Coastal Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ucmg20

Opportunities for U.S. State Governments and in-Region Partners to Address Ocean Acidification through Management and Policy Frameworks

Jessie Turner, Parker Gassett, Charlotte Dohrn, Hanna Miller, Chris Boylan & Eric Laschever

To cite this article: Jessie Turner, Parker Gassett, Charlotte Dohrn, Hanna Miller, Chris Boylan & Eric Laschever (2021) Opportunities for U.S. State Governments and in-Region Partners to Address Ocean Acidification through Management and Policy Frameworks, Coastal Management, 49:5, 436-457, DOI: 10.1080/08920753.2021.1947126

To link to this article: https://doi.org/10.1080/08920753.2021.1947126

Published online: 01 Aug 2021.

COASTAL MANAGEMENT
2021, VOL. 49, NO. 5, 436–457
https://doi.org/10.1080/08920753.2021.1947126

Opportunities for U.S. State Governments and in-Region Partners to Address Ocean Acidification through Management and Policy Frameworks

Jessie Turner[a], Parker Gassett[b], Charlotte Dohrn[c], Hanna Miller[c], Chris Boylan[c] and Eric Laschever[c]

[a]Cascadia Policy Solutions, Olympia, Washington, USA; [b]Maine Sea Grant, Orono, Maine, USA; [c]School of Marine and Environmental Affairs, University of Washington, Seattle, Washington, USA

ABSTRACT
Increasing OA, combined with other stressors like warming and loss of oxygen, threatens marine species and ecosystems, including those that sustain jobs and support coastal economies. For the last 10 years, U.S. coastal states have played a key role in responding to OA specifically. In 2019, OA practitioners from the U.S. east and west coasts assembled for a multi-day conference focused on sharing and documenting advances in OA collaborations, governance and management strategies. Since that time, conference attendees, supported by conference organizer the International Alliance to Combat Ocean Acidification, have worked to distill the lessons learned and to synthesize collective experiences. To assist governments, agencies, and organizations in addressing OA, this paper describes state-level efforts to develop and implement OA actions within policy and management frameworks. We outline pathways to action and illustrate approaches that link OA with climate policy and environmental management.

KEYWORDS
ocean acidification; governance; management; climate policy; state actions

Introduction

For the last 10 years, U.S. coastal states have been playing a key role in responding to ocean acidification (OA.) Building on a legacy of collaborative activities among state and non-state partners, the International Alliance to Combat Ocean Acidification (OA Alliance) convened a multi-day conference in September 2019 focused on sharing best practices across state governments addressing OA, including those that have developed and implemented a state Ocean Acidification Action Plan (action plan) as prescribed by the OA Alliance. Action plans serve as coordinating documents that help states better understand and respond to climate-related changing ocean and coastal conditions. Typically, they include strategies for reducing carbon emissions and local land-based pollution, strengthening nearshore monitoring to understand and predict local conditions, identifying adaptive measures in partnership with impacted industry and communities, and increasing funding for projects that are essential for implementation.

CONTACT Jessie Turner Jturner@cascadiapolicy.com Cascadia Policy Solutions, Olympia, WA, USA

For continuity, this paper will use OA as shorthand for both open ocean acidification, caused by increasing global emissions of carbon dioxide (Doney et al. 2009), and for coastal acidification which is driven by multiple, local factors and processes (Duarte et al. 2013 and references therein). In many instances it will be evident that monitoring, regulation, and management actions discussed are distinctly relevant to coastal acidification.

This paper documents discussions emerging from the 2019 conference and ongoing collaboration to share and capture best practices for implementing state government-led action. The paper outlines example frameworks for pursuing integrated management strategies to address OA. First, we provide a foundation for understanding U.S. states' unique role in responding to OA by summarizing relevant literature. Second, we describe a collaboration initiated in 2019–2020 to share knowledge and distill collective experiences to help guide other governments and organizations interested in OA action. Third, we outline pathways to action commonly used by states. Fourth, we present examples from states that are increasingly linking OA with climate policy and existing environmental management strategies.

Thematically, state actions to date are founded upon collaboration with academic institutions, relevant federal agencies, Tribal governments and a variety of stakeholders and non-governmental organizations. The examples and guidance collected here demonstrate government and non-government partnerships to build and maintain momentum for OA action, and include considerations related to priority setting, capacity building, regional collaborations, and funding. The aim of this paper is to inform decision-makers, resource managers and other partners in their own response strategies.

U.S. State action on ocean acidification: the formative years

State actions to understand and respond to OA originate from 2005 to 2008 when U.S. west coast scientists and the shellfish industry identified that OA was causing large die-offs of oyster larvae in hatcheries (Barton et al. 2012). Sudden economic losses galvanized advocacy and engagement from the shellfish industry leading Washington State to convene a Blue-Ribbon Panel on Ocean Acidification in 2012 (Washington State Blue Ribbon Panel on Ocean Acidification (2012). The Blue-Ribbon Panel was charged with comprehensively assessing the current science of OA and making recommendations for mitigation and adaptation. The approach brought together university and federal scientists, Tribal leaders, shellfish growers, conservation interests and multiple state agencies charged with regulating air and water quality and managing coastal and marine resources.

From 2012 – 2018, several other states formed legislative commissions or task forces to assess environmental, economic, and cultural vulnerabilities to OA. These bodies were charged to recommend mitigation and adaptation actions available to state governments along with establishing partnerships to advance recommendations and fill knowledge gaps (see reviews by Cooley et al. 2016 and Cross et al. 2019). During this time, OA synthesis reports surfaced as a primary mechanism to examine and respond to the emergent environmental hazard in state and regional waters. Consistently across reports, a call to action emerged to mitigate causes, reduce the environmental stressors that exacerbate conditions of OA, fill knowledge gaps and to carry-out public and agency education.

In addition to individual state-led activities, regional collaboration emerged. The West Coast Ocean Acidification and Hypoxia Science Panel (Panel) formed in 2013, comprised of scientific experts from California, Oregon, Washington and British Columbia (Chan et al. 2016). The Panel focused on the environmental and economic impacts of OA and low oxygen (i.e., hypoxia) and recommended local and regional management strategies (Chan et al. 2016). Additionally, in 2013 the Pacific Coast Collaborative (PCC)—representing the U.S. states of California, Oregon, Washington and the Canadian province of British Columbia, incorporated OA and hypoxia into existing collaborative policy efforts on climate, energy, and ocean health.

The National Oceanic and Atmospheric Administration (NOAA) established regional Coastal Acidification Networks (CANs) to advance monitoring, identify and fill knowledge gaps, and educate communities and stakeholders about the issue at regional scales. The CANs illustrate the significant role of partnership, as these networks often emerged from long standing personal and professional relationships that, "quickly grew into an interdisciplinary network of scientists, resource managers, industry and others from local, state, federal and tribal entities," alongside federal programs including Sea Grant, the National Estuary Program and the Integrated Ocean Observing Systems (Cross et al. 2019, relying on work by Feely et al. 2008 and Barton et al. 2015). While competing priorities and the relative feasibility and scalability of mitigation and adaptation options for OA remain challenges to state action, CANs have acted as hubs of information sharing and have helped reduce some barriers to local action caused by scientific uncertainty (Cross et al. 2019).

Regarding state governance and management approaches to OA, it was understood that OA occurs in the context of multiple stressors to the marine environment (e.g., Cooley et al. 2016). In coastal systems, processes including upwelling, nutrient loading (magnified by wastewater), freshwater inputs, and other development related impacts and pollutions can further exacerbate acidification (e.g., Duarte et al. 2013 and references therein; Waldbusser and Salisbury 2014 and references therein) Additionally, climate related impacts including ocean warming and deoxygenation (hypoxia) occur alongside OA and have known, though varying, impacts on coastal systems (Hales et al. 2015; IPCC 2019). These interacting factors vary across spatial and temporal scales, generating unique risks and challenges for state agencies to predict and manage for change. Cooley et al. 2016 further note that "[i]n some locations, actions may even already be under way to address other issues (e.g., hypoxia, nutrient runoff) that coincidentally enhance the resilience of marine resources at risk from ocean acidification." While the multi-stressor nature of marine degradation complicates state responses, this characteristic also provides states an opportunity to proactively incorporate OA action and information across existing efforts to address other stressors.

State actions to directly mitigate and reduce the impacts of OA can be advanced upon the premise that smaller units of government can use existing statutory authority and regulatory programs (Cooley et al. 2016; Kelly and Caldwell 2016). Kelly and Caldwell developed a list of ten state and local actions to address OA. Seven of the ten actions recommended by Kelly and Caldwell derive from federal programs, with five of them being state powers granted by the Clean Water Act, one by the Clean

Air Act, and the other under the National Estuary Program. The remaining three actions include: (a) directly regulating CO_2 emissions, (b) using state level NEPA-like programs to identify and mitigate OA impacts, and (c) using nuisance laws to enforce against activities that contribute to OA. “Policy frameworks, management strategies and leveraging regulations” explores state application of these recommendations in more detail.

During the formative years, states had little precedent for directly governing OA, either as a singular issue or together with other stressors (Cooley et al. 2016) even though effective action on OA implicates many state-level programs and policies regarding climate, oceans, coastal and watershed management, fisheries and habitat management, coastal development and pollution control. Rather than creating stand-alone agencies responding to OA, states sought to leverage existing agencies and their relevant programs, calling for novel collaboration at various scales. Such integration highlighted the need to better understand the linkages between OA (drivers, stressors, and impacts), potential management interventions, and the link to other environmental, ecological, economic, and cultural policy priorities. “Policy frameworks, management strategies and leveraging regulations” explores the extent to which this has occurred.

Coast-to-coast collaboration and information sharing

In 2019, the OA Alliance hosted a multi-day conference in New York City, coinciding with the United Nation’s Climate Action Summit. During the conference, states in all stages of activity shared their experiences, challenges, and successes responding to OA, through formal action planning and other mechanisms. Since its launch, the OA Alliance has prioritized strengthening U.S. state and regional collaboration. The conference served as a *state-of-the-policy* workshop, akin to state-of-the science events previously used to convene scientific understanding of OA. Common themes included priority setting, capacity building, regional collaborations, and funding related to producing and implementing OA action plans.

Conference participants included 60 representatives across 14 states that had participated in key events and seminal policy development for OA as described in “U.S. State action on ocean acidification: the formative years” of this paper. The events and policy developments that informed the conference are chronologically listed in Table 1 Timeline of OA Action. Additionally, Table 1 reflects key events and seminal policy actions taken by U.S. states after the 2019 conference, which have also helped inform this paper.

Authors of this paper summarized proceedings of the conference in a document that was shared with participants (Summary of Proceedings 2019). Over the following year, authors continued to document emerging themes, discussions and examples shared across conference participants—during and after the conference—to assist governments, practitioners, agencies, and organizations in addressing OA. In sharing emerging examples of state-level efforts, we: 1) outline pathways to action commonly used by states, and 2) further illustrate approaches that increasingly link OA with climate policy and environmental management strategies.

“Pathways to action” describes pathways to action and distills state experience into a visual diagram followed by discussion. “Policy frameworks, management strategies

Table 1. Timeline of OA Action, summarizes key events and seminal policy actions taken by U.S. states during 2005-2021 (For previously compiled timelines, see Cooley et al. 2016; Cross et al. 2019; and Summary of Proceedings 2019).

Year	Event
2005-8	West coast oyster hatchery failures and die offs
2009	First Regional Coastal Acidification Network established (CAN)
2012	Washington Governor convenes State Blue Ribbon OA Panel; panel issues report (recognized as first OA Action Plan)
2013	Washington Legislature established Marine Resources Advisory Council and the Washington OA Center to focus on OA
2013	Maine Sea Grant, the Island Institute, the Sustainable Fisheries Partnership, and Global Ocean Health focus on OA at the Maine Fishermen's Forum
2013	Maine Legislature adopts resolution identifying acidification as a threat to its coastal economies and way of life
2013	West Coast Ocean Acidification and Hypoxia Science Panel formed
2014	Maryland state delegate sponsors bill to create OA task force
2014	Maryland scientists and resource managers convene a workshop on OA
2014	Maine Legislature establishes OA commission to prepare report
2014	Massachusetts scientists, natural resource managers, state legislators, and NGO representatives convene to discuss OA
2015	Maryland issues OA report and recommendations
2016	West Coast Ocean Acidification and Hypoxia Science Panel issues recommendations
2016	PCC forms the International Alliance to Combat Ocean Acidification (OA Alliance)
2016	Alaska stakeholders launch the Alaska Ocean Acidification Network coordinated by the Alaska Ocean Observing System
2016	Maine Ocean and Coastal Acidification (MOCA) partnership forms
2016	Miami's Rosenstiel School of Marine and Atmospheric Science in collaboration with Ocean Conservancy host OA conference[1]
2017	Washington State updates original Blue Ribbon Panel Recommendations as OA Action Plan
2017	New York releases Ocean Action Plan
2018	PCC partners with Federal Interagency Working Group on OA to create West Coast Inventory of OA assets and projects
2018	California forms OA and Hypoxia Science Task Force and releases OA Action Plan
2018	Oregon convenes OA and Hypoxia Coordinating Council
2018	New York convenes OA Task Force to provide further recommendations across state's ocean policy
2018	Hawai'i commits to OA Action Plan
2019	Oregon releases OA and Hypoxia Action Plan
2019	U.S. state multi-day conference on OA policy and management strategies
2020	Maine Climate Council releases recommendations including OA priorities
2021	Maryland releases OA Action Plan
2021	Massachusetts releases OA recommendations, including priorities for action plan and subsequent implementing legislation
2021	New Jersey commits to OA Action Plan

and leveraging regulations" describes emerging policy frameworks, management strategies and regulations currently being leveraged by states to understand and respond to OA.

Pathways to action

The 2019 workshop further elucidated the multiple pathways for initiating and sustaining a state-level response to OA. The Pathways to Action diagram (Figure 1), outlines two broad approaches including example steps and decisions that many states have taken. The Pathways to Action diagram describes and synthesizes choices related to enabling conditions for OA policy, vehicles for action, partnership opportunities, and implementation strategies for states or non-government entities. The process draws from the emerging history of OA governance examples described by conference participants and documented in Cross et al. (2019) and Cooley et al. (2016). The Pathways to Action diagram may inform future OA action planning though is not intended to be prescriptive; as unique political and cultural contexts require tailored strategies and consensus building. The section begins with A) getting started and presents the Pathways to Action diagram by discussing a number of guiding questions. The rest of this section explores core themes in more detail including B) government vs. grassroots leadership; C) building partnerships to help define objectives, assess vulnerabilities, and fill knowledge gaps; D) and sustaining momentum and funding.

Getting started

There are many decision points that may help a state government, Tribal government, or non-governmental stakeholders start action planning. The Pathways to Action diagram (Figure 1) provides questions, common actions, and planning pathways to guide and navigate this process.

> **Guiding questions (dark green):** Guiding questions outline the high-level scope and focus of an action planning effort. Answers to guiding questions help identify the degree of state leadership, scope of local or regional concerns, knowledge gaps, and partners that help shape a holistic and relevant narrative. A discussion of guiding questions is below.

> **Common actions (light green)**: Common actions are categories of actions that states will likely need to consider and undertake as part of a comprehensive strategy for addressing OA across existing policy and management frameworks.

> **Planning pathways (blue):** Planning pathways offer steps for states undertaking a government-led, or "top-down," process (*left side*) or for non-government entities undertaking a grassroots, or "bottom-up," process (*right side*). The relevance of each planning pathway depends on the feasibility and effectiveness of action through a government-directed process (i.e., Executive Order, legislation, formation of a task force, and/or formal commitment) or in the absence of state government engagement. In both pathways, partners convene groups, develop plans, implement, and adaptively manage. Either pathway benefits from diversity among decision-makers, stakeholders, and scientific community leaders.

Discussion of guiding questions across Figure 1 pathways to action diagram

Evaluating government vs. grassroots leadership: Is there explicit state government support for OA Action?

> To begin, it is important to evaluate the potential for government leadership and consider other supportive leaders. Some states have acted through Executive Order, legislation, created an OA task force/commission or have used existing climate change policy directives or voluntary commitments such as joining or signing on to an initiative. In other cases, stakeholder groups or volunteer partnerships, such as the Maine Ocean and Coastal Acidification Partnership (MOCA, introduced inTable 1 and discussed further below) have initiated collaboration to address OA without government mandates.

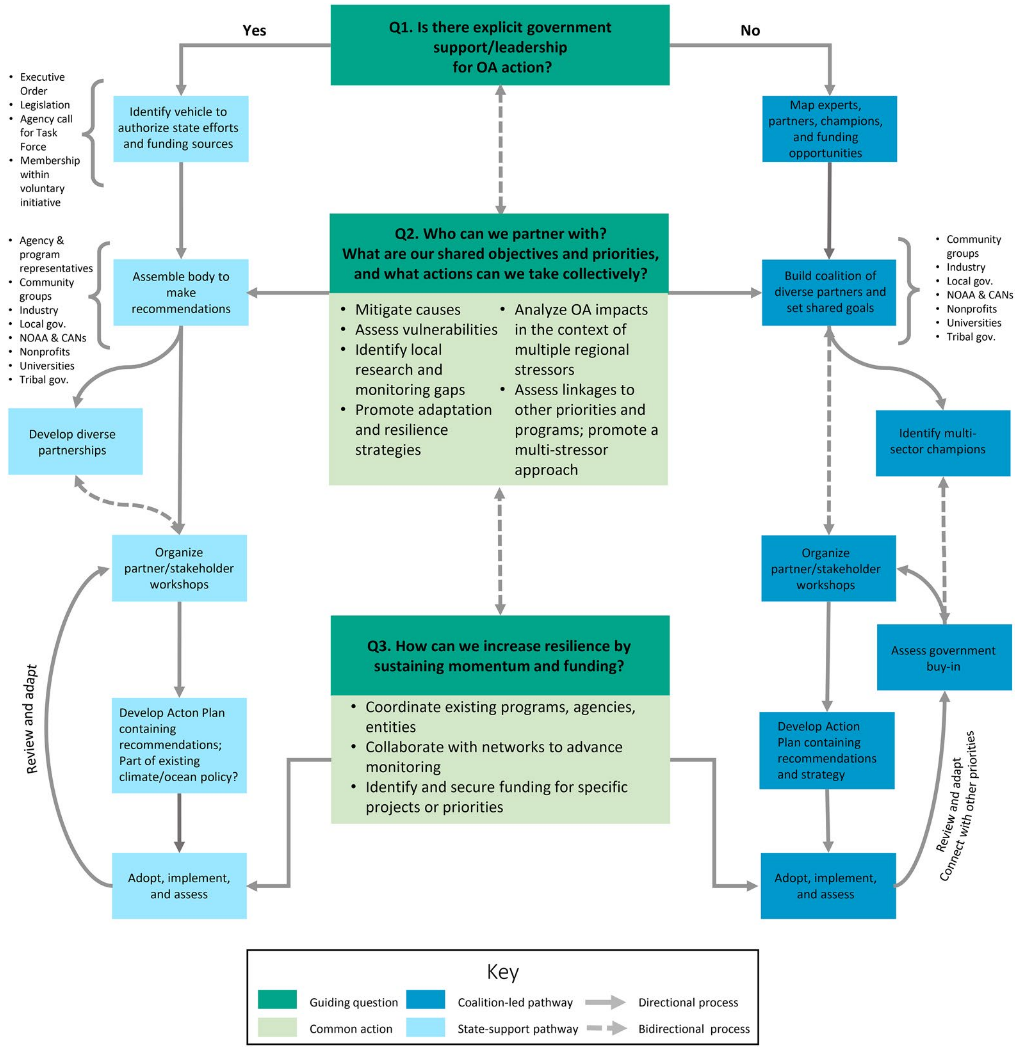

Figure 1. Pathways to Action diagram describes and synthesizes choices related to enabling conditions for OA policy, vehicles for action, partnership opportunities, and implementation strategies for states or non-government entities.

With strong government leadership, processes may be more streamlined, but states will need to build support among stakeholders and partners in both cases. The advantage of beginning with a government mandated framework, is that it allows for a more thorough examination of applicable agency programs, regulations, and collective responsibilities among actors that align with an action plan. Without strong government support, planning processes will need to place greater emphasis on identifying multi-sector champions, opportunities for collaboration, and inroads to foster government buy-in.

Who can we partner with? What are our shared objectives and priories?

A number of scoping questions help identify and cultivate partners. Do local decision-makers and stakeholders understand OA processes and potential impacts? How are coastal economies, communities and resources evaluated or prioritized in your state or region? Is there an economic or cultural dependance on key species impacted by OA? Are there any agencies, department programs, universities in your region that are currently working to better understand and characterize local impacts of climate or ocean change on marine species?

Once participants determine the framework or vehicle for action, they can begin to engage relevant government and non-government partners to help define scope and objectives. Objectives could include maintaining livelihoods; ensuring ecosystem productivity, health, and services; preserving human health and safety; and/or combating climate change. Defining objectives early, and refining objectives when necessary, helps focus a collective response.

Once objectives are defined, participants can explore applicable mitigation options, knowledge and information gaps, and adaptation strategies.

How can we increase coastal resilience by sustaining momentum and funding?

Once objectives and priorities for action are identified, guiding question number three helps determine how to implement and fund activities over time. It is possible that some, even most actions cannot be accomplished with state government capacity alone—whether due to limited expertise, equipment, or funding or due to limited interest from political advisors or constituents. Sustained partnerships with other governments, monitoring networks, university or federal researchers, industry and community groups broaden government capacity.

Government vs. grass roots leadership

The formative years of OA action illustrate that state governments and their partners can initiate a response to OA in several ways, often characterized as top down or bottom up. Among states, the role of elected officials, governor's offices and agency leads represented on each task force or working group varied; whereby state government's predominant political endorsement or opposition characterized initial actions for OA as either "top down" or "bottom up." While the distinction is simplistic, it helps clarify whether a state has the support from top level government officials. This will help inform whether recommendations can immediately emphasize a state management response, or whether efforts should emphasize building capacity to help achieve political support for future recommendations. In reality, top-down political support and grass roots, bottom-up processes occur iteratively, and mutually reinforce commitment in responding to OA. As described below, even where government leadership emerges early, it is often catalyzed by grassroots engagement. Similarly, grassroots effort can sustain OA action during periods when government is inactive or has limited capacity.

In Washington, shellfish growers first called for action after working with scientists who determined that OA was the underlying cause of larval mortality in hatcheries (Barton et al. 2012). The governor of Washington responded by issuing an Executive Order forming the Blue-Ribbon Panel (Washington State Blue Ribbon Panel on Ocean Acidification 2012). In California, the state legislature authorized the Ocean Protection Council to convene a task force in 2018 to address OA and hypoxia using the best available science to create policies to address OA (Phillips et al. 2018). The Oregon legislature created the Oregon Coordinating Council on Ocean Acidification and Hypoxia (OAH Council) in 2017, and the council finalized a 5-year Action Plan in 2019 (Oregon Governor's Natural Resource Office 2019).

The State of Hawai'i joined the OA Alliance in 2018 and motivated by the state's voluntary commitment as a member, has begun the processes of outlining an OA action plan. To help accomplish this, the state allocated staff within the Division of Aquatic Resources and University of Hawai'i Sea Grant to convene multi-agency, researcher, and stakeholder meetings with the goal of producing recommendations to the state.

In Maine scientist, NGOs, and fisheries advocates spurred collaboration leading the Maine Legislature to establish an OA Study Commission in 2014 which reported back to the Legislature the following year. The report recommended an on-going OA commission and OA mitigation and adaptation strategies (Maine State Legislature Maine Office of Policy and Legal Analysis, Bentley, and Schneider 2015). When the legislature declined to authorize an ongoing commission, a group of public and private interests formed the Maine Ocean and Coastal Acidification Partnership (MOCA) to advance the Study Commission's recommendations. Consequently, scientists, fishers, aquaculturists, Maine citizens, and even engaged legislators and agency representatives continued collaborating and information sharing informally. Since 2016, MOCA has helped coordinate and amplify activities studying and responding to Maine's OA impacts. In 2019, after a change in governorship and inaugural efforts of Maine's Climate Council, Climate Council members helped to incorporate MOCA's recommendations and guidance from the Northeast CAN into the State's Climate Action Plan.

Similarly, in the absence of express state level leadership in Alaska, diverse stakeholders convened around OA in 2014 leading to the Alaska Ocean Acidification Network (part of the federal CAN program) in 2016. The Network now includes participants from federal government, Tribal governments, local academic institutions, commercial and recreational fishing communities and educators. The Network is advancing the science and understanding of OA impacts locally and state-wide, emphasizing biological impacts. It has also successfully produced targeted outreach and education materials for diverse audiences.

In 2017, New York released a ten-year Ocean Action Plan, as directed by the state legislature. The plan set out an integrated, adaptive approach to manage, restore and conserve ocean resources (NY Ocean Action Plan 2017–2027). The plan addressed the need to monitor OA and its potential impacts on shellfish and crustaceans. In 2018, New York's State Legislature established an OA Task Force (OATF) to facilitate research, public education, and information-sharing regarding acidification and its environmental economic and social impacts on New York State (New York State Senate, Assembly Bill A10264 2015–2016).

The state of Massachusetts convened an Ocean Acidification Commission which released a report in 2021 characterizing the extent of ocean and coastal acidification in Massachusetts waters; the factors contributing to it; how to mitigate it; and recommendations to the legislature for supporting future research and public outreach on the issue (Massachusetts Special Legislative Commission on Ocean Acidification Recommendations 2021).

These examples illustrate that state governmental response depends on each state's familiarity with OA, political context, and other priorities. In practice, both government and grassroots leadership are important for progress. Governmental leadership can institutionalize OA response through legislation or executive powers in a way that grass roots efforts alone cannot. However, even after governments institutionalize a response to OA, grassroots collaboration is valuable, if not essential, to ensure continued focus and participation in research and implementation.

Building partnerships to help define objectives, assess vulnerabilities and fill knowledge gaps

Informal and formal partnerships are a key step to catalyze state action. Identifying and filling local and regional knowledge gaps is an initial priority for many jurisdictions. As research capacity builds and local priorities emerge from collaborative processes, states need to assess vulnerabilities and place OA within larger policy and management context.

Coordinating as a region can also build capacity for action. The CANs continue to specialize in compiling, advancing, and disseminating scientific assessments and convene diverse groups of interdisciplinary researchers, Tribal, federal, and state agency representatives, resource managers, and industry partners to support regional coordination. State governments look to regional CANs as critical partners in defining and advancing state-led efforts, as well as leverage existing knowledge (Cross et al. 2019). Ongoing engagement with regional networks can institutionalize monitoring programs and generate long-term datasets needed to understand and better anticipate ocean change. A coordinated approach with in-region academic institutions can help a state prioritize gaps and secure funding from a variety of sources. Regional activities can expedite processes or avoid unnecessary duplication.

Just as civic or industry stakeholders can be instrumental in advocating for support from outside of government, equally important is identifying advocates within government. Many states have underscored the value of identifying and working closely with "legislative champions" who move OA policy forward, advocate for funding, and call attention to the issue. Nonprofit organizations and networks such as the National Caucus of Environmental Legislators, the Ocean Conservancy, and The Ocean Foundation have recognized and invested in the important work of educating and empowering legislative champions in recent years. State representatives have joined OA task forces or "coastal causes" that examine the linkages between climate and ocean change at a state level (National Caucus of Environmental Legislators, Ocean Acidification Fact Sheet).

Sustaining momentum and funding

Over the last decade, five states have produced first generation action plans and now face the challenge of implementing them with dedicated funding. Given the dynamic nature of OA and other challenges facing coastal environments, action plans should be considered living documents that are supporting and informing adaptive management.

Outlining a process for updating key reports and implementation strategies is critical for maintaining momentum, fostering accountability, and ensuring a greater case for the need to increase capacity and funding to support an action plan over time. States may also consider nesting funding within broader climate policy priorities or marine and coastal management frameworks once an action plan has been created.

As noted in the Timeline of OA Action (Table 1), Washington developed its original action plan in 2012. Shortly after, the state created the Marine Resources Advisory Council (MRAC) to sustain a coordinated focus on OA by advising the Washington Ocean Acidification Center to advance scientific understanding, seeking public and private funding resources for plan implementation, and assisting in public education. In 2017, MRAC updated the original 2012 report with an addendum describing progress to date and new focus areas (Washington Marine Resources Advisory Council 2017). To date, Washington State has invested nearly $10 million—mostly in actionable research. This investment has, in turn, spurred $14.5 million in federal and private funding.

California is implementing its 2018 action plan, including refining monitoring strategies and addressing research gaps. The California Ocean Protection Council (OPC) recently released its "Strategic Plan to Protect California's Coast and Ocean 2020–2025," which integrates the OA action plan through specific targets to a) better understand the relationship between nutrient inputs and acidification hot spots to support water quality objectives, b) reduce nutrient loading through wastewater reuse and recycling, c) develop an OA and hypoxia (OAH) monitoring system optimized to deliver decision-relevant information, and d) advance the science on OAH vulnerability and identify risks to California's biological resources, communities, and economies.

Additionally, the California OAH Science Task Force (Task Force), OPC's science advisor, has identified outstanding gaps in monitoring and proposed research (California Protection Council: Update from Ocean Acidification and Hypoxia Science Task Force and Item 4A 2020.) The recommendations support state managers ability to describe the spatial extent of biological effects from acidification, including where OA and hypoxia have the most consequential effects, where the most rapid changes are being observed and how quickly. OPC intends to invest up to $3.5 million in 2021 to support these recommendations through both a discretionary process focused on standardizing biologically sensitive OA measurements across existing regional monitoring efforts and developing a competitive call for additional proposals based on the Task Force's report (California Ocean Protection Council Executive Director's Report, December 15, 2020–February 16, 2021).

Policy frameworks, management strategies and leveraging regulations

As discussed in "U.S. State action on ocean acidification: the formative years," OA occurs in an environment subjected to multiple stresses from physical, chemical, and biological factors. While this multi-stressor context creates management challenges, it also provides states the opportunity to reduce exacerbating causes, remediate impacts and build resilience to OA, while continuing work on other established environmental challenges. Coastal areas experiencing warming, hypoxia, eutrophication and/or seasonal harmful algal blooms may already be working to address the acute drivers and stressors which exacerbate OA. Taking a multi-stressor approach to monitoring and management, which emphasizes the co-benefits of combining actions to remediate cumulative impacts, can be effective.

As further described below, many states are moving forward with innovative policies or initiatives that incorporate OA actions into existing management strategies. This move toward integrated information and management has highlighted the need to better understand the linkages between OA drivers, stressors, and impacts. In this section we explore innovative examples from states working to integrate OA across existing programs and priorities.

Enhancing monitoring, modeling and forecasting of future conditions to inform management

Increasing scientific study of OA's harmful impacts has prompted a fundamental question for resource managers across localities; "*what are the OA conditions or trends in my region?*" Answering this question requires observations at the local level, and states on both coasts have begun to assess their existing monitoring capacity for OA and the observational and research gaps which are critical to address (e.g., Weisberg et al. 2020; Oregon Governor's Natural Resource Office (2019); New Hampshire Coastal Marine Natural Resources and Environment Commission 2017). State led studies are emerging. A recent study in Puget Sound, led by Washington State Department of Ecology sought to: a) produce a marine CO_2 system dataset capable of distinguishing between long-term anthropogenic changes and natural variability, b) characterize how rivers and freshwater drive OA conditions in the region, and c) understand the relative influence of cumulative anthropogenic forcing on regional OA conditions (see Gonski et al. 2021, in this issue). Such efforts can provide a blueprint for future state-wide approaches and scientific efforts elsewhere.

States have also increased the frequency of existing monitoring activities measuring parameters related to OA. For example, seasonal carbonate measurements are now collected in the New York Bight, when, before 2018, such observations occurred only once every several years. The expansion of this program is positioned to better discern OA trends and coastal variability, and new research cruises in the New York Bight have already identified distinctive CO_2 dynamics pertinent to management interventions (Summary of Proceedings 2019).

States have called for OA science to better align with the informational needs of resource managers. For example, California's Ocean Protection Council charged its Ocean Acidification and Hypoxia Science Task Force (Task Force) with enhancing California's OAH monitoring network specifically to support decision-making (Weisberg et al. 2020). The Task Force recommended:

1. Better connecting chemical and biological monitoring to improve managers' understanding of how marine life is affected and to help managers develop OAH water quality criteria.
2. Adopting OAH models as decision-support tools and to expedite the validation of those models with additional monitoring data collection.
3. Strengthening the continuity of OAH monitoring programs across California's coastal environments by investing to develop spatially representative data sets statewide.

Oregon's action plan similarly recommends pairing chemical and biological data by co-locating OA monitoring with ongoing biological sampling in Marine Reserves. Here, concern for OA has additionally motivated the Department of Fish and Wildlife to enhance observations of shellfish and submerged aquatic vegetation (Oregon Governor's Natural Resource Office 2019).

A further example of increasing attentiveness to integrate and expand environmental data streams is seen through Maine's Department of Environmental Protection, who in 2020 proposed additional staff to measure OA indicators simultaneously with targeted water quality sampling and state-wide surveys of benthic infaunal communities and eelgrass cover. Concurrently, the Maine Climate Council is reviewing opportunities to expand private and nonprofit monitoring activities as a component of a state-coordinated network (Maine Climate Council 2020).

Scientific models of OA are a component of understanding anthropogenic impacts to marine environments. Yet, concern for OA is also motivating a need to improve baseline oceanographic forecasting. Washington's OA action plan, for example, prescribes improved forecasting of upwelling events. While upwelling is known to be a natural, wind driven phenomenon (Phillips et al. 2018), it is also one which introduces carbon rich deep-ocean water into coastal estuaries, thereby worsening conditions of OA (Washington Marine Resources Advisory Council (2017). Forecasting tools have been made available to—and in some cases were produced with—shellfish growers and hatcheries to help industry plan for better or worse conditions.

In addition to efforts focusing on state waters, states are collecting regional data and information about changing ocean chemistry. Across the west coast, states have worked with the Federal Interagency Working Group on Ocean Acidification (IWG-OA) to inventory all the OA and hypoxia monitoring infrastructure along the North American Pacific Coast. Similar inventories have occurred in the Northeast CAN and are being developed through other Coastal Acidification Networks. The goal of these regional inventories is to create a highly functioning coast-wide or region-wide monitoring network that answers management questions about OA, hypoxia and other concerns and enables effective mitigation, adaptation, and resilience building (Summary of Proceedings 2019).

Characterizing and reducing nutrients that exacerbate OA

As discussed earlier, excess nutrients from a variety of sources can contribute to OA by increasing primary production, which subsequently increases CO_2 concentrations during respiration and decay of excess organic matter (e.g., Wallace et al. 2014). Thus, local actions to reduce nutrient pollution in areas at risk of eutrophication increase the resilience of marine species and ecosystems to OA while supporting multiple water-quality benefits. By linking OA with management plans that seek to address nutrient runoff, states can increase knowledge about OA impacts and assess targeted management interventions. While eutrophication is an extensively monitored and well understood primary stressor to coastal ecosystems, potentially leading to "dead zones" that are significantly oxygen depleted, expanding such monitoring to include OA specifically is a growing strategy for states looking to better understand the need for specific interventions in coastal environments where economically or culturally important farmed or fished species are present (Environmental Protection Agency (EPA). (n.d.).

For example, the Washington State Department of Ecology and the Pacific Northwest National Laboratory (PNNL) are modeling how nutrients, particularly from wastewater treatment facilities, may exacerbate OA and low dissolved oxygen in Puget Sound. Early modeling shows human sources of nutrient pollution are responsible for a ~15–20% increase in acidity in some areas of Puget Sound. Continued analysis using the Salish Sea Model will help inform state managers about nutrient reduction strategies from point and nonpoint sources (Washington Department of Ecology, 2019-2020).

At the local and municipal level, where municipal governments have specific requirements under the federal Clean Water Act, governments can focus on the role of stormwater management in building resilience to OA. Seattle's 2030 District, a nonprofit, is working to promote effective management of non-point source pollutions, including stormwater run-off with the goal of limiting nutrient pollution to local water channels or bodies. The Green Stormwater Initiative promotes rooftop gardens, on-site vegetation, bio-swales, rainwater collection, permeable pavement, and other stormwater mitigation best practices as part of their overall climate resilience strategy relevant to reducing OA.

Groups such as California Coastkeeper Alliance are engaging city and county leaders to prevent wastewater discharges from causing acidification and hypoxia hot-spots and preventing agricultural nutrient inputs from causing harmful algal blooms which impair water quality (KPBS, "California Coastkeeper Alliance Releases Climate Change Plan For Coastal Areas" 2019). Watershed coalitions nationwide advocate for similar practices and are beginning to frame nutrient and pollution reduction within a context of OA and other climate related changing ocean conditions (see Gassett et al. 2021 in this issue). Such strategies, including vegetation-based remediation systems and riparian buffers for use in upland habitats and in vulnerable areas, reduce the flow of nutrients and sediments from rivers and coastal catchments into bays, estuaries, and onto coral reefs.

States are also leveraging the National Estuary Program (NEP), administered by U.S. Environmental Protection Agency (EPA) as one of the ten actions identified by Kelly and Caldwell (2016) that states could take under existing programs. In 2018, EPA published guidelines for monitoring acidification in the eastern United States (Pimenta and Grear 2018) and is currently collaborating with nine National Estuary Programs to document OA in estuaries and encourage programs to work collaboratively with partners to reduce nutrient pollution that exacerbates OA.

Examples of NEP projects include the Casco Bay Estuary Partnership, which incorporates partnerships with shellfish growers to discuss findings produced in their monitoring. Additionally, an Urban Watersheds project is comparing OA impacts in both urban and rural watersheds. (Environmental Protection Agency (EPA). (n.d.); NEP Coastal Ocean Acidification Research Critical to Economic Development 2017).

Restoring and conserving aquatic vegetation

Restoration activities and habitat protection have been introduced among approaches that build local resilience to OA, as aquatic vegetation, including kelp, sea grasses and salt marshes sequester carbon. Emergent studies show some ability of ecosystems to locally ameliorate conditions of OA.

For example, the California Ocean Science Trust on behalf of California's Ocean Protection Council (OPC), assessed the potential co-benefits of restoring and conserving seagrass beds and kelp as an OA management tool (Nielsen et al. 2018). They found that in some locations seagrass restoration appears to have locally increased ocean pH. The Chesapeake Biological Laboratory is studying how the comeback of underwater grasses may be offsetting acidification while also removing nutrient pollution and providing habitat for juvenile crabs and rockfish (Su et al. 2020).

In Maine, ongoing research led by the Bigelow Laboratory for Ocean Sciences, has explored kelp farming as a strategy to remediate OA and improve shellfish cultivation ("New Research to Explore Seaweed for Ocean, Economic Health" 2021). Here, preliminary results shared at conferences demonstrate how growing kelp among blue mussels can result in stronger shells, increased product value and reduce the waste of mussels which break during harvest. These initial findings corroborate that kelp raises pH and oxygen concentration and absorbs excess nutrients that could otherwise contribute to eutrophication, thus improving growing conditions for shellfish (Price and Arnold 2019).

Further research by Nielson et al. (2018) suggests that kelp forest growth may locally ameliorate OA while providing critical habitat, food, and potential opportunities of biofuel, agricultural amendments, and water pollution treatment. Additionally, aquatic vegetation including kelp, seagrasses, and salt marshes provide a range of valuable ecosystem services including stabilizing the seabed, attenuating wave energy, water quality benefits, carbon sequestration, and habitat creation for fish, crabs, and other species. States with aquatic vegetation restoration and conservation programs are positioned to incorporate OA responses alongside myriad co-benefits of efforts to support the health of benthic infauna communities.

Regulations to reduce CO_2 emissions

To varying degrees, governments are both incorporating climate targets into OA action plans and including OA—along with other coastal impacts—within climate policies and resilience building strategies. Given the direct linkage between reducing carbon emissions and directly reducing OA, it remains consequential that regulatory regimes to address CO_2 emissions account for OA as both: 1) further rationale to set aggressive targets for reducing carbon dioxide emissions; and (2) a necessary component of local climate adaptation and resilience building strategies.

Washington, Oregon, and California's OA action plans include directions to reduce CO_2 emissions, work with other entities engaged in such efforts, call for more examination of local climate change impacts, or all of these approaches (Washington State Blue Ribbon Panel on Ocean Acidification 2012; Oregon Governor's Natural Resource Office 2019; Phillips et al. 2018). Maryland's OA action plan explicitly identifies the state's Green House Gas Reduction Act Plan as one of three foundational policy frameworks on which the OA action plan is based ("State-Led OA Action Planning in the Mid-Atlantic" 2021; Maryland Ocean Acidification Plan 2020). The 2020 Maine Won't Wait Climate Action Plan has similarly integrated OA action with broader climate preparedness needs ("Maine Won't Wait: A Four-Year Plan for Climate Action" 2020). As states set targets for green-house gas and CO_2 emissions reductions, policy frameworks and approaches to achieving targets have proliferated. Bromley-Trujillo and Homan thoroughly review state climate change policy making as of 2020, including mitigation and adaptation, and focus particularly on state legislation (Bromley-Trujillo and Holman 2020). Within this broad discussion, they identify two categories of greenhouse gas regulation.

First, several states have established green-house gas reduction targets (Bromley-Trujillo and Holman 2020). Second, several states directly regulate utilities requiring them to reach specified percentages of renewable energy (so-called Renewable Portfolio Standards) and to provide for net metering, a tracking protocol that allows energy consumers who use on-site renewable sources, such as solar, to build credit for the energy they supply to the grid (Bromley-Trujillo and Holman 2020). On another front, the transportation sector is the largest U.S. greenhouse gas source (Cremen 2019). The federal Clean Air Act allows California to adopt tail pipe emission standards for mobile sources (e.g., trucks and cars) that are stricter than the national standard. The Act allows other states to adopt these stricter standards; as of 2019 13 states, including many coastal states have done so (Cremen 2019). Other actions continue to unfold, for example, Maine recently passed legislation to divest from fossil fuels.

Increasingly states are moving forward with aggressive greenhouse gas reduction targets, regulation, adaptation priorities and financing schemes. It will be critical that policy makers, managers and agencies charged with design and implementation understand the interrelated causes and impacts of OA and climate-related changing ocean conditions.

Assessing the Clean Water Act applicability

The federal Clean Water Act (CWA) empowers states to protect water quality in several ways. Specifically, Section 303(d) requires states provide a list to the EPA every two years listing water bodies or segments that are not meeting water quality standards. Once listed, states are required to identify the cause or source of the impairment, and if known, are required to intervene and reduce sources of impairment. States add water bodies to the Section 303(d) list based on new data, application of new or revised water quality standards, or information showing water quality has declined. The narrative impairment clause of CWA (Section 303(d) subsection c) requires waters and sediments to be substantially free from pollutants that "interfere with propagation or habitats of shellfish, finfish, and wildlife."

If listing a water body as impaired by OA or hypoxia, state managers could establish limits to pollutants that are shown to directly contribute to OA or hypoxia. However, direct causal links that are needed to activate narrative criteria related to OA or hypoxia are challenging, especially as ex-situ and in-situ research and observation is still emerging and difficult to isolate within dynamic marine environments. Additionally, establishing "normal" ranges for OA—a deviation from which would be cause concern—is complicated as estuarine and coastal pH vary dynamically across daily, seasonal and decadal cycles driven by both natural and anthropogenic forces (e.g., Melzner et al. 2013, Waldbusser and Salisbury 2014 and references therein).

That said, in the 2018/2020 Integrated Report required from states to the EPA under the CWA, the State of Oregon determined that acidification is a potential concern in Oregon's coastal waters, but that the data are currently insufficient to identify the water as impaired. The state's determination of potential concern included reference of biocriteria for pteropods and also hypoxia under the listing of oxygen impairment in marine waters. (Oregon Department of Environmental Quality 2020). This is the first Section 303(d) recognition by a state for potential failure to meet water quality criteria due to OA and hypoxia.

In California, the Water Quality Control Plan for Ocean Waters of California (Ocean Plan) adopted in accordance with CWA Section 303 (c)(1) and the California Water Code governs the protection of the state's coastal waters by controlling the discharge of waste into the ocean, including stormwater runoff, municipally treated sewage outflow and industrial flows regulated by regional and State Board permits.

California State Water Resources Control Board (SWRCB) released a report in 2019 prioritizing several topics for future projects and rule-making actions that could amend or improve the State's Water Quality priorities, including updates to the Ocean Plan. The report listed "ocean acidification, hypoxia and climate change impacts" in the top 5 priority issues that could warrant either future amendments to the Ocean Plan or continued work by the State Board to evaluate how to best develop water quality objectives and improve the resilience of the coastal environment. A coupled physical-biogeochemical model is helping to inform when and where local nutrient pollution from wastewater treatment plant discharges and agricultural runoff may contribute to coastal acidification and hypoxia.

Highlighting the authority of CWA in advancing measures to protect water quality is an asset to states who are pioneering resilience to OA. For example, Maryland's use of the CWA illustrates the strategic use of existing programs, taking a multi-stressor approach to respond to OA. Specifically, the state's 2020 OA action plan identifies its Chesapeake Bay Watershed Plan as a key element of the action plan's policy framework ("State-Led OA Action Planning in the Mid-Atlantic" 2021). Maryland produced the Watershed Plan as part of its management of Total Daily Loads of nutrients have caused Chesapeake Bay to be impaired with regards to several nutrient loading pollutants (Chesapeake Bay Watershed Plan).

Conclusion

This paper has synthesized conversations among states and partners working to address OA at local and regional scales. Providing specific examples of pathways to action, policy options and management approaches we aim to help government and non-government partners build and maintain momentum for OA action. There is no "one size fits all" solution to addressing OA, both because its origins and impacts are multifaceted and because there are many actions that can improve information and understanding of the phenomenon, mitigate causes, inform adaptation response, and build resilience. State actions to date illustrate how understanding and adopting OA as an issue of concern can motivate and provide direction to multiple management agencies and partners to align and begin to address this novel challenge (see Keil et al. 2021 in this issue).

Information and traction for addressing climate-related ocean change through policy is increasing. The last decade has witnessed a growing number of state OA task forces, panels, and commissions that have been working to translate the best available regional science into government-led priorities, policy actions and sustained investments. As frameworks for action develop into the future, it is essential that there is a high-level of coordination between ocean, coastal and climate experts, scientists, policy implementers and other impacted communities and stakeholders.

Concluding takeaways and recommendations:

1. States are integrating OA responses and responsibilities among applicable departments, actors, and scales. To do this effectively requires a better understanding of OA drivers and impacts which will help distinguish the roles of various departments and identify shared priorities. States and in-region partners are collaborating to identify and prioritize gaps in knowledge that will inform local intervention strategies and provide managers a more complete picture of local drivers, conditions, trends, and vulnerabilities.
2. Managing for OA in a multi-stressor landscape may require action despite some uncertainty. Considering the co-benefits of OA actions to other coastal management priorities may help states move forward in the context of uncertainty. State-level resource managers increasingly recognize the value of taking various no-regrets strategies to more ambitiously address ocean change. Taking a multi-stressor approach to OA governance can provide "on-ramps" for engaging new partners (e.g., cities, counties, ports, NGOs and other community led initiatives) reinforcing commitments to social-ecological sustainability.
3. While action planning may be easier with supportive governments and political champions, priorities that are brought forward and implemented by non-government local and regional actors can drive momentum until a window is open for deeper state government engagement and leadership. Diverse partnerships build capacity for sustained implementation with or without strong government engagement.
4. States are reflecting OA and ocean change within climate policies both as: (1) further rationale to set aggressive targets for reducing carbon dioxide emissions; and (2) a necessary component of local climate adaptation and resilience building strategies.

State efforts on OA, in addition to emerging studies and collaborations across the field, have identified many areas for improvement, priorities for future work or continued research and analysis.

1. The need for dedicated funding has consistently emerged as an essential issue. More systematic analysis of funding sources for OA efforts—including those related to greenhouse gas mitigation programs or adaptation activities—can broaden the scope of ongoing activities.
2. In the absence of funding for additional monitoring, targeted research to establish empirical relationships between carbonate chemistry parameters and other more commonly monitored oceanographic parameters (i.e., oxygen, salinity, temperature) can help a region, or set of decision makers, estimate the landscape of OA stressors (e.g., Rheuban et al. 2021). Alin et al. (2012) provides a set of empirical relationships for southern California and the U.S. West Coast. Additionally, there are new machine learning methods to estimate carbonate system variables, such as described in Fourrier et al. (2020), which could help

regions that have not yet invested in widespread OA monitoring to more rapidly build capacity to understand OA stress in their region.

3. The global Covid-19 Pandemic, alongside public protests and demands for racial justice across the U.S., have brought increased attention to environmental justice and equity across research and decision-making settings. Many states have formed environmental justice task forces, or similar bodies, to produce recommendations to the state legislature. Scholarship and analysis on this topic will be an important component of OA response given the underlying economic, community, and cultural risks posed by climate and ocean change. This could include potential impacts to Tribal Treaty Rights relative to ocean and marine resources.
4. Scientific understanding of OA processes is maturing, and both researchers and decision-makers must remain nimble to incorporating new insights. For example, a 2021 study explored the release of CO_2 from organic ocean sediments because of fish trawling (Sala et al. 2021). OA action plans and management approaches can be designed to evolve iteratively with contemporary landscapes of science and policy.
5. As states continue to link and integrate OA with existing and future climate policy and environmental management, the relevant actors, agencies, organizations and stakeholders involved will likewise expand. New partners will benefit from a deeper understanding of the connectivity among OA drivers, stressors, and impacts as they relate to potential societal and policy interventions. A broadening constituency of those who prioritize OA will also bring diverse perspectives which are new to the field and should be incorporated into environmental, economic, and cultural considerations.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Note

1. **Leaders: Ocean Acidification a Growing Threat to Florida** JUNE 17, 2016 https://oceanconservancy.org/news/leaders-ocean-acidification-growing-threat-florida/ (last visited May 14, 2021)

Acknowledgements

The authors would like to thank J. Hennessey, S. Cooley, J. Kimball, M. Liebman, H. Galavotti, H. Carter, and E. Turner for their input and feedback on the paper. Special thanks also to the many participants and contributors to the 2019 *state-of -the-policy* conference, your leadership charts a path for others.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Alin, S. R., R. A. Feely, A. G. Dickson, J. M. Hernández-Ayón, L. W. Juranek, M. D. Ohman, and R. Goericke. 2012. Robust empirical relationships for estimating the carbonate system in the southern California Current System and application to CalCOFI hydrographic cruise data (2005–2011). *Journal of Geophysical Research: Oceans* 117 (C5):1–16. doi: 10.1029/2011JC007511.

Barton, A., B. Hales, G. G. Waldbusser, C. Langdon, and R. A. Feely. 2012. The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects. *Limnology and Oceanography* 57 (3):698–710. doi: 10.4319/lo.2012.57.3.0698.

Barton, A., G. Waldbusser, R. Feely, S. Weisberg, J. Newton, B. Hales, S. Cudd, B. Eudeline, C. Langdon, I. Jefferds, et al. 2015. Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response. *Oceanography* 25 (2):146–59. doi: 10.5670/oceanog.2015.38.

Bromley-Trujillo, R., and M. Holman. 2020. Climate change policymaking in the states: A view at 2020. *Publius: The Journal of Federalism* 50 (3):446–72. doi: 10.1093/publius/pjaa008.

California Ocean Protection Council Executive Director's Report, December 15, 2020–February, 16 2021. https://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20210216/ED-Report_February_16_2021_FINAL.pdf

California Protection Council: Update from Ocean Acidification and Hypoxia Science Task Force, Item 4A. 2020, June. https://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20200619/Item4a_OAH_Task_Force_Memo_FINAL.pdf

Chan, F., A. B. Boehm, J. A. Barth, E. A. Chornesky, A. G. Dickson, R. A. Feely, B. Hales, T. M. Hill, G. Hofmann, D. Ianson, et al. 2016, April. *The West Coast Ocean Acidification and Hypoxia Science Panel: Major findings, recommendations, and actions*. Oakland, CA: California Ocean Science Trust.

Chesapeake Bay Watershed Implementation Plans. https://www.epa.gov/chesapeake-bay-tmdl/chesapeake-bay-watershed-implementation-plans-wips

Cooley, S. R., C. R. Ono, S. Melcer, and J. Roberson. 2016. Community-level actions that can address ocean acidification. *Frontiers in Marine Science* 2:128. doi: 10.3389/fmars.2015.00128.

Cremen, A. 2019. California emissions standards: What they are, when they started and why they may end. abc10.com, September 18. https://www.abc10.com/article/news/local/california/whats-californias-emissions-standards-trump-administration/103-96808a92-d6bb-43f3-92a7-fb908039a378.

Cross, J. N., J. A. Turner, S. R. Cooley, J. A. Newton, K. Azetsu-Scott, R. C. Chambers, D. Dugan, K. Goldsmith, H. Gurney-Smith, A. R. Harper, E. B. Jewett, D. Joy, T. King, T. Klinger, M. Kurz, J. Morrison, J. Motyka, E.H. Ombres, G. Saba, E.L. Silva, E. Smits, J. Vreeland-Dawson and L. Wickes. 2019. Building the knowledge-to-action pipeline in North America: Connecting ocean acidification research and actionable decision support. *Frontiers in Marine Science* 6: 356. doi: 10.3389/fmars.2019.00356.

Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas. 2009. Ocean Acidification: The other CO_2 problem. *Annual Review of Marine Science* 1 (1):169–92. doi: 10.1146/annurev.marine.010908.163834.

Duarte, C. M., I. E. Hendriks, T. S. Moore, Y. S. Olsen, A. Steckbauer, L. Ramajo, J. Carstensen, J. A. Trotter, and M. McCulloch. 2013. Is ocean acidification an open-ocean syndrome? Understanding anthropogenic impacts on seawater pH. *Estuaries and Coasts* 36 (2):221–36. doi: 10.1007/s12237-013-9594-3.

Environmental Protection Agency (EPA). (n.d.). EPA research supports National Estuary Program. https://www.epa.gov/eco-research/epa-research-supports-national-estuary-program

Feely, R. A., C. L. Sabine, J. M. Hernandez-Ayon, D. Ianson, and B. Hales. 2008. Evidence for upwelling of corrosive "acidified" water onto the continental shelf. *Science* 320 (5882):1490–2. doi: 10.1126/science.1155676.

Fourrier, M., L. Coppola, H. Claustre, F. D'Ortenzio, R. Sauzède, and J. Gattuso. 2020. Regional neural network approach to estimate water-column nutrient concentrations and carbonate system variables in the Mediterranean Sea: CANYON-MED. *Frontiers in Marine Science* 7:1–20. doi: 10.3389/fmars.2020.00620.

Hales, B., Chan, F. Boehm, A. B. Barth, J. A. Chornesky, E. A. Dickson, A. G. Feely, R. A., T. M. Hill, G. Hofmann, D. Ianson, T. Klinger, et al. 2015. Multiple stressor considerations: Ocean acidification in a deoxygenating ocean and a warming climate. www.westcoastoah.org

IPCC. 2019. *IPCC special report on the ocean and cryosphere in a changing climate* (H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, J. Petzold, et al., eds.). *Intergovernmental Panel on Climate Change*.

Kelly, R., & Caldwell, M. R. 2016. Ten ways states can combat ocean acidification (and why they should). *Washington Journal of Environmental Law & Policy* 6 (2): 287. Washington, USA: UW Law Digital Commons, https://digitalcommons.law.uw.edu/wjelp/vol6/iss2/5.

KPBS. 2019., California coastkeeper alliance releases climate change plan for coastal areas. https://www.kpbs.org/news/2019/nov/13/california-coastkeeper-alliance-releases-climate-c/

Maine Climate Council. (2020). About. https://climatecouncil.maine.gov/about

Maine State Legislature Maine Office of Policy and Legal Analysis, C. Bentley, and D. Schneider. 2015. *Report of the Commission to study the effects of coastal and ocean acidification and its existing and potential effects on species that are commercially harvested and grown along the Maine Coast*. https://digitalmaine.com/opla_docs/145

"Maine Won't Wait: A Four-Year Plan for Climate Action". 2020, December. https://www.maine.gov/future/sites/maine.gov.future/files/inline-files/MaineWontWait_December2020.pdf

Maryland Departments of the Environment and Natural Resources, University of Maryland Center for Environmental Sciences and International Alliance to Combat Ocean Acidification, Draft Maryland Ocean Acidification Plan. 2020.

Massachusetts Special Legislative Commission on Ocean Acidification Recommendations. 2021, February. https://www.whoi.edu/news-insights/content/massachusetts-ocean-acidification-shellfishing/

Melzner, F., J. Thomsen, W. Koeve, A. Oschlies, M. A. Gutowska, H. W. Bange, H. P. Hansen, and A. Körtzinger. 2013. Future ocean acidification will be amplified by hypoxia in coastal habitats. *Marine Biology* 160 (8):1875–88. doi: 10.1007/s00227-012-1954-1.

National Caucus of Environmental Legislators, Ocean Acidification Fact Sheet. https://www.ncel.net/ocean-acidification

NEP Coastal Ocean Acidification Research Critical to Economic Development. 2017, June 27th, https://nationalestuaries.org/2017/06/27/nep-ocean-acidification-project-featured-on-boston-public-radio (last viewed May 7, 2021).

New Hampshire Coastal Marine Natural Resources and Environment Commission (COMNARE). 2017. Ocean acidification summary and recommendations. https://mypages.unh.edu/comnare/file/6844

"New Research to Explore Seaweed for Ocean, Economic Health". 2021. Bigelow Laboratory for Ocean Science, February. https://www.bigelow.org/news/articles/2021-02-02.html

New York OA Task Force. https://www.dec.ny.gov/lands/114877.html

New York Ocean Action Plan 2017–2027. https://www.dec.ny.gov/docs/fish_marine_pdf/nyocean-actionplan.pdf

New York State Senate, Assembly Bill A10264. New York state ocean acidification task force. https://www.nysenate.gov/legislation/bills/2015/A10264

Nielsen, K., J. Stachowicz, H. Carter, K. Boyer, M. Bracken, F. Chan, F. Chavez, K. Hovel, M. Kent, K. Nickols, J. Ruesink, J. Tyburczy, and S. Wheeler. 2018, January. *Emerging under-*

standing of the potential role of seagrass and kelp as an ocean acidification management tool in California. Oakland, CA: California Ocean Science Trust.

Oregon Department of Environmental Quality. 2020. Oregon's 2018/2020 Integrated Report. https://www.oregon.gov/deq/wq/Pages/2018-Integrated-Report.aspx

Oregon Governor's Natural Resource Office. 2019. Oregon ocean acidification and hypoxia action plan 2019–2025. https://www.oregonocean.info

Pimenta, A. R., and J. S. Grear. 2018. EPA guidelines for measuring changes in seawater pH and associated carbonate chemistry in coastal environments of the eastern United States, EPA/600/R-17/483. March.

Phillips, J., W. Berry, H. Carter, L. Whiteman, and L. Chornesky, eds. 2018. *State of California ocean acidification action plan*. San Diego, CA: California Ocean Protection Council.

Price, N., and S. Arnold. 2019. Kelp farming as a potential strategy for remediating ocean acidification and improving shellfish cultivation, AGU Ocean Sciences 2019 Presentation. https://agu.confex.com/agu/osm20/preliminaryview.cgi/Paper655955.html

Rheuban, J. E., P. R. Gassett, D. C. McCorkle, C. W. Hunt, M. Liebman, C. Bastidas, K. O'Brien-Clayton, A. R. Pimenta, E. Silva, P. Vlahos, et al. 2021. Synoptic assessment of coastal total alkalinity through community science. *Environmental Research Letters* 16 (2):024009. doi: 10.1088/1748-9326/abcb39.

Sala, E., J. Mayorga, D. Bradley, R. Cabral, T. Atwood, A. Auber, W. Cheung, C. Costello, F. Ferretti, A. Friedlander, et al. 2021. Protecting the global ocean for biodiversity, food and climate. *Nature* 592 (7854):397–402. doi: 10.1038/s41586-021-03371-z. Epub 2021 Mar 17

Song, L. 2019. Cap and trade is supposed to solve climate change, but oil and gas company emissions are up. Probulica, November 15.

State-Led OA Action Planning in the Mid-Atlantic. 2021. Webinar hosted by Mid-Atlantic Coastal Acidification Network, April. https://www.youtube.com/watch?v=lx9EUKdaW20

Su, J., W.-J. Cai, J. Brodeur, B. Chen, N. Hussain, Y. Yao, C. Ni, J. M. Testa, M. Li, X. Xie, et al. 2020. Chesapeake Bay acidification buffered by spatially decoupled carbonate mineral cycling. *Nature Geoscience* 13 (6):441–7. doi: 10.1038/s41561-020-0584-3.

Summary of Proceedings. 2019. International Alliance to Combat Ocean Acidification U.S. State Coast-to-Coast Workshop. http s: // sta tic 1.squa resp ace.co m/sta tic/6006 d8424 7a6a5 1d636 dd219 /t/6 064f 24b9c a986717 860 173 f/161 7228 364 625/ OA+A llian ce+ U.S.+ State+ Coast +to+ Coast+ Worksh op +% 28S ummary + of + Proc eedin gs %29+ FIN AL.pdf

Taking Action on Climate Change and Building a More Resilient Connecticut for All-GC3 Governor's Council on Climate Change. Phase 1 Report: Near-Term Actions. 2021. https://portal.ct.gov/-/media/DEEP/climatechange/GC3/GC3_Phase1_Report_Jan2021.pdf

Waldbusser, G. G., and J. E. Salisbury. 2014. Ocean acidification in the coastal zone from an organism's perspective: Multiple system parameters, frequency domains, and habitats. *Annual Review of Marine Science* 6 (1):221–47. doi: 10.1146/annurev-marine-121211-172238.

Wallace, R. B., H. Baumann, J. S. Grear, R. C. Aller, and C. J. Gobler. 2014. Coastal ocean acidification: The other eutrophication problem. *Estuarine, Coastal and Shelf Science* 148:1–13. doi: 10.1016/j.ecss.2014.05.027.

Washington Department of Ecology. (2019-2021). Puget sound nutrient reduction project. https://ecology.wa.gov/Water-Shorelines/Puget-Sound/Helping-Puget-Sound/Reducing-Puget-Sound-nutrients/Puget-Sound-Nutrient-Reduction-Project

Washington Marine Resources Advisory Council. 2017. *2017 addendum to ocean acidification: From knowledge to action, Washington State's Strategic Response*. EnviroIssues (eds). Seattle, WA: Enviroissues.

Washington State Blue Ribbon Panel on Ocean Acidification. 2012. *Ocean acidification: From knowledge to action. Washington State's Strategic Response* (H. Adelsman and L. W. Binder, Eds.). Olympia, WA: Washington Department of Ecology.

Weisberg, S. B., F. Chan, J. P. Barry, A. B. Boehm, S. Busch, S. R. Cooley, R. A. Feely, and L. A. Levin. 2020, June. *Enhancing California's Ocean Acidification and Hypoxia Monitoring Network*. Sacramento, CA: California Ocean Science Trust.