for data management and data quality assessment

Second Institute of Oceanography, Ministry of Natural Resources, P.R.C

Asia-Pacific Economic Cooperation

Paracas, Peru Oct.1st, 2024

Global DO map are generally based on Winkler and CTD data.

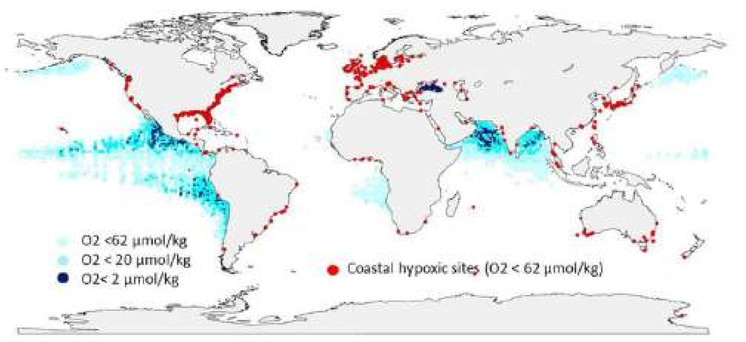
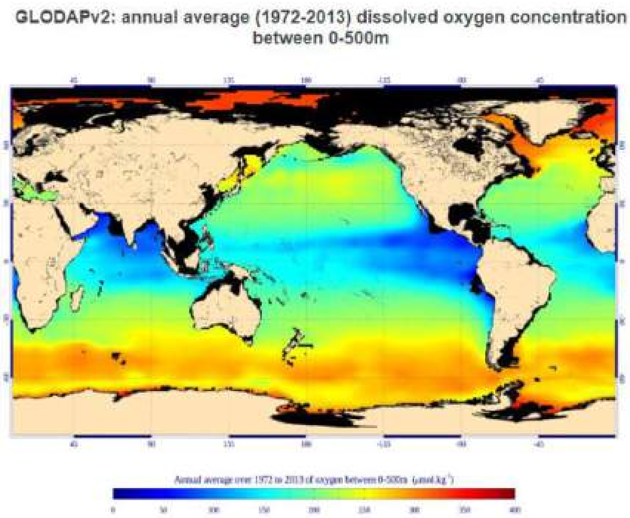


FIGURE 1 | Global distribution of low O_2 areas (i.e., O_2 < 62 μmol kg^{-1}) in the coastal and global ocean (from Breitburg et al., 2018). In the coastal area, more than 500 sites have been inventoried with low O_2 conditions in the past half century (red dots) while in the open ocean the extent of low O_2 waters amounts to several millions km^2 (the blue dots refer to conditions at 300 m).

(Breitburg et al. 2018)



Outline

- ◆ **Introduction**
- ◆ **Current Trends in Ocean Monitoring Data Management**
- ◆ **Best Practices in Data Management**
- ◆ **Why and How to Carry Out Data Quality Assessment**
- ◆ **Summary**

Introduction

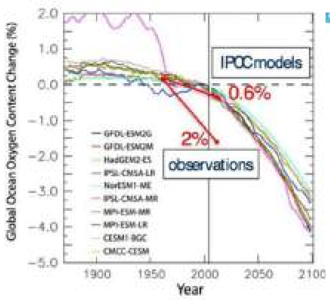
- **Why Data Management and Quality Assessment Matter?**

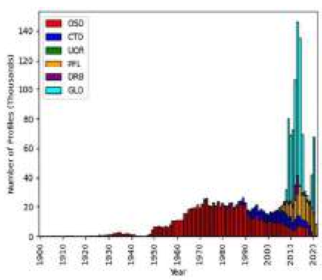
✓ Disagreement among analyses and models

✓ Uncertainties and differences due to the scarcity of accessible data, the use of different datasets

✓ A precise quantification of the O_2 trend in the global coastal zone is still debated

✓ The increasing number of autonomous technologies and observation platforms, such as gliders.





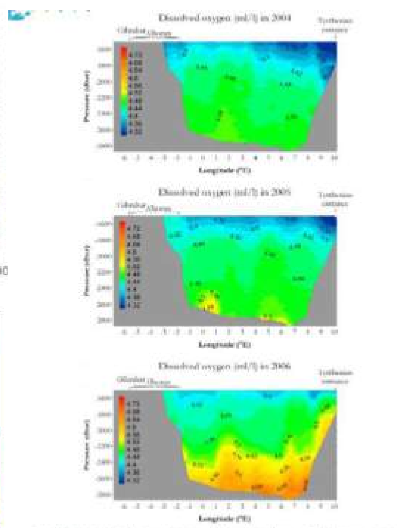


Fig.2 Vertical O2 distributions (ml/l) below 1500 m depth along an East-West transect in the NW Mediterranean Sea in 2004, 2005 and 2006 (from Schroeder et al. 2008). The increase of oxygen in the deep waters shows the presence of a new deep-water mass coming from the Eastern basin

(1) Accurate data is crucial for identifying hypoxia and deoxygenation trends, assessing environmental health, and informing decision-making.

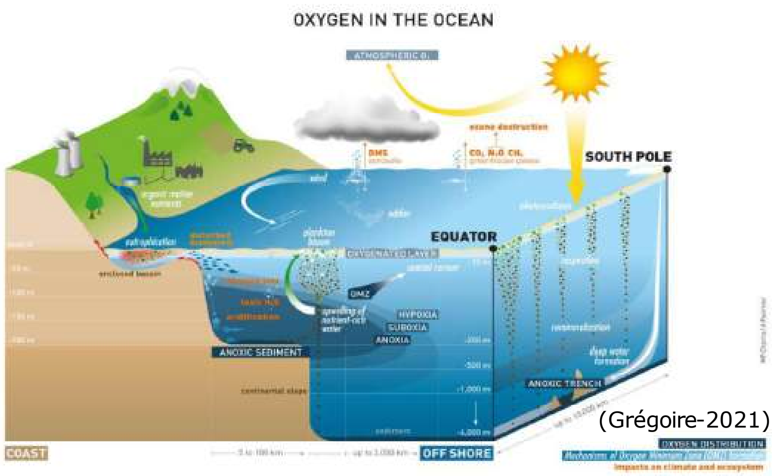
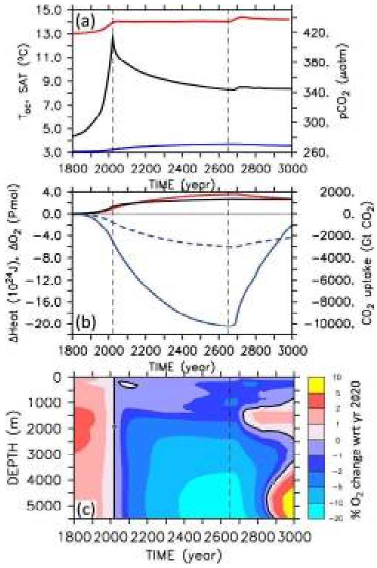
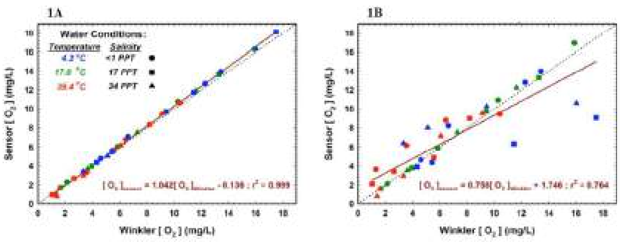


FIGURE 4 | Processes affecting the O_2 dynamics in the ocean and mechanisms of oxygen minimum zones (OMZs) formation (figure from Paulmier, 2017).



Simulated global annual-mean oxygen loss change relative to 2020. (Oschlies, 2021)

- **Data from multiple sources (e.g., satellite, buoys, ships) generate vast amounts of data that need systematic management.**



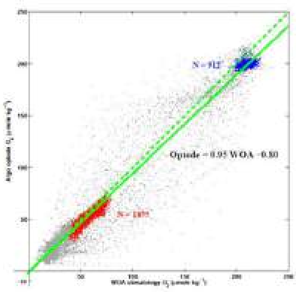


Fig.5 A plot of the dissolved oxygen measurements from University of Washington float 5089 (WMO 5901159) for the period 8/21/2006 to 3/17/2011, compared to the climatology from the World Ocean Atlas (WOA) 2009.

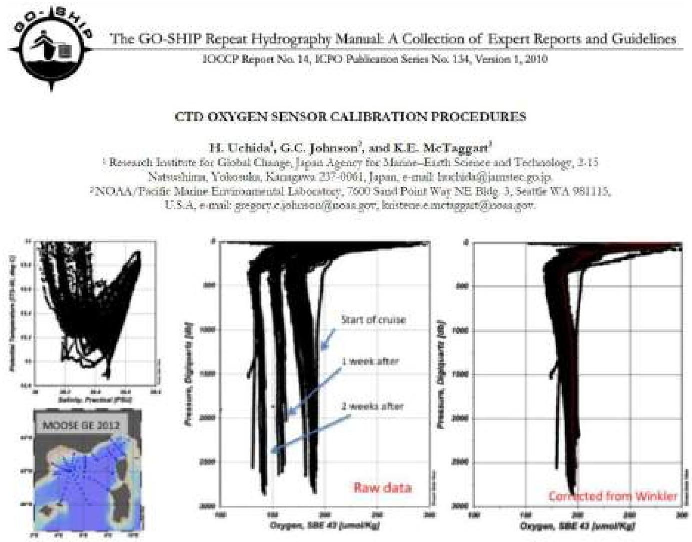


Fig.4 Example of SBE43 data drift during a two weeks cruise performed in the NW Mediterranean Sea in July-August 2012 (MOOSE-GE). Correction of O2 data has been possible from O2 Winkler measurements performed once per day (L.Coppola, personal communication)

(2) Data Integration and Harmonization:

TABLE 3 | Characteristics of the last generation of ocean O_2 observing systems: (1) Bittig and Körtzinger, 2015; (2) Thierry et al., 2018; (3) Thierry and Bittig, 2018; (4) Bittig et al., 2019; (5) BGC-Argo data are freely available from the Global Data Assembly Centres (GDACs: ftp://ftp.ifremer.fr/ifremer/argo/ and ftp://usgodae.org/pub/outgoing/argo/); (6) Testor et al., 2019; (7) oceangliders (https://www.oceangliders.org/); (8) Uchida et al., 2010; (9) WOCE and GO-SHIP protocols; (10) WOCE and GO-SHIP data are freely available on CLIVAR and Carbon Hydrographic Data Office; (11) Coppola et al., 2016; (12) Best Practices EMSO/OceanSites (OBPS); (13) National Data Buoy Center (NDBC) in the United States and Coriolis at IFREMER; (14) in delayed mode (see GO-SHIP method); (15) under development; (16) based on Winkler or 100%-0% calibration of sensors; (17) no DAC but Stratmann et al., 2019.

Observing platform	Methods	Spatial and temporal scales resolved	Spatial and temporal coverage	Community-agreed calibration and best practices	Community-agreed QF	Secondary community-agreed correction	GDAC	(N)RT/DM	FAIR
Profiling floats	Sensors	Horizontal: $10–10^2$ km Vertical: 10^{-3} km 5–10 days	$10^2–10^3$ km 3–5 years	With the atmosphere [1]	Yes [2,3]	Yes *In situ* Drift [4]	Yes [5]	NRT and DM	Yes
Gliders	Sensors	Horizontal: 10^{-1}-1 km Vertical: 10^{-3} km Hourly-daily	$1-10^2$ km Several days-weeks	In progress[6]	No	No	Yes [7]	NRT and DM	Yes
Ship-based Repeat Hydrography	Winkler + Sensors	Horizontal: 10 km Vertical: 10^{-3} km Decadal	$10^2–10^3$ km Multi-decadal	At sea or in delayed mode using Winkler	Yes [8]	Yes [9]	Yes[10]	DM	Yes
Moored fixed point observatories	Mainly optical sensors	Hourly	Multi-year	Yes [11]	Yes [12]	No	Yes [13]	NRT & DM	No
Ship-based Fixed-point Observatories	Winkler + Sensors	Monthly	Multi-year	No[14]	Yes[8]	Yes	Yes [10]	DM	Yes
Ship-based underway observations	Optical sensors	Sub-weekly to monthly	$10–10^2$ km	No[15]	No	No	No	DM	No
Coastal/benthic	Winkler + Sensors	Vertical: 10^{-5} - 10^{-4} km Temporal:punctual	$10-10^2$ km	Yes [16]	No	No	No [17]	DM	No

Table adapted from the Global Ocean Observing System (GOOS) Panel-Biogeochemistry-01-EOV-Oxygen Essential Ocean Variables (EOV) version 2.0 (August, 2017) see here https://www.jcomm.info/index.php?option=com_oe&task=viewDoclistRecord&doclistID=168.

(Grégoire-2021)

Data Standardization
↓
Metadata Harmonization
↓
Unified QC Protocols
(such as QARTOD)
↓
Data Formats and Interoperabilit
(NetCDF or CSV, compatibility)
↓
Data Integration Platforms
(EMODnet, ODV, or GLODAP)
↓
Interpolation and Gap-Filling
↓
Version Control and Documentatic

Current Trends in Ocean Monitoring Data Management

- **Big Data and Real-Time Monitoring:** ARGO, gliders, and fixed sensor networks

- **Cloud-Based Data Systems:** NOAA's IOOS、**EMODnet、GOOS etc.

- **Open Data Initiatives:** Global Ocean Oxygen Database and Atlas (GO2DAT), aims to increase the usability of large-scale oxygen datasets.

- **Data Integration and Modeling:** datasets must integrate DO with other variables (T,S, nutrients), Tools like Ocean Data View (ODV) and Python libraries (SciPy, NumPy)are used for data visualization and processing.

Challenges:

- The volume and variety of data sources make managing it complex. Combining in-situ measurements (e.g., from buoys) with remote sensing data requires advanced interoperability standards.

- Gaps in spatial and temporal coverage can affect the interpretation of DO trends. While sensor networks provide real-time data, remote regions or deep areas may still be under-sampled.

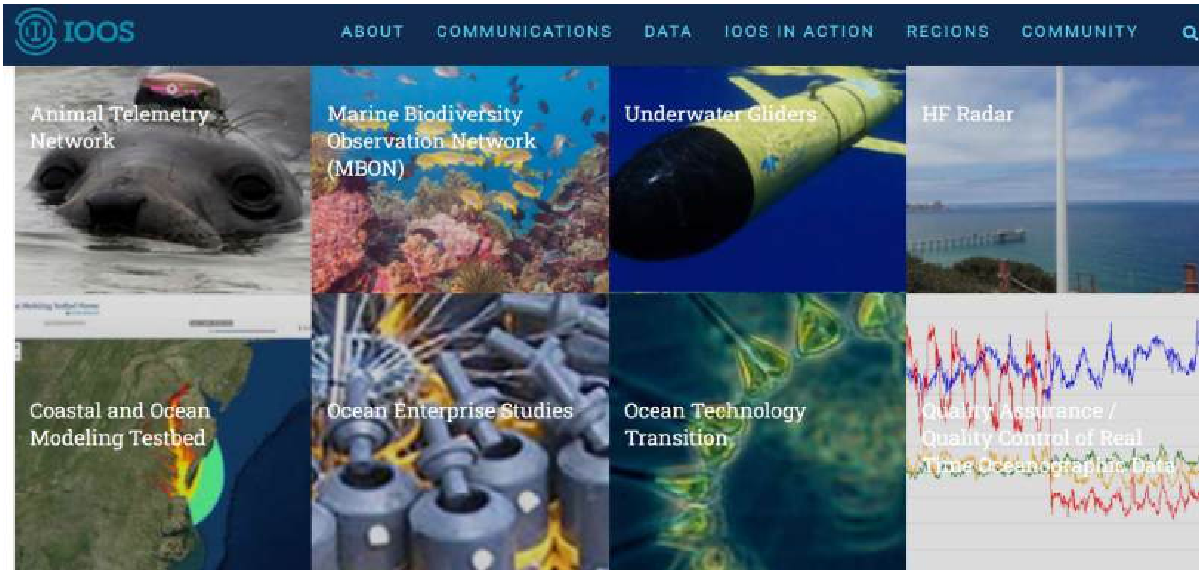
- ***Domestic* Oceanographic Data Centers (NODCs)** : *BODC, CMDS, CODC;*
- ***International oceanographic databases:*** *WOCE, GLODAP, GEOTRACERS, GO2DAT;*
- ***Other Useful links:*** *COMM,IOOS, ACT. etc.*

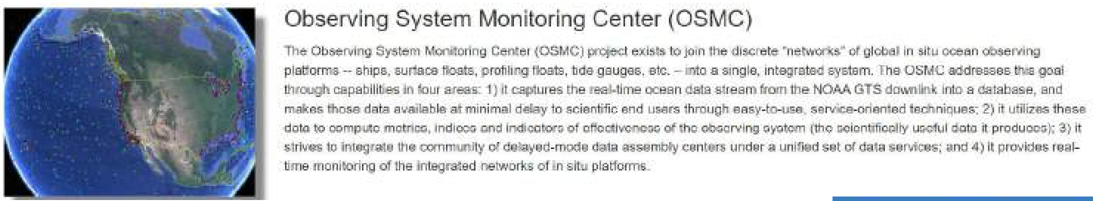
Figure 1: IODE Network of National Oceanographic Data Centres (NODCs)(2006)

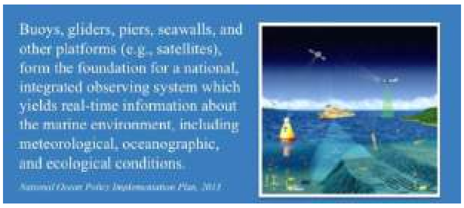
Example 1: Domestic Oceanographic Data Centers (NODCs) -BODC

- The **European Environment Agency (EEA)** and Eurostat serve as major repositories for environmental data.
- High levels of cross-border collaboration facilitated by EU-wide projects and funding (e.g., Copernicus for Earth observation).

Example 2: NOAA's Integrated Ocean Observing System (IOOS)



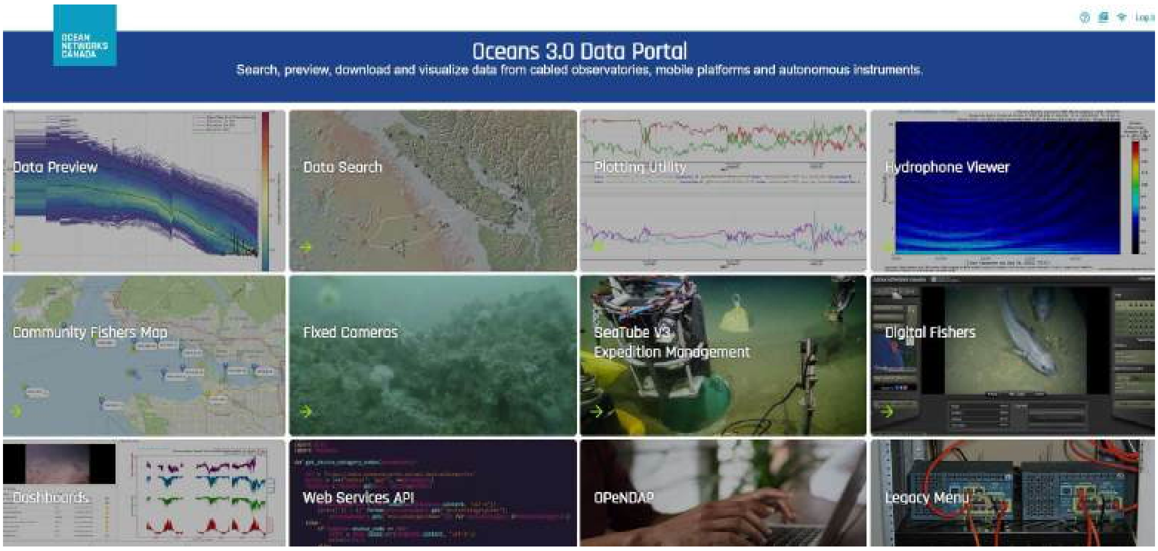




- The Environmental Protection Agency (EPA) and the Domestic Oceanic and Atmospheric Administration (NOAA) set the standards for monitoring dissolved oxygen levels.
- The EPA's National Coastal Condition Assessment (NCCA) and NOAA's Integrated Ocean Observing System (IOOS) utilize in-situ sensors, buoys, and satellite data.

Example 3: Ocean Networks Canada (ONC)

- Real-time oxygen concentrations in the Northeast Pacific Ocean can be accessed through Ocean Networks Canada's data portal system, Ocean 3.0.

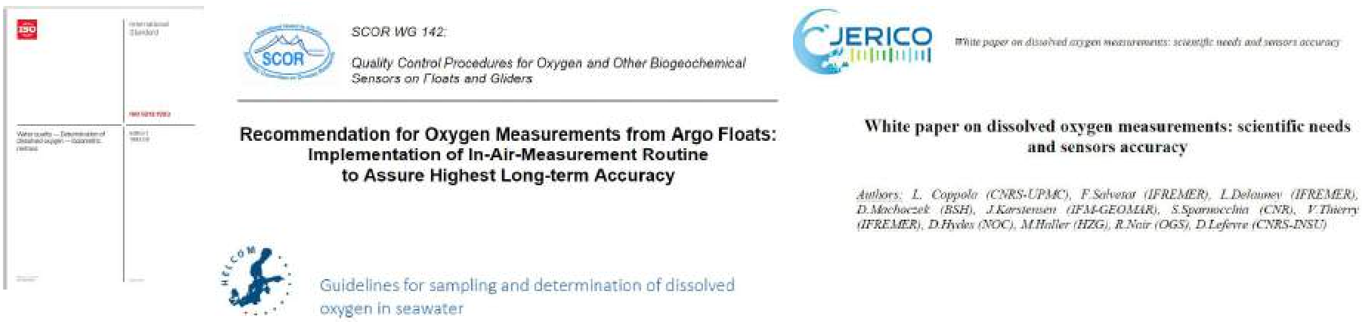


Best Practices in Data Management

1. Standardized Protocols for Data Collection

✓ Standardized data collection protocols across monitoring stations to ensure consistency and comparability.

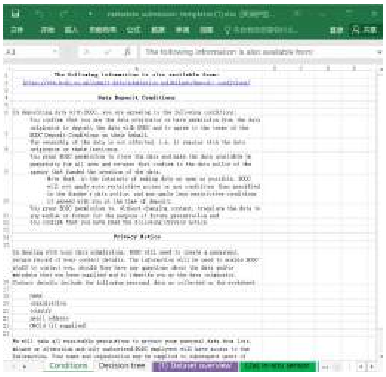
Example: The Winkler Titration Method is often used to validate sensor-based DO measurements. Combining high-frequency sensor data with discrete samples ensures reliability.

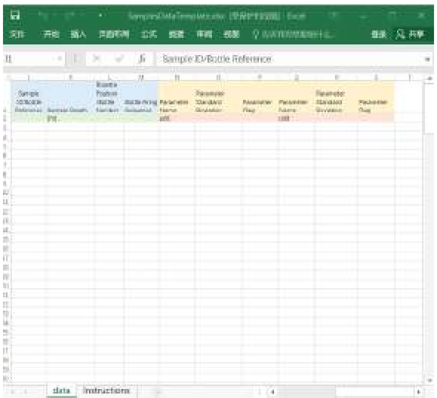


2. Metadata Documentation

- Robust metadata for understanding the context and methodology behind data collection. Accurate metadata ensures the **traceability and reliability** of the dataset.

- **Instrument information** (model, calibration dates).
- **Sampling conditions** (location, depth, temperature, salinity).
- **Data processing steps** (corrections, quality flags).





https://www.bodc.ac.uk/submit_data/submission_guidelines

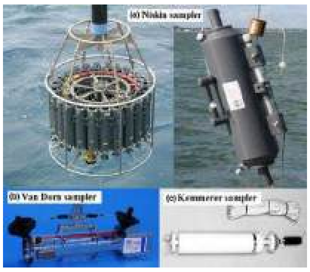
Example 1: Metadata specific to water sample data

- **Collection details** : Ship and cruise identifier. Project , CTD station identifier . Sample identifier (i.e. bottle number, rosette position or firing sequence). Date/time of the measurement. Position and method of position fix . Depth of sample

- **Instrument details**
  Instrument description, reference number, manufacturer and model, sampling rate— provide a literature reference, web site reference or briefly describe.

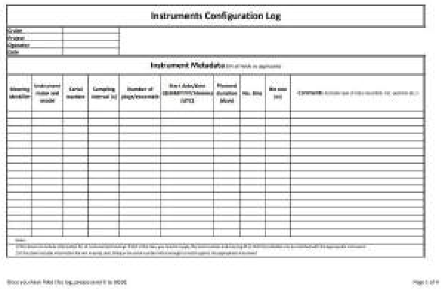
- **Analysis**
  A description of or reference to full laboratory methods and procedures.
  Details of any external sample analysis, including the laboratory name and accreditation level.
  A description of or reference to any internal or external quality assurance procedures.

- **Data sampling/processing**
  Editing and quality control methods.
  Identification of trace values (i.e. values below the detection limit).
  Handling of missing values (null versus zero, or 'blanks').
  Equations used for computed values.
  Precision of methods (i.e. number of significant figures).
  Quality control report.



- **Units per volume and per mass**

☐ Example 2: Metadata specific to Moored instrument data


Instruments Configuration Log

Instrument Metadata

- **Deployment details**

The mooring type. The ship/cruise which deployed the mooring. Date/time of deployment/recovery for each instrument. Position and method ofposition fix (i.e. DGPS, GPS). Instrument depth

- **Instrument details**

Instrument description, reference number, manufacturer, model, principle of measurement, method of recording — provide a literature reference, or briefly describe. Include — accuracy, resolution and response range of individual sensors.

Standard of calibration — method, quality, dates and calibration coefficients.

- **Mooring details**

Brief description or diagram of the mooring structure. Performance of the mooring. Include — condition on recovery, whether dragged or damaged. Any event that might affect the data.


Mooring Deployment Log

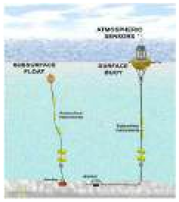
Ship/Cruise		Mooring identifier	
Project		Anchor Latitude (+ve N)	
Person responsible		Anchor Longitude (+ve E)	
Start date and time			
End date and time		Seafloor depth (m)	
		Method for seafloor depth	

Instrument Metadata

Instrument make and model	Serial number	Planned height above seabed/Water depth (m)	Release code	Comments

- **Data sampling/processing**

Sampling scheme of raw data e.g. continuous recording, instantaneous, averaged.
Interval between samples and the duration of individual samples (raw data).
Number of raw samples.
Nominal interval of processed data (excluding gaps resulting from editing).
Methods of averaging, filtering or compression.
Gaps in the data record.
Timing and corrections applied.
De-spiking/smoothing/interpolating methods and editing procedures.
Data quality report.



☐ Drift in O_2 measurements over time

- optical sensors are more common due to their long-term stability
- The response time of optical sensors is slower.
- The drift is principally due to:
  (1) degradation
  (2) marine biofouling
  (3) time dependent pressure hysteresis of the sensing element (only on very deep moorings >1000 m).

In particular, **biofouling** may rapidly degrade the quality of O2 and CTD data collected at shallow depths (<200 m).

☐ Example 3: Metadata specific to Underway data

- **Underway collection details**

Ship and cruise identifier. Project Date/time of the start/end of the sampling. Location of the all individual sensors .Method of positional fixing (i.e. GPS, DGPS).
Depth of the water intake. Flow volume per unit time, flow rate, size of water line. Time lag for water moving between sensors.

- **Instrument details**

Instrument description, reference number, manufacturer, model, principle of measurement, method of ,Include - accuracy, resolution and response range of individual sensors.
Instrument modifications and their effect on the data.

- **Sample data - for calibration purposes**

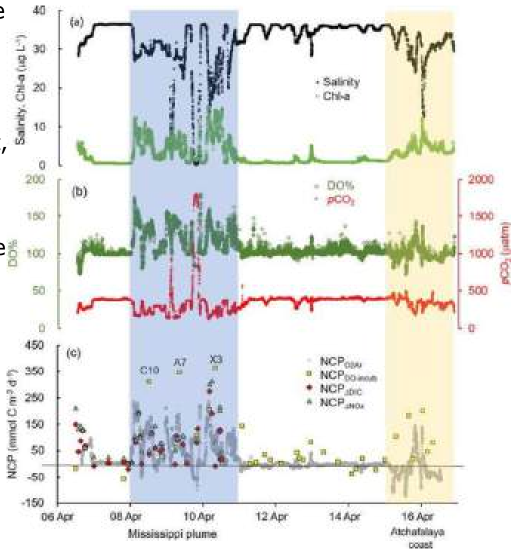
Details of water sampling system (automatic - manufacturer, model, number serial numbe or manual).
Water sampling method, volume and time interval.
Details of analyses and the elapsed time between collection and analysis.

- **Corrections and calibrations**

Correction for time lag between sensors.
Correction for ships movement — for wind speed and direction.
Laboratory calibrations.
In situ calibrations (i.e. comparisons with lowered near surface CTD or water samples).

- **Data sampling/processing**

Filtering, de-spiking or smoothing methods.
Editing and quality control methods.
Quality control report.



(Jiang et al., 2019)

BODC request (ASCII) format

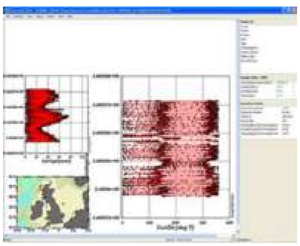
● Ocean Data View (ODV) format

QXF (a netCDF) format

CF netCDF format

AXF (historical) format

Sea level formats



- **Format**

The data format follows that of a spreadsheet — a collection of rows (comment, column header and data) with each data row having the same fixed number of columns. Data rows contain three types of column
•Metadata columns
•Primary variable data columns (one column for the value plus one for the qualifying flag)
•Data columns — two columns per variable (value and flag)
with rows containing exactly the same parameters grouped together — known as 'stations'.

- **Data mapping**

Data of different 'shape' (profile, time series and trajectory) are mapped into the spreadsheet as follows

- Profile data — CTD and bottle data
- Point time series — current meter or sea level data
- Chronological Julian Date [days]
- Trajectories — underway data

- **BODC (SeaDataNet) ODV file**

Data rows

Cruise Station Type yyyy-mm-dd hh:mm:ss.sss Longitude [degrees_east] Latitude [degrees_north] LOCAL_CDI_ID EDMO_code.
Bot. Depth [m]
Primary variable value
Quality flag

Tips: If there is no data value then the data value column is left blank with the flag field set to '9' - missing value.

3. Data Storage and Security

- Use redundant, cloud-based systems to securely store data and ensure long-term accessibility.

For example, platforms like ERDDAP(Environmental Research Division Data Access Program) allow users to access, visualize, and download large datasets in real-time.

- -Backup strategies should be employed to prevent data loss, particularly for long-term projects.

4. Data Sharing and Accessibility

- Promote open data policies that make DO data freely available to researchers, policymakers, and stakeholders. This enhances collaboration and allows for more comprehensive studies across regions.

Example: The ARGO program's real-time DO profiles are freely accessible, allowing researchers worldwide to track ocean deoxygenation trends. Open access to such data has enabled large-scale analysis of oxygen minimum zones (OMZs)

Why and How to Carry Out Data Quality Assessment

- **Why Data Quality Assessment is Essential?**

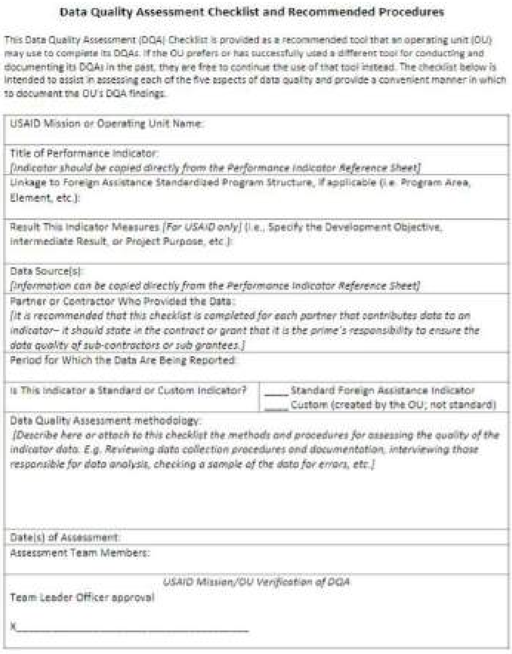
-Accuracy: High-quality DO data is critical for making informed decisions about marine resource management, fisheries, and coastal conservation.

- **Comparability**: Quality-controlled data ensures that measurements taken across different platforms or regions are comparable, allowing for large-scale analyses of oxygen trends.

Table 5.2a Sensors capacity in the FixO3 stations network

Variables	Type of sensor	Range	Accuracy
Temperature	SBE37	-5 to 45 °C	± 0.002 °C
Conductivity	SBE37	0 to 7 S/m	± 0.0003 S/m
Currents	Aquadopp, Seaguard RCM	0 to 3 / 0 to 0.3 $m.s^{-1}$	±1 % / ± 0.05 %
Dissolved oxygen	Optode 4330, SBE63	0-150 %/120 % saturation	± 8 µM / 3 µM
Chl-a	ECO FLNTU, Turner Cyclops	0-50 µg/l Chla	0.025 µg/l Chla
Nitrate	ISUS, SUNA	0.5 to 2000 µM/3000 µM	± 2 µM
pCO2	Contros, Pro-Oceanus, Aanderaa	0 to 1000 ppm / 0-600 ppm	± 4 ppm / 2 ppm
pH	SeaFet, SP101-SM	6.5 - 9.0 pH	0.05 pH/ 0.005 pH
Acoustics (passive)	SQ42	50-180 dB	3 dB

Five standards for data quality assessment: Validity, Reliability, Timeliness, Precision, Integrity



Data Quality Assessment Checklist and Recommended Procedures

This Data Quality Assessment (DQA) Checklist is provided as a recommended tool that an operating unit (OU) may use to complete its DQAs. If the OU prefers or has successfully used a different tool for conducting and documenting its DQAs in the past, they are free to continue the use of that tool instead. The checklist below is intended to assist in assessing each of the five aspects of data quality and provide a convenient manner in which to document the OU's DQA findings.

USAID Mission or Operating Unit Name:

Title of Performance Indicator:
[Indicator should be copied directly from the Performance Indicator Reference Sheet]

Linkage to Foreign Assistance Standardized Program Structure, if applicable (i.e. Program Area, Element, etc.):

Result This Indicator Measures *[For USAID only]* (i.e., Specify the Development Objective, Intermediate Result, or Project Purpose, etc.):

Data Source(s):
[Information can be copied directly from the Performance Indicator Reference Sheet]

Partner or Contractor Who Provided the Data:
[It is recommended that this checklist is completed for each partner that contributes data to an indicator– it should state in the contract or grant that it is the prime's responsibility to ensure the data quality of sub-contractors or sub grantees.]

Period for Which the Data Are Being Reported:

Is This Indicator a Standard or Custom Indicator? ____ Standard Foreign Assistance Indicator ____ Custom (created by the OU; not standard)

Data Quality Assessment methodology:
[Describe here or attach to this checklist the methods and procedures for assessing the quality of the indicator data. E.g. Reviewing data collection procedures and documentation, interviewing those responsible for data analysis, checking a sample of the data for errors, etc.]

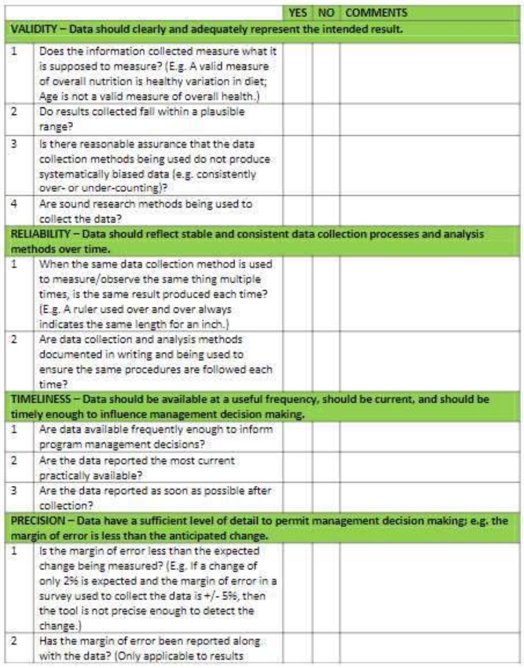
Date(s) of Assessment:

Assessment Team Members:

USAID Mission/OU Verification of DQA

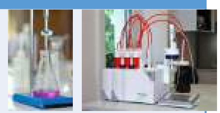
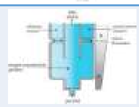
Team Leader Officer approval

X________________________________



		YES	NO	COMMENTS
VALIDITY – Data should clearly and adequately represent the intended result.				
1	Does the information collected measure what it is supposed to measure? (E.g. A valid measure of overall nutrition is healthy variation in diet; Age is not a valid measure of overall health.)			
2	Do results collected fall within a plausible range?			
3	Is there reasonable assurance that the data collection methods being used do not produce systematically biased data (e.g. consistently over- or under-counting)?			
4	Are sound research methods being used to collect the data?			
RELIABILITY – Data should reflect stable and consistent data collection processes and analysis methods over time.				
1	When the same data collection method is used to measure/observe the same thing multiple times, is the same result produced each time? (E.g. A ruler used over and over always indicates the same length for an inch.)			
2	Are data collection and analysis methods documented in writing and being used to ensure the same procedures are followed each time?			
TIMELINESS – Data should be available at a useful frequency, should be current, and should be timely enough to influence management decision making.				
1	Are data available frequently enough to inform program management decisions?			
2	Are the data reported the most current practically available?			
3	Are the data reported as soon as possible after collection?			
PRECISION – Data have a sufficient level of detail to permit management decision making; e.g. the margin of error is less than the anticipated change.				
1	Is the margin of error less than the expected change being measured? (E.g. If a change of only 2% is expected and the margin of error in a survey used to collect the data is +/- 5%, then the tool is not precise enough to detect the change.)			
2	Has the margin of error been reported along with the data? (Only applicable to results			

Summary of different dissolved oxygen (DO) measurement methods

	Method	Advantages	Disadvantages	*Best Use Case	Instruments
1	Winkler Titration (Iodometric titration)	High accuracy, low cost, versatile	Labor-intensive, not suitable for continuous monitoring	Labor-intensive, not suitable for continuous monitoring	
2	Electrochemical Sensors (Clark Electrode)	Real-time data, portable, affordable	Requires regular calibration, sensitive to temperature and fouling	Continuous monitoring in various environments (e.g., potentiometry, amperometry)	
3	Optical Sensors	High stability, low maintenance, unaffected by flow	Higher cost, power consumption	Long-term deployments, low-flow environments|	
4	Optode Sensors (Fluorescence quenching)	Long-term use, low power, fouling-resistant	Expensive, complex data analysis	Extended field monitoring, remote areas	
5	Paramagnetic Sensors	Very high accuracy, unaffected by water vapor	Expensive, complex, not suitable for real-time field use	Specialized laboratory applications	

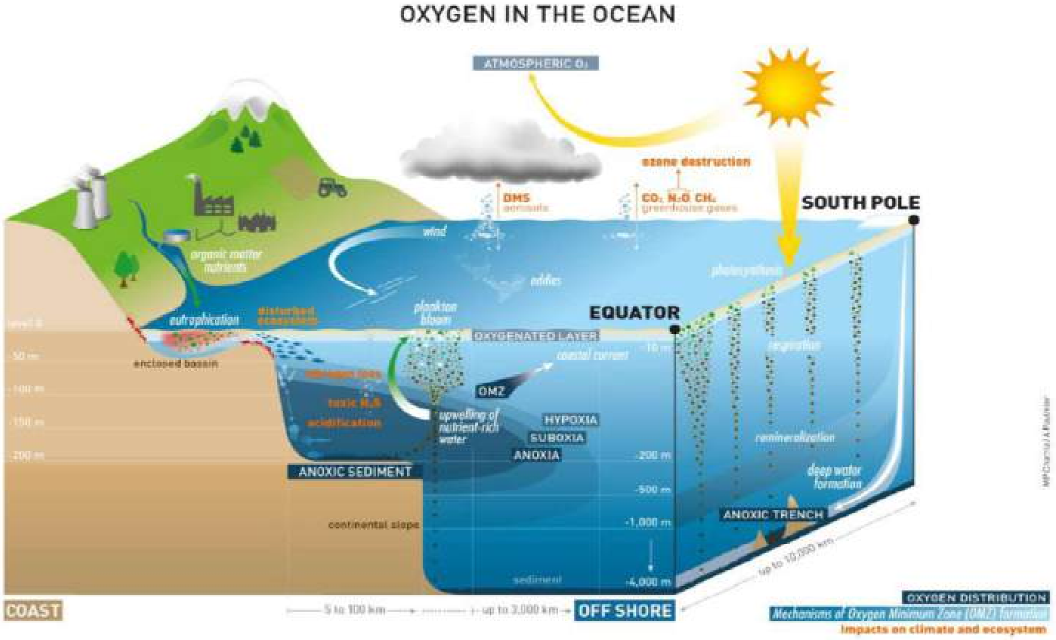


FIGURE 4 | Processes affecting the O_2 dynamics in the ocean and mechanisms of oxygen minimum zones (OMZs) formation (figure from Paulmier, 2017).

(Grégoire-2021)

- **The challenges in coastal hypoxia monitoring, including variability, data gaps, and the need for high-quality, standardized data.**

- Net Community Production (i.e.,NCP) : A 0.5% (1 µmol kg-1) error in O2 measurements significantly degrades the quality of the retrieved NCP (Emerson et al., 2008; Soetaert and Grégoire, 2011).
- In OMZs, because, nanomolar levels O_2 inhibit denitrification and anaerobic ammonium oxidation, studies of these processes require sensors with detection limits of a few nanomoles (Tiano et al., 2014).
- For ecological analyses, depends on questions (hypotheses) being addressed.

  Quantifying, the O_2 effects on individual organisms in terms of:

(1) presence, absence or abundance

(2) energetics-related physiology

(3) (3) behavior and vital process rates of growth, mortality, and reproduction (Batiuk et al., 2009).

● How to Perform Data Quality Assessment?

1. Calibration and Sensor Maintenance:

- Pre-deployment calibration: DO sensors should be calibrated in controlled conditions using standardized solutions (air-saturated water or chemical standards).
- Routine calibration ensures that sensors provide accurate readings over time.

2. Real-Time and Post-Deployment Quality Control (QC):

- Real-time QC: Automated systems flag suspicious data points as they are collected. These flags could be based on range checks, where measurements outside expected thresholds are flagged for review.

*Example: **QARTOD** (Quality Assurance of Real-Time Oceanographic Data) provides guidelines for automatically flagging outliers or erratic DO readings from buoys or gliders.*

-**Post-deployment QC**: After sensors are retrieved, DO data should be compared against reference measurements (e.g., Winkler titration). Post-deployment calibration can reveal sensor drift that occurred during deployment, which can then be corrected in the dataset.

3. Data Flagging Systems

- Implement a flagging system to indicate the quality of each data point (e.g., good, suspect, or bad). This allows users to easily filter out low-quality data for analysis.

Table 5.1.1a OceanSites quality flags signification

Code	Meaning	Comment
0	Unknown	No QC was performed
1	Good data	All QC tests passed.
2	Probably good data	
3	Potentially correctable bad data	These data are not to be used without scientific correction or re-calibration.
4	Bad data	Data have failed one or more tests.
5	-	Not used
6	-	Not used.
7	Nominal value	Data were not observed but reported. (e.g. instrument target depth.)
8	Interpolated value	Missing data may be interpolated from neighbouring data in space or time.
9	Missing value	This is a fill value

QARTOD Data Flag Protocol

The IOC 54:V3 Primary Level flagging standard (UNESCO 2013) is shown in table 1.

Table 1. Primary Level Flagging Standard.

Value	Primary-Level Flag Short Name	Definition
1	Good	Passed documented required QC tests
2	Not evaluated, not available or unknown	Used for data when no QC test performed or the information on quality is not available
3	Questionable/suspect	Failed non-critical documented metric or subjective test(s)
4	Bad	Failed critical documented QC test(s) or as assigned by the data provider
9	Missing data	Used as place holder when data are missing

QARTOD discourages use of the *Flag 2 Not Evaluated* flag, as this violates the very first of the *Seven QARTOD Data Management Laws*, which is that "every real-time observation distributed to the ocean community must be accompanied by a quality descriptor" (NOAA 2009).

4. Gap-Filling and Data Interpolation:
- Missing or erroneous data points in long-term time series are inevitable. Use advanced interpolation techniques, such as kriging or spline interpolation, to estimate missing values.


frontiers in Marine Science

A Global Ocean Oxygen Database and Atlas for Assessing and Predicting Deoxygenation and Ocean Health in the Open and Coastal Ocean

Global Ocean Oxygen Network (GO_2NE)
https://en.unesco.org/go2ne
Contact: Kirsten Isensee (France) - Executive Officer

Variability in the Oxycline and its ImpCts on the Ecosystem (VOICE)
http://www.ioccp.org/voice
Contact: Veronique Garcon (France), Johannes Karstensen (Germany)

Surface Ocean-Lower Atmosphere Studies (SOLAS)
https://www.solas-int.org/
Contact: Jessica Gier (Germany) - Executive Director

Biogeochemical Argo
http://biogeochemical-argo.org/data-access.php
Contact: Ken Johnson (USA) & Hervé Claustre (France)

GO-SHIP
https://www.go-ship.org
Contact: Martin Kramp - Coordinator

Summary

- **The volume and complexity of DO data demand robust systems that ensure data is accurate, comparable, and accessible. As we continue to observe the impacts of climate change on oceanic oxygen levels, particularly in sensitive regions like the estuaries, adhering to best practices in data management will allow researchers to track trends, inform policy, and protect marine ecosystems.**

- **Adopt standardized protocols for data collection and ensure rigorous calibration of sensors. Document metadata comprehensively, including instrument details and environmental conditions. Use real-time and post-deployment QC procedures to maintain data accuracy.**

- **Support open data sharing to enhance collaboration and large-scale research efforts.**

Thanks! Q & A

APEC Project OFWG 201 2023 workshop

Best practices for data processing, spatial mapping and time-series development

Second Institute of Oceanography, MNR, PRC

Asia-Pacific Economic Cooperation

Paracas, Peru Oct.2rd, 2024

Outline

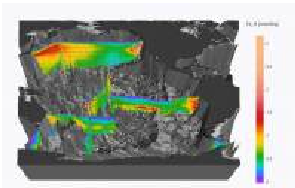
- Introduction
- Best Practices in Ocean Dissolved Oxygen Data Processing
- Spatial Mapping of Dissolved Oxygen
- Time Series Development
- Closing Remarks and Q&A

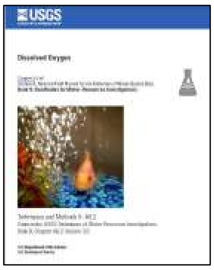
Introduction

-**Monitoring dissolved oxygen (DO)** is crucial for understanding the health of marine ecosystems, particularly in coastal areas where hypoxia (low oxygen) and deoxygenation are major concerns.

-DO data is critical for identifying hypoxic zones, tracking the impacts of climate change, and informing management decisions. However, the raw data collected from monitoring systems needs to **be processed, mapped, and analyzed in a time series** to **reveal meaningful patterns and trends**.

(IOC Workshop Report No. 228).





- **Data Collection planning**: Define Objectives → Choose Appropriate Tools/methods
- **Data Quality Assurance (DQA)**: Develop Standard Operating Procedures (SOPs) Train Personnel Conduct Pre-Deployment Checks
- **Data Collection**: Systematic Data Collection Calibration and Maintenance Record Metadata
- **Data Entry and Storage**: Data Entry Protocols → Organize Data → Backup Data
- **Data Quality Control (QC)**: Automated QC Checks → Manual Review → Cross-Validation
- **Data Processing**: Data Cleaning → Data Normalization → Time-Series Analysis
- **Data Archiving and Documentation**: Comprehensive Documentation → Standardized Formats → Data Archiving
- **Data Analysis and Interpretation**: Statistical Analysis Uncertainty Analysis Visualization

Best Practices in Ocean Dissolved Oxygen Data Processing

1. Raw Data Handling

-Raw data acquisition from sensors and monitoring systems (e.g., CTDs, sensors, ARGO floats, etc.).
-Challenges such as **sensor drift**, **calibration errors**, and **missing data**, and best practices for overcoming these issues.

2. Data Cleaning and Preprocessing

- **Error Detection:** Automated systems can flag suspicious data points based on range checks or rapid fluctuations that exceed natural variability.
- **Real-time quality flags**, such as those implemented by QARTOD protocols, ensure continuous data accuracy.

3. Data Standardization

- Standard protocols for processing DO data to ensure consistency across datasets (e.g., converting raw sensor outputs to standardized oxygen units like μmol/kg or mg/L).

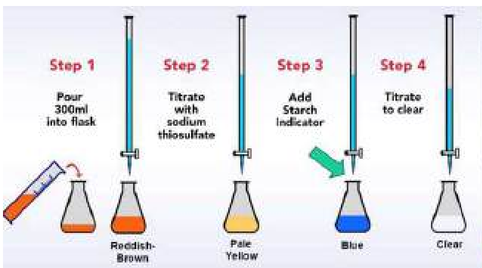
4. Data Validation

- Cross-validate sensor data with discrete water samples collected via CTD-rosette systems.
- These samples are analyzed in the lab using Winkler titration, considered the gold standard for oxygen measurements, providing an additional layer of data validation.

1. Sample bottle data (Discrete sampling)

Winkler titration for accuracy: ±0.15 to 0.87 μmol kg^{-1} (Saunders, 1986; Langdon, 2010).

- Regent blank → track before and after the measurement
- Potassium Iodate Standards (KIO3 standards) → choose primary standards
- analyzed immediately, or preserved properly → keep cool , analyzed within 8 hours
- NO_2 effects → add sulfamic acid reagent
- extremely low oxygen, anoxia water → Double the Sample Volume, Limit Sample Exposure, Alternative sensor methods



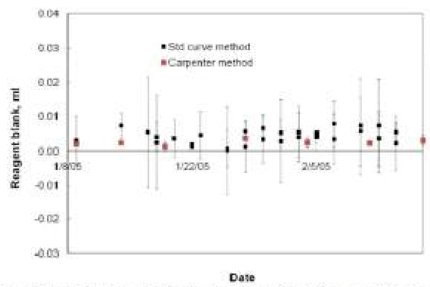


Figure 3. Reagent blanks determined by Carpenter method (red) and Standard Curve method (black). Error bars are the 95% CI.

➢ Chemical sample data (nutrients, oxygen)

(IOC Workshop Report No. 228).

• Minimum quality control checks

(1) Data range checks;

(2) Excessive gradient;

(3) Excessive spike;

(4) No gradient.

• Applicable to both vertical profiles and time-series/horizontal distributions.

(1) to develop **data ranges** at different spatial scales ranging from basin to regions to improve QC checks (objective tests).

(2) to use **property-property plots**. such as nitrate versus phosphate, nitrate vs. temperature, oxygen vs. temperature, depth or time plots as a mean to visually check the data (subjective tests).

(3) when available we recommend the use of **local climatologies** as a quantitative or visual guide.

(4) to seek **community-wise effort** to develop less subjective tests.

(5) to compile a list of available statistical and objectively **analyzed climatologies available** such as Brickman and Petrie 2003, World Ocean Atlas 2009, Hydrobase, GLODAP, Gouretski and Koltermann 2004, the Baltic Atlas of long term inventory and climatology, Oceanographic Atlas for the Black and Azov seas 2009, MEDAR/MEDATLAS, etc.

☐ Range check

ANNEX IV

PARAMETER RANGE LIMITS USED FOR WOD09

Oxygen
Standard unit or scale: ml·l⁻¹

Depth (m)	North Atlantic Low	North Atlantic High
0	0.00	11.00
10	0.00	11.00
20	0.00	11.00
30	0.00	11.00
50	0.00	11.00
75	0.00	11.00
100	0.00	10.00
125	0.00	10.00
150	0.00	10.00
200	0.00	10.00
250	0.00	10.00
300	0.00	9.00
400	0.00	9.00
500	0.00	9.00
600	0.00	9.00
700	0.00	9.00
800	0.00	9.00
900	0.00	9.00
1000	0.00	9.00
1100	0.00	9.00
1200	0.00	9.00
1300	0.00	9.00
1400	0.00	9.00
1500	3.00	9.00
1750	3.00	9.00
2000	3.00	9.00
2500	3.00	8.00
3000	3.00	8.00
3500	3.00	8.00
4000	3.00	8.00
4500	3.00	8.00
5000	3.00	8.00
5500+	3.00	8.00

IOC Workshop Report No. 228
Annex IV - Page 2

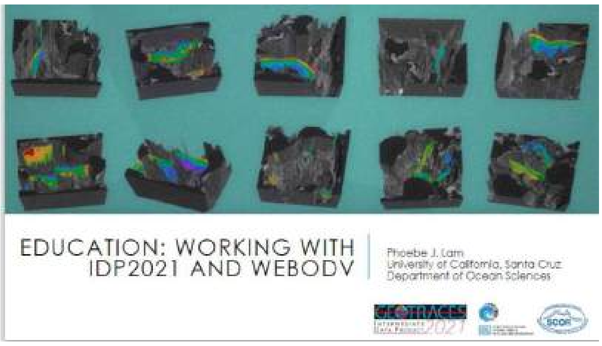
Oxygen (continued 1)
Standard unit or scale: ml·l⁻¹

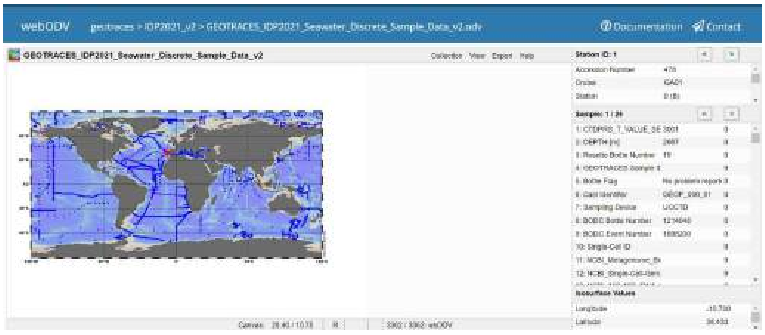
Depth (m)	South Pacific Low	South Pacific High	Coastal S. Pacific Low	Coastal S. Pacific High	North Indian Low	North Indian High	Coastal N. Indian Low	Coastal N. Indian High	Equatorial Indian Low	Equatorial Indian High	Coastal Eq. Indian Low	Coastal Eq. Indian High	South Indian Low	South Indian High	Coastal S. Indian Low	Coastal S. Indian High	Antarctic Low
0	0.00	8.00	0.00	8.00	0.00	7.00	0.00	7.00	0.00	10.00	0.00	6.00	0.00	10.00	0.00	9.00	5.25
10	0.00	8.00	0.00	8.00	0.00	7.00	0.00	7.00	0.00	10.00	0.00	6.00	0.00	10.00	0.00	9.00	5.25
20	0.00	8.00	0.00	8.00	0.00	7.00	0.00	7.00	0.00	10.00	0.00	6.00	0.00	10.00	0.00	9.00	5.25
30	0.00	8.00	0.00	8.00	0.00	7.00	0.00	7.00	0.00	10.00	0.00	6.00	0.00	10.00	0.00	9.00	5.00
50	0.00	8.00	0.00	7.00	0.00	7.00	0.00	7.00	0.00	10.00	0.00	6.00	0.00	10.00	0.00	9.00	4.00
75	0.00	8.00	0.00	7.00	0.00	7.00	0.00	7.00	0.00	10.00	0.00	6.00	0.00	8.00	0.00	9.00	3.75
100	0.00	8.00	0.00	7.00	0.00	7.00	0.00	7.00	0.00	7.00	0.00	6.00	0.00	8.00	0.00	9.00	3.50
125	0.00	8.00	0.00	7.00	0.00	5.00	0.00	5.00	0.00	7.00	0.00	5.00	0.00	8.00	0.00	9.00	3.50
150	0.00	8.00	0.00	7.00	0.00	5.00	0.00	5.00	0.00	7.00	0.00	5.00	0.00	8.00	0.00	9.00	3.50
200	0.00	7.00	0.00	7.00	0.00	5.00	0.00	5.00	0.00	5.00	0.00	5.00	0.00	8.00	0.00	9.00	3.50
250	0.00	7.00	0.00	7.00	0.00	5.00	0.00	5.00	0.00	5.00	0.00	5.00	0.00	8.00	0.00	7.00	3.50
300	0.00	7.00	0.00	7.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	7.00	0.00	7.00	3.50
400	0.00	7.00	0.00	7.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	7.00	0.00	7.00	3.50
500	0.00	7.00	0.00	7.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	7.00	0.00	7.00	3.50
600	0.00	7.00	0.00	7.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	7.00	0.00	6.00	3.50
700	0.00	7.00	0.00	6.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	7.00	0.00	6.00	3.50
800	0.00	7.00	0.00	6.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.50
900	0.00	7.00	0.00	6.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.50
1000	0.00	6.00	0.00	6.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.50
1100	0.00	6.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.25
1200	0.00	6.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	4.75
1300	0.00	6.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.00
1400	0.00	6.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.00
1500	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.00
1750	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.00
2000	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.00
2500	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.25
3000	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.50
3500	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	3.25
4000	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	4.00
4500	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	4.00
5000	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	4.25
5500+	0.00	5.00	0.00	5.00	0.00	5.00	0.00	4.00	0.00	5.00	0.00	5.00	0.00	6.00	0.00	6.00	4.50

Oxygen (continued 2)
Standard unit or scale: ml·l⁻¹

Depth (m)	Mediterranean Low	Mediterranean High	Black Sea Low	Black Sea High	Baltic Sea Low	Baltic Sea High	Persian Gulf Low	Persian Gulf High	Red Sea Low	Red Sea High	Sulu Sea Low	Sulu Sea High
0	0.00	8.00	0.00	10.00	0.00	12.00	0.00	12.00	0.00	12.00	0.00	5.00
10	0.00	8.00	0.00	10.00	0.00	12.00	0.00	12.00	0.00	12.00	0.00	5.00
20	0.00	8.00	0.00	10.00	0.00	12.00	0.00	12.00	0.00	12.00	0.00	5.00
30	0.00	8.00	0.00	10.00	0.00	12.00	0.00	12.00	0.00	12.00	0.00	5.00
50	0.00	8.00	0.00	10.00	0.00	12.00	0.00	12.00	0.00	12.00	0.00	5.00
75	0.00	7.00	0.00	8.00	0.00	9.50	0.00	9.50	0.00	9.50	0.00	5.00
100	0.00	7.00	0.00	8.00	0.00	9.50	0.00	9.50	0.00	9.50	0.00	4.00
125	0.00	7.00	0.00	8.00	0.00	9.50	0.00	9.50	0.00	9.50	0.00	4.00
150	0.00	7.00	0.00	8.00	0.00	9.50	0.00	9.50	0.00	9.50	0.00	4.00
200	0.00	7.00	0.00	5.00	0.00	9.00	0.00	9.00	0.00	9.00	0.00	3.00
250	0.00	7.00	0.00	5.00	0.00	9.00	0.00	9.00	0.00	9.00	0.00	3.00
300	0.00	7.00	0.00	5.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	3.00
400	0.00	7.00	0.00	2.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	3.00
500	0.00	7.00	0.00	2.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	3.00
600	0.00	7.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	3.00
700	0.00	7.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	3.00
800	0.00	7.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	3.00
900	0.00	7.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	3.00
1000	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	3.00
1100	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	3.00
1200	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
1300	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
1400	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
1500	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
1750	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
2000	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
2500	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
3000	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
3500	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
4000	0.00	6.00	0.00	2.00	0.00	7.10	0.00	7.10	0.00	7.10	0.00	2.00
4500	0.00	6.00	0.00	2.00	0.00	6.00	0.00	6.00	0.00	6.00	0.00	2.00
5000	0.00	6.00	0.00	2.00	0.00	6.00	0.00	6.00	0.00	6.00	0.00	2.00
5500+	0.00	6.00	0.00	2.00	0.00	6.00	0.00	6.00	0.00	6.00	0.00	2.00

☐ Visualization of data products check





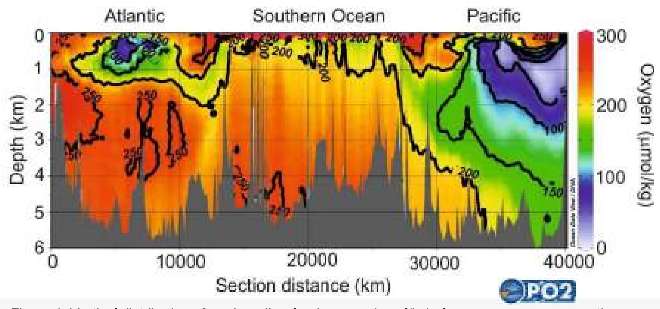


Figure 1: Vertical distribution of modern dissolved oxygen (µmol/kg) along an ocean cross-section connecting the Atlantic, Southern, and Pacific Oceans. Reconstructed using GLODAP bottle data.

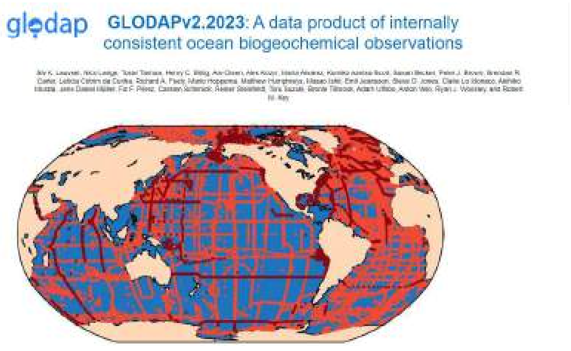
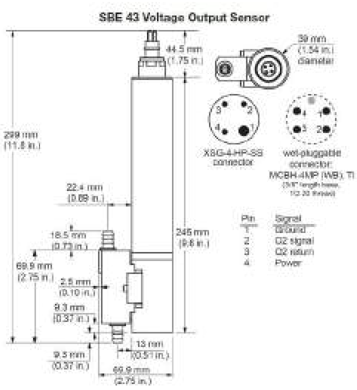


Figure 1. Station locations of all stations in GLODAPv2.2023. Stations in dark red indicate stations new to this edition.

2. Sensor Data

Example: Electrochemical sensors (eg. SBE43)



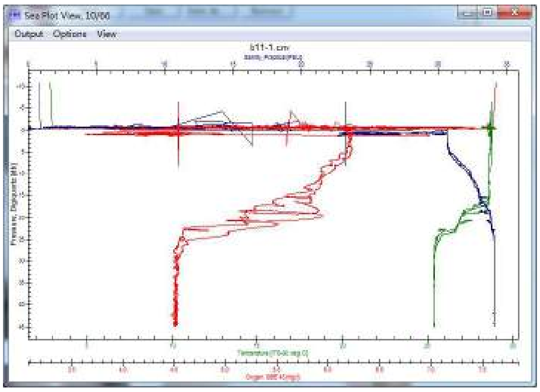
precision：0.5% /1000h (clean membrane)
Response time：
2-5 sec for 0.5-mil membrane,
8-20 sec for 1.0-mil membrane

Data Conversion
↓
Fliter
↓
Align CTD
↓
Cell Thermal Mass
↓
Loop Edit
↓
Derive
↓
Bin Average

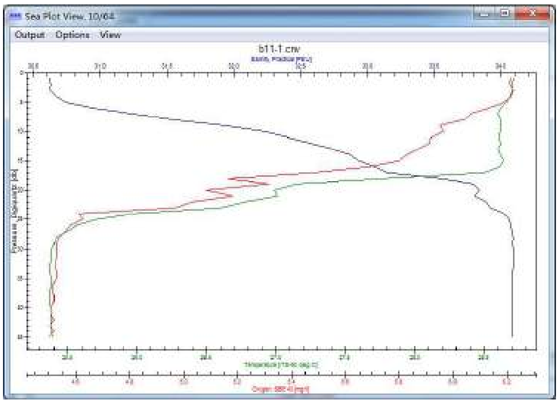
TIPS:

- For the dual temperature and dual conductivity data obtained this time, data from the primary sensor should be prioritized.
- For multiple profiles at the same station, the profile with the deeper observation range should be prioritized.
- For single profiles, the descent data should be prioritized.
- Remove data segments where the pump has not yet started.

Before

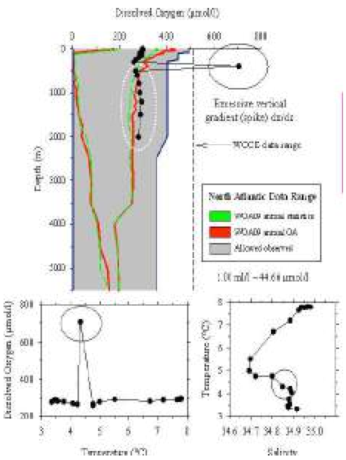


After



Examples for Minimum quality control checks

- Data range checks



use a fixed data range as a function of depth

- Excessive gradients check

Depth profiles and Time-series

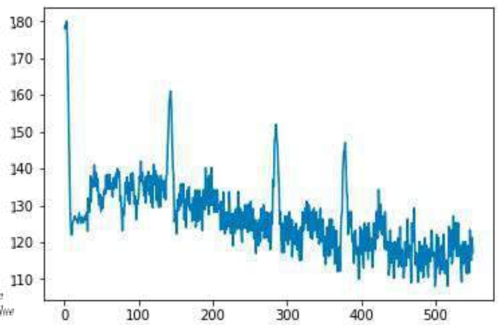
$$gradient=\frac{v_2-v_1}{z_2-z_1}$$

VARIABLE	Maximum Inversion Value (z<400m)	Maximum Gradient Value (z<400m)	Maximum Inversion Value (z>400m)	Maximum Gradient Value (z>400m)
Oxygen	checks not available			
Phosphate	1.000	1.000	0.500	0.500
Silicate	checks not available			
Nitrate and Nitrate+Nitrite	1.000	1.000	0.500	0.500
Ammonium	checks not available			

Table 2. Maximum gradient and inversion factors used for WOD09. Excessive gradients represent a negative excessive gradient in the value over depth. Excessive inversions represent a positive excessive gradient in value over depth.

- Excessive spike checks

$$\text{test value} = \left|V_2 - \frac{(V_3 + V_1)}{2}\right| - \left|\frac{(V_3 - V_1)}{2}\right|$$



Examples for time series data checks

- **Correlations**

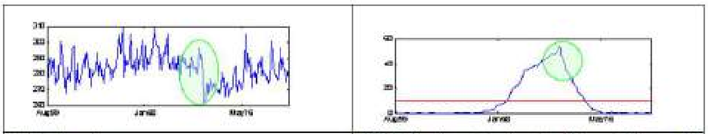
1. Calculate the Pearson's correlation coefficient between residual series
2. Select nearby stations with correlation coefficients above 0.7
3. Calculate the linear regression between them and fill the gaps. (Only fill gaps within the time series; not at the beginning or end of the series)

- **Standard Normal Homogeneity Test**

Alexanderson (1986) developed the Standard Normal Homogeneity Test (SNHT) which is widely used in climatic time series studies. The SNHT gives the points where an inhomogeneity exists and provides information about the probable break magnitude. However, the inhomogeneity could be due to an error or to an anomalous, but real, behavior of the variable. For this reason, the series are only corrected following comparison with other series in the same climatic region and supported by historical information about the incidences on the tide gauge.

- **EOF Analysis**

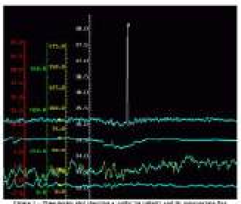
The Empirical Orthogonal Functions (EOFs) analysis applies to a group of time series stations can be used not only to find special coherent signals or regional variability but also to detect possible errors in the time series. In fact, relevant differences on the variance of the first EOF may indicate errors in one or more time series. This technique is well documented in “Development of a Quality Checked Tide Gauge Data Set (A.G.P Shaw, M.N. Tsimplis, et all)” and in “Consistency of long sea-level time series in the northern coast of Spain (M. Marcos, D. Gomis, et. al.)



Original series.	SNHT for the original series. Tmax indicates the shift that can be seen in the original series. Red line is the confidence level.

Figure 8: Time series and the result of SNHT

Time-series data



Data Analysis for DO monitoring data

(1) Data cleaning. Check for inconsistencies, outliers, and correct any errors in the collected data.

(2) Descriptive statistics Calculate mean, median, standard deviation of DO levels and time periods to understand tendency and variability.

(3) Temporal and trend analysis

Diurnal fluctuations: Analyze how DO levels change throughout the day to assess the impact of photosynthesis and respiration.

Seasonal trends: Examine how DO levels vary across seasons to understand the effects of environmental factors like temperature and blooms

(4) Spatial analysis

Gradients: Identify spatial trends in DO levels to pinpoint potential sources of pollution or areas with low oxygen.

Mapping: Visualize DO data on maps to identify patterns and areas of concern.

(5) Anomalies and Hypoxia Events:** Identify and analyze low oxygen (hypoxic) events, including their duration, frequency, and potential causes.

(6) Correlation analysis

Environmental factors: relationships between DO and other environmental parameters like temperature, salinity, and nutrient.

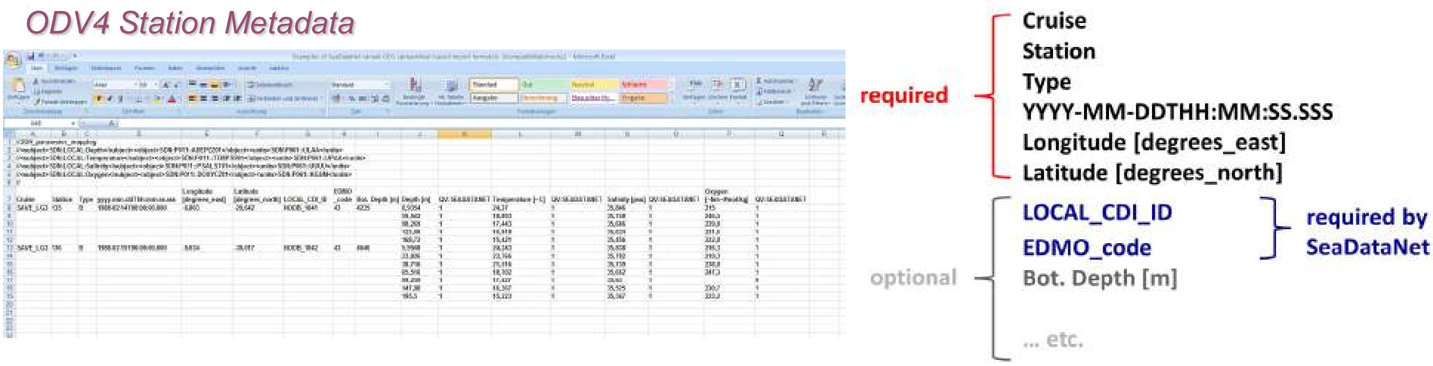
Biological indicators: Compare DO levels with observed aquatic life populations to assess ecosystem health.

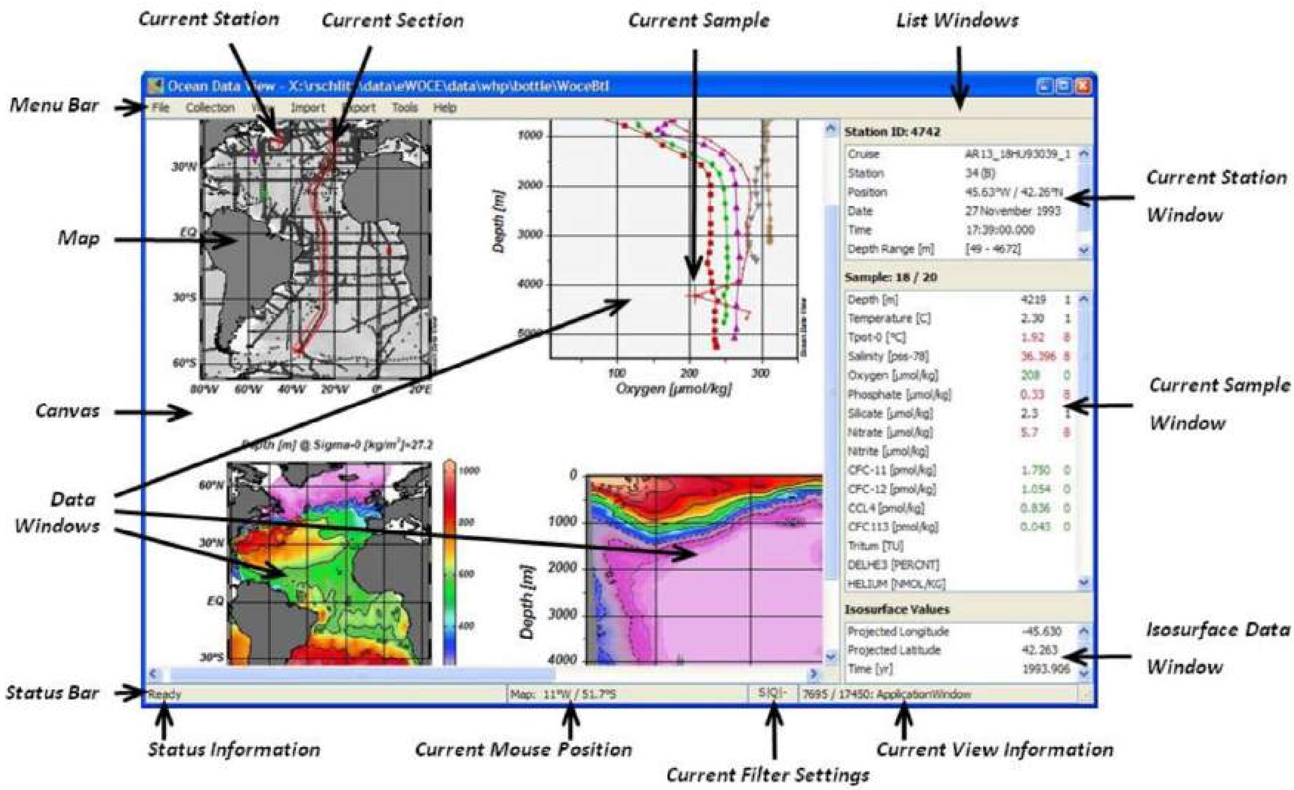
Ecosystem health: fishery, food-web, biodiversity, etc.

