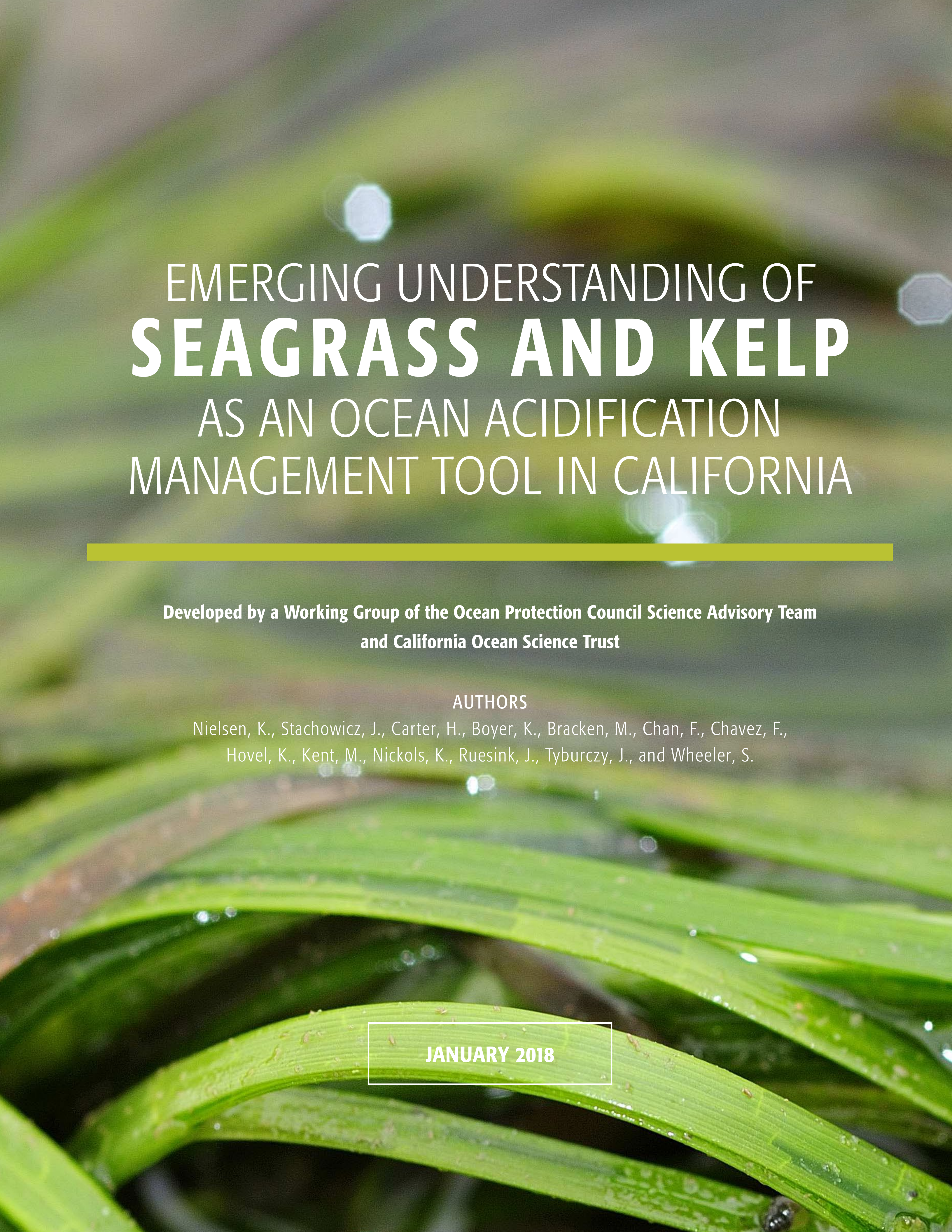

EMERGING UNDERSTANDING OF SEAGRASS AND KELP AS AN OCEAN ACIDIFICATION MANAGEMENT TOOL IN CALIFORNIA

Developed by a Working Group of the Ocean Protection Council Science Advisory Team and California Ocean Science Trust

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The role of the Ocean Protection Council Science Advisory Team (OPC-SAT) is to provide scientific advice to the California Ocean Protection Council. The work of the OPC-SAT is supported by the California Ocean Protection Council and administered by Ocean Science Trust. OPC-SAT working groups bring together experts from within and outside the OPC-SAT with the ability to access and analyze the best available scientific information on a selected topic.

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California Ocean Science Trust

The California Ocean Science Trust (OST) is a non-profit organization whose mission is to advance a constructive role for science in decision-making by promoting collaboration and mutual understanding among scientists, citizens, managers, and policymakers working toward sustained, healthy, and productive coastal and ocean ecosystems. A unique asset to the State of California, OST was established under the California Ocean Resources Stewardship Act (CORSA) of 2000. www.oceansciencetrust.org

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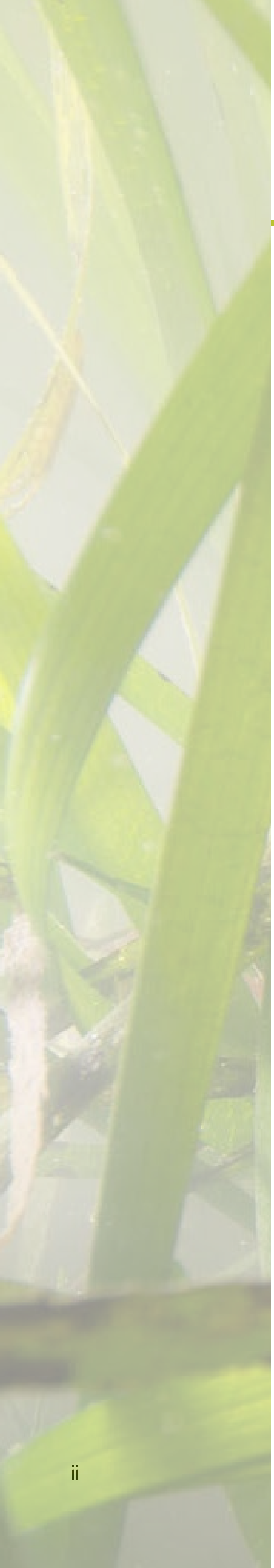


About the Report

Goal of this Report

This report was produced by the OPC-SAT working group and Ocean Science Trust on behalf of the Ocean Protection Council (OPC) and the broader community of California managers with the aim of:

