

MACAN BIENNIAL STATE OF THE SCIENCE AND TECHNICAL WORKSHOP

Smithsonian Environmental Research Center
July 15 – 17, 2025



Mid-Atlantic Coastal Acidification Network

MACAN's 2025 State of-the-Science and Technical Training Workshop

July 15-17, 2025 Smithsonian Environmental Research Center, Edgewater, MD

Summary

Every two years, MACAN hosts a workshop that focuses on updates to the community on the state of acidification science. This year MACAN responded not only to the scientific call for community updates, but also to provide technical assistance to the community and share information on marine carbon dioxide removal and nature-based solutions to acidic conditions. In partnership with NOAA's Ocean Acidification Program, the Smithsonian Environmental Research Center (SERC), and the Mid-Atlantic Regional Council on the Ocean's (MARCO) Coastal Carbon Collaborative (CCC), and the Mid-Atlantic Regional Coastal Ocean Observing System (MARACOOS), MACAN expanded the state-of-the-science (SOST) workshop to include technical field and laboratory demonstrations. This report outlines the breakout discussions, presentations from workshop participants, and the coastal and ocean acidification (COA) monitoring technologies demonstrated. The main takeaways from the meeting were: 1) marine carbon dioxide removal (mCDR) policy, reporting, and permitting processes need to catch up with the research; 2) weather quality pH data will be useful for expanding the monitoring network though it is important to understand what its limitations are; 3) state agencies, federal National Estuarine Research Reserves (NERRs), and National Estuary Partnerships are eager to participate in data sharing and expanded collection should funding become available. This workshop followed Chatham House rules, where notes on comments and discussion were taken without names being identified. The full agenda for the meeting can be found in Appendix A and a participant list in Appendix B.

Workshop Objectives

- Improve/support regional collaboration on standards of practice/validation methods for various types of instruments in coastal and estuarine waters
- Build capacity to fill spatio-temporal gaps in coastal acidification monitoring, by connecting people and resources to set up effective monitoring, while leveraging existing programs/sensors
- Build capacity for mCDR readiness (monitoring, research, and validation)
- Strengthen connections and collaborations across regional coastal acidification networks (CANs)

Potential future additional deliverables could include: a technical memorandum on best practices/standard methodology on validation sampling and community needs, the opportunity for an internal consistency check for participants, and identifying whether there is a need for a low-cost suite of monitoring equipment.

Acknowledgements and Disclaimers

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Day One and Day Two SOST Panel Sessions

Speaker presentations were 10 to 15 minutes, with at least 15 minutes for audience questions and answers at the end of each session. The slides for each presentation can be found in Appendix B.

Monitoring

This session highlighted monitoring priorities and provided examples of how data are used, presented, and integrated into broader modeling and observing programs.

- **Jonathan Sharp** - Leveraging surface fugacity observations and machine learning to map OA indicators in LMEs, National Oceanic and Atmospheric Administration (NOAA)
- **Maria Kavanaugh** - Satellite seascapes, OA, and in situ data integration, Oregon State University
- **Austin Pugh & Amy Trice** - NECAN Monitoring Plan, North East Regional Association Coastal Ocean Observing System & The Northeast Regional Ocean Council
- **Gregg Sakowicz** - Utility of the NERRs system and the wealth of data, Jacques Cousteau National Estuarine Research Reserve
- **Nichole Ruiz** - Evaluating Satellite Chlorophyll as an Indicator of Coastal Acidification, Mid-Atlantic Regional Council on the Ocean/MACAN

Responsible Implementation of mCDR

This session highlighted current mCDR technologies and projects in the Mid-Atlantic and provided opportunities to discuss the responsible implementation and permitting of mCDR.

- **Wil Burns** - How The BBNJ Can Help Us Foster Responsible mCDR, American University Institute for Carbon Removal Law and Policy
- **Grace Andrews** - Current field trials for OAE and mCDR, Hourglass Climate
- **Kyle Hinson** - Enhancing ocean alkalinity enhancement simulations through integrated experimental and modeling approaches, Pacific Northwest National Laboratory
- **Jeremy Testa** - Overview of the pH adjustment at a water treatment plant project, University of Maryland Center for Environmental Science
- **Ashwin Murthy** - State and federal permitting and compliance requirements in mCDR/OAE, Sabin Center for Climate Change Law (Columbia University)

Nature-Based Solutions (NbS) and Blue Carbon

This session provided success stories from acidification mitigation experiments, nature-based solutions to acidification and carbon sequestration, and how these actions are factoring into state planning for CO₂ reduction and capture.

- **Stephen Tomasetti** - Seagrass carbon sequestration under warming stress, University of Maryland Eastern Shore
- **Annie Tamalavage** - How can we use open source databases to leverage regional policy?, Smithsonian Environmental Research Center
- **Sylvia Troost** - Efforts for states to incorporate blue carbon planning into climate plans, science behind this, policy work, education, etc, Pew Charitable Trusts

Biological Impacts

This session addressed new developments for species-specific impacts due to acidification, how multi-stressors are taken into account when developing management plans, and how data tools can be used to inform risk assessment and define vulnerability. The session also included what data is needed to define risk, how to define risk and vulnerability, what kinds of outcomes and tools can be useful, and lessons learned to support adaptation and resilience.

- **Emily Hall** - Acidification and HABs with a focus on work around Florida red tide, Mote Marine Lab/Southeast Ocean and Coastal Acidification Network (SOCAN)
- **Janet Reimer** - Planning tools for identifying locations at risk for acidification, Mid-Atlantic Regional Council on the Ocean/MACAN
- **Halle Berger** - Swimming a mile together: Navigating transdisciplinary currents in Atlantic Sea Scallop research to build climate resilience in the fishery, University of Connecticut
- **Daphne Munroe** - Commercial shellfish species in NJ: surf clams vulnerable and adaptability to acidification, Rutgers University

Day One and Two Breakout Discussion Notes

What are the barriers to states integrating mCDR, OAE, blue carbon accounting, nature-based solutions and climate mitigation/adaptation plans into regulatory frameworks and monitoring?

SUMMARY

This discussion identified the barriers preventing states from effectively integrating marine carbon dioxide removal (mCDR), ocean alkalinity enhancement (OAE), blue carbon accounting, and other nature-based climate solutions into regulatory frameworks, monitoring, and climate/ocean action plans.

Key Barriers

1. Knowledge & Expertise Gaps
 - State managers often lack technical expertise in carbon stock analysis, carbonate chemistry, and carbon accounting, despite strong interest.
 - There is a disconnect between scientists and policymakers; many officials are at an early awareness stage (e.g., just “looking at blue carbon” without identifying opportunities). While the science is being carried out, results are difficult for managers to interpret on their own, and there are often large gaps in data that result in high uncertainty and a lack of information for managers to use.
 - Climate action plans historically focused on energy and transportation modifications and accounting, with only recent recognition of blue carbon, nature-based solutions, and recognizing COA as a problem that can be addressed at the state level.

2. Monitoring & Data Challenges

- There is currently limited infrastructure and knowledge capacity for comprehensive COA monitoring (e.g., at NERRs).
- Equipment costs and procurement delays hinder small states.
- There is a lack of standardized protocols and reporting of uncertainty across datasets. Datasets can also be disparate, and managers do not always have the expertise to incorporate data into state resource planning.
- States often rely on partners for data synthesis and lack user-friendly public data tools.
- A “lending library” of rapid-deployment monitoring kits could address technical gaps, especially for short permit windows in mCDR field trials.
- Establishing baseline conditions for tracking the progress of mCDR is essential, but this work has not yet been done.

3. Regulatory & Institutional Barriers

- It is often unclear who has permitting authority: jurisdiction varies (CZM programs, coastal regulators, and agriculture runoff left under-regulated). The regulatory framework is still catching up with the science.
- States are often assumed to have the authority to set standards, but in reality, due to the lack of a regulatory framework, there is still confusion over federal consistency guidelines. The lack of federal direction creates fragmented approaches across states.
- Permit hurdles and long wait times slow down innovation, with high costs and delays threatening funding.

4. Political & Public Engagement Barriers

- Limited public understanding and low buy-in; people see climate issues as pollutants or quick-fix problems.
- Distrust in science, misinformation, and issue fatigue contribute to low buy-in for COA projects.
- Politically divided climate priorities lead to uneven adoption across states.
- Success depends on framing (e.g., COA as a water quality issue; nature-based solutions marketed as protecting wetlands and coasts).

5. Economic & Practical Concerns

- There is a weak or unclear economic case for mCDR and blue carbon in many regions. Carbon credit and accounting are not well understood or consistently defined across states and federal agencies.
- Even in states that have strong datasets, there is a struggle to elevate information to decision-makers for implementation.
- Funding limitations and a lack of clear return on investment cause slow adoption of practices. This is where lessons from other states would be helpful to those states that are building their frameworks.

Opportunities

- Targeted and goal specific (not just broad climate goals) to guide state action.
- Embedding COA/blue carbon into existing climate, water quality, and carbon management frameworks rather than siloing.
- Leveraging partnerships (e.g., MARCO, MARACOOS, MACAN, OAP, and international monitoring efforts) to provide technical expertise and public-facing tools.
- Building public support by connecting COA/blue carbon to local economic and public safety benefits (coastal protection, fisheries, aquaculture siting).
- Encouraging open data sharing between states, researchers, and startups in exchange for access to monitoring resources.

Key Takeaway

Progress on integrating mCDR, OAE, and blue carbon into state-level climate strategies is hampered by limited expertise, fragmented regulation, limited monitoring infrastructure, political divides, and low public engagement. Overcoming these barriers requires federal guidance, stronger state-science partnerships, standardized monitoring, and better communication strategies that tie ocean carbon solutions to water quality, economic resilience, and public benefits.

How is mCDR planning using carbon stock assessments, and how can nature-based solutions and mCDR complement each other? Are ecosystem services being considered, and the co-benefits being identified?

SUMMARY

This session discussed how carbon stock assessments are (or are not) being used in marine carbon dioxide removal (mCDR) planning, and how these approaches can complement or conflict with nature-based solutions (NbS) such as marsh, seagrass, or oyster reef restoration.

Key Points

1. Current Use of Carbon Stock Assessments
 - mCDR planning does not consistently use carbon stock assessments.
 - Baseline blue carbon inventories (e.g., marsh exports and sequestered carbon) are essential to understand net benefits and track the durability of carbon credits.
 - Observing systems and strategic monitoring at tidal creek and/or sites where marshes are flushed can support both mCDR and NbS evaluation.

2. mCDR and Nature-Based Solutions: Complement or Conflict

- Need to evaluate co-location opportunities where mCDR could enhance NbS (e.g., COA mitigation for shellfish industries, wastewater treatment co-benefits).
- Avoid scenarios where mCDR undermines NbS benefits; important to assess interactions and net ecosystem effects. Though NbS benefits need to be established first to ensure that any mechanical mCDR is not impacting NbS and vice versa.
- Nature-based solutions already incorporate ecosystem services and community co-benefits (storm protection, erosion control, biodiversity, recreation). mCDR should not negatively impact natural ecosystem services but could enhance them.

3. Challenges and Barriers

- There is a current lack of durability assurance for carbon credits and uncertainty about long-term impacts.
- There is limited monitoring and a need for more instrumentation/industry involvement.
- There are questions about scalability, especially for wastewater treatment applications and enhancement methods.
- Broader climate strategy demands large-scale emission reductions, not just offsets from mCDR and NbS.

4. Economic & Social Dimensions

- Carbon markets are still uncertain and financially weak, and the general public does not strongly connect with carbon reduction as a motivator.
- Stronger public support emerges when mCDR and NbS are framed around tangible co-benefits (e.g., stormwater control, fisheries, hunting, local ecosystems).
- Early experiments:
 - First seagrass carbon market (The Nature Conservancy with the Virginia Institute of Marine Science).
 - "Resilience credits" (e.g., some hotels in Mexico do this).
 - Artificial oyster reefs in Florida are gaining local support.
- Carbon credit prices may remain low, but some companies still want "green branding."
- Most companies, state agencies, and people do not participate in carbon credits, and there is little general knowledge about them

5. Broader Context

- U.S. policies and markets fluctuate with political cycles, limiting long-term consistency for carbon markets and climate priorities.
- Compared to Europe, U.S. land-use and energy policies treat land as disposable and continue to subsidize fossil fuels heavily, making it difficult to advance carbon markets, mCDR, and NbS.
- Ultimately, many people believe that emissions reductions and renewable energy investments are more cost-effective than relying solely on CDR.

Key

Takeaway

Carbon stock assessments are underutilized in mCDR planning but could provide essential baselines for evaluating durability, co-benefits, and tradeoffs. Integrating mCDR with nature-based solutions offers opportunities for localized benefits (e.g., COA mitigation, shellfish resilience), but risks undermining ecosystem services if poorly planned. The success of these approaches will depend on robust monitoring, clear carbon accounting, stronger public engagement via co-benefits, and consistent policy frameworks.

What are some of the environmental risks of mCDR, how are they being defined, and who is enforcing them?

SUMMARY

Participants discussed the known environmental risks of marine carbon dioxide removal (mCDR), how they are being defined, and the challenges of enforcing safeguards. While the discussion on barriers to implementing mCDR defined most of the challenges, it is difficult to define risks without also discussing how risks are related to challenges.

Key Points

1. Uncertainty & Regulatory Hesitancy

- Regulators are reluctant to permit mCDR projects because risks are poorly defined and frameworks for enforcement do not yet exist.
- Current oversight is fragmented, and no one agency is responsible for it. Approval of permits often depends on methodologies vetted by different bodies (e.g., EPA, peer review, community-based monitoring).

2. Types of Risks

- There are different method-specific risks for distinct environments
 - *Mineral OAE*: involves extractive processes with local/regional impacts that must be included in assessments. Also, some minerals have small amounts of heavy metals that can be harmful to ecosystems (e.g.,

olivine can release chromium and zinc, which can be toxic to phytoplankton).

- *Artificial upwelling/downwelling*: seen as highly risky due to potential ecosystem disruptions.
- Scaling risks: Environmental effects may change dramatically as projects move from small pilot tests to larger deployments. Stepwise upscaling is essential to avoid unintended harm.
- Reversibility risks: If harm occurs, reversing impacts could require massive effort, potentially impossible at large scales.

3. Monitoring & Detection Challenges

- Small-scale *in-situ* experiments show that even intensive sampling often fails to detect signals due to the time scales of variability in coastal environments.
- Mechanistic modeling can help bridge this gap and reduce reliance on trial-and-error ocean dumping.
- Monitoring, reporting, and verification (MRV) remains underdeveloped. Some methodological progress (e.g., LiCor and other infrared gas analyzer direct flux measurements) is underway in the pilot studies.

4. Long-term & Systemic Concerns

- Unknown durability of carbon storage and impacts in deep water. The time scales of storage are also unknown, and how deep biological communities will respond to the increase in acidification.
- Projects may have future regulatory implications beyond their duration, particularly if the industry scales up. How long will monitoring be needed and provided after the termination of a study?
- Raises broader question: *what are the risks of NOT pursuing mCDR compared to those of doing it?*
 - Potential benefits (e.g., pulling 1% of CO₂ from the air) could outweigh risks if trade-offs are managed. But the trade-offs are not clearly defined over space and time.
 - Risks of climate inaction must be weighed alongside risks of intervention. mCDR could detract from rapid decarbonization.

5. Enforcement Gaps

- Enforcement capacity is weak: few state or federal employees are available to monitor and regulate projects.
- Current assessments often focus narrowly on what is required for permitting, not long-term ecosystem effects.

Key Takeaways

Environmental risks of mCDR are not yet well-defined, monitored, or enforced, leaving regulators hesitant. Risks vary by method, scale, and reversibility, and monitoring challenges make detection difficult. Stepwise scaling, robust modeling, and new regulatory frameworks are needed to minimize unintended harm. At the same time, risks of inaction on climate change must also be weighed, since delaying solutions could have even greater long-term consequences. mCDR should only be viewed as one part of the overall solution to climate change, but the localized impacts are important as a bottom-up approach.

What are some of the defining characteristics of “responsible” implementation of human-induced OAE and mCDR, and how are they being monitored?

SUMMARY

This session defined the known characteristics of responsible implementation of marine carbon dioxide removal (mCDR) and ocean alkalinity enhancement (OAE), along with the challenges of monitoring, regulation, and public acceptance.

Key Points

1. Data Transparency: Startups often do not share data, creating misalignment with academic research and slowing scientific validation.
2. Community Engagement: Early and genuine engagement with local communities is critical. Past projects (e.g., Cornwall, Martha’s Vineyard) show that a lack of trust and late outreach can lead to rejection. Successful efforts (e.g., Ebb Carbon, Vesta in Southampton, NY) involved communities early.
3. Regulation & Monitoring: Currently, there is little regulation or standardized monitoring of mCDR projects, though disparate efforts are underway. Permitting processes are inconsistent across states, and permitting offices often lack scientific expertise. Pilot projects are too small for robust oversight but highlight the need for future frameworks. Pre-application deconfliction of projects could move them faster in permitting if they did prior engagement and got community buy-in.
4. Scientific Challenges: Different challenges exist for the various projects and can also co-occur:
 - Misalignment between lab research and real-world applications.
 - Lack of baseline environmental data, especially in dynamic estuarine systems.
 - Difficulty balancing ambition with measurable impact.

5. Scale & Responsibility: Responsible projects usually partner with scientific institutions, conduct thorough baseline and environmental monitoring, and pursue transparency across the supply chain. Projects should prioritize minimizing harm, measuring durability, and considering life-cycle impacts. Projects should also have post-project monitoring plans to ensure that implementation does not produce unforeseen risks after the termination of the deployment period.
6. Easily findable and searchable data: Publicly available data is essential for transparency and broad research.
 - Data, even from startups, should be required to be submitted to data repositories that are frequently used by the acidification community, such as NCEI, SOCAT, MARACOOS's OceansMap, and MARCO's Ocean Data Portal.
7. Societal & Market Concerns: Skepticism, misinformation, and lack of understanding can hinder projects, granting of permits, and development of policy.
 - Public trust issues, skepticism, and conspiracy fears.
 - Tension between commercial profit motives and environmental integrity.
 - Carbon offset markets and corporate climate strategies may influence adoption.
 - Cutting emissions remains the most important climate solution; mCDR is a complementary tool, not a replacement.

Key Takeaways

Responsible mCDR requires early community involvement, transparent science-driven practices, stronger regulatory frameworks, and safeguards against unintended harm. Scaling these technologies will require balancing urgency, co-benefits, trust-building, and rigorous monitoring.

How are risk assessments incorporating biological metrics?

SUMMARY

This session discussed how risk assessments are (and are not) incorporating biological metrics in the context of climate change, COA, and ecosystem impacts. With the challenges surrounding ecosystem-scale biological risk assessments, there are also many opportunities to improve current methods and models.

Key Points

- **Current Use of Biological Metrics**

- Some assessments now consider concomitant species-specific responses (e.g., corals, oysters, seagrasses), shell conditions, spat counts, and habitat-scale water chemistry.
- However, these efforts remain limited due to high project costs, resource constraints, and difficulty in capturing ecosystem-wide impacts.

- **Gaps & Challenges**

- Most climate risk assessments focus on physical risks (e.g., sea-level rise, flooding), not detailed biological impacts. Since different species react to COA at varying levels, each species needs to be considered.
- State-level risk assessments often focus only on one state, with limited capacity or funding for in-situ biological monitoring. Therefore, states rely on partners or publicly available information.
- Biological monitoring tends to focus on economically valuable species, leaving broader biodiversity underrepresented.
- There is a lack of baseline biological data that makes it difficult to evaluate long-term changes. Data syntheses of biological metrics could be used to create baseline datasets for comparison against acidified conditions.

- **Research Examples**

- Scallop shell study (long-term shell record, showing degradation).
- Steve's oyster reef chemistry study (showing differences in carbonate chemistry inside vs. outside reefs).
- Seagrass studies show buffering effects against OA.
- Coral biodiversity studies (large-scale tank experiments in Hawaii).

- **Integration of Biological Metrics Issues**

- Biological and chemical linkages are critical, but rarely incorporated together.
- Managers often emphasize biological data, as the result of chemical conditions, but abiotic drivers (e.g., pH, carbonate chemistry, nutrients) are needed to understand where risk occurs.
- Coastal systems are especially complex, with positive feedback loops where biology influences chemistry, which in turn affects biology.

- **Opportunities for Improvement**

- Use of omics, eDNA, and remote sensing could expand biological monitoring that could be colocated with chemical studies.
- Collaboration among researchers, managers, and states is needed to integrate both biotic and abiotic metrics.

- Defining “risk” more carefully (quantitatively) will help standardize assessments.
- Data portals and state-academic partnerships (e.g., VIMS) can bridge knowledge gaps and expand species assessments.

Key Takeaways

Environmental risk assessments are only beginning to incorporate biological metrics, with attention on economically important species. To become robust, practitioners must integrate biology with chemistry, use new technologies, and overcome funding and capacity challenges. Without this, risk assessments could discount key ecosystem vulnerabilities and services. Using existing data for desktop studies could help negate funding shortfalls for new data collection.

Are there any ecosystem-scale biological assessments that incorporate acidification metrics into their frameworks?

SUMMARY

Ecosystem-scale biological assessments that fully integrate COA metrics are still uncommon, but emerging efforts exist in regions such as the Florida Keys (coral restoration projects) and the U.S. West Coast (especially Oregon, where hatcheries depend on carbonate chemistry modeling as an early warning data product for acidified waters). These examples highlight the need for greater coordination and collaboration to expand such modeling work in areas like the Mid-Atlantic.

Some examples of how COA is being incorporated into biological frameworks and applied applications include:

- Mid-Atlantic/Chesapeake Bay: Some research (e.g., self-buffering by hatcheries and aquaculture facilities in the northern Chesapeake, pH databases from Climate Adaptation Science Centers, carbonate chemistry work by individual researchers), but no large-scale ecosystem framework exists.
- Florida Keys: Incorporating carbonate chemistry, flow modeling, and nutrient monitoring into coral restoration projects/monitoring, showing ecosystem-level differences.
- West Coast/Oregon: Strong modeling efforts due to hatchery reliance on carbonate energy; effective integration of OA in ecosystem studies.
- National Large Marine Ecosystem Assessments: Some acidification data (pH) has been included in the National Marine Ecosystems Status assessment:

<https://ecowatch.noaa.gov/>. This is regional, however, and may not capture the heterogeneity of coastal regions.

- Individual State and Research Institutions: Fisheries management strategy assessments (acidification embedded in natural mortality in their models). A VIMS group is building an ecosystem-based mechanistic model that includes acidification.

Challenges

- Lack of established methods and multi-stressor frameworks that connect OA with broader ecosystem impacts. Multi stressor frameworks are key for integrating biological, physical, and chemical components into predictive modeling for regional\ and finer scales.
- There is still a need to co-locate carbonate chemistry with biological response metrics (growth, mortality, population size) to inform restoration, aquaculture siting, and fisheries management.
- Communication barriers, particularly in framing COA in the context of water quality and risk assessments, without oversimplifying its link to climate change
- Current management tools like Total Maximum Daily Loads (used for temperature or bacteria) do not translate well for COA-related parameters. It is difficult to directly regulate acidification variables such as pH, which can result from coastal eutrophication and localized CO₂ inputs.

Opportunities

- Push for collaborative, multi-institutional efforts in regions lacking ecosystem-scale assessments.
- Embed OA into fisheries management strategies. While fisheries already indirectly use acidification in natural mortality parameters in some models, this does not take into account reduced reproduction or population migration away from low pH waters.
- Build new methodologies where none exist, leveraging existing databases and modeling expertise (e.g., VIMS mechanistic ecosystem model under development).

Key Takeaways

There are few but growing examples of ecosystem-scale biological assessments incorporating acidification. Scaling this work requires new methods, stronger collaboration, and effective communication strategies to embed COA into ecosystem and management frameworks.

How does the community envision incorporating NERRs and state agency water quality pH data into syntheses?

SUMMARY

This session explored how National Estuarine Research Reserves (NERRs) and state agency water quality data, specifically pH and alkalinity measurements, can be better incorporated into regional and national syntheses to strengthen long-term COA monitoring and related environmental variability.

Key Points

1. Current Value of the Data and Challenges
 - NERRs, state agencies, and partners already collect valuable water quality data (pH, alkalinity, salinity, temperature, turbidity, nutrients).
 - There is a misconception that much of the state data is not standardized, not uploaded to public portals, and not collected consistently, creating missed opportunities for regional/national OA assessments. Within each state, the water quality programs are well standardized; however, not every state has the same standards.
 - NERRs data is standardized across the entire NERRs system and is housed through one central data portal <https://cdmo.baruch.sc.edu/>.
 - Data often exists but is difficult for managers and the public to access; states rely on external partners to make data user-friendly.
2. Standardization & Training Needs
 - Consistent sample collection protocols and QA/QC standards are essential across all sectors (academia, states, NERRs, NEPs, federal agencies).
 - Training programs for students, agency staff, and local groups could improve data quality and increase participation.
 - Reporting uncertainty as well as errors around measurements is critical for integration into broader syntheses.
3. Examples & Regional Notes
 - Delaware: Coordination between NERRs and CZM programs, with state councils meeting regularly.
 - New Jersey: 30-year datasets exist but need more visibility; estuarine variability makes site-specific monitoring important.
 - Maryland: The Maryland Water Monitoring Council meets frequently, but data integration is uneven.

- Florida NERRs: Collect alkalinity data, but often not uploaded to portals because it is not part of the NERRs system-wide monitoring program and is on a project-to-project basis when external funding and partners are involved.
- USGS: Long history of pH and alkalinity data collection, offering collaboration opportunities. This data is publicly available, but the methodology and reporting units often differ from COA community standards.
- North American and international synthesis (U.S., Canada, Mexico): linked to global datasets (e.g., GLODAP, CODAP, SOCAT).

4. Opportunities for Improvement

- Shared observing systems can serve multiple research and management needs.
- Regional partnerships (e.g., MARCO, MACAN, MARACOOS) are critical for aggregating state data into accessible, public-facing tools.
- Leverage short-term equipment leasing (e.g., LI-COR sensors) for high-frequency monitoring during targeted experiments.
- Use existing data, even if it is not climate quality, to detect long-term trends and fill gaps. Statistical methods are used to remove noise from high-frequency datasets to find trends over long enough periods of time to assess if acidification is occurring over decadal scales.
- Identify which NERRs monitor which parameters to highlight regional gaps in coverage. Working with NERRs to use their data will close monitoring gaps and increase the monitoring network. Inclusion of NERRs data will also ultimately help resource managers identify areas at risk for acidification, those that need more monitoring, areas that could benefit from mCDR, and attention to other management issues. Provide funding to create local, regional, and national syntheses of existing weather quality data from water quality monitoring programs.

Key Takeaways

NERRs and state agencies collect a wealth of water quality data relevant to COA, but a lack of standardization, accessibility, and consistent protocols limits its usefulness for large-scale syntheses. Strengthening coordination, training, data protocols, and partnerships can unlock the full potential of these datasets for monitoring trends, guiding management decisions, and informing national and regional OA efforts.

How would managers envision using Mid-Atlantic Ocean Portal Data layers?

Summary

The session explores how managers can use data layers from regional portals (e.g., pH, temperature, water quality) to support science-based permitting and ecosystem management under frameworks like the Clean Water Act. These data tools can guide aquaculture, fisheries, and restoration decisions in the context of COA, warming, and other stressors.

Current Uses of Key Data Layers

- Permitting & Regulation
 - Identify suitable sites for aquaculture/fisheries and assess where permits could be advantageously issued to avoid COA, temperature, or other stressors that would make operations unviable.
 - Identify areas where oyster hatcheries and fisheries may need to adjust operations (e.g., shutting off seawater intake during poor conditions).
 - Link directly to regulatory thresholds (e.g., pH under the Clean Water Act) or identify areas where temperature thresholds for species migration, spawning, or water quality alerts could be exceeded.
- Monitoring & Baselines
 - Track long-term water quality, carbonate chemistry, and ecosystem health.
 - Provide baseline data layers for COA parameters to aid in tracking marine CDR (mCDR) projects and habitat modeling.
 - Identify gaps in monitoring and where proxy and/or model data may be needed.
- Decision Support & Funding
 - Prioritize project locations and allocate funding (e.g., using data as criteria in RFP scoring).
 - Provide justifications for management or restoration proposals.
 - Facilitate cross-regional comparisons and unified continental-scale assessments.
- Communication & Outreach
 - Translate scientific data into public-facing products (dashboards, report cards, graphs, posters).
 - Use “stoplight systems” (green/yellow/red) to simplify ecosystem health messaging.
 - Provide training for end-users and walk them through how to access the data layers as well as interpret information for planning purposes.

Challenges & Needs

- Translation Gaps exist: Managers often need scientists or designated liaisons to interpret technical parameters (e.g., carbonate chemistry).
 - Infographics and web stories could also be useful for describing data and helping managers interpret data
- Collaborations with other data sharing entities could produce additional data tools and data layers.
- Topic-specific trainings could be useful for managers who need to incorporate data and information, similar to NOAA's Digital Coast.

Key

Takeaway

Data layers offer a powerful way to connect environmental monitoring with management decisions, from permitting and aquaculture siting to restoration planning and public communication. Success depends on interpretable tools, strong partnerships, and user-friendly platforms that turn complex data into actionable insights for both managers and the public.

Field Trip to SERC's Global Change Research Wetland (GCREW)

The field trip to GCREW provided participants with a guided tour of the experiments being conducted, and an opportunity to learn carbonate chemistry discrete water sample collection techniques, as well as view demonstrations of in situ sensors used to measure CO₂. This portion of the workshop was designed to introduce industry, state agencies, and other practitioners to methodologies used to collect climate quality acidification monitoring parameters. In situ water sampling is used to validate and provide internal consistency among the various methods used to measure carbonate system parameters. Many facilities do not have the resources to provide climate quality monitoring; however, with the collection of samples for dissolved inorganic carbon (DIC) and total alkalinity (TA) and collaboration with academic and research partners, water quality monitoring programs can improve the quality and usefulness of their data. Currently, [climate quality data](#)¹ is the only data used for larger synthesis efforts due to community standards. With the growing need to expand monitoring networks, there is a growing movement to incorporate weather quality data from state-level monitoring programs into regional and greater syntheses. To do so, however, there needs to be a standardization of the data quality and methods used for validation and quality assurance. The goal of the demonstrations of the various methodologies was to show practitioners how these methods can be incorporated into current programs, should appropriate funding become available.

¹Newton J.A., Feely R. A., Jewett E. B., Williamson P. & Mathis J., 2015. Global Ocean Acidification Observing Network: Requirements and Governance Plan. Second Edition, GOA-ON, http://www.goa-on.org/docs/GOA-ON_plan_print.pdf.

Demonstration of Equilibration System & Miller Lab Research on Using Radon (Rn) as a Groundwater Signature for Carbon Budget & Lateral Transport of Carbon- *Whitman Miller & Stephanie Wilson (SERC)*

The Spherical Falling Film Equilibrator is an alternative design for making measurements of dissolved trace gases in water. Because this equilibrator uses free flowing, falling water to produce a surface for gas exchange, it is very resistant to clogging and freezing, and therefore well suited to long term deployment in highly productive waters like estuaries where CO₂, CH₄, and Rn concentrations can fluctuate hourly, daily, and seasonally. When generated across a spherical surface, the falling film is not adversely affected by tilting off vertical, conditions that are common on a ship, small vessel, or buoy. The Spherical Falling Film Equilibrator is easily ported to any number of traditional gas analyzer technologies (e.g., NDIR, CRDS, OF-CEAS, OA-ICOS) and measurement accuracy will be partially dependent on the gas analyzer selected. Equilibration response times are comparable to many other designs ($\tau = \sim 3$ min for CO₂; CH₄ and Rn have not been fully validated) and equilibration precision is high (e.g., $x\text{CO}_2 = 7578 \pm 12.2$ ppmv when validated against experimental water saturated with a 7579 ppmv $\pm 1\%$ certified gas standard (see [Miller et al. 2019](#) for details on operation and performance)).

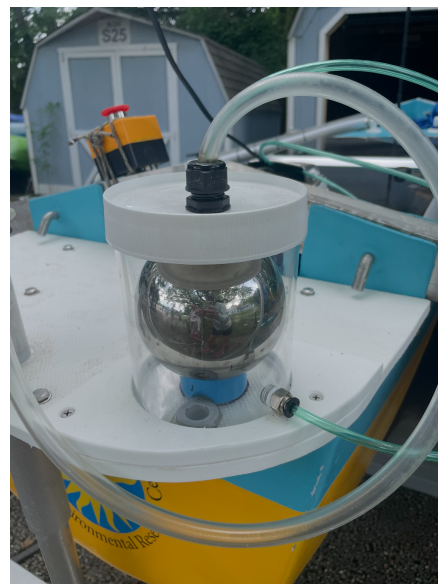


Figure 1: A Spherical Falling Film Equilibrator. Photo credit: Emily Hall.

Pro-Oceanus pCO₂ sensor demonstration – Mark Barry, Pro-Oceanus

The CO₂-Pro instrument measures the partial pressure of CO₂ gas dissolved in water using infrared detection. Standard ranges from 0-600 ppm to 0-2000 ppm and custom ranges are available from the manufacturer to measure all the way from the open ocean to coastal marshes, where CO₂ values can reach into the 1000s ppm. This ensures the full spectrum of pCO₂ is covered for accurate measurement of CO₂ in any application. These systems use non-dispersive infrared



Figure 2: Mark Barry showcases a Pro-Oceanus pCO₂ sensor.

technology to measure the partial pressure of CO₂ in water. The precision is 0.05% and the resolution is 0.01 ppm.

Dissolved inorganic carbon (DIC) and total alkalinity (TA) discrete water sample collection demonstration

The water sample collection demonstration showed participants the proper handling techniques for coastal waters with higher turbidity. A peristaltic pump was used to collect the water from a mid-column depth using Tygon tubing. A 0.45 µm GF/F cartridge filter was used to reduce the organic material in the sample. Proper bottle rinsing, filling, and reduction of bubbles were also highlighted as important steps to be taken in all carbonate chemistry water sample collection. These samples were not preserved with Mercuric Chloride (HgCl₂) but were tightly capped with minimal headspace and refrigerated in the laboratory overnight. The discrete samples were collected alongside the SERC autonomous CO₂ sensor to demonstrate validation and internal consistency frameworks.



Figure 3: Amanda Reynolds demonstrates discrete water sample collection.

Figure 3 shows a demonstration of discrete water sample collection using a peristaltic pump, Tygon tubing, a 0.45 µm cartridge filter, and Pyrex screw-top bottles. Bottles are filled to minimize headspace. This discrete sample collection can be accomplished in most field environments as long as there is a power source for the pump. In addition, a Niskin bottle can also be used if power sources are not available.

Laboratory Demonstrations and Data Discussions

Li-Cor Biosciences Demonstration of Apollo Sensors

Representatives from Li-Cor brought DIC and TA systems to analyze the estuarine water samples collected during the field trip. The DIC system is a non-dispersive infrared gas analyzer with automatic valves for acid injection. With the autosampler, up to 10 samples can be set up to analyze at one time. Li-Cor staff demonstrated how to initiate sampling with a calibration curve, described the theory, and analyzed samples. The TA analyzer consists of an auto titrator and a glass electrode. The samples are acidified to a given end-point of approximately pH 3, then the TA is calculated from the amount of acid that is used to neutralize the base content of the sample. The same samples that were analyzed for DIC were also analyzed for TA.

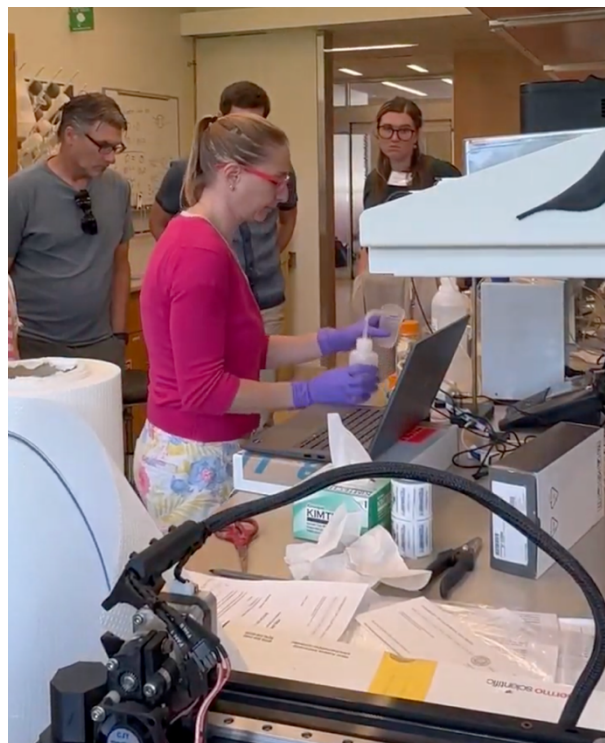


Figure 4: Janet Reimer demonstrating sample analysis using Li-Cor equipment.

The DIC and TA data that were analyzed as part of the field and laboratory demonstrations were used to calculate $p\text{CO}_2$ using the program CO2SYS². During the data discussion session, the calculated $p\text{CO}_2$ was compared to the values that were measured by the Pro-Oceanus and the Spherical Falling Film Equilibrator methods in the field to demonstrate internal-consistency frameworks.

Data and Data Quality Presentations and Discussions

Small Group Discussions

How do you think you could use COA data in your field of practice? What are you looking at, how do you think you could use it?

Group 1 Highlights (Federal & State Agencies, NY DEC, OAP)

- Applications of COA Data:
 - Connecticut DEP uses hypoxia mapping as a model, the same could work as a framework for mapping corrosive water volumes.

² CO2SYS Program: <https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system/oceans/CO2SYS/co2rprt.html>

- NYDEC uses OA indicators (aragonite saturation) with seasonal/interpolated modeling.
- The general use of OA data for nutrient loading, habitat sensitivity, and hatchery operations.
- Identification of Surveys & Gaps:
 - Reliant on gliders, vessels (e.g., institution-specific vessels), ECO-MON surveys, but face gaps due to equipment/capacity failures.
 - Coordination with OAP and other labs could enhance coverage and cross-validation.
- Examples of Data Integration & Dissemination:
 - There is interest in regional and national coordination via NCEI/OCADS.
 - Strong emphasis on moving from data collection to dissemination (user accessibility).
 - Proposal of an Acidification Intensity Index and development of species sensitivity indices.
- Challenges Identified by the Group:
 - Estuarine data gaps due to gaps in the monitoring network
 - There are multiple repositories and restrictive data ownership rules (delays from collection to public availability).
 - There is a need for training and outreach on accessing/using OCADS to familiarize the community with how data repositories work.
 - Framing COA is challenging.

Group 2 Highlights (Academic Researchers, NERRS)

- Scientific & Educational Use of COA Data:
 - Training students in data mining and message development.
 - NERRS could expand into COA data collection; challenges with estuarine variability and carbonate constants.
 - Blue carbon projects need DIC/DOC data for carbon inventories.
- Messaging & Applications:
 - SERC emphasizes storytelling and synthesis; science must be framed into knowledge and relevance for a wide audience.
 - PNNL uses mCDR projects and links corrosive waters to impacts to marine infrastructure.
 - One suggestion is to explore economic framing: Can COA impacts be expressed in dollar terms?
- Repositories & Access:
 - There is no one single “confusion” issue, but there are still challenges in metadata organization and data discoverability.
 - AI could support discovery but raises bias concerns.

- Regulatory Context:
 - Many agencies and organizations may only collect data, such as pH, tied to compliance (e.g., Clean Water Act).
 - There is currently no regulatory framework for carbonate chemistry parameters, only pH monitoring and compliance programs for outflow discharge.
 - Framing COA data as valuable beyond compliance is key.

Group 3 Highlights (State Agencies, Academic Researchers, Federal Agencies)

- State Perspective:
 - Long-term monitoring (37 years) of Chesapeake Coastal Bays has nutrient, dissolved oxygen, and pH data that is weather quality.
 - All the Mid-Atlantic states (agencies) collect weather quality pH data throughout their intracoastal waters and some of the states also collect samples within their state ocean waters.
 - There are several publicly accessible data repositories for Chesapeake Bay (Eyes on the Bay, Chesapeake Bay Program, WQX), which could be confusing for end-users.
 - Continuous pH records available; potential to integrate COA data into MARACOOS OceansMap.
 - MARACOOS OceansMap is designed to provide publicly accessible real-time and near-real-time data and visualizations whereas the MARCO Ocean Data Portal provides synthesized data products.
 - COA was included in Maryland's 2015 Climate Action Plan.
 - New York has its own Acidification Action Plan
 - New Jersey has been working on an Acidification Action Plan that is expected to be released before the end of 2025.
 - Delaware and Virginia are currently developing Ocean Action Plans that will include sections on acidification.
- Data Needs & Challenges:
 - Requires funding for additional monitoring and discrete sample collection and analysis.
 - Continuous data QA/QC is critical; NCEI collects summary products from the multiple datasets that it receives.
 - Carbonate chemistry data can be challenging because there is quite a bit of QA/QC that occurs post deployment of instruments for climate quality data.
 - Weather quality pH is commonly transmitted to near-real time data portals.
 - Many portals exist but accessibility is perceived to be difficult (technical barriers). Easier access is needed (e.g., spreadsheets) and better metadata.

- **Standardization & Methods:**
 - Currently, there are differences between standardized SOPs (e.g., NERRs) and independent researchers.
 - Due to the heterogeneity of coastal sites, different field and water sample collection methods may need to be customized to each site (e.g., filtering, preserving samples, how often to sample).
 - Researchers worry about transparency and criticism if not aligned with well accepted and established protocols, especially under resource constraints.
 - Specific discussions about DOC/DIC methods (filtered vs. unfiltered, mercuric chloride preservation) should result in best-possible practices versus acceptable/not acceptable methods.

Overall Themes Across Groups

1. **Governance & Coordination:** Shared recognition that data repositories are fragmented, and governance structures are needed to unify approaches.
2. **Accessibility & Usability:** Repositories exist but are often too technical; there's demand for simpler, user-friendly access.
3. **Integration & Storytelling:** Data need to be framed into actionable insights—for managers, policymakers, and communities.
4. **Monitoring Gaps:** Estuarine systems and certain high-risk areas remain under-monitored.
5. **Standardization vs. Flexibility:** SOPs exist but resource limitations push some groups to adapt, raising concerns about credibility.
6. **Application Potential:** Ranges from fisheries and habitat protection to infrastructure risk, blue carbon inventories, and marine carbon dioxide removal (mCDR).

Day Three Student Talks

A specific session was designed for students to present and discuss their data with meeting attendees. The discussions were designed to give feedback and provide a small group atmosphere to promote information and knowledge sharing. There were two students in attendance and each gave 10-minute presentations to all three small groups that were rotating throughout the session.



Mid-Atlantic Eelgrass Carbon Sequestration: Present and Future Responses to Warming and Population Decline

Katie Tanner

PhD Student, University of Maryland Eastern Shore

As blue carbon ecosystems, eelgrass (*Zostera marina*) meadows are globally important carbon sinks with particularly high rates of carbon sequestration. Eelgrass is a cold-water species, however, and rising temperatures increase stress and mortality, threatening mid-Atlantic populations (and potentially their sequestered carbon) near the species' southern limit. Thermal stress may further reduce eelgrass carbon sequestration by altering individual plants' energy budgets, with more energy allocated to leaves and reproductive shoots than to carbon-storing roots and rhizomes under stressful conditions. Eelgrass' carbon sequestration capacity has high spatial and temporal variability, however, and the effects of rising temperatures and subsequent eelgrass loss on carbon sequestration in eelgrass meadows have not been quantified. A sampling design was developed to assess sequestration responses to varying temperatures at three National Seashores along a latitudinal gradient: Fire Island (NY), Assateague Island (MD), and Cape Hatteras (NC). In situ temperature data from each seashore confirmed a latitudinal gradient in temperature and verified that summer 2024 temperatures routinely exceeded 30°C, the threshold for eelgrass population decline, with Cape Hatteras peaking at 32°C (July 9). At each seashore, healthy, partially degraded, and completely degraded meadows were identified by change in percent cover over ten years. Employing a space-for-time substitution, total Corg in sediment cores taken at these sites will be quantified to project future changes in carbon sequestration under eelgrass declines. Sediment cores will also be analyzed for 210Pb, $\delta^{13}\text{C}$, and $\delta^{15}\text{N}$. These data will provide insights into the ability of mid-Atlantic eelgrass meadows to sequester atmospheric CO₂ under increasing thermal stress and to retain sequestered carbon amid population decline.

Big shells, bigger data: cohort analysis of Chesapeake Bay *Crassostrea virginica* reefs

Madison Griffin

PhD Student, Virginia Institute of Marine Science

Oysters in Virginia Chesapeake Bay oyster reefs are "age-truncated", possibly due to a combination of historical overfishing, disease epizootics, environmental degradation, and climate change. Oysters may display resilience to environmental stressors; however, the current understanding of oyster lifespan is limited. The Virginia Oyster Stock Assessment and Replenishment Archive (VOSARA), a spatially (222 reefs) and temporally (2003-2023) expansive (more than 2,000,000 individual measurements) dataset of shell lengths (SL, mm), has yet to be comprehensively examined in the context of resilience. We developed a

novel method using Gaussian mixture modeling (GMM) to estimate the age groups in 64 reefs using yearly SL data and then link age groups over time to estimate cohorts and their lifespan. We fit univariate GMMs for each year (t) and reef (r) to estimate 1) the mean and 80th quantile of shell length for each (r,t)th age group, and 2) the percentage of the (r,t)th population in each age group. We linked age groups. Their final lifespan equals the number of years the cohort was found in the data plus its estimated starting age. This method shows promise in identifying oyster cohorts and estimating lifespan solely using SL data. Results show signals of resiliency in almost all river systems: oyster cohorts live longer and grow larger in the mid-to-late 2010s compared to the early 2000s. Future work includes investigating how climate change and management influence oyster resiliency in Chesapeake Bay.

Data Presentations and Q&A

This session provided three presentations to participants to provide direction on how weather versus climate quality data can be useful to broader synthesis studies, data submissions to public repositories, and how time series of CO₂ can be interpreted in coastal regions.

- **Dwight Gledhill** - The utility of weather quality data, NOAA Ocean Acidification Program
- **Li-Qing Jiang** - What is OCADs and how can you contribute?, NOAA National Centers for Environmental Information
- **Mark Barry** - Introduction to the Pro-Oceanus Systems for Monitoring, Pro-Oceanus

Discussion Notes

The discussion following the Data Presentations was an open, full group discussion on data needs, quality, synthesis, and participations. One of the topics that came up was the need for assistance with incorporating weather quality data into broader syntheses and what is needed to make that a reality.

Weather Quality Data

- Weather quality monitoring is used in coastal waters and can be useful for biological timescales.
- Estuaries are unique and have their own set of challenges. Best practice standards specific to estuaries would be helpful for incorporating water quality monitoring program data into the community. These guidelines would also be useful for designing monitoring efforts that can provide weather quality data that can be submitted to data repositories.
- More metrics that are directly related to acidic events are needed to help define the usefulness of weather quality data.
 - Additional metrics can include the number of days per year/season/month with corrosive events.

- Ecological measurements should also accompany weather quality data, including but not limited to, biological stock assessments, spawning times, identification of species present, seagrass area extent, shell size, changes in epiphytes.
- Biological metrics in the context of physiological measurements would also be helpful.
- Determination of organismal community shifts can be used to help understand the broader impacts of corrosive events and long-term acidification.
- National Estuarine Research Reserves (NERRs) were identified as key partners for expanding validation efforts and data inclusion.

Other Data

- Standardizing and recognizing the need for calcium ion data collection is needed to update out-of-date constants in carbonate chemistry data software such as CO2SYS and SeaCarb.
- A freshwater-specific carbonate chemistry calculation package for software would also be useful since many water quality monitoring programs at the state level include freshwater regions.
- A multi-laboratory internal consistency activity would be useful to help introduce NERR and other participants to the community and strengthen the validity of weather and climate data comparisons.

Field Measurements and Equipment

- A lending system of climate quality sensors and laboratory analyzers would be helpful to programs such as NERRs to help with internal consistency and validation.
- Pre-packaged kits, such as GOA-ON In A Box (pH kit) or similar to South Carolina River Keeper nutrient monitoring program would help organizations and also promote citizen science participation.

Overall Meeting Takeaways

The main takeaways from MACAN's 2025 workshop are:

- Weather quality pH data will be useful for expanding the monitoring network, though it is important to understand its limitations.
- State agencies, federal National Estuarine Research Reserves (NERRs), and National Estuary Partnerships are eager to participate in data sharing and expanded collection should funding become available.
- mCDR policy, reporting, and permitting processes need to be ready to respond to scalable projects.
- There are various ongoing field trials for mCDR that will need rigorous carbonate chemistry baseline data and community understanding to be ready for scaling.

From the overall meeting discussions, progress on integrating mCDR, OAE, and blue carbon into state-level climate strategies is hampered by limited expertise, fragmented regulation, limited monitoring infrastructure, political divides, and low public engagement. Overcoming these barriers requires federal guidance, stronger state-science partnerships, standardized monitoring, and better communication strategies that tie ocean carbon solutions to water quality, economic resilience, and public benefits. Easily accessible and standardized data and metadata will be crucial for state natural resource planners to be able to understand and incorporate weather quality data from available sources.

In addition to the discussion takeaways from this meeting, there were requests and suggestions for materials that could be used, individually or in conjunction, by different practitioners for developing site-specific best practices. These materials can be found in Appendix D. There was an unanimous consensus that each site has its own unique challenges and that a blanket best practices is not realistic, especially in the coastal zone. Group discussion resulted in new connections between practitioners from across the region that will promote collaboration and information sharing when designing new COA monitoring plans and frameworks.

Appendix A: Meeting Agenda

Day 1 Agenda

July 15, 2025

9:00-9:55	Breakfast and Registration
9:55-10:30	Introductory Remarks Dr. Janet Reimer and Emma Venarde, Coordinators, MACAN Dr. Dwight Gledhill, Director, NOAA Ocean Acidification Program Dr. Monty Graham, Director, SERC
10:30-11:45	Monitoring (15 minute Presentations)
	Jonathan Sharp - Leveraging surface fugacity observations and machine learning to map OA indicators in LMEs National Oceanic and Atmospheric Administration (NOAA)
	Maria Kavanaugh - Satellite seascapes, OA, and in situ data integration Oregon State University
	Austin Pugh - NECAN Monitoring Plan North East Regional Association Coastal Ocean Observing System
	Gregg Sakowicz - Utility of the NERRs system and the wealth of data Jacques Cousteau National Estuarine Research Reserve
	Nichole Ruiz - Evaluating Satellite Chlorophyll as an Indicator of Coastal Acidification Mid-Atlantic Regional Council on the Ocean/MACAN
11:45-12:00	Session Q&A
12:00-1:00	Lunch

1:00-1:50	Responsible Implementation of mCDR (15 minute Presentations)
	Wil Burns – How The BBNJ Can Help Us Foster Responsible mCDR American University Institute for Carbon Removal Law and Policy
	Grace Andrews – Current field trials for OAE and mCDR Hourglass Climate
	Kyle Hinson – Enhancing ocean alkalinity enhancement simulations through integrated experimental and modeling approaches Pacific Northwest National Laboratory
	Jeremy Testa – Overview of the pH adjustment at a water treatment plant project University of Maryland Center for Environmental Science
	Ashwin Murthy –State and federal permitting and compliance requirements in mCDR/OAE Sabin Center for Climate Change Law (Columbia University)
1:50-2:00	Session Q&A
2:00-2:15	Break
2:15-3:00	Nature-Based Solutions and Blue Carbon (15 minute Presentations)
	Stephen Tomasetti – Seagrass carbon sequestration under warming stress University of Maryland Eastern Shore
	Annie Tamalavage – How can we use open source databases to leverage regional policy? Smithsonian Environmental Research Center
	Sylvia Troost – Efforts for states to incorporate blue carbon planning into climate plans, science behind this, policy work, education, etc Pew Charitable Trusts
3:00-3:15	Session Q&A
3:15-4:30	World Cafe Breakout Discussions
4:30-5:00	World Cafe Report Out

Day 2 Agenda

July 16 2025

9:00-9:30	Breakfast and Registration
9:30-10:30	Biological Impacts (15 minute Presentations)
	Emily Hall - Acidification and HABs with a focus on work around Florida red tide Mote Marine Lab/Southeast Ocean and Coastal Acidification Network (SOCAN)
	Janet Reimer - Planning tools for identifying locations at risk for acidification Mid-Atlantic Regional Council on the Ocean/MACAN
	Halle Berger - Swimming a mile together: Navigating transdisciplinary currents in Atlantic Sea Scallop research to build climate resilience in the fishery University of Connecticut
	Daphne Munroe - Commercial shellfish species in NJ: surf clams vulnerable and adaptability to acidification Rutgers University
10:30-10:45	Session Q&A
10:45-11:00	Break
11:00-12:00	World Cafe Breakout Discussions
12:00-12:15	World Cafe Report Out
12:15-1:15	Lunch

1:15-4:30	FIELD TRIP: Demonstration of Equilibration System and Research on Using Radon as a Groundwater Signature for Carbon Budget and Lateral Transport Carbon
	Whitman Miller Smithsonian Environmental Research Center
	Stephanie Wilson Smithsonian Environmental Research Center
	Discrete Water Sample Collection, in situ pH Glass Electrode Measurement, and Pro-Oceanus $p\text{CO}_2$ Sensor Demonstration
	Mark Barry Pro-Oceanus
	Janet Reimer MACAN

Day 3 Agenda

July 17 2025

9:00-9:30	Breakfast and Registration
9:30-12:00	Concurrent Sessions: • Li-Cor Laboratory Demonstrations for Total Alkalinity & Dissolved Inorganic Carbon Analysis • Small Group Data Discussions
	Mike Scaboo and Jim Le Moine Li-Cor Amanda Reynolds SERC
	Data Discussions
	Student Flash Talks
12:00-1:00	Lunch
1:00-2:15	Data Collection, Processing, Submission, and Internal Consistency Discussions
	Dwight Gledhill - The utility of weather quality data NOAA Ocean Acidification Program
	Li-Qing Jiang - What is OCADs and how can you contribute? NOAA National Centers for Environmental Information
	Mark Barry - Introduction to the Pro-Oceanus Systems for Monitoring Pro-Oceanus
	Q&A and Discussion
2:15-2:30	Break

2:30-3:45	Data Processing, Submission, and Internal Consistency Discussions
	Topics will be defined by questions that come up from the laboratory demo, CO2SYS data calculations, and data QA/QC brought up earlier in the day
3:45-4:00	Closing Remarks: Janet Reimer and Emma Venarde

Appendix B: Participant List (note, this list may not be inclusive of all the online participants)

PARTICIPANT	AFFILIATION
Daphne Munroe	Rutgers University
Ashwin Murthy	Sabin Center for Climate Change Law, Columbia Law School
Austin Pugh	NERACOOS
Sylvia Troost	Pew Charitable Trusts
Will Isenberg	Virginia CZM
Stephen Tomasetti, PhD	University of Maryland Eastern Shore
Mollie Yacano, PhD	DNREC - Delaware Coastal Programs
Madison Griffin	Virginia Institute of Marine Science (VIMS)
Julie Reichert-Nguyen	NOAA
Avalon Bristow	MARCO
Katie Tanner	University of Maryland Eastern Shore
Mike Scaboo	LI-COR Environmental
Anthony Campbell	NASA/UMBC
Whitman Miller	Smithsonian Environmental Research Center
Alex Moya	Pew Charitable Trusts
Li-Qing Jiang	University of Maryland, College Park
Jeremy Testa	UMCES Chesapeake Biological Laboratory
Liza Wright-Fairbanks	UCAR/NOAA
Annie Tamalavage	Smithsonian Environmental Research Center
Wil Burns	Institute for Responsible Carbon Removal, American University

Maria Kavanaugh	Oregon State University
Maddie Wood	Sea Grant Knauss Fellow
Gabrielle Canonico	NOAA/US IOOS
Melissa Stefun	MDE, WQSA
Shannon McKenrick	Maryland Department of the Environment
Fredrika Moser	Maryland Sea Grant/UMCES
Daniel L Warner	Delaware Geological Survey
Mark Trice	Maryland Department of Natural Resources
Dwight Gledhill, NOAA	NOAA
Dylan Burgevin	Maryland Department of the Environment
Bailey Robertory	Maryland DNR
Amy Trice	Northeast Regional Ocean Council
Elliott Campbell	Maryland Department of Natural Resources
Paul C. Ticco	NY Department of State
Stephanie Jacobs	US EPA
Amanda Reynolds	Smithsonian Environmental Research Center
Emily Hall	Mote Marine Laboratory
Casey Personius	NYS DEC
Jim Le Moine	Li-Cor, Inc.
Grace Andrews	Hourglass Climate
Gregg P. Sakowicz	Jacques Cousteau NERR / Rutgers University
Kyle Hinson	Pacific Northwest National Laboratory
Halle Berger	University of Connecticut
Emma Venarde	MARACOOS

Mark Barry	Pro-Oceanus Systems
Sara Cernadas-Martín	NYSDEC / NEIWPCC
Sarah Gray	Stockton University
Janet Reimer	MARCO
Kirstin Wakefield	MARACOOS
Grace Chiu	William & Mary's Batten School, VA Institute of Marine Science
Elise Frazier	VA Coastal Zone Management Program
Meghan Seipp	MARCO
Alison Novara	University of Maryland Eastern Shore
Matthew Brown	Flagler College

Appendix C: Presentation Slides

This appendix of slides is not inclusive of every presentation. In some instances, participants were not willing to publicly share slides since their work is in the process of publication. Any reference to information in the slides should be done so at the discretion of the reader and does not reflect the rigors of peer review.



MACAN BIENNIAL STATE OF THE SCIENCE AND TECHNICAL WORKSHOP

Smithsonian Environmental Research Center

July 15 - 17, 2025

MONITORING

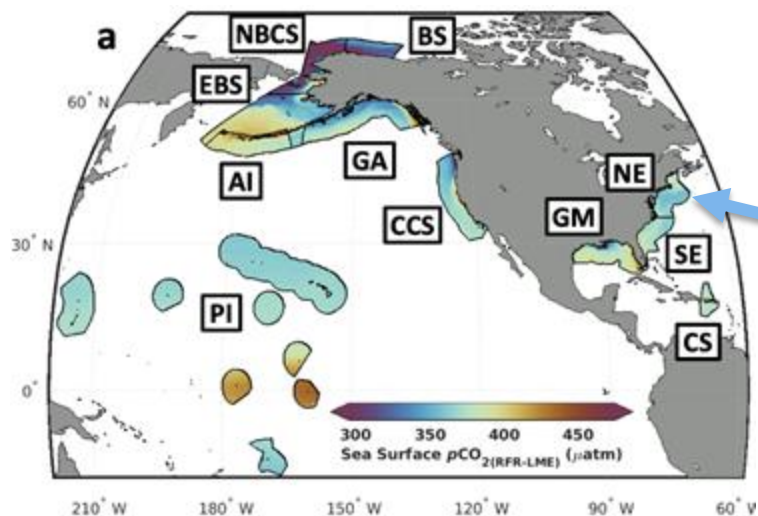
Mapping and Monitoring Ocean Acidification in the Mid-Atlantic and Beyond

Jon Sharp^{1,2}, Hyelim Yoo^{3,4}, Liqing Jiang^{3,4}, Brendan Carter², Paige Lavin^{3,5}, Scott Cross⁴

¹UW CICOES, ²NOAA/OAR PMEL, ³UMD CISESS, ⁴NOAA/NESDIS NCEI, ⁵NOAA/NESDIS STAR



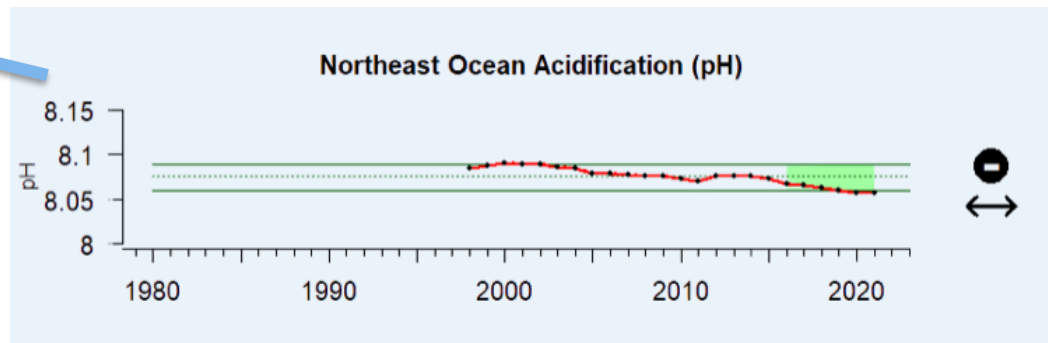
NOAA OCEAN ACIDIFICATION PROGRAM



Cooperative Institute for
CLIMATE, OCEAN &
ECOSYSTEM STUDIES

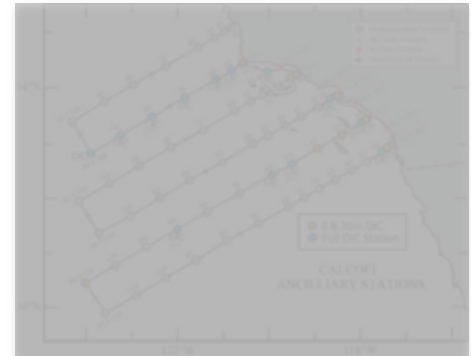
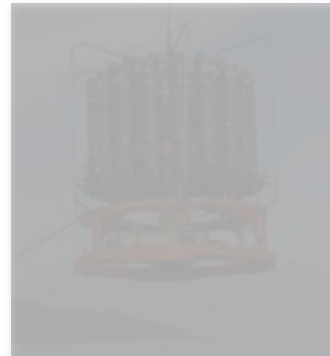
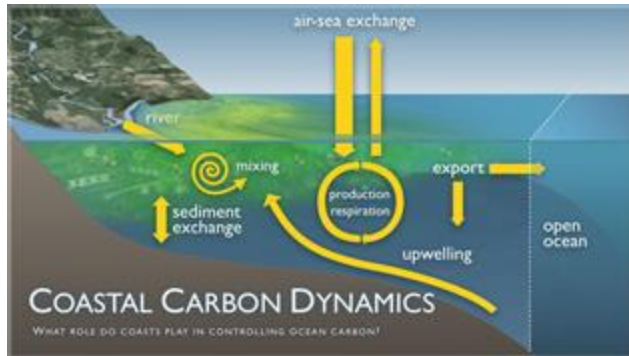


NATIONAL CENTERS FOR
ENVIRONMENTAL INFORMATION



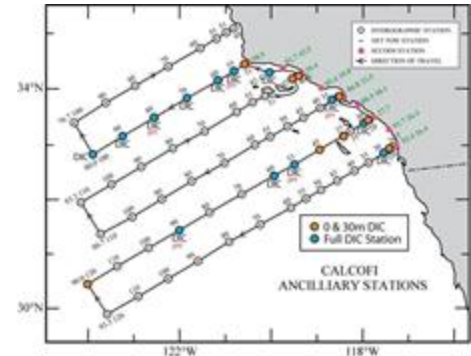
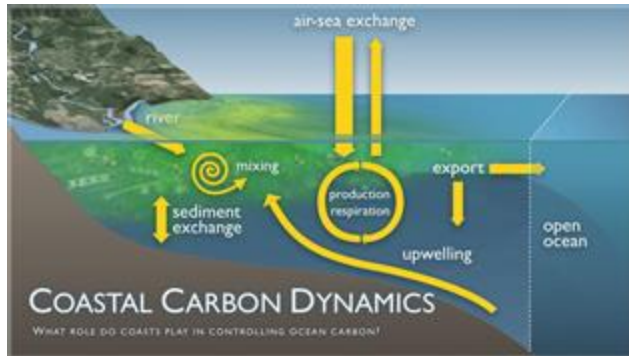
Ocean Acidification Monitoring in Coastal US Waters

- **Coastal Acidification** represents a combination of oceanic CO₂ uptake with other unique coastal phenomena: freshwater and nutrient input, organic matter respiration, lateral transport, atmospheric pollution, coastal upwelling
- Monitoring of coastal acidification in US waters includes **coastal research cruises** that are repeated every few years and **fixed time series sites** where observations are made at seasonal resolution over many years



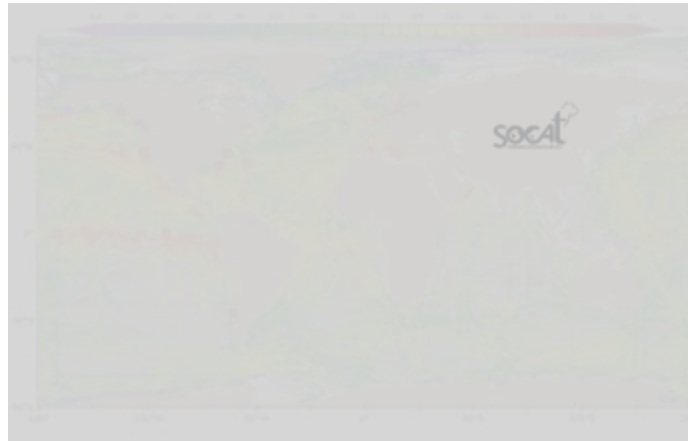
Ocean Acidification Monitoring in Coastal US Waters

- **Coastal Acidification** represents a combination of oceanic CO₂ uptake with other unique coastal phenomena: freshwater and nutrient input, organic matter respiration, lateral transport, atmospheric pollution, coastal upwelling
- Monitoring of coastal acidification in US waters includes large-scale **coastal research cruises** that are repeated every few years and **fixed time series sites** where observations are made at seasonal resolution over many years



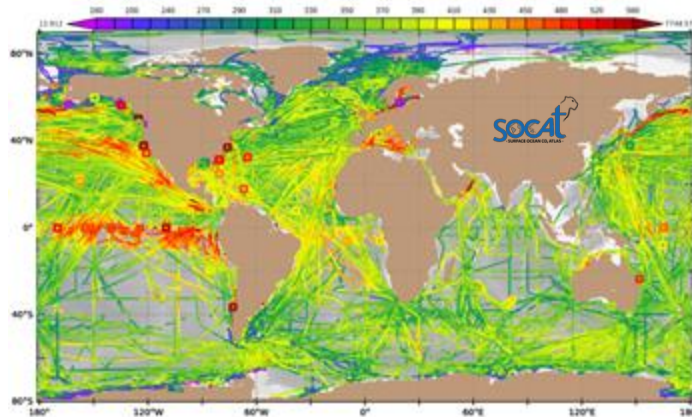
Ocean Acidification Monitoring in Coastal US Waters

- **Moored buoys** that make continuous measurements in one location throughout the year and **surface underway carbon observations** from volunteer observing ships and scientific vessels also contribute to coastal OA monitoring
- Many observations of surface carbonate chemistry in marine waters off U.S. coastlines are aggregated annually in the **Surface Ocean CO₂ Atlas (SOCAT)**



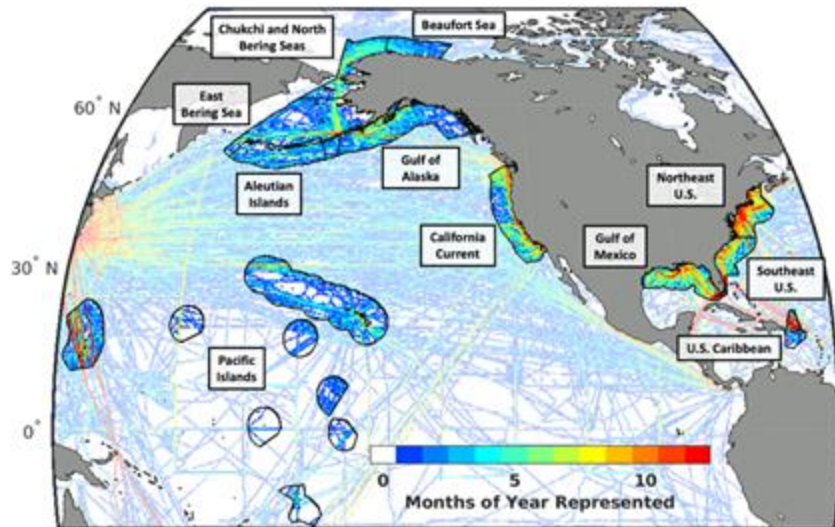
Ocean Acidification Monitoring in Coastal US Waters

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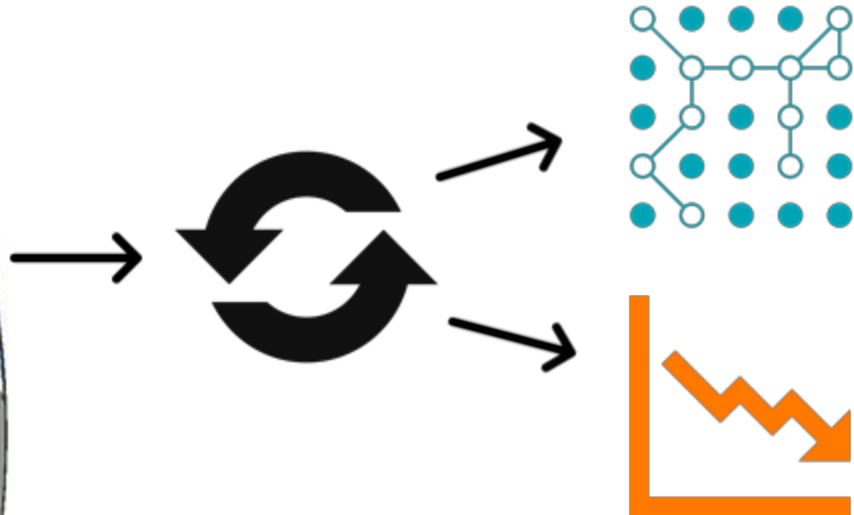


Ocean Acidification Monitoring in Coastal US Waters

- To gain insight into coastal ocean ecosystem status, spatial and temporal variability, and the drivers of variability and change, it is helpful to **translate observation-level data** into **synthesis products** and **useful metrics**



Adapted from Figure 2 (Sharp et al., 2024)



National Marine Ecosystem Status Dashboard Provides Indicators of Ecosystem Health in U.S. Large Marine Ecosystems

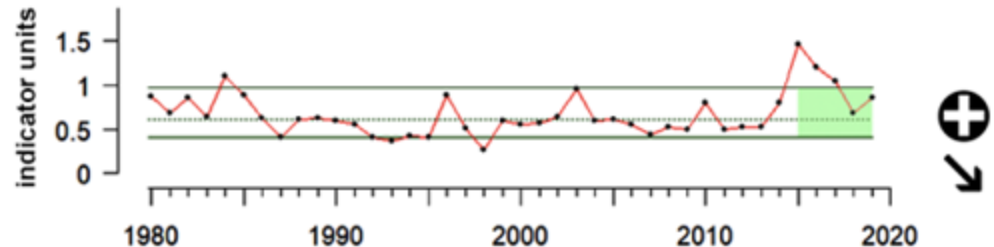
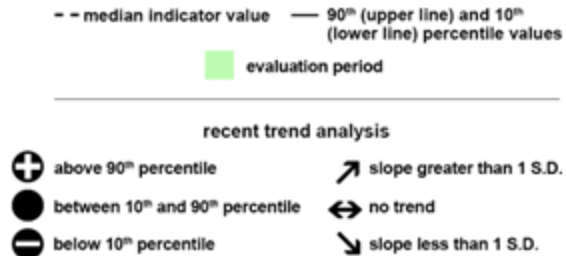


ecowatch.noaa.gov



Indicator criteria:

- Theoretically sound
- Demonstrable importance
- Relevant and understandable
- Responsive with directional expectations
- Provide early warning of ecosystem change
- Complement other indicators



National Marine Ecosystem Status Dashboard Provides Indicators of Ecosystem Health in U.S. Large Marine Ecosystems



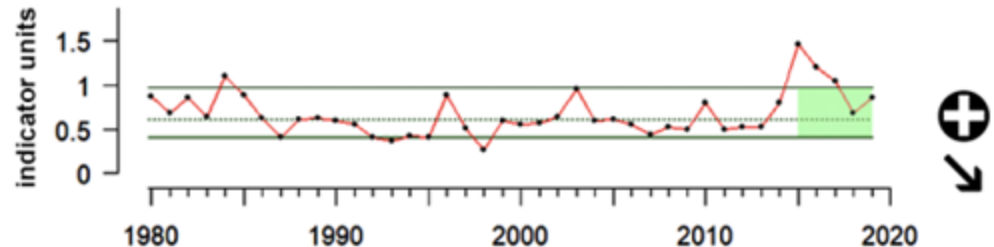
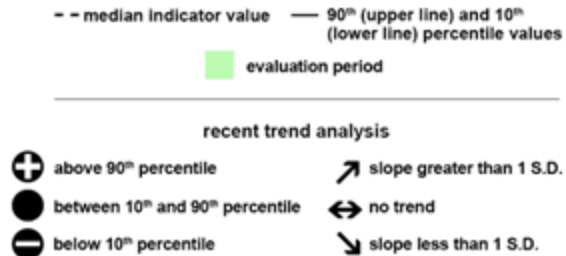
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OA



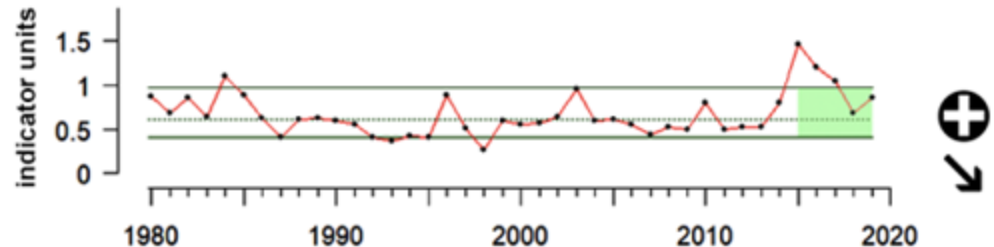
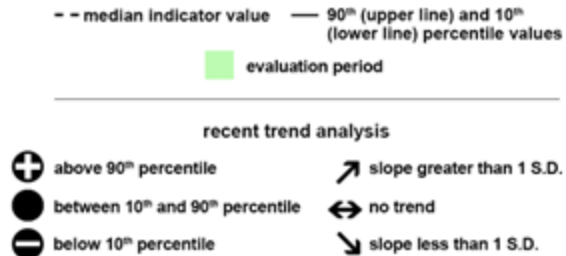
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- Publicly available, quantitative, specific
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- Sufficient signal-to-noise ratio



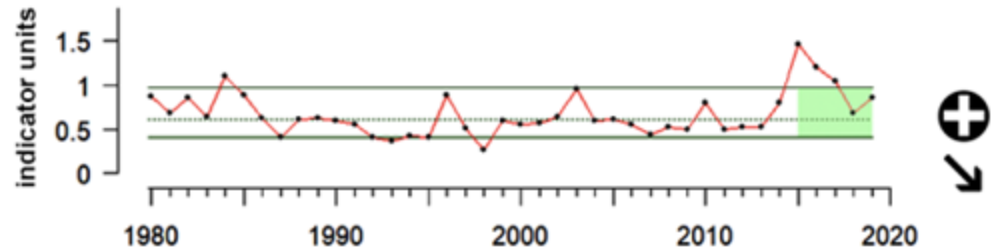
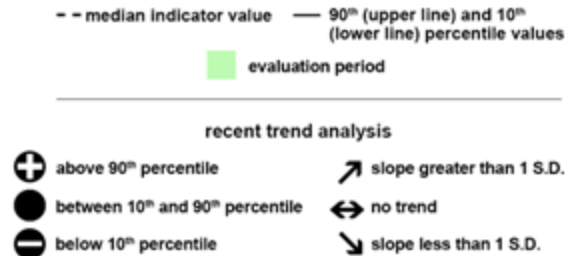
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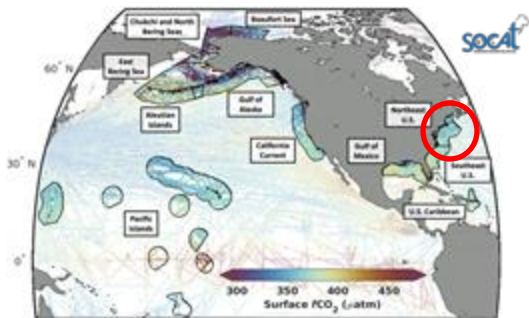
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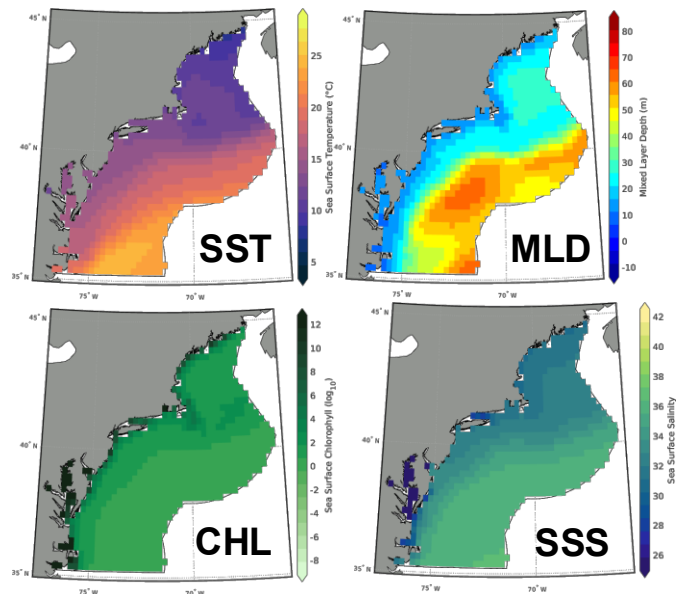
Surface Ocean CO₂ Atlas (SOCAT) Data Used with Two-Step Machine Learning Scheme and Alkalinity Estimates to Reconstruct OA Indicators Across U.S. LMEs

1. Bin SOCAT data to $\frac{1}{4}^\circ$ monthly grid cells.

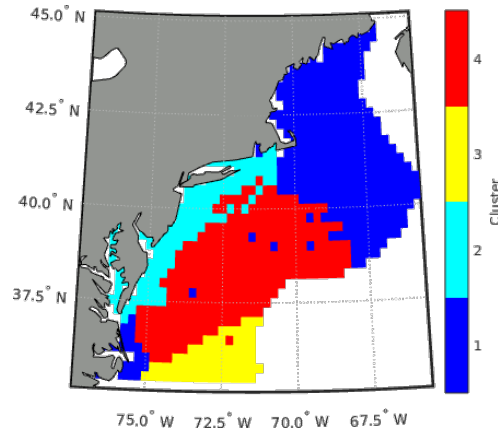


Adapted from Figure 2 (Sharp et al., 2024)

2. Co-locate data with gridded predictors

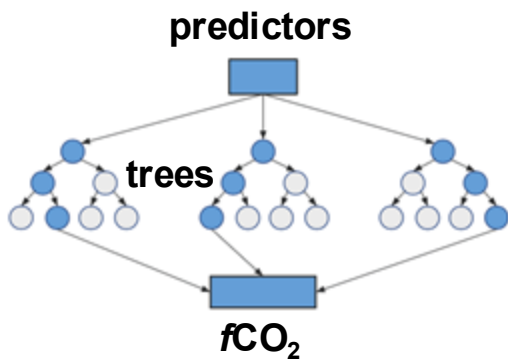


3. Use predictor variability with Gaussian mixture modelling to define similar spatial clusters

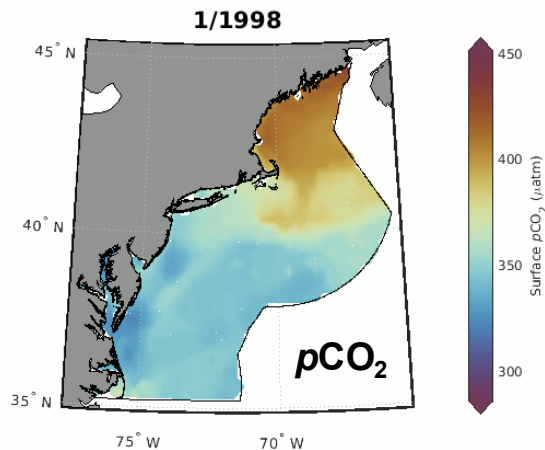


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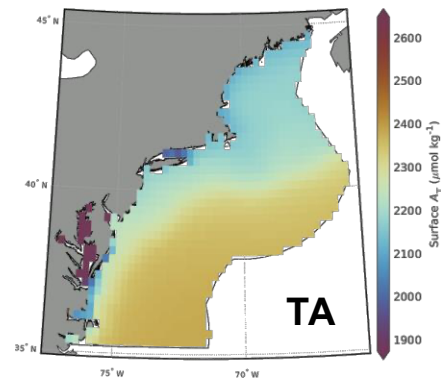
4. Train random forest regression models in individual clusters



5. Apply models to continuous predictor fields to reconstruct monthly $p\text{CO}_2$

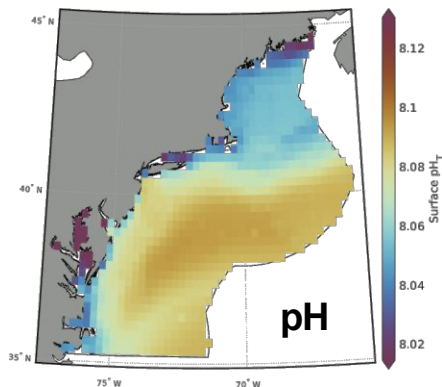


6. Use Empirical Seawater Property Estimation Routines (ESPERs; Carter et al., 2021) with sea surface temperature and salinity to estimate total alkalinity

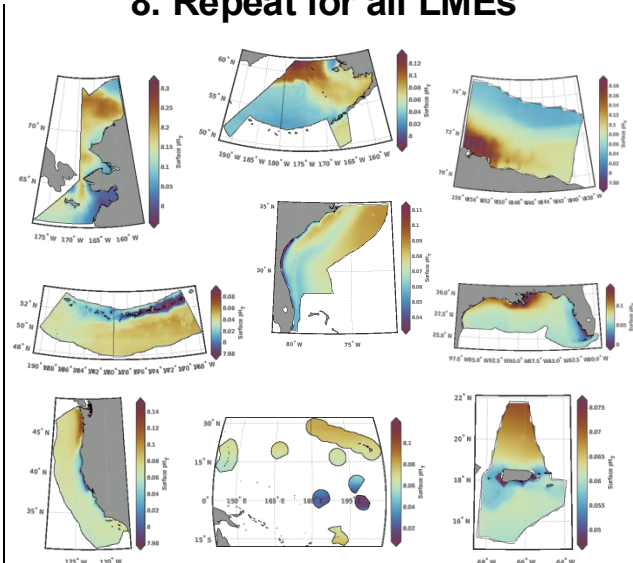


Surface Ocean CO₂ Atlas (SOCAT) Data Used with Two-Step Machine Learning Scheme and Alkalinity Estimates to Reconstruct OA Indicators Across U.S. LMEs

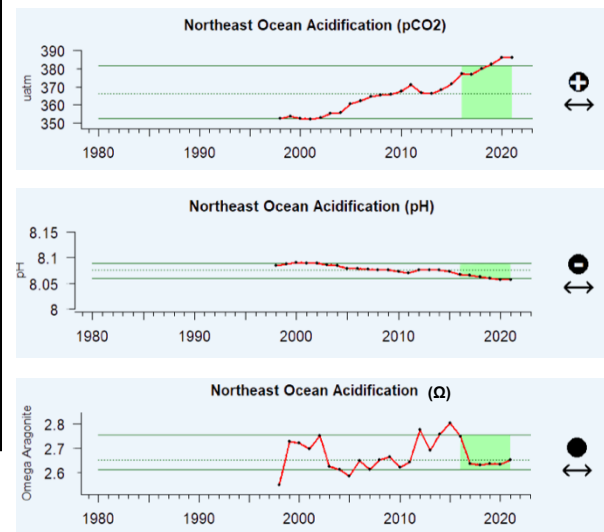
7. Pair CO₂ fugacity with TA to compute other OA indicators



8. Repeat for all LMEs



9. Compute regional timeseries for NaMES dashboard



NaMES Dashboard Provides Snapshot of OA Indicator Progression in U.S. Large Marine Ecosystems

[Home](#)[About](#)[Indicators By](#)[Region](#)[Indicators By](#)[Theme](#)[National](#)[Status](#)[More](#)[Resources](#)

Spanning the area from North Carolina to Florida, the Southeast contains over 18,000 miles of coastline. With extensive riverine, estuarine, marsh, barrier island, mangrove, and coral reef systems, the Southeast has the largest wetland acreage and coral reef track in the contiguous United States, and one of the world's largest shallow water coral reef ecosystems.

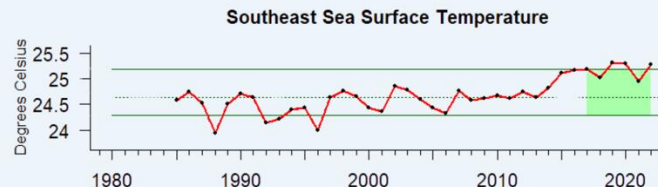
A diversity of life is supported in this region, including 18 protected marine species. The Southeast region provides the only known calving grounds for the highly endangered North Atlantic Right Whale. Bottlenose dolphins, sea turtles, diverse coral, sawfish, Bryde's whales, manta rays, and shortnose and Atlantic sturgeon also reside in this region.

The Gulf Stream is an important influence on biological, chemical, and physical characteristics of the region. Natural hazards include

[Climatological](#)[Physical-chemical](#)[Biological](#)[Human Dimensions](#)

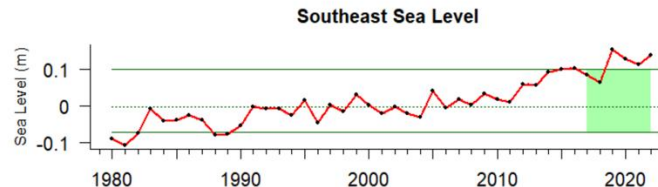
Sea Surface Temperature

During the last five years there has been no notable trend and values have remained within the 10th and 90th percentiles of all observed data in the time series.



Sea Level

During the last five years, there has been no trend but values are greater than 90% of all observed data in the time series.



Marine Heatwave Intensity

During the last five years there has been no trend but the five-year average is above the 90th

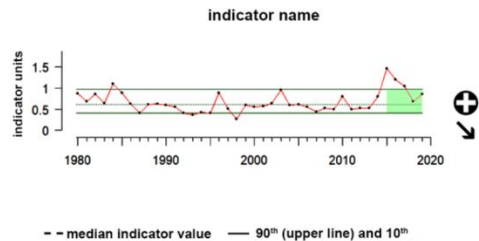


NaMES Dashboard Provides Snapshot of OA Indicator Progression in U.S. Large Marine Ecosystems

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Understanding the Time series plots

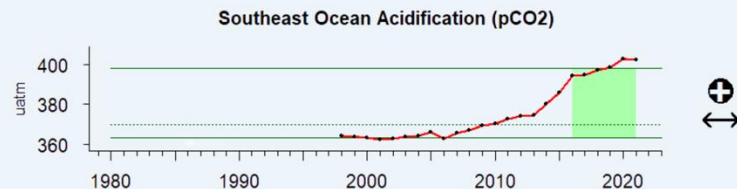
Time series plots show the changes in each indicator as a function of time, over the period 1980-present. Each plot also shows horizontal lines that indicate the median (middle) value of that indicator, as well as the 10th and 90th percentiles, each calculated for the entire period of measurement. Time series plots were only developed for datasets with at least 10 years of data. Two symbols located to the right of each plot describe how recent values of an indicator compare against the overall series. A black circle indicates whether the indicator values over the last five years are on average above the series 90th percentile (plus sign), below the 10th percentile (minus sign), or between those two values (solid circle). Beneath that an arrow reflects the trend of the indicator over the last five years; an increase or decrease greater than one standard deviation is reflected in upward or downward arrows respectively, while a change of less than one standard deviation is recorded by a left-right arrow.



Sea Surface pCO₂

Between 2016 and 2021

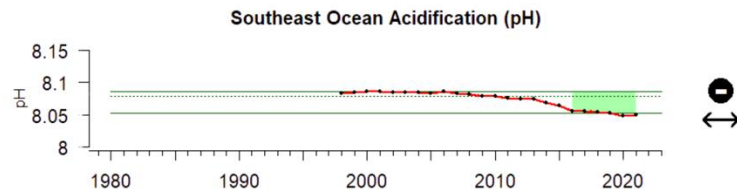
pCO₂ showed no significant trend but was near the top of the range of historical values.



Sea Surface pH

Between 2016 and 2021

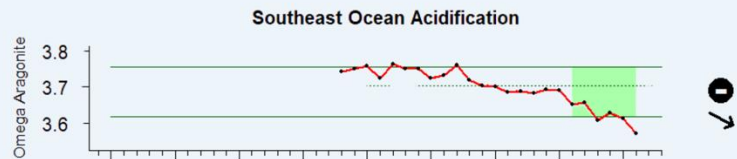
pH showed no significant trend and was below historical values.



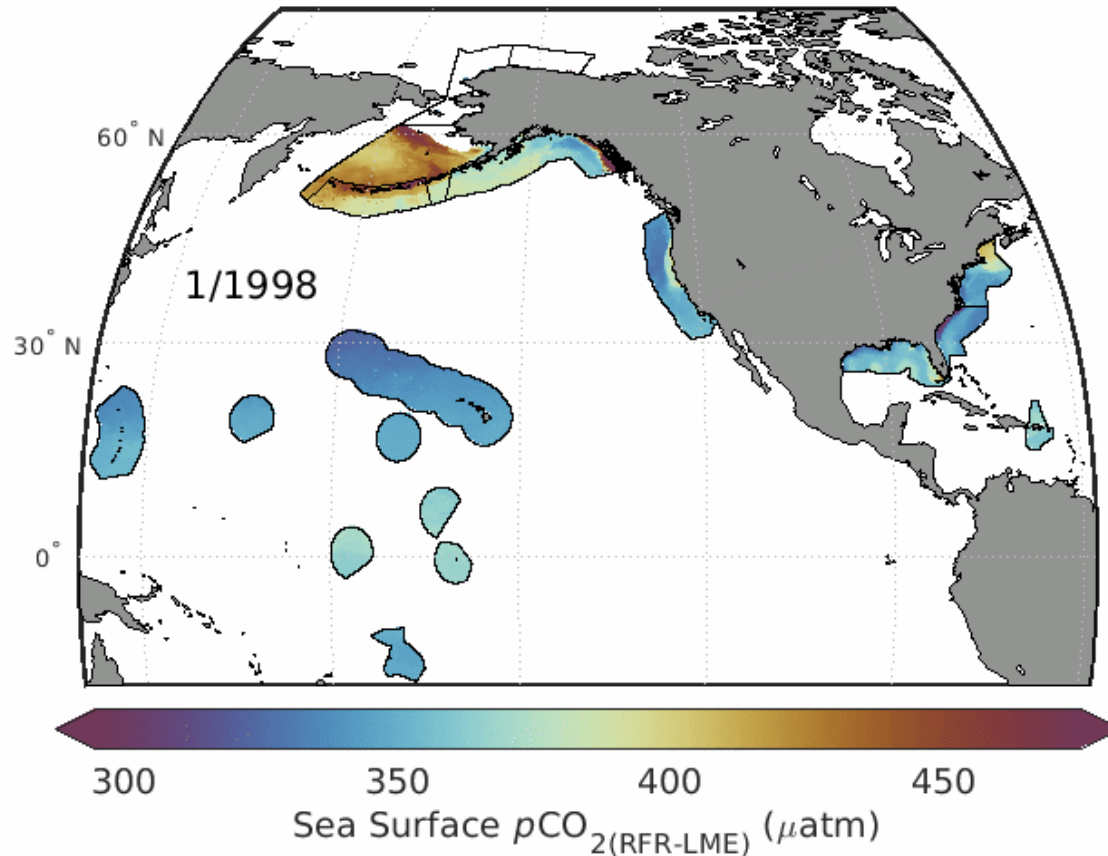
Sea Surface Ω_{ar}

Between 2016 and 2021 Sea

Surface Ω_{ar} showed a significant downward trend and was below historical values.



Mapped Indicators are available via NCEI



 National Centers for Environmental Information
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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RFR-LME Ocean Acidification Indicators from 1998 to 2023 (NCEI Accession 0287551)


Preview graphic

This dataset consists of Gridded monthly data products of surface ocean acidification indicators from 1998 to 2023 and on a 0.25° by 0.25° spatial grid have been developed for eleven U.S. Large Marine Ecosystems (LMEs) using a machine learning algorithm called random forest regression (RFR). The data products are called RFR-LMEs, and were constructed using observations from the Surface Ocean CO₂ Atlas — co-located with

[Show more...](#)

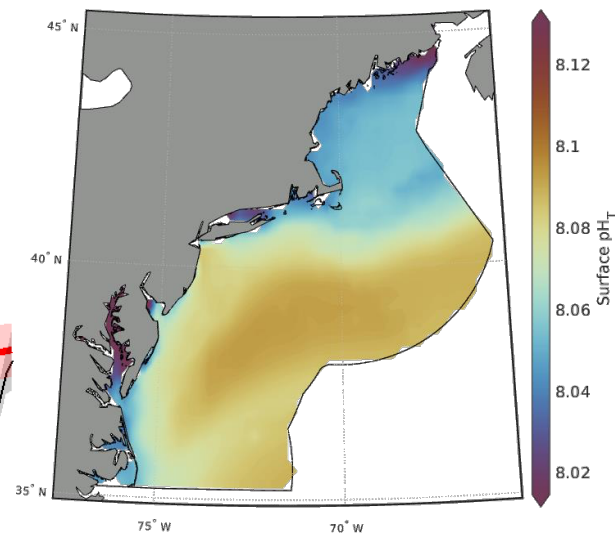
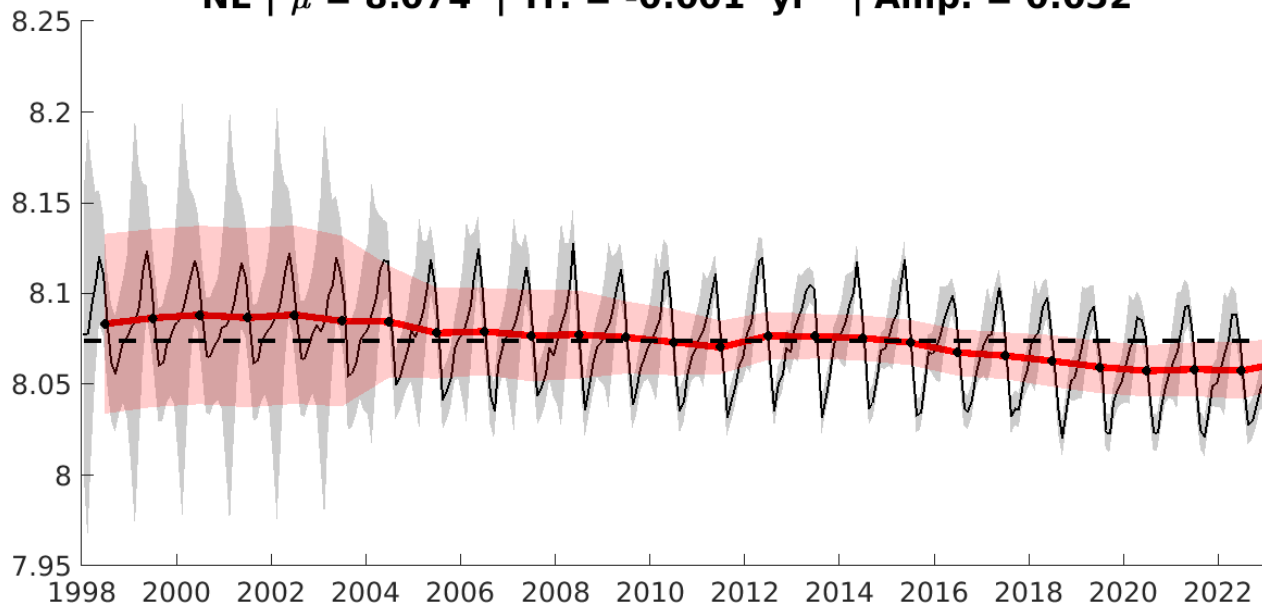
[Access](#) [Time & Location](#) [Documentation](#) [Description](#) [Credit](#) [Keywords](#)

[Constraints](#) [Lineage](#)

[Dataset Citation](#)
[Dataset Identifiers](#)
[ISO 19115-2 Metadata](#)

Region-wide OA signals in the Mid-Atlantic

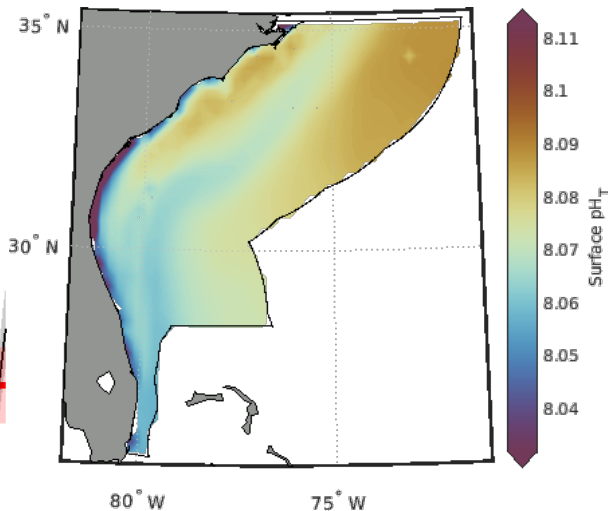
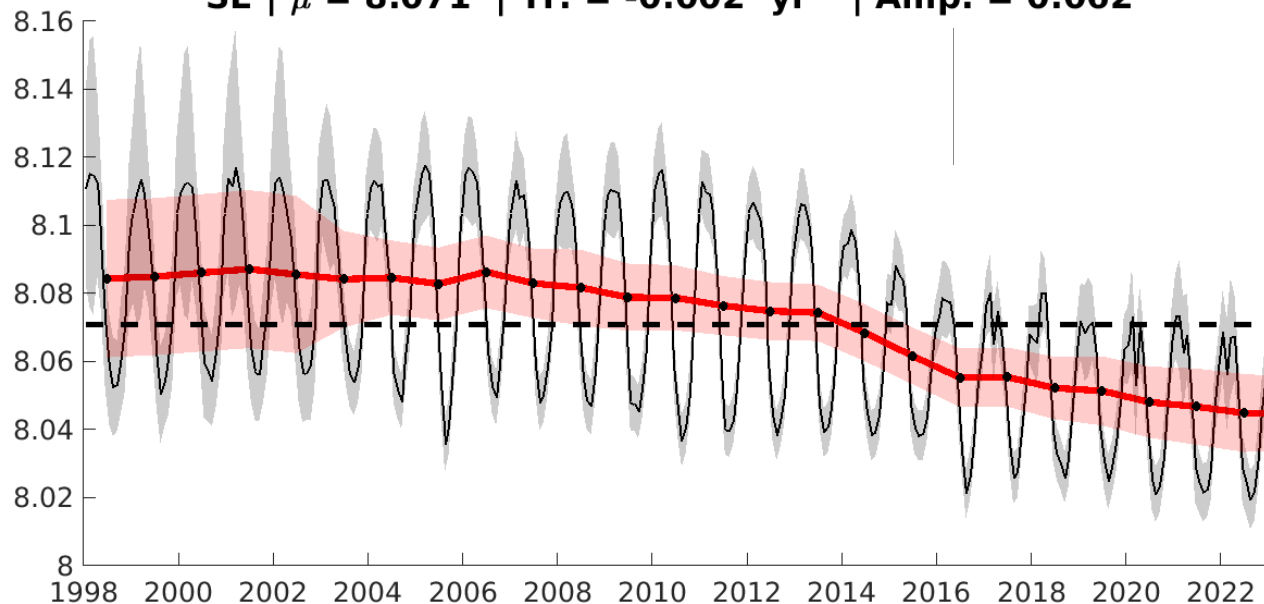
NE | $\mu = 8.074$ | Tr. = -0.001 yr^{-1} | Amp. = 0.052



	$p\text{CO}_2$	A_T	C_T	pH_T	$[\text{H}^+]_T$	RF	Ω_{ar}	Ω_{ca}	$[\text{CO}_3^{2-}]_T$
LME	$\mu\text{atm/yr}$	$\mu\text{M/yr}$	$\mu\text{M/yr}$	$10^{-3}/\text{yr}$	$\text{nM} \cdot 10^{-2}/\text{yr}$	$10^{-2}/\text{yr}$	$10^{-3}/\text{yr}$	$10^{-3}/\text{yr}$	$\mu\text{M} \cdot 10^{-1}/\text{yr}$
NE	1.3 ± 0.1	1.0 ± 0.5	0.8 ± 0.3	-1.2 ± 0.1	2.3 ± 0.2	-0.3 ± 0.5	2.3 ± 3.2	2.7 ± 4.7	1.3 ± 2.2
SE	1.8 ± 0.2	0.3 ± 0.1	1.0 ± 0.1	-1.7 ± 0.2	3.4 ± 0.4	1.1 ± 0.1	-6.5 ± 0.7	-10.5 ± 1.0	-4.4 ± 0.4

Region-wide OA signals in the Mid-Atlantic

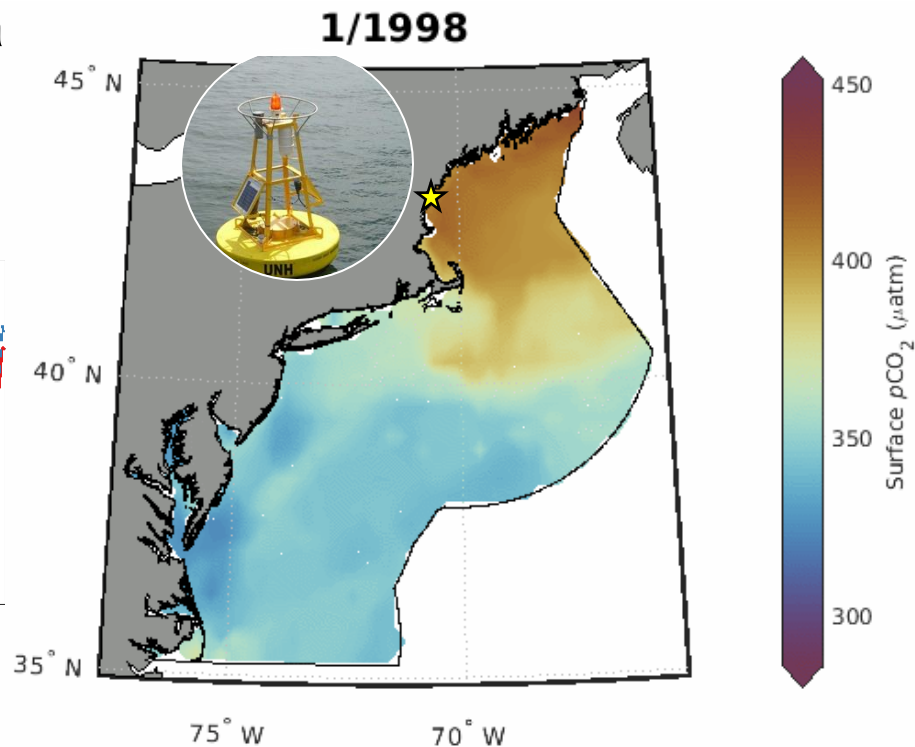
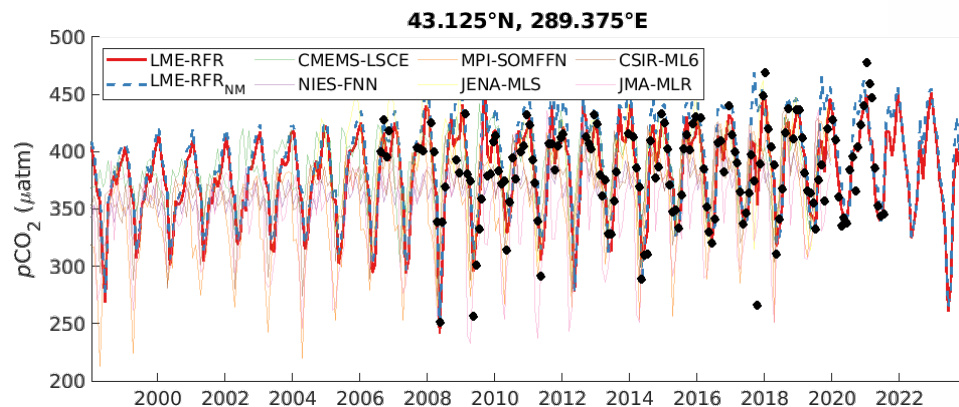
SE | $\mu = 8.071$ | Tr. = -0.002 yr^{-1} | Amp. = 0.062



	$p\text{CO}_2$	A_T	C_T	pH_T	$[\text{H}^+]_T$	RF	Ω_{ar}	Ω_{ca}	$[\text{CO}_3^{2-}]_T$
LME	$\mu\text{atm/yr}$	$\mu\text{M/yr}$	$\mu\text{M/yr}$	$10^{-3}/\text{yr}$	$\text{nM} \cdot 10^{-2}/\text{yr}$	$10^{-2}/\text{yr}$	$10^{-3}/\text{yr}$	$10^{-3}/\text{yr}$	$\mu\text{M} \cdot 10^{-1}/\text{yr}$
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Buoy Data Support RFR-LMEs

Inclusion of Gulf of Maine Buoy data significantly increases RFR-LME agreement with buoy timeseries



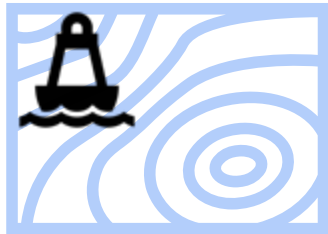
$\Delta f\text{CO}_2$ (buoy - map)

	RFR-LME	RFR-LME-NM	CMEMS-LSCE	NIES-FNN	MPI-SOMFFN	JENA-MLS	CSIR-ML6	JMA-MLR
Gulf of Maine	0.2 ± 17.8	-10.1 ± 32.2	-5.6 ± 43.3	12.8 ± 45.9	12.5 ± 64.8	-2.2 ± 50.1	7.4 ± 53.8	39.7 ± 53.8

Buoy Data Support RFR-LMEs

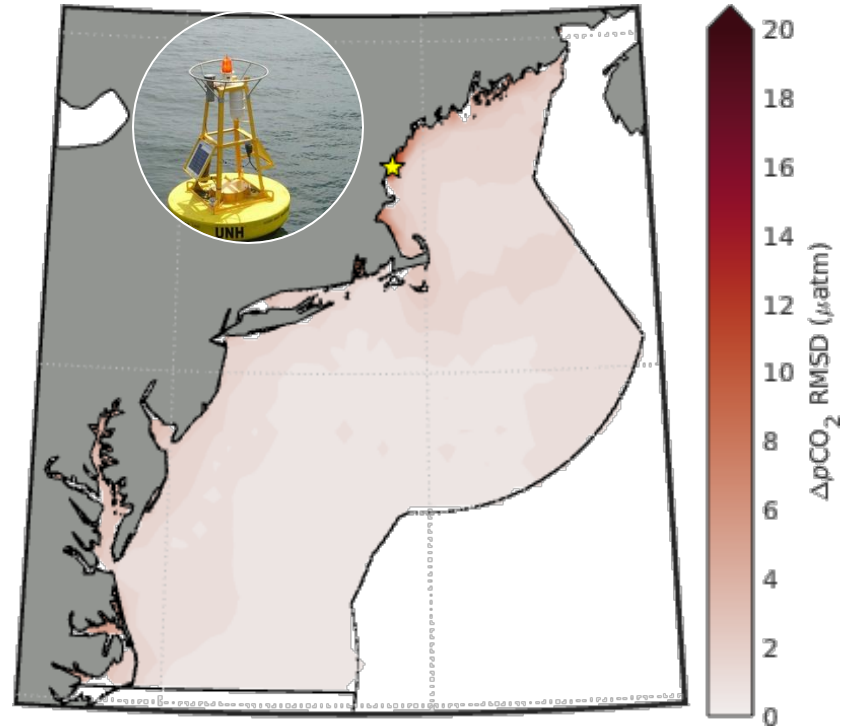
The data also exerts a “sphere of influence” that extends beyond the exact buoy location

Include buoy data



vs.

Exclude buoy data



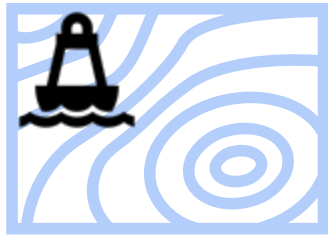
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Buoy Data Support RFR-LMEs

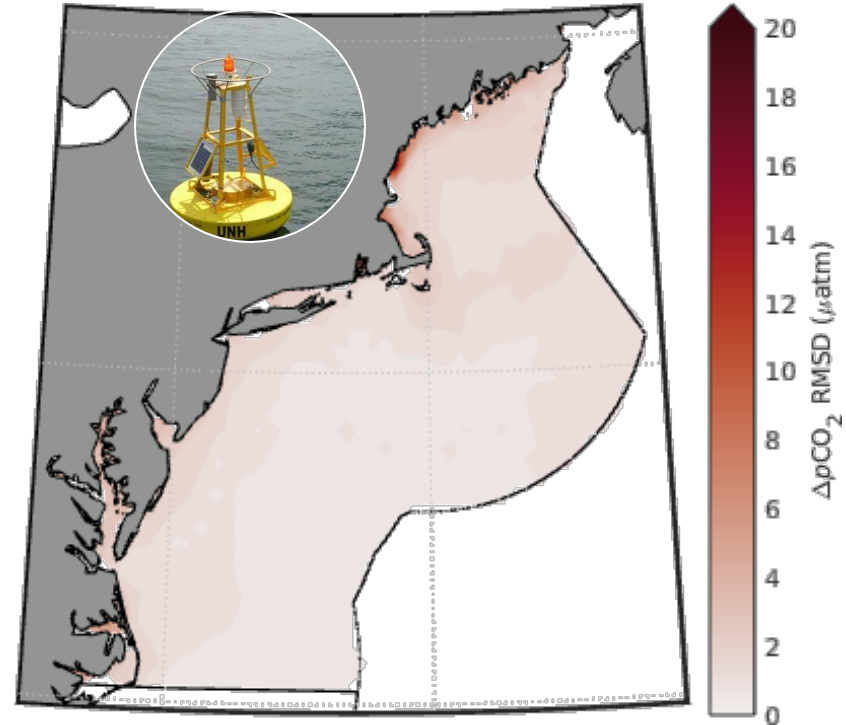
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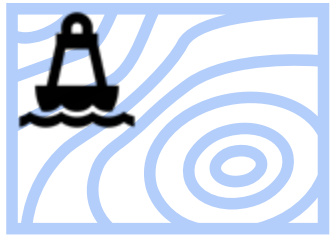
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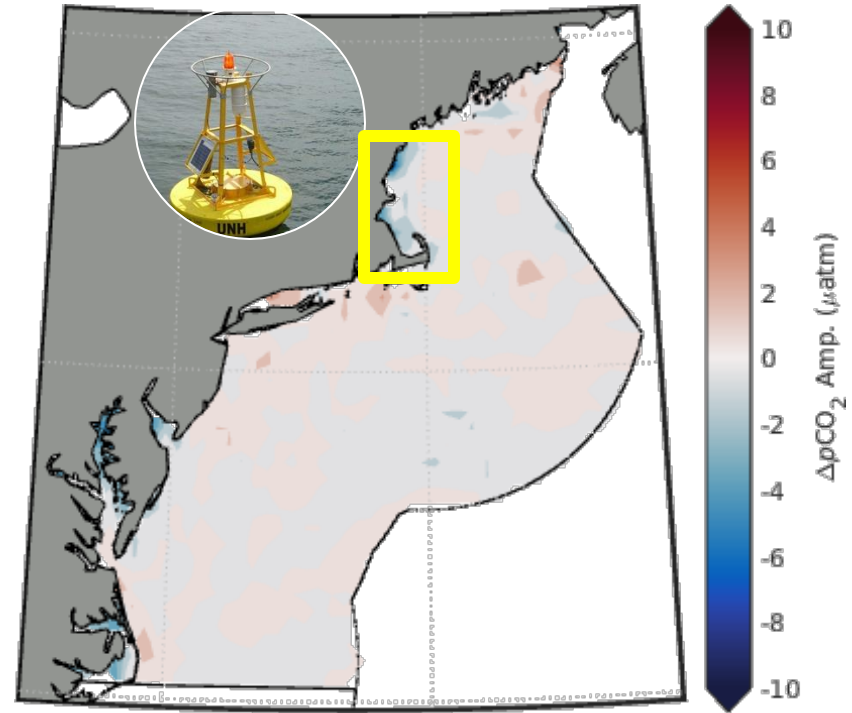
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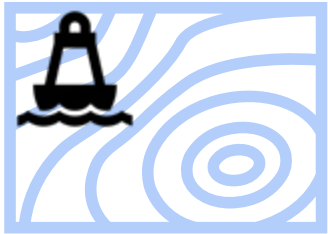
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Buoy Data Support RFR-LMEs

The influence of the buoy data is concentrated around the buoy location, especially in grid cells adjacent to the coast

Include buoy data

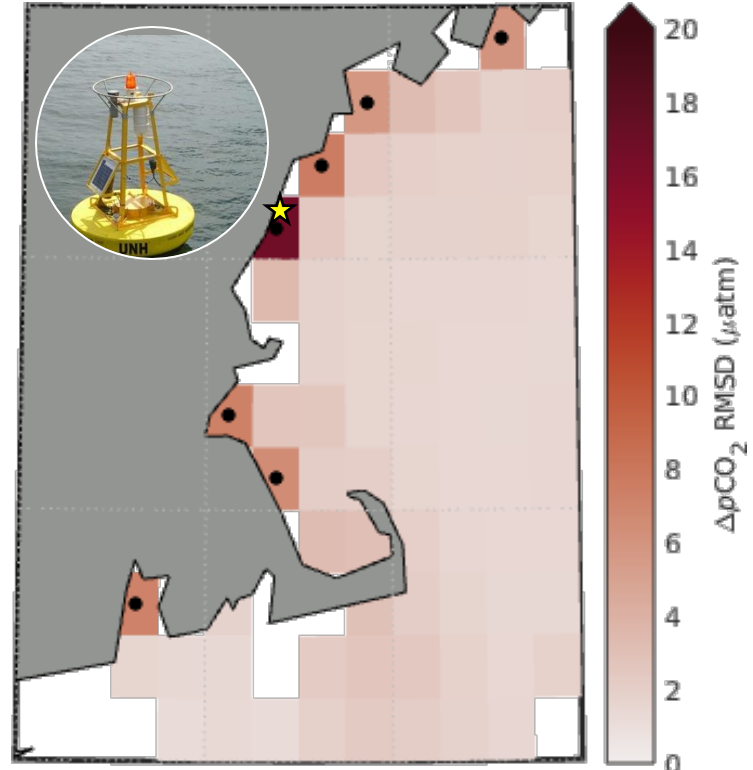


vs.