(7) Modeling Develop or apply biogeochemical models to simulate DO dynamics and predict future changes under different scenarios

Spatial Mapping of Dissolved Oxygen -ODV

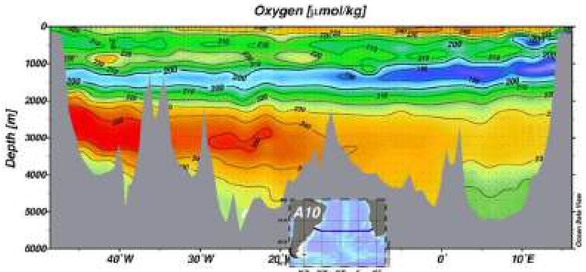
- **1. Spatial Data mapping**
  - Collecting spatial data, such as ship-based surveys, gliders, remote sensing, and autonomous floats.
  - Spatial data at different scales (local, regional, global) can offer insights into DO variability.



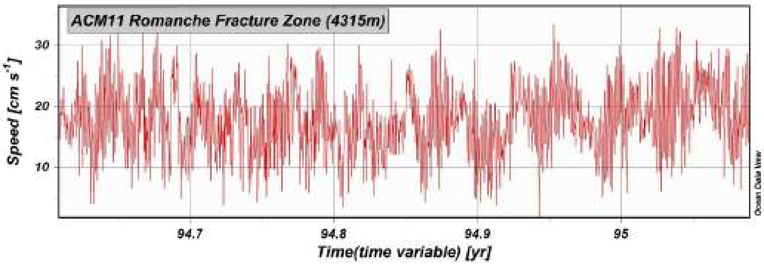


Supported Data Types

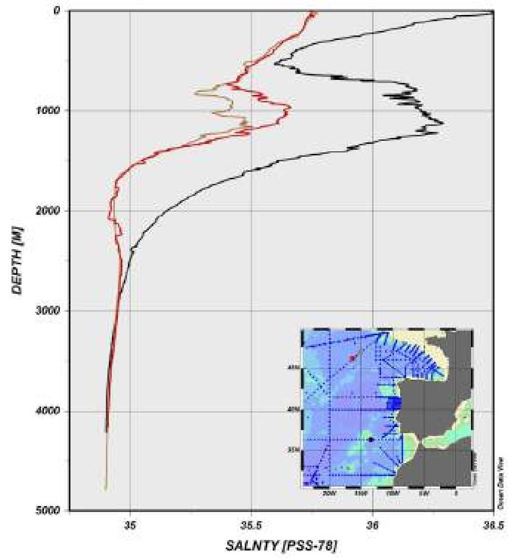
Spatial Mapping



Time series



Profiles



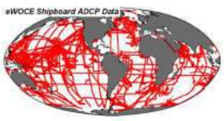
Oceanography - WOCE

eWOCE Data

eWOCE provides global or basin-wide data collections for most WOCE data streams, including ADCP, CTD, XBT, current meters, profiling floats, sea-level, sea surface T/S, subsurface floats, surface drifters, hydrography, nutrients and tracers.

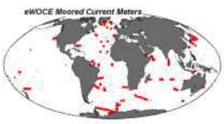
ADCP Data

Shipboard ADCP velocity profiles for more than 240,000 stations and 540 cruises from the ADCP Program.



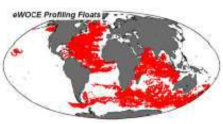
Current Meter Data

Velocity and hydrographic data for more than 1300 moored current meters from the Current Meter Program.



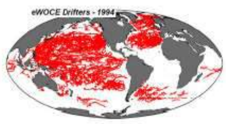
Profiling Float Data

More than 31,000 temperature and salinity profiles from more than 1600 profiling floats.



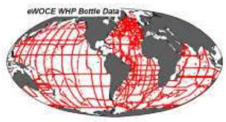
Surface Drifter Data

Trajectories and velocity data for more than 12,000 drifters from the Surface Velocity Program (daily data organized by years, 1979-2000).



WHP Bottle Data

Hydrographic, nutrient and tracer data from the WOCE Hydrographic Program (>17,400 stations).

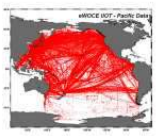


WHP CTD Data

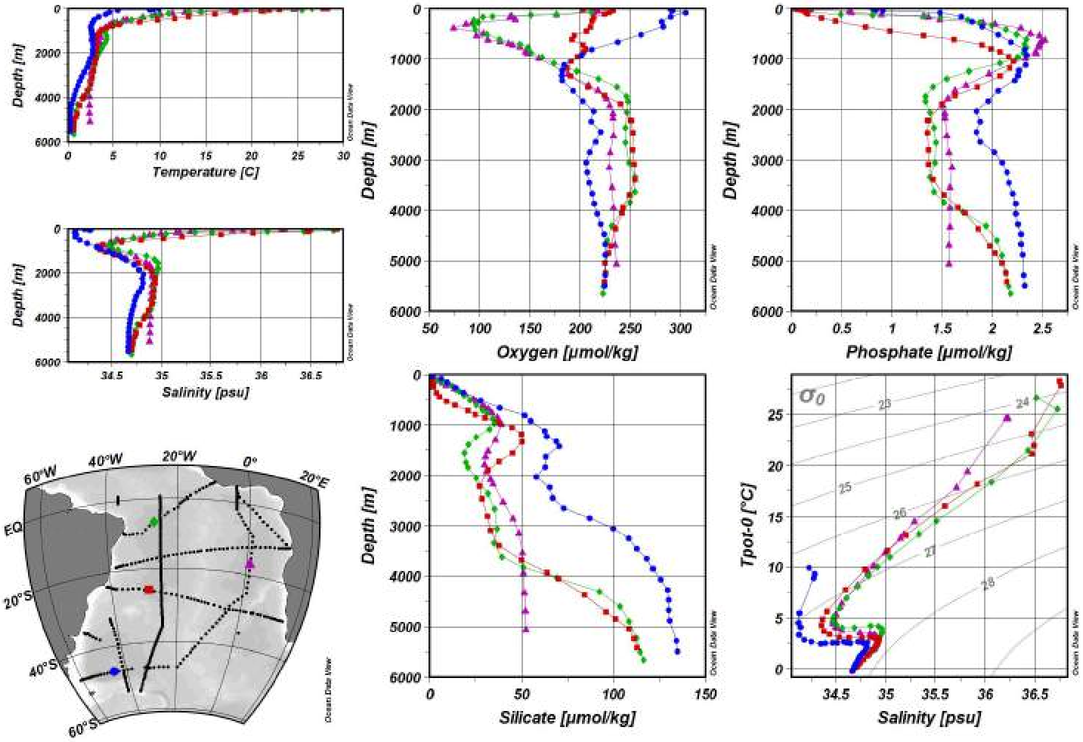
High resolution CTD data from the WOCE Hydrographic Program (>18,500 stations).

Upper Ocean Thermal Data

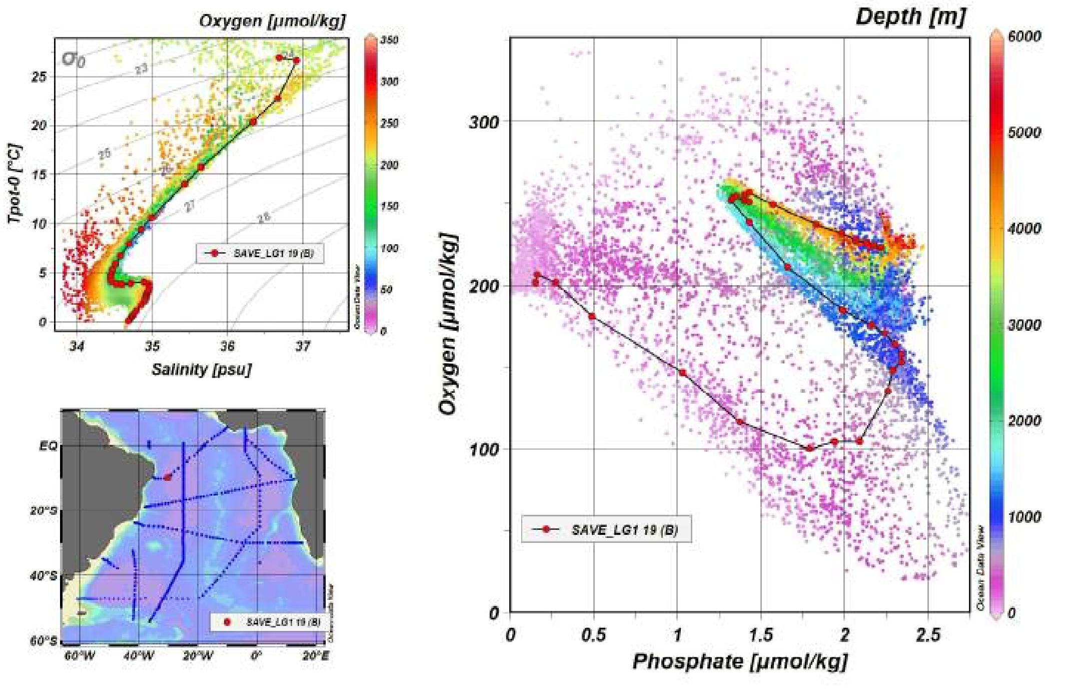
More than 1 million temperature and salinity profiles from the Upper Ocean Thermal Program (organized by ocean basins; separate data collection for high density lines).



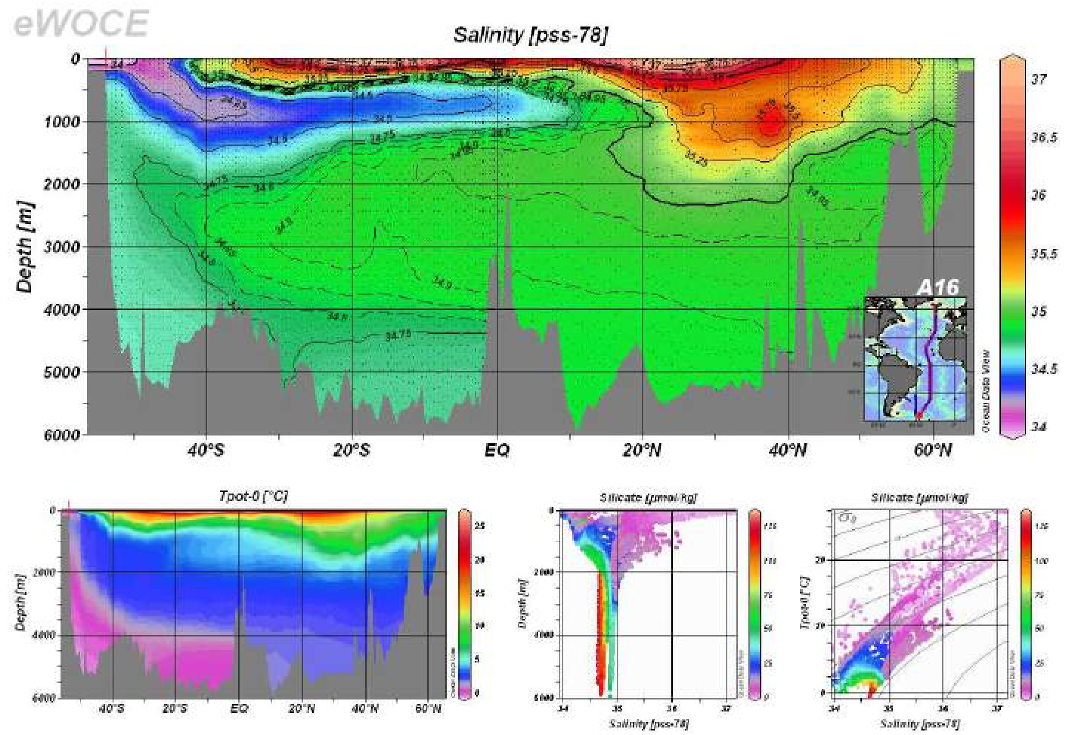
STATION



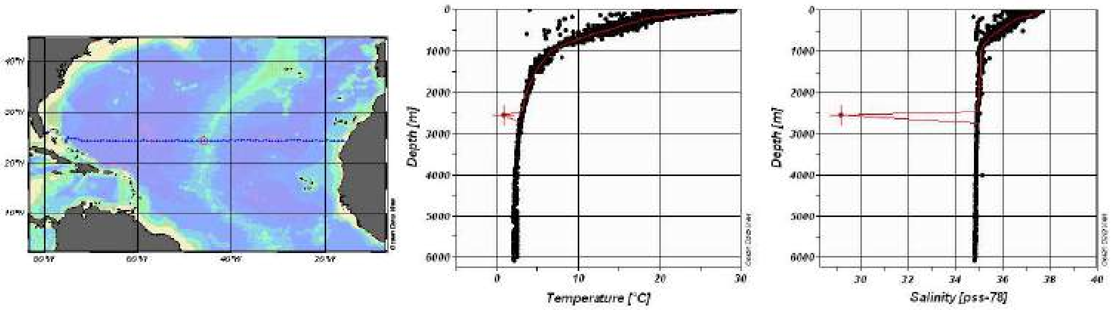
SCATTER



SECTION

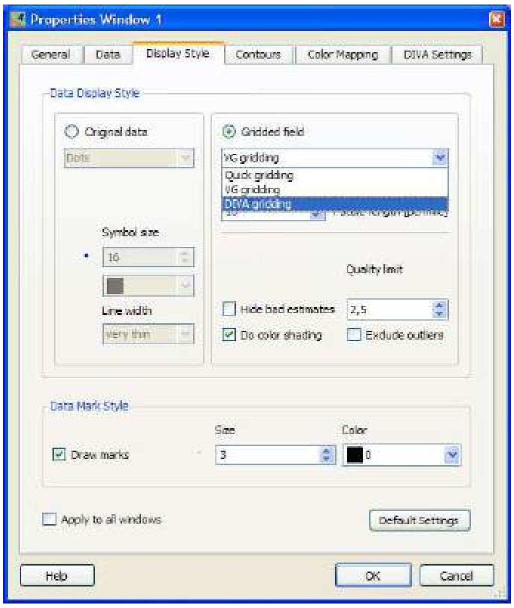


Data Quality Control



- ***easy spotting and identification of outliers or offsets***
- ***painless editing of data value and quality flag***
- ***logging of all value or flag modifications***
- ***automatic range checks and manual or automatic editing***

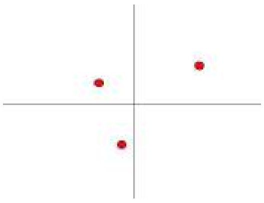
2. Gridding and Interpolation



ODV will automatically...

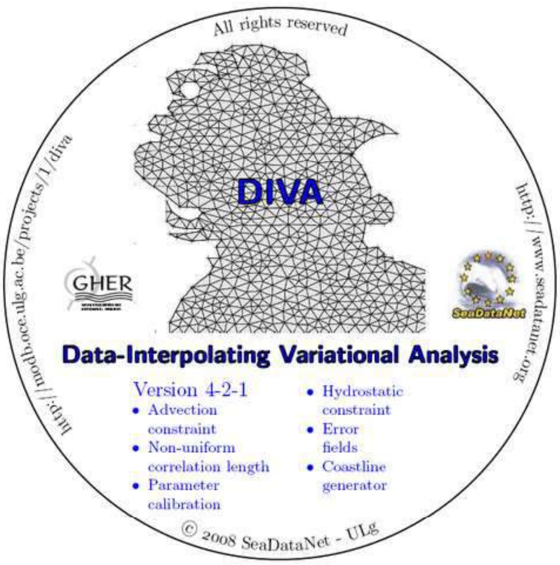
- *create all files for DIVA*
- *run DIVA mesh generation and estimation*
- *read and display the gridded field*

Grid Value Estimation by Weighted Averaging



$$estimate = \frac{\sum w_i d_i}{\sum w_i}$$

DIVA



- ***Developed at U Liege***
- ***2-Step procedure:***

(1) Triangular mesh generation on possibly complex domain(s)

(2) Variational fitting to data and estimation at arbitrary points

- ***Supports:***

(1) Variable mesh resolution

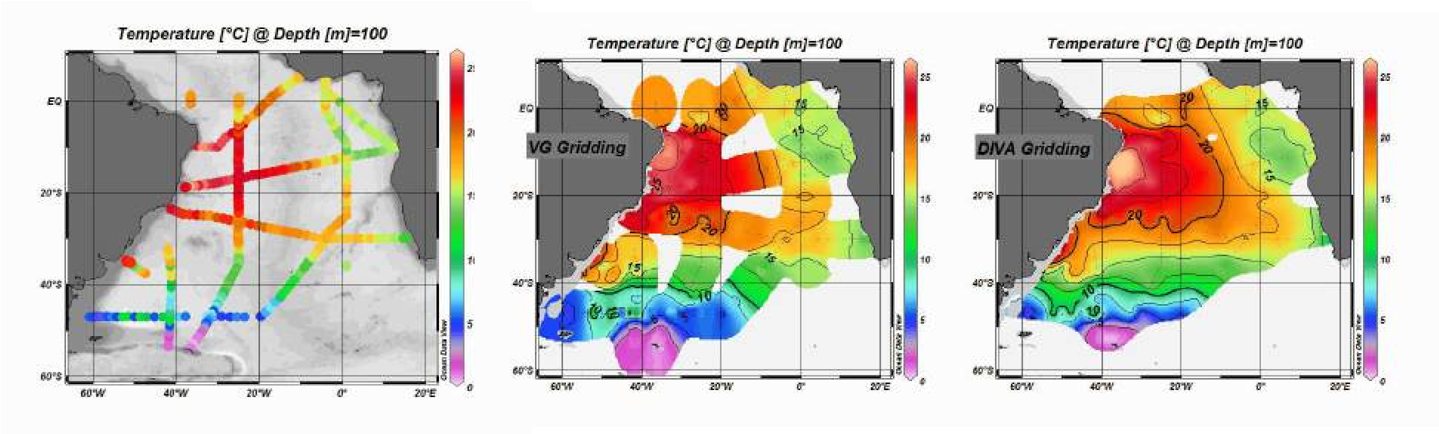
(2) Multiple sub-domains

(3) Anisotropic statistics

http://modb.oce.ulg.ac.be/projects/SeaDataNet/DivaUserGuide2008.pdf

„Honest" Way

Gridded Field



Gridding Methods

Gridding is …

- *important and definitely needed*
- *challenging mathematical problem*
- *obtaining reliable fields is an „art"*

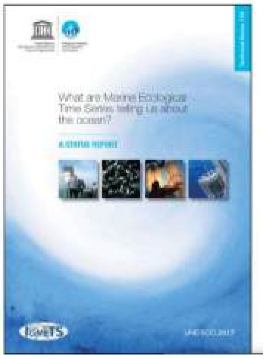
Methods

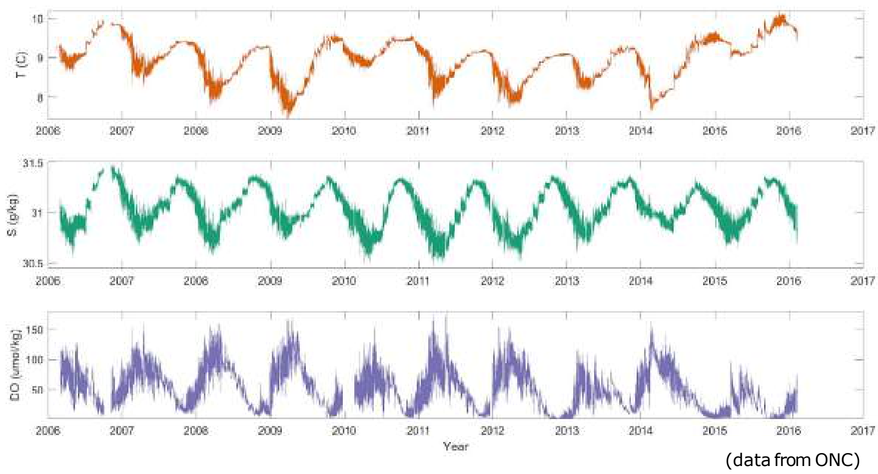
Inverse distance weighting	***Pros:** fast, good results for homogenous data coverage* ***Cons:** erodes extrema; poor results for sparse and inhomogenous data coverage*
Objective analysis	***Pros:** optimal estimation* ***Cons:** very slow, requires knowledge of data statistics, „small" datasets only*
Variational data interpolation (DIVA)	***Pros:** quite fast, optimal estimation, supports domain separation, anisotropic statistics and rotated correlation ellipses*

Time Series Development

- Time series data is critical for understanding trends in ocean oxygen levels, particularly for long-term studies on deoxygenation and hypoxia.

10-year time-series (T, S, DO) from 2006 to 2016 in Saanich Inlet

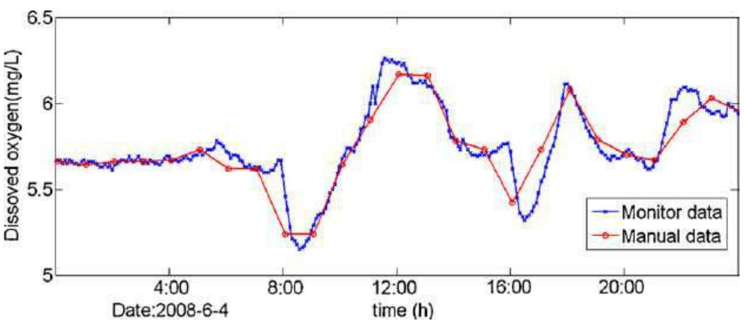




(data from ONC)

- **Data Aggregation and Time Series Construction**

- Raw data is aggregated (e.g., hourly, daily, monthly averages) to create meaningful time series datasets.



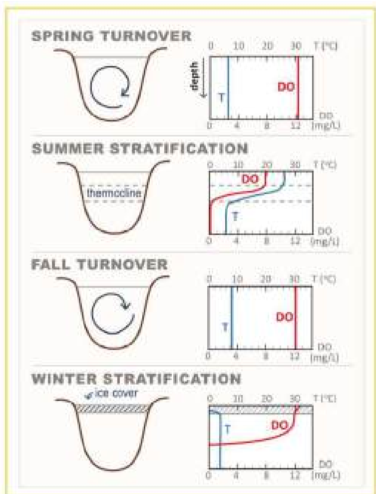
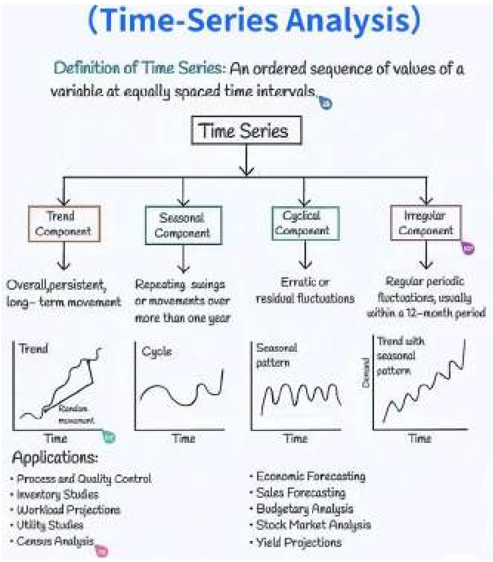
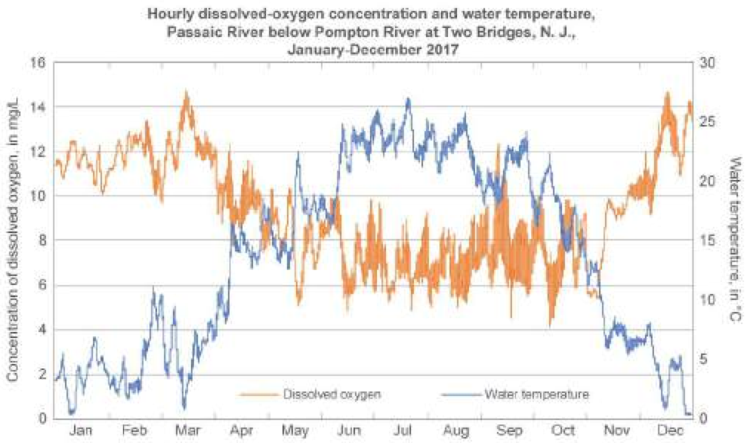


Figure 2. DO and temperature trends in eutrophic (nutrient rich) lakes by season. Adapted from Wetzel (1975)

● Trend Analysis and Seasonal Variation





Example 1: Using Excel for DO Time Series Development

Excel is often the first choice for quick time series analysis due to its user-friendly interface and accessibility. It's ideal for smaller datasets and basic time series plotting.

● Steps in Excel:

- Data Preparation: Organize the DO data in a tabular format with columns for Date/Time, DO concentration**, and other variables like temperature and salinity.
- Plotting: Use the line chart feature to plot DO concentration over time.

● Analysis in Excel:

- Trend lines: Apply linear or polynomial trend linesto detect long-term changes in DO levels. the R^2 value provided by Excel gives insight into the fit of the trendline.

- Seasonal Decomposition: Excel can also be used for basic moving averages to smooth out seasonal fluctuations. You can calculate moving averages by averaging specific intervals (e.g., 7-day, 30-day) and plotting those values.

Example 2: Using R for DO Time Series Development

R is a powerful programming language for statistical analysis and visualization, making it ideal for developing more complex time series of DO data.

- **Steps in R**

- Data Import: Import datasets using functions like `read.csv()` or `read.table()` for flat files, or more complex tools like `RNetCDF` for NetCDF files.

-Data Manipulation: Use packages like dplyr to clean, filter, and organize your dataset. Ensure the Date/Time column is properly formatted to work with time series functions.

- **Time Series Visualization in R:**

- Basic Plotting: Use the `plot()` function or the ggplot2 package to create time series plots.

- **Decomposition and Trend Analysis:**

- Use the stats package's `decompose()` function to break down the time series into seasonal, trend, and residual components.

This is especially useful for understanding seasonal cycles in DO data due to temperature changes or nutrient loading.

```
do_ts <- ts(data$DO, frequency=12)
decomp <- decompose(do_ts)
plot(decomp)
```

Summary

Each tool offers distinct advantages for **DO time series development**:

- **Excel**: Best for simple visualizations and smaller datasets.
- **R:** Offers advanced time series decomposition, trend analysis, and forecasting capabilities.
-**Python:** Provides extensive libraries for machine learning, advanced statistical modeling, and visualization.
- **MATLAB and SPSS**: Powerful for advanced statistical analysis and time series modeling with user-friendly interfaces.

Closing Remarks and Q&A

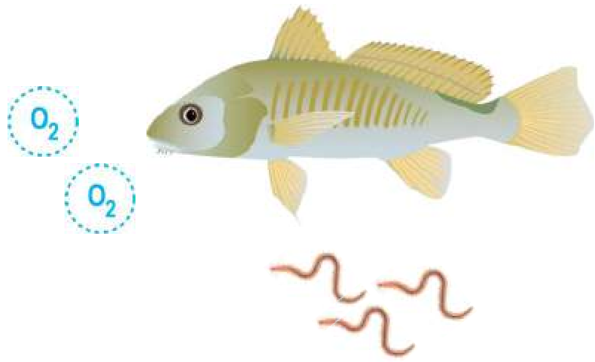
- In summary, managing and analyzing coastal dissolved oxygen data requires a comprehensive approach that includes: Robust data processing、 Spatial mapping、 Time series development.

- **Robust data processing** is to ensure data accuracy and reliability, including rigorous quality control and validation against known standards.

- By **mapping oxygen distribution** both horizontally and vertically, we can better understand how hypoxia develops and impacts marine ecosystems.

- The **development of long-term time series** is crucial for tracking trends in ocean oxygen levels, identifying seasonal patterns, and predicting future changes. Tools like **Python** and **R** are effective for creating time series plots and performing trend analyses that inform management strategies.

Session 4: Biological applications of coastal hypoxia indices and monitoring



USGS Wetland and Aquatic Research Center

Paracas, Peru

U.S. Department of the Interior
U.S. Geological Survey

Biological Responses to Coastal Hypoxia

Methods:

- Laboratory experimental work
- Field observations

Biological Responses May Differ Because of:

- Species physiological limits to oxygen deficiency
- History or severity of low oxygen (Rabalais et al. 2001)

Photo credit: K. St. Pé

Biological Responses to Coastal Hypoxia

Mobile Animals
Fish and shrimp move vertically or laterally out of hypoxia

Deoxygenation Indicator:
Behavioral Change

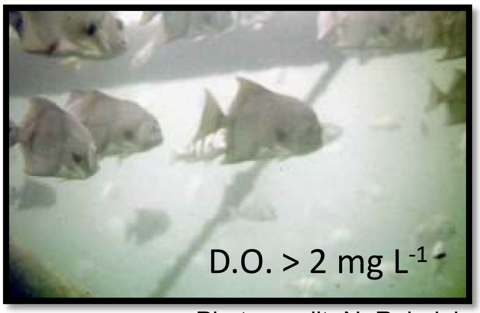


Photo credit: N. Rabalais

Less Mobile Animals
Worms and small crabs can die in the mud

Deoxygenation Indicator:
Mortality and Diversity

Photo credit: F. Viola

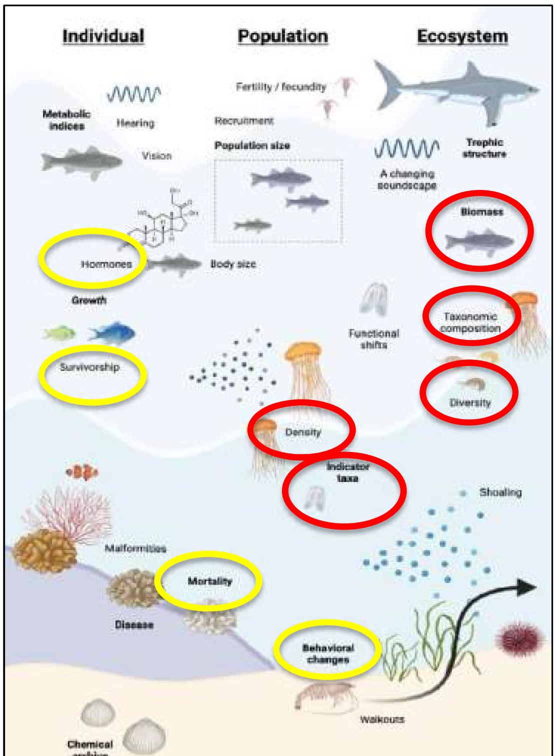
USGS

Deoxygenation Indicators

Individual
- Hormones
- Survivorship
- Mortality
- Behavioral changes

Population
- Density
- Indicator taxa

Ecosystem
- Biomass
- Taxonomic composition
- Diversity



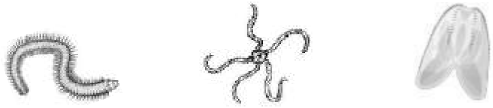
Roman et al. 2024

USGS

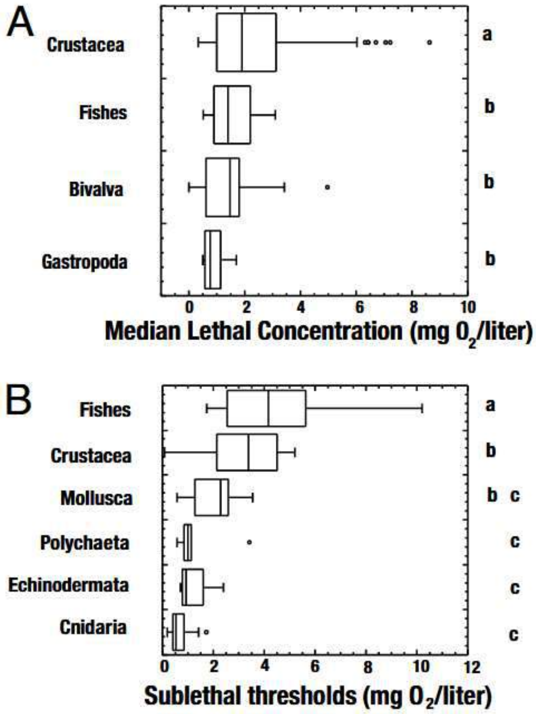
Thresholds

- **Lethal (median: ~0.75 - 1.5 mg/L) and sublethal (0.5 - 4 mg/L) thresholds**
- **Taxa more sensitive to low D.O.:**
  - Fishes, crustaceans and molluscs

- **Taxa less sensitive to low D.O.:**
  - Polychaetes, echinoderms, cnidarians



- **Conventional definition of 2 mg O_2 L^{-1} might underestimate the severity**

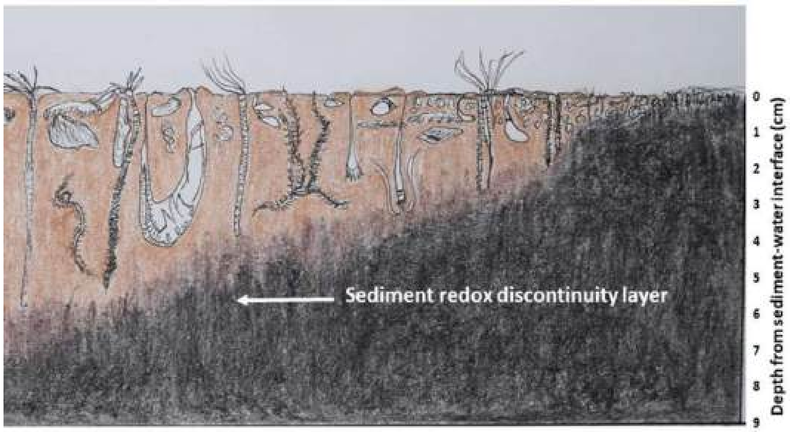


Vaquer-Sunyer and Duarte 2008

Benthic Responses to Hypoxia

Benthic Habitats
- Macroinfauna (> 0.5 mm sieve):
  - Polychaetes
  - Clams
  - Gastropods
  - Amphipods
  - Brittle stars

Low D.O. Impacts Benthic Macroinfauna
- Less mobile animals become stressed
- Eliminates important prey items, thus have potential effects on rest of the food web

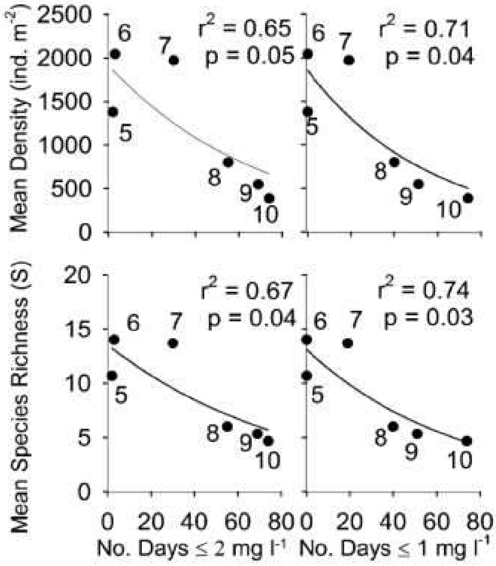


Rabalais 2019

Threshold: ≤ 2 vs. ≤ 1 mg DO L^{-1}

Density

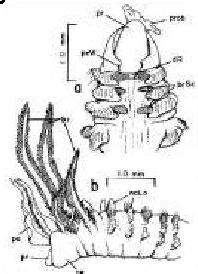
Diversity



Baustian and Rabalais 2009

Benthic Macroinfauna Responses

- **Density (ind. m^{-2})**
  - Declines exponentially from May (5) to October (10), reduced by 4
- **Diversity, Species Richness (S)**
  - Declines exponentially from May (5) to October (10), reduced by 3



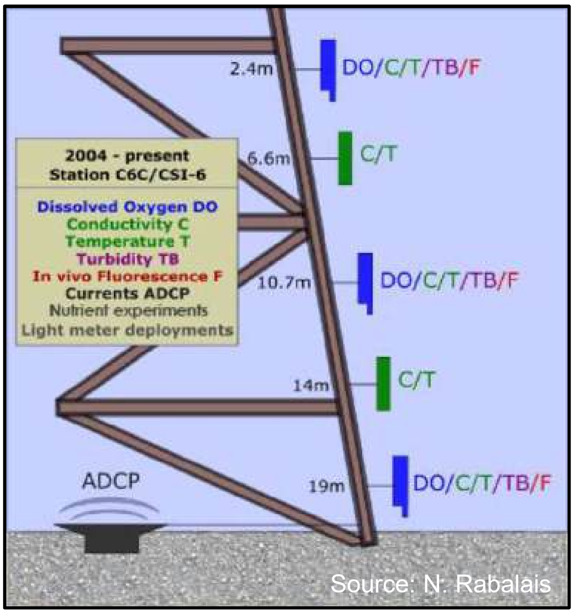
Polychaete: *Paraprionospio pinnata*

USGS

Measuring Time Series of Dissolved Oxygen & Biological Responses

USGS

Collecting Time Series of D.O.



Oil and Gas Platforms, Gulf of Mexico

Time Series of D.O. – 1990s

Dissolved Oxygen

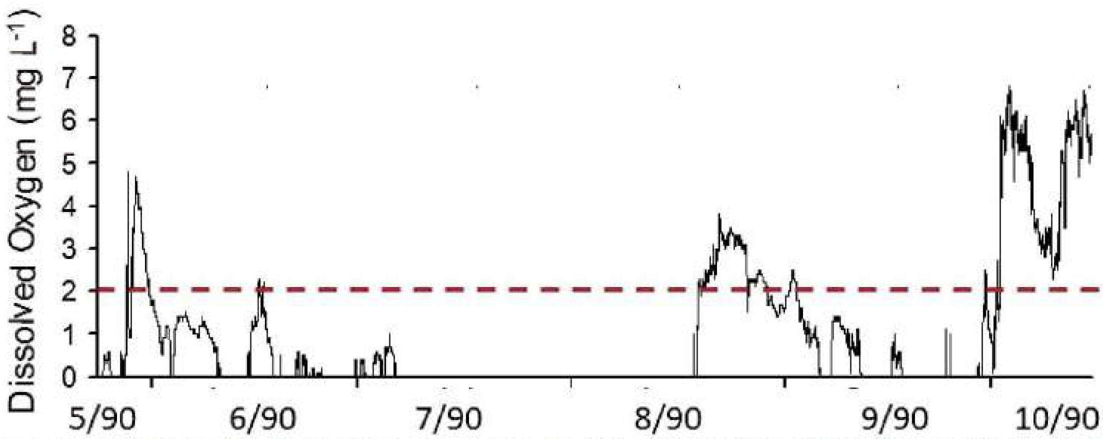
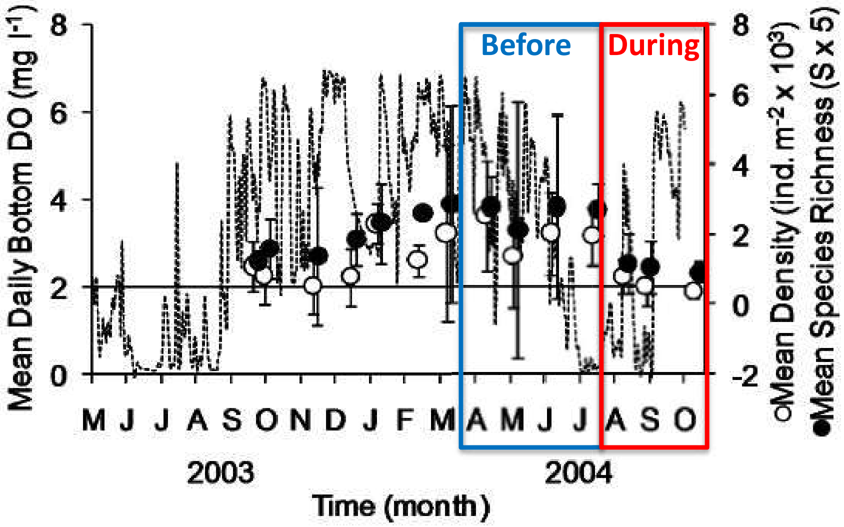


Figure 8.7.11 Time series plot of near-bottom dissolved oxygen concentration at a 20 m station 100 km west of the Mississippi River delta in 1990 (modified from Rabalais et al., 1994, 2001b). The horizontal dashed line defines hypoxia (from Rabalais et al., 2007).

Rabalais 2019

Time Series of D.O. – 2003 & 2004

Dissolved Oxygen

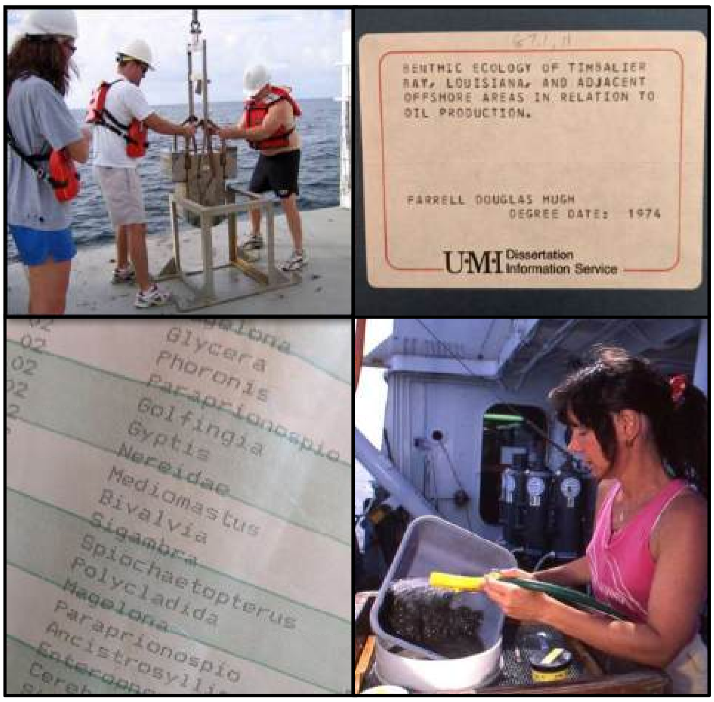


USGS

Baustian and Rabalais 2009

Benthic Macroinfauna Studies

- Farrell 1974
- Fitzhugh 1978
- Harper et al. 1981
- **Gaston 1985**
- **Gaston et al. 1985**
- **Boesch and Rabalais 1991**
- Harper et al. 1991
- Rabalais & Harper 1992
- **Rabalais et al. 2001**
- **Baustian et al. 2009**
- **Baustian and Rabalais 2009**



USGS

Benthic Infauna – Taxonomic Composition

Deoxygenation Indicator: Indicator Taxa

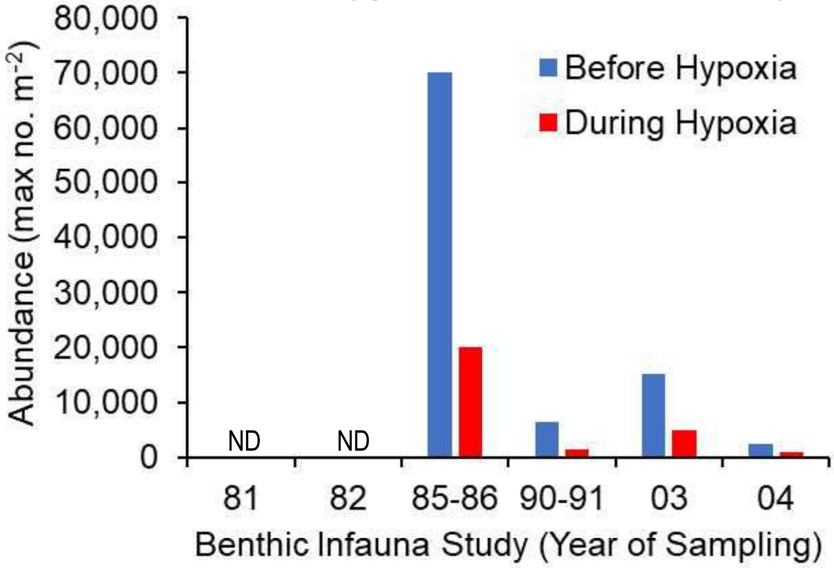
Benthic Macroinfauna	Hypoxia	
	Before	During
Crustaceans 	✓	
Polychaetes 	✓	✓
Nemerteans 	✓	
Mollusks 	✓	✓

USGS

Baustian and Rabalais 2009, Rabalais and Baustian 2020

Benthic Macroinfauna Density

Deoxygenation Indicator: Density

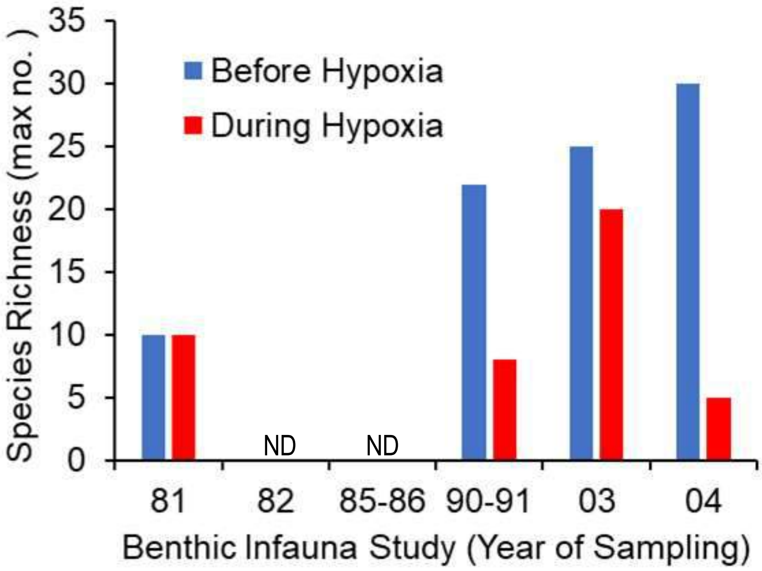


Hypoxia impact:
Decreased by 3 to 5x

USGS

Benthic Macroinfauna Diversity

Deoxygenation Indicator: Diversity



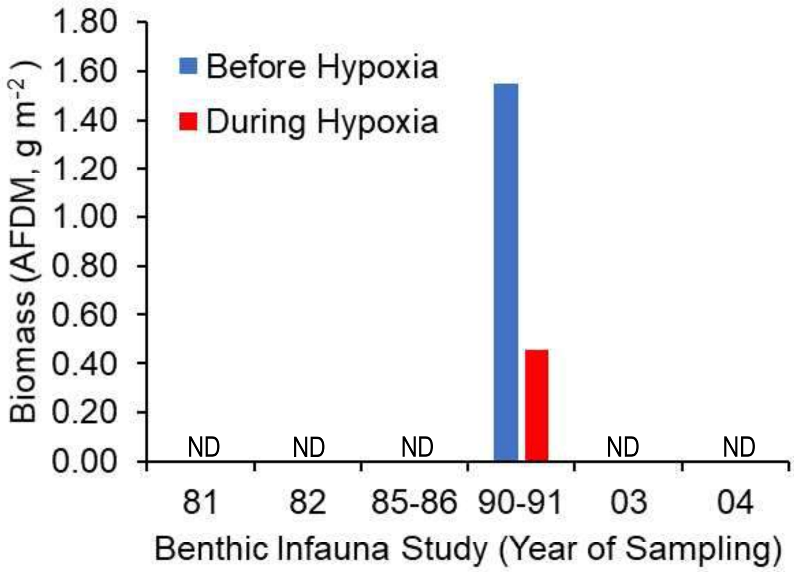
Hypoxia impact:
Decreased by 3-6 x

Photo credit: D. E. Harper, Jr.

USGS

Benthic Macroinfauna Biomass

Deoxygenation Indicator: Biomass



Hypoxia impact:
Decreased by 3x

Photo credit: F. Viola

USGS

Research Cruises to Map Coastal Hypoxia

LOUISIANA UNIVERSITIES MARINE CONSORTIUM LUMCON

LSU LOUISIANA STATE UNIVERSITY

RV Pelican
- 116 feet long
- 16 scientific crew
- 5 work crew
- 18-day endurance

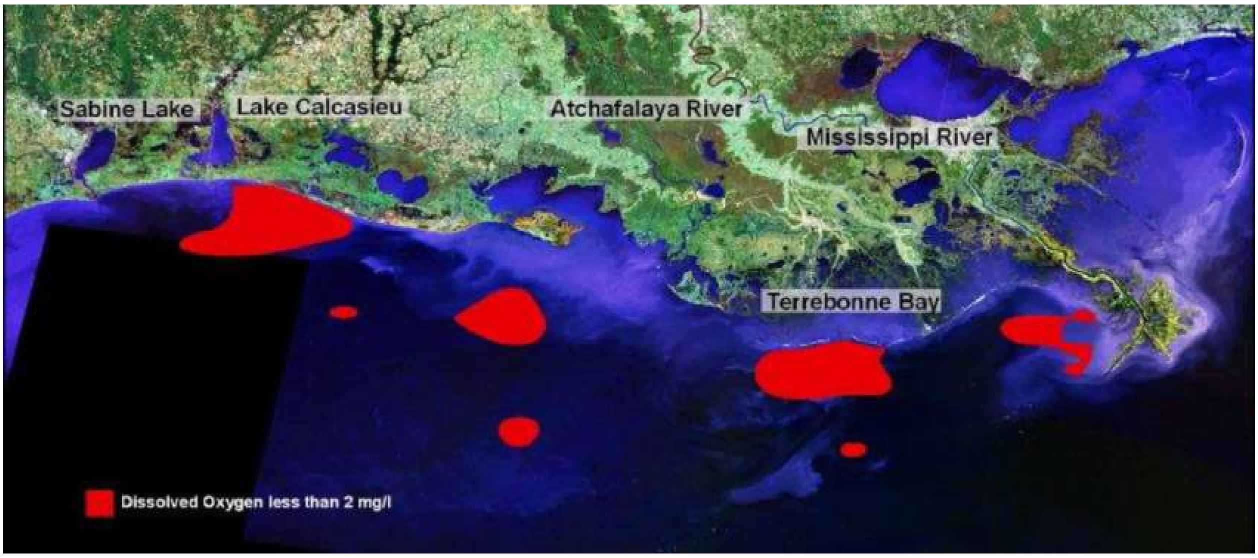
www.lumcon.edu

USGS

Collecting Water Quality Data

USGS

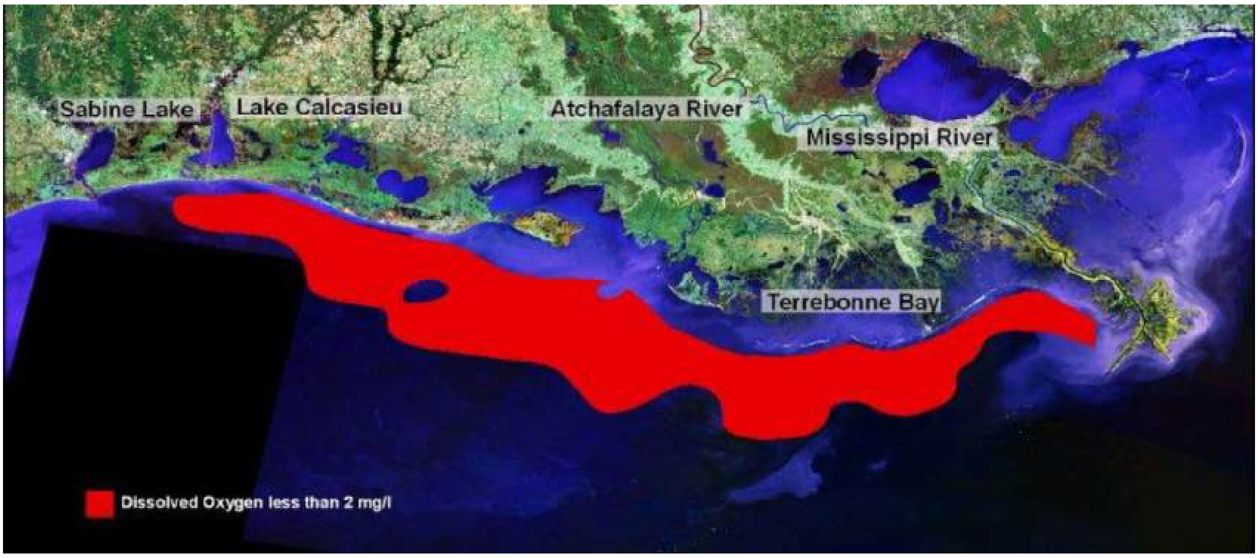
Annual Shelfwide Cruise - 2003



Source: N. Rabalais

USGS

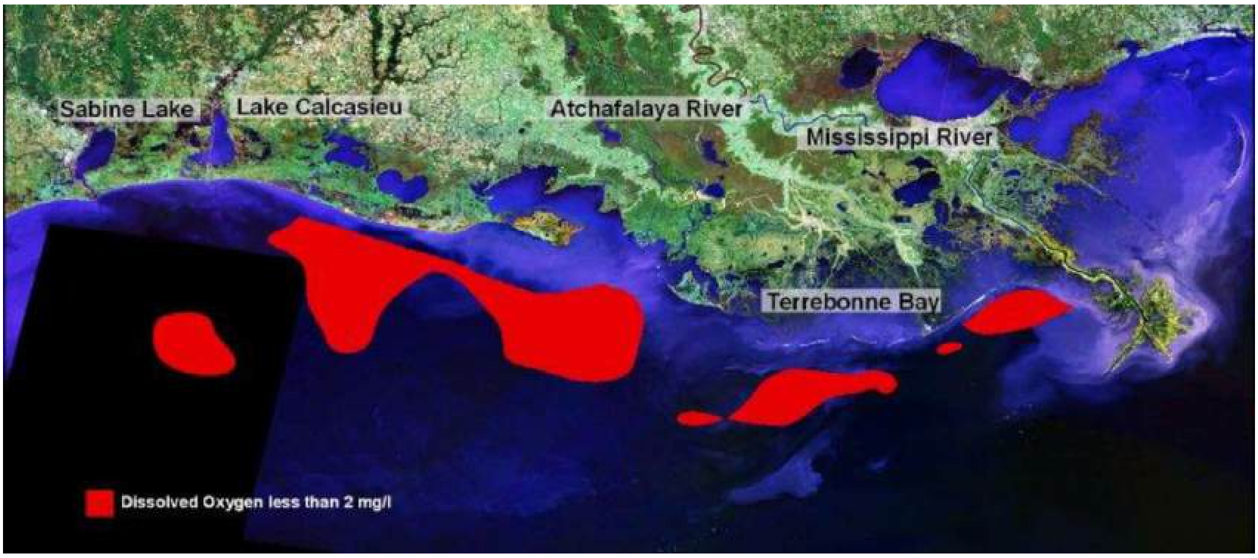
Annual Shelfwide Cruise - 2004



Source: N. Rabalais

USGS

Annual Shelfwide Cruise - 2005

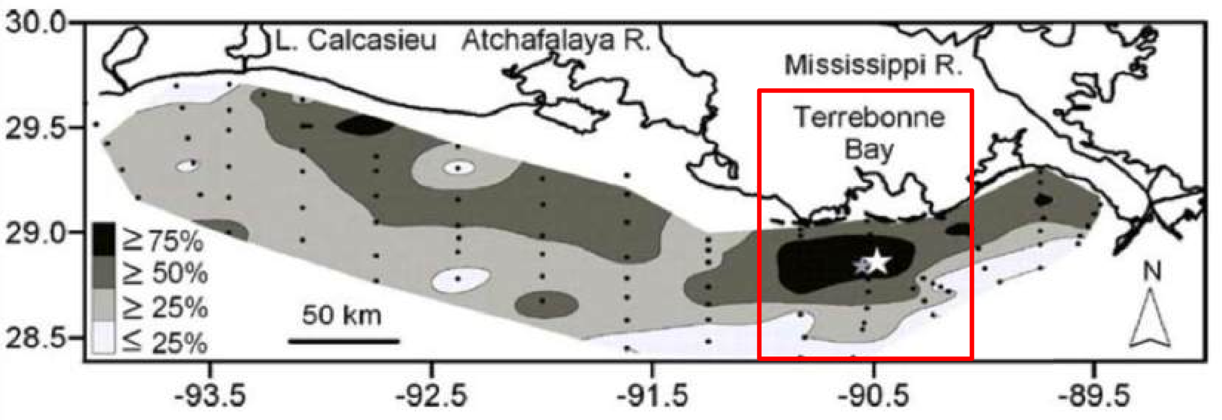


Source: N. Rabalais

USGS

Stations Visited Each Summer

Estimate Frequency of Occurrence (1985-2005)
e.g., > 75% to help determine where to monitor more often and measure biological responses

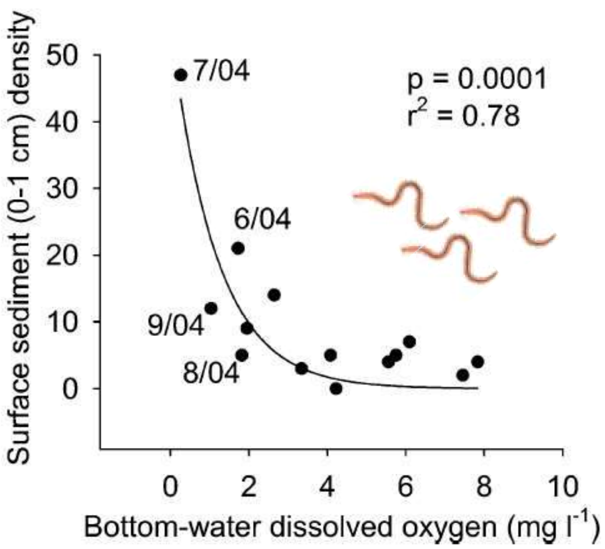


Baustian and Rabalais 2009

USGS

Benthic Macroinfauna Move to Sediment Surface

Density at Sediment Surface (0-1 cm)



Deoxygenation Indicator:
Behavioral Change

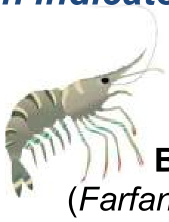
- Near 0 mg L^{-1}, benthic macroinfauna move to sediment surface (Baustian and Rabalais 2009)
- Vulnerable as potential prey for fish and shrimp

USGS

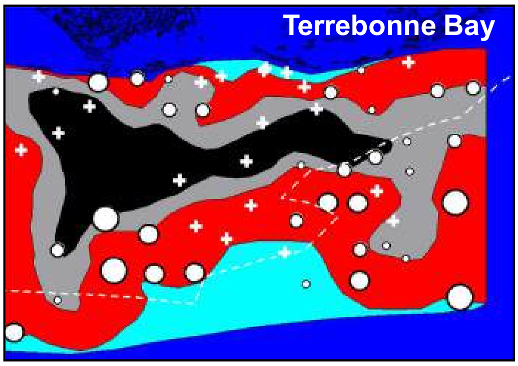
Loss of Fisheries Habitat - Summer 2003

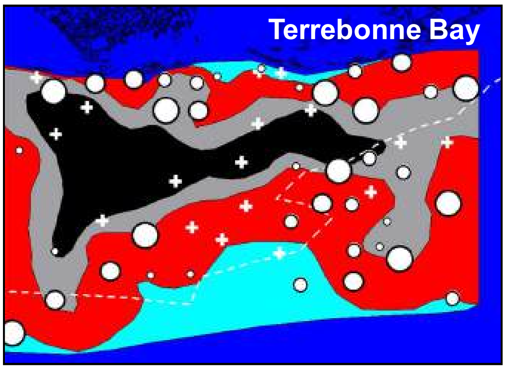
Deoxygenation Indicator: Behavioral Change

Atlantic croaker
(*Micropogonias undulatus*)



Brown shrimp
(*Farfantepenaeus aztecus*)





Dissolved Oxygen (mg l^{-1})

- 0-1
- 1-2
- 2-4
- >4

Catch Percentiles

- + 0
- 1-25%
- 25-50%
- 50-75%
- 75-100%

Source: J.K. Craig

USGS

Living Resources Affected by Coastal Hypoxia

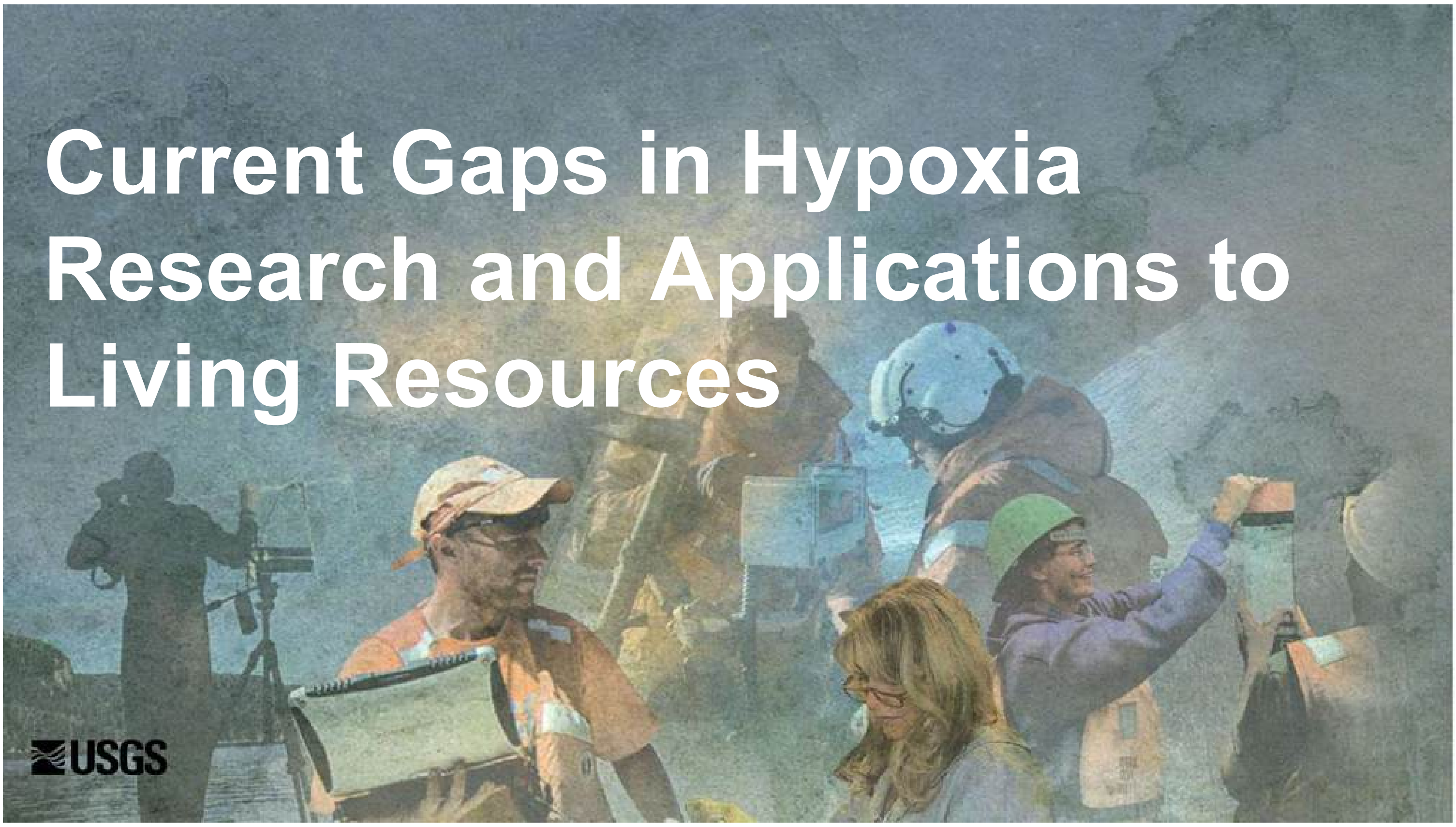
Atlantic croaker
(*Micropogonias undulatus*)

Deoxygenation Indicator: Hormones

Source: P. Thomas

USGS

Current Gaps in Hypoxia Research and Applications to Living Resources



Monitoring Future Conditions

Warmer Temperatures

- Larger hypoxic areas
- Combined stress of hypoxia and temperature on metabolic index (Deutsch et al. 2024)

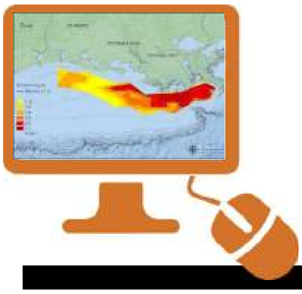
Benthic Food webs

- Reduction of benthic habitat and prey
- Exposure to harmful algal blooms (HABs) including toxins

Biological Vulnerability to Hypoxia from Climate Warming and Eutrophication in the Northern Gulf of Mexico

PIs: Jun-Hong Liang, Curtis Deutsch, Nancy Rabalais, Cassie Glaspie, Melissa Baustian, and Bingqing Liu

Project period: 2023-2027

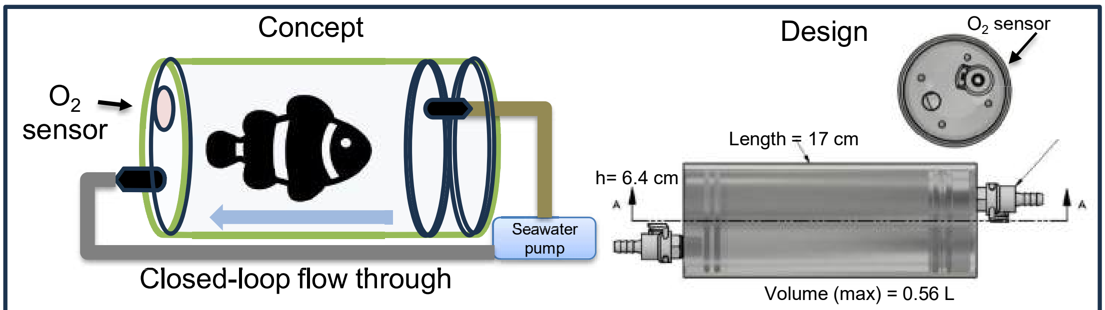


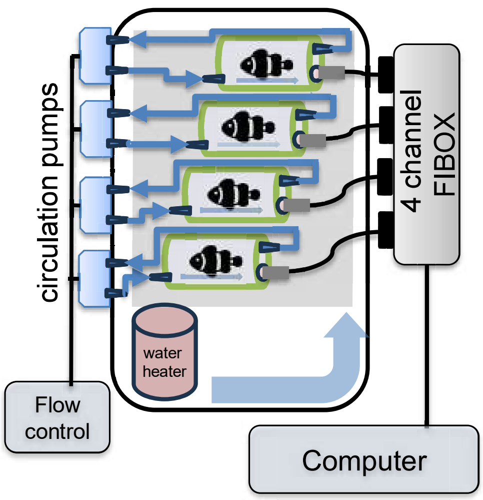
Computer Modeling of future ocean conditions over the northern Gulf of Mexico under different warming and nutrient discharge scenarios

Laboratory Experiments of the hypoxia tolerance of important Gulf species in warmer water

Products:
Maps of suitable habitats and body size change for important Gulf species

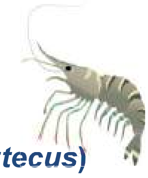
Laboratory Experiments





Species to test:

1. Atlantic brief squid
2. **Gulf menhaden (*Brevoortia patronus*)**
3. Striped anchovy
4. Brittle star
5. Blue crab
6. **Brown shrimp (*Farfantepenaeus aztecus*)**



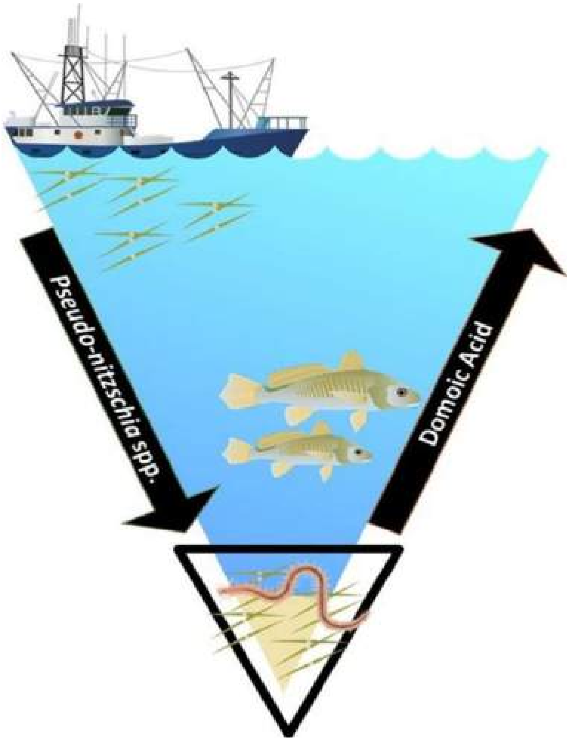
Temperatures:

- 15 ℃
- 20 ℃
- 25 ℃

Monitoring Harmful Algal Blooms (HABs) & Hypoxia

- *Pseudo-nitzschia* spp. have been observed in surface sediments and guts of polychaetes
- Demersal fish and penaeid shrimp could be impacted by grazing on these potentially toxic polychaetes

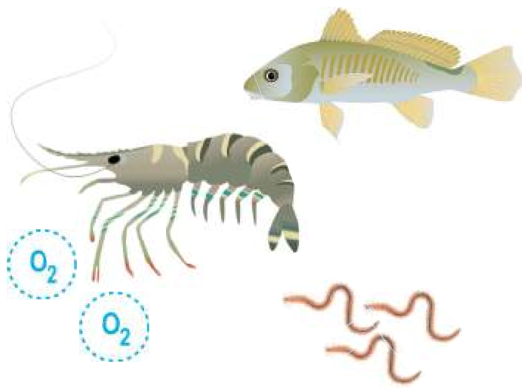
Baustian et al. (2009, 2011, 2018)



USGS

Conclusions

- Various deoxygenation indicators are available to understand biological responses
  - From individual to ecosystem level
- Hypoxia impacts benthic macroinfauna including:
  - Density
  - Biomass
  - Taxonomic Composition
  - Diversity
- Future research can help assess hypoxia impacts on upper trophic levels of coastal food webs with:
  - Warmer temperatures
  - Harmful algal blooms



USGS

Acknowledgements

Funded by:

- NOAA Center for Sponsored Coastal Ocean Research Coastal Ocean Program
- NOAA Domestic Centers for Coastal Ocean Science

Captain and crew:

- R/V *Longhorn*
- R/V *Pelican*
- R/V *Acadiana*

Special thanks to APEC for sponsoring this workshop!

USGS

Thank You!

¡Grasias!

Annex 4. Invited presentations

A global ocean oxygen database and atlas for assessing and predicting deoxygenation and ocean health in the open and coastal ocean

The GO_2DAT Project

unesco

Intergovernmental Oceanographic Commission

GOOD

Global Ocean Oxygen Decade

APEC Workshop, October 2nd, 2024

Assessing and predicting deoxygenation and ocean health

- **Oxygen is critical to the health of the planet**

Where do we get our oxygen?
the ocean is responsible for about 50% of the oxygen produced on the planet
over geological time scales, the ocean has provided a large fraction of the oxygen we take in today

- **Oxygen decline (deoxygenation)** is increasing in the coastal and open ocean, due to human activities (CO_2-induced warming) and increasing loads of nutrients.

- **But we are still not able to contain the rate of deoxygenation.**

- **High quality data are needed for monitoring ocean deoxygenation** and to advance our understanding of ocean extreme events.

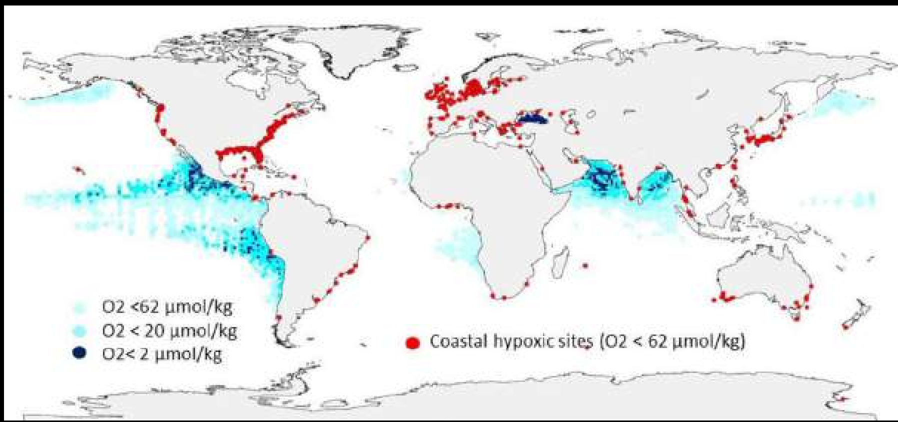
- **No single entry point to download oxygen data**, heterogeneous procedures across databases, GDACs, regional hubs, users

Why now?

Why GO_2DAT is needed?

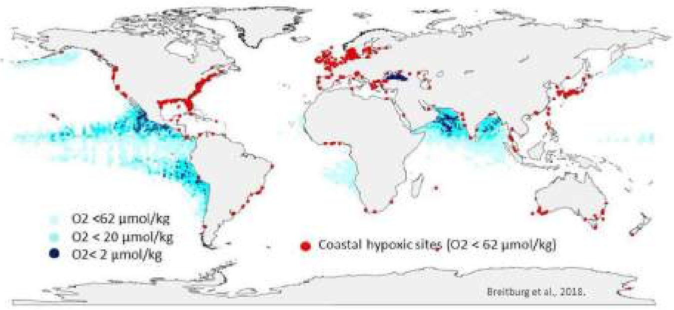
Global Ocean Oxygen Decade

High quality data needed for monitoring deoxygenation



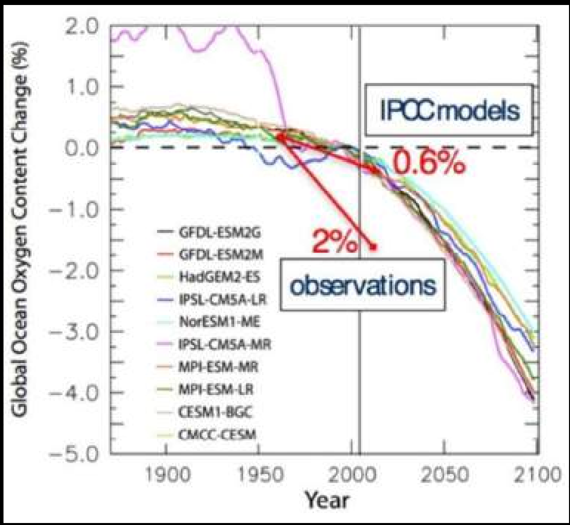
Since the 1950s : Over 500 coastal systems identified with ≤20-25% oxygen saturation.
Since the 1960s: The open ocean has lost 2% of its oxygen inventory = 77 billion tons O_2.

Breitburg et al., 2018



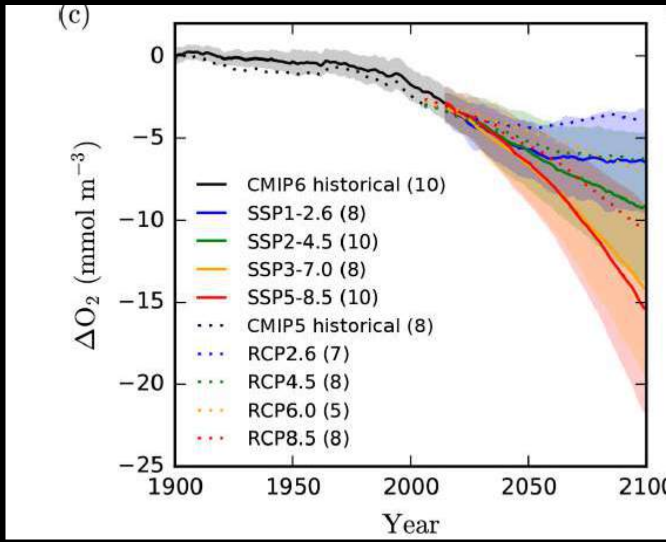
Insufficient coverage to characterize hypoxia dynamics in the coastal ocean

The amount of deoxygenation is not well constrained



Deoxygenation trend over 1960–2005 differs between 0.6% and 2 %

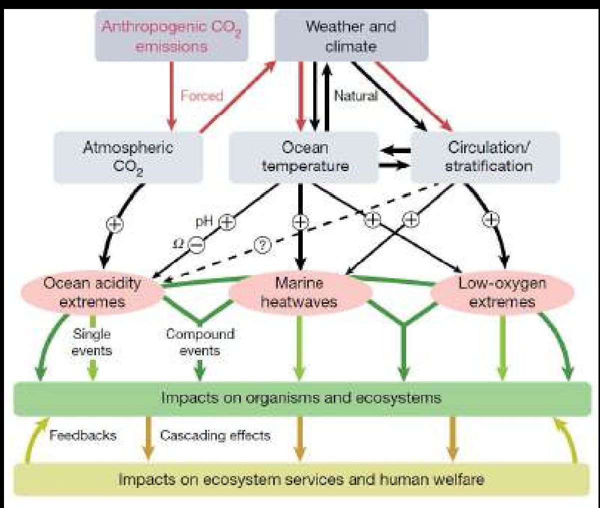
Oschlies et al., 2018

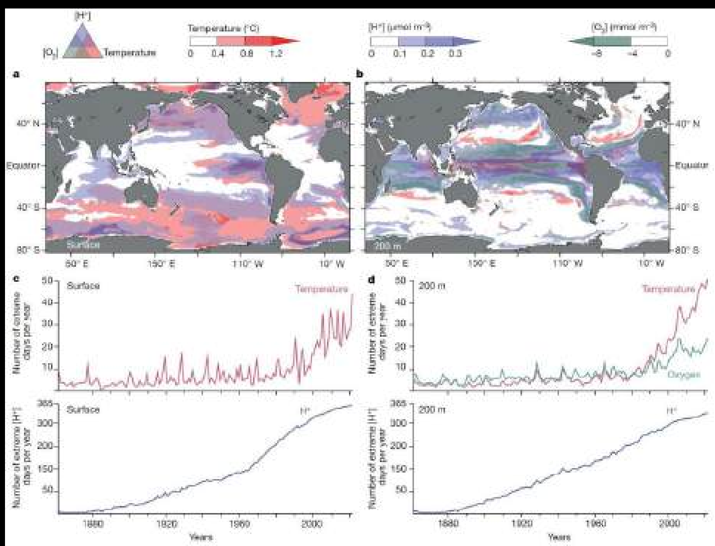


Averaged between 100 and 600 m

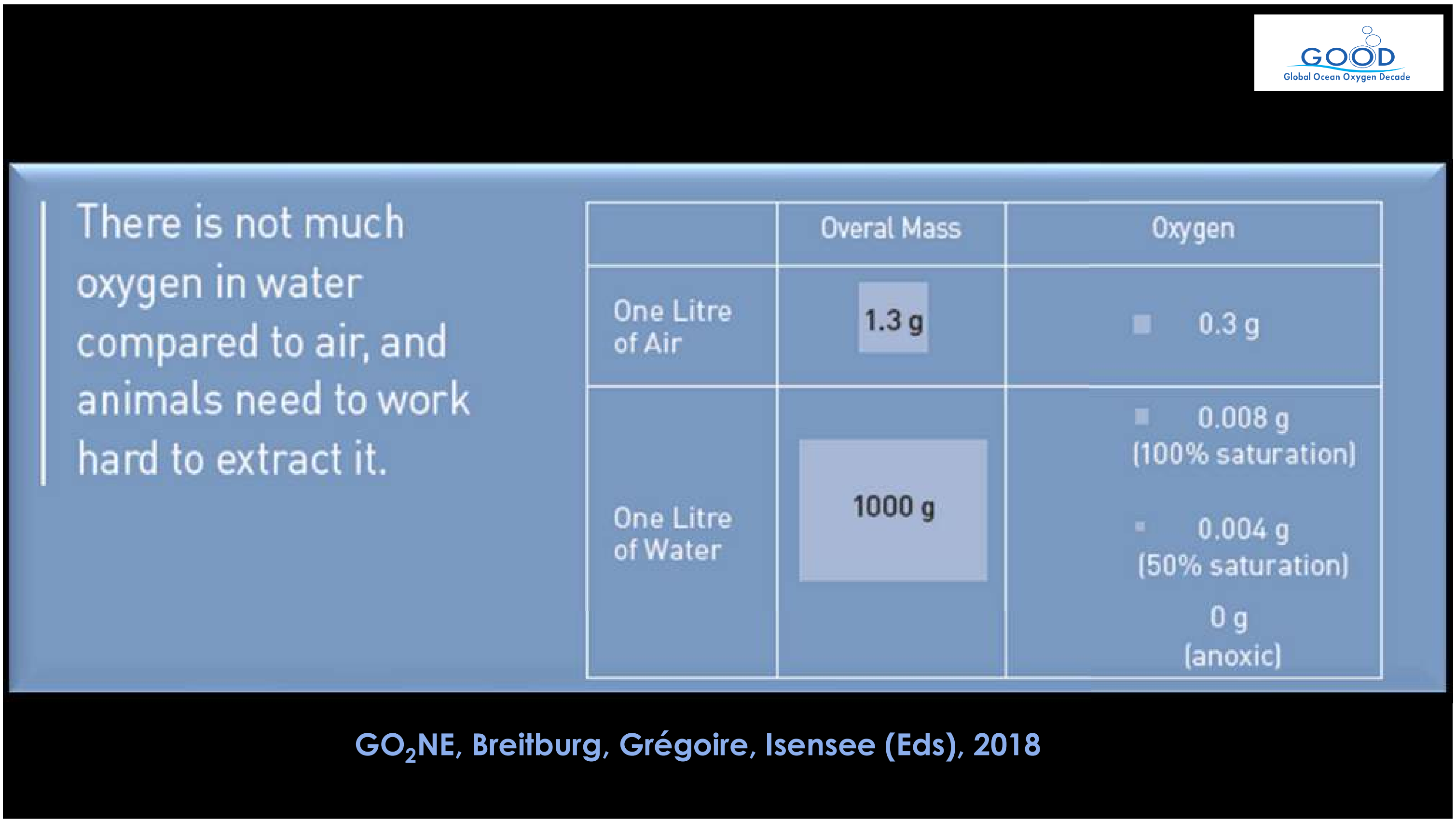
Kwiatkowski et al., 2020

To advance our understanding of ocean extreme events





Gruber et al., 2021



Quality flagging differs across data bases

Flag Description (EMODnet)	Emodnet	WOD	ARGO
no quality control	0	0	0
good value	1	0	1
probably good value	2	0	2
probably bad value	3	4	3
bad value	4	4	4
changed value	5	0	5
value below detection	6	0	0
value in excess	7	0	0
interpolated value	8	0	8
missing value	9	0	9
value phenomenon uncertain	A	0	0
value below limit of quantification	Q	0	0

Flag Description (WOD)	WOD	EMODnet	ARGO
accepted value	0	1	1
range outlier (outside of broad range check)	1	3	3
failed inversion check	2	3	3
failed gradient check	3	3	3
observed level "bullseye" flag and zero gradient check	4	3	3
combined gradient and inversion checks	5	3	3
failed range and inversion checks	6	4	4
failed range and gradient checks	7	4	4
failed range and questionable data checks	8	4	4
failed range and combined gradient and inversion checks	9	4	4

Comparison of the flagging system used in Emodnet, WOD and Argo (figure from Schlitzer, 2020).

Quality control levels differs across data bases

QUALITY CONTROL LEVELS

QC=0 **Basic checks**
1. Duplicates
2. Metadata
3. Position, platform, sensor, units, date,..
4. Format

QC =1 **Automatic and manual checking**
1. Range, gradient and spikes
2. Depth/density Inversion, systematic offset,
3. Drift, flat or stuck line
4. Property-property plots

QC=2 Additional Checking – Adjustment
- Bias and drift correction
- Intercomparison
- Post calibration (e.g. air-calibration for BGC Argo)

QC=3 **Consistency check with climatologies**
QC=4 **Tailored data product development**

Quality control procedure and levels adopted in the WOD (Garcia et al., 2024).

LIST OF QUALITY CHECKS

QC=1 **Automatic checking**
1. Geographical location : position, platform, sensor, units, date,..
2. Format
3. Duplicates

QC =2 **Automatic checking**
1. Range check (gross range 0 to 500 mol/kg)
2. Removal of any blunders

QC=3 **Automatic checking**
3. Crude range check (temperature/oxygen, oxygen/pressure)

QC=4 **Automatic checking**
4. Maximum solubility check

QC=5 **Automatic checking**
5. Stucked value check

QC=6 **Automatic checking**
7. Spike check

QC=7 **Automatic checking**
8. Multiple extrema checks (profile shape check)

QC=8 **Automatic checking**
9. Oxygen vertical gradient check

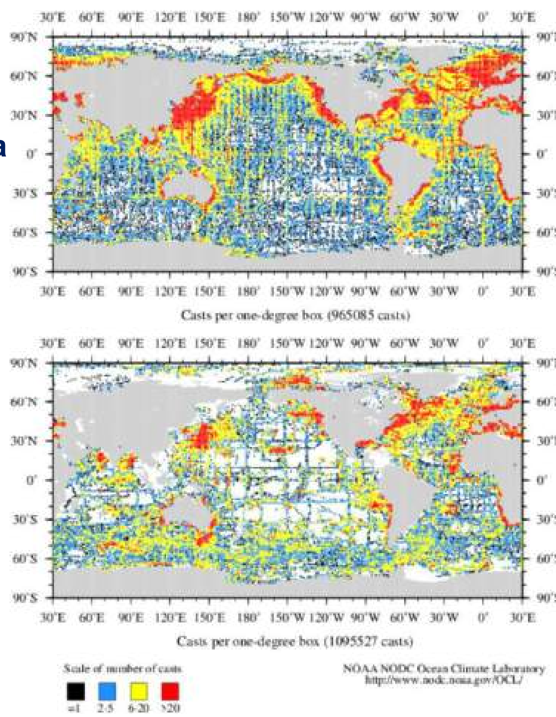
QC=8 **Automatic checking**
10. Local climatological range

List of quality control checks adopted in the IAP dataset (Gourteski et al., 2024; L. Cheng, pers.com.) In the sequence of 8 checks, each test will be attributed a 0 (passed) or a 1 (failed) (0 and 1 are the quality flags).

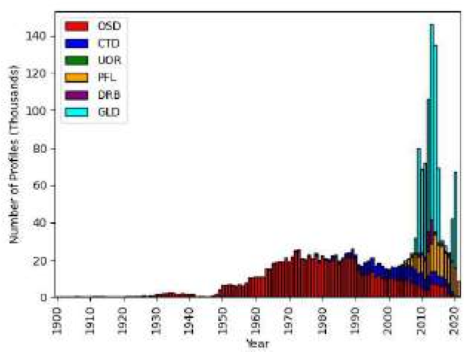
WHY NOW? CHANGE OF PARADIGM IN OUR CAPABILITIES TO OBSERVE O2

Winkler data

Sensor data



 # Winkler data since 1900 ≅
 # sensors data over the last 10 years

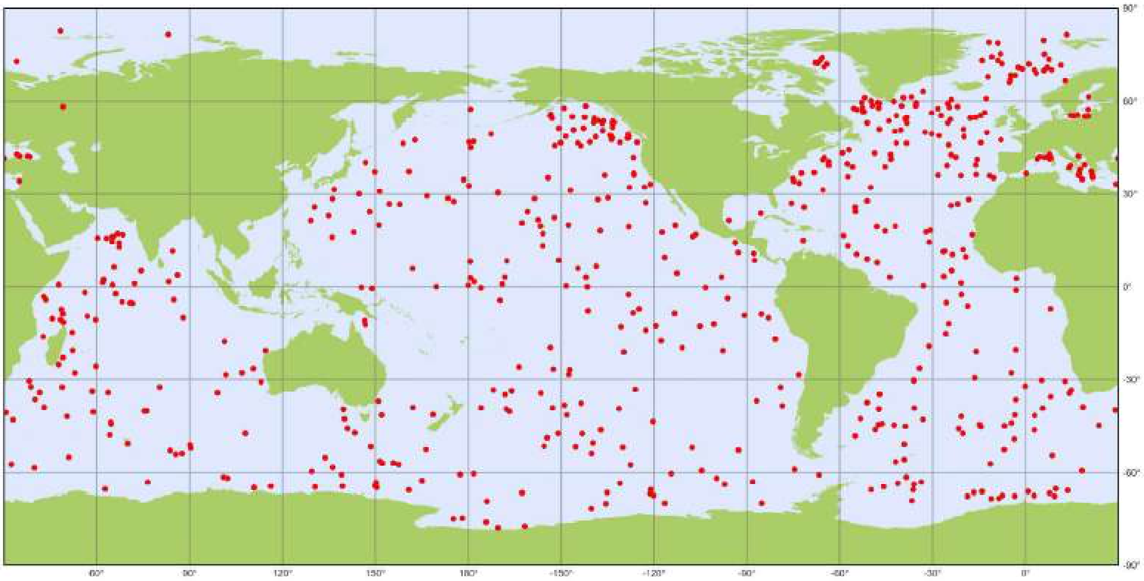


January 2024

O_2 sensors

576

15% of core Argo



Courtesy from Mathieu Belbéoch and Magali Krieger, OceanOPS

DATA INTEGRATION: OPEN AND COASTAL DATABASES

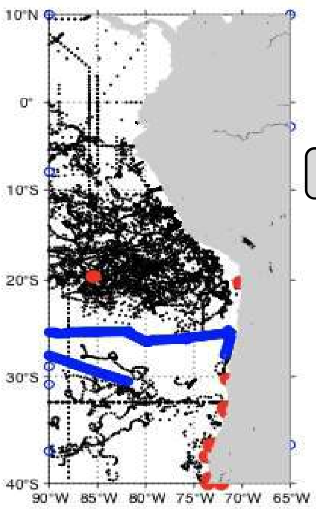
OPEN OCEAN DATABASES
- World Ocean Database — Read_WOD.m
- Mirai R/V 2017/2019 — Read_mirai.m

COASTAL DATABASES (CHILE)
- Mooring (CEAZA, POSAR, CDOM.CL)
- Cruises-CTD profiles (IFOP, CIMAR)
- Winkler (POAL Army program)
- Gliders

Read_coastal.m — QA/QC

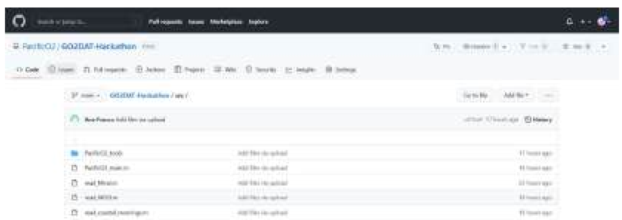
PacificO2_main.m

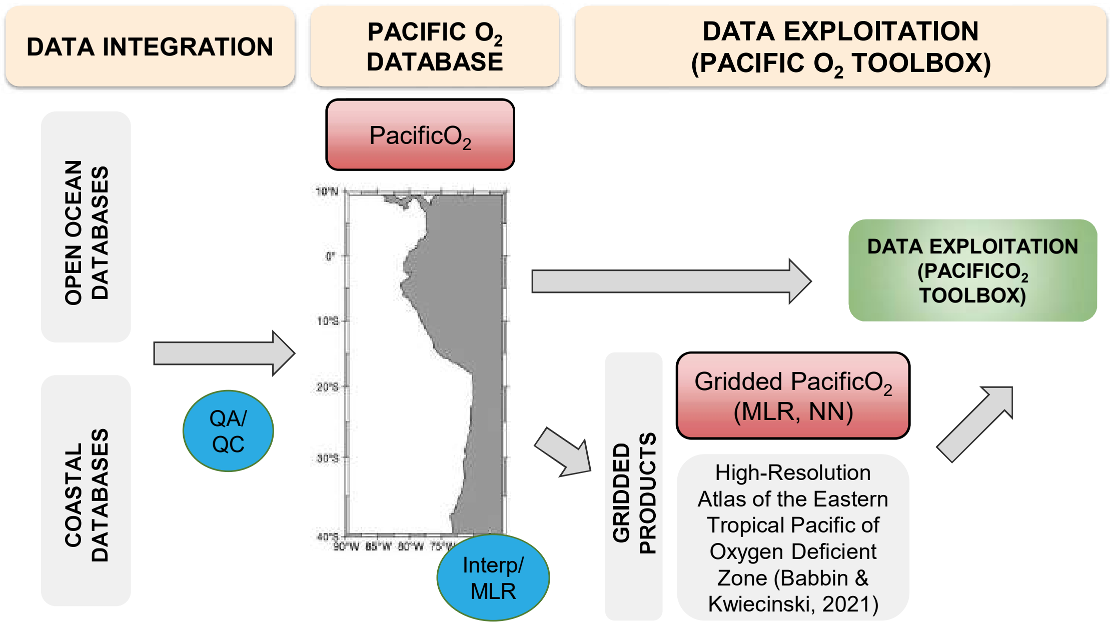
$PacificO_2$.nc



- WOD data (Ships, Argo profiles)
- Mirai data (only surface data)
- Coastal mooring data

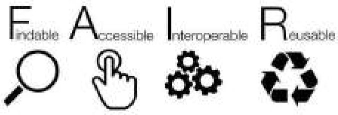
GitHub




DATA INTEGRATION
PACIFIC O_2 DATABASE
DATA EXPLOITATION (PACIFIC O_2 TOOLBOX)
OPEN OCEAN DATABASES
COASTAL DATABASES
QA/ QC
PacificO$_2$
Interp/ MLR
DATA EXPLOITATION (PACIFICO$_2$ TOOLBOX)
GRIDDED PRODUCTS
Gridded PacificO$_2$ (MLR, NN)
High-Resolution Atlas of the Eastern Tropical Pacific of Oxygen Deficient Zone (Babbin & Kwiecinski, 2021)


COASTAL DATABASES (CHILE)
Mooring (CEAZA, POSAR, CDOM.CL)
Tongoy Bay 30º S (2014-Present)
Cochamó, Puyuhuapi, Seno de Reloncavi, Isla Irene, Puerto Cisnes
CEAZA
OSTIMAR
Posar buoy 36.4ºS (2016-Present)
Boya POSAR
Cruises-CTD profiles (Instituto de Fomento Pesquero and CIMAR-Chilean Army)
CIMAR 25 años
Winkler (POAL Army program - Programa de observación del ambiente litoral) 1993-Present
P.
O.
A.
L.
Gliders
Create a list with the glider data owners. Under request.
CAMPAÑAS DE GLIDER EN CHILE POR CADA REGIÓN (2009-2020)

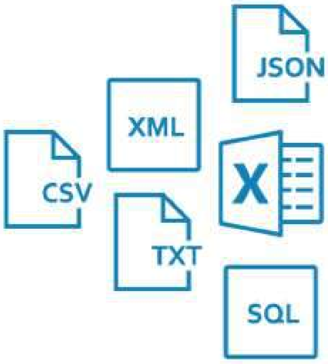
PacificO$_2$ DATABASE (PACIFICO$_2$.nc)

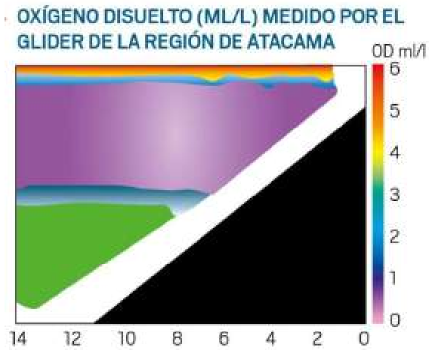


Data accessibility: Download data in different formats and units

Download maps and figures in different formats (.png, .pdf, .jpeg) - stakeholders

Glider data: Contact PIs for possible collaboration



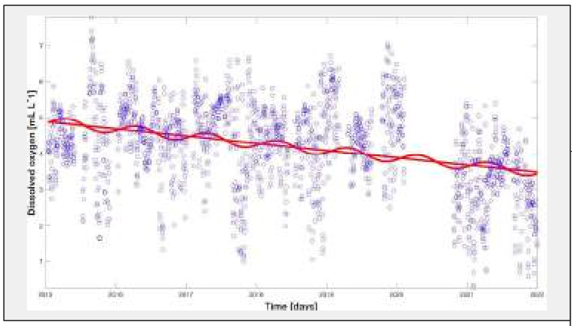


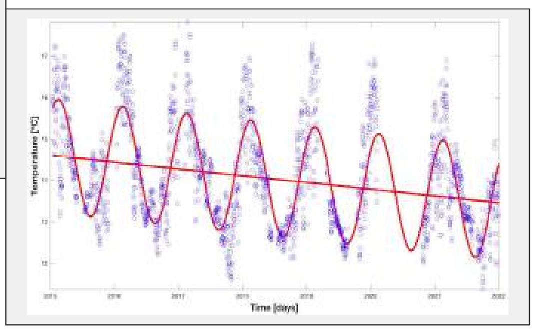
Source:
http://met.igp.gob.pe/variabclim/argo.html

PacificO2 toolbox: example 2

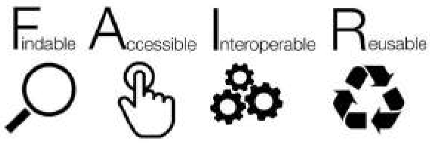
Time series (e.g., data from Tongoy buoy)

plot_seas_cycle.m





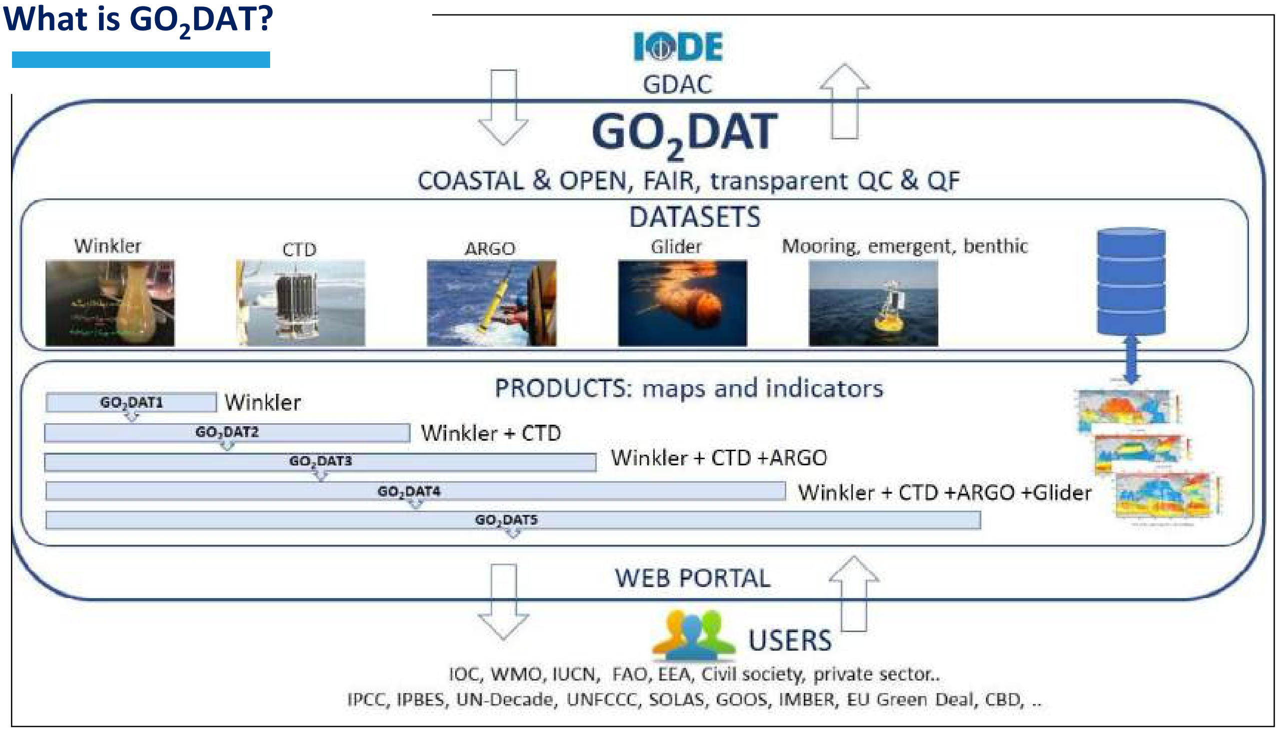
OUTREACH AND STAKEHOLDERS



- Metadata
- Documentation
- Data disclaimer
- Github PacificO_2
- App: Stakeholders input
- Website (English and Spanish)
- Tutorials (inclusion: subtitles and sign language)
  - How to download the data
  - How to use the Toolbox
- Infographics
- Transfer of knowledge program (public institutions, universities, Army, coastal community, users)

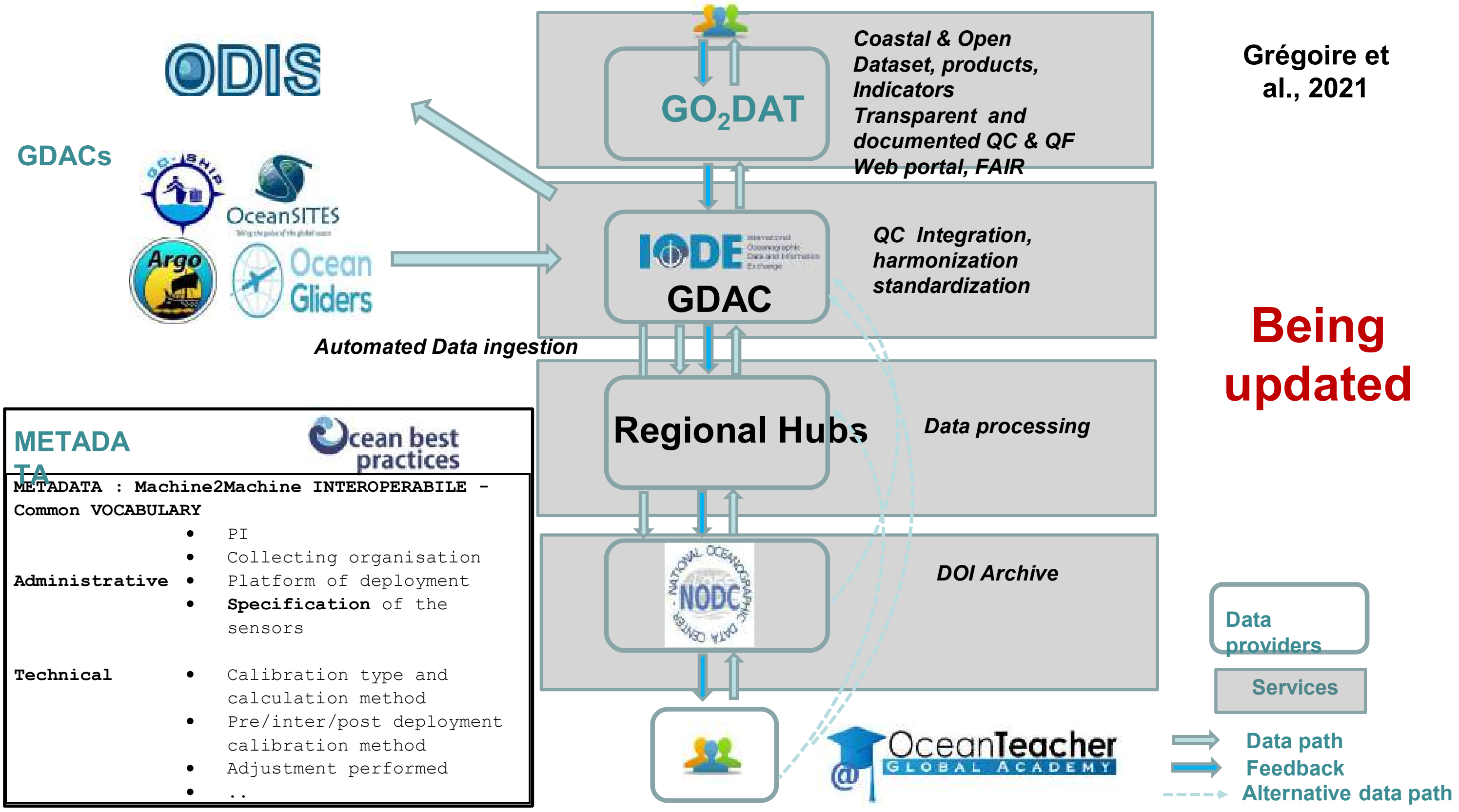
OCEAN LITERACY

What is GO_2DAT?



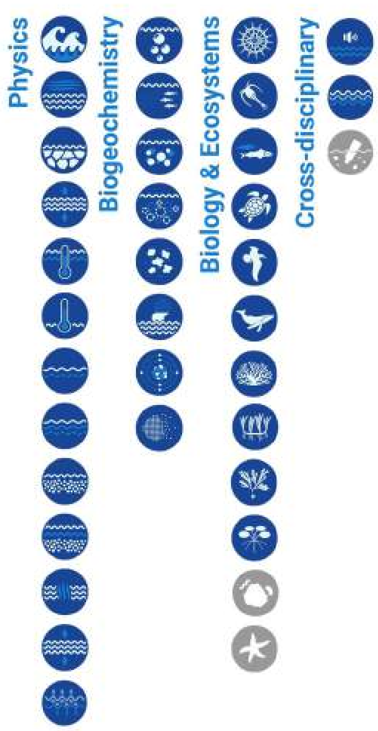
Being updated !

Grégoire et al., 2021



What do our users want from a GOOS digital ecosystem infrastructure?

- Access for each EOV to all observational data, from wherever in the world, with a known uncertainty
  - *how represent uncertainty in different EOVs*
- EOV products to be user-led
  - *GOOS specify and partners produce (e.g. WOD)?*
  - *GOOS branded EOV products?*
- GOOS ocean data ecosystem that establishes/is foundation for the IODE 2030 Data, Decade 2030 Data IP, WMO WIS 2.0?



Courtesy, Emma Heslop, GOOS, IOC UNESCO

1. Automated checks/tests

Based on the established ones. For instance, each test of the IAP AutoQC system is attributed a 0 (passed) or a 1 (failed) (0 and 1 are the quality flags). They are carried out sequentially and if a test fails then an overall QC flag 1 is assigned but still the individual test results are visible to the data user.

2. Manual QC

Potentially not to be applied as this requires checks by humans

3. Bias/Crossover checks

4. Uncertainty attribution

Uncertainties based either upon instrument precision, or crossover consistencies, or replicate measurements, are not comparable.

Collect a precise information on precision (based on replicate measurements, indicated by the relative variability) and on accuracy (based on a fit with golden standard which could be e.g. GO-SHIP cruises).

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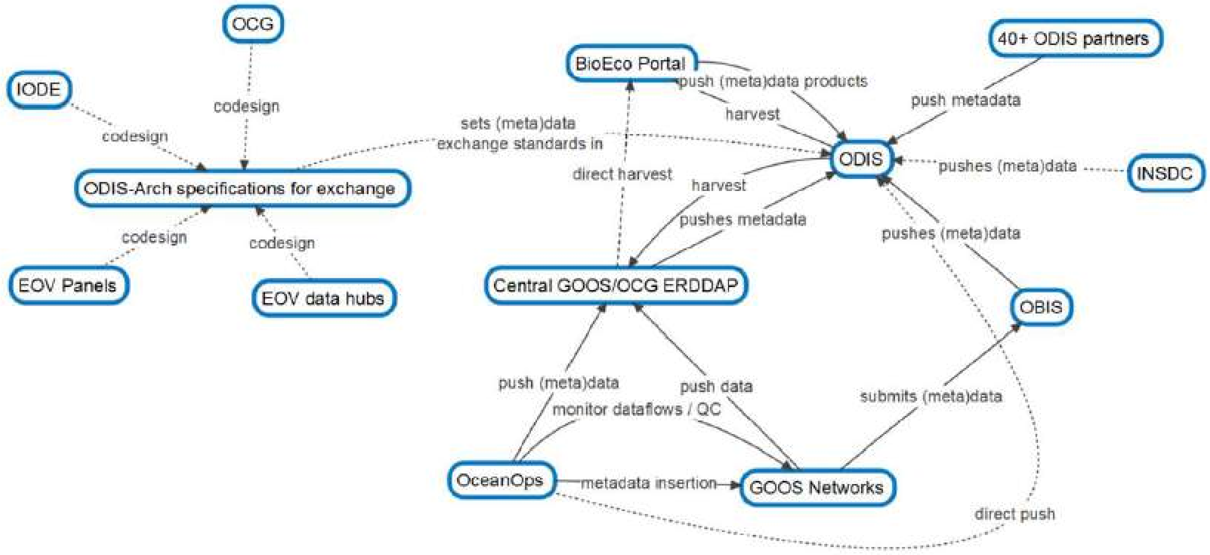
Solutions

- **Create and adopt a cross GOOS Digital Infrastructure/Ecosystem Strategy**
- **2 day meeting** data experts, to develop core of this - working-writing group - in the next months, timeline, resources - for adoption end 2024
- **EOV data products are an element** of this strategy. ERDDAP/ODIS means we have the means to draw EOV data together - but we need to **define what we mean as an EOV product**
- **Consider a GOOS data brand** - data and EOV products
- **Identify key partners -** EOV products process/deliver GOOS EOV products, support in-kind, financing
- **Set up a persistent cross GOOS data team -** (not TT-) data experts across components to manage strategy and implementation - connected to DCO, WMO, IODE

Courtesy, Emma Heslop, GOOS, IOC UNESCO

Start of mapping visualising digital infrastructure across GOOS - BioEco - OCG

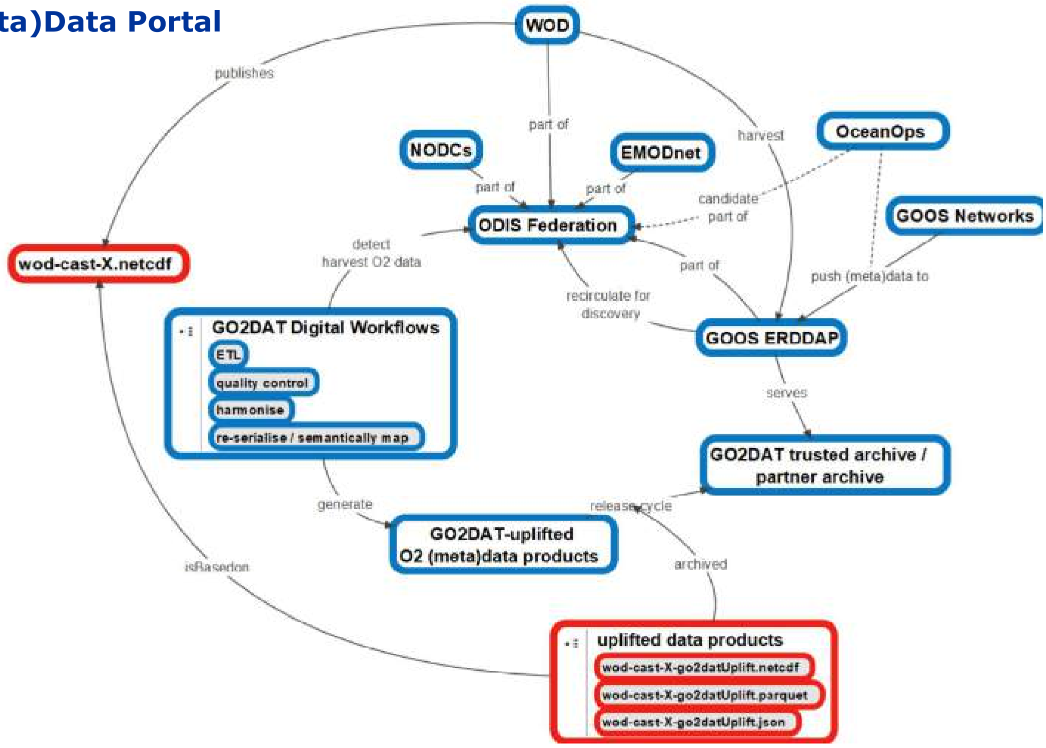


Courtesy, Emma Heslop, GOOS, IOC UNESCO

Developing the BGC (Meta)Data Portal

GO_2DAT Prototype

- O_2 highest ranked EOV in feasibility and impact
- Builds upon existing structures and common structured metadata
- Utilizes ODIS-federation (IODE initiative) for (meta)data harvesting
- Automates data ETL Extract,Transform,Load)
- Utilizes ERDDAP as a service for flexible data extraction (single access point)
- Establishes feedback loops to original data sources



Recommendations to GOOS SC

Document BGC EOV data currently being collected by the GOOS networks and GRAs

Document the associated data pathways (focus on what kind of / when / where) as a primary step in progressing

At the provider and data management level, push the adaption of

- Common vocabularies
- Structured metadata templates

Identify resources/staff that can develop an automated connection and "translation" service between different data sources : **FTEs of skilled data scientists within ODIS in close contact with GOOS panels scientists**

→ **future recruitment of an FTE on the CHO_IP Hypoxia and Eutrophication GEF funded project starting early 2025 for Oxygen EOV**

Garçon et al., 2024, in prep : GO_2DAT: A best practices, documented metadata format and consistent quality control procedure and quality flagging (QF) system for open and coastal ocean oxygen data

Abstract
Introduction
EOV Oxygen measurement best practices
Best practices for meta and data formats, vocabularies
Data quality control of oxygen observations and assessment, including flagging system
GO_2DAT Data Flow
Discussion and conclusion

Box 1- Survey list of questions and answers about oxygen measurements SOP and best practices
Box 2 Survey answers on Quality control checks and flags specification

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Phone: +48 58 731 16 10 / Fax: +48 58 551 21 30, **www.ioccp.org**
Biogeochemistry Panel

Garçon et al., 2024, in prep : GO$_2$DAT: A best practices, documented metadata format and consistent quality control procedure and quality flagging (QF) system for open and coastal ocean oxygen data

Appendix 1 : List of "EOV Oxygen" documents from OBPS repository (as of February 20, 2024)

"Refereed" according to OBPS are indicated in bold italics

Green color indicates the NOAA-funded Alliance for Coastal Technologies (ACT) documents

Red color indicates documents produced by oceanographic consortia such as Argo, OceanGliders, SOTS, IMDOS, JERICHO-S3

Blue color indicates peer-reviewed articles in journals

Black colour indicates all other sorts of documents

** indicates being refereed and GOOS endorsed according to OBPS

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Box 2 Appendix 1. Distribution of quality flagging systems per oceanic basin and per regional groupings as defined for SDG indicators (see https://unstats.un.org/sdgs/indicators/regional-groups).

Appendix 2: List of "EOV Oxygen" best practices documents not referenced in the OBPS repository (as of February 20, 2024)

Carval, T, Keeley R, Takatsuki Y, Yoshida T, Loch S, Schmid C, Goldsmith R, Wong A, McCreadie R, Thresher A, Tran A, 2022, Argo data management. Argo user's manual. https://doi.org/10.13155/29825

Garcia-Robledo, E, Paulmier A, Borisov S.M., and Revsbech N.P., 2021, Sampling in low oxygen aquatic environments: The deviation from anoxic conditions, Limnol. and Oceanogr. Methods, https://doi.org/10.1002/lom3.10457

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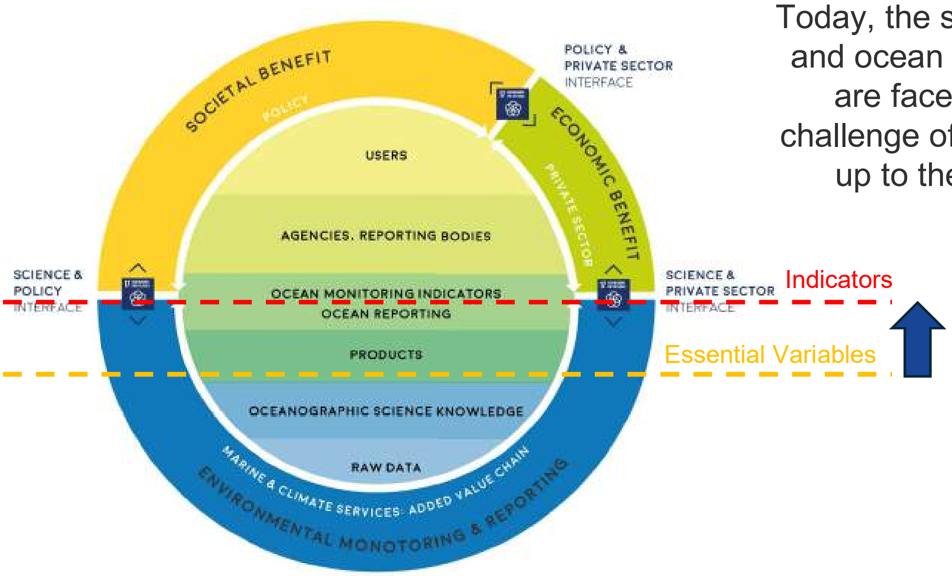
Thank you for your attention

Ocean indicators: Challenge today



Today, the scientific community and ocean & climate services are faced to the current challenge of lifting our capacity up to the indicator level

von Schuckmann et al., 2020

Courtesy, Emma Heslop, GOOS, IOC UNESCO

- Requirements: What do we require to facilitate the delivery of interoperable data at the individual EOV level a across EOVs, etc?

>>>>> Accomplish steps of data discovery and data harmonization, following step is data aggregation and distribution, this could be achieved through ERDDAP

>>>>> FTEs of skilled data scientists within ODIS in close contact with GOOS panels scientists

- Steps to progress: Could a task team/working group of data specialists/experts from all panels with the inclusion of OBIS, ODIS, IODE and Ocean OPS be created to progress this? Are there other alternative mechanisms for moving this forward?

- Support: What support will be required from GOOS or others to facilitate this work?

>>>>> One dedicated team of data scientists within ODIS supported financially by GOOS (?) to help us building a digital ecosystem for each EOV : clones of Kevin, Jeff, Doug, Pier Luigi, etc…

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1. Agree on a common minimum metadata requirements form - this GO_2DAT has already achieved.

2. Translate the common metadata file into JSON-LD/schema.org format which will be used to access and index all oxygen resources in ODIS (or anywhere else) - facilitated by the OIH Team

3. Each data provider/aggregator adds a JSON-LD snippet to the individual resource webpages - to be done by data managers with ODIS support

4. A GO_2DAT community (GO_2DAT Steering Committee) is formed "inside" OIH as a "coalition of the willing" from among those who agree to connect existing databases. This could include mutual archival of resources - so essentially creating regional DACs with healthy redundancy. A basic agreement needs to be outlined - ODIS Team has some examples/templates from other communities

5. There should be no need to re-submit anything as done in SOCAT or GLODAP. All resources are accessible centrally from where they are.

6. QC/QF - Proposed in the Best practices document and part of the common metadata requirements sheet

7. Once all oxygen resources can be pulled together through OIH, the visualization (the actual atlas) can be implemented. OIH plans to develop such features too, but otherwise, any GO_2DAT partner could take that role on.

Biogeochemistry Panel

WORKSHOP
DEVELOPING BEST PRACTICES TO ADDRESS COASTAL MARINE OXYGEN LOSS IN APEC ECONOMIES FOR IMPROVING THE MANAGEMENT OF MARINE LIVING RESOURCES

PHYSIOLOGY OF MARINE SPECIES IN THE CONTEXT OF LOW OXYGEN CONDITIONS (HYPOXIA)

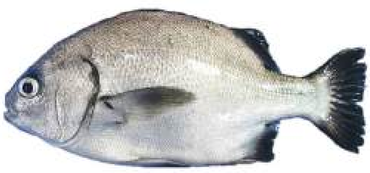
LABORATORIO DE ECOFISIOLOGÍA ACUÁTICA

ÁREA FUNCIONAL DE INVESTIGACIONES EN ACUICULTURA (AFIA)

Martes 01 de octubre de 2024

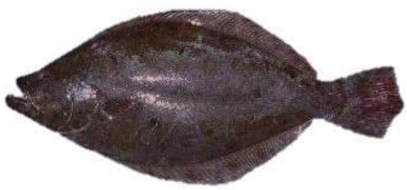
ESPECIES ESTUDIADAS

Engraulis ringens



Anisotremus scapularis

Paralabrax humeralis



Paralichthys adspersus

Argopecten purpuratus

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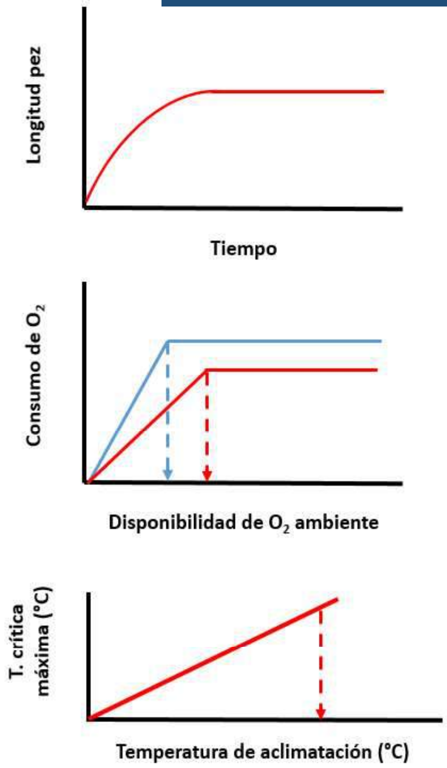
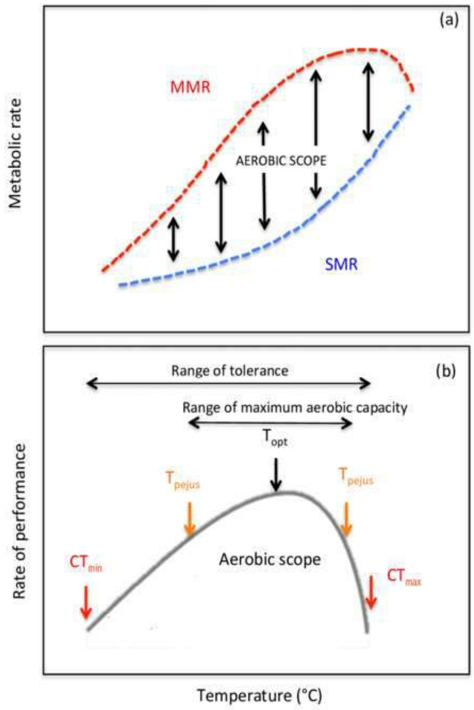




> J Fish Biol. 2022 Jun;100(6):1497-1509. doi: 10.1111/jfb.15060. Epub 2022 Apr 25.

Tolerance of juvenile Peruvian rock seabass (Paralabrax humeralis Valenciennes, 1828) and Peruvian grunt (Anisotremus scapularis Tschudi, 1846) to low-oxygen conditions

Rebeca Montero-Taboada [1 2 3], Giovanna Sotil [2 4], Jhon Dionicio-Acedo [2], Maryandrea Rosado-Salazar [2], Arturo Aguirre-Velarde [2]

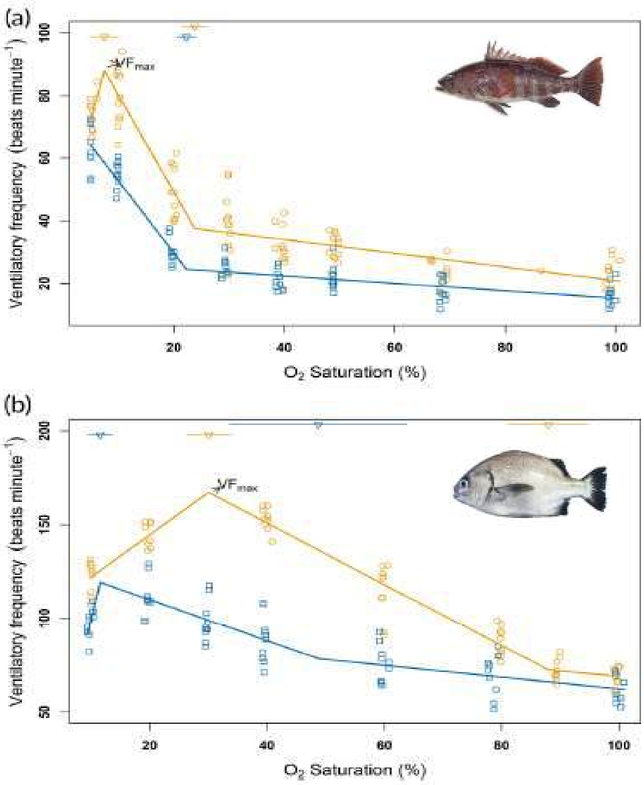
Affiliations + expand

PMID: 35398900 DOI: 10.1111/jfb.15060

TABLE 1 Ventilatory critical point (Vcp) of *Paralabrax humeralis* ($n = 20$) and *Anisotremus scapularis* ($n = 20$) during progressive hypoxia at 16 and 22°C

	Vcp (% ± CI)	
Temperature (°C)	*P. humeralis*	*A. scapularis*
16	22.3% ± 0.9	48.7% ± 7.6
		11.59% ± 1.0
22	23.8% ± 1.2	98.6% ± 0.9
	7.5% ± 1.3	29.9% ± 1.9

Note. ANCOVA of slope segments prior to the Vcp ($P < 0.001$). CI, 95% confidence interval.



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Tolerance of juvenile Peruvian rock seabass (Paralabrax humeralis Valenciennes, 1828) and Peruvian grunt (Anisotremus scapularis Tschudi, 1846) to low-oxygen conditions

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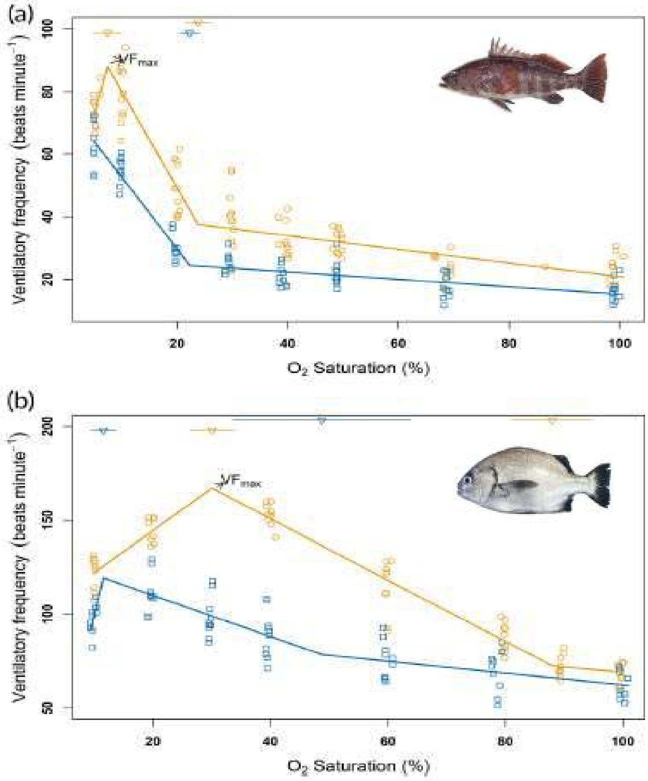


TABLE 2 Lt50 and changes in the behaviour of *Paralabrax humeralis* ($n = 4$) and *Anisotremus scapularis* ($n = 4$) observed over a period of 31 days at 5% oxygen saturation (*P. humeralis*) and 60% oxygen saturation (*A. scapularis*)

	Lt50	
Species	**Mortality**	**Behaviour**
P. humeralis	No	Reduced active swimming
(5% O_2 sat)		No loss of balance
		Remained at the bottom
A. scapularis	36 min	Increased active swimming
(60% O_2 sat)	43 min 13 s (total mortality)	Remained lying down at the bottom

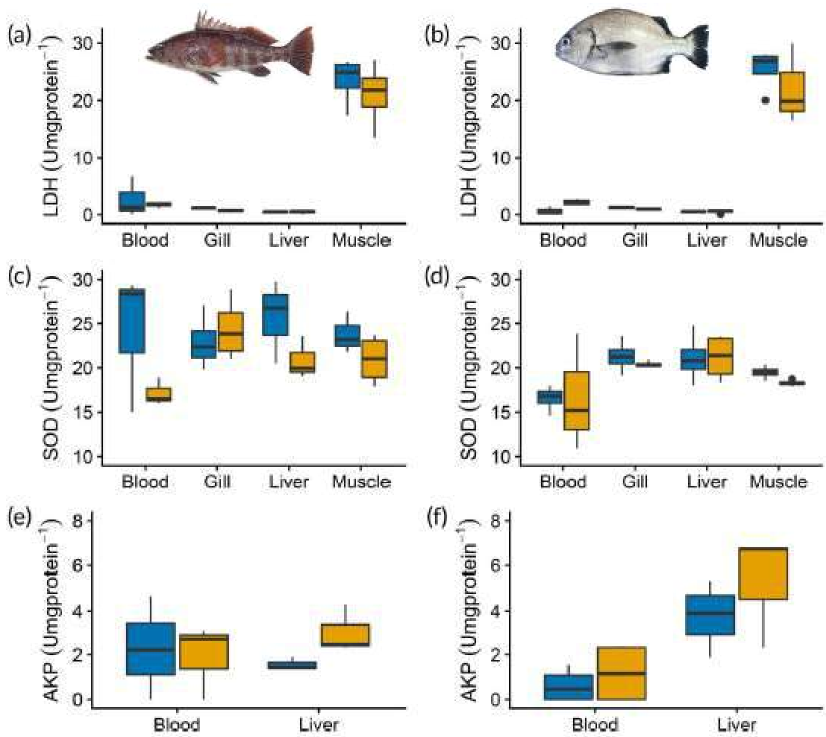
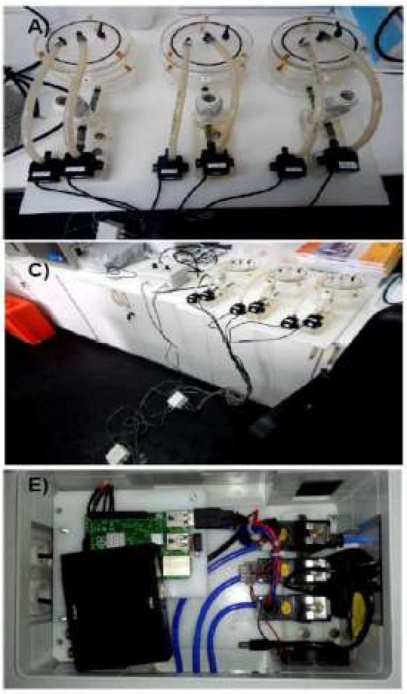
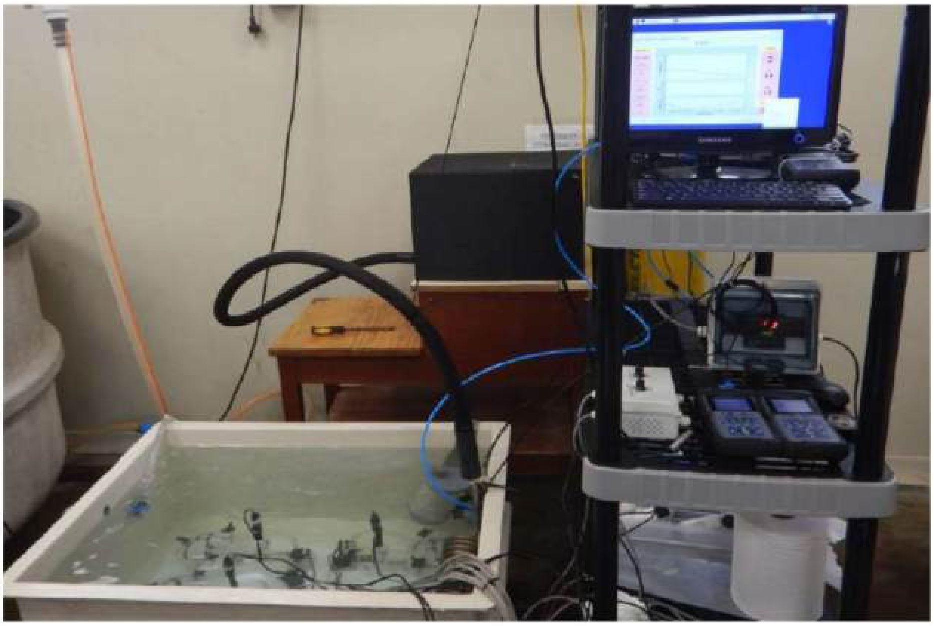


FIGURE 3 Enzymatic activity of lactate dehydrogenase (LDH; a, b), superoxide dismutase (SOD; c, d) and alkaline phosphatase (AKP; e, f) in blood, gill, liver and muscle of *Paralabrax humeralis* ($n = 8$) and *Anisotremus scapularis* ($n = 8$), respectively, after 2 h of exposure to hypoxic (15% oxygen saturation) and normoxic (100% oxygen saturation). Treatment (■) Hypoxia, and (■) Normoxia

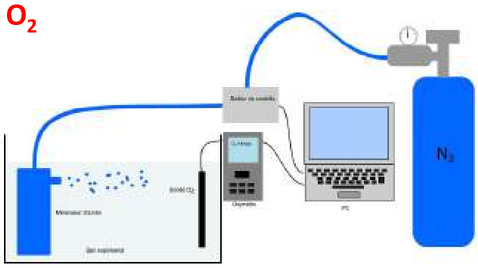
RESPIROMETRÍA EN HIPOXIA

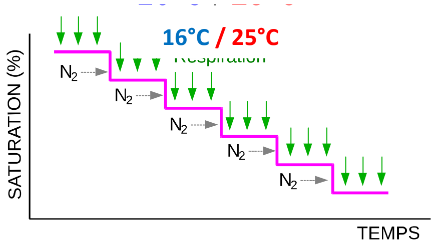




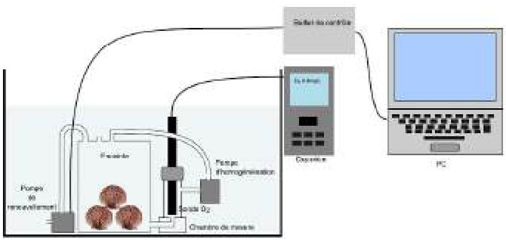
ENSAYO RESPIROMETRÍA EN HIPOXIA

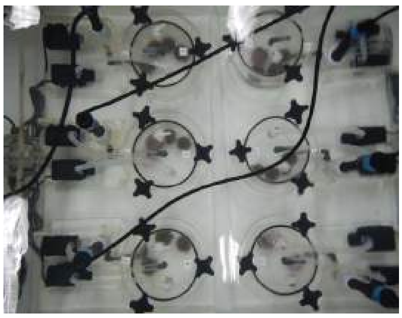
- Control de la saturación de O_2



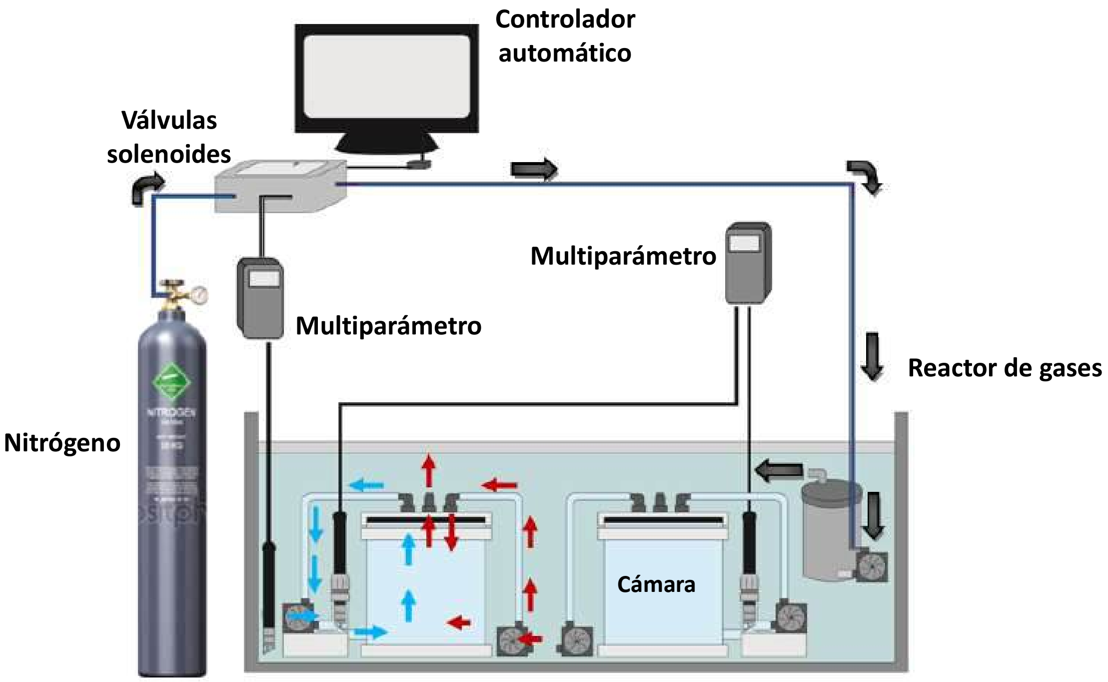


- Medición de la respiración (VO_2)

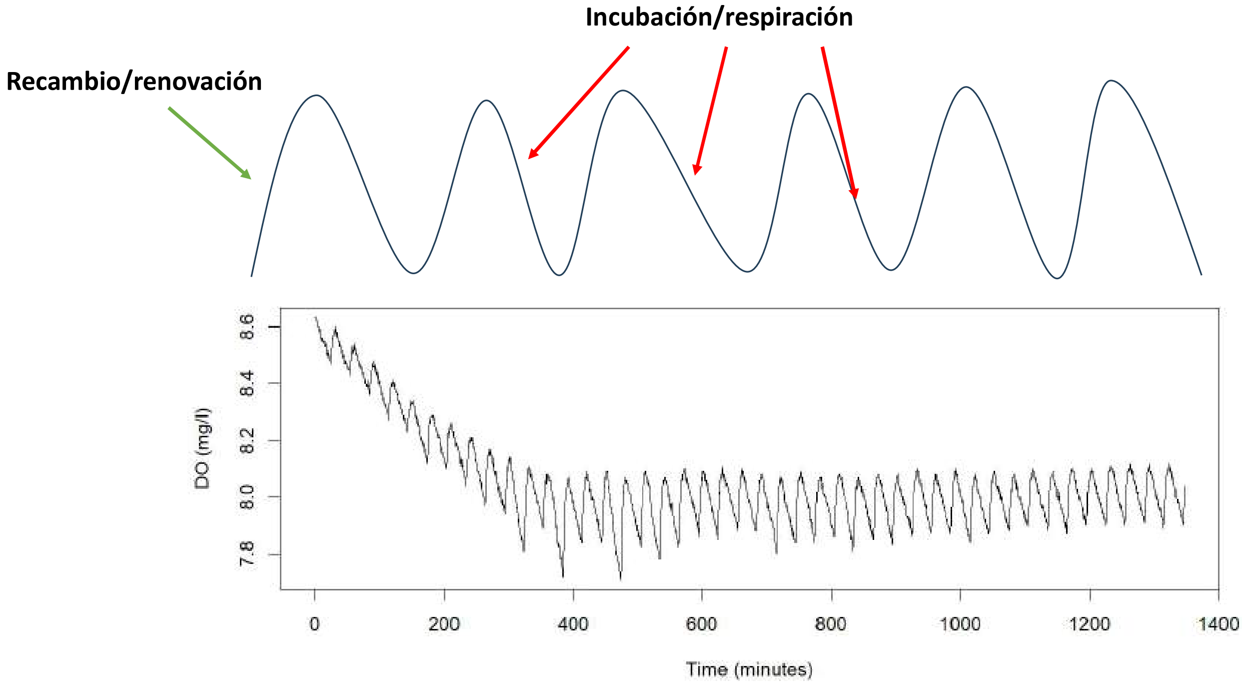




ESQUEMA SISTEMA DE RESPIROMETRÍA



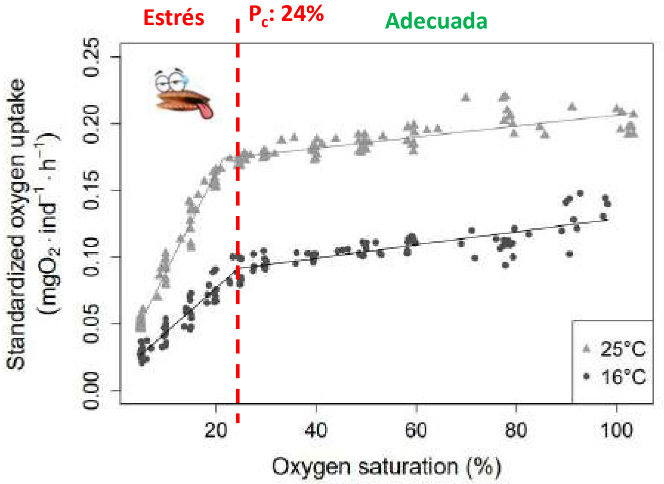
FASES DEL ENSAYO DE RESPIROMETRÍA

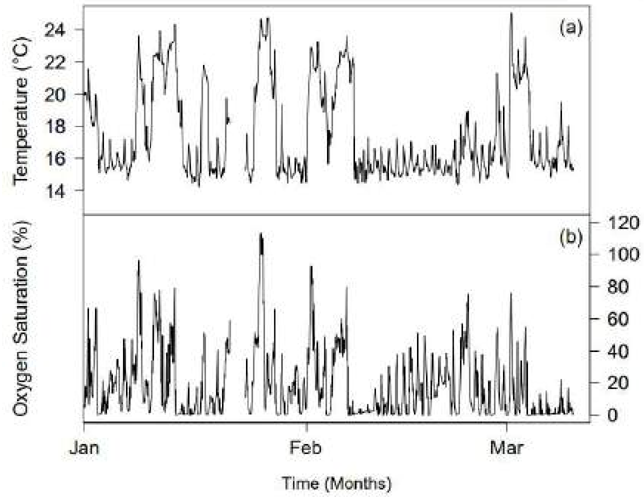


Effects of progressive hypoxia on oxygen uptake in juveniles of the Peruvian scallop, *Argopecten purpuratus* (Lamarck, 1819)

Arturo Aguirre-Velarde[a,b], Fred Jean[a], Gérard Thouzeau[a], Jonathan Flye-Sainte-Marie[a,*]

[a] LEMAR, UMR 6539 (UBO/CNRS/IRD/Ifremer), IUEM, Rue Dumont d'Urville, 29280 Plouzané, France
[b] Laboratorio de Ecofisiología Acuática, Instituto del Mar del Perú (IMARPE), Esquina Gamarra y General Valle S/N Chucuito Callao, Peru





Temperature (°C)	P_cO_2 (% ±CI)	Linear segment slopes: Segment < P_cO_2	Linear segment slopes: Segment > P_cO_2	% Regulation (%)
16	24.4 ±1.9	$3.34\ 10^{-3} \pm 3.3\ 10^{-4}$	$4.97\ 10^{-3} \pm 7.6\ 10^{-5}$	74
25	21.4 ±0.7	$7.44\ 10^{-3} \pm 3.4\ 10^{-4}$	$4.13\ 10^{-3} \pm 6.7\ 10^{-5}$	82

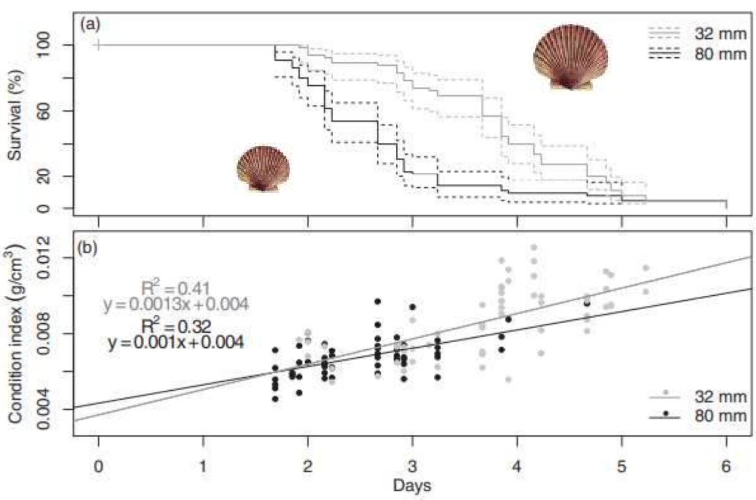
FUNDAMENTAL STUDIES

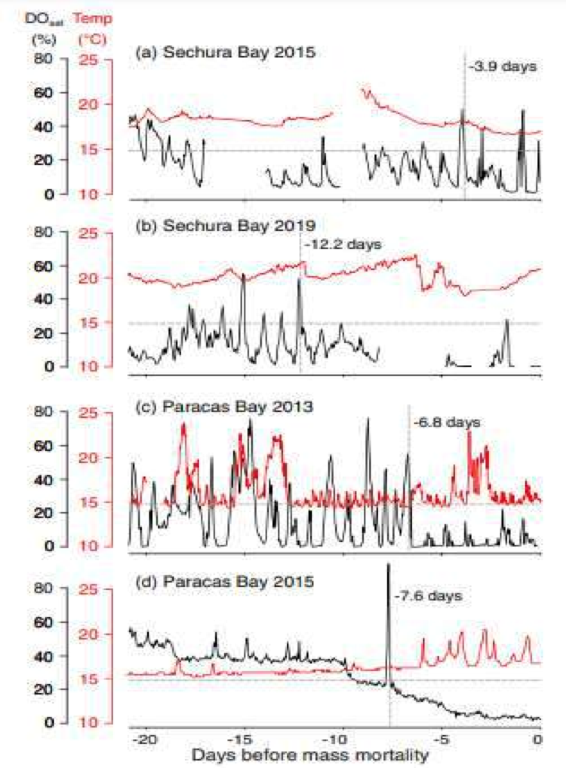
World Aquaculture Society

WILEY

Size-based survival of cultured *Argopecten purpuratus* (L, 1819) under severe hypoxia

Rosa Cueto-Vega[1,2] | Jonathan Flye-Sainte-Marie[1] | Arturo Aguirre-Velarde[3] | Fred Jean[1] | Patricia Gil-Kodaka[2] | Gérard Thouzeau[1]





PHYSIOLOGY OF MARINE SPECIES IN THE CONTEXT OF LOW OXYGEN CONDITIONS (HYPOXIA)

THANK YOU

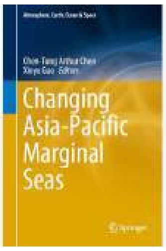
Martes 01 de octubre de 2024

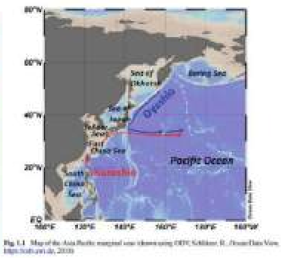
Annex 5. Case studies

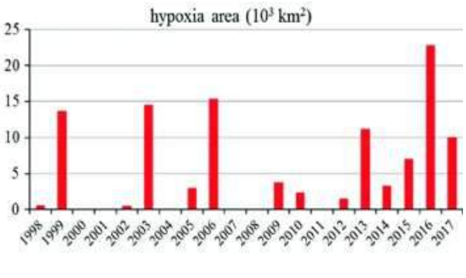
Case study: seasonal hypoxia off Changjiang Estuary

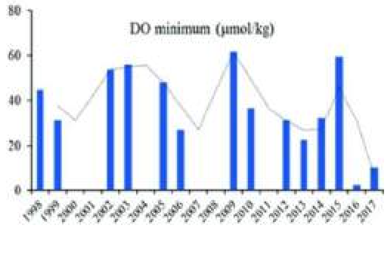
- **From DO monitoring to ecosystem health**
- **Will nutrient reduction help release the hypoxia?**
- **Extreme weather events might be the problem, especially for living resources**

● From DO to ecosystem — community shifting **Phytoplankton**

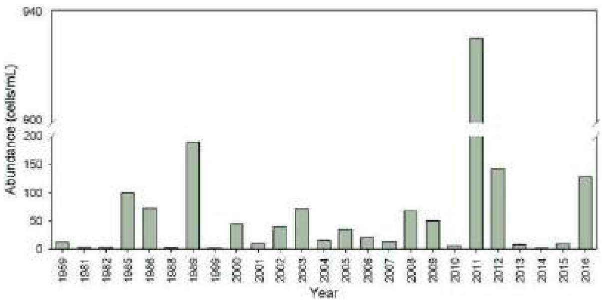




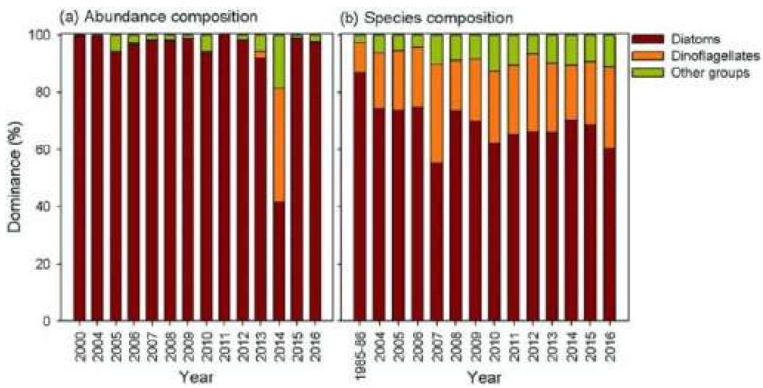




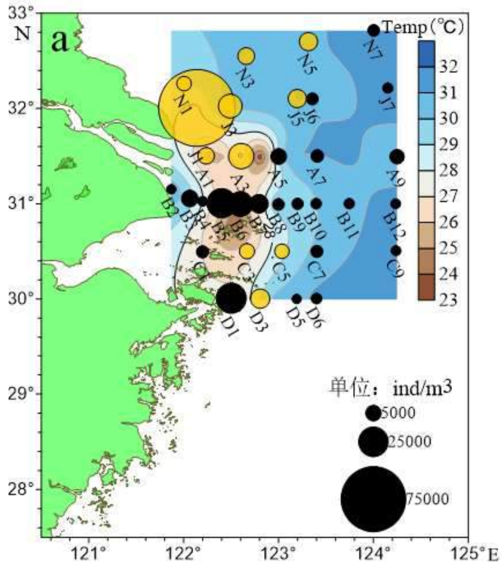
☐ Phytoplankton

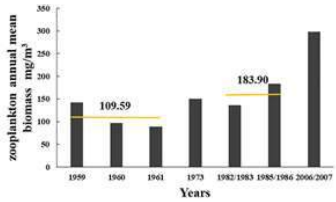


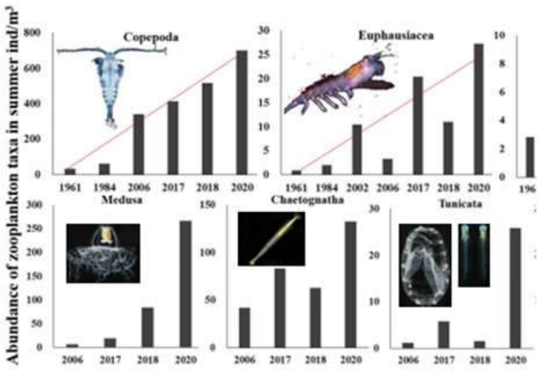
Abundance of net-collected phytoplankton



☐ Zooplankton

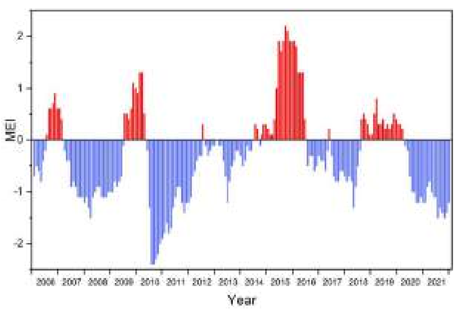


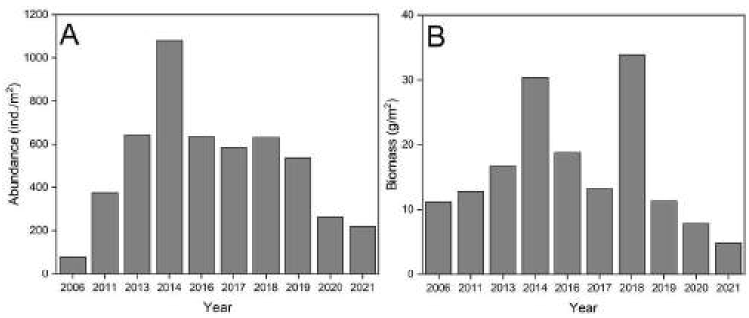


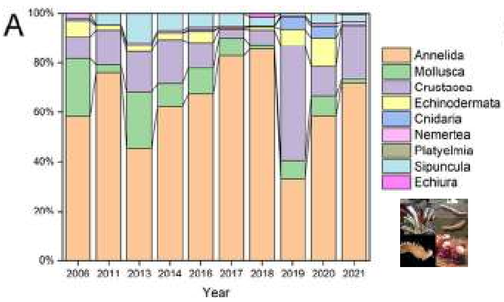


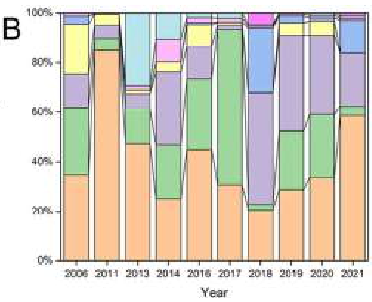
（Du et al., 2022）

☐ Microbenthos



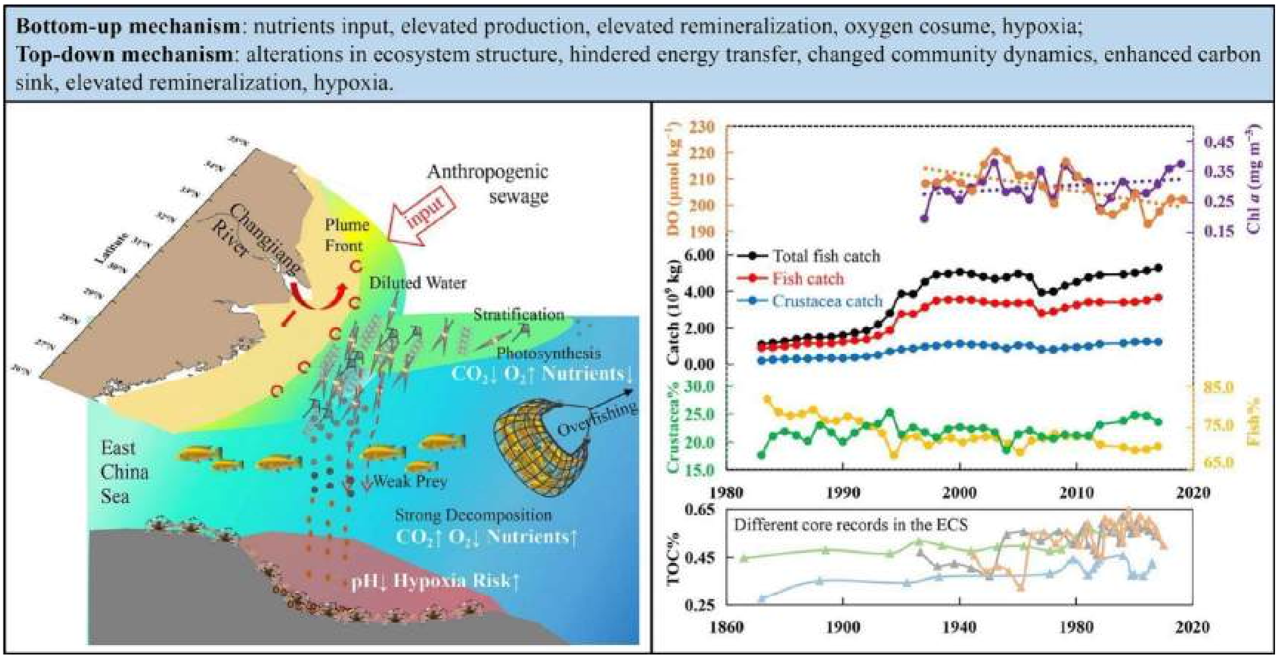






(Tang, Y., Wang B., et al., under review).

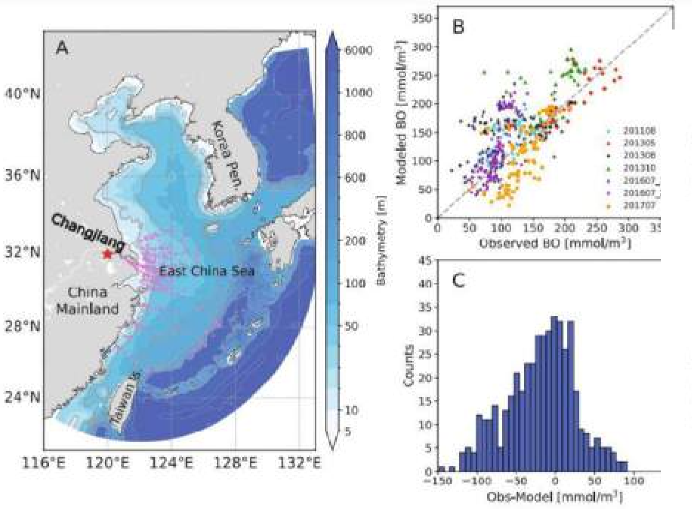
- The microbenthic abundance and biomass increased from 2006 and decreased significantly from 2014 to 2021.
- Annelida species were the main contributors (>50%).
- Canonical correspondence and redundancy analyses revealed salinity, and DO were the main factors.



(Xu et al.,2024).

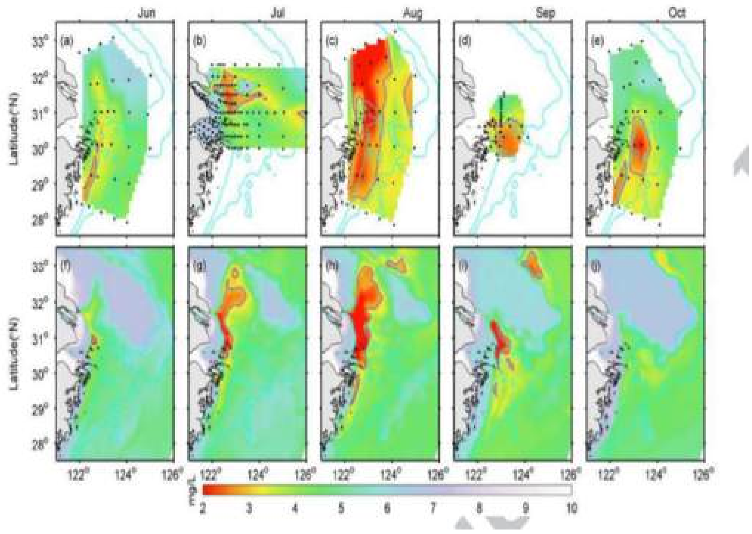
Will nutrient reduction help release the hypoxia?- Model

● **Will nutrient reduction help release the hypoxia?- model**



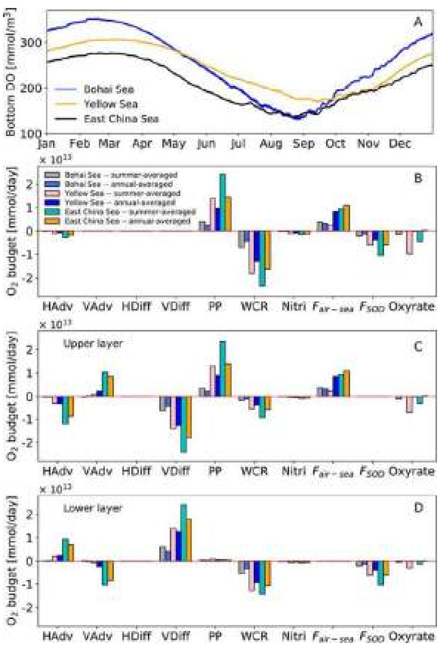
(Zhang, W., Zhou F., et al.,2024).

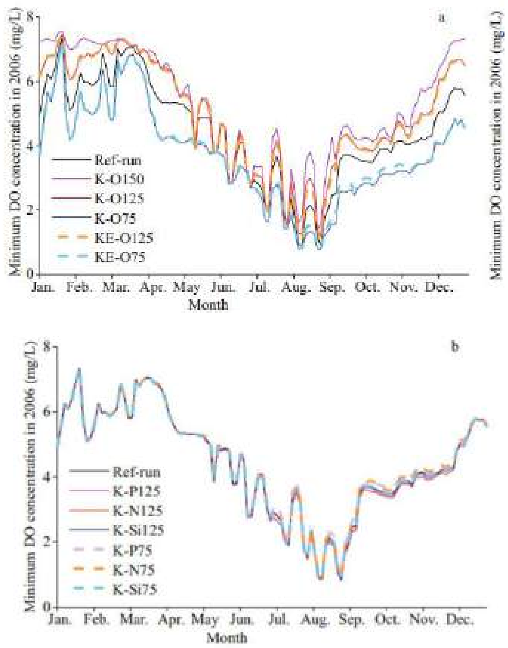
✓ ROMS+CoSiNE model



(Zhou F., et al.,2019).

● **Will nutrient reduction help release the hypoxia?- model**

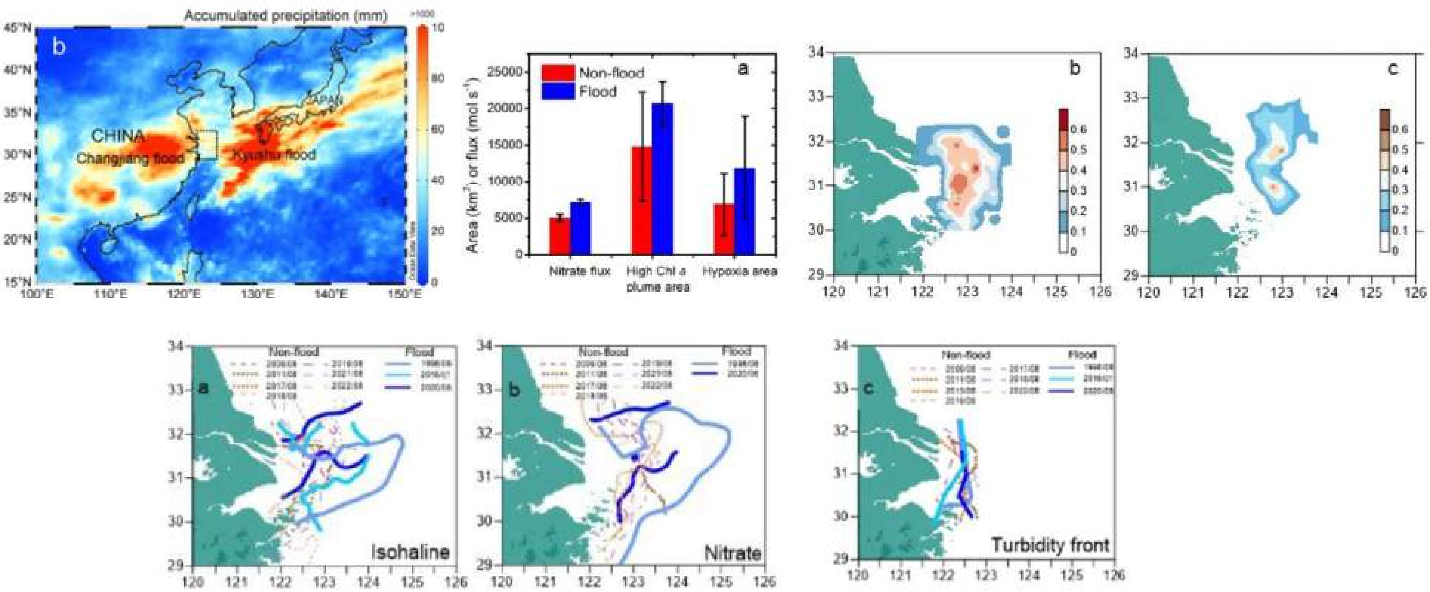




✓ ROMS+CoSiNE model

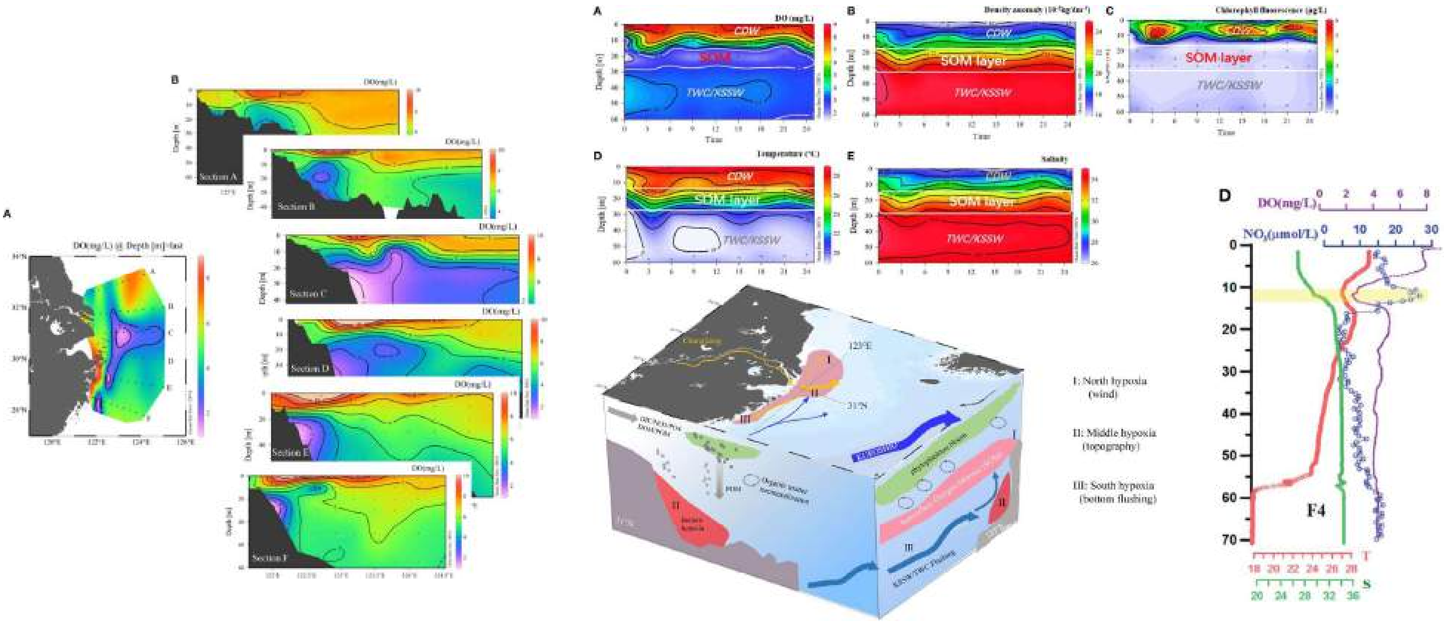
Extreme weather events might be the problem, especially for living resources?

◻ Hypoxia triggered by expanding river plume on the East China Sea inner shelf during flood years.



(Li, D. W., Chen J.F.*., Wang B., et al.,2024).

□ **Subsurface oxygen minima (SOM) regulated by remineralization and bottom flushing.**



(Wang B., Li, D. et al., 2023).

- **From DO to ecosystem – multidiscipline cooperation, coastal resilience**
- **Will nutrient reduction help release the hypoxia?- Model and monitoring**
- **Extreme weather events might be the other problem, especially for living resources- yes! But how?**

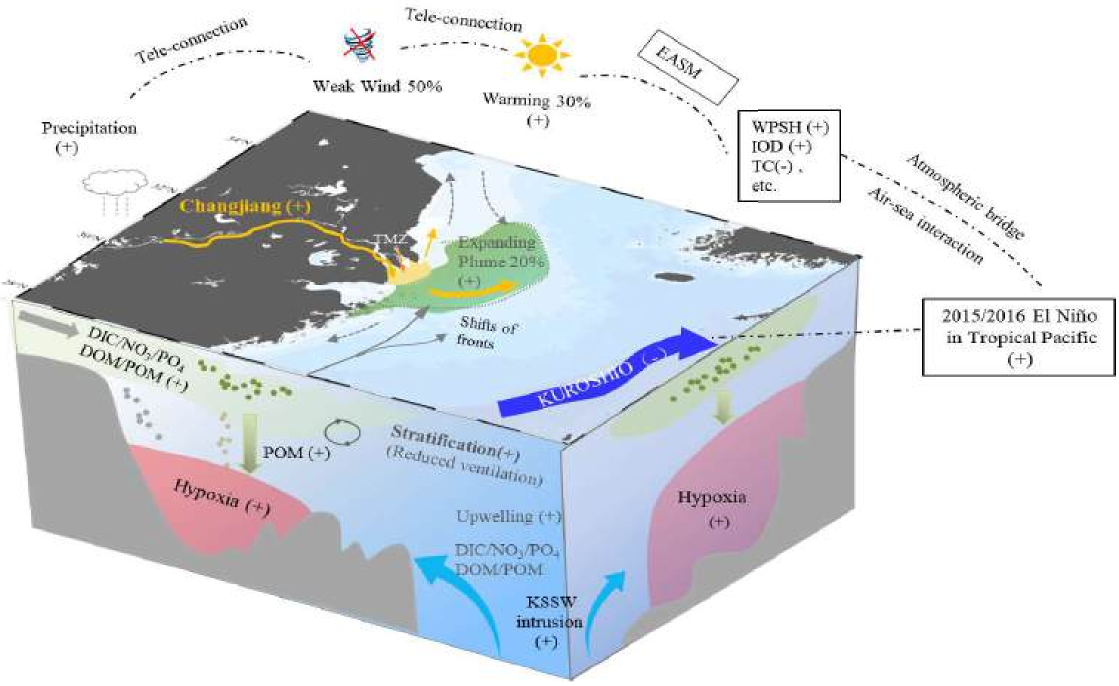
OMZ in open ocean & hypoxia in coastal ocean

Definition:|

- Hypoxia: 2mg/L
- Mild hypoxia: 3mg/L
- Severe Hypoxia: 1mg/L
- Suboxia: 0.16 mg/L
- Anoxia: 0 H_2S

Seawater quality standard（GB-3097-1997）：

	Grad I	Grad II	Grad III	Grad IV
DO mg/L（>）	6	5	4	3
pH	7.8～8.5		6.8～8.8	



Learning Lessons of Coastal Oxygen Monitoring and Tracking of Oxygen Loss, case study: **Gulf of Mexico**

USGS Wetland and Aquatic Research
Center mbaustian@usgs.gov

Paracas, Peru

U.S. Department of the Interior
U.S. Geological Survey

Northern Gulf of Mexico Hypoxia

Member Economy: the USA

Definition: ≤ 2 mg O_2 L^{-1}

Duration (Time Series): mid-May through mid-September

Extent (Area): up to 23,000 km^2

Earliest Monitored D.O.: 1970s
(Rabalais et al. 2002)

D.O. Index: area (km^2)

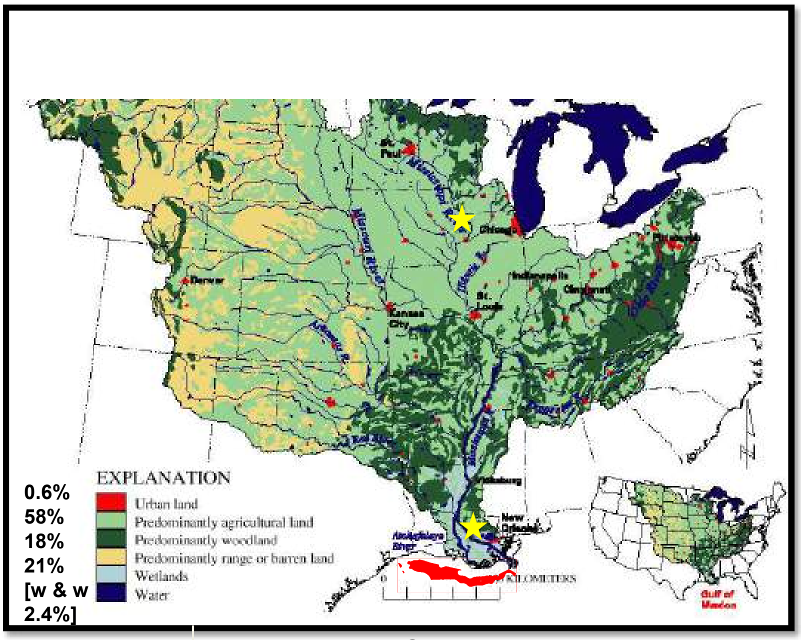
Fishery: shrimps, crabs, fishes

Source: US EPA

Agricultural Runoff Drives Nutrient Enrichment

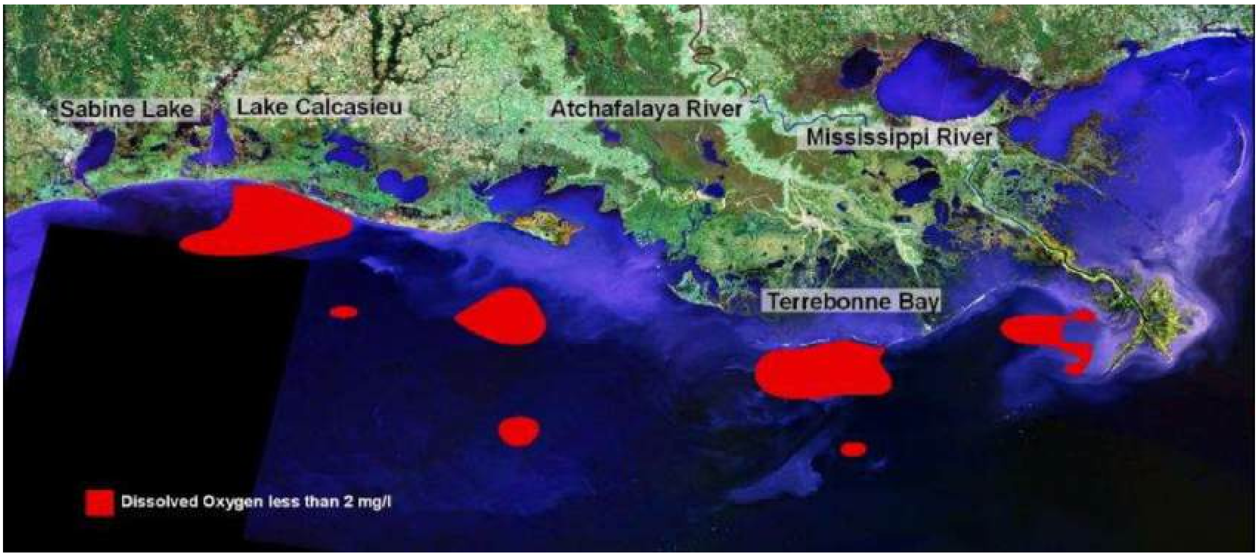
Mississippi River Basin

- 3rd largest drainage basin in the world
- Drains 41% of continental USA
- 31 USA states & 2 Canadian provinces



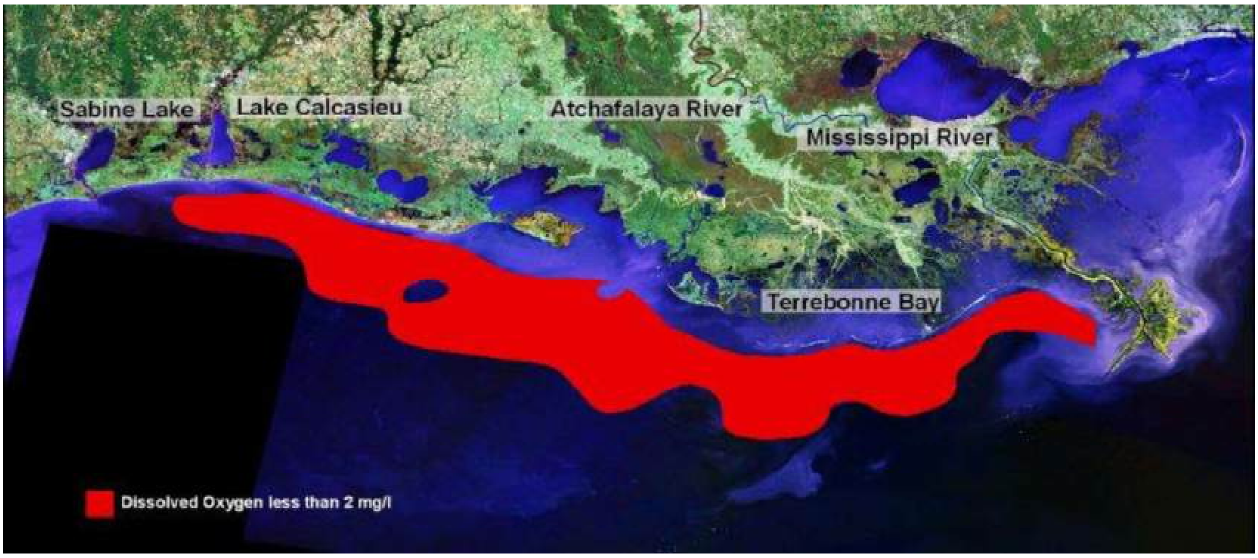
Goolsby et al.,1999, Rabalais 2002

Annual Shelfwide Cruise - 2003



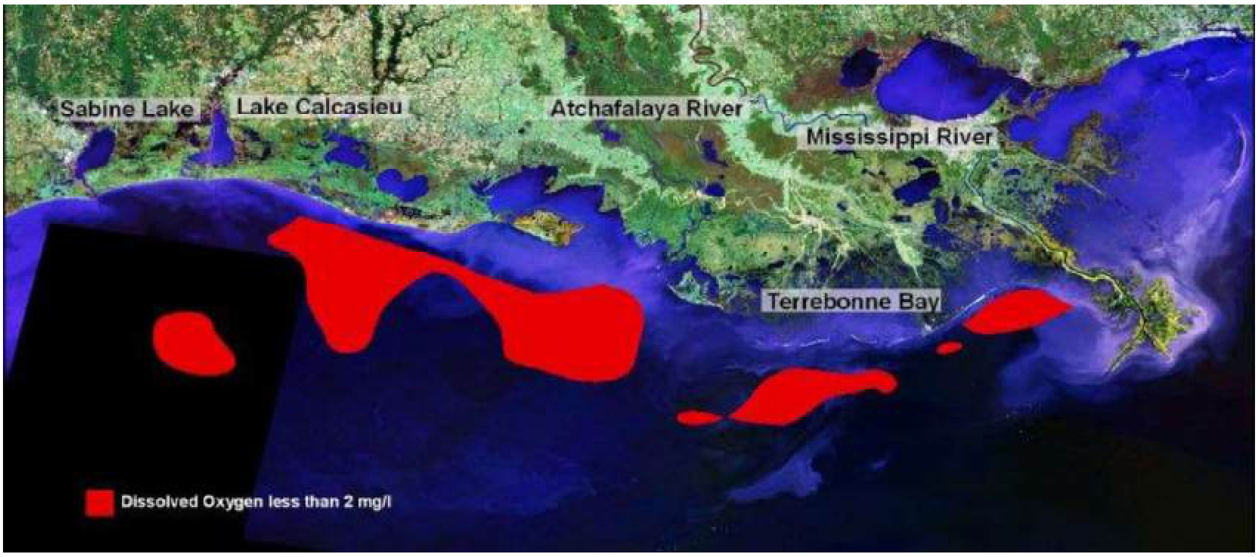
Source: N. Rabalais

Annual Shelfwide Cruise - 2004



Source: N. Rabalais

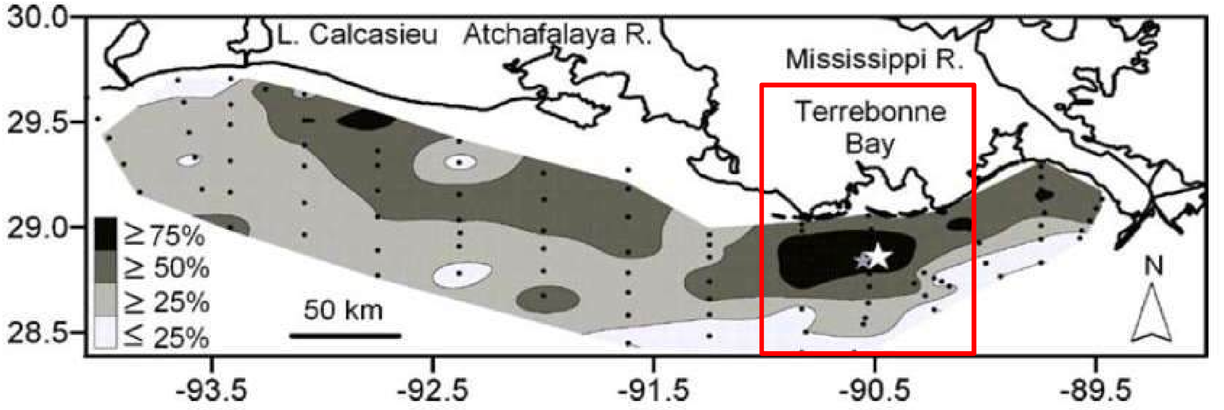
Annual Shelfwide Cruise - 2005



Source: N. Rabalais

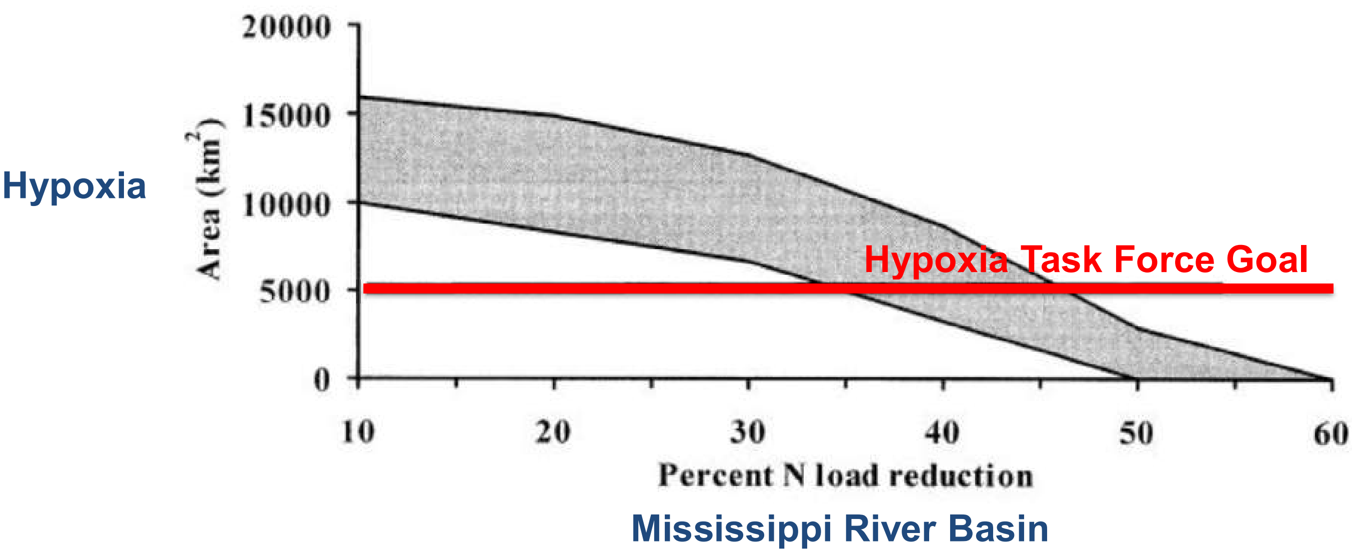
Estimating Frequency of Occurrence

1985-2005, > 75% occurrence
Can help determine where to monitor more often (time series) to measure impacts to fisheries and aquaculture



Baustian and Rabalais 2009

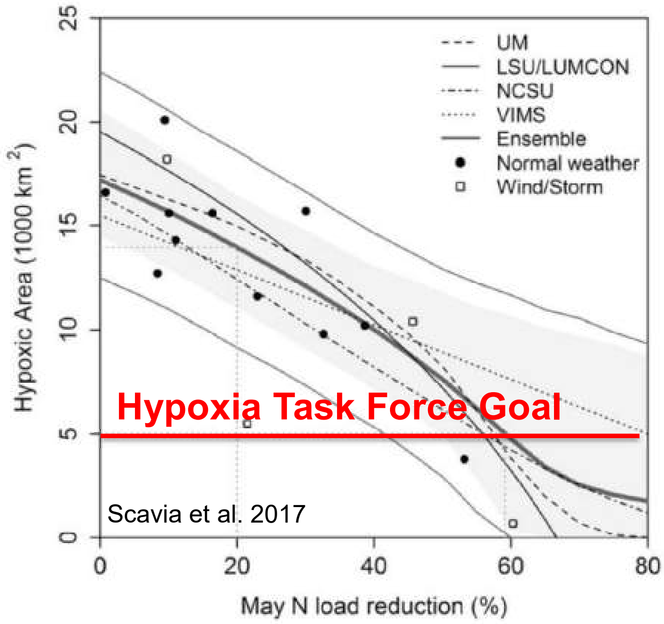
Reducing N Load to Reduce Hypoxia



Scavia et al. 2003

Monitoring Informs Models & Goals

Hypoxia



Mississippi River Basin

Monitoring Hypoxia Area

- Informs models
- Helps with assessing Hypoxia Task Force goal

US EPA Grants Funding for Nutrient Reduction

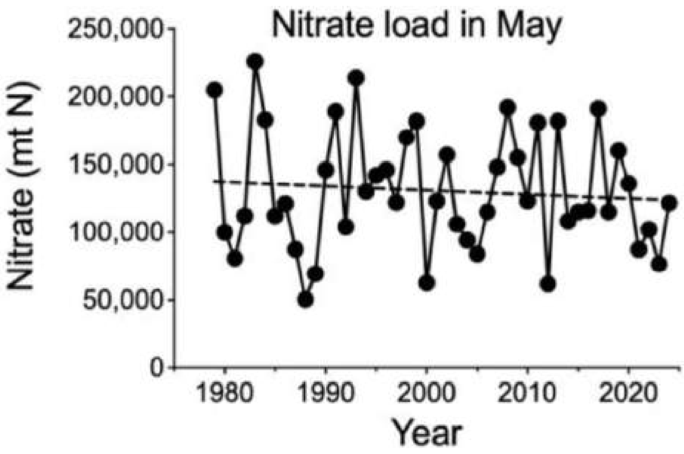
- **Announced in 2019 – *first time funding was provided***
  - 12 state and Tribe members of the Hypoxia Task Force, each will get:
    - 2022: $1M
    - 2023: $1M
    - 2024: $1M
    - 2025: $1M
    - 2026: $1M

- To reduce excess nutrients in the Mississippi River/Atchafalaya River Basin.

$60 million for the Gulf of Mexico Hypoxia Task Force

Monitoring Future Hypoxia Area

- Monitoring can help assess potential impacts from US EPA funding (2022-2026)



Turner and Rabalais 2024 Press Release

Thank You!

¡Grasias!

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Case study of coastal oxygen monitoring: The Paracas Bay

Paracas, October 1st of 2024

The Paracas case

Cabello et al. (2002)

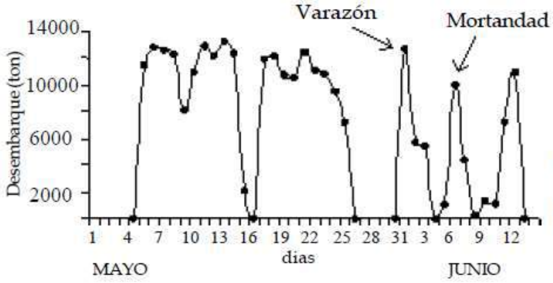
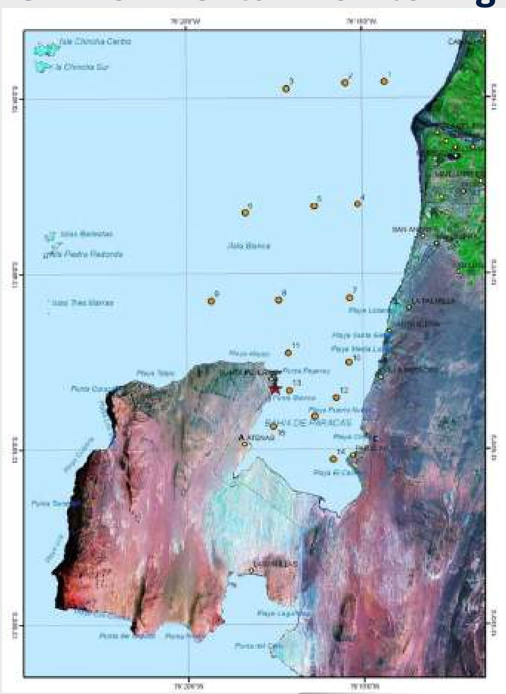


Figura 2. Desembarques diarios de anchoveta en Pisco (Fuente: Lab. Costero de Pisco).

IMARPE Stations of environmental monitoring



At least monthly, 16 stations are monitored by collecting water samples on the surface and bottom since 2005

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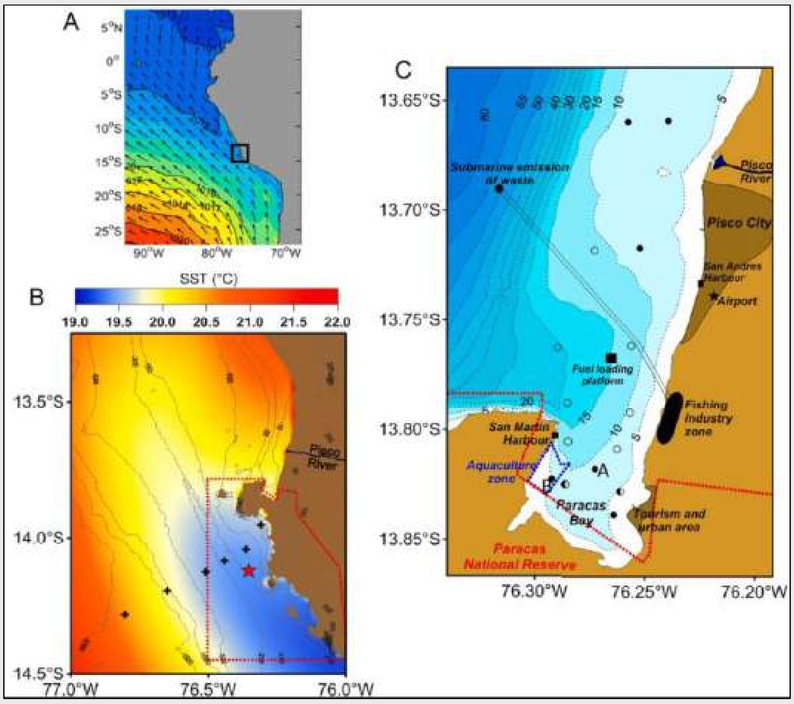

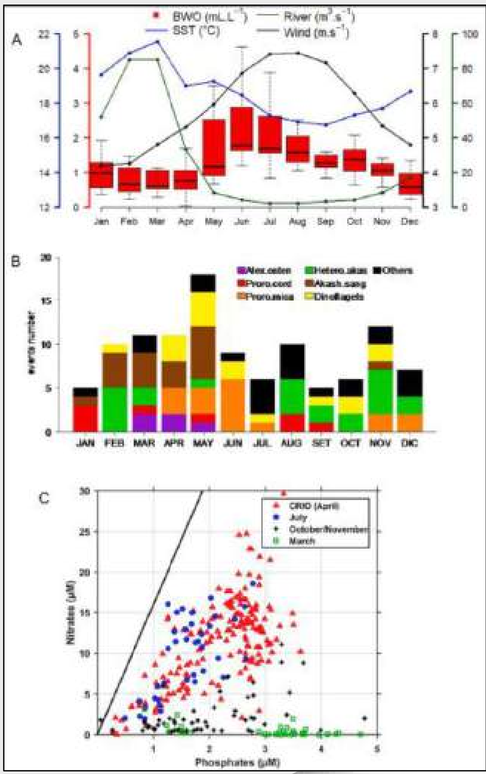

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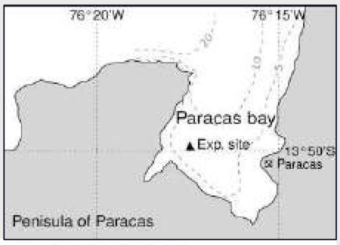
Pitcher et al. (2021)

System controls of coastal and open ocean oxygen depletion

First high frequent measurements



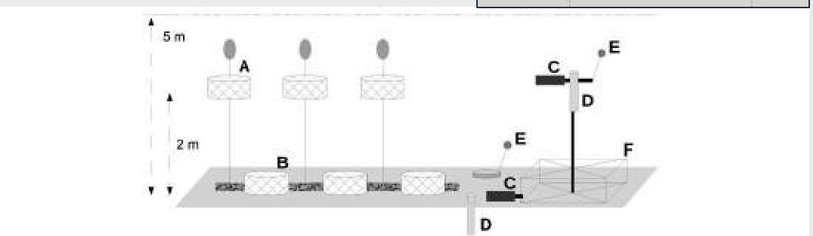
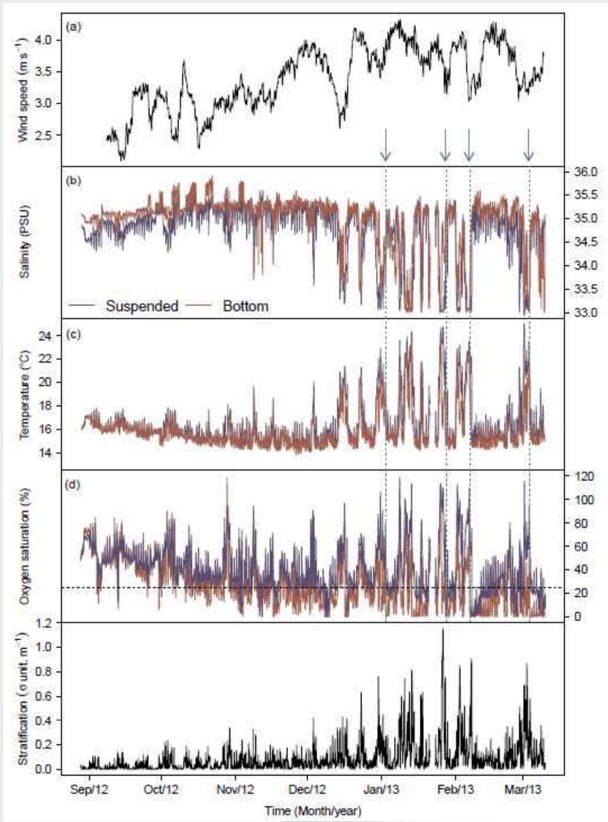


Fig. 2. Schematic representation of the experimental set-up for scallop culture and environmental monitoring installed at Paracas Bay showing: suspended and bottom cages for scallop culture (respectively A and B), monitoring sensors (C), sediment traps (D), current meters (E) and the frame supporting the equipments (F).



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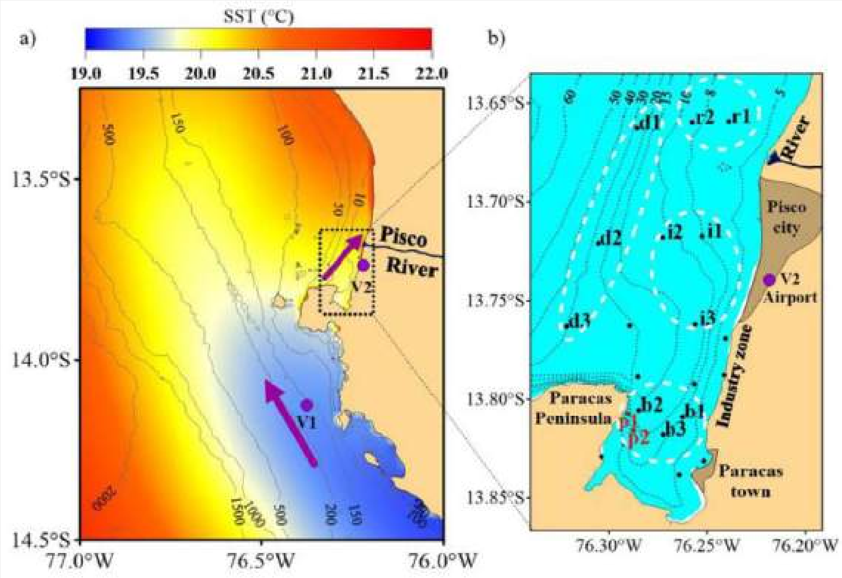
Aguirre-Velarde et al. (2019)

Patterns and trends of DO in Pisco-Paracas



Merma-Mora et al. (2024)

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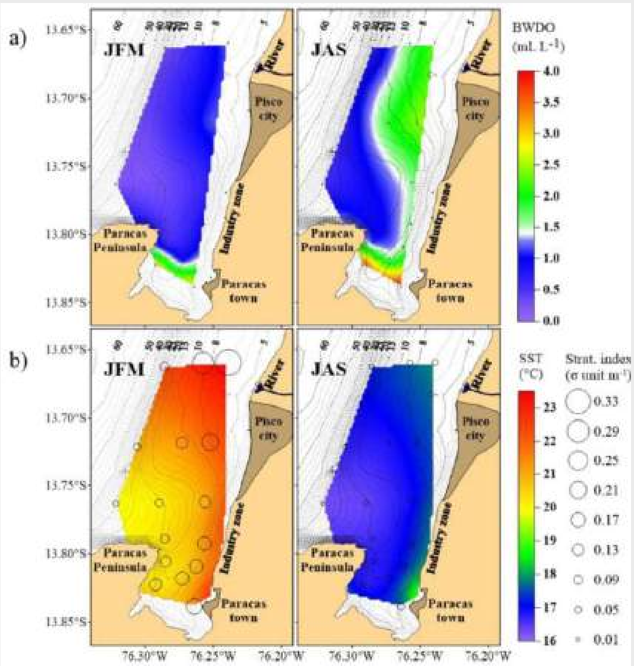
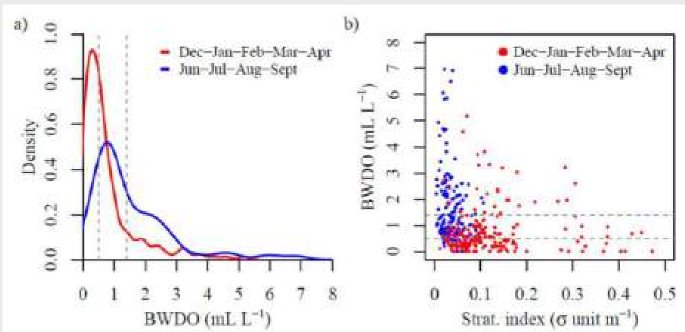


Hypoxic: DO < 1.4 mL/L (2mg/L) (Rabalais et al. 2010)

Inside the bay (8-12 m depth)



Merma-Mora et al. (2024)

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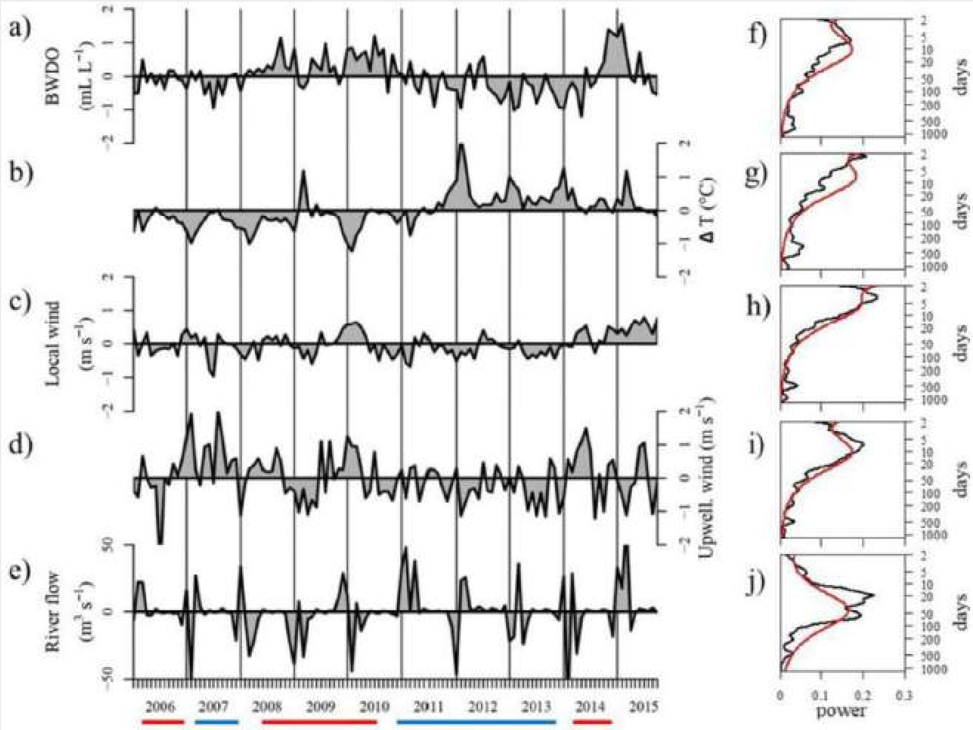
Inside the bay (P1) ~ 7m depth

Daily data (anomalies)

Main time scales of variability were inter-annual and synoptic.

Inter-annual variability is likely related to coastal ENSO.

Time synoptic variability of winds (upwelling-offshore and local) is well correlated to the BWDO and ΔT in P1.



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Merma-Mora et al. (2024)

Inside the bay (P2) ~ 10m depth

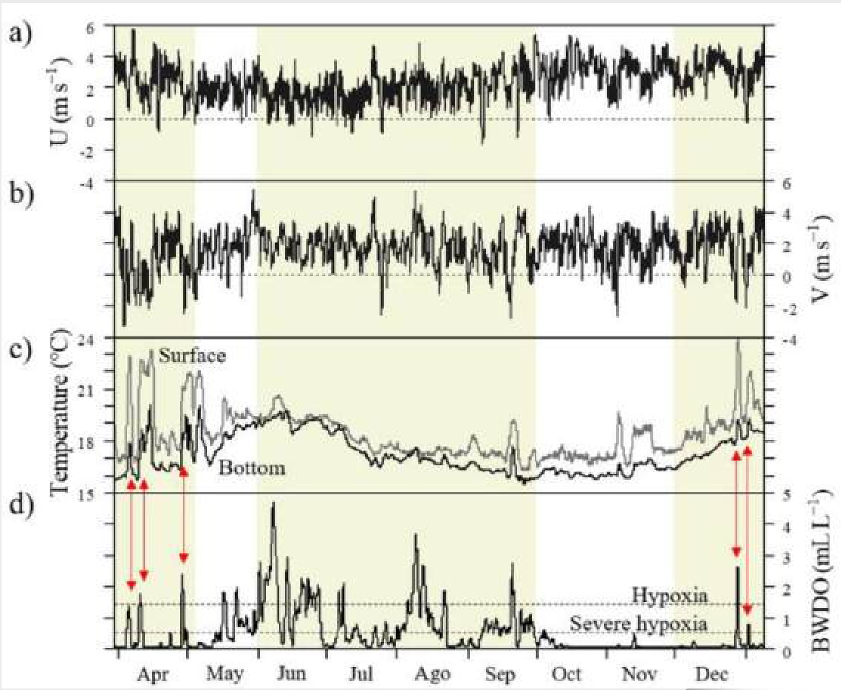
Hourly data

Greater variability in the meridional component (V) of local wind.

Surface and bottom temperature very similar in JJAS but showing stratified conditions in DJFM.

Hypoxia most of the time in the sediment overlying waters.

Anoxic and oxygenation events associated with temporal synoptic variability of winds: Upwelling bay (Largier 2020).



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Merma-Mora et al. (2024)

Ecological/Biological impacts of hypoxic events

Hypoxic: DO < 2mg/L (1.4 mL/L) (Rabalais et al. 2010)
Hypoxic event definition: DO < 2mg/L during at least 6 consecutive hours
Hypoxia intensity index (HII): concentration and duration
Hypoxia biological effects index (HBEI): DO saturation and duration

Position in the bay	Coordinates		Depth	Period of deployment
	Latitude	Longitude	(m)	
NW	13°48′52″S	76°17′14″W	10	Mar 2015 - Feb 2016; Oct - Nov 2016
C	13°49′32″S	76°16′53″W	10	Mar 2015 - Apr 2016; Oct - Nov 2016
SE	13°50′35″S	76°15′59″W	6	Mar 2015 - Mar 2016
SW1	13°49′35″S	76°17′43″W	5	Sept 2012 - Mar 2013
SW2	13°49′28″S	76°17′58″W	5	Mar 2016 - Feb 2017

Table 2
Hypoxia intensity index (a) and hypoxia biological effect index (b) developed for each hypoxic event quantified in Paracas bay using duration as the main variable of ecological significance. Four categories were assigned for the hypoxia intensity index and three to the hypoxia biological effect index.

(a) Hypoxia Intensity Index (HII)

DO concentration (mg L^{-1})	Hypoxic event duration (hours)			
	6–20	21–50	51–100	> 100
0–0.5	1	2	3	4
0.5–1.0	1	2	3	3
1.0–2.0	1	1	1	1
1: low intensity	3: high intensity			
2: moderate intensity	4: severe intensity			

(b) Hypoxia Biological Effect Index (HBEI)

DO saturation (%)	Hypoxic event duration (hours)		
	6–20	21–40	> 40
> 24%	1	1	1
5–24%	1	2	2
< 5%	2	2	3
1: innocuous	2: sublethal	3: lethal	

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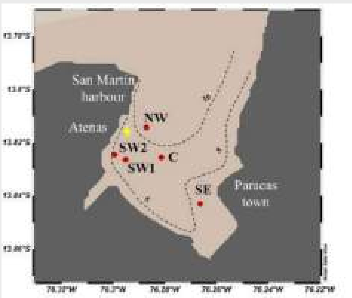
Igarza et al. (2024)

Ecological/Biological impacts of hypoxic events



Hypoxic: DO < 2mg/L (1.4 mL/L)
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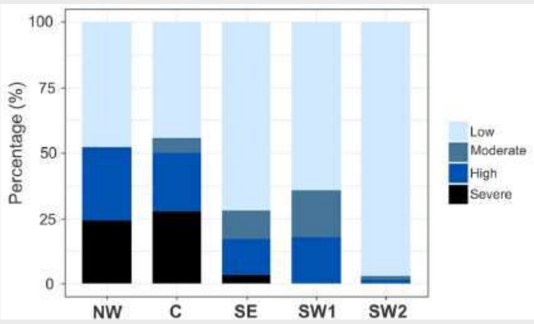

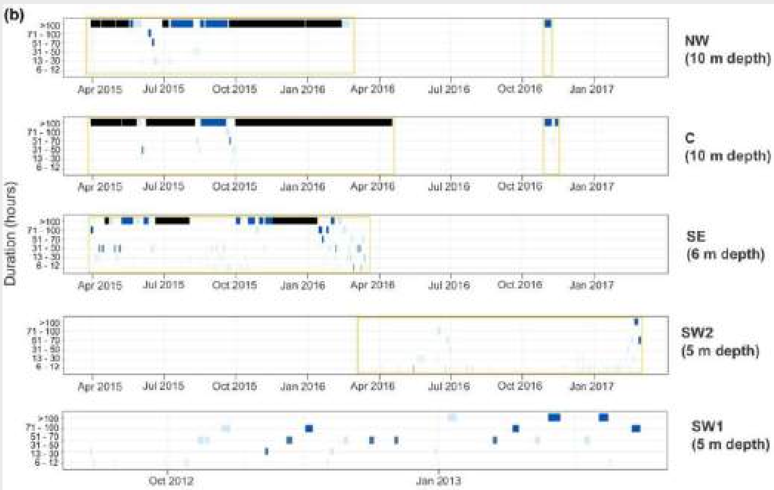

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Igarza et al. (2024)

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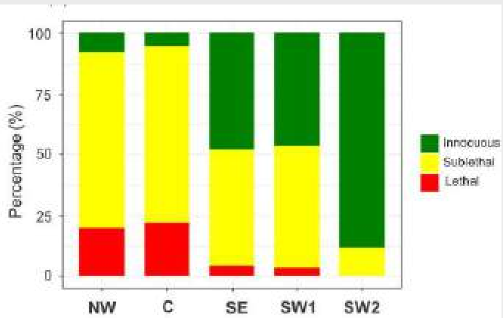

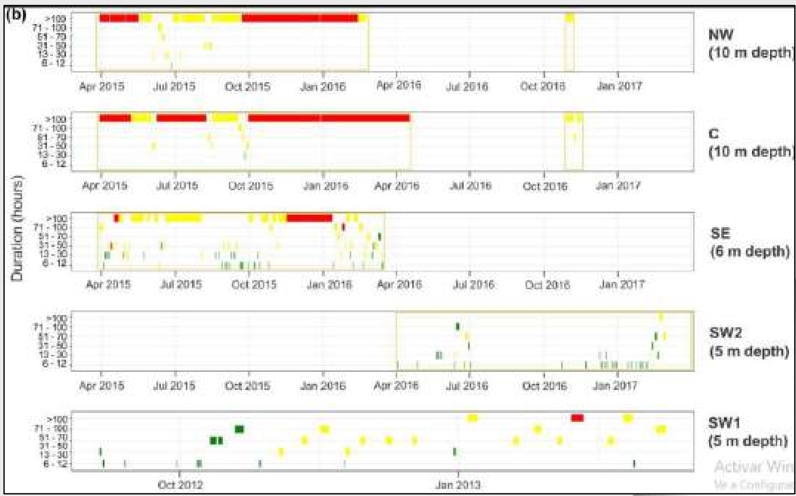

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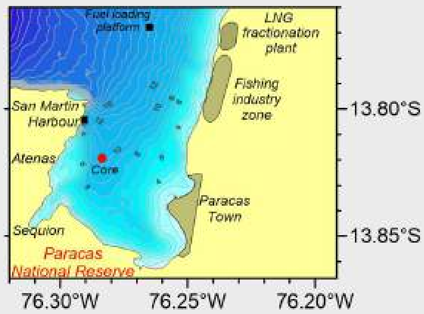
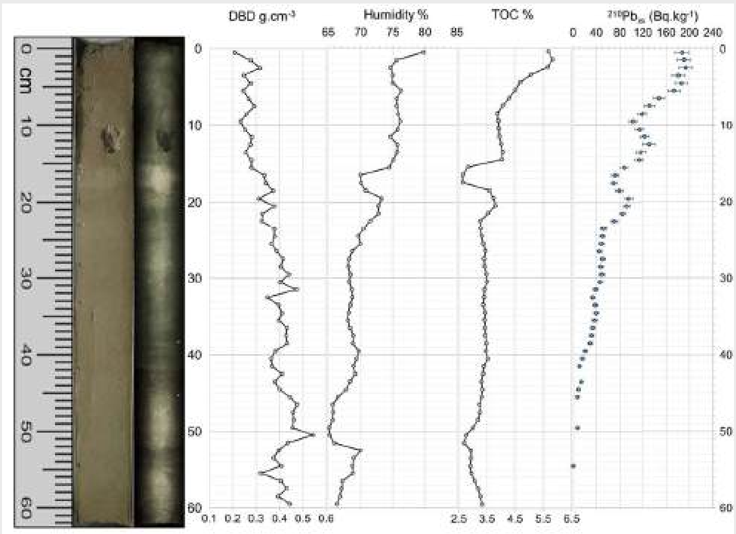
Igarza et al. (2024)

Palaeo-ecology and geochemistry of the last 100 years in the Paracas Bay sediments



Core inside the bay ~ 10m depth



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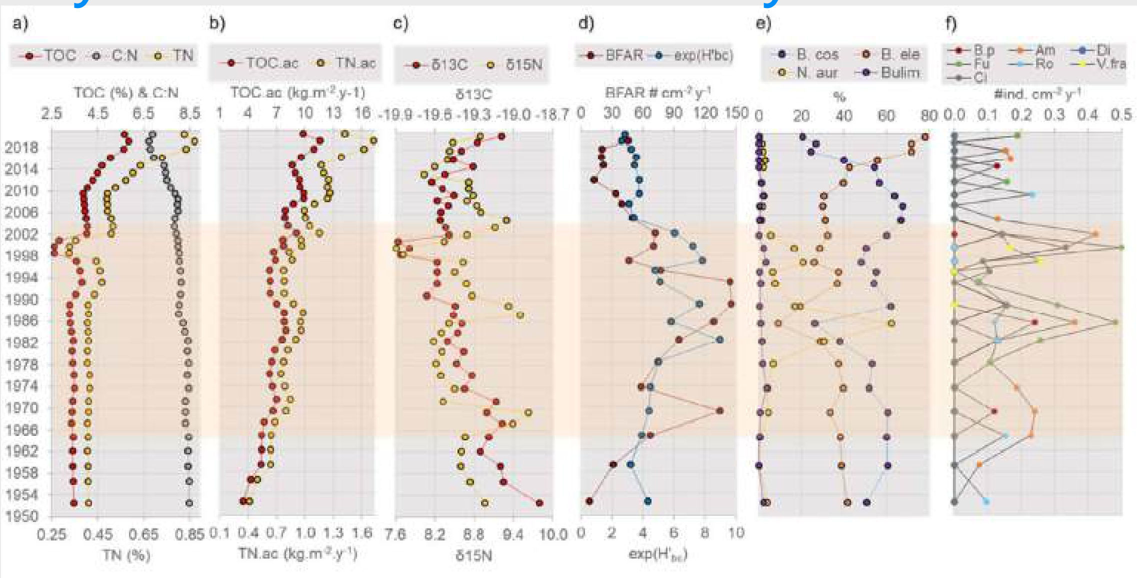
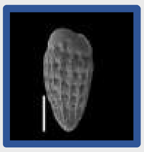
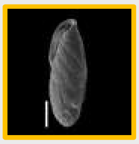
Merma-Mora PhD Thesis (2024)

Palaeo-ecology and geochemistry of the last 100 years in the Paracas Bay sediments







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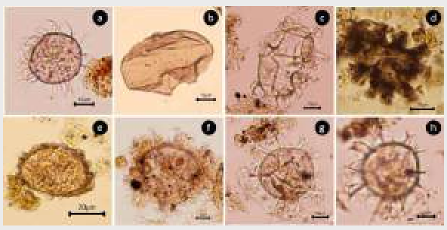
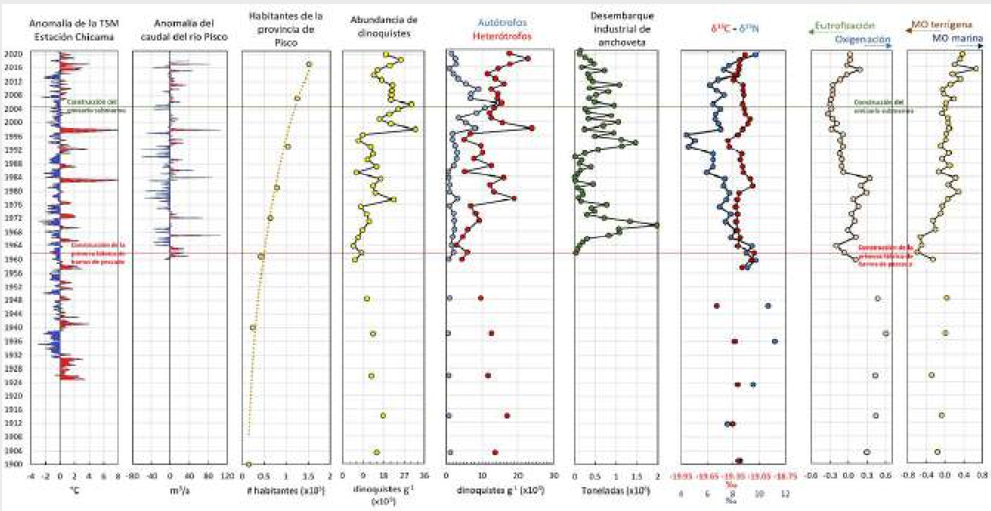
Palaeo-ecology and geochemistry of the last 100 years in the Paracas Bay



a) Echinidinium spp., b) Quinquecuspis concreta, c) Spiniferites sp., d) Quistes de Polykrikos kofoidii, e) Polykrikos schwartzii, f) Spiniferites pachydermus, g) Spiniferites ramosus., h) Spiniferites ramosus.



Alvarado Ing. Thesis (2024)

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Conclusions

- Hypoxic conditions in the Pisco-Paracas coastal area are almost permanent in greater depths (>15m), but also very frequent since 8m.
- Hypoxia in the Paracas Bay are controlled by the variability of winds (upwelling and local) and may be prolonged by stratification events.
- Only shallower waters (<8m depth) show more innocuous conditions for scallop aquaculture, but even so lethal conditions are not unlikely to occur.
- Human-derived eutrophication (fishmeal/oil industry and urban wastewaters) could be worsened the bottom conditions of the bay making them more likely to promote HABs even years after of the pollution treatments.

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Thank You

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Annex 6. Economy reports

Dissolved oxygen variability along the coast of Chile

- Undersecretary of Fisheries and Aquaculture| Monday, 30 September 2024

GENERAL CONTEXT

Northern and central Chile

The Oxygen Minimum Zone (OMZ) off the coast of Chile extends in the South Pacific from approximately 18°S to 37°S, with concentrations of less than 1 ml of oxygen per liter. Generally, this zone extends to depths between 50 and 300 meters.

The depth, extent, and position of the OMZ vary according to El Niño and La Niña phenomena and coastal upwelling. Upwelling generates an ascent of subsurface waters, bringing these low-oxygen waters to the surface, impacting marine resources located in the upper levels of the sea.

This upwelling also carries nutrients that generate high productivity of microalgae in the area. However, when swells occur, this oxygen minimum zone reaches the coast, causing large die-offs of octopuses, sea urchins, or if these low-oxygen waters remain trapped for several days in a specific area, they can cause die-offs and strandings of various species (e.g., hake, jack mackerel, and jumbo squid). These events have been recurrent in recent years, etc.

Southern Chile

In the Chilean Patagonia, we have identified hypoxia in some fjords and channels. This hypoxia is caused by the arrival of deep waters with low dissolved oxygen content from the equatorial zone and by the irregularity of the seabed, which hinders the exchange with waters richer in dissolved oxygen (sill).

Associated Regulations
Undersecretary of Fisheries and Aquaculture

Fisheries and Aquaculture

Fisheries and Aquaculture law

Research:

Article 91.- The Undersecretariat shall develop the necessary research program for the regulation of fisheries and aquaculture, which is currently executed by the Fisheries Development Institute.

Aquaculture

<u>Environmental Regulation for Aquaculture</u>

Indicate the environmental protection measures for aquaculture establishments to operate at levels compatible with the carrying capacities of lacustrine, fluvial, and marine water bodies, aquatic life, and the prevention of conditions arising in aquaculture impact areas.

Online Monitoring Regulation, which primarily establishes the requirements and conditions that the online monitoring or control system for environmental parameters of concession groups must meet.

The monitoring system consists of:

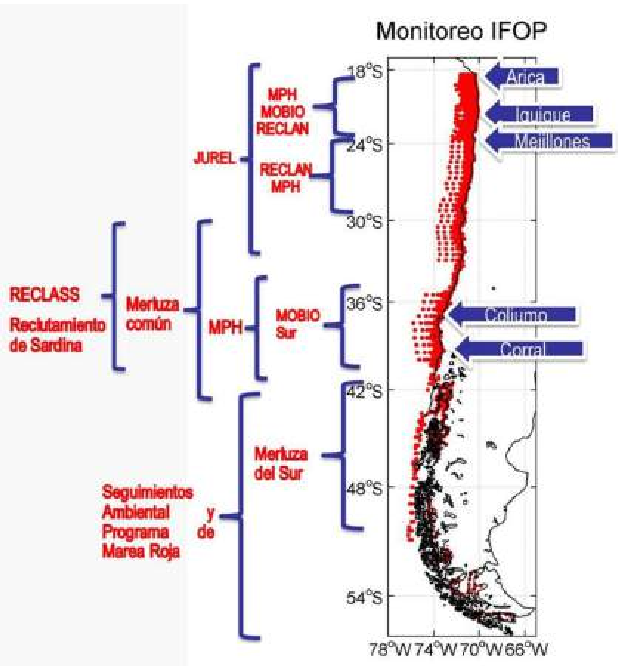
-Collection of meteorological and oceanographic variables

- Reception and transmission of these variables

- Storage and processing of information

- Technical specifications regarding the standards that the equipment must meet, as well as the location, height, and depth at which the sensors must be installed, the frequency of information recording, and standards for equipment certification.

Fisheries Research Programs



In oceanic waters, cruises were conducted during the peak reproductive season. Sampling was carried out at 1, 5, 10, 20, 40, 60, 80, and 100 nautical miles from the coast.
In coastal waters, oceanographic transects were conducted perpendicular to the coast at 1, 5, 10, and 20 nautical miles. These were carried out in the areas of Arica, Iquique, and Mejillones in the north, and Coliumo and Corral in the south.

Sampling

Oceanographic stations for temperature (°C), salinity, dissolved oxygen (mL/L), and fluorescence (volt) were conducted to a maximum depth of 500 m using a Sea Bird CTD/OF model 911 equipped with dual temperature and salinity sensors, operated in real-time along with a vertical sampling Rosette system equipped with 12 Niskin bottles of 5 L capacity. Standard depths were 0, 5, 10, 20, 30, 50, 75, 100, 150, 200, 300, and 500 m, from which water samples were collected for oxygen and chlorophyll-a analysis.

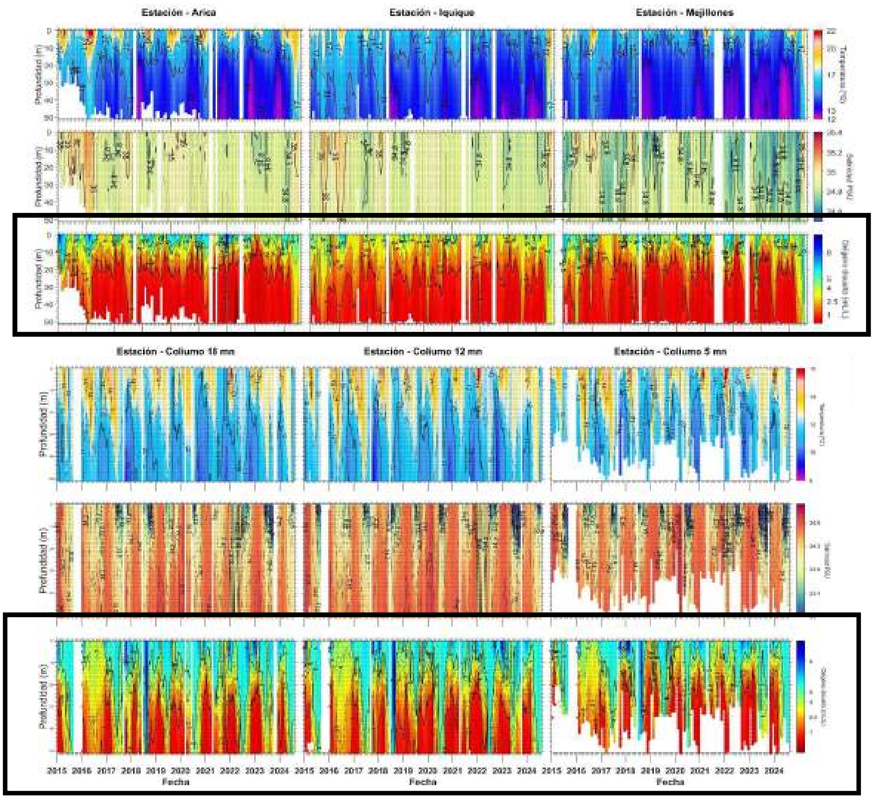
Dissolved oxygen (DO) analysis was performed in triplicate at all depth levels at oceanographic stations located 10 nm and 80 nm from the coast and at the surface level of all oceanographic stations.

DO analysis was conducted on board using the Winkler method modified by Carpenter (1965). Dosimat burettes (precision 0.001 mL) and automatic dispensers were used.

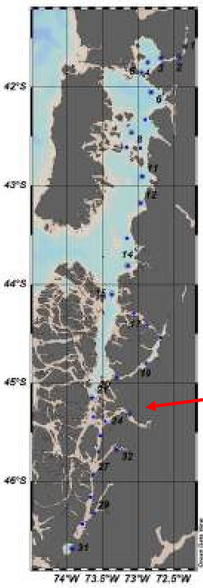
Results of Coastal Waters Fisheries Research Programs

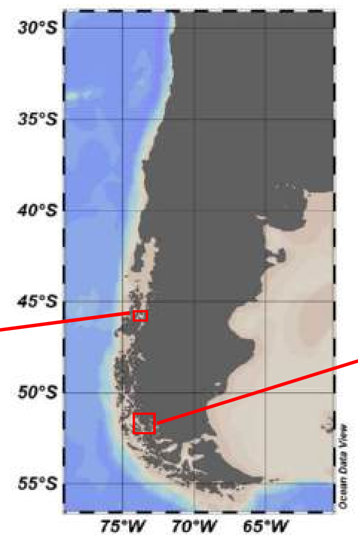
Northern Chile: Regarding oxygen, the 1 mL/L isoline was around 20 meters for most of the time series, except between late 2015 and early 2016, mid-2017, late 2020, and April 2023, when a deepening of this isoline to 50 meters was observed.

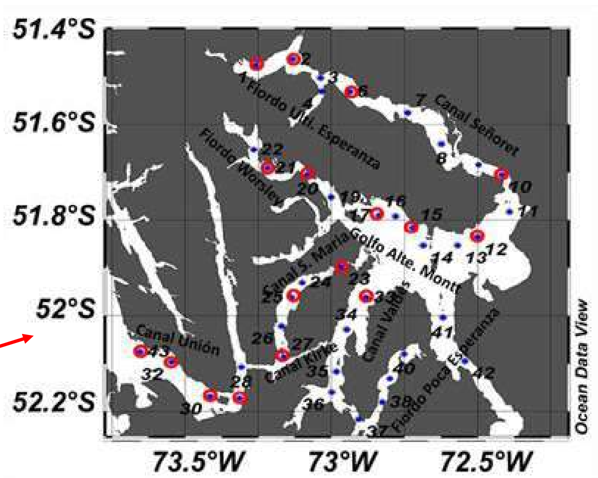
Central Chile: The water column at the more coastal stations (5 nm and 12 nm) showed values above 5 mL/L, while at the more oceanic station, oxygen decreased at greater depths, with values below 4 mL/L recorded at 50 meters depth.



Aquaculture Research Programs Sampling Stations







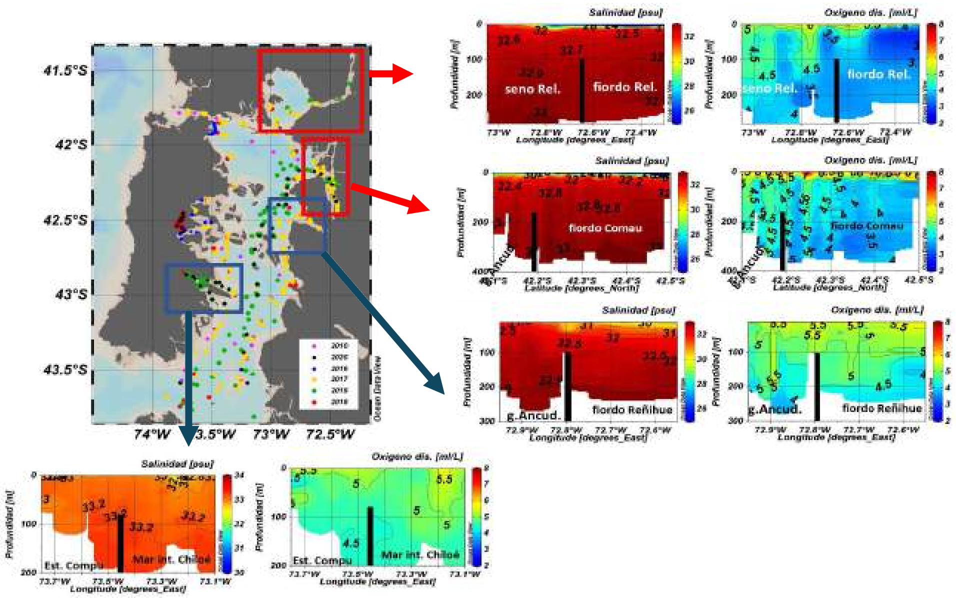
Inland Waters in Channels and Fjords

Northern Patagonia

Part of Southern Patagonia

Almirante Montt Gulf

Inland Waters in Channels and Fjords
Northern Patagonia



In spring, the Reloncaví Fjord, where oxygen is low (~4 ml L^{-1}).

In summer, the dissolved oxygen concentration from the surface to 100 m depth fluctuated between 4 - 6 ml L^{-1} along the entire transect, with low concentrations highlighted in the Moraleda and Jacaf channels (<3 ml L^{-1}) and in the Reloncaví Fjord.

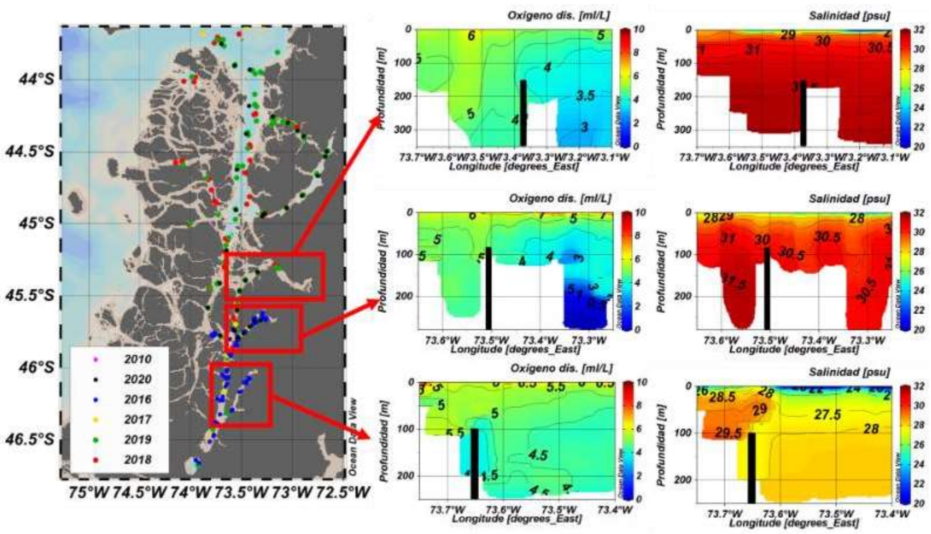
Soto G., Pinilla E., Reche P., Soto C. & Cortes J. (2023). Monitoreo Y Modelación de la Variabilidad Espacial y Temporal de Procesos Oceanográficos en Canales y Fiordos Australes, 2022-2023.. (Informe final). Valparaíso: Instituto de Fomento Pesquero. Documento disponible en https://chonos.ifop.cl/wiki/proyectos-e-informes-tecnicos/.

Inland Waters in Channels and Fjords
Northern Patagonia – Aysén Region

In front of the Guafo mouth and in the Moraleda Channel (MR), all waters, particularly the ESSW, manage to enter from the south, reaching the Jacaf Channel (JF) and Puyuguapi.

The Puyuguapi Fjord, which has a certain degree of influence from a remote connection, is related to low oxygen levels that occur with the influx of low-oxygen oceanic waters (ESSW) (Pérez-Santos et al., 2017).

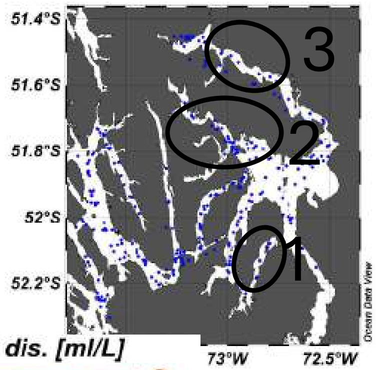
The Quitralco Fjord is associated with its low dissolved oxygen values, especially in the depression and head areas. On average, dissolved oxygen values fluctuated from year to year, with minimum values recorded since 2019, reaching anoxic conditions (<0.5 ml L^{-1}).



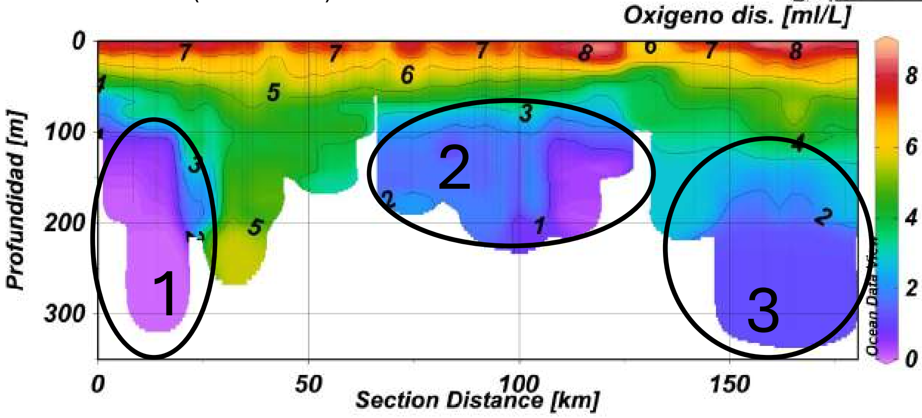
Soto G., Pinilla E., Reche P., Soto C. & Cortes J. (2023). Monitoreo Y Modelación de la Variabilidad Espacial y Temporal de Procesos Oceanográficos en Canales y Fiordos Australes, 2022-2023.. (Informe final). Valparaíso: Instituto de Fomento Pesquero. Documento disponible en https://chonos.ifop.cl/wiki/proyectos-e-informes-tecnicos/.

Inland Waters in Channels and Fjords

Northern Patagonia – Magallanes Region



In the period 2022-2023, low dissolved oxygen conditions (<4 ml L^{-1}) were detected in the fjords and deeper interior areas of the Almirante Montt Gulf, corroborating the presence of hypoxia in the Worsley Fjord and Vattuone Pass detected in 2013 (<2 ml L^{-1}), indicating that this is a permanent condition of the system. In the period 2022-2023, new areas with low oxygen levels were detected, with more extreme conditions (<0.5 ml L^{-1}).



Soto G., Pinilla E., Reche P., Soto C. & Cortes J. (2023). Monitoreo Y Modelación de la Variabilidad Espacial y Temporal de Procesos Oceanográficos en Canales y Fiordos Australes, 2022-2023.. (Informe final). Valparaíso: Instituto de Fomento Pesquero. Documento disponible en https://chonos.ifop.cl/wiki/proyectos-e-informes-tecnicos/.

Aquaculture Regulation

Environmental Regulation for Aquaculture

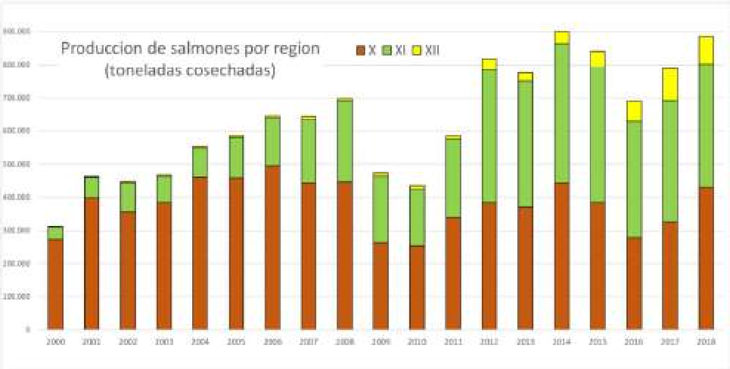
Preliminary Site Characterization and Environmental Reports (INFA)

This environmental regulation is to protection measures to ensure that aquaculture establishments operate at levels compatible with the capacities of lacustrine, fluvial, and marine water bodies.

Acceptability Limits

Variables	Límite de Aceptabilidad
Materia Orgánica Total (MOT)	≤ 9%
Potencial de Óxido-Reducción (REDOX) y pH	≥ 50mV y ≥7,1
Oxígeno disuelto (1 m del fondo) (Zona Sur)	> 2,5 mg/L
Registro Visual (Filmación submarina)	-Ausencia de cubiertas de microorganismos visibles y/o burbujas de gas. -Presencia <30% del fondo duro, para centros categoría 4 mixta.

Salmon Farming Activity in the Regions of Los Lagos, Aysén, and Magallanes



Fuente WWW-INCAR

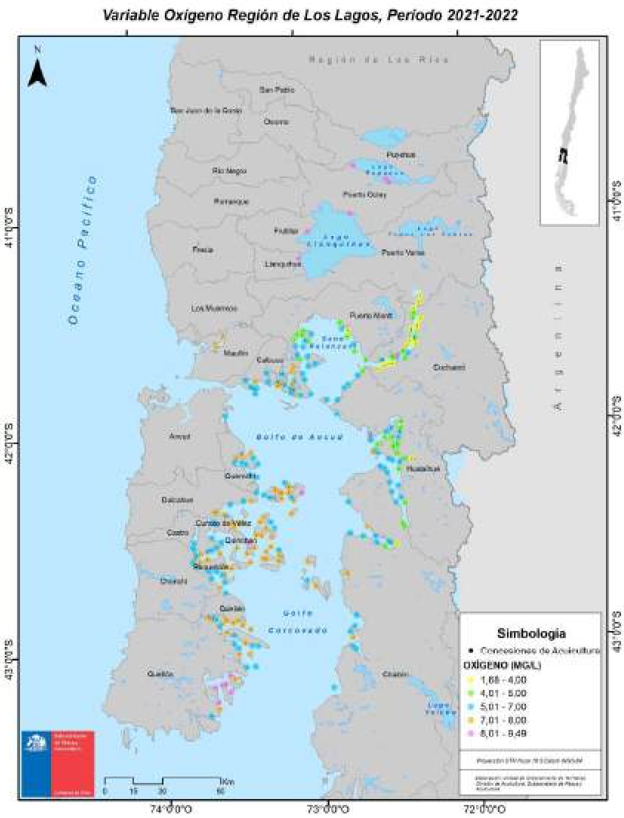
The Chilean salmon farming industry has grown exponentially since the late 1980s, primarily due to the increased production of salmonids, particularly Atlantic salmon (Salmo salar), rainbow trout (Oncorhynchus mykiss), and coho salmon (Oncorhynchus kisutch).

In the last 10 years, total salmonid production increased from around 600,000 tons in 2007 to 840,000 tons in 2018, with a significant drop between 2009 and 2010 due to the ISA epidemic.

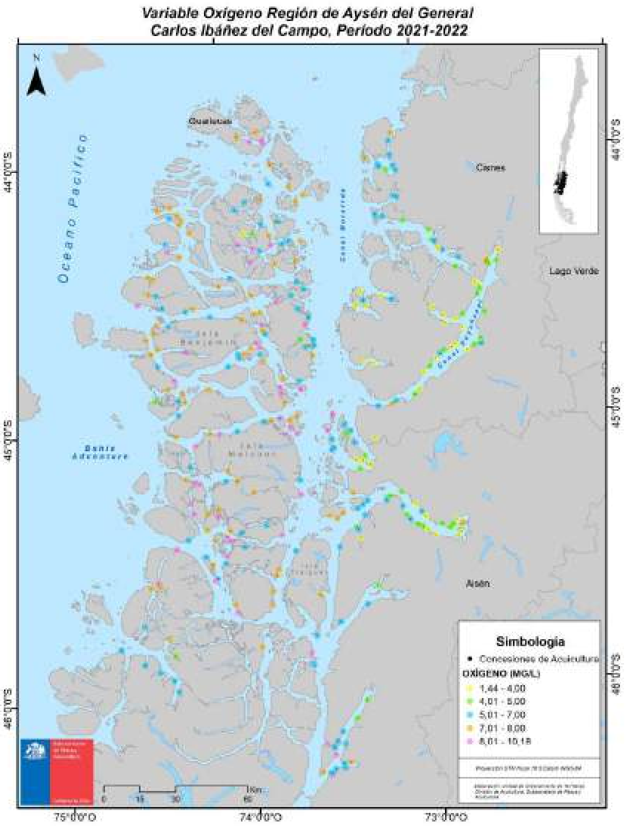
Production has mainly increased in the Aysén Region and to some extent in the Magallanes Region.

Between April 2010 and July 2023, salmon farming centers have reported 1340 instances of anaerobia in the ecosystem, which means insufficient oxygen levels in the seabed, according to the Environmental Report for Aquaculture (INFA) prepared by Sernapesca.

In the Los Lagos region, according to information obtained from the INFAs for the years 2021-2022, there is a predominance (>80%) of dissolved oxygen concentrations greater than 5,00 mg L^{-1} throughout the region. However, the Reloncaví Estuary and the Hornopirén Channel show the lowest average oxygen values for the period compared to the rest of the region.



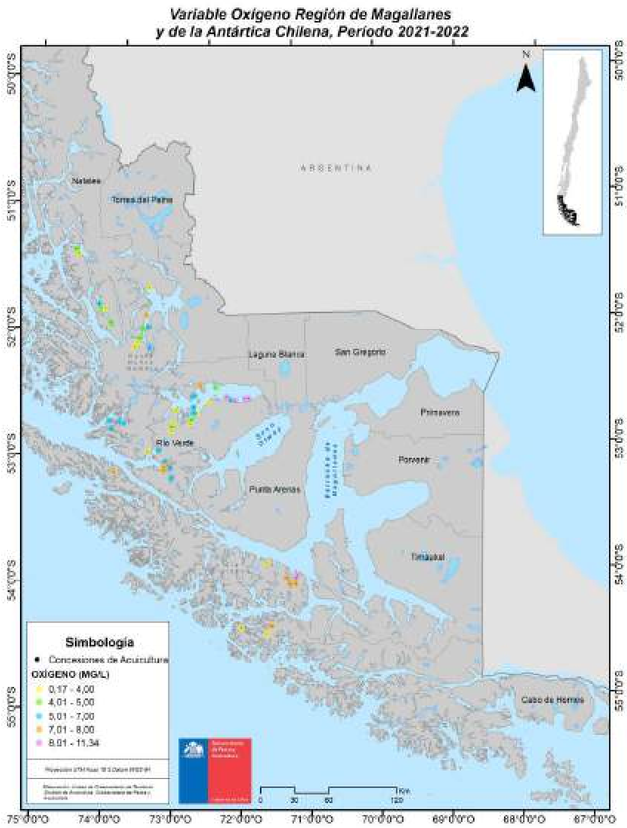
Oxygen concentration one meter above the seabed in the Los Lagos Region, average for the years 2021-2022 (INFAs from 366 centers).



In the Aysén del General Carlos Ibáñez del Campo Region, there are areas with oxygen values ranging from 1,44 to 5,00 mg L^{-1} (less than 25% of the centers). In comparison to the rest of the region, the average fluctuates between 5,01 and 10,18 mg L^{-1}.

Oxygen concentration one meter above the seabed in the Aysén del General Carlos Ibáñez del Campo Region, average for the years 2021-2022 (INFAs from 356 centers).

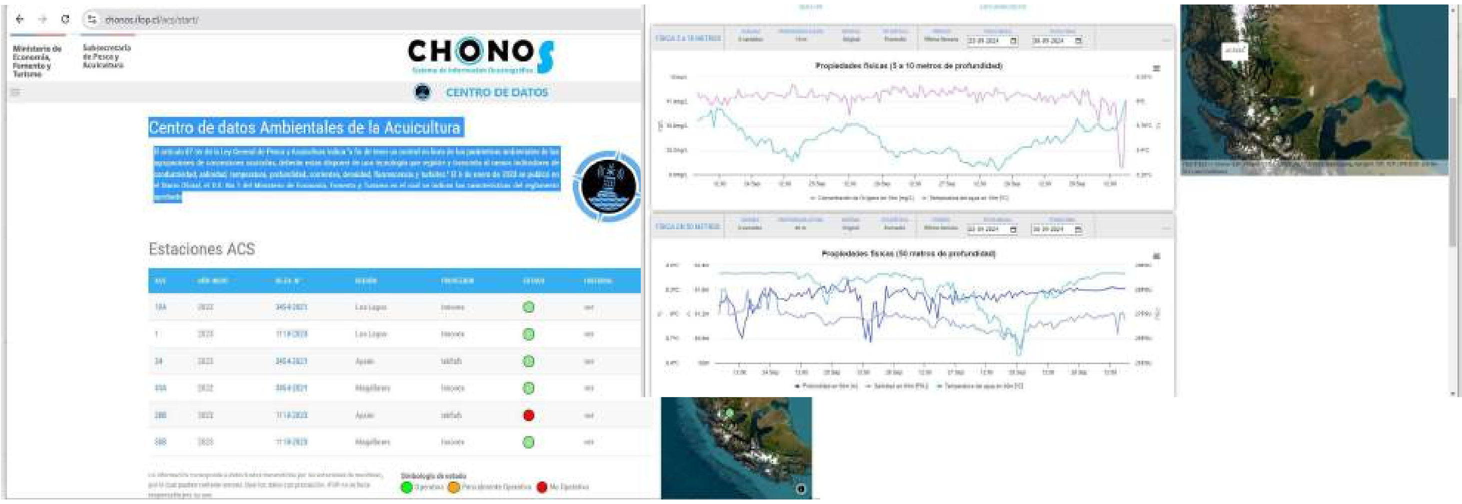
Additionally, in the Magallanes and Chilean Antarctic Region, the average dissolved oxygen values fluctuate between 0,17 and 11,34 mg L^{-1}.



Oxygen concentration one meter above the seabed in the Magallanes and Chilean Antarctic Region, average for the years 2021-2022 (INFAs from 59 centers).

Regulation D.S. No. 1 of 2020

Article 87 ter of the General Law on Fisheries and Aquaculture states: "In order to have online control of the environmental parameters of aquaculture concession groups, they must have technology that records and transmits at least indicators of conductivity, salinity, temperature, depth, currents, density, fluorescence, and turbidity." On January 6, 2020, D.S. N° 1 of the Ministry of Economy, Development, and Tourism was published in the Official Gazette, indicating the characteristics of the approved regulation.



https://chonos.ifop.cl/acs/start/

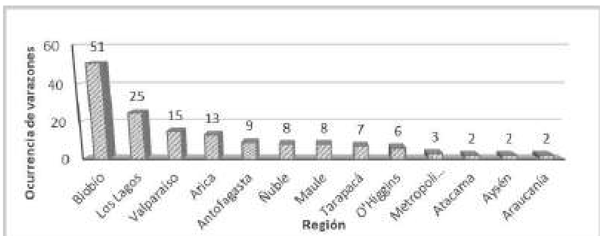
Consequences of Low Oxygen Levels in Central Chile

Four mass stranding events of pelagic resources, anchovies, and silversides (125 tons), were recorded between February 19 and 21 in Coliumo Bay, located in the Biobío region, where the dissolved oxygen found was 1.2 mg L^{-1}.

Several of these stranding events have been associated with upwelling events or the emergence of low-oxygen waters.

Strandings have increased exponentially since 2006 to date, with the Biobío region being the most recurrent area for this phenomenon.

Additionally, more than 80% of the events have occurred during the summer months, with species such as the common sardine and anchovy being the most associated with these events, followed by some species of mollusks and crabs.



Occurrence (N°) of total strandings of marine organisms between the years 2000 and 2021 by regions of Chile based on Sernapesca database (2021).

Consequences of Low Oxygen Levels in Southern Chile

Mass Salmon Mortality 2016

This event is considered the largest recorded mortality of farmed fish, with estimated losses of 40.000 tons of specimens and more than 800 million dollars, representing 15% of the estimated annual production for that year in Chile.

Possible causes:

•Extreme climatic conditions (El Niño “Godzilla” of 2016);

•The waters in the southern zone between 40°-42° South Latitude (off the coast of Chiloé) experienced a sea surface temperature increase of two to four degrees above a normal year;

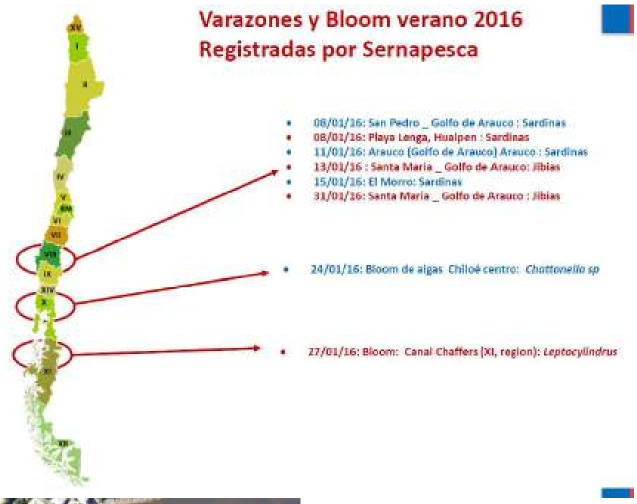
•A strengthened and southward-displaced anticyclonic system, especially during the summer, which increased drought towards the Los Lagos and Aysén regions;

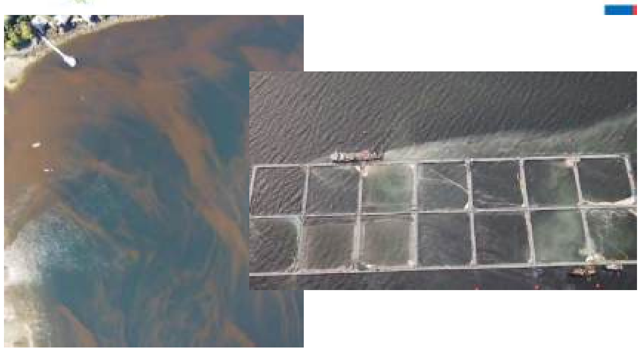
•Clear skies and southern winds favorable to coastal upwelling, which results in low oxygen levels and high nutrient content further south.

Mass Salmon Mortality 2021

In 2021, 6,000 tons of fish died due to lack of oxygen in the Comau Fjord and the Jacaf and Puyuhuapi channels in the Chilean regions of Los Lagos and Aysén, caused by the growth of a harmful algal bloom attributed to climate change and the industry itself.

The Comau Fjord hosts one of the most important cold-water coral banks on the planet, and it has been estimated that a massive algal bloom caused a hypoxic situation.





THE CURRENT GAPS IN OXYGEN MONITORING AND ITS APPLICATION FOR THE MANAGEMENT OF LIVING RESOURCES

- We do not have continuous dissolved oxygen monitoring at key locations along the Chilean coast for decision-making purposes.
- Not everyone follows the known protocols for conducting measurements (protocols for performing measurements, calibration frequency, correction methods).
  - Researchers
  - Consultants
  - State Professionals
- There is a lack of measurements of other parameters to relate the causes of oxygen loss and to forecast future scenarios (strandings, harmful algal blooms, etc.).

Undersecretariat
for Fisheries
and Aquaculture

Chilean Government

Thank you!!!

Asia-Pacific Economic Cooperation

APEC Project OFWG 201-2023 workshop (Sep.30th- Oct.3rd, 2024)

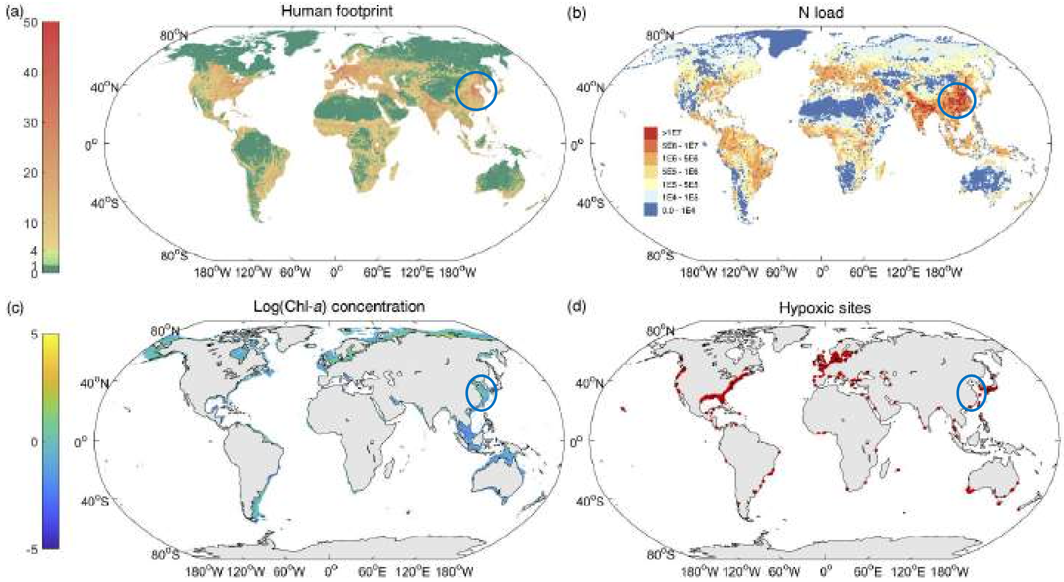
Hypoxia and ocean deoxygenation in estuary and coastal seas in China

Second Institute of Oceanography, MNR,
PRC Sep. 30, 2024

Outline

- Drivers of hypoxia and deoxygenation in coastal seas
- Relevant ecological and economic consequences
- Current ocean deoxygenation observation system
- Summary and Perspectives

#Key drivers for hypoxia and deoxygenation in coastal seas



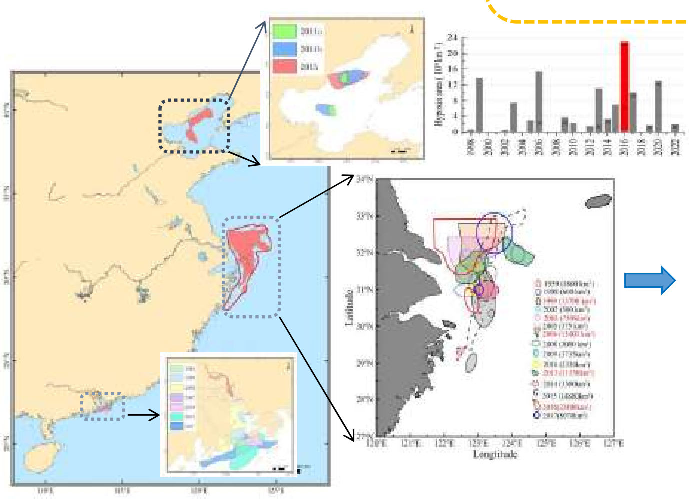
(Dai et al.,2023)

Global distributions of (a) the human footprint index in 2018, (b) N loads in 2020 (kg N yr−1), (c) log(Chl-a) concentration (μg L−1), and (d) hypoxic sites.

#Seasonal Hypoxia off the Changjiang Estuary and Pearl River Estuary

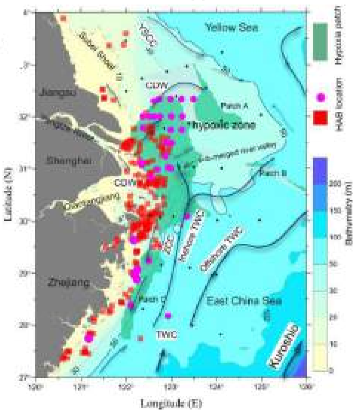
	GDP (10^{12}USD)	Fertilizer (10^{6}t)	N load (10^{3} t yr-1)	Regional	Water residence time(days)	DIN (μmol/L)	Chl a(μg/L)	Months of occurrences	Maximum area
Changjiang Estuary	5.09	18.3	1,738	River-dominated	20-65	34.4	2.1	June-Oct	22,800
Pearl River Estuary	3.52	11.7	1,374	River-dominated	15-20	59.2	5.1	Jun-Sep	660

(Dai et al., 2023 and therein)



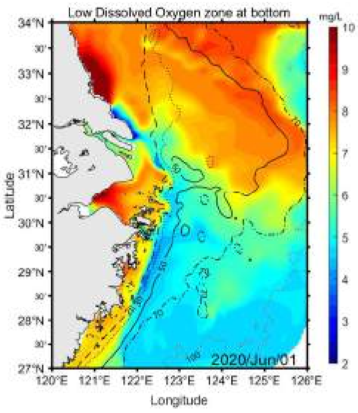
Typical hypoxia hotspots in coastal China Sea (Chen et al., 2020)

HAB and hypoxia



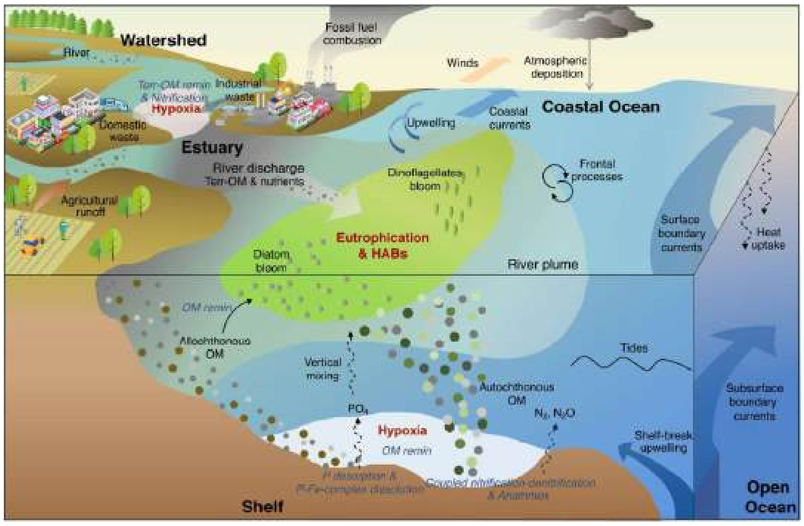
(Zhou et al., 2019)

Hypoxia development simulation



(Meng et al., 2023)

#Key drivers for hypoxia and deoxygenation in coastal seas

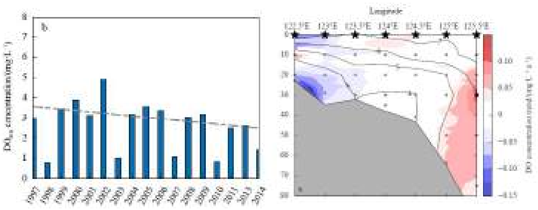


Conceptual diagram of the drivers of and interactions between eutrophication and hypoxia in the coastal ocean. (Dai et al.,2023)

- **Nutrient enrichment (Eutrophication)**
  - ✓ Microbial respiration and nitrification
  - ✓ Respiration of autochthonous OM
- **Climate change, upwelling**
  - ✓ Rising temperature
  - ✓ Upwelling from KSSW with low oxygen
  - ✓ Extreme weather events
- **habitat degradation**
  - ✓ Marine food web
  - ✓ Reducing resilience
- **Land use change**
  - ✓ Urbanization and deforestation
  - ✓ Dam and construction

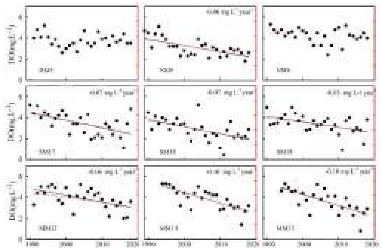
#Ocean deoxygenation rates in coastal seas is 5-30 times higher than global

- **The Bohai and Yellow Sea: -0.010 mg/L/year**
- **Changjiang estuary and ECS : -0.07 mg/L/year.**



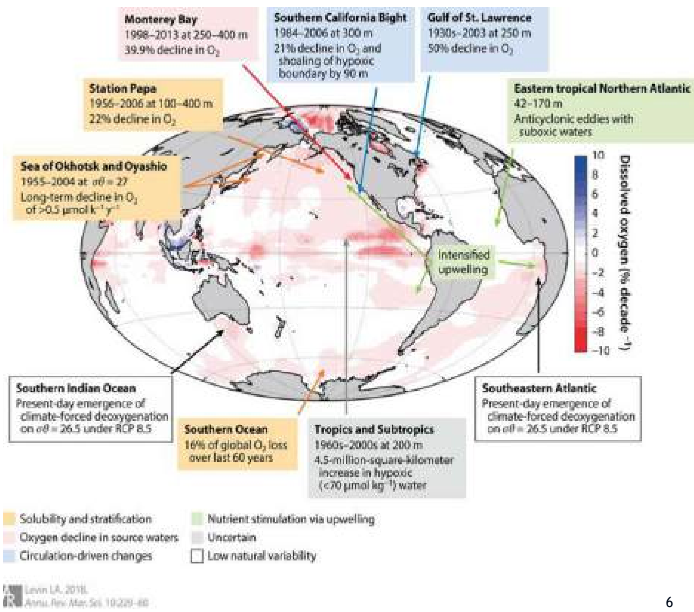
(Ma et al., 2022; Liu et al.,2024)

- **Peal River estuary : -0.06-0.10 mg/L/year.**



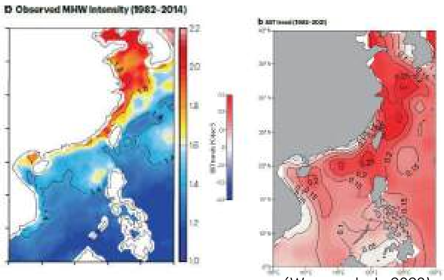
(Qian et al., 2022)

- The open ocean lost an estimated 2%, of its oxygen over the past 50 years.



#Key drivers for hypoxia and deoxygenation in coastal seas

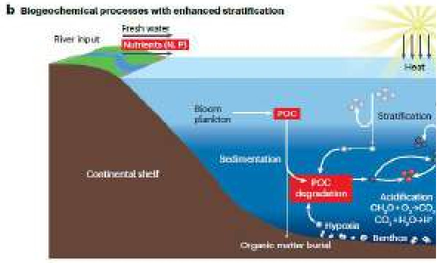
- SST increasing



(Wang et al., 2023)

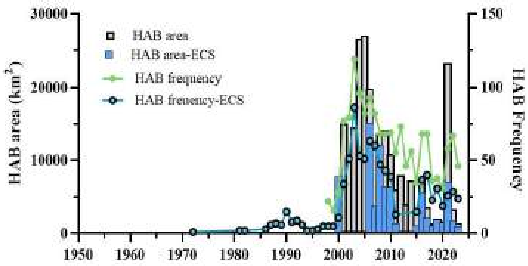
marine heatwave, 0.1–0.3 °C dec^{-1}

- Strengthened Stratification



Enhanced stratification in summer

- Eutrophication with excess N

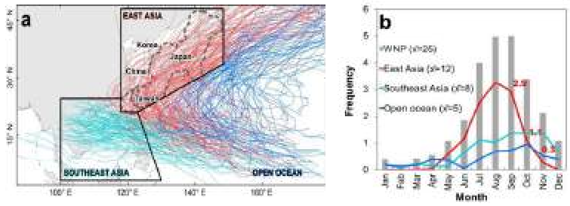


(Wu et al., 2023)

- habitat degradation

- Marine aquaculture

- Extreme weather events (flooding, typhoon, etc)



(Moon, et al.,2022)

Outline

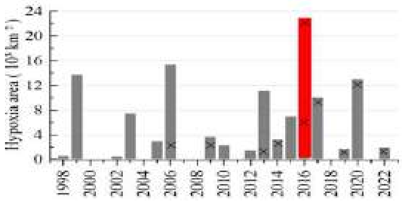
- Drivers of hypoxia and deoxygenation in coastal seas
- Relevant ecological and economic consequences
- Current Ocean deoxygenation observation system
- Summary and Perspectives

Asia-Pacific Economic Cooperation

#Living resources affected by oxygen loss

■ **Fisheries and Aquatic Species**

- ➢ **Fish Species**, like croakers and hair tail, are highly sensitive to low oxygen levels.
- ➢ **Shellfish:** Hypoxia can severely impact shellfish such as scallops, oysters, and clams, leading to mass die-offs.
- ➢ **Juvenile and Larval Fish:** Breeding and feeding grounds
- ➢ **Benthic Communities shifting**
- ➢ **Habitat degradation:** nursery



August 2016.

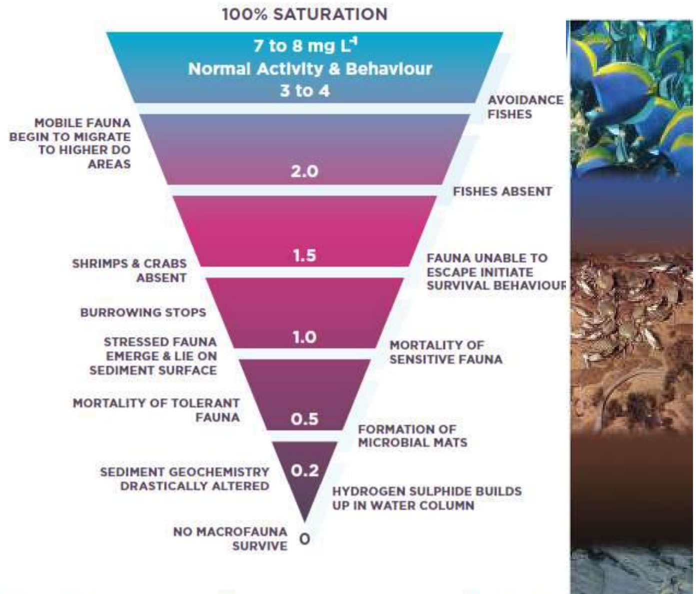


Figure 2.5.8 Range of behaviour and ecological impacts as dissolved oxygen levels drop from saturation to anoxia.

ions,

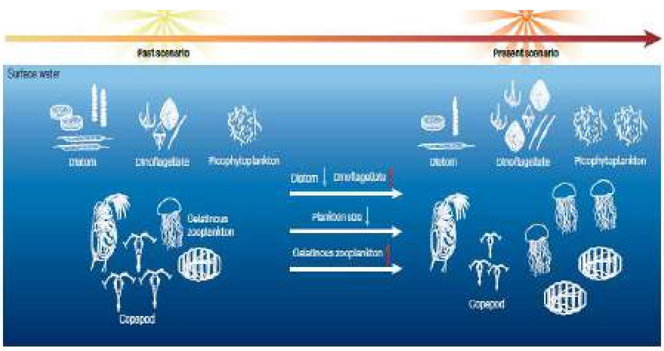
#Living resources affected by oxygen loss in ECS

■ **Ecological Consequences**

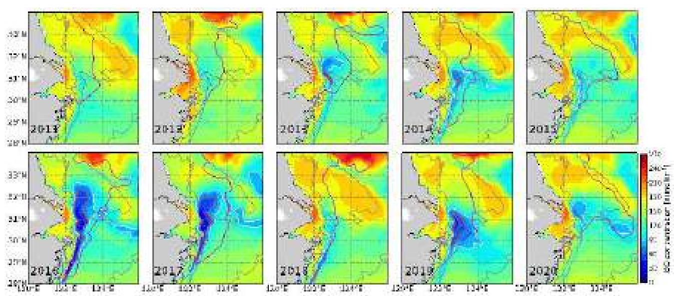
- ✓ **Biodiversity Loss**
- ✓ **Habitat Degradation**
- ✓ **Species Shifts**
- ✓ **Expansion of Dead Zones**

■ **Economic Consequences**

- ✓ **Fisheries Decline**
- ✓ **Aquaculture Losses**
- ✓ **Tourism Impact**
- ✓ **Rising Mitigation Costs**



(Wang et al., 2023)



(Zhang et al., 2023)

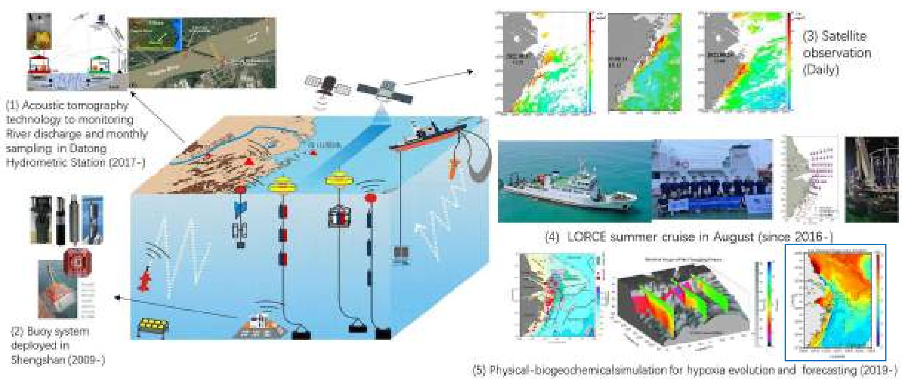
Outline

- Drivers of hypoxia and deoxygenation in coastal seas
- Relevant ecological and economic consequences
- Current ocean deoxygenation observation system
- Summary and Perspectives

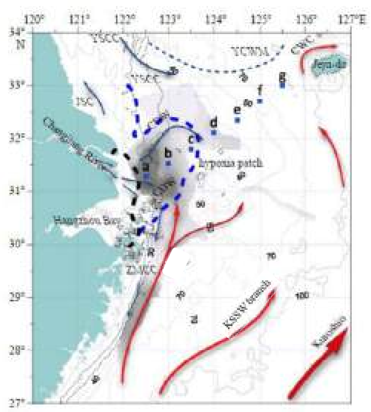
Asia-Pacific Economic Cooperation

Current Ocean deoxygenation observation platform

- SOA → MNR-supported: Coastal Ocean Ecological Warning and Monitoring system √
- MEE- Ministry of Ecology and Environment → Marine Environment Monitoring Center: water quality
- MOST Projects: NSFC-funded Open Research Cruise : NORCxxxx-xx, since 2009
- Institutions and Universities: SIO, CAS, XMU, OUC, ECNU, SJU, ZJU…



SIO-LORCE Project (Long Term Observation and Research Plan in the Changjiang Estuary and the Adjacent East China Sea)
(2016-)



Ningbo Marine Environment Monitoring Center, SOA

MNR- Coastal Ocean Ecological Warning and Monitoring System

- ◆ Integrated observation and monitoring system integrating ocean stations, buoys, ships, and satellites.

⇩

- ◆ Each year, the MNR organizes ecological trend monitoring for 15 offshore marine standard sections and 1,614 monitoring stations.

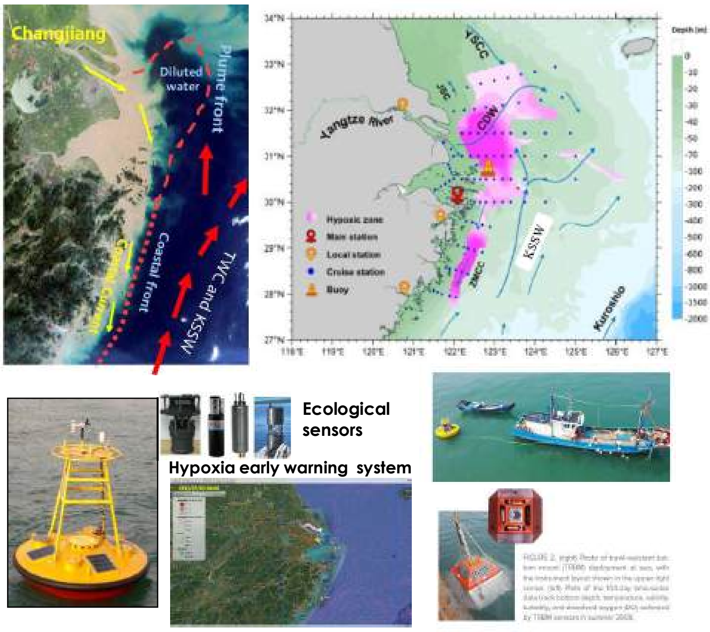
⇩

- ◆ Track 34 HAB high-risk areas, early warning and monitoring for ecological disasters such as red tide, hypoxia and coastal erosion.

⇩

- ◆ Timely release of marine ecological early warning, monitoring, alerts and communiqués.

Hypoxia and acidification warning and monitoring system off CJE (SIO-MNR)



(Ni, X., Li, D., J. et al.,Oceanography)

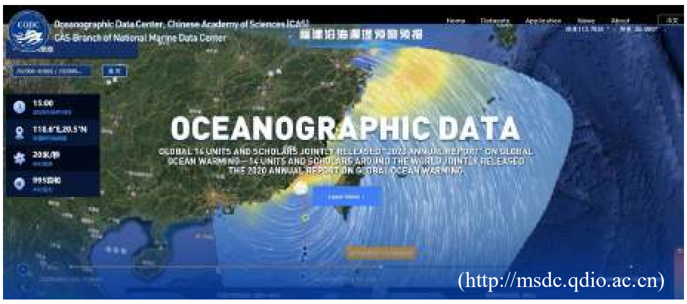
The Databases for dissolved oxygen data

- **The Domestic Marine Data Center (NMDC)-MNR**

- NMDC is led by Domestic Marine Data and Information Service (NMDIS)
- Observation data in Chinese oceanic stations , transect and buoy data. (since 1995-)

(https://mds.nmdis.org.cn/pages/home.html)

- **Global Ocean Science Database (CODC)-CAS**
  - Constructed by the Oceanographic Data Center, Chinese Academy of Sciences (CASODC).
  - The survey data of 24 open voyages in the Yellow Sea and East China Sea conducted by NSFC from 2006 to 2014.



- **Domestic Open Research Cruise (NSFC-NORC) -MOST**

共享航次计划　海洋资料共享服务平台

11 inclusive cruises
6 scientific cruises

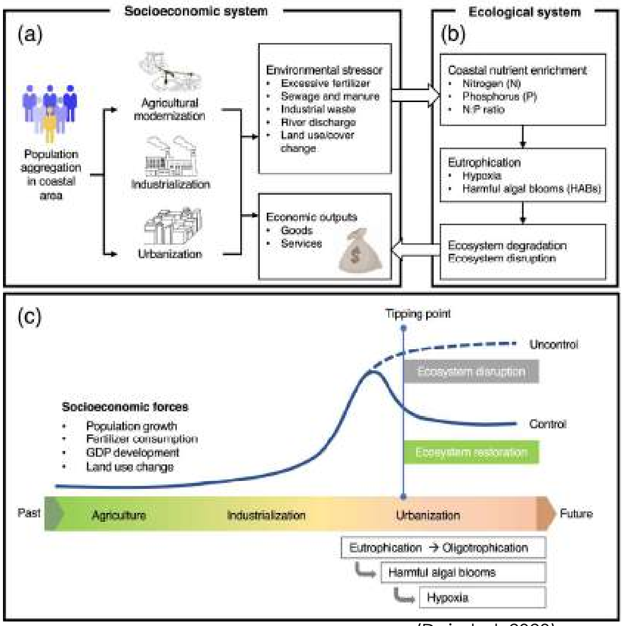
NSFC Ship time Sharing Project (2009-) https://www.nsfcodc.cn/

Outline

- ☐ Drivers of hypoxia and deoxygenation in coastal seas
- ☐ Relevant ecological and economic consequences
- ☐ Current Ocean deoxygenation observation system
- ☐ Summary and Perspectives

Asia-Pacific
Economic Cooperation

#Challenge in oxygen monitoring and application for the managements



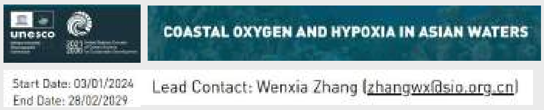
(Dai et al.,2023)

Schematic of socioeconomic forcing and ecological response in coastal ecosystems.

- ✓ **Gaps in Spatial and Temporal Coverage**
  Lack continuous or high-resolution data
- ✓ **Integration of Multisource Data**
  Combining data from various platforms and standards.
- ✓ **Climate adaptation and sustainability**
  Tipping point, ecosystem resilience.
- ✓ **International Sensor Calibration and Testing System**
  DO sensors duration, calibration, biofouling…

Summary and Perspectives

- Hypoxia exacerbation and expansion is occurring, together with the long-term deoxygenation in coastal areas. For living resources, fishery, community shifting and habitat loss are mainly affected.
- Drivers of deoxygenation mainly due to excess nutrients input, however the ENSO/IOD-related extreme weather events can trigger the severe hypoxia, even in this highly dynamic coastal seas.
- Ocean deoxygenation cannot be fully reversed, but it is something that can be slowed if the right actions are taken（such as nutrient input control, NBS-ecological restoration, monitoring…）.
- Strengthening International Collaboration and Policy Frameworks about ocean deoxygenation.



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This work is jointly supported by MNR, NSFC, SOED etc.

Thanks for your attention!

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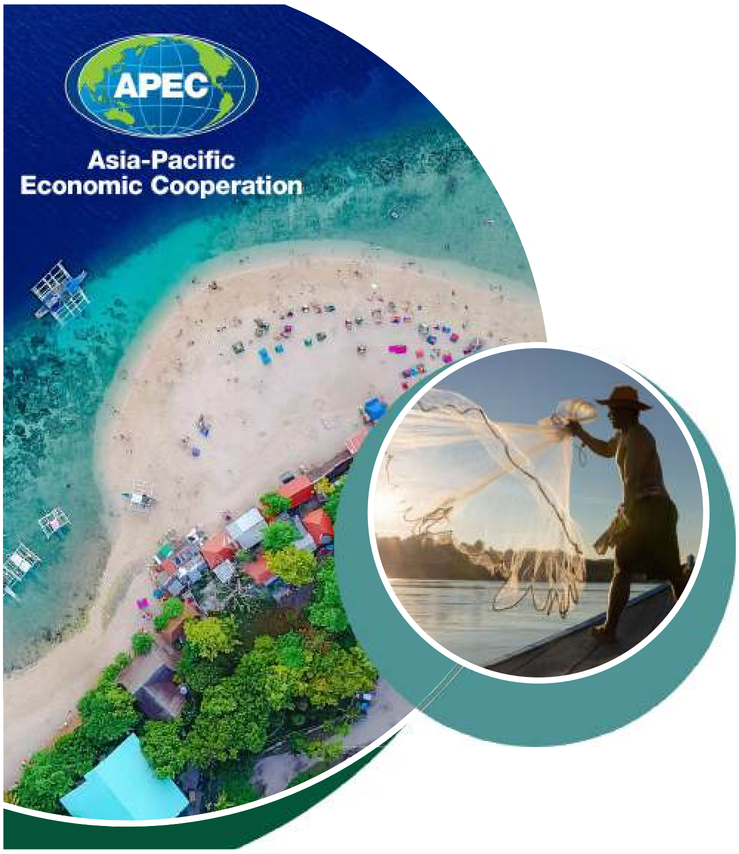
Special thanks to APEC for sponsoring this workshop!



Economy Report

Coastal Deoxygenation in Malaysia: Status, Impacts, and Policy Solutions

Center for Policy Research (CPR), Universiti Sains Malaysia, 11800, Pulau Pinang.

Marine Research Station (MARES), Faculty of Applied Sciences, Universiti Teknologi MARA Cawangan Perlis, Kampus Arau, 02600 Arau, Perlis.

Introduction

- Malaysia boasts a coastline over 4,809 kilometers long, encompassing Peninsular Malaysia and East Malaysia (Sabah and Sarawak). Its coastal waters are part of important marine ecosystems, including the Straits of Malacca, South China Sea, and Sulu Sea.
- These areas feature diverse habitats like mangroves, seagrass beds, coral reefs, and estuaries, supporting rich biodiversity and essential ecosystem services.

23% Significance of ocean related economies

- Malaysia's coastal waters are not only rich in biodiversity but also serve as the foundation for a wide range of economic activities that are crucial to the nation's development.
- It is estimated that the coastal economy contributes approximately 30-40% of Malaysia's GDP

70%

population lives along 4,800 kilometres of coastline

Malaysia possesses an extensive coastal and marine area of 614,159 square kilometres, almost twice its landmass, and the size of its Exclusive Economic Zone (EEZ) alone is 453,186 square kilometres. Being a economy with an abundance of natural resources, Malaysia has a huge potential to leverage these advantages for its economic value and prospects

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Overview of **Coastal Economy**

Fisheries and Aquaculture

- Fisheries and aquaculture collectively contribute around 21% of ocean related economy, with aquaculture showing rapid growth due to increasing demand for seafood

Tourism

- Coastal and marine tourism is a significant driver of Malaysia's economy, contributing to the broader tourism sector, which accounts for 26% of ocean related economy

Shipping and Maritime

- Malaysia's strategic position along the Straits of Malacca makes it a critical hub for global trade
- The shipping and ports sector contributes 39%.

Oil and Gas

- The majority of Malaysia's oil and gas production comes from offshore fields in the South China Sea. The industry contributes about 4% of ocean related economy

PEMSEA (2021).

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SIGNIFICANT DRIVERS OF LOW OXYGEN IN COASTAL WATERS OF MALAYSIA

One of the most urgent challenges facing Malaysia's marine waters is deoxygenation, primarily caused by organic pollution and the influx of nutrients.

Sewage Treatment Systems | Agricultural Runoff | Industrial Pollution | Livestock Farming | Wet Markets

Biochemical Oxygen Demand (BOD)

Wastewater from sewage treatment systems is the largest contributor to water pollution, responsible for 53.02% of BOD load.

Ammoniacal Nitrogen

Agriculture-based industries contribute significant pollution in the form of ammoniacal nitrogen, leading to nutrient enrichment (eutrophication) and subsequent oxygen depletion in water bodies.

Manufacturing Industries

Industrial effluents, including chemicals and organic pollutants, are responsible for around 6.70% of BOD load.

Waste Discharge

Livestock farming contributes significantly to organic pollution, accounting for 36.18% of BOD load. The waste contains high nutrient levels, increasing oxygen demand in water and causing deoxygenation.

Organic Waste

Although smaller in scale, wet markets with slaughtering activities contribute 0.11% of BOD load, adding organic waste into nearby rivers and coastal waters.

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Coastal Water Living Resources in Malaysia Affected by Oxygen Loss

01 Fisheries

Declining fish stocks due to oxygen depletion jeopardize Malaysia's fishing industry, affecting both food security and the livelihoods of coastal communities.

02 Aquaculture

Oxygen depletion often leads to harmful algal blooms (HABs), in certain farms in Malaysia.

03 Environmental Sensitive Habitats

Environmentally sensitive habitats like coral reefs, seagrass beds, and mangroves are at risk, as their health is tightly linked to stable oxygen levels.

04 Biodoversity

Decreases in populations of economically important fish species

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MONITORING AND DATA COLLECTION IN MALAYSIA

Malaysia does not have a fully consistent, nationwide monitoring program specifically focused on deoxygenation in coastal waters. Monitoring efforts are generally fragmented, regionally focused, and tend to be short-term or project-based rather than forming part of a coordinated domestic framework

1. Department of Environment (DOE)

The DOE, under the Ministry of Environment and Water, monitors water quality via its Domestic Water Quality Monitoring Network, focusing on pollution control in coastal areas and assessing parameters like dissolved oxygen, but not specifically addressing deoxygenation.

2. Department of Fisheries Malaysia (DOF)

The DOF oversees coastal ecosystems, particularly in areas vital for fisheries and aquaculture. Although this includes monitoring oxygen levels, the focus is primarily on fish farm locations and regions of significant economic value.

3. Universities and Research Institutes

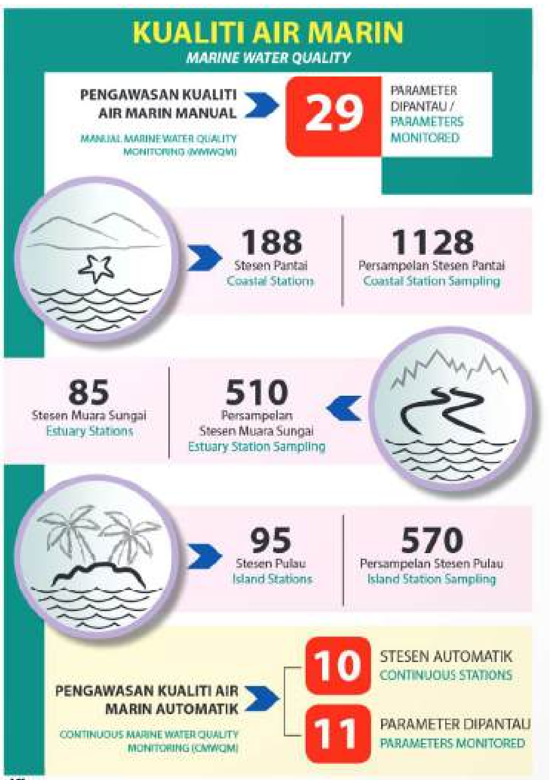
Academic institutions have conducted research on deoxygenation, but these are typically part of funded research projects with a limited timeframe

4. Collaborative Projects

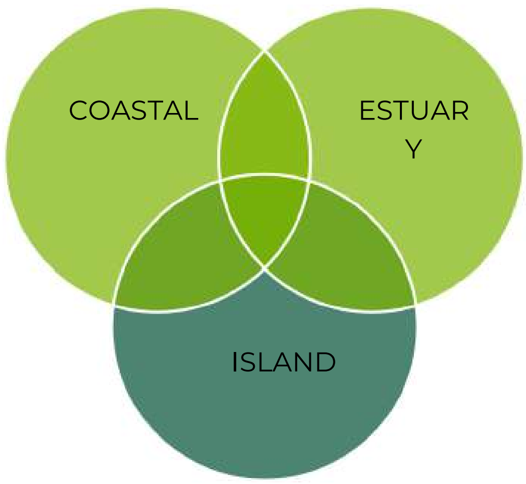
This includes international partnership for research grants or other research activities.

5. Environmental Impact Assessment -EIA

Data collected from EIA projects is intended to enhance specific development initiatives. While this information is valuable, it is important to note that it has a limited timeframe.



MARINE WATER QUALITY MONITORING IN MALAYSIA



Enviromental Quality Report (EQR) 2023

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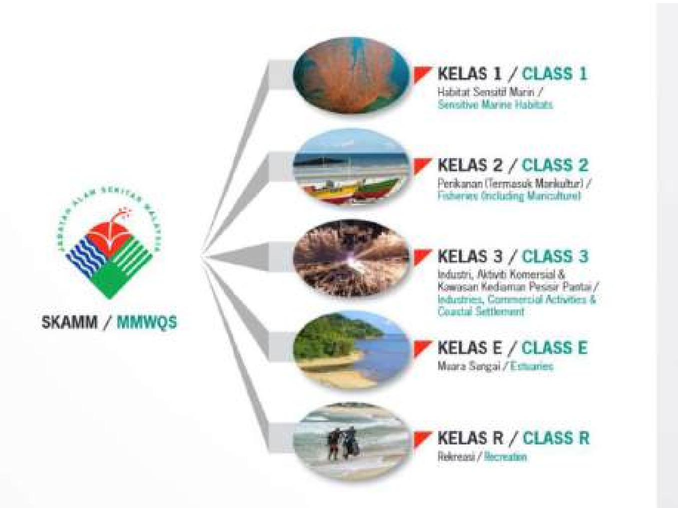
MALAYSIAN MARINE WATER QUALITY STANDARDS

PARAMETER (µ g/l) UNLESS OTHERWISE STATED	CLASSIFICATION					
	CLASS 1	CLASS 2	CLASS 3	INTERIM CLASS E1	INTERIM CLASS E2	INTERIM CLASS E3
				ESTUARIES		
	SENSITIVE MARINE HABITATS	FISHERIES (INCLUDING MARICULTURE)	INDUSTRY, COMMERCIAL ACTIVITIES & COASTAL SETTLEMENTS	COASTAL PLAIN	LAGOON	COMPLEX DISTRIBUTARY NETWORK
Dissolved Oxygen (mg/l)	>6.0	>5.0	>3.0	>5.0	>5.0	>5.0
Suspended Solids (mg/l)	25.0	50.0	100.0	30.0	30.0	30.0
Phosphate	5.0	75.0	670.0	100.0	180.0	180.0
Nitrate	10.0	60.0	700.0	200.0	570.0	430.0
Ammonia	35.0	50.0	320.0	5.0	10.0	10.0
Mercury	0.04	0.04	0.04	0.04	0.04	0.04
Cadmium	0.50	2.00	3.00	1.00	1.00	1.00
Chromium (VI)	0.14	10.00	20.00	10.00	10.00	10.00
Copper	1.30	2.90	8.00	1.00	1.00	1.00
Cyniade	2.00	7.00	14.00	5.00	5.00	5.00
Lead	2.20	8.50	12.00	1.30	2.00	2.00
Zinc	7.00	50.00	100.00	16.00	5.00	5.00
Arsenic (III)	1.00	3.00	3.00	3.00	1.00	1.00
Aluminium	27.00	27.00	55.00	27.00	27.00	27.00
TBT	0.001	0.010	0.050	0.002	0.002	0.002
PAH	100.0	200.0	1000.0	5.0	5.0	5.0
Total Phenol	1.0	10.0	100.0	10.0	10.0	10.0
Oil & Grease (mg/l)	0.01	0.14	5.00	1.00	1.00	1.00
Faecal Coliform (cfu/100ml)	70	70	70	70	70	70
Temperature (°C)	< 2 °C increase over maximum ambient					
pH	6.5 - 9.0					
Marine Litter	Free from marine litter					



The Application of the Malaysian Marine Water Quality Standards (MMWQS) based on the Pre-determined Marine Water Classification

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Department of Environment

WATER QUALITY PARAMETER

The Application of the Malaysian Marine Water Quality Index (MMWQI) is a method used to summarize a large number of water quality parameters into one index value that gives an overview of the marine's water quality.

Malaysian Marine Water Quality Index (MMWQI) Classification

KATEGORI / CATEGORY	NILAI INDEKS / INDEX VALUE
Terbaik / Excellent	90 - 100
Baik / Good	80 - <90
Sederhana / Moderate	50 - <80
Tercemar / Poor	0 - <50

$$MMWQI^{*} = q_{iDO}^{0.18} \times q_{iFC}^{0.19} \times q_{iNH_3}^{0.15} \times q_{iNO_3}^{0.16} \times q_{iPO_4}^{0.17} \times q_{iTSS}^{0.15}$$

Whereby,

q_{iDO}	=	$-85.816+55.4768(DO)-4.142(DO^2)$	When DO is < 3 mg/l, q_{iDO} = 10 When DO is > 10 mg/l, q_{iDO} = 10
q_{iFC}	=	100*EXP[illegible]	IF FC > 500 Faecal coliform count/100ml, q_{iFC} = 8
q_{iNH_3}	=	100 EXP[illegible]	
q_{iNO_3}	=	94.8 EXP[illegible]	
q_{iPO_4}	=	95.2 EXP[illegible]	When PO_4 > 900 µg/l, q_{iPO_4} = 10
q_{iTSS}	=	95.8 EXP[illegible]	When TSS > 100 mg/l, q_{iTSS} = 20

*Salinity of the marine water quality data shall be higher than 10 ppt

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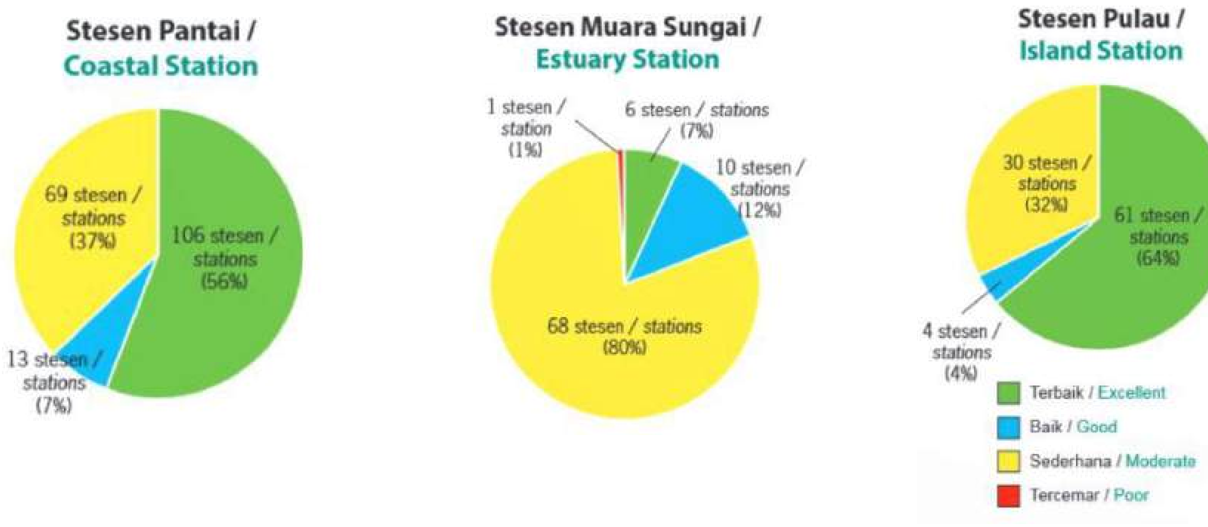

MARINE WATER QUALITY STATUS 2023

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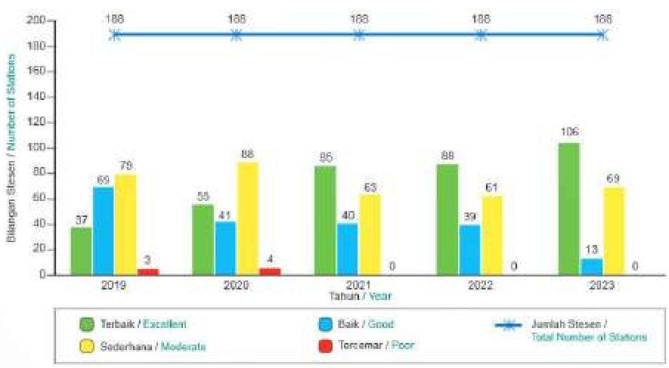
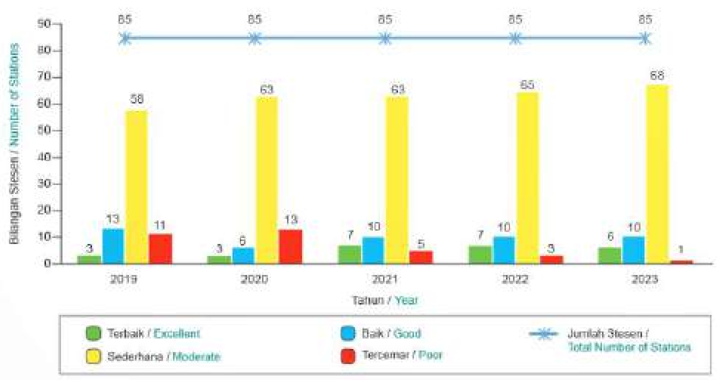
Enviromental Quality Report (EQR) 2023



The Marine Water Quality Status Trend for Coastal Area, 2019-2023

The Marine Water Quality Status Trend for Estuary, 2019-2023



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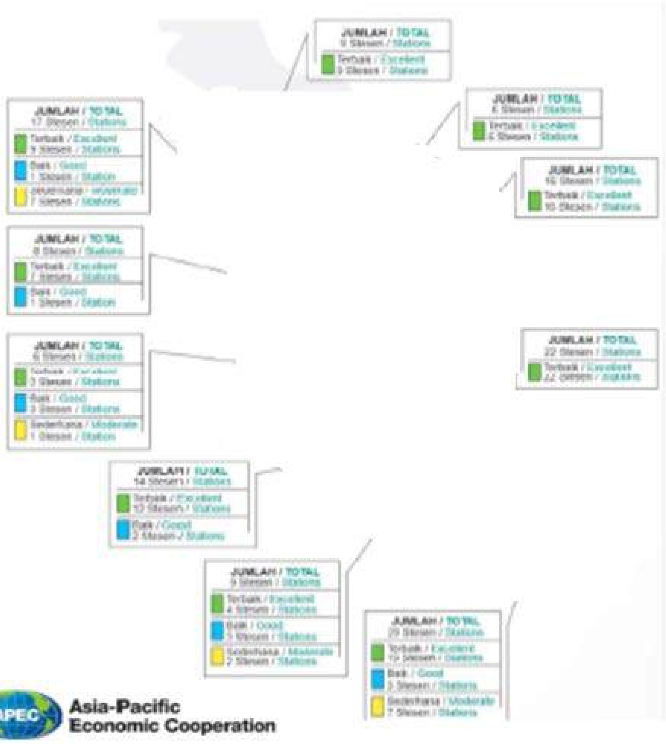
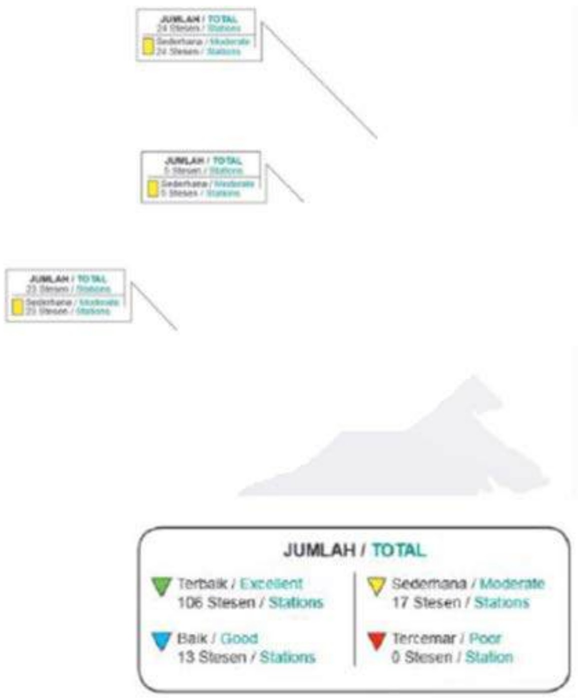
Enviromental Quality Report (EQR) 2023

Marine Water Quality Status based on the Location of **Coastal** Monitoring Stations in Malaysia





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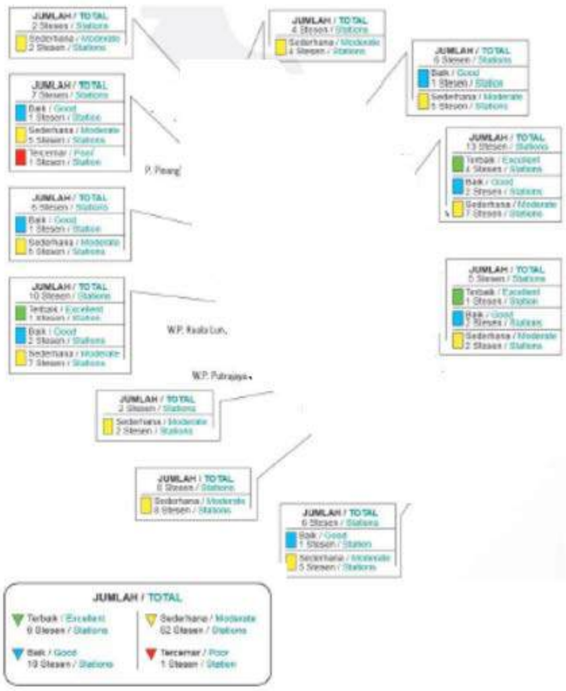
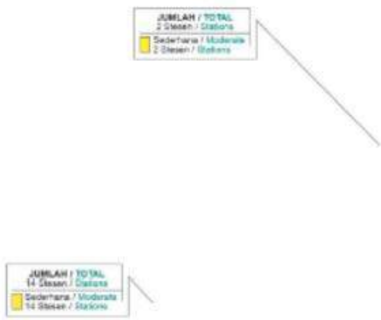
Enviromental Quality Report (EQR) 2023



Marine Water Quality Status based on the Location of **Estuary** Monitoring Stations in Malaysia



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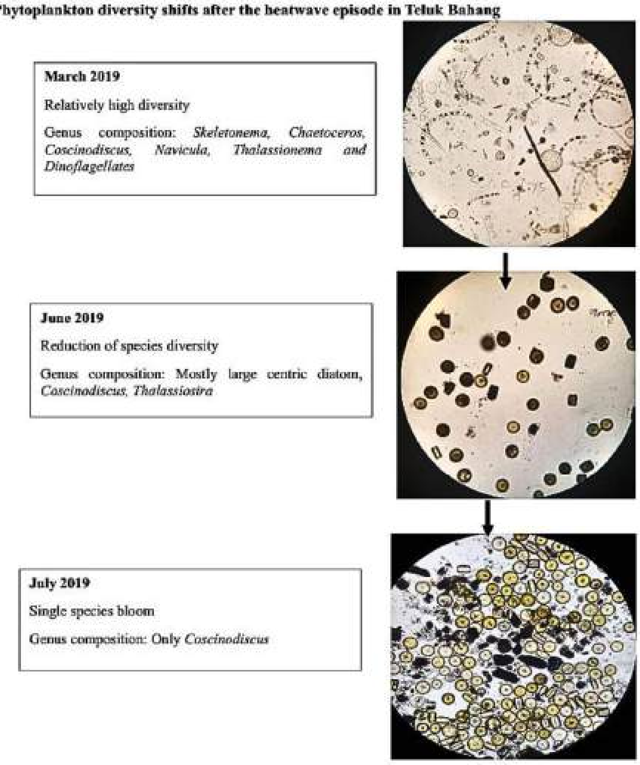
Enviromental Quality Report (EQR) 2023

https://mqims.doe.gov.my/mqims_manual/home_manual.html

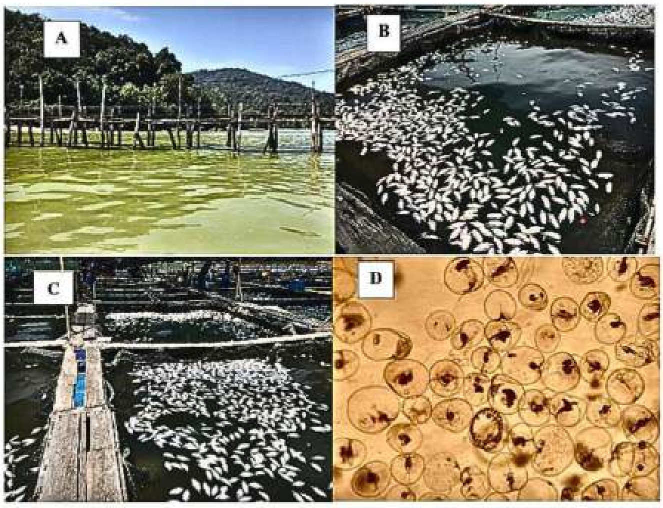
Discoloration and massive fish mortality events along the coasts of Malaysia
(San Diego-McGlone et. al., 2024)

Appendix 1

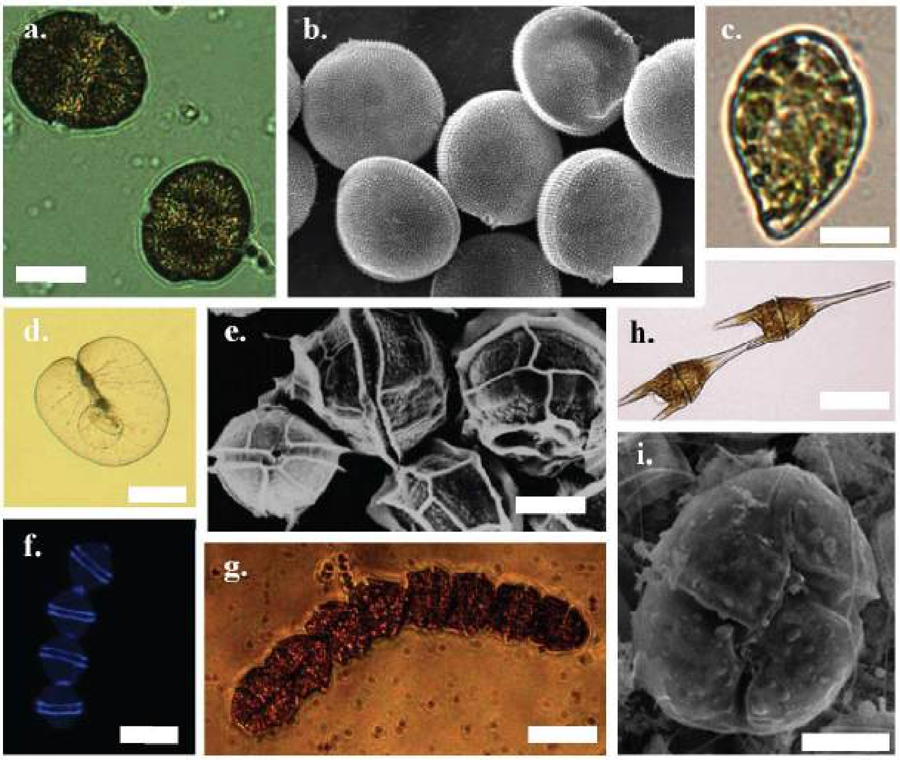
Phytoplankton diversity shifts after the heatwave episode in Teluk Bahang



Images by: Sazlina Salleh, Marine Studies, Centre for Policy Research, Universiti Sains Malaysia



Images by: Mr Sim Yee Kwang, Centre for Marine and Coastal Studies, Universiti Sains Malaysia (Reports in local news: eg: https://www.thestar.com.my/news/nation/2023/08/30/algal-bloom-doe-finds-oxygen-levels-off-teluk-bahang-too-low-to-sustain-marine-life and https://www.thevibes.com/articles/news/98773/human-activities-among-possible-factors-in-teluk-bahang-fish-deaths-report.



Harmful and potentially harmful marine microalgae found throughout the waters of Malaysia. Micrographs of (a) *Alexandrium minutum,* (b) *Prorocentrum minimum,* (c) *Chatenella ovata* (d) *Noctiluca scintillans,* (e) *Pyrodinium bahamense var. compressum,* (f) *A. tamiyavanichii,* scale bar = 50 μm, (g) *Gymnodinium catenatum*, (h) *Neoceratium furca*, scale bar = 50 μm and (i) *Karlodinium veneficum.* Scale bar = 10 μm (Teen et al., 2012)

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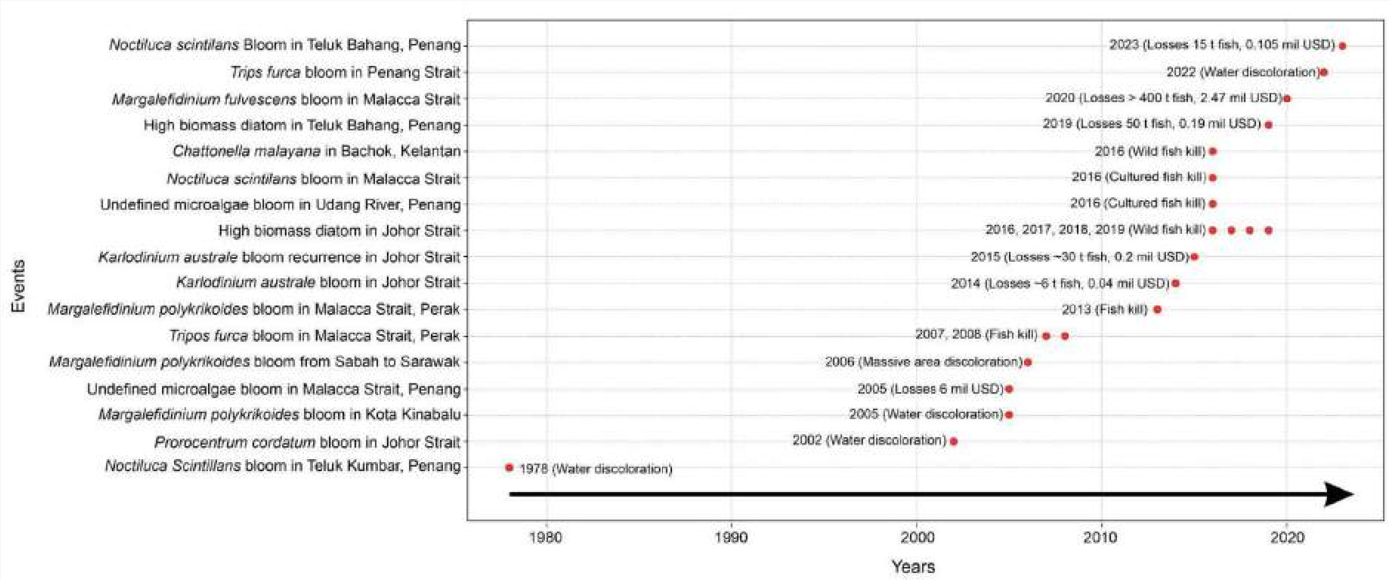

Chronology of fish kill events in Malaysian waters (2000–2023) related to harmful algal blooms (San Diego-McGlone et. al., 2024)

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Occurrence of HABs Event in Malaysia from year 1978-2023
(San Diego-McGlone et. al., 2024; Noor et al., 2023; Hee et al., 2023; Mohd Din et al., 2020; Lee et al, 2020)

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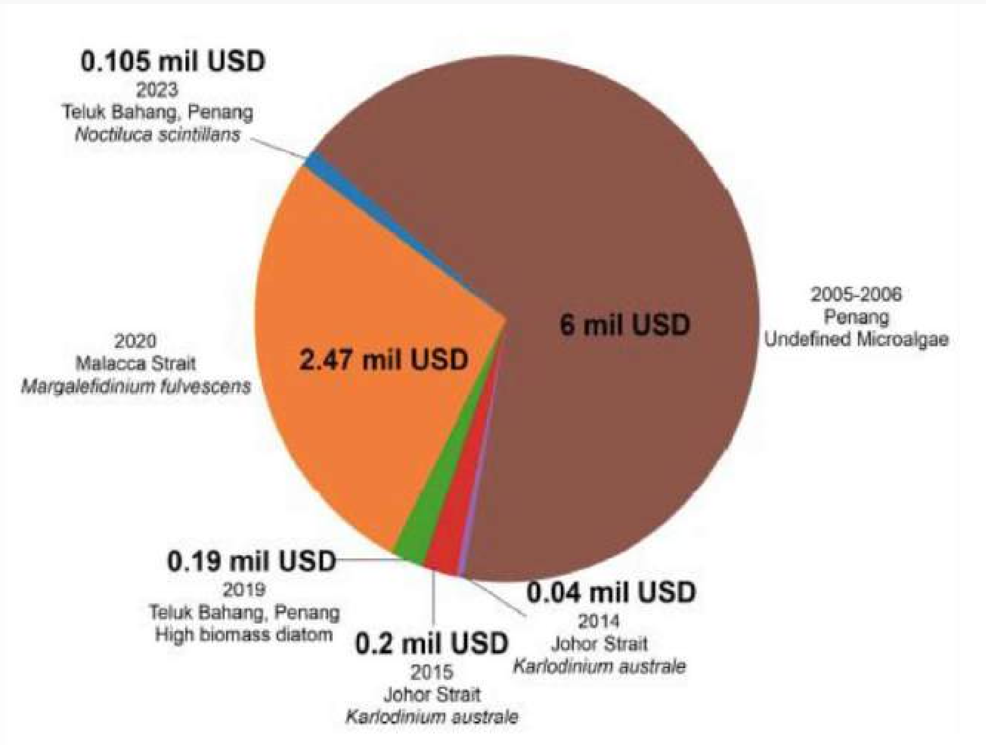
Economic Implications of Oxygen Loss in Malaysia

Fishery Losses | **01**
Mass fish deaths reduce income for fishermen.

02 | **Aquaculture Damage**
Fish farms suffer from lower productivity and profits.

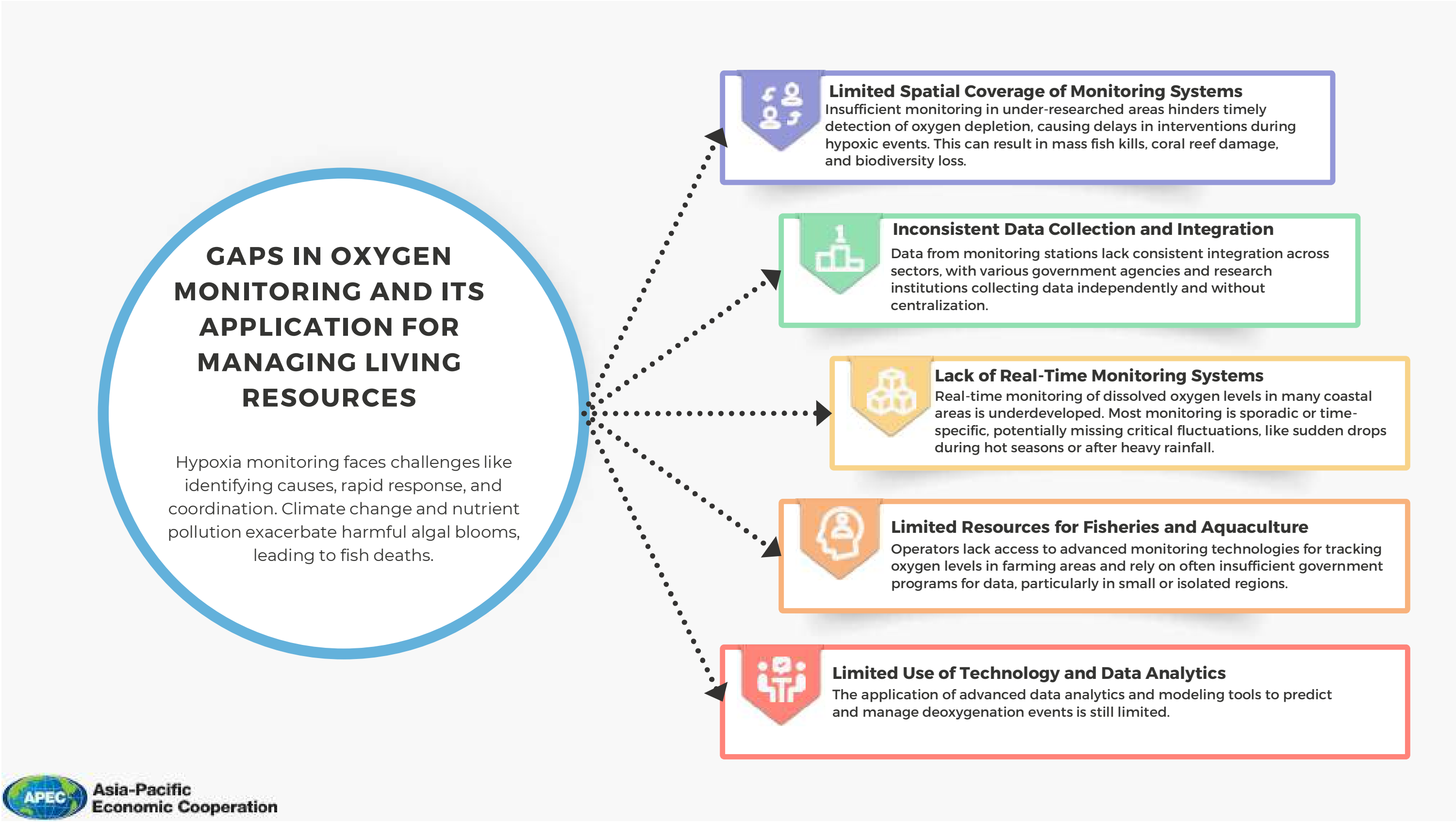
Tourism Decline | **03**
Poor marine health harms tourism.

04 | **Higher Costs**
Managing and restoring ecosystems becomes more expensive.



Fish kill losses due to microalgae with monetary values reported from Malaysia since 1978 (San Diego-McGlone et. al., 2024)

APEC Asia-Pacific Economic Cooperation


GAPS IN OXYGEN MONITORING AND ITS APPLICATION FOR MANAGING LIVING RESOURCES
Hypoxia monitoring faces challenges like identifying causes, rapid response, and coordination. Climate change and nutrient pollution exacerbate harmful algal blooms, leading to fish deaths.
Limited Spatial Coverage of Monitoring Systems
Insufficient monitoring in under-researched areas hinders timely detection of oxygen depletion, causing delays in interventions during hypoxic events. This can result in mass fish kills, coral reef damage, and biodiversity loss.
Inconsistent Data Collection and Integration
Data from monitoring stations lack consistent integration across sectors, with various government agencies and research institutions collecting data independently and without centralization.
Lack of Real-Time Monitoring Systems
Real-time monitoring of dissolved oxygen levels in many coastal areas is underdeveloped. Most monitoring is sporadic or time-specific, potentially missing critical fluctuations, like sudden drops during hot seasons or after heavy rainfall.
Limited Resources for Fisheries and Aquaculture
Operators lack access to advanced monitoring technologies for tracking oxygen levels in farming areas and rely on often insufficient government programs for data, particularly in small or isolated regions.
Limited Use of Technology and Data Analytics
The application of advanced data analytics and modeling tools to predict and manage deoxygenation events is still limited.
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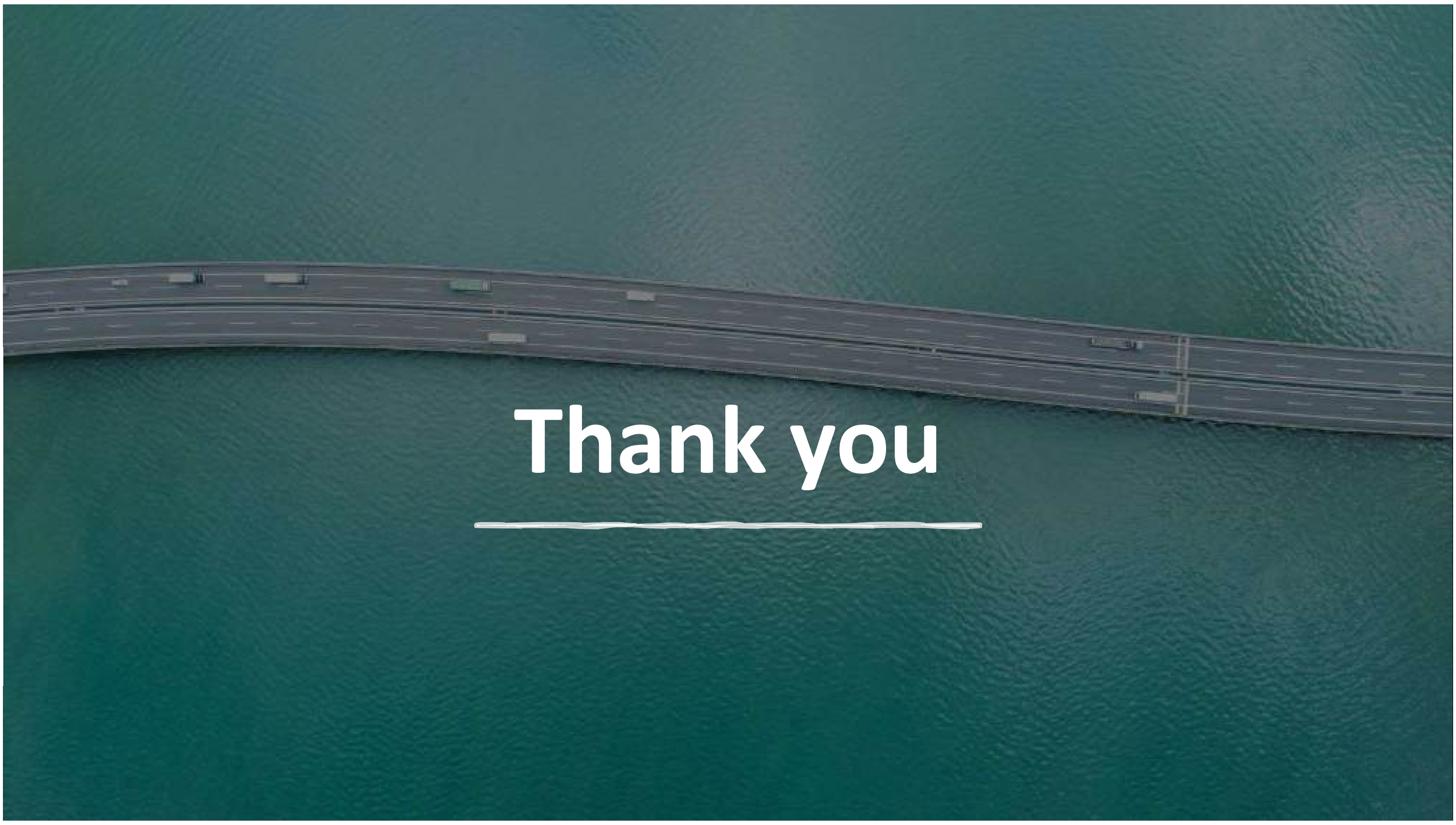
Thank you

Coastal hypoxia

Coastal observatories of global change in Mexico

UNAM, Mexico

September 30 2024

Instituto de Ciencias del Mar y Limnología, UNAM

Questions:

1. The drivers of low oxygen in the coastal waters of your economies:

Upwelling, eutrophication.

2. The types of coastal water living resources in your economy that may be affected by oxygen loss.

Fisheries, aquaculture.

3. The economic implications of oxygen loss in environments of your economy (e.g. in fisheries and aquaculture sectors).

I do not know.

4. An emblematic case of oxygen monitoring in a coastal environment in your economy.

See presentation (Mazatlán, entrance of the Gulf of California).

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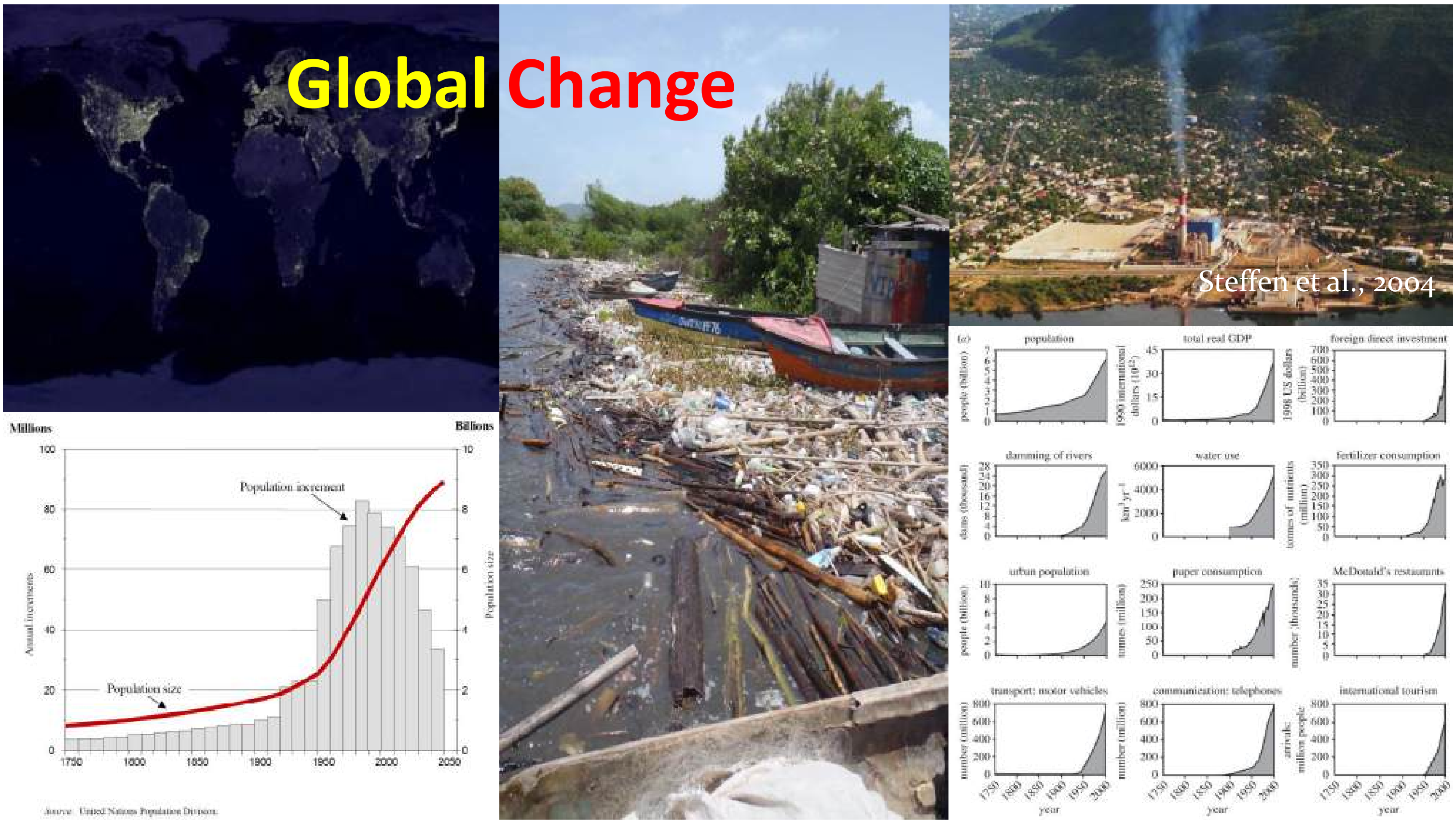
5. The current gaps in oxygen monitoring and its application for the management of



Coastal observatories of global change in Mexico (2013 – 2113 ???)

Operational Oceanography

Journal of Operational Oceanography

ISSN: 1755-876X (Print) 1755-8778 (Online) Journal homepage: http://www.tandfonline.com/loi/tjoo20

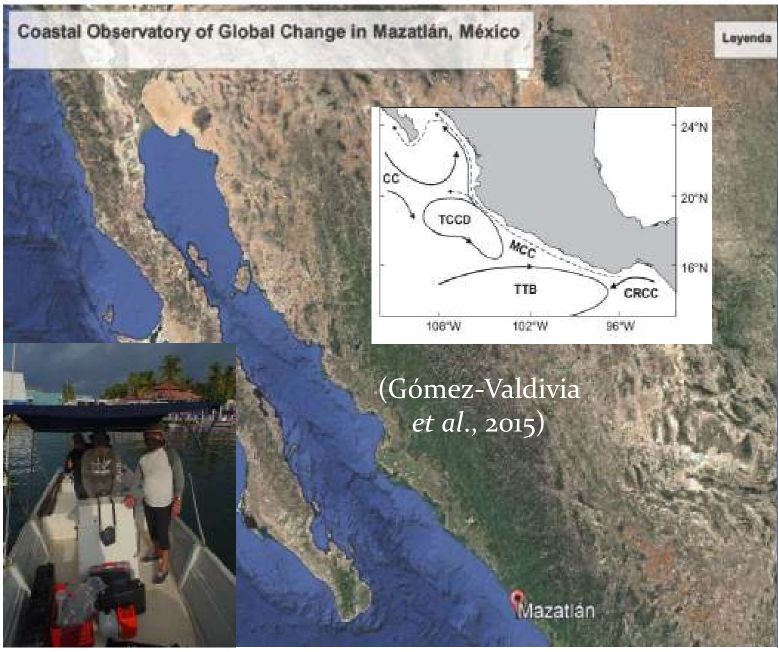
A low-cost long-term model of coastal observatories of global change

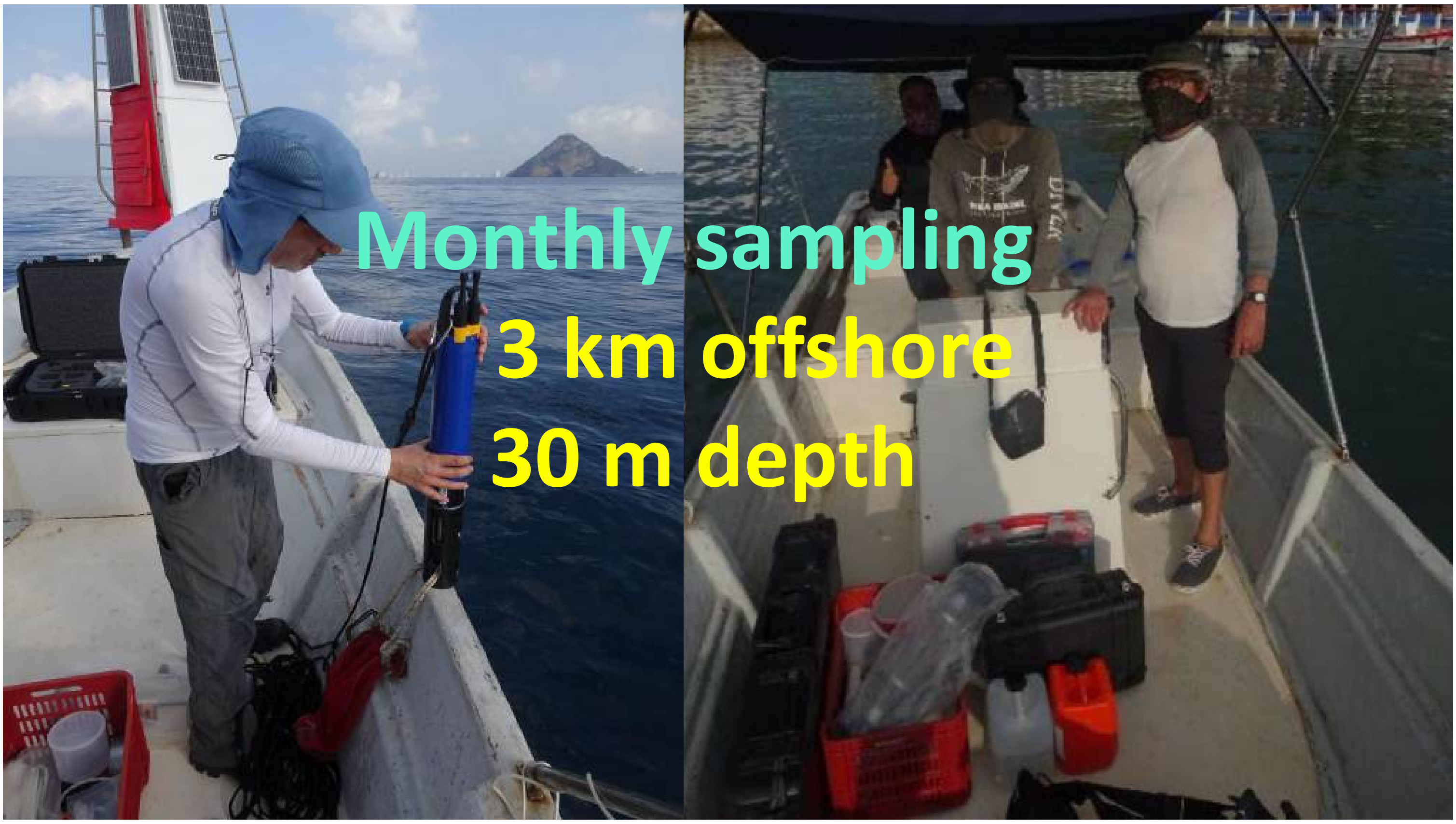
Joan-Albert Sanchez-Cabeza, León Felipe Álvarez Sánchez, José Gilberto Cardoso-Mohedano, Edgar Escalante Mancera, Misael Díaz-Asencio, Hugo López-Rosas, Maria Luisa Machain-Castillo, Martín Merino-Ibarra, Ana Carolina Ruiz-Fernández, Rosalba Alonso-Rodríguez, Mario Alejandro Gómez-Ponce, Enrique Ávila, Serguei Rico-Esenaro, Miguel Ángel Gómez-Reali, Carlos Alberto Herrera-Becerril & Michel Grutter

Sustainable strategy and technology

Institut de Recherche pour le Développement
FRANCE

Mazatlán
Entrance of the Gulf of California



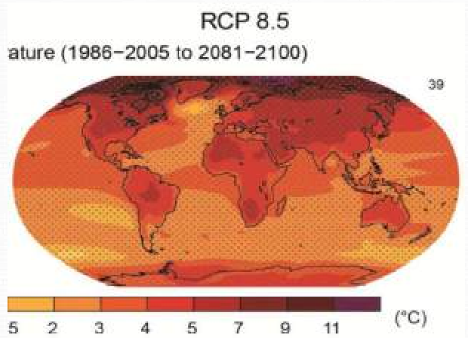


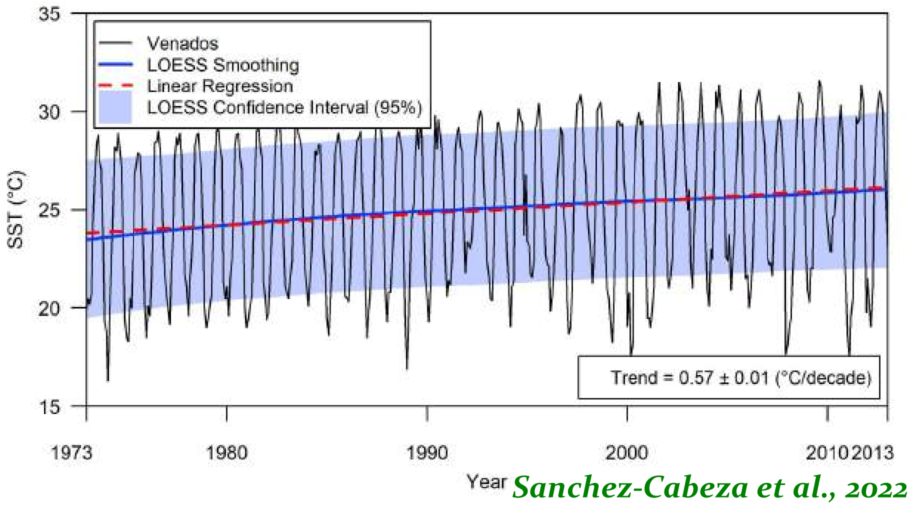

Progress in Oceanography 202 (2022) 102746
Contents lists available at ScienceDirect
Progress in Oceanography
journal homepage: www.elsevier.com/locate/pocean

Rapid surface water warming and impact of the recent (2013–2016) temperature anomaly in shallow coastal waters at the eastern entrance of the Gulf of California

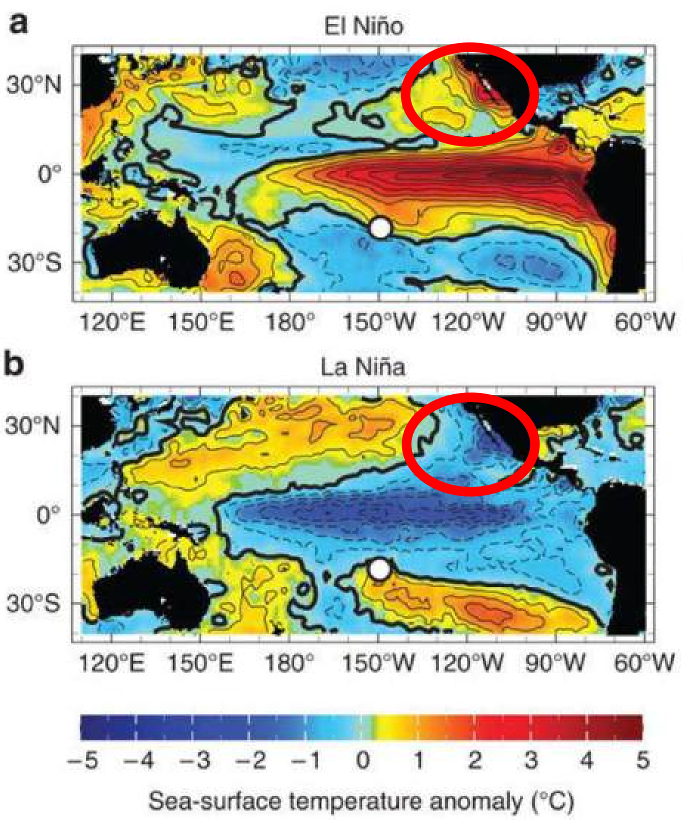
Joan-Albert Sanchez-Cabeza[a,*], Carlos Alberto Herrera-Becerril[b], José Luis Carballo[a], Benjamín Yáñez[a], León Felipe Álvarez-Sánchez[c], José-Gilberto Cardoso-Mohedano[d], Ana Carolina Ruiz-Fernández[a]

Global warming (IPCC, 2013): global ocean ~ 0.17 °C / decade
Mazatlán: 0.57 °C / decade



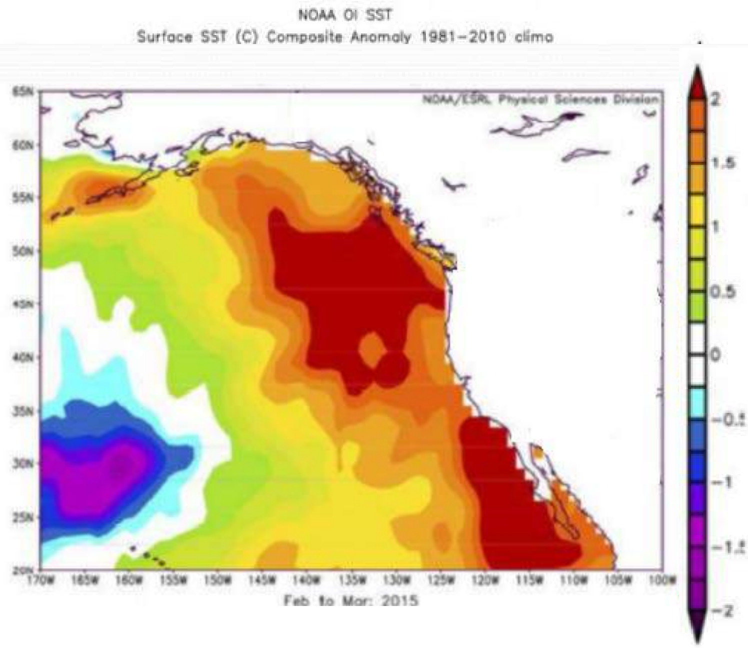


Sanchez-Cabeza et al., 2022



ENSO

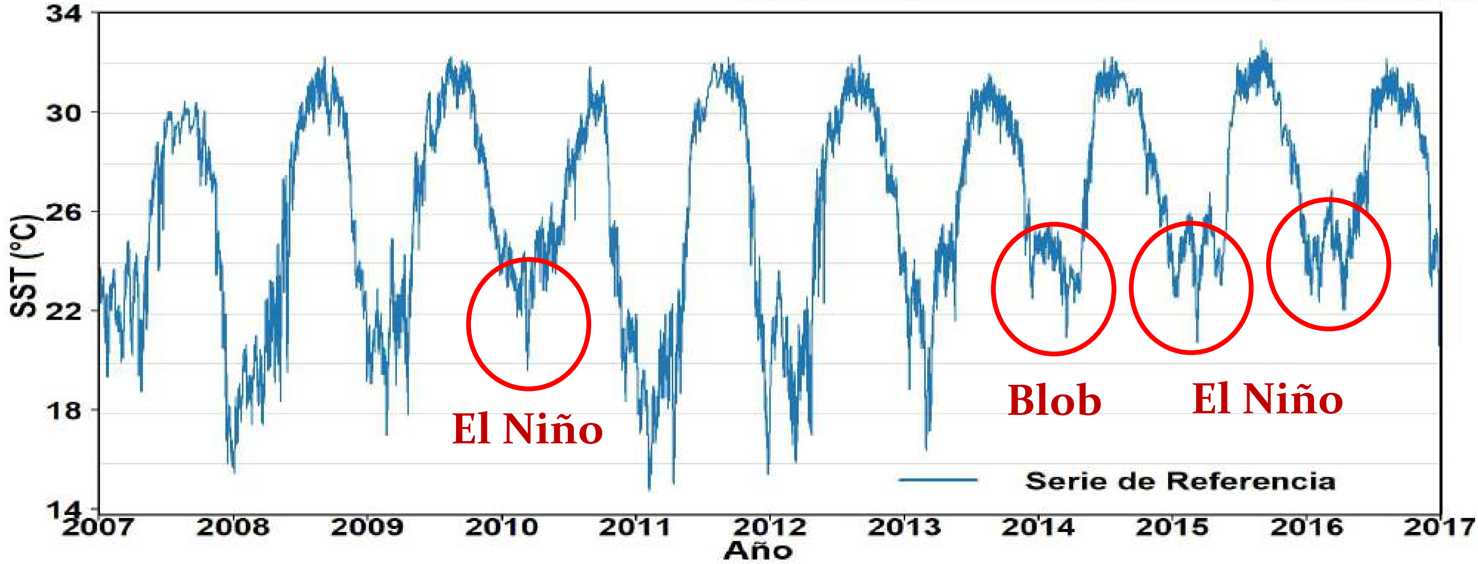
Marine heatwaves



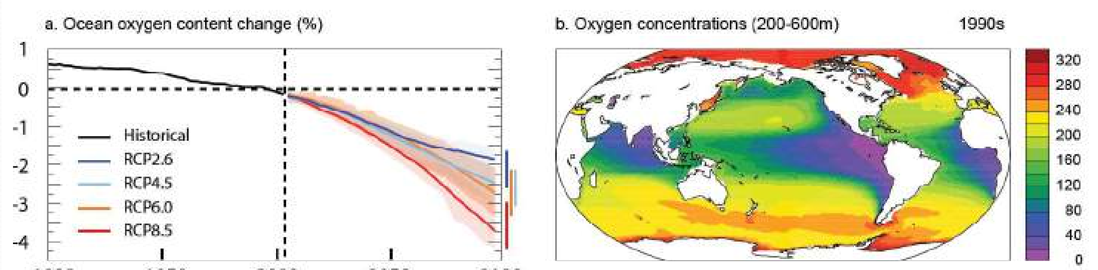
Progress in Oceanography 202 (2022) 102746
Contents lists available at ScienceDirect
Progress in Oceanography
journal homepage: www.elsevier.com/locate/pocean

Rapid surface water warming and impact of the recent (2013–2016) temperature anomaly in shallow coastal waters at the eastern entrance of the Gulf of California

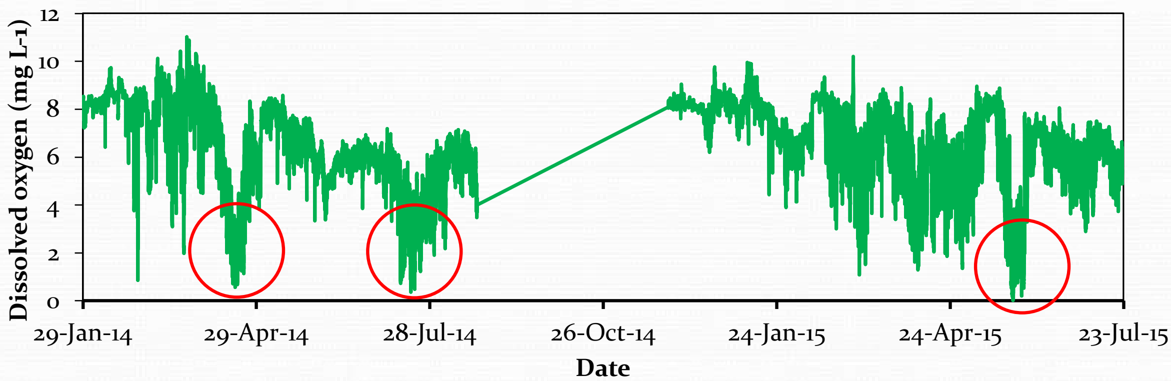
ENSO impacts minimum temperatures



Deoxygenation and hypoxia



IPCC, 2013



Dissolved oxygen profiles (spring, El Niño conditions)

MAZ1: 2015-04-28
MAZ2: 2016-03-31

Hypoxia: 2 mg/L = 64 μmol L^{-1}

Continental Shelf Research 233 (2022) 104634

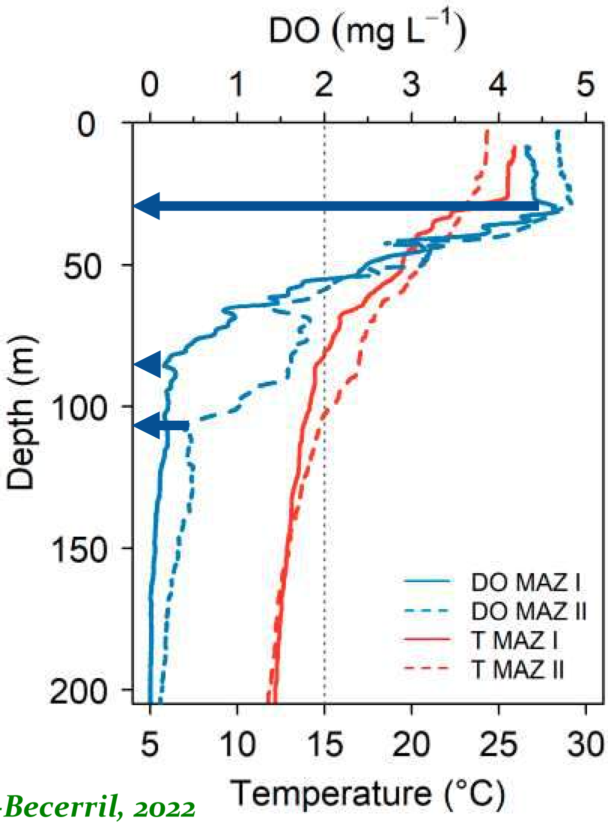
Contents lists available at ScienceDirect

Continental Shelf Research

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

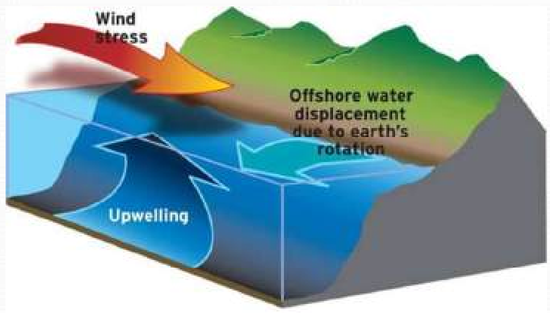
Statistical identification of coastal hypoxia events controlled by wind-induced upwelling

Carlos Alberto Herrera Becerril[a], Joan Albert Sanchez Cabeza[b,*], León Felipe Álvarez Sánchez[c], Andrea Rebeca Lara-Cera[a], Ana Carolina Ruiz-Fernández[b], José-Gilberto Cardoso-Mohedano[d], María Luisa Machain-Castillo[e], François Colas[f]

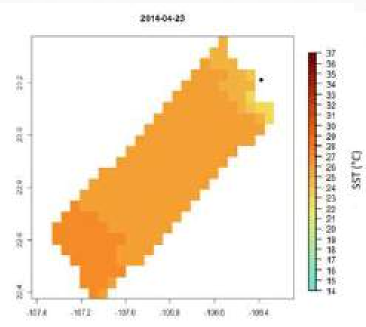


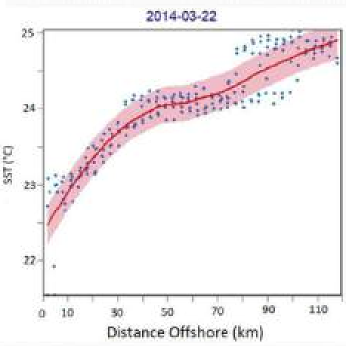
Herrera-Becerril, 2022

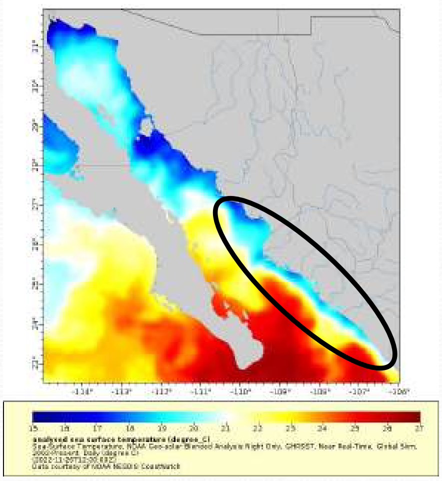
Wind-induced coastal upwelling



Sea Surface Temperature gradient (SSTGrad)

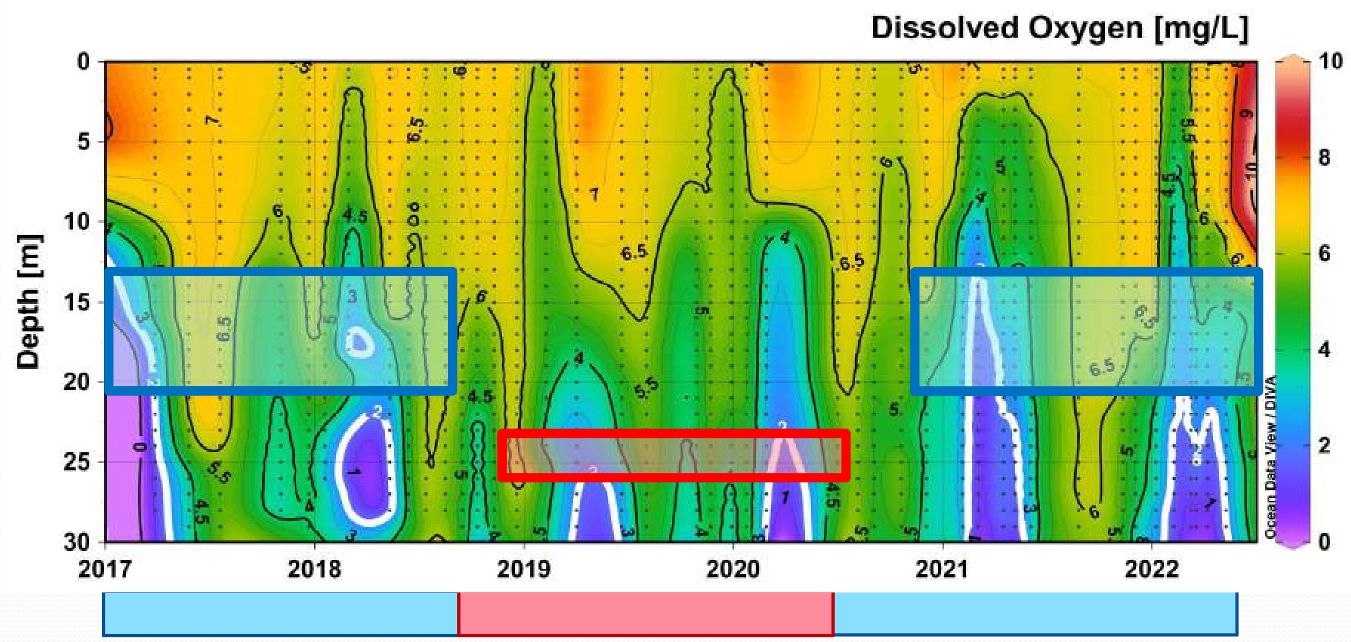






Lara Cera, 2020

La Niña conditions: 13 – 21 m
Weak El Niño conditions: 23 – 26 m depth



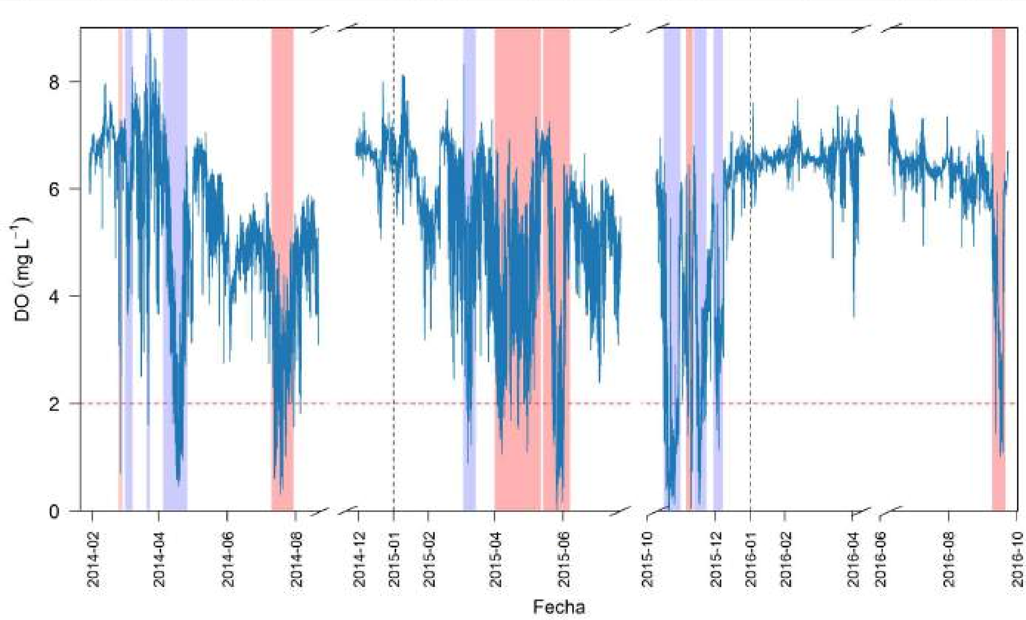
Hypoxia and upwelling?

Blue:

- **56% upwelling**.

Red:

- **44% other processes**.



Herrera Becerril et al., 2022

Asia-Pacific
Economic Cooperation

Coastal hypoxia

Coastal observatories of global change in Mexico

UNAM, Mexico

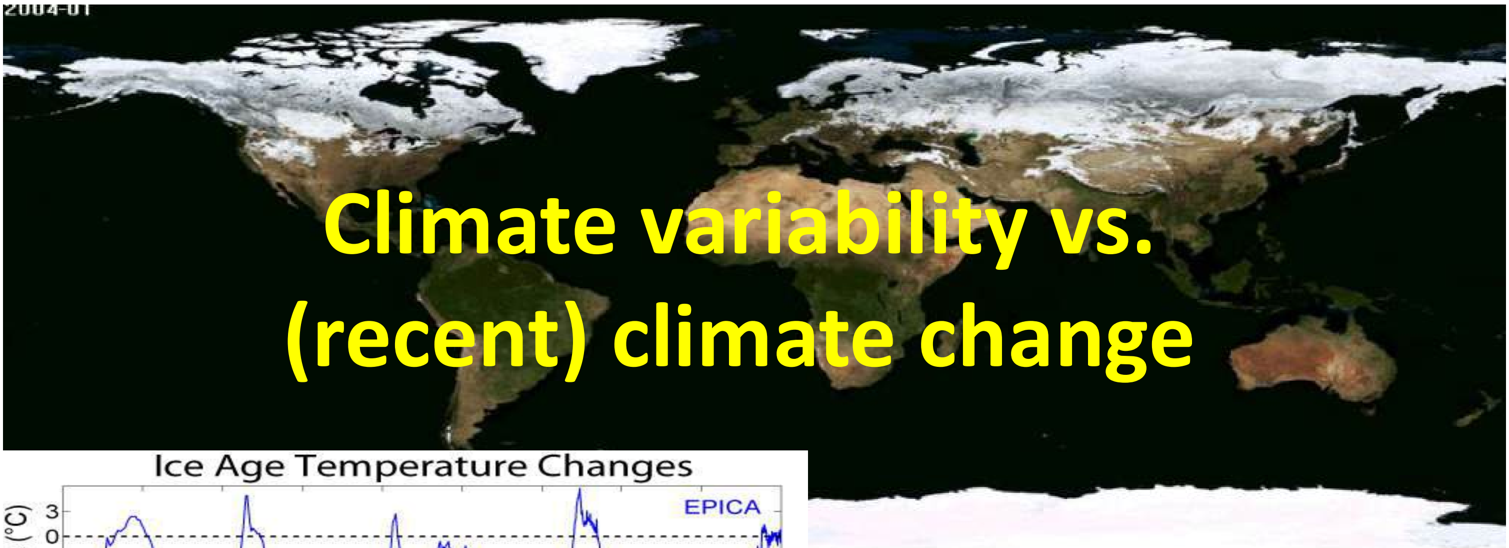
September 30 2024

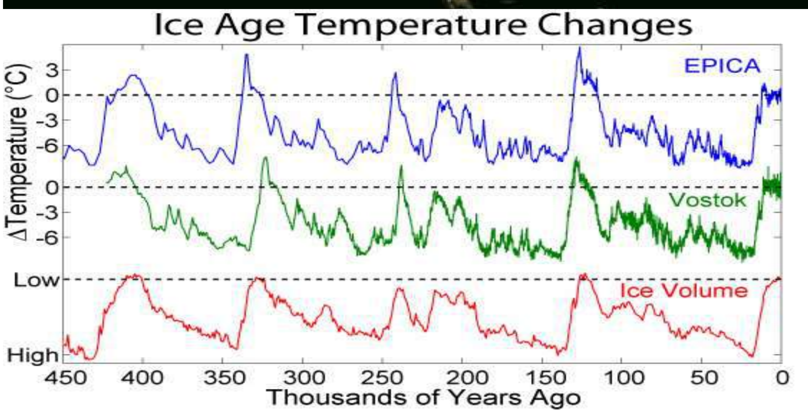
Acknowledgements.

UNAM, ICML.

Projects:

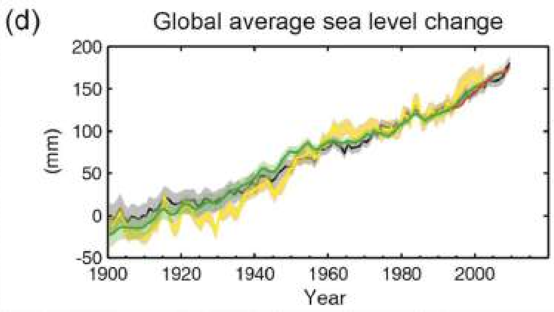
- UNAM-DGAPA PAPIIT-IB201612-2 and IN110518.
- CONACYT INFR-2013-01 204818, PDCPN-214349, SEMARNAT-278634 and CNR C0013-2016-05-277942.
- IAEA RLA7020, RLA7025 and INT7019
- TUBITAK.



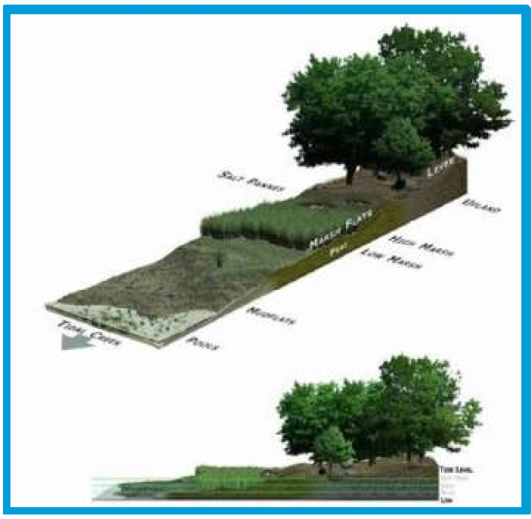


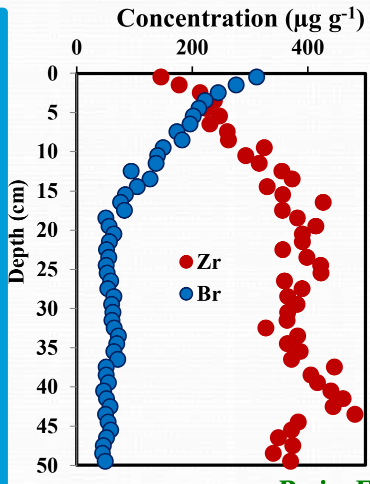
Interglacial: $CO_2 \leq 280$ ppm
Today ~ 421 ppm

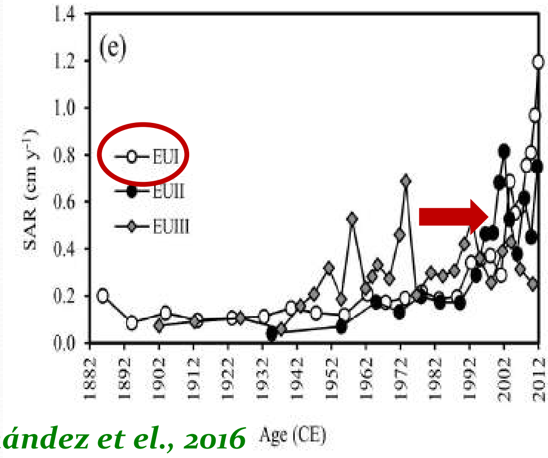
1.5 times higher



Sea Level

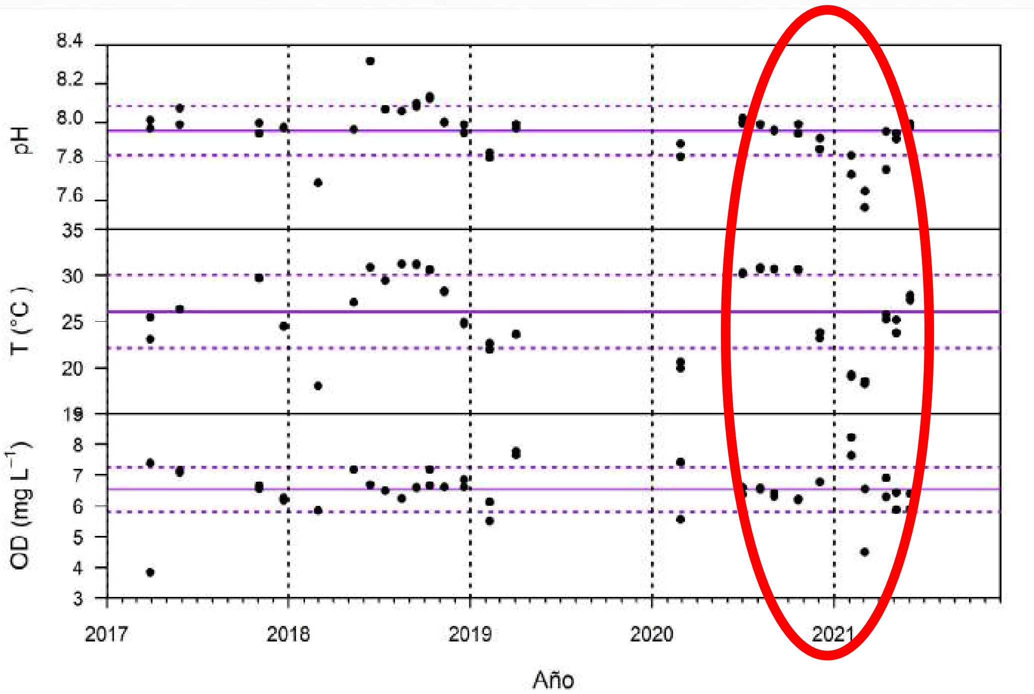




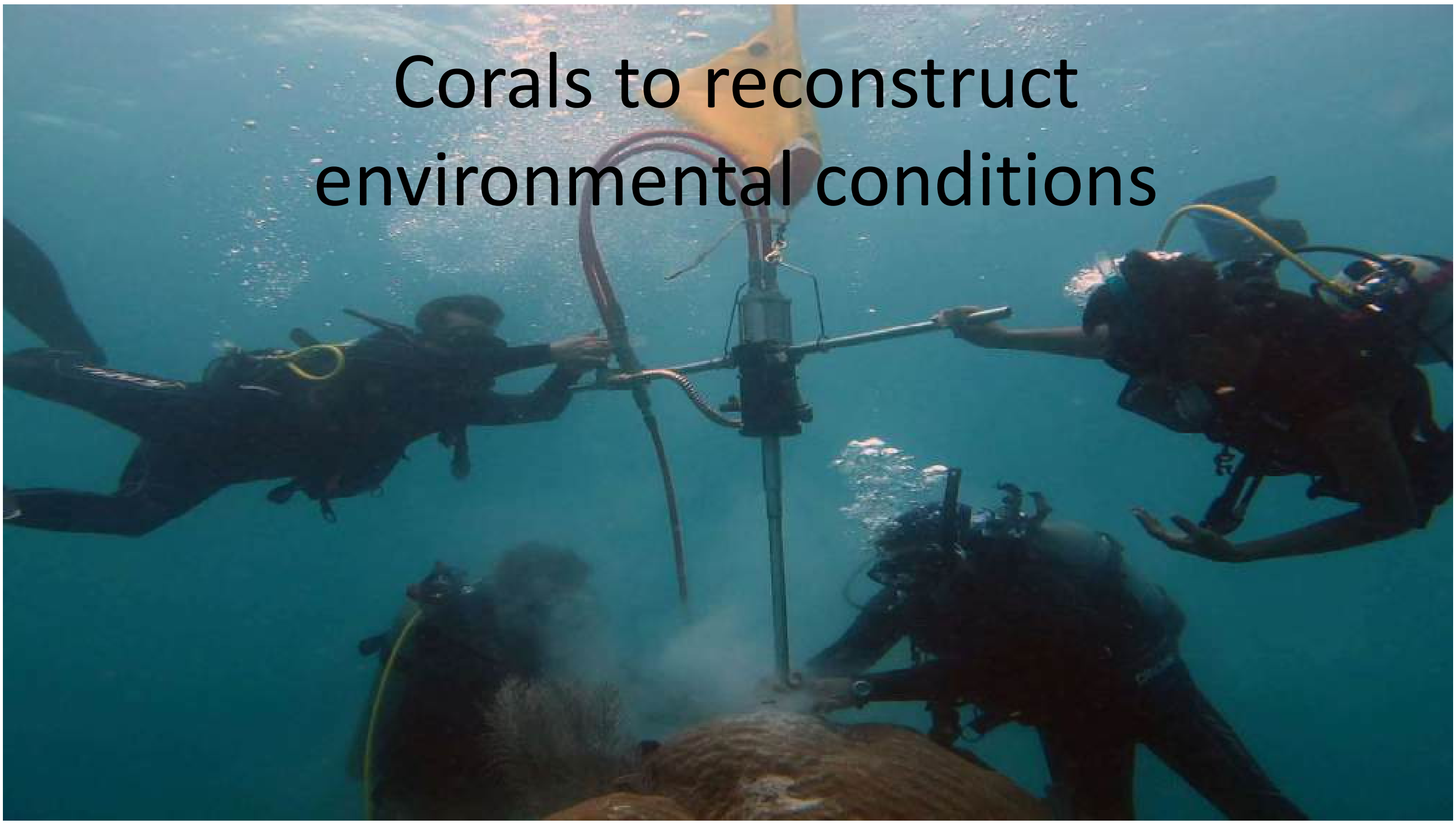


Ruiz-Fernández et al., 2016

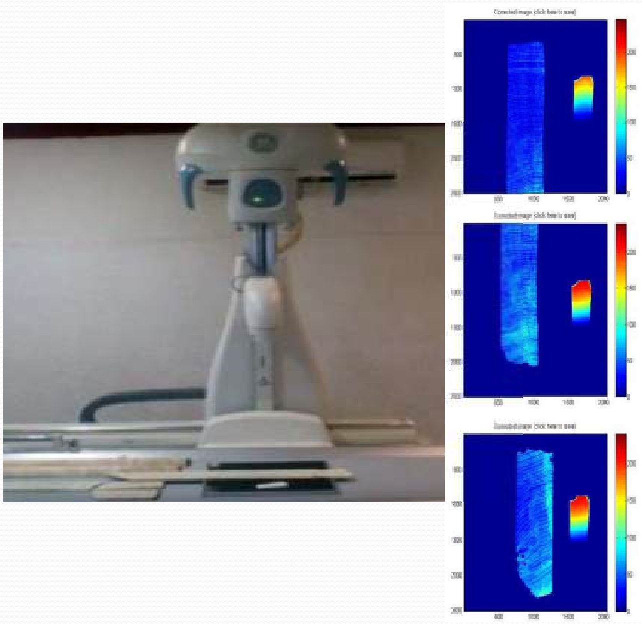
Coastal acidification and upwelling



Corals to reconstruct environmental conditions



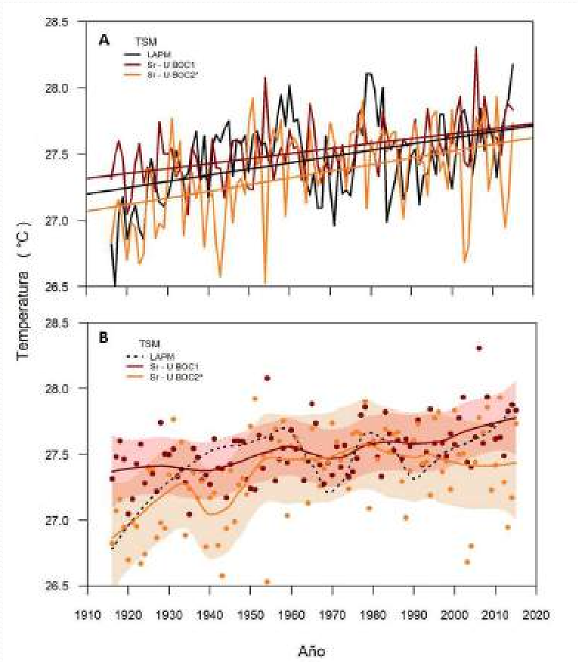
Sclechronology (X-rays)



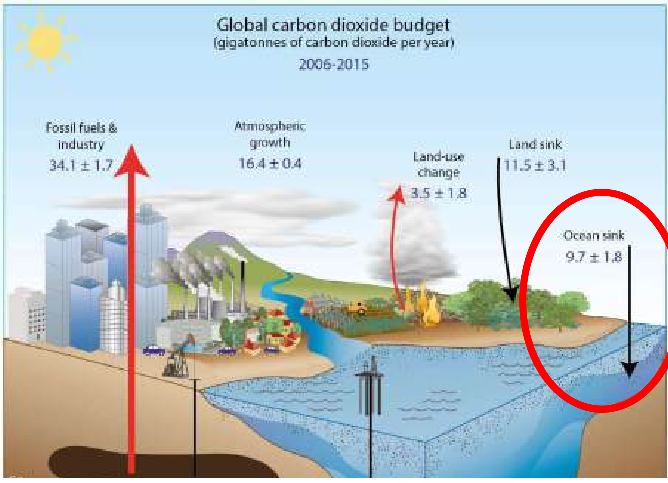
SST (U-Sr)

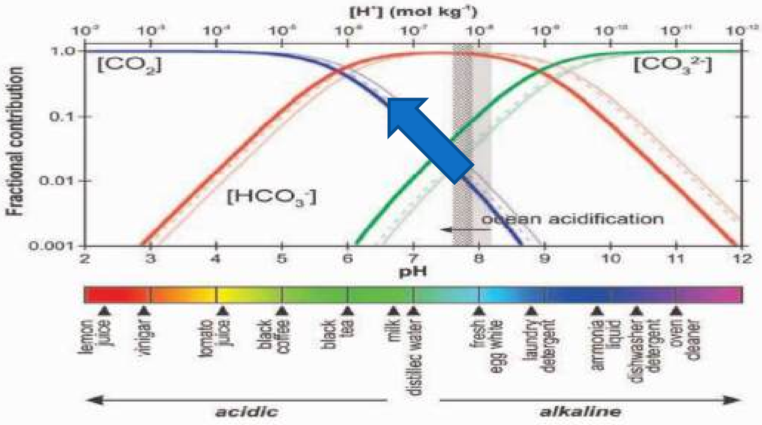
Instrumental
0.4 ± 0.3 °C

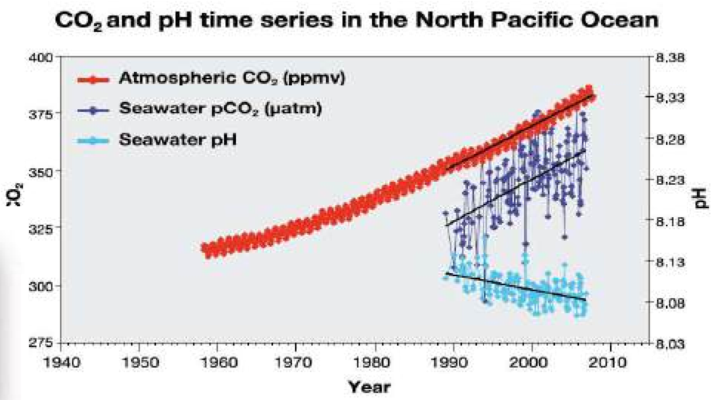
Sr-U
0.4 ± 0.1 °C

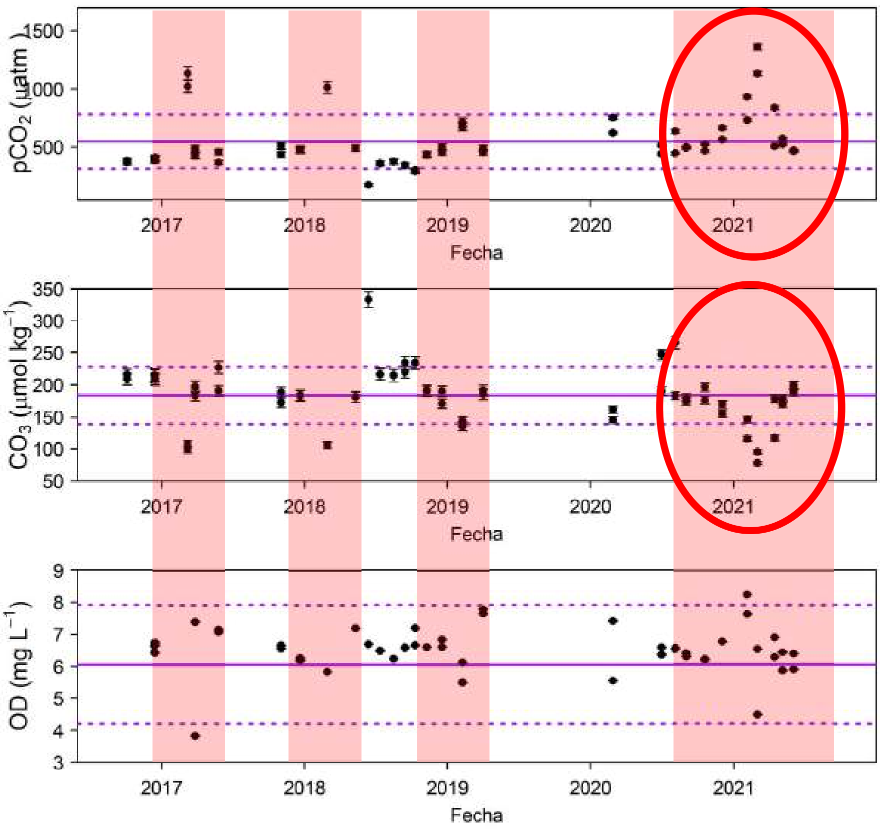


Marine acidification









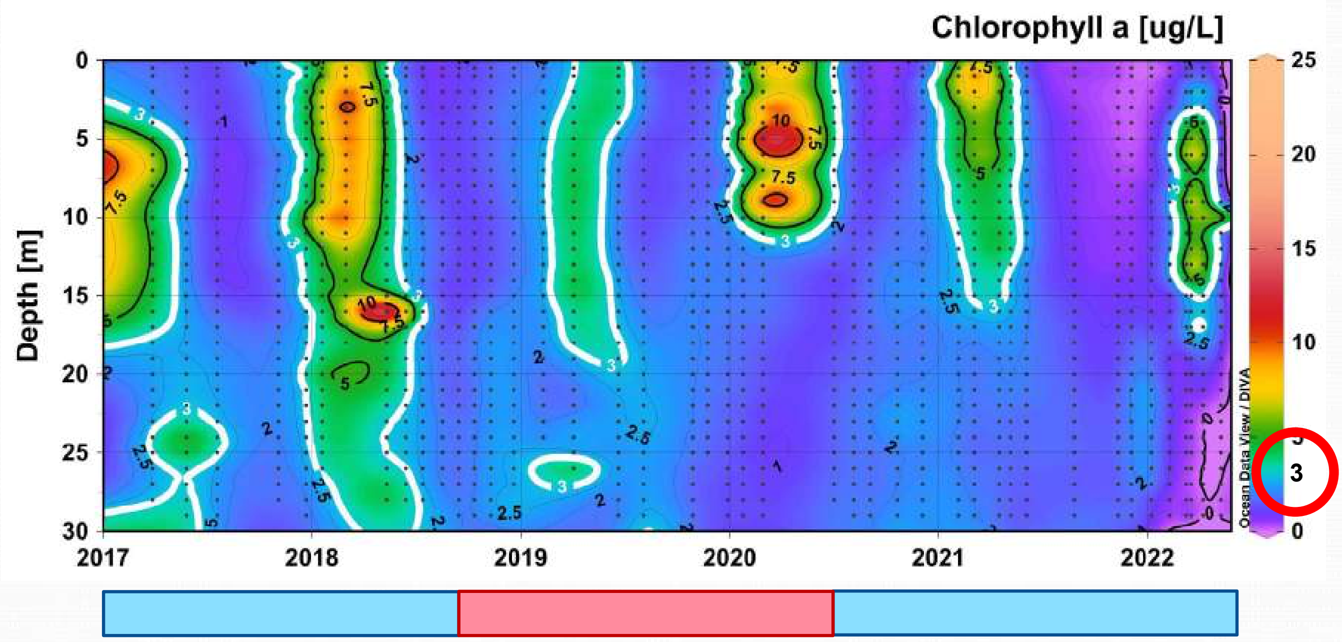
pCO_2 time series in the coastal zone

Since 2016

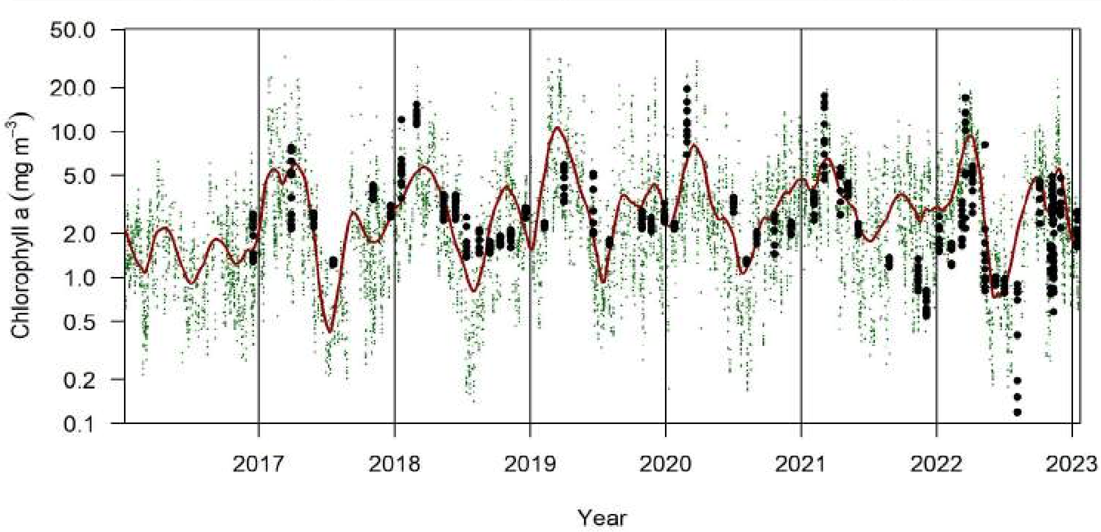
pCO2 high variability

Winter máxima -> upwelling impact

Chlorophyll a – La Niña

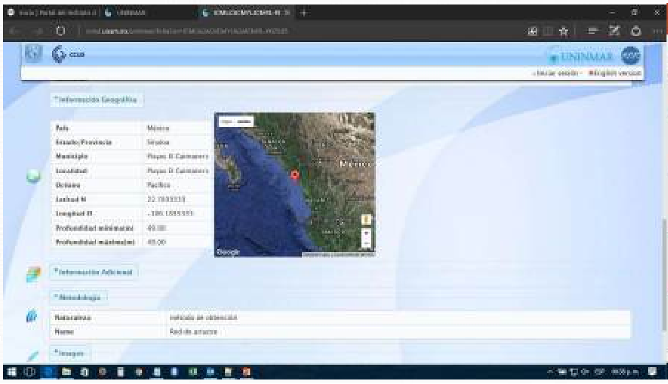


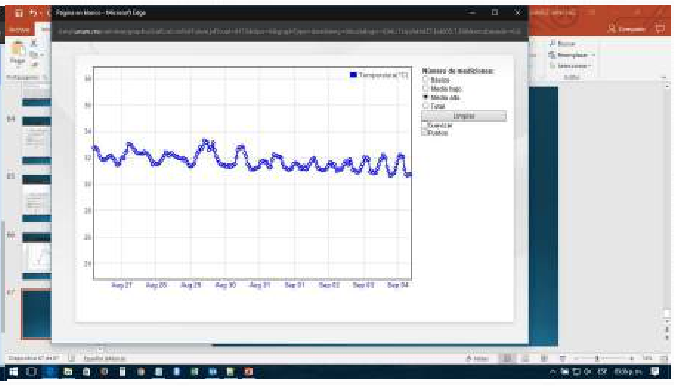
Satellite data



UNINMAR - TULUM

- > 70 million data.
- ~ 2 million data online.
- 1500 visits in 2023.



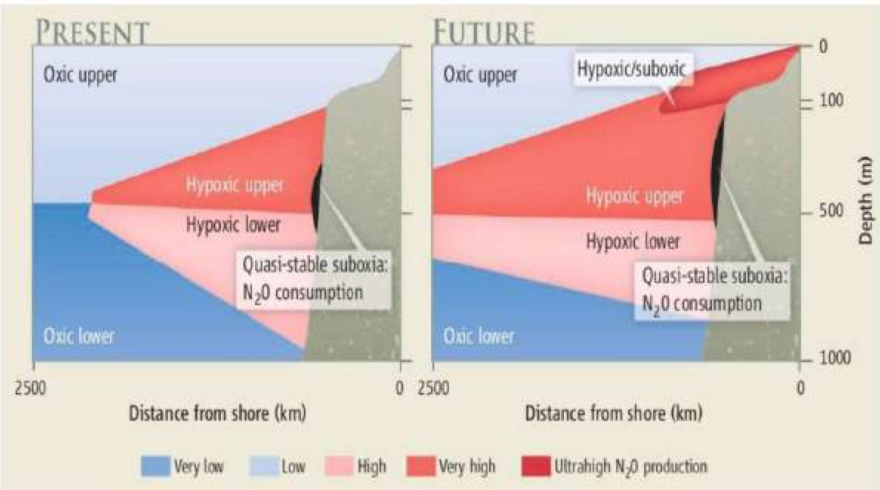


“Developing best practices to address coastal marine oxygen loss in APEC economies for improving the management of marine living resources”

"Peru’s efforts to address coastal marine oxygen loss in order to enhance the management of living marine resources“

Esquina Gamarra y General Valle s/n, Chucuito, Callao | Central telefónica: (051) 208 8650 | www.gob.pe/imarpe

Codispoti, 2010. Interesting times for marine N_2O
Science, 327 (5971) (2010), pp. 1339-1340
DOI: 10.1126/science.1184945

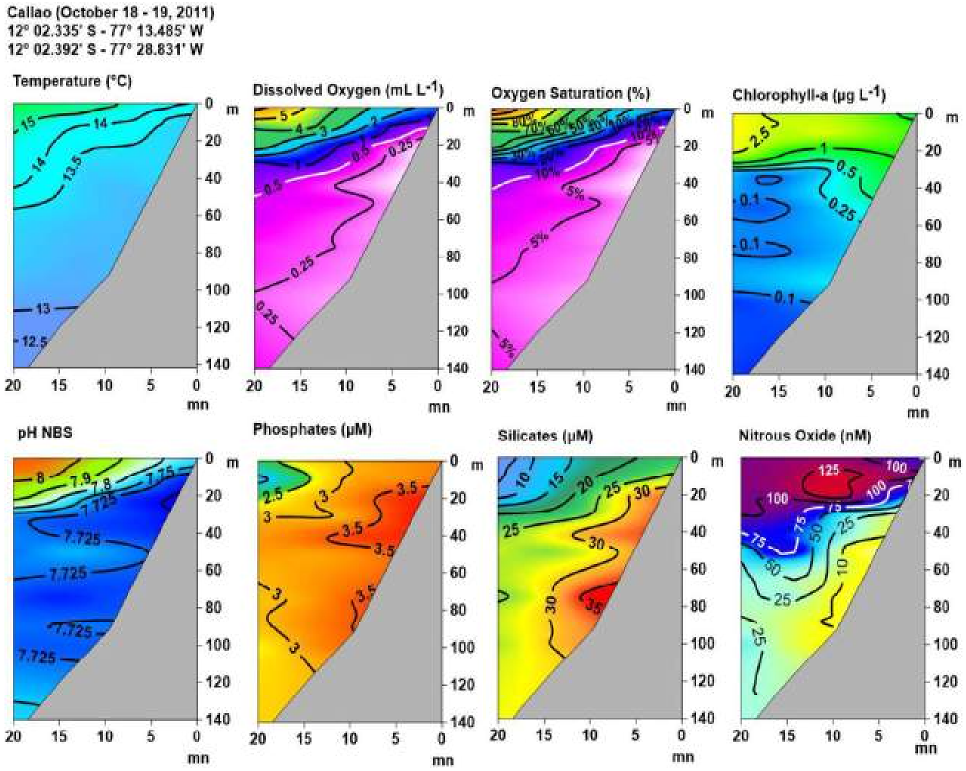


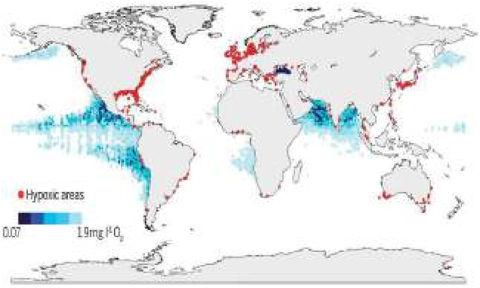
A generic eastern boundary in present-day and future oceans. Suboxia can extend further offshore than shown here, but is absent from a large portion of the oceanic eastern boundary.

The ongoing loss of oxygen in the ocean (i.e., deoxygenation; Levin, 2018) is mainly a consequence of global warming caused by climate change (Deutsch *et al.,* 2011; Schmidtko *et al.,* 2017; Oschlies *et al.,* 2018).

Regions with historically very low oxygen concentration (i.e., Oxygen Minimum Zones, OMZs) are expanding (Stramma *et al.,* 2010; Schmidtko *et al*., 2017), and new oxygen-deficient areas are emerging, mainly in coastal regions (e.g., Rabalais *et al.,* 2002; Dubosq *et al.,* 2022).

He effects of deoxygenation on marine biota are diverse (e.g., Breitburg *et al.,* 2018) and vary depending on the organism, species interactions, species tolerance, trophic group, mobility, and magnitude, frequency and duration (permanent versus episodic) of deoxygenation events (Limburg *et al*., 2020).

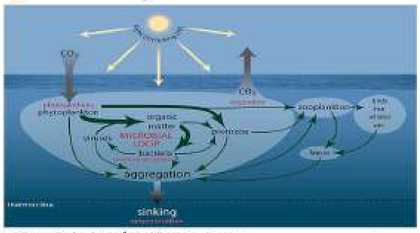




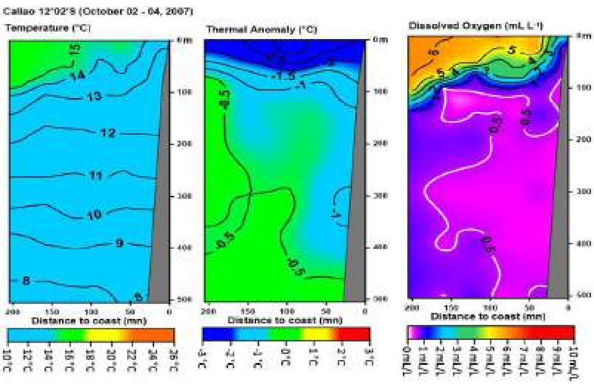
Low and declining oxygen levels in the open ocean and coastal waters affect processes ranging from biogeochemistry to food security. The global map indicates coastal sites where anthropogenic nutrients have exacerbated or caused O_2 declines to <2 mg L^{-1}(<63 mmol L^{-1} or 1,40 mL L^{-1}) (red dots), as well as ocean oxygen-minimum zones at 300 m of depth (blue shaded regions). [Map created from data provided by R. Diaz, updated by members of the GO2NE network, and downloaded from the World Ocean Atlas 2009].

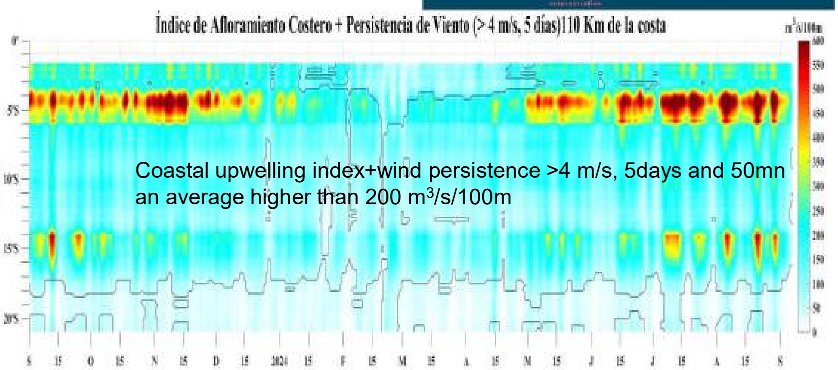
Breitburg *et al.,* Science 359, 46 (2018)
DOI: 10.1126/science.aam7240

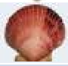
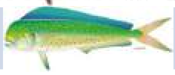
Factors that cause low oxygen levels in coastal waters



- ✓ Coastal upwelling: The Humboldt Current is associated with upwelling, a process where deep, cold, nutrient-rich waters rise to the surface. These deep waters are also low in oxygen, contributing to low-oxygen zones (hypoxia) near the coast.
- ✓ High biological productivity: The nutrient-rich waters of upwelling support phytoplankton proliferation, which increases primary productivity. However, when phytoplankton die, their decomposition by bacteria consumes oxygen, contributing to decreased oxygen levels in the water.
- ✓ Remineralization: The flow of organic matter from the surface to the bottom also contributes to the consumption of oxygen in the water column. The process of remineralization of organic matter by microorganisms consumes oxygen as it decomposes.
- ✓ Oxygen Minimum Zones (OMZ): Off the Peruvian coast there is a very extended OMZ, which is a layer of water with extremely low levels of oxygen..





Main Fishery Resources			Approximate Annual Catch	Imagen
English name	Spanish name	Scientific name		
Peruvian Anchovy	Anchoveta	*Engraulis ringens Jenyns, 1842*	4 to 8 million tons	
Jack mackerel or horse mackerel	Jurel	*Trachurus murphyi Nichols, 1920*	300,000 to 500,000 tons	
Mackerel	Caballa	*Scomber japonicus Houttuyn, 1782*	200,000 to 300,000 tons	
Hake or South pacific hake	Merluza	*Merluccius gayi peruanus Ginsburg, 1954*	40,000 to 60,000 tons	
Peruvian Scallop	Concha de abanico	*Argopecten purpuratus (Lamarck, 1819)*	60,000 to 70,000 tons	
Jumbo flying squid or Humboldt squid	Pota o calamar Gigante	*Dosidicus gigas (d'Orbigny [in 1834-1847], 1835)*	400,000 to 600,000 tons	
Pacific bonito	Bonito	*Sarda chiliensis chiliensis (Cuvier, 1832)*	30,000 to 60,000 tons	
Dolphinfish / Mahi Mahi	Perico o Dorado	*Coryphaena hippurus Linnaeus, 1758*	30,000 to 50,000 tons	

https://biodiversidadacuatica.imarpe.gob.pe/Catalogo/Grupos_Biologicos?id=127

Summary of employment figures

- ✓ Industrial fishing: Around 30,000 people.
- ✓ Artisanal fishing: More than 200,000 people.

The fishing sector represents approximately between 0.5% and 1.5% of Peru's Gross Domestic Product (GDP or PBI), although its contribution can be higher in years of high fish productivity and favorable exports.

Impact of the Fishing Sector on Employment In addition to economic income, fishing is a sector that generates direct employment for more than **230,000 people**, including both artisanal fishermen and workers in processing plants and the industrial fleet.

Peru's fishing sector is a key source of income, generating between USD 1,000 and 1,500 million annually, with fishmeal and fish oil leading exports. Artisanal fishing and aquaculture also play an important role, especially in products for direct human consumption, complementing revenues and diversifying the country's export offerings.

Bertrand A, Chaigneau A, Peraltilla S, Ledesma J, Graco M, Monetti F, et al. (2011) Oxygen: A Fundamental Property Regulating Pelagic Ecosystem Structure in the Coastal Southeastern Tropical Pacific. PLoS ONE 6(12): e29558. https://doi.org/10.1371/journal.pone.0029558

In the southeastern tropical Pacific anchovy (Engraulis ringens) and sardine (Sardinops sagax) abundance have recently fluctuated on multidecadal scales and food and temperature have been proposed as the key parameters explaining these changes. However, ecological and paleoecological studies, and the fact that anchovies and sardines are favored differently in other regions, raise questions about the role of temperature. Here we investigate the role of oxygen in structuring fish populations in the Peruvian upwelling ecosystem that has evolved over anoxic conditions and is one of the world's most productive ecosystems in terms of forage fish. This study is particularly relevant given that the distribution of oxygen in the ocean is changing with uncertain consequences.

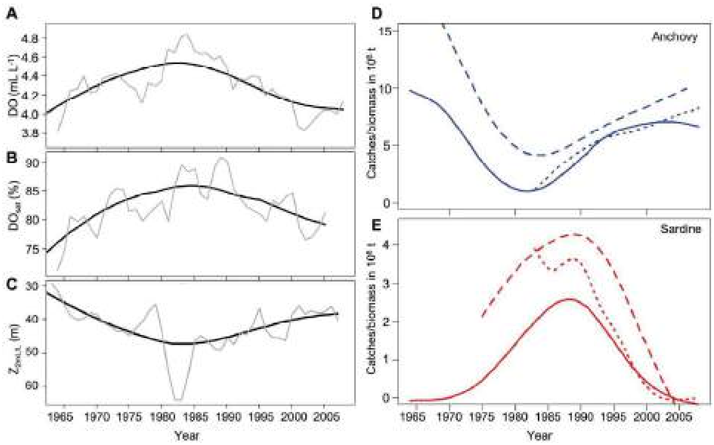
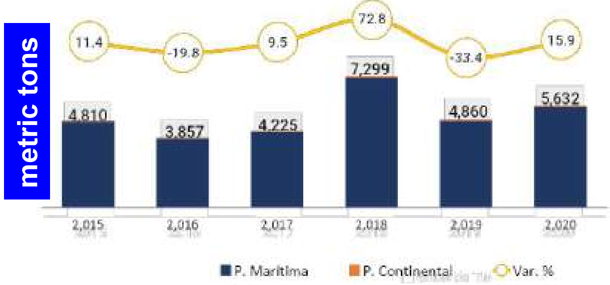


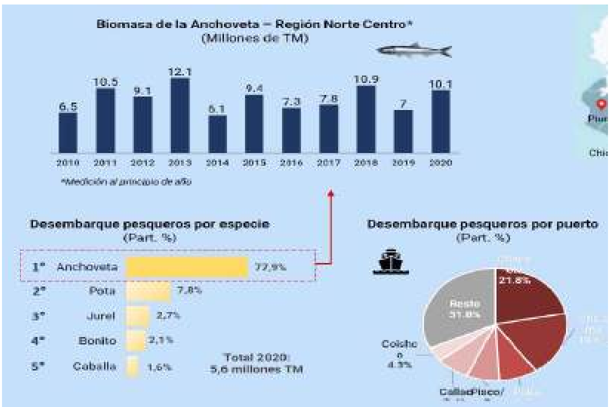
Figure 1. Time series (1964–2009) of oxygen and fish. Temporal variations of DO in mL L21 (black dotted line) (A), DOsat in % (black dashed line) (B), Z2 mL/L, in m (black solid line). Black solid line show the smoothed time series; gray solid line show the 4-years moving average. C. anchovy catches (blue solid line), biomass by VPA (blue dashed line) and acoustic biomass (blue dotted line). D. Temporal variations of sardine catches (red solid line), biomass by VPA (red dashed line) and acoustic biomass (red dotted line).
doi:10.1371/journal.pone.0029558.g001

Evolution of GDP of the Fishing Industry, 2010 – 2019

CHI indirect human consumption CHD direct human consumption

Evolution of fishing landings
Thousands of MT





Source INEI
Elaboration:
IEES – SNI

IMARPE monitors strandings along the Peruvian coast

Between March 19th and 25th, 2024, the Peruvian Marine Institute (IMARPE) reported the stranding of various marine organisms in the regions of La Libertad, Lima, and Ica, **associated with different factors**.

In the Lima region, on March 19th, the stranding of **"munida" *Grimothea monodon***, a species typical of cold coastal waters, was recorded at Puerto Supe beach (Barranca), covering an area of **810 m²**, with a total of 968.8 kg. This event was caused by the displacement of tropical water masses near the coast and the increase in sea surface temperature off the coast of Supe.

Additionally, on March 25th, at San Bartolo beach (Lima), an area of 900 m² saw the stranding of 31 species: 26 invertebrates, 4 macroalgae, and 1 fish. The sea surface temperature in the area was 27.4°C. Similar to the stranding in Paracas Bay, this event was associated with a deficiency in dissolved oxygen in the sea, caused by the algal proliferation of *A. sanguinea*.

https://www.gob.pe/institucion/imarpe/noticias/930369-imarpe-monitorea-varazones-a-lo-largo-del-litoral-peruano

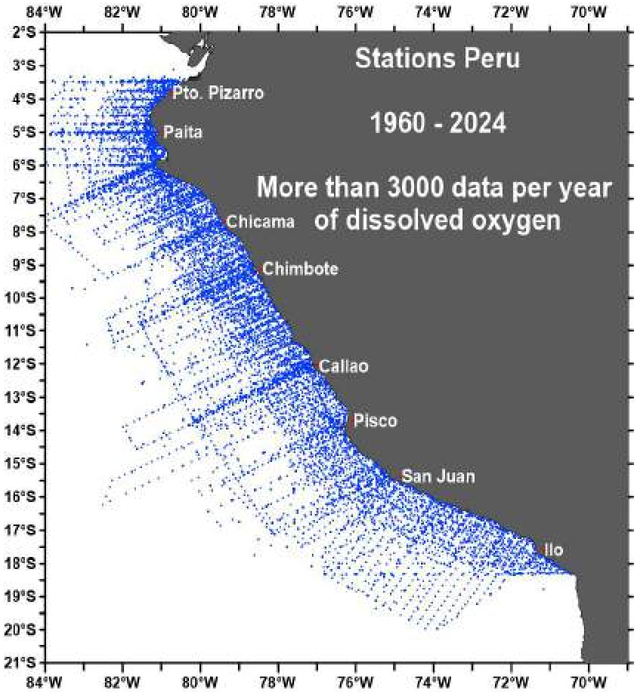
Fish stranding due to anoxia

The decrease in oxygen in the ocean represents a significant threat to Peruvian fisheries, affecting both the availability of species and the ecological structure of marine ecosystems. This phenomenon is combined with other environmental challenges, such as climate change and overexploitation, which aggravates the situation.

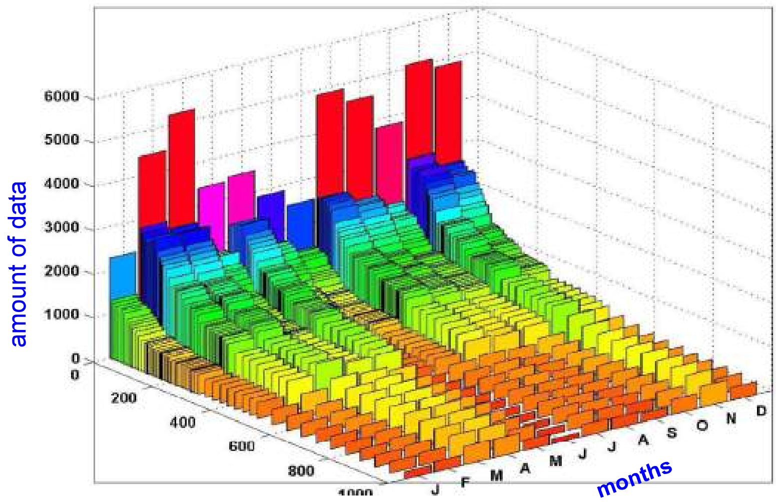
Station	Date	Hour	Depth (m)	Dissolved Oxygen (mL L^{-1})	pH NBS	Chlorophyll (µg L^{-1})	Phosphates (µmol L^{-1})	Silicates (µmol L^{-1})
Muelle Chorrillos	25/03/2024	11:55	0	3,35	**7,62***	**33,92**	5,13	**41,96***
Playa La Herradura	25/03/2024	12:22	0	5,21	7,96	6,19	2,23	20,62
Playa San Bartolo (sur) Muestra Turbia	25/03/2024	13:10	0	**0,00***	**7,30***	**57,20**	**-----**	**25,95**
Playa San Bartolo (norte)	25/03/2024	15:09	0	**6,11***	**8,43***	**206,64***	**4,51**	**19,37**



Peru Observatory



Data distribution by month and depth



Methods and equipment for determining dissolved oxygen

Winkler's volumetric Method

Volumetric technique based on a series of chemical reactions that allow the titration of the oxygen present in an aqueous sample by oxidation of the iodide by the oxygen dissolved in the water sample, followed by the titration of the iodine released with sodium thiosulfate.

$$Mn^{++} + 2OH^- \rightarrow Mn(OH)_2$$

$$4Mn(OH)_2 + 1O_2 \rightarrow 4Mn(OH)_3$$

$$4Mn(OH)_3 + 4I^- + 12H^+ \rightarrow 4Mn^{++} + 2I_2 + 12H_2O$$

$$2I_2 + 2I^- \rightarrow 2I_3^-$$

$$2I_3^- + 4S_2O_3^{2-} \rightarrow 6I^- + 2S_4O_6^{2-}$$

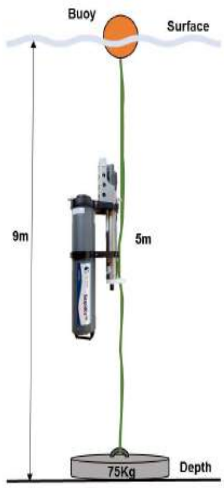
OD(mL/L)=112*Vx/(V-2)

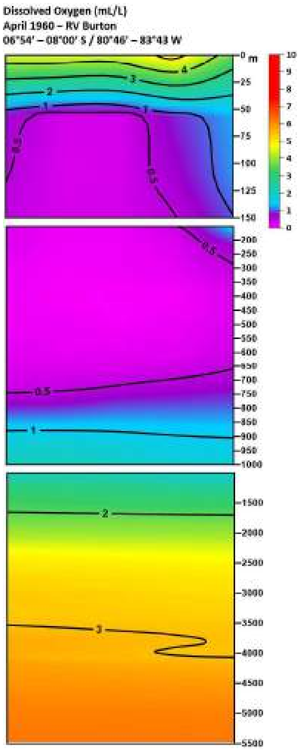
Polarographic Method

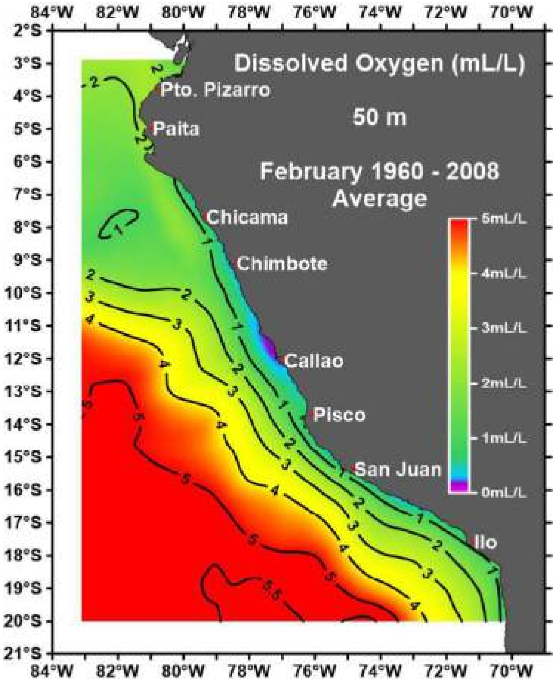
CTD Seabird - SBE43 is a polarographic oxygen sensor or membrane sensor. The sensor has an oxygen-permeable membrane that separates the surrounding water from an electrode array.

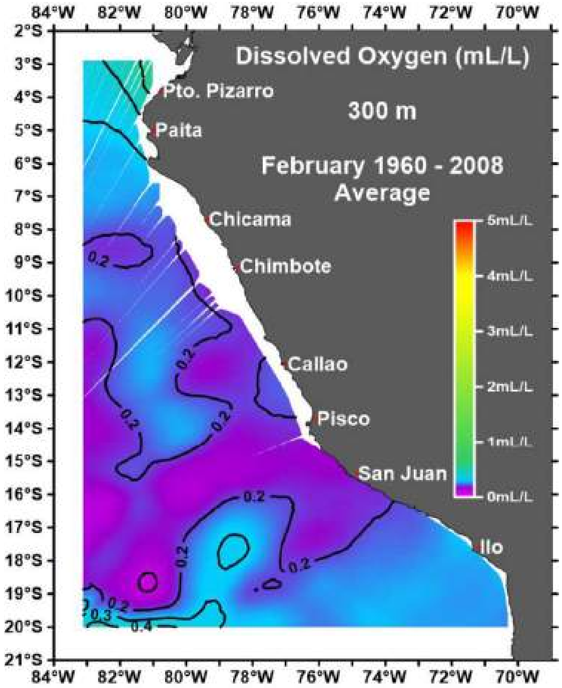
Optical Method

The optical method measures dissolved oxygen based on the attenuation of fluorescence by oxygen. SBE63 and Minidot





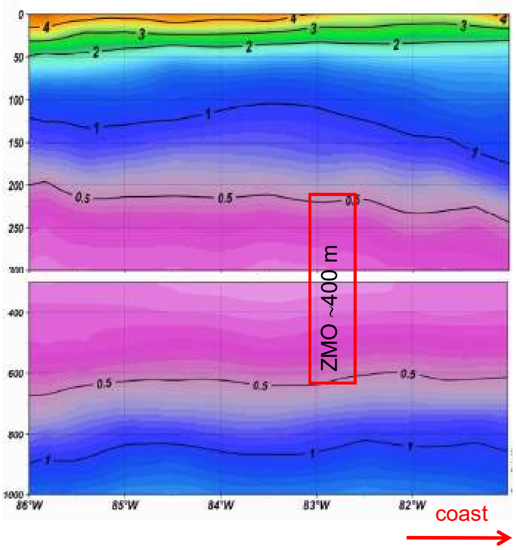




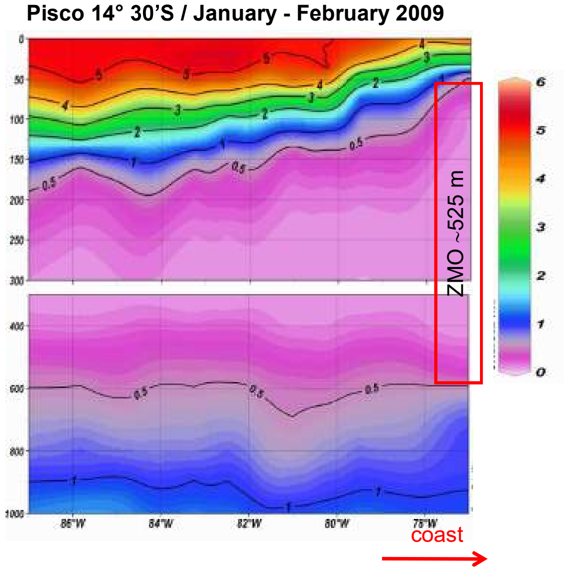
The extension of the Oxygen Minimum Zone increases towards the coast and south of 6°00' S. It also intensifies on the coast

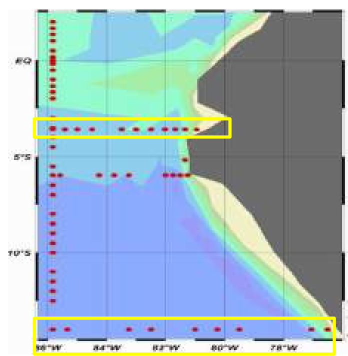
Dissolved Oxygen

Puerto Pizarro 3° 30'S / February 2009

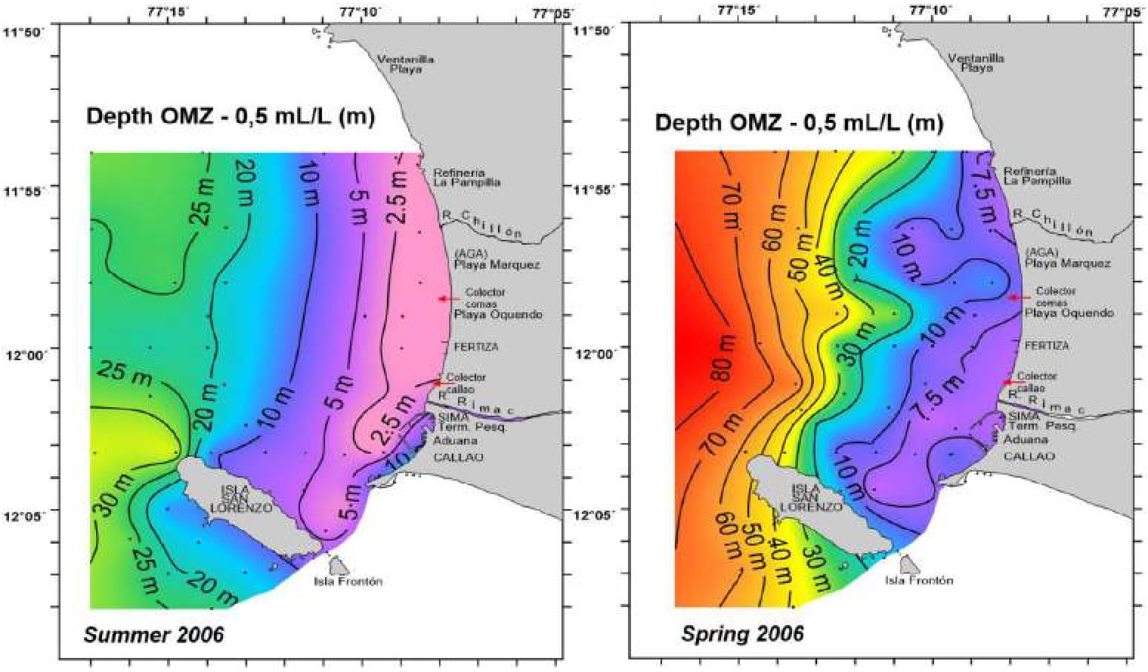


Pisco 14° 30'S / January - February 2009

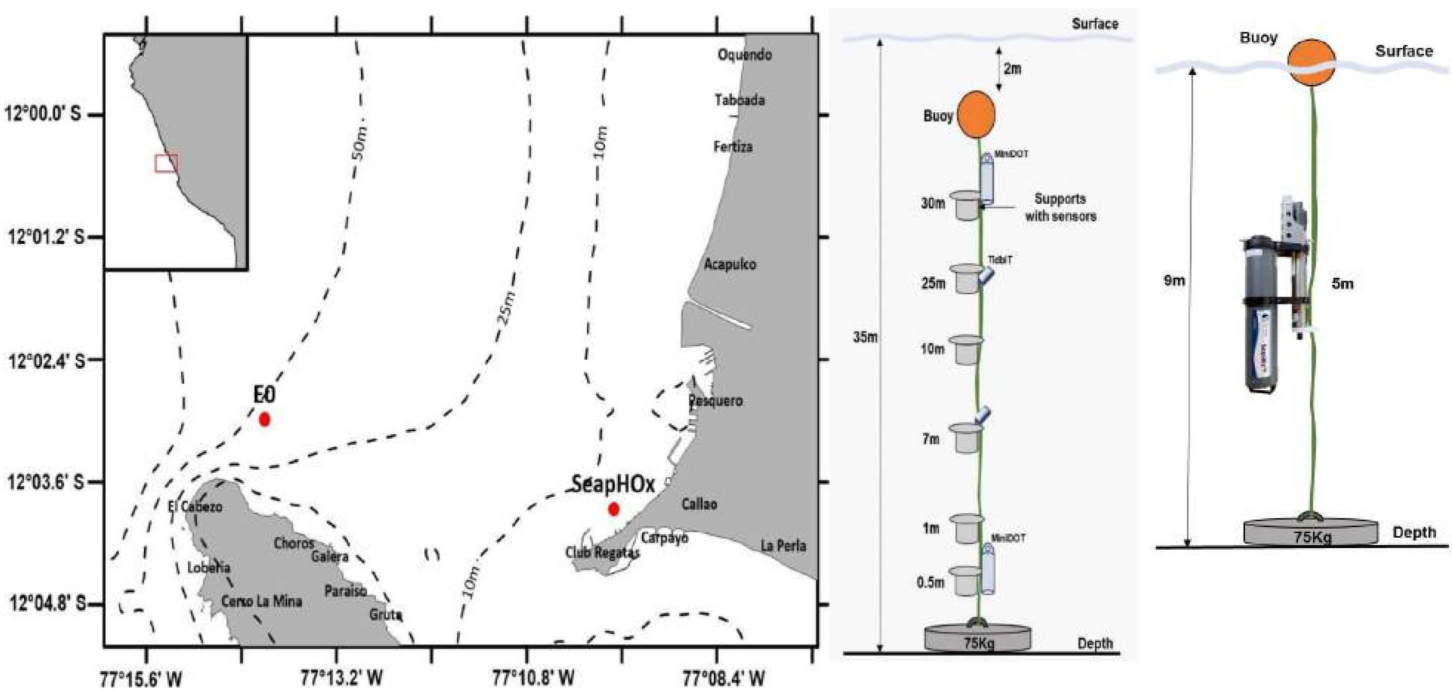




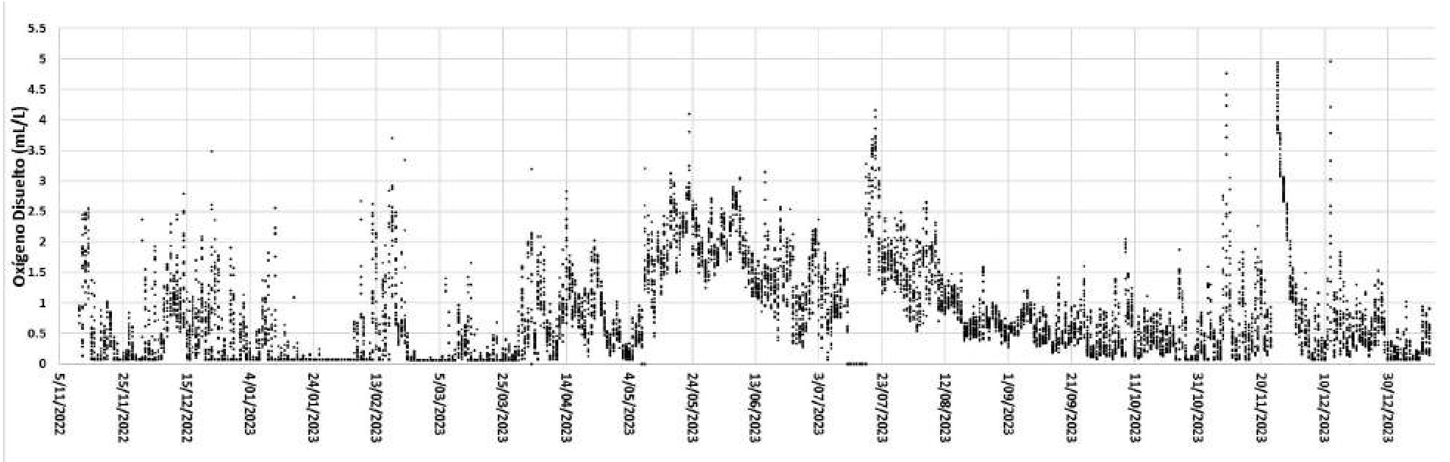
The upper limit of the Oxygen Minimum Zone is shallow on the coast of Callao, at approximately 20 m in the summer. During extreme El Niño periods, it is located at depths greater than 140 m.

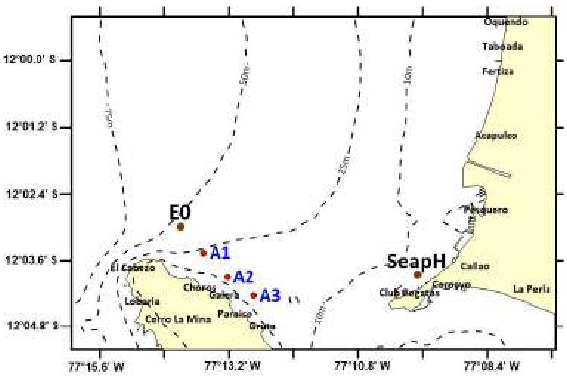


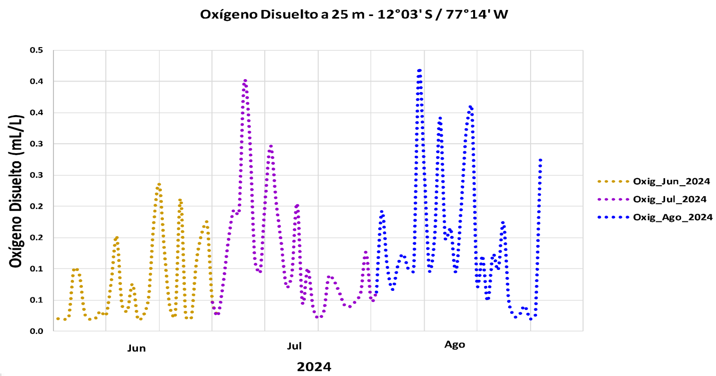
Callao Observatory – 12°02' S

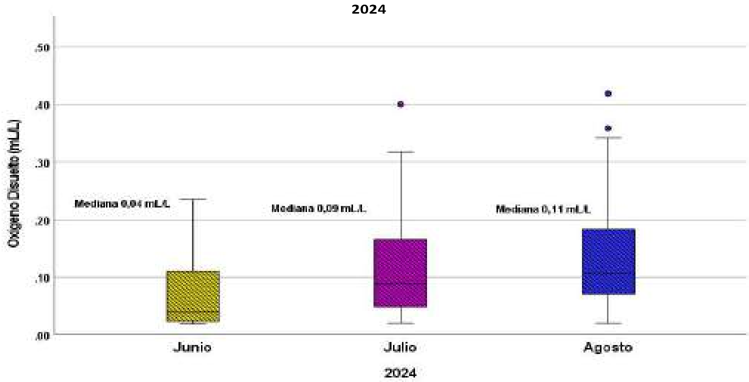


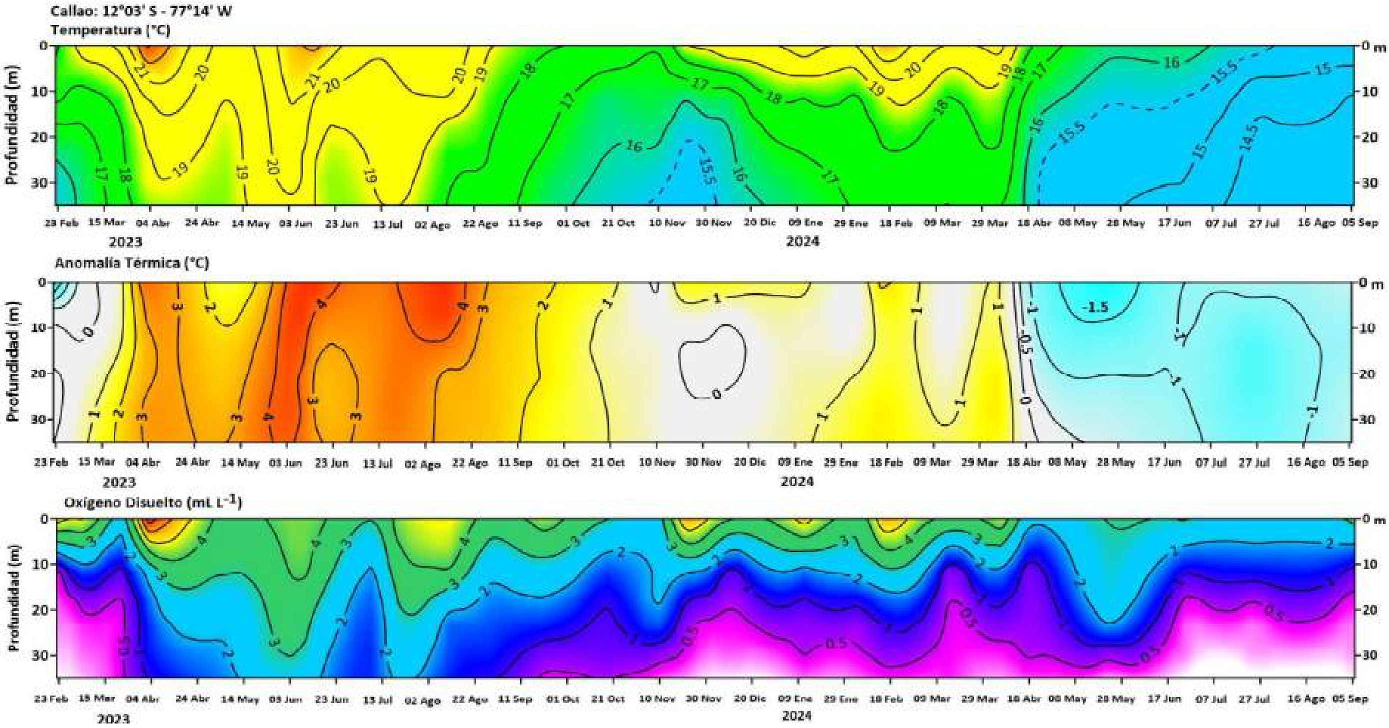
Dissolved Oxygen variability during 2023 – Depth 5 m

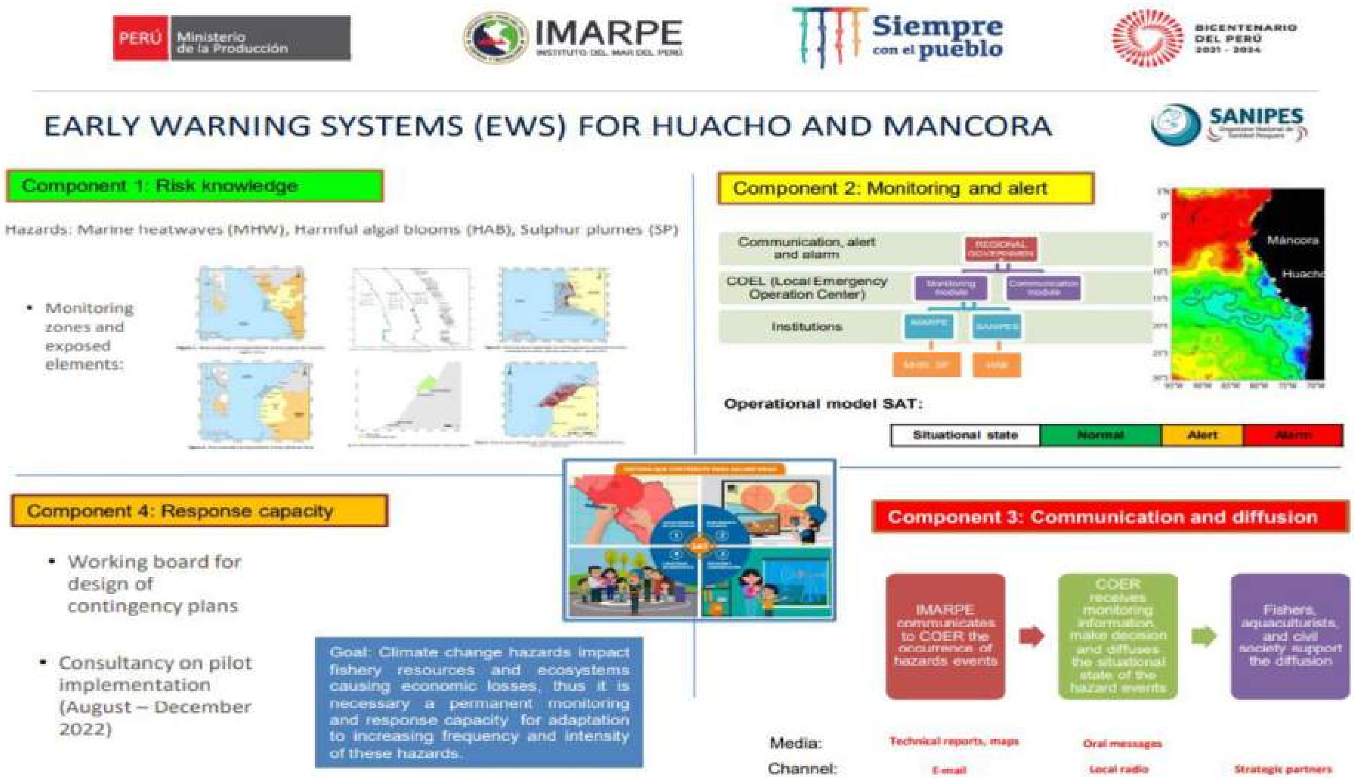




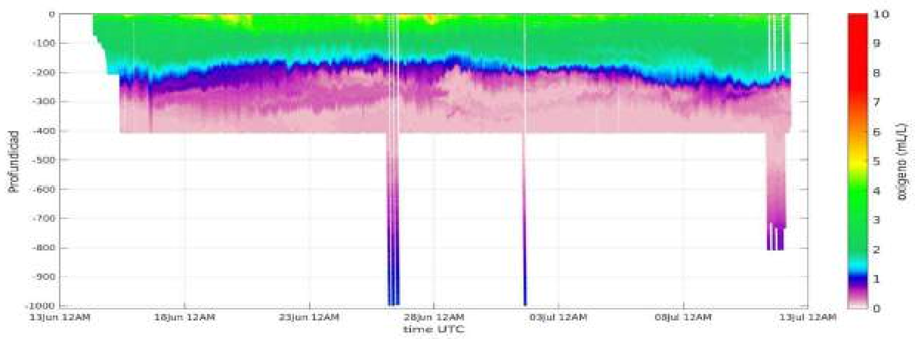





Callao: 12°03' S - 77°14' W
Temperatura (°C)
Profundidad (m)
Anomalía Térmica (°C)
Oxígeno Disuelto (mL L-1)
23 Feb 15 Mar 04 Abr 24 Abr 14 May 03 Jun 23 Jun 13 Jul 02 Ago 22 Ago 11 Sep 01 Oct 21 Oct 10 Nov 30 Nov 20 Dic 09 Ene 29 Ene 18 Feb 09 Mar 29 Mar 18 Abr 08 May 28 May 17 Jun 07 Jul 27 Jul 16 Ago 05 Sep
2023
2024

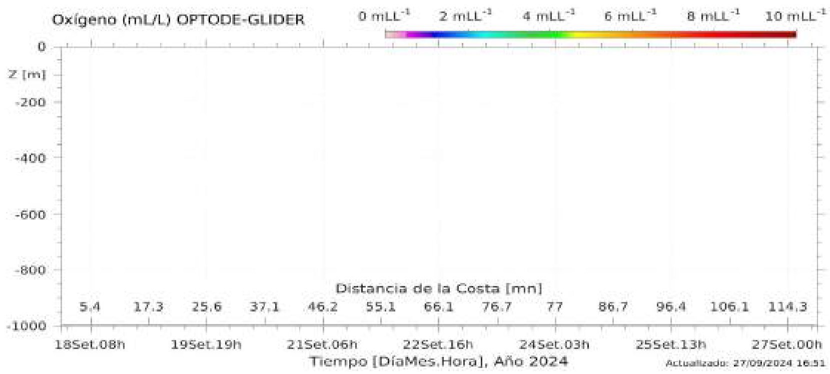

PERÚ Ministerio de la Producción
IMARPE
Siempre con el pueblo
BICENTENARIO DEL PERÚ 2021 - 2024
EARLY WARNING SYSTEMS (EWS) FOR HUACHO AND MANCORA
SANIPES
Component 1: Risk knowledge
Hazards: Marine heatwaves (MHW), Harmful algal blooms (HAB), Sulphur plumes (SP)
• Monitoring zones and exposed elements:
Component 2: Monitoring and alert
Communication, alert and alarm
REGIONAL GOVERNMENT
COEL (Local Emergency Operation Center)
Monitoring module
Communication module
Institutions
IMARPE
SANIPES
HAB
Máncora
Huacho
Operational model SAT:
Situational state
Normal
Alert
Alarm
Component 4: Response capacity
• Working board for design of contingency plans
• Consultancy on pilot implementation (August – December 2022)
Goal: Climate change hazards impact fishery resources and ecosystems causing economic losses, thus it is necessary a permanent monitoring and response capacity for adaptation to increasing frequency and intensity of these hazards.
Component 3: Communication and diffusion
IMARPE communicates to COER the occurrence of hazards events
COER receives monitoring information, make decision and diffuses the situational state of the hazard events
Fishers, aquaculturists, and civil society support the diffusion
Media:
Technical reports, maps
Oral messages
Channel:
E-mail
Local radio
Strategic partners

The main problem is the maintenance of high-tech equipment



Glider

June 2023 Optical sensor ok



September 2024 Optical sensor out of service

IMARPE
INSTITUTO DEL MAR DEL PERÚ

www.gob.pe/imarpe /imarpe.pe @ImarpePeru

ImarpePeru institutodelmardelperu

Reports of current protocols and activities for oxygen monitoring in APEC economies

RUSSIA

Content:

- Seas and oceans of Russia
- Main directions of Russian research on the World Ocean
- Main Research Institutes of Oceanology in Russia
- State system of control over the hydrochemical condition of Russian seas
- Standards of dissolved oxygen in sea water
- Dissolved oxygen monitoring stations in the Russian Far East
- Oxygen conditions in the seas of the Russian Far East
- Sea of Japan/East Sea, Amurskiy Bay
- Conclusion

Seas and oceans of Russia

ARCTIC OCEAN
- Barents Sea
- Kara Sea
- Laptev Sea
- East Siberian Sea
- Chukchi Sea

PACIFIC OCEAN
- Bering sea
- Okhotsk Sea
- Sea of Japan/East Sea

ATLANTIC OCEAN
- Baltic sea
- Black Sea

Caspian Sea

Russia has access to the seas of Pacific, Arctic and Atlantic Oceans. These seas are very important for the Russian economy. Fishing, marine tourism and marine pharmacy have great economic potential. On the other hand, the successful development of these areas requires significant government control.

The main directions of Russian research in the study of the World Ocean

Climate

Oceans play a key role in regulating global climate processes by absorbing carbon dioxide and heat. Changes in the world's oceans lead to climate change. Scientists face the task of predicting and controlling these changes

Ecosystems and biodiversity

Marine ecosystems are a complex of living organisms and habitats. Ecosystems are dynamic, dependent on and influenced by their environment. Assessing the state of marine ecosystems is important for their protection and efficient use

Resources

The world's oceans contain vast reserves of minerals and food raw materials. However, their utilization requires prudent management and control in order to preserve and enhance them.

Environmental protection

Overfishing, pollution, climate change and habitat destruction are problems of the world's oceans. It is necessary to identify sources of pollution, assess its impact on the ecosystem and develop strategies for protection.

Global economic activity

Fisheries, marine tourism, marine pharmaceuticals have great economic potential. Stable development of these industries requires significant governmental attention and control.

Scientific research

The world's oceans still hold many secrets. Scientists are faced with the task of searching for new biological and pharmacological resources, creating a digital atlas of the world's oceans and a global ocean observation system

The most important Oceanography Research Institutes in Russia

- Russian Federal Research Institute of Fisheries and Oceanography
- Institute of Oceanology of the Russian Academy of Sciences
- State Oceanographic Institite

There are more than twenty marine research institutes in Russia. The main institutes are located in large cities and there is a network of branches covering the Russia, especially in coastal cities. Over 200 branches in total.

State system of control of hydrochemical conditions and pollution of the marine environment of Russia

Since 1959:

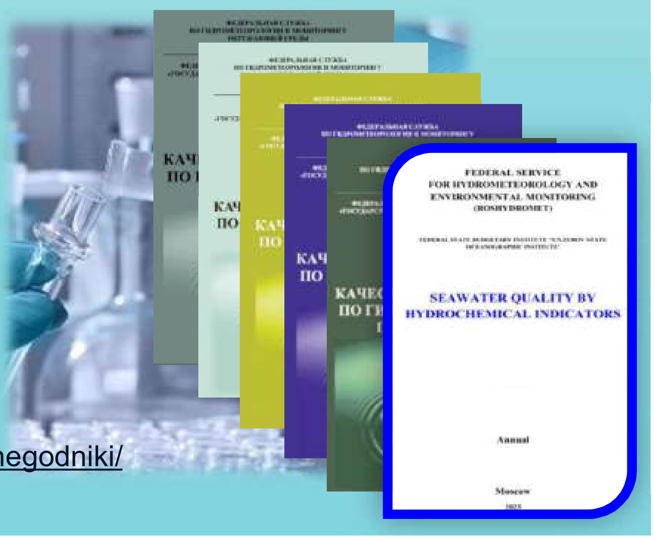
Network for monitoring the hydrological conditions of the seas

Publish reports based on data from research institutes, control laboratories and marine expeditions

- ✓*Metal and organic pollution levels*
- ✓*Multiannual trends in marine water quality*
- ✓*Mean, minimum and maximum values of hydrological data*

- ✓*Ice conditions*
- ✓*Temperature and Salinity*
- ✓*Water colour and Visibility*
- ✓***Oxygen content***
- ✓*pH data*
- ✓*Alkalinity*
- ✓*Concentration of nutrients*
- ✓*Radioactivity*

N.N. Zybov State Oceanographic Institute



http://гоин.рф/service/monitoring-zagryazneniya/ezhegodniki/

Annual reports are available on the Internet, free access

Standards for dissolved oxygen in seawater

HEALTH STANDARDS

Dissolved oxygen content in recreational waters (swimming, water sports, etc.)

≥ 6 mg/l

STANDARDS FOR FISHING WATER AREAS

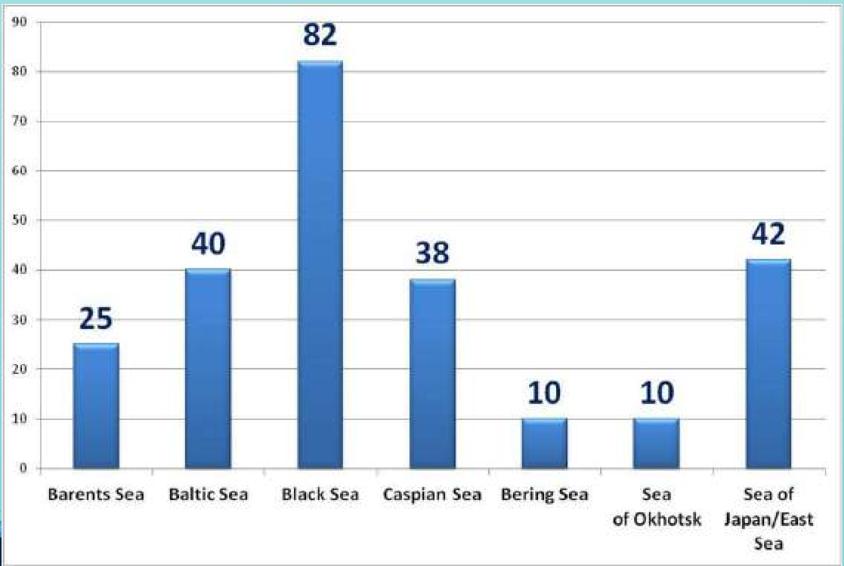
Dissolved oxygen content for valuable fish species

≥ 6 mg/l

Dissolved oxygen content for other fish species

≥ 4 mg/l

Number of monitoring stations of the hydrochemical conditions and the pollution level of the Russian seas



Year 2022

247 stations

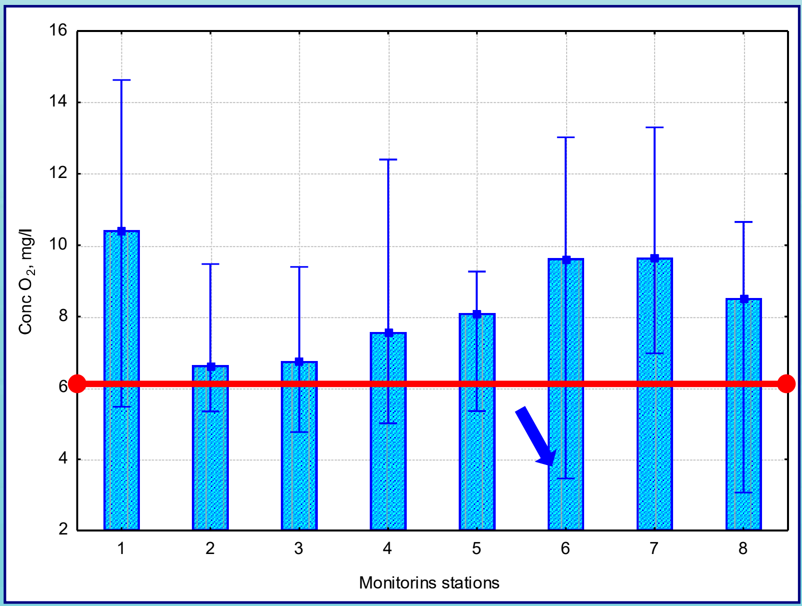
2019 water samples

72 control parameters

47110 chemical analyses

There are monitoring stations in all regions of Russia. The total number of stations is 247. The number of stations is almost the same every year. It's just monitoring. Research data aren't considered

Oxygen monitoring stations and oxygen content in the seas of the Russian Far East (bottom layer, 2022)



1.Kamchatka, Avacha bay;
2.Sea of Okhotsk, Aniva bay;
3.Sea of Okhotsk, Korsakov;
4.Sea of Japan, Zolotoy Rog bay;
5.Sea of Japan, str. Bosfor Vostochnyy;
6.Sea of Japan, Amurskiy bay;
7.Sea of Japan, Ussuriyskiy bay;
8.Tatar str.

Monitoring is carried out from ships and coastal stations. On average, oxygen concentrations are good for all stations. Lower oxygen concentrations were found during the summer season when water temperatures increased.
The worst results are observed at stations 2 and 3. These stations are located on Sakhalin Island, near the Liquefied Natural Gas plant.
The situation is even worse at stations 4, 5 and 6 in summer season. These control stations are located near Vladivostok.

Changes in dissolved oxygen concentration in the Amurskiy Bay of the Sea of Japan

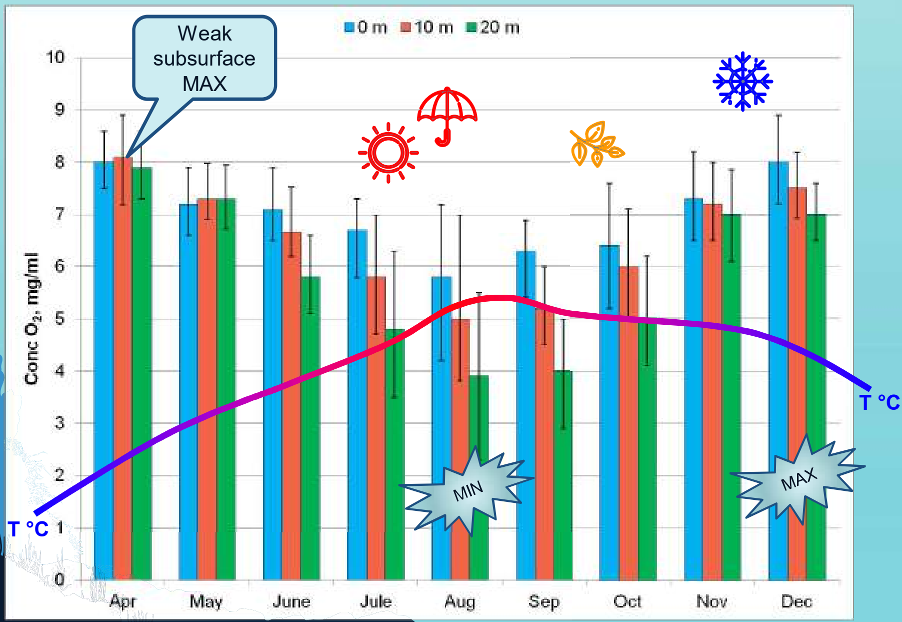
AMURSKIY BAY

- *near the city of Vladivostok*
- *extends deep into the land*
- *closed to the open sea*
- *average depth is 30 m*
- *maximum depth is 53 m*
- *northern part of the bay is shallow (depth ~10 m)*
- *Razdolnaya River flows into the bay from the northwest*

Changes in dissolved oxygen levels in the Amurskiy Bay of the Sea of Japan

Vertical and Seasonal distribution of dissolved oxygen in the Amurskiy Bay of the Sea of Japan

Summary of research data from 1925 to 2020



Water temperature has the greatest effect on the oxygen content of the water.

In winter the oxygen content is at its maximum.

In spring, a weak subsurface maximum is formed as the surface water warms.

In summer, a significant increase in water temperature creates an annual minimum of oxygen at depth and near the bottom.

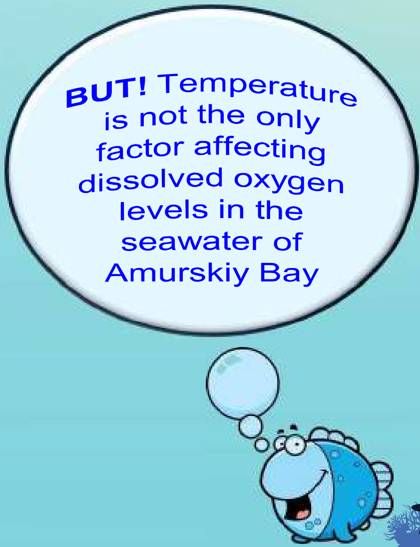
In autumn, as the surface waters begin to cool, exchange processes intensify and the oxygen concentration in the depths of the bay balances and increases again.

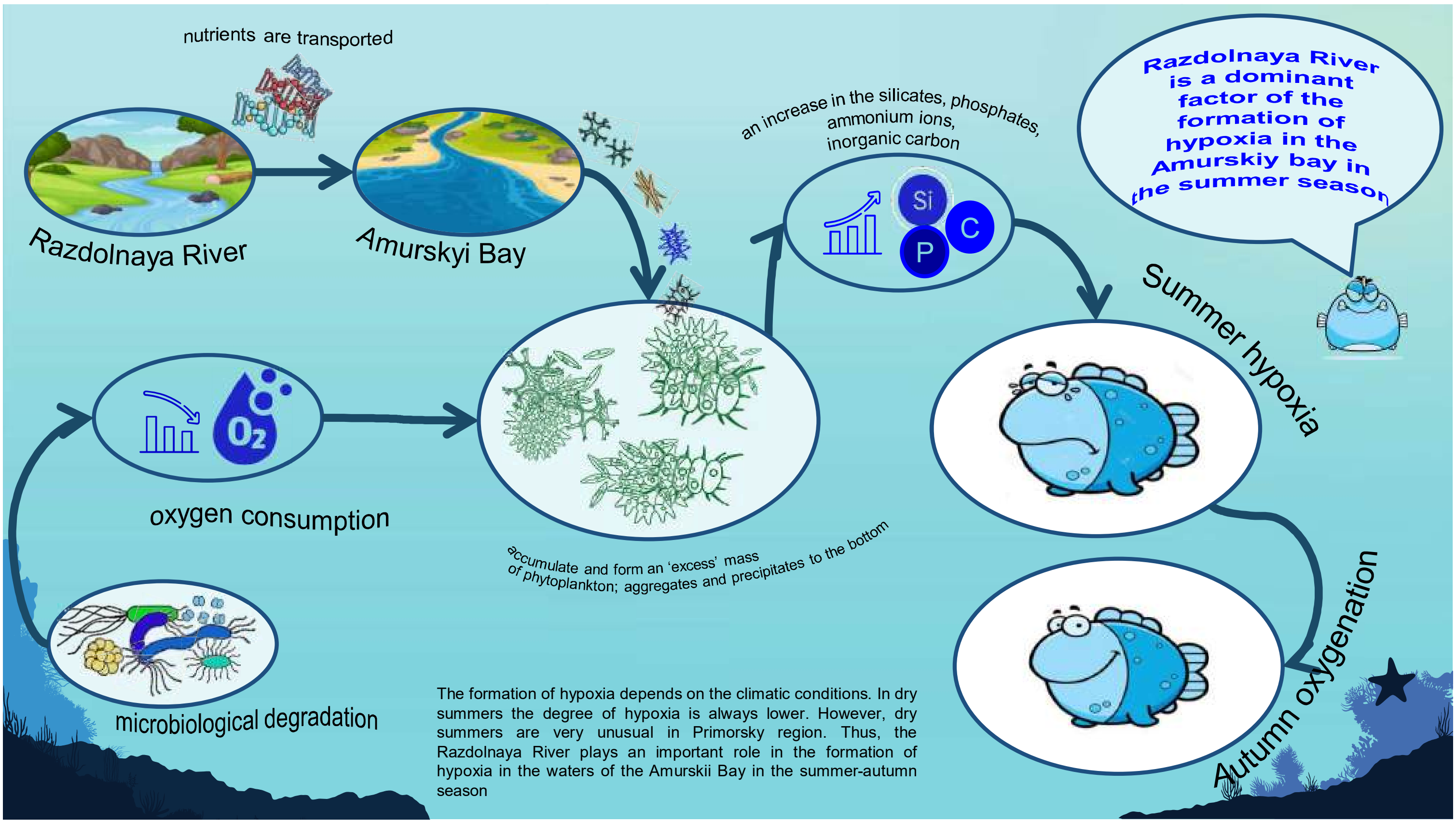
Changes in dissolved oxygen levels in the Amurskiy Bay of the Sea of Japan

Vertical and Seasonal distribution of dissolved oxygen in the Amurskiy Bay of the Sea of Japan

Summary of research data from 1925 to 2020

The decrease in oxygen levels as the temperature increases during the summer season





Conclusion

- Monitoring of the oxygen content of seawater in Russia is regulated by the state and carried out regularly.
- The work involves scientific institutes, branches, research and fishing vessels, and coastal laboratories.
- Reduced oxygen levels are observed in summer and are associated with both seasonal temperature increases and eutrophication of closed bays during the flood period.
- In general, hypoxia is short-term and does not cause irreversible changes in marine ecosystems


Thank you for your attentions!

Overview of Oxygen Monitoring and Situation in Coastal Waters of Thailand

Asia-Pacific Economic Cooperation

Senior Expert on Marine Fisheries

Director of Coastal Aquaculture Technology and Innovation Research and Development Center

Department of Fisheries, Thailand

30 September – 3 October 2024

Paracas, Peru

Outline

A. Introduction and overview of Thai fishery

B. Oxygen monitoring and situation

1. **Drivers of low oxygen in the coastal waters of Thailand**
2. **Types of coastal water living resources**
3. **Economic implications of oxygen loss in environments**
4. **Emblematic cases of oxygen monitoring in a coastal environment**
5. **Current gaps in oxygen monitoring**

A. Introduction : Thailand

- Southeast Asian **economy**
- Capital city : Bangkok
- Land area: 513,120 sq.km.
- Maritime area: 350,000 sq.km.
- Coastline: 2,815 km. /1,760 miles

A. Introduction : The Nation's Fisheries

Fisheries in Thailand
2.47 million ton*

- **Capture fisheries** — **1.47 m ton (59.5%)**
  - Marine fisheries — 1.35 m ton (91.8%)
  - Inland fisheries — 0.12 m ton (8.2%)
- **Culture fisheries** — **1.00 m ton (40.5%)**
  - Coastal aquaculture — 0.54 m ton (54.1%)
    - **Whiteleg shrimp**, **Green mussel**, **Asian sea bass**, **Blood clam**, **Oyster**
  - Freshwater aquaculture — 0.46 m ton (45.9%)

*** Production in 2023**

1. Drivers of low oxygen in the coastal waters of Thailand

Nutrient pollution

- Untreated or poorly treated wastewater from cities contributes to nutrient overload.
  - Communities
  - Industries
- Fertilizers from farms, rich in nitrogen and phosphorus, enter coastal waters through rivers and streams.
  - Aquaculture
  - Livestock

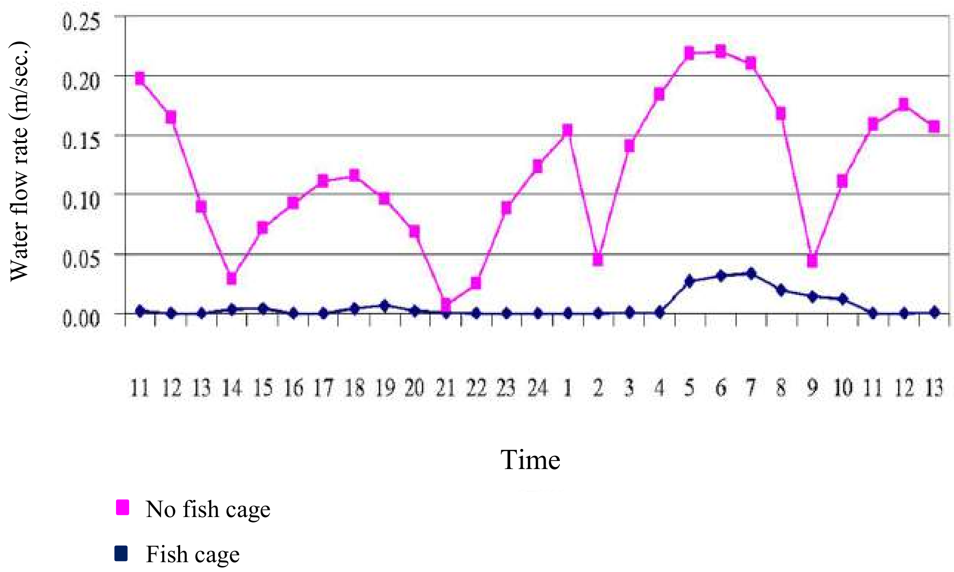
An example of coastal community in the Gulf of Thailand

1. Drivers of low oxygen in the coastal waters of Thailand

Oxygen depletion from coastal aquaculture

- Normally occurred at fish cage culture areas
- Low oxygen caused by several factors
    - Fish respiration
    - Tidal flow (blocked by the dense of fish cage)
    - Biofouling
    - Algal bloom
- Usually found lowest DO content at dawn

Water flow in coastal cage culture area



2. Types of coastal water living resources

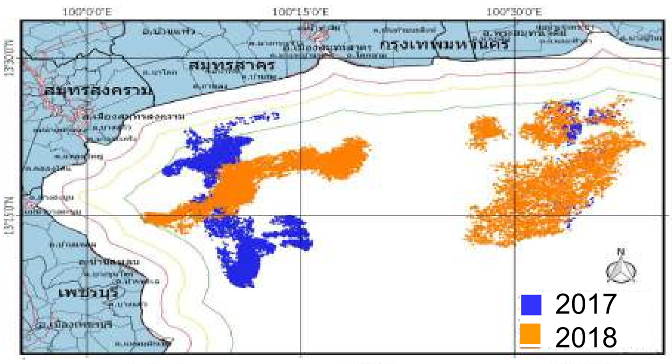
- ✓ Several coastal species of fishes, shrimps, crabs, squids, etc.
- ✓ Bivalves
  - ➢ Undulate venus (*Paratapes undulatus*)
  - ➢ Blood clam (*Anadara granosa*)
  - ➢ Green mussel (*Perna viridis*)

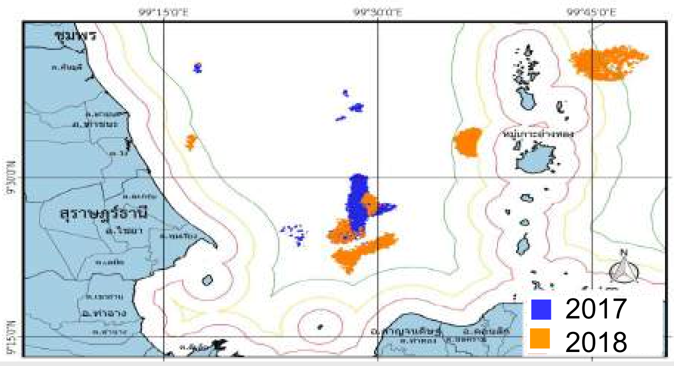

Undulate venus (*Paratapes undulatus*)


Blood calm (*Anadara granosa*)


Green mussel (*Perna viridis*)

Undulate venus fishing ground





Blood clam culture area

Green mussel culture area

3. Economic implications of oxygen loss in environments

➢ Effect on tourism

➢ Effect on fisheries resources

3. Economic implications of oxygen loss in environments

- Effect on fish cage culture

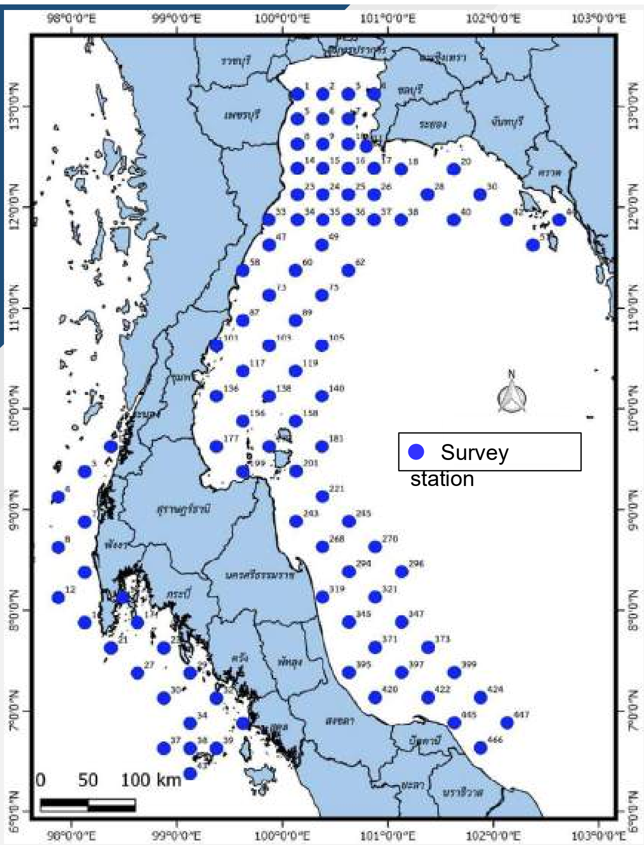
  

15

4. Emblematic cases of oxygen monitoring in a coastal environment

- ✓ DO monitoring by research vessel in Thai waters
- ✓ DO monitoring in Songkhla Lake

16



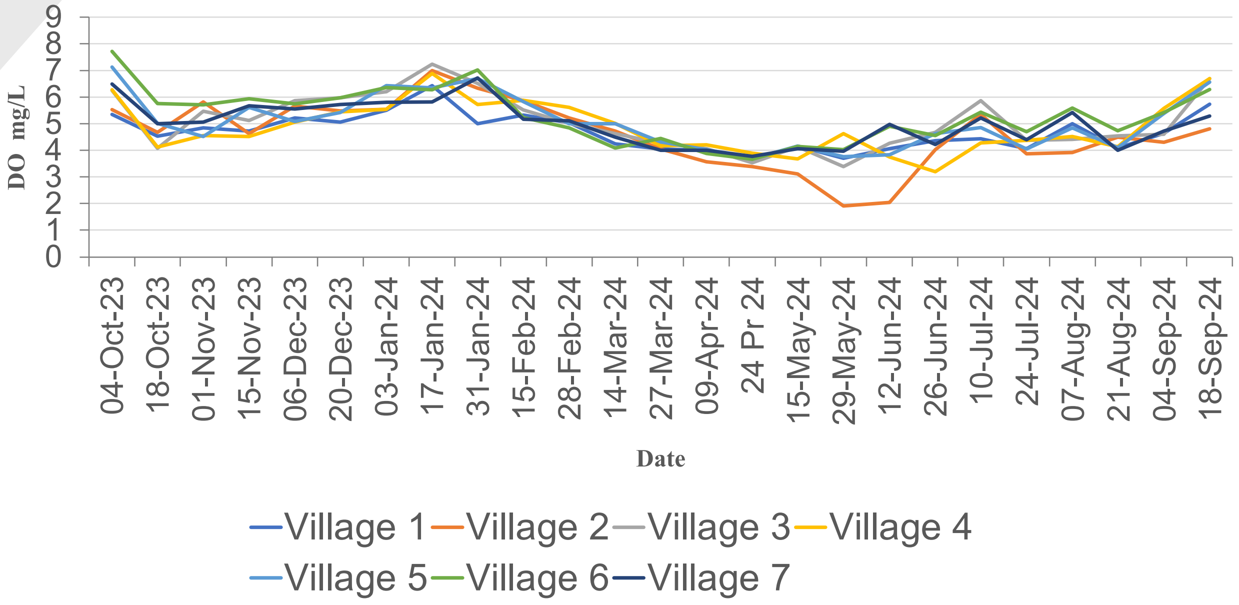
DO monitoring by research vessel in Thai waters

- ✓ Four trips a year
- ✓ Using CTD

DO monitoring in Songkhla Lake

- High density of Asian sea bass cage farming
- DO monitoring in the morning every two weeks at 7 villages
- Report the DO level to farmers by using a mobile application
- In case of low DO, farmers can prepare for aeration

Results of annual DO monitoring at Songkhla Lake



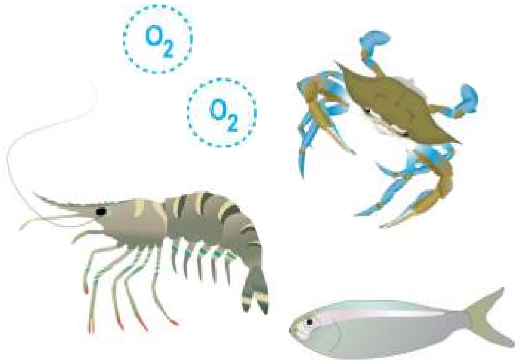
5. Current gaps in oxygen monitoring and its application for the management of living resources

- Data quality affected by personnel skill
- No real-time DO monitoring both in aquaculture and natural water body
- Lack of timely DO monitoring in coastal and offshore area
- No integrated database, many authorities are responsible for DO monitoring
- Lack of expertise in DO modeling


Thank you

Reports of current protocols and activities for oxygen monitoring in APEC economies: The USA

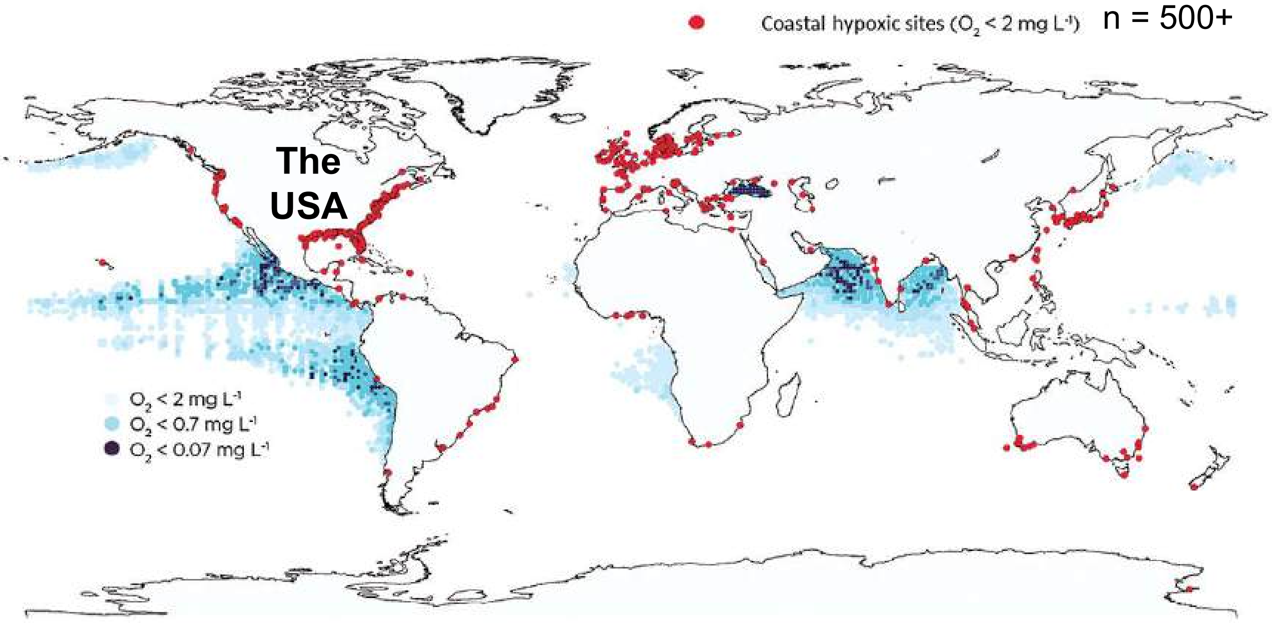
USGS Wetland and Aquatic Research Center



Paracas, Peru

U.S. Department of the Interior
U.S. Geological Survey

Hypoxia is found worldwide

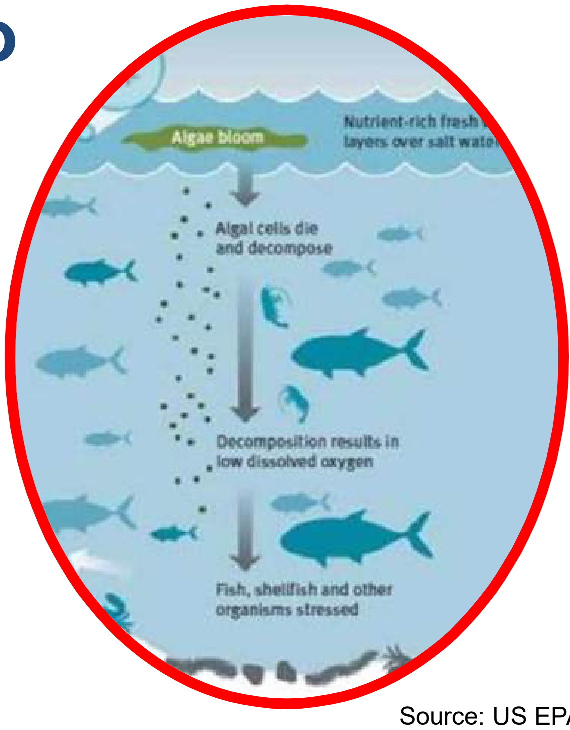


Grégoire et al. 2019

Northern Gulf of Mexico

Drivers of Bottom-water Low Oxygen are:

- Natural **stratification** of the water column
- **Nutrient-rich** water promote algal blooms



Source: US EPA

Northern Gulf of Mexico Hypoxia

Member Economy: the USA

Definition: ≤ 2 mg O_2 L^{-1}

Duration (Time Series): mid-May through mid-September

Extent (Area): up to 23,000 km^2

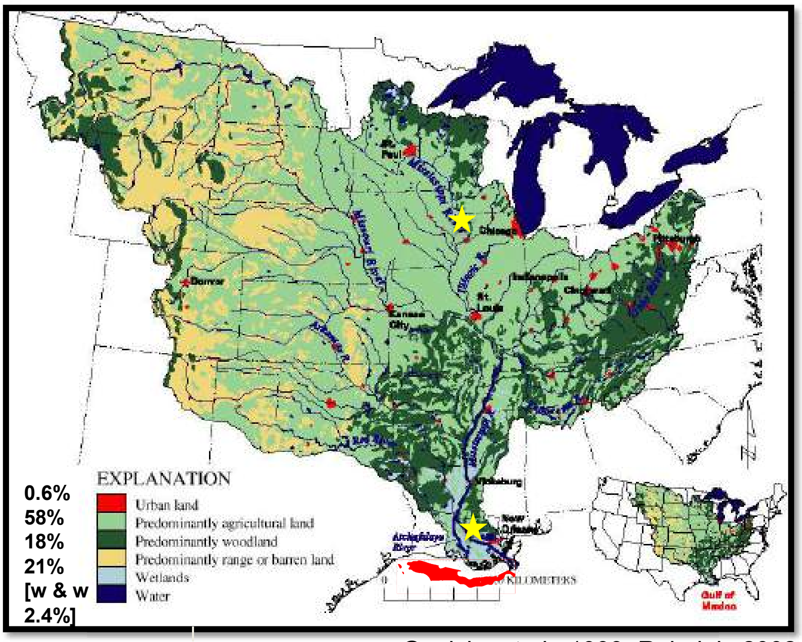
Earliest Monitored D.O.: 1970s (Rabalais et al. 2002)

D.O. Index: area (km^2)

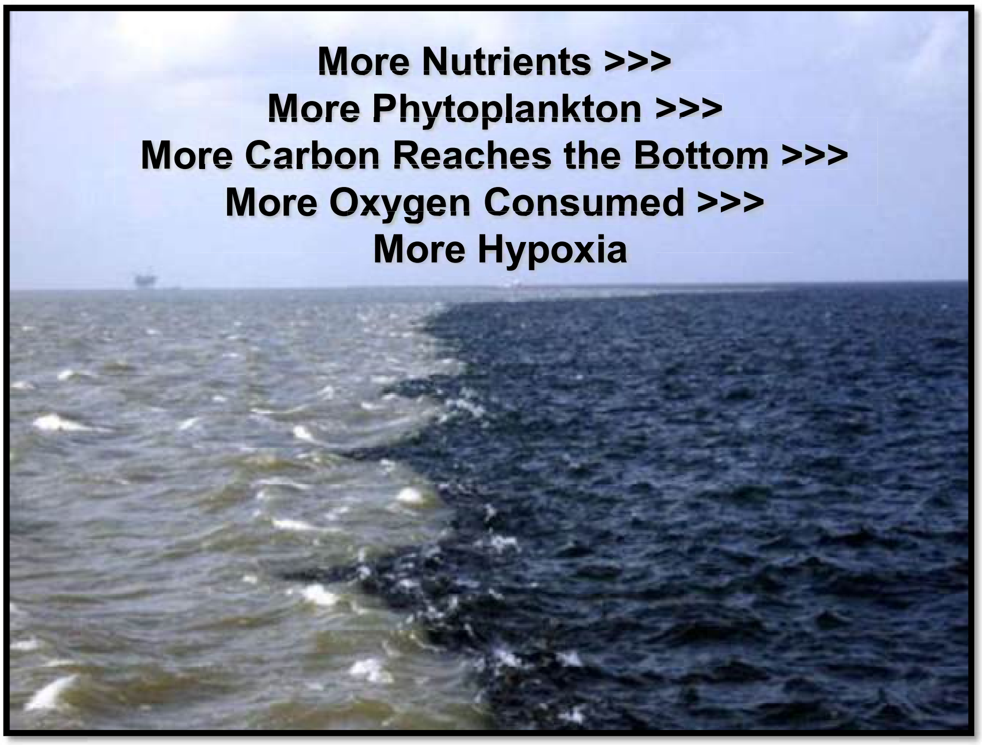
Fishery: shrimps, crabs, fishes

Source: US EPA

Agricultural Runoff Drives Nutrient Enrichment



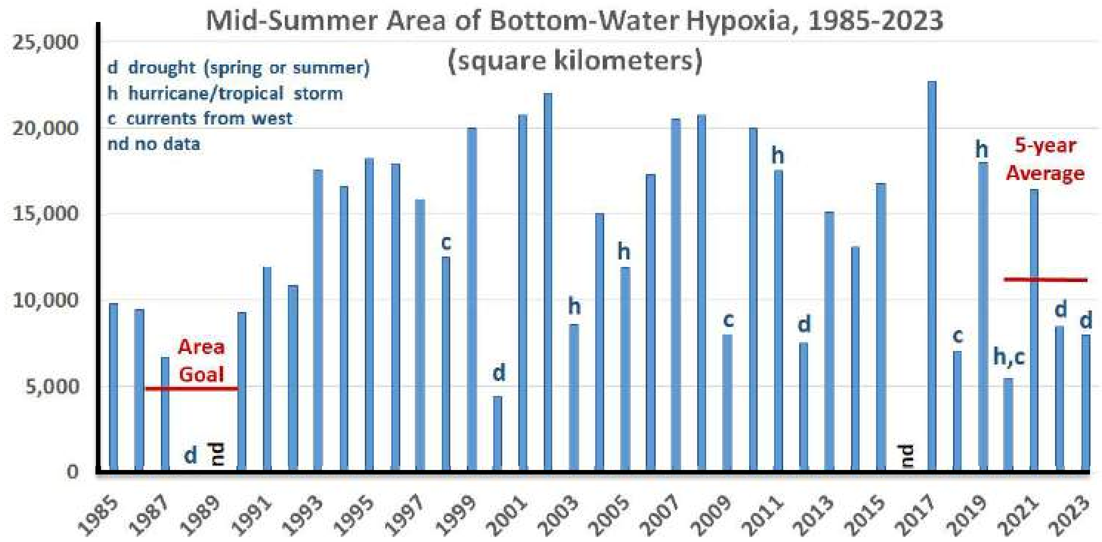
Goolsby et al., 1999, Rabalais 2002



Source: N. Rabalais

Long-term Monitoring of Area

Hypoxia Area (km²)



Source: N. Rabalais and R.E. Turner

2017 Hypoxia Similar to Ica Region

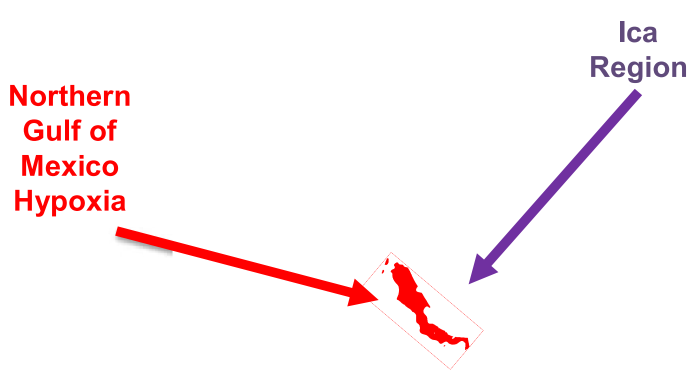
Peru

Northern Gulf of Mexico Hypoxia

- 2017 Largest area: 22,720 km²

Ica Region, Peru

- Area: 21,328 km²



Living Resources Affected by Coastal Hypoxia

Shrimp

- Brown shrimp (*Farfantepenaeus aztecus*)
- White shrimp (*Litopenaeus setiferus*)
  - Example: $232M USD, 2022 landings in Gulf of Mexico

Crabs

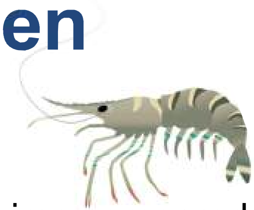
- Blue crab (*Callinectes sapidus)*

Fish

- Gulf menhaden (*Brevoortia patronus)*
- Atlantic croaker (*Micropogonias undulatus*)

Source: NOAA Fisheries

Economic Implications of Oxygen Loss



- Bottom-water hypoxia **increases the relative price** of large shrimp compared to small shrimp
- The effects of **fuel prices** of shrimping fleet provide supporting evidence

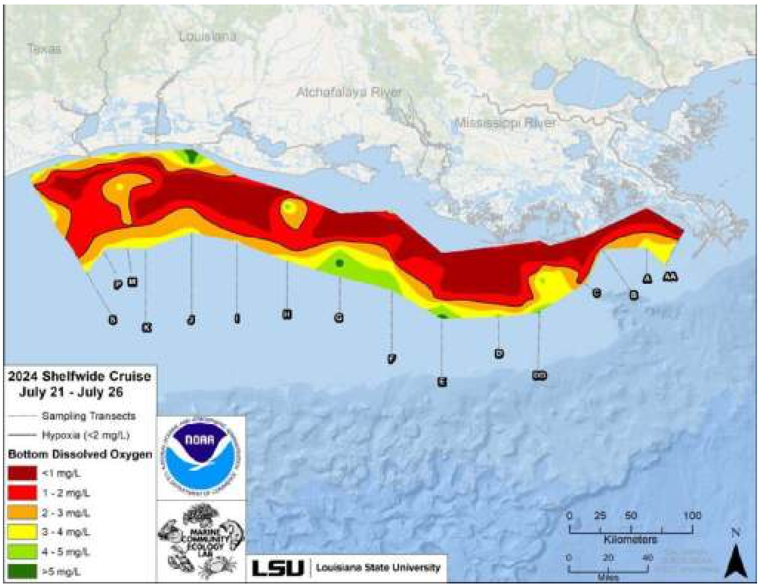
Smith et al. 2017

Source: M. Baustian

Current Monitoring Gaps and Opportunities

- **Long-term funding to continue annual area monitoring with ships**
    - Use of unmanned autonomous surface vehicles

- **Interactions with warmer waters on ecology of coastal hypoxia**
    - Incorporate into hypoxia forecasting models



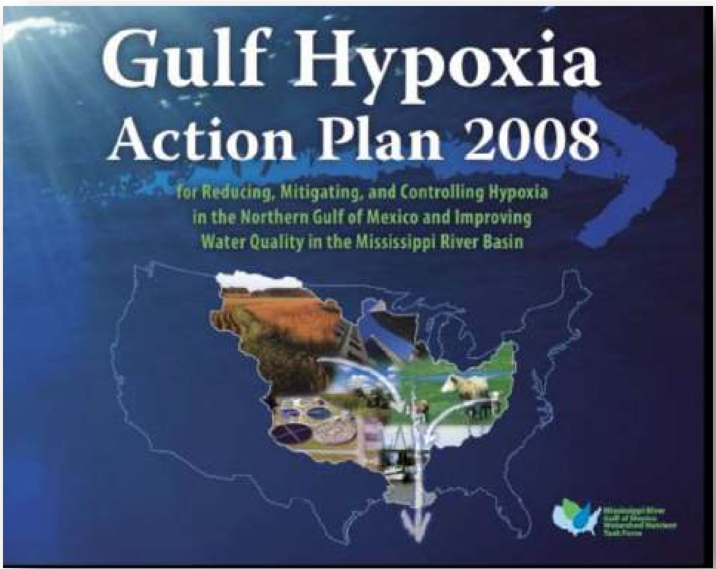
Source: N. Rabalais

Management of Hypoxia

Gulf Hypoxia Action Plan:

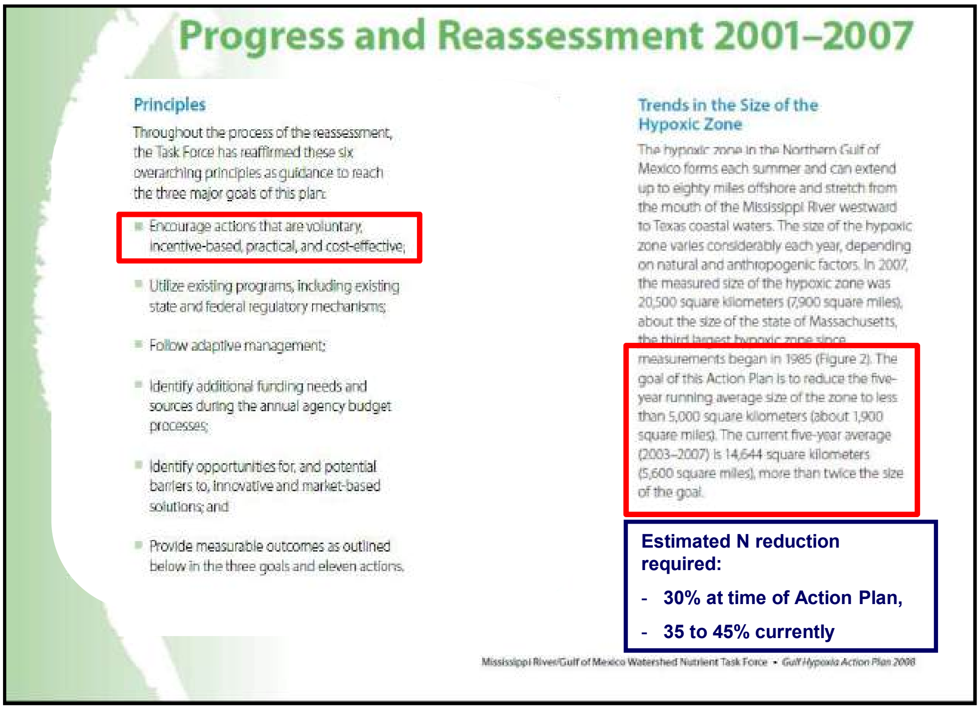
- 2001: Established
- 2008: Updated
- 2015: Coastal goal updated
    - Reduce 5-year running average of hypoxia area to **5,000 km² or less** by 2035
    - **20% reduction of TN and TP** loading by 2025

"Federal agencies, States, Tribes and other partners will work collaboratively"



Source: US EPA

Action Plan 2008



Progress and Reassessment 2001–2007

Principles

Throughout the process of the reassessment, the Task Force has reaffirmed these six overarching principles as guidance to reach the three major goals of this plan:

- Encourage actions that are voluntary, incentive-based, practical, and cost-effective;
- Utilize existing programs, including existing state and federal regulatory mechanisms;
- Follow adaptive management;
- Identify additional funding needs and sources during the annual agency budget processes;
- Identify opportunities for, and potential barriers to, innovative and market-based solutions; and
- Provide measurable outcomes as outlined below in the three goals and eleven actions.

Trends in the Size of the Hypoxic Zone

The hypoxic zone in the Northern Gulf of Mexico forms each summer and can extend up to eighty miles offshore and stretch from the mouth of the Mississippi River westward to Texas coastal waters. The size of the hypoxic zone varies considerably each year, depending on natural and anthropogenic factors. In 2007, the measured size of the hypoxic zone was 20,500 square kilometers (7,900 square miles), about the size of the state of Massachusetts, the third largest hypoxic zone since measurements began in 1985 (Figure 2). The goal of this Action Plan is to reduce the five-year running average size of the zone to less than 5,000 square kilometers (about 1,900 square miles). The current five-year average (2003–2007) is 14,644 square kilometers (5,600 square miles), more than twice the size of the goal.

Estimated N reduction required:

- 30% at time of Action Plan,
- 35 to 45% currently

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force • *Gulf Hypoxia Action Plan 2008*

Source: US EPA

Acknowledgements

Funded by:

- NOAA Center for Sponsored Coastal Ocean Research Coastal Ocean Program
-
-
-

Special thanks to APEC for sponsoring this workshop!

Shelfwide Cruise, Summer 2007

Useful Links

www.gulfhypoxia.net
Lead researcher: Dr. Nancy Rabalais

https://coastalscience.noaa.gov/crp/hypoxia/
NOAA website

https://www.epa.gov/ms-htf/gulf-hypoxia-program
US EPA website

Thank You!

¡Grasias!

Asia-Pacific Economic Cooperation

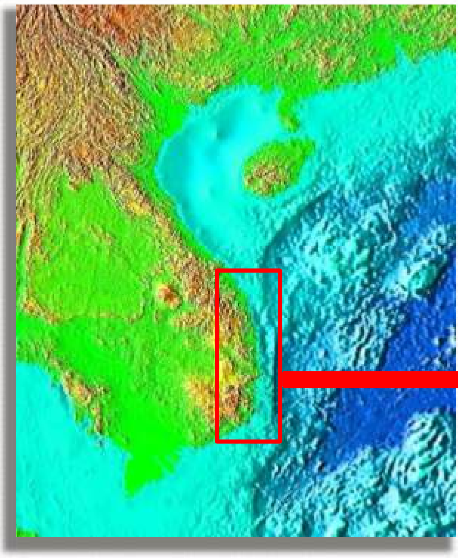
Developing best practices to address coastal marine oxygen loss in APEC economies for improving the management of marine living resources

Current situation of the oxygen monitoring in Viet Nam

Research Institute for Marine Fisheries (RIMF)

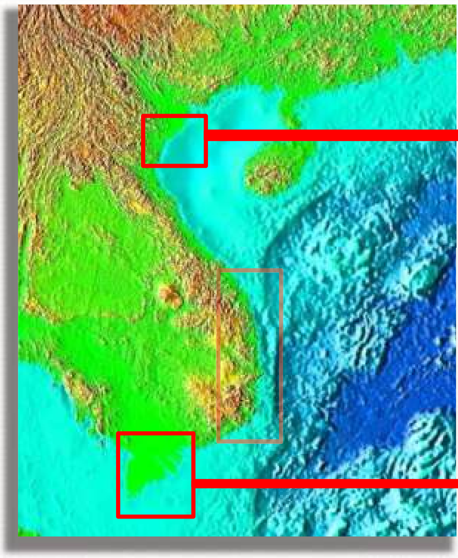
September 30th – October 3rd 2024, Paracas, Peru

Overview of Vietnam coastal water & habitat and the current utilization



- Steep coastline
- No problem with DO

Overview of Vietnam coastal water & habitat and the current utilization

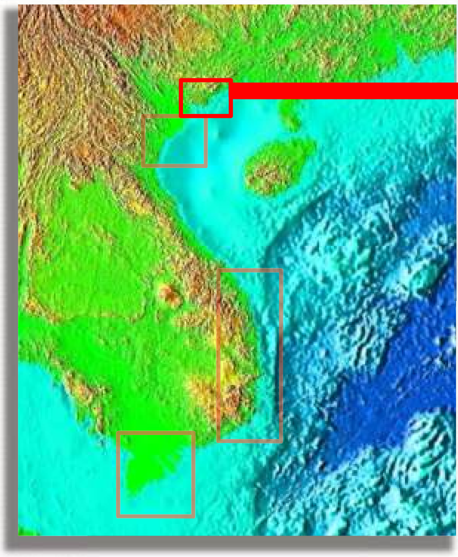


Red-river river mouth

No problem with DO

Mekong river mouth
No problem with DO

Overview of Vietnam coastal water & habitat and the current utilization



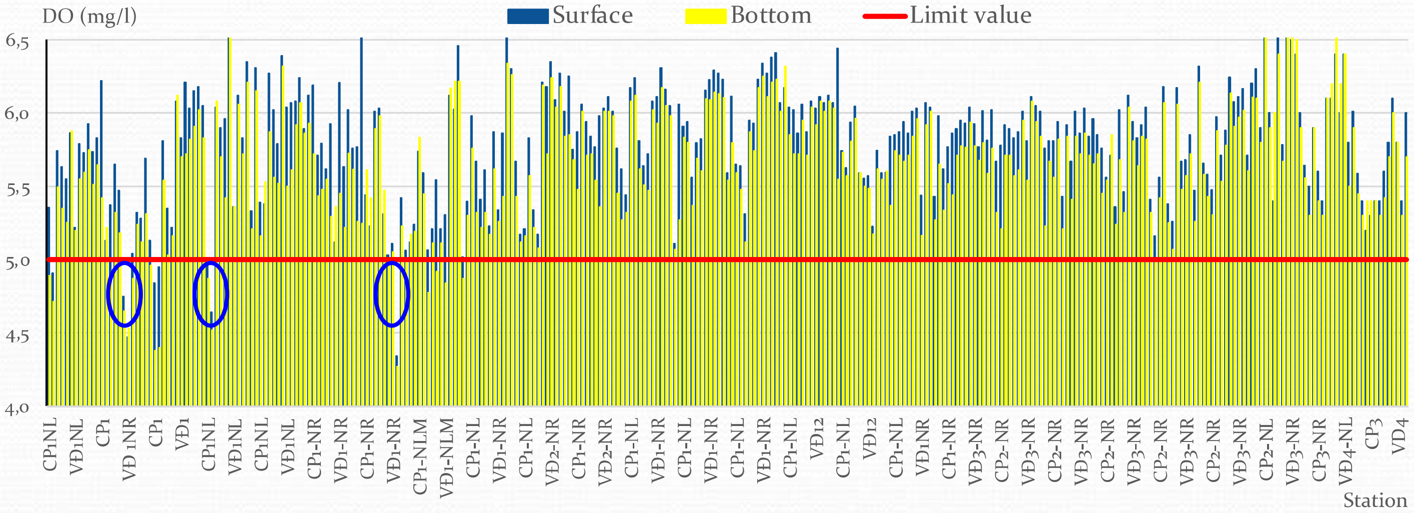
Monitoring sites:
1. Quang Ninh
2. Hạ Long Bay

Low DO in semi-close waters links with fish cages

Marine environment monitoring system 2001-2023

DO data set from monitoring program

1. Cage fish farming area

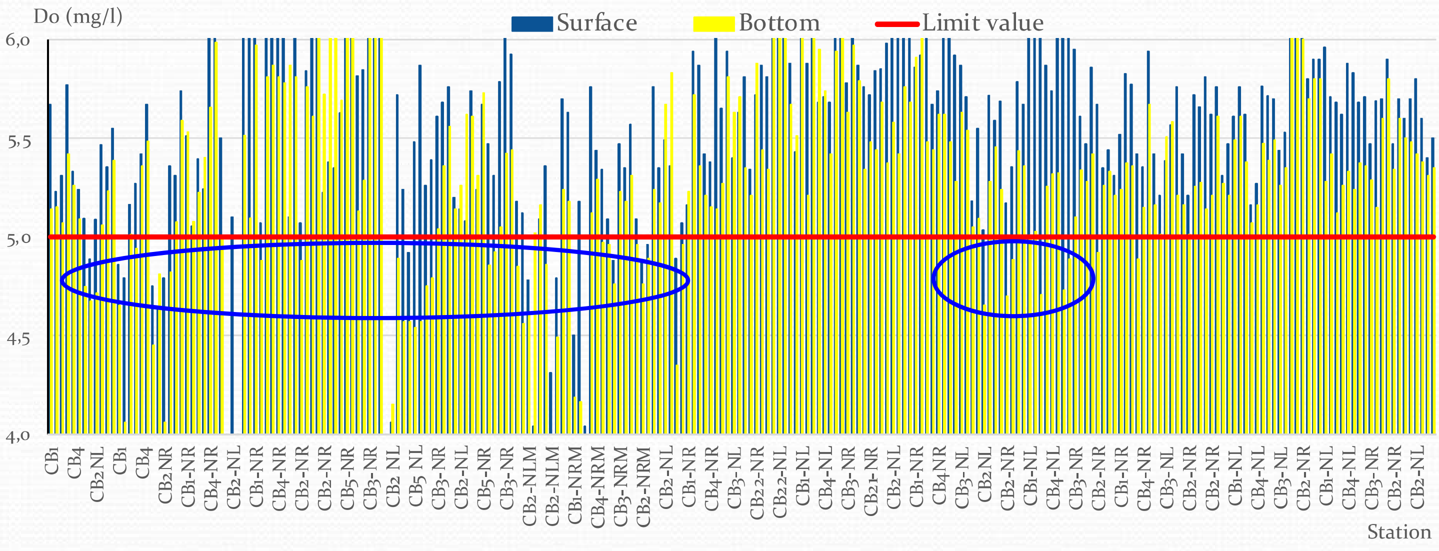


Quang Ninh

Marine environment monitoring system 2001-2023

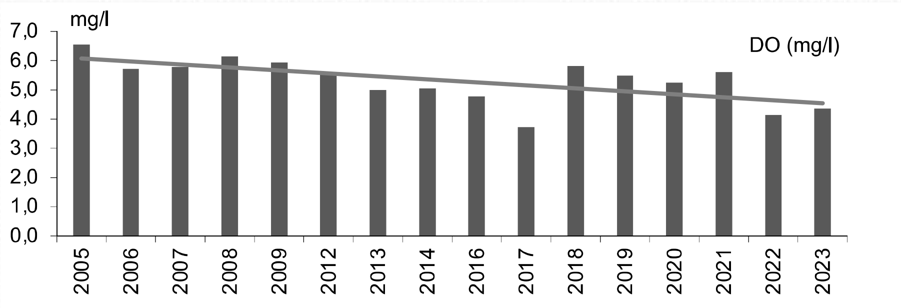
DO data set from monitoring program

1. Cage fish farming area

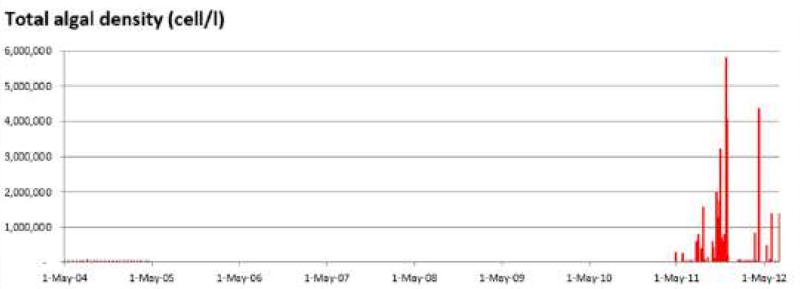


Hai Phong

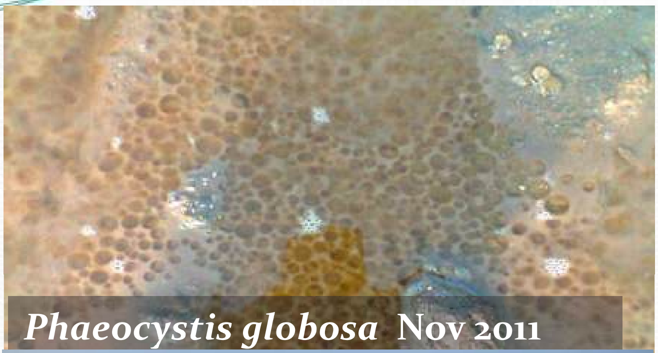
DO in site 2 during 2005-2023



DO reduction links with the increase in phytoplankton density

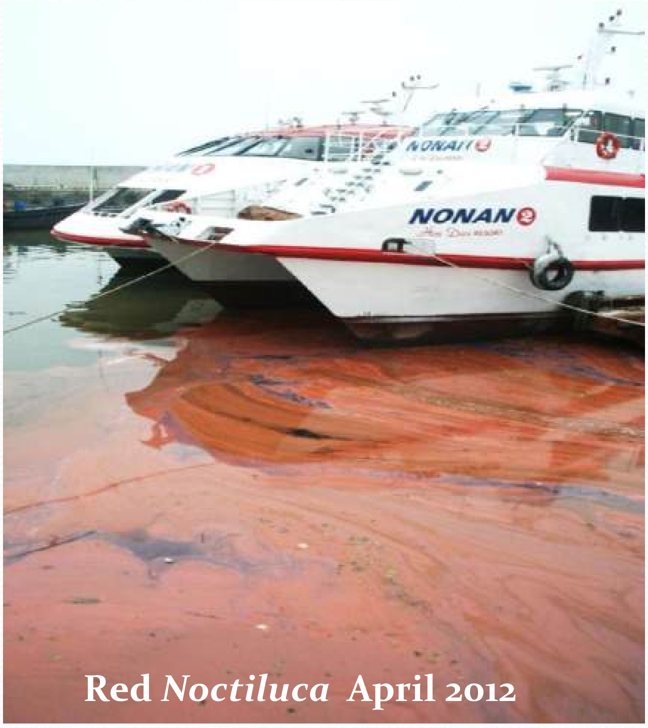


These redtides never happens before



Phaeocystis globosa Nov 2011

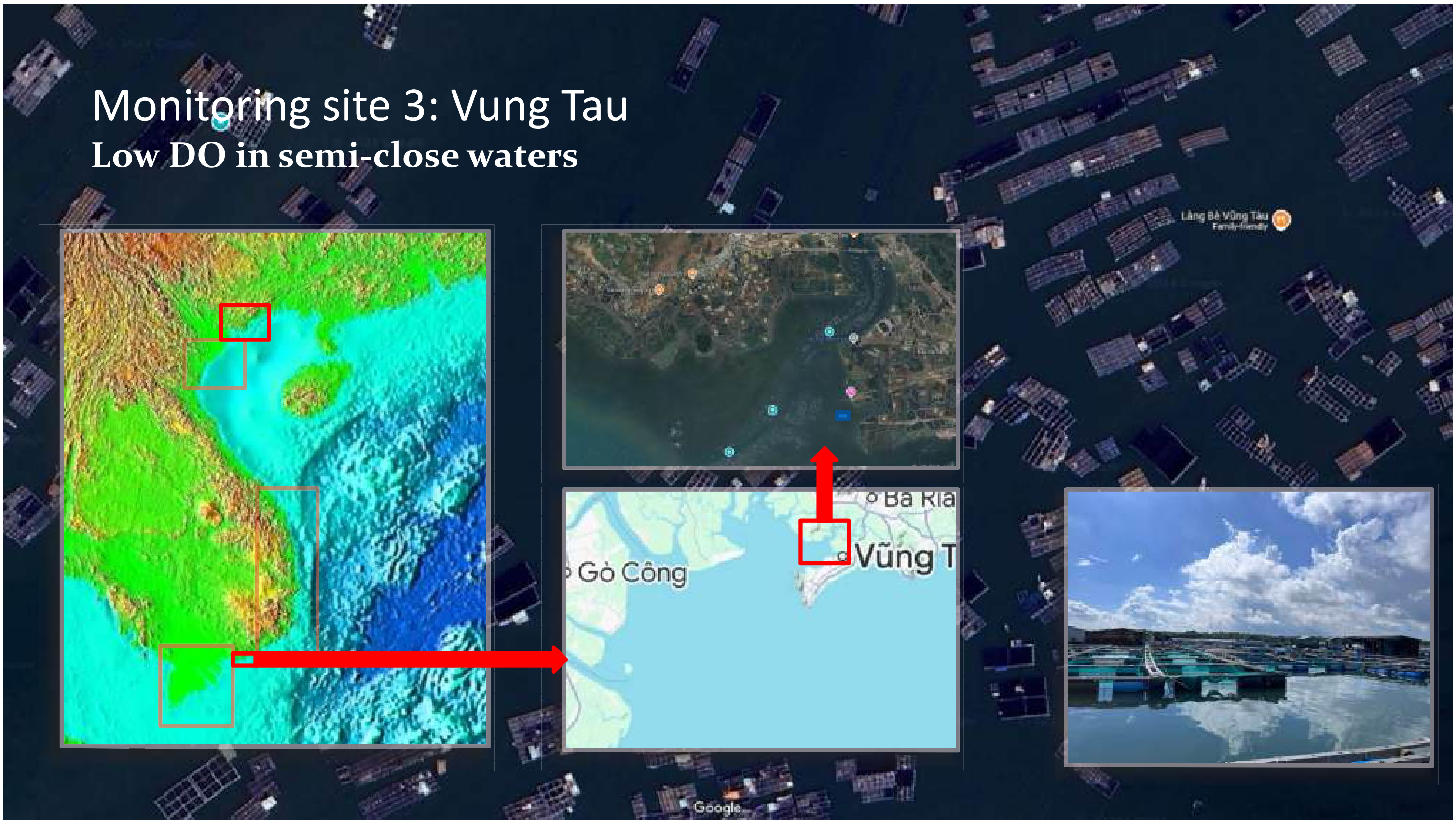
Trichodesmium Apr 2014



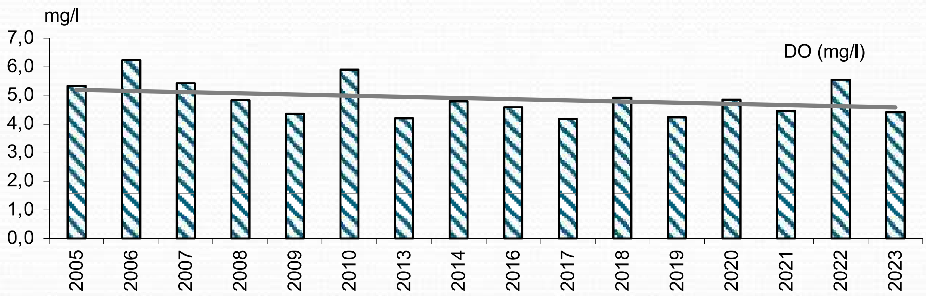
Red *Noctiluca* April 2012

Impact on aquaculrure

- Mass mortality of bival
- White sediment turns dark
- Fish cages needs aeration

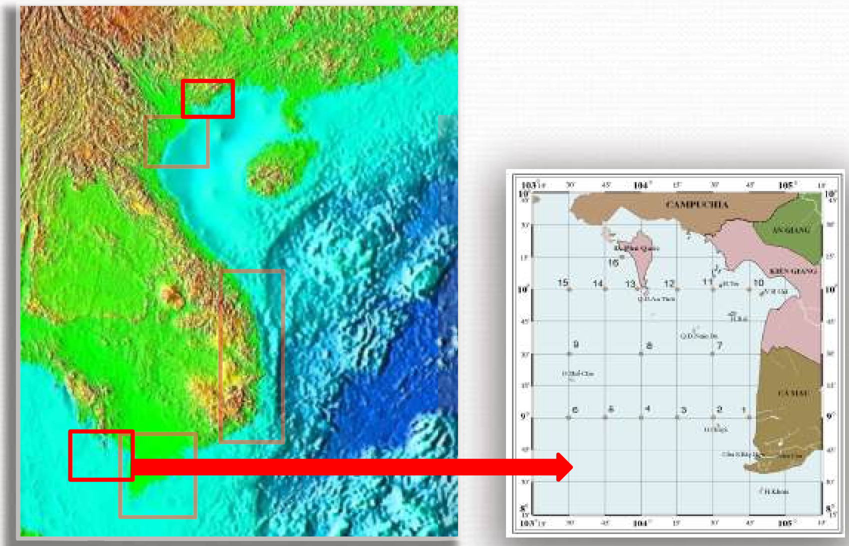


DO in site 3



Long Son - Vung Tau

Monitoring sites 4: The gulf of Thailand



Sampling site:

- Gulf of Thailand (off Mekong coast)

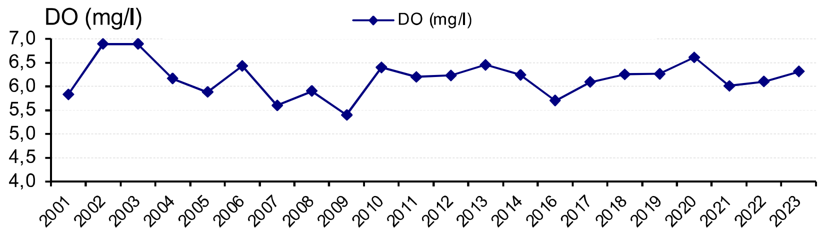
Data sery:

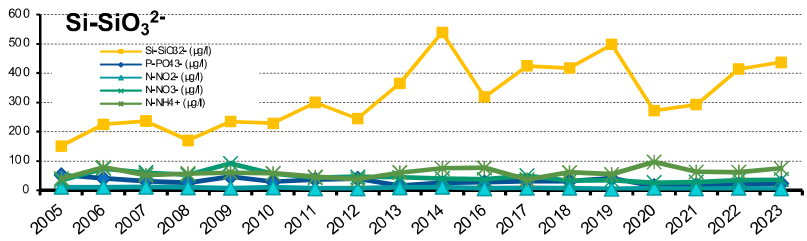
- 23 years of monitoring
- 16 fixed stations
- Twice/year (May-June and Oct-Nov)

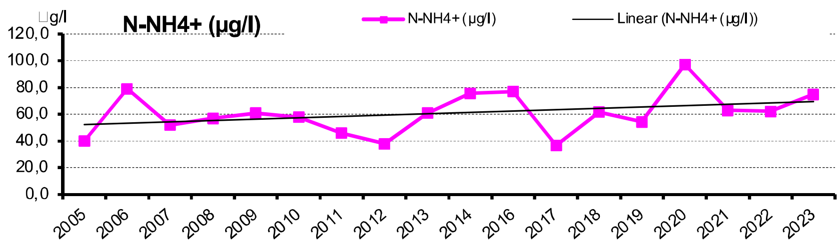
Parameters observed

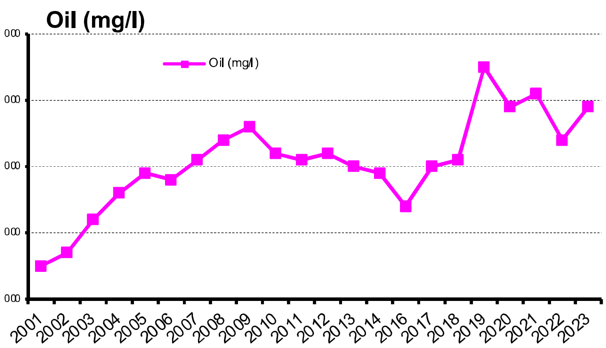
- Temp, Sal, DO, pH, Turb
- Nutrients in form of N, P, Si (NO_2, NO_3, NH_4, PO_4, SiO_3)
- Heavy metals
- Phytoplankton, zooplankton

Trends of water quality in the Gulf of Thailand

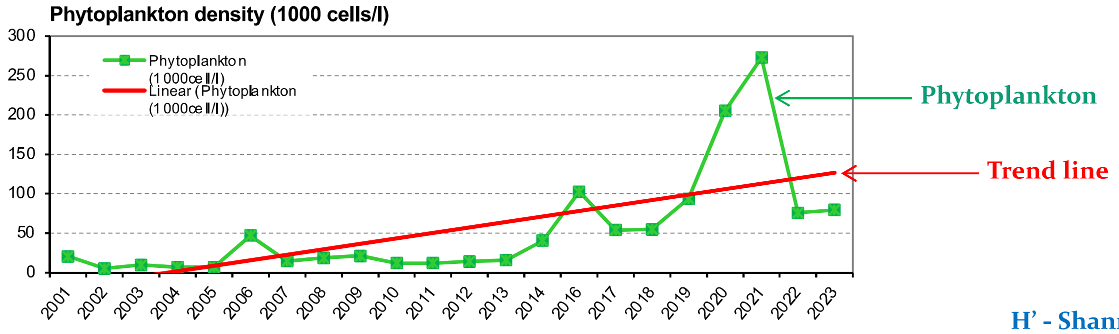


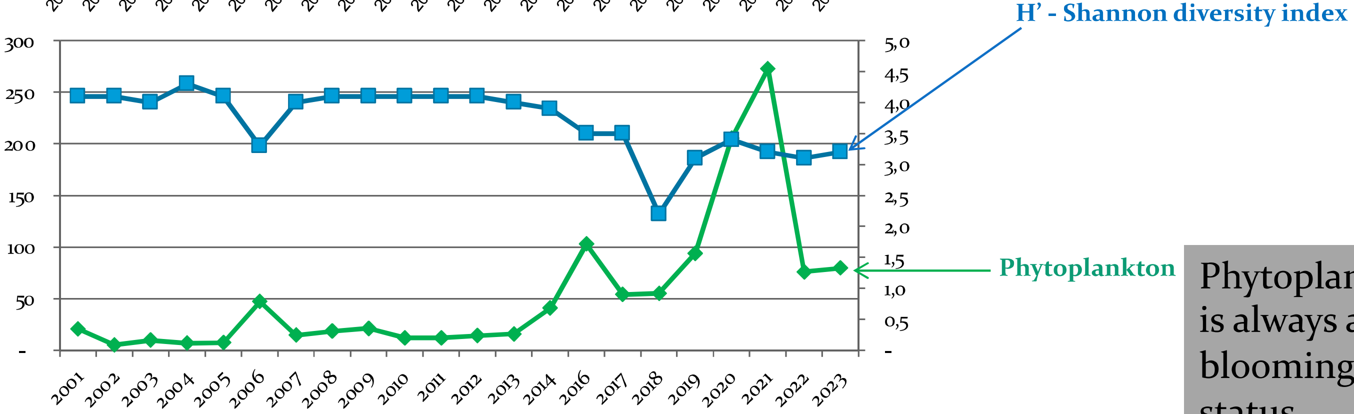




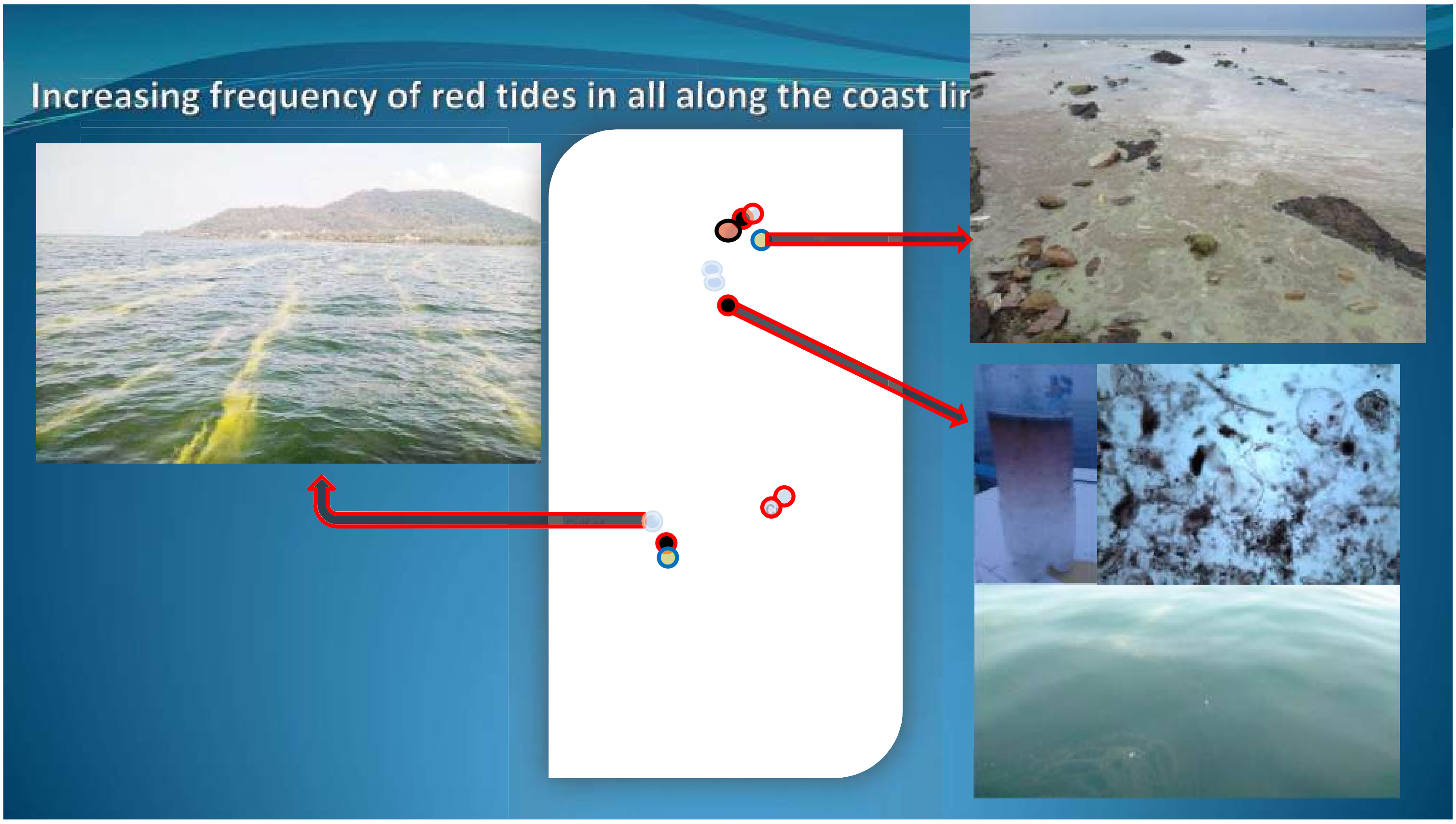


Trends of water quality in the Gulf of Thailand





Phytoplankton is always at blooming status



The drivers of low oxygen in the coastal waters

- Eutrophication:
  - Aquaculture
  - Discharge from residential areas (large city, untreated seawage)
  - Tourist
- Other reasons: unknown (climate change?)

The types of coastal water living resources may be affected by oxygen loss

- Benthic habitats: bivalves, corals ect.
- Planktonic communities: modification of food web
- Biodiversity
- Aquaculture/ fisheries living resources

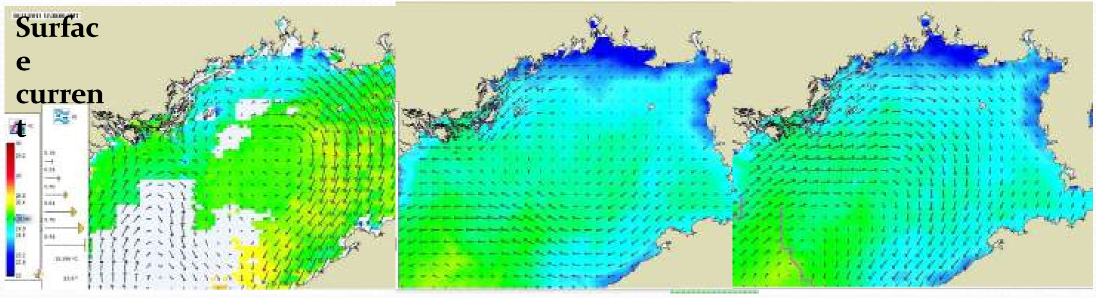
The current gaps in oxygen monitoring and its application for the management of living resources

- Lack of automatic online monitoring system
- Limit monitoring sites
- Lack of sharing data

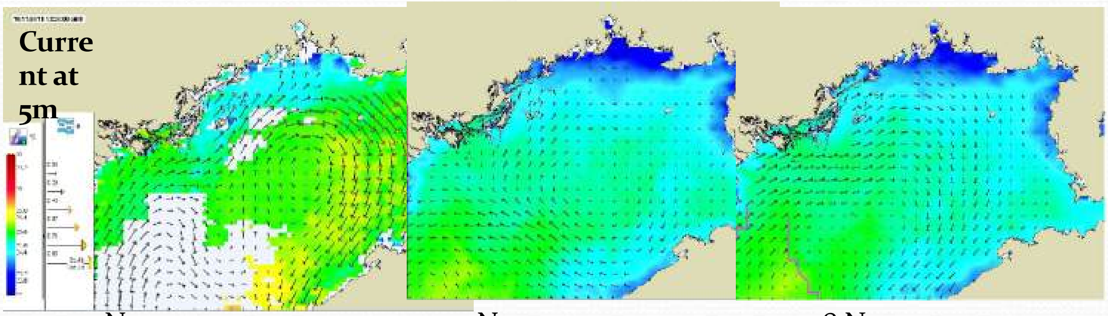
Need regional cooperation

Photo by FaJun Jiang (Guangxi Academy of sciences, China)

Water current patterns during bloom



10 Nov 15 Nov 18 Nov



10 Nov 15 Nov 18 Nov

Need regional view

✓How is the situation in the other economies
✓Need a wider view
✓A network?
✓A common project?

Annex 7. Roadmap discussion

Ideas for Roadmap

Introduction

- Motivation
  - Why this is needed now
  - Fisheries and aquaculture – food security, communities, etc.
  - Deoxygenation
  - Eutrophication and climate change

- Goal

Introduction

- Purpose of roadmap
  - Propose steps
  - Some are being done
  - Others are needed
  - Fit together

- History and development
  - How was the roadmap produced
  - Details in workshop report

Strategy

- Group effort
  - Consistency while flexible
  - Shared data and experiences
  - Case studies

- Audience(s)

- Opportunities

Climate change & Eutrophication

Received: 29 December 2022 | Revised: 7 June 2023 | Accepted: 9 June 2023
DOI: 10.1002/mcf2.10260

THEMED ISSUE
Hypoxia and Living Resources in the Gulf of Mexico

Sometimes (often?) responses to multiple stressors can be predicted from single-stressor effects: A case study using an agent-based population model of croaker in the Gulf of Mexico

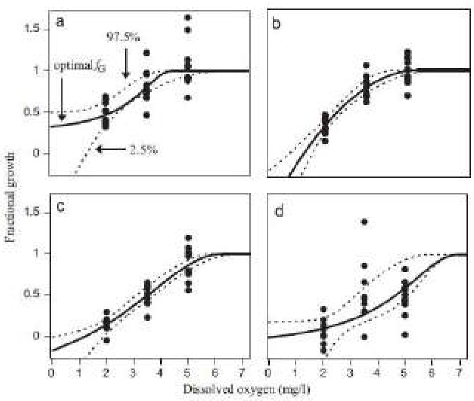
Kenneth A. Rose

Contents lists available at ScienceDirect
Journal of Theoretical Biology
journal homepage: www.elsevier.com/locate/yjtbi

Simulating the effects of fluctuating dissolved oxygen on growth, reproduction, and survival of fish and shrimp

Rachael Miller Neilan [a,*], Kenneth Rose [b]

Climate change & Eutrophication



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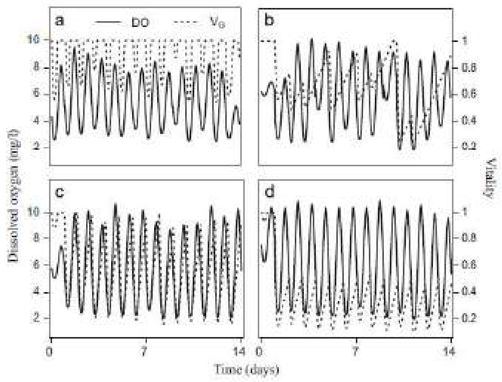

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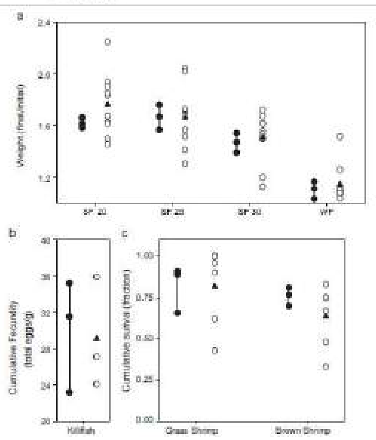

Option A: Narrative case studies

- Use what is available
- Suggestive or conclusive
- Already saw several good examples at workshop
- Fisheries
- Aquaculture

Option B: Quantitative case studies

- Analyze the oxygen data
- Could relate the oxygen to:
  - Fish and shellfish
  - Growth, Mortality, Reproduction, Movement → productivity of the stock
  - Habitat
  - Applies to both fisheries and aquaculture

Option B: Quantitative case studies

- Can try to also use fisheries data
  - Separate from oxygen data
  - Merged with oxygen data

- Fisheries data
  - Time series (landings, CPUE, population indices)
  - Spatial, Where boats fish
  - Historical fishing patterns
  - Landings by port
  - Available from stock assessments

- Aquaculture
  - Existing siting tools
  - How to incorporation of oxygen if not and should be

Option C: Vulnerability

- Usually done for climate change with fisheries

- Hypoxia include?

- Should it be added and how?
  - Species distributions (life cycle) overlap with historical and future hypoxia areas and seasons

PLOS | ONE

RESEARCH ARTICLE

A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast U.S. Continental Shelf

Jonathan A. Hare[1*], Wendy E. Morrison[2], Mark W. Nelson[2], Megan M. Stachura[3¤a], Eric J. Teeters[2], Roger B. Griffis[4], Michael A. Alexander[5], James D. Scott[5], Larry Alade[6], Richard J. Bell[1¤b], Antonie S. Chute[6], Kiersten L. Curti[6], Tobey H. Curtis[7], Daniel Kircheis[8], John F. Kocik[8], Sean M. Lucey[6], Camilla T. McCandless[1], Lisa M. Milke[9], David E. Richardson[1], Eric Robillard[6], Harvey J. Walsh[1], M. Conor McManus[10¤c], Katrin E. Marancik[10], Carolyn A. Griswold[1]

Option D: Habitat suitability

- Applied to fisheries and to Aquaculture
- Likely existing habitat models can be used
- If not available, relatively easy to develop models
- Perhaps overlap with case study species?

Option D: Habitat suitability

- Need good spatial information on oxygen
- Generate habitat quality maps without and with hypoxia
- Can be done for a few examples species

Monitoring and reporting oxygen

- ??

Next Steps - Today

- Group A – oxygen data
  - Now that you have heard for 3 days (F&A)
  - What oxygen monitoring or studies data is relevant from your economy?
  - Does it include covariates (e.g., temperature)?
  - Are the data available?
  - What documentation on protocls?
- Group B – case studies

Next Steps - Today

- Group A
- Group B – case studies
  - Suggestive or in the idea stage or documented
  - What species? Where and when life stages are exposed to hypoxia?
  - Basics about the fishery
  - Where is aquaculture occurring relative to past hypoxia or possible future hypoxia?

Pieces fit together

- Case studies – deep dive
- Vulnerability – broad coverage
- Habitat suitability
  - High confidence – known methods and data
  - Medium relevance to people – not biomass

Asia-Pacific Economic Cooperation

PERÚ Ministerio de la Producción

IMARPE INSTITUTO DEL MAR DEL PERÚ

Developing best practices to address coastal marine oxygen loss in APEC economies for improving the management of marine living resources: Building a roadmap - brainstorming

GO$_2$NE Global Ocean Oxygen Network

PARACAS - PERU

September 30th, 2024

Expected outcomes of the project

→

Outcome #1

Improved knowledge on best practices for data management, data quality control and data processing of coastal dissolved oxygen and derived metrics for fisheries and aquaculture management

Outcome #2

Enhanced collaboration to implement, optimize and sustain oxygen monitoring for fisheries and aquaculture applications among APEC economies (e.g. building a roadmap in order to ensure the sustainability of the initiative)

Asia-Pacific Economic Cooperation

Motivation for the roadmap

Provide information to improve management, adaptation and sustainable practices in fisheries and marine aquaculture in coastal waters, involving their exposure to pollution-driven and climate change-driven deoxygenation

Asia-Pacific Economic Cooperation

Conceptual basis for fisheries

Coastal oxygen deoxygenation negatively impact on growth, reproduction and mortality of fishery resources, thus impacting on fishery yields.

Conceptual basis for aquaculture

While coastal oxygen loss impair growth and reproduction, and severe hypoxia/anoxia might cause mortality in open mariculture systems, non sustainable practices in mariculture are also drivers of eutrophication and oxygen loss

Food security, livelihood and economic implications

Asia-Pacific Economic Cooperation

- Challenges **and opportunities**:
  - Application of knowledge of coastal deoxygenation impact on fisheries and aquaculture resources is becoming increasingly recognized and important
  - Wide variety of oxygen data sources and methods
  - Low oxygen conditions are tied with other stressors (warming, pollution, low pH, HABs…)
  - Need to disentangle natural processes driving low oxygen conditions versus (coastal) anthropogenic drivers of low oxygen
  - Data management, data quality procedures should be further standardized among APEC economies
  - Opportunity of integration of coastal waters' oxygen data across economies (GO_2DAT?)
  - Monitoring design not necessarily fit for fisheries and aquaculture management/adaptation purposes (e.g. time resolution, spatial coverage, exposure indices)

Asia-Pacific Economic Cooperation

- **Going forward…**
  - Opportunities for filling the gaps related to coastal oxygen data management
  - Opportunities to assess impacts of low oxygen on fisheries and aquaculture
  - Deliver information products for easy uptake by managers and stakeholders

APEC Asia-Pacific Economic Cooperation

Several layers of actions to implement the best practices:

- At data generation and data management level (data collection, pre-treatment, QC), including the historical data

- Monitoring design and research for F/A applications should be economy-specific based (not a unique recipe), to resolve:
  - Natural low oxygen versus human (global change?)-driven low oxygen
  - Daily cycles? Variance?
  - Time of exposure to given thresholds >>> thresholds based on physiological/behavioral info of the resources

- For stakeholders:
  - Meaningful information products
  - Building (participatory?) early warning systems /co-management?
  - Climate change scenarios for resource-use

APEC Asia-Pacific Economic Cooperation

Priorities for developing best practices to address coastal marine oxygen loss in APEC economies & improving the management of marine living resources

- Implement or optimize of data quality control and data management
  - Online training webinars
- Data availability and data sharing at international level for studies on trends and F/A impacts of low oxygen
- Monitoring design and research for F/A applications (development of exposure indices)
  - Online workshop
- Promote climate vulnerability studies and habitat suitability studies (current and future), taking into account the role of hypoxia
  - Online workshop

Asia-Pacific Economic Cooperation

- Share / harmonize protocols
- Adopt standardized/harmonized data quality procedures
- Data sharing/availability – how to move to FAIR (Findable, Accesible, Interoperable, Reusable) standards
- Data integrating (fisheries-derived, fishery-independent (scientific cruises), aquaculture-derived, WQ-derived)

- Update map of coastal low-oxygen sites in the APEC fórum
- Regional approaches to assess low-oxygen impacts on fishery resources

- Increase analysis of climate change-driven and pollution-driven hypoxia
- Identify or implement metrics for exposure to hipoxia
- Building early warning capacities
- Habitat suitability / early warning systems

- Increase awareness on the low oxygen impacts issue as extreme events
- Improve communication and engagement of stakeholders
- Profit UNESCO/IOC GO2NE for communication strategies

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Beyond the project

- Promote integration of coastal oxygen data in international databases / GO2DAT
- Cross environmental data with fisheries-derived data (spatial/temporal changes of fishing grounds, CPUEs, etc)
- Promote habitat suitability studies & indices (involve mapping/modelling/ecophysiology)
- Climate vulnerability studies for F&A involving hypoxia
- Enhance communication with stakeholders and policy makers
- Develop or promote pilot/study cases – fund raising

APEC Asia-Pacific Economic Cooperation