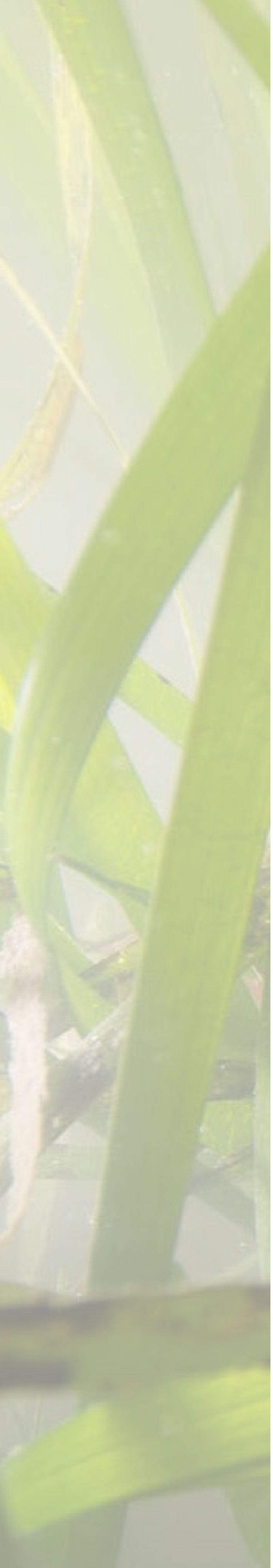
- communicating emerging scientific understanding of the ability of seagrass and macroalgae (kelps) to ameliorate ocean acidification (OA) in a California-specific context,
- summarizing knowledge gaps and opportunities for filling them through research and monitoring, and
- providing guidance on next steps for the State as it considers future nature-based actions to reduce the negative impacts of OA in California and beyond.

California Management Context

California is interested in addressing the global challenge of OA and is exploring local and regional management strategies that can reduce exposure and enhance the ability of biota to cope with OA stress. In early 2016, the West Coast Ocean Acidification and Hypoxia Science Panel, convened by Ocean Science Trust at the request of the OPC, recommended that West Coast states advance approaches that remove CO_2 from seawater, including exploring the role of coastal and estuarine vegetation. The Panel effort informed legislation in California (Senate Bill No. 1363, Monning, 2016) calling for scientific and evidence-based approaches to protect and restore seagrass as a critical strategy in enhancing California's ability to withstand OA (Box 1). Under SB 1363, the OPC is tasked with administering an OA reduction program that focuses on conservation or restoration of submerged aquatic vegetation (SAV) for the purposes of removing carbon from surrounding waters. Scientists and decision-makers across the West Coast are actively working to understand three key questions about seagrasses and kelps, hereafter referred to as SAV, in reducing exposure to OA:

1. *Do SAV habitats measurably lessen the severity of OA exposure?*
2. *If so, when, where, and under what conditions do SAV habitats best ameliorate OA?*
3. *Can SAV habitats be managed in a way that reduces the environmental stress of OA on species along the West Coast?*

At their October 17, 2016 public meeting, the OPC approved funding for carbonate chemistry monitoring and research on natural and restored eelgrass (*Zostera marina*) beds at several sites across California, including in Humboldt Bay, Bodega Harbor, Tomales Bay, Elkhorn Slough, Newport Back-Bay, and San Diego Harbor. Working closely with Alaska, British Columbia, Washington, and Oregon through a state-federal task force, the OPC is also developing an inventory of OA monitoring assets throughout the state, and has funded the Ocean Science Trust to build a tool to visualize OA "hotspots" that include SAV habitat considerations. These projects are important first steps in broadening our understanding of how SAV might be managed in California to maximize their benefit to coastal ecosystems, including reducing the exposure of marine life to the negative impacts of OA.



About the Working Group

To begin implementation of SB 1363, and to prioritize next steps for California, the Ocean Science Trust convened a working group of the OPC-SAT in early 2017. The working group focused on synthesizing emerging research and findings on the capacity of seagrasses and kelps to provide short-term OA amelioration in field settings. Ocean Science Trust hosted a workshop in May 2017 with working group members, agency staff, and other experts to explore current scientific progress towards addressing the three questions identified above (Appendix A).

This report summarizes workshop discussion and provides synthesis and interpretation of emerging data and results from research and monitoring in progress. It also provides technical guidance on the potential application of these emerging findings in contemporary management practices. It highlights where there is scientific uncertainty and gaps in knowledge that should be filled to accelerate our understanding and inform near-future management efforts. Additional knowledge and new findings are expected when these studies are completed.

Box 1: Senate Bill SB 1363 - Ocean Protection Council: Ocean Acidification and Hypoxia Reduction Program

In 2016, the California legislature passed Senate Bill 1363 (Monning) which tasked the California Ocean Protection Council, in consultation with the State Coastal Conservancy, with establishing and administering the Ocean Acidification and Hypoxia Reduction Program to achieve the following goals:

1. Develop demonstration projects to research how important environmental and ecological factors interact across space and time to influence how geographically dispersed eelgrass beds function for carbon dioxide removal and hypoxia reduction.
2. Generate an inventory of locations where conservation or restoration of aquatic habitats, including eelgrass, can be successfully applied to mitigate ocean acidification and hypoxia.
3. Incorporate consideration of carbon dioxide removal for eelgrass restoration projects during the habitat restoration planning process in order to fully account for the benefits of long-term carbon storage of habitat restoration in addition to the habitat value.
4. Support science, monitoring, and coordination to ensure that ocean and coastal policy and management in California reflect best readily available science on strategies to reduce ocean acidification and hypoxia.

For the full bill text, visit here.

Key Messages

1. **Investing in protection and restoration of SAV is a "no-regrets" coastal management strategy for maintaining functional, resilient ecosystems in the face of OA and other stressors.** Aside from the potential carbon reduction benefits, SAV conservation and restoration provide many benefits to a variety of marine life including ones known to be sensitive to OA or that are commercially valuable. There are actions that can be taken now to protect and restore these ecosystems to help reach broadly recognized regional habitat goals even with only limited specific information on the magnitude of their ability to ameliorate exposure to low pH waters in particular locations. Natural resource managers should prioritize preservation of existing habitats, and where feasible, restoring sites where conditions are favorable and long-term success is most likely.

2. **Recent investments in SAV research and monitoring are rapidly advancing our understanding of where and when SAV habitats may ameliorate OA.** Seagrass and kelp remove carbon from seawater via the process of photosynthesis and the effect can be measured. However, various other factors including the vegetation type, time of day or year, and the chemical and physical conditions (e.g., ambient conditions, local currents, and water residence times) have a strong influence on the magnitude of this effect. Building on emerging scientific advances to clarify where and when the effect will be greatest is likely to yield useable information in the near-term.