Exclude buoy data



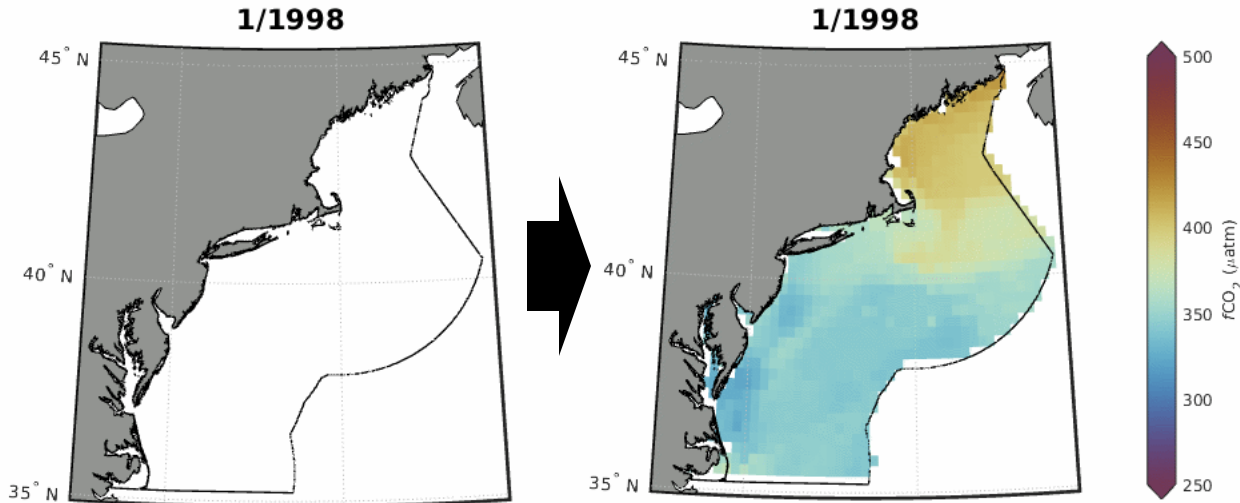
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* Top ten grid cells influenced by inclusion of mooring data

Key Takeaways

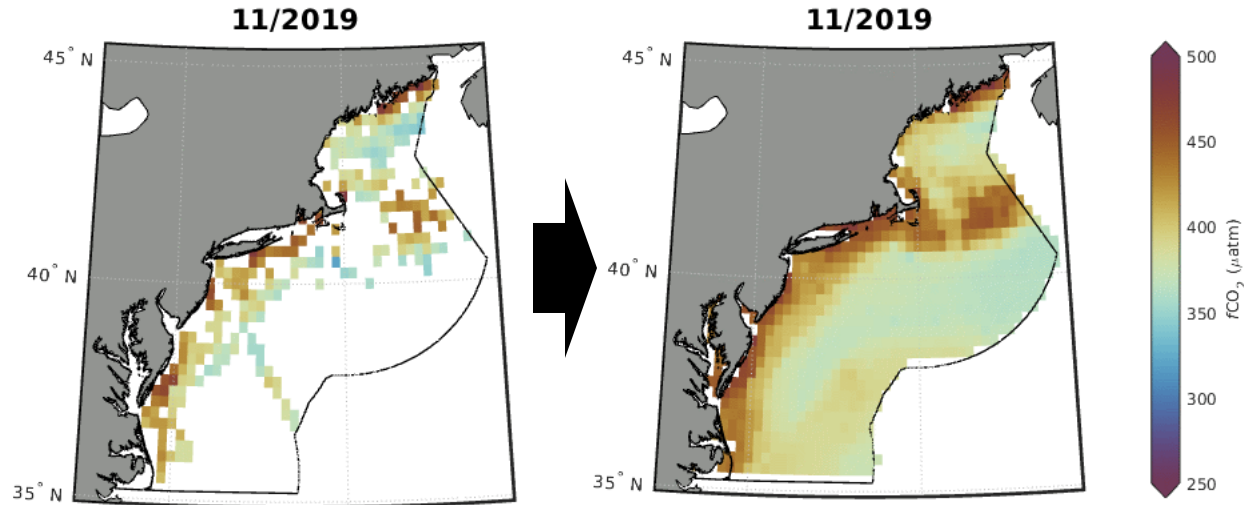
Surface carbonate chemistry observing system can be leveraged with machine learning to monitor ocean acidification along U.S. coastlines



RFR-LME maps can provide regional context for OA studies and can summarize OA status in U.S. coastal ecosystems

Key Takeaways

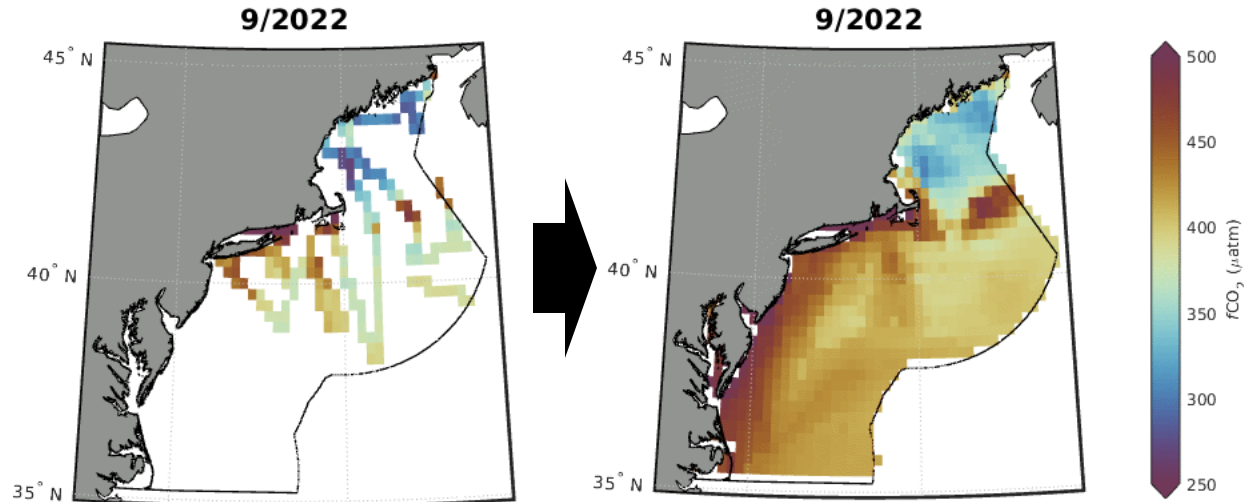
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Key Takeaways

Surface carbonate chemistry observing system can be leveraged with machine learning to monitor ocean acidification along U.S. coastlines



RFR-LME maps can provide regional context for OA studies and can summarize OA status in U.S. coastal ecosystems

**Maria Kavanaugh and Burke Hales,
Oregon State University**

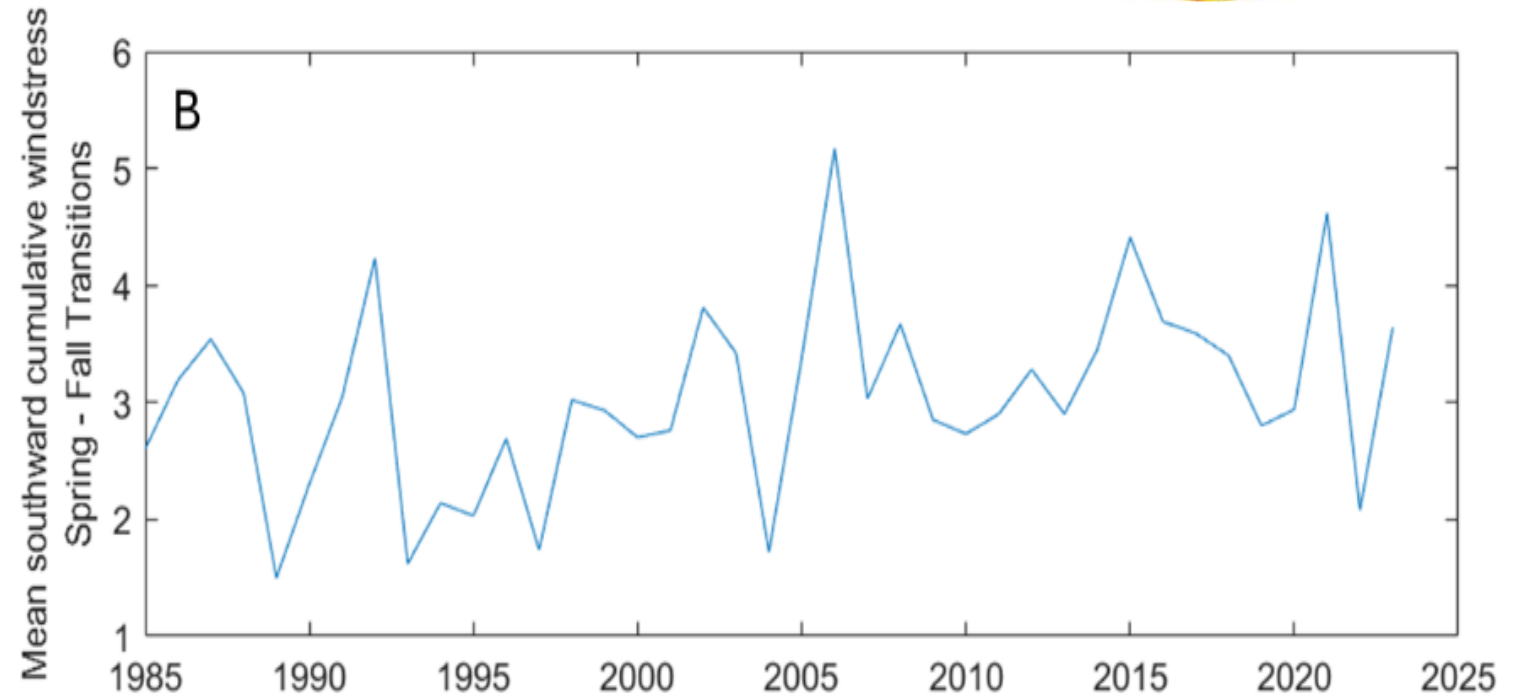
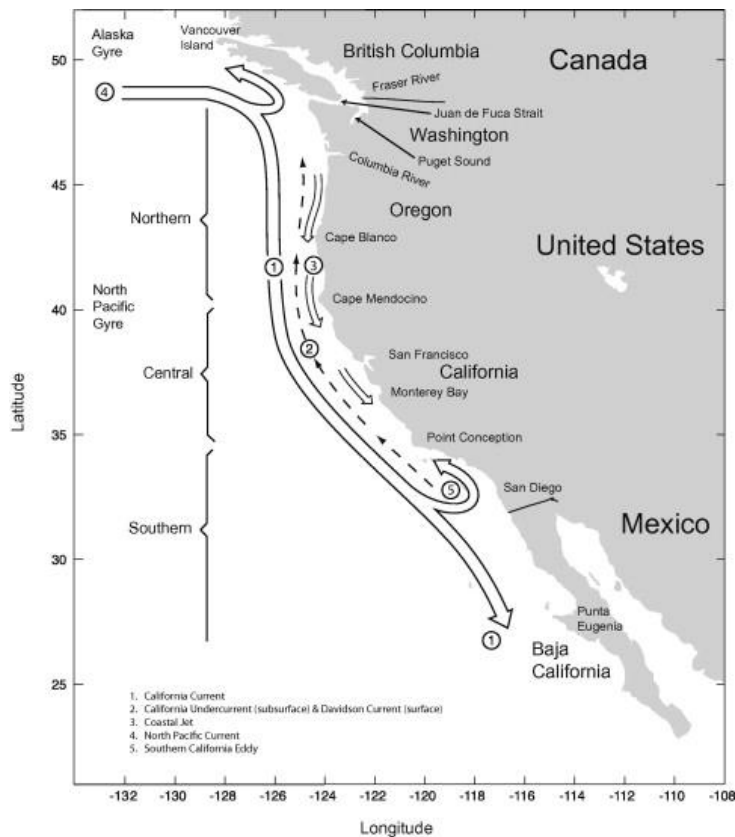
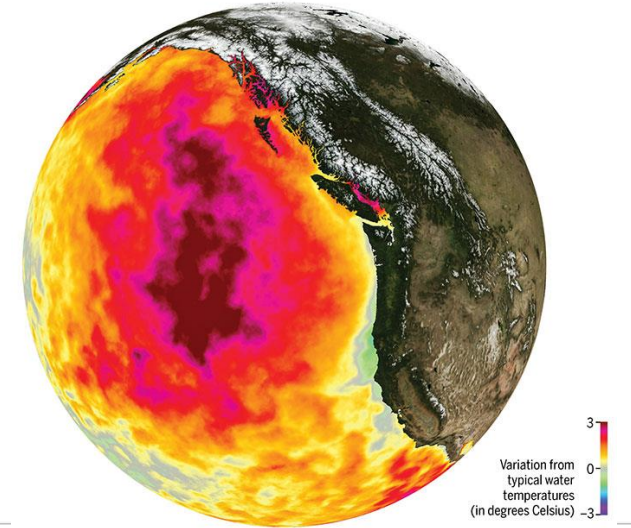
**Scott Doney,
University of Virginia
MARCAN 07152025**

Seascape integration of in situ and satellite data: dynamic, semi-mechanistic carbonate parameterization



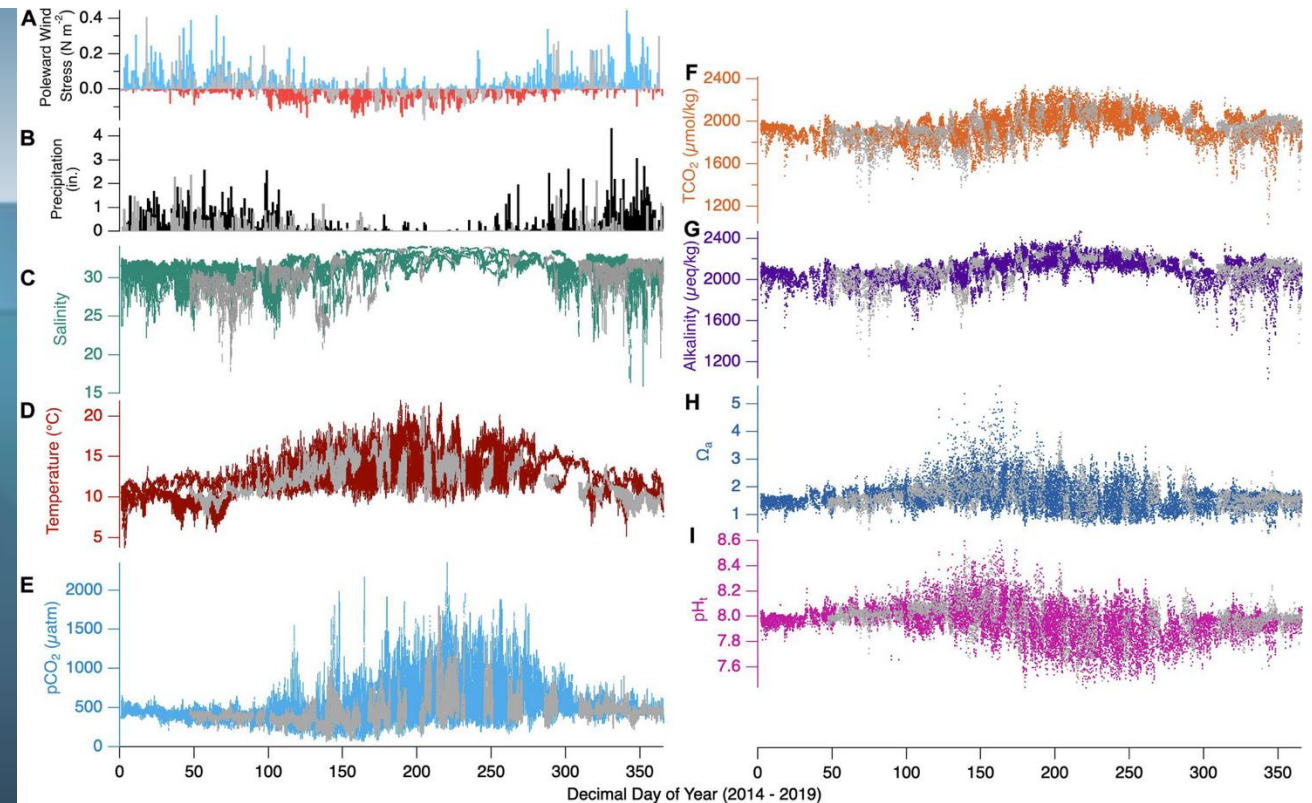
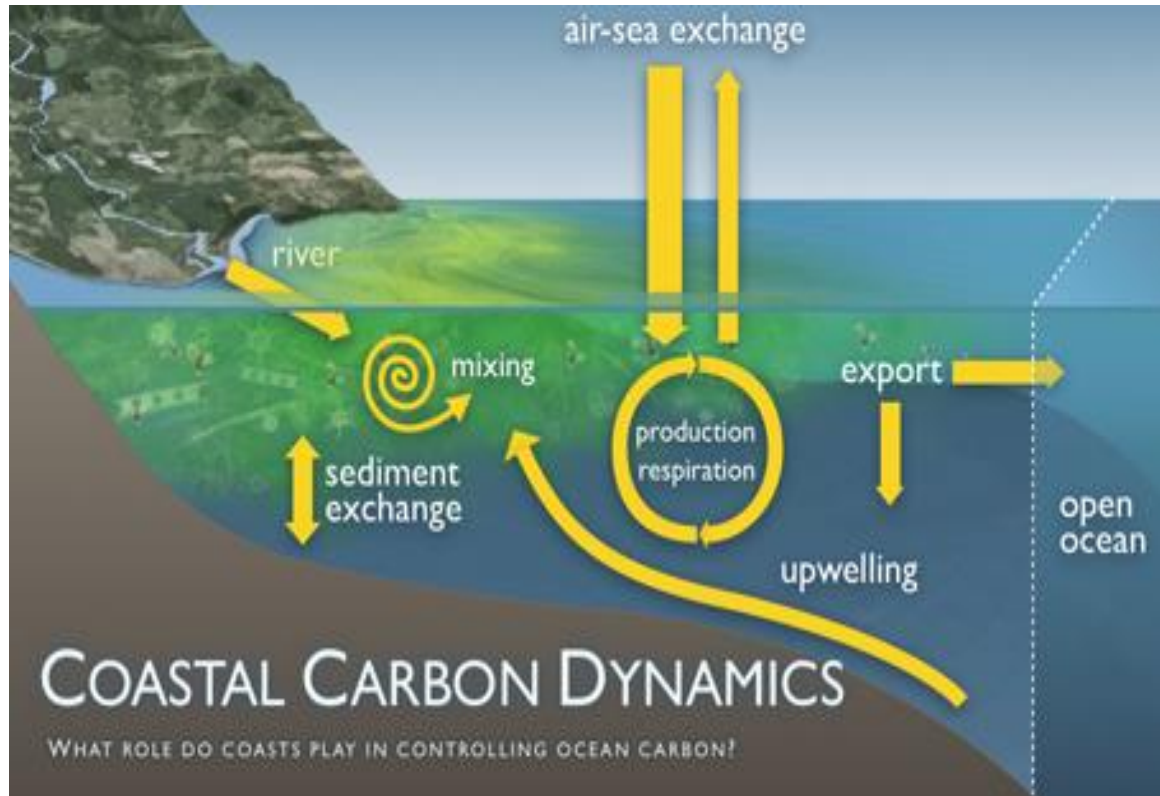
The California Current

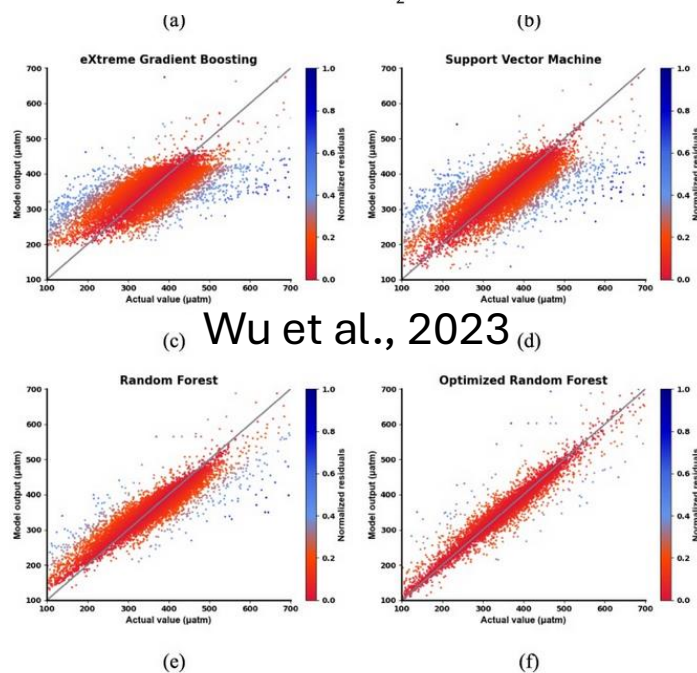
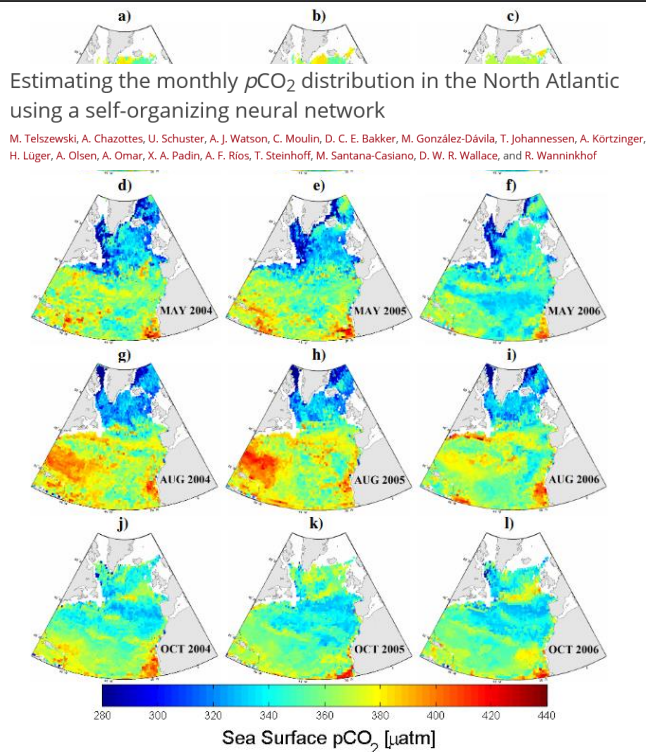
- Seasonal intermittent upwelling: dynamic and productive
- Changing temperature, circulation, chemistry



Figures: Checkley and Barth, 2009, ODFW, NOAA, Data from NANOOS (Pierce and Barth)

Challenge in upwelling systems: regional specificity, high variability





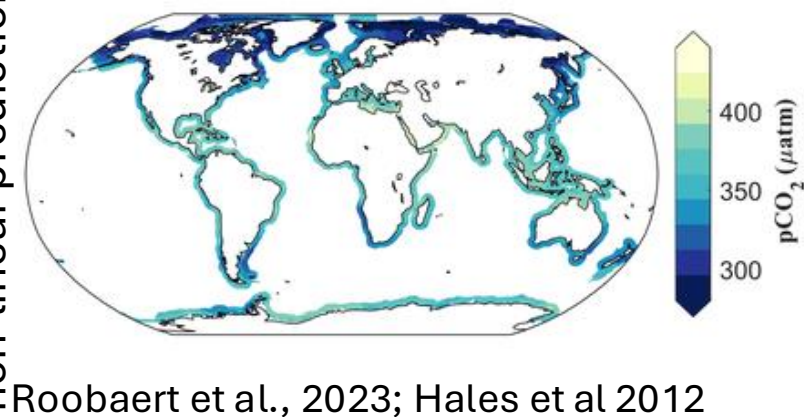
SOM as predictor

Current $p\text{CO}_2$ prediction:
uses a combo of
machine learning &
semi-mechanistic
models.

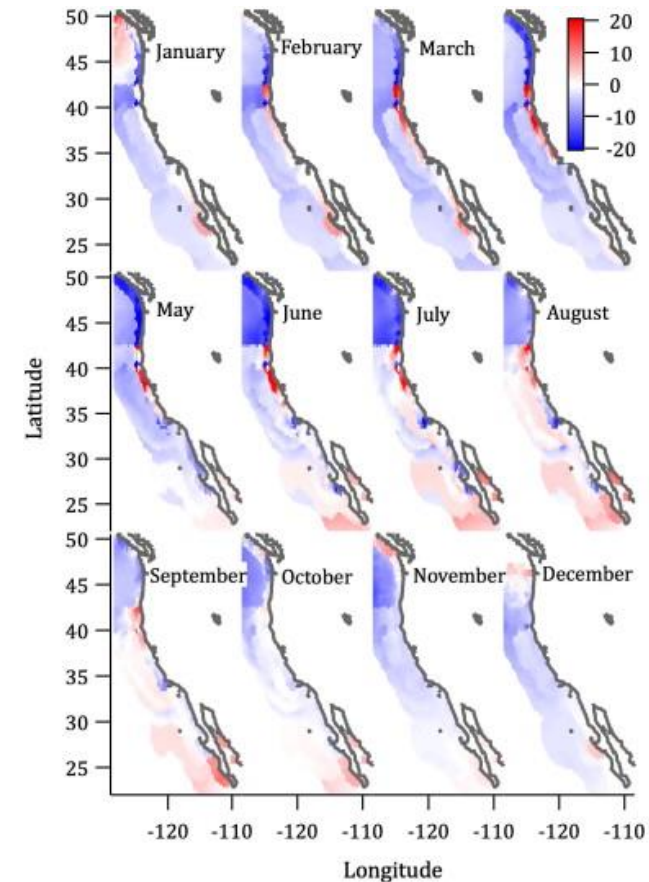
NN and RF as predictor

Assumption:
environmental
boundaries are
static

SOM regions +
FFN-non-linear prediction

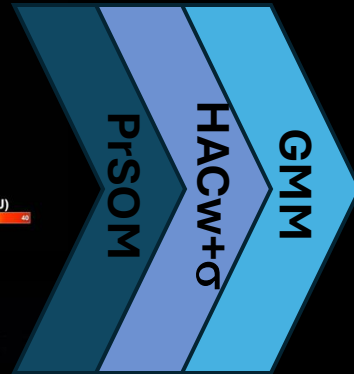
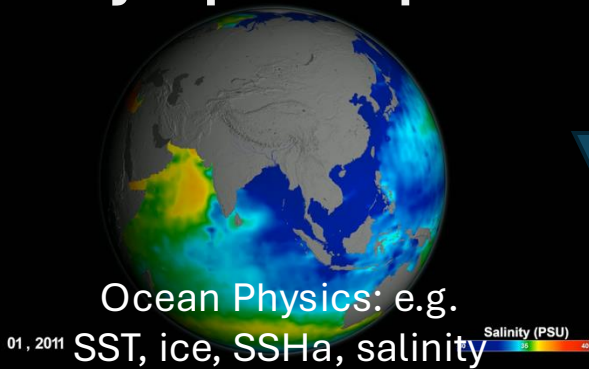


SOM regions +
Semi-mechanistic predictors



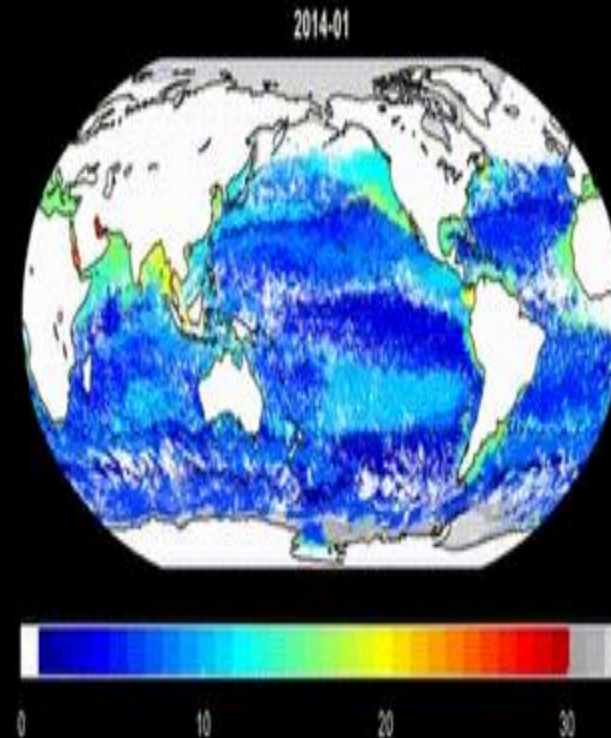
Pelagic seascapes: dynamic, relationship-preserving multidimensional, multiscale and global habitat classification

Satellite-based
Synoptic & updated



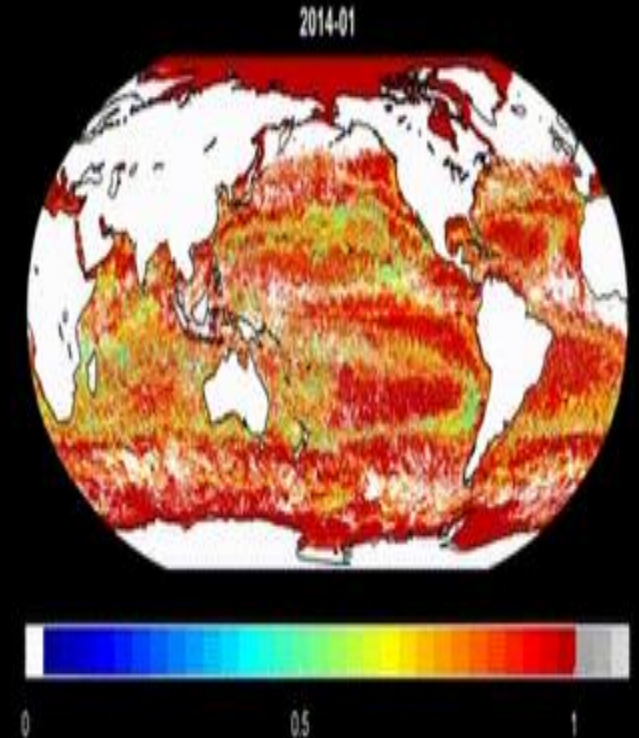
ML pipeline
Probabilistic
Topology-
preserving

33 unique classes



Water mass extent

Max(P): (un) certainty



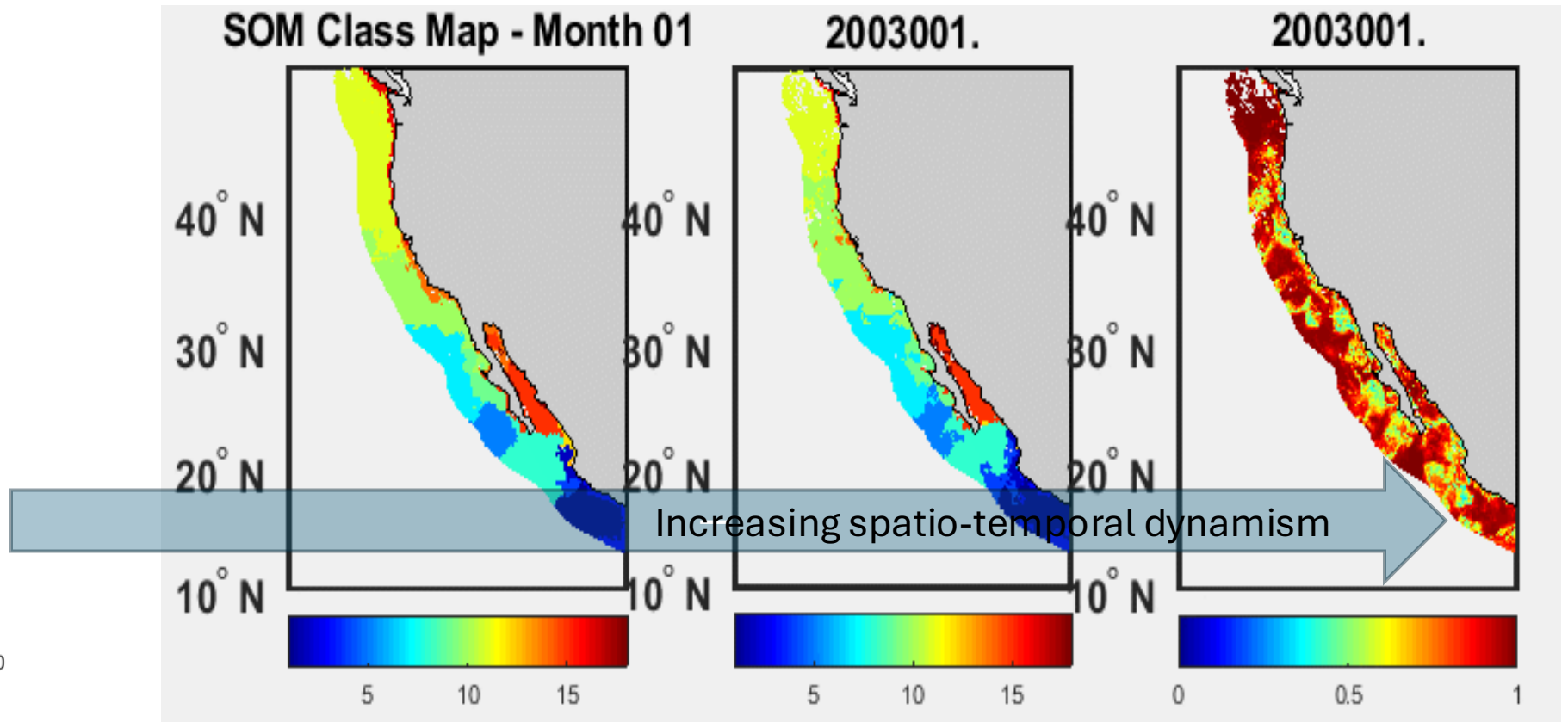
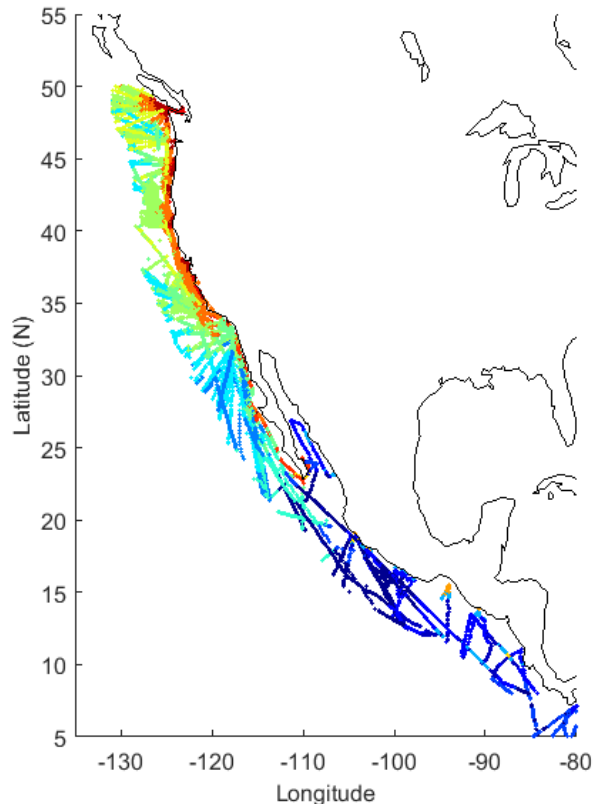
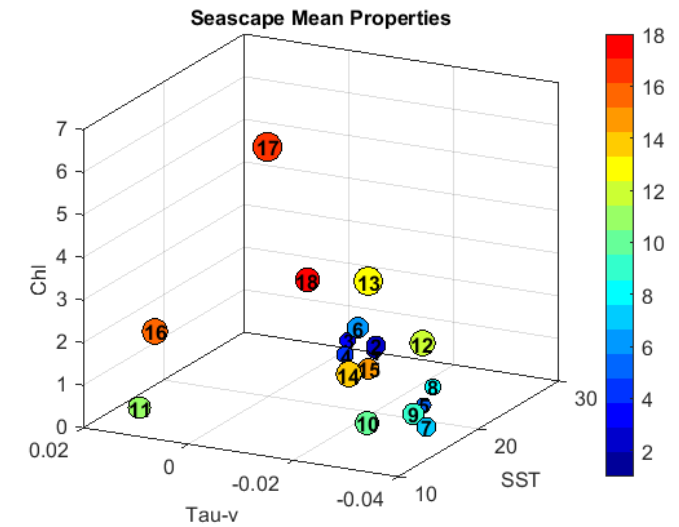
Novel conditions/fronts

Ocean Biology:
MODIS, VIIRS, PACE
Chl-a, nFLH, CDOM

Kavanaugh et al., 2015; 2016; 2018; 2021;
See also Oliver and Irwin, 2008; Sonnewald et al., 2021;

Seascapes for CO₂

- Reduced complexity : SST, Chl-a, and Tau-v. → 18 Seascapes
- >300K pCO₂, SST, SSS obs:
CDIAC + Hales (seasonally balanced and through 2006)
- Control the water mass: different physical and metabolic constraints on the carbonate system



Semi-mechanistic model (Hales et al., 2012): mixing, thermal, metabolic effects on TCO_2 *changes*

$$T_{\text{CO}_2} \cong T_{\text{CO}_2}^0 + \gamma \theta (T - T^0) + \beta \text{Chl.}$$

$$\Delta T_{\text{CO}_2} = \left. \frac{\partial T_{\text{CO}_2}}{\partial T} \Delta T \right]_{\text{mixing}} + \left. \frac{\partial T_{\text{CO}_2}}{\partial \text{Chl}} \Delta \text{Chl} \right]_{\text{biology}}$$

Concentration + thermal effect + metabolic efficiency

$$T_{\text{CO}_2} = T_{\text{CO}_2}^0 + \Delta T_{\text{CO}_2} \quad T_{\text{Alk}} = T_{\text{Alk}}^0 + \Delta T_{\text{Alk}}$$

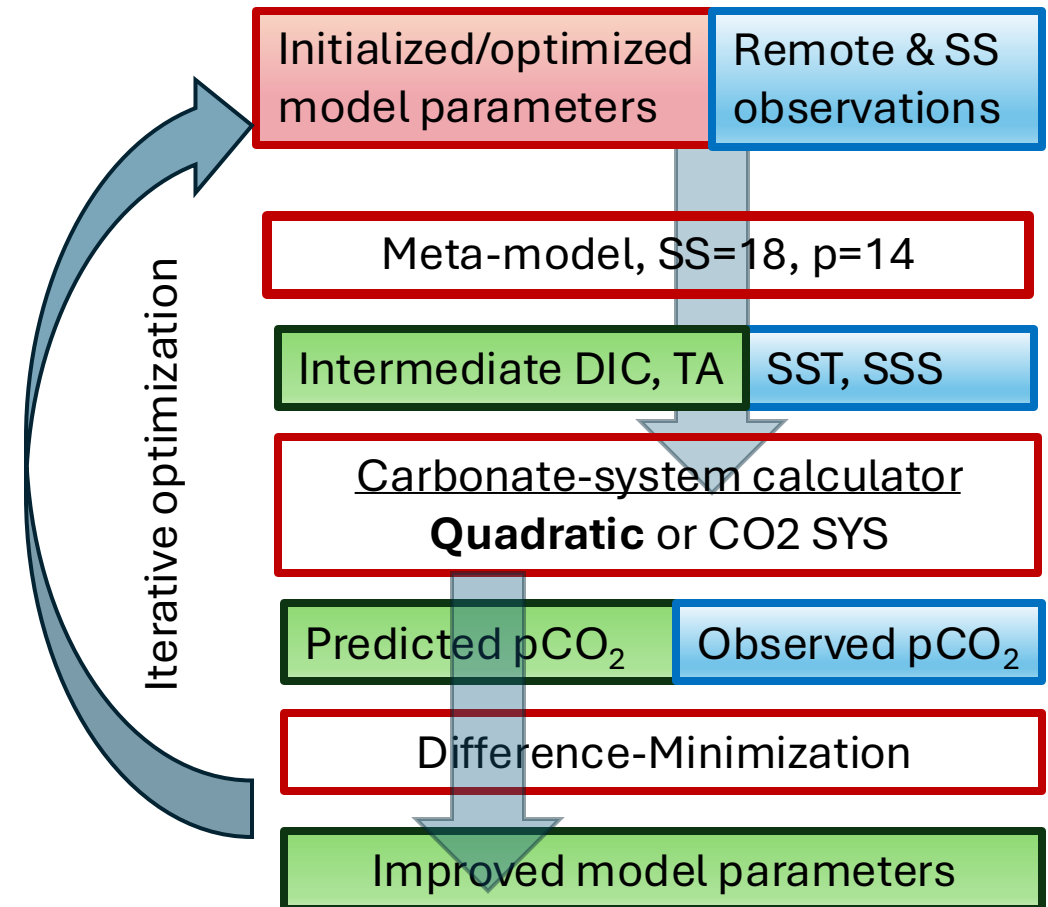
$$\Delta T_{\text{Alk}} = -0.15 \Delta T_{\text{CO}_2}$$



Progress in Oceanography
Volume 103, September 2012, Pages 1-15

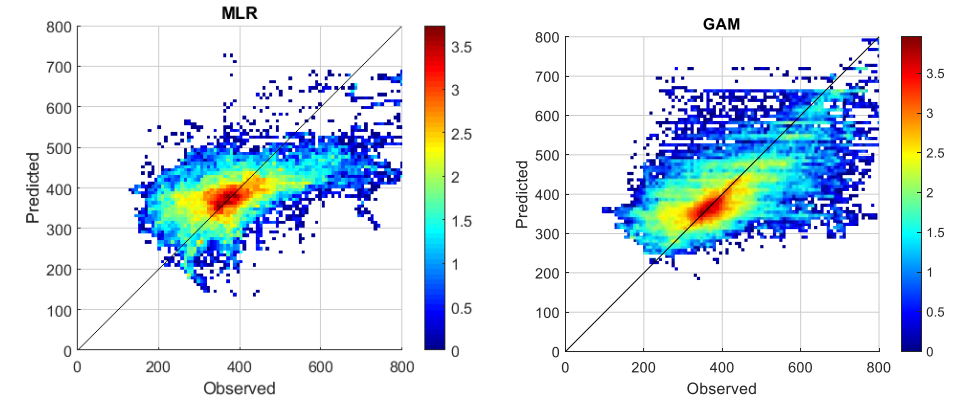
Satellite-based prediction of pCO_2 in
coastal waters of the eastern North
Pacific

Burke Hales ^a ✉, Peter G. Strutton ^a, Martin Saraceno ^{b c}, Ricardo Letelier ^a,
Taro Takahashi ^d, Richard Feely ^e, Christopher Sabine ^e, Francisco Chavez ^f

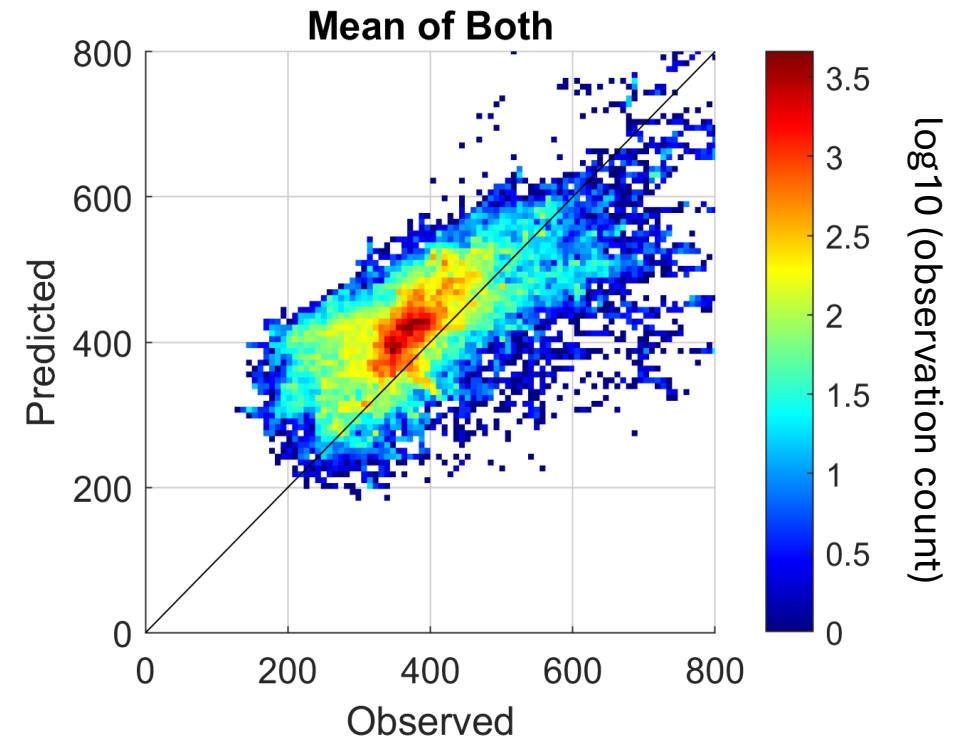
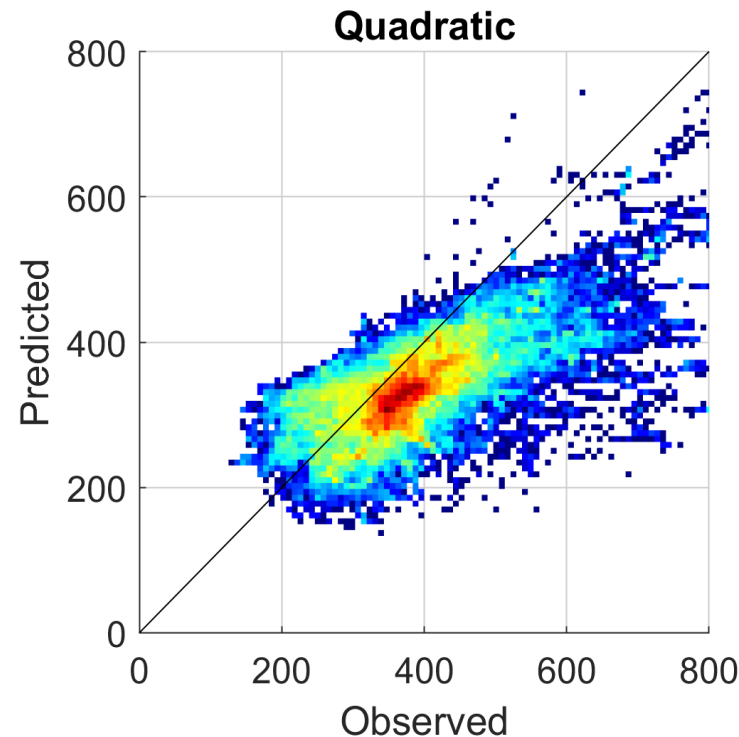
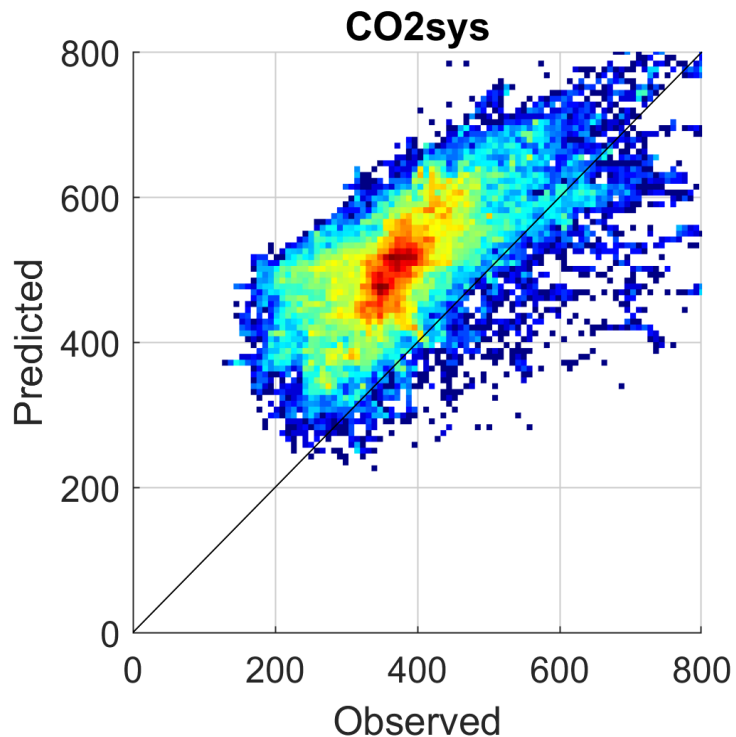


Optimized model predicted pCO₂

- RMSE: 32 uatm, r²=0.48, bias accountable (~40 uatm) for quadratic + thermo4 realisation
- Individual seascape RMSE even lower <10 uatm
- Parameter space: minimal imposed space-time



MLR: RMSE= 56 uatm, r²=0.31, not robust
GAM: RMSE=55 uatm, r²=0.5 but failed all tests

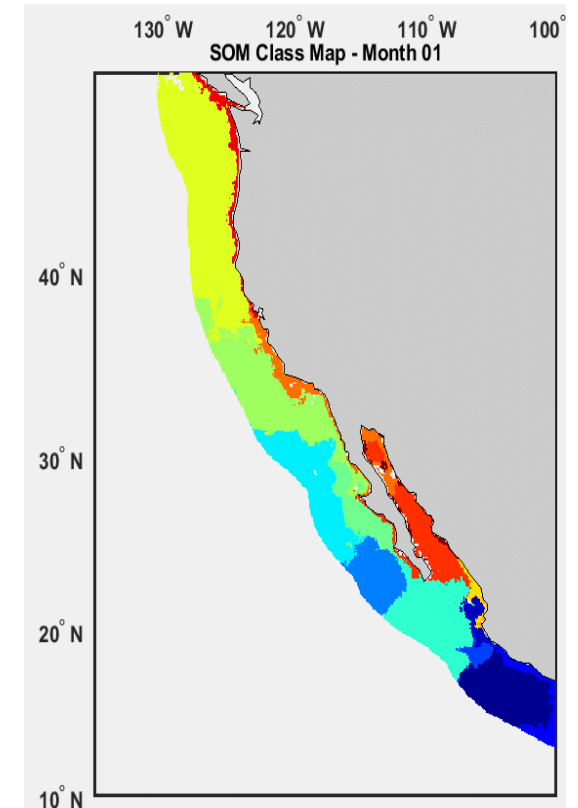
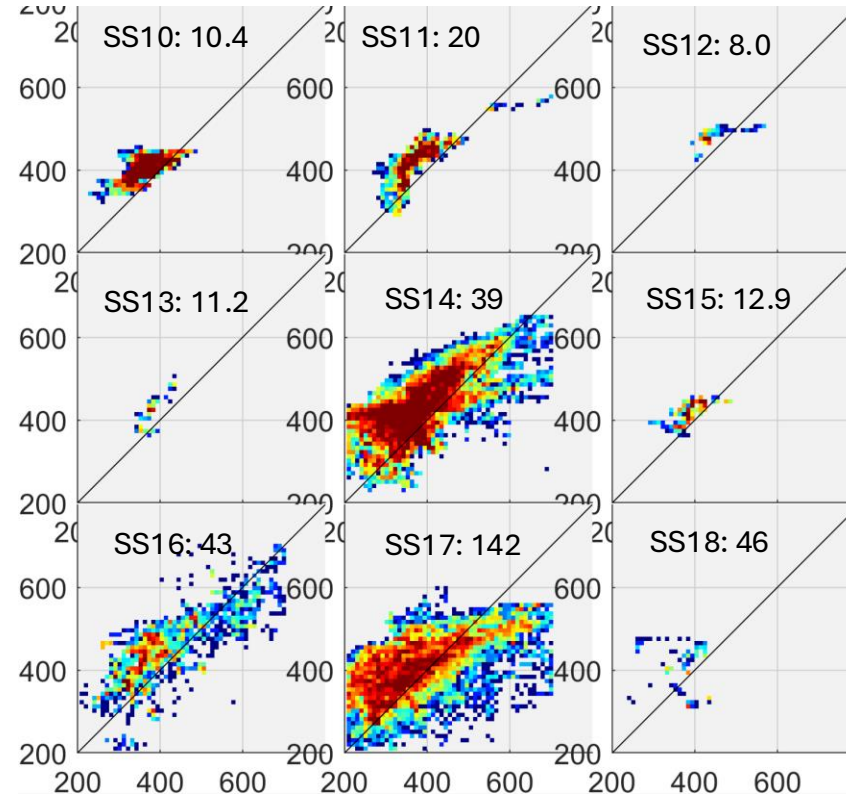
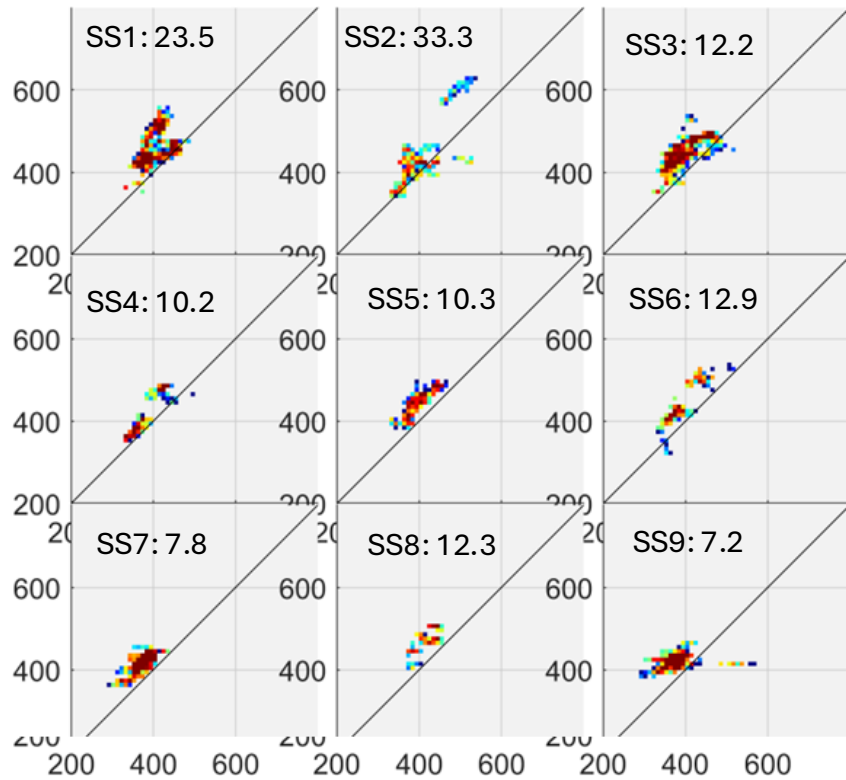
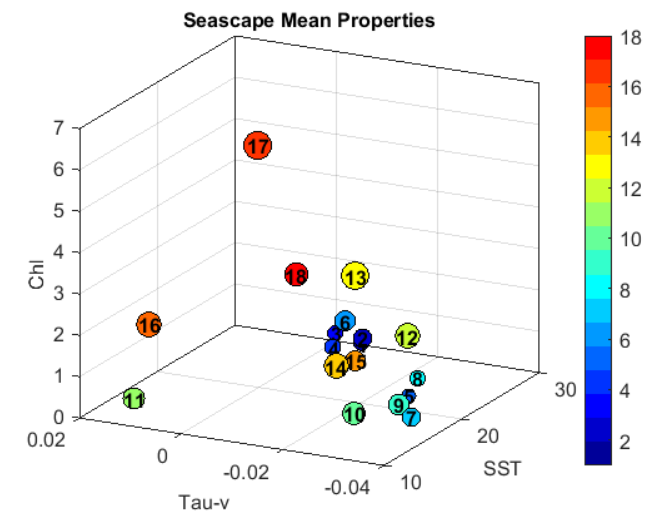


Optimized model predicted pCO₂ by seascape

RMSE offshore waters < very nearshore seascapes (not surprising)

Despite variability- dynamic range captured in upwelling seascapes (14-17)

High productive, high saline Baja CA, MX



Meta-model and regional (seascape) intercomparison

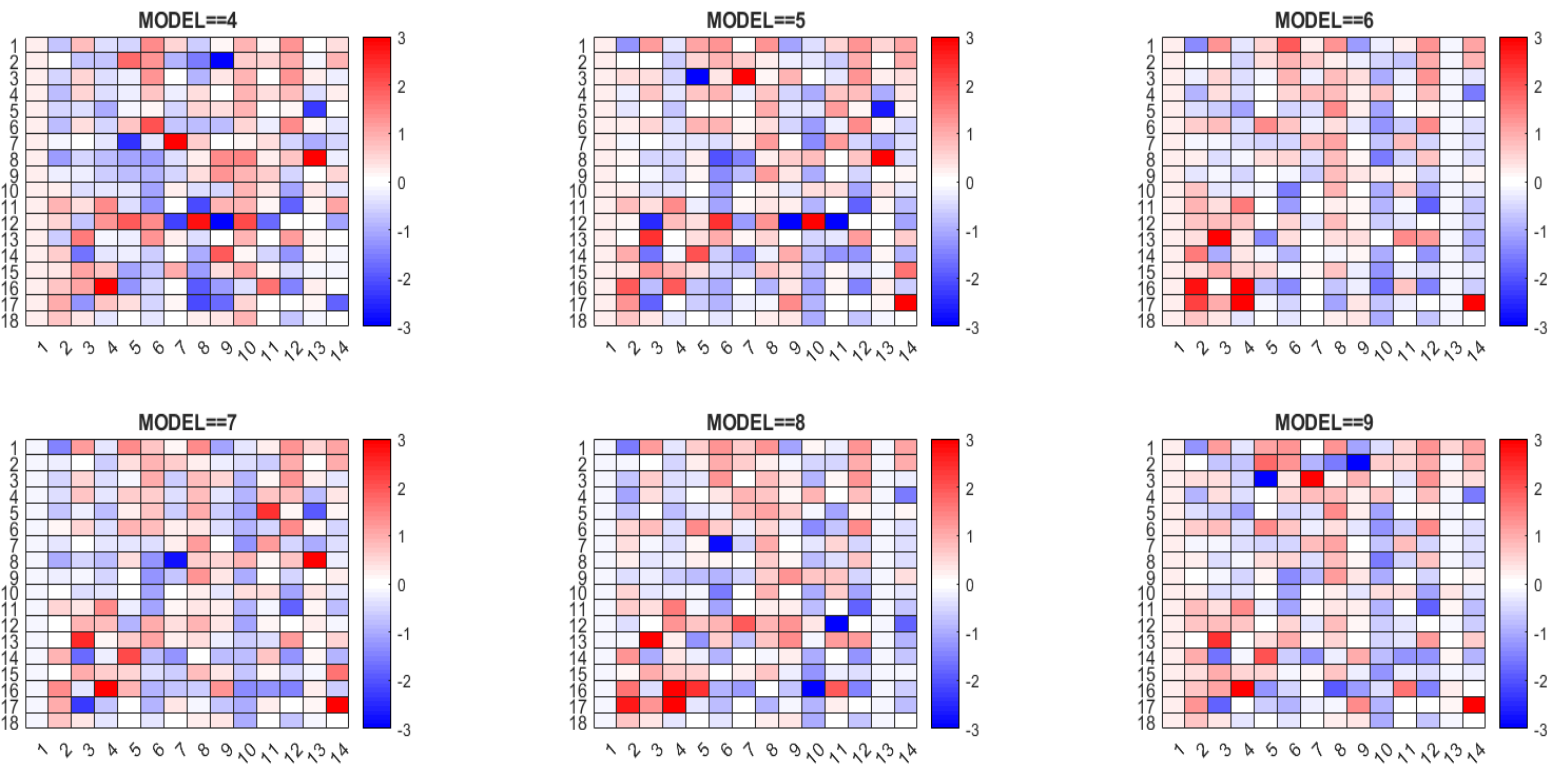
initialization and skill

Baseline Alkalinity: 2275 and 2300

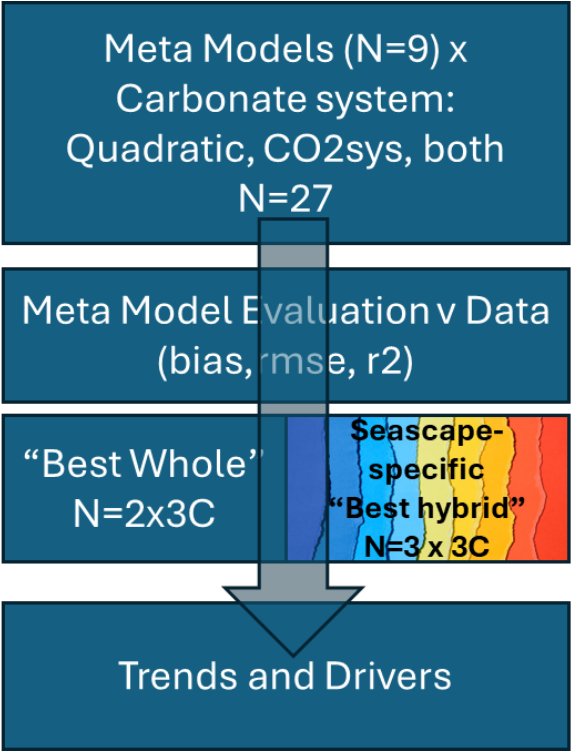
Regionally varying metabolic efficiency or constant.

Allocation of thermal effect to heating or mixing (0= no heating, 1=no mixing)

Seascape Regions (N=18)



Normalized optimized parameters
Z-score (seascapes x metamodel)



Generalized pipeline
Metamodel selection

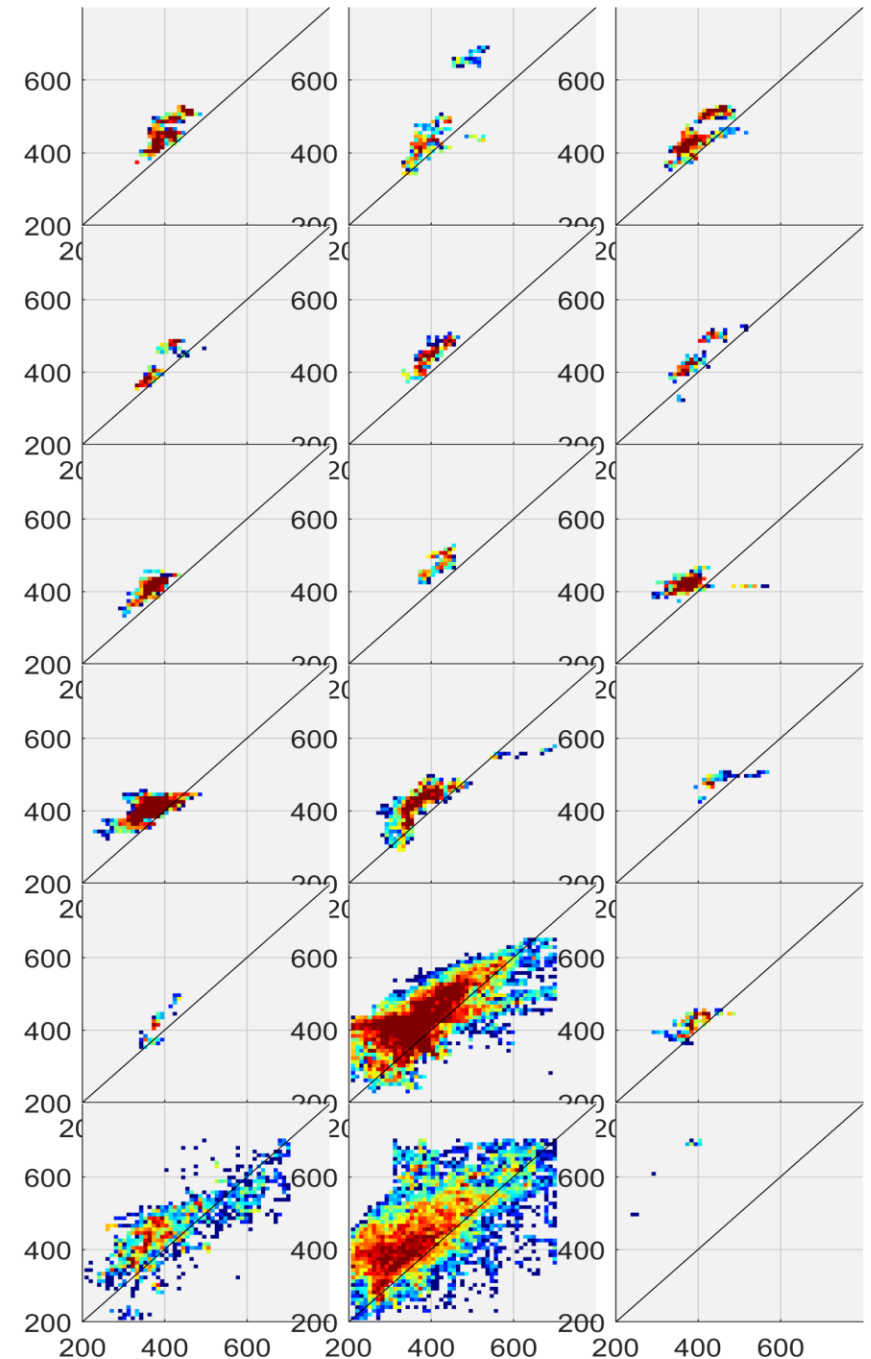
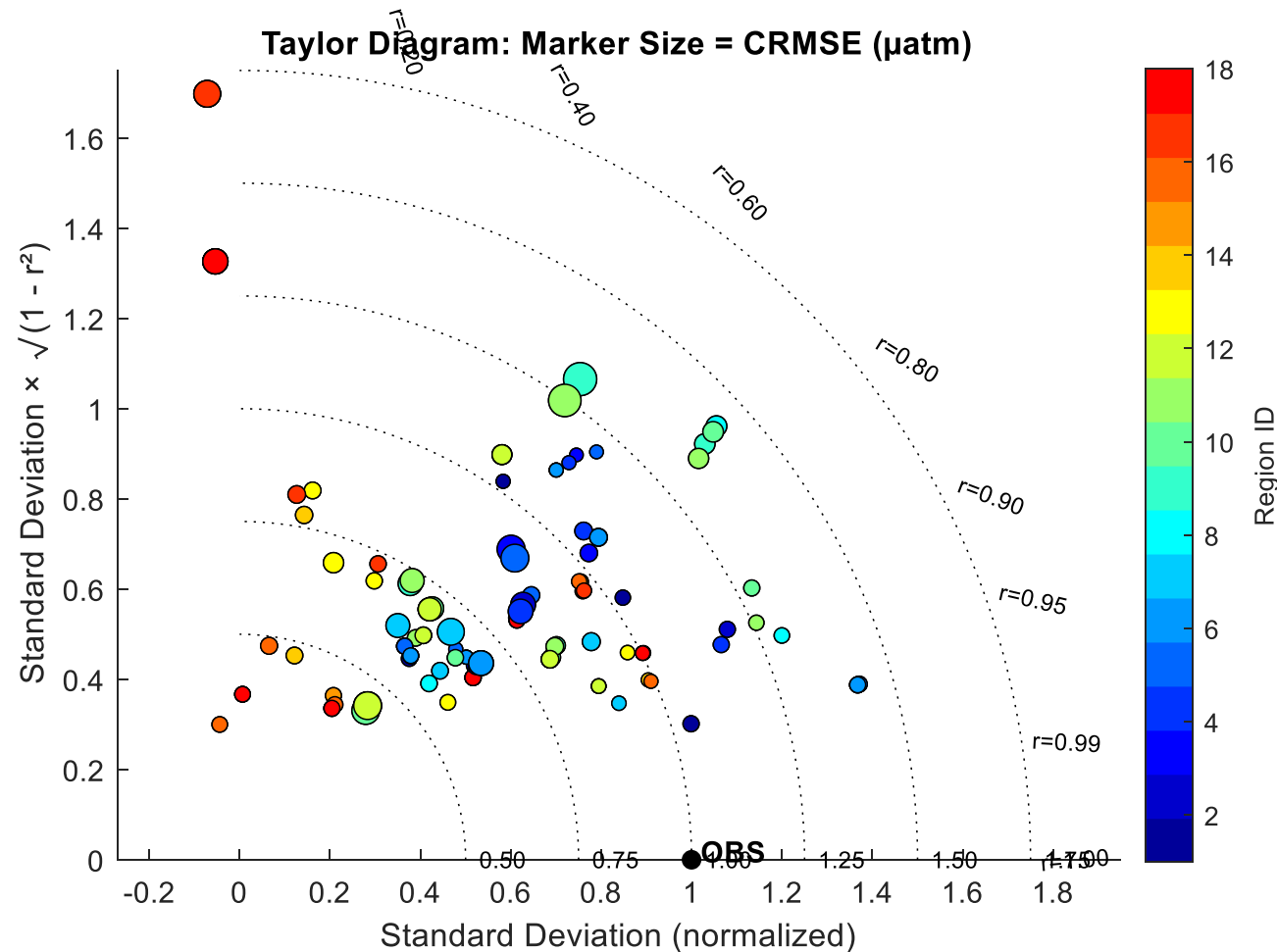
Hybrid models

Optimized Metamodels: different initial conditions or constraints

Hybrids (SS param selected from different metamodels)

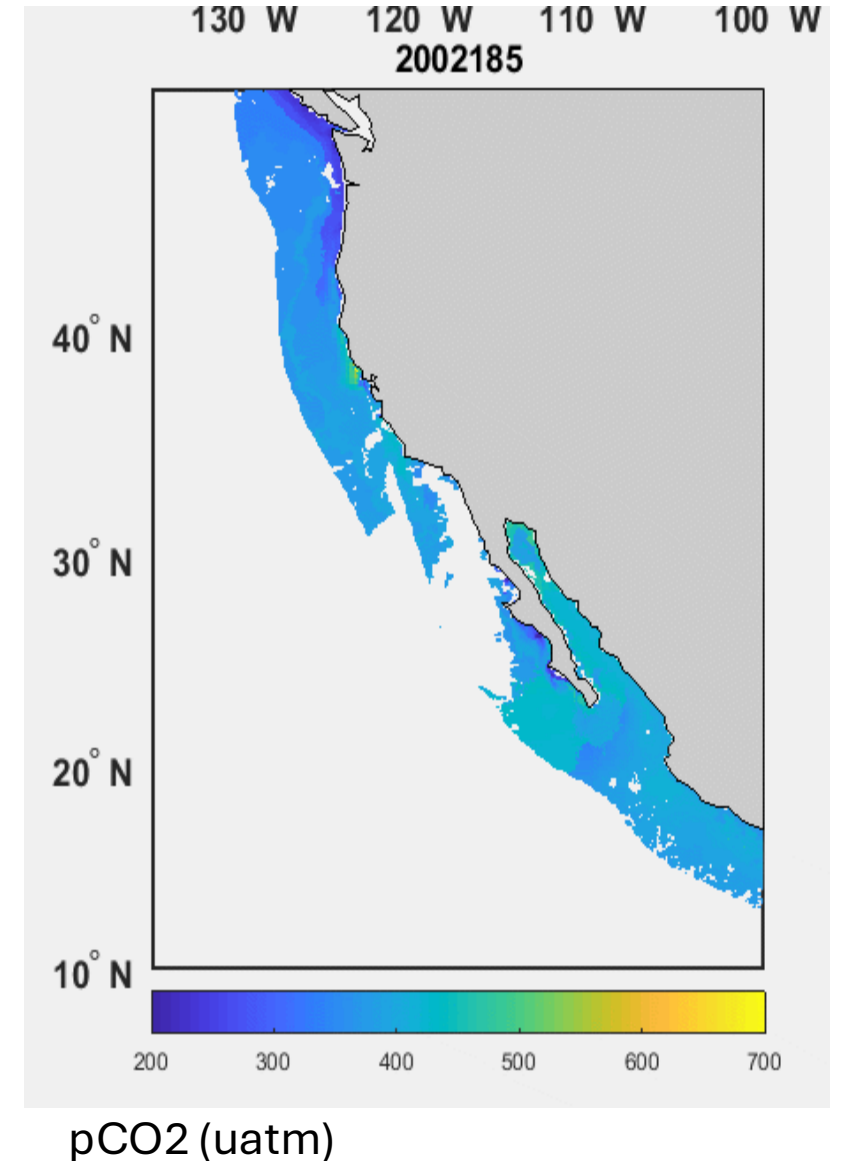
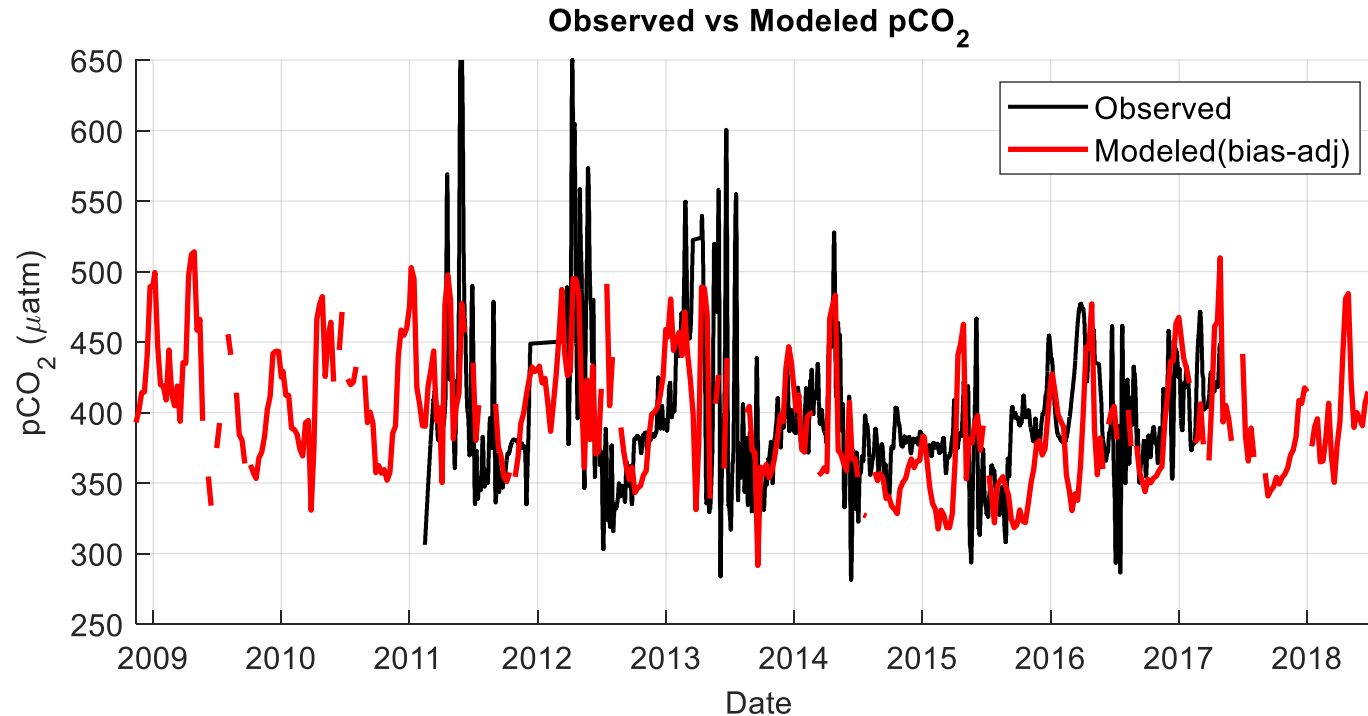
No affect overall, but increases r^2 of individual seascapes.

Which models dampen variability? Which seascapes are robust to model initial conditions?



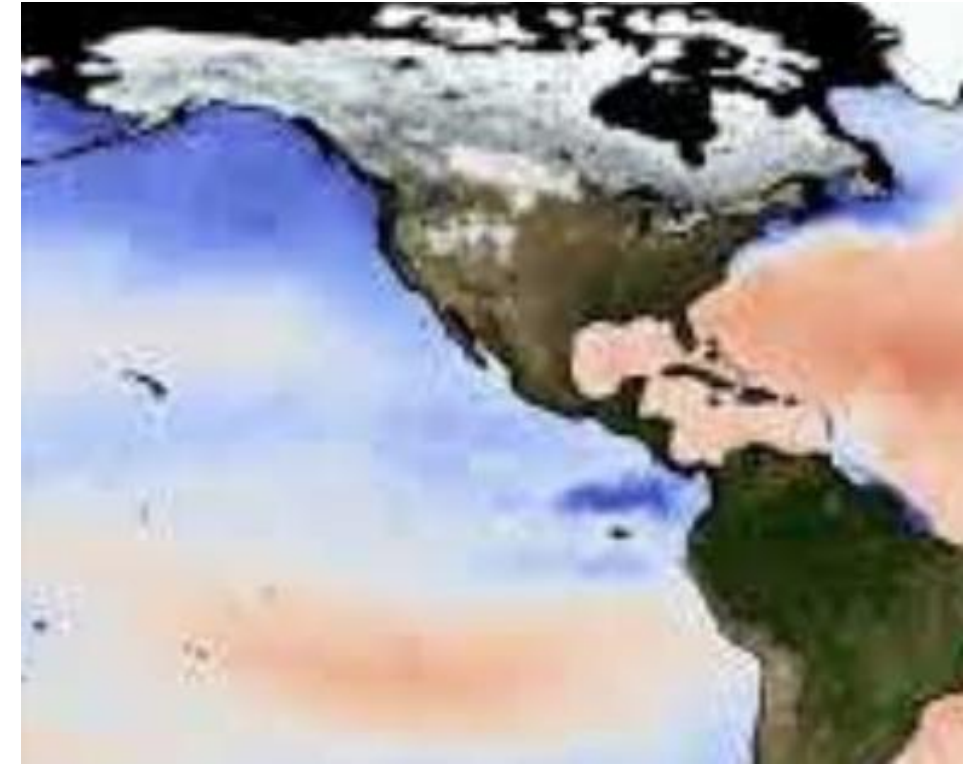
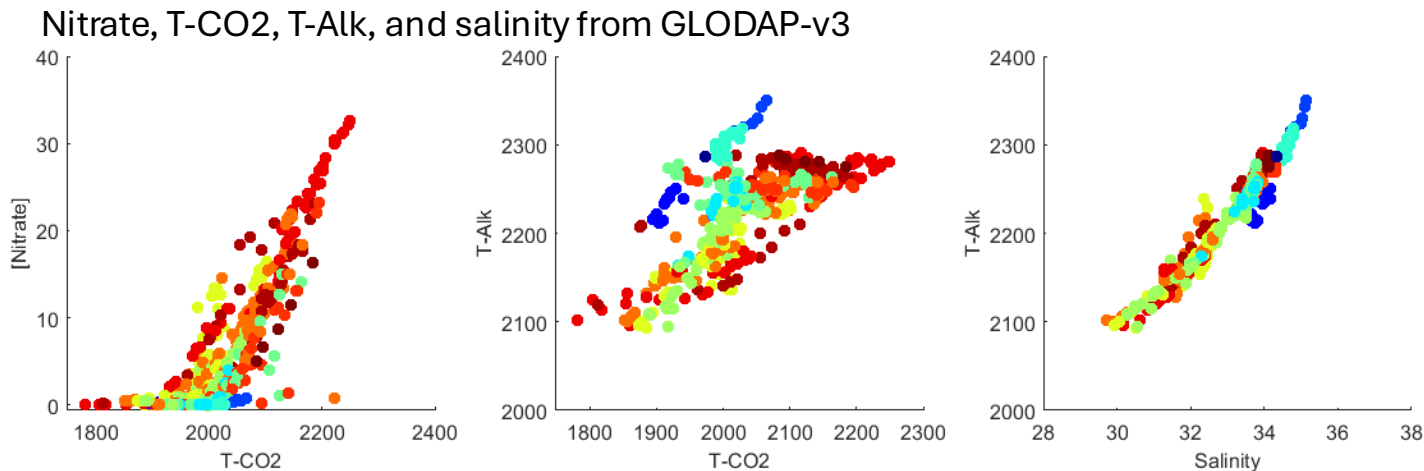
Dynamic pCO₂ match-up: very promising!

NOAA PMEL mooring 2.5 hr data binned to 8 day running averages.
CO₂-scape metamodel evaluated with Aqua-MODIS SST and chl-a .
Captures phenology, seasonality, events, and interannual variability.
NOTE: Training data were pre-2006!!!



T-Alk and Salinity

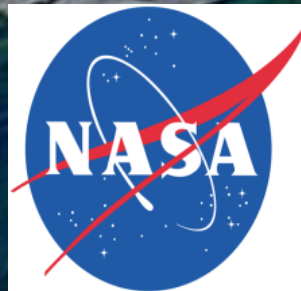
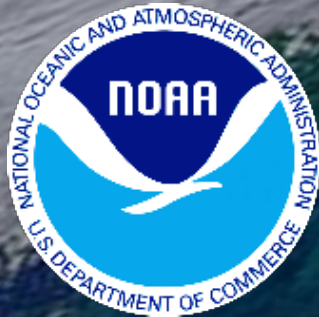
- Nitrate follows Redfield, but accounts for much less variation in T-Alk than salinity (4x the effect). But together they account for ~ 90% of T-Alk variability.



- The **OISSS Level 4 multi-mission sea surface salinity** product: **2011 to present**, on a **0.25° × 0.25°** grid with a **4-day temporal resolution**
 - Aquarius (2011–2015),** **SMAP (2015–present),** Supplementary **SMOS data**

Summary and thank you!!!!

- Semi-mechanistic models can perform as well or better than MLR or machine learning models.
- Dynamic seascape classifications can facilitate constraint of water mass differences and history.
- Seascapes + semi-mechanistic models (CO₂-scapes, carbonate scapes?) can reproduce patterns of events, phenology, seasonality, and interannual variability of pCO₂ in upwelling systems.
- Inclusion of satellite salinity will yield full carbonate system parameterization from space



Seascapes on NOAA CoastWatch



Ocean and Coastal Acidification Monitoring Priorities for the Northeast U.S. and Eastern Canada

Austin Pugh, NERACOOS



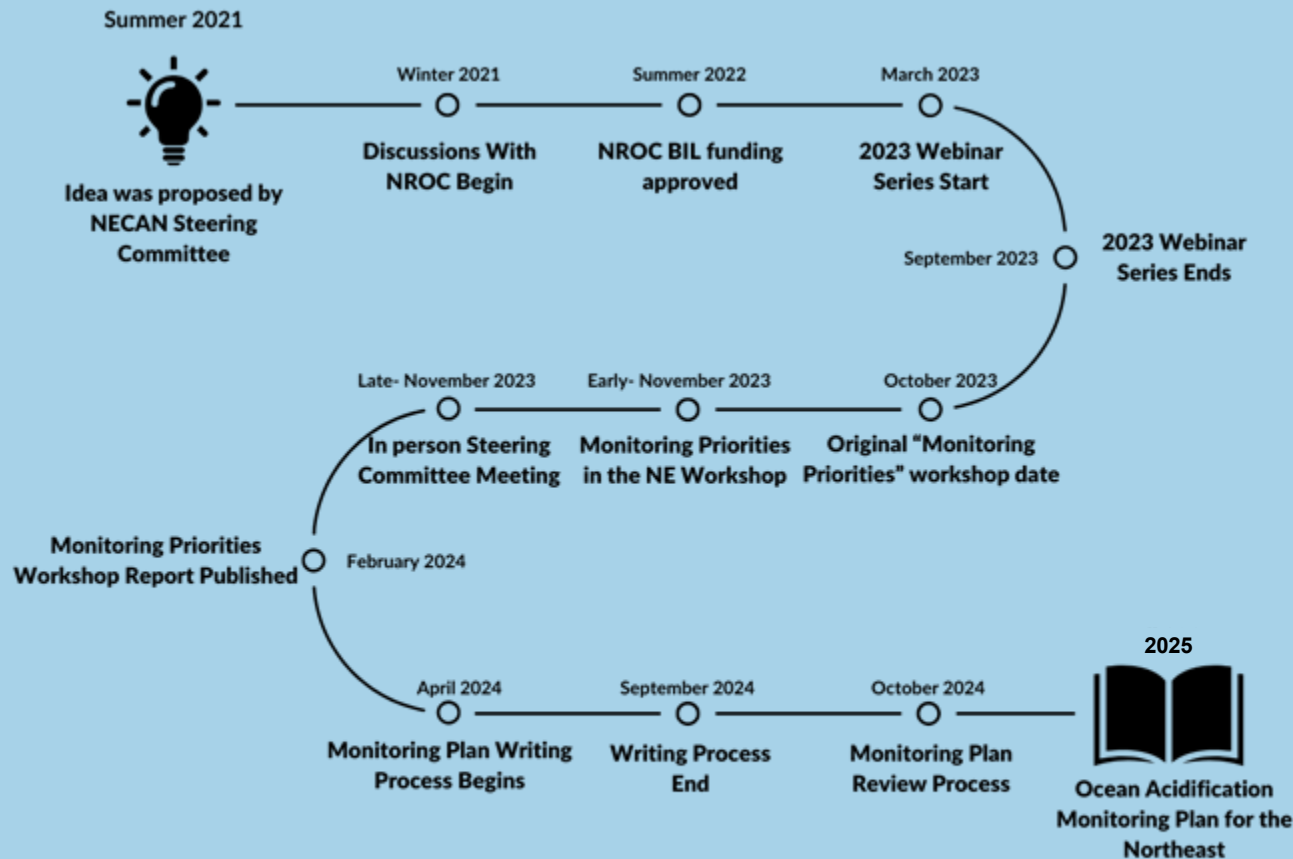
NECAN
NORTHEAST COASTAL
ACIDIFICATION NETWORK

Goal of Monitoring Plan

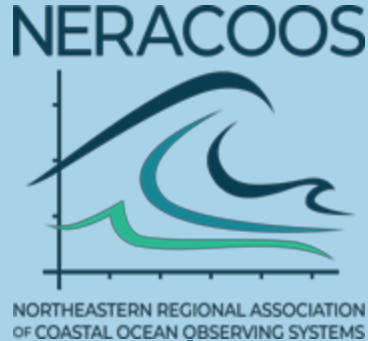
The NECAN monitoring plan identifies specific actions to improve the monitoring and future decision making of acidification in the Northeast monitoring region

Caveats: Due to the size of the NECAN region and the high variability of the coastal zone this monitoring plan could not consider and make recommendations for all locals in the region.





NROC Comes on Board



NECAN
NORTHEAST COASTAL
ACIDIFICATION NETWORK

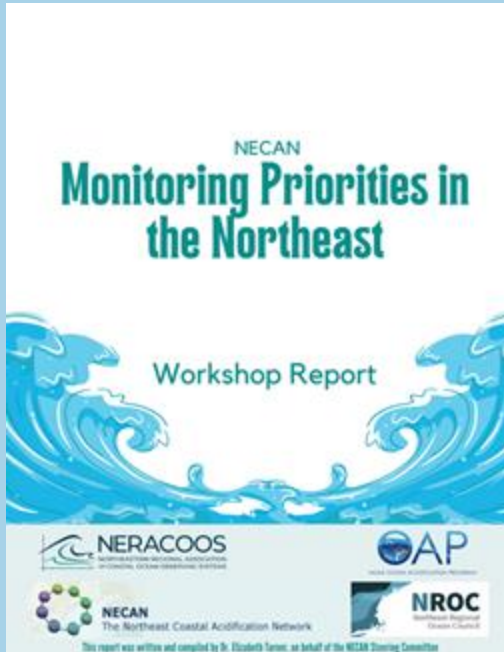
2023 NECAN Webinar Series

Topics:

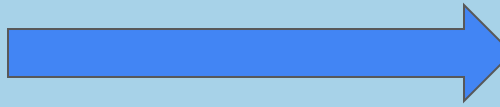
- Current Assessments
- Climate
- Modeling
- Biological Impacts
- New Technologies/Sensors/Methods
- User Needs & Products
- Indigenous Perspectives & Concerns
- Rapid Response



2023 NECAN Workshop



www.NECAN.org



NECAN
NORTHEAST COASTAL
ACIDIFICATION NETWORK

Monitoring need	Imp	Feas	Cost	Avg
MN:A <i>Improve spatial and temporal scale of monitoring co-located OCA variables and biological measurements to better resolve variability of acidification dynamics in concert with biological processes</i>	1st	1st	2nd	2
MN:B <i>Increase subsurface monitoring to understand how conditions vary at depth</i>	2nd	1st	2nd	2.7
MN:C <i>Increase the number of high-frequency monitoring assets that measure at least two of four carbon parameters</i>	3rd	3rd	1st	3.1
MN:D <i>Increase near-real-time and rapid response observing capacity to capture episodic events</i>	4th	5th	5th	3.9
MN:E <i>Increase spatial coverage of “climate”-quality observations</i>	6th	4th	4th	3.9
MN:F <i>Determine fluxes and rates that would help parameterize and constrain regional modeling efforts to understand past conditions and project future trends</i>	5th	6th	6th	4.7



Writing Process



Began in April 2024

SC and partnering authors

First draft Made available for comment by webinar presenters and workshop participants in October of 2024

Second Draft available for comment by anyone November 8th-24th:

- NROC meeting
- NECAN Mailing list
- OAIE

Final version available 2025



NECAN
NORTHEAST COASTAL
ACIDIFICATION NETWORK



OCEAN AND COASTAL ACIDIFICATION

Monitoring Priorities for the
Northeast US and Eastern Canada



Monitoring Need A:

Improve spatial and temporal scale of monitoring co-located OCA variables and biological measurements to better resolve variability of acidification dynamics in concert with biological processes



Monitoring Need B:

Increase subsurface monitoring
to understand how conditions
vary at depth



Monitoring Need C:

Increase the number of high-frequency monitoring assets that measure at least two of four carbon parameters



Monitoring Need D:

Increase near real time and
rapid response observing
capacity to capture episodic
events



Monitoring Need E:

Better spatial coverage of
“climate”-quality observations



Monitoring Need F:

Determine fluxes and rates that would help parameterize and constrain regional modeling efforts to understand past conditions and project future trends.



Examples of Proposed Actions

Bolstering existing monitoring programs and surveys such as ECOA and the NERR/NEP networks.

Development of a documented “lending library” of available assets in the region

Bolster tools like the Northeast Ocean Data Portal can be used to identify sites ideally suited to collaborative climate-quality monitoring.

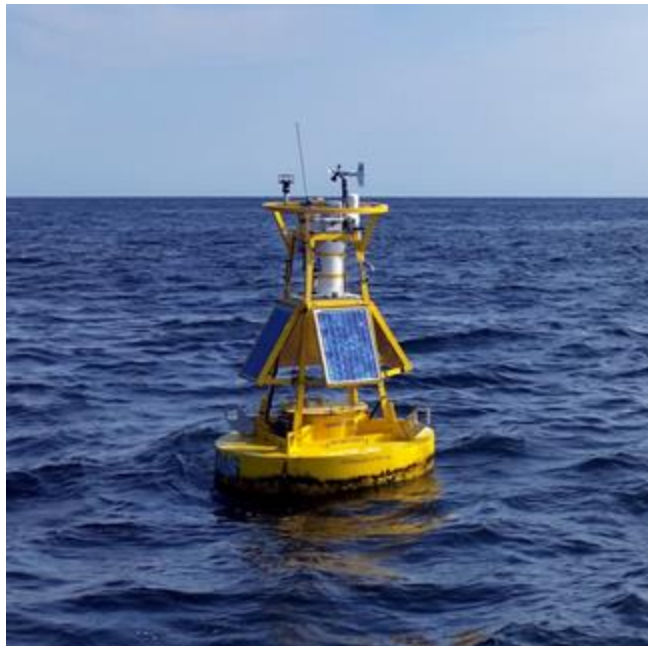




Northeast Regional Ocean Council

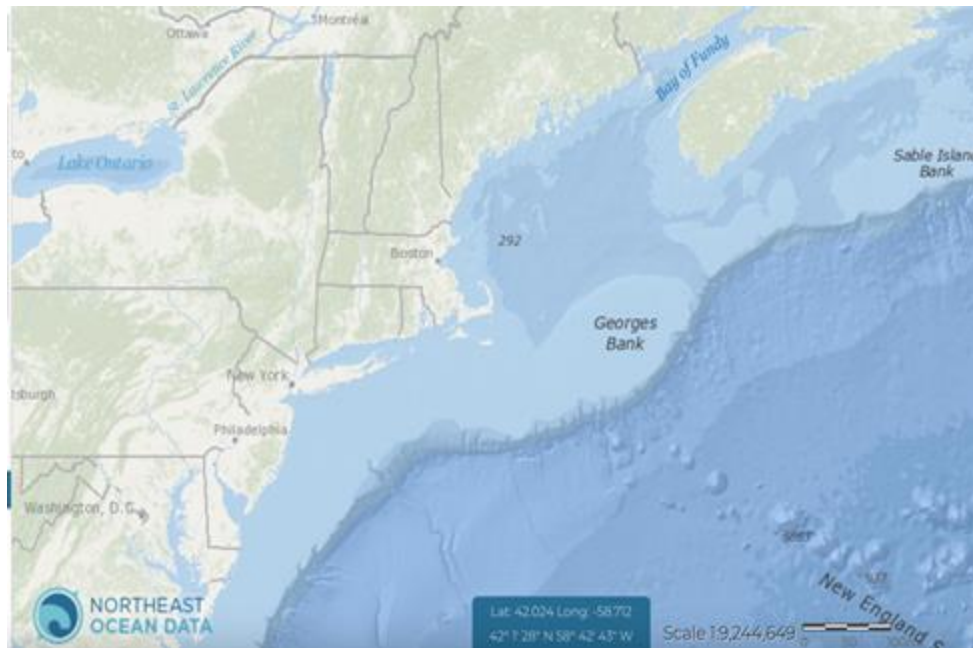
OCEAN ACIDIFICATION OUTREACH

OCEAN ACIDIFICATION MONITORING IN THE NORTHEAST



- Robust data collection and monitoring of environmental variables associated with OA are essential.
- NROC has played a leading role in supporting OA monitoring and management efforts in the region.
- In November 2023, NECAN-NROC hosted workshop to identify priorities for understanding OA in the region and impacts.
- Workshop outcomes served as basis for development of draft Ocean Acidification Monitoring Plan.

DEVELOPMENT OF OCEAN ACIDIFICATION MANAGEMENT TOOLS



- NROC is prioritizing the development of an OA theme on the Northeast Ocean Data Portal.
- Conducting outreach to Tribes, scientists, managers, and regional partners to inform the development of the OA theme.
- Key findings related to data needs, species specific concerns, thresholds, regions of interest, and other info will be key in developing data layers.

NROC OCEAN ACIDIFICATION ENGAGEMENT TO DATE



- NROC began outreach in Spring 2025 with [state coastal managers](#) in Maine, New Hampshire, Massachusetts, Rhode Island and Connecticut.
- Engagement with [Tribes](#), [regional scientists](#), and [SeaGrant](#) program representatives currently underway.
- NROC Ocean Acidification [webinars in September](#) for [regional](#) scientists and other regional partners (wildlife managers, National Estuarine Partnerships, National Estuarine Research Reserves, others).

MANAGEMENT QUESTIONS FOR NORTHEAST OCEAN DATA PORTAL

- What are the [species of concern](#) as it relates to ocean acidification in New England for your entity and why (i.e., lobsters, oysters, scallops, others). What specific management/regulatory activities apply?
- What types of [maps, tools, or data products](#) could help inform your entities' engagement in those management activities? Specifically, information beyond the monitoring being conducted in specific locations – for example, maps of ocean acidification concentrations and risks to individual species sensitivity?
- Have efforts been employed to map species and areas that are increasingly vulnerable to ocean acidification in your agency/entity or more broadly within New England? If so, who were these efforts carried out by? What types of data and information were collected to support their characterization as vulnerable? Where are these data/information/products stored?
- Anything additional you want to discuss related to management needs? Are there others in your agency/entity/community we should engage?

ENGAGEMENT TO DATE: MANAGEMENT NEEDS AND PRIORITIES

Overview of species concerns, management needs, and recommended data products to inform decision making:

- Interest in mapping the regional extent of ocean acidification risk and identifying habitats that might be at risk for species of concern.
- Species of high importance include American lobsters, oysters, clams (softshell, quahog/hard, razor, Atlantic surf clam), mussels, seagrass, eel grass, squid, forage fish species, sand lance, and bay anchovies.
- Interest in data products that inform aquaculture site selection and decisions related to permitting, use of technology and other management needs.
- Data products that allow the visualization of regional ocean acidification hot spots and the characterization of coastal acidification, particularly at it relates to natural beds and important aquaculture growing areas.
- Interest in mapping the extent of ocean/coastal acidification to assess the success of ocean acidification mitigation strategies (i.e., multitrophic interventions).

Preliminary feedback on data product development:

- Integration of existing ocean acidification data variables collected from various regional assets and monitoring programs into Northeast Ocean Data Portal.
- Potential development of species vulnerability mapping features based on known ocean acidification thresholds (i.e., saturation state, pCO_2).

REPORTING AND NEXT STEPS



- Following engagement with states, Tribes, scientists and industry representations, NROC will compile responses into a report which will be published in Fall 2025.
- The findings documented in this report will include:
 - Summary of what we heard
 - Series of key recommendations
 - Agencies/organizations listed (no name specifics).
- If you would like to provide feedback or recommend an entity that we should engage, please let us know!

QUESTIONS/FEEDBACK?



CONTACT INFORMATION

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Regional Ocean Council
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Thank You



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Jake Kritzer (co-chair), NERACOOS

Samantha Siedlecki (co-chair), University of Connecticut

Kumiko Azetsu-Scott, Fisheries and Oceans, Canada

Gabriela Bradt, University of New Hampshire

Steve Couture, New Hampshire Department of Environmental Services

Parker Gassett, Maine Climate Science Information Exchange Office, University of Maine.

Dwight Gledhill, NOAA Ocean Acidification Program

Christopher W. Hunt, University of New Hampshire

Carolina Bastidas, MIT Sea Grant

Ivy Mlsna, Environmental Protection Agency

Adam Pimenta, US Environmental Protection Agency

Amy Trice Northeast Regional Ocean Council

Justin Ries, Northeastern University

Elizabeth Turner, NOAA National Centers for Coastal Ocean Science (retired)

Other members of the Editorial Team:

Diane Lavoie, Fisheries and Oceans Canada

Contact: austin@neracoos.org



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National Estuarine Research Reserve System
Centralized Data Management Office

National Estuarine Research Reserve System (NERRS) System Wide Monitoring Program (SWMP)

Gregg P. Sakowicz

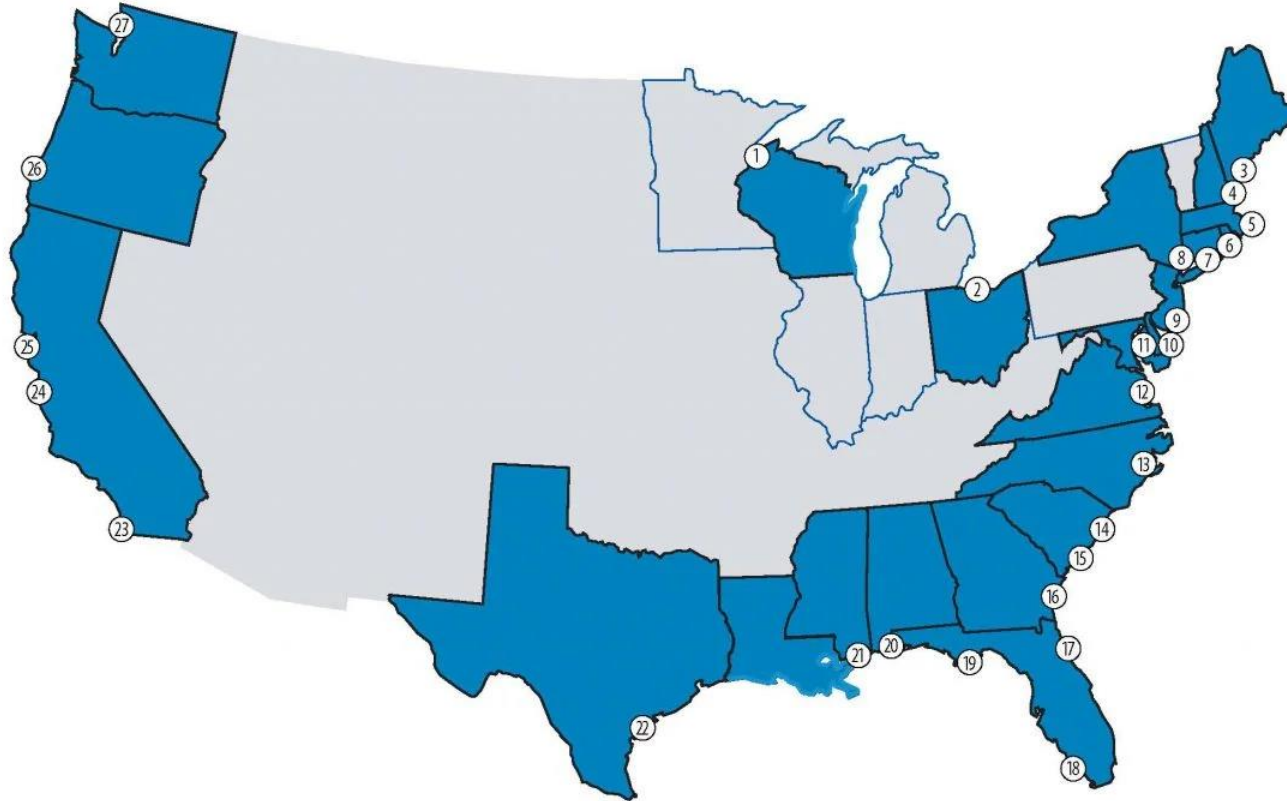
Assistant Research Coordinator/Field Researcher III

Jacques Cousteau National Estuarine Research Reserve

15 July 2025



NATIONAL ESTUARINE RESEARCH RESERVES



Great Lakes

1. Lake Superior, Wisconsin
2. Old Woman Creek, Ohio

Northeast

3. Wells, Maine
4. Great Bay, New Hampshire
5. Waquoit Bay, Massachusetts
6. Narragansett Bay, Rhode Island
7. Connecticut

Mid-Atlantic

8. Hudson River, New York
9. Jacques Cousteau, New Jersey
10. Delaware
11. Chesapeake Bay, Maryland
12. Chesapeake Bay, Virginia

Southeast

13. North Carolina
14. North Inlet-Winyah Bay, South Carolina
15. ACE Basin, South Carolina
16. Sapelo Island, Georgia
17. Guana Tolomato Matanzas, Florida

Gulf of Mexico

18. Rookery Bay, Florida
19. Apalachicola, Florida
20. Weeks Bay, Alabama
21. Grand Bay, Mississippi
22. Mission-Aransas, Texas

West

23. Tijuana River, California
24. Elkhorn Slough, California
25. San Francisco Bay, California
26. South Slough, Oregon
27. Padilla Bay, Washington
28. Kachemak Bay, Alaska

Pacific

29. He'eia, Hawai'i

Caribbean

30. Jobos Bay, Puerto Rico

PROPOSED

Bay of Green Bay, Wisconsin
Louisiana



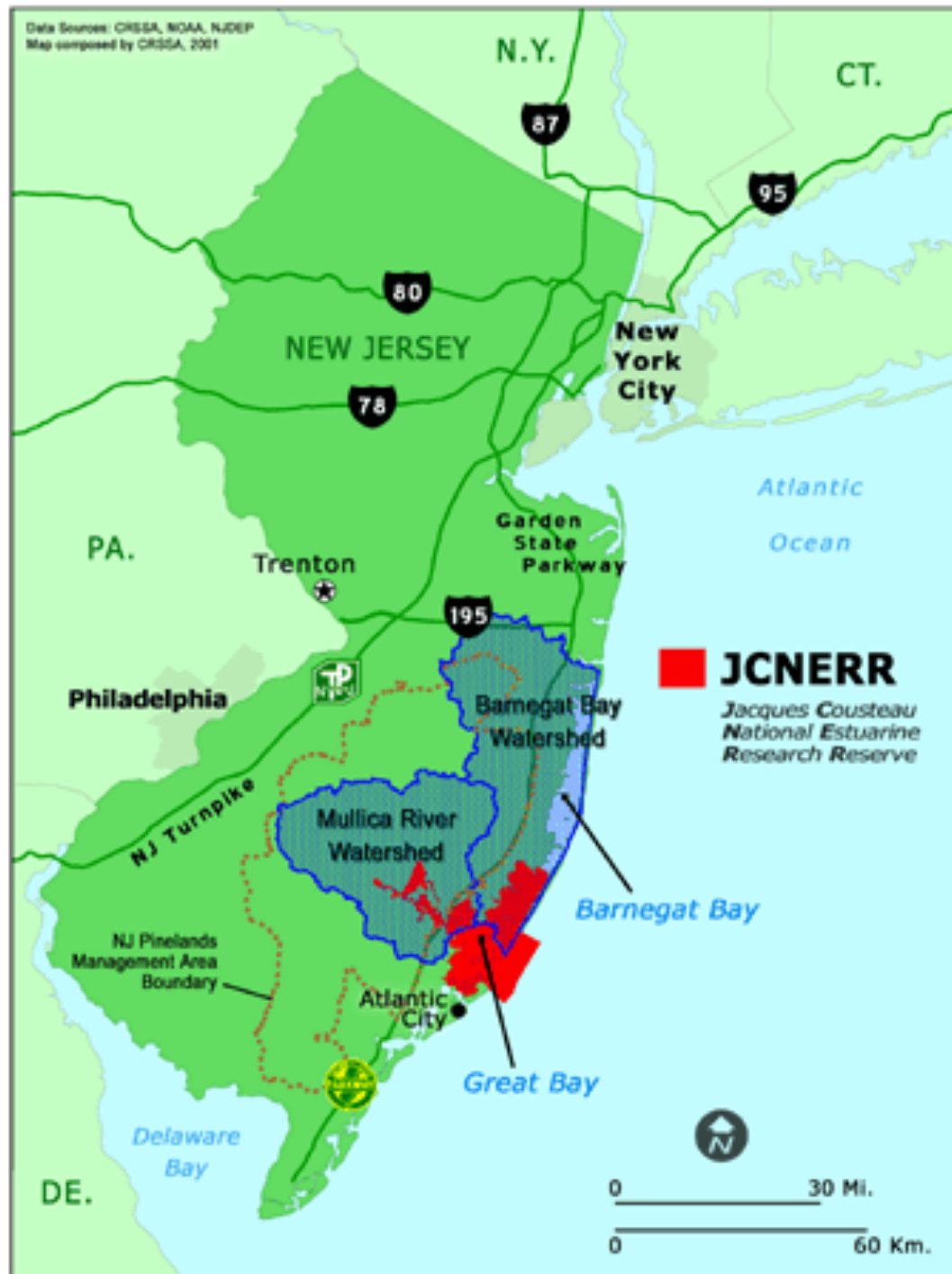
System-Wide Monitoring Program

- “SWMP”
- Water, Weather, and Nutrients
- Same at all 30 reserves
- Centralized Data Management Office (CDMO)
 - Data Management Committee (DMC)
 - Oversight Committee (OC)

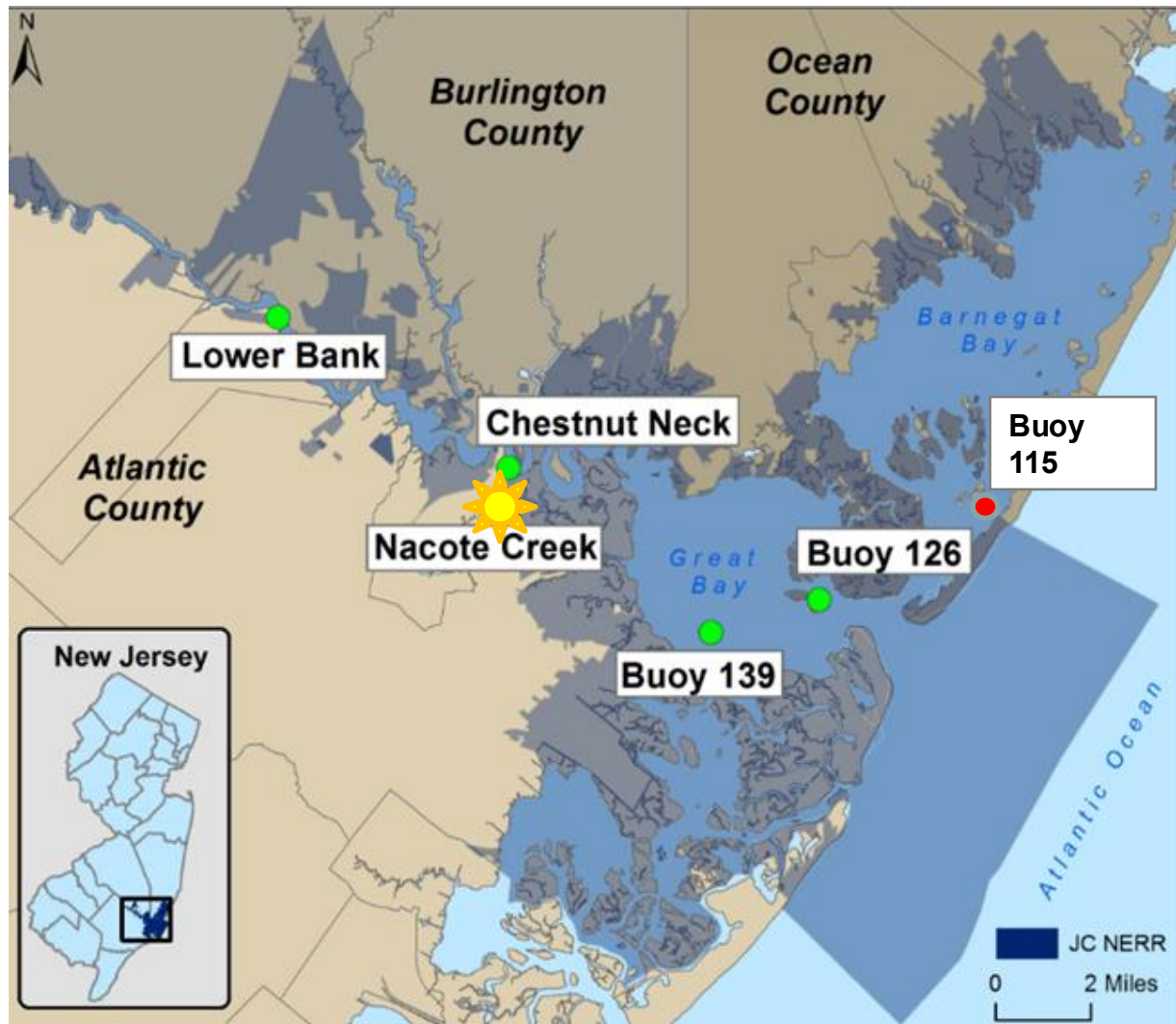
SWMP Monitoring at NERRs

- Four Water Quality (WQ) stations
- One Meteorological (MET) station
- Nutrient (NUT) sampling conducted at the WQ stations
- Option of additional “Secondary SWMP” stations

Data Sources: CRSSA, NOAA, NJDEP
Map composed by CRSSA, 2001



Example: JC NERR SWMP Stations



● = SWMP Water and Nutrient Station

★ = SWMP Weather Station

● = Secondary SWMP Nutrient Station

Types of Data Recorded

- **WQ:** Temperature, Specific Conductivity, Salinity, Dissolved Oxygen, Depth, pH, and Turbidity.
- **MET:** Temperature, Humidity, Atmospheric Pressure, Wind Speed, Wind Direction, Precipitation, sunlight intensity (PAR)
- **NUT:** Orthophosphate, Nitrate, Nitrite, Ammonium, Dissolved Inorganic Nitrogen, Chlorophyll



Water Quality (WQ) Station



SWMP “pluses”

- High frequency, long term
 - 15 minute interval, 30 year dataset
- Excel at baseline monitoring and capturing event impacts
- SOP's standardized
 - Equipment, operation, QAQC, authentication
- Open-source with continued support

SWMP “minuses” (re: acidification)

- **One OA/CA parameter: pH**
 - Accuracy: +/- 0.01 units within +/- 10° of calibration temperature, +/- 0.02 units for entire temperature range
 - Resolution: 0.01 units
 - **Reported: single decimal (tenths) place**
- Too low-res for climatological examinations (?)
- Fouling and drift
 - 30-45 day deployments

NERRS has Potential!

- Capable research and monitoring community
 - Varied expertise shared among community
 - Collaboration and sub-contract opportunities
- Tradition of innovation and collaboration
 - Workgroups, pilot efforts, internal and external grants

Some Acidification Work by NERRS

- Wells NERR participating w/ UNH and Friends of Casco Bay “Sensor Squad”
 - To evaluate the accuracy of glass bulb/electrode sensors
 - Explore the ability to model or derive TA (and possibly other carbonate chemistry parameters) using sonde data
 - Provide guidance on best practices/methods for collecting carbonate chemistry data from continuous monitoring programs

Some Acidification Work by NERRS

- Waquoit Bay NERR
 - Spatial mapping of dissolved inorganic carbon
 - Forecasting sediment nutrient & metal fluxes under coastal acidification
 - Quantifying impacts on estuarine nitrogen removal
 - ECHOES: Oxygen metabolism & pH exchange system

Some Acidification Work by NERRS

- Jacques Cousteau NERR
 - Monitoring services and tech support to Haskins Shellfish Laboratory and Aquatic Innovation Center
 - Provision of data, calibration and verification data to NOAA affiliates examining “cold pool”
 - Goldsmith, K., et al. **Scientific Considerations for Acidification Monitoring in the U.S. Mid-Atlantic Region**. Estuarine, Coastal, and Shelf Science Volume 225, 30 September 2019, 106189
 - A number of proposals over the years

Quite a Bit of Work In NERRS

- Chesapeake Bay

Su, J., Cai, WJ., Brodeur, J. et al. **Chesapeake Bay acidification buffered by spatially decoupled carbonate mineral cycling.** Nat. Geosci. 13, 441–447 (2020). <https://doi.org/10.1038/s41561-020-0584-3>

- West Coast NERRS (all five)

- Bednaršek, N. et al. **Natural Analogues in pH Variability and Predictability across the Coastal Pacific Estuaries: Extrapolation of the Increased Oyster Dissolution under Increased pH Amplitude and Low Predictability Related to Ocean Acidification.** Environmental Science & Technology 2022 56 (12), 9015-9028. DOI: 10.1021/acs.est.2c00010

Summary

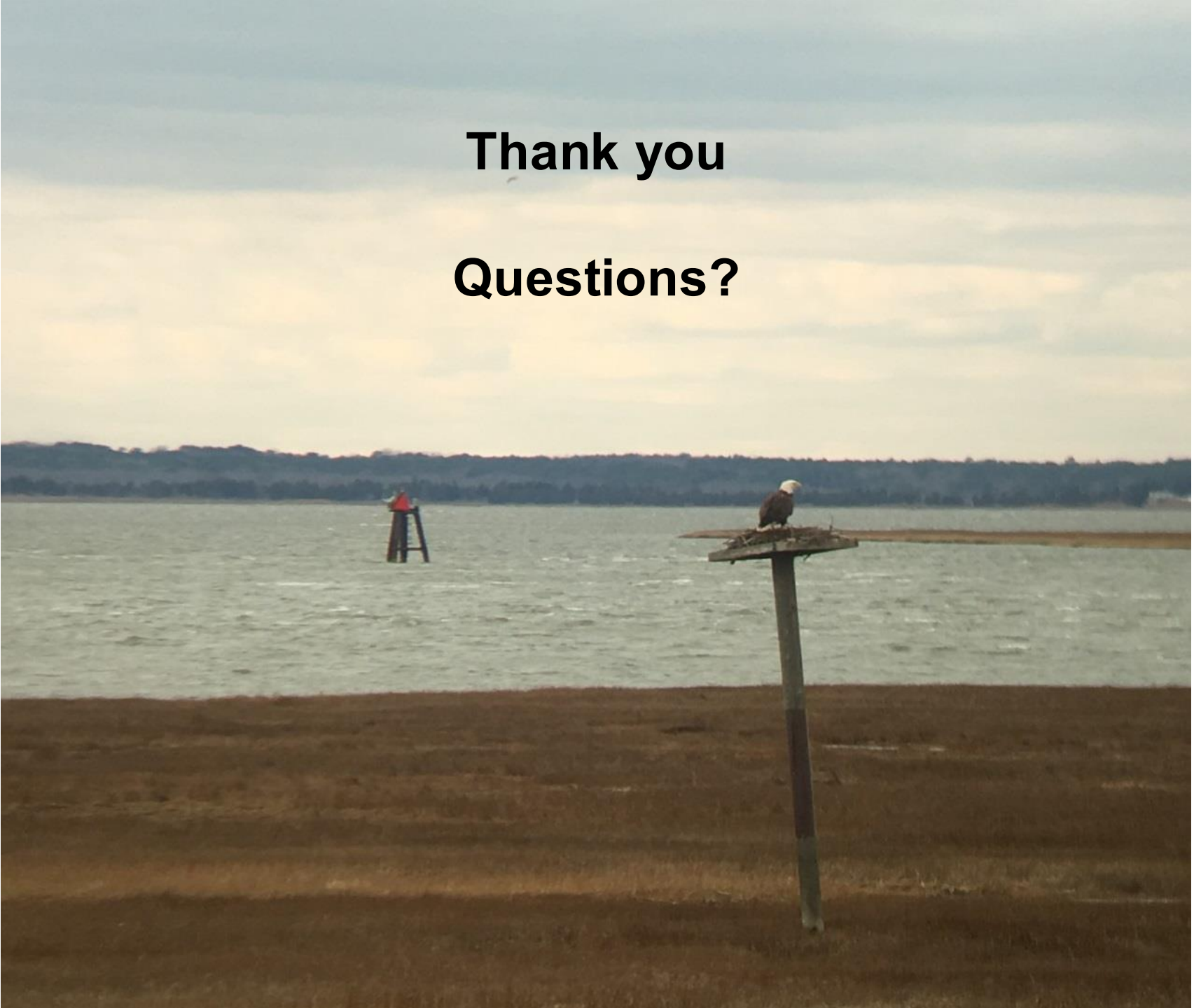
- NERRS has long-term datasets to share
 - Water, weather, nutrients, *more*
 - Available at nerrsdata.org
- Place-based program with facilities and infrastructure
- Looking for opportunities to engage and collaborate in research

Some Links and Contact Info

- Sakowicz@marine.Rutgers.edu
- www.jcnerr.org
JC NERR website
- www.nerrsdata.org
access to SWMP data

Thank you

Questions?



Supplementary Slides

- *The following slides will not be presented during the session but may be utilized during the Q&A to answer potential/anticipated questions during the Q&A*

Autonomous Robotics Program

REMUS



Autonomous Robotics Program

Calypso

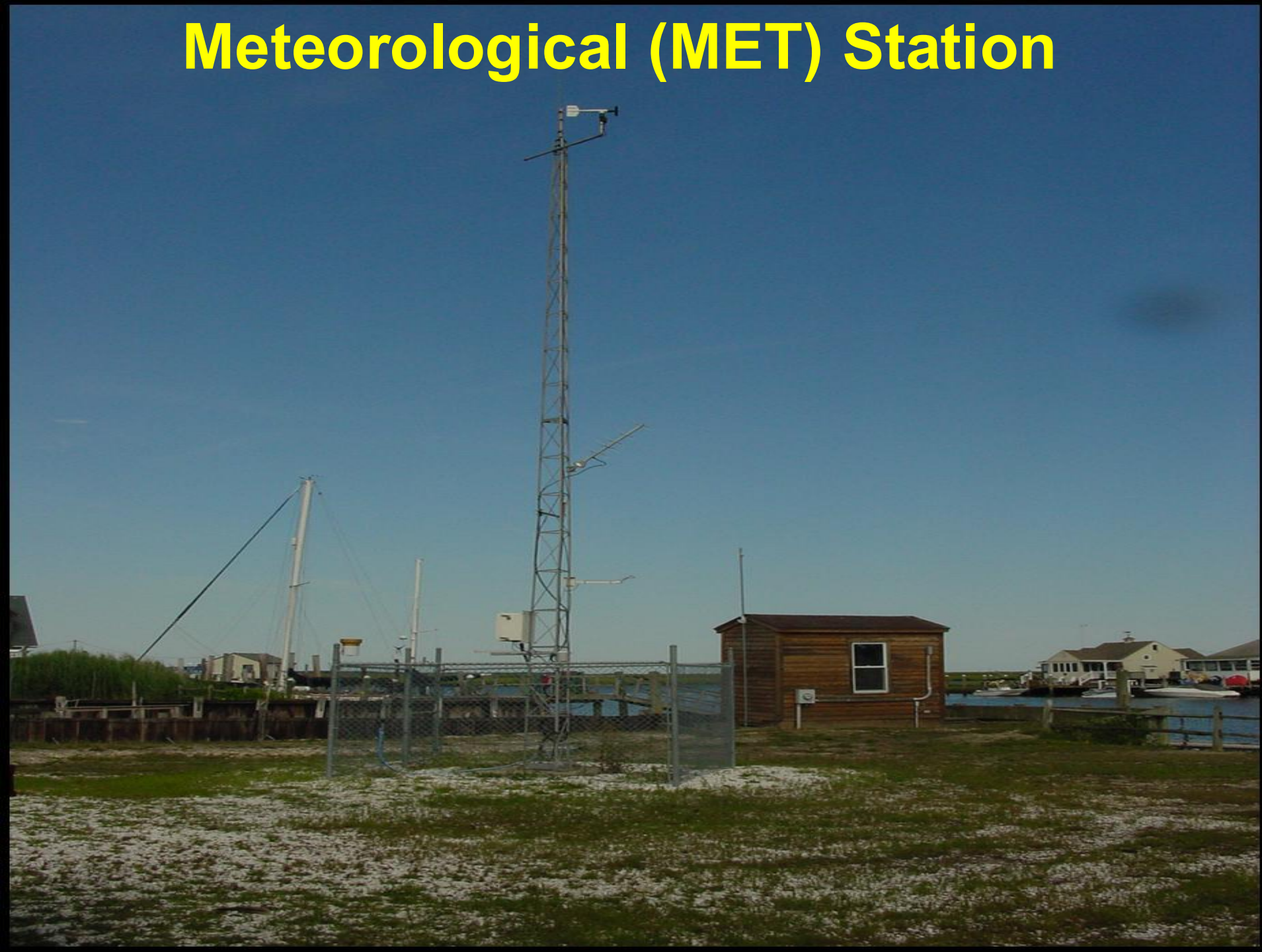


Water Quality (WQ) Station





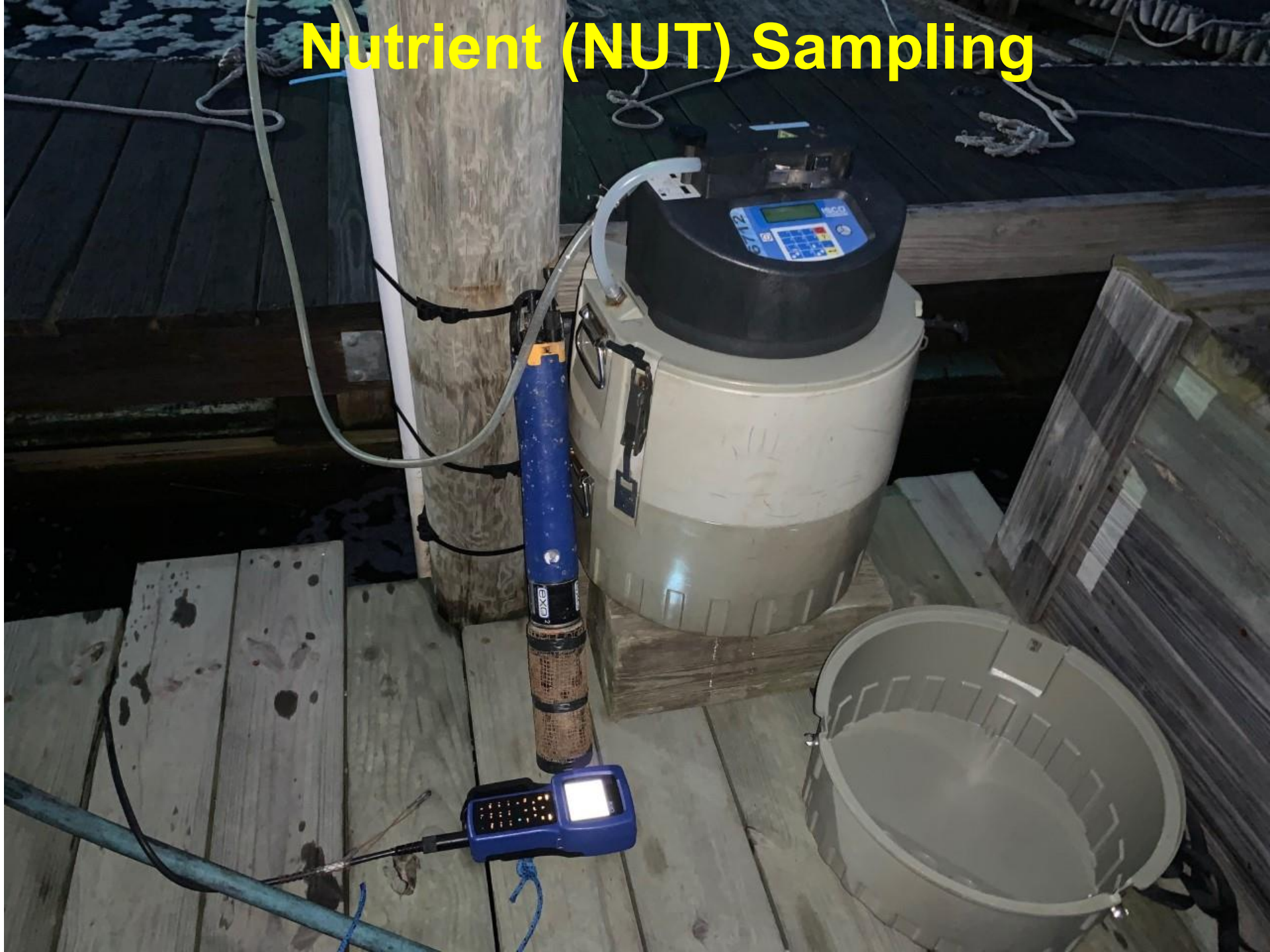
Meteorological (MET) Station



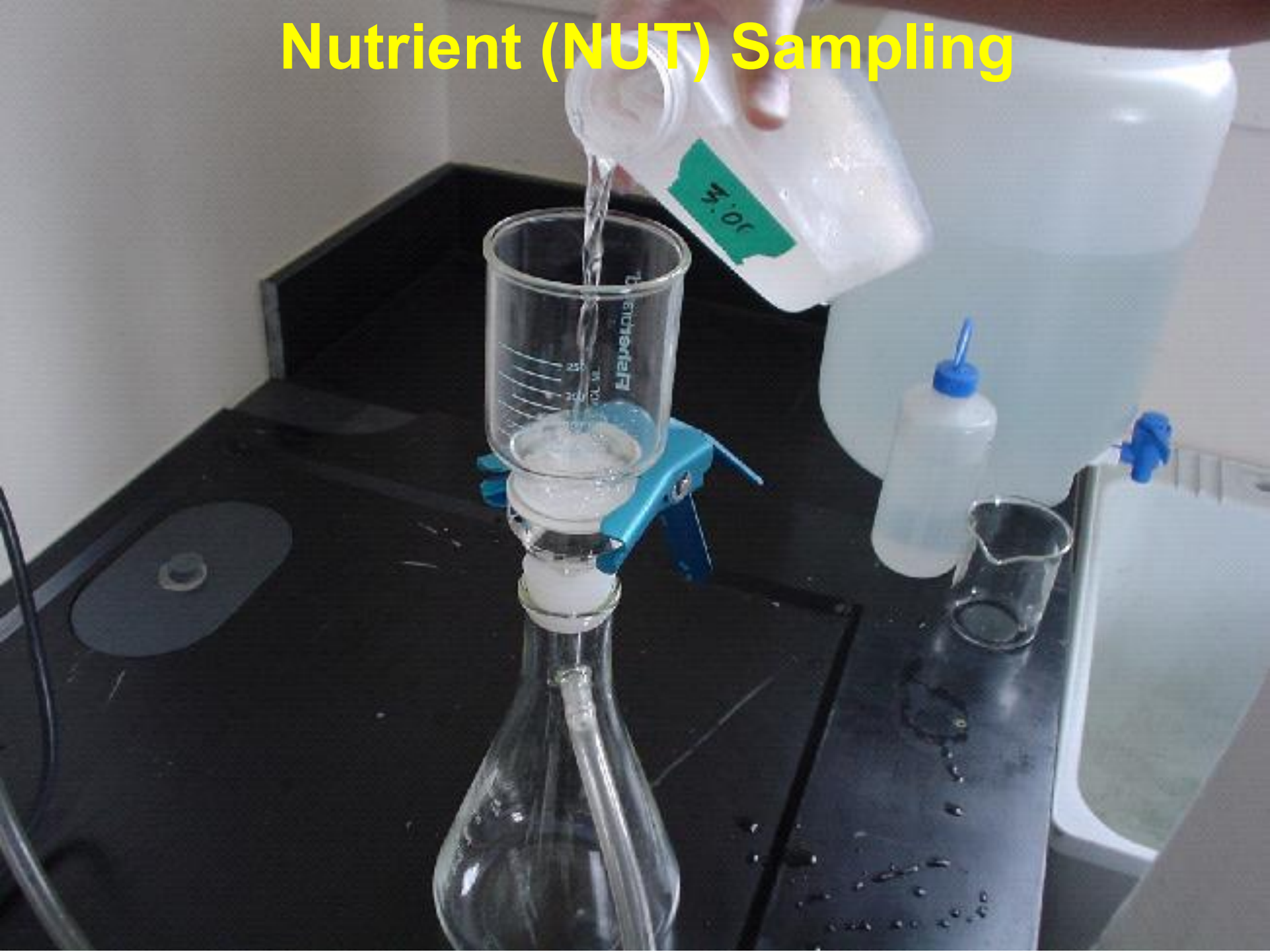
Nutrient (NUT) Sampling



Nutrient (NUT) Sampling



Nutrient (NUT) Sampling





NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

Centralized Data Management Office

[Home](#)[About CDMO](#)[About Data](#)[Get Data](#)[Web Services](#)[Science Collaborative](#)

View / Download Data



[Suggested Citation Format](#)

Real Time Monitoring Data

Choose Reserve...

DELSJMET 05/07/18 11:30 AM

DELSLWQ 05/07/18 11:30 AM



Air Temperature: 19.3 °C (67 °F)

Wind Speed: 2.3 m/Sec (05 mph)

Water Temperature: 20 °C (68 °F)

Salinity: 3.9 PPT

Dissolved Oxygen: 4.5 mg/L

CDMO News

The CDMO is excited to announce the launch of our new **SWMP Mobile application**. Near real-time SWMP data is now available on your smartphone or tablet at: www.nerrsdata.org/mobile

Our **Data Graphing and Export System** has been updated and now has enhanced graphing capabilities! Want to easily export or graph data? If so, check out our [Data Graphing and Export System](#)!

[Department of Commerce](#) | [NOAA](#) | [National Ocean Service](#) | [Office for Coastal Management](#) | [NERRS](#) | [Webmaster](#)

Site hosted by NOAA's National Estuarine Research Reserve System, Centralized Data Management Office.





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Data Graphing and Export System

The DGES was developed to provide the majority of users with quick and intuitive access to SWMP data. The DGES utilizes a map-based interface for Reserve and station selection, displays current conditions at real-time stations, offers powerful graphing capabilities, allows data exports for a single station at a time, and provides the ability to download yearly nutrient/pigment data files which may contain additional non-standard parameters.

[To launch the Data Graphing and Export System, click here.](#)



Advanced Query System

The AQS was developed to specifically address the data delivery needs of those end-users looking for large amounts of data exported in a format that can be easily imported and manipulated for data analysis. The AQS offers three different query options allowing for mass downloads of annual files, customized queries for specific parameters and multiple stations in the same file, and an option to merge water quality, meteorological and nutrient datasets.

[To launch the Advanced Query System, click here.](#)



Real Time Data Application

The Real Time Application allows users to view near real time data, real time gauges, and 24 hour graphs with multiple parameters. You may use a bookmarked link to directly access the station of interest, or browse and select your station. The display will update automatically with the latest information as it comes in.

[To launch the Real Time Data Application, click here.](#)



NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

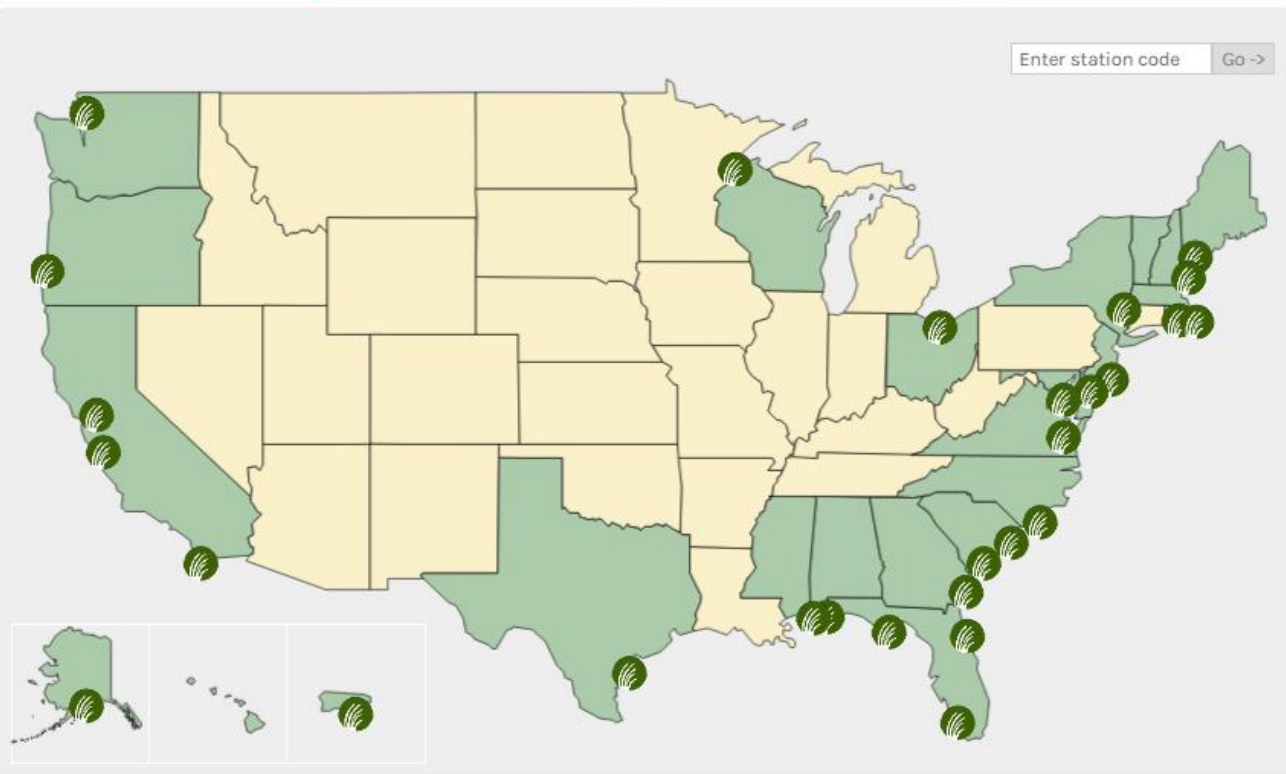
Centralized Data Management Office

[Home](#)[About CDMO](#)[About Data](#)[Get Data](#)[Web Services](#)[Science Collaborative](#)**1. Choose Reserve**

2. Choose Station

3. Choose Data

4. Get Data





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1. Choose Reserve

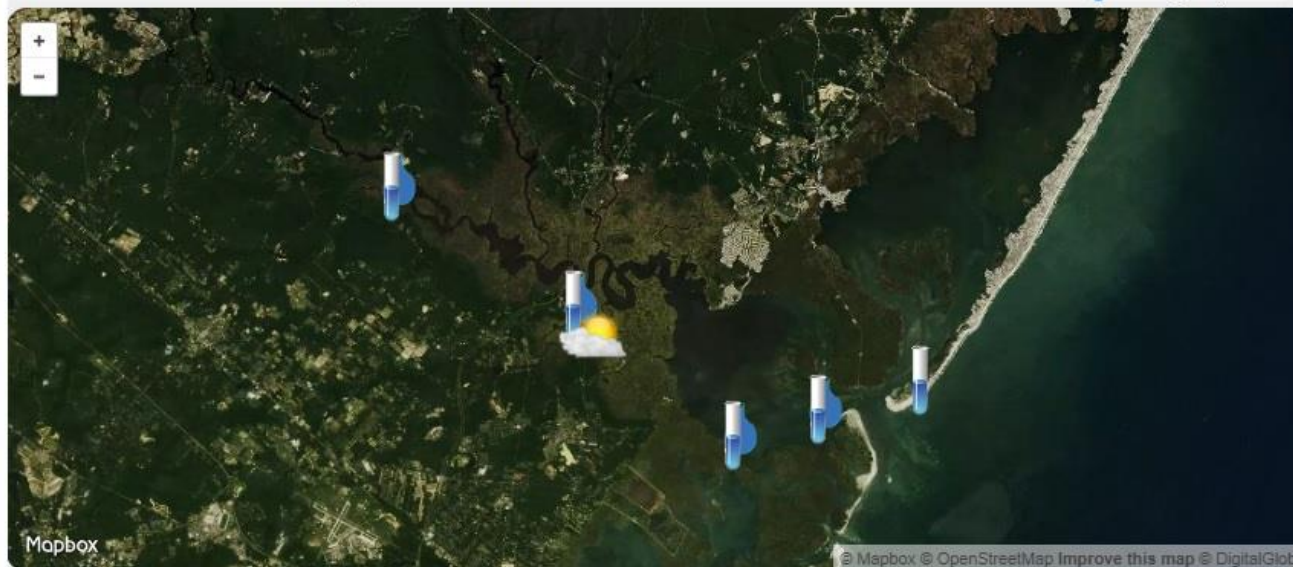
✓ Jacques Cousteau

2. Choose Station

3. Choose Data

4. Get Data

 SWAMP Status 	Station Code	Station Name	Active Dates	Data Type
 P	JACNEWQ	Chestnut Neck	Aug 1996-	 Water Quality
 P	JACNCMET	Nacote Creek	Oct 2002-	 Meteorological
 P	JACB6WQ	Buoy 126	Aug 1996-	 Water Quality
 P	JACNENUT	Chestnut Neck	Feb 2002-	 Nutrient
 P	JACBAWQ	Lower Bank	Oct 1996-	 Water Quality



Mapbox

© Mapbox © OpenStreetMap Improve this map © DigitalGlobe



NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

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[Home](#)[About CDMO](#)[About Data](#)[Get Data](#)[Web Services](#)[Science Collaborative](#)**1. Choose Reserve**☒ Jacques Cousteau**2. Choose Station**☒ Chestnut Neck**3. Choose Data****4. Get Data**

Jacques Cousteau



JACNEWQ



salinity

01/19/2018



Metric

Optl. 2nd paramete

Select station...

Select a parameter.

04/26/2018



Graph

Zoom

1m

3m

6m

YTD

1y

All

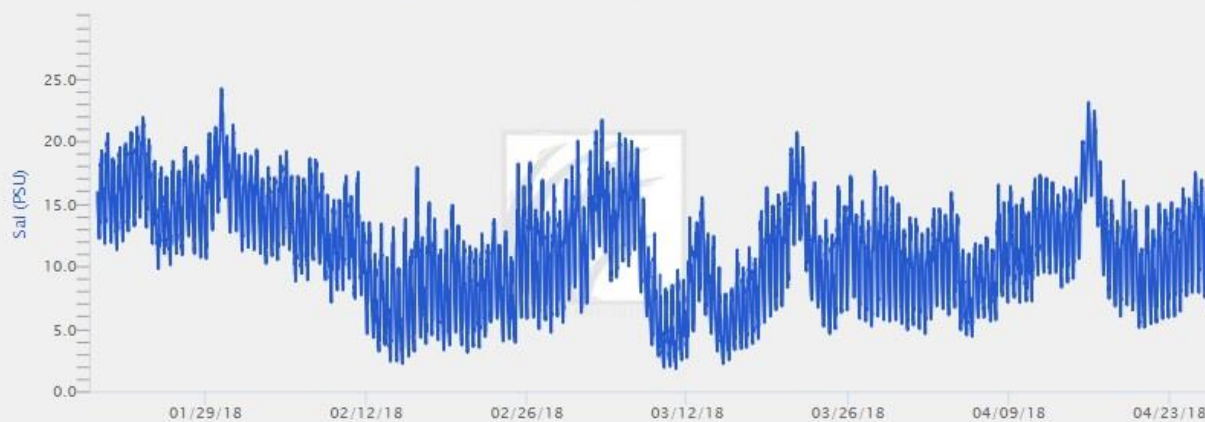
— JACNEWQ

From

Jan 19, 2018

To

Apr 26, 2018



Highcharts.com



NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

Centralized Data Management Office

[Home](#)[About CDMO](#)[About Data](#)[Get Data](#)[Web Services](#)[Science Collaborative](#)**1. Choose Reserve**

✓ Jacques Cousteau

2. Choose Station

📍 Chestnut Neck

3. Choose Data**4. Get Data**

Jacques Cousteau ▼



JACNEWQ ▼

salinity ▼

01/19/2018



Metric ▼



Jacques Cousteau ▼

JACNCMET ▼

cumulative precipit ▼

04/26/2018



Graph

Zoom 1m 3m 6m YTD 1y

All

— JACNEWQ – Sal

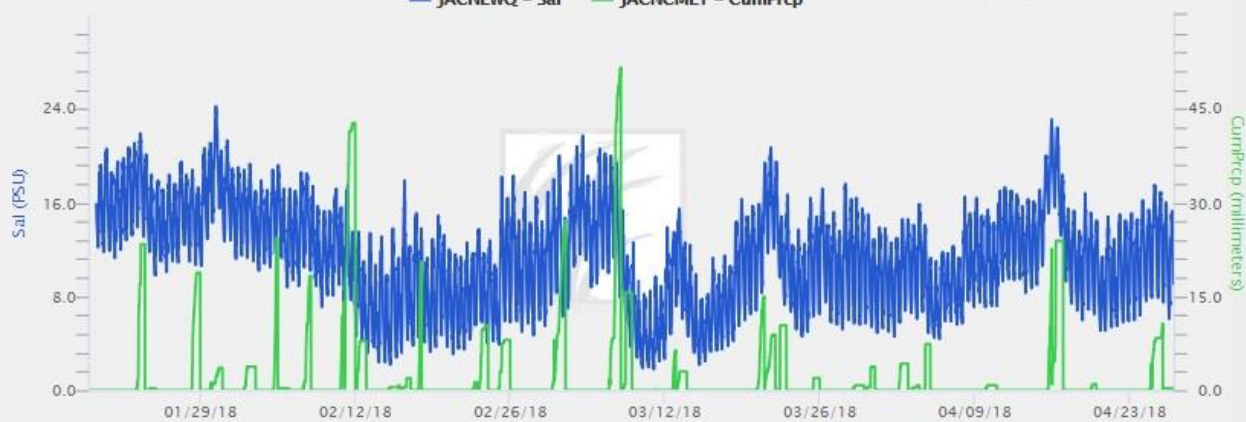
— JACNCMET – CumPrp

From

Jan 19, 2018

To

Apr 26, 2018



Highcharts.com



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1. Choose Reserve

☒ Jacques Cousteau

2. Choose Station

☒ Chestnut Neck

3. Choose Data

4. Get Data



Please note the active dates for this station and choose a date range for your data request. There is a 5 year maximum request limit with the Data Export System, for larger and more complex query options please use the [Advanced Query System](#) also found on the [Get Data](#) page. Note that all appropriate metadata will be included with your download package.

Active dates for station:

Aug 1996 - Present

Select dates:

Start Date

End Date

Choose dataset type:

Best Available Dataset

Proceed to download >>



NATIONAL ESTUARINE RESEARCH RESERVE SYSTEM

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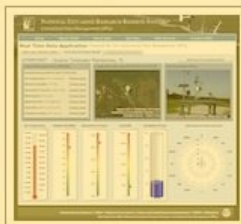
[To launch the Data Graphing and Export System, click here.](#)



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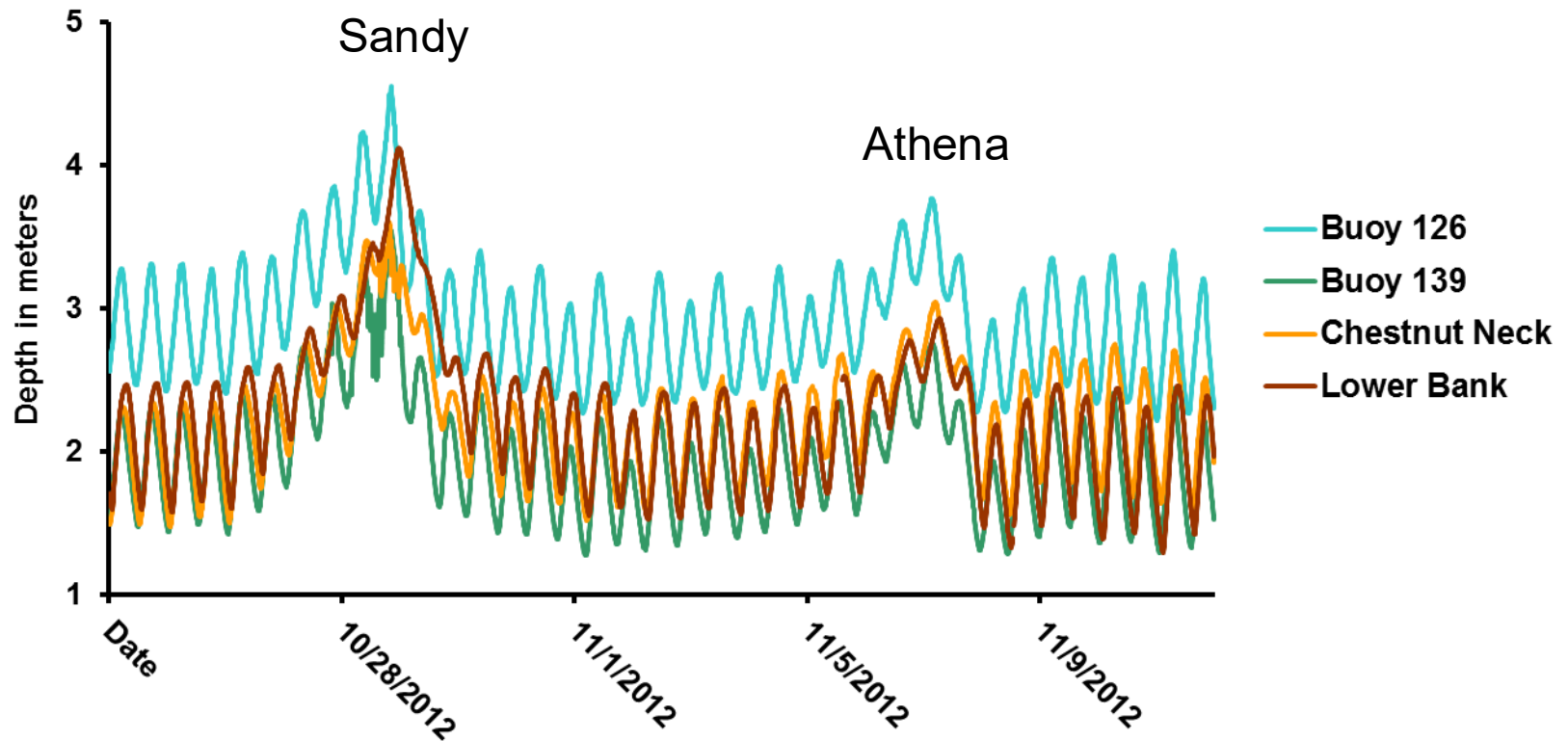


Real Time Data Application

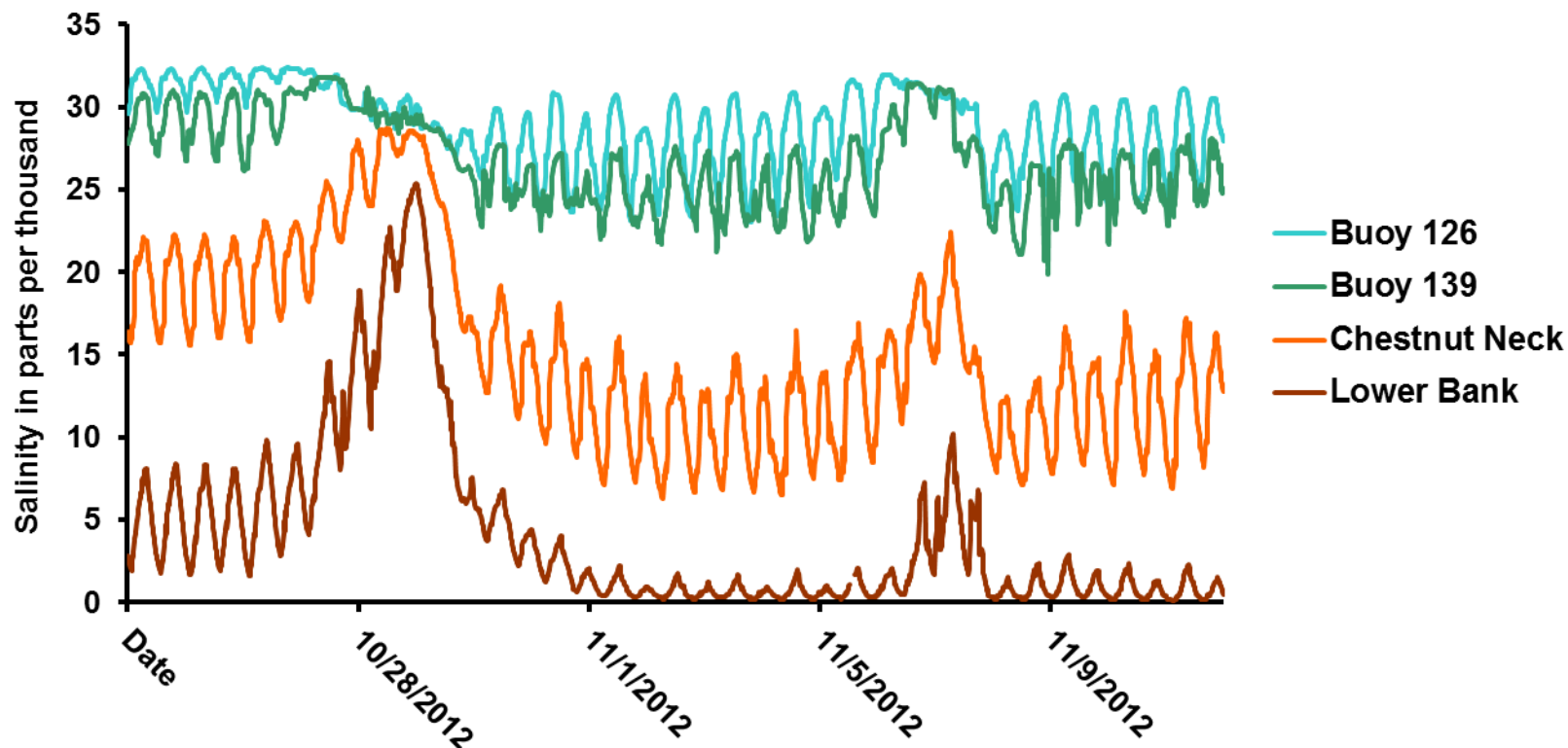
The Real Time Application allows users to view near real time data, real time gauges, and 24 hour graphs with multiple parameters. You may use a bookmarked link to directly access the station of interest, or browse and select your station. The display will update automatically with the latest information as it comes in.

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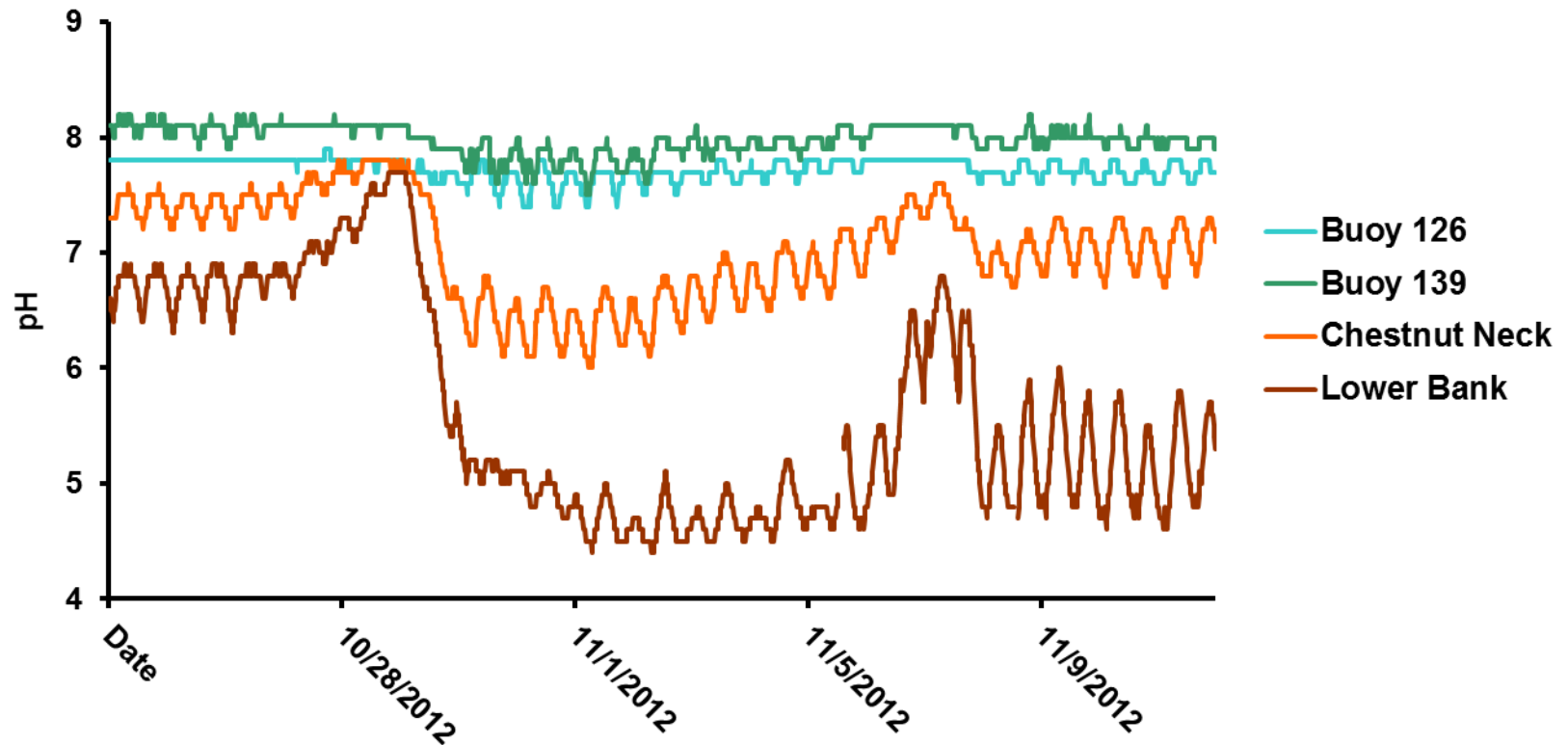
Superstorm Sandy and Winter Storm Athena Depths at the JCNERR SWMP Stations



Superstorm Sandy and Winter Storm Athena Salinities at the JCNERR SWMP Stations



Superstorm Sandy and Winter Storm Athena pH at the JCNERR SWMP Stations



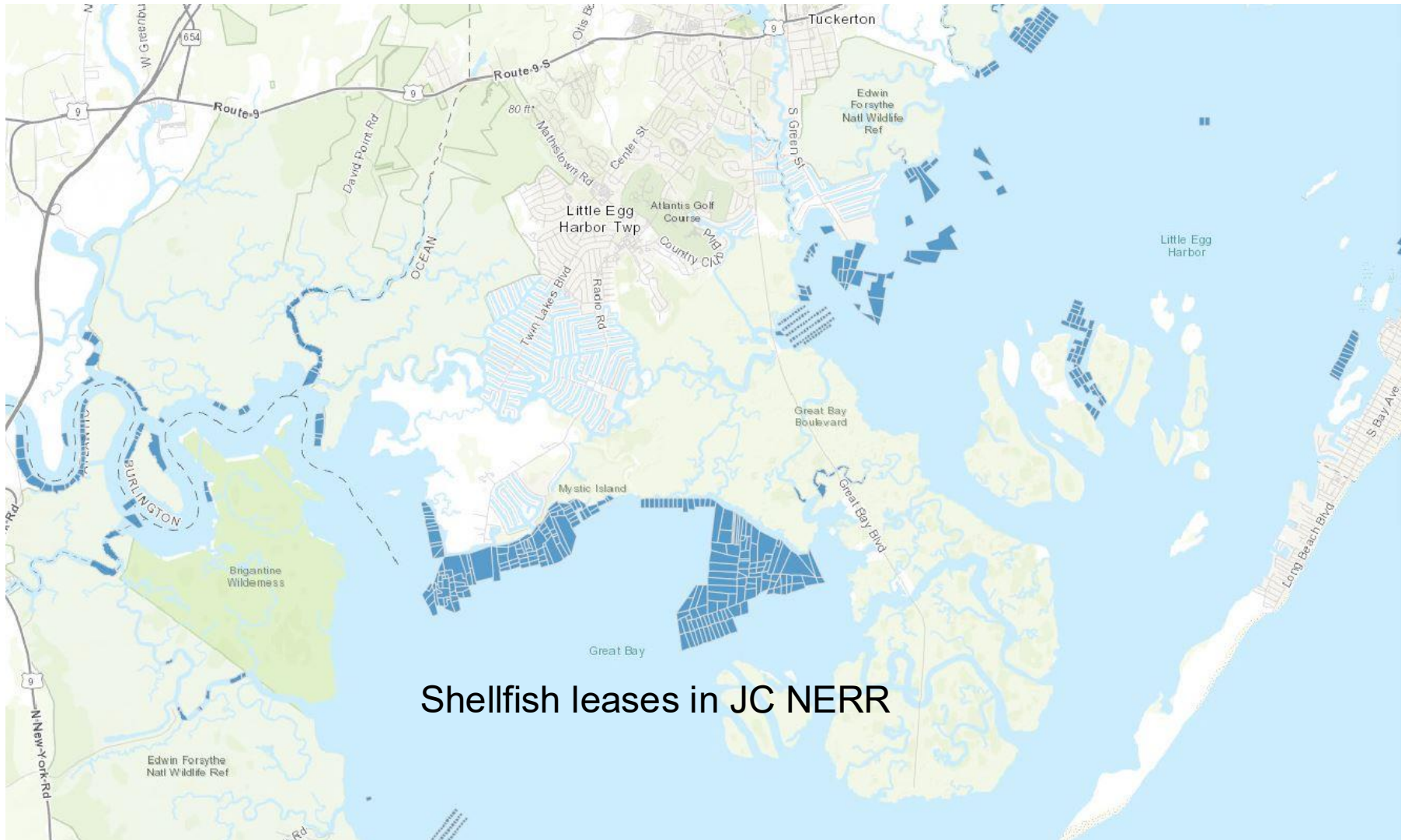
Shellfish growers use SWMP



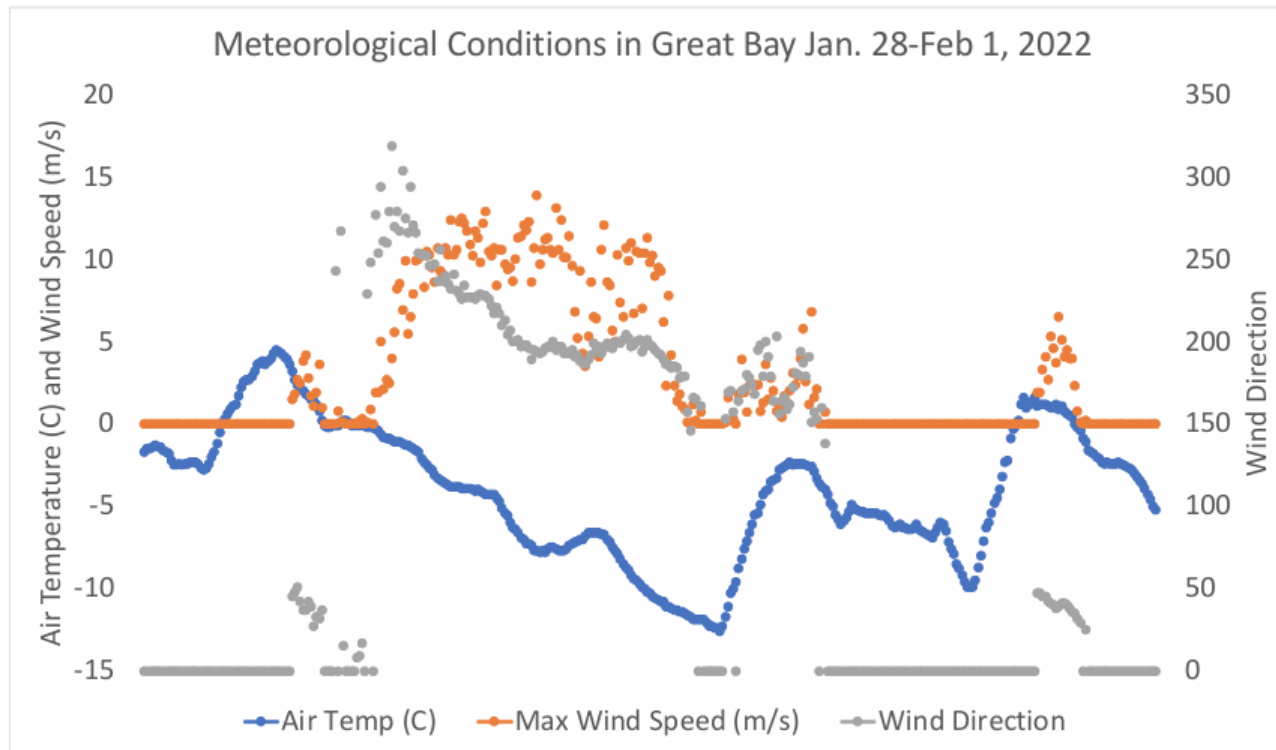
Dale Parsons



Shellfish Leases in JC NERR



Conditions leading to Mass Mortality event at clam farms



Wind and Tide
conditions
expose clam
beds to freezing
air temperature

Documentation
from SWMP
secures
insurance claim

9/15/2025

JCNERR Robotics Program

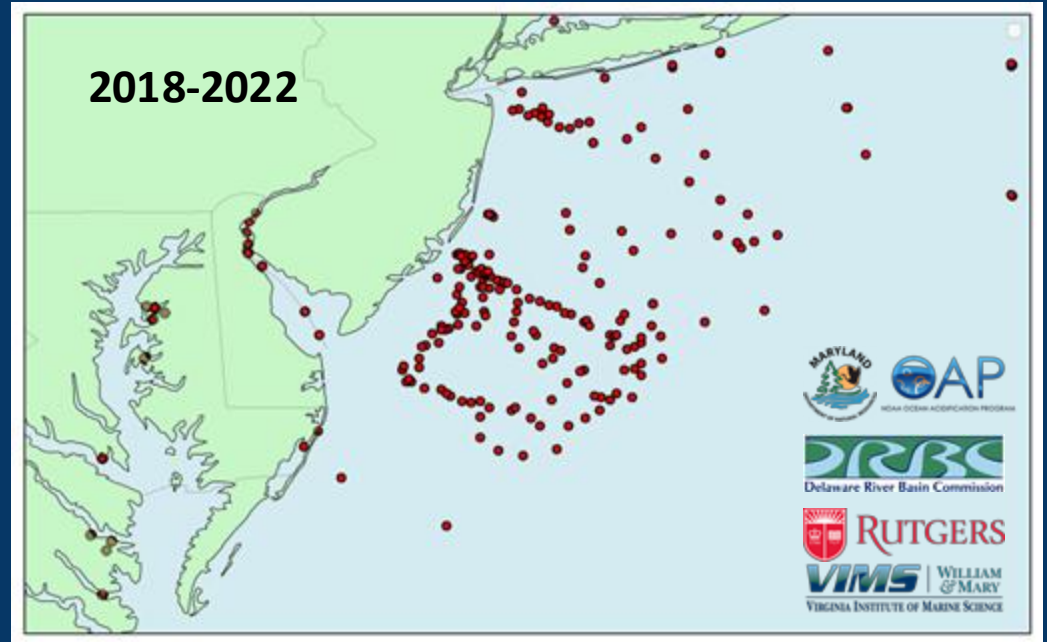
*Expandable Payload
Capabilities*

Evaluating Satellite Chlorophyll as an Indicator of Coastal Acidification

Nichole Ruiz^{1,3}, Janet Reimer¹, Kari St. Laurent², Kirstin Wakefield¹

¹Mid-Atlantic Coastal Acidification Network, ²NOAA NCCOS, ³Barnard College

**MAB in-situ
acidification data is
often spatially-limited
and sporadic.**



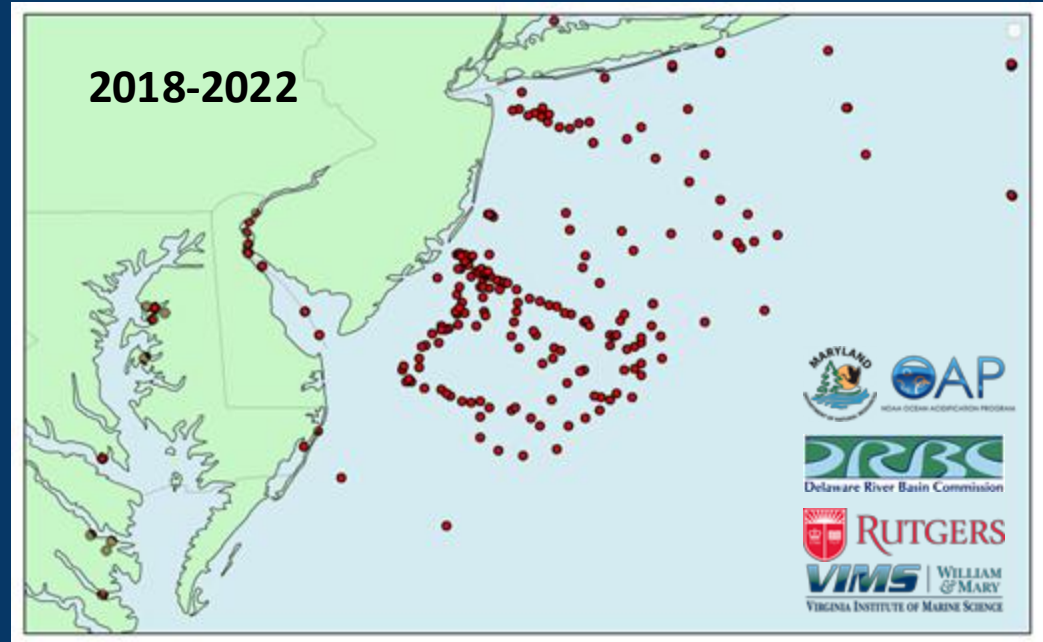
We also know that satellite *chlorophyll-a* provides a robust proxy for phytoplankton biomass, a driver of pH.

We also know that satellite chlorophyll-a provides a robust proxy for phytoplankton biomass, a driver of pH.

Can we use satellite chlor-a to infer biologically-driven changes in pH?

We compiled available carbonate chemistry data for the bounding box using various data sources.

- MACAN data portal
- MARACOOS Oceans Map
- NCEI
- Individual contributors



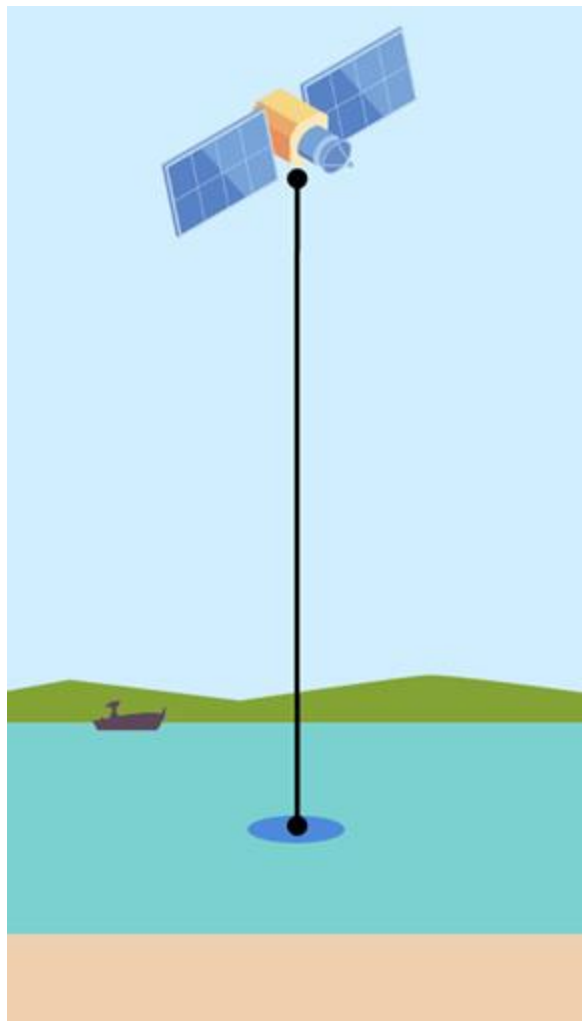
We used a chlor-a satellite product with an improved coastal pixel algorithm.

Gap-filled DINEOF; NOAA S-NPP, NOAA-20 VIIRS, Copernicus S-3A OLCI

- 2km resolution
- Bands at 400-700 nm
- Surface data



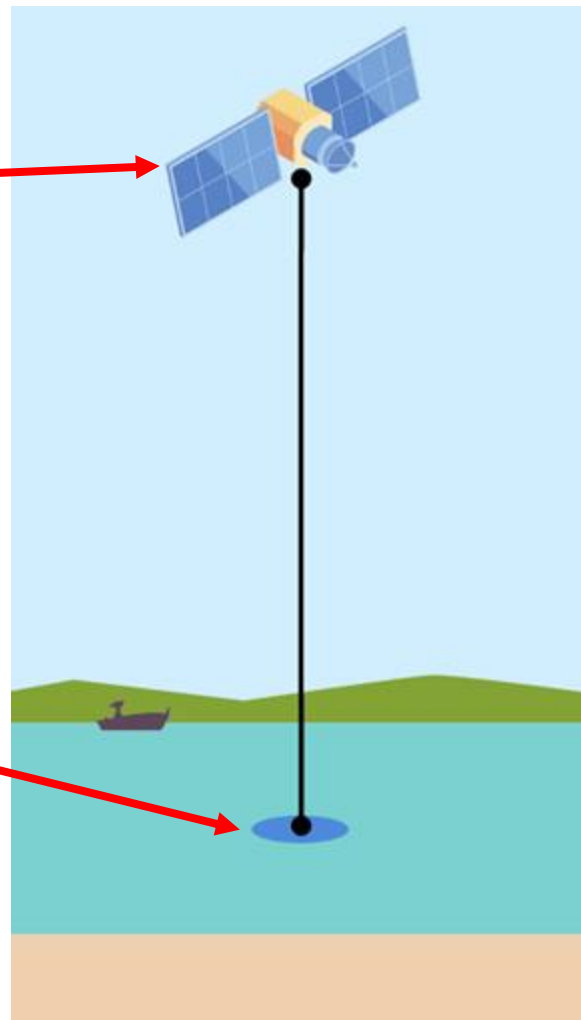
How do we incorporate **satellites** to infer **pH-phytoplankton** relationships?



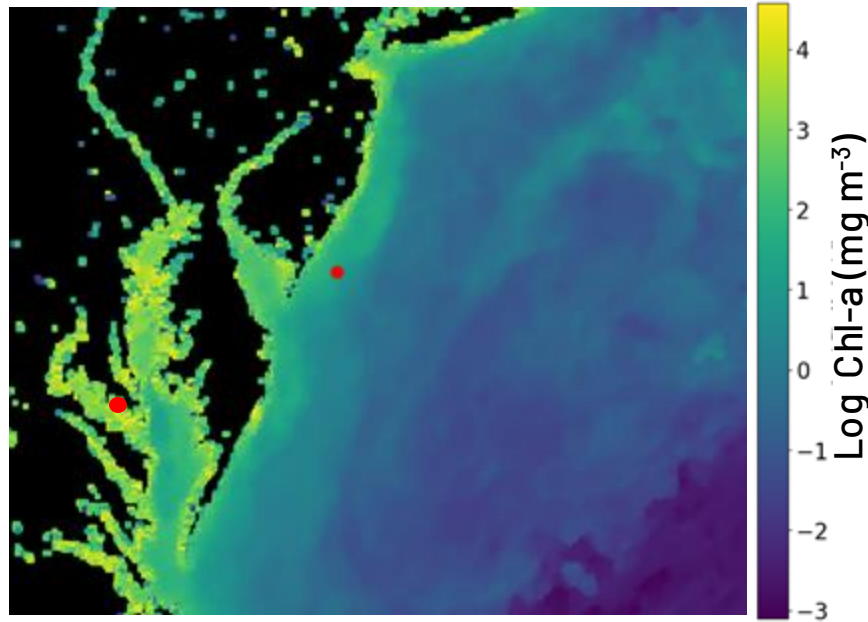
**Satellite chlorophyll
pixel**

Nearest coordinate indexing

**In-situ sample of a
carbonate parameter**



Pixel-indexing accounts for chlorophyll
heterogeneity among ecosystems.

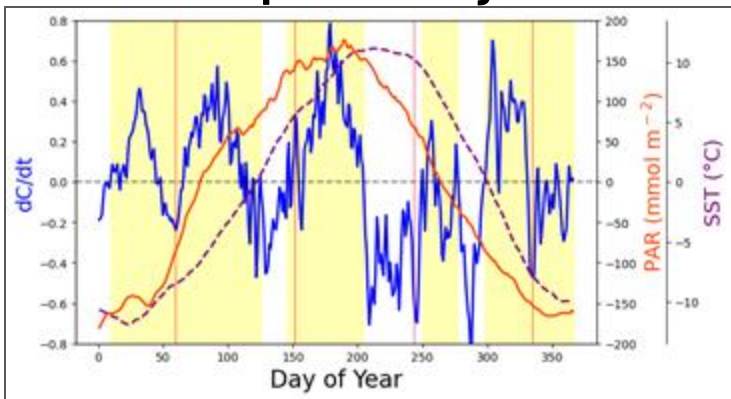


The directionality and strength of pH-phyto relationships are season-dependent.

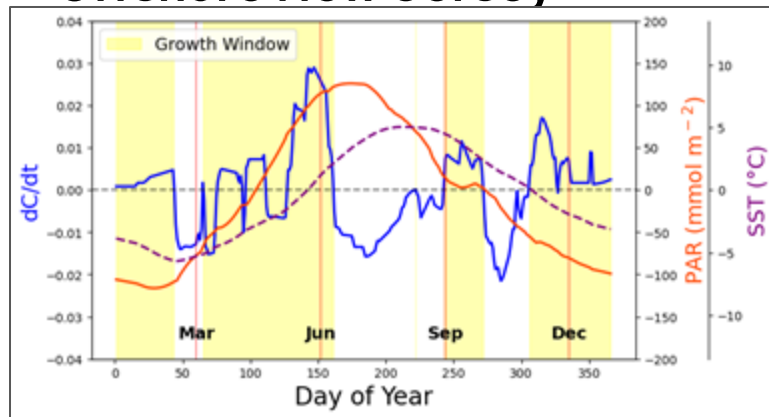
We used **seasonal cycles** of biomass growth rate, sea surface temperature, and photosynthetically active radiation to **identify these seasons.**

Seasonal windows of biomass growth are site-specific.

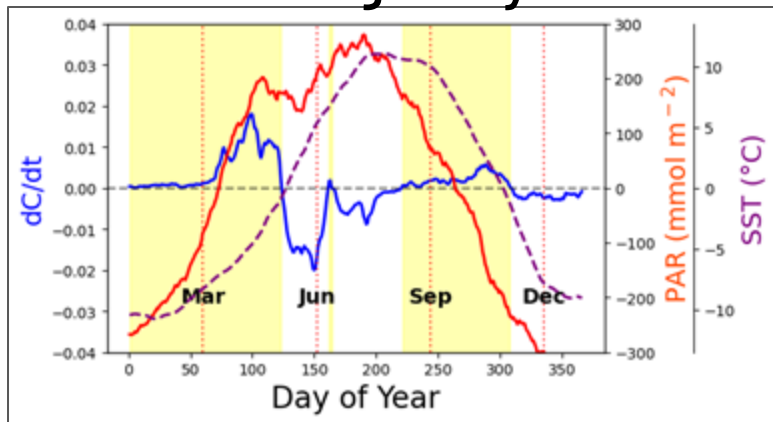
Chesapeake Bay



Offshore New Jersey

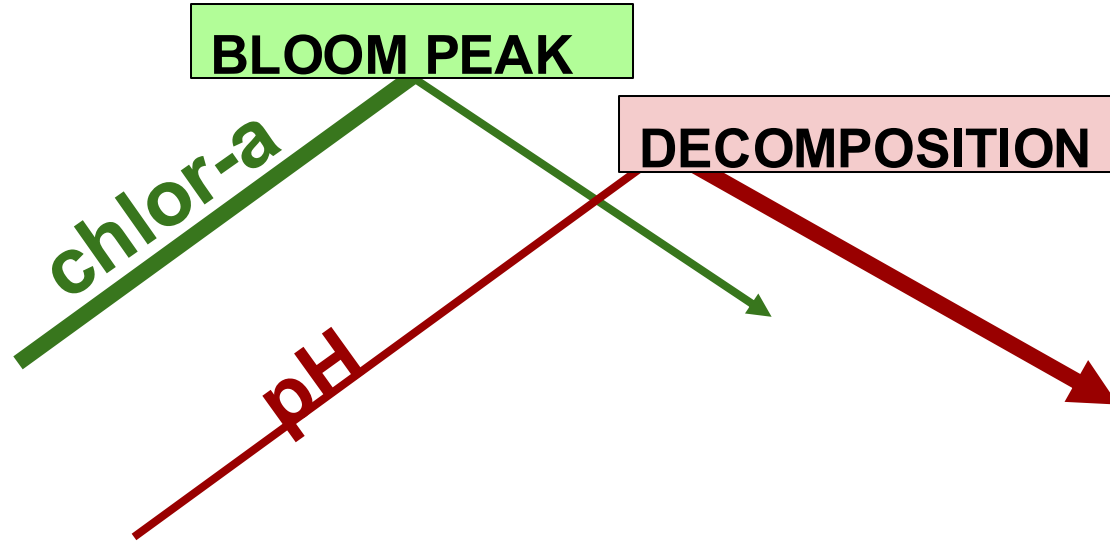


Barnegat Bay



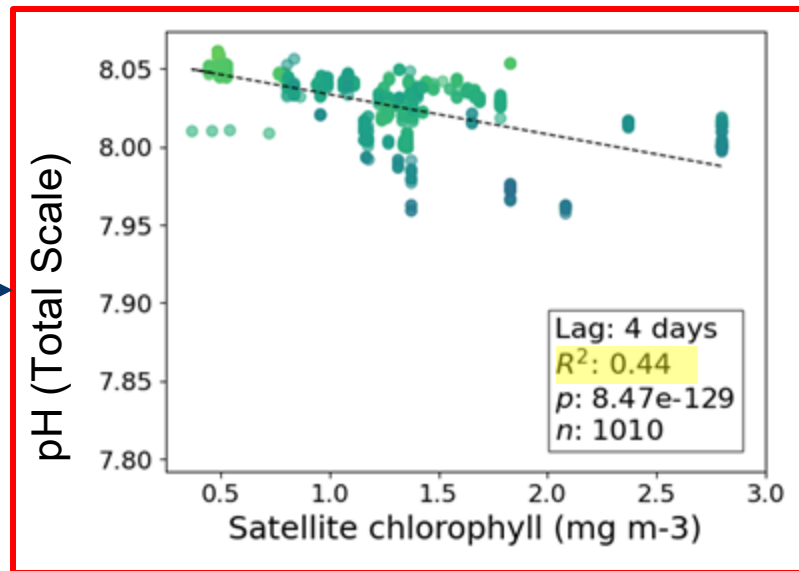
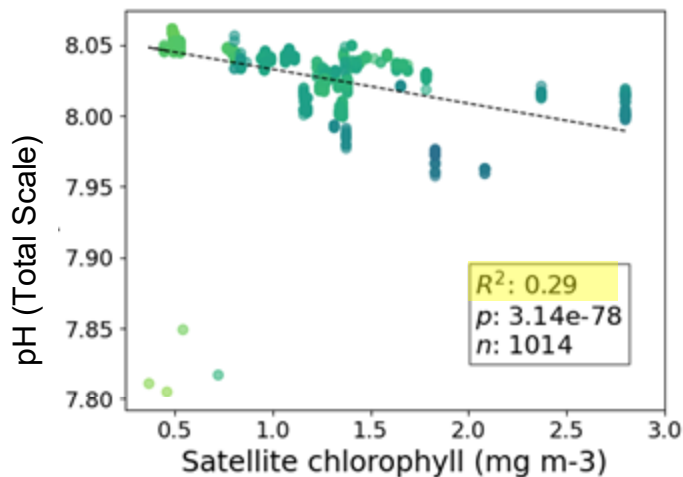
dC/dt = first derivative of chlor-a data
PAR = photosynthetically active radiation
(National Estuarine Research Reserve System)

pH has a delayed signal response to decomposition.



We calculated the cross correlation coefficient to identify each seasonal windows' lag response time.

Applying time lag to chl-a **improves relationship with pH.**

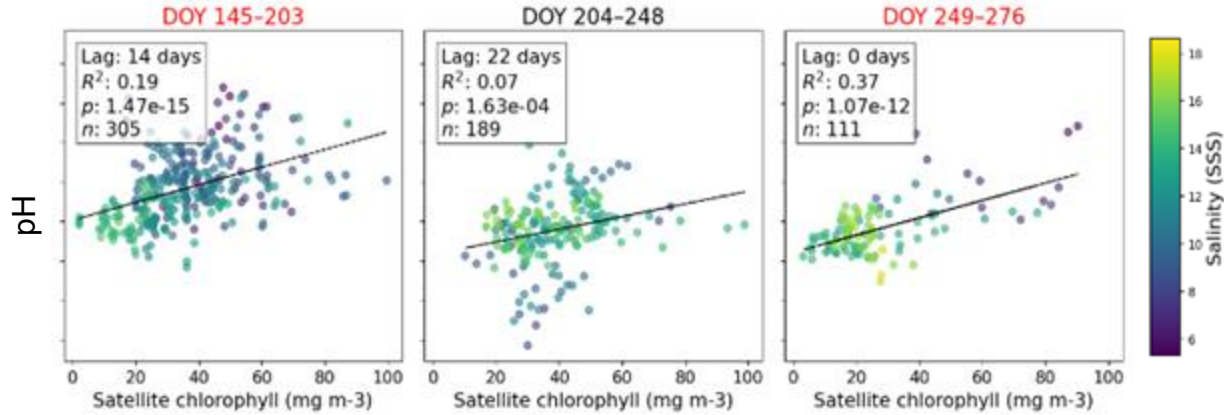


Offshore New Jersey, DOY window 305–42

Hypothesis: during seasons of high biomass growth, phytoplankton will be the dominant driver of pH.

Chesapeake Bay has high biological influence.

Red = biomass growth window



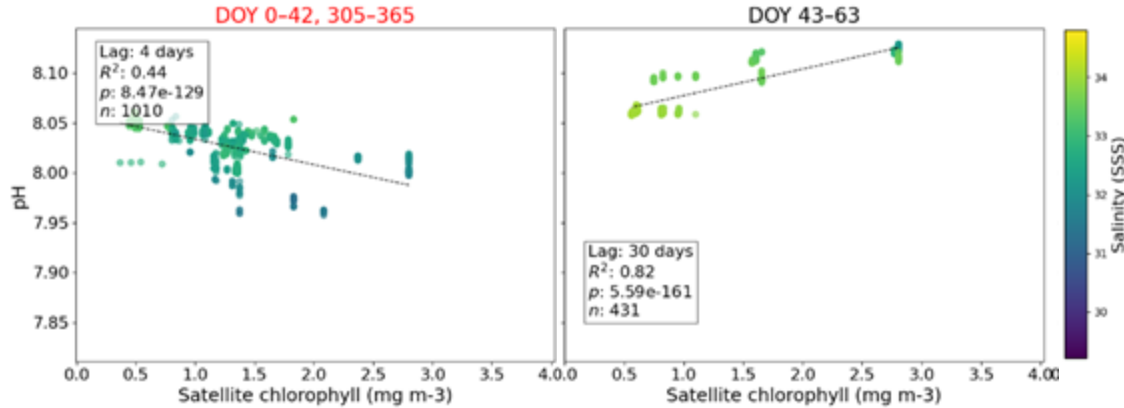
Stormwater runoff +
warmer SSTs may be
triggering summer bloom

Outgassing
dominates pH during
the peak of summer

Fall bloom;
heavily dominated
by diatoms



Offshore New Jersey has less biological influence.

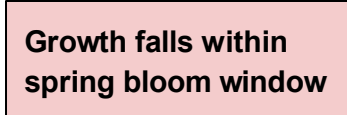


CO₂ ingassing under colder SST may dominate phytoplankton influence despite significant growth rate

Short spring season with high lag suggests *low but sustained photosynthesis*, likely muted by grazing or low biomass. Suggests why it wasn't isolated as a growth window by our identification method.

An aerial photograph of a coastal area. A yellow star marks a location on the shoreline near Red Bay. Other labels include "Harvey's Pier", "Long Beach Harbor", "Long Beach", "Expresswood", "Little Egg Harbor Township", "Little Egg", "Swan Island Wildlife Refuge", and "Marlboro Township". A copyright notice "© 2017 ESRI" is visible in the bottom right corner.

Nutrient depletion following bloom, respiration > photosynthesis



Phytoplankton growth is limited during winter + CO₂ accumulation in the water column due to colder SST

Takeaways & recommendations

- Growth windows must be identified **objectively**.
 - E.g., some seasons where $dC/dt < 0$ exhibited **positive** pH–chlor relationship due to confounding biological influences
 - Improving identification method can improve accuracy of relationship
- **Cross correlation coefficient** quantifies biological response time and should be applied to **pH–chlor-a correlations**.
- Satellite chlor-a vs. pH relationships should be validated with **in-situ chlor-a** for BGCMs

Our analysis suggests that phytoplankton are the primary driver of pH at sites whose seasons experience positive pH-chlorophyll regressions.

*Our approach has been performed best for estuarine bay ecosystems (Chesapeake Bay, Barnegat Bay).

This is one step in a larger effort to resolve data gaps in acidification monitoring.

Implications for modeling and coastal communities

- Modelers will need to consider seasonal variability of phytoplankton blooms for acidification forecasts.
- Citizen science + satellite proxies are powerful assets for sourcing and informing long-term water monitoring.

Thank you!

ndr2141@barnard.edu

Acknowledgements

Thanks to MACAN for funding this research through the MACAN Workforce Development Fellowship Program, my mentors J. Reimer, K. St. Laurent, K. Wakefield, and G. Saba and T. Schwemmer for their helpful insight.



mCDR



INSTITUTE *for* RESPONSIBLE
CARBON REMOVAL

BBNJ and mCDR in the Open Oceans: A Potential Policy Framework

Wil Burns, Co-Director, IRCR
MACAN State of the Science Meeting
July 15, 2025

Article 17: Objectives

The objectives of this Part are to:

- (a) Conserve and sustainably use areas requiring protection, including through the establishment of a comprehensive system of area-based management tools, with ecologically representative and well-connected networks of marine protected areas;
- (b) Strengthen cooperation and coordination in the use of area-based management tools, including marine protected areas, among States, relevant legal instruments and frameworks and relevant global, regional, subregional and sectoral bodies;
- (c) Protect, preserve, restore and maintain biodiversity and ecosystems, including with a view to enhancing their productivity and health, and strengthen resilience to stressors, including those related to climate change, ocean acidification and marine pollution;
- (d) Support food security and other socioeconomic objectives, including the protection of cultural values . . . [emphasis added]

Agreement under the
United Nations
Convention on the Law
of the Sea on the
conservation and
sustainable use of
marine
biological diversity of
areas beyond national
jurisdiction (2023)

Article 28: Obligation to conduct environmental impact assessments

1. Parties shall ensure that the potential impacts on the marine environment of planned activities under their jurisdiction or control, which take place in areas beyond national jurisdiction, are assessed . . . before they are authorized [emphasis added]

Article 28: Obligation to conduct environmental impact assessments

(b) Ensure that activities covered by this Part are assessed and conducted to prevent, mitigate and manage significant adverse impacts for the purpose of protecting and preserving the marine environment [emphasis added]

Agreement under the
United Nations
Convention on the Law
of the Sea on the
conservation and
sustainable use of
marine
biological diversity of
areas beyond national
jurisdiction (2023)

BBNJ: Article 30: Thresholds and criteria for environmental impact assessments

1. When a planned activity may have more than a minor or transitory effect on the marine environment or the effects of the activity are unknown or poorly understood, the Party with jurisdiction or control of the activity shall conduct a screening of the activity . . .

(a) The screening shall be sufficiently detailed for the Party to assess if it has reasonable grounds for believing whether the planned activity may cause substantial pollution of or significant and harmful changes to the marine environment ...
[emphasis added]

UNCLOS: Article 206: Assessment of potential effects of activities

When States have reasonable grounds for believing that planned activities under their jurisdiction or control may cause substantial pollution of or significant and harmful changes to the marine environment, they shall, as far as practicable, assess the potential effects of such activities on the marine environment ...

Agreement under the
United Nations
Convention on the Law
of the Sea on the
conservation and
sustainable use of
marine
biological diversity of
areas beyond national
jurisdiction (2023)

Article 39: Strategic environmental assessments

1. Parties shall, individually or in cooperation with other Parties, consider conducting strategic environmental assessments for plans and programmes relating to activities under their jurisdiction or control, to be conducted in areas beyond national jurisdiction, in order to assess the potential effects of such plans or programmes, as well as of alternatives, on the marine environment.
2. The Conference of the Parties may conduct a strategic environmental assessment of an area or region to collate and synthesize the best available information about the area or region, assess current and potential future impacts and identify data gaps and research priorities.

Agreement under the
United Nations
Convention on the Law
of the Sea on the
conservation and
sustainable use of
marine
biological diversity of
areas beyond national
jurisdiction (2023)

Thank You!



AMERICAN UNIVERSITY
WASHINGTON, DC



Enhancing OAE simulations through integrated experimental and modeling approaches

Kyle Hinson¹, Zhaoqing Yang¹, Nicholas Ward¹, Ally Savoie¹, Chinmayee Subban¹, Jessica Cross¹, Pierre St-Laurent², Alexa Labossiere², Marjy Friedrichs², Remi Pages³, Claudine Hauri³, Aurora Leeson⁴, Parker MacCready⁴

- (1) Pacific Northwest National Laboratory
- (2) Virginia Institute of Marine Science
- (3) University of Alaska Fairbanks
- (4) University of Washington



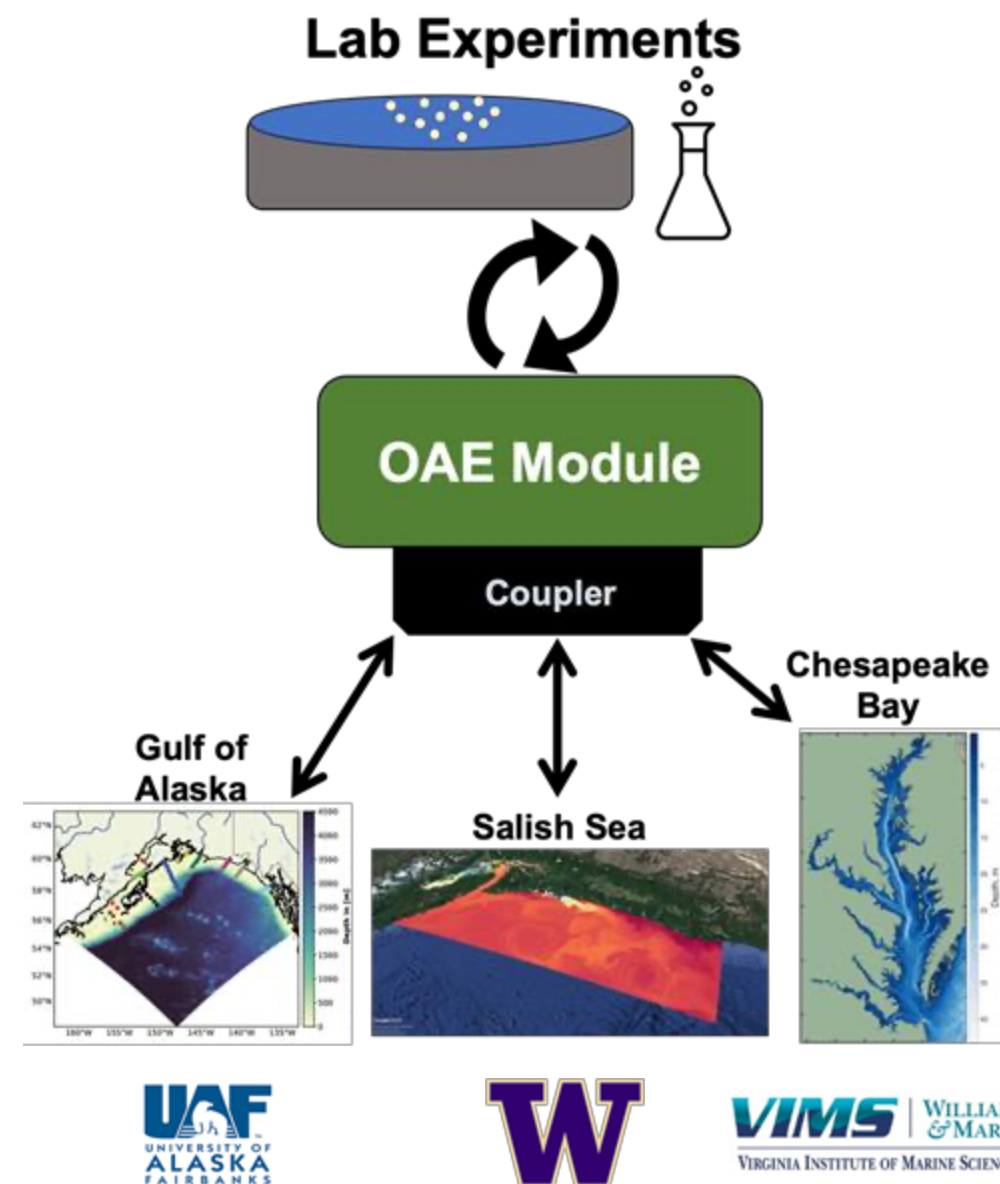
PNNL is operated by Battelle for the U.S. Department of Energy



mCDR
@PNNL

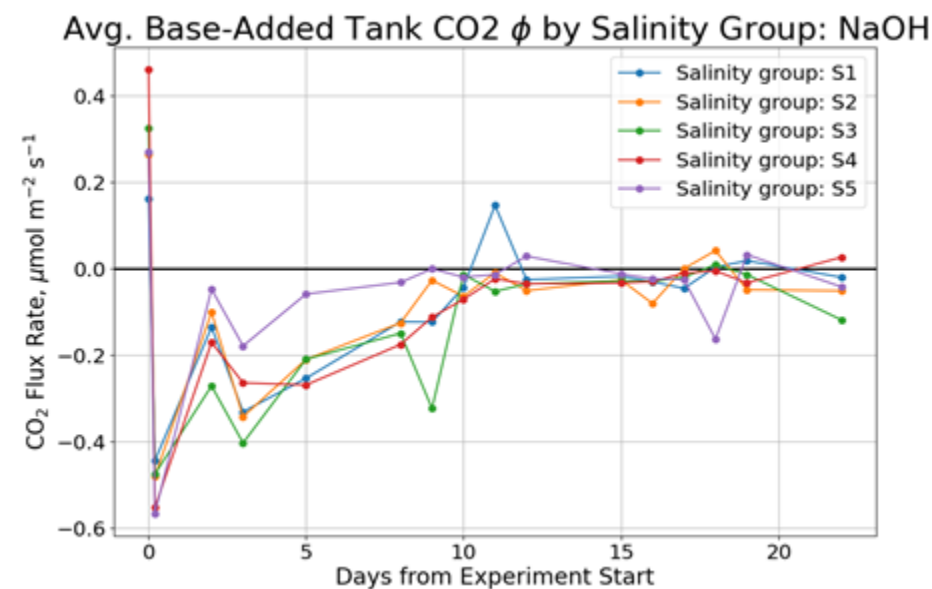
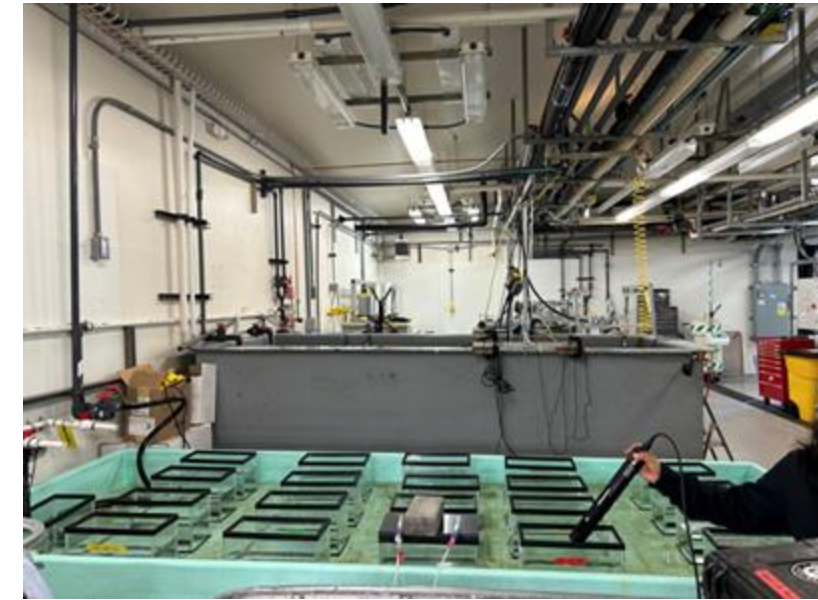
Project Objectives and Approach

- **Vision and Relevance:** Support mCDR industry's ability to optimize OAE applications with experimentally supported modeling tools
- **Technical Innovation:** A flexible OAE module integrated with regional ocean models in multiple domains
- **Research Approach and Application**
 - Improved OAE dynamics improves simulated CO₂ removal/impacts under realistic conditions
 - MRV framework for OAE life cycle assessment using regional model outputs



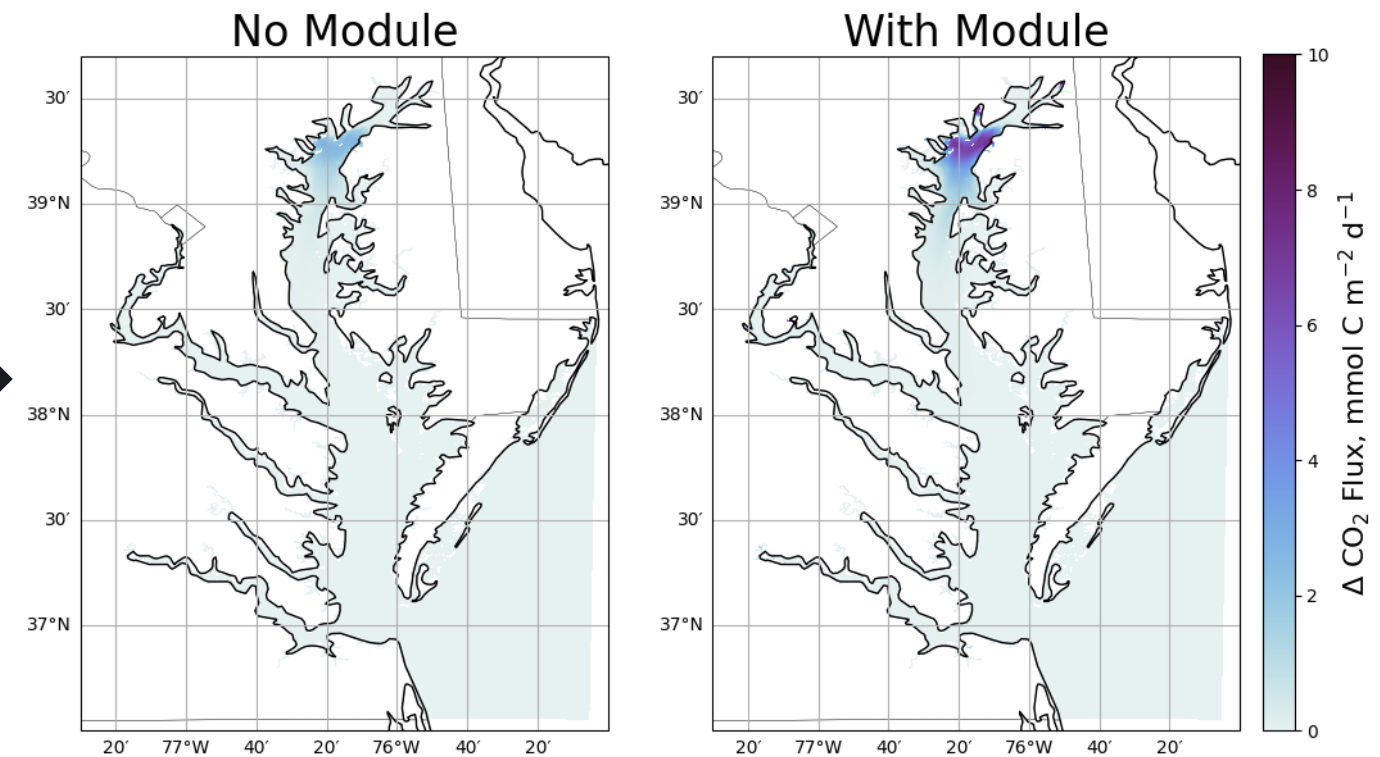
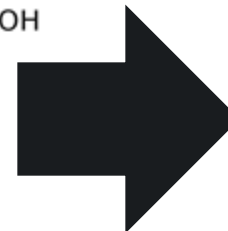
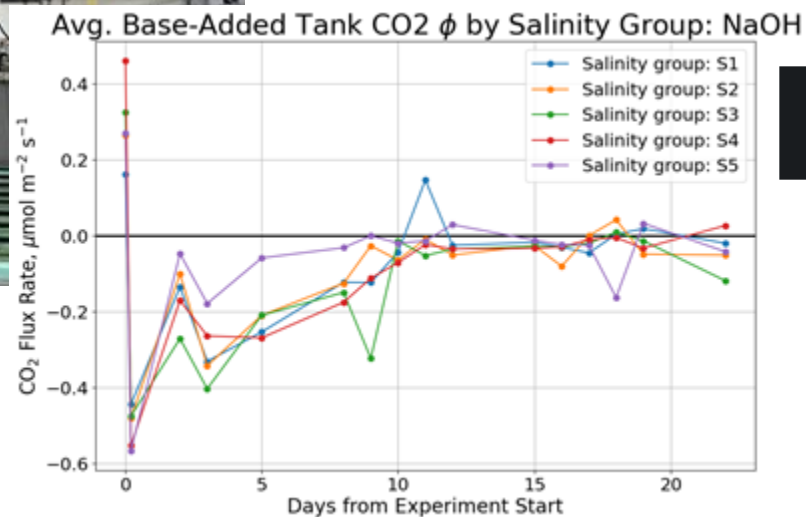
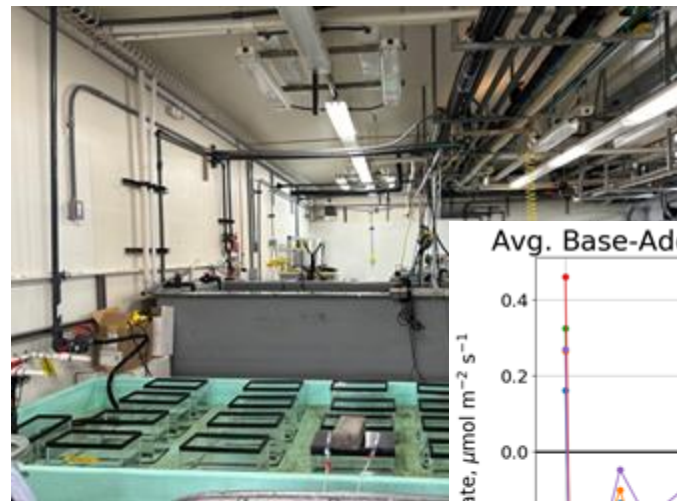
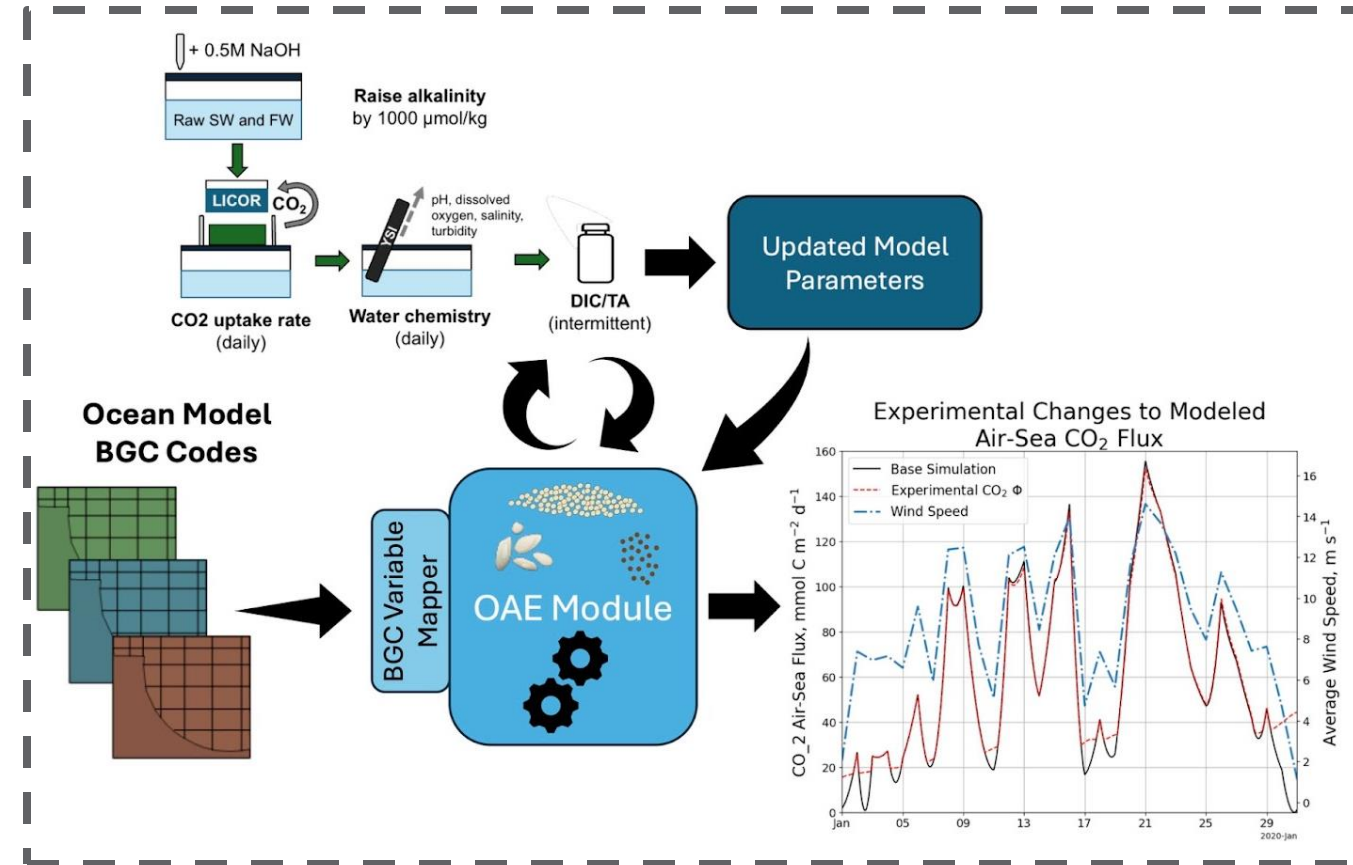
OAE Lab Experiments

- Completed and ongoing microcosm experiments in Sequim Bay Laboratory have focused on air-sea gas exchange rates, secondary precipitation
- Preliminary results have demonstrated increased CO₂ uptake following alkalinity additions in microcosm tanks
- Additional permission has been granted for open water testing in Sequim Bay



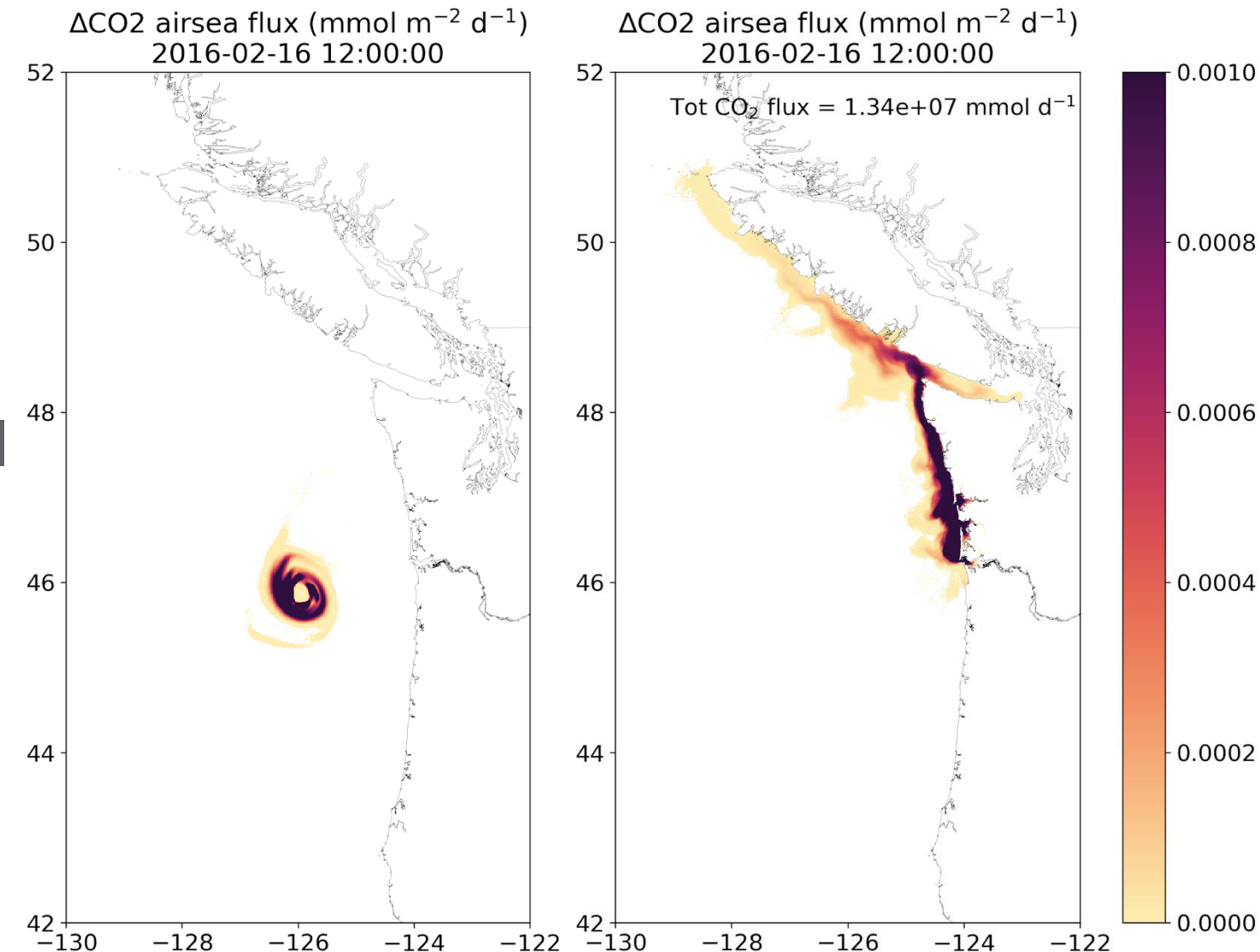
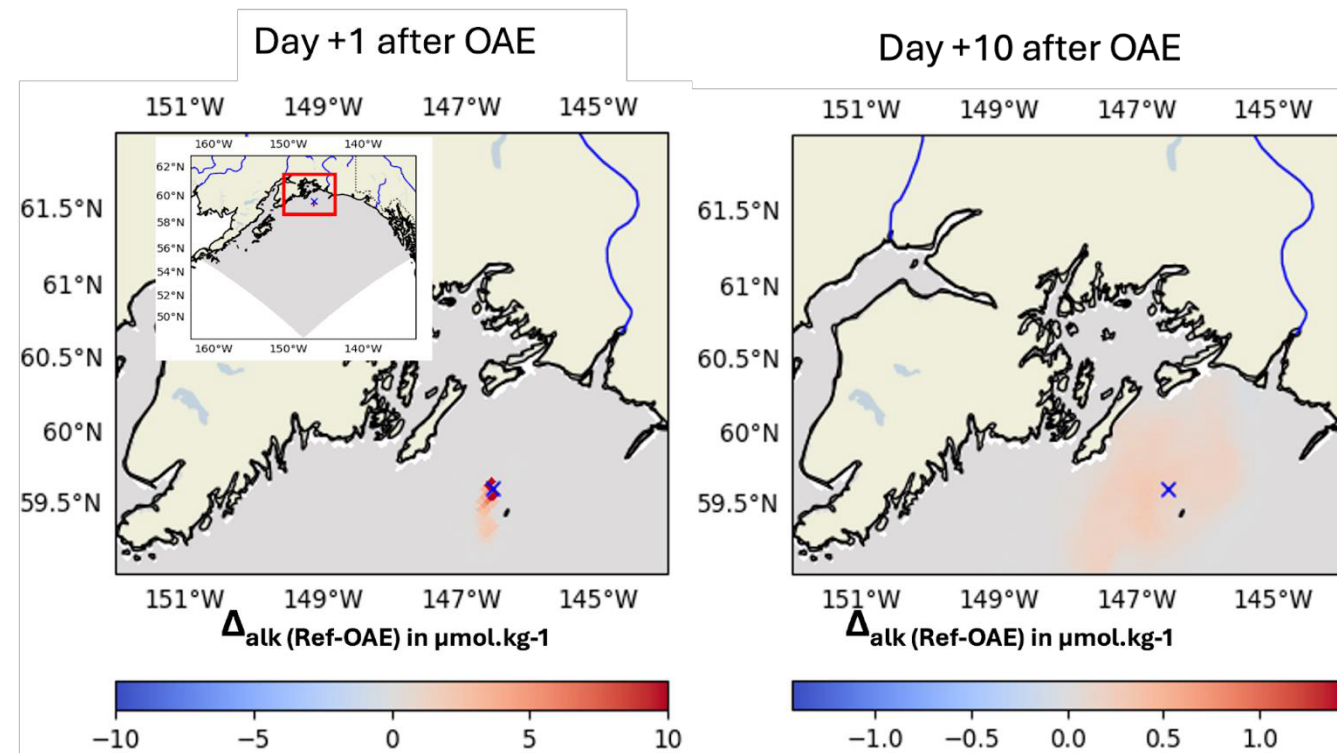
OAE Lab Experiments and Modeling

- Experimental results are used to directly inform the development of parameters/processes in the OAE module
- Simulations of Chesapeake Bay with OAE module show increase in CO_2 uptake of $\sim 7\%$ over 3-month period

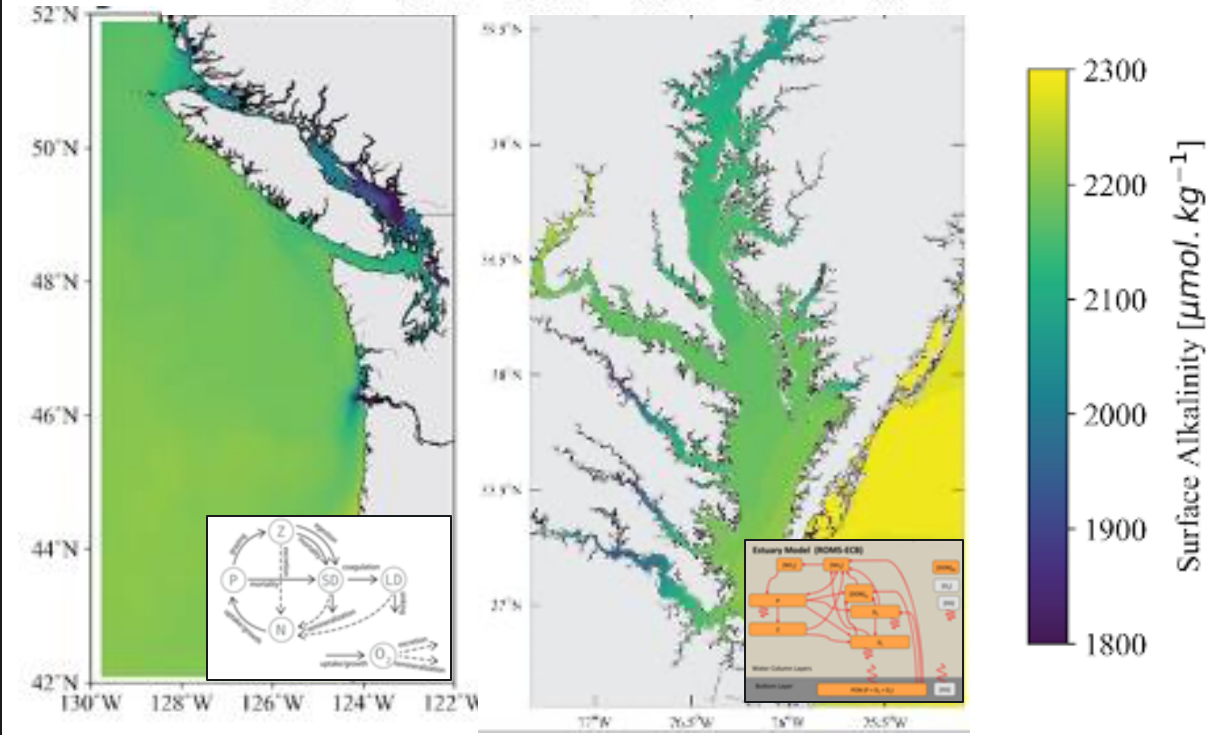


OAE Modeling

- Model experiments have identified OAE efficiency hotspots in Salish Sea, Gulf of Alaska, & Chesapeake Bay
- Extensive testing also found that signal detectability dependent upon internal BGC feedbacks and bit-reproducibility



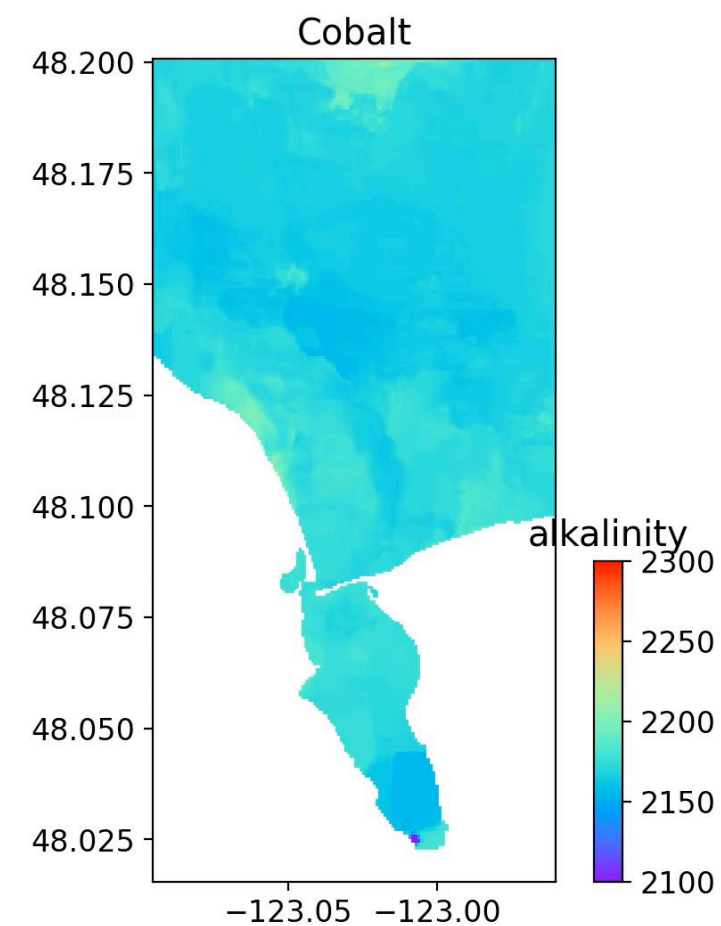
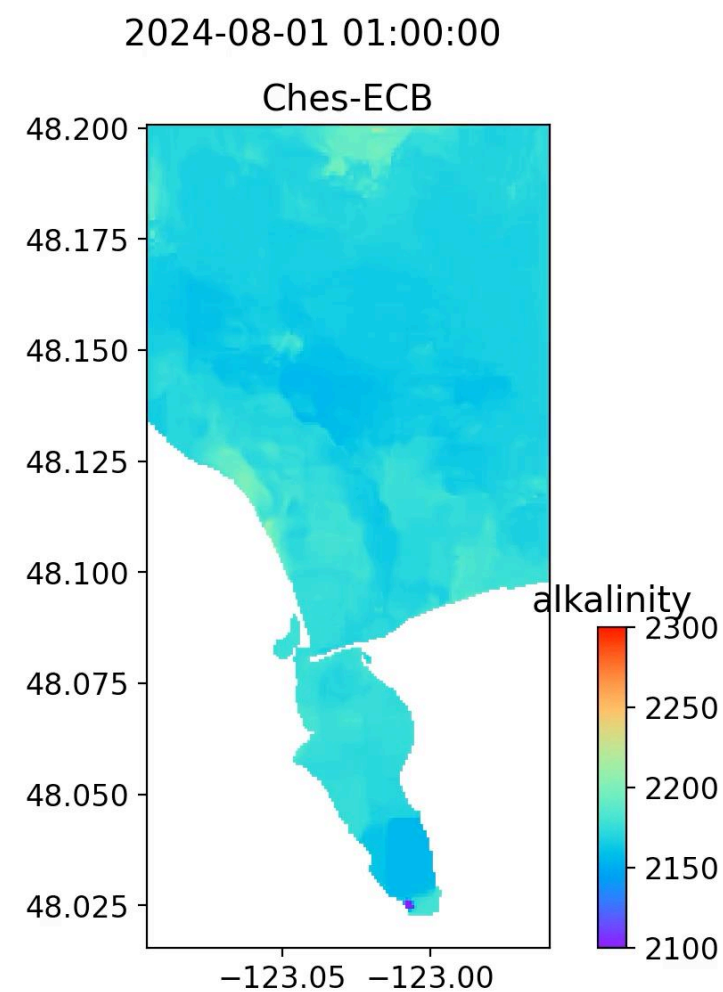
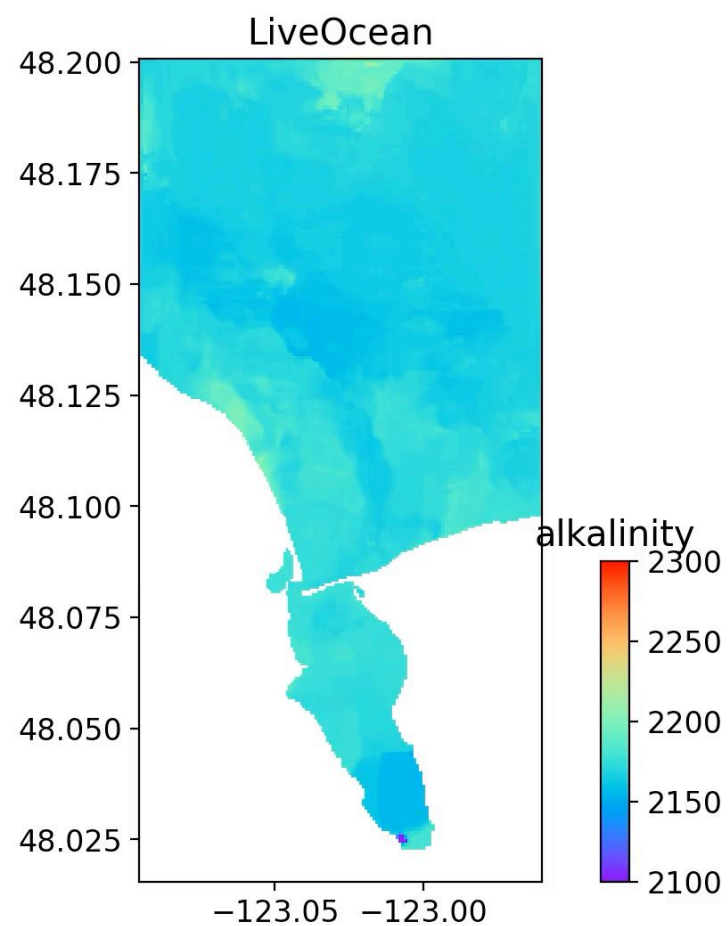
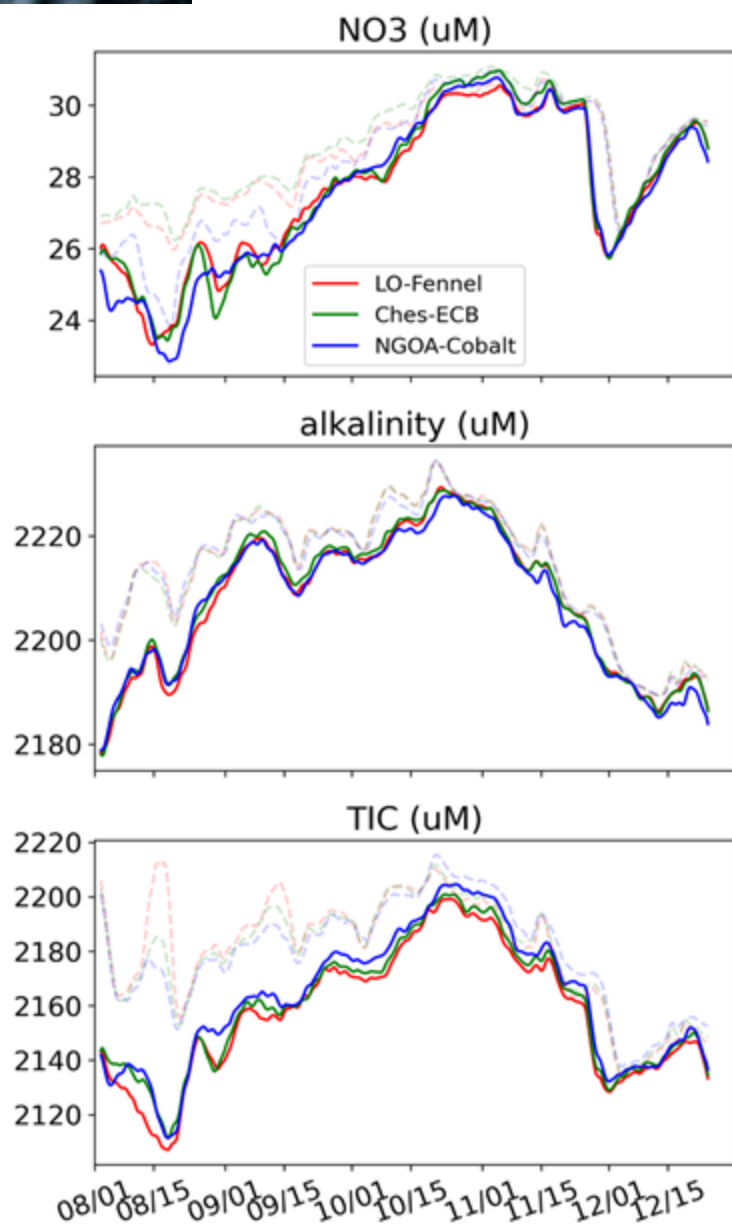
Future testing in multiple domains will allow us to determine regional OAE “carrying capacity” with/without module



- Project will integrate OAE module in 3 distinct regional models with varied BGC codes and background conditions
- Alkalinity STD in 3 regions is ~100x larger than previously simulated OAE additions

Benchmark Test – Sequim Bay, WA

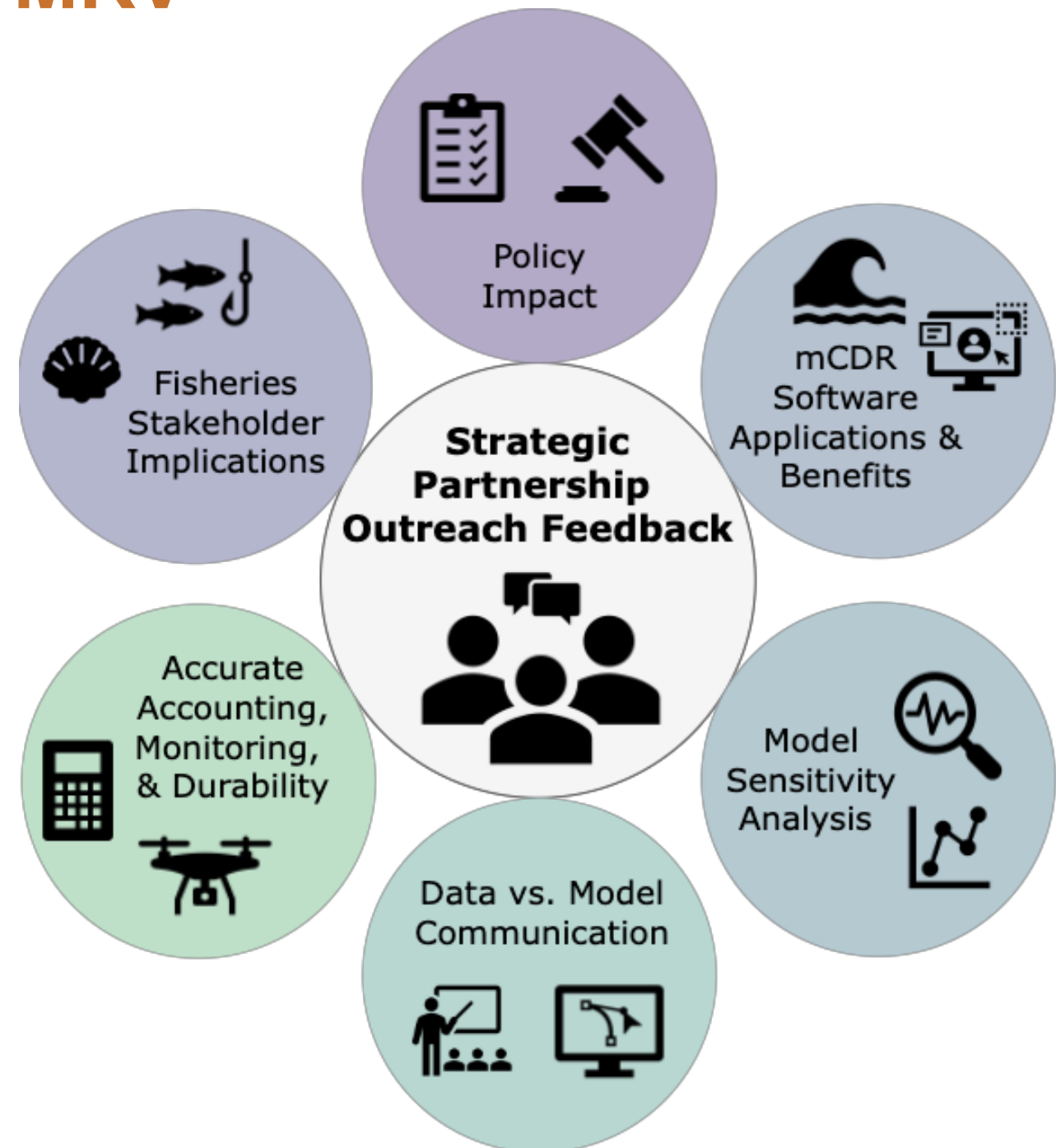
Surface Alkalinity (Aug-Dec, 2024)



- High resolution comparison of 3 different biogeochemical codes will permit consistent OAE module testing in realistic domains

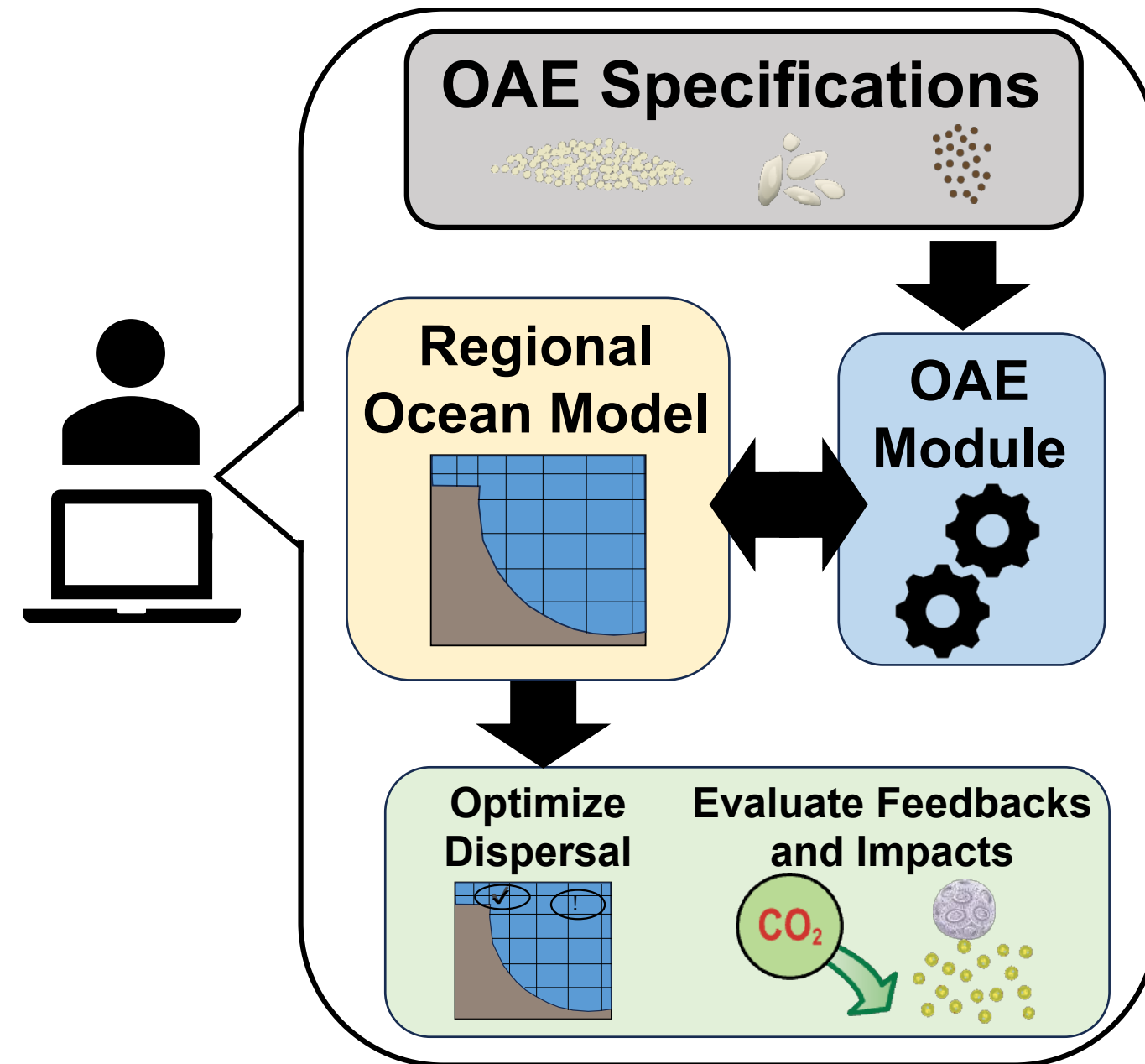
Model Applications for MRV

- Interviews with MRV practitioners have highlighted key opportunities for applications of this research effort in carbon accounting
- Applicability of OAE module to MRV is dependent upon
 - Trustworthy experimental and field data
 - Confidence-building modeling tests in real-world environments
 - MRV protocol consistency



Conclusions

- Developing standardized OAE module capable of interfacing with multiple ROMS biogeochemical configurations
- Experimental findings help modify rates of CO₂ uptake, simulate secondary precipitation dynamics in OAE module
- Future work could also help inform sensor placement in testable small coastal domain like Sequim Bay





Questions?

Kyle Hinson
Pacific Northwest National Laboratory
kyle.hinson@pnnl.gov



mCDR
@PNNL

Funding for this work provided by the U.S. Department of Energy's Advanced Research Projects Agency– Energy



U.S. DEPARTMENT
of ENERGY



Quantifying the Efficacy of Wastewater Alkalinity Enhancement on mCDR and Acidification Mitigation in a Large Estuary



Jeremy Testa, Casey Hodgkins: UMCES Chesapeake Biological Laboratory

Wei-Jun Cai, Zhendong Ji: University of Delaware

Ming Li, Yuren Chen: UMCES Horn Point Laboratory

Will Burt, Sarah Van Pelt, Robert Izett: Planetary Technologies, Inc.

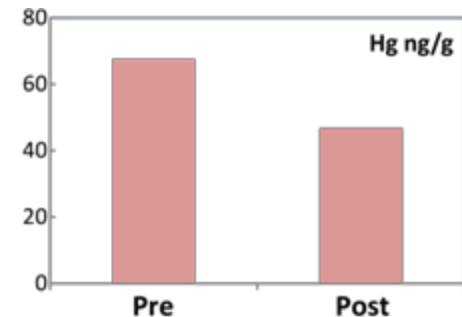
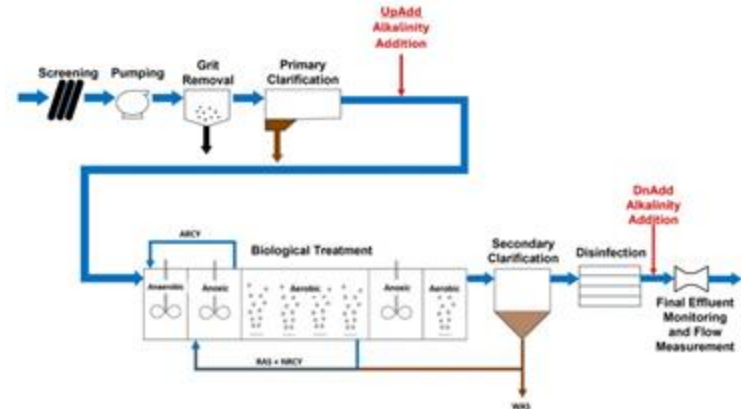
Charles Bott, Alexandria Gagnon, Riley Doyle: HSRD

Special Thanks: Amanda Moore, Najid Hussain,
Zhentao Sun, Omar Sadoon, Alex Whitworth,
Greg Rau, Dhruv Mehta, Kat Yetka, Scott Fentress



Outline

- Project Rationale and Motivation
- Field Trial and Estuarine MRV
- Real-time data to help understand high-frequency changes
- Environmental impacts



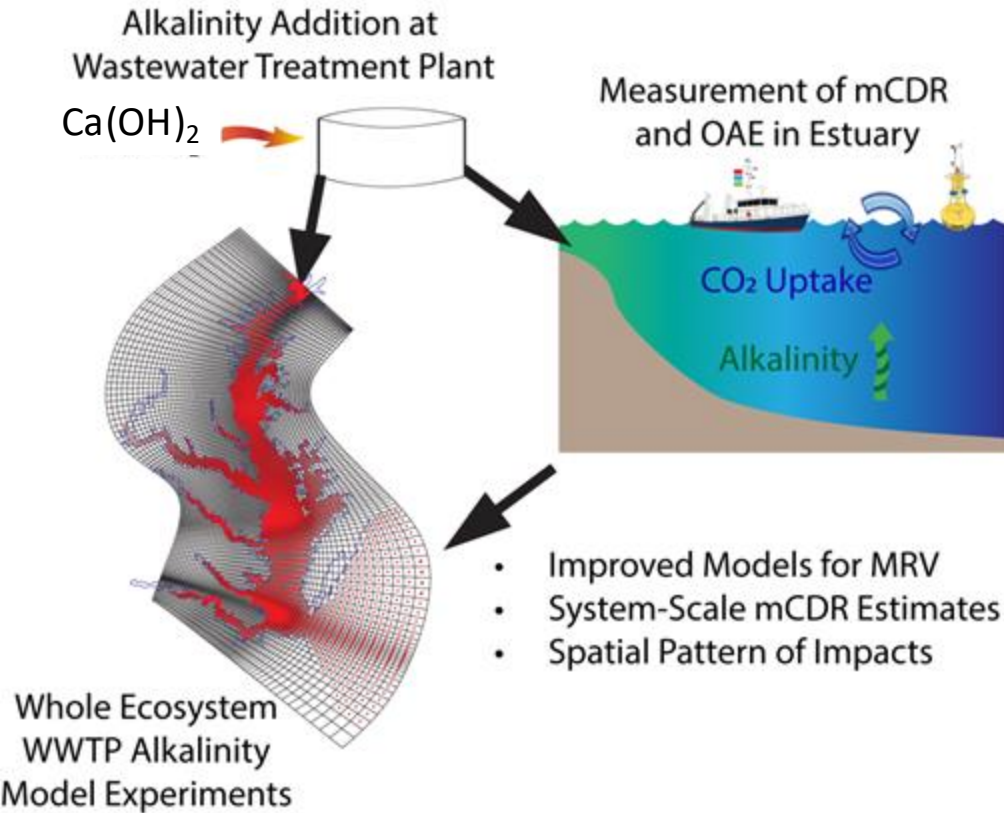
Benefits of WWTP as a Vehicle for OAE

- (1) Supports existing plant process (nutrient removal) while elevating alkalinity/mCDR
- (2) No new permits needed
- (3) Low pH in WWTP allows for rapid dissolution, limited precipitation
- (4) Low-cost delivery (contrast with transporting material to open ocean)
- (5) If alkalinity added upstream, reduced CO₂ emission = 1.6% of greenhouse gas emissions (GHG)
WWTP pCO₂ >10,000 ppm
- (6) Potential to reduce acidity of discharged wastewater

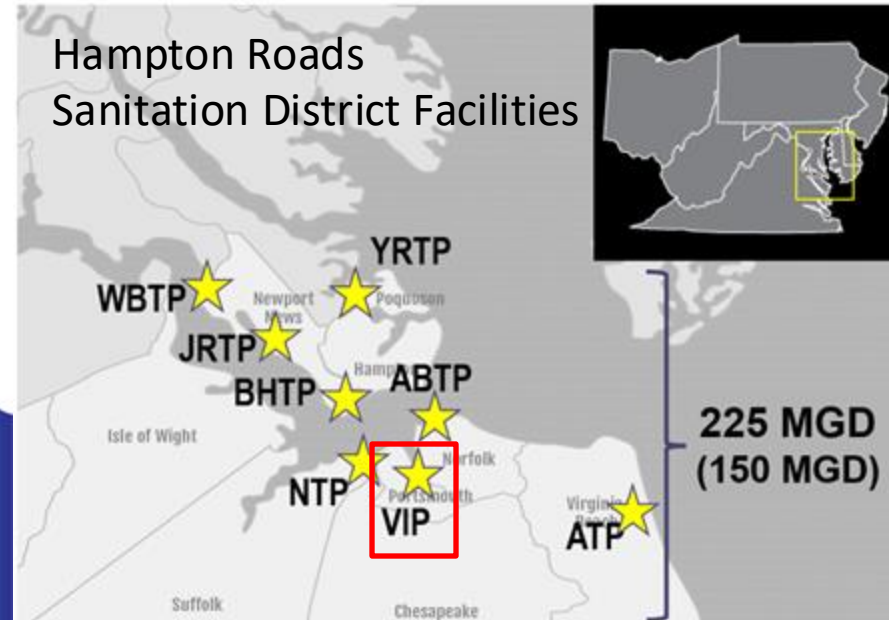


Project Overview

Project Overview



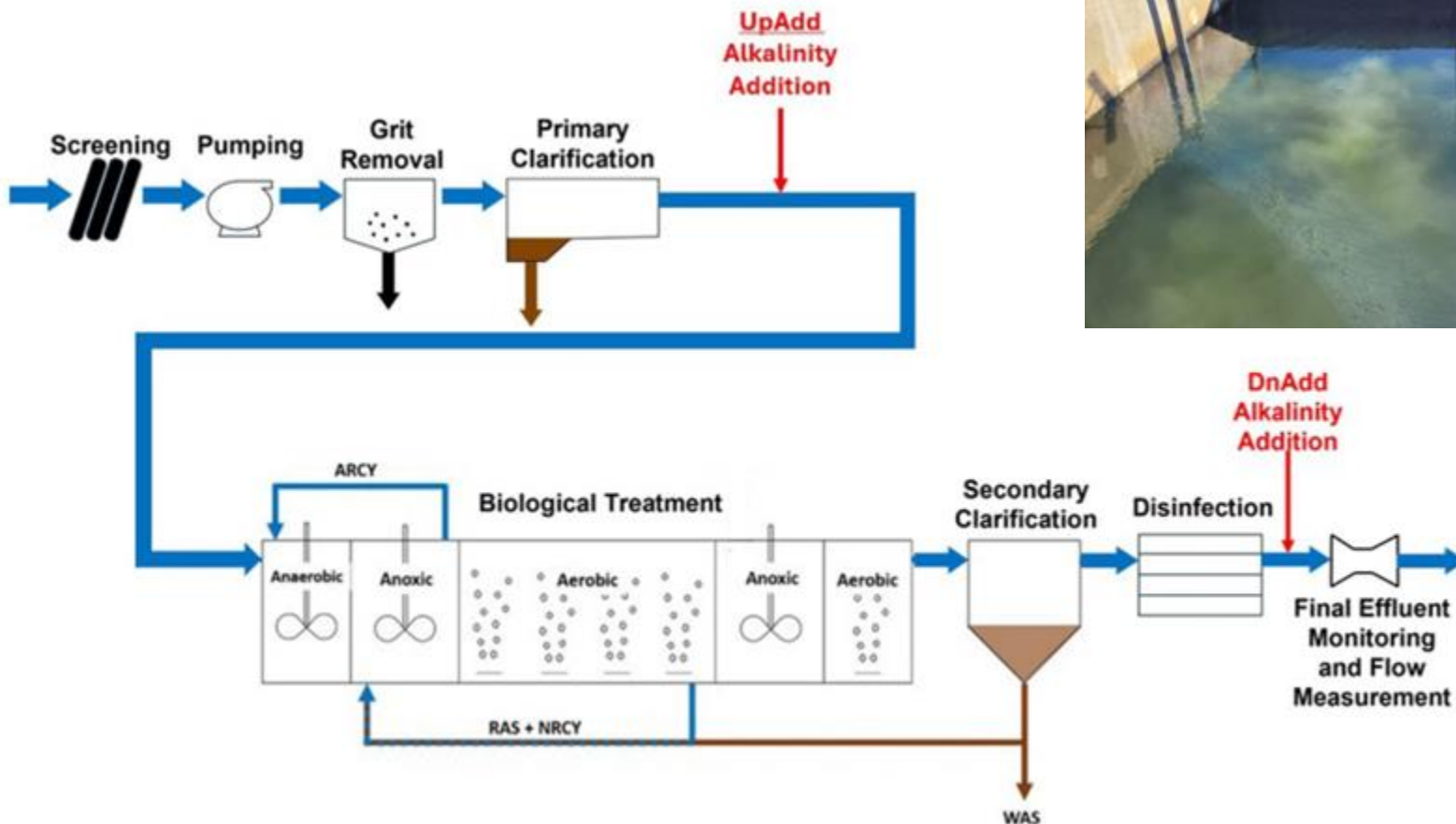
Hampton Roads Sanitation District Facilities



Two Field Trials: Fall 2024, Summer 2025

Timeline: Oct 28 – Nov 2, 2024

- Downstream Addition: Oct 28 – Oct 30, 2024
- Upstream Addition: Oct 31 – Nov 2, 2024



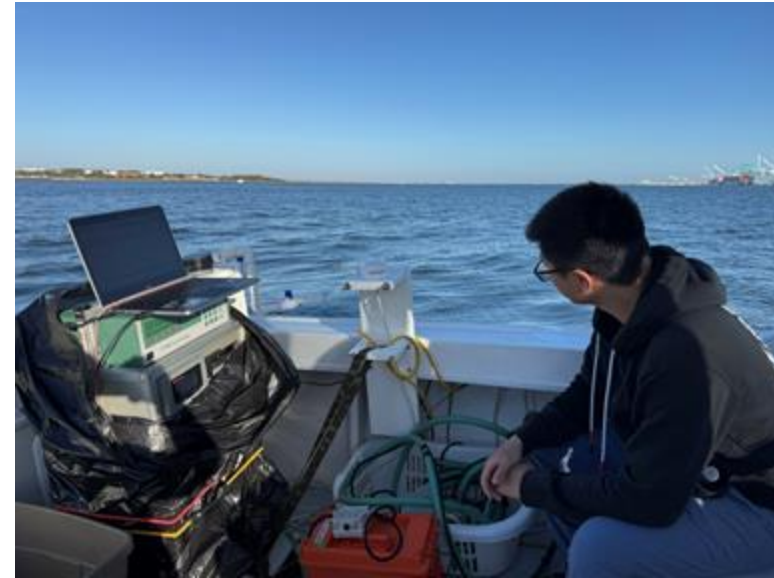
Measurement, Reporting, and Verification (MRV)

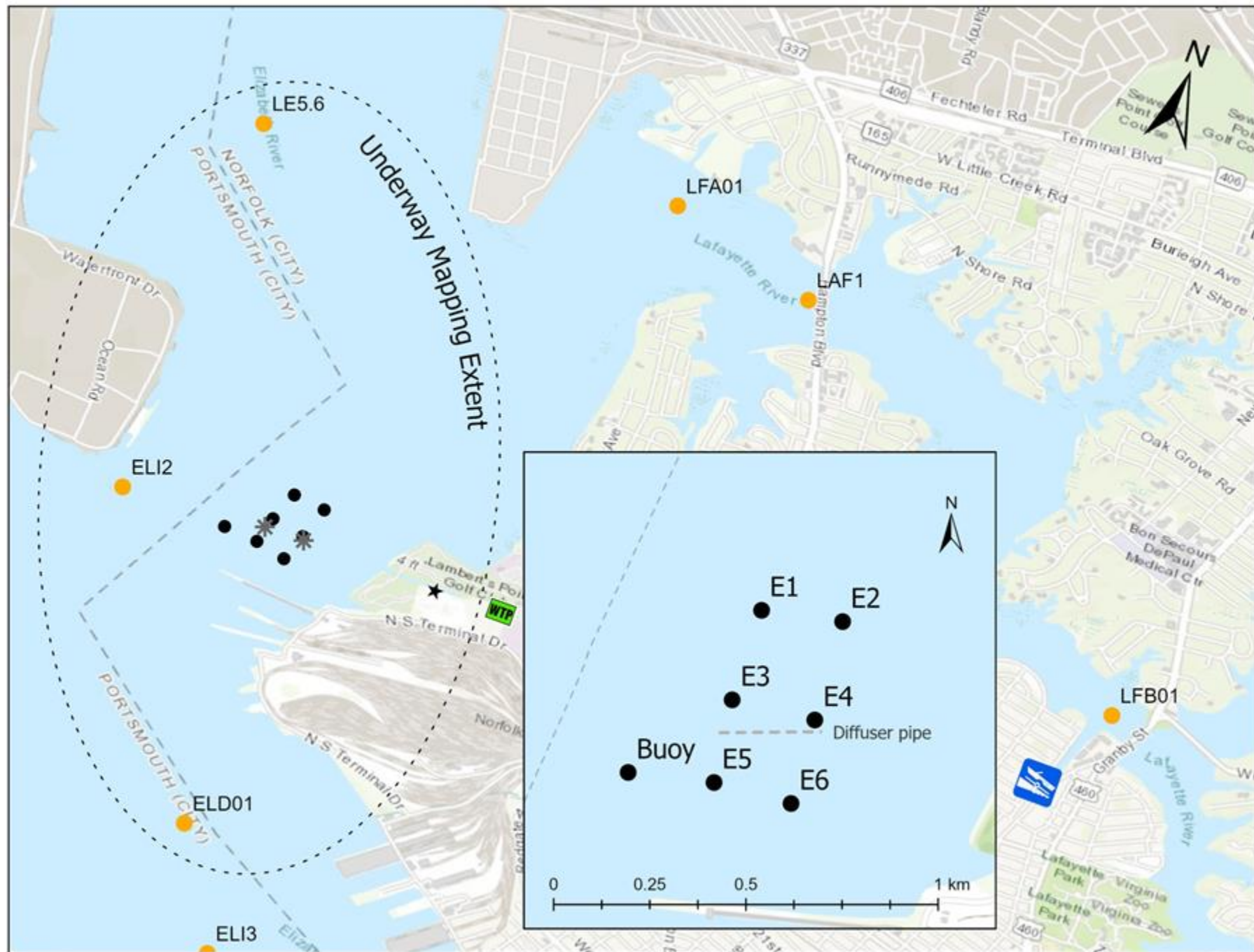
Estuary

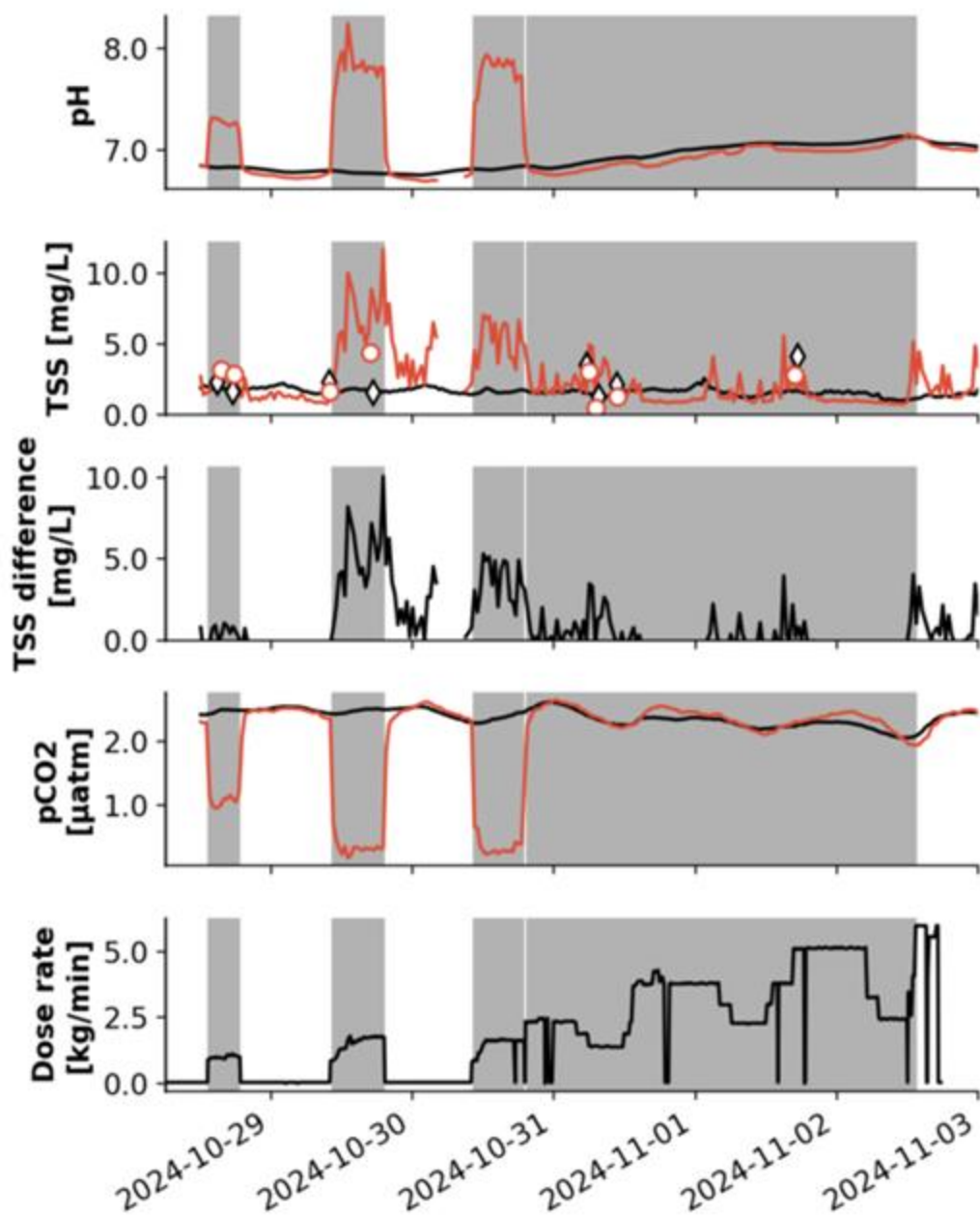
- $p\text{CO}_2$: Underway $p\text{CO}_2$ system
- Discrete DIC, TA, pH (high and low tide)
- Real-time CTD, oxygen, turbidity, fluorescence
- Discrete Chl-a, TSS, nutrients, metals

WWTP Outfall

- Discrete DIC, TA, pH, $p\text{CO}_2$ (hourly-daily-weekly)
- Real-time pH, $p\text{CO}_2$, turbidity
- Discrete pH, metals

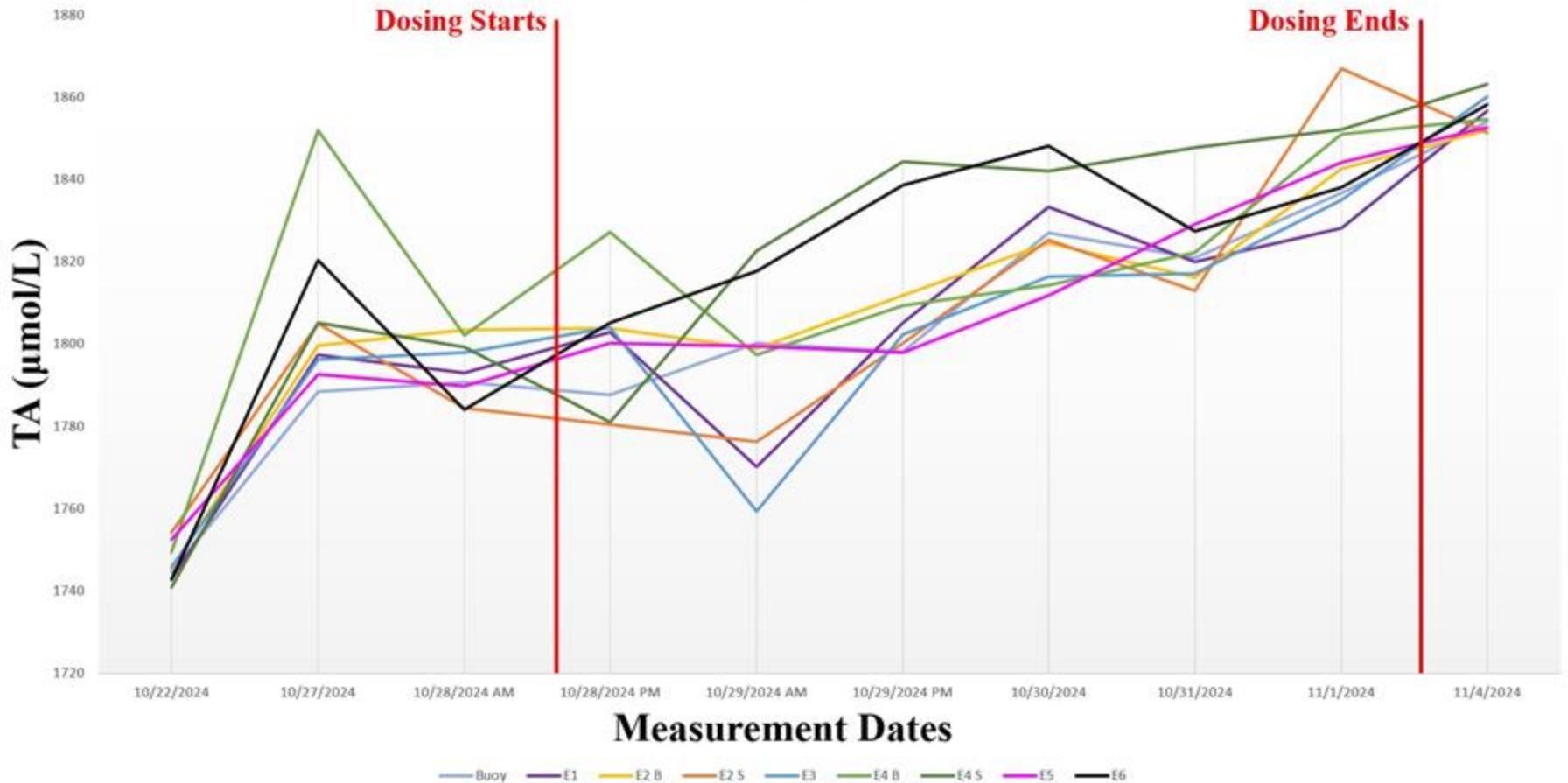




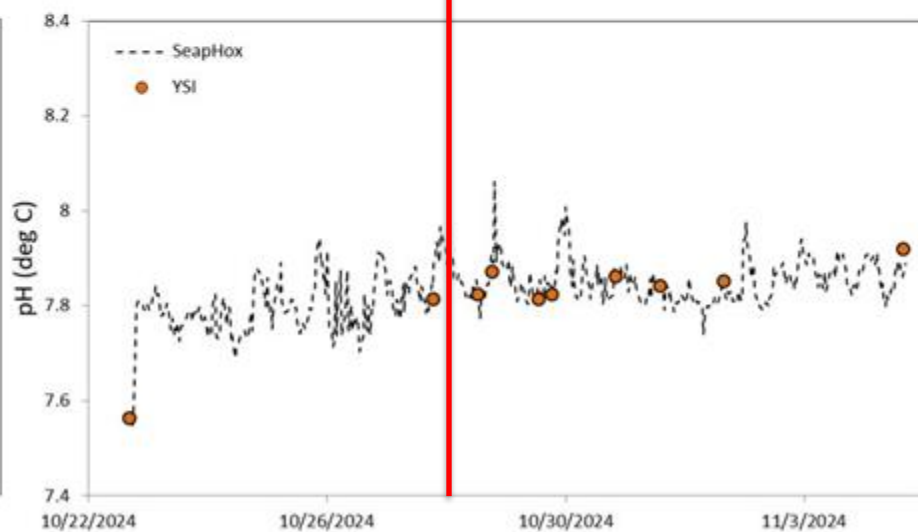
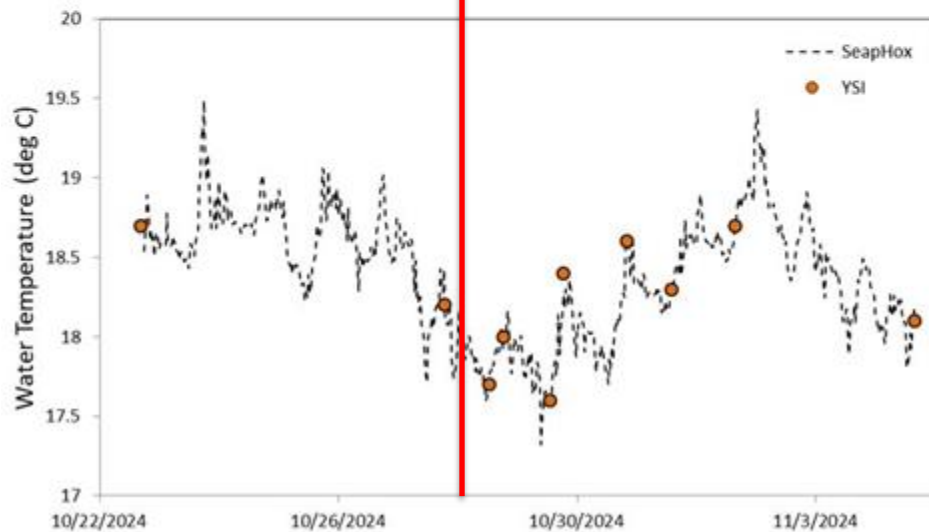
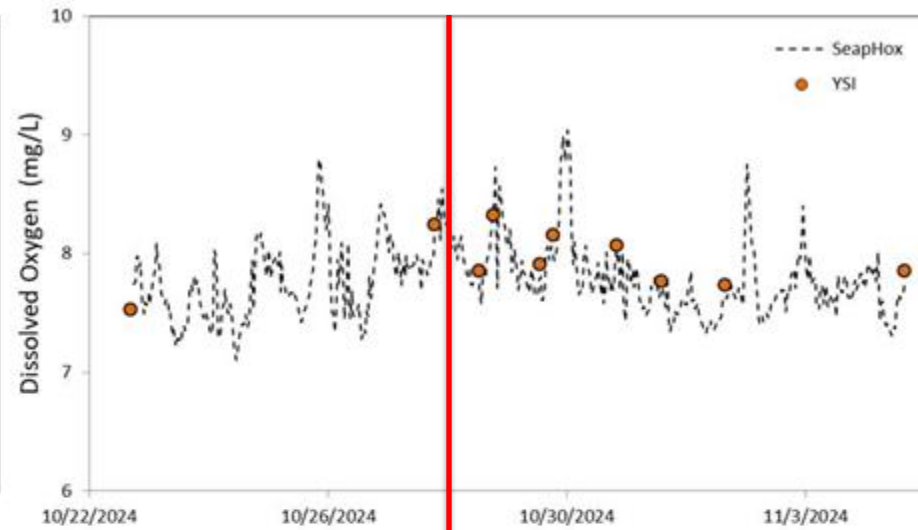
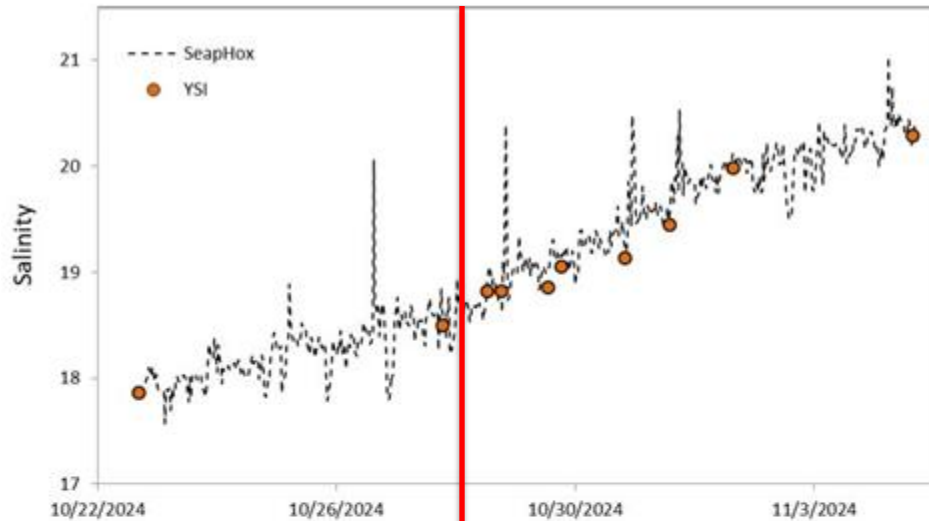


Fall 2024 Trial Estuary TA

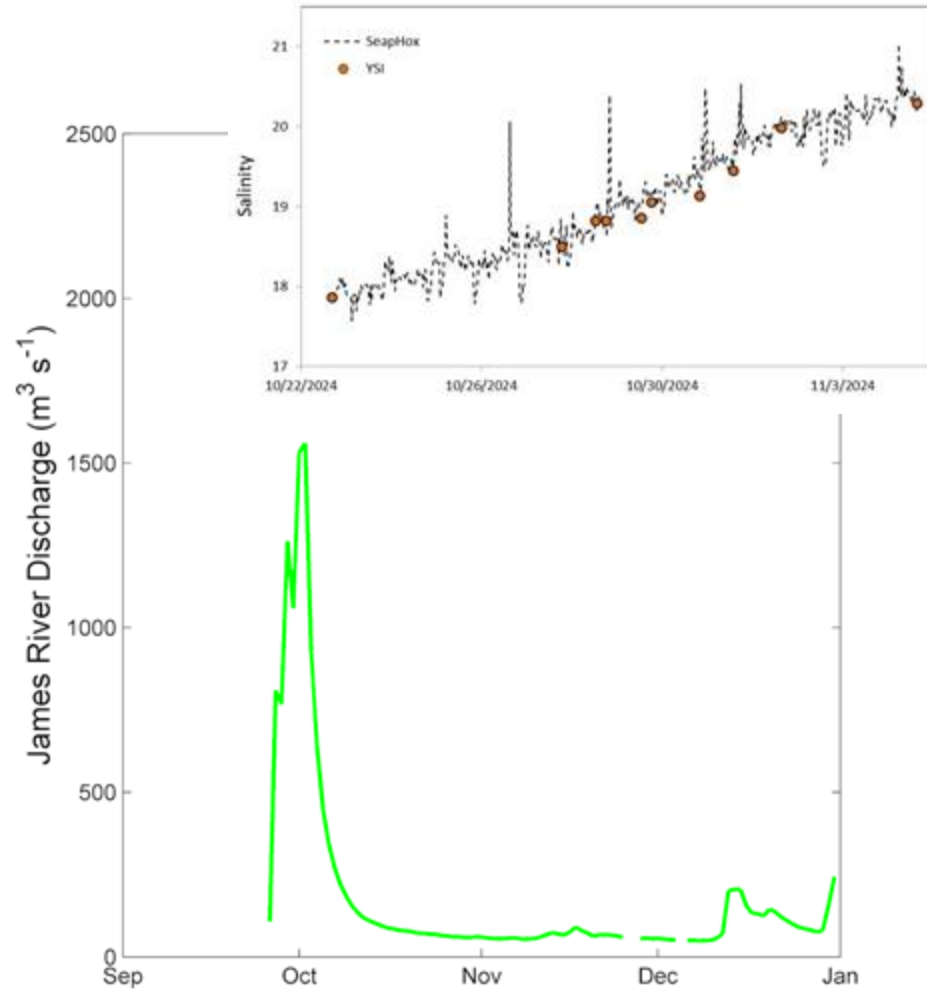
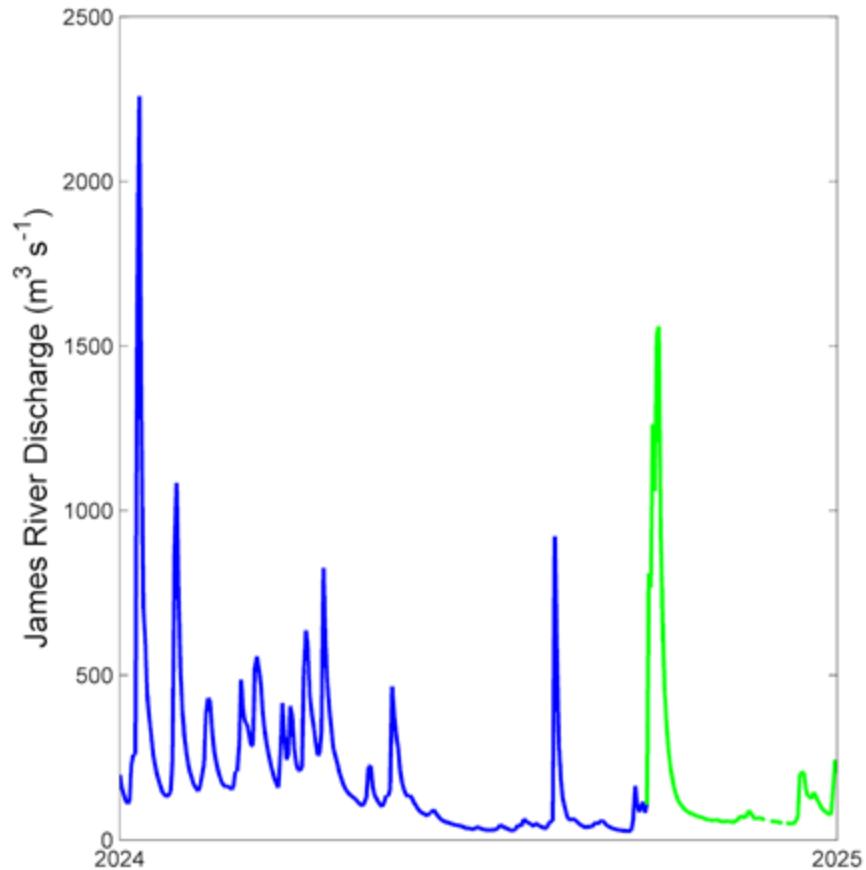
Estuary TA



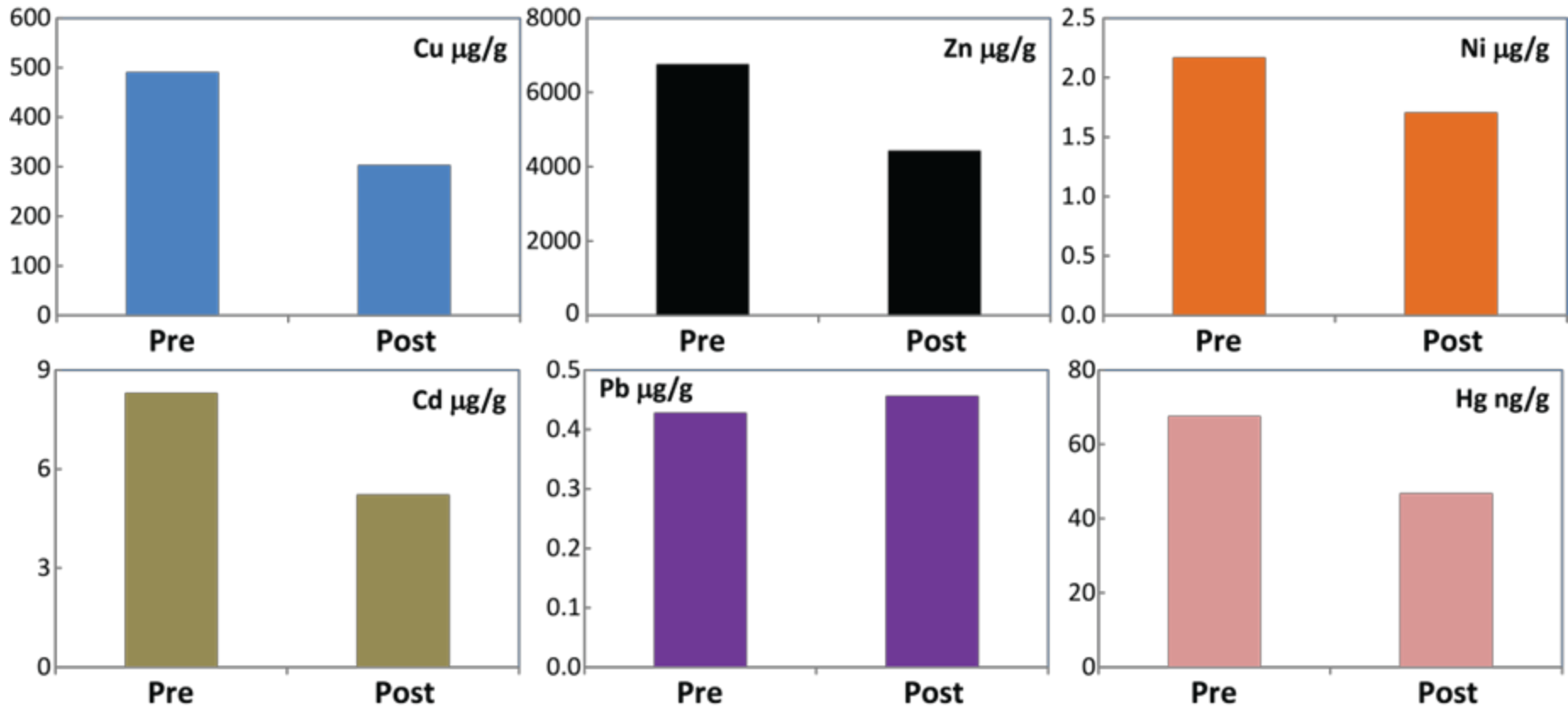
Fall 2024 Trial Estuary Sensors



The Messy Estuary



Biological Monitoring

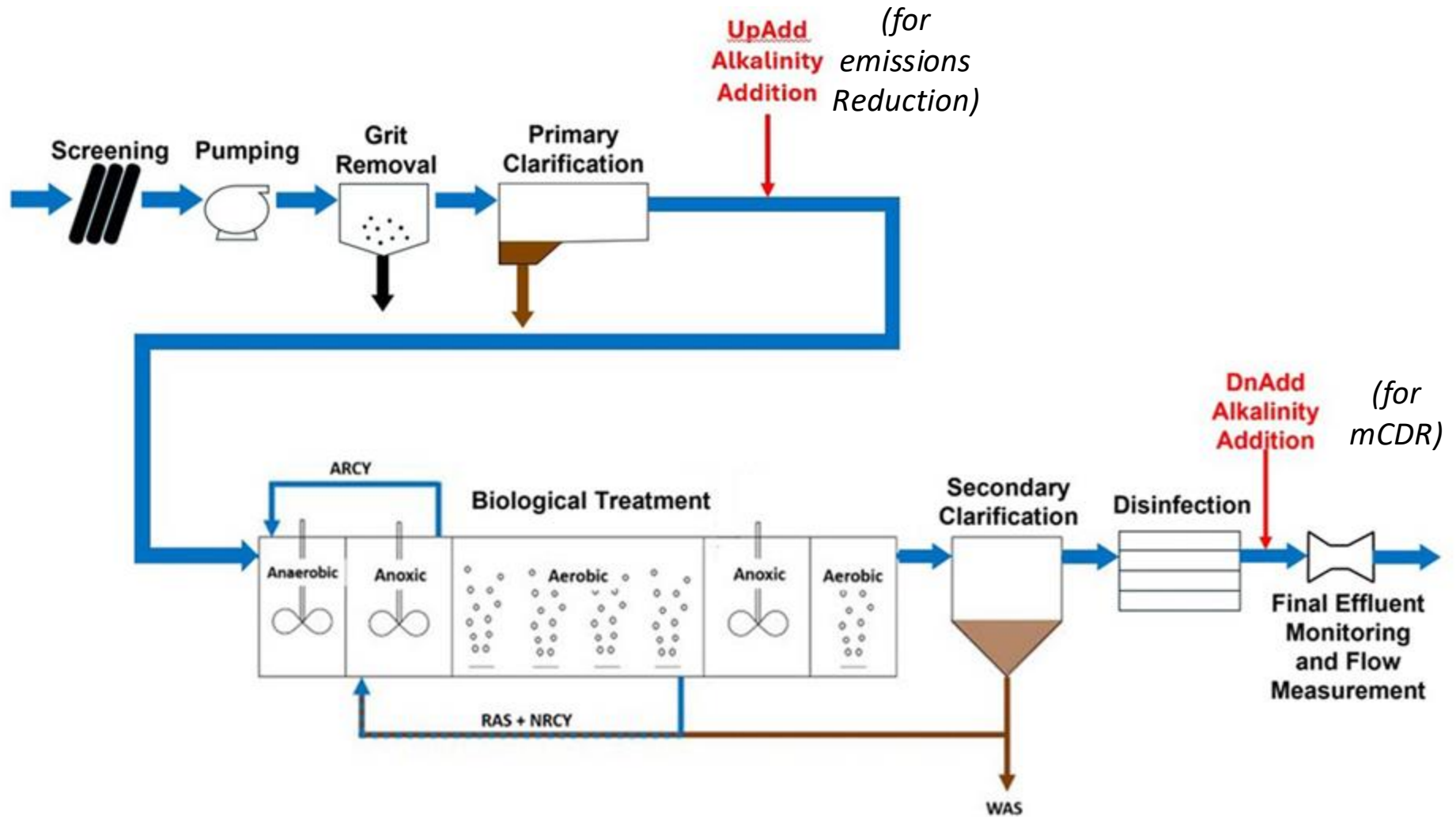


Conclusions and Thank you

- WWTP-based OAE is feasible, scalable, but utility may be site-specific
- Downstream OAE successfully increased pH, TA, and DIC in effluent, reduced CO₂
- Alkalinity and pH increased in estuary during the trial, but some of this likely due to changes not associated with OAE
- No obvious biological impacts of the trials

Two Approaches

Process Diagram at VIP



ENVIRONMENTAL RESEARCH LETTERS

LETTER

Wastewater alkalinity enhancement for carbon emission reduction and marine CO₂ removal

Ming Li^{1,*} , Yuren Chen¹ , Riley Doyle^{2,3} , Jeremy M Testa⁴ , Alexandria Gagnon² , Charles Bott² 
and Wei-Jun Cai⁵ 

¹ Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, MD, United States of America

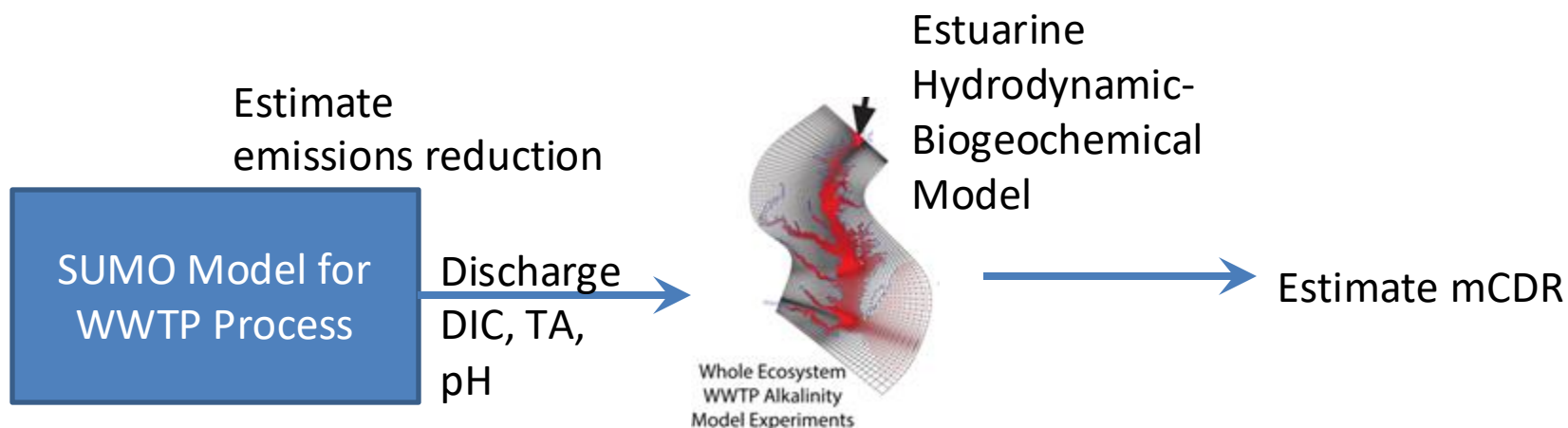
² Hampton Roads Sanitation District, Virginia Beach, VA, United States of America

³ Département de génie civil et de génie des eaux, Université Laval, Québec City, Québec, Canada

⁴ Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, MD, United States of America

⁵ School of Marine Science and Policy, University of Delaware, Newark, DE, United States of America

* Author to whom any correspondence should be addressed.



SUMO Simulations of Alkalinity Addition

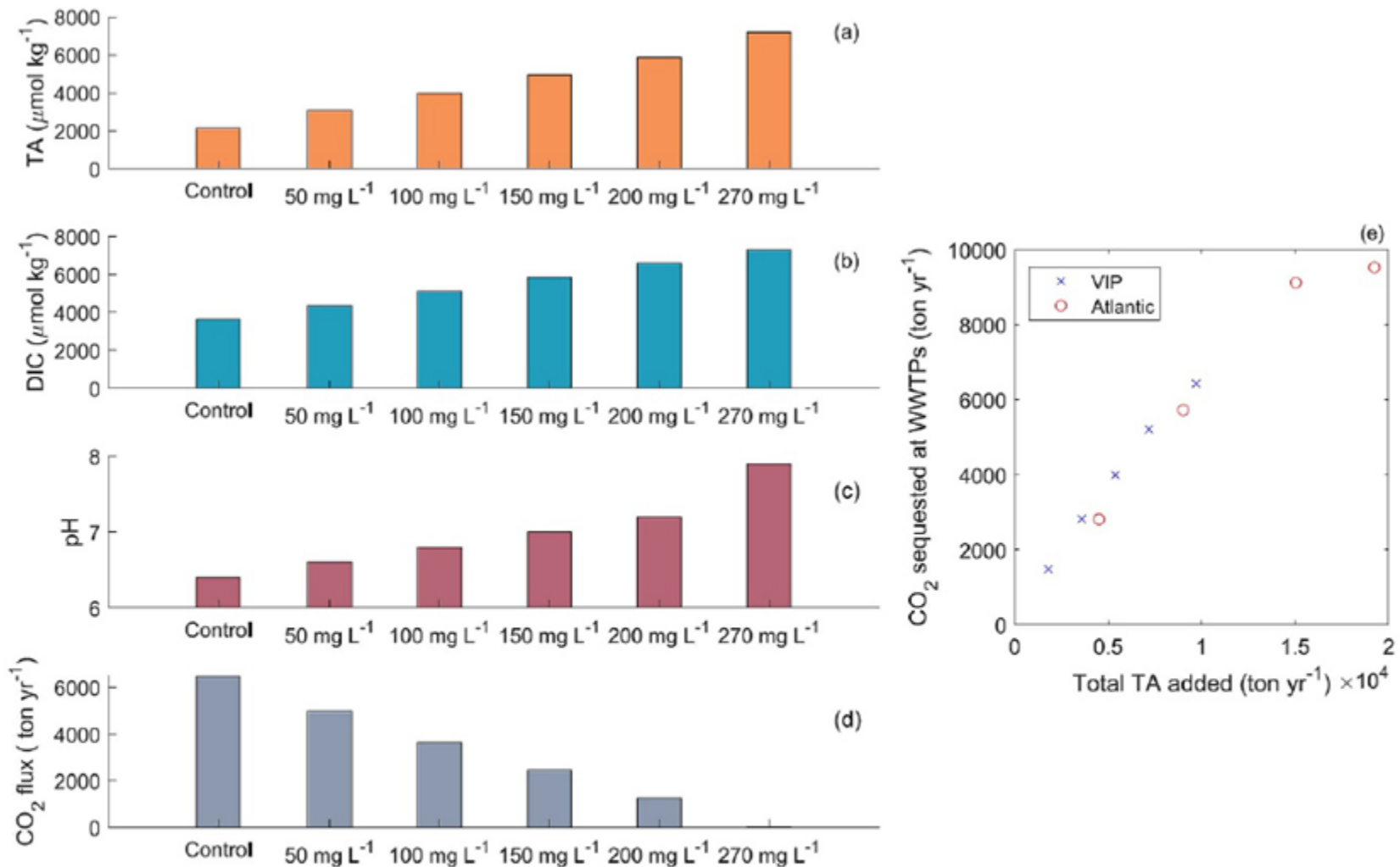


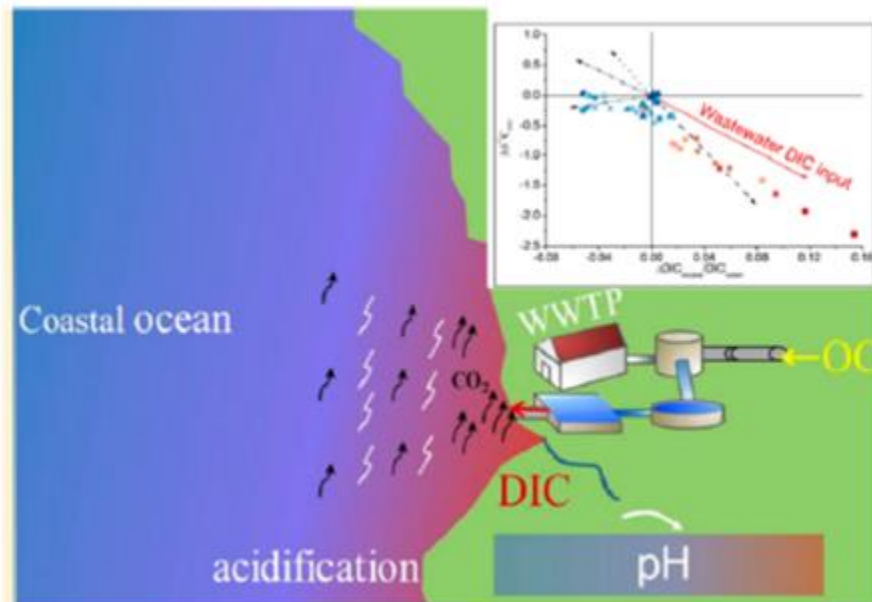
Figure 2. SUMO simulation results for two WWTPs: the VIP and the Atlantic treatment Plant (ATL) located in the lower Chesapeake Bay. (a)–(d) TA, DIC, and pH in the discharge effluent, and the total CO₂ efflux at the VIP. No alkalinity is added in the control model run. Alkalinity is added as CaCO₃ at five different dosages: $\Delta\text{TA} = 50, 100, 150, 200,$ and 270 mg l^{-1} . (e) Total CO₂ emission reduction versus total TA added to the VIP (blue stars) and the Atlantic Treatment Plant (red circles).

Why this project?

- With a near-consensus that negative emissions technologies are required to meet global warming mitigation goals, all options can be explored for removing carbon
- marine Carbon Dioxide Removal (mCDR) is one mode of negative emissions, where manipulations of marine water lead to uptake and long-term sequestration of carbon in the ocean
- Wastewater treatment plants present an opportunity to support mCDR, as they are existing, industrial-scale infrastructure that discharges to estuarine and marine waters

Wastewater Treatment for OAE and Emissions Reduction

- 1000 km³ of wastewater generated globally: 300 km³ discharged as municipal wastewater and over 600 km³ as industrial wastewater.
- Sewage has high DIC (3000-5000 mmol C/kg) and high $p\text{CO}_2$ (>10,000 ppm), an important source of coastal acidification (Yang et al. 2018)
- Wastewater plants account for 3% of global electricity consumption and 1.6% of greenhouse gas emissions (GHG) – 0.77 Gt CO₂ eq. (Lu et al. 2018).



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SABIN CENTER FOR CLIMATE CHANGE LAW

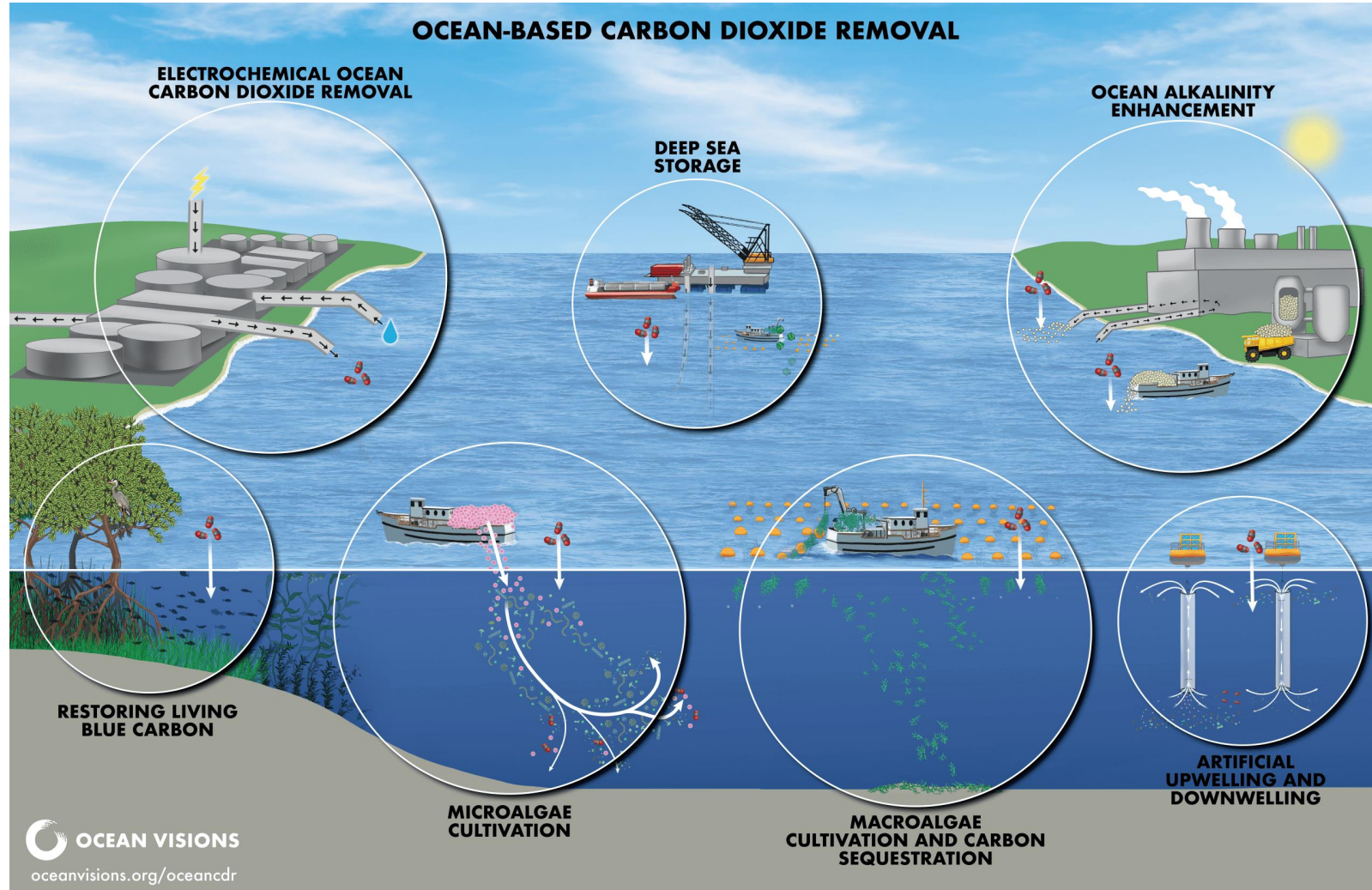


Federal and State Permitting Requirements for mCDR

Ashwin Murthy

July 15, 2025

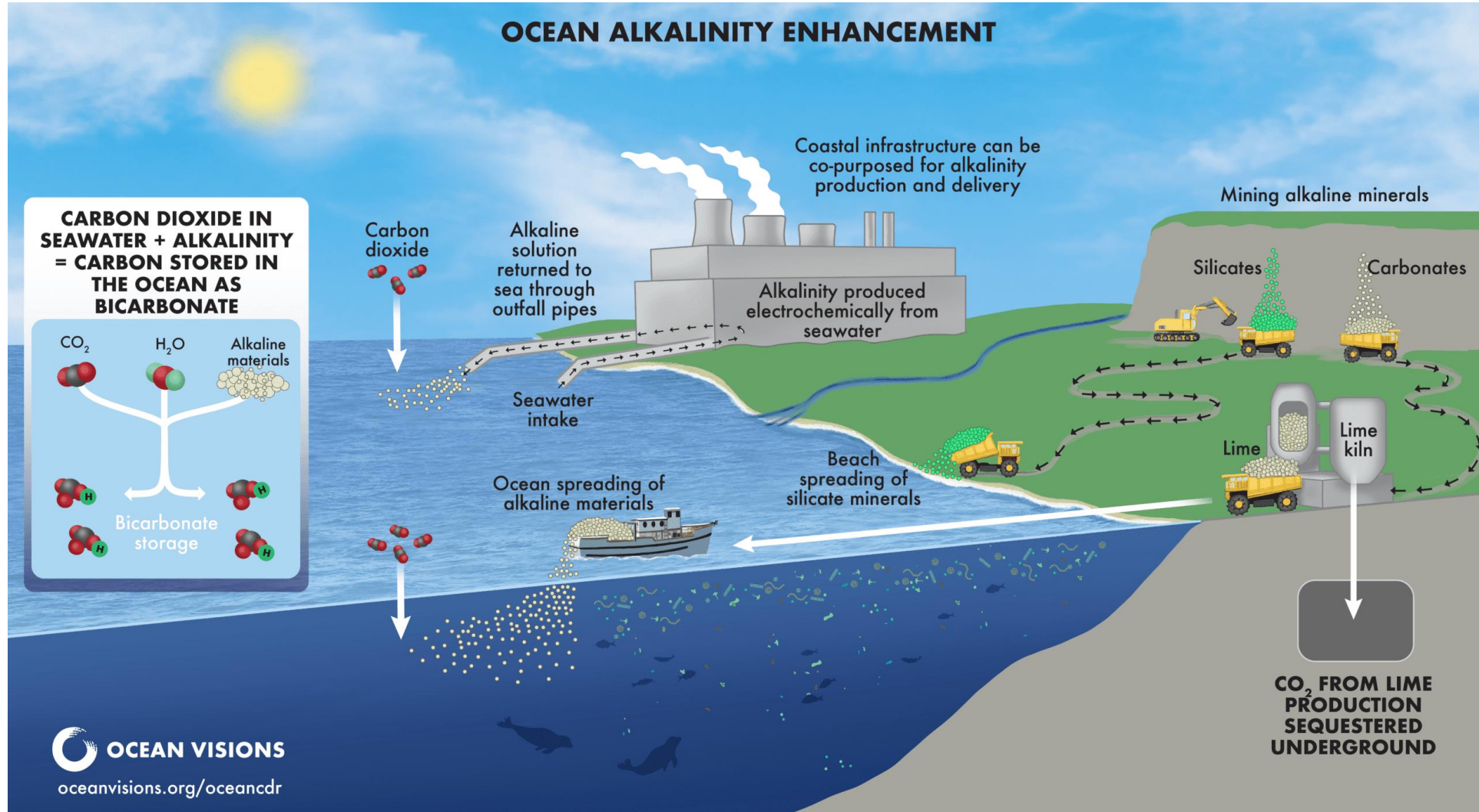
Marine Carbon Dioxide Removal



Ocean-Based Carbon Dioxide Removal © 2023 by Ocean Visions is licensed under CC BY-NC-ND 4.0.



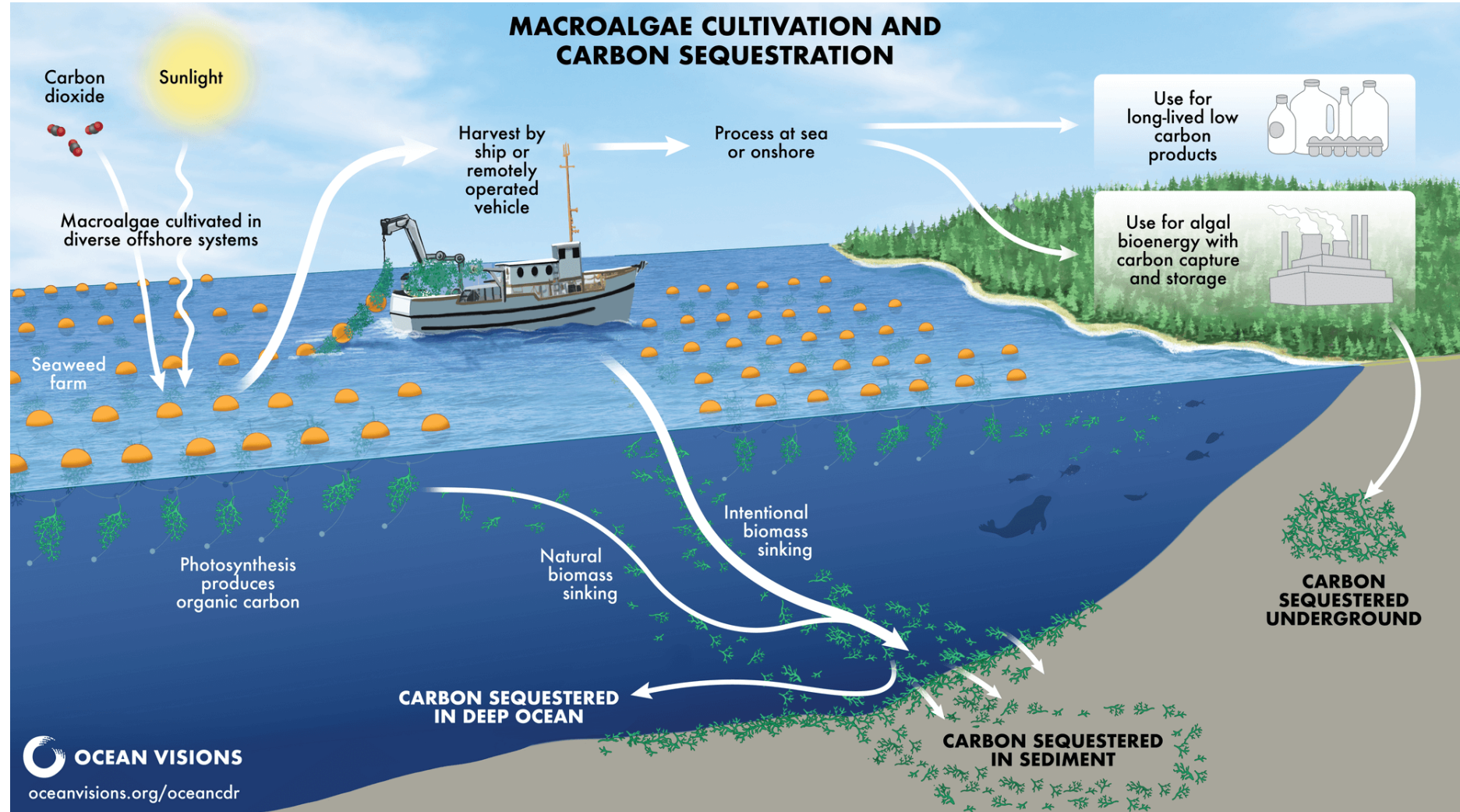
Ocean Alkalinity Enhancement



Ocean Alkalinity Enhancement © 2023 by Ocean Visions is licensed under CC BY-NC-ND 4.0.



Biomass Sinking



Federal Laws

- Marine Protection, Research, and Sanctuaries Act
- Clean Water Act
- Rivers and Harbors Act
- Coastal Zone Management Act
- National Environmental Protection Act
- Endangered Species Act
- Marine Mammal Protection Act
- Magnuson-Stevens Fishery Conservation and Management Act
- National Historic Preservation Act
- Migratory Birds Act



MPRSA: Prohibition

PROHIBITED ACTS

SEC. 101. [33 U.S.C. 1411] (a) Except as may be authorized by a permit issued pursuant to section 102 or section 103 of this title, and subject to regulations issued pursuant to section 108 of this title,

(1) no person shall transport from the United States, and

(2) in the case of a vessel or aircraft registered in the United States or flying the United States flag or in the case of a United States department, agency, or instrumentality, no person shall transport from any location.¹

any material for the purpose of dumping it into ocean waters.

(b) Except as may be authorized by a permit issued pursuant to section 102 of this title, and subject to regulations issued pursuant to section 108 of this title, no person shall dump any material transported from a location outside the United States (1) into the territorial sea of the United States, or (2) into zone contiguous to the territorial sea of the United States, extending to a line twelve nautical miles seaward from the base line from which the breadth of the territorial sea is measured, to the extent that it may affect the territorial sea or the territory of the United States.



MPRSA: Dumping

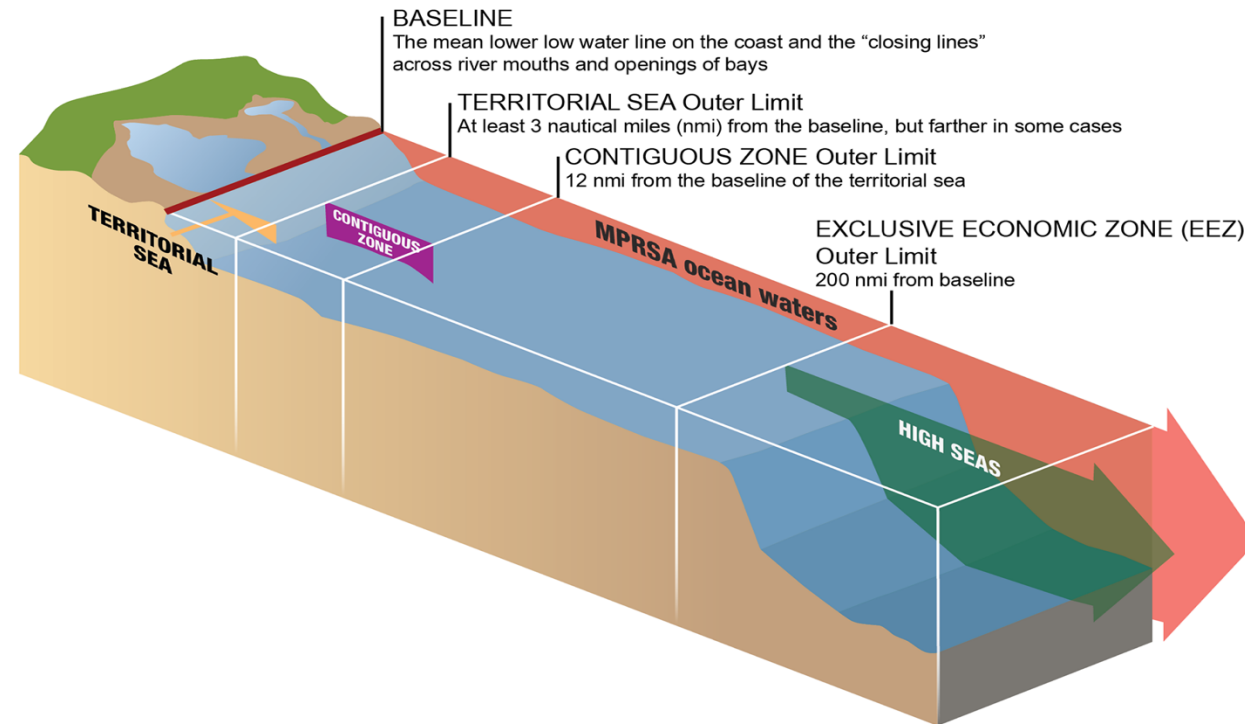
- Dumping means a “disposition of material”
 - Broad definition
 - Distinct from the London Convention – MPRSA includes disposal for beneficial purposes under dumping
 - “Material” is to be read broadly (like pollutants under the CWA)
- “Transportation”
 - Trigger for the MPRSA
 - Must be through vessels (which includes aircrafts)
- mCDR
 - Mineral-based OAE
 - Biomass sinking
 - Associated dumping (potentially fertilizer, nets, etc.)



MPRSA: Jurisdiction

MPRSA Ocean Waters

The Marine Protection, Research, and Sanctuaries Act (MPRSA) applies in “ocean waters.” Ocean waters are waters of the open seas lying seaward of the baseline from which the territorial sea is measured and include the territorial seas, the contiguous zone, the U.S. exclusive economic zone, and the high seas.



Clean Water Act: Text

- Any discharge of “pollutant” from “point source” requires a permit
 - Pollutants to be read broadly
 - Point sources are any “conveyance” (pipes, outfall structures, etc.)
- NPDES permits (CWA S.402)
 - Effluent limitations – Technology-based and water quality-based
 - Narrative limitations
 - Issued by EPA
- S.404 permits
 - Discharge of dredge and fill material
 - Issued by Army Corps of Engineers



Clean Water Act: State Implementation

- Envisages a cooperative framework between federal government and state governments
 - CWA provides the federal baseline of regulation
- Delegated permitting authority to states
- States permitted to set standards - water quality standards, TMDLs
- States issue water quality certifications (CWA S.401)
- MPRSA preempts the CWA and state permitting
 - However, states can still add additional requirements



Clean Water Act: mCDR



Planetary – mineral OAE through established coastal facilities ([link](#)). Copyright © 2025 Planetary Technologies, Inc



Ebb Carbon – electrochemical OAE ([link](#)). ©2024 by Ebb Carbon, Inc.



Rivers and Harbors Act

- Governed by the Army Corps of Engineers
- Structures that modify or interfere with a navigable waterway
- Could be applicable to OAE depending on the project
 - Could be relevant in constructing facilities
 - Especially relevant to seaweed cultivation
- ACE can issue combined RHA and CWA S.404 permits



State Regulation of mCDR

- MPRSA
- CWA
 - Water quality standards
 - Water quality certification
- Coastal Zone Management Act
 - Coastal zone management plan
 - Federal consistency certification
- State laws - NEPA equivalents (e.g. SEQRA, MEPA)



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Thank you!

Sabin Center for Climate Change Law useful links:

 <https://climate.law.columbia.edu/>

 <https://www.instagram.com/sabincenter/>

 <https://www.linkedin.com/company/sabin-center-for-climate-change-law>





Nature-Based Solutions

Seeding Resilience:

Assisted Gene Flow in Eelgrass

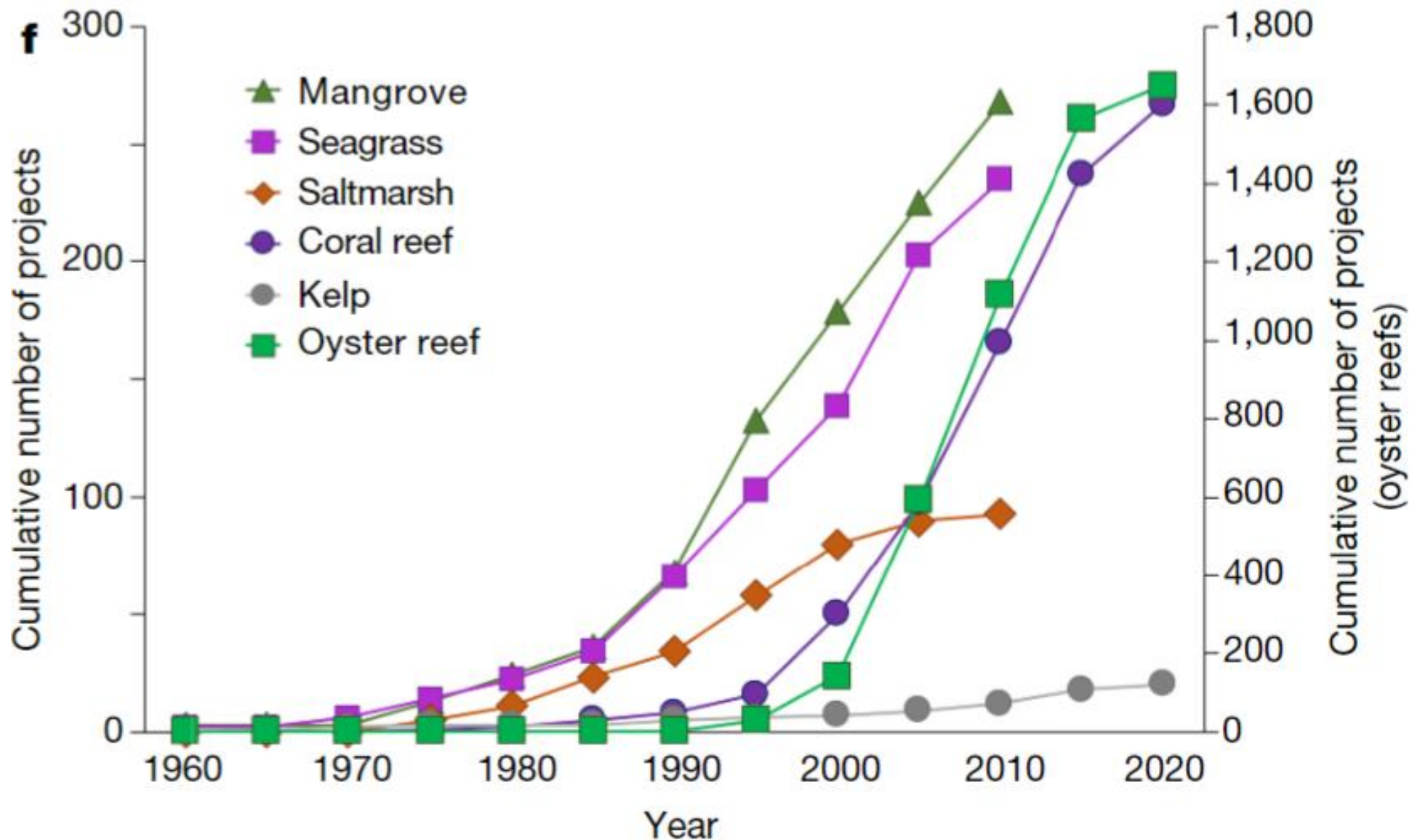
Stephen J. Tomasetti¹, Jessie Jarvis, Stephanie Kamel,
Jonathan Lefcheck, Stephen Heck, Bradley Peterson,
Jamie Vaudrey, Alyssa Novak, Katherine Tanner¹,
Rachel Schaefer, Audrey Brown, Karina Scavo,
Holly Plaisted

¹University of Maryland Eastern Shore
Marine, Estuarine, & Environmental Sciences Program, Princess Anne, MD

Nature-based Solutions (NbS)



Coastal and marine ecosystem restoration as a NbS



Climate-ready adaptive restoration

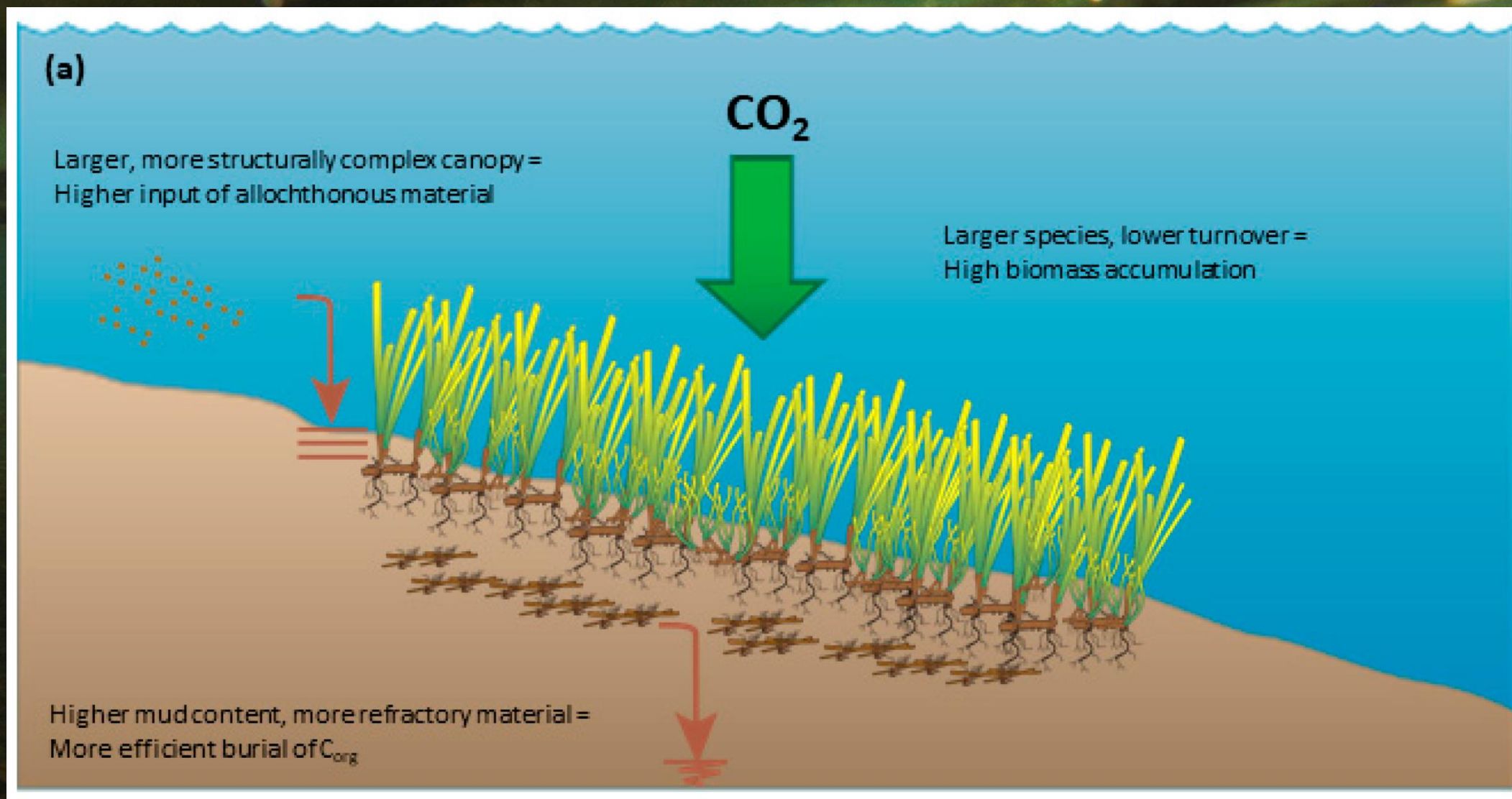
Oyster reefs' control of carbonate chemistry—Implications for oyster reef restoration in estuaries subject to coastal ocean acidification

Stephen J. Tomasetti¹  | Michael H. Doall² | Brendan D. Hallinan² |
Jeffrey R. Kraemer Jr.² | Christopher J. Gobler²

 Global Change Biology **WILEY**



Seagrass Restoration



Seagrass restoration success

Rebuilding A Collapsed Bivalve Population, Restoring Seagrass Meadows, and Eradicating Harmful Algal Blooms In A Temperate Lagoon Using Spawner Sanctuaries



Frontiers in Marine Science

Christopher J. Gobler¹, Flynn DeLaney¹, Ryan Brooke K. Morrell¹, John M. Carroll⁴, Doreen Ann Marie E. Famularo¹, Stephen M. Heck¹, and Jonathan S. Lefcheck^{a,b,1}

Long-term nutrient reductions lead to the unprecedented recovery of a temperate coastal region

Jonathan S. Lefcheck^{a,b,1}, Robert J. Orth², Jennifer Keisman^e, Cassie Gurbisz^{f,9}, Michael Jeremy Testa^k, Donald E. Weller^h, and R. Scott Weinstein¹

ARTICLE

<https://doi.org/10.1038/s41467-019-11340-4>

OPEN

Recent trend reversal for declining European seagrass meadows

Carmen B. de los Santos¹, Dorte Krause-Jensen^{2,3}, Teresa Alcoverro⁴, Núria Marbà⁵, Carlos M. Duarte⁶, Marieke M. van Katwijk⁷, Marta Pérez⁸, Javier Romero⁸, José L. Sánchez-Lizaso⁹, Guillem Roca⁵, Emilia Jankowska¹⁰, José Lucas Pérez-Lloréns¹¹, Jérôme Fournier¹², Monica Montefalcone¹³, Gérard Pergent¹⁴, Juan M. Ruiz¹⁵, Susana Cabaço¹, Kevan Cook¹⁶, Robert J. Wilkes¹⁷, Frithjof E. Moy¹⁸, Gregori Muñoz-Ramos Trayter¹⁹, Xavier Seglar Araño¹⁹, Dick J. de Jong²⁰, Yolanda Fernández-Torquemada⁹, Isabelle Auby²¹, Juan J. Vergara¹¹ & Rui Santos¹

Seagrass sensitivity to heat

Global Change Biology

celebrating 20 years

Global Change Biology (2014), doi: 10.1111/gcb.12694

Extreme temperatures, foundation species, and abrupt ecosystem change: an example from an iconic seagrass ecosystem

JORDAN A. THOMSON¹, DEREK A. W. FOURQUREAN¹, MATTHEW W.

¹Department of Biological Sciences, School of Environmental and Ocean Sciences, North Miami, FL 33181, USA, ²UWA Oceans Institute, Crawley, WA 6009, Australia, ³Botanic Garden, West Perth, WA 6005, Australia

PRIMARY RESEARCH ARTICLE

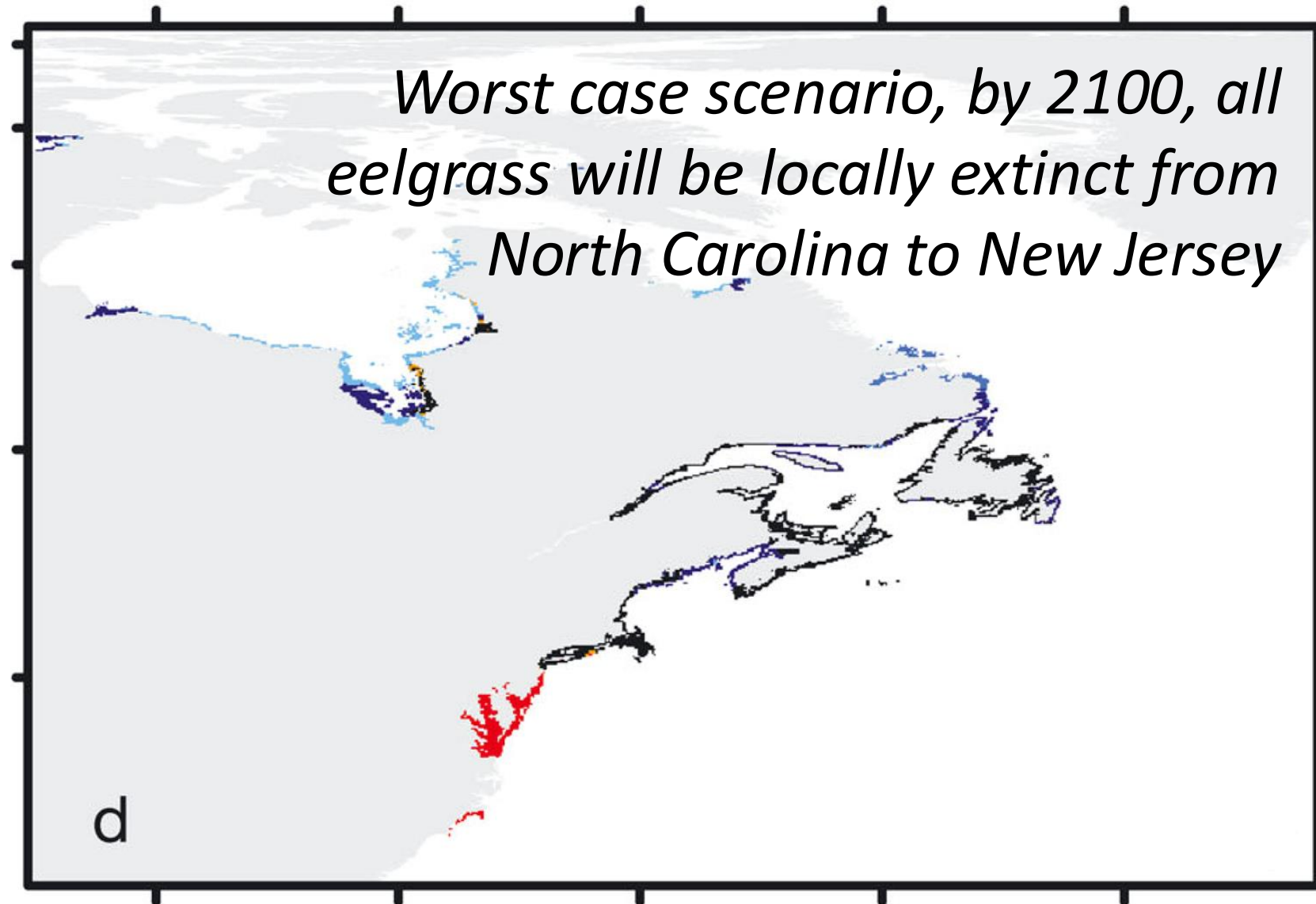
Too hot to handle: Unprecedented seagrass death driven by marine heatwave in a World Heritage Area

Simone Strydom^{1,2}  | Kathy Murray³ | Shaun Wilson^{1,4} | Bart Huntley³ | Michael Rule¹ | Michael Heithaus⁵ | Cindy Bessey⁶ | Gary A. Kendrick⁴ | Derek Burkholder⁷ | Matthew W. Fraser⁴ | Katherine Zdun

Influence of Rising Water Temperature on the Temperate Seagrass Species Eelgrass (*Zostera marina* L.) in the Northeast USA

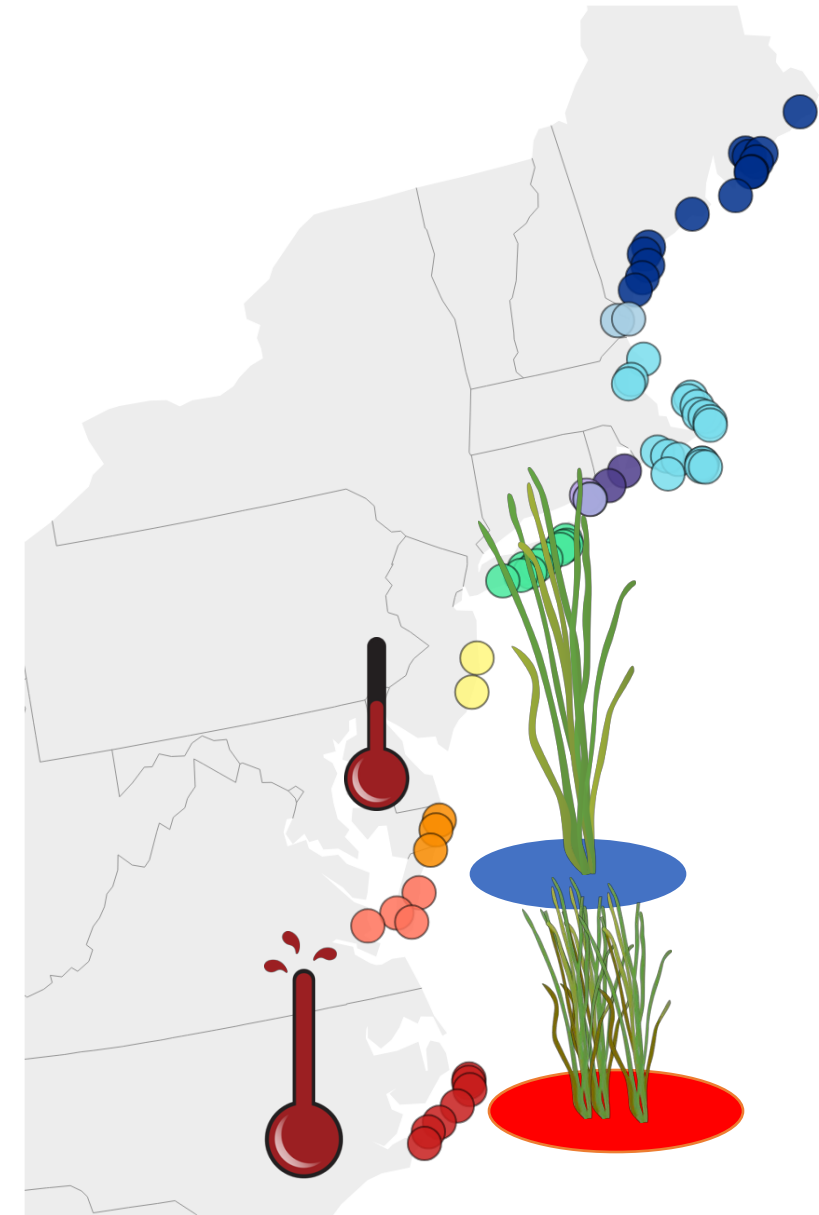
Holly K. Plaisted^{1*}, Erin C. Shields^{2,3}, Alyssa B. Novak⁴, Christopher P. Peck⁵, Forest Schenck⁶, Jillian Carr⁷, Paul A. Duffy⁵, N. Tay Evans⁶, Sophia E. Fox⁸, Stephen M. Heck⁹, Robbie Hudson¹⁰, Trevor Mattera¹¹, Kenneth A. Moore³, Betty Neil Kirk^{2,3}, David B. Parrish^{2,3}, Bradley J. Peterson⁹, Frederick T. Short¹² and Amanda I. Tinoco⁹

RCP 8.5 – projected *Zostera marina* loss



Seeding resilience: assisted gene flow in Eelgrass

- ***Assisted gene flow:*** move thermally tolerant plants to areas where we want to build climate resilience



Genotyping Følørass

Maximum canopy height (cm)

150

100

50

0

37

39

41

43

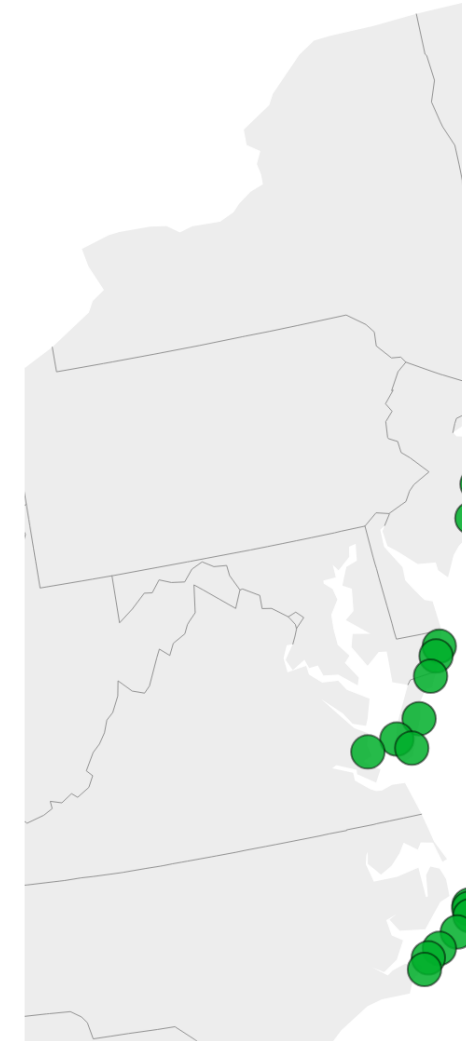
45

Latitude

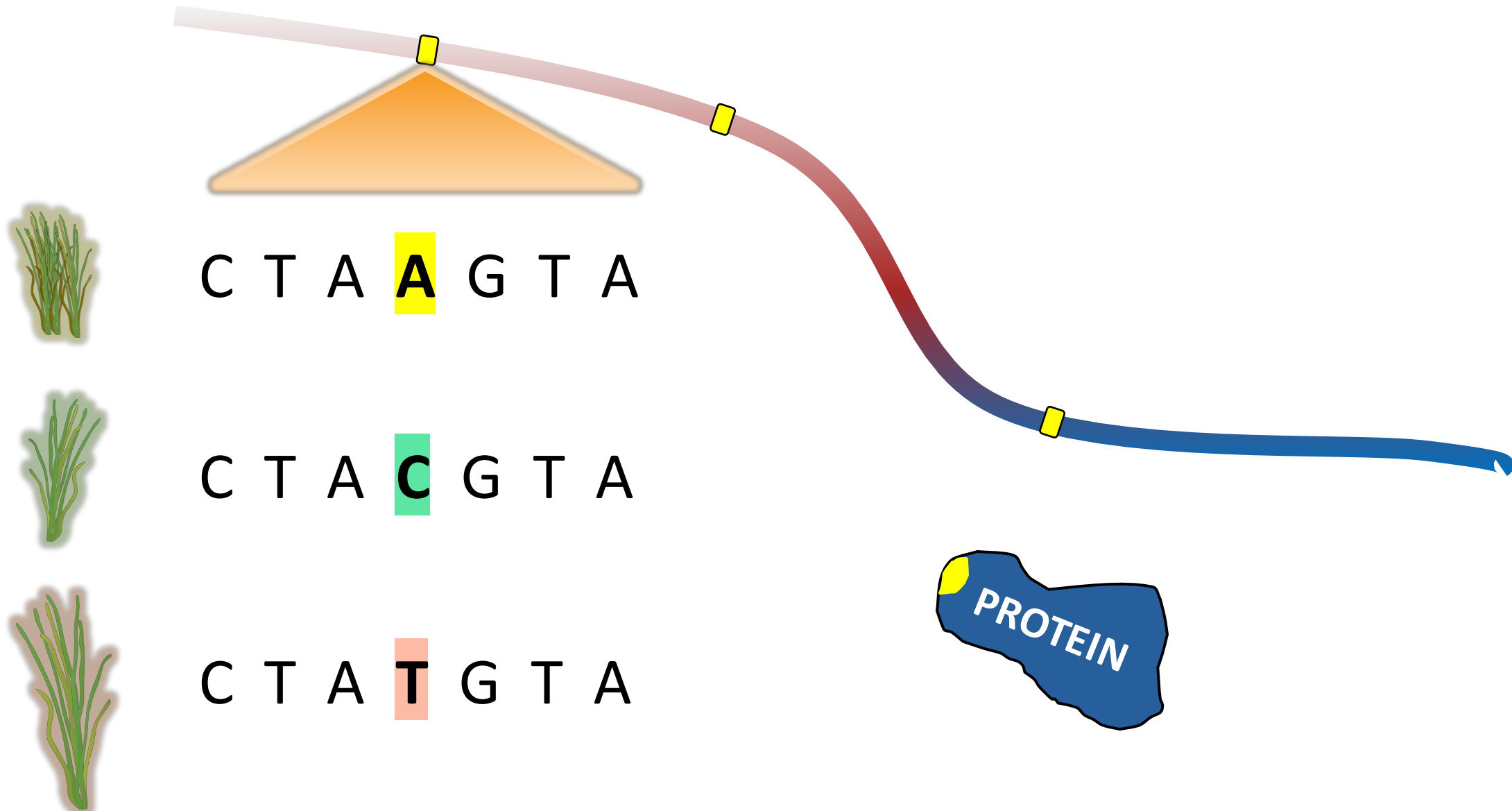
s to sample **65**
ates from NC to

population, **768**

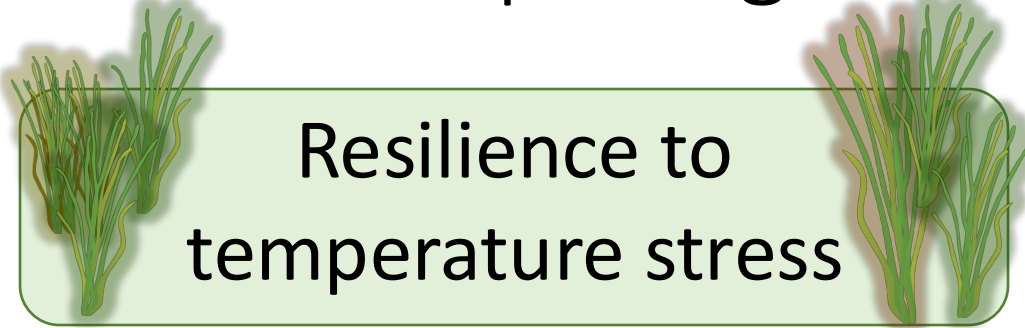
height, depth,
emps (*in situ*),



Identifying single nucleotide polymorphisms (SNPs)

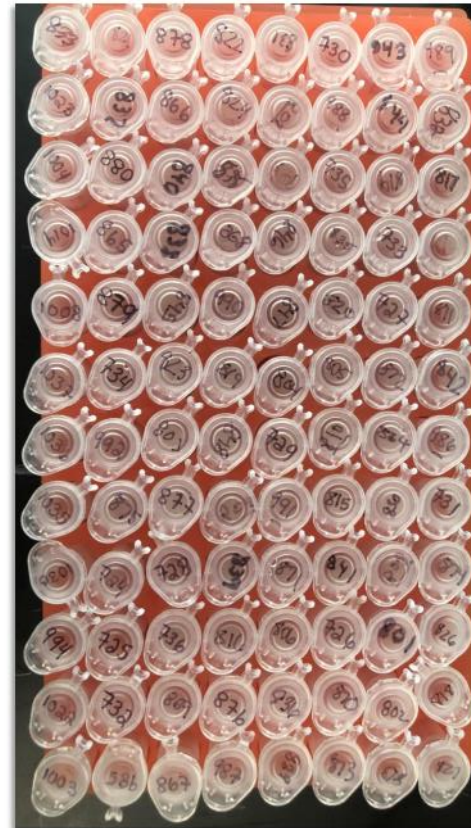


Adaptive potential and adaptive genetic differentiation



Genetic diversity /
adaptive potential

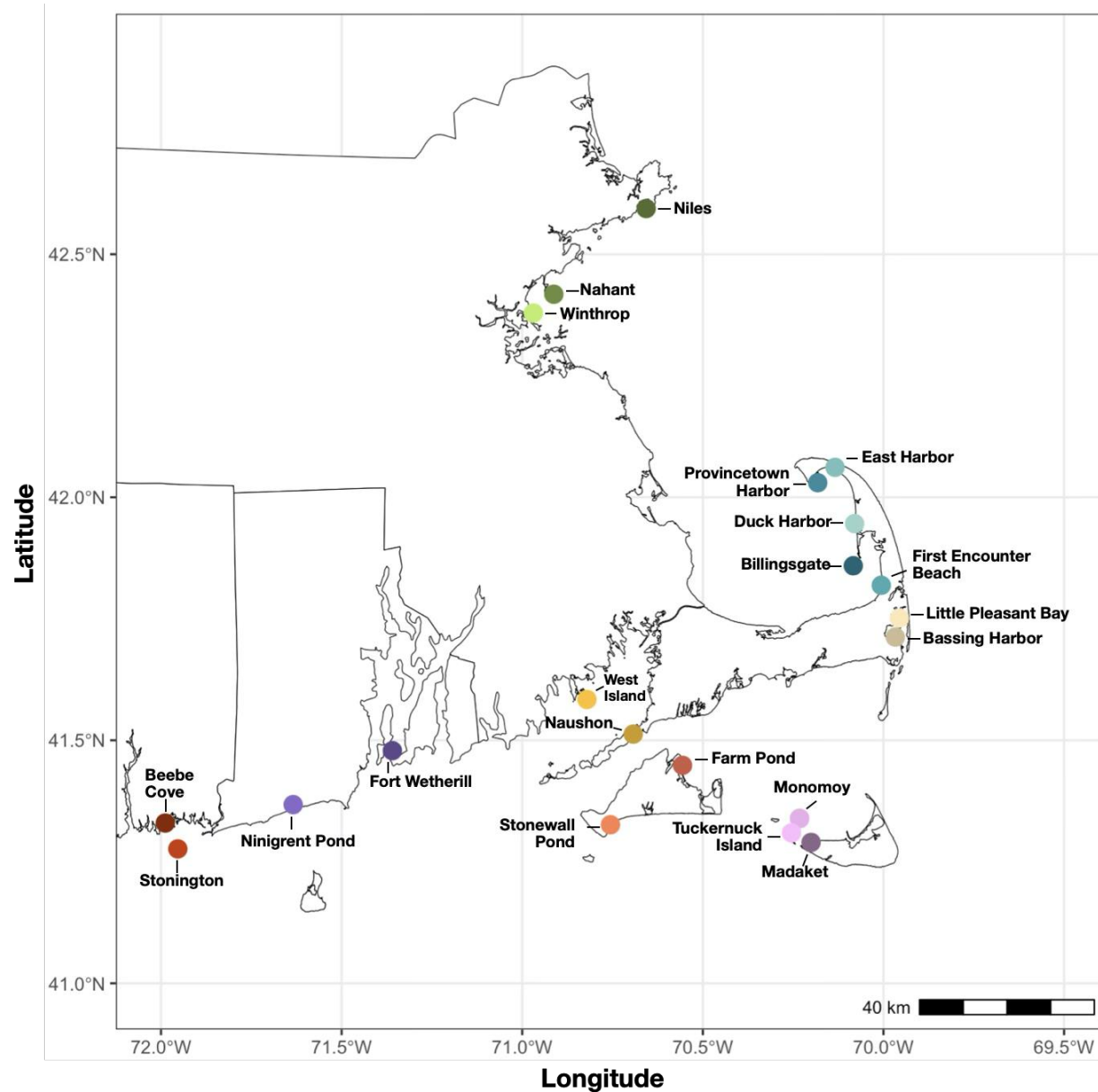
Neutral SNPs



Adaptive genetic
variation

Identify SNPs under selection

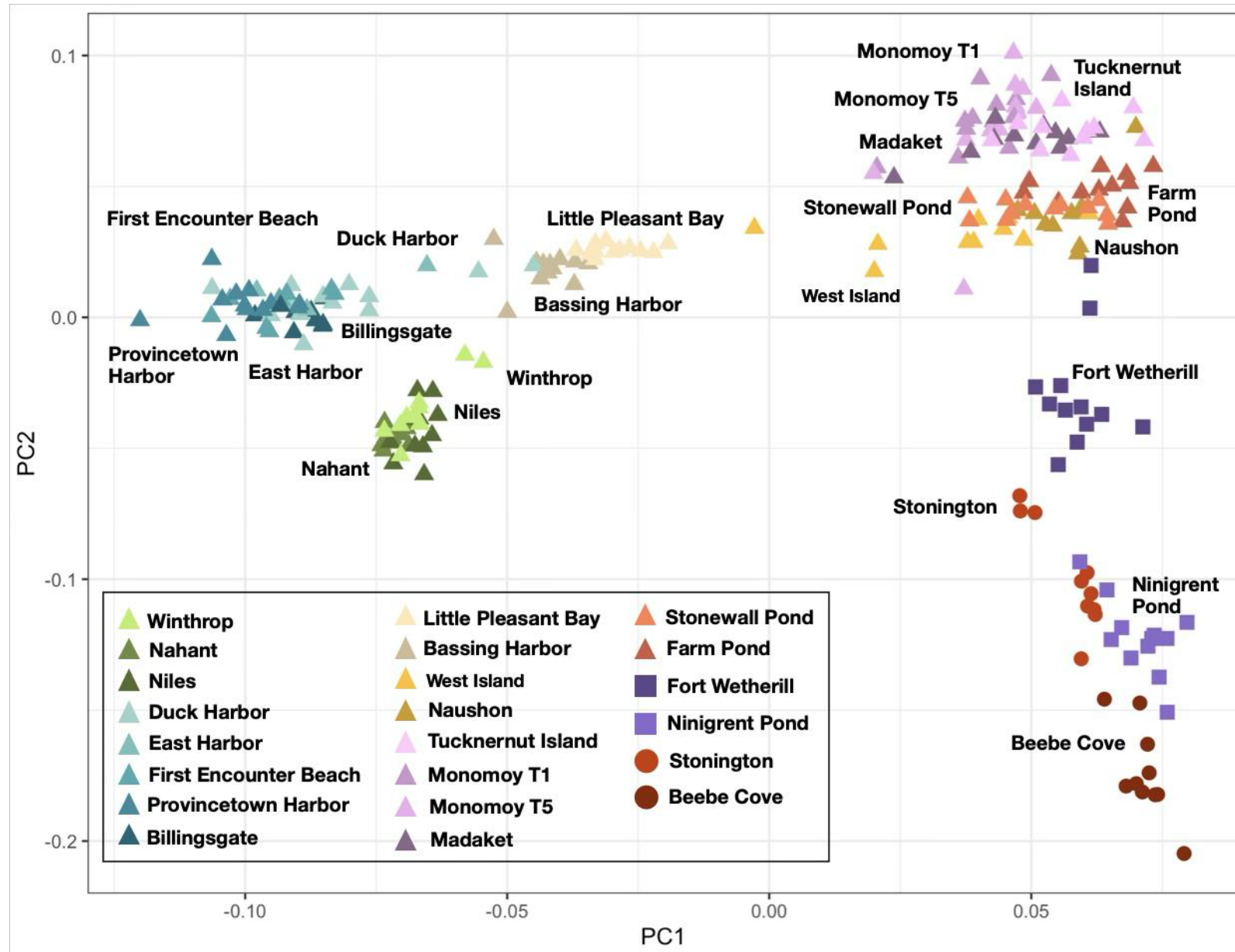
Preliminary SNP results: CT to MA



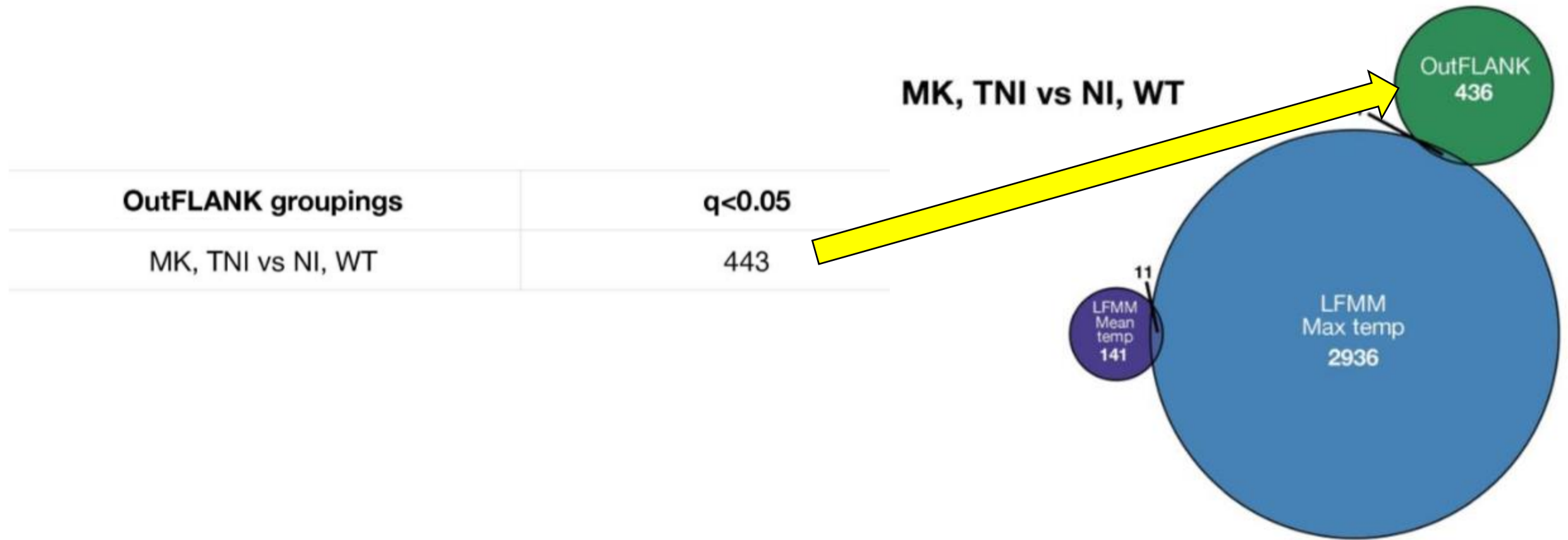
○ Introduction — ● Resiliency and Genetics — ○ AGF and Common Gardens — ○ Next Steps

Figure courtesy of A. Novak, S. Kamel

Population Differentiation: CT to MA

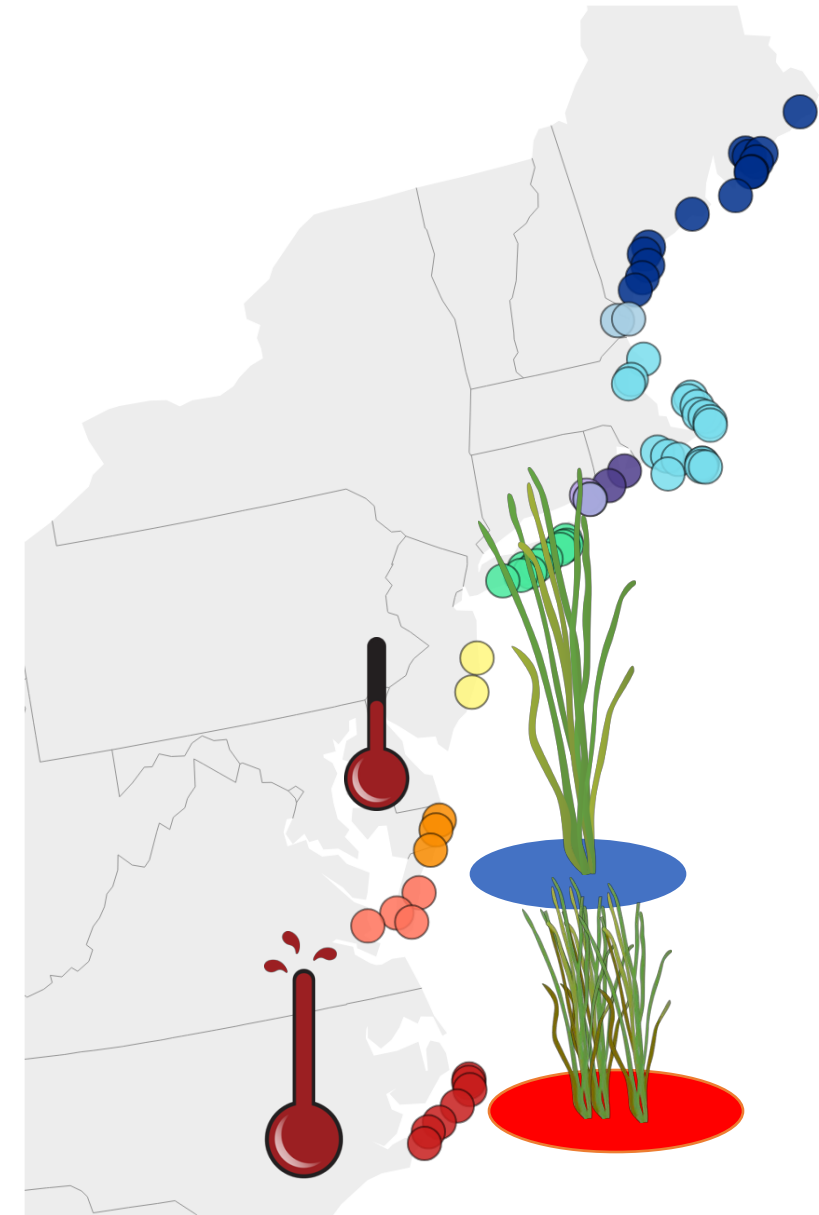


MA site temperature associated divergence?

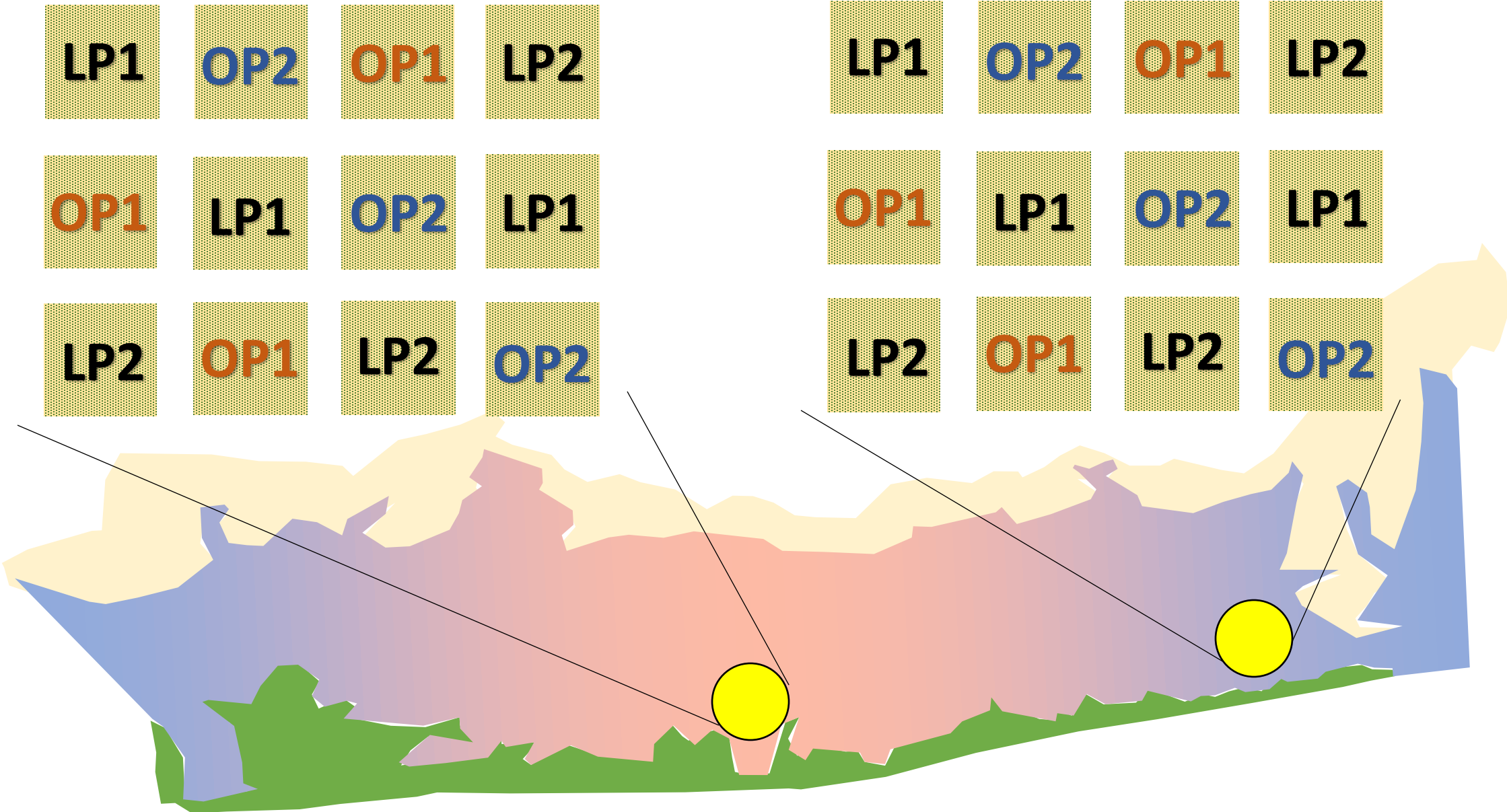


Seeding resilience: assisted gene flow in Eelgrass

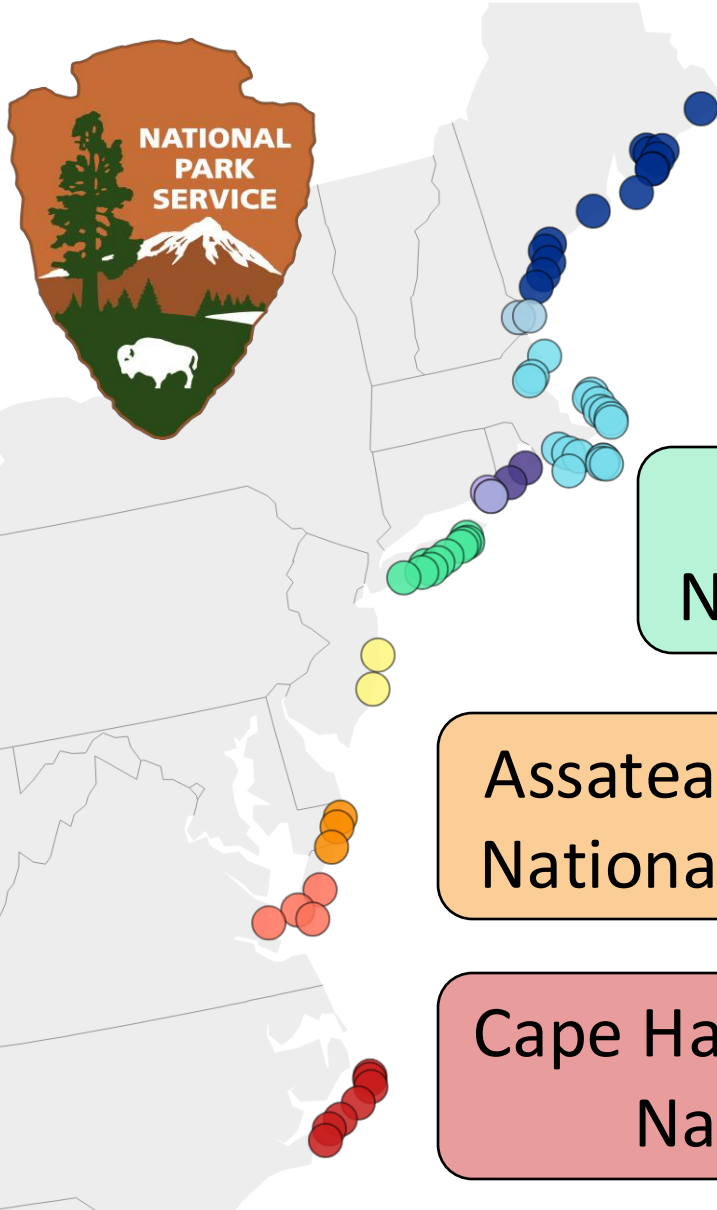
- ***Common Garden Experiments:*** seeds sourced from local and outsourced populations are grown under the same conditions to assess differences in performance



Common garden implementation and monitoring



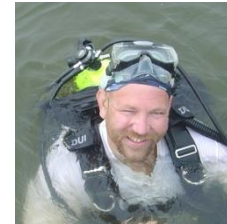
Partners experimenting across five National Seashores



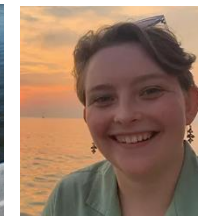
Cape Cod
National Seashore



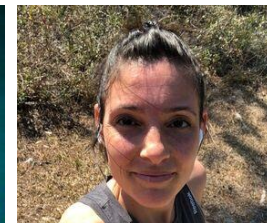
Fire Island
National Seashore



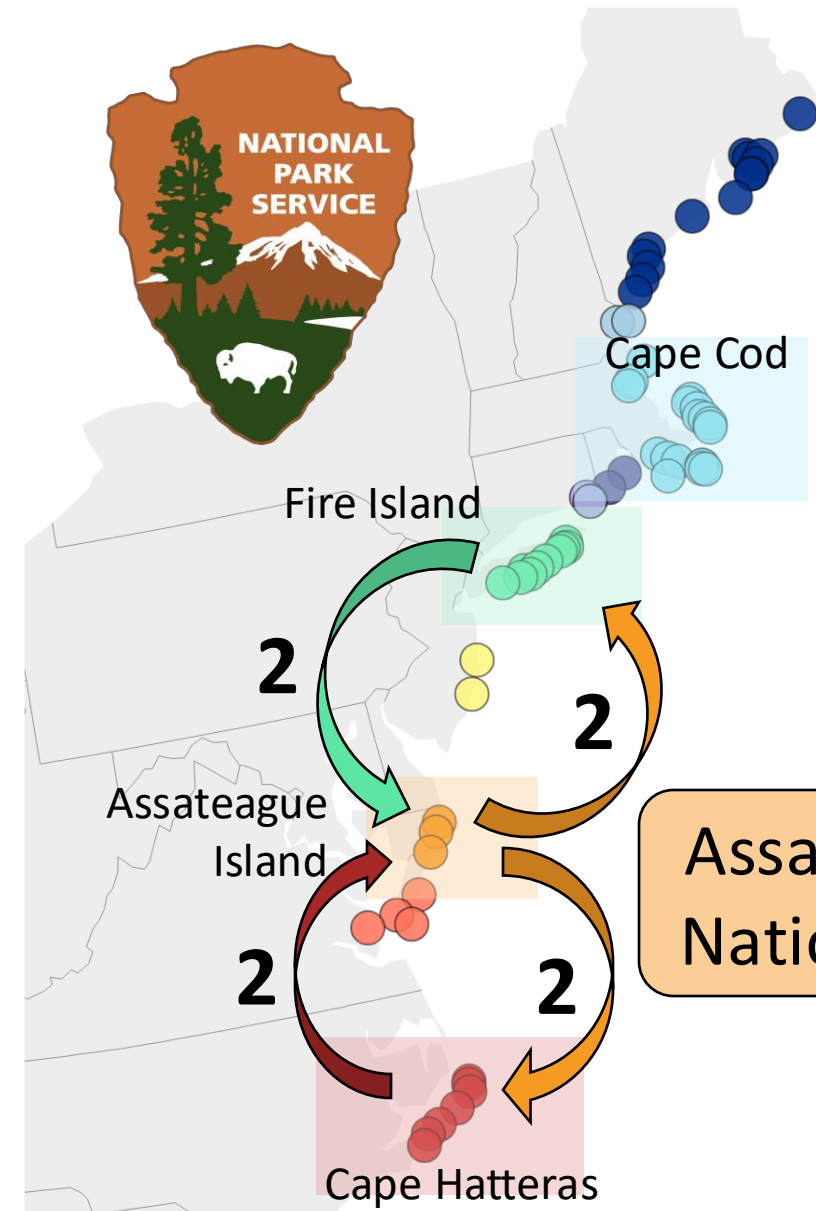
Assateague Island
National Seashore



Cape Hatteras / Cape Lookout
National Seashores



Experimental Design



- Select 2 – 3 local populations from each seashore
- *Shifting windows approach*: populations dispersed within a restricted window to prevent “transplant shock”
- 1 seashore immediately north and 1 seashore immediately south

Assateague Island
National Seashore

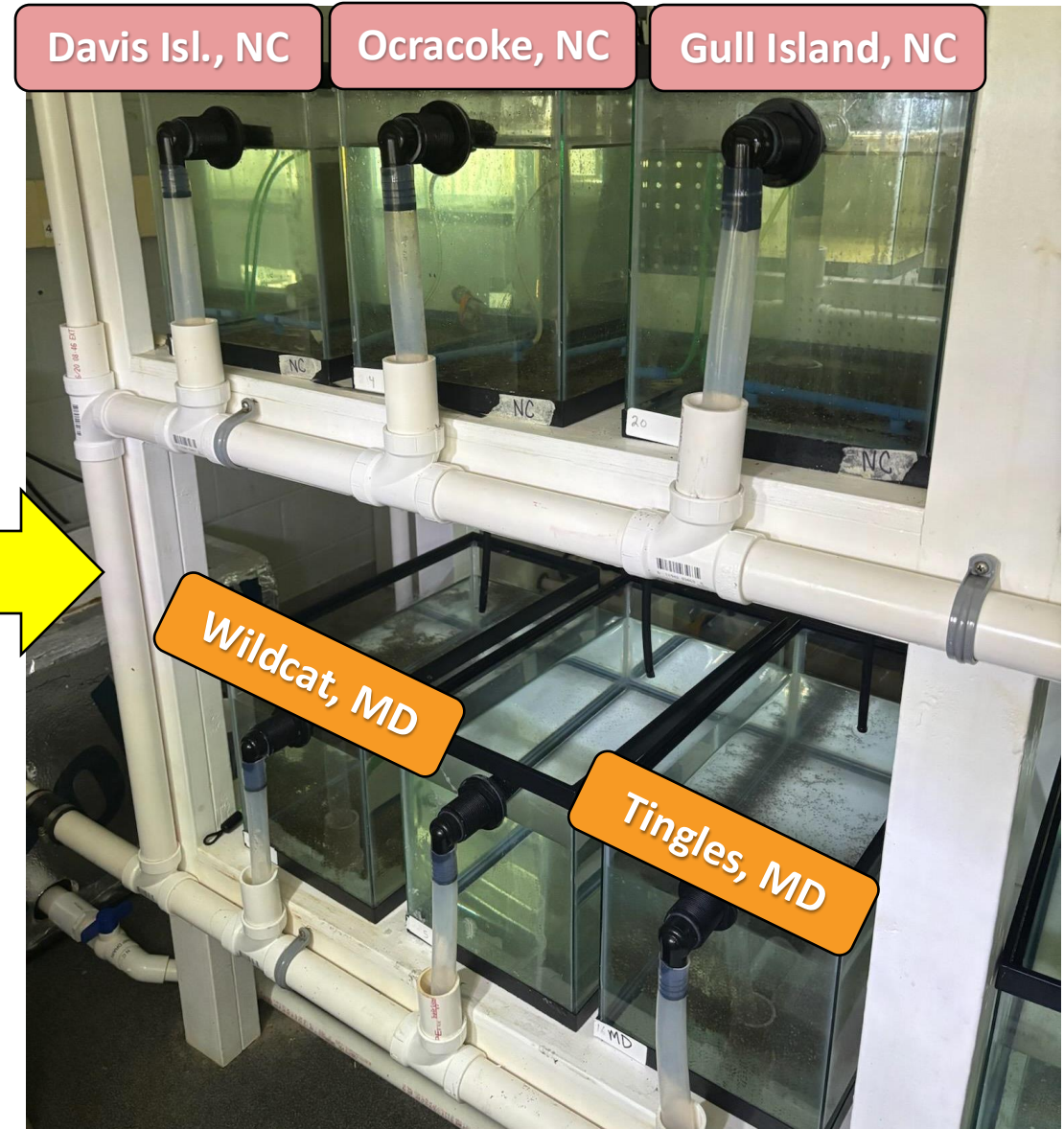
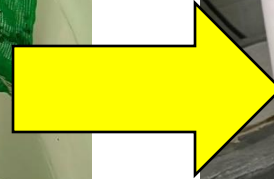
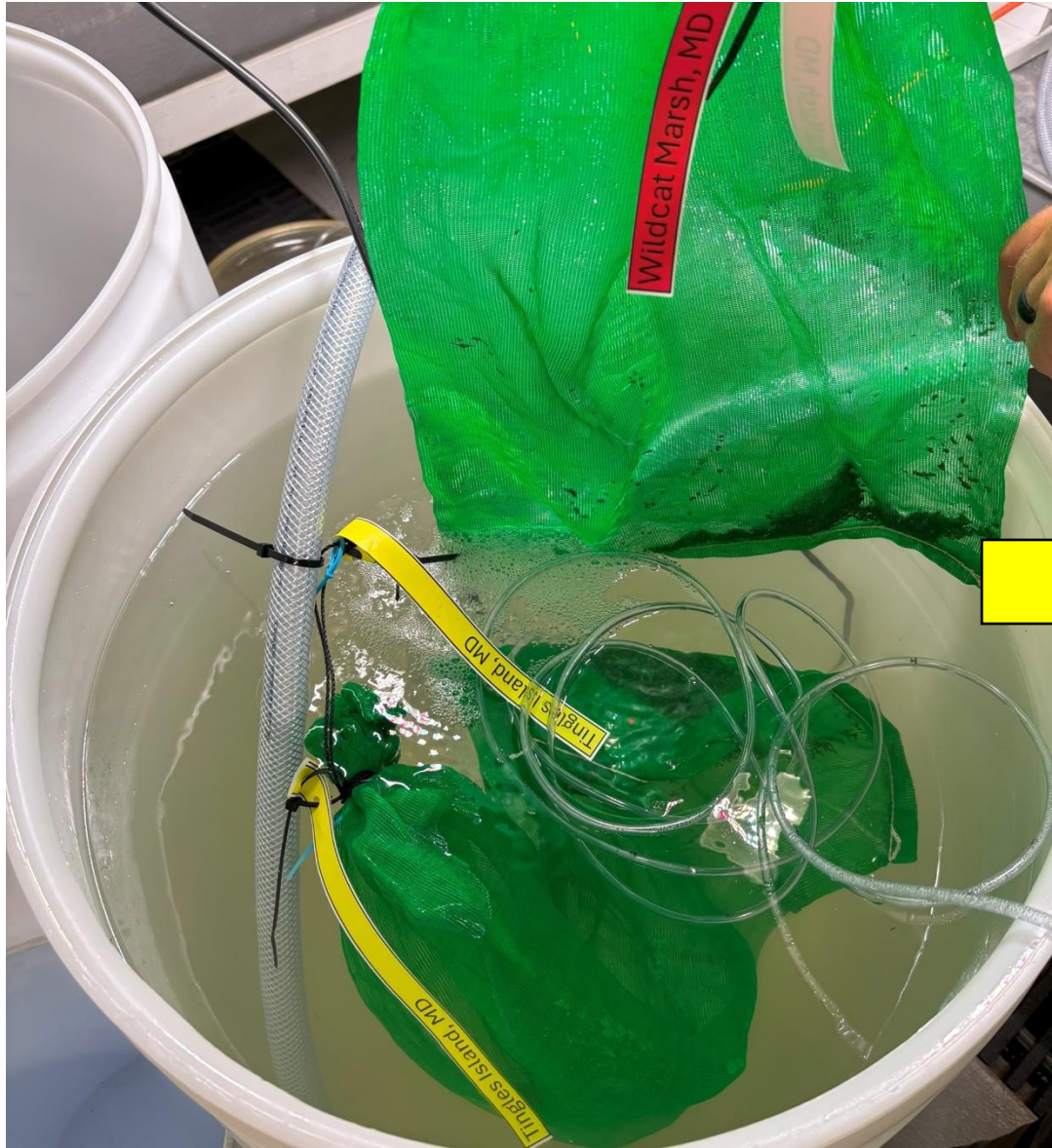
Seeding Resilience: Repro-shoot collection & storage



Seeding Resilience: Seed quantification



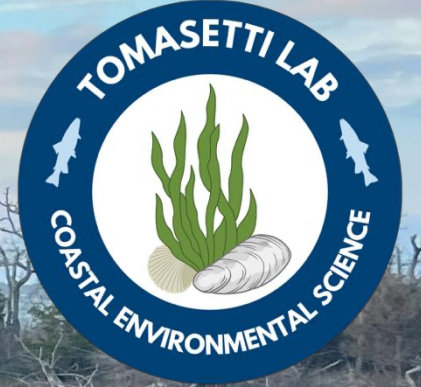
Seeding Resilience: Seed transfer and storage



Next steps

- Implement common garden experiments, monitor performance
- Assess success and identify source populations for future iterations
- Review regulations and define permitting process for non-federally managed waters
- Cultivate resilient genotypes on a large scale (e.g., nurseries or farms along the coast)
- KT: Quantify carbon sequestration across a latitudinal (~ temperature) gradient and degradation sequence

UMES Coastal Environmental Science Lab / Partners



○ Introduction — ○ Resiliency and Genetics — ○ AGF and Common Gardens — ● Next Steps

My contact information

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UMES

sjtomasetti@umes.edu

<https://www.tomasettilab.org>





The Coastal Carbon Network can contribute to Nature Based Solutions

Annie Tamalavage, PhD



SMITHSONIAN
ENVIRONMENTAL
RESEARCH CENTER



LIFE ON A SUSTAINABLE PLANET
Smithsonian

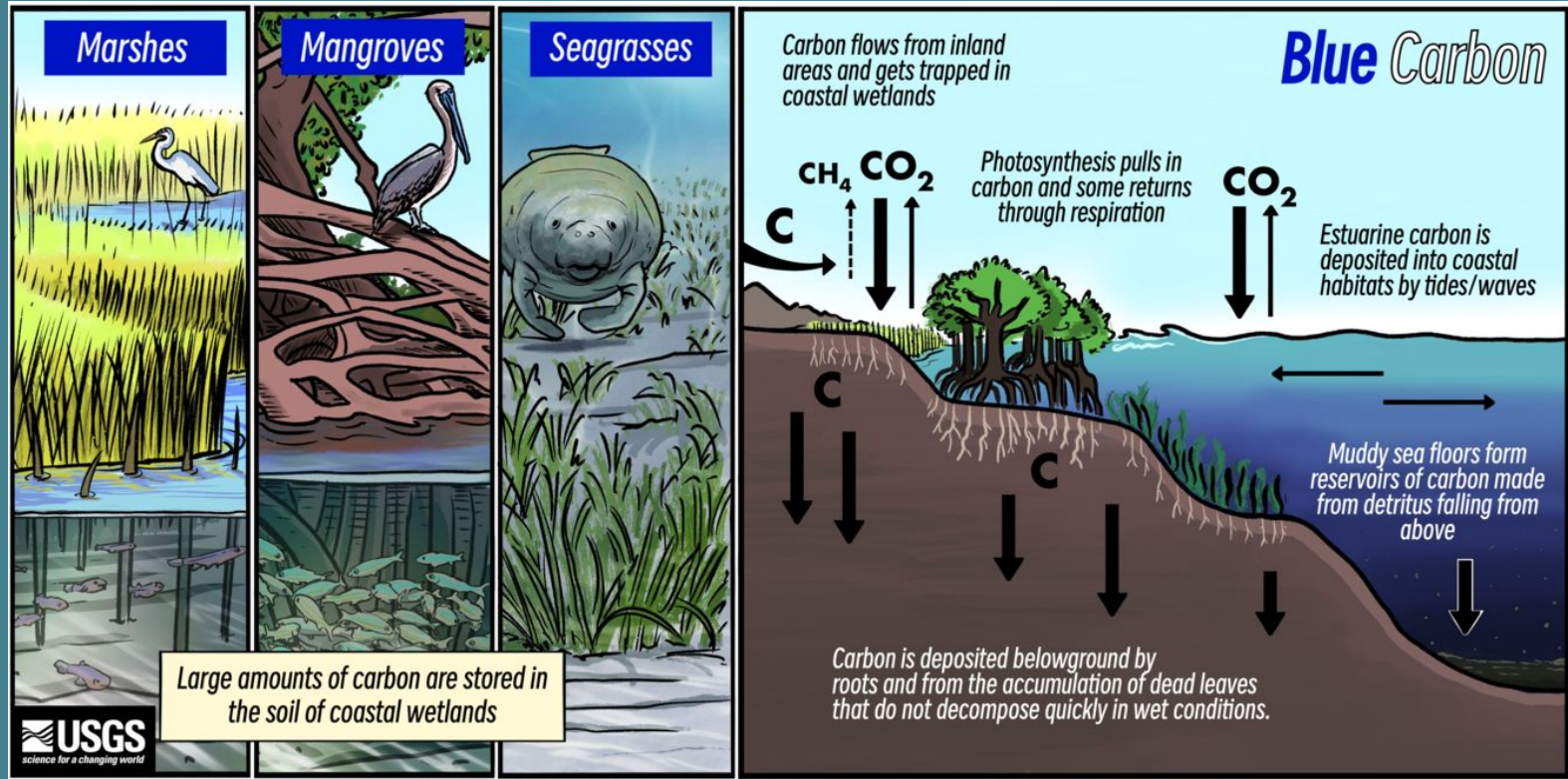
Other SERC-based Coastal Carbon Network team:

Andre Rovai, Jaxine Wolfe, Jim Holmquist, Rose Cheney

Pat Megonigal, Hannah Morrisette, Steve Canty, Abby Lewis

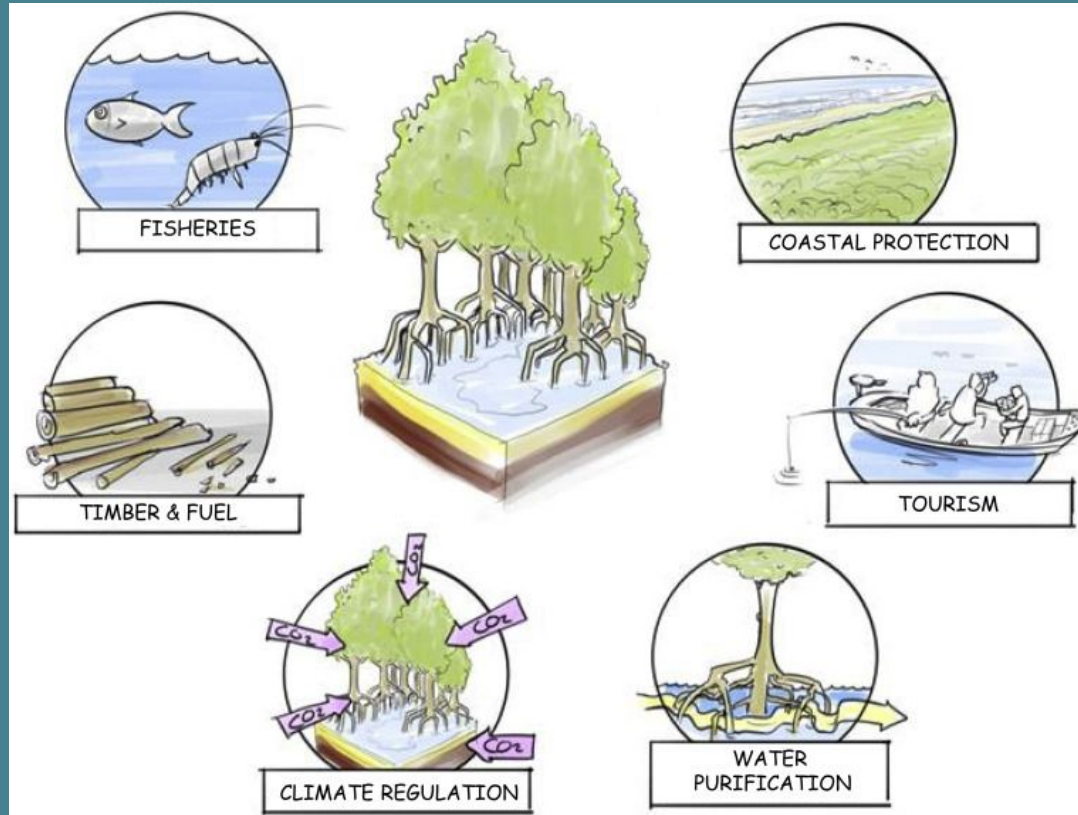


Blue Carbon as a Nature Based Solution



- Carbon crisis? Let's understand and preserve ecosystems that store carbon efficiently.
- BC: carbon captured by the world's ocean and coastal ecosystems, less GHGs to the atmosphere (mitigation)
- Coastal wetlands like mangroves, seagrasses, salt marshes, and macroalgae are commonly accounted for C sinks, but can be threatened.

Blue carbon ecosystems services not limited to mitigation



Worthington et al., 2020

NbS: interventions that use nature and the natural functions of healthy ecosystems to tackle some of the most pressing challenges of our time. -WRI

What is the Coastal Carbon Network?

Our goal is to accelerate the pace of discovery in coastal carbon science by **serving a global community of researchers and practitioners** with access to data, synthesis opportunities, and analysis tools.

How?

- Fostering a community dedicated to coastal wetland carbon science for basic research, policy development, and management.
- Exploring the ecological links between coastal wetlands, estuaries, and the atmosphere.
- Co-development of data and analysis tools that support the diverse needs of scientists, policy makers, and managers.



Tracey Saxby & Annie Carew,
IAN UMCS

The Coastal Carbon Data Library & Atlas

Provides publishing services and maintain an archive of open-source data, called the Coastal Carbon Data Library.

The Coastal Carbon Atlas enables users to explore, query and download data from the Coastal Carbon Data Library.

16,143 soil profiles across
11 habitats

70 countries

Collected across 64 years

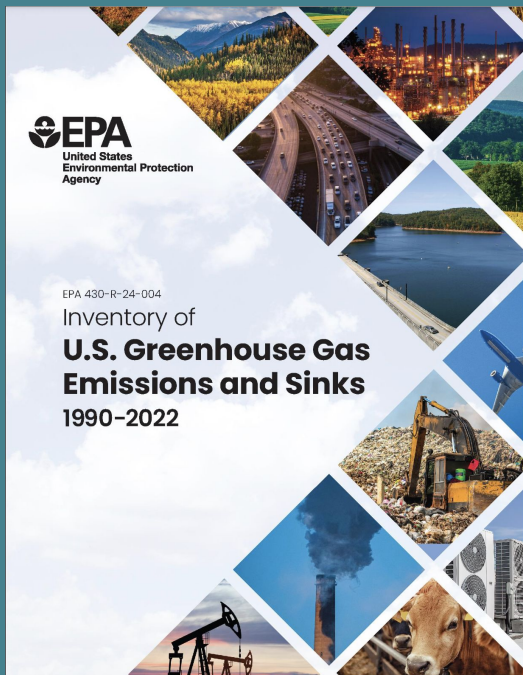
What can the CCN do?



CCN data contributions → GHG inventories

Leveraged the data library to inform the 1990-2022 National GHG Inventory

J. Wolfe, J. Holmquist, Silvestrum Climate Associates



- Integrated soil carbon sequestration rates from new studies across land use categories and climate zone for vegetated coastal wetlands.
- “The updated synthesis resulted in a general increase in soil carbon accumulation rates for estuarine emergent and scrub/shrub wetlands, which resulted in an annual average increase of removals of 2.3 MMT CO₂ eq. For the entire time series.”

Table 6-70: Annual Soil Carbon Accumulation Rates for Vegetated Coastal Wetlands (t C ha⁻¹ yr⁻¹)

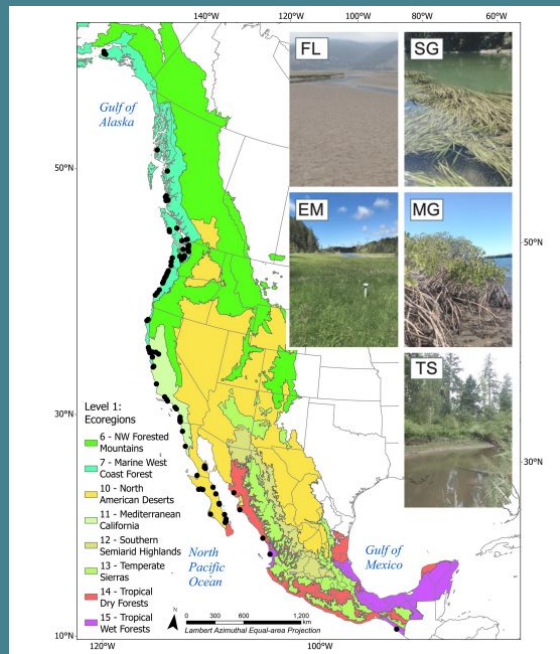
Climate Zone	Cold Temperate	Warm Temperate	Subtropical	Mediterranean
Palustrine Scrub/Shrub Wetland	1.010	1.544	0.45	0.845
Palustrine Emergent Wetland	1.010	1.544	0.454	0.845
Estuarine Forested Wetland	N/A	N/A	0.821	N/A
Estuarine Scrub/Shrub Wetland	1.254	1.039	0.821	0.845
Estuarine Emergent Wetland	1.254	1.039	1.587	0.845

Source: All data from CCRCN (2023)⁶²; N/A means there are no estuarine forested wetlands outside of subtropical regions.

CCN data contributions → research for regional stocks

Blue Carbon Stocks Along the Pacific Coast of North America Are Mainly Driven by Local Rather than Regional Factors

C. Janousek et al., Global Biogeochemical Cycles (2025)



- Sediment organic carbon stocks were greatest in woody tidal wetlands.
- Unvegetated tideflats store much greater sediment carbon stocks
- Most stocks variability was explained by local-scale drivers (e.g., elevation) rather than large-scale climate gradients

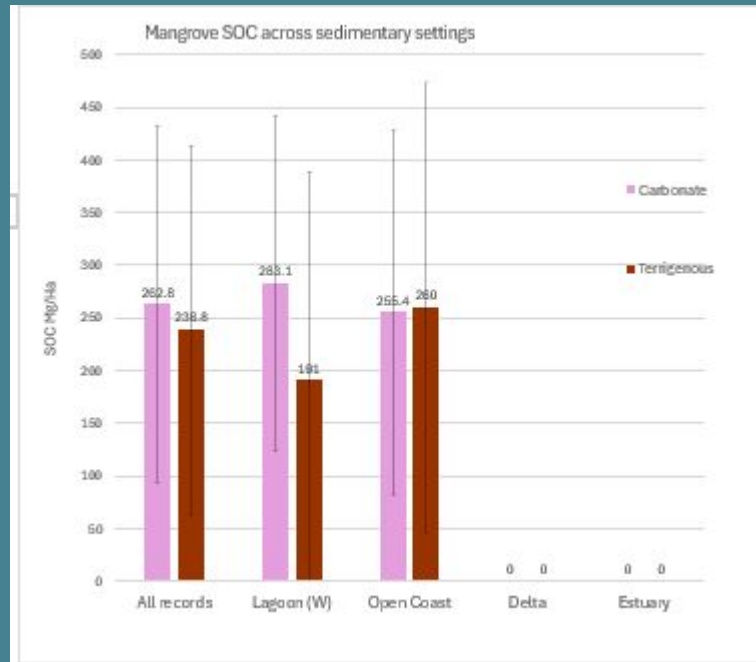
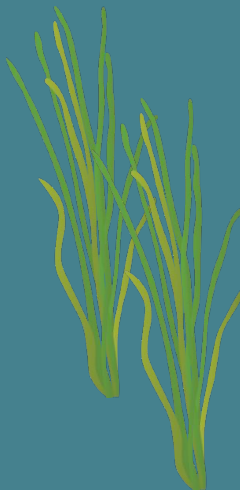
→ management implications and anticipation of habitat change to stock efficiency

CCN data contributions → Evaluating global coastal settings + stocks

Using publicly accessible datasets to evaluate the impacts of geomorphic setting on blue carbon storage across the seascape

Tamalavage et al., in prep

- Mangroves in carbonate sedimentary settings hold more soil organic carbon.
- Seagrasses near carbonate coastlines hold less soil organic carbon.
- Loss on Ignition organic carbon data is still useful when evaluating global-scale patterns of soil carbon.



CCN data contributions → help develop Nationally Determined Contributions (NDCs)

Including coastal wetlands into Nationally Determined Contributions, determined by in-country needs

Hannah Morrisette & Steve Canty, Marine Conservation Lab, SERC



Adaptive management

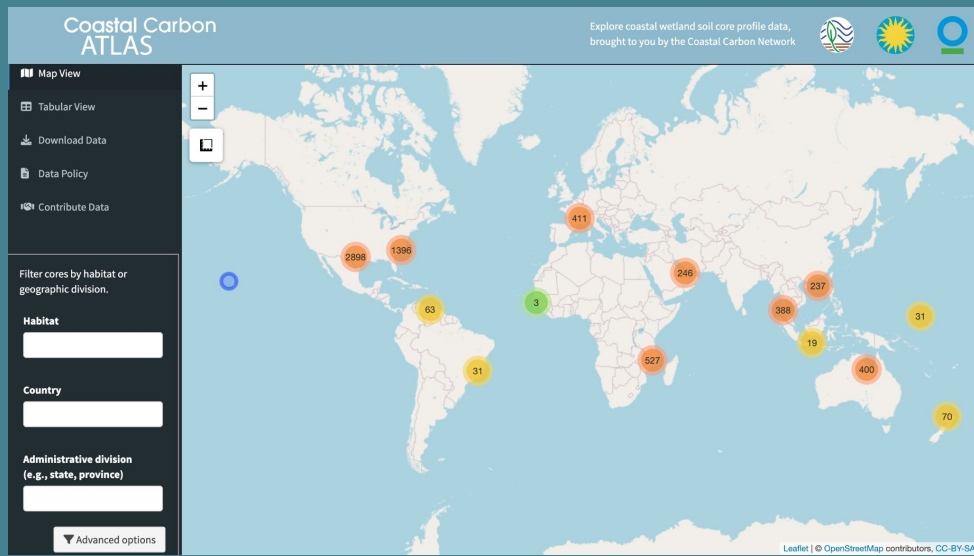
continued pipeline



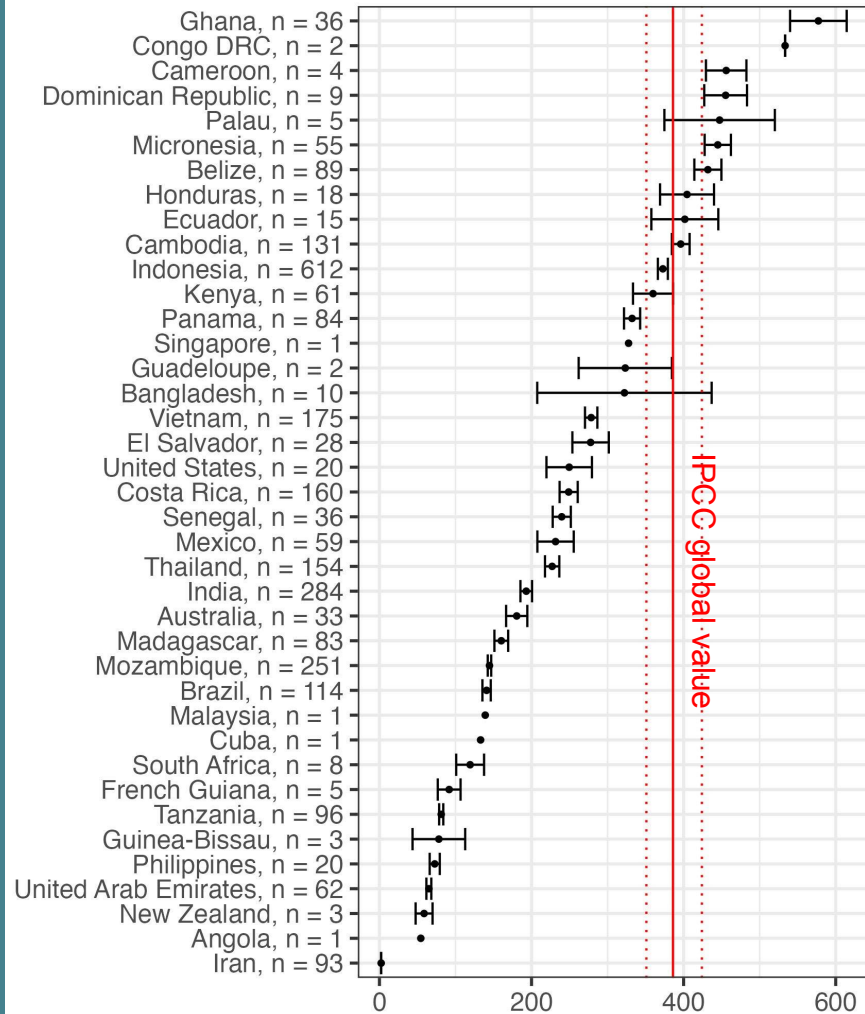
Community investment, social ecological support (Grimm et al. 2023/2025, Bonilla et al., 2025)

Building Inventorying Capacity through Data Stewardship

Through targeted outreach and data discovery efforts, the Coastal Carbon Network has worked to help increase representation of available inventory-supporting data for countries.



1m Mangrove Soil Carbon (Mg/ha)



Welcome to the Coastal Carbon Inventory Tool!

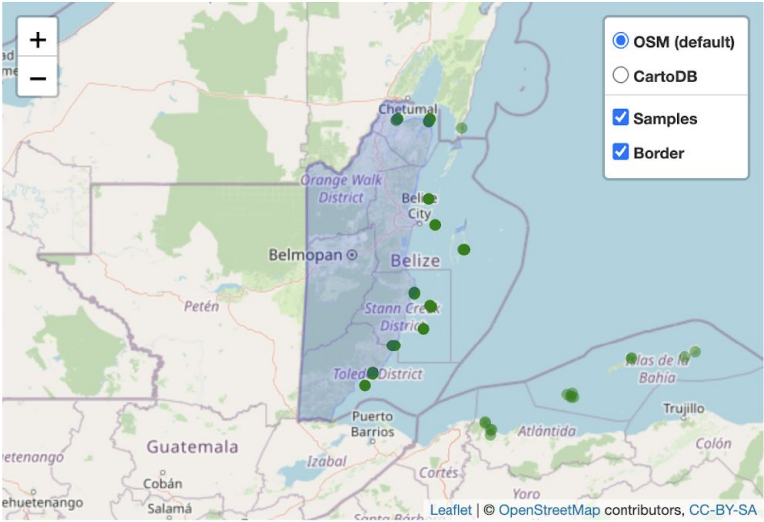
Select a geography

Belize

Reset map to world view

Reset

Please direct any questions or suggestions to CoastalCarbon@si.edu

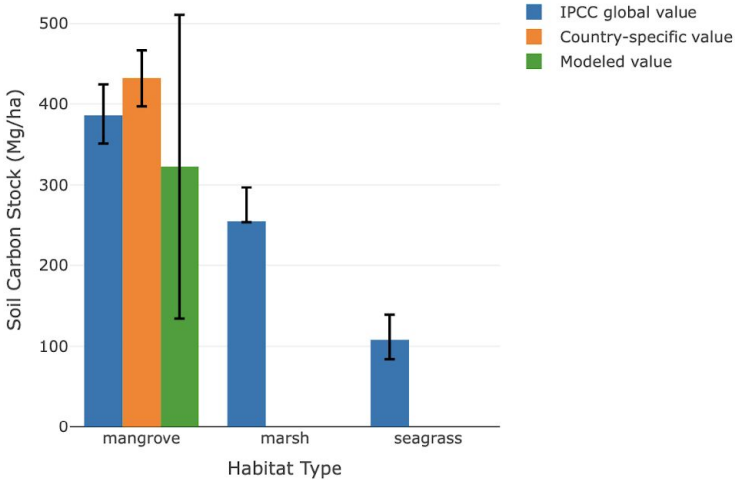


Global Stocks

Country Stocks

Habitat Area

Data Availability



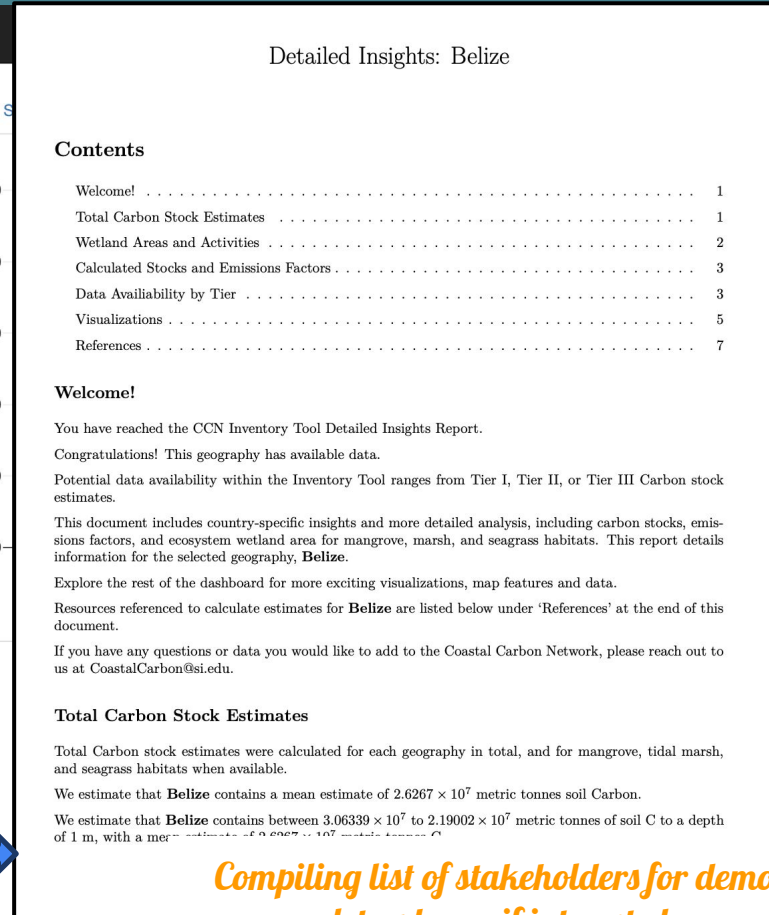
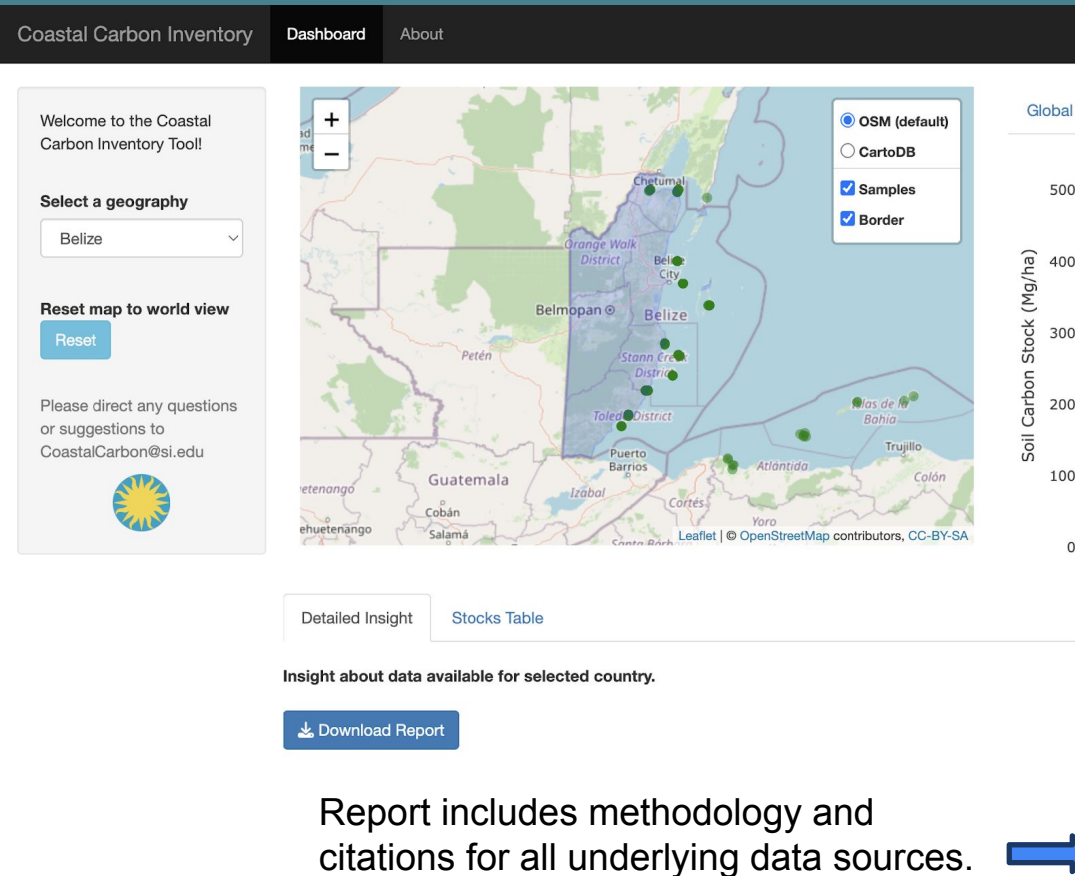
Detailed Insight

Stocks Table

Carbon stocks estimated for tidal wetland ecosystems in Belize

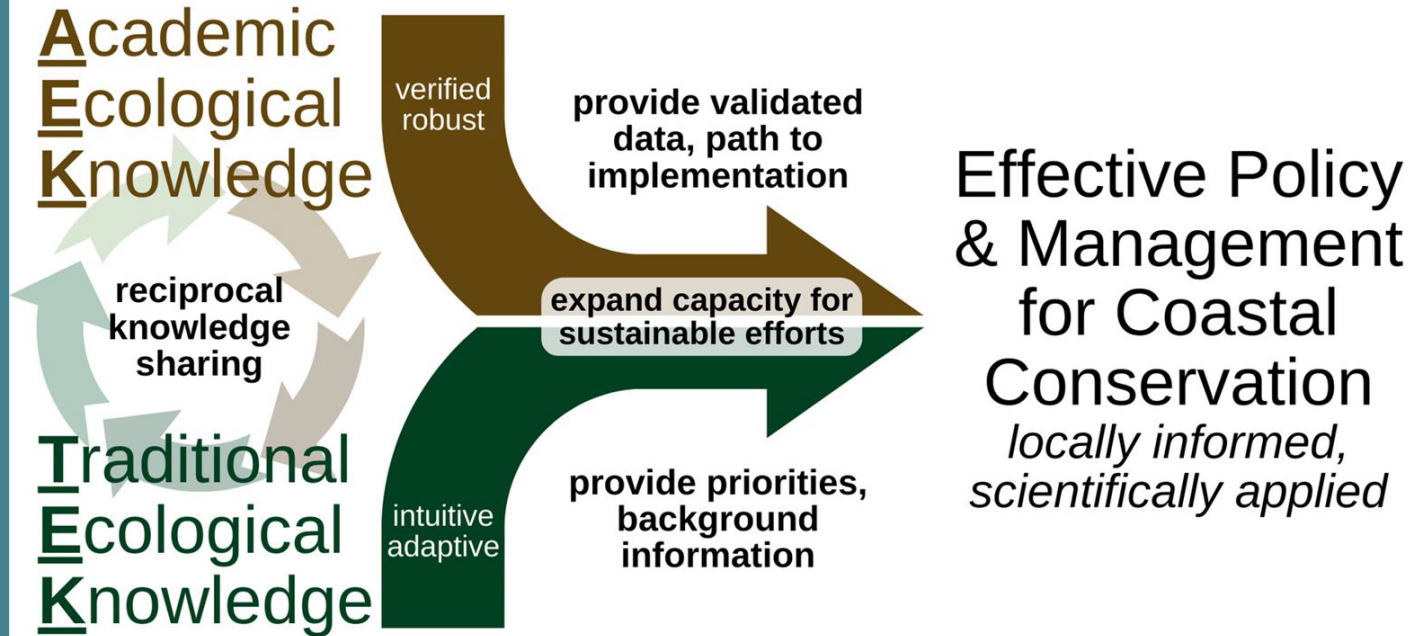
Habitat	Habitat Area (ha)	Mean Soil Stock (MgC/ha)	Mean Biomass Stock (MgC/ha)	CO2 equivalent (Tg)	Reporting Tier
mangrove	56776.7	431.89 (+34.9/-34.9)	73.47 (+/-6.15)	89.99	Country-specific value
marsh	6846.64	255 (+42/-1)		6.41	IPCC global value
seagrass	484784	108 (+31/-24)		192.15	IPCC global value

New tool from the CCN can help inform decision-makers



*Compiling list of stakeholders for demo,
let us know if interested*

Multi-stakeholder engagement is impactful

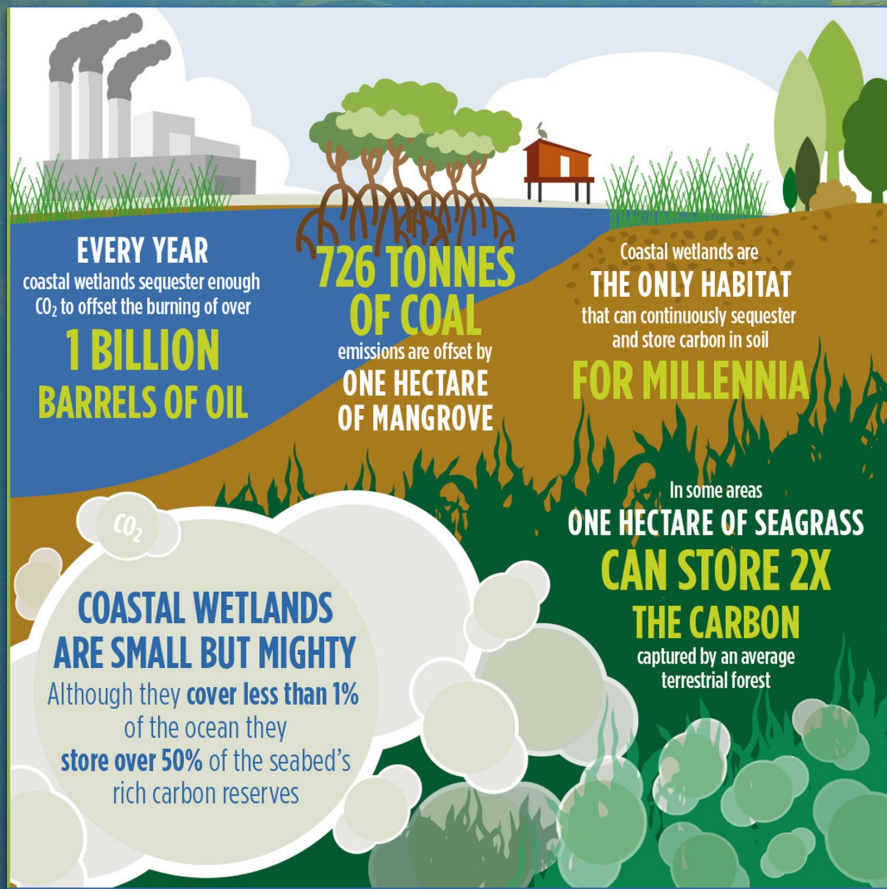


Morrisette for Macreadie et al., submitted

NDCs!

NbS: interventions that use nature and the natural functions of healthy ecosystems to tackle some of the most pressing challenges of our time. -WRI

Considering coastal wetlands is great, complex



Evaluation
Conservation/Protection
Restoration
Establishing baselines

..... or carbon + many ecosystem
services!

The CCN can help to achieve various goals across different interests



*Contributions
welcome!*

Habitats within the CCN atlas: algal mat, mangrove, marsh, microbial mat, mudflat, sabkha, scrub/shrub, seagrass, swamp, unvegetated, upland

More in the future?

TamalavageA@si.edu

Making Blue Carbon Count: Incorporating Coastal Wetlands into State Climate Response



MACAN State of the Science Workshop
July 15, 2025

Pew

Introduction to The Pew Charitable Trusts

- Founded in 1948
- Nonpartisan, evidence-based approach
- Government performance, health, environment
- US environmental work
 - Energy Modernization
 - U.S. Conservation
 - Cross cutting international – US work e.g., plastics
- Pew & blue carbon
 - International work – climate goals (NDCs)
 - US work –state climate planning, blue carbon network, peatlands
 - Targeted research, data driven policy advocacy, outreach/communications

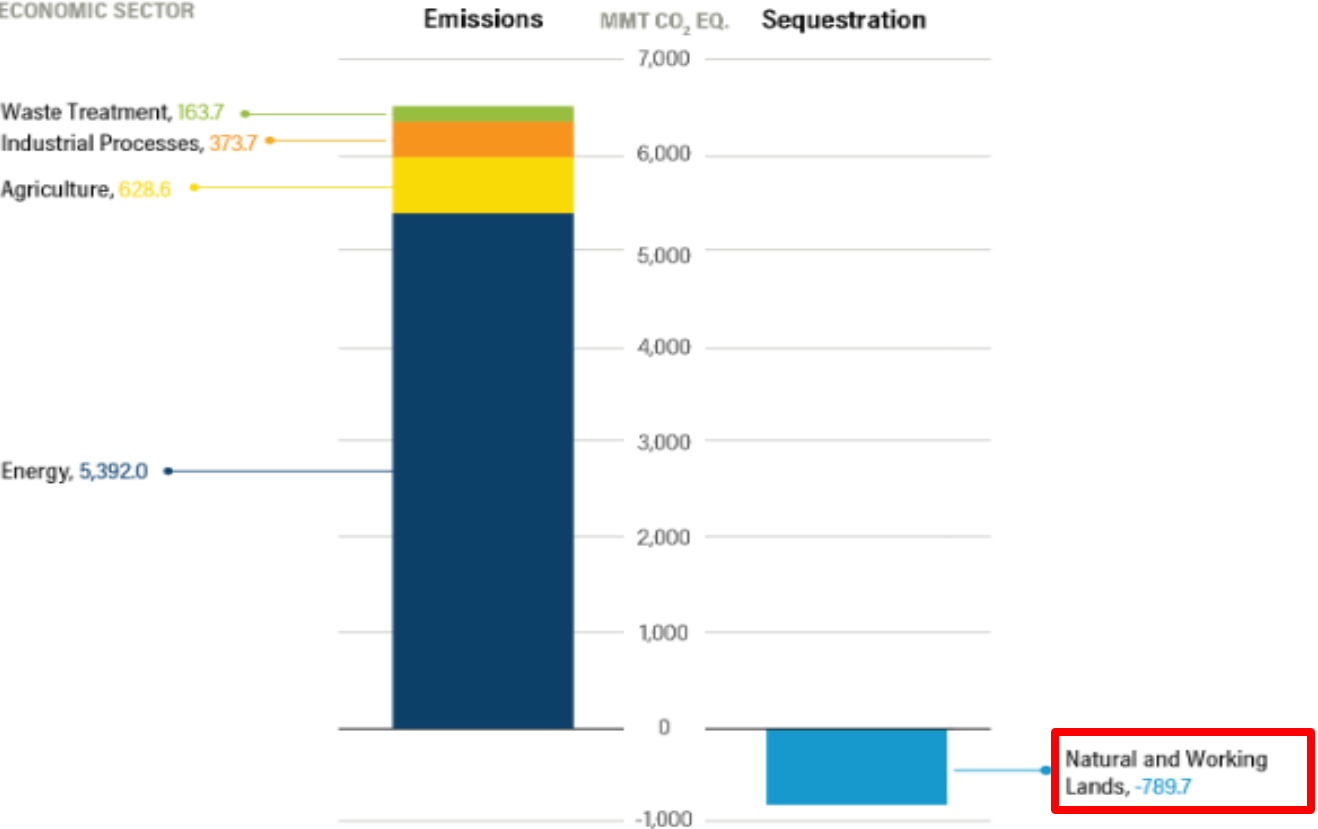


Leveraging Nature for Climate Action

Natural and Working Lands Remove 12% of Gross U.S. GHG Emissions (2019)

US Totals

ECONOMIC SECTOR



Source: EPA, 2021

Nature is not the silver bullet BUT has to be part of the solution

- Climate-fueled impacts – fire, drought, sea level rise – erode the stability of our carbon sinks
- Forests may become a net **source** of emissions
- Peatlands may flip from **sink** to **source**
- Coastal wetlands are vulnerable to sea level rise
- Action is urgently needed to –
 - Protect natural carbon sinks from development, other disturbances
 - Restore degraded habitats wherever feasible
 - Build resilience to climate impacts
 - Marsh migration zones
- “A good resilience strategy is a good blue carbon strategy”



Natural and Working Lands & Climate



Land management: farms, ranches, grasslands, forests, wetlands



Manage for multiple benefits: reduce carbon pollution, clean water, provide flood protection and more



Reduce carbon pollution (e.g., restore degraded landscapes, improve ag practices)

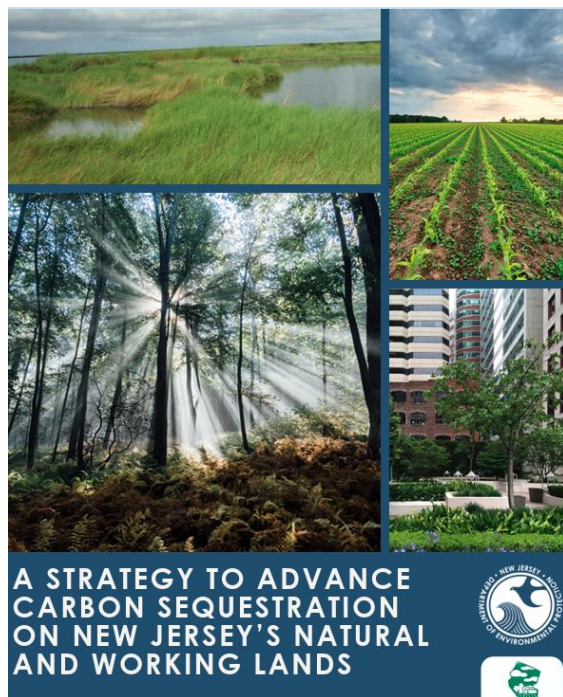


Avoid carbon pollution (protect existing carbon sinks from conversion)



Expand natural carbon sinks (restoration)

Blue carbon habitats as part of Natural and Working Lands



- Need/opportunity to elevate tidal wetlands/seagrasses
- Need to understand (measure) climate impacts (estimates of stocks, fluxes)
 - Tidal wetland/seagrass extent
 - How they are changing over time e.g., tidal wetland to open water
- Multiple benefits
 - Coastal protection
 - Food, biodiversity, culture
 - SAV & localized amelioration of OA
- Opportunity for new policy commitments, funding
- Growing # of states incorporating blue carbon into NWL plans
 - Leadership from Mid Atlantic States

Blue Carbon Policy Progress (non exhaustive)

North Carolina

- Blue carbon inventory, NWL action plan
- \$30 million from CPRG

New Jersey

- Nature-based targets for wetlands, aquatic habitats included in NWL strategy

Oregon

- Blue carbon inventory
- Climate Action Commission NWL roadmap
- Natural Climate Solutions Fund

California

- Nature-based targets for wetlands, aquatic habitats
- Blue carbon habitats eligible for funding under \$10 billion “Climate Bond” passed in 2024

Washington

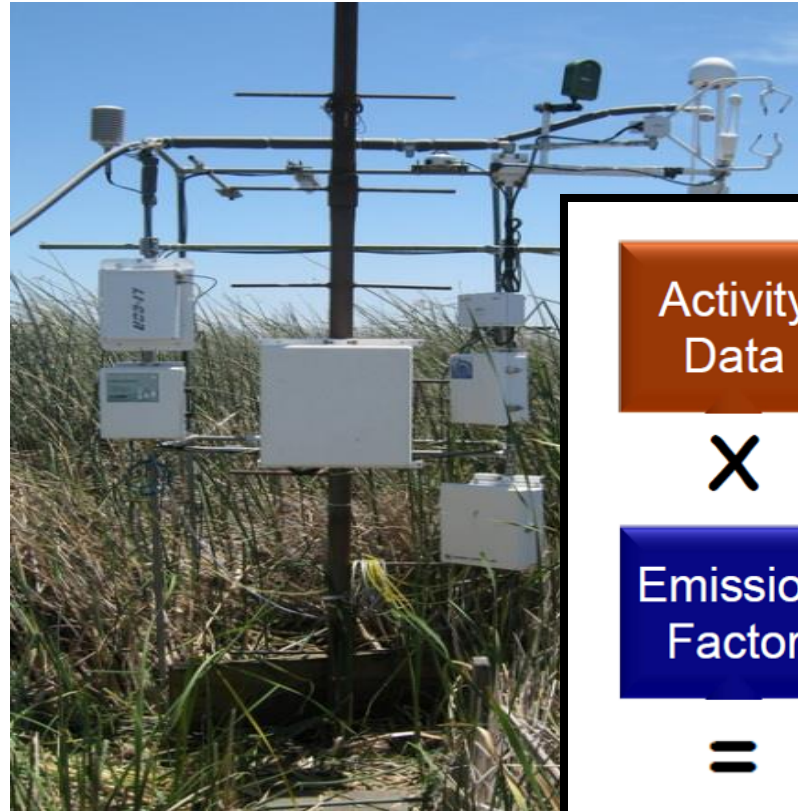
- Dept. of Ecology developing blue carbon inventory, incorporating Tribal Knowledge
- Exploring carbon offsets

WETLANDS				
Recommendation Type	ID	Target	2030	2050
Restoration	WL1	Complete tidal reconnection projects	1 site/yr	2 sites/yr
	WL2	Increase cover of salt marsh vegetation	70 acres/yr	200 acres/yr
	WL3	Restore Atlantic White Cedar Swamps	10,000 acres	20,000 acres
	WL4	Install X linear feet of living shorelines	7,800 ft/yr	10,000 ft/yr
Wetland Protection	WL5	Minimize disturbance of wetland soils	Reduce by 10%	Reduce by 30%
	WL6	Protect tidal wetland migration zones	X	20% of migration zones
AQUATIC HABITATS				
Recommendation Type	ID	Target	2030	2050
Monitoring	AQ1	Assess SAV density and health with ongoing monitoring	X	X
Conservation	AQ2	Protect existing SAV from further loss	Limit to 10% loss	No net loss
Restoration	AQ3	Restore X acres per year (to be quantified after baseline is updated via monitoring)	Within 5 years	Expand program

Science and data to support states - model inventories

Blue Carbon inventories: to what extent do state blue carbon habitats currently remove or emit GHGs?

- Inventories are **retrospective** – provide “middle of the road” estimates of GHG emissions and removals over time (e.g., 1990-2023), can be used to track impact of management actions towards climate goals
- IPCC guidance, tiers 1-3
- Oregon, North Carolina, Maryland have completed inventories
- California, Washington, New Jersey - in process
- Others?



Activity
Data

×

Emission
Factor

=

Emission
Estimate

Science and data to support states - PNW decision support tools

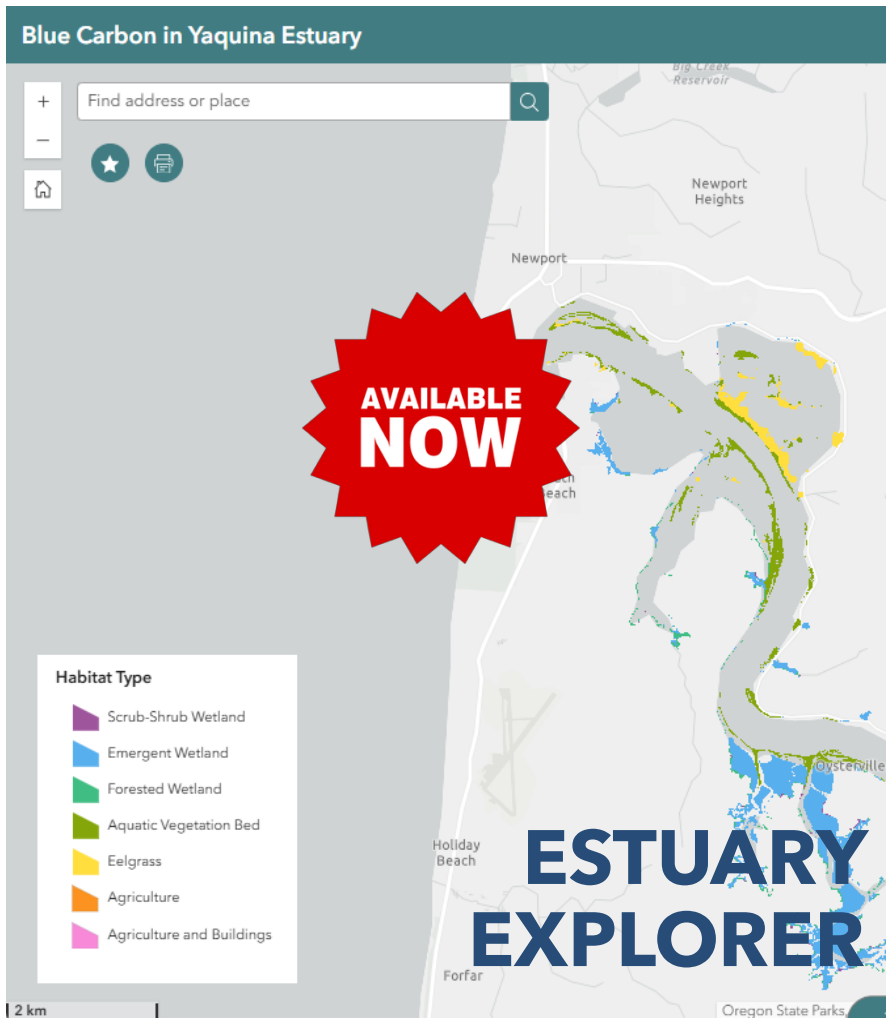
Blue Carbon Heat Map: What are the carbon benefits of protecting & restoring specific coastal areas?

- [Pilot tool](#) developed for Oregon Yaquina estuary
- Illustrates areas where tidal wetland protection & restoration would help maintain and/or expand blue carbon sequestration & storage and reduce GHG emissions
- Explore current habitat types, blue carbon emissions/removals, locations already undergoing restoration, areas with potential for restoration
- Workflow: Explore the map through popups & filters
- Final product: areas to explore for further restoration & data that could be used as input for calculator

Blue Carbon Calculator: What are the GHG emissions & removal impacts of specific land actions in coastal wetlands?

- Online tool to assess acre-by-acre land actions, as input by the user, and applies regional emissions factors to estimate the direct GHG impact.
- Region: PNW generally
- Workflow: Spreadsheet or online data entry
- Final product: Report of action-specific emissions over 0-100 year time period (coming soon)

PNW Blue Carbon Working Group



1. Enter a project name

Scenario 2

2. Select a salinity range for the project site

Range 1
0.0-0.5 PSU

Range 2
0.5 -5.0 PSU

Range 3
>5.0 PSU

3. Select an elevation for the project site

Below MHHW

Above MHHW

4. Select method for calculating CO2 equivalents

Sustained Global Warming Potential [Default]

Global Warming

COMING SOON

Physical Setting		Land Disturbance			
Location	Hydrology	Land Cover Category	Wetland area to be excavated (acres)	Wetland area to be diked & drained (acres)	Wetland area to be filled (acres)
Tidal Wetlands	Tidal	Tidal Forested Wetland			
		Tidal Scrub-Shrub Wetland			
		Tidal Emergent Wetland			
		Seagrass			
		Tide Flat			
Non-Tidal	Wet	Open water			
		Reed canarygrass			
		Wet Forest			
		Wet Scrub-Shrub			
		Wet meadow			
	Dry	Dry Forest			
		Dry Scrub-Shrub			
		Dry Meadow			
		Dry Cropland			
Total:			0.00	0.00	0.00

PACIFIC NORTHWEST REGIONAL BLUE CARBON CALCULATOR

Science and data to support states

SERC Coastal Carbon Atlas

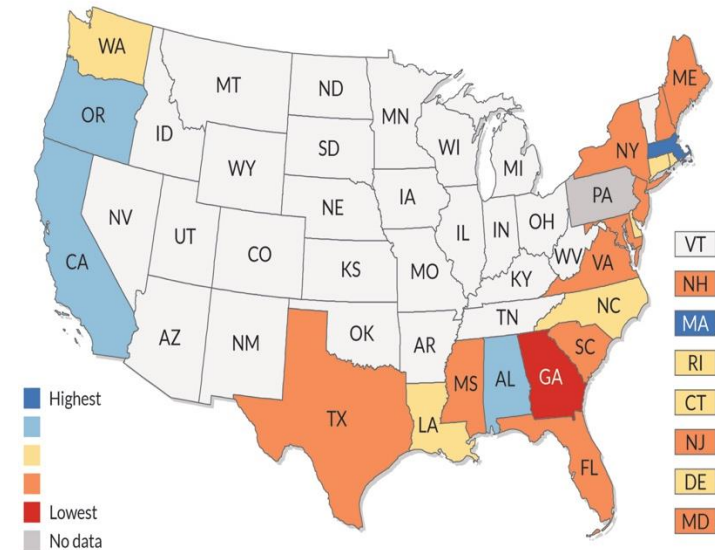
- State Blue Carbon Report Cards ([updated August 2024](#))
- Carbon Accumulation Rate work flow (report winter 2025)
- States can use to estimate stocks & sequestration rates for blue carbon inventories

Freshwater wetlands & carbon

- National map of peatlands (CONUS)
- State can use to prioritize opportunities for protection, restoration & associated climate benefits

States Improve Blue Carbon Data

Update of inaugural 2021 blue carbon report card finds 91% of states increased data quantity, 70% improved quality



Note: Rankings reflect composite averages derived from quantity, quality, and spatial and habitat coverage of soil carbon data, from the Smithsonian Environmental Research Center's "Coastal Carbon Atlas," as of July 2024.

Source: J. Wolfe, Smithsonian Environmental Research Center, "State of the Data: United States Blue Carbon Data Report" (2024).

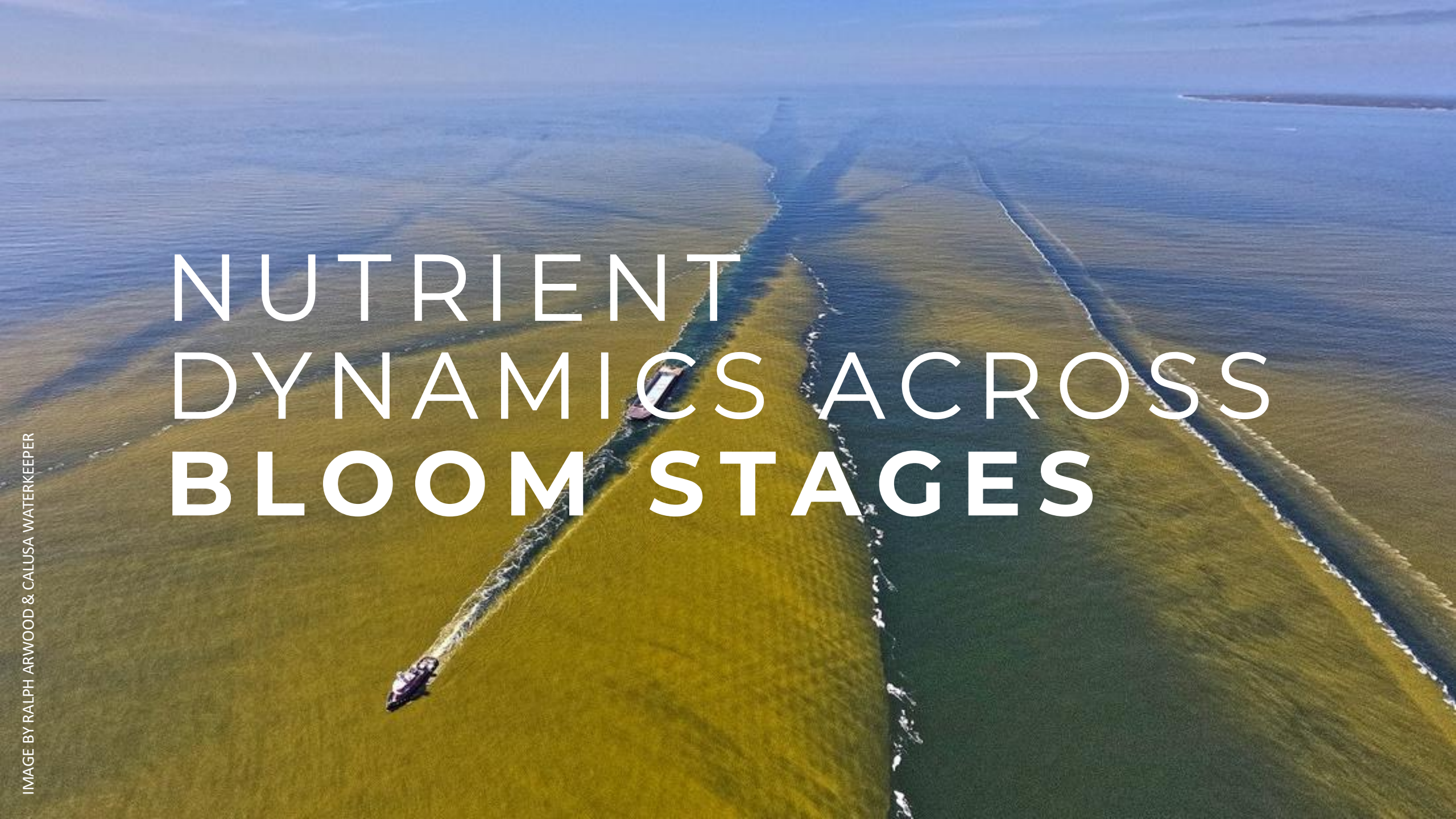
© 2024 The Pew Charitable Trusts



Thank you!

Sylvia Troost - Stroost@pewtrusts.org

BIOLOGICAL IMPACTS

An aerial photograph of a large body of water, likely a bay or estuary, showing a significant greenish-yellow bloom. A small boat is visible in the lower left, moving through the bloom. The text "NUTRIENT DYNAMICS ACROSS BLOOM STAGES" is overlaid in white, bold, sans-serif capital letters.

NUTRIENT DYNAMICS ACROSS BLOOM STAGES

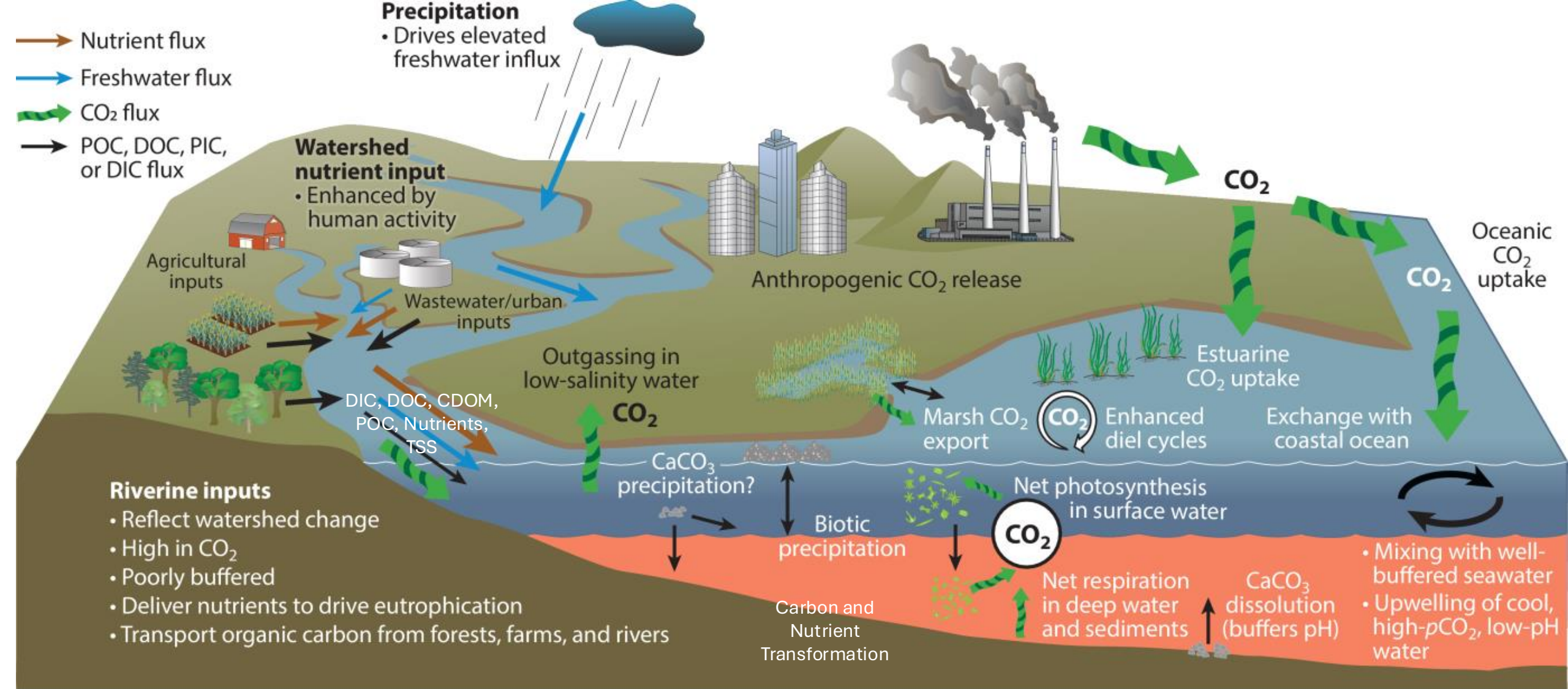
Nutrients and Carbonate Chemistry Associated with HABs

Emily R. Hall, Ph.D.

Senior Scientist and Program Manager

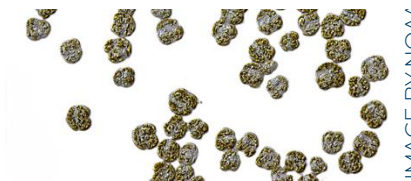
Mote Marine Laboratory



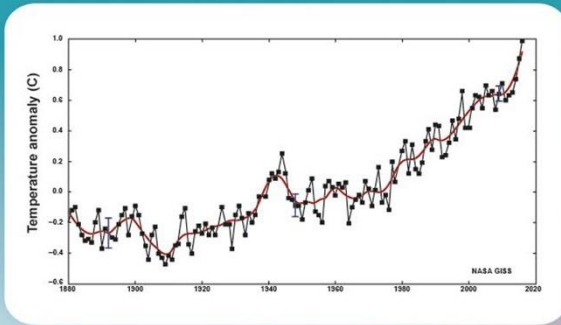


AR Cai W-J, et al. 2021
Annu. Rev. Mar. Sci. 13:23–55

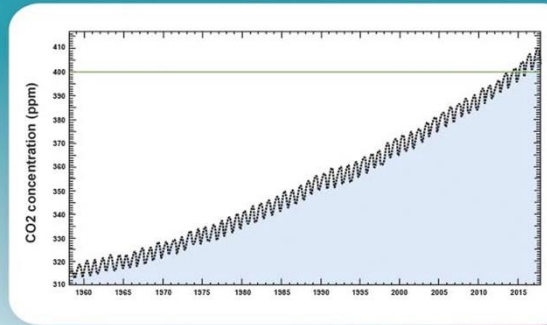
Carbonate Chemistry – Ocean and Coastal Acidification



Global temperatures



Atmospheric CO₂

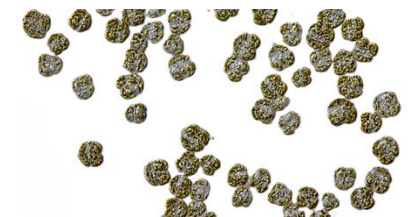
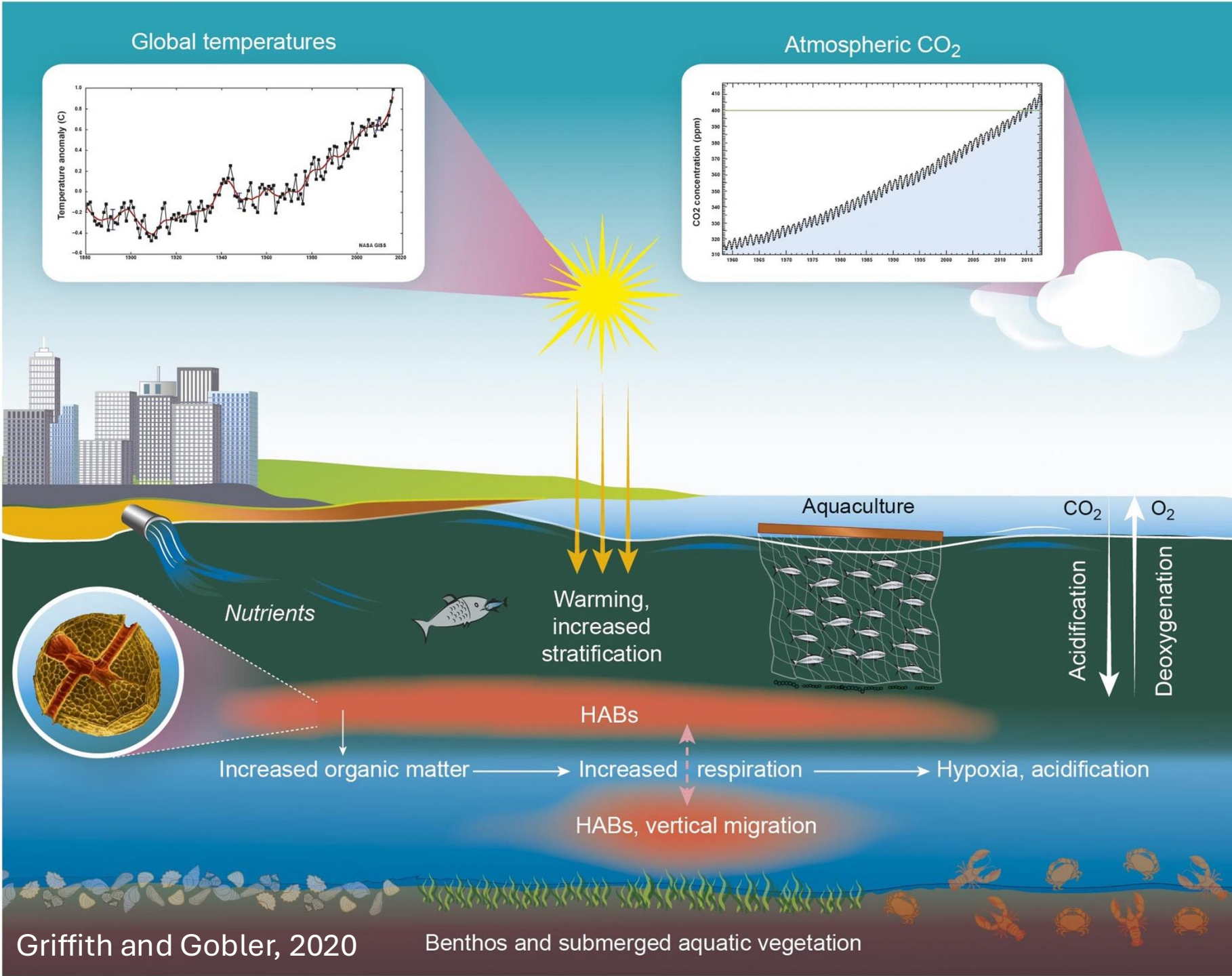


Acidification and HABs as co-stressors

HABs are intensifying in parallel with climate change (warming, hypoxia, acidification)

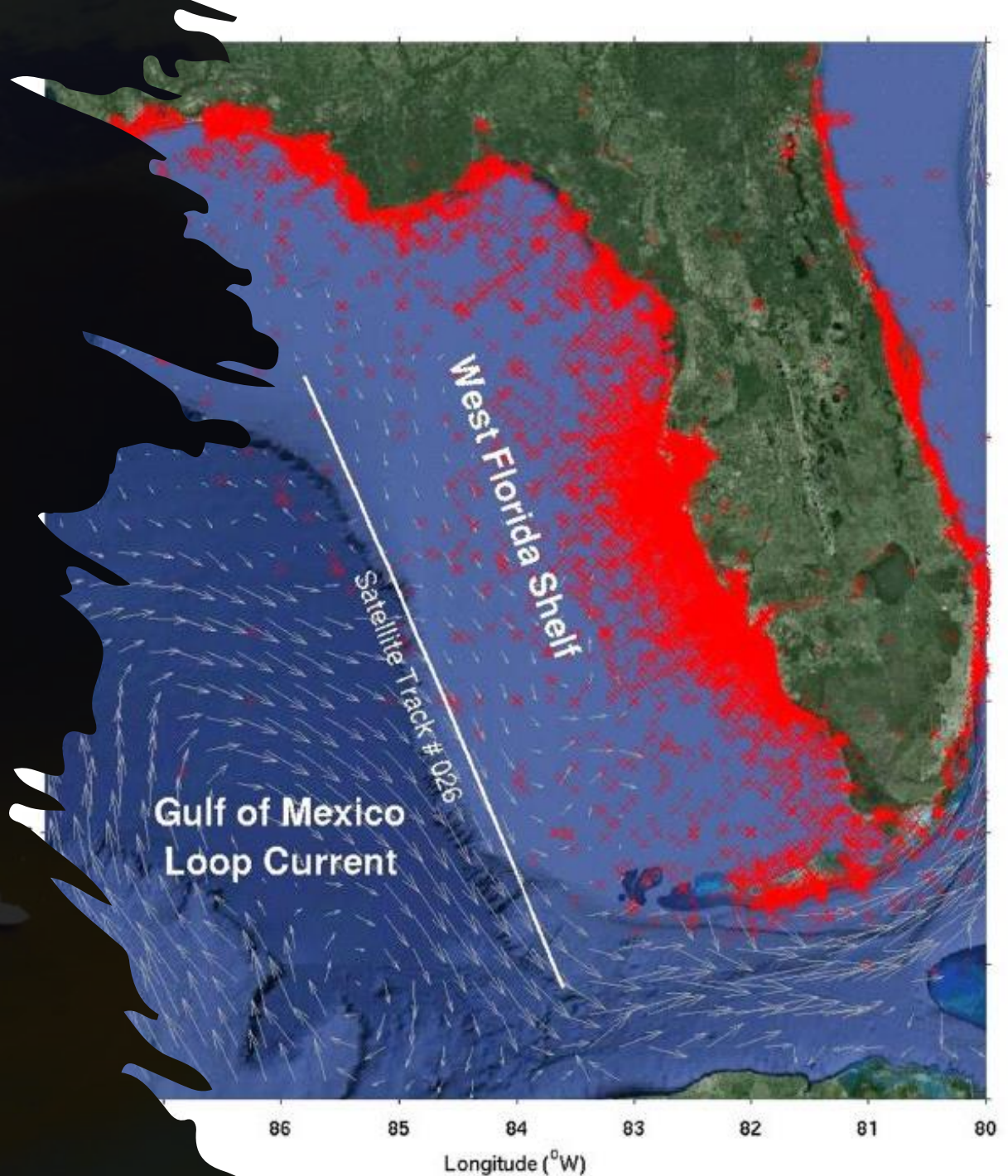
Large amounts of organic matter associated with algal blooms can stimulate microbial respiration that depletes DO and produces CO₂ promoting hypoxia and acidification

Diurnal patterns, DO and pH lowest at night and deeper, vertical migration to bottom, more stressors on benthos



“Florida Red Tide”

- Mostly *Karenia brevis* & brevetoxins
- Natural occurrences dating back centuries
- Blooms form nearly annually along SW FL coast
- Blooms start 10 - 40 miles offshore, away from the direct influence of land-based nutrient pollution, but once moved inshore blooms can use both human-contributed and natural nutrients for growth
- Cooperative effort between Mote and FWRI/FWC
- Other efforts with USF, FSU, FGCU, NOAA, USGS, EPA, TBEP, CHNEP, SBNEP

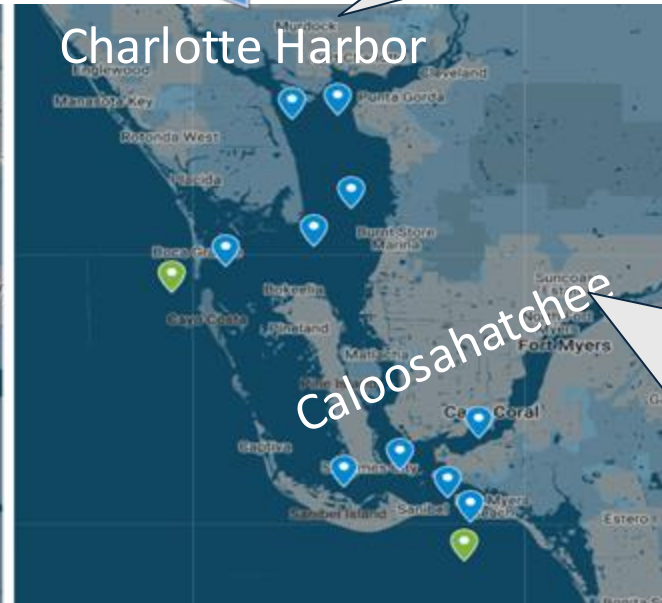
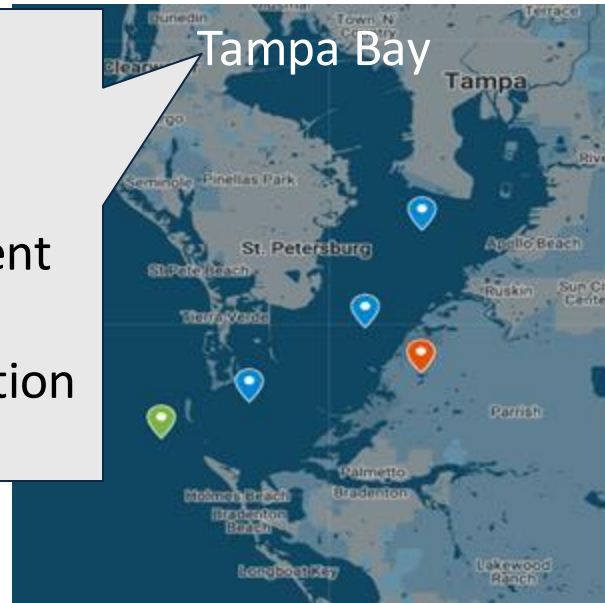


Estuaries



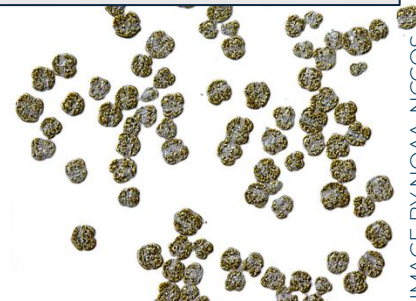
- Large estuarine lagoon with barrier islands
- Nitrogen-limited system
- Increased nitrogen loading

- Large open water estuary
- Urbanized
- Nutrient management planning
- Ephemeral acidification events

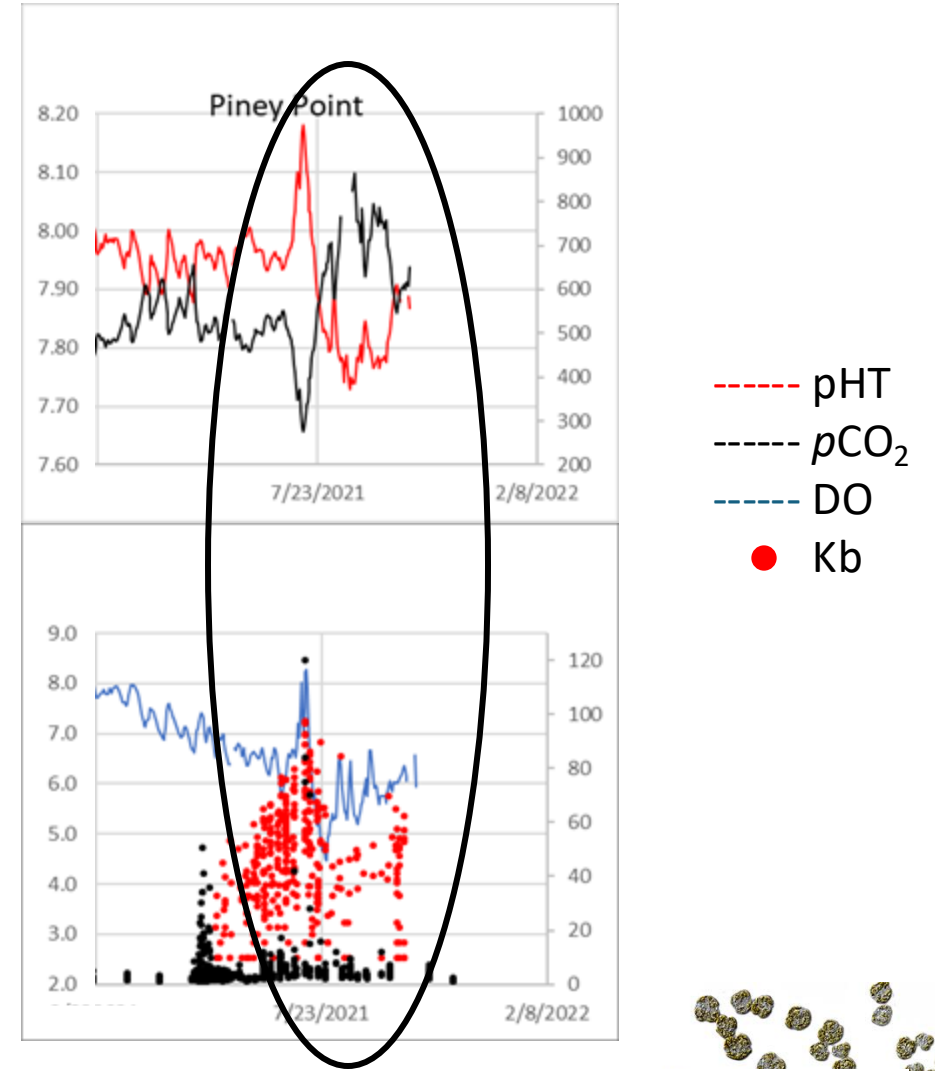
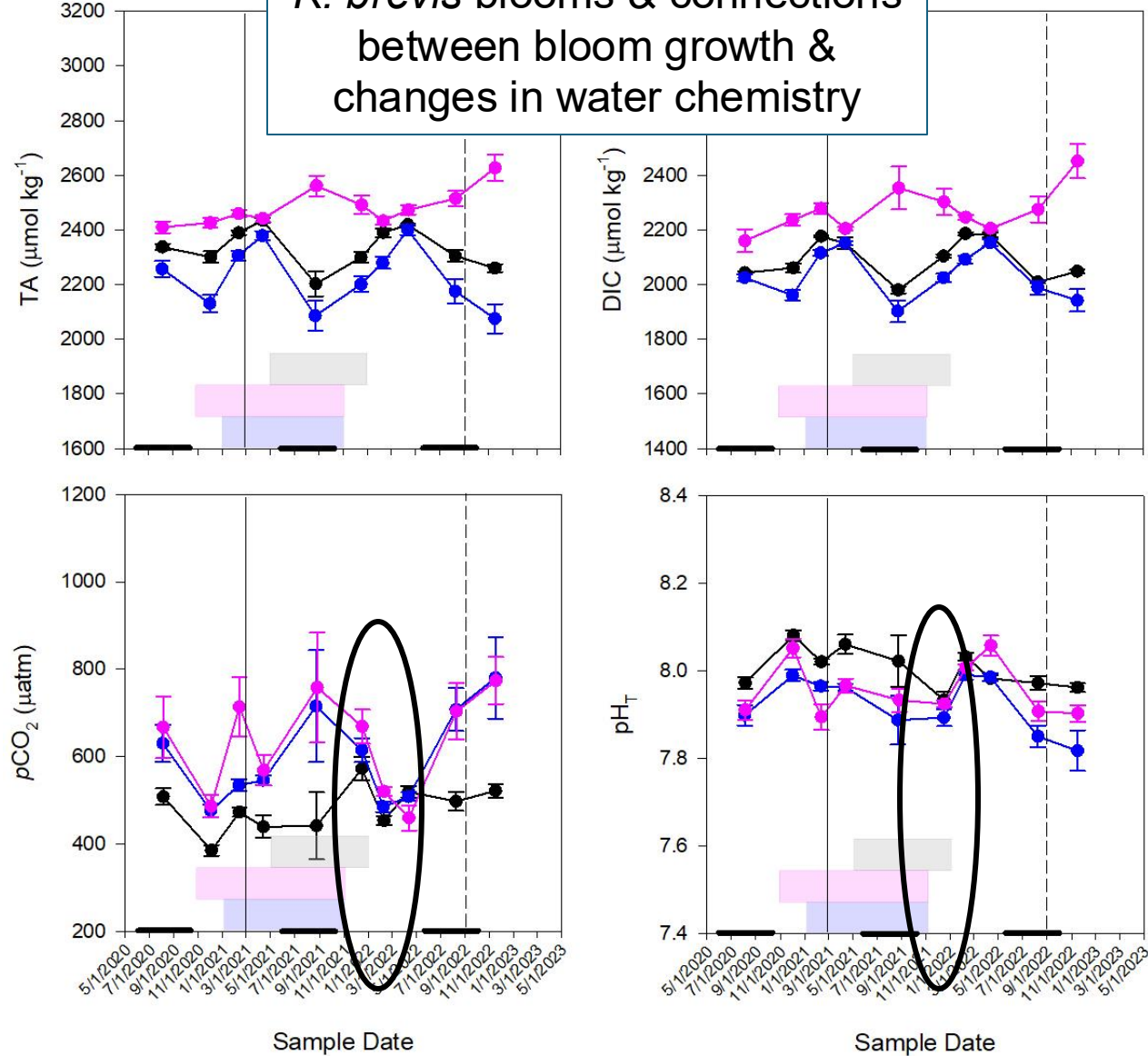


- Subtropical riverine estuary
- Physically altered
- Declining water quality
- Larger freshwater output

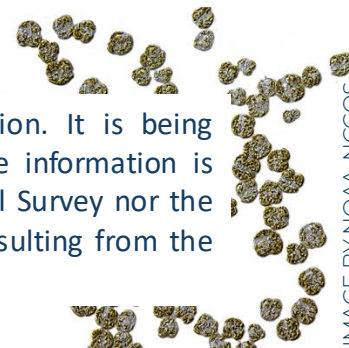
Beck et al., 2019; Greening et al., 2014; Tullis-Joyce & Roy, 2021; Yates et al., 2023; Durr et al., 2011; Heil et al., 2014; Osborne, 2018; Weisberg et al., 2019; Turner et al., 2006; Liu et al., 2009; Qiu & Wan, 2013; Dixon et al., 2014; Sun et al., 2016; Doering & Chamberlain, 1999; Steinman et al., 2002; Rumbold & Doering, 2020

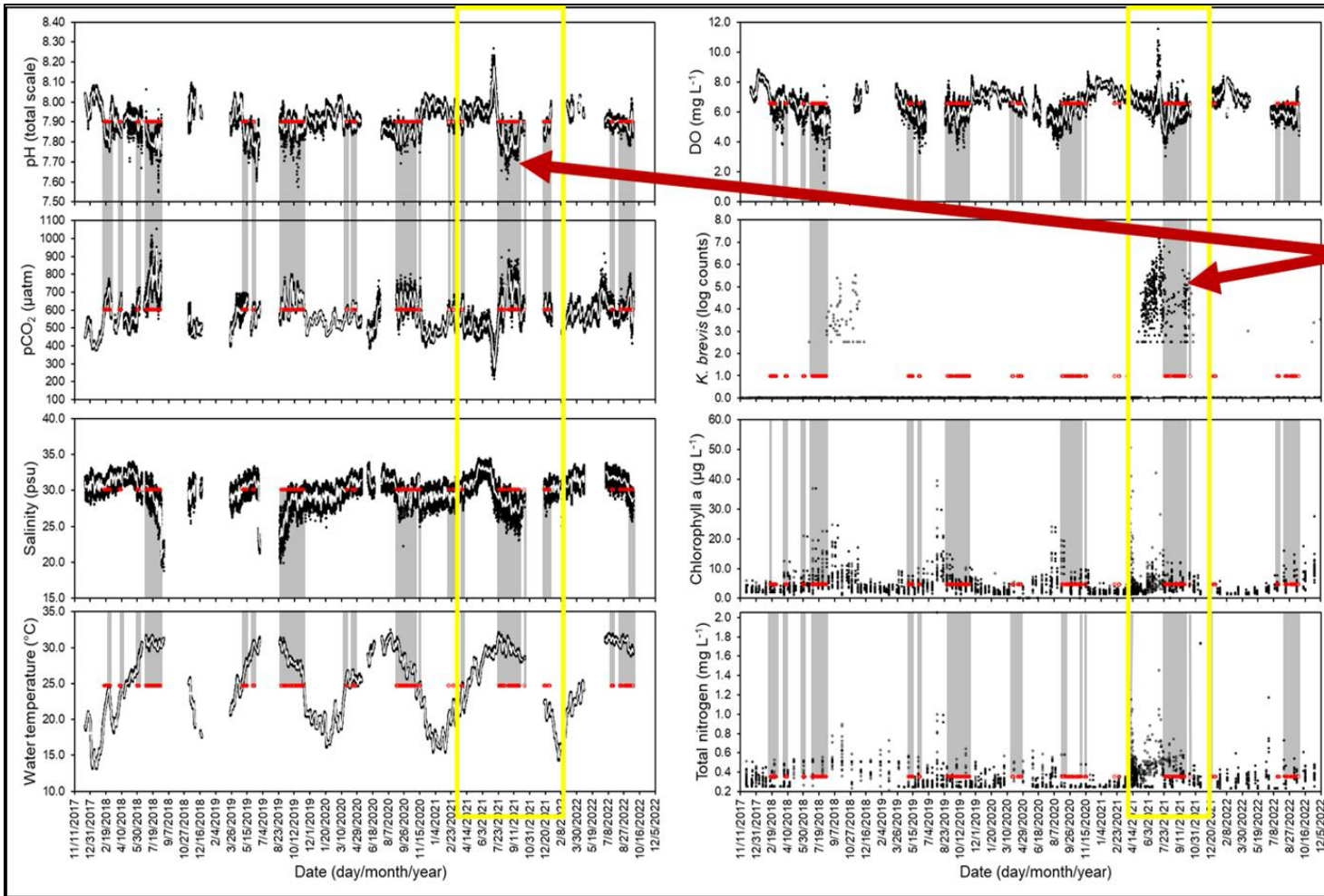


Showed distinct acidification events occurred during or after *K. brevis* blooms & connections between bloom growth & changes in water chemistry



This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information





...including those associated with *Karenia brevis* bloom!

Sensor data analysis identified 32 distinct acidification events & potential drivers over 5yrs from 2017 to 2022.

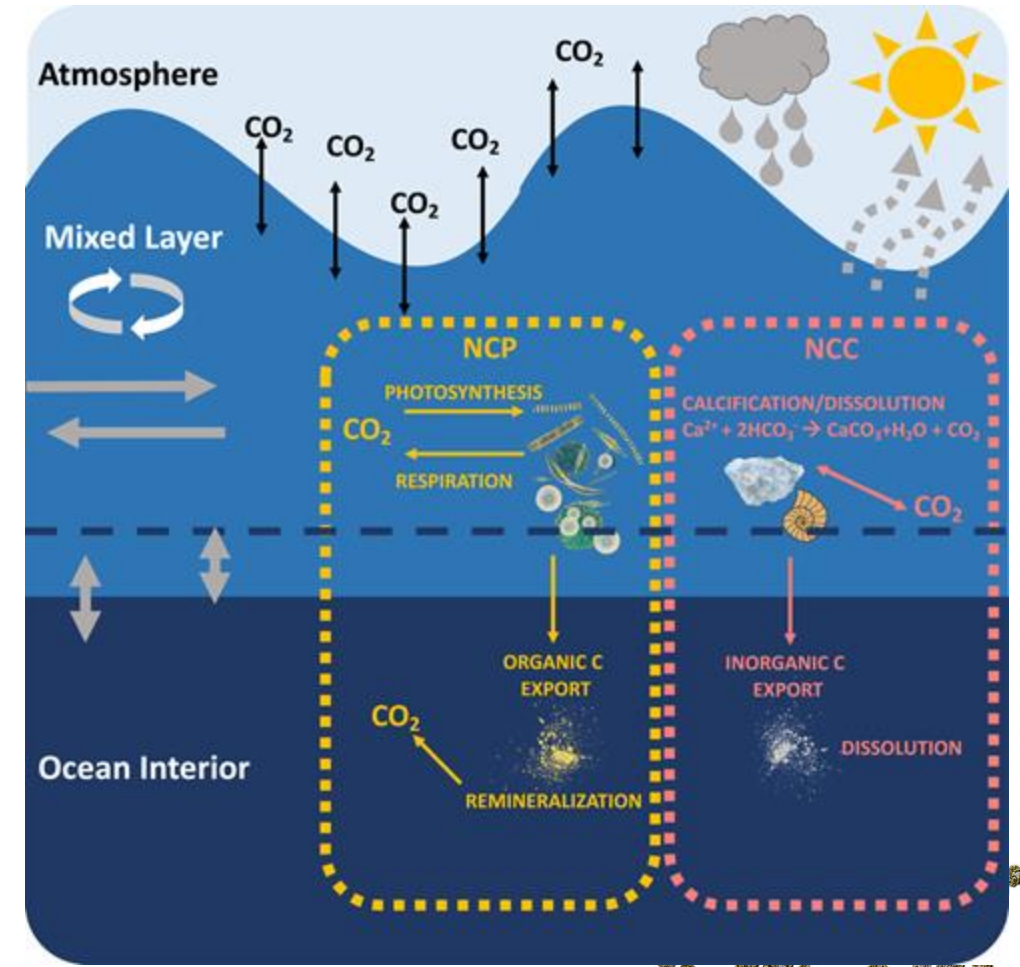
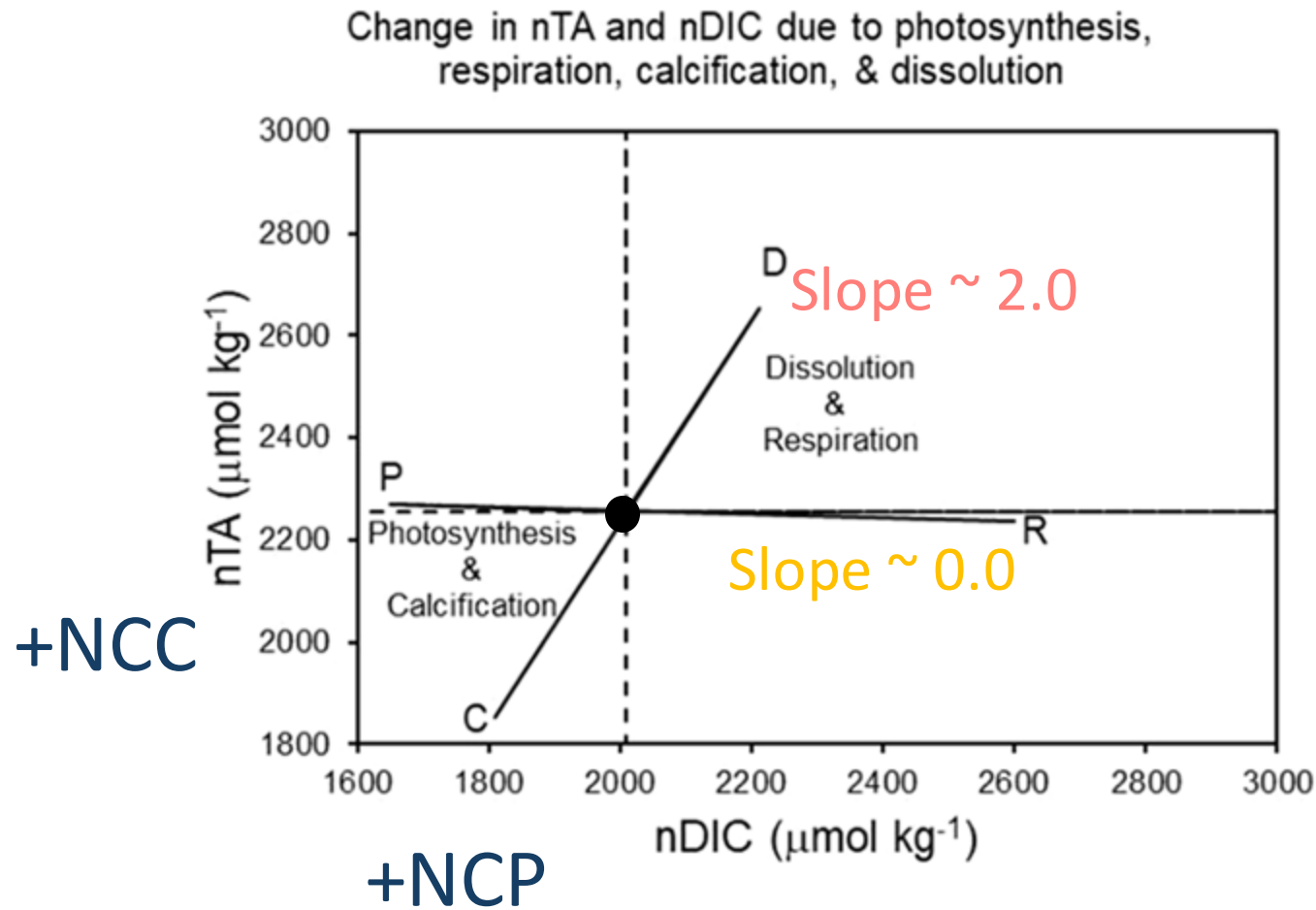
These data help us parameterize pH and other variables for lab experiments.

Gray shaded areas indicate acidification events in Tampa Bay.

This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information

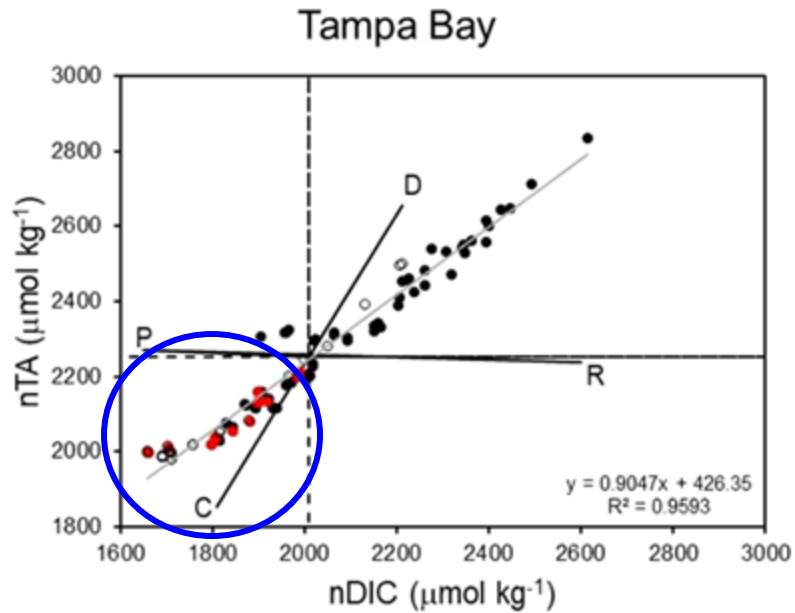


TA/DIC Curves & Net Community Calcification/Production

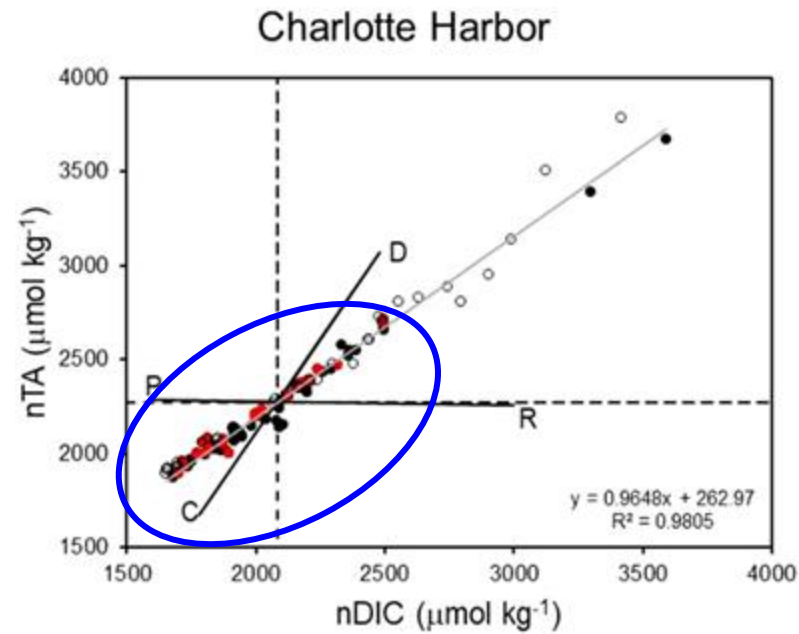


Suzuki & Kawahata, 2003; Muehllehner et al., 2016; Hall et al., 2024; Knor et al., 2023

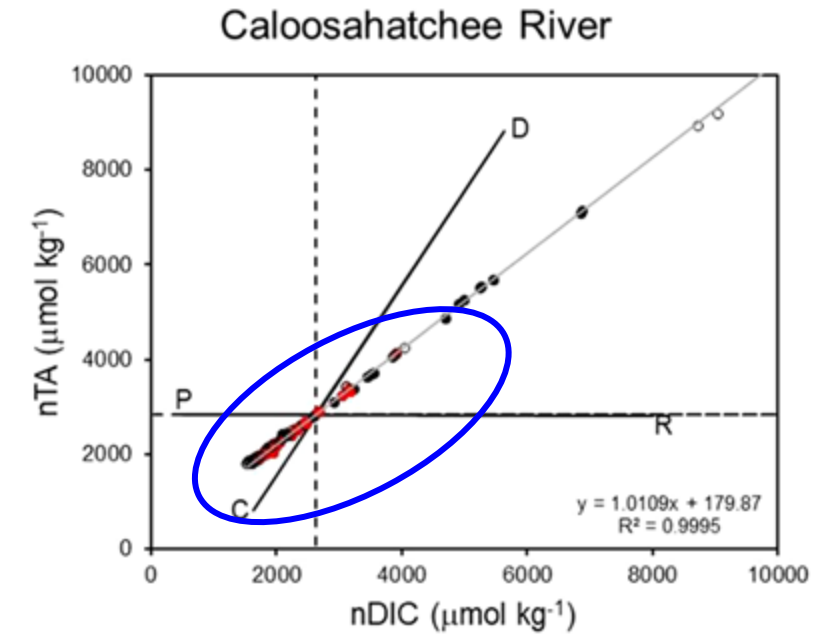
TA/DIC Curves



Slope ~ 0.90
 $R^2 = 0.95$



Slope ~ 0.96
 $R^2 = 0.98$



Slope ~ 1.01
 $R^2 = 0.99$



REFLECTION

- Localized eutrophication and acidification might amplify patterns of harmful algae
- There is evidence of linkages among seasonal variability in the carbonate system, *K. brevis* blooms, and other environmental influences
- Studies show that photosynthetic responses to acidification might be small, however the growth and termination of a HAB can intensify or even cause localized acidification events
- Future directions: long-term data sets of higher resolution time series observations to fully understand the drivers and evolution of nutrient impacts and acidification



ACKNOWLEDGEMENTS

Mote Marine Laboratory – Jessica Frankle, Ari Nissanka, Susan Launay, Camia Charniga, David Gordon, Reese Kober, Ryan McGoldrick, Caroline Matute, Kathleen Sway, Kelley Breeden, Erin Cuyler, Jaci Martinez, Kelsey Thompson, Vince Lovko, Val Palubok, Devin Burris, William Scott, Briana Mays, Giandria Greene, Tristyn Bercei, Sarah Klass, Chloe Manley, Claire O’Neal, Amanda Muni-Morgan, Cody Cole, Greg Byrd, Dean Dougherty

Mote Interns – Emmanuel Perry, Olivia Shaffer, Anne Harper, Javier Pujols, Lily Goerlitz, Bethaney Ryder, Sarah McCready, Victoria Vossler, AG Camara, Erin Schneider

FWC - Rebecca Rash, Alexa Iorillo, Chloe Mikus

USGS – Kim Yates, Chris Moore

Funding provided by the FWC/FWRI – Mote Cooperative Red Tide Research Program, FWC Agreement #20034, NSF OCE #2050892



MACAN

Mid-Atlantic Coastal Acidification Network

MARCO MID-ATLANTIC OCEAN
DATA PORTAL

Planning tools for identifying locations at risk for acidification

Janet J. Reimer, MARCO
Kirstin Wakefield, MARACOOS
Teresa Schwemmer, MACAN
Carly LaRoche, MACAN

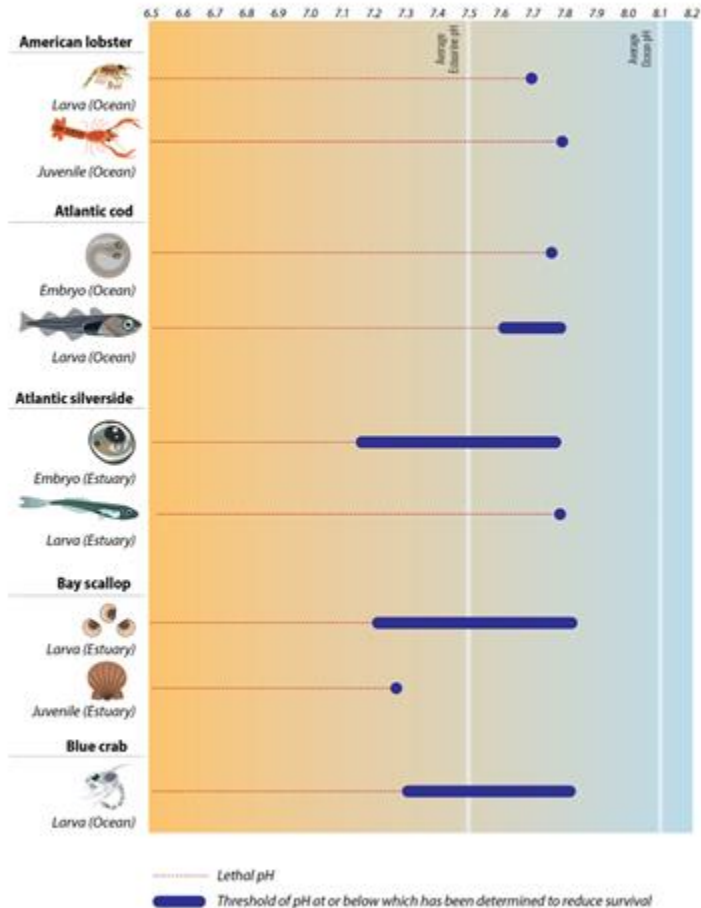
MACAN Provides Actionable Information



How do we link biological responses and water chemistry together to form one metric?

- Biological Metrics
 - Species Survival
 - Species Reproduction
 - Population Size
- Water Chemistry (Carbonate) Parameters
 - pH
 - Aragonite Saturation State - calculated from regional data
- Acidification vs Acidic Events
 - Seasonal, sporadic, long-term

pH Threshold At Which Mortality Occurs For Various Life Stages Of Mid-Atlantic Species



Swimming a mile together: Navigating transdisciplinary currents in Atlantic Sea Scallop research to build climate resilience in the fishery

Samantha Siedlecki, Shannon Meseck, Lisa Colburn (co-leads),
Halle Berger, Catherine Matassa, Zhuomin Chen, Felipe Soares,
Enrique Curchitser, Dave Bethoney, Susan Inglis, James LaChance,
Becca Selden, Emilien Pousse, Dvora Hart, Antonie Chute



Meet the multidisciplinary project team

Lisa Colburn



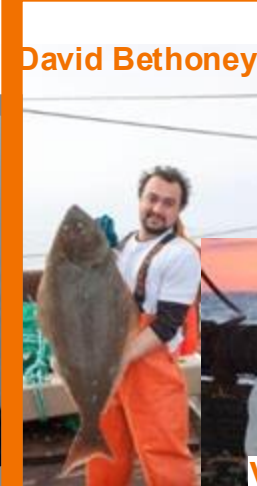
Shannon Meseck



Dvora Hart



David Bethoney



Susan Inglis



Victoria Thomas



CFRF

Fishing industry feedback is a core component of the success of this project

Enrique Curchitser



Catherine Matassa



Becca Seldon



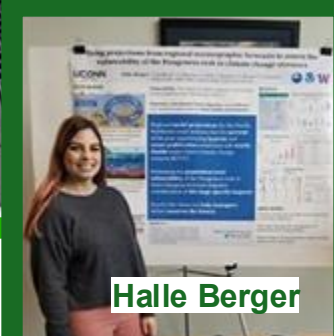
Jim LaChance



Samantha Siedlecki



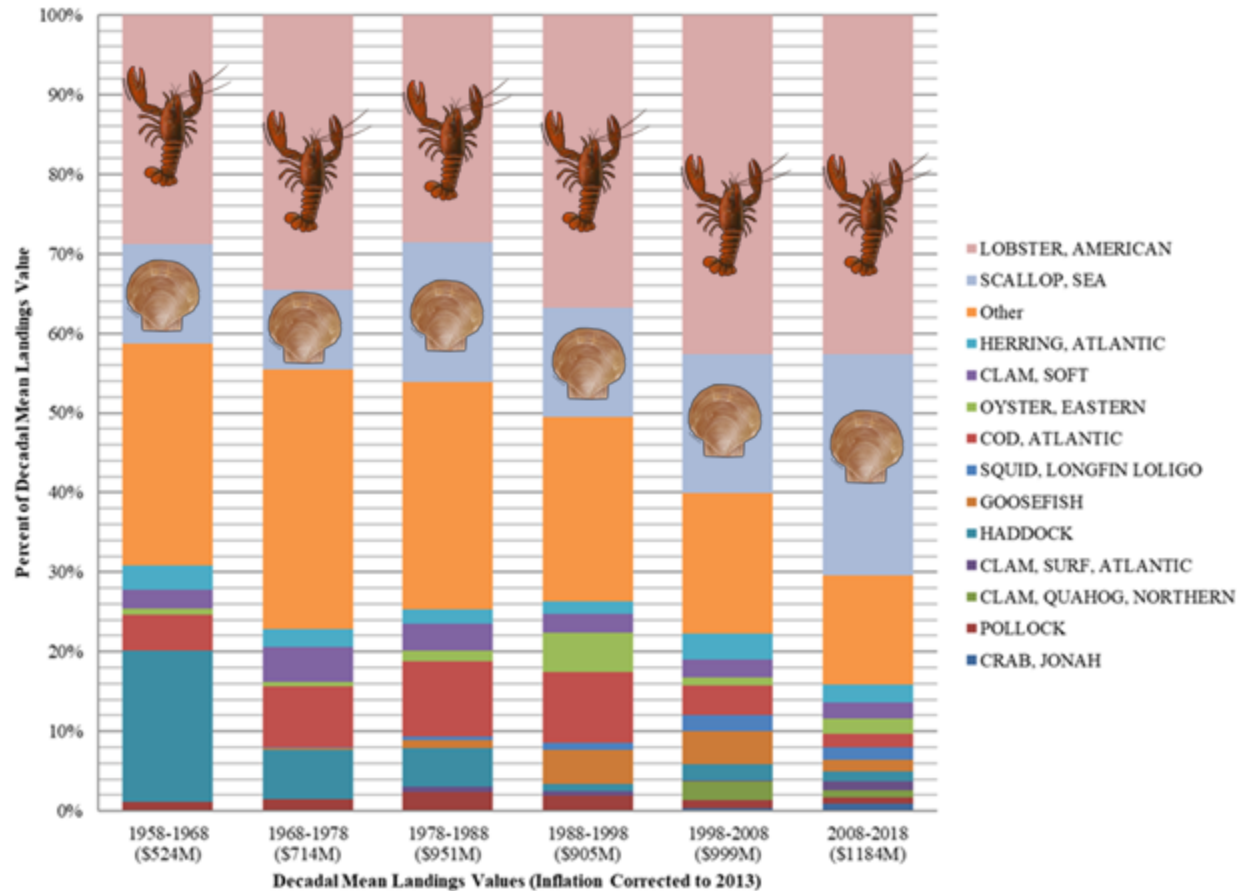
Halle Berger



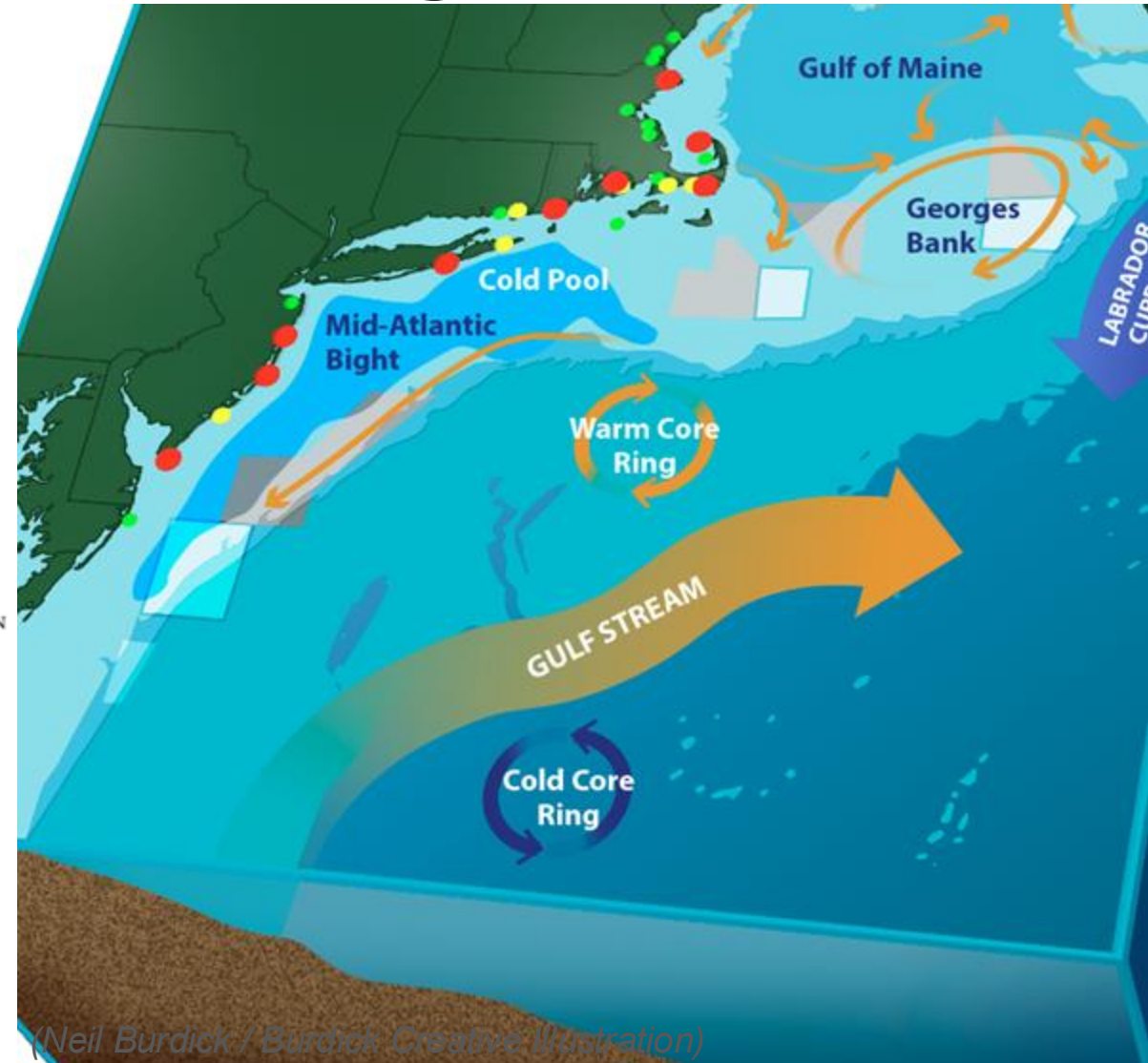
Emilien Pousse



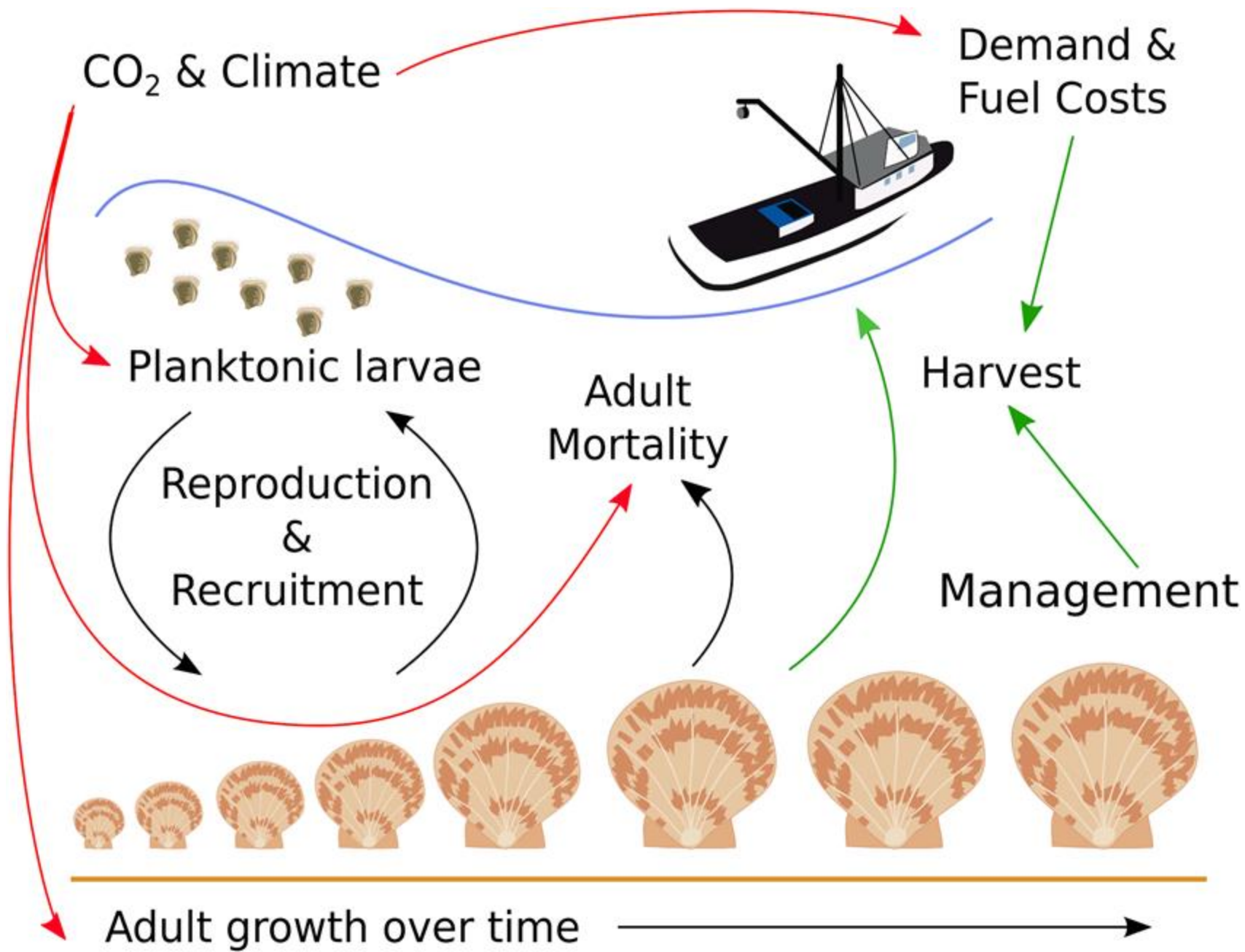
Changing conditions threaten coastal shellfish harvest in the region



(From Siedlecki et al. 2021,
updated from Gledhill et al. 2015)



(Neil Burdick / Burdick Creative Illustration)



The Atlantic sea scallop fishery is the 2nd highest valued in the U.S. (\$360M in 2023)

Sea scallops live for a **long time** – up to 20 years, with first spawn at age 2

Adults grow for a **long time** – 4 to 5 years until harvest size currently

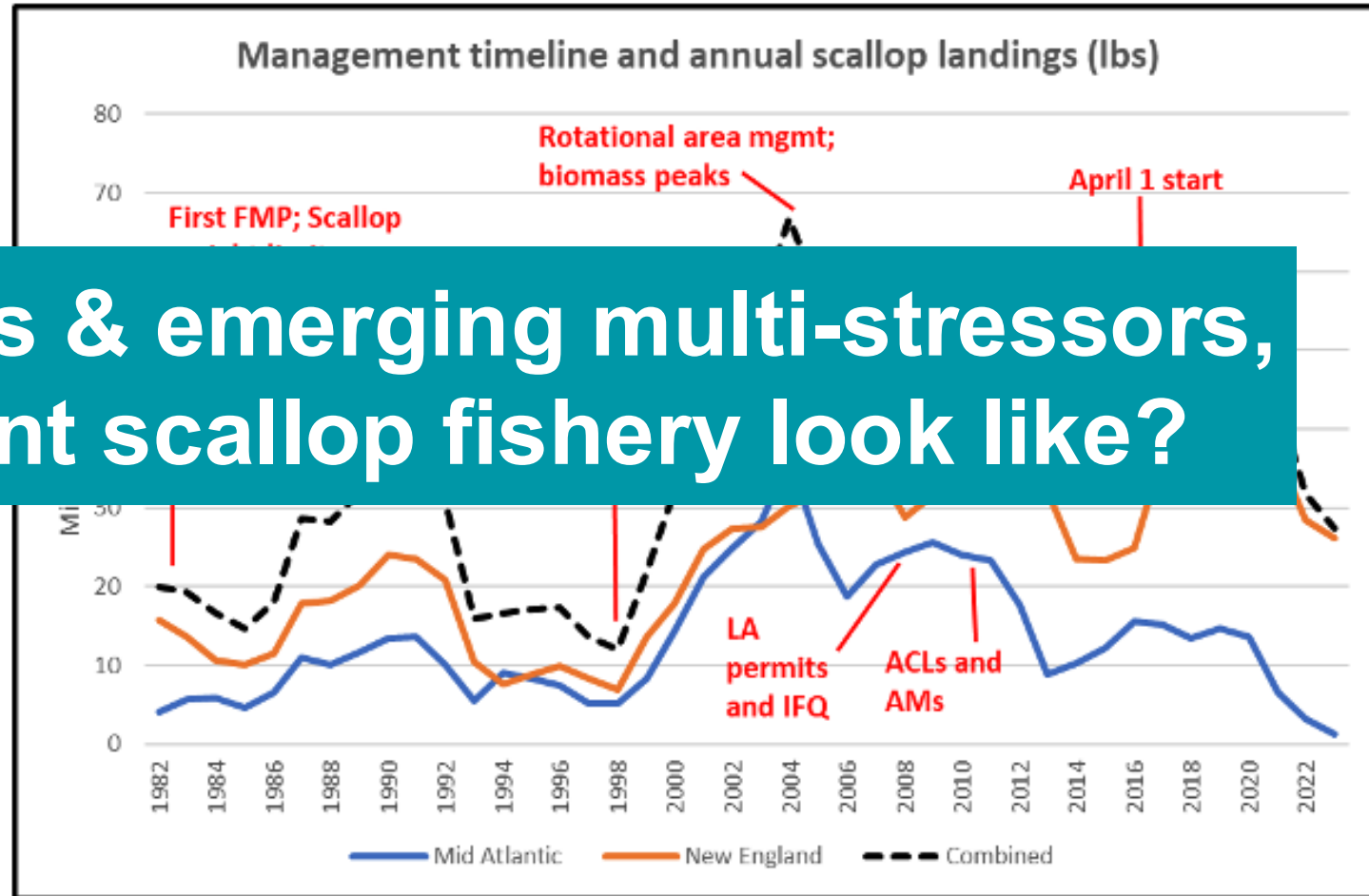
Fishery already seeing changes

Shift in biomass north into New England observed over many decades

Given recent changes & emerging multi-stressors, what does a resilient scallop fishery look like?

NEFMC closes areas with a lot of small, fast-growing sea scallops to protect them

This boosts sea scallop meat yield & yield per recruit (Hart 2003)



<https://www.fisheries.noaa.gov/foss/f?p=215:200:16215374987733:Mail:::>

How do we plan to achieve this?



2021-2025: Workshops & Interviews



Industry input has been important!

- 12 workshops with 104 participants
- 62 interviews

Perspectives from the scallop fishery

“Science has a role. Regulations have a role. And managing has a strong role. And hopefully we can be good stewards. That’s my goal.”

- New Bedford, MA

“If we’re dealing with ocean acidification let’s start to get some ideas of what’s where. And then what’s it like next year? Is it changing? Is it moving? Is it getting worse in that area?”

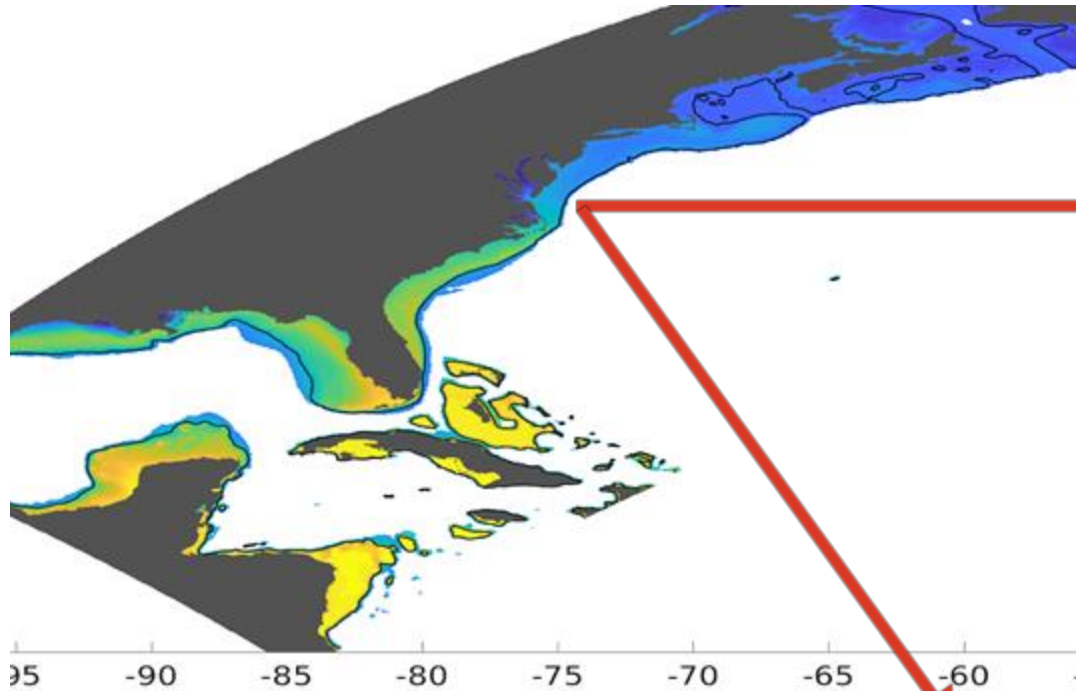
- Barnegat Light, NJ



Natural Science tools applied to the issue – Models

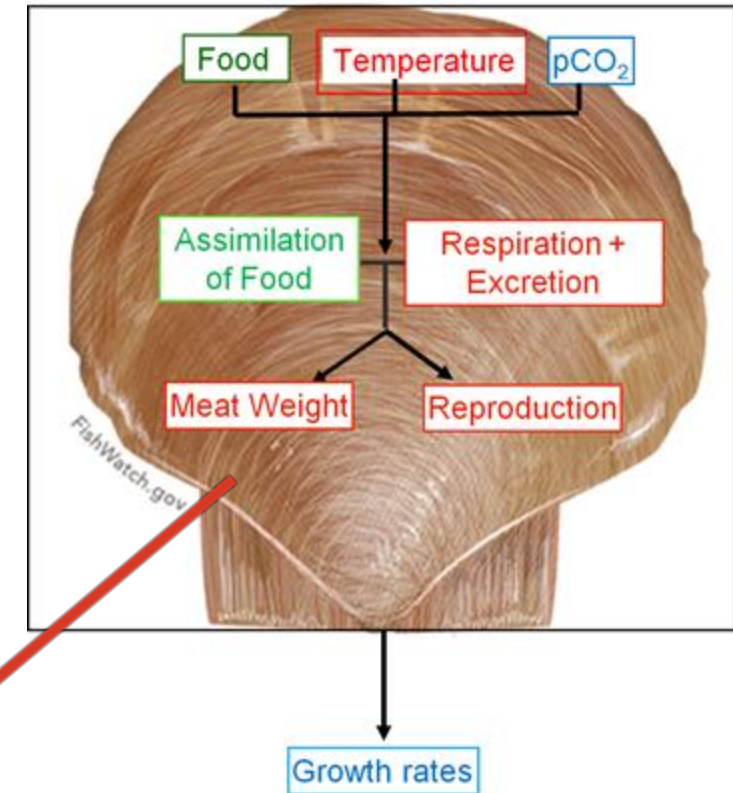
Ocean Conditions

Historical trends & projections using NWA-ROMS



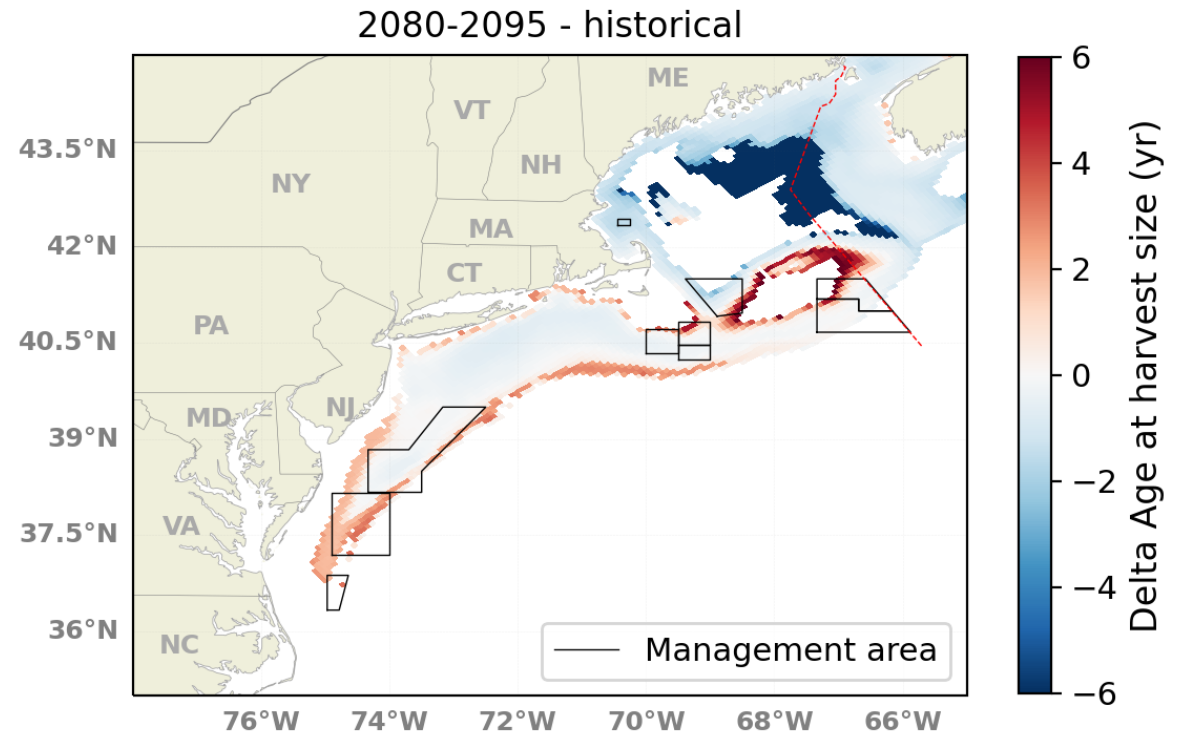
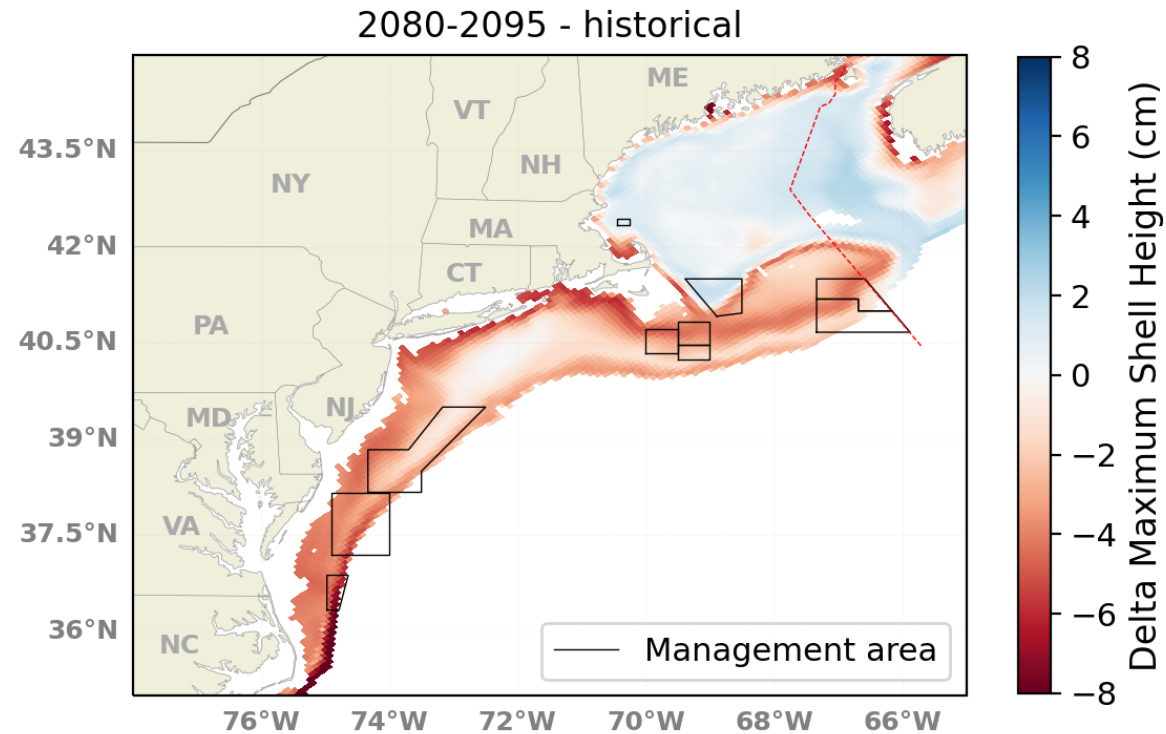
Scallop Biology

Dynamic Energy Budget Model



Maps of projected growth
(maximum size & age at harvest size)

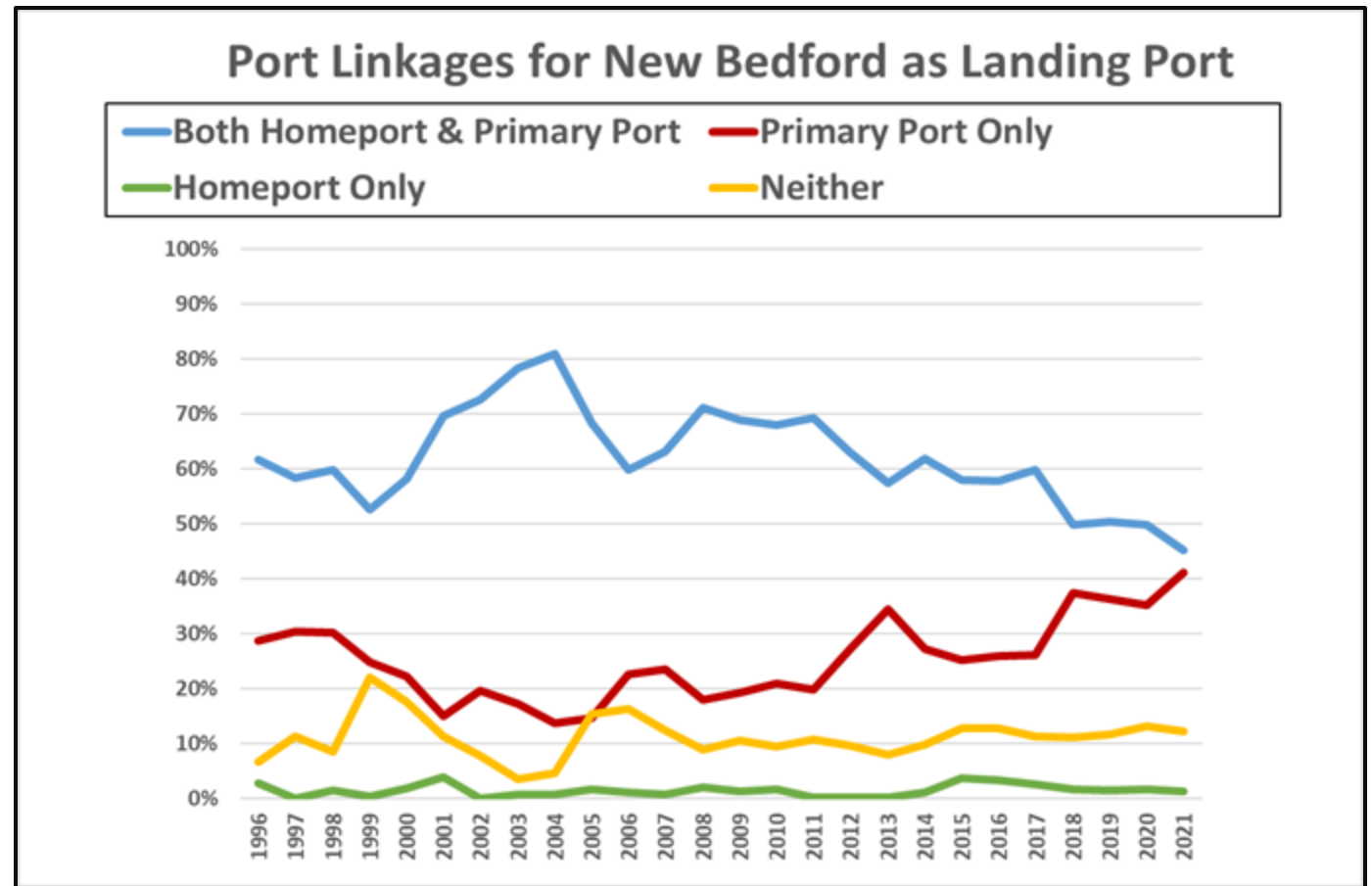
Simulations reveal spatial variability & future changes in max size and age at harvest size that can inform rotational closures



Changes driven by both warming & OA

New Bedford has become a primary landing port even if their home port is elsewhere

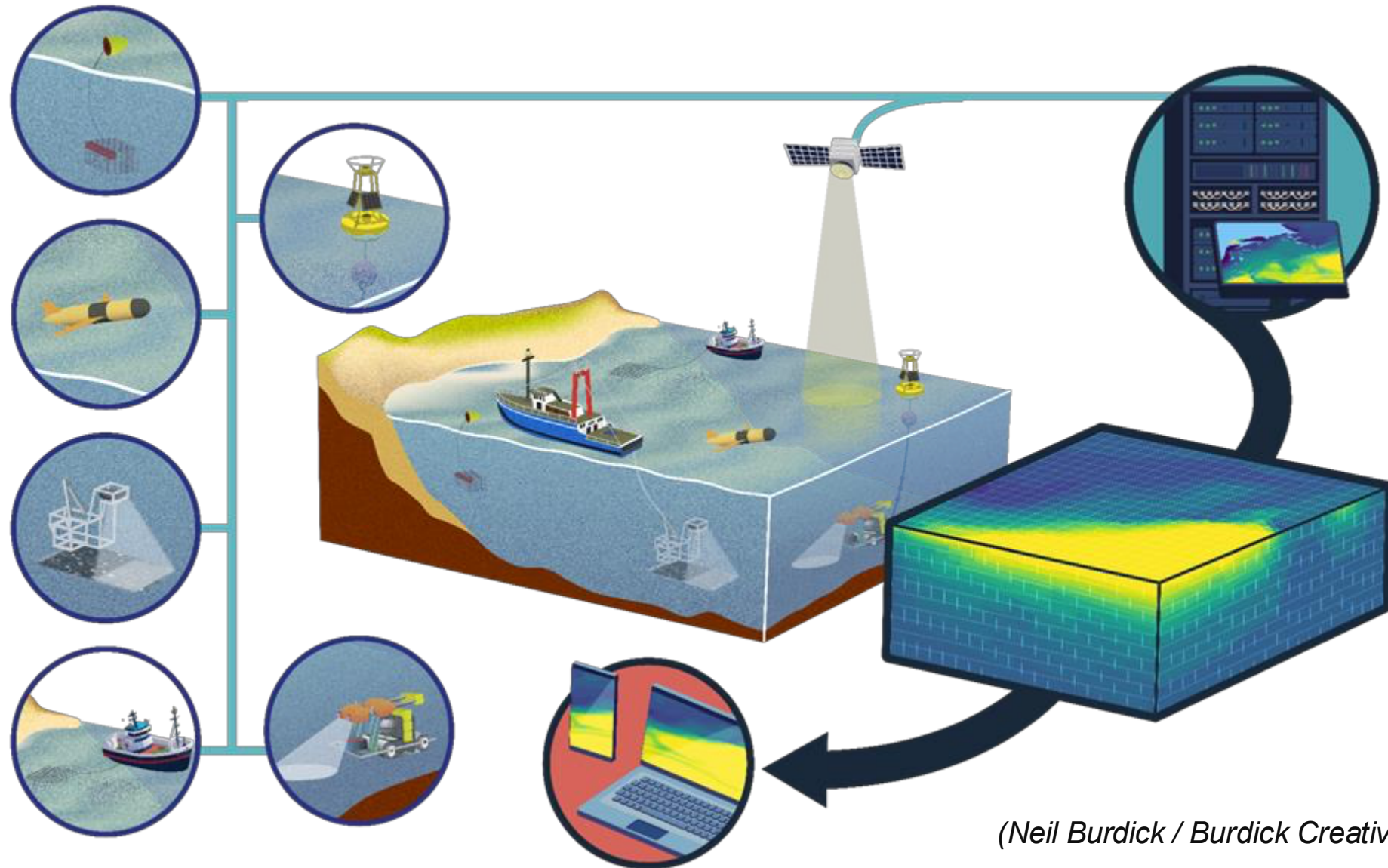
An increasing percentage of the trips landed in New Bedford are being made by vessels that have a home port elsewhere but use New Bedford as their primary landing port (**red line**)



Takeaways from our research and conversations/ workshops overall

1. OA variables affect scallop growth in concert with temperature and food
2. Current rotational management decisions are informed by observations and models that *do not consider* environmental information - including temperature, ocean acidification variables, and oxygen
3. Industry is eager to help and interested in collecting observational data
4. Catch is moving north and so are landings despite home port locale
5. The fishery is motivated to act and asking what they can do
6. Subsurface real-time observations are possible but currently do not occupy rotational management areas
7. Warm events are increasingly common and tend to occur in late summer/early fall

What does a resilient scallop fishery look like?



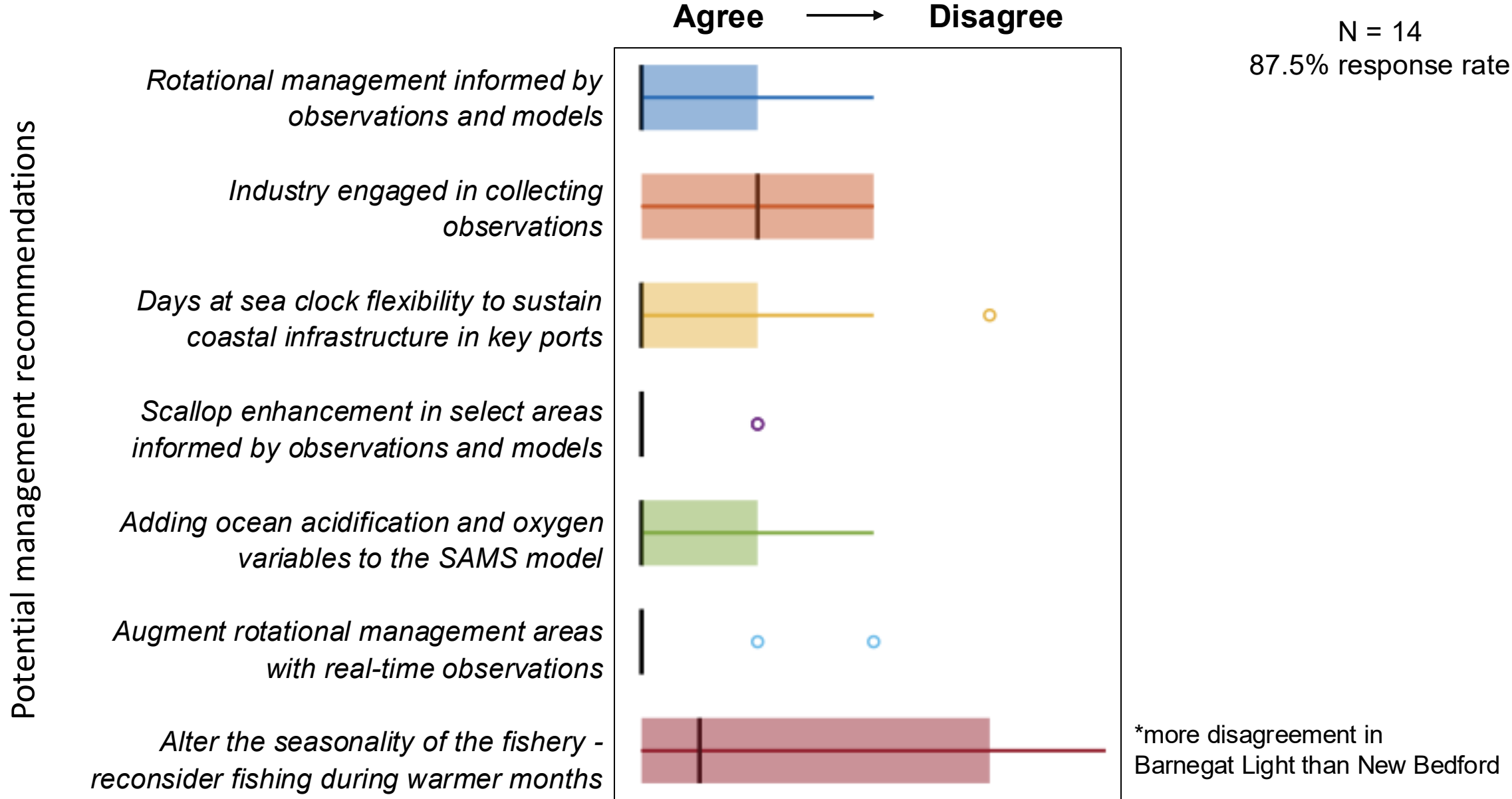
(Neil Burdick / Burdick Creative Illustration)

Siedlecki et al. *(in prep)*

By trying to define what a resilient scallop fishery looks like and thinking about what the fishery could do based on these takeaways, we developed recommendations for building resilience into management and discussed them at the 2024 workshops

1. Rotational management informed by observations and models
2. Industry engaged in collecting observations
3. Days at sea clock flexibility to sustain coastal infrastructure in key ports
4. Scallop enhancement in select areas informed by observations and models
5. Adding ocean acidification and oxygen variables to the SAMS model
6. Augment rotational management areas with real-time observations
7. Alter the seasonality of the fishery - reconsider fishing during warmer months

Industry feedback on management recommendations



Example Timeline for the Scallop Fishery

April

NEFMC sets specifications and measures for fishing year (sometimes 2 years out)



New England
Fishery Management
Council

May-August

Survey of Scallop
Biomass



September

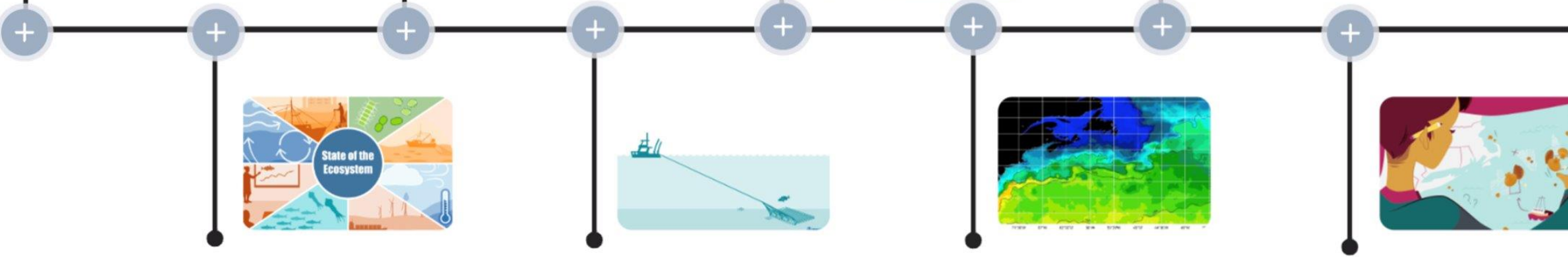
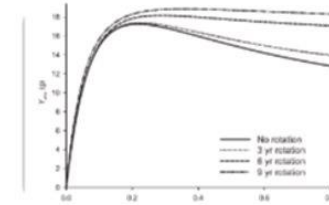
Fall ECOMON survey -
which happens 4xs a
year

Fall Trawl Survey



September/October

SAMS model run and
environmental information is
analyzed



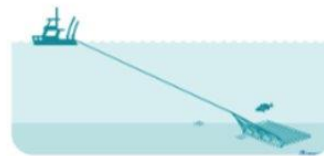
May

NOAA state of the Ecosystem
delivered; RSA share day



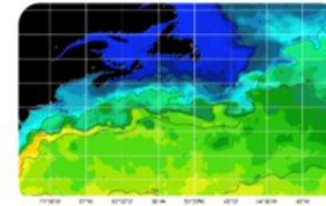
April-September

Prime fishing season
and observing by the
fleet



September

Seasonal and multi-
annual ocean forecasts
ideally generated



Nov/December

SSC meets and advances
Framework adjustments for
following year which take
effect in April



Conclusions

- This process was iterative -along the lines of co-production of knowledge
 - 4 years of workshops
- We communicated the latest science to industry and industry shared their concerns as part of the workshops
- We developed responses to their concerns with robust data and analysis
- Together, end-of-century warming & OA are predicted to cause slightly faster scallop growth but smaller maximum size
- The cold pool and deep Gulf of Maine may serve as thermal refugia
- Landings moving north are complicated by primary land ports moving north as well despite home ports residing elsewhere
- Industry was interested in making environmental information more available and accessible to the industry and management by increasing monitoring by the fleet itself and adding real-time observing to rotational management areas
- These actions may increase flexibility in the management process which is important to be more responsive or adaptive to emerging events

Questions?

*Funded by the NOAA
Ocean Acidification Program*

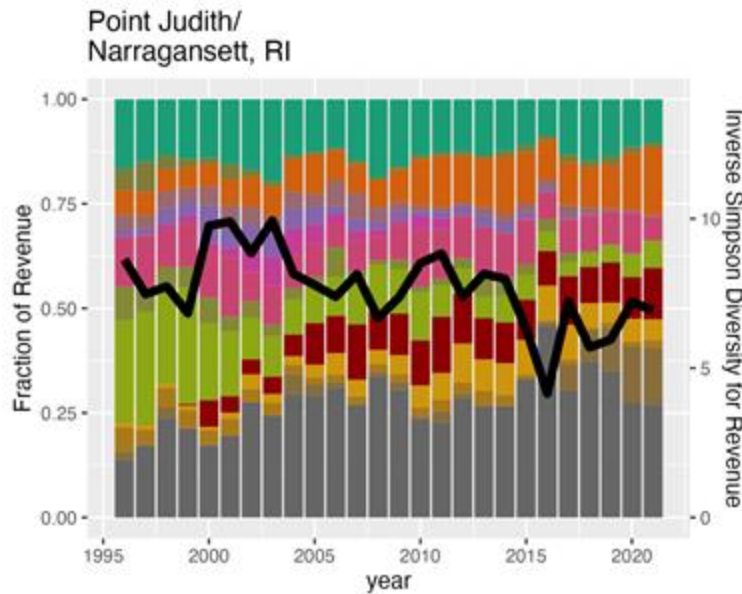
more info



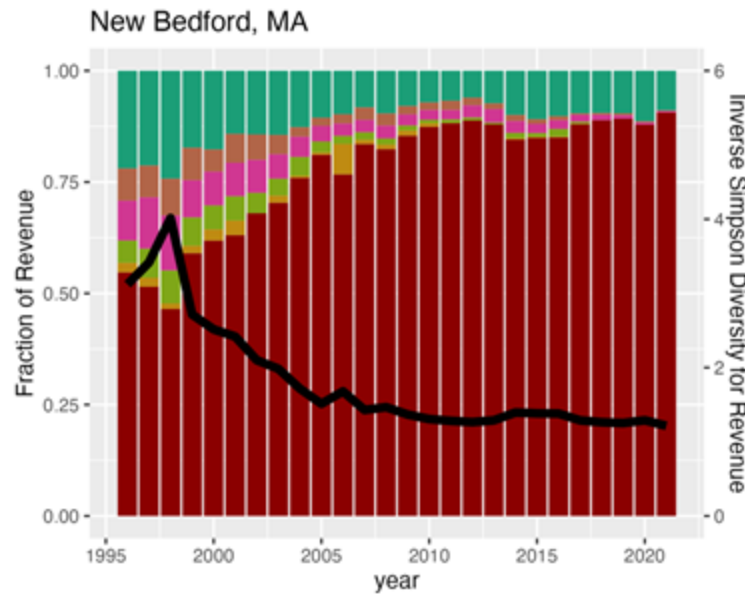
Extra slides

How much do different ports rely on scallops?

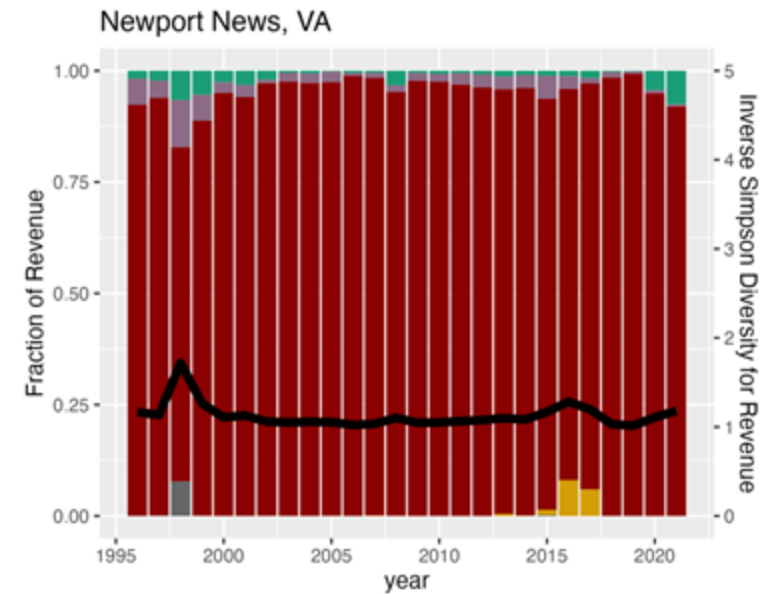
Less Reliant



Increasing Reliance



Always Reliant



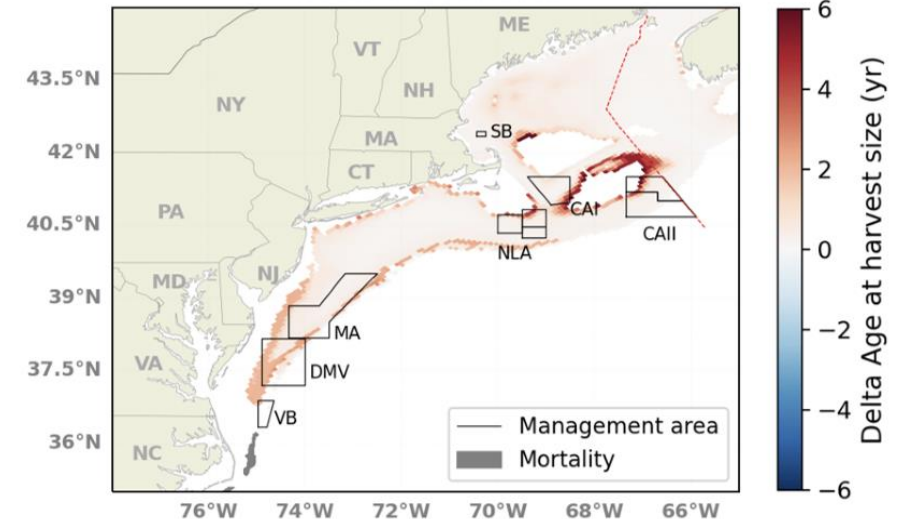
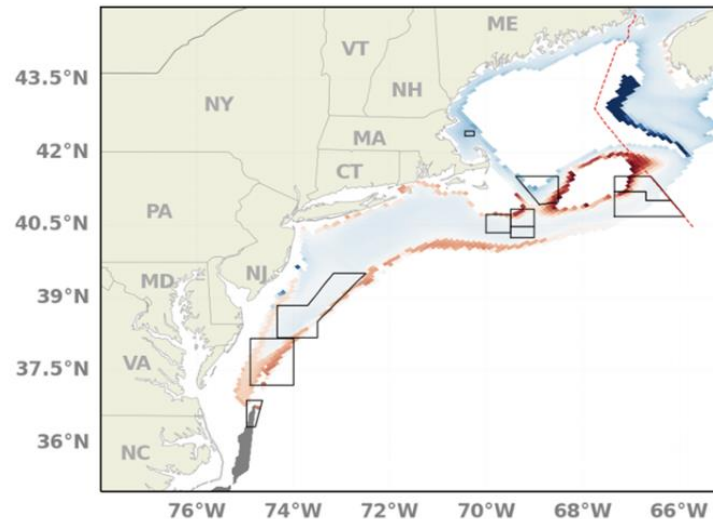
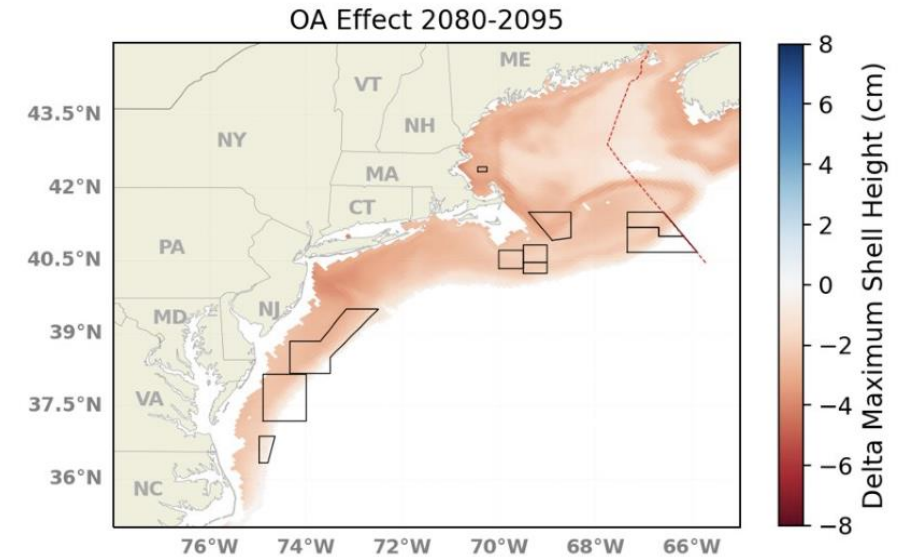
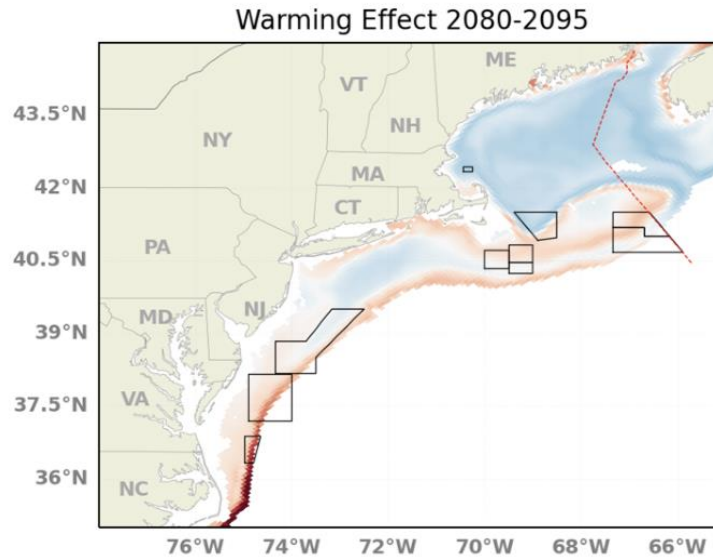
■ Scallop

More Resilient? ← ————— → Less Resilient?

Are future changes driven by warming, OA, or both?

Warming effects range from positive in the north to lethal in the south

Sublethal effects of OA are relatively uniform across the region



MULTISTRESSOR LABORATORY EXPERIMENTS WITH THE ATLANTIC SURFCLAM (*Spisula solidissima*): OCEAN WARMING AND ACIDIFICATION

Daphne Munroe & Laura Steeves

MACAN

Mid-Atlantic Coastal Acidification Network

MACAN's 2025 State-of-the-Science and Technical Training Workshop
July 15-17, 2025 Smithsonian Environmental Research Center, Edgewater MD



RUTGERS

New Jersey Agricultural
Experiment Station

HASKIN SHELLFISH
RESEARCH LABORATORY

THE ATLANTIC SURFCLAM

Widely distributed along the east coast
Cape Hatteras to Gulf of Saint Lawrence

Supports a large **commercial fishery**
Concentrated in NJ and DELMARVA

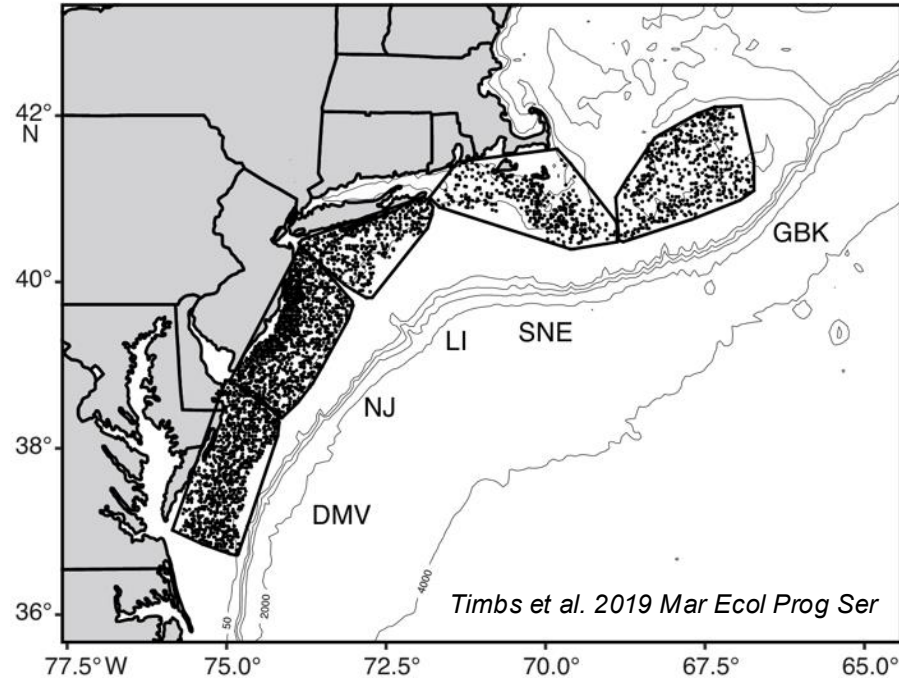
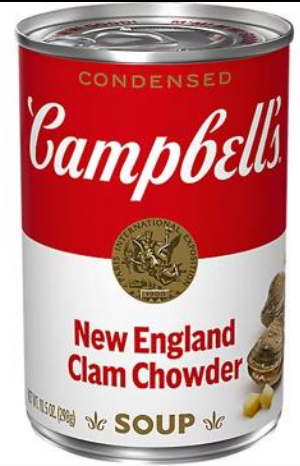


Fig. 1. Tow locations (dots) for the Atlantic surfclam stock assessment surveys from 1982 to 2011. Solid lines delineate the regions of interest (DMV:

Impacted by **climate change**
Temperature, ocean acidification
Changing distribution

OCEAN ACIDIFICATION & THE ATLANTIC SURFCLAM

Shell

- Composed of two primary layers of crystalline **calcium carbonate**
 - In surfclams, both layers are composed of **aragonite**
 - Low saturation state can impact shell **formation and dissolution** (Green et al. 2004, Waldbusser et al. 2011)

Physiology

- Sublethal impacts are complex, often studied as a function of energy acquisition and expenditure (Pousse et al. 2020, 2022)
 - **Energy gain:** Feeding + digesting
 - **Energy loss:** Respiration (metabolic rate), excretion



LABORATORY EXPERIMENT

- **Research Questions**

1. How does decreasing the level of pH (ambient, medium, low) affect surfclam physiology and growth?

Experiment 1

2. What are the interactive effects between OA and temperature on surfclam physiology and growth?

Experiment 2

- **Environmental Monitoring**

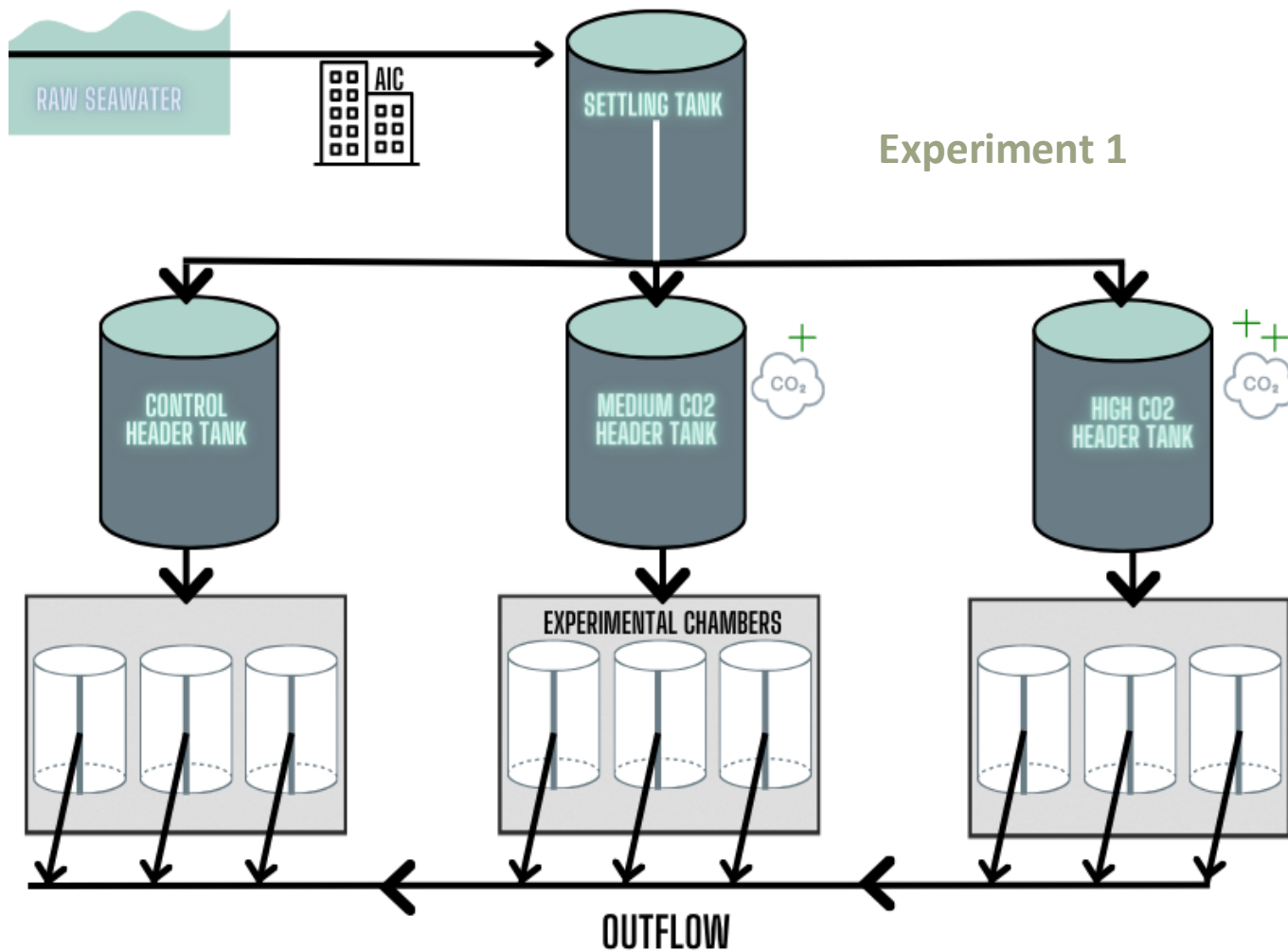
Seawater: temperature, salinity, O₂, pH, carbonate chemistry, chlorophyll *a*, organic content

- **Clam Physiology**

Feeding, and growth rates, shell strength, metabolic rate, gene expression (transcriptomics)

24h, 2 weeks, and 6 weeks after experiment starts

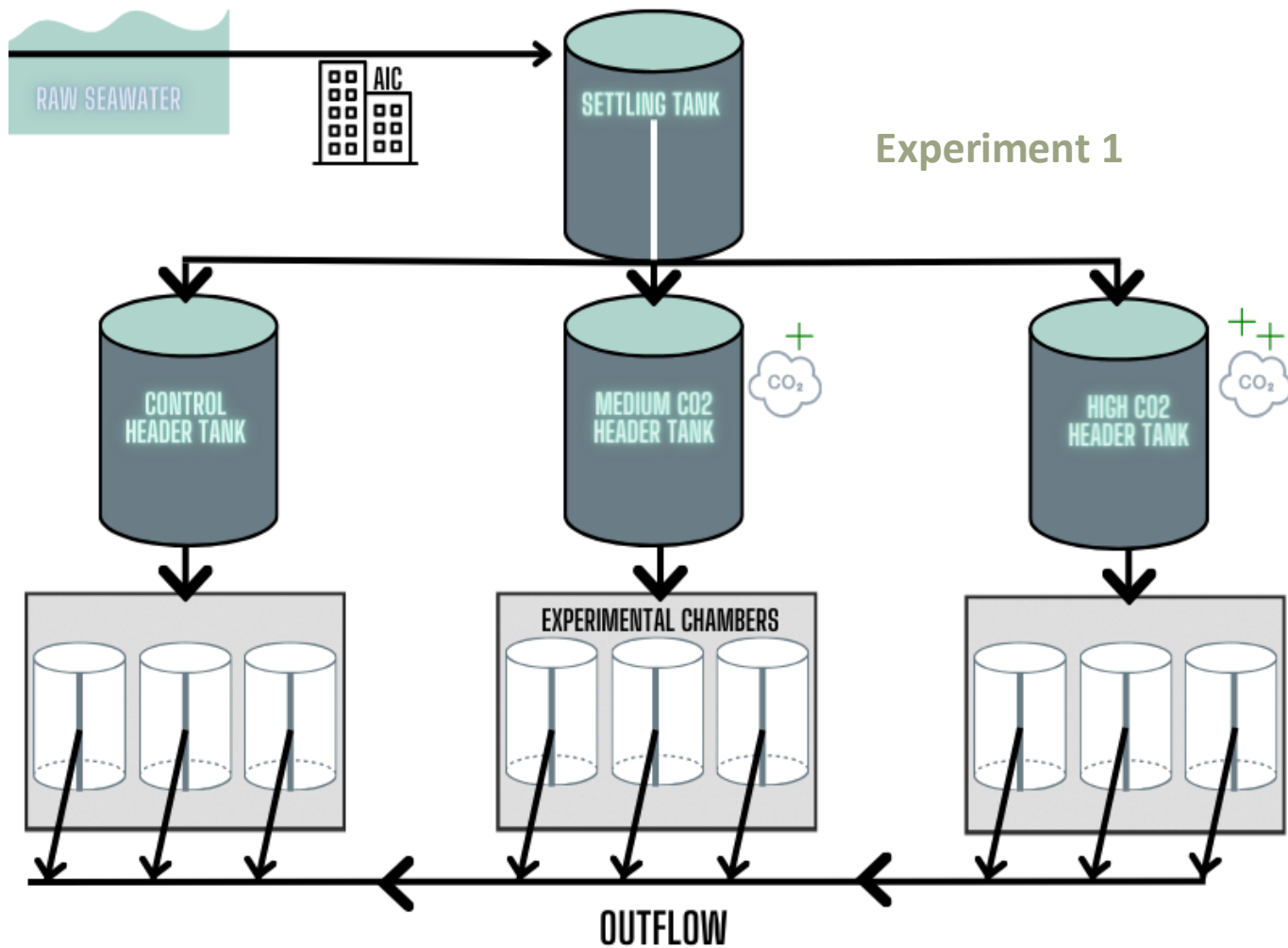




Experiment 1

- Natural diet
- Fluctuations in salinity, temperature, oxygen, pH
- **pH** treatments not static, but consistent offsets from ambient pH

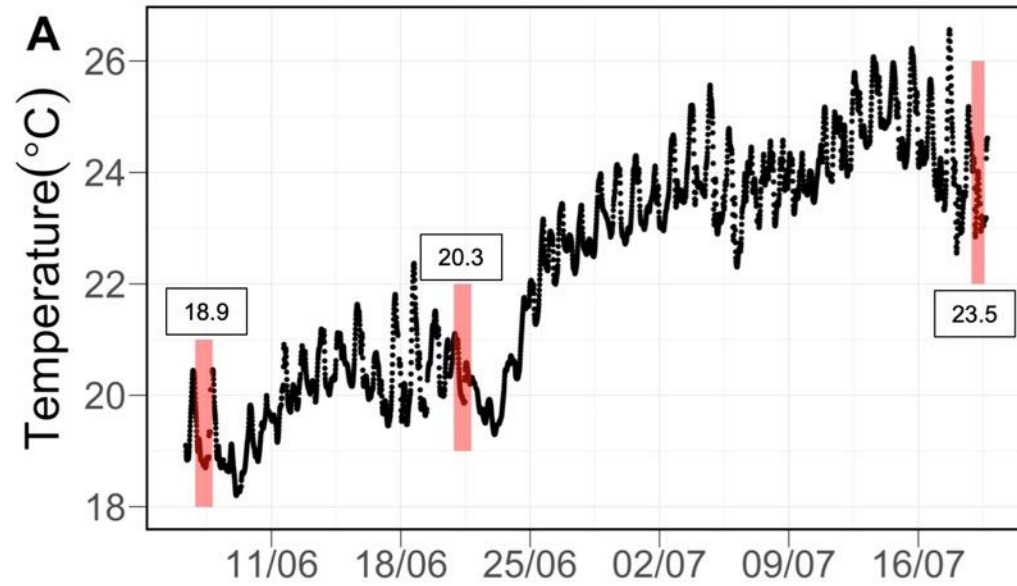
EXPERIMENTAL DESIGN



pH Treatment	pH in situ (seawater scale)	ρCO_2^* (μatm)	Ω^* Aragonite
Ambient (control)	7.81 ± 0.07^a	1002.10 ± 288.35^a	1.30 ± 0.27^a
Medium	7.51 ± 0.11^b	2274.74 ± 369.15^b	0.62 ± 0.09^b
Low	7.20 ± 0.10^c	4293.57 ± 1289.67^c	0.37 ± 0.11^c

EXPERIMENTAL DESIGN

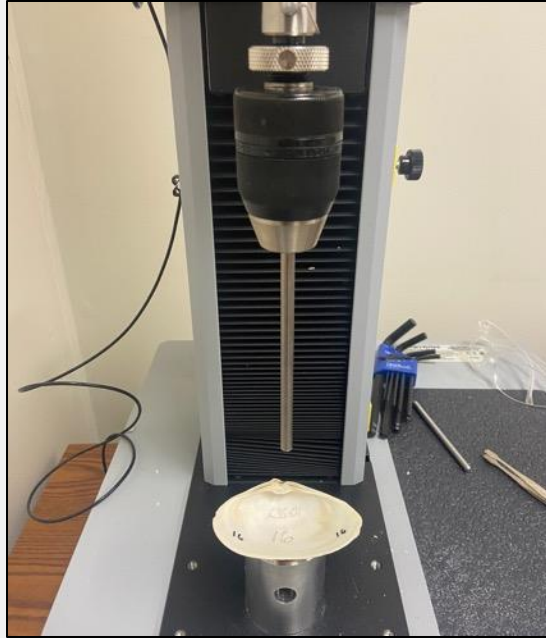
ENVIRONMENTAL DATA Experiment 1



Growth



Shell strength



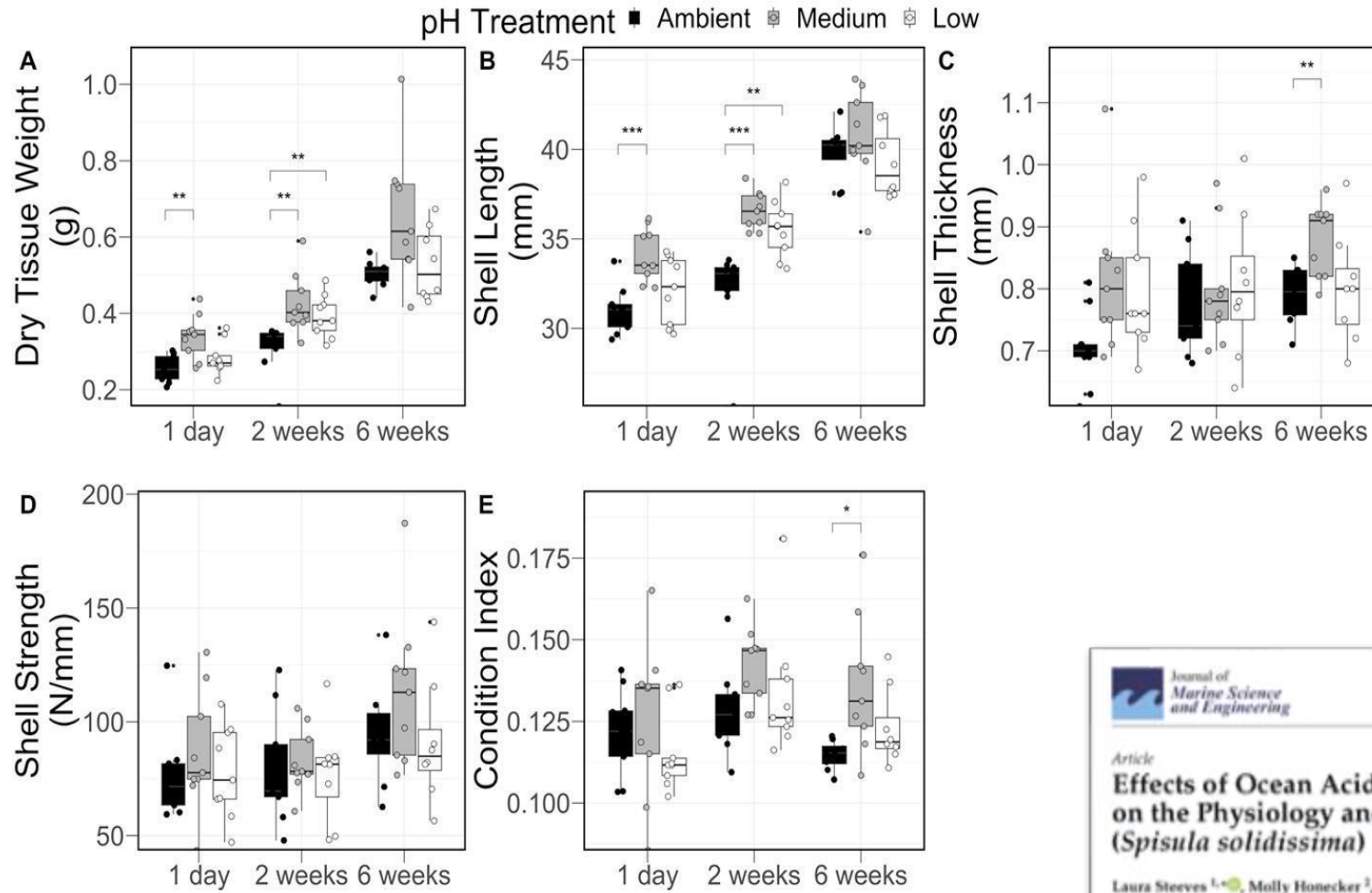
Biodeposition (feeding & digestion)



BIOLOGICAL MEASUREMENTS

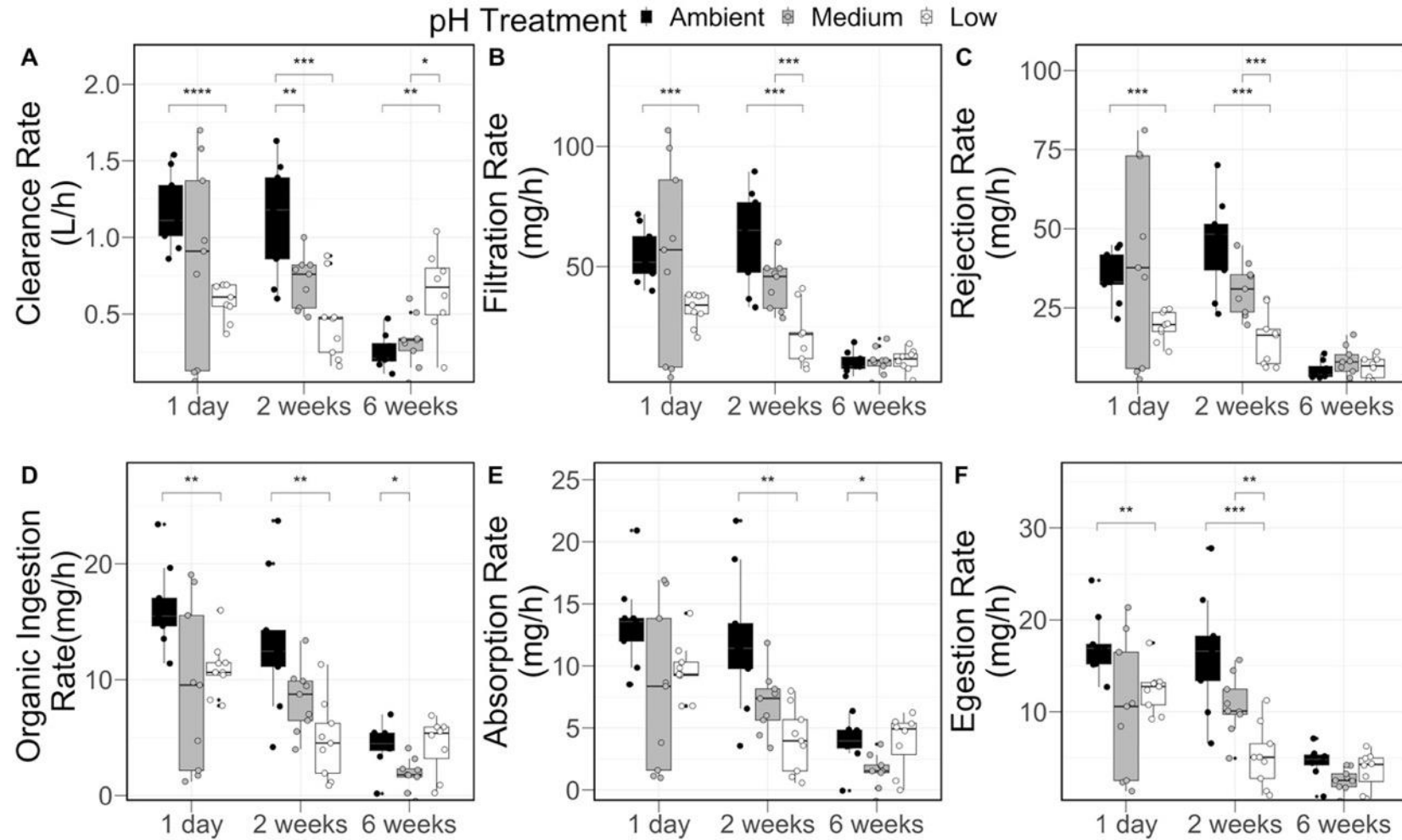
Experiment 1

- **Growth:** shell & tissue
- **Shell strength** (N/mm)
- **Biodeposition:** Feeding: clearance rate, filtration rate, rejection rate... Digestion: absorption rate



GROWTH:
No clear impacts of pH over 6 weeks

Experiment 1



PHYSIOLOGY:
Clear impact of low pH over time
thermal stress at week 6?

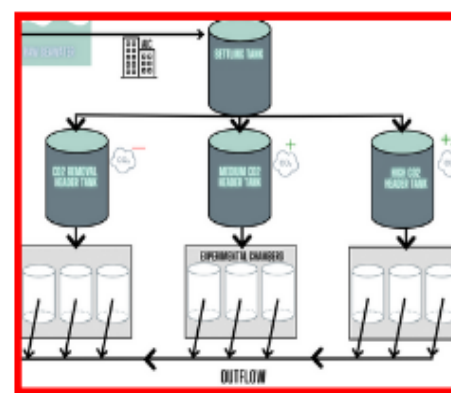
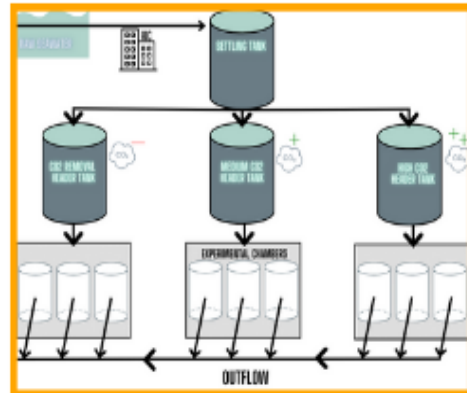
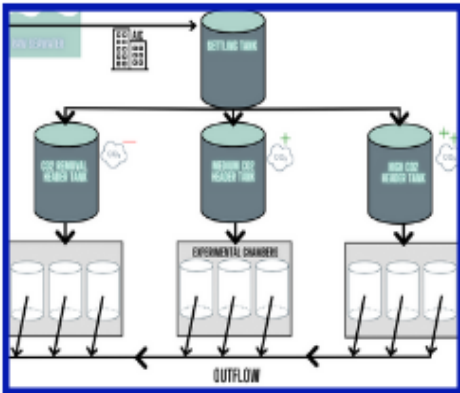
Experiment 1

Experiment 2

**Ambient
Temperature**

+ 2°C

+ 5°C



EXPERIMENTAL DESIGN

Experiment 2



Water Flow



CO₂ Control

Biodeposition (feeding & digestion)



Metabolic rate



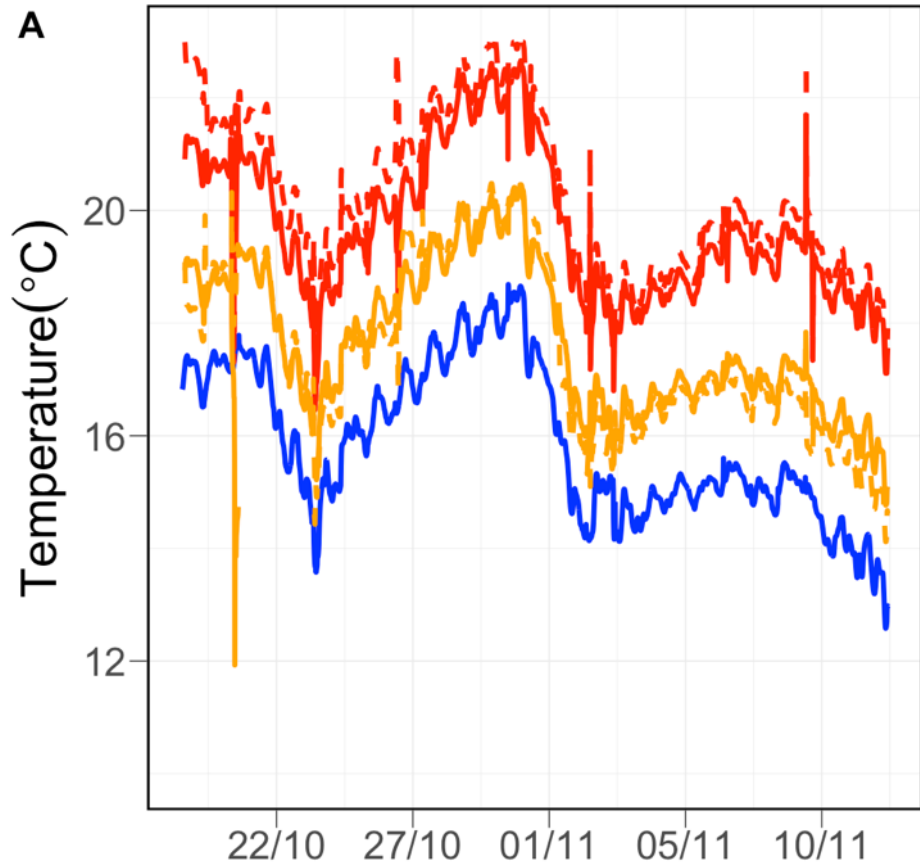
Gene expression



PHYSIOLOGICAL MEASUREMENTS

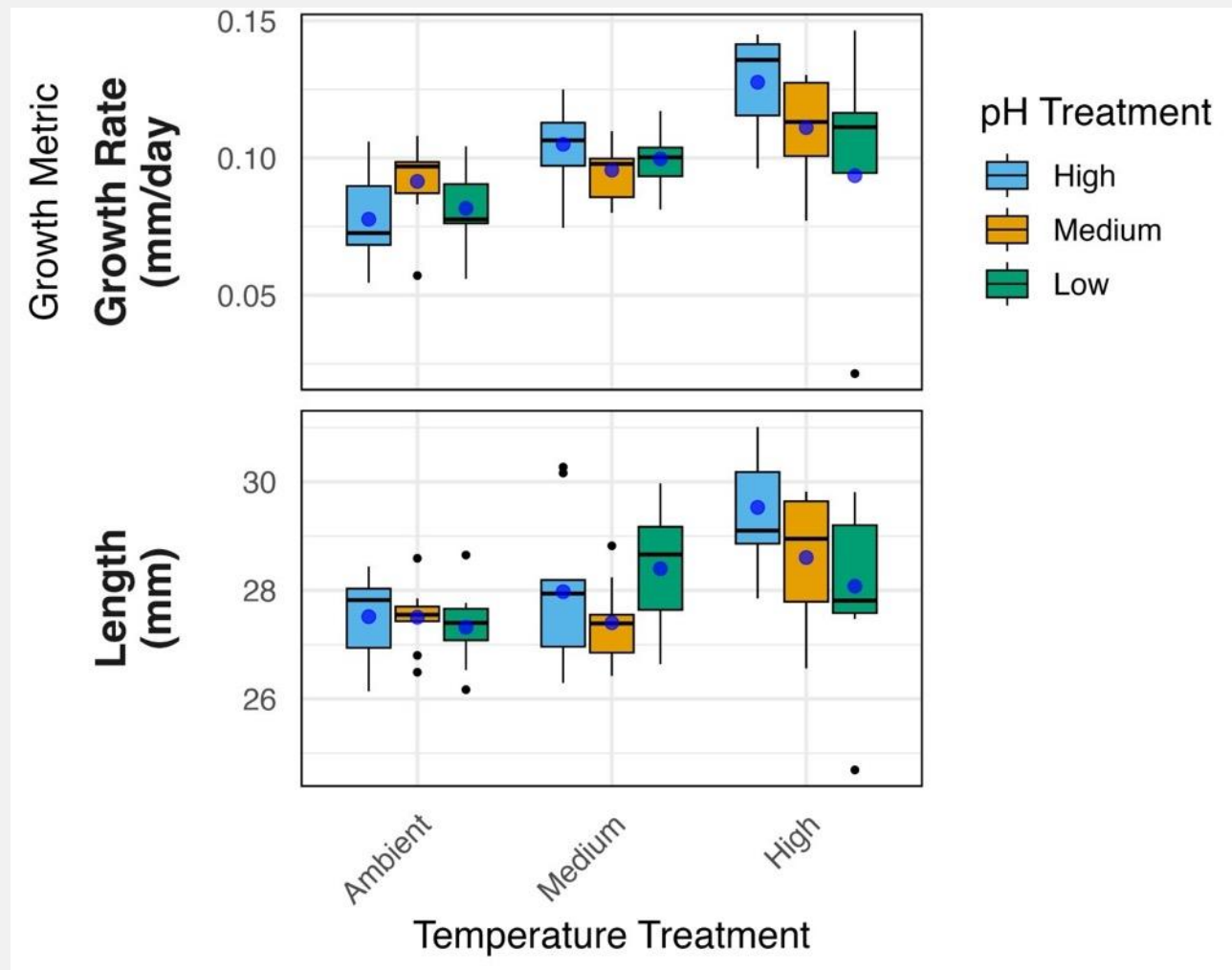
Experiment 2

- **Growth:** shell & tissue, **Shell strength**
- **Biodeposition:** Feeding and digestion
- **Metabolic Rate:** Oxygen consumption
- **Gene expression:** Transcriptomics - gill tissue



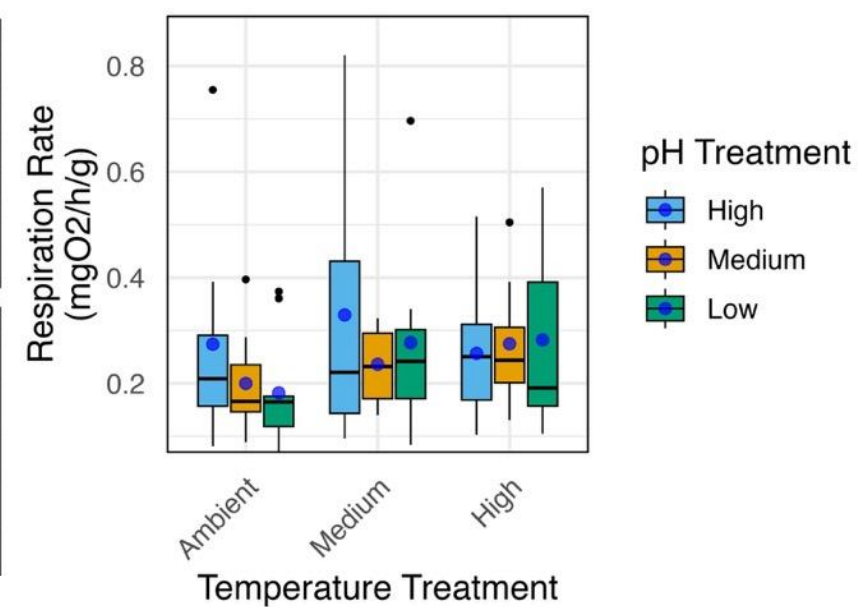
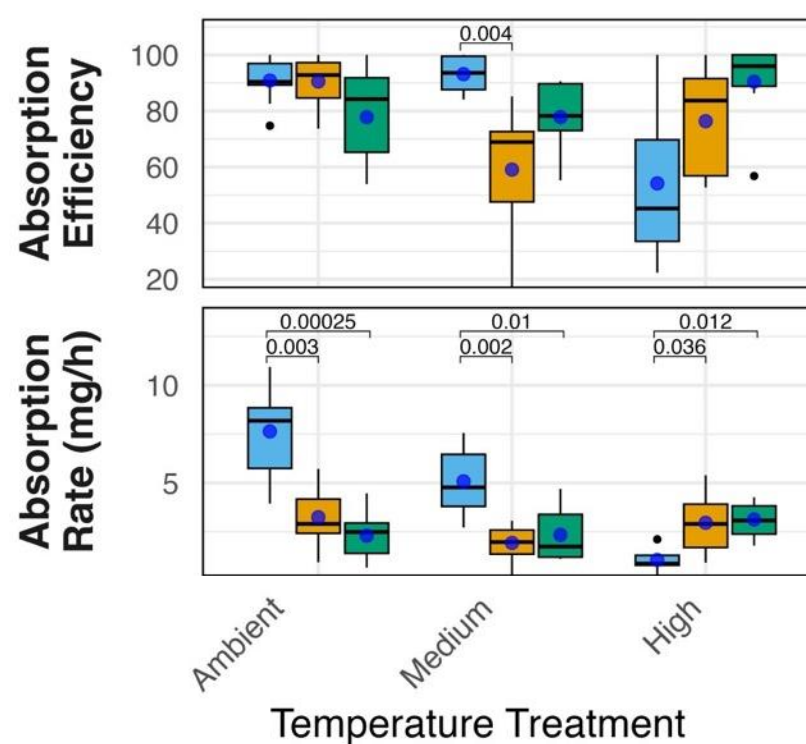
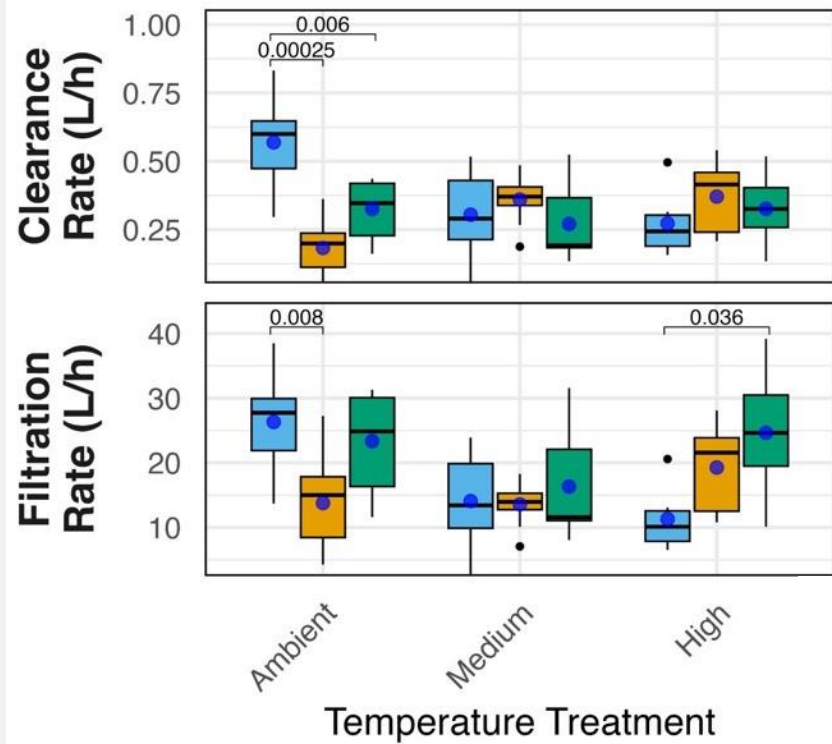
High Temp - - - Low pH
High Temp - Medium pH
Medium Temp - - - Low pH
Medium Temp - Medium pH
Ambient Temp - High pH

ENVIRONMENTAL DATA



GROWTH:
No clear impacts of pH over 6 weeks

Experiment 2



PHYSIOLOGY:
No clear impact of low pH at week 6

Experiment 2



CONCLUSIONS & NEXT STEPS

No clear effects of OA on growth or shell strength after 6 weeks

Despite $\text{pH} = 7.2$ & $\Omega_{\text{aragonite}} = 0.37$

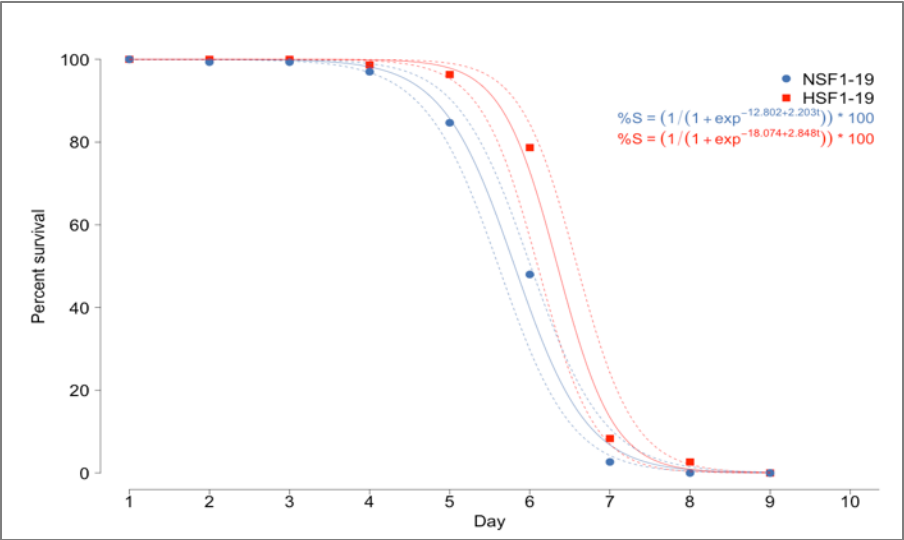
Reduced feeding and digestion rates after 2 weeks in medium and low pH treatments

Interactive effect of OA and temperature when temperature is high

Experiment 2

- Examine transcriptomic data

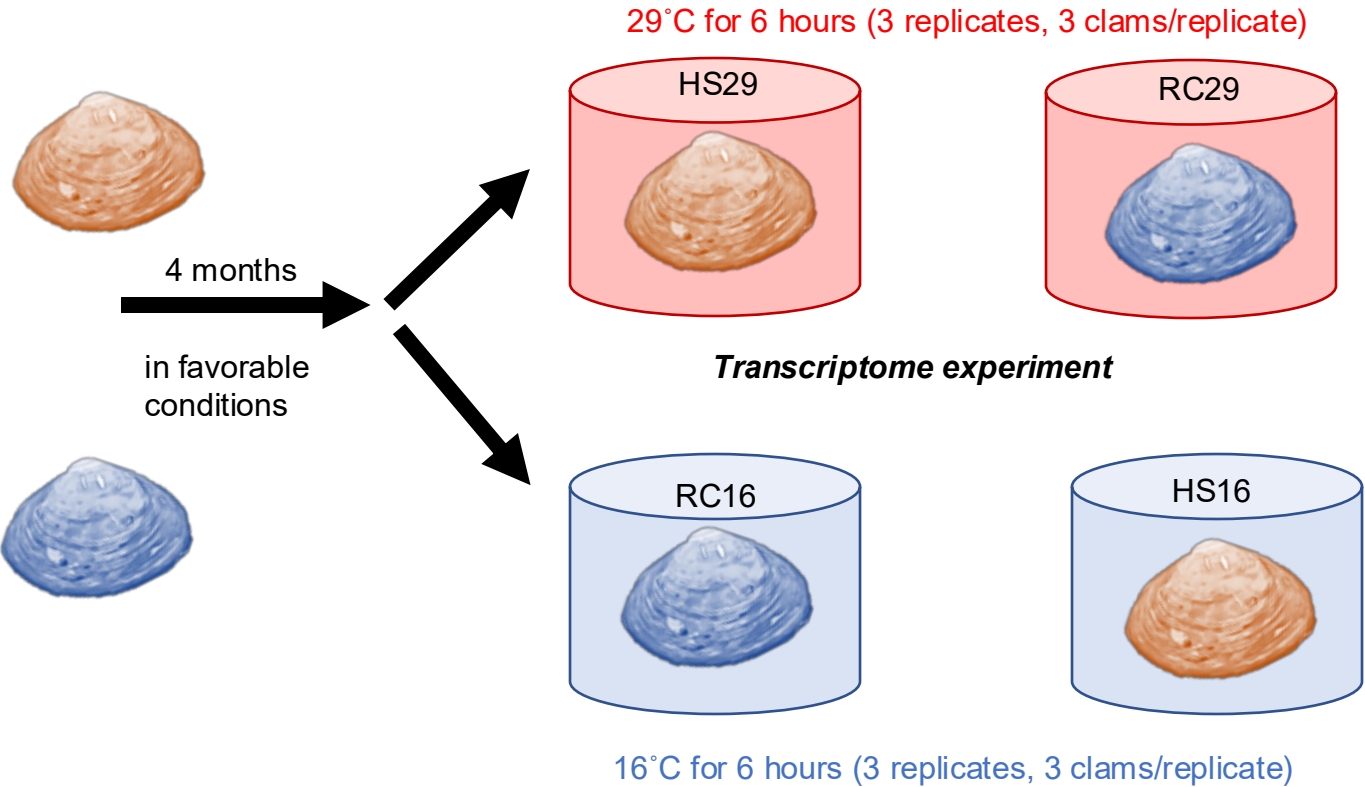
Can we Selectively Breed Atlantic surfclams (*Spisula solidissima*) for heat tolerance?



Heat-Selected-17 (HS)



Non-Selected-17 =
Random Control (RC)

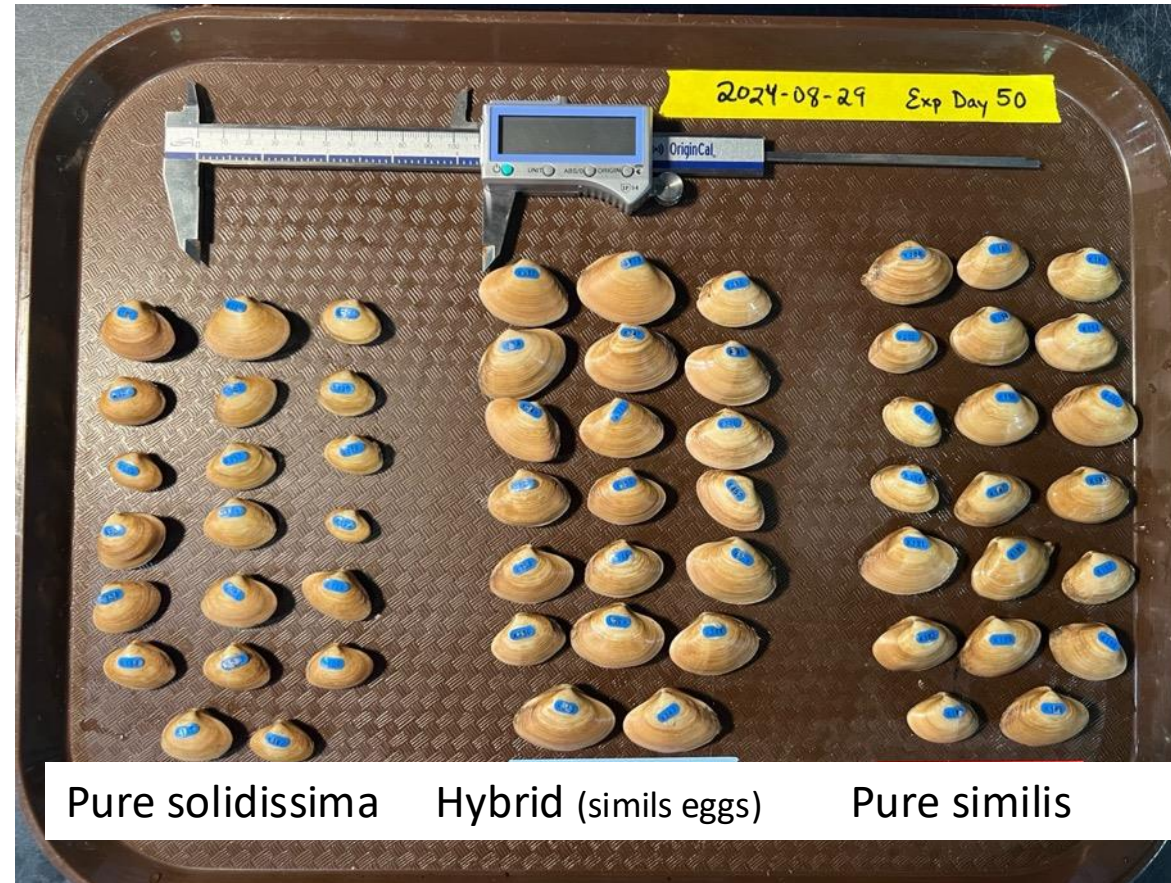


Dr. Mike Acquafredda



Possibility of surfclam hybrids

Determine whether northern (*S. s. solidissima*) and southern (*S. s. similis*) surfclams are capable of producing hybrid offspring

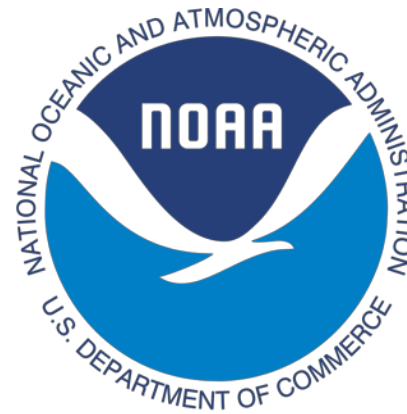


ACKNOWLEDGEMENTS

National Sea Grant Office & Ocean Acidification Program NA21OAR4170318

Aquaculture Innovation Center: Sean Towers, Becca Giplin, Josh Kiernan, David Jones, Mark Baranoski

Rachel Davitt, Ailey Sheehan, Becca Horwitz, Laura Versaggi, Meghan Nadzam, Alex Ambrose, Hails Tanaka, Sarah Borsetti, Zhenwei Wang



RUTGERS

New Jersey Agricultural
Experiment Station
**NEW JERSEY AQUACULTURE
INNOVATION CENTER**



OFFSHORE AQUACULTURE POTENTIAL FOR THE ATLANTIC SURFCLAM

Two deployments:

Winter: 4 cages (2023)

Spring: 2 cages (2024)

Retrieved: Summer 2024



Worked well under summer conditions.
Not a replacement for fishery.
Provided important biological information.





STUDENT TALKS

Mid-Atlantic Eelgrass Carbon Sequestration: Present and Future Responses to Warming and Population Decline

Katie Tanner, University of Maryland Eastern Shore
Marine-Estuarine Environmental Science PhD Student



Eelgrass (*Zostera marina*)

Cold water seagrass species

Dominant in northwest Atlantic, polyhaline regions of Chesapeake Bay

Numerous ecosystem services

- Water clarity improvement
- Sediment stabilization
- Erosion protection
- Nursery habitat, scallop habitat



Carbon Sequestration



(g C m⁻² yr⁻¹)

Blue carbon ecosystem: nature-based solution, management and carbon accounting opportunities

~50% of carbon sequestered in eelgrass meadows comes from outside the meadow

Sediment carbon pool is largest by far

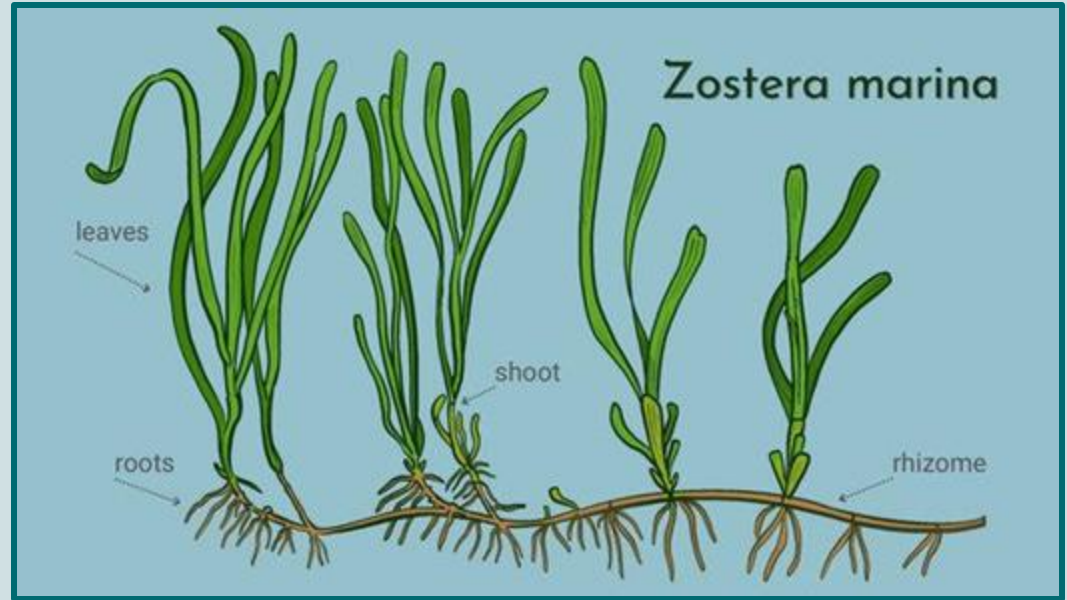
Carbon Sequestration

Roots and rhizome network

- Stabilizes sediment
- Sequesters carbon

Anoxic environment

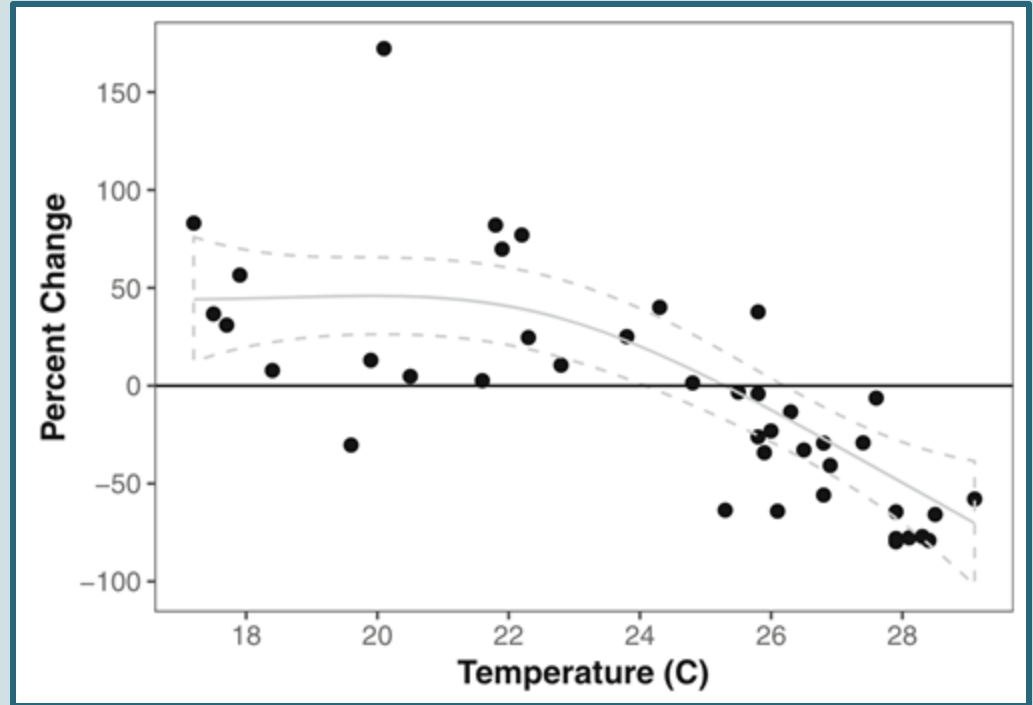
- Slow microbial decomposition
- Carbon can remain stored for centuries



Thermal Limits

25°C: thermal limit, ideal temperatures < 25°C

30°C: mortality and large-scale declines

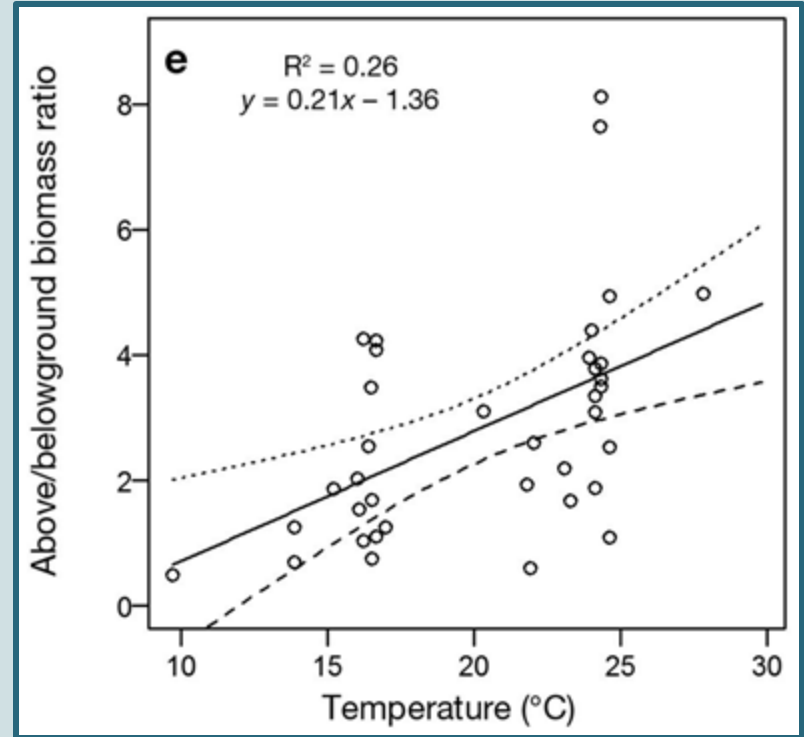


(Fig 5, Shields et al., 2019)

Carbon Sequestration + Heat?

Several mechanisms

1. **Altered energy budgets:** plants direct more energy to shoots than to rhizome (where carbon is stored) under thermal stress

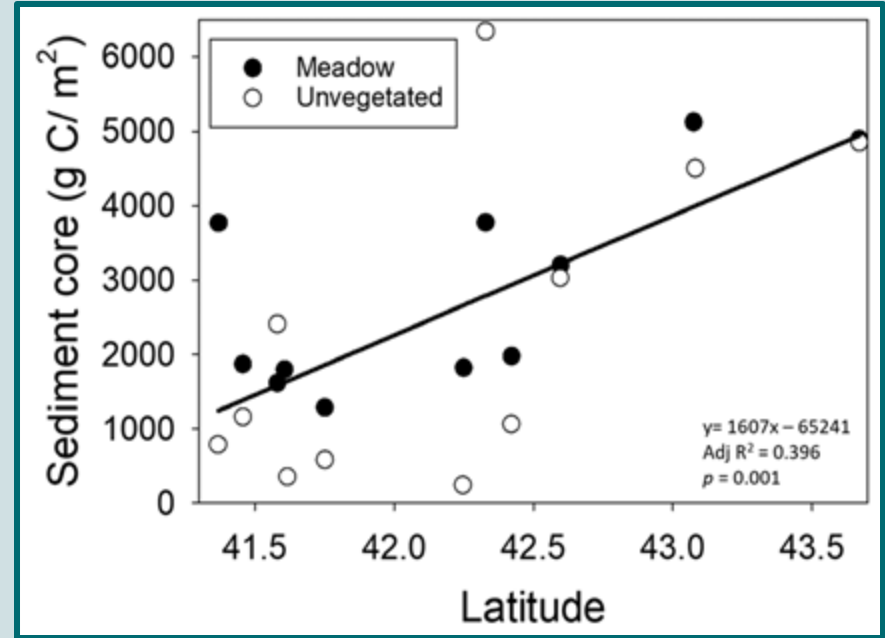


(Fig 4e, Clausen et al., 2014)

Carbon Sequestration + Heat?

Several mechanisms

1. **Altered energy budgets:** plants direct more energy to shoots than to rhizome (where carbon is stored) under thermal stress
2. **Heat induced mortality:** sustained thermal stress causes mortality and population decline
 - a. Loss of aboveground biomass = total loss of carbon? Over what timeframe?



(Fig 5, Novak et al., 2020)

Research Question

How will carbon sequestration in mid-Atlantic eelgrass meadows respond to thermal stress and subsequent population decline?



Methods



Objectives

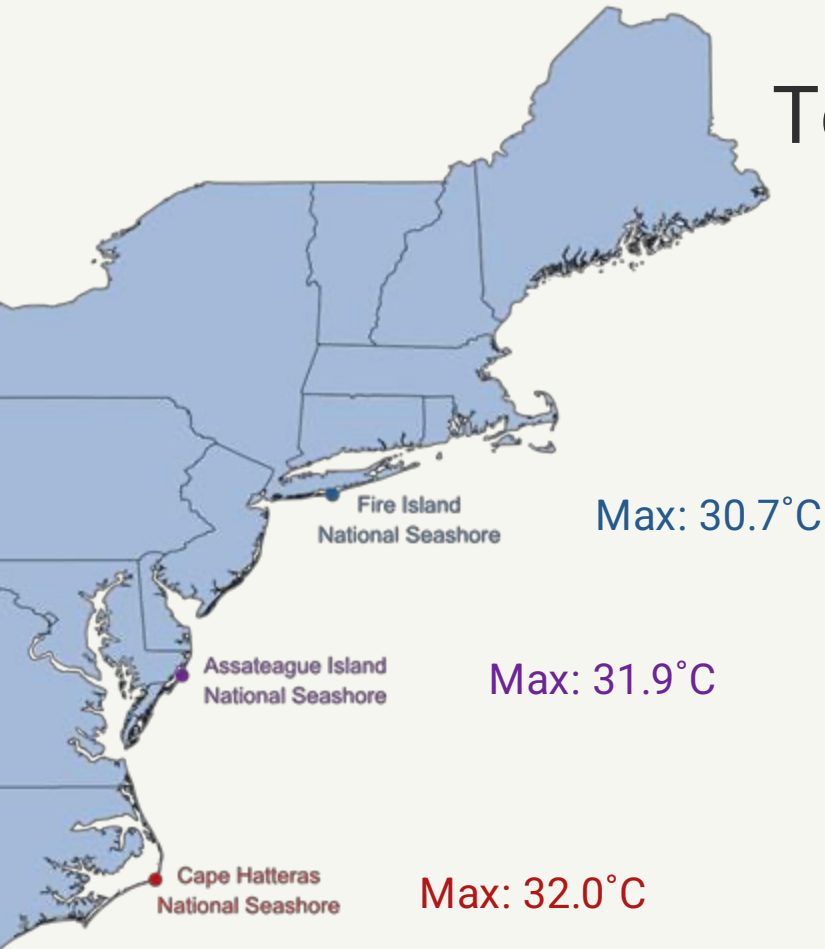
**Quantify carbon sequestration
across a latitudinal
(temperature) gradient**

**Hypothesis: sediment C pool will
decrease as temperatures increase**

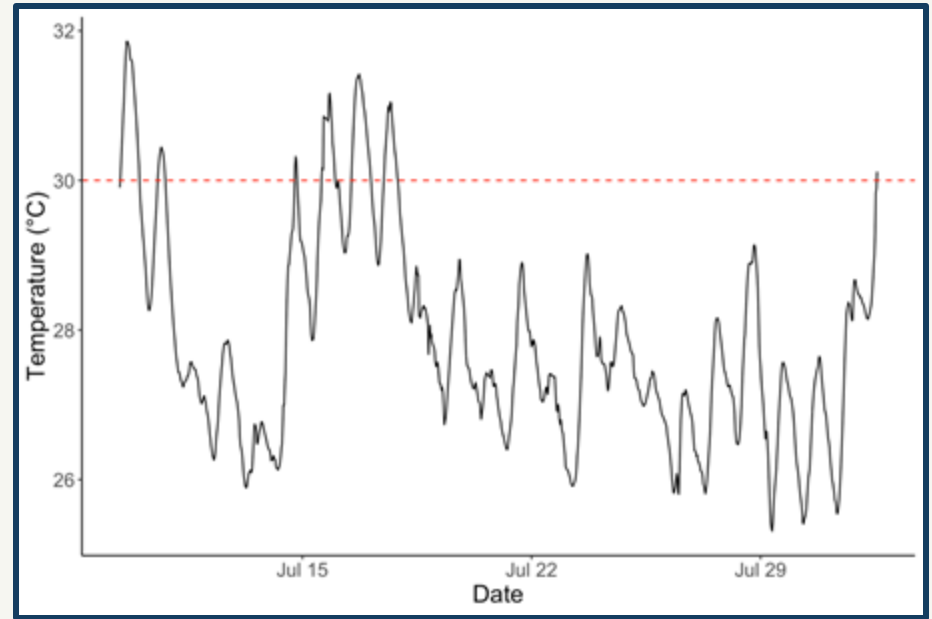
**Quantify carbon
sequestration across a
degradation gradient**

**Hypothesis: sediment C pool will decrease
as eelgrass shoot density decreases**

Temperature Gradient Results



Assateague Island, July 9 - August 1, 2024



*Temperatures from in situ NPS water quality monitoring, July 9 - August 1, 2024

Defining the Degradation Gradient

Healthy

Maintained or
increased
shoot density

Partially Degraded

Lost ~50%
shoot density

Completely Degraded

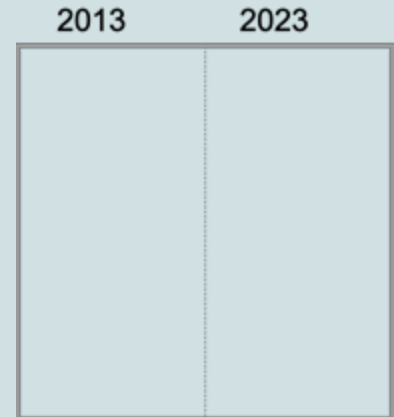
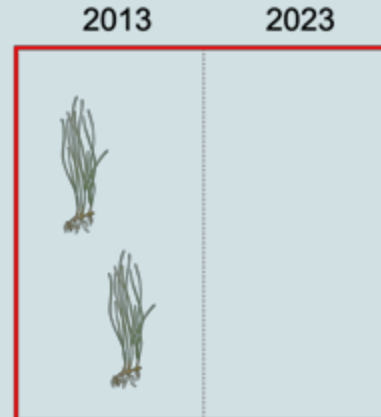
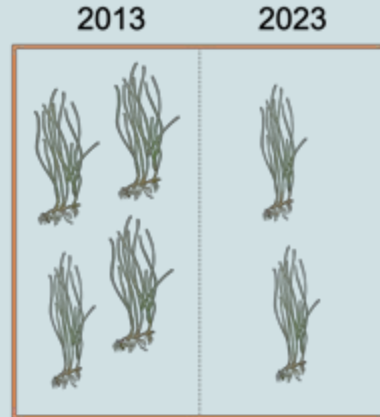
Lost 100% shoot density

Recently unvegetated

Unvegetated Control

Nearby open sand

No record of eelgrass



Site Selection Results: Assateague Island

Healthy

Tingles Island

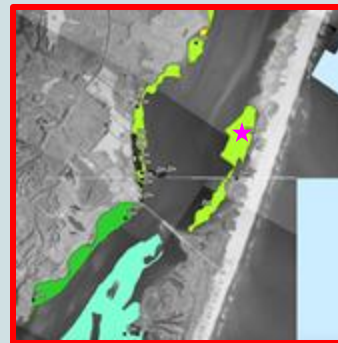
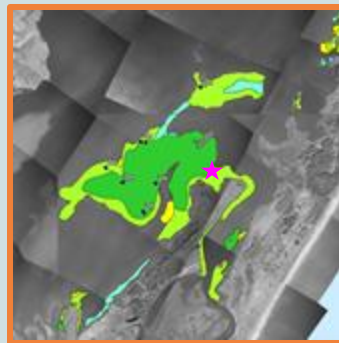
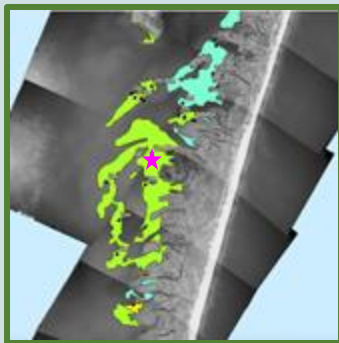
Partially Degraded

Wildcat Marsh

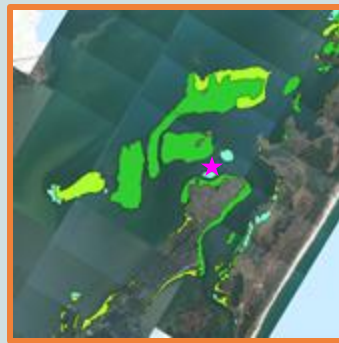
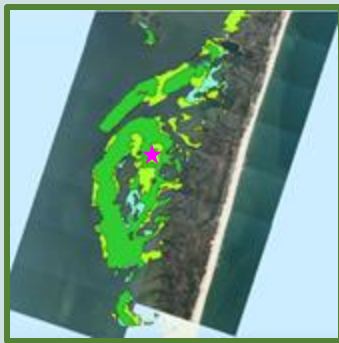
Completely Degraded

Verrazano Bridge

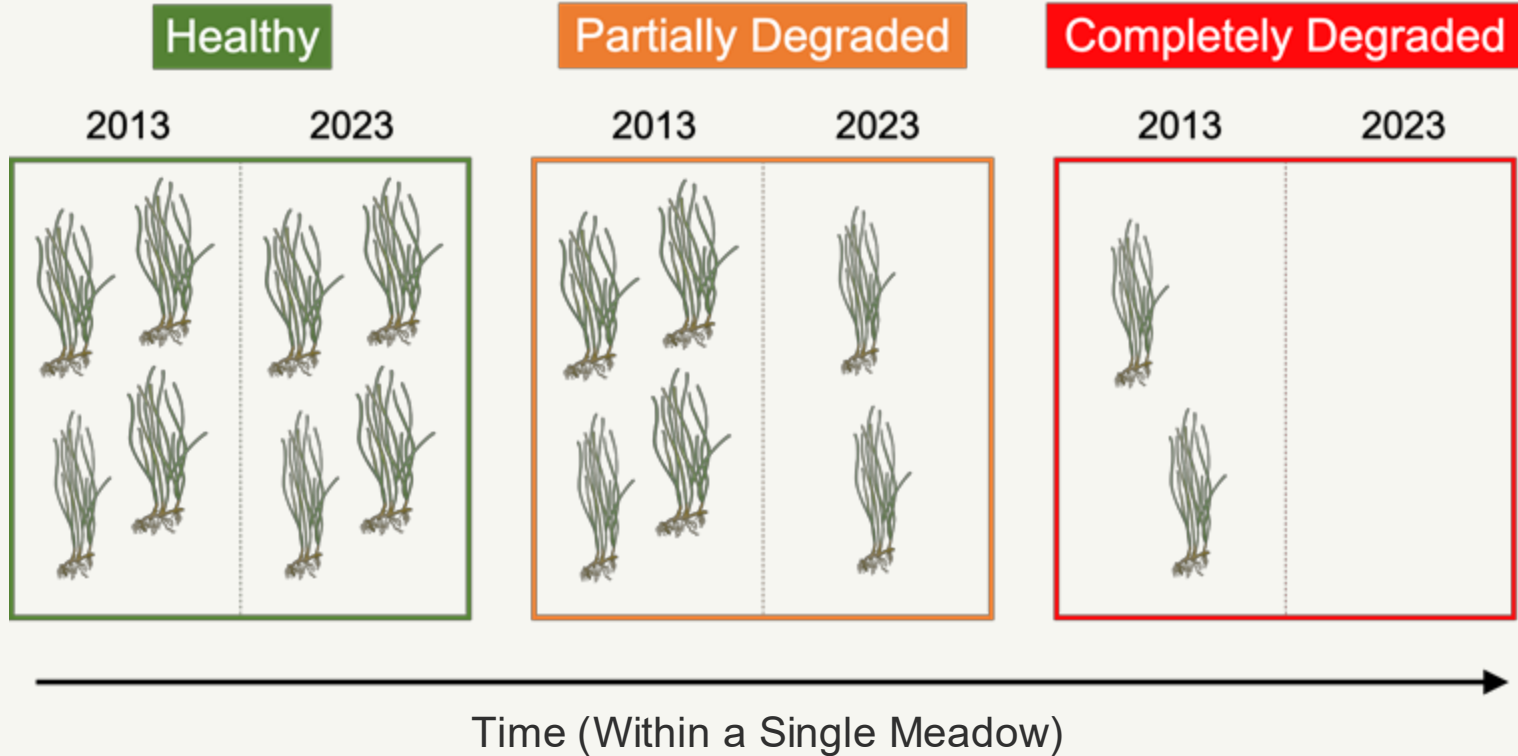
2013



2023



Space-for-Time Substitution



Sediment Core Sampling Survey

50cm cores (peat corer)

3 replicate cores at each site (4 sites per National Seashore)

Take sediment cores at peak aboveground biomass (April - June)

 = 1 sediment core



Tingles Island, Assateague Island

Sediment Core Subsampling



(Mazie et al., 2023)

Subsample Analyses

C_{org}

Dry bulk density of subsamples

Elemental analyzer for % Corg

δ¹³C

Carbon fixation

Unique seagrass signature

²¹⁰Pb

Sediment deposition dating

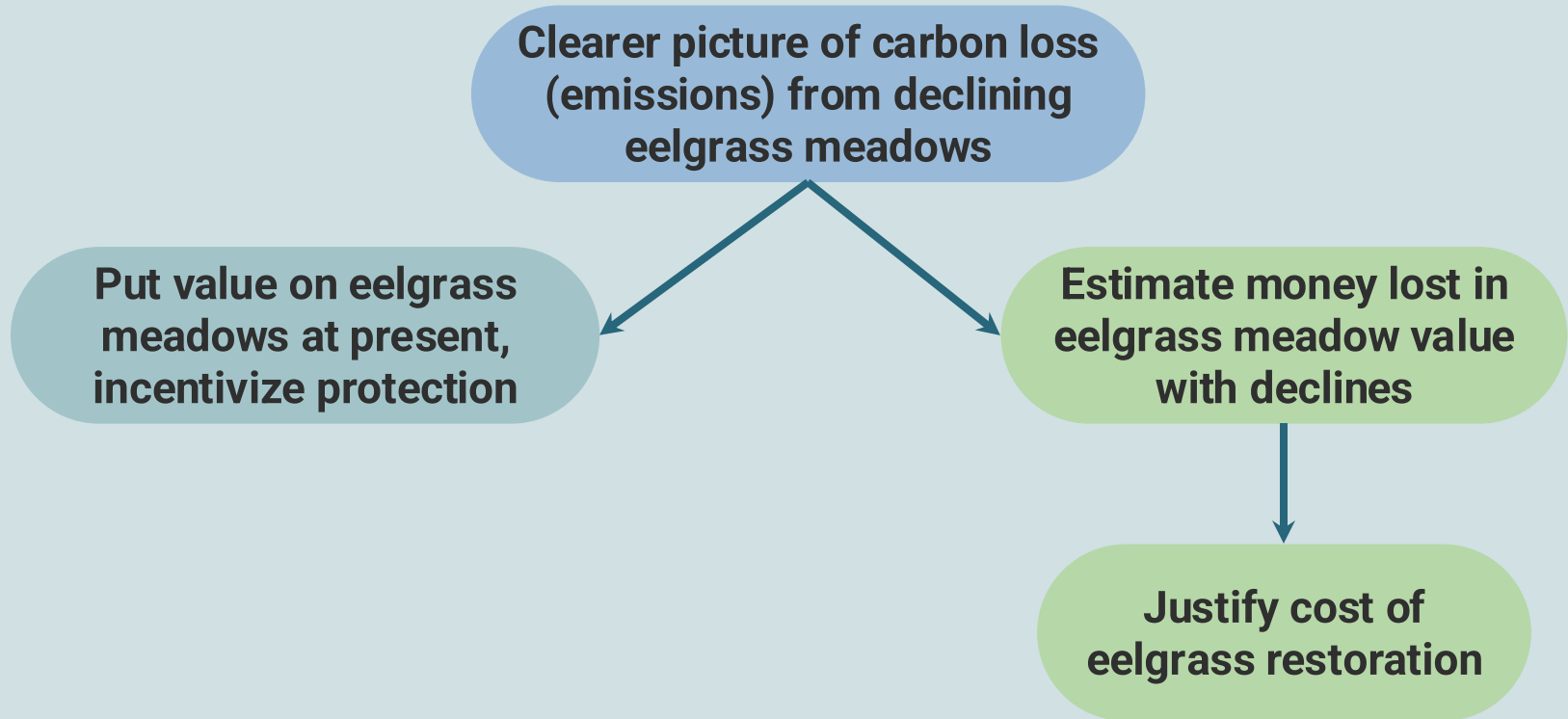
Sediment accretion → carbon accumulation

δ¹⁵N

Eutrophication scenarios

Alternate explanation for decline?

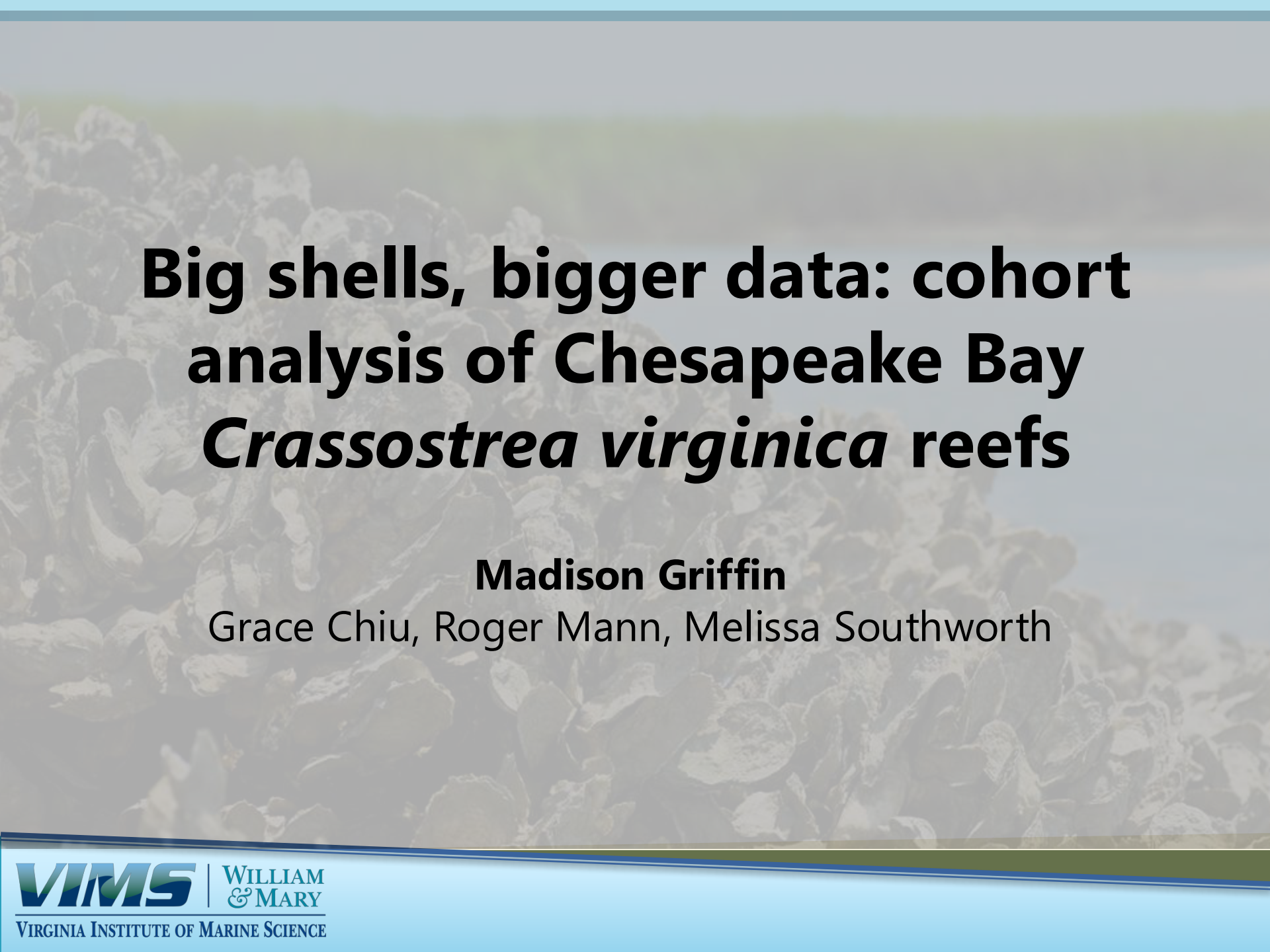
Future Directions, Applications



Thank you!

Contact: kltanner@umes.edu
[Tomasetti Lab Website](#)



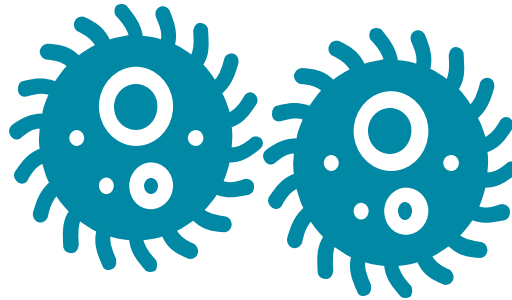


Big shells, bigger data: cohort analysis of Chesapeake Bay *Crassostrea virginica* reefs

Madison Griffin

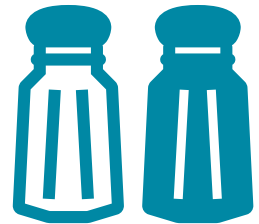
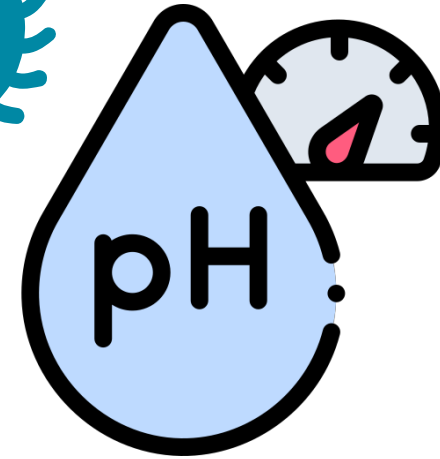
Grace Chiu, Roger Mann, Melissa Southworth

The Battles of the Eastern Oyster

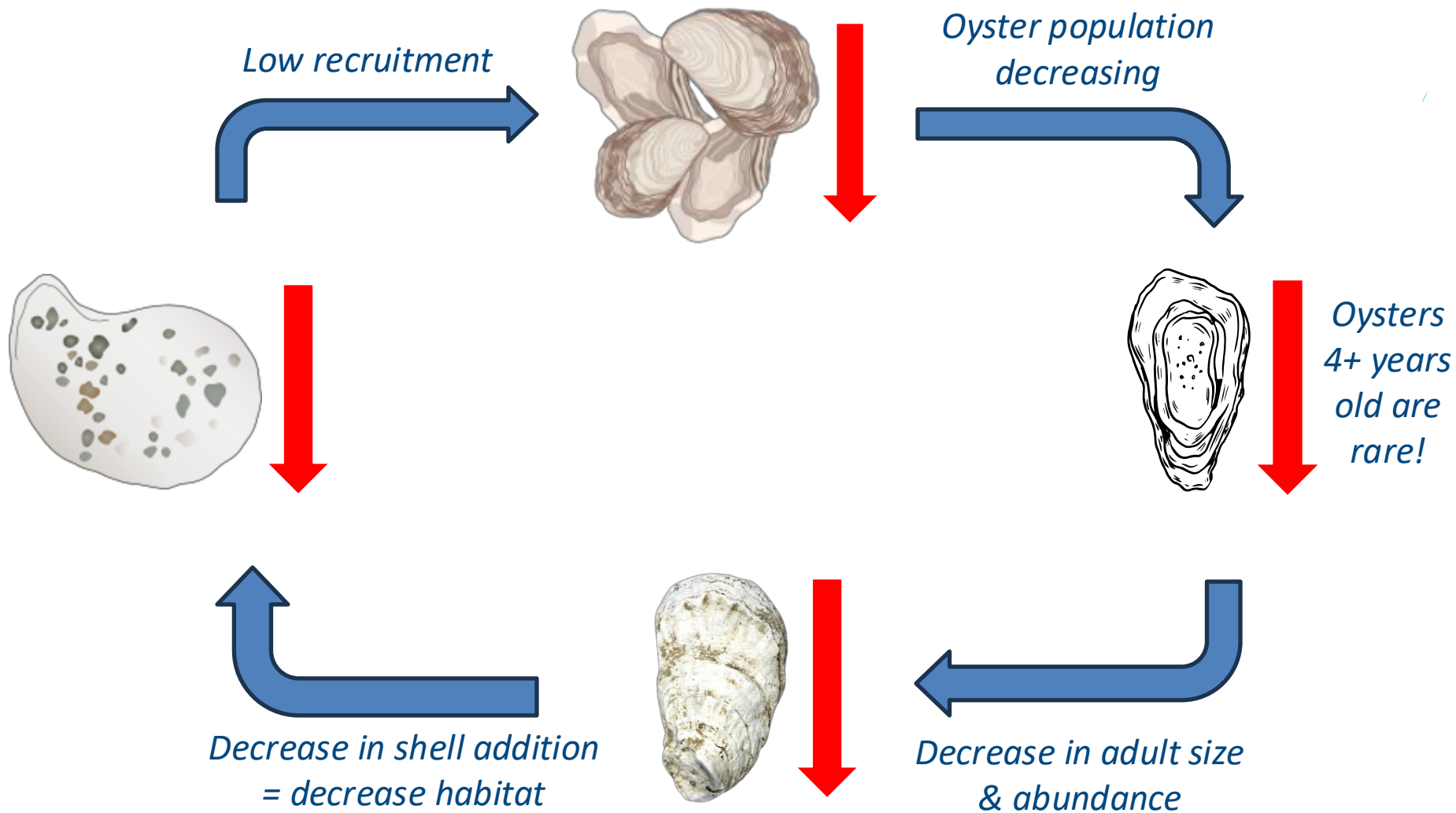


Dermo

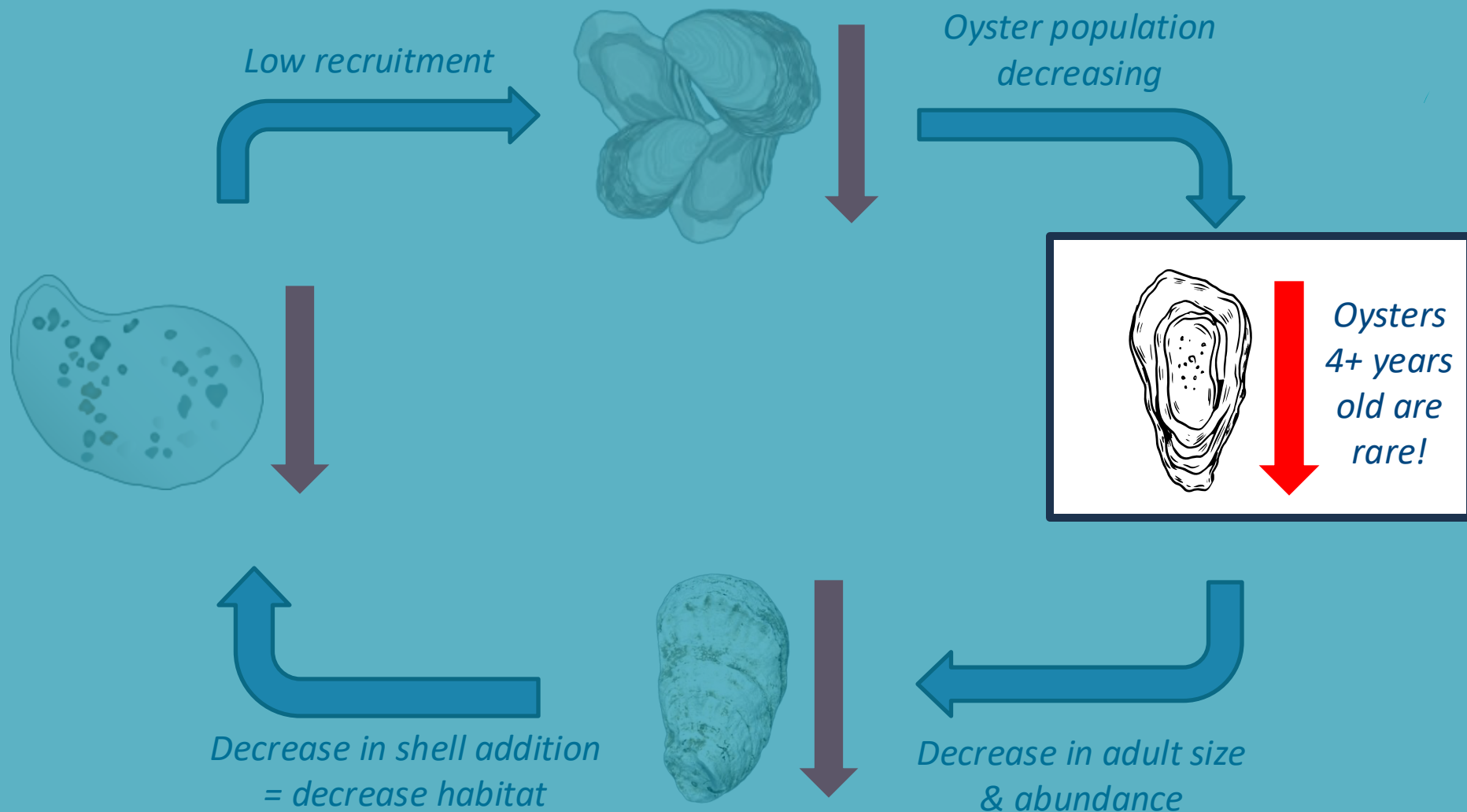
MSX



Unsustainable Reefs



Unsustainable Reefs

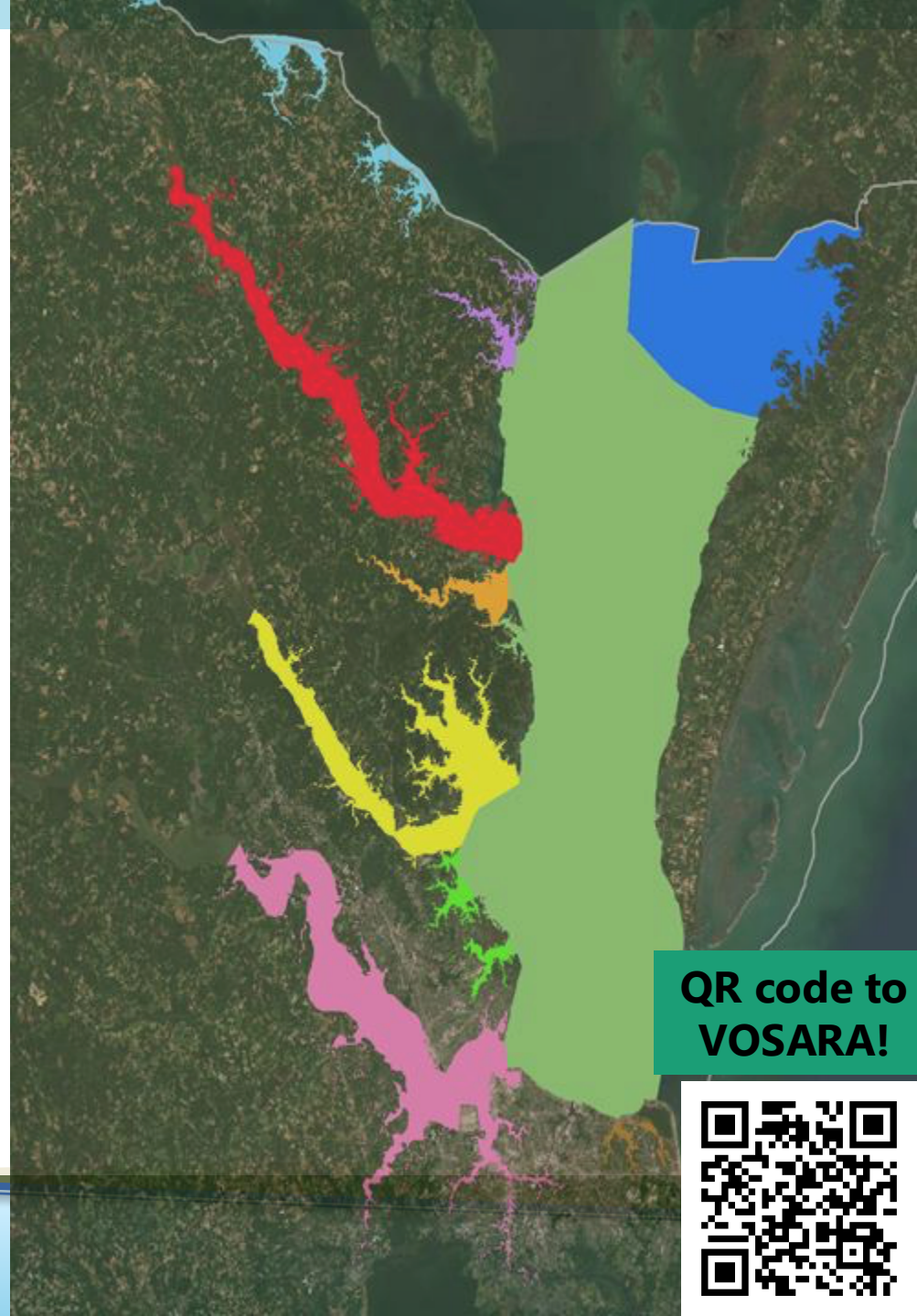


Research Objectives

1. Apply a Gaussian Mixture Model (GMM) to estimate age groups of oysters **only using shell length (mm)**
2. Link and track age groups over time
3. Evaluate the state of age-truncation and shrinking in the Chesapeake Bay population
4. Investigate signals of resiliency

Data Description

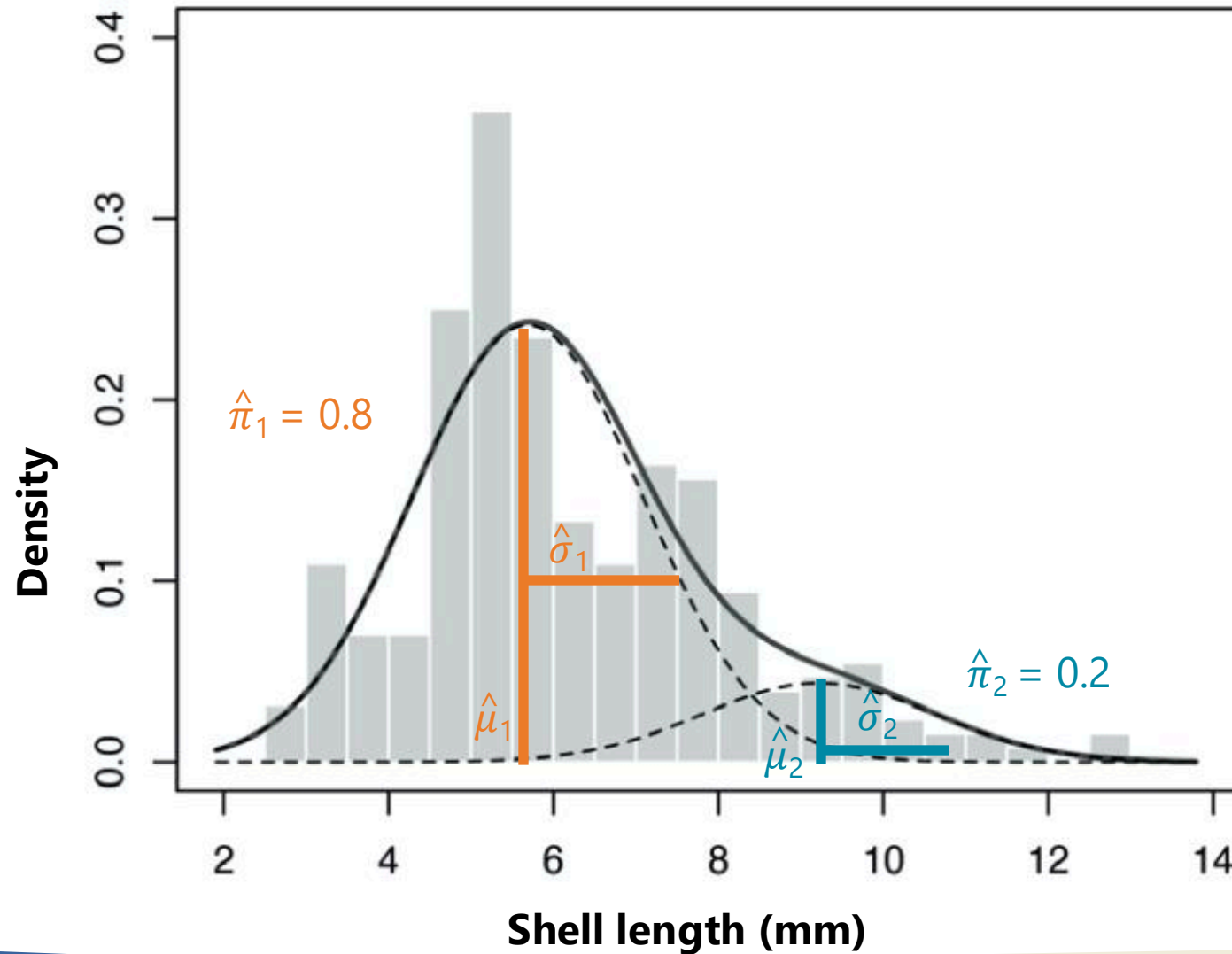
- Virginia Oyster Stock Assessment Replenishment Archive
- Years 2003-2023
- 64 reefs across the Virginia CB
- ($N = 1,205,165$ oysters)



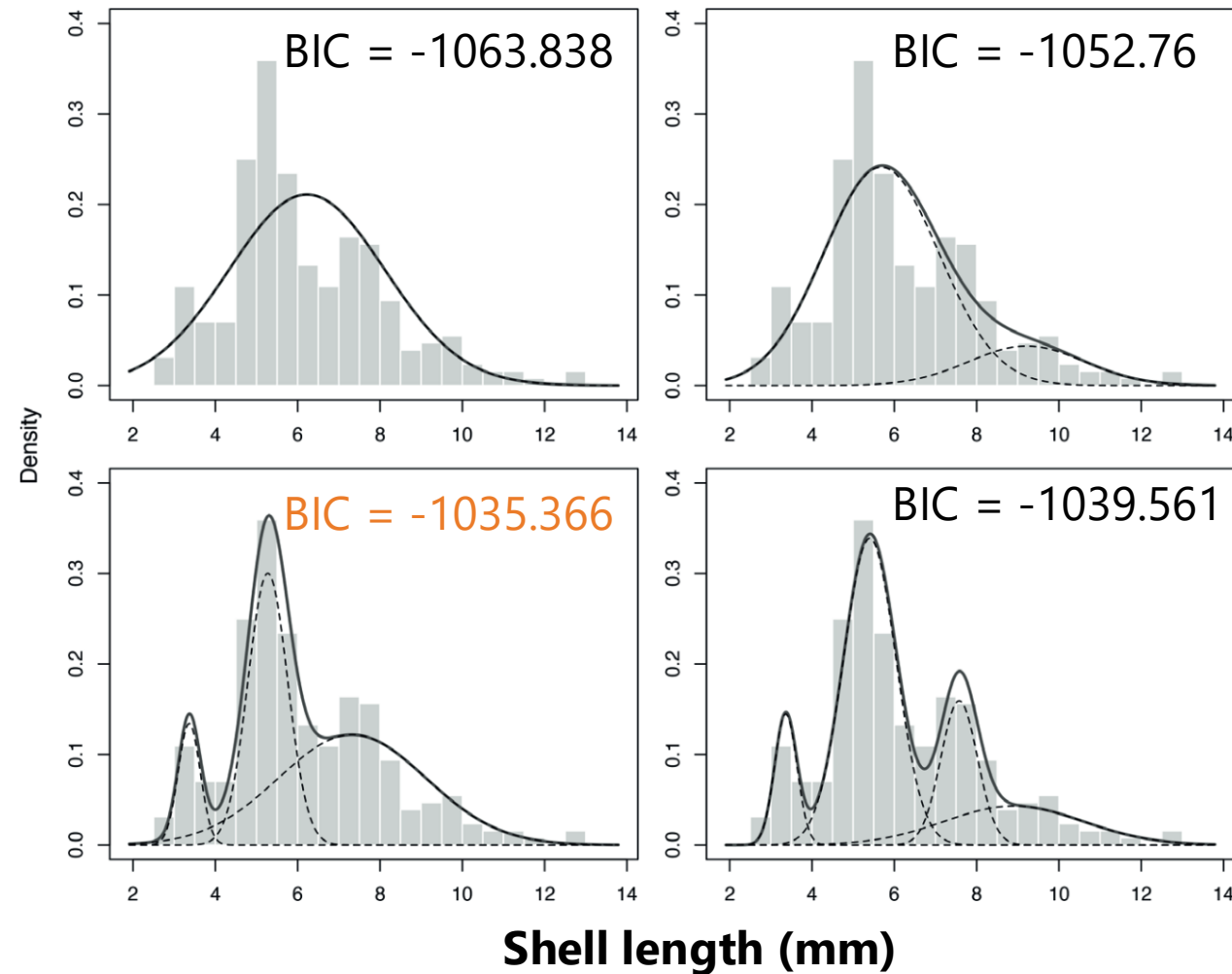
QR code to
VOSARA!



What is a Gaussian Mixture Model (GMM)?

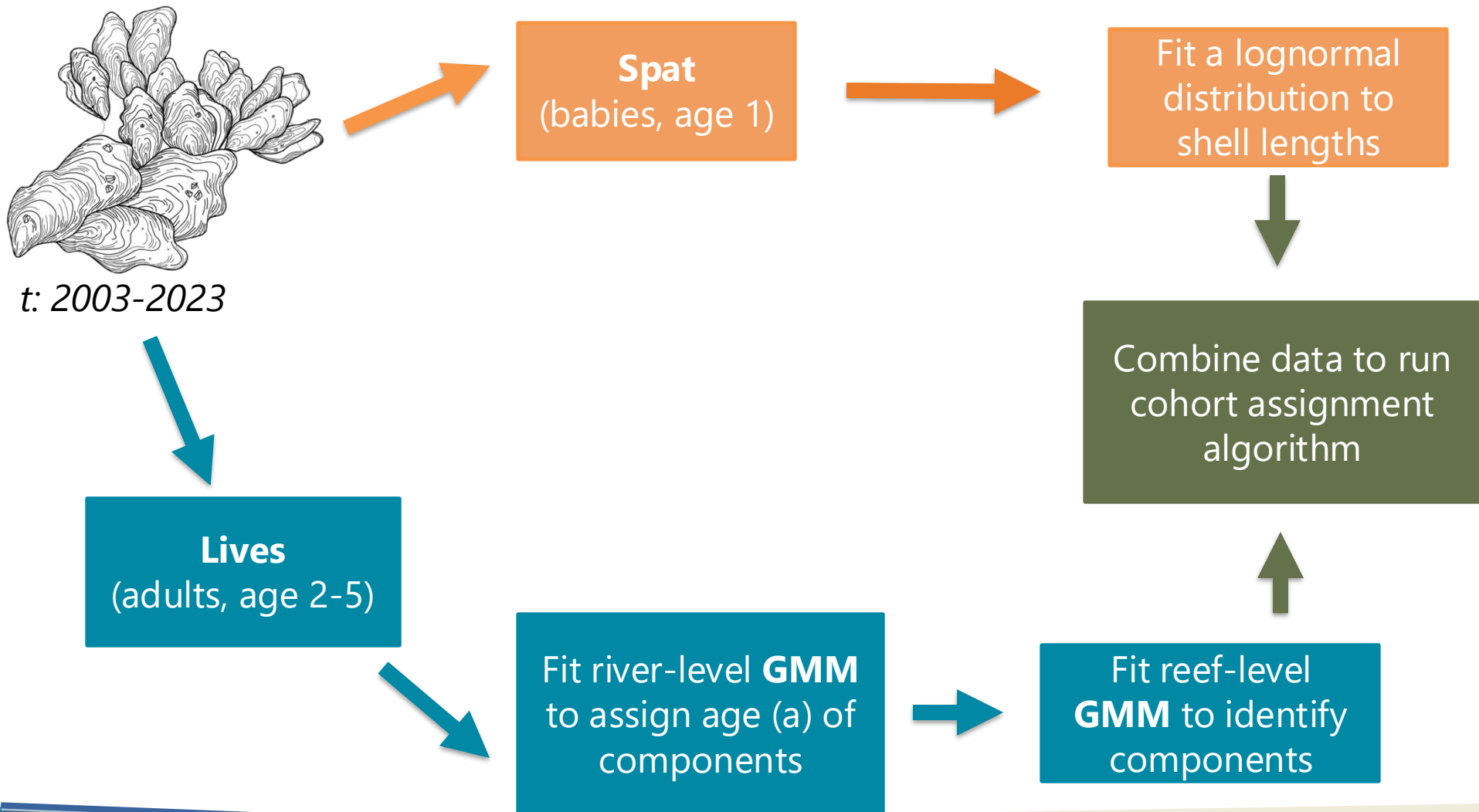


Why is this a novel method for aging oysters?



- Estimate age with size only
- No method to cross-validate GMM estimates to “known” ages
- Age structure has never been estimated on this scale in VA CB
- The **mclust** package is flexible, and we can let it pick the best number of components using BIC

Methodological Workflow

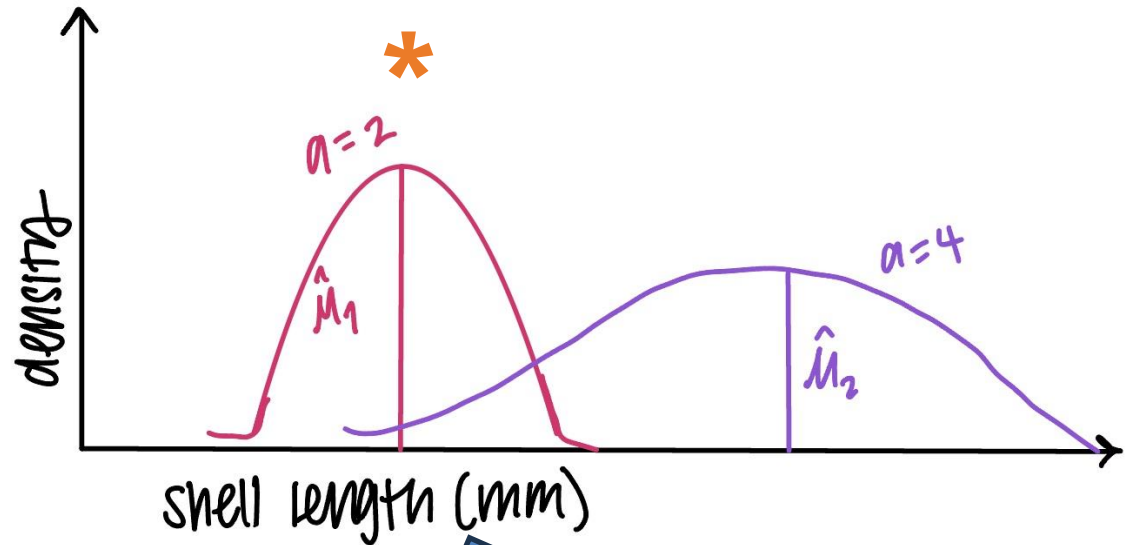


Cohort Assignment

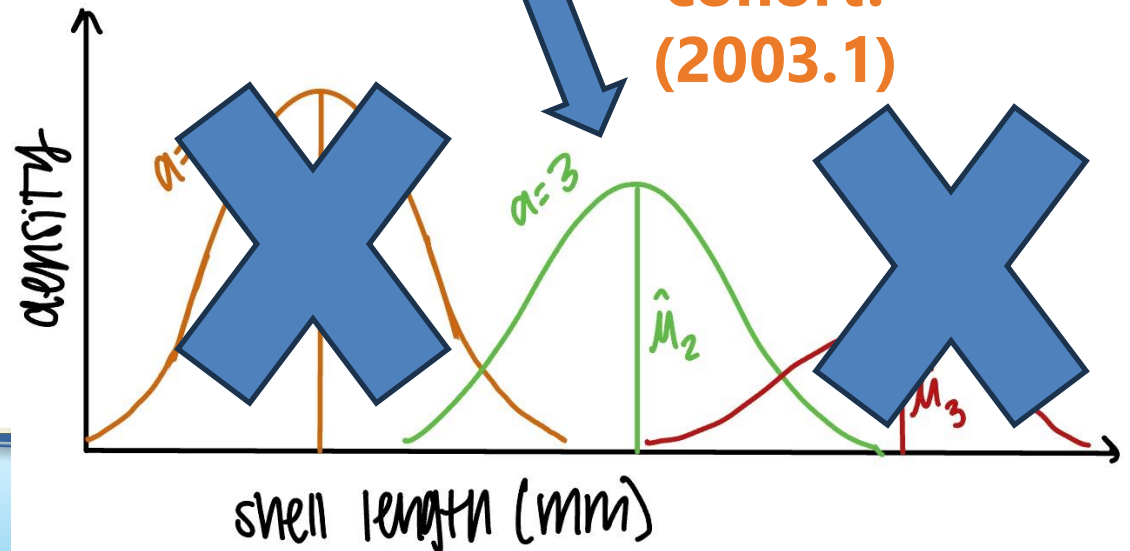
RULES:

- $\hat{\mu}_{t+1} > \hat{\mu}_t$
- $a_{t+1} = a_t + 1$
- If two components in the same year share an age, combined them
- If a is N.A., exclude from cohort assignment

2003 (t)



2004 (t+1)

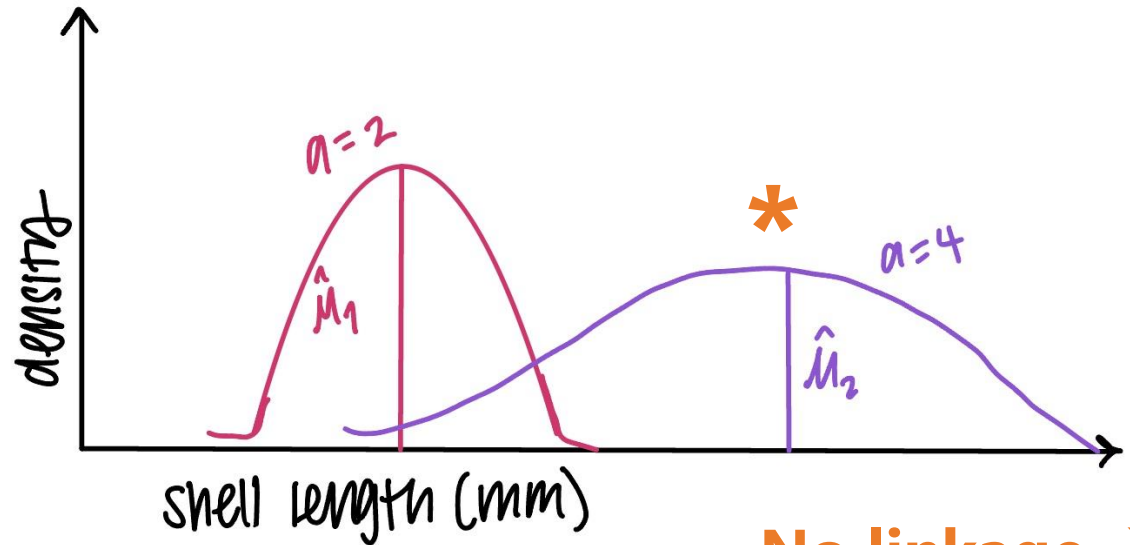


Cohort Assignment

RULES:

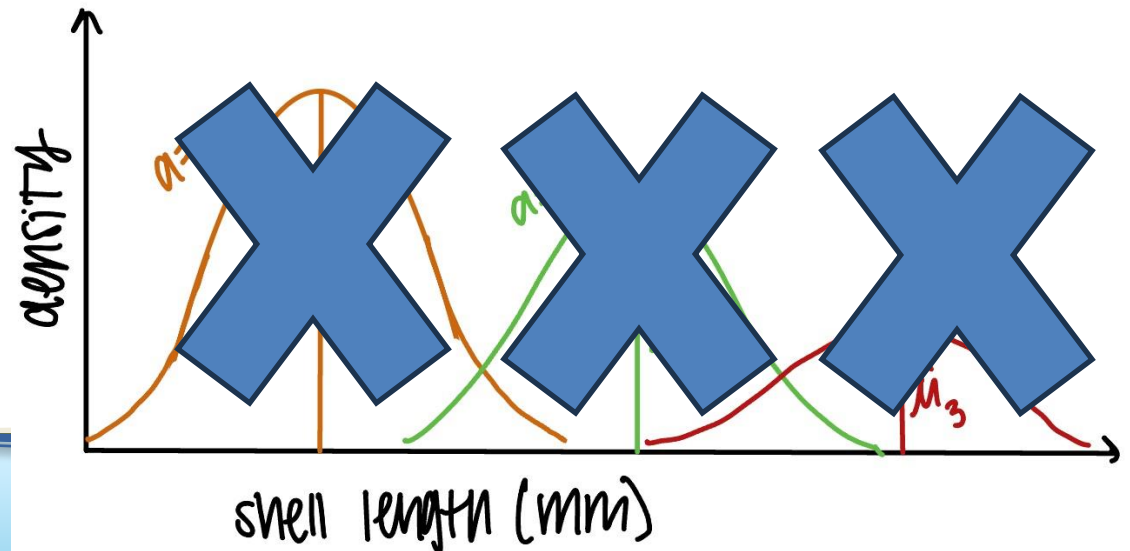
- $\hat{\mu}_{t+1} > \hat{\mu}_t$
- $a_{t+1} = a_t + 1$
- If two components in the same year share an age, combined them
- If a is N.A., exclude from cohort assignment

2003 (t)



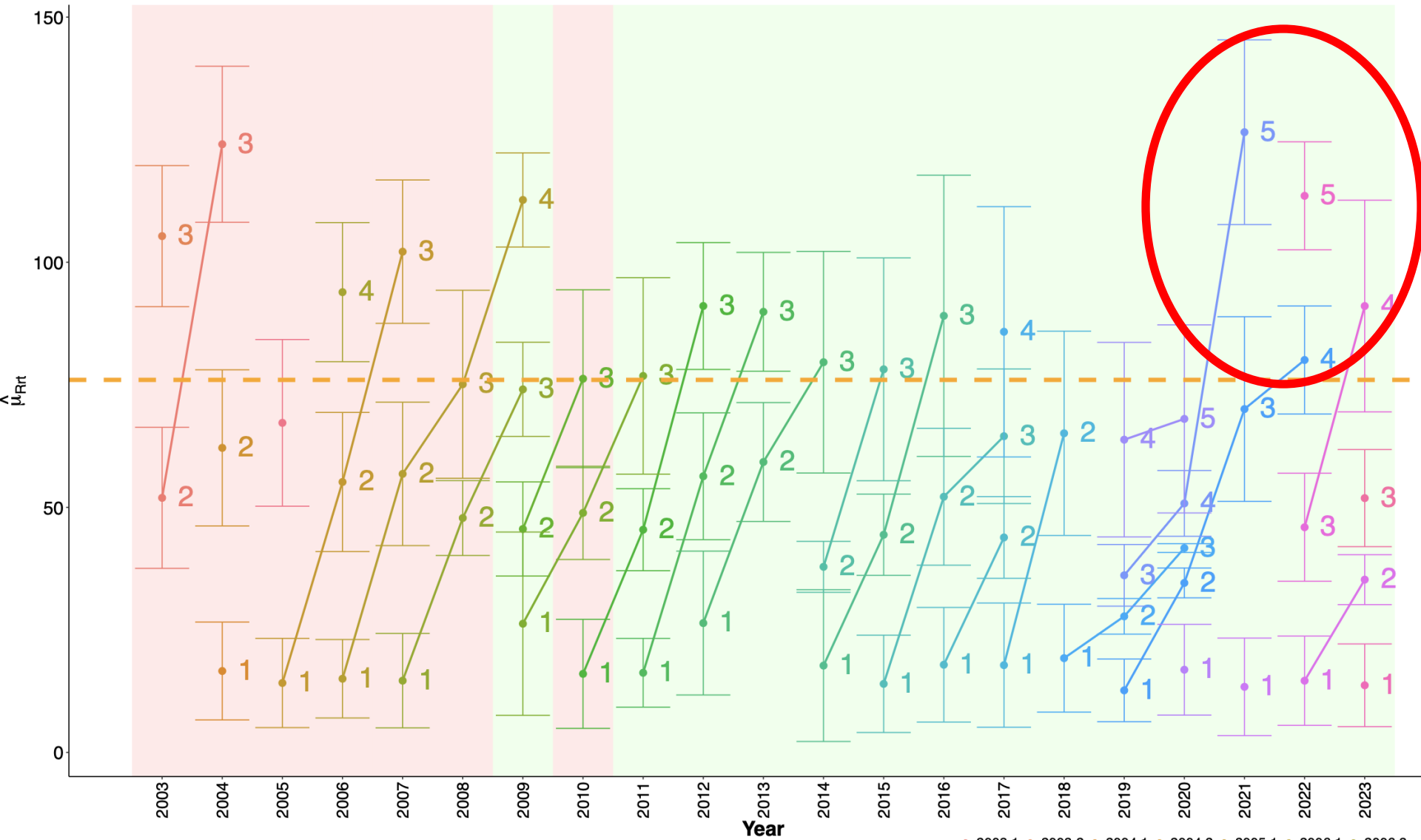
No linkage →
assume cohort
died

2004 (t+1)



Results

357 Chesapeake Bay Mainstem

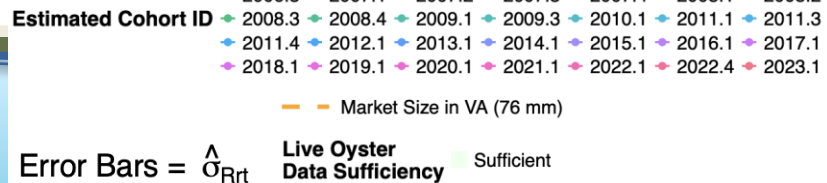


Estimated Cohort ID

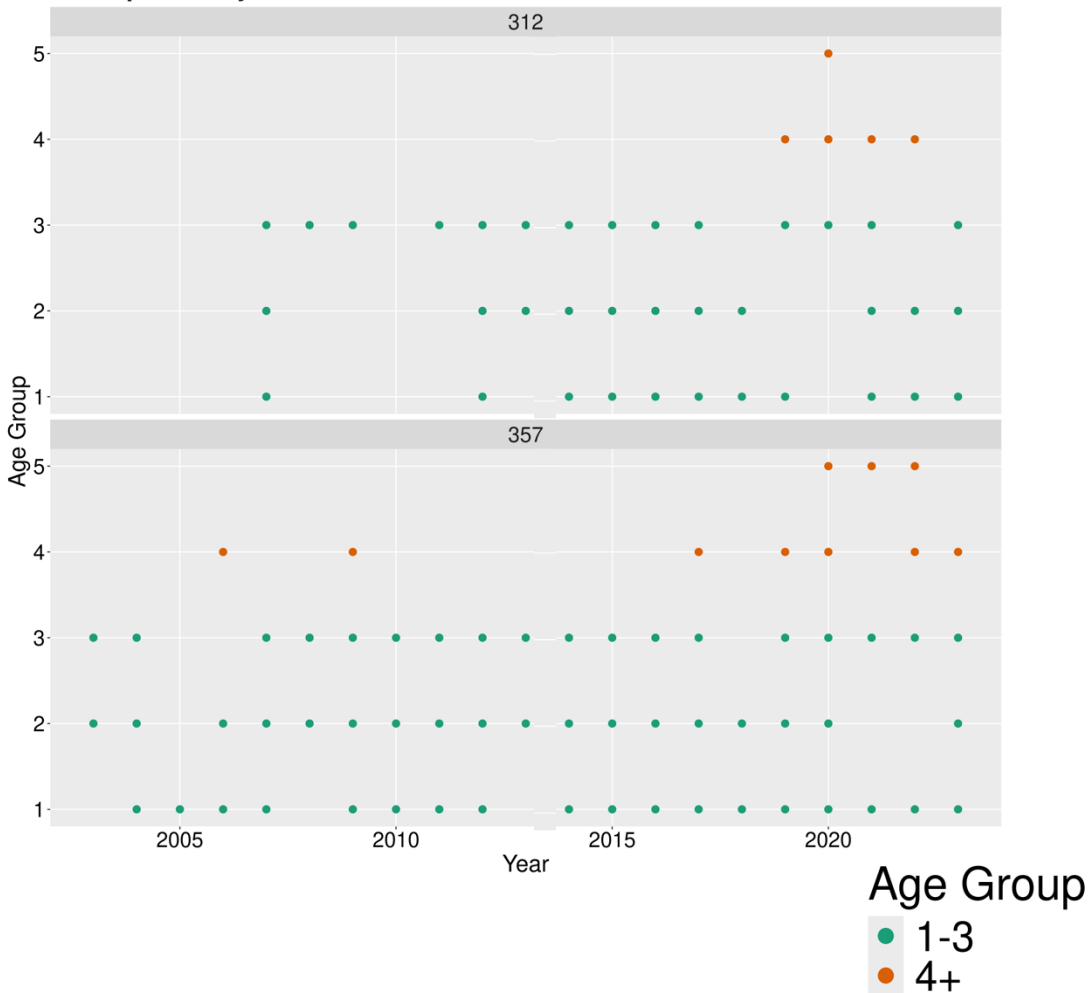
2003.1 2003.2 2004.1 2004.2 2005.1 2006.1 2006.3
2007.1 2009.1 2009.2 2010.1 2011.1 2012.1 2014.1
2014.2 2015.1 2015.2 2016.1 2017.1 2017.4 2018.1 2019.1
2019.3 2019.4 2020.1 2021.1 2022.1 2022.2 2022.4
2023.1 2023.3 N.A_1

— Market Size in VA (76 mm)

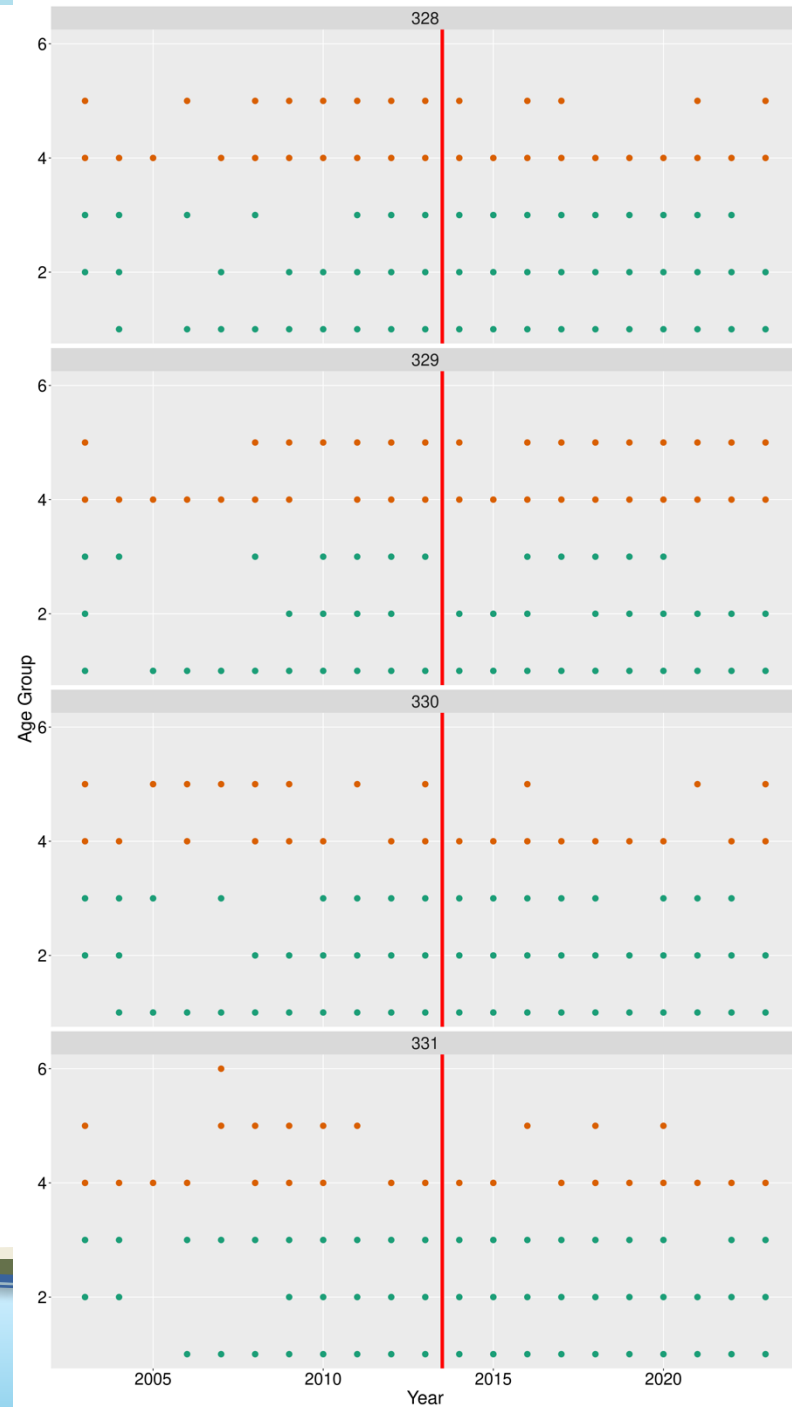
Error Bars = λ_{Rt} Oyster Sufficiency Insufficient Sufficient



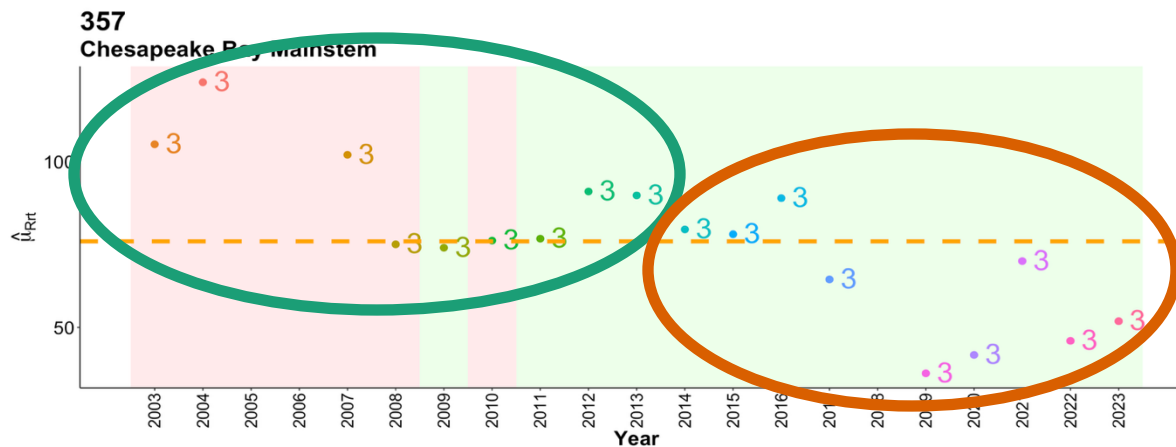
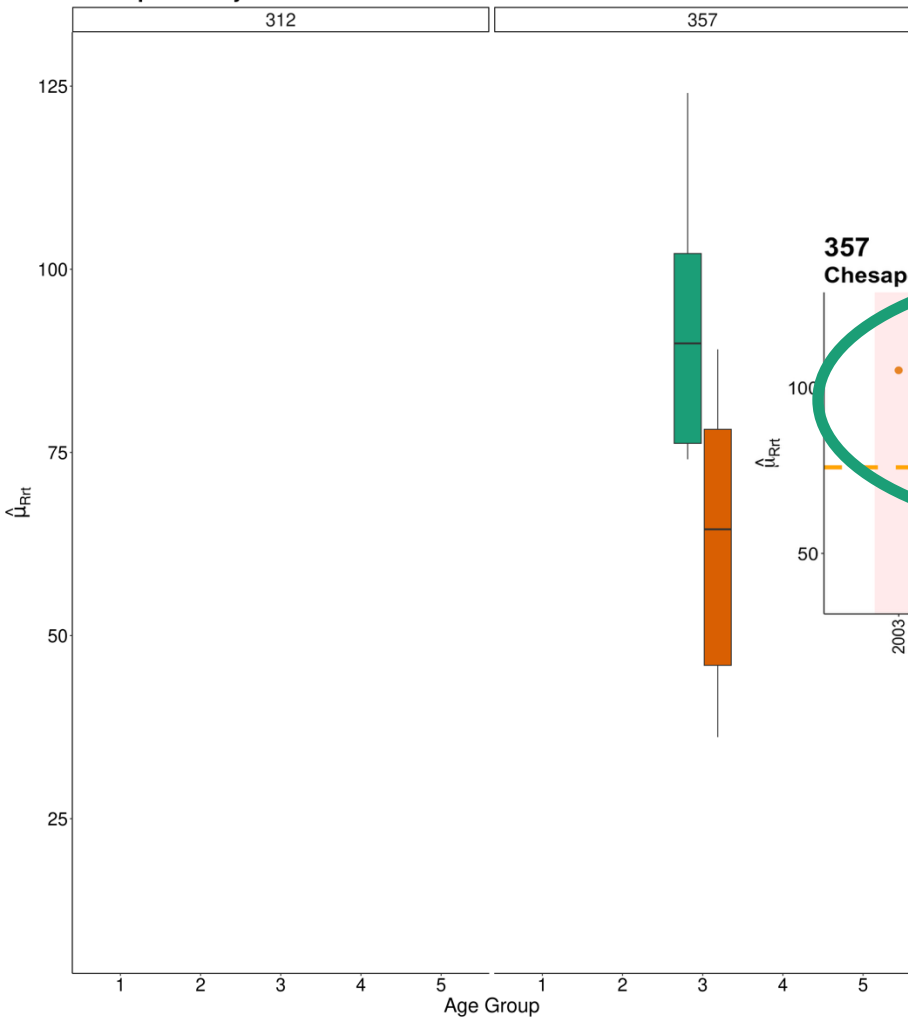
Chesapeake Bay Mainstem



James River



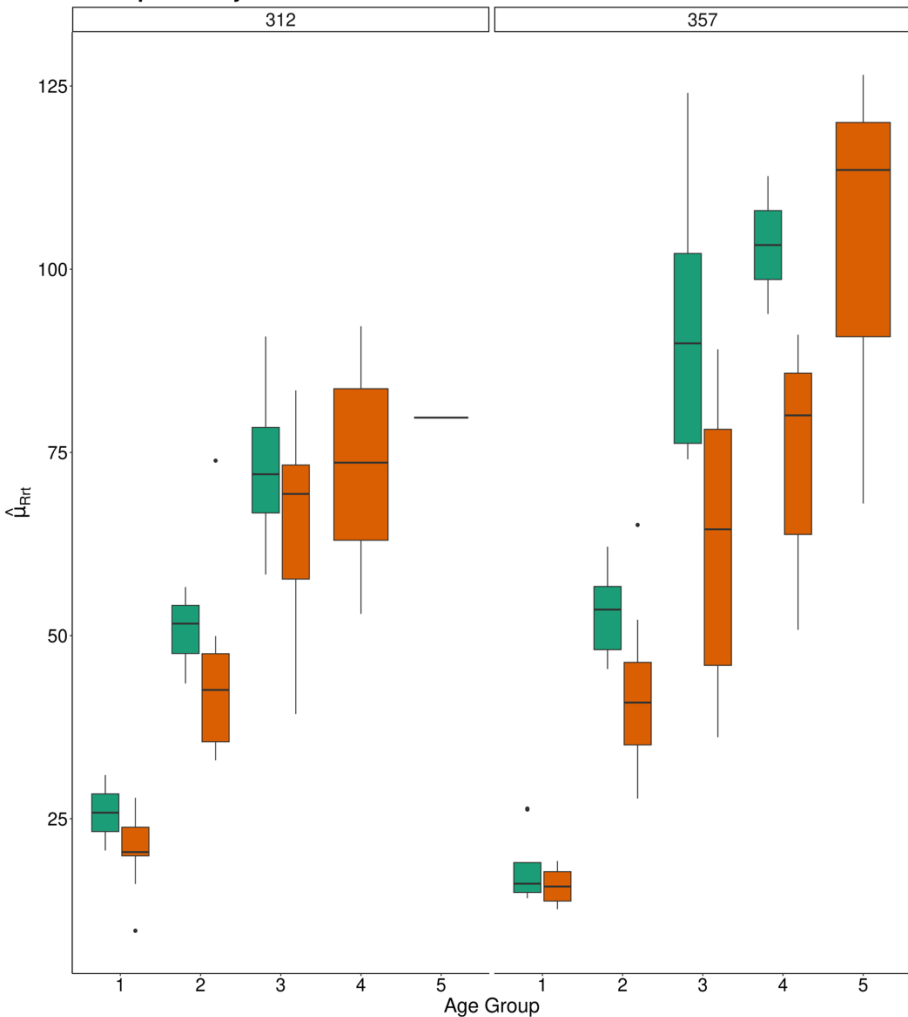
Chesapeake Bay Mainstem



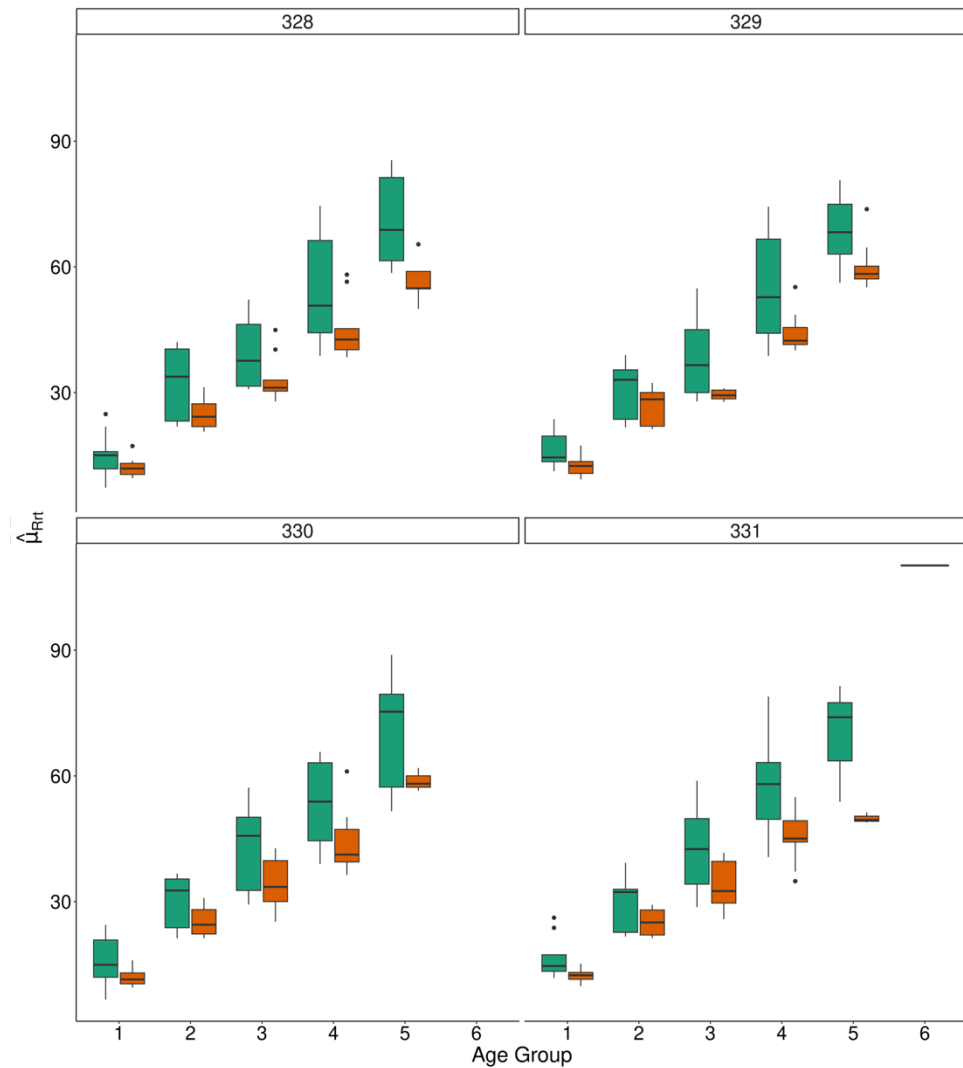
Decade

- 2003-2013
- 2014-2023

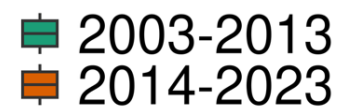
Chesapeake Bay Mainstem



James River



Decade



Key Takeaways

- Novel method for identifying, tracking, and aging oysters **only** using size data is effective and informative!
- Age truncation may be improving and or/stable in Chesapeake Bay, but shrinking is still a major concern
- Improvement of age-truncation suggests resiliency, but if oysters are shrinking in size, how self-sustainable are oysters in the long term?

Future Work

- Further investigate these trends with climate variables
 - Acidification, marine heat waves, disease, salinity
- Further investigate these trends with harvest and management data
 - Size limits, gear restrictions, rotational closures, *etc*
- Apply the method to other shellfish species and/or oysters in around the Mid-Atlantic region and compare the strength of resiliency

Questions?
mdgriffin@vims.edu



Thank you!



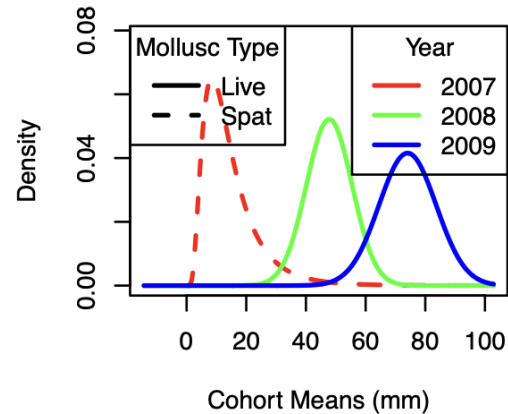
Acknowledgements

John Thomas
W&M HPC Resources

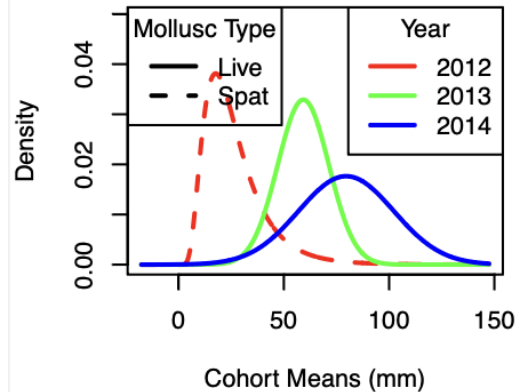
Assessing Method Effectiveness

"Behaving" Cohort Examples in Reef 357

Cohort 2007.1

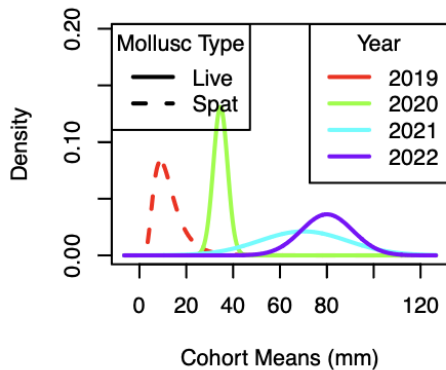


Cohort 2012.1

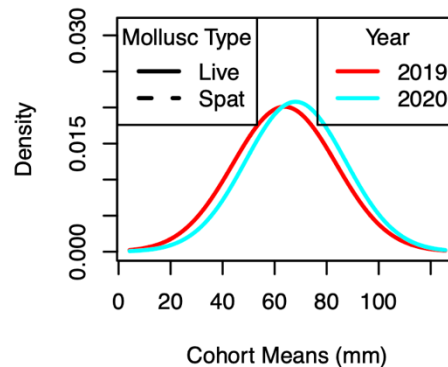


"Wonky" Cohort Examples in Reef 357

Cohort 2019.1



Cohort 2019.4



River	"Wonky" Cohorts (%)
Chesapeake Bay Mainstem	26.8%
Piankatank River	16.4%
Rappahannock River	18.6%
James River	28.4%
Great Wicomico River	14.3%
York River & Mobjack Bay	20.3%
Tangier & Pocomoke Sounds	20.8%
Total	23.1%

DATA DISCUSSIONS



NOAA OCEAN ACIDIFICATION PROGRAM



THE UTILITY OF "WEATHER" QUALITY OCEAN ACIDIFICATION MONITORING FOR COASTAL RESILIENCE



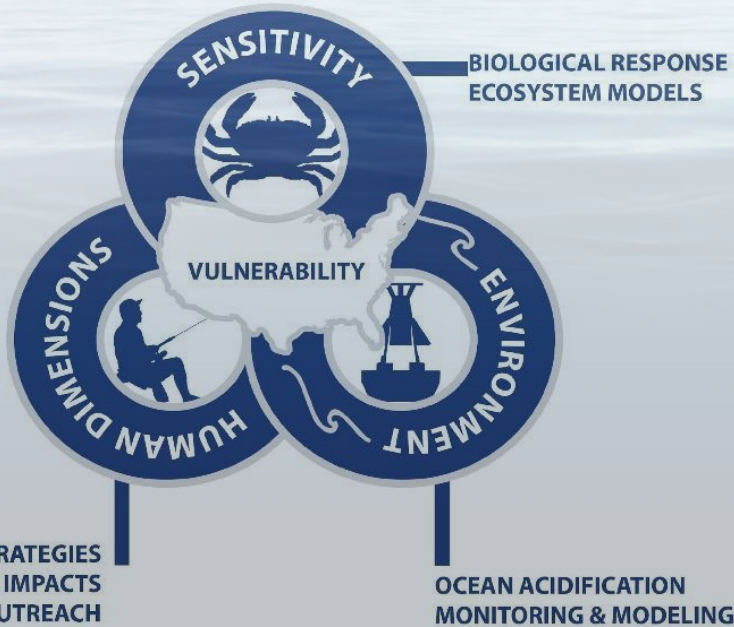
MACAN State-of-the-Science and Technical Assistance Workshop

July 17, 2025

Dwight Gledhill, NOAA OAP, Acting Director



Office/Program
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

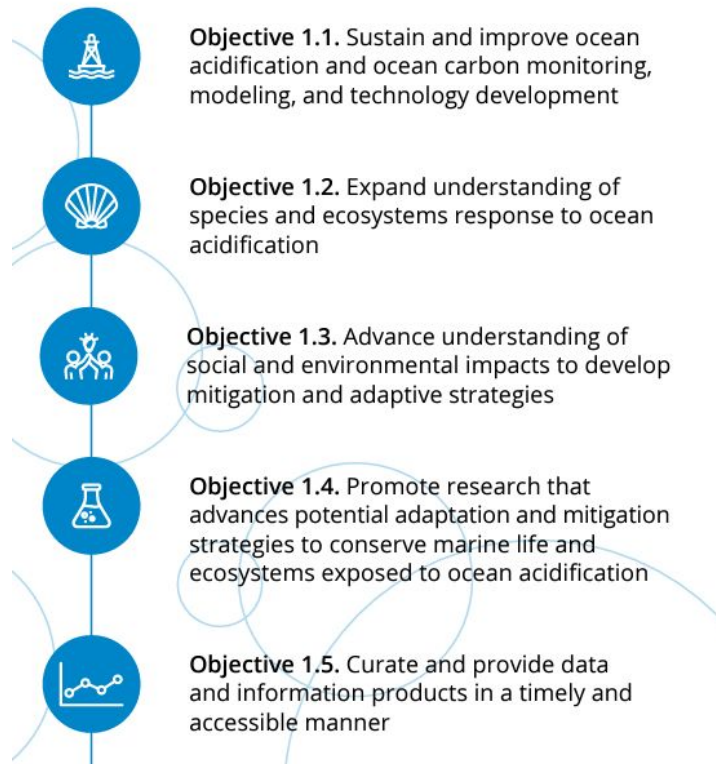


The OAP Mission

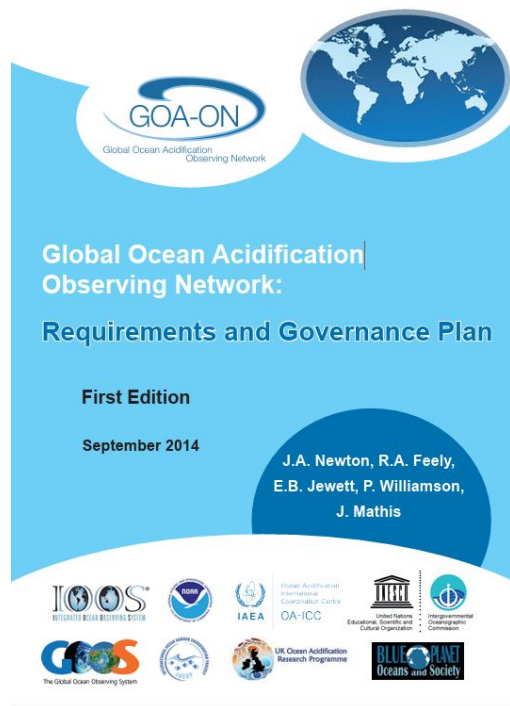
Better prepare society to respond to ocean, coastal and Great Lakes acidification by fostering transdisciplinary research, education, and outreach

OAP Strategic Plan

oceanacidification.noaa.gov/resources/oap-strategic-plan-2021-2025/

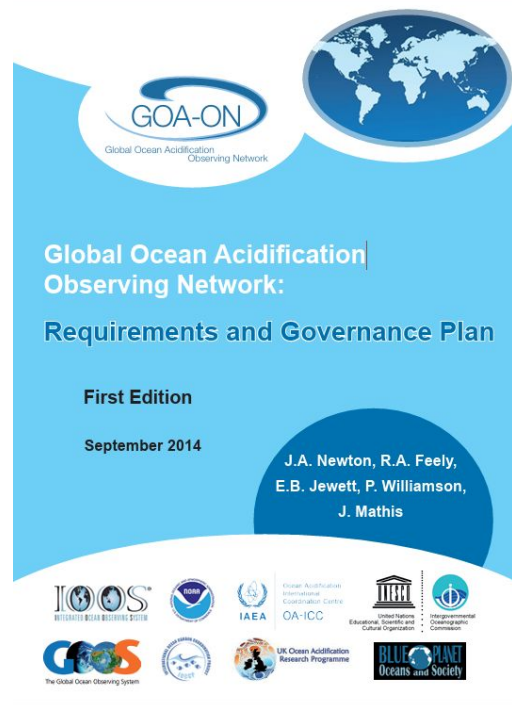


'Weather' vs 'Climate' Quality OA Observing



- Measurements made are of **appropriate** quality for their intended purpose.
- **Comparable** beyond immediate users (external consistency).
- Uncertainty must be **known and communicated** (as important as the measurement itself).

'Weather' vs 'Climate' Quality OA Observing



Box 2. MEASUREMENT QUALITY GOALS FOR GOA-ON

"Climate"

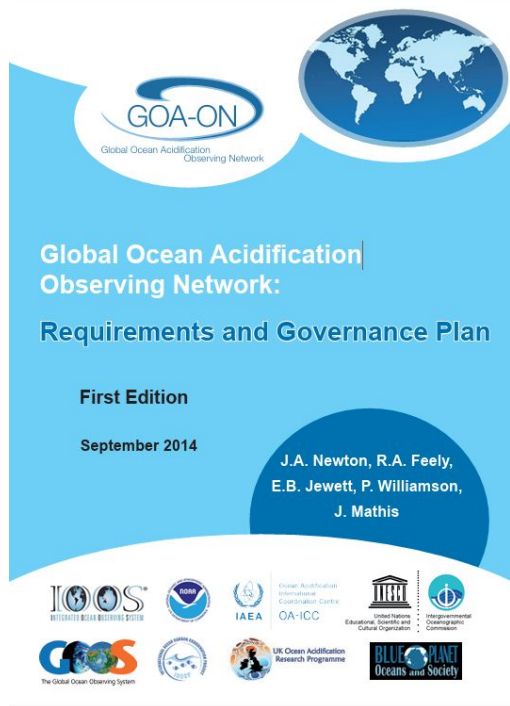
- Defined as measurements of quality sufficient to assess long term trends with a defined level of confidence
- With respect to ocean acidification, this is to support detection of the long-term anthropogenically-driven changes in hydrographic conditions and carbon chemistry over multi-decadal timescales

"Weather"

- Defined as measurements of quality sufficient to identify relative spatial patterns and short-term variation
- With respect to ocean acidification, this is to support mechanistic interpretation of the ecosystem response to and impact on local, immediate OA dynamics

'Weather' vs 'Climate' Quality OA Observing

The term uncertainty (ISO, 1993; Ellison & Williams 2012).



- *Permits a statement of the dispersion (interval) of reasonable values of the quantity measured, together with a statement of the confidence that the (true) value lies within the stated interval.*
- *Standard uncertainty of measurement; that is with the associated confidence interval equivalent to that for a standard deviation.*

(not error)

'Weather' vs 'Climate' Quality OA Observing

'Weather' - requires the CO_3^{2-} to have a relative standard uncertainty of 10%.

NOAA AOML monitoring SAMI-pH in the FKNMS

	pH	TA ($\mu\text{mol kg}^{-1}$)	DIC ($\mu\text{mol kg}^{-1}$)	pCO ₂
Weather	± 0.02	± 10	± 10	2.5%

Example system -

pH Sensor (e.g., Sunburst Sensors iSAMI pH Sensor): This is the core instrument. For "weather" quality data, the pH sensor would need to be highly accurate (with an uncertainty of approximately ± 0.02 pH units, as specified by GOA-ON for "weather" objective). It would continuously measure seawater pH, transmitting data wirelessly in near real-time.

'Weather' vs 'Climate' Quality OA Observing

NOAA OAP Coastal Ocean
Acidification Cruise nearby a NOAA-ON
station



'Weather' - requires the CO_3^{2-} to have a relative standard uncertainty of 10%.
'Climate' - requires the CO_3^{2-} to have a relative standard uncertainty of 1%*.

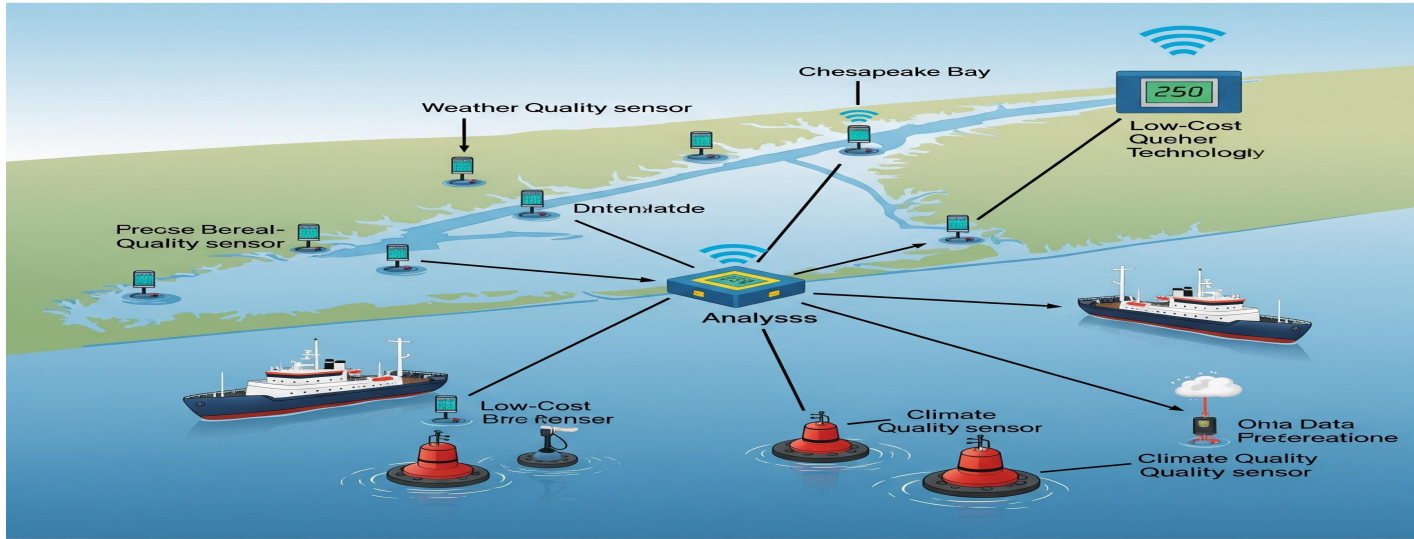
	pH	TA ($\mu\text{mol kg}^{-1}$)	DIC ($\mu\text{mol kg}^{-1}$)	pCO ₂
Weather	± 0.02	± 10	± 10	2.5%
Climate	± 0.003	± 2	± 2	0.5%

*<uncertainty in the CO_3^{2-} itself

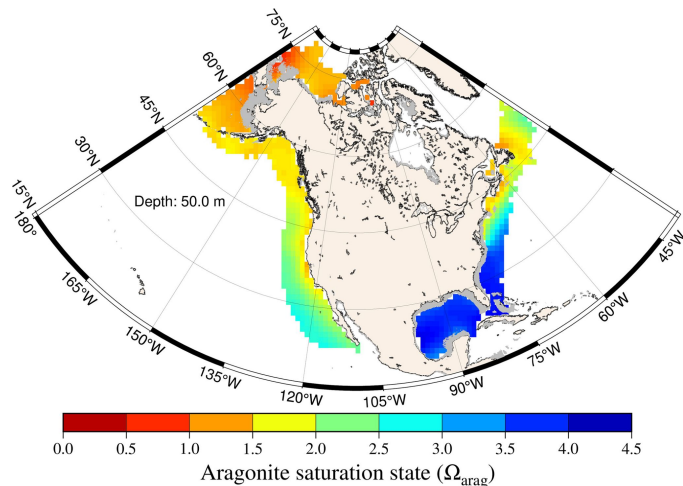
Example system -

GO-SHIP, COA (e.g., ECOA survey, NOAA-ON Station): Discrete seawater sample collection achieved aboard dedicated biogeochemical survey campaigns include potentiometric (TA) and coulometric (DIC) titration $\pm 2 \mu\text{mol kg}^{-1}$, spectrophotometric pH ± 0.003 , and underway pCO₂ $\pm 5\%$ calibrated against Certified Reference Materials (CRMs). NOAA-ON Stations presently adopt a MAPCO₂ with an internal calibration gas able to achieve $\pm 2 \mu\text{atm}$.

Optimized monitoring design (as hallucinated by ChatGPT)



Applications Differ

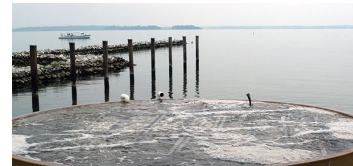
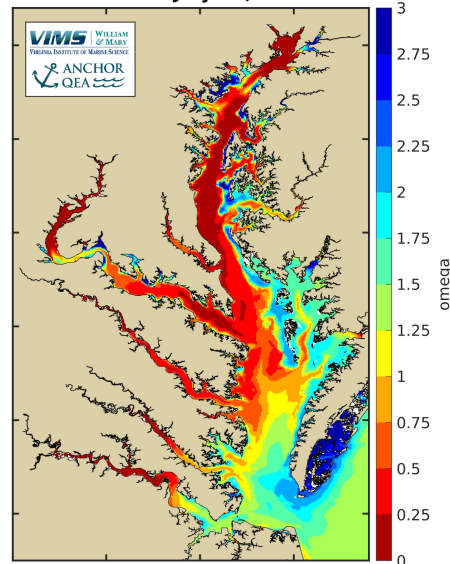


Climatological distribution of ocean acidification variables along the North American ocean margins (2024) Li-Qing Jiang, Tim P. Boyer, Christopher R. Paver, et al., Earth Syst. Sci. Data

Climate

- Global & Regional multidecadal Trends
- Regional Differences & Drivers
- Earth System Projections
- Chronic Ecosystem Risks
- National Mitigation Policy

Bottom Aragonite Saturation State
Nowcast: July 16, 2025



Weather

- Short-term variability & Extremes
- Acute Acidification Events
- Assessing Habitat Suitability
- Inform short-term management
- Ground-truthing Now/Forecast

Closing Remarks

“Weather” quality acidification monitoring represents a subset of NOAA’s responsibilities.

However, they are critical to providing actionable environmental intelligence.

Greater impact could be derived if national (or regional) SOPs were established to cross-reference between climate & weather.

National Oceanic and Atmospheric Administration

Ocean Acidification Program

We study our changing ocean to better understand impacts of ocean acidification and how to adapt.

- ✓ How is ocean chemistry changing?
- ✓ What marine life and people are vulnerable?
- ✓ How can we adapt to changing ocean chemistry impacts?



oceanacidification.noaa.gov
www.oainfoexchange.org

Data management and quality control

Li-Qing Jiang^{1,2}, Alex Kozyr^{1,2}, John Relph², Hyelim Yoo^{1,2}

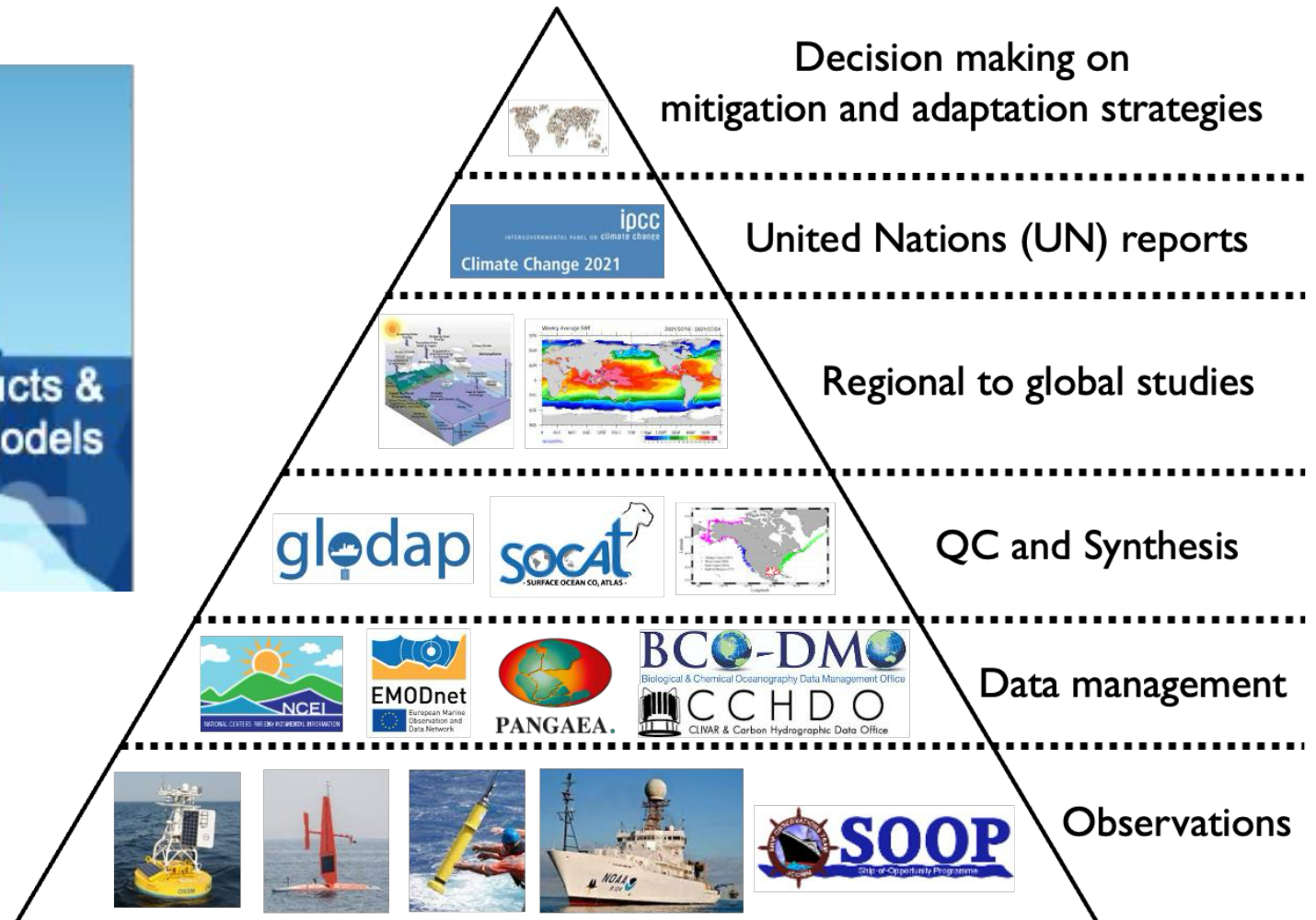
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(MACAN, July 17, 2025)

Importance of data management



Jiang, et al. (2023), adapted from Guidi et al. (2020)



Ocean Carbon and Acidification Data System (OCADS)

<https://www.ncei.noaa.gov/products/ocean-carbon-acidification-data-system>

The Ocean Carbon and Acidification Data System (OCADS) is a data management system specializing in the management of [ocean carbon](#) and [ocean acidification \(OA\)](#) data within NCEI. See the [OCADS Paper in Nature](#) for more information.

About

Data Access

Data Submission

Resources

Updates

Scope, Mission, and Services

OCADS manages a wide range of ocean carbon and acidification data, including chemical, physical, and biological observations collected from research vessels, ships of opportunity, and uncrewed platforms, as well as laboratory experiment results, and model outputs. Additionally, OCADS serves as a repository for Global Ocean Observing System (GOOS) biogeochemistry Essential Ocean Variables (EOVs) that are closely related to ocean carbon and acidification research, e.g., oxygen, nutrients, transient tracers, and stable isotopes. As a new development, OCADS accepts submissions of data generated from marine Carbon Dioxide Removal (mCDR) and Ocean Alkalinity Enhancement (OAE) related research.

Jiang, L.-Q., Kozyr, A., Relph, J.M. *et al.* The Ocean Carbon and Acidification Data System. *Sci Data* **10**, 136 (2023).

<https://doi.org/10.1038/s41597-023-02042-0>.

Data management:

- [NCEI] Long-term archive with version control
- [NCEI] Data citations with DOIs
- [OCADS] Metadata templates, leveraging controlled vocabularies
- [OCADS] Submission, data discovery and access

Data research:

- Quality control and synthesis efforts
- OA indicator development

scientific data

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The Ocean Carbon and Acidification Data System

[Li-Qing Jiang](#) , [Alex Kozyr](#), [John M. Relph](#), [Errol I. Ronje](#), [Linus Kamb](#), [Eugene Burger](#), [Jonathan Myer](#), [Liem Nguyen](#), [Krisa M. Arzayus](#), [Tim Boyer](#), [Scott Cross](#), [Hernan Garcia](#), [Patrick Hogan](#), [Kirsten Larsen](#) & [A. Rost Parsons](#)



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Ocean Carbon and Acidification Data System (OCADS)

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Metadata Templates

Controlled Vocabularies

Data Standards

EXPOCODES & Platform Codes

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Front. Mar. Sci., 20 January 2022
Sec. Ocean Observation
Volume 8 - 2021 |
<https://doi.org/10.3389/fmars.2021.705638>

This article is part of the Research Topic
Best Practices in Ocean Observing
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Best Practice Data Standards for Discrete Chemical Oceanographic Observations


Li-Qing Jiang^{1,2*}


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Richard A. Feely⁴


Bronte Tilbrook⁵


Simone Alin⁴


Leticia Barbero^{3,6}


Robert H. Byrne⁷


Brendan R. Carter^{4,8}


Andrew G. Dickson⁹


Jean-Pierre Gattuso^{10,11}


Dana Greeley⁴


Mario Hoppema¹²


Matthew P. Humphreys¹³


Johannes Karstensen¹⁴


Nico Lange¹⁴


Siv K. Lauvset¹⁵


Ernie R. Lewis¹⁶


Are Olsen¹⁷


Fiz F. Pérez¹⁸


Christopher Sabine¹⁹


Jonathan D. Sharp^{4,8}

Profile Data

CTD, discrete bottle water samples, etc.

- [Column Header Names Description](#)
- [Data File \(.XLSX\) Example](#)
- [Jiang et al. \(2022\)](#)

Underway Data

- [Column Header Names Description](#)
- [Data File \(.XLSX\) Example](#)

Autonomous Sensor Data

Mooring, Saildrone, Argo, glider, etc.

- [Column Header Names Description](#)
- [Data File \(.XLSX\) Example](#)

Physiological Response Data

Laboratory experiment, Mesocosm, Field experiment, Natural analogue, etc.

- [Column Header Names Description](#)
- [Data File \(.XLSX\) Example](#)

Metadata display format

Partial pressure (or fugacity) of carbon dioxide, temperature, salinity and other variables collected from surface underway observations using carbon dioxide gas analyzer, shower head equilibrator and other instruments from R/V Wecoma in the U.S. West Coast California Current System during the 2011 West Coast Ocean Acidification Cruise (WCOA2011) from 2011-08-12 to 2011-08-30 (NODC Accession 0123607)

Simone R. Alin {NOAA Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA, 98115, USA}
Richard A. Feely {NOAA Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA, 98115, USA}
Lauren W. Juranek {Oregon State University, College of Earth, Ocean, and Atmospheric Sciences, 104 CEOAS Administration Bldg, Corvallis, OR, 97331, USA}

ABSTRACT: This archival package contains the surface underway pCO₂ data of the first dedicated West Coast Ocean Acidification cruise (WCOA2011). The cruise took place August 12-30, 2011 aboard the R/V Wecoma. Ninety-five stations were occupied from northern Washington to southern California along thirteen transect lines. At all stations, CTD casts were conducted, and discrete water samples were collected in Niskin bottles. Underway measurements of pCO₂ were collected during the duration of the cruise. The cruise was designed to obtain a synoptic snapshot of key carbon, physical, and biogeochemical parameters as they relate to ocean acidification (OA) in the coastal realm. During the cruise, some of the same transect lines were occupied as during the 2007 West Coast Carbon cruise, as well as many CalCOFI stations. This effort was conducted in support of the coastal monitoring and research objectives of the NOAA Ocean Acidification Program (OAP).

CITE AS: Alin, Simone R.; Feely, Richard A.; Juranek, Lauren W.; Cosca, Catherine E. (2015). Partial pressure (or fugacity) of carbon dioxide, temperature, salinity and other variables collected from surface underway observations using carbon dioxide gas analyzer, shower head equilibrator and other instruments from R/V Wecoma in the U.S. West Coast California Current System during the 2011 West Coast Ocean Acidification Cruise (WCOA2011) from 2011-08-12 to 2011-08-30 (NODC Accession 0123607). Version 1.1. National Oceanographic Data Center, NOAA. Dataset. doi:10.7289/V51R6NGD [access date].

[NCEI metadata](#)

[Download data](#)

IDENTIFICATION INFO OF THIS DATA PACKAGE:

NCEI ACCESSION: 0123607
NCEI DOI: 10.7289/V51R6NGD
EXPCODE: 32WC20110812
CRUISE ID: WCOA2011
SECTION/LEG: West Coast Ocean Acidification Cruise (WCOA)

TYPES OF STUDY:

Surface underway;

TEMPORAL COVERAGE:

START DATE: 8/12/2011 END DATE: 8/30/2011

SPATIAL COVERAGE:

NORTH BOUND: 46.126
WEST BOUND: -127.552 EAST BOUND: -117.74
SOUTH BOUND: 31.95

GEOGRAPHIC NAMES:

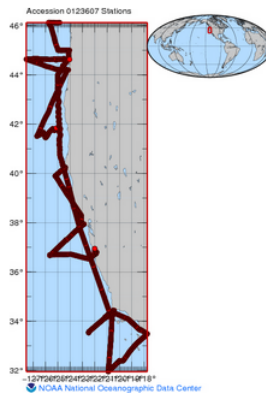
U.S. West Coast California Current System; North Pacific Ocean;

LOCATION OF ORGANISM COLLECTION:

N/A;

PLATFORMS:

Wecoma (ID: 32WC);



Dissolved Inorganic Carbon

Abbreviation: DICumol/kg

Unit: umol/kg

Observation type: Discrete measurements from samples collected on CTD casts

In-situ / Manipulation / Response variable: In-situ observation

Measured or calculated: Measured

Sampling instrument: Niskin bottle

Analyzing instrument: Two systems consisting of a coulometer (UIC Inc.) coupled with a Dissolved Inorganic Carbon Extractor (DICE) inlet system. DICE was developed by Esa Peltola and Denis Pierrot of NOAA/AOML and Dana Greeley of NOAA/PMEL to modernize a carbon extractor called SOMMA (Johnson et al. 1985, 1987, 1993, and 1999; Johnson 1992)

Detailed sampling and analyzing information: Samples for DIC measurements were drawn according to procedures outlined in the 2007 PICES Special Publication, Guide to Best Practices for Ocean CO₂ Measurements, from Niskin bottles into 310 ml borosilicate glass flasks using silicone tubing. The flasks were rinsed once and filled from the bottom with care not to entrain any bubbles, overflowing by at least one-half volume. The sample tube was pinched off and withdrawn, creating a ~7.5 ml headspace and 0.133 ml of saturated HgCl₂ solution was added as a preservative. The sample bottles were then sealed with glass stoppers lightly covered with Apiezon-L grease. DIC samples were collected from variety of depths with approximately 10% of these samples taken as duplicates. The accuracy of the DICE measurement is determined with the use of standards (Certified Reference Materials (CRMs), consisting of filtered and UV irradiated seawater) supplied by Dr. A. Dickson of Scripps Institution of Oceanography (SIO). The CRM accuracy is determined manometrically on land in San Diego and the DIC data reported to the data base have been corrected to this batch 109 CRM value. The CRM certified value for this batch is 2026.33umol/kg. During this cruise both systems reported values which were consistently lower than the certified value. This offset we believe to be due to the fact that the temperature of the gas loop housing was offset from the lab temperature in which the gas cylinder was kept. As the gas loops and CRM values were consistent throughout, we have great confidence in our final value after correcting for this CRM offset. Summary The overall performance of the analytical equipment was good during the cruise. We were able to sample every niskin Niskin made available to us; and including the duplicates and samples drawn from the underway seawater line, 1450 samples were analyzed for dissolved inorganic carbon.

Replicate information: Duplicate samples were collected from approximately 10% of the Niskins sampled, as a check of our precision. These replicate samples were interspersed throughout the station analysis for quality assurance and integrity of the coulometer cell solutions. The average absolute difference from the mean of these replicates is 1.04umol/kg. No systematic differences between the replicates were observed.

Standardization description: Each coulometer was calibrated by injecting aliquots of pure CO₂ (99.999%) by means of an 8-port valve (Wilke et al., 1993) outfitted with two calibrated sample loops of different sizes (~1ml and ~2ml). The instruments were each separately calibrated at the beginning of each cell with a minimum of two sets of these gas loop injections and then again at the end of each cell to ensure no drift during the life of the cell.

Standardization frequency: 1) Gas loops were run at the beginning and end of each cell; 2) CRM is supplied by Dr. A. Dickson of SIO, were measured near the beginning; and 3) Duplicate samples were typically run throughout the life of the cell solution.

CRM manufacturer: Dr. A. Dickson (SIO)

Poison name: Mercuric Chloride Solution

Poison volume: 0.133 ml

Poison correction: The DIC values were corrected for dilution by 0.133 ml of saturated HgCl₂ used for sample preservation. The

Jiang, L.-Q., O'Connor, S. A., Arzayus, K. M., and Parsons, A. R. (2015). A metadata template for ocean acidification data, Earth Syst. Sci. Data, 7, 117–125, <https://doi.org/10.5194/essd-7-117-2015>.

Done

Cancel

Manage Metadata: CODAP_NA_climatologies_update.zip

✓ Data Submitter

Investigators

Citation Information

✓ Time and Location Information

✓ Funding

Platforms

✓ DIC

✓ TA

✓ pH

✓ pCO2A

pCO2D

✓ Variable

Metadata

Preview

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Choose file:

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Enter the Information about this Citation.

(*) Denotes a required field.

Title *

Coastal climatologies of ocean acidification indicators from surface to 5

Abstract *

This data package contains 1x1 degree coastal climatologies (mean fi
geographic grid at specific depths) of fugacity of carbon dioxide, pH on
free hydrogen ion content, carbonate ion content, aragonite saturation s
inorganic carbon content, total alkalinity content, and Revelle Factor, al
to 500 meters water depth on North American ocean margins. These cl
Ocean Atlas (WOA) gridding technologies of the NOAA National Center

List of Authors for Citation *

Jiang, Li-Qing; Boyer, Tim; Paver, Christopher; Reagan, James; Alin, S

Data License *

☐ Internal NOAA Source Dataset?

☒ CC0-1.0

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Purpose

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Ocean Carbon and Acidification Data Portal

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☒ Search ocean carbon and acidification project managed data sets only

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Match ☐ any ☒ all of the following terms: [0 selected]

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Select a variable

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Observation Category

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Additional Terms

Please use "" to search for an exact phrase (e.g., "Ocean Acidification Program") and use ** to
match a substring of a keyword (e.g., *SOFS* will bring results containing
MOORING_SOFS_142W_46S).

Observation Dates

Start: End:

Please use date format: YYYY-MM-DD

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Reset

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Esri, HERE, Garmin, NGA, USGS

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Submission interface

Data access portal

7

mCDR-compatible metadata template

Manipulated or not

1	Natural
2	Manipulated
3	Model generated
4	Social

OAE treatment types

1	Mineral alkalinity addition
2	Synthetic alkalinity addition

mCDR Pathways

1	Ocean alkalinity enhancement
2	Biomass sinking
3	Direct ocean capture
4	Ocean nutrient fertilization
5	Artificial upwelling and downwelling
6	Marine ecosystem recovery

Jiang, L.-Q., Subhas, A. V., Basso, D., Fennel, K., and Gattuso, J.-P.: Data reporting and sharing for ocean alkalinity enhancement research, in: Guide to Best Practices in Ocean Alkalinity Enhancement Research, edited by: Oschlies, A., Stevenson, A., Bach, L. T., Fennel, K., Rickaby, R. E. M., Satterfield, T., Webb, R., and Gattuso, J.-P., Copernicus Publications, State Planet, 2-oae2023, 13, <https://doi.org/10.5194/sp-2-oae2023-13-2023>, 2023.

OAE field trials

OAE field trial	Experiment description	
	Site description	
	Previous mCDR research in the area	
	Co-located operations	
	Meteorological and tidal conditions	
	Alkalinity feedstock type	
	Alkalinity feedstock description	
	Dosing location	
	Dosing depth (meters)	
	Dosing duration	Start date and time
		End date and time
	Dosing mechanism	
	Dosing effluent density	
	Dosing regimen	
	Dosing rate data	
	Permit number	
	Permit approval document	
	Permitting authority	
	Data conflicts and unreported data:	
	Additional details	

Physiological response studies

Physiological response studies	Manipulation method	
	Targeted acidity or Alkalinity levels	
	Natural vs artificial seawater	
	Is the seawater filtered, sterilized, or UVed?	
	Biological subject (repeatable)	Organism or community
		Species Identification code (if available)
		Taxonomic code system used [controlled vocabulary]
		Life stage [controlled vocabulary]
	Treatment duration	Start date and time (UTC)
		End date and time (UTC)
	Location where the experiment was carried out	
	Location where biological subject was collected	
	Additional details	

Model output

Model outputs (applicable to both OA and mCDR studies)	Model name	
	Model version	
	Physical component name and version	
	BGC component name and version	
	Modelled region	
	Model resolution	Longitudinal
		Latitudinal
		Vertical
		Temporal
	Model configuration	
	Boundary conditions	
	Atmospheric forcing	
	Tidal forcing	
	Other model forcing details	
	River and sediment flux details	
	Spin up protocol	
	Description of acid or alkalinity addition	
	Codebase link	
	Additional details	

[QC2: T, S & DO plots]

World map showing the location of the data collection area in the North Atlantic Ocean.

X: CTDOXY-DOE:-150.5($\mu\text{mol/kg}$)

Y: Depth:12.9 (m)

Sta: 57 Cast: 1

Dep: 13 (m) DL: 1

Temp: 17.14 Sal: 32.25

Lon: -74.222 Lat: 39.449

Date: 2012-08-07 UTC:12:15

Profile: 58 SamID: 57101

File: v1E05_GOMECC2RR

Row: 968

Cruise: GOMECC2 [No.1]

EXPO: 33RO20120721

ACCN: 117971

Clear

☒ Enable multiple panel pinpointing

☐ When clicking, write to the log file.

Reference Data File **Browse**

v1E05_GOMECC2F

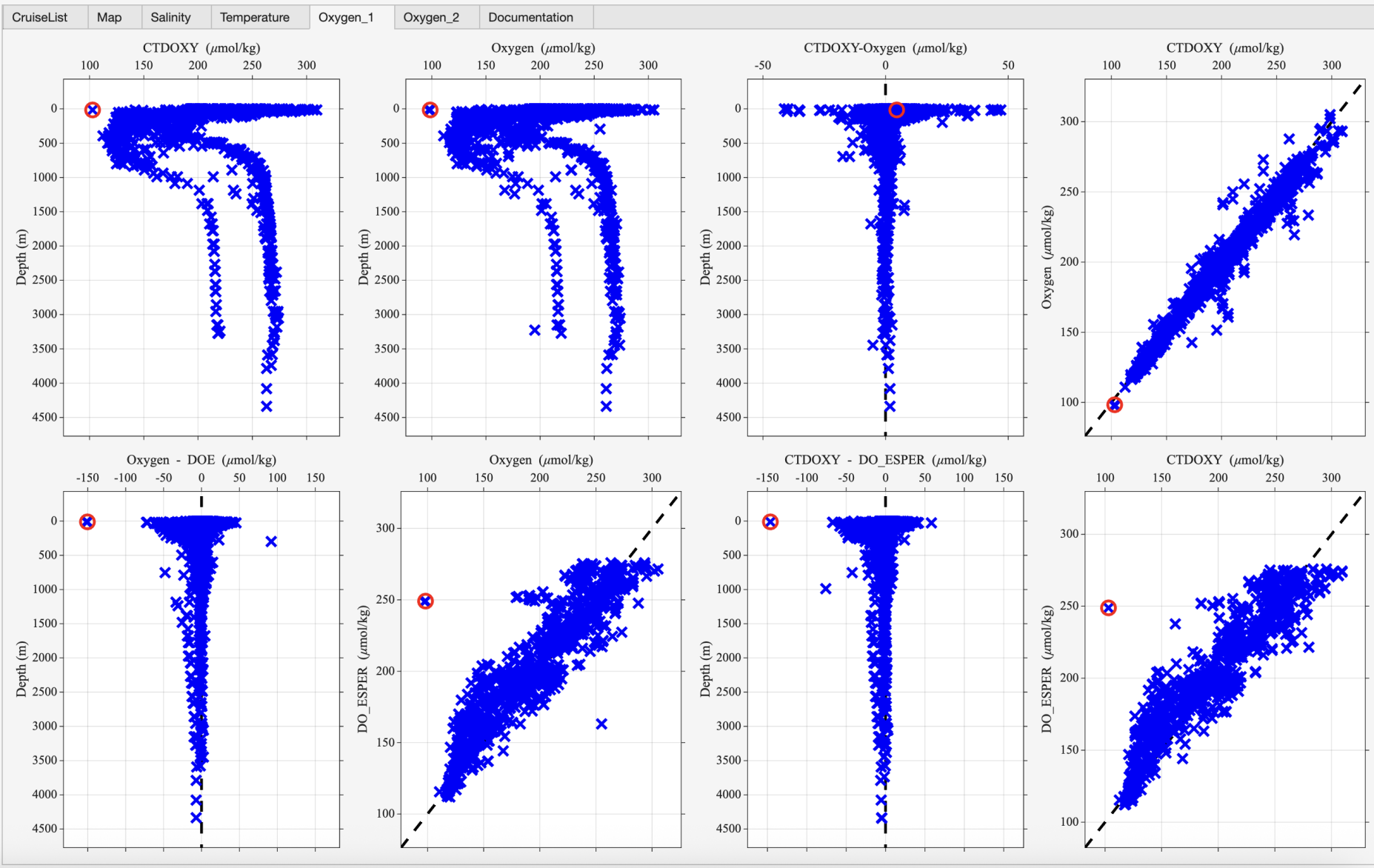
Browse (1)

- ☒ Profile to profile
- ☐ Profile within a cruise
- ☐ Cruise to cruise
- ☐ Sigma_theta
- ☒ Depth

Std: 0 Cruise: 1 of 1

Profile: 1 to 94 of 94

Load (2) **<** **Plot (3)** **>**



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Article Data product

Articles / Volume 13, issue 6 / ESSD, 13, 2777–2799, 2021

<https://doi.org/10.5194/essd-13-2777-2021>
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Data description paper | 

15 Jun 2021

Coastal Ocean Data Analysis Product in North America (CODAP-NA) – an internally consistent data product for discrete inorganic carbon, oxygen, and nutrients on the North American ocean margins

Li-Qing Jiang , Richard A. Feely, Rik Wanninkhof, Dana Greeley, Leticia Barbero, Simone Alin, Brendan R. Carter, Denis Pierrot, Charles Featherstone, James Hooper, Chris Melrose, Natalie Monacci, Jonathan D. Sharp, Shawn Shellito, Yuan-Yuan Xu, Alex Kozyr, Robert H. Byrne, Wei-Jun Cai, Jessica Cross, Gregory C. Johnson, Burke Hales, Chris Langdon, Jeremy Mathis, Joe Salisbury, and David W. Townsend

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Short summary

Coastal ecosystems account for most of the economic activities related to commercial and...

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Article Climatologies

Articles / Volume 16, issue 7 / ESSD, 16, 3383–3390, 2024

<https://doi.org/10.5194/essd-16-3383-2024>
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Data description paper | 

24 Jul 2024

Climatological distribution of ocean acidification variables along the North American ocean margins

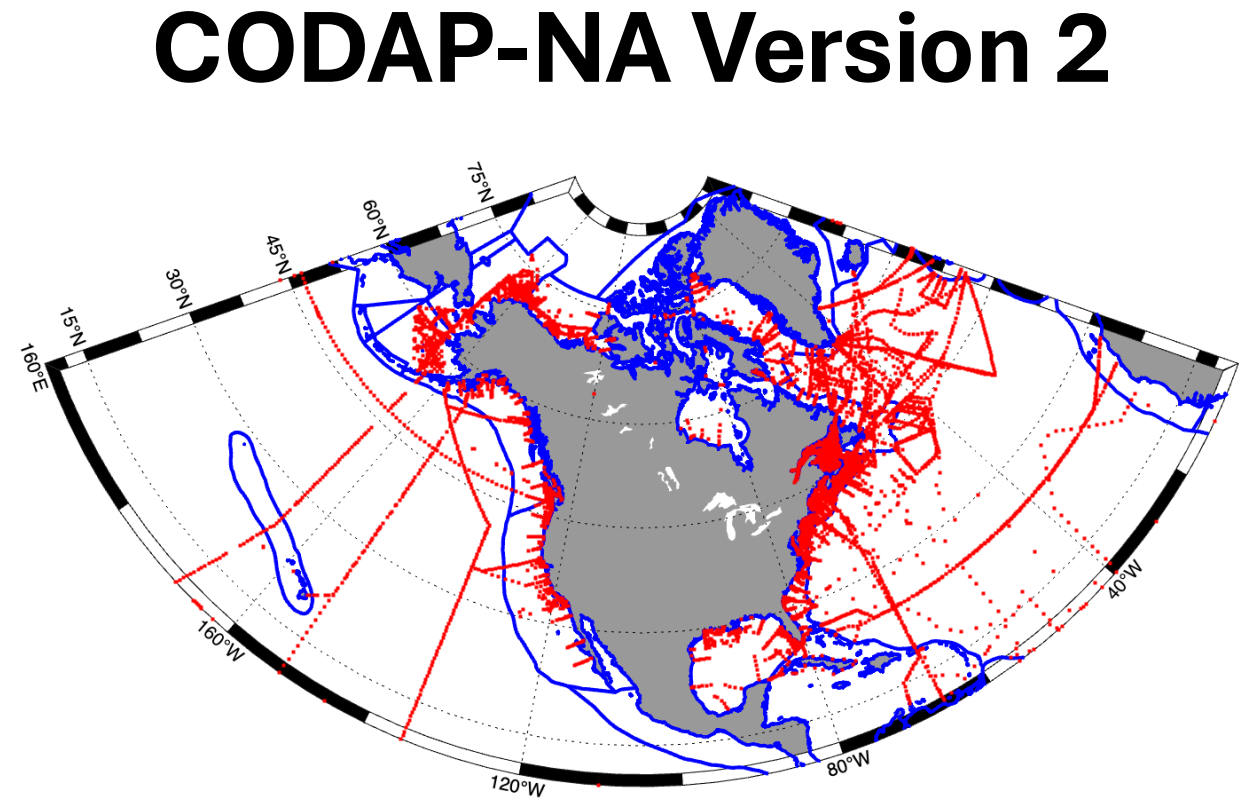
Li-Qing Jiang , Tim P. Boyer, Christopher R. Paver, Hyelim Yoo, James R. Reagan, Simone R. Alin, Leticia Barbero, Brendan R. Carter, Richard A. Feely, and Rik Wanninkhof

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Short summary

In this paper, we unveil a data product featuring



CODAP-NA data product:
<https://doi.org/10.5194/essd-13-2777-2021>.

CODAP-NA climatologies:
<https://doi.org/10.5194/essd-16-3383-2024>.

Thank you

- **OCADS:**

<https://www.ncei.noaa.gov/products/ocean-carbon-acidification-data-system>

- **Send comments to:**

Liqing.Jiang@noaa.gov



PRO OCEANUS

Autonomous Membrane-based
pCO₂ Sensors

About Us

- Located in Nova Scotia, Canada
- In business for since 1998
 - Academic science and engineering
 - Industry including aquaculture
- Sales globally through distribution network
- 16 employees
 - 13 technical/scientific staff
- Partnered with many institutes creating new and innovative solutions



National
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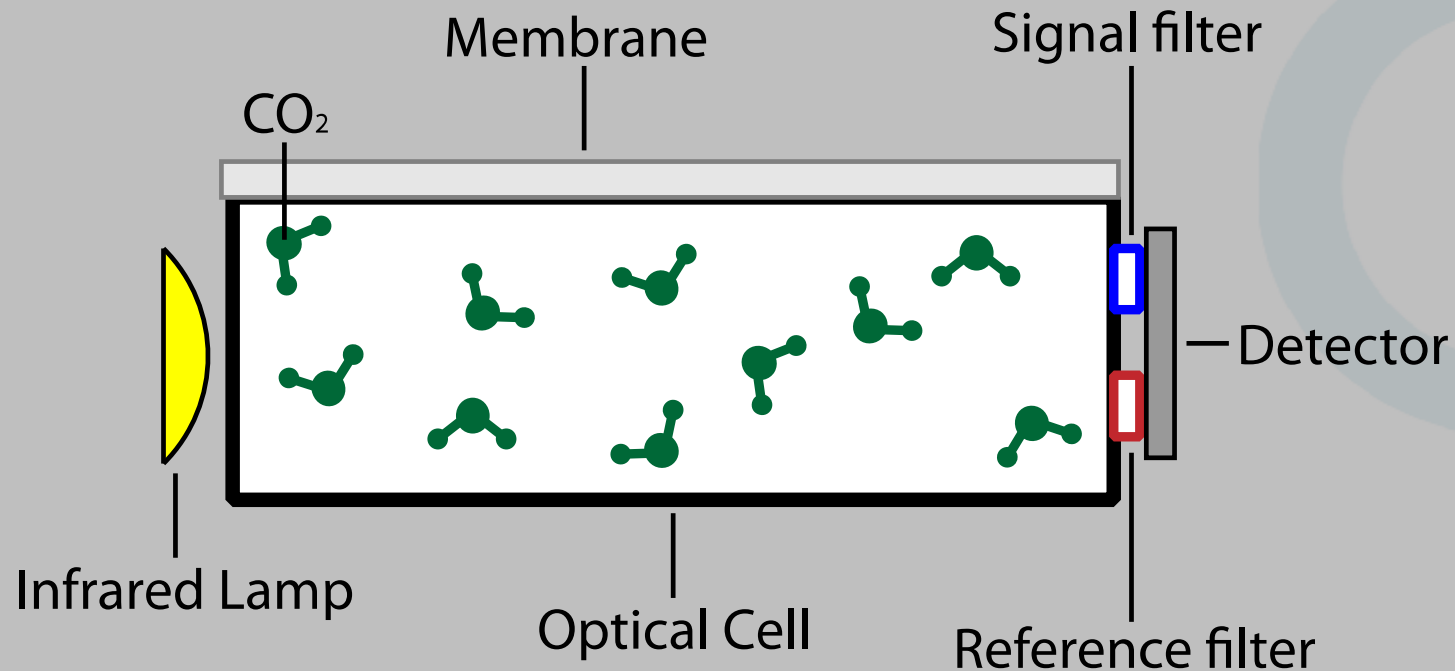
Sensor Solutions

- Submersible sensors for measuring dissolved CO₂, CH₄, and Total Dissolved Gas Pressure
- Three lines of sensors:
 - PRO Series
 - Oceanographic dissolved gas sensors
 - the best in accuracy, stability, and response time
 - Mini Series
 - Smaller, rugged, and more affordable
 - Less accurate and stable than the Pro-Series
 - Solu-Blu Series
 - Newest addition and designed for shallow water, including aquaculture and laboratory and groundwater



CO₂ Measurement

- Gases diffuse from water through the membrane into an optical cell where CO₂ is detected using IR detection

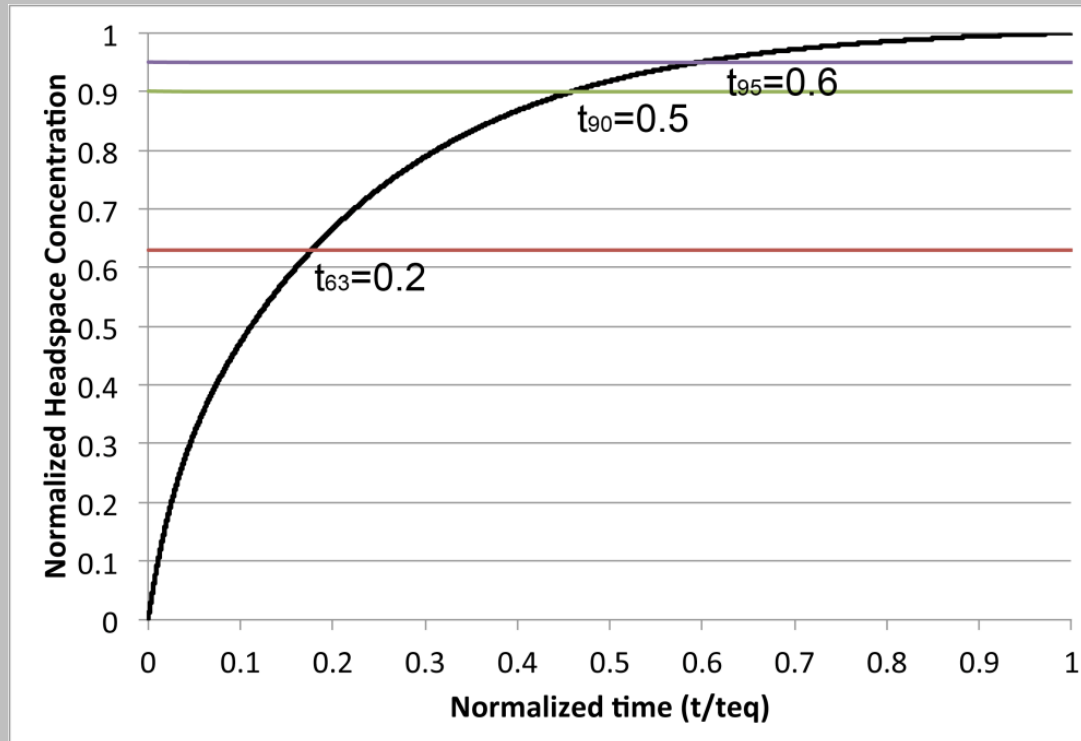


CO₂ Measurement

- IR optical cell measures the molar ratio of CO₂ to all other gases present, also known as the mixing ratio, xCO₂
- Partial pressure of CO₂, pCO₂ must be calculated from xCO₂ and the pressure at which the measurement is made
- $p\text{CO}_2 = x\text{CO}_2 * P$
- pCO₂ can be calculated as “wet” or “dry”, depending on the conditioning of the gas entering the optical cell, but for membrane-based NDIR sensors, the measurement is almost always made “wet” with water vapor present.

Membrane Equilibrium

- The equilibration of gas across the instrument membrane is governed by diffusion as well as flow dynamics next to the membrane



t_{63} is taken as one fifth of the total time to equilibrate,
 t_{90} is approximately half the time to equilibrate,
 t_{95} is roughly 60% of the time to equilibrate.
 t_{99} is taken as t_{eq} .

Membrane Equilibrium

- Movement of gases from dissolved in liquid through a membrane to gas head space dependent on:
 - Membrane thickness
 - Membrane surface area
 - Gas head space volume
 - Advective movement of gas molecules
 - Water and air side of membrane
 - Diffusive movement of gas molecules
 - Water-side
 - Membrane
 - Air-side

Sensor Options Based on Data Needs

- Understand what data is needed. The most appropriate sensing options are dependent on:
 - Accuracy and long-term stability
 - Measurement range
 - Type of data
 - Biofouling control



Application-Specific Needs

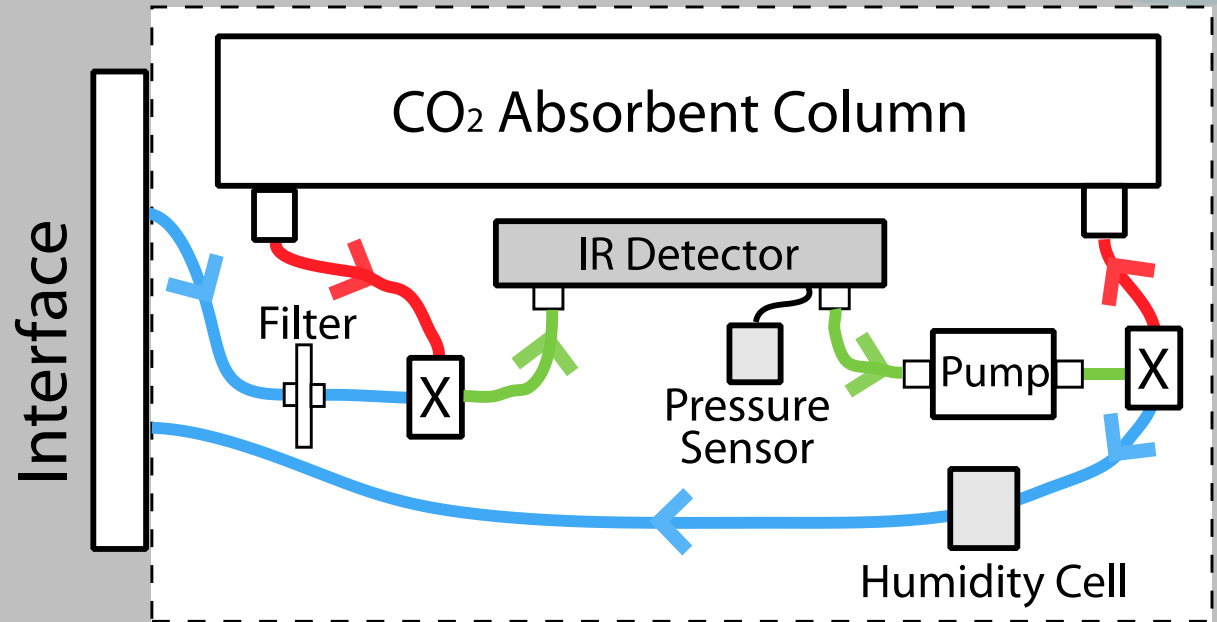
- Open ocean vs Coastal vs Freshwater
- Multi-year vs seasonal vs weekly to daily
- Spatial vs Temporal
- Chemistry vs Biology vs Physics
- Flux vs absolute measurement
- Database flag needs, eg. SOCAT, ICOS

CO₂ Pro Series



Sensor Operation

- Gas flows through optical cell path in contact with a semi-permeable membrane (blue and green)
- When a zero CO_2 measurement is made, the gas is sent through an absorption column (red and green)
- Measures $w\text{CO}_2$ and dissolved gas pressure to allow calculation of $p\text{CO}_2$



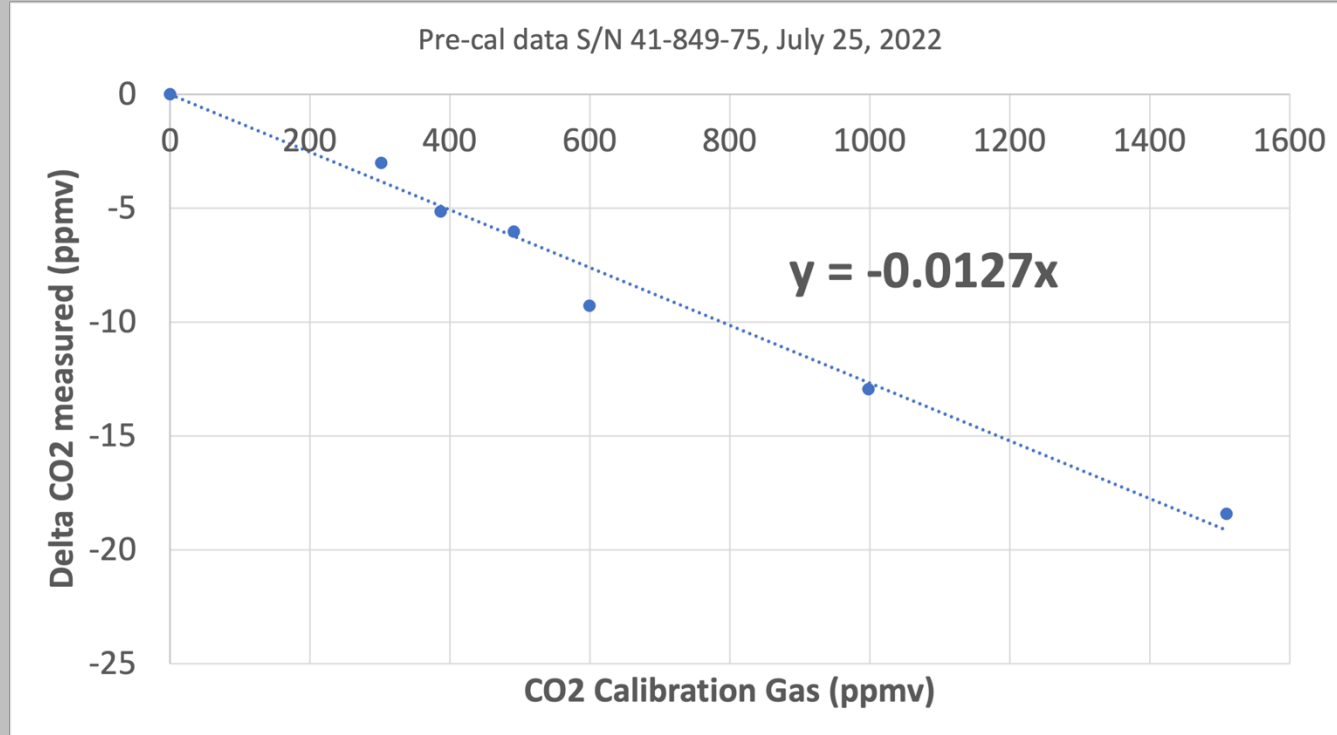
Accuracy and Stability

- Requires stable and accurate temperature measurement
 - Stable cell temperature to $\pm 0.1^{\circ}$ Celsius
 - Maintained above ambient to prevent condensation in the detection cell and to keep thermal stability when water temperature changes
- The cell gas pressure is balanced against the in situ dissolved gas pressure and can be used to calculate $p\text{CO}_2$
- Humidity measurement to correct for spectrum broadening effect

Accuracy and Stability

- IR light source decay affects the performance through signal drift
- Can use an Automatic Zero Point Compensation, AZPC
- Removal of CO₂ from detector gas stream allows for frequent zero measurement and correction for detector zero drift
- Correction is automatic and in real-time, no post-deployment baseline drift correction of data needed (when AZPC is used)
- Typical drift per year dependent on sampling frequency – run time of the optical cell

Sensor Drift



Typical drift over 5000 hours of on time

*NOTE, no drift experienced when not in operation

- Take the drift equation above and factor in linear change over time leads to:
 - $\Delta p\text{CO}_2 = [0.0127/(5000/t)] \times p\text{CO}_2(\text{meas})$

Sensor Calibration

- Pro-Oceanus uses WMO-traceable NOAA standard gases
- Minimum 5-8 point gas calibration using a 3-segment polynomial curve fit, linear fit is not accurate enough
- Gas pressure sensor calibration
- Improved temperature stability, internal corrections for pressure and humidity

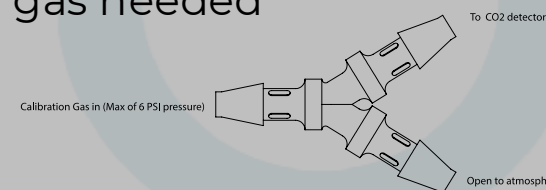


Field Validation of Data Accuracy

- Water sample collection at beginning and end of deployment at same location as sensor
 - Sampling through the deployment period as well if possible
- Laboratory analysis of samples*
- Comparison of lab sample data to in situ sensor data
 - Corrections in sensor drift during deployment can be made based on offsets between sensor and lab CO₂ values
 - Assume linear change over time in the drift

Lab Validation of Data Accuracy

- **In air:** Easiest to do and can be done in two ways
 - Flow calibration gases across outside of membrane and wait for full equilibration
 - Process requires flow of gas for up to 15 minutes to allow for full equilibrium of each gas
 - Open the sensor and flow gases directly into the optical cell
 - Flow of calibration gas must allow for the internal air pump to pull the gas through the detector and not push the calibration gas through due to high pressure of calibration gas, a Y-joint to bleed off excess calibration gas needed
- Each calibration gas can take a few minutes to run and calibration check is quick
- Calibration gases are dry, but a humidifier can be placed inline to create standard operating conditions



Lab Validation of Data Accuracy

- **In water:** Time and calibration gas consuming
 - Bubbling of water sample with calibration gas can take more than an hour to fully equilibrate and stabilize
 - Water temperature must be kept constant or changes in CO₂ solubility can change the partial pressure
 - Can be difficult to obtain stable conditions of both CO₂ concentration and water temperature
 - Mixing, interaction with air above, NDIR sensors generate heat

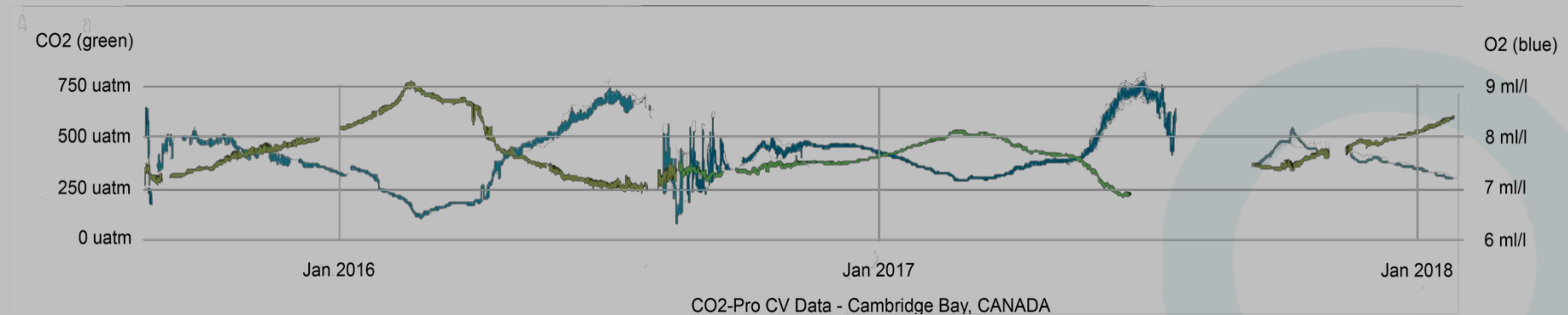
CO₂-Pro CV – Moorings, Buoys, Profiling

- Most versatile sensor option
- Flexible design options
- Ratings up to 6000m depth
- Internal or external battery power
- Profiling and moored mode features



Example from Cambridge Bay, Canada

- Long-term deployment, 10 months under ice per year
- Continuous sampling



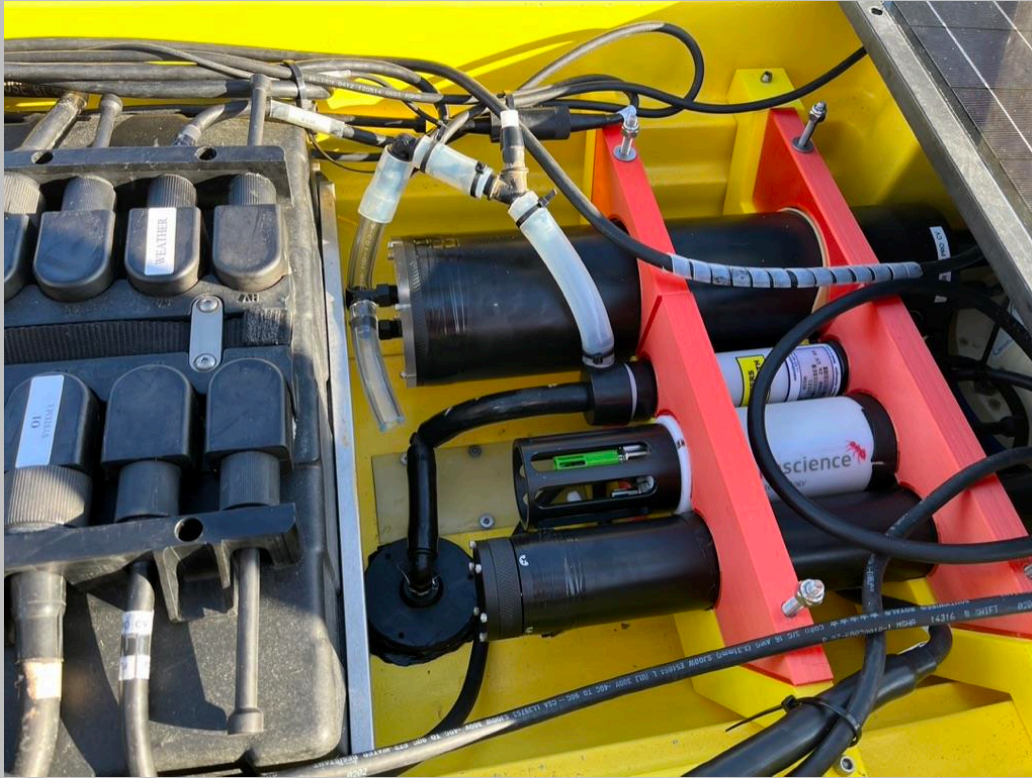
Compact Fully Autonomous CO₂ Sensor

- CO₂-Pro CV with internal battery



Left, CO₂ Profiling in the St. Lawrence Estuary. Top, measuring CO₂ levels at seabed seeps by divers in the Philippines

Mobile Autonomous Platforms



CO₂-Pro CV installed both in hull of the LRI WaveGlider (above) and in a towed body (right)

CO₂-Pro Designed for Surface Buoys

- Unique and patented antifouling protection
- Only suitable for shallow deployments
- Same design used on the CO₂-Pro sensors

OGS Italy E2M3A Buoy
CO₂-Pro Installed



CO₂ Surface Flux Measurement



- The CO₂-Pro ATM sensor was designed for integration onto Buoy platforms and shipboard use to facilitate a means of measuring both surface water and air-side pCO₂ in order to determine CO₂ flux into or out of the ocean.
- It utilizes a single CO₂ detector for both measurements to minimize errors.

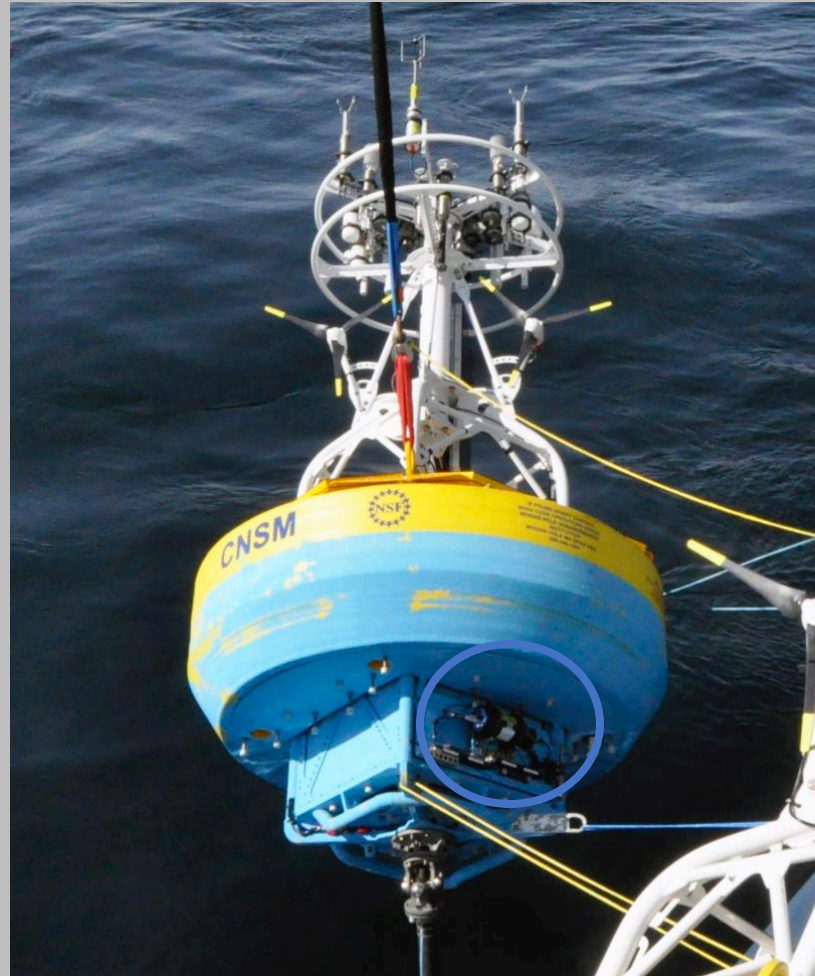
Standard Equipment for CO₂-Pro Atmosphere

- Sensor comes complete with:
 - Modified CO₂-Pro
 - NEMA air-side box for air pCO₂ measurement (bottom left)
 - 5 meters of Tygon tubing for connecting air-side box to CO₂-Pro (other lengths optional)
 - Pelican carrying case

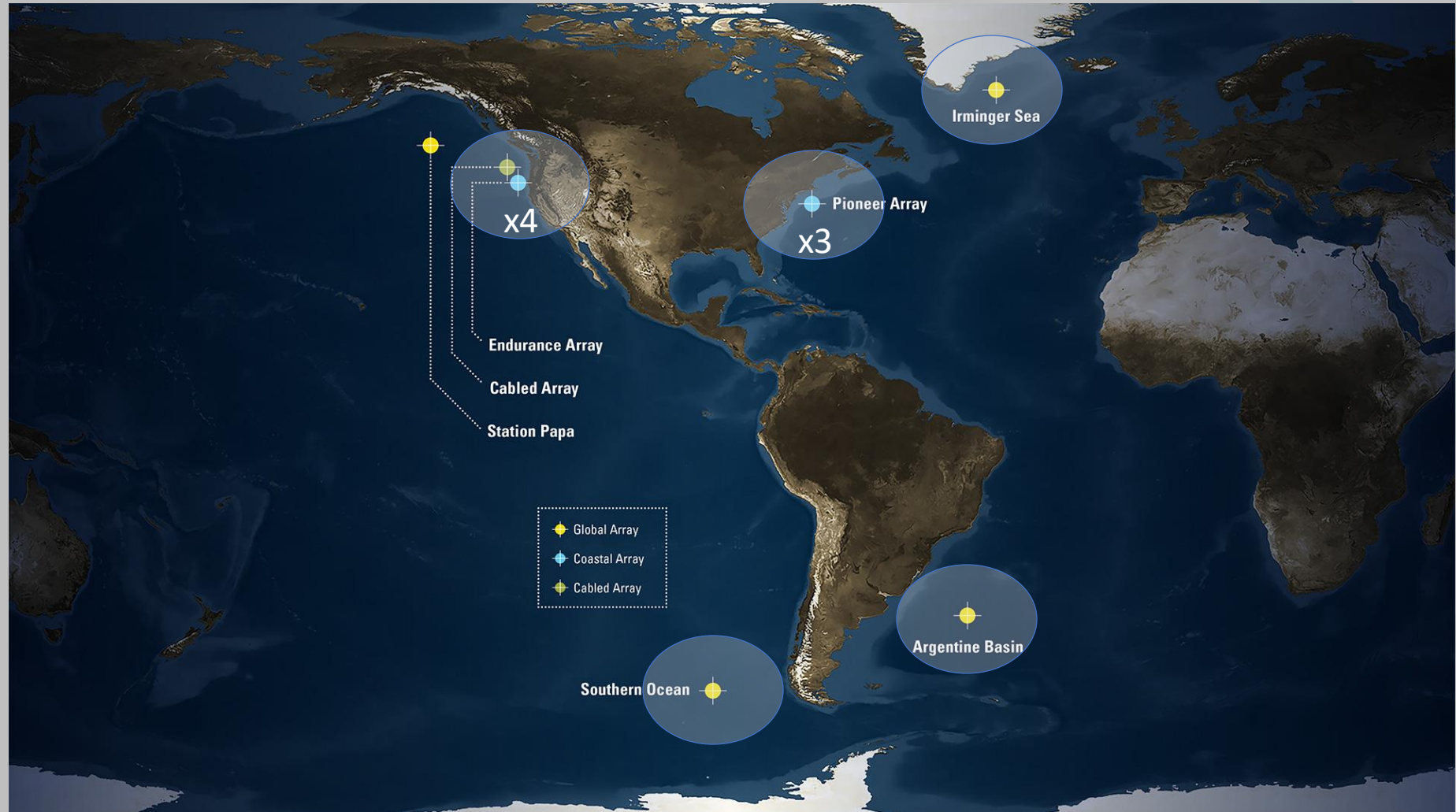


CO₂-Pro ATM on one of the US OOI Nodes

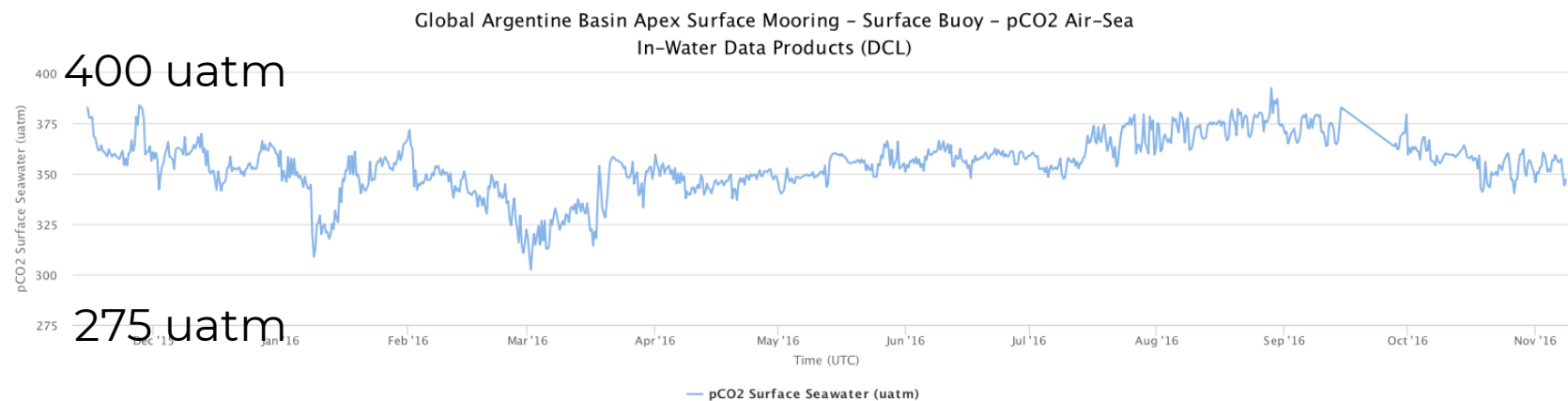
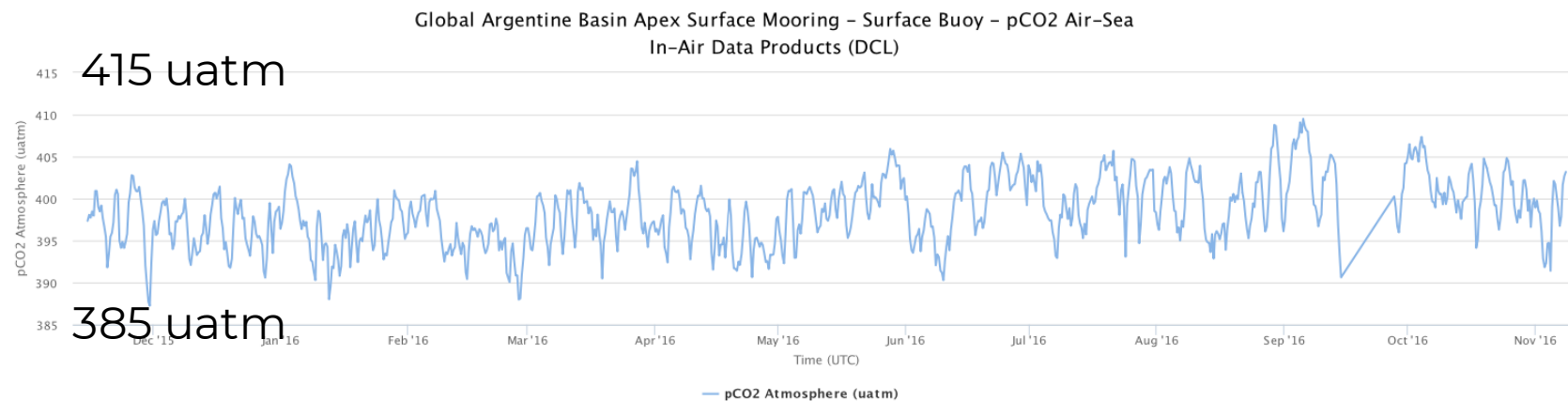
- The Central Coastal Surface Mooring buoy is deployed from the starboard rail of the R/V Atlantis. CO₂-Pro ATM sensor installed on the buoy



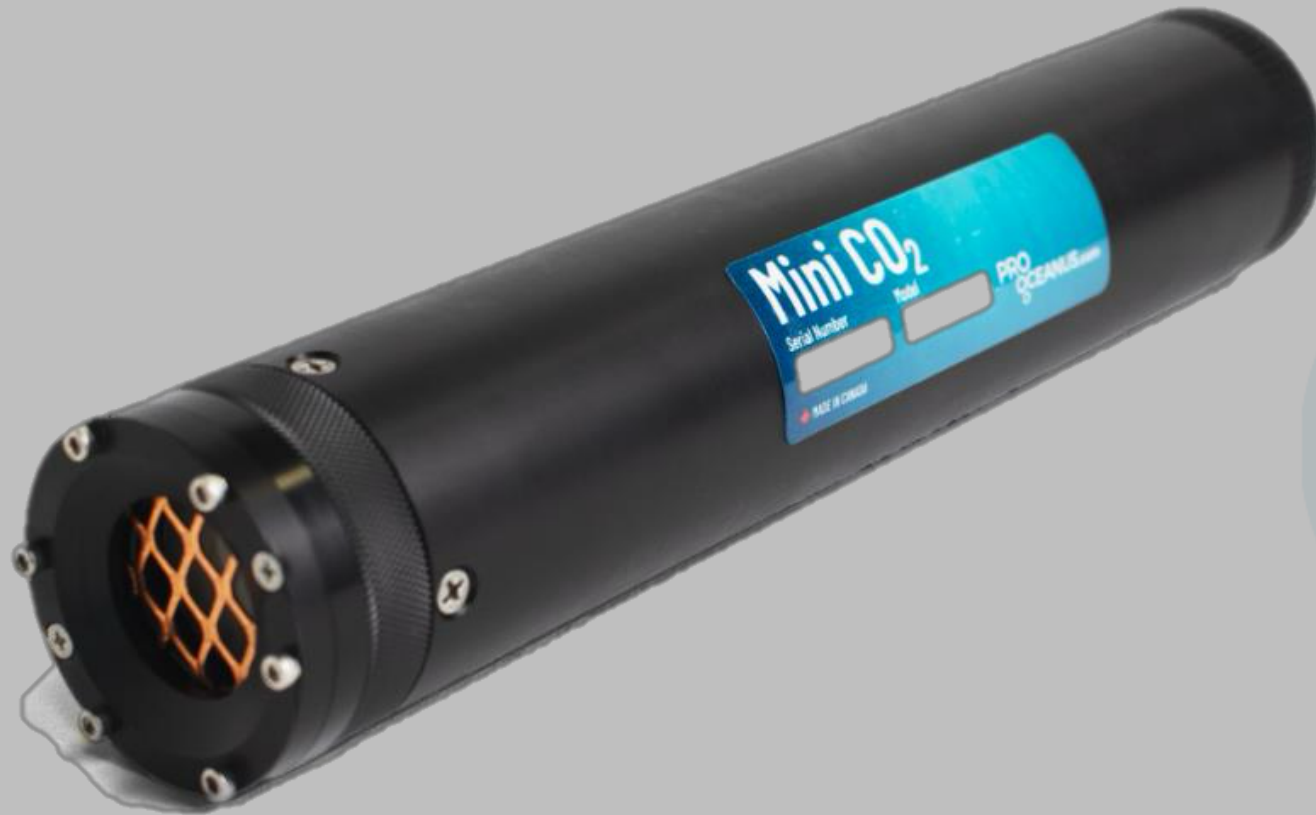
CO₂-Pro ATM Installed on 10 US OOI Buoys



Example Data from US OOI Buoy



Mini Series



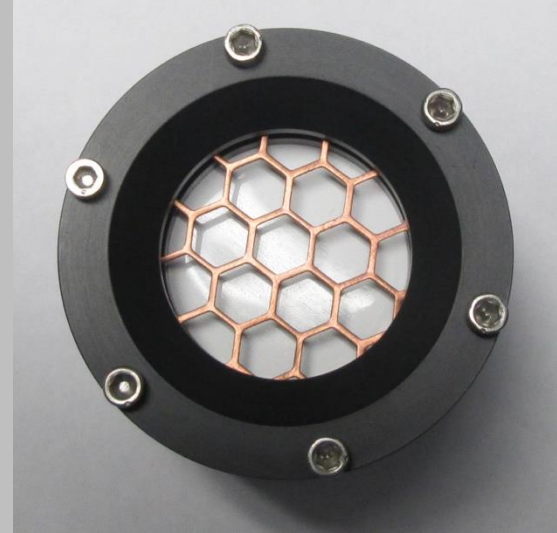
Mini CO₂ Applications

- Aquaculture monitoring of dissolved CO₂ for fish and shellfish health
- Coastal zone CO₂ fluxes
- Groundwater and wellwater monitoring
- Carbon budget studies for lakes and rivers
- Carbon capture storage monitoring of aquifer and surface water levels of pCO₂
- Wastewater greenhouse gas emissions
- Ocean glider and profiler missions



Mini CO₂

- Customizable
- Wide CO₂ calibration ranges
- Plastic, SS or titanium housings
- Digital RS 232 output
- Analog output 4-20mA or 0-5V
- External and internal battery solutions
- Flow-through options
- Power communications Deckbox
- Mounting brackets
- Variety of connectors
- Pipe Insert



Solu-Blu Series



Solu-Blu CO₂ Applications

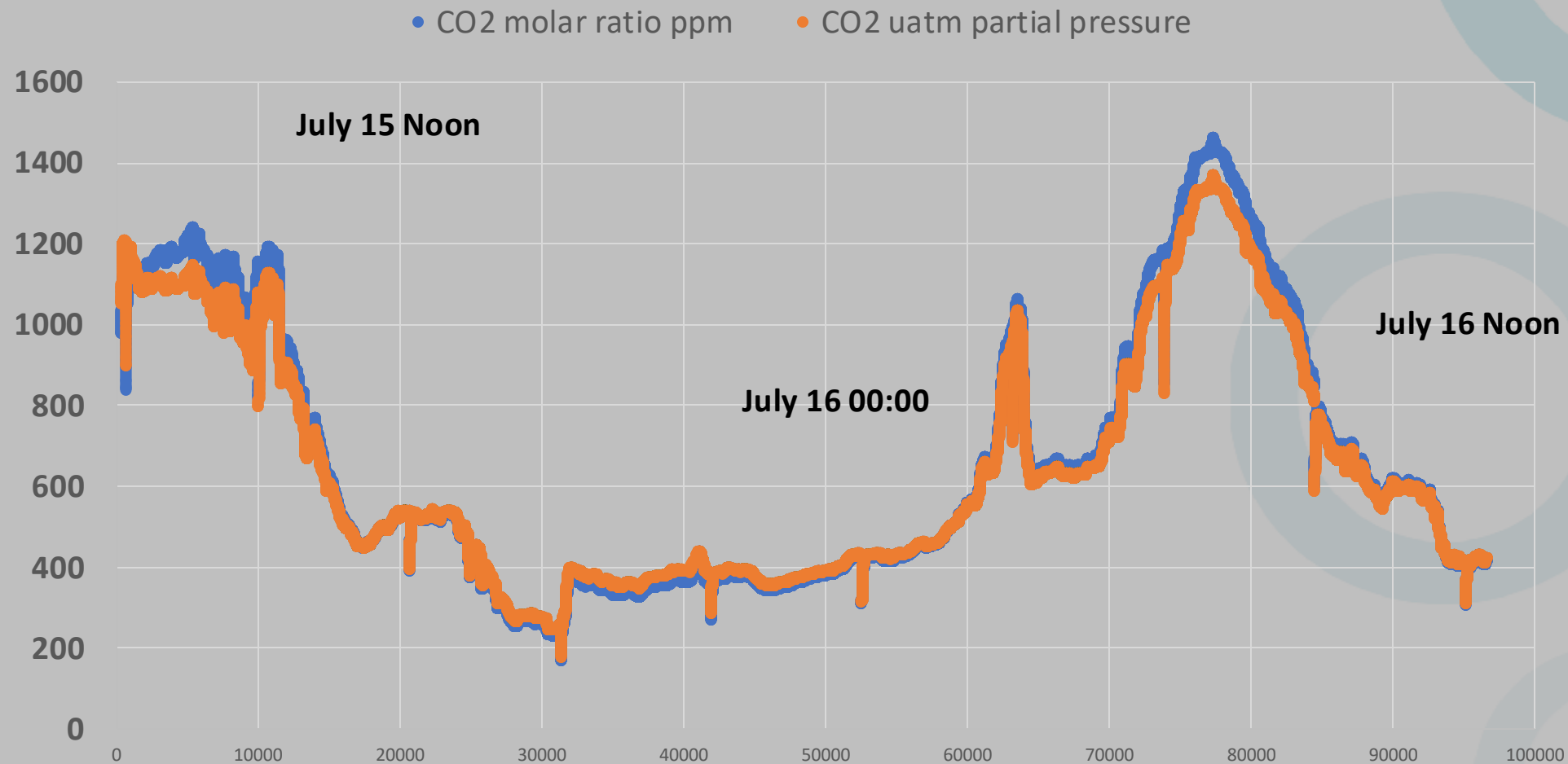
- Integrated systems, PLCs
- Aquaculture monitoring of dissolved CO₂ for fish and shellfish health
 - Well boats
 - Recirculating Aquaculture Systems
- Wastewater greenhouse gas emissions



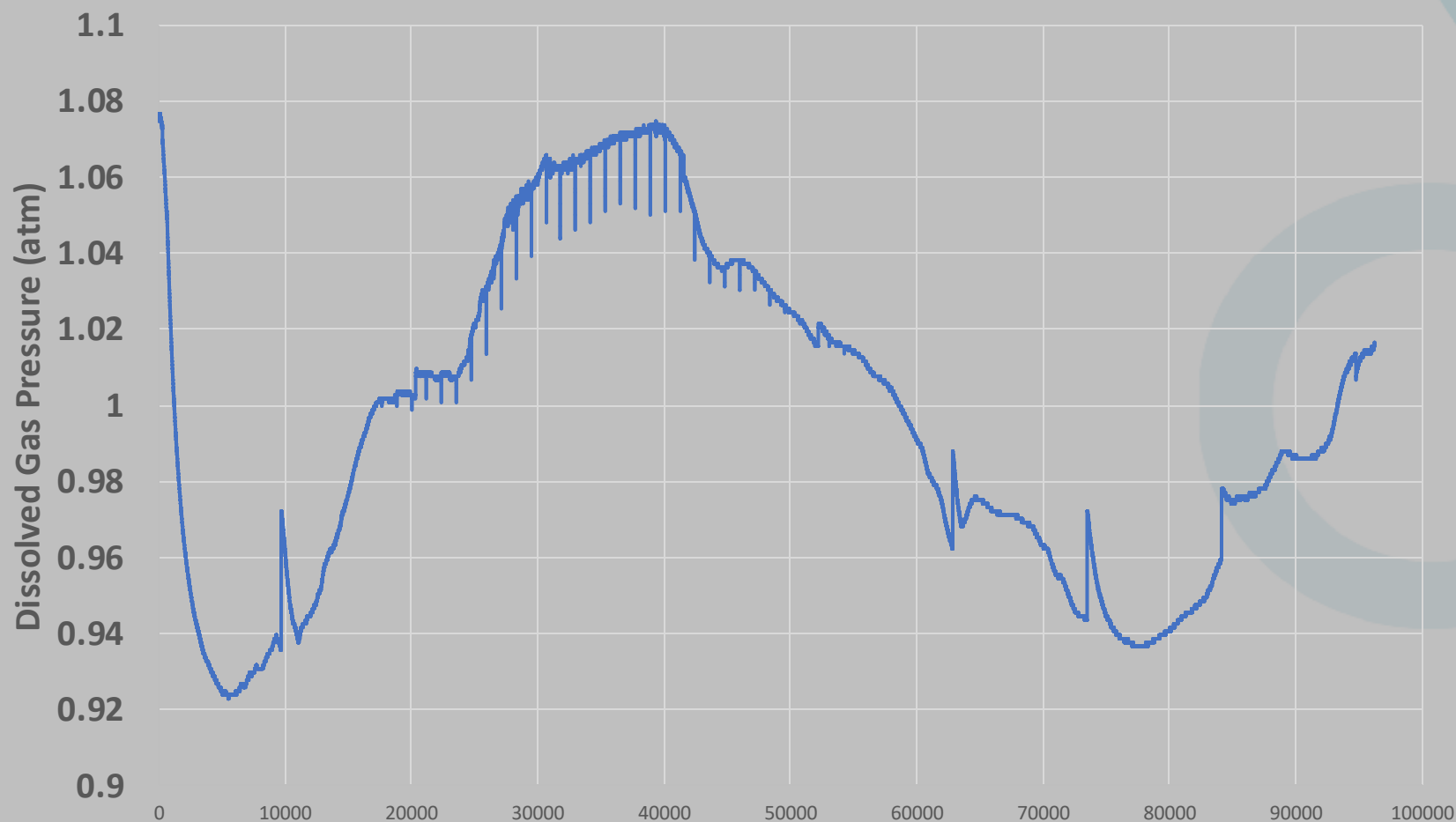
Dock Data – CO₂-Pro CV

- ~1.5 days of continuous data collection in 0.2-0.5m of water at the SERC Dock location
- Sensor measures Molar Fraction of CO₂ in the optical cell, as well as the gas stream pressure in equilibrium with the water
- Molar Ratio is NOT Partial Pressure which is the parameter used to determine CO₂ fugacity that is used in carbonate system calculations
- Partial Pressure = Molar Ratio x in situ dissolved gas pressure

Dock Data – CO₂-Pro CV



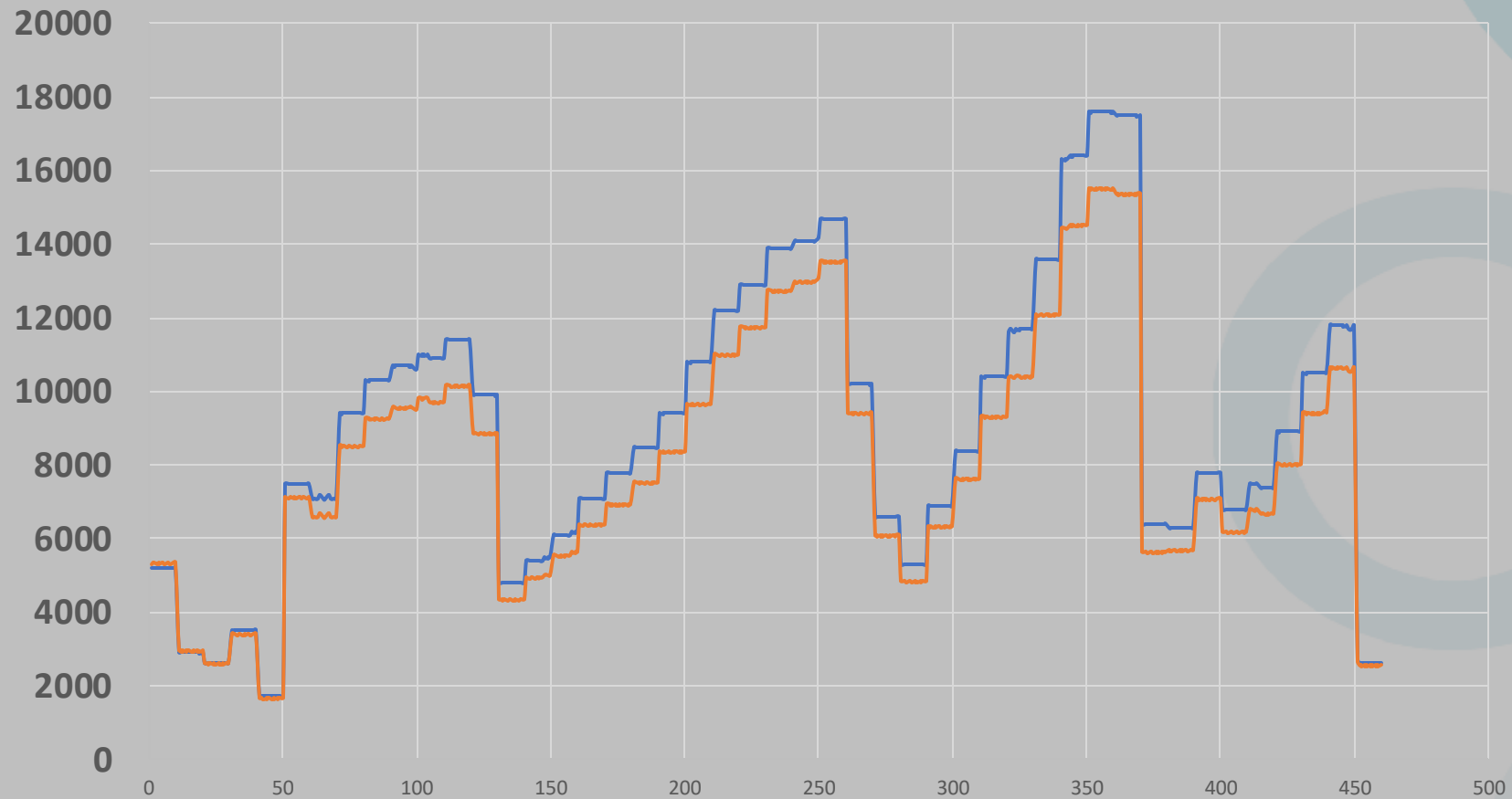
Dock Data – CO₂-Pro CV



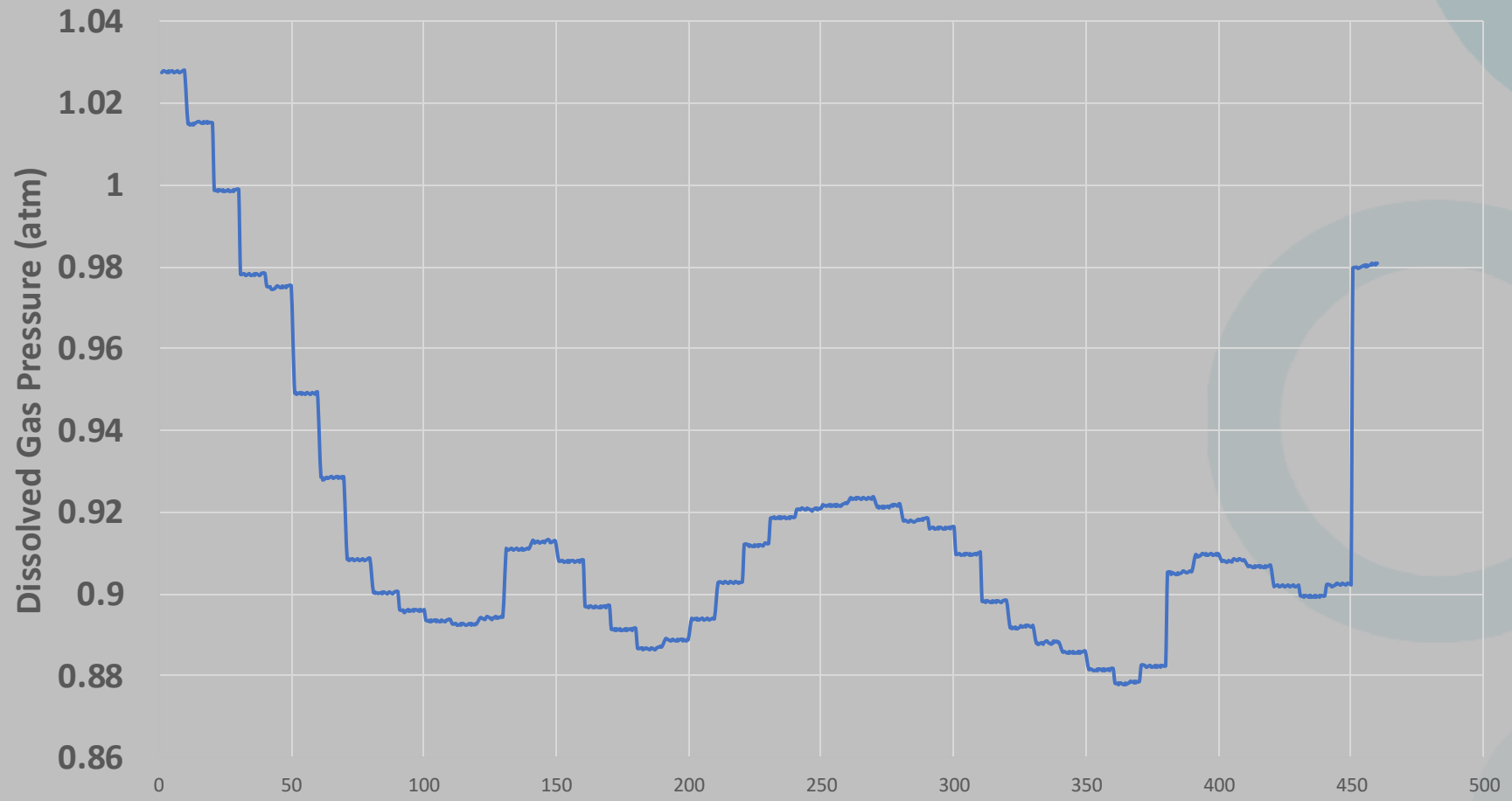
Marsh Data – Mini CO₂

- ~2 days of hourly data collection in 0.2-0.5m of water at the SERC March location
- Sensor measures Molar Fraction of CO₂ in the optical cell, as well as the gas stream pressure in equilibrium with the water

Marsh Data – Mini CO₂



Marsh Data – Mini CO₂



Appendix D References and Recommendations

Publications

Bockmon, Emily E., Dickson, Andrew G., (2015). An inter-laboratory comparison assessing the quality of seawater carbon dioxide measurements Marine Chemistry, 171, 36-43 Link: <https://doi.org/10.1016/j.marchem.2015.02.002>

Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. *Guide to best practices for ocean CO₂ measurements*. PICES Special Publication 3, 191 pp. Link: https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system/oceans/Hanbook_2007.html

Christopher S. Moore, Robert H. Byrne, Kimberly K. Yates. An assessment of HgII to preserve carbonate parameters in organic-rich estuarine waters. Limnol. Oceanogr.: Methods 22, 2024, 93-102. doi: 10.1002/lom3.10593 Link: <https://aslopubs.onlinelibrary.wiley.com/doi/pdfdirect/10.1002/lom3.10593>

Ashwin Murthy, Korey Silverman-Roati and Romany M. Webb Columbia Law School, Sabin Center for Climate Change Law. State Authority to Regulate Ocean Alkalinity Enhancement. November 2024. Link: https://scholarship.law.columbia.edu/sabin_climate_change/237/

JA Newton, RA Feely, EB Jewett, P Williamson, J Mathis. Global Ocean Acidification Observing Network: Requirements and Governance Plan First Edition September 2014. Link: <https://archimer.ifremer.fr/doc/00651/76343/>

Oschlies, A., Stevenson, A., Bach, L. T., Fennel, K., Rickaby, R., Satterfield, T., Webb, R., and Gattuso, J.-P. (Eds.): Guide to Best Practices in Ocean Alkalinity Enhancement Research. Copernicus Publications, State of the Planet, 2023 2-oae2023, doi 10.5194/sp-2-oae2023, Link: <https://www.fpa2.org/en/news/speeding-up-knowledge-generation-in-a-transparent-and-responsible-way-08379>

Miller AW, Reynolds AC, Minton MS (2019) A spherical falling film gas-liquid equilibrator for rapid and continuous measurements of CO₂ and other trace gases. PLOS ONE 14(9): e0222303. <https://doi.org/10.1371/journal.pone.0222303>

For using CO2SYS in coastal waters, it was suggested to use the following:

Jiang et al. (2022):

<https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2021.705638/full>

Table 4. Updated programs that are being released in this paper. All programs can take total dissolved inorganic carbon content (DIC), total alkalinity content (TA), pH, and carbon dioxide partial pressure ($p\text{CO}_2$) or fugacity ($f\text{CO}_2$), and each can take one or more of carbonate ion content ($[\text{CO}_3^{2-}]$), bicarbonate ion content ($[\text{HCO}_3^-]$), the sum of dissolved carbon dioxide ($[\text{CO}_{2(aq)}]$) and carbonic acid content ($[\text{H}_2\text{CO}_3]$) ($[\text{CO}_2^*]$), and mole fraction of carbon dioxide in a dry gas sample ($x\text{CO}_2$). All programs now allow the inclusion of hydrogen sulfide (H_2S) and ammonium (NH_4^+) equilibria in the TA-pH equation. All programs now have their own uncertainty propagation functions.

Program	Version	Link	Additional variables
CO2SYS_v3.0 _Err.xlsm	3.0	https://github.com/dpierr ot/co2sys_xl	$[\text{CO}_3^{2-}]$
CO2SYS.m, errors.m	3.1.1	http://doi.org/10.5281/zenodo.3950562	$[\text{CO}_3^{2-}]$, $[\text{HCO}_3^-]$, $[\text{CO}_2^*]$
PyCO2SYS	1.8.0	https://PyCO2SYS.readthedocs.io	$[\text{CO}_3^{2-}]$, $[\text{HCO}_3^-]$, $[\text{CO}_2^*]$, $x\text{CO}_2$
Seacarb	3.2.13	https://CRAN.R-project.org/package=seacarb	$[\text{CO}_3^{2-}]$, $[\text{HCO}_3^-]$, $[\text{CO}_2^*]$

Example Standard Operating Procedures for LiCor Total Alkalinity and Dissolved Inorganic Carbon IRGA Systems

The following SOP is provided by LiCOR as an example methodology for TA and DIC IRGA systems. This information is provided as suggested guidelines for laboratory analyses. Practitioners will need to tailor such procedures to their own needs, budget, and facilities. Screenshots of the user interface may not be up-to-date.

SOP for Alkalinity measurements

1. Total alkalinity system comprises of the following components:
 - Apollo SciTech Alkalinity Titrator: Model AS-ALK2
 - Thermo Scientific Orion benchtop meter
 - Orion 8102 BN – Ross combination pH electrode
 - Stir plates (x2)
 - Isotemp water bath – 2100
 - Computer with TA software and connecting cables.
2. Chemicals, standards, and other apparatus required include:
 - o 0.1N HCl (8.5 ml conc. HCl + 29.5 g NaCl to 1.0 L with DI water)
 - o pH Buffer standards – 4.01, 7.00, and 10.01
 - o Glass syringes (zero dead-space) – 1.0 ml and 25.0 ml
 - o 50 ml beakers and magnetic stir bars
 - o Flow-through jackets to house two 500 ml bottles and one 50 ml beaker
 - o Flexible rubber or tygon tubing
3. Install syringes through their appropriate flow-through (FT) jackets on the Titrator.
4. Complete the constant temperature bath water loop by connecting the isotemp bath outlet to all four FT jackets in series using flexible tubing. Outlet of the last jacket returns the fluid back to the isotemp water bath (IWB) inlet.
5. Fill 0.1N HCl in the acid bottle and put the bottle in FT jacket. Add a stir bar in the bottle and mount the FT jacket with bottle on a magnetic stirrer. Hook the acid line to the 1 ml syringe.
6. Connect pH probe to the meter and the meter and Titrator to the computer using appropriate cables (BNC, RS232, and USB respectively).

Steps 3, 4, 5, and 6 are not required for the lab system already in operation. Just ensure cables from the pH probe, Titrator, and pH meter are connected to computer; there is enough HCl in the bottle; and water bath tubing are secured without leaks.

7. Turn on IWB and set the temperature to 22 °C. Start the flow.
8. Turn on the Titrator and the computer.
9. Fill aliquots of three pH buffers in three small vials and place them in the IWB for temperature equilibration.
10. Put all sample bottles to be analyzed, and at least one CRM Alkalinity standard solution in the IWB for temperature equilibration.

A minimum half hour must be allowed for temperature equilibration.

11. Start the program by double clicking on 'TALK shortcut'.
12. Window shown in Fig. 1 will appear displaying the last user name and data destination directory:
13. Change the user name if needed and click 'Measure' box.
14. 'Initialize Wizard' window (Fig. 2) will appear. **Do not change communication ports by clicking on "Yes"**. Simply click on the 'Next' box. System will initialize and communications between the computer, pH meter, and the Titrator will be established. Click 'next' to go to the next step.

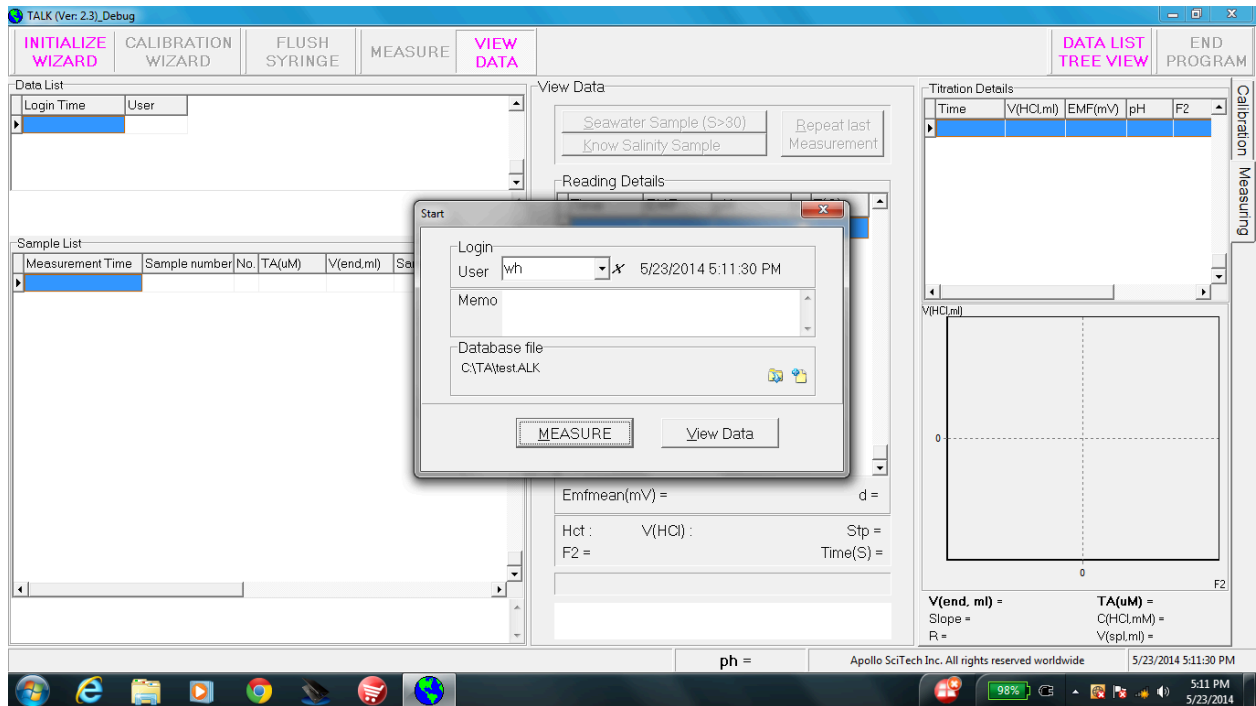


Fig. 1

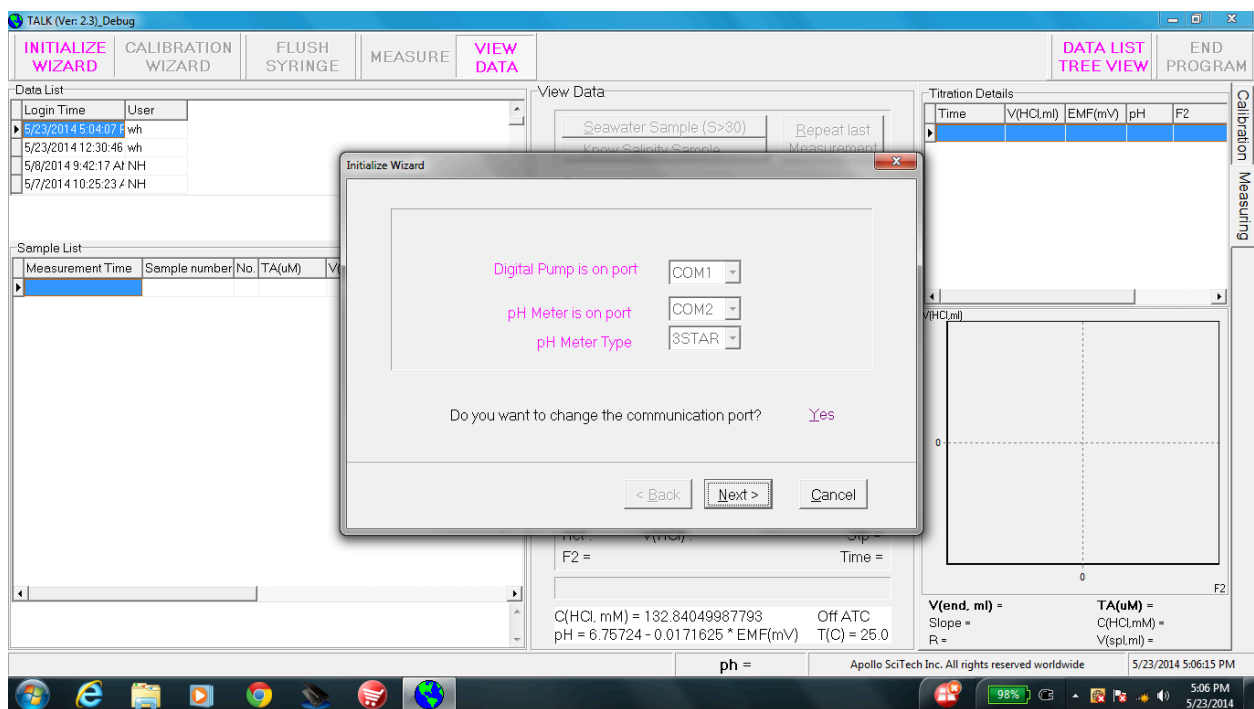


Fig. 2

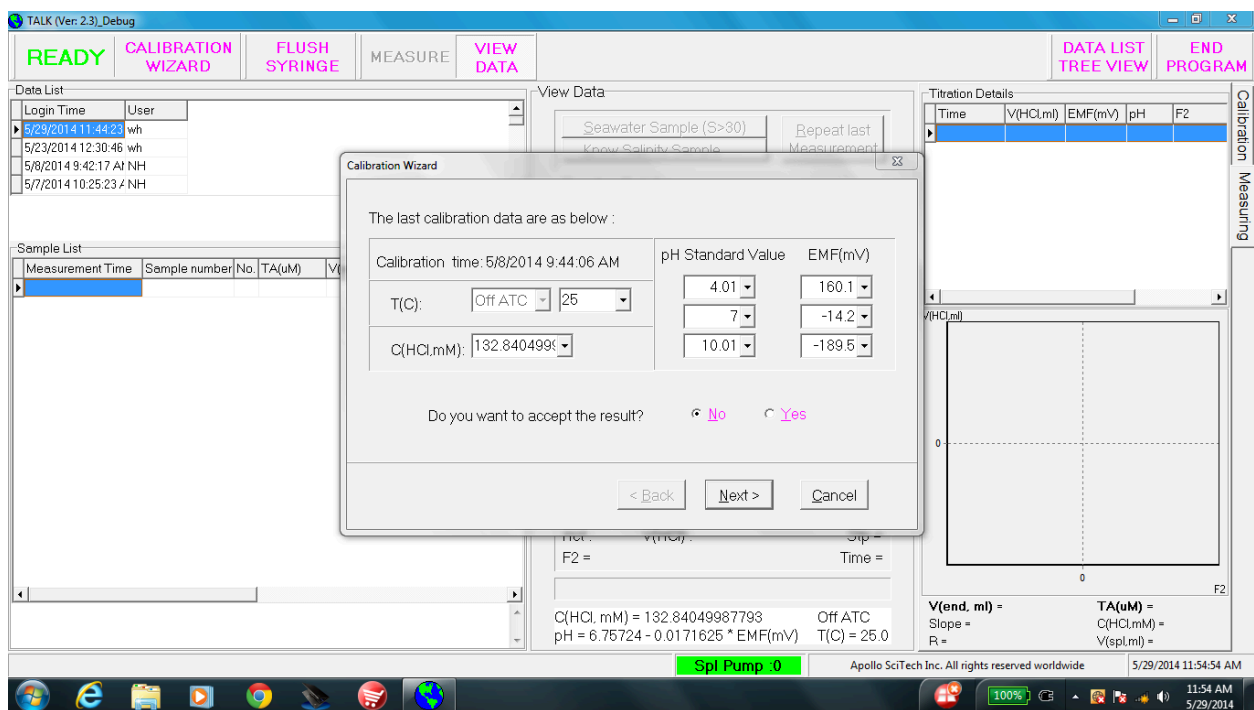


Fig. 3

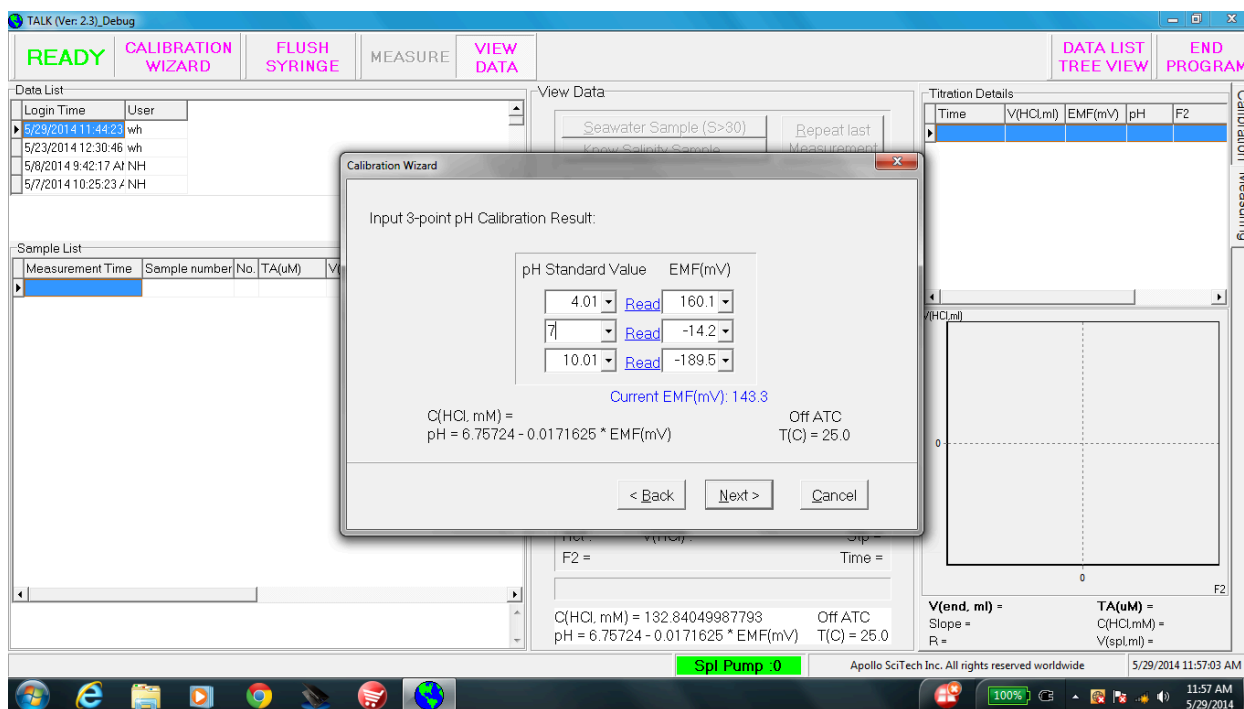


Fig. 4

15. Resulting menu box will show "digital pump will be flushed with acid once". **Ensure acid line is connected to the acid bottle and the outlet is placed in a waste beaker to collect flushed acid.** Click 'next'.
16. pH calibration data of the last run will be displayed in the next window (Fig. 3). Accept if appropriate, or choose 'No' and click next. Window shown in Fig. 4 will appear.
17. Set the first buffer (4.01) in a beaker with 22 °C water from the bath and lower the previously cleaned pH probe gently into the buffer. Set the pH meter to read EMF (mV) and read the value. Wait until it shows a steady value over at least 30 seconds.

Buffer bottles must be checked to ensure the quality of buffer solution. If visible precipitate, or growth seen, discard the solution. Buffer solutions must be renewed, if not every working day, once a week.

18. Insert the EMF value in the window against 4.01 (Fig. 4).
19. Repeat steps 17 and 18 for the remaining two pH buffers of 7.00 and 10.01 respectively. Click next.

Following every change of buffer, pH probe should be adequately rinsed with distilled water

20. Before proceeding further, attach the acid dispensing tube to the pH probe such that the tip hangs close to the lower end of the probe but half inch away. Secure it in that position with a piece of para film, **making sure para film is at least 2" above the lower tip of the probe.**

21. Program will ask if you want to accept old value for acid concentration, or determine HCl by titration. **Select "determine HCl by titration".**
22. Next several steps will be self-explanatory with the program providing suggestions and guidance. Follow each one properly and do as directed by the program. Briefly:
- Place the CRM standard bottle in the sample FT jacket and insert the sample-line attached to the 25 ml syringe, in the sample bottle.
 - Place the output line from the 25 ml syringe in the waste bottle.
 - At the end of the wash, place that line in a clean 50 ml beaker with a magnetic stir bar.
 - Lower the sample beaker in the smaller FT jacket with adequate water level to cover sample height in the beaker.
 - Start the stirrer. Adjust speed to form a few mm deep water cone at the surface – typically at about 100 rpm.
 - Click ok. Titration will start. At the end of first titration, program will provide directions to the next step. Follow the directions and complete at least three CRM analyses. At the end of the third analysis, program will yield standard acid concentration value and error.
 - If the error is less than 0.1%, click "Accept". Otherwise "Continue" for the fourth analysis and then "Accept".
 - To begin sample analysis, replace CRM bottle with the sample bottle and connect the required tubing.
 - If the sample is seawater with $S > 30$, click on the box "seawater sample ($S > 30$)" as shown in Fig. 5 and follow directions.
 - If the sample is with salinity less than 30, choose "know salinity sample" option and type in sample salinity in the box (Fig. 5). **An exact salinity value is not necessary. Lower value is preferable. Value exceeding the actual salinity should be avoided.**
 - Fill in sample ID in the box below salinity value and click 'ok'.
 - When the analysis is complete and result displayed in the left side window, click on "Repeat test" and follow directions to complete repeat analysis.
 - Ensure the second result is within 0.1% of the first value. If not, click on Repeat test and make one more measurement. Continue until two consecutive results are within 0.1%.

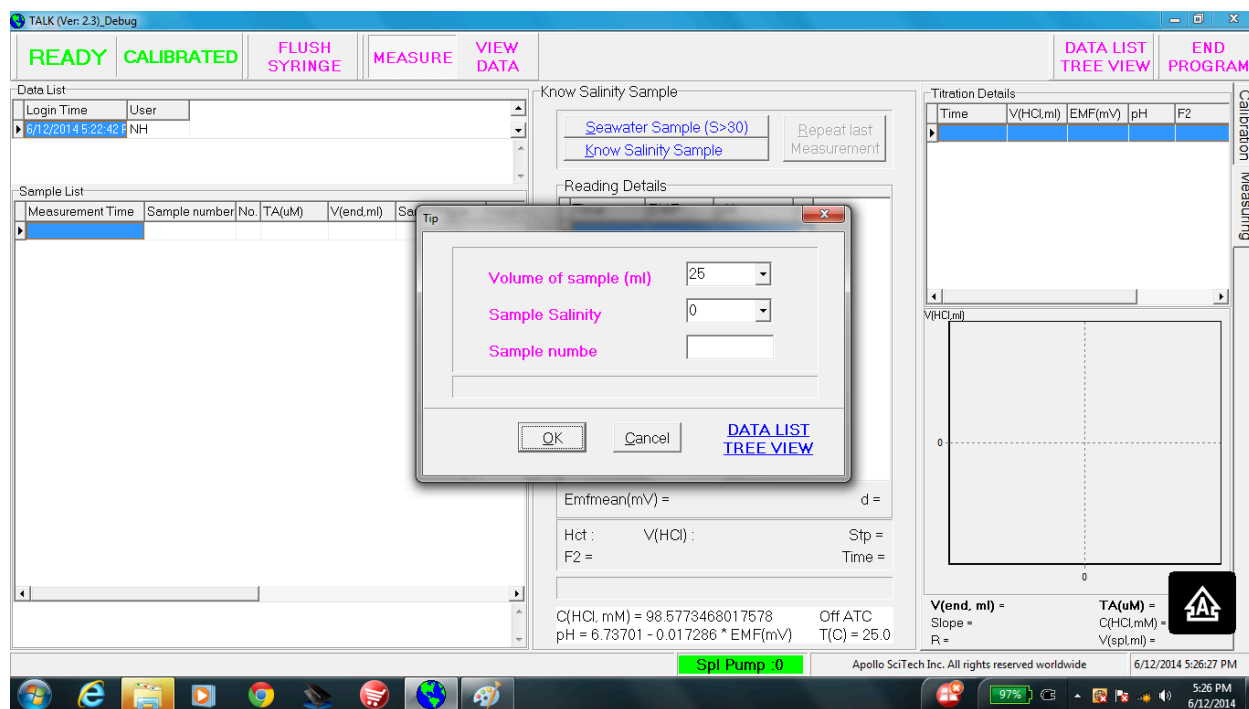


Fig. 5

- When all samples are analyzed, analyze CRM standard again.
- To end program, click on the top right icon "End Program" and follow the direction to exit. Choose the flush syringes option.
- Turn off the Alkalinity titrator and thermal baths as needed. Secure the pH electrode per electrode guidelines.

SOP for DIC measurement

1. Dissolved Inorganic Carbon (DIC) is measured by neutralizing a water sample with 10% phosphoric acid and quantitatively measuring the evolved CO₂ gas. The analyzer comprises of the following units:
 - DIC Analyzer: Apollo AS-C3
 - LiCor 7000
 - Isotemp water bath 2100
 - Computer with DIC software and connecting cables
2. Chemicals, standards, and other apparatus required include:
 - 5% phosphoric acid (50 ml conc. H₃PO₄ + 100 g NaCl to 1.0 L with DI water)
 - CRM Standard of known DIC concentration
 - Grade 5.0 Nitrogen gas
 - Kloehe syringe (zero dead-space) – 2.5 ml
 - Luer syringe – 30 ml glass
 - Nafion drying tube, with air circulation pump and a drying cartridge
 - Flow-through jackets to house two 500 ml bottles
 - 500 ml beaker for collecting waste solution from the analyzer
 - Flexible rubber or Tygon tubing and connectors
3. Install the 2.5 ml Kloehe syringe at the syringe port of the 3-way distribution valve attached to the analyzer.
4. Connect the computer to the I/O port on the analyzer
5. Connect the gas line to the nitrogen tank.
6. Complete the constant temperature bath loop by connecting the isotemp bath water outlet to the two FT jackets and the copper coil surrounding the Luer syringe, in series, using flexible tubing and appropriate connectors. Outlet from the copper coil returns the fluid back to the isotemp water bath (IWB) inlet.

Steps 3 - 6 are not required if the system is already connected and has been in operation

7. Place the drain tube from the analyzer in the waste beaker
8. Start N₂ flow by opening the valve on the tank. Adjust the flow pressure to about 15 psi.
9. Turn on the analyzer and 10 seconds later the LiCor7000.
10. Turn on the computer and enter the DIC software by double clicking the DIC icon. Screen shown in Fig. 1 will appear displaying the peak and settings from the last run.
11. Turn on the air circulation pump connected to the Nafion drying tube. **Ensure this air circulation loop is routed through the drying cartridge (filled with MgClO₄).**
12. Fill 5% phosphoric acid solution in the acid bottle and put the bottle in FT jacket. Insert the acid inlet tube from port C of the 3 way distribution valve in acid bottle.
13. Place CRM standard bottle in the other FT jacket and insert the tubing connected to the Luer syringe outlet in the bottle such that it is dipping well in the solution.
14. Turn on the isotemp water bath and set the temperature to 15°C. Start circulation.

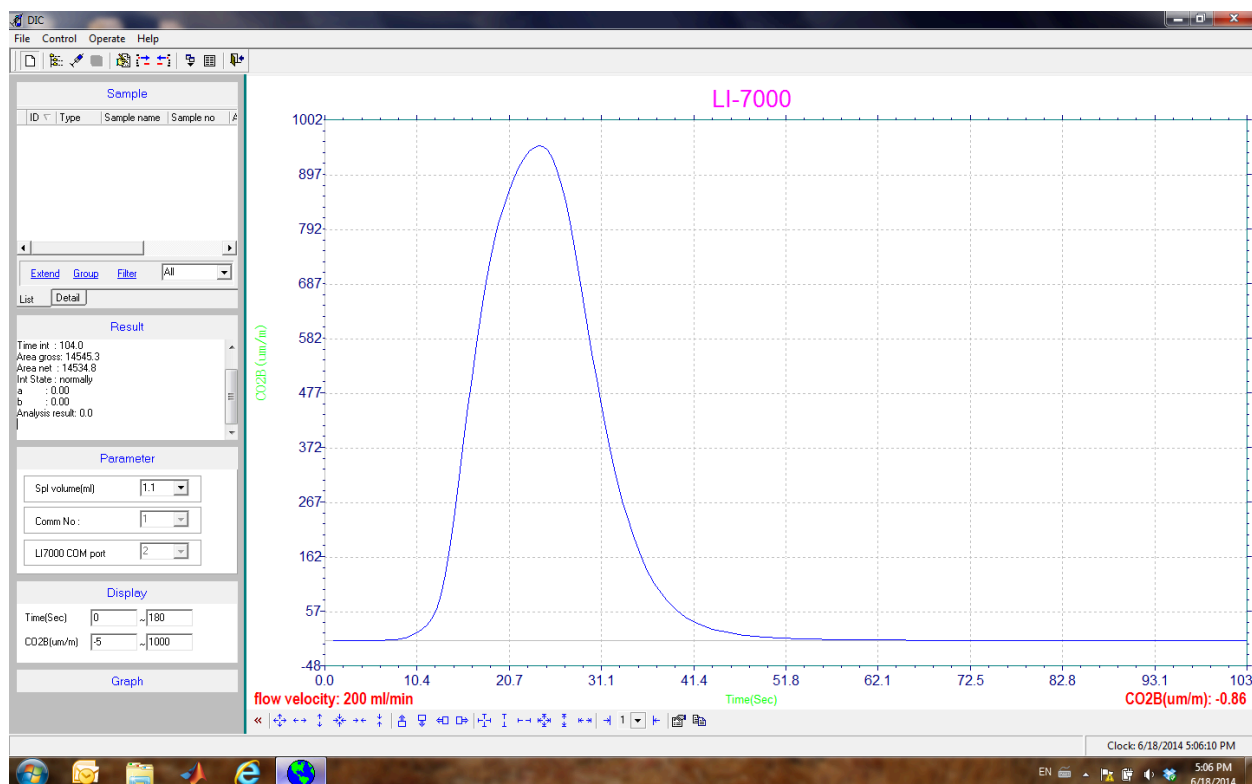


Fig. 1

15. Allow at least 30 minutes to bring the acid and CRM standard solution temperatures to 15°C.
16. Carefully draw CRM standard in Luer syringe. Ensure there are no air bubbles in the syringe.
Draw enough volume of the standard to last calibration and CCV (continuous calibration verification) needs. 25 to 30 ml is good volume.
17. Attach the syringe to port B of the distribution valve with appropriate Tygon tubing and connectors. Remove the CRM standard bottle from the FT jacket and place a previously cooled sample bottle in its place.
18. In the program window (Fig. 1) select "Connect/disconnect" from the top Control menu. This action returns control of the analyzer to the computer and initializes the KloeHN syringe and other system drivers.
19. From "Control" menu, select "Sample Analysis". This will enable a single run of the CRM standard. The step helps cleanup/fill sample and acid lines with appropriate solutions and remove air bubbles.
20. Choose "Batch Process" from "Control" menu. A menu box shown in Fig. 2 will appear.
 - Set up a measurement scheme as shown in "Scheme Name: a" of the box. New parameters can be entered by clicking on a box and typing the numbers.
 - Ensure the solid black triangle in the extreme left column remains against line a. If not, click in the box to bring the triangle on line a.
 - Click on "Sample List" from the top menu. A box shown in Fig. 3 will appear.

Functions of #18-20 can also be accessed directly from the second menu line.

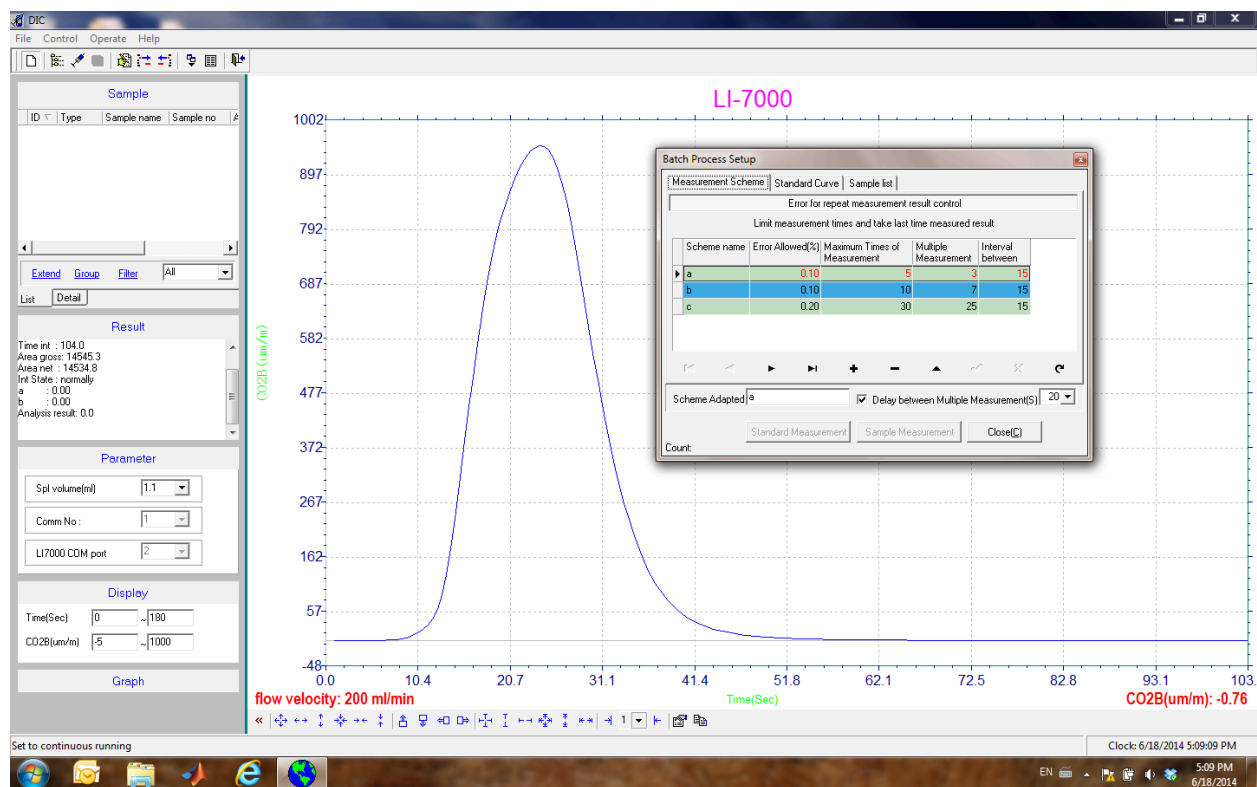


Fig. 2

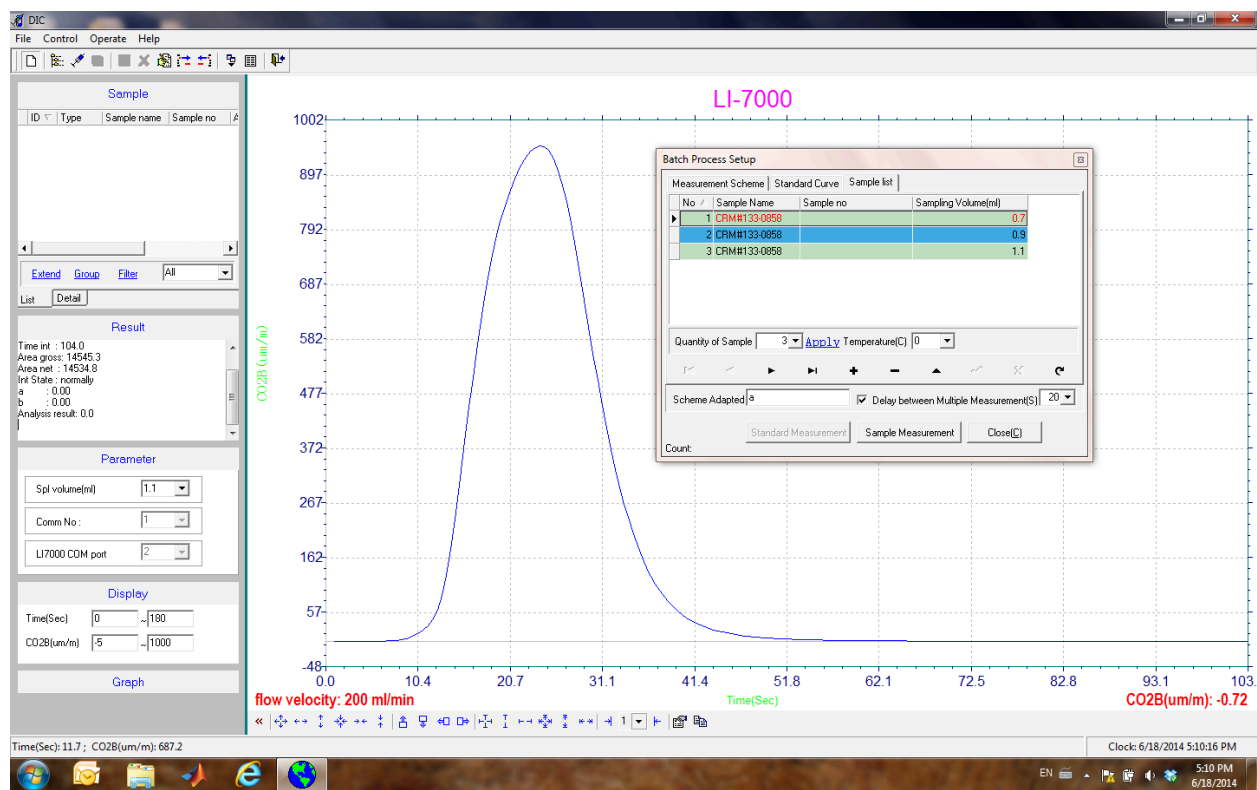


Fig. 3

- Setup calibration Standard ID and calibration volumes as shown in Fig. 3. Bring the black triangle next to line 1(0.7 ml injection) and click on the “Sample Measurement”. Analysis will start. Five injections of the standard at 0.7 ml will be followed by five at 0.9 ml and then five at 1.1 ml respectively.

If the criteria set on “line a” of Fig. 2 (ie. 5 measurements with at least 3 within 0.1% variance) is not satisfied, automatic measurements will stop. The system will wait for the operator to intervene – correct the error causing larger than tolerable variance, or override the failure – and restart the sequence.

- When all three standard volumes are successfully processed, check the analysis results by clicking on “Test Results” from the “File” menu. A Test Result box as shown in Fig. 4 will display results of the analyses.

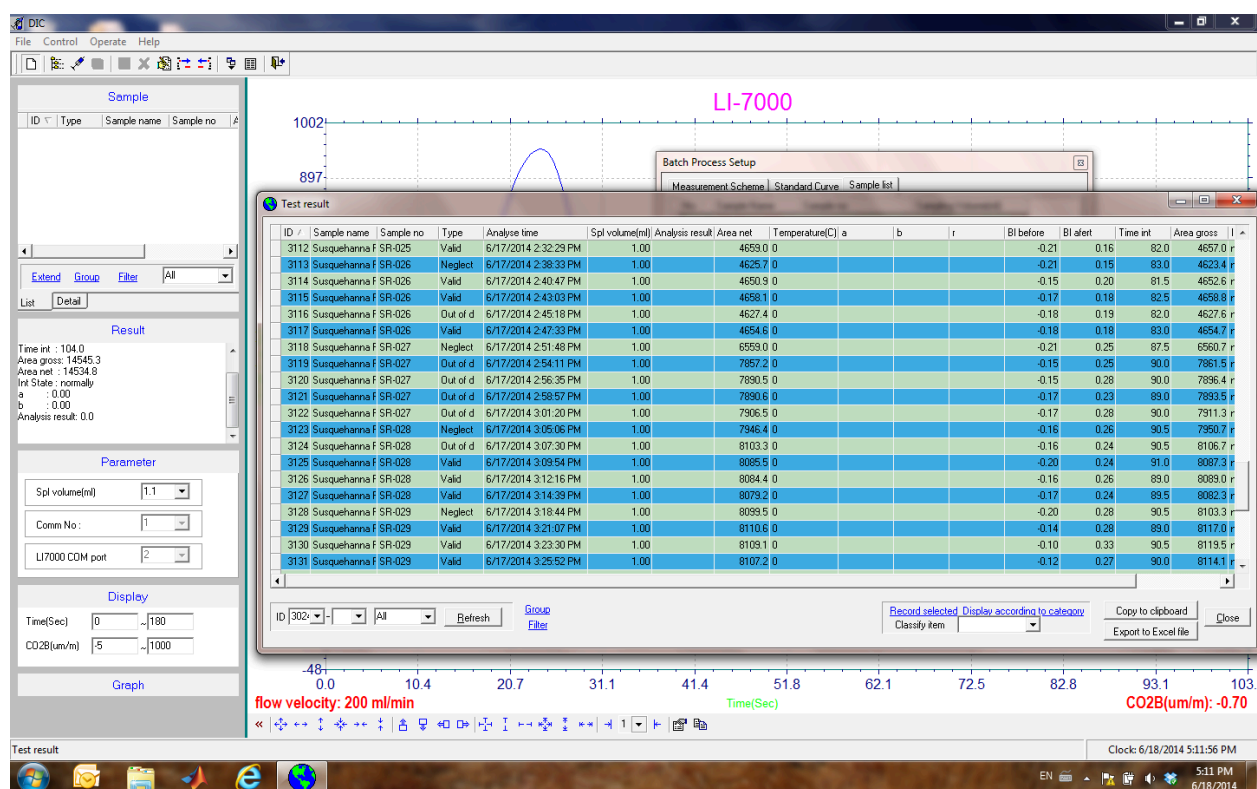


Fig. 4

- Enter the calibration results in the DIC Logbook. Note down room temperature, humidity, and the temperature of the isotherm bath.
21. Carefully remove the sample uptake tube, currently connected to the Luer syringe, and insert it in the sample bottle after wiping the end with a clean tissue paper.
- Return to Batch Processing Setup box of Fig. 3 and click on “+” sign from the bottom menu line. An extra line (Line 4) will be added in the box.
 - Enter sample ID on line 4 and set the volume to 1.0 ml on the last column.

- Bring the black triangle on line 4, and click "Sample Measurement" box. Sample analysis will start. Five injections and processing of sample will follow. New results can be seen and noted by refreshing the "Test Results" box.
- Continue with the remaining samples by following the above steps of Article 21, each time altering sample ID info on Line 4 with the new ID.

22. At the end of the analyses, in order to ensure initial calibration did not change, run CRM standard again by connecting the sample line to the Luer syringe with the Standard, setting the triangle against Line 1 of the Batch Processing Setup box (Fig. 3), and clicking on "Sample Measurement".

It is a good practice to repeat continuous calibration verification check every 10 sample analyses. It is also advisable to use a different CRM standard for such verifications.

23. At the end of the run, note down all the results in DIC Logbook. To export the data, use "Export" option from the "File" menu. Specify the format and file destination for the export.
24. To shut down the instrument, first disconnect the computer from the analyzer by choosing "Connect/Disconnect" option from the "Control" menu. Program will direct you to the next few steps to clean sample and acid lines. Follow those. When completed,
- Exit the DIC program
 - Switch off the analyzer – first LiCor 7000 and then AS-C3 unit.
 - Turn off the air circulation pump on the nafion tube.
 - Close the valve on nitrogen cylinder.
 - Shut down isotherm bath.
 - Clean Luer syringe so as to keep it ready for the next run.
 - Return CRM standard bottle to the refrigerator.