3. **A key knowledge gap is documenting the magnitude and spatial extent of potential OA amelioration by SAV across a range of habitat types and geographic locations.** Ongoing work suggests any chemical amelioration effects are likely to be local. In order to inform effective application in California, investigations are needed in local regions of interest and under the conditions of temperature, water flow and pH present in the region to determine where and under what circumstances SAV may be most effective in favorably influencing water chemistry. While OA monitoring on the West Coast is expanding, relatively few sites in California are monitored for both carbonate chemistry alongside SAV and species impacts. More informed and specific management practices could be advanced with additional investments in both chemical and biological monitoring in conjunction with controlled biological field experiments.

4. **Translating documented impacts of SAV on pH to biological effects is a critical knowledge gap.** While a better picture of the effects of SAV on carbonate chemistry is beginning to emerge, what these potential changes mean to organisms living within and near SAV requires additional research. For example, even if average pH does not change with the presence of SAV, the daily minima and maxima are usually more extreme than when SAV is absent. Whether organisms are most sensitive to changes in mean vs. minimum or maximum pH is still unclear. Future paired chemical and biological laboratory and field studies should address this.

1. Introduction

Studying eelgrass at Keller Beach in Richmond, CA. Credit: A.J. Maher

Naturally pervasive, low pH waters in the California Current Ecosystem put coastal communities on the U.S. West Coast at a higher risk for negative, long-term economic impacts of ocean acidification (OA). OA is an ocean-wide phenomenon associated with changes in carbon dioxide (CO_2) concentrations in seawater. Compared with natural fluxes in CO_2 that affect seawater pH (due for example to respiration, photosynthesis, and coastal upwelling), increases in atmospheric CO_2 due to the combustion of fossil fuels and land use changes are resulting in lower average pH levels and other chemical changes across the global ocean. The U.S. West Coast is already exposed to some of the lowest and most variable pH waters recorded for the surface ocean because of its intense and persistent summer upwelling (Chan et al., 2017), and it is likely to be among the first places to experience the biological effects of human-caused OA.

Consequences of changes in carbonate chemistry associated with OA can range from making it more difficult for calcifying marine species like oysters and pteropods to build shells, to changing the behavior of fishes, and altering predator-prey relationships (Cripps et al., 2011; Kroeker et al., 2013; Munday et al., 2010; Watson et al., 2017). As a result of these impacts and their associated indirect effects, the larger scale effects of OA have the potential to drastically modify marine food webs and fisheries along the California Current (Marshall et al., 2017). Some evidence indicates that several of California's top coastal fishery resources, including West Coast Dungeness crab, market squid, and shellfish aquaculture species (e.g., oysters, mussels) among others, may be threatened by the impact of rising acidity on the development and survival of early life stages (Miller et al., 2016; Navarro et al., 2016). However, given the naturally low and seasonally variable carbonate chemistry in California coastal ecosystems, some species may be adapted to tolerate such variation and extremes or have the potential to adapt to future acidification. Such adaptation has been shown in some estuarine, intertidal, and coastal dwelling species (Kelly et al., 2013; Pespeni et al., 2013; Ruesink et al., 2017), for example. The variability in responses to OA among species highlights the importance of research on local populations and species at scales of management interest.

Decision-makers globally and across the U.S. West Coast are investigating strategies to mitigate and manage for the impacts of OA that are informed by scientific evidence (Chan et al., 2016; Griscom et al., 2017; Klinger et al., 2017). In recent years, there has been significant management and policy interest in exploring whether regional-scale restoration, protection, and cultivation of coastal and estuarine **submerged aquatic vegetation** (SAV) could contribute in a substantive way to California's climate change adaptation and mitigation strategies (Box 2). SAV habitats provide many benefits to a variety of marine life including ones known to be sensitive to OA or that are commercially valuable. A previously underappreciated ecological benefit may be their potential for **OA amelioration** and **carbon sequestration and storage** (i.e., blue carbon) (Box 2).

Determining the magnitude of potential carbon benefits provided by SAV is complex and an actively evolving area of research and monitoring. As a first step, the working group focused on assessing current understanding of the short-term OA amelioration capacity of two major SAV habitats – seagrasses and kelps – in a California-specific context. While the working group scope was centered on communicating emerging findings on OA amelioration, the report includes some discussion of carbon sequestration and storage. This report considers previously published work along with emerging data and findings from research in progress in order to provide decision-makers with the most current scientific information available.

Why focus on seagrasses and kelps?

On the West Coast, two dominant SAV habitats, seagrass (which includes eelgrass) and kelp, are the main focus of developing a capacity to ameliorate acidification on local scales. These groups of species occupy different habitats throughout California and exhibit characteristics that are amenable to management and restoration. While other species undoubtedly impact water pH and the carbonate cycle via photosynthesis and respiration, we focus on seagrasses and kelps because:

- they use dissolved forms of inorganic carbon for photosynthesis and so directly affect the aquatic carbonate system, whereas other coastal vegetation (e.g., emergent salt marsh plants) use CO_2 gas from the atmosphere;
- they are widespread, can be locally persistent, and represent among the most productive and extensive SAV found in estuaries and along rocky coastlines, respectively.

Furthermore, seagrass and kelp provide a range of valuable ecosystem functions, including providing refuge and nursery habitat for commercially and recreationally important species, improving water quality, and protecting coastal zones from storm surge, erosion, sea level rise, and ecotourism. Thus significant alternative benefits of restoring these ecosystems have already been observed and quantified (Arkema et al., 2013; Barbier et al., 2008; Carr and Reed, 2016; Guannel et al., 2015; Hemminga and Duarte, 2000; Lamb et al., 2017; McDevitt-Irwin et al., 2016; Mtwana Nordlund et al., 2015; Pinsky et al., 2013; Waycott et al., 2009; Zedler and Kercher, 2005).

Within seagrasses and kelps, there are certain species in California that are likely to be the best candidates for conferring OA amelioration, described below and in Table 1. These species are the main focus of the discussion within this report.

Box 2. Key definitions.

Submerged aquatic vegetation (SAV) – In this report, SAV refers to all underwater plants or seaweed that live at or below the water surface. This report focuses primarily on seagrasses (e.g., eelgrass, surfgrass) and kelps (e.g., giant kelp, bull kelp). Freshwater SAV is outside the scope of this report and are not discussed here.

OA amelioration – SAV assimilates carbon dioxide from seawater into tissues via the process of photosynthesis, removing CO_2 from the water. This reduction in CO_2 in the waters surrounding actively photosynthesizing aquatic vegetation can potentially offset, or ameliorate, the pH reductions induced by OA on a local scale. Due to daytime net photosynthesis and nighttime respiration, SAV is expected to increase pH during the day and reduce it at night. Where photosynthetic biomass is increasing or exported from a bed, an overall positive effect of unknown magnitude on mean pH is expected.

Carbon sequestration and storage (i.e., blue carbon) – On longer time scales, some SAV, particularly those with extensive root and sediment systems (e.g., seagrasses), may also serve as natural carbon sinks and have the potential to sequester (measured as a rate of uptake over time) and store (measured as total weight) carbon for decades to millennia when they are intact and healthy (Duarte et al., 2005; Mcleod et al., 2011). This occurs when carbon dioxide from water is converted into SAV tissues which are subsequently buried in sediment or are exported to the deep sea for long-term storage. SAV also tends to slow down water flow, encouraging particulate organic matter (from any source) to be deposited and potentially buried. This is also known as “blue carbon.”

Seagrass species under consideration

In California, the most common coastal marine and estuarine-dwelling seagrasses include eelgrass (*Zostera marina, Z. pacifica,* and the non-native *Z. japonica*) and surfgrass (*Phyllospadix scouleri* and *P. torreyi*). Here we focus largely on the native eelgrass *Z. marina* as it is the best candidate for conferring OA amelioration benefits for several reasons. First, the non-native and invasive eelgrass *Z. japonica* has only been observed in California in Humboldt Bay. Further, field studies in Oregon have found that *Z. japonica* modifies seawater chemistry far less and confers less benefit to oysters than *Z. marina* (Smith, 2016). Second, since the ability of SAV to impact water chemistry is proportional to the residence time of the water in the bed (details discussed more in the following section), *Z. pacifica* (occupying a small area of the outer coast in southern California) and surfgrasses are less likely to impart a substantial OA amelioration effect because they occur where water flow and mixing are very high, and residence time is very short. However, there is some evidence to suggest *Z. pacifica* may be considered for small, localized efforts.

Kelp species under consideration

Although there are rich algal assemblages associated with kelp forests, two canopy-forming species dominate the California coast and are likely to be the best candidates for OA amelioration because of their high biomass and productivity: giant kelp (*Macrocystis pyrifera*) and bull kelp (*Nereocystis luetkeana*). Giant kelp prefers areas of low water motion, whereas bull kelp is more tolerant of high water motion and wave exposure (Edwards and Foster, 2014; Molles, 1999). Giant kelp is more prominent from Baja California to Central California, and bull kelp tends to dominate forests north of San Francisco. In addition, giant kelp is a perennial species and its photosynthetic blades occur throughout the water column, whereas bull kelp is an annual species (grows from new spores each year) and its blades exist almost exclusively at the water surface.

Eelgrass
Zostera marina
Photo: Lliam Rooney

Eelgrass
Zostera pacifica
Photo: Thien Mai

Giant kelp
Macrocystic pyrifera
Photo: NOAA National Marine Sanctuaries

Bull kelp
Nereocystis luetkeana
Photo: Dan Hershman

Table 1. Summary and comparison of seagrass and kelp habitats, including characteristics that may play a role in their efficacy as an OA management tool in California.

	SEAGRASS	**KELP**
Species under consideration in California	Eelgrass *Zostera marina* is likely to have the largest OA amelioration benefit *Z. pacifica* may be considered for small, localized efforts	*Macrocystis pyrifera* (giant kelp) is likely to have a larger OA amelioration benefit than other species of kelp *Nereocystis luetkeana* (bull kelp) is another species to consider because like *M. pyrifera*, it forms kelp forests
Habitat location and substrate	• Shallow waters (4m to intertidal) in bays and estuaries; occupies sandy and muddy bottoms in locations where current speeds and wave energy are not excessive, and where light penetration is sufficient; a few species live on wave swept shores or in deeper waters of the open coast • Humboldt Bay and San Francisco Bay have the largest areal extent of eelgrass cover in the state	• Temperate seas; anchored to submerged rocky reefs and outcrops; found in patches along the entire California coastline • *M. pyrifera* – prefer areas of low water motion; more prominent from Baja California to Central California • *N. luetkeana* – tolerant of higher water motion and wave exposure; more prominent north of San Francisco
Growth characteristics / primary productivity rates	*Z. marina* - predominately perennial and occasionally annual; spreads clonally by rhizomes (runners) or sexually by seed; maximum growth rates correlated with light availability	• Both species reproduce sexually via spores; maximum growth correlated with nutrient availability (upwelling of cold, nutrient and CO_2 rich water) • *M. pyrifera* – perennial; dies back in winter but regrows from holdfast attached to rock, blades occur throughout the water column • *N. luetkeana* – annual; blades exist solely in the canopy
Summary of processes driving water chemistry dynamics	• Daily patterns due to semidiurnal tidal dynamics and photosynthesis/respiration • Seasonal differences due to changes in light availability • Light attenuation changes due to water clarity, sediment load (daily to decadal)	• Wintertime dynamics driven by physical processes • Springtime patterns driven by photosynthesis (phytoplankton and kelp) • Daily variability strongest in spring/summer
Capacity to ameliorate OA inside habitat	Preliminary research in California suggests some beds can have a measurable effect on pH during certain seasons; benefits likely to be conferred locally; under active investigation	Existing research suggests some kelp forests may buffer exposure to low pH waters in the canopy where photosynthetic rates and biomass are greatest
Capacity to ameliorate OA outside habitat	Unknown; under active investigation	Unknown; under active investigation
Potential for long-term carbon storage (i.e., “blue carbon”)	Limited data on *Z. marina* but under active investigation; available evidence suggests that eelgrass beds can facilitate carbon storage, but the magnitude of this is smaller than that reported for some other “mat forming” species (i.e., species that develop in large mats that shade the water column and sea floor below), and can vary considerably among eelgrass beds based on underlying sediment and water flow characteristics, water depth, and seagrass biomass	Under active investigation but likely not an effective long-term carbon sink in California since carbon is stored in tissue only and species are short lived; some potential for storage of biomass transported out of ecosystem (deep sea)
Current habitat status	Some stable areas and some have shown rapid decline or considerable annual fluctuations due to oceanographic conditions (El Niño); a protected habitat in California waters due to significant habitat loss in recent history primarily caused by land use change and other anthropogenic impacts; worldwide abundance is declining	Highly variable from year to year; directional trends are currently uncertain
Restoration potential	Challenging but with careful consideration of current conditions informing site selection, restoration has the potential to augment eelgrass populations; underlying causes of seagrass stress/decline must be addressed; in some locations, restoration goals have been articulated and potential suitable sites for eelgrass restoration have been mapped (San Francisco Bay Subtidal Goals, Baylands Goals Science Update)	Restoration of kelp by reducing urchin densities have been attempted, including the recent Palos Verdes Kelp Restoration Project. Results are suggestive, but inconclusive (The Bay Foundation, 2016).

2. Chemistry Changes in SAV Habitats

Credit: Sarah Finstad

A key component in determining the OA amelioration potential of SAV is knowing the magnitude and direction of carbon flux in and out of these ecosystems. These habitats are biologically and hydrodynamically complex environments where multiple factors influence water chemistry, including other organisms and the physical and oceanographic conditions present. SAV communities are composed of not only seagrass or kelp, but also microbes, algae, invertebrates, and fishes living on the plants and in the surrounding water, the root systems, and organic-rich sediments. The biogeochemistry and capacity of these communities to ameliorate exposure to acidified waters is a product of the community interactions, the component species' eco-physiological attributes, and physical factors such as tidal flow, currents, waves, water residence times, light, temperature, and salinity. In addition, SAV biomass fluctuates seasonally, increasing in the spring and summer (due to light and nutrients) and declining in the winter (due to storm damage and senescence). Thus, any potential carbon benefits associated with these habitats will not be constant and will depend on species and location.

While community dynamics are complex, the ways in which carbon enters and exits SAV habitats can be broken down into several key pathways (Fig. 1). Ongoing monitoring and modeling efforts are helping to illuminate the magnitude of each pathway, and the conditions that may maximize the potential for OA amelioration. A summary of what is known about the major carbon pathways in eelgrass and kelp forests is described below.

2.1 Emerging Understanding of pH in Eelgrass Habitats in California

In general, eelgrass communities have naturally high daily and seasonal variability in pH inside the bed due to a range of factors, including the linked processes of photosynthesis and respiration (Fig. 1A). Much of what we know about their ability to ameliorate OA is based on studies of systems outside of California. Tropical seagrass meadows have been shown to increase water pH on average, as well as increase the frequency, magnitude and duration of high-pH waters, without changing the minimum pH (Duarte et al., 2010; Hendricks et al., 2014; Unsworth, 2012). These results appear to be species- and site-specific. As such, several ongoing OPC funded monitoring efforts across California are exploring differences in the ability of eelgrass to ameliorate OA based on geography, bed biomass and density, and restored vs. naturally established beds to help inform amelioration potential (Appendix B). Preliminary results from these and other studies are summarized below.

Eelgrass: Net Ecosystem Productivity and Local Effects on Seawater pH

Preliminary results suggest a modest, but measurable net positive effect of seagrass on pH within a bed (Fig. 2A). However, the presence of seagrass will also lead to increased variation in pH and other chemical parameters. Unpublished data from one active monitoring site in Tomales Bay, California suggest that *Z. marina* habitats can have a measurable positive effect on seawater pH inside a bed during summer months when productivity may be high (Hill et al., 2017, unpublished data). Another study in California off the Channel Islands found measurable differences in seawater pH in *Z. pacifica* beds (Kapsenberg and Hofmann, 2016) when compared to kelp and open ocean sites, suggesting some potential for *Z. pacifica* to impact local ocean chemistry as well.

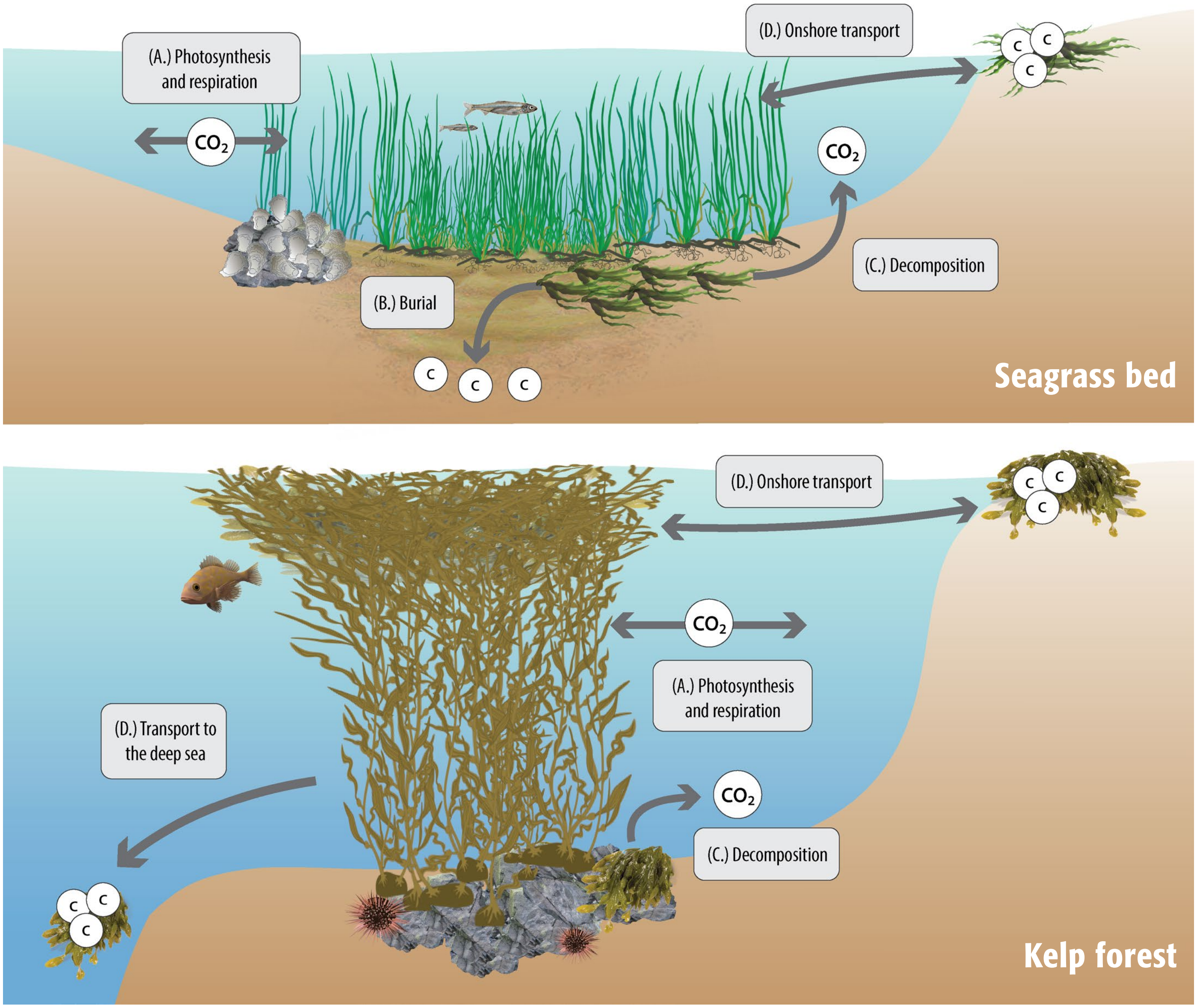


Figure 1. Potential carbon pathways in seagrass beds and kelp forests in the coastal ocean.

(A.) Photosynthesis and respiration. Photosynthesis is the process by which CO_2 is taken up from seawater and incorporated into plant tissues during the day. By removing CO_2 from water, active photosynthesis can create the "OA refuge effect" by raising pH in the surrounding water. The effect is reversed when photosynthesis ceases at night when light is not available, yet respiration continues. OA amelioration potential is maximized when the community productivity of a habitat is net positive (i.e., when the rate of photosynthesis is greater than the rate of respiration). **(B.) Carbon burial.** Eelgrass and other members of the community (especially suspension feeders) can promote settlement of organic-rich particles from the water by slowing currents and trapping them in the dense network of roots and rhizomes. In some SAV (eelgrass, but not kelp), these can accumulate and form thick organic deposits in the sediment over long time scales (Duarte et al., 2011). When organic material is captured and buried in a low oxygen environment, slow decomposition can result in long-term storage of carbon. **(C.) Decomposition.** Sediments support microbes that decompose organic matter (dead and decaying material, including plant matter), releasing CO_2 (lowering pH) and consuming oxygen in the process. The depth and biogeochemical character of the sediments, and the balance of accumulation vs. decomposition must be considered when assessing the amelioration and carbon storage potential of SAV, since the CO_2 uptake by plants could be offset by respiration from microbes or animals in the bed. **(D.) Transport of biomass out of the ecosystem.** Both seagrass and kelp have the potential to serve as an organic carbon donor to other ecosystems in the form of detached detritus or wrack. This includes either transport onshore or to the deep sea. Considerations for carbon storage of this material depends on the decay rate during transport and the burial efficiency at receiver sites (Hill et al., 2015). Aside from its role in the carbon cycle, this wrack is an extremely important resource for food webs and as habitat at the land-water interface (Dugan & Hubbard, 2016).

A theoretical box model of eelgrass impacts on OA based on accumulated knowledge of seagrass beds and their surrounding environment using information from northern California suggests that changes in the average pH in eelgrass beds are relatively modest (~0.03 units), but can be higher for brief periods (Koweek et al., 2017a, submitted). Considering the effects of seasonal variation in eelgrass density and environmental conditions, the model arrived at two general conclusions : 1) the largest eelgrass biomass does not necessarily result in the largest net positive effect on pH due to self-shading and a lower ratio of photosynthesis to respiration in the most dense beds, and 2) the timing of low tides (and therefore a shallower water column) strongly influences net pH change because eelgrass changes pH most rapidly in shallow water due to higher light availability and lower water volume. In many northern California estuaries, winter low tides occur during daylight hours, whereas during the summer low tides occur at night when it is dark, leading to predictions of greater positive effects on pH from eelgrass in winter than in summer in this model. In addition, shallow marine water is likely to show day-night variation in pH even away from seagrass beds because of other photosynthetic organisms including microalgae (e.g., Ruesink et al., 2015), so distinguishing the eelgrass-specific signal can be challenging.

While field and model results may not agree on the magnitude and conditions that confer the largest pH effect, they begin to shed light on the complex biological and chemical dynamics in California estuaries, and suggest a need for investigations across a range of habitat types.

Eelgrass: Potential for Carbon Burial and Decomposition

Many of the high estimates of seagrass as a carbon store come from studies of *Posidonia oceanica* in the Mediterranean, which has a massive, persistent rhizome (underground storage) system that is a large, long-term sink for carbon. In contrast, rhizomes of *Z. marina* sever naturally and are short-lived such that the value of eelgrass for carbon sequestration will be less than the estimates for *Posedonia* published in the literature (Poppe and Rybczyk, 2017; Rohr et al., unpublished) and may not differ from carbon stores in surrounding unvegetated mud (Richardson et al., 2008). However, studies at different sites show that, accounting for sediment type, carbon burial increases with the amount of eelgrass present (O'Donnell et al., unpublished; Ricart et al., 2015). A worldwide survey (Rohr et al., unpublished) indicates considerable local and regional variation among eelgrass beds in the amount of carbon stored and that a substantial fraction of the carbon in many beds is derived from eelgrass itself, suggesting some sequestration potential. The largest effect of eelgrass on carbon content of sediments occurs in sandier sediments rather than fine muds that naturally trap organic material regardless of eelgrass presence (O'Donnell 2017, in prep). This is because sediment grain size is a dominant control on sediment organic carbon content in temperate coastal estuaries, with low flow leading to fine particle (mud) deposition and these fine mud particles trapping more organic matter due to their higher surface area to volume ratio (Dahl et al., 2016; Serrano et al., 2016), regardless of seagrass presence.

Available evidence suggests that eelgrass beds can facilitate carbon storage, but the magnitude of this is smaller than that reported for some other "mat forming" species (i.e., those that develop in large mats that shade the water column), and can vary considerably among eelgrass beds based on underlying sediment and water flow characteristics, water depth, and seagrass biomass (Fig. 1B). Within the next year we expect publication of sufficient data from California and global seagrass beds to place the storage potential of California in context.

Eelgrass: Transport Out of the Ecosystem

While it is possible to study and quantify the amount of seagrass transported out of the ecosystem (e.g., deposited on beaches), this topic has not been heavily investigated in this context. Seagrass wrack can serve as an important subsidy of organic matter and nutrients along beaches, in salt marshes, and deep-water habitats (Britton-Simmons et al., 2012; Chapman and Roberts 2004; Orr et al. 2005). In Morro Bay, eelgrass wrack may be associated with successful establishment of a very rare (federally endangered) salt marsh plant, *Suaeda californica* (Baye 2006). A recent decline in eelgrass (97%, from 344 acres to 10 acres) in Morro Bay (State of the Bay, 2014) has led to concerns that *S. californica* seedling recruitment and perhaps adult plant vigor will suffer. In addition, studies are underway to examine the use of eelgrass wrack in the reintroduction of *S. californica* to San Francisco Bay, where the plant is now locally extinct (K. Boyer, unpublished data). However, understanding the role of this transport in carbon dynamics depends on knowing fate: in habitats where it decomposes, it may provide a local CO_2 increase and pH decrease; in places where it is ultimately buried and decomposition slowed or prevented, it could represent a significant mechanism of carbon storage.

2.2 Emerging Understanding of pH in Kelp Habitats in California

As with seagrass habitats, kelps inhabit highly variable coastal nearshore systems. Temperature, salinity, upwelling, mixing, freshwater inputs, and other biogeochemical processes fluctuate on short term to decadal cycles (e.g., Pacific Decadal Oscillation) which can all influence carbonate chemistry (Freider et al., 2012). Kelp forests are highly studied ecosystems (Carr and Reed, 2016) and much is known about the driving processes affecting water chemistry, though few studies specifically test whether kelp forests have the capacity to ameliorate OA. A summary of what is known is provided below.

Kelp: Net Ecosystem Productivity and Local Effects on Seawater pH

Much like seagrass, the ability of kelp to alter water chemistry and provide pH amelioration is a function of both biological activity and the physical environment (Fig. 1). Dissolved oxygen and pH are tightly linked (Frieder et al., 2012) and are influenced by photosynthesis and respiration (of kelp, other benthic algae, and phytoplankton) (Fig. 1A), calcification or dissolution of shelled invertebrates, respiration of animals and heterotrophic microbes, air-sea gas exchange, advection from waves and local currents, and regional-scale upwelling of high-CO_2 water (Frieder et al., 2012; Koweek et al., 2017c). Water chemistry within kelp forests exhibits strong vertical gradients, with large fluctuations in pH at depth and less variability closer to the surface (Fig. 2B). This results from oceanographic processes in the nearshore ocean that determine the extent of water column mixing and stratification, the layering of water that prevents mixing when density differences between layers is high. Forest-level processes such as horizontal mixing, current attenuation within beds, and tidal currents also contribute to differences in carbonate chemistry of waters within beds compared to waters outside of beds. Importantly, the physical structure of the kelp itself also influences the movement of waters within the kelp forests and exchange between kelp forest and offshore waters (Gaylord et al., 2012) by attenuating water motion, thus influencing the movement of biogeochemical constituents. Coastal upwelling lowers pH but also increases kelp growth and kelp canopy biomass, which may help ameliorate low pH when waters are most likely to be corrosive.

Kelp forests in Monterey Bay show strong week-to-week, site-to-site, and seasonal variability in pH, with some indication that the presence of giant kelp increases pH (Koweek et al., 2017c). Studies in southern California have indicated that the high productivity of kelp forests can increase pH on short time scales (days to weeks) relative to surrounding waters (Frieder et al., 2012) (Fig. 2B). More work is needed to understand the magnitude of this increase, and how this may vary from site-to-site. Studies in other regions suggest that dynamics driving chemical changes within a forest vary by season. Winter conditions are driven primarily by physical processes, while springtime conditions are driven largely by photosynthesis and exhibit daily variations in pH (Delille et al., 2009).

Kelp: Potential for Carbon Burial and Decomposition

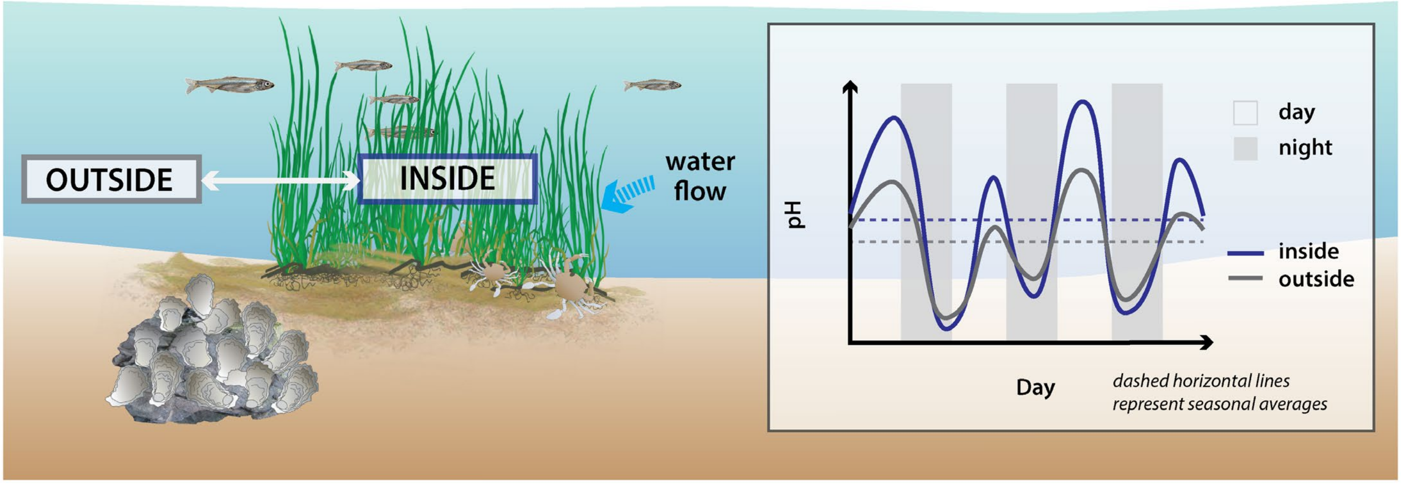
Kelps grow on and are attached to hard bottom submerged surfaces. As a result, kelp detritus does not accumulate where kelps grow. Therefore, in contrast to some seagrasses, dead and detrital kelp biomass is not likely to play an appreciable role in long-term carbon storage in the ecosystems where they occur (Dierssen et al., 2009; Duarte et al., 2013), unless it is transported to a habitat where it can be buried (see below).

Kelp: Transport Out of the Ecosystem

Kelp forests may serve as significant carbon donors via the transport of vegetative biomass (free floating, detached, or dead kelp) to other ecosystems (Filbee-Dexter and Scheibling, 2016; Hill et al., 2015; Howard et al., 2017; Liebowitz et al. 2016) with documented burial of carbon in the deep sea (Krause-Jensen and Duarte 2016) (Fig. 1C,D). Additional research is needed in U.S. West Coast systems to better understand and quantify this potential on local scales.

In addition to natural processes that remove kelp, kelp farming is being explored globally, and on the West Coast, to determine whether it can be used as a means to remove carbon from seawater (Davis et al. 2016; Duarte et al. 2017). This includes a 5-year project currently underway to investigate aquaculture of sugar and bull kelp as a means to extract CO_2 and nutrients in order to mitigate OA and eutrophication in Puget Sound, Washington (Davis et al., 2016).

(A.) Seagrass bed



(B.) Kelp forest

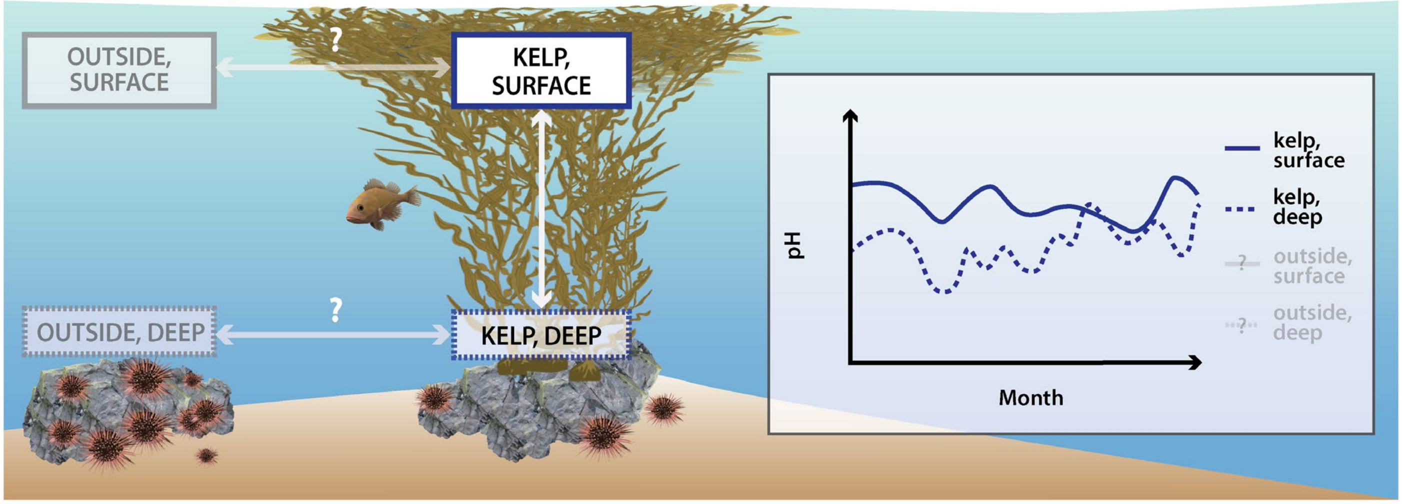


Figure 2. Generalized pH profiles inside and outside SAV habitats based on emerging research.

(A.) Seagrass beds. During summer months in California, it is hypothesized that seagrass habitats have the potential to offset water chemistry when averaged over an entire season, as noted by the dashed and solid horizontal lines representing seasonal pH averages inside and outside of seagrass beds. The variance in pH can be greater inside seagrass beds compared with outside, where both higher high pH and lower low pH values are observed. In the winter, differences between the seasonal mean pH inside vs. outside beds may be less notable, though baseline pH is higher overall due to the absence of upwelling. (Figure based on emerging data from OPC-funded monitoring efforts listed in Appendix B)

(B.) Kelp forests. Generalized pH profiles inside and outside of kelp forests based on emerging research. Within a single site, kelp forests have strong surface-to-bottom differences in pH, with higher pH values present, on average, in the canopy compared with deeper water. This gradient is largest during the upwelling season when kelp biomass is higher and there is less mixing of the water column. Kelp free areas located outside but adjacent to a kelp forest are influenced by water modified from the kelp forest, though the magnitude and spatial extent of chemistry changes due to the presence of kelp, and how chemistry differs from areas offshore (uninfluenced by kelp) is under investigation. (Figure modified from Koweek et al., 2017c and Frieder et al., 2012).

2.3. Potential Indicators of OA Amelioration in SAV Habitats

In principal, OA amelioration by SAV is likely to be more prominent during spring to summer months when SAV biomass is increasing, day length is longer, and growth or leaf turnover rates are rapid. While there still is scientific uncertainty about whether, when, and where these generalizations hold true, scientists have identified some characteristics that may be the best indicators of the extent to which SAV will alter local pH (Koweek et al. 2017b, submitted) (Table 2):

- **During times or locations with high net ecosystem productivity (NEP).** NEP is the difference between ecosystem production (carbon fixed via photosynthesis) and ecosystem respiration within a seagrass bed or kelp forest ecosystem. If NEP is > 0, the SAV ecosystem is net autotrophic, meaning it produces more carbon than what is lost through respiration. NEP of SAV ecosystems is typically higher in summer months when conditions favor increased photosynthesis - day length is longer and during the daytime when light is plentiful. Water clarity, bed density, self shading, and the abundance of epiphytic algae may also affect light availability and should be considered when assessing favorable conditions for SAV. In kelp forests, rates of photosynthesis are greatest in the kelp canopy where the highest concentration of kelp biomass resides and light intensities are higher. Kelp forests exhibit strong vertical gradients in pH, where pH is less variable at the surface and increases with depth. Forest canopy biomass shows strong seasonal changes, and can result in seasonal differences in its ability to alter water chemistry. Different species are likely to vary based on their specific growth characteristics (Koweek et al., 2017c).
- **Long residence time of the water within a bed or forest.** Residence time is defined here as the amount of time water spends within a given location, which is calculated from the velocity of the water and the distance that the water flows through the bed. The longer the water stays within a bed, the more time that SAV has to alter water chemistry. However, if water is too stagnant, production can decline such that it is exceeded by respiration, leading to a net decrease in pH. In kelp forests, locations that are protected from wave exposure due to reduced water exchange are more likely to ameliorate OA. An additional complication arises when considering amelioration potential beyond local effects: if water motion is too stagnant, altered waters will not spread out to other areas. In addition, the higher the ratio of SAV habitat relative to the volume of the body of water (e.g., estuary), the greater the potential effect on overall water chemistry.

These characteristics provided a starting point for determining the potential for a SAV habitat to ameliorate OA, though predicting the conditions under which these benefits are most likely to be realized remains an active area of scientific investigation. For effective application in California, investigations are needed in local regions of interest and under the conditions of temperature, water flow, and pH present in the region to determine where and under what circumstances SAV may be most effective in favorably influencing water chemistry. Appropriate long-term environmental monitoring of extant SAV habitats, and coupling observations with ongoing restoration or mitigation projects would help advance the science and our predictive capacity.

Table 2. Emerging characteristics that may be correlated with greater OA amelioration potential.

	General characteristics for greater OA amelioration
Both SAV habitats	• High net ecosystem productivity (NEP) • Long residence time of the water within a bed or forest • Seasons or conditions that offer greater light availability where photosynthesis is maximized • High biomass relative to the water volume of the ecosystem
Eelgrass-specific	• Moderate biomass where self-shading is minimized
Kelp-specific	• In the canopy at or near the surface • In forests protected from wave exposure

3. Translating Chemical Changes into Species' Responses

Credit: Eric Heupel

While we are beginning to gain a better understanding of the effects of SAV on carbonate chemistry, the effects of these changes in pH mean and variability on a given species' growth, calcification or survival is still an active area of research. There are many complex community interactions and species attributes that must be considered when exploring the ability of SAV to ameliorate OA to a degree that will have a positive benefit to species. These include organisms' growth rates and biomass, water flow, particle concentrations, nutrients, light, dissolved gases and predation (Fig. 3).

In addition to teasing apart community interactions, it is still unclear whether organisms are most sensitive to changes in mean vs. minimum or maximum pH. For example, there may be instances where average pH may not change with the presence of SAV, but the minima or maxima may be affected. To date, most organismal studies have focused on the effect of mean state chemical changes on organisms (e.g., Kroeker et al., 2010; Kroeker et al., 2013). Whether these effects are larger or smaller than effects of changing the minimum or maximum pH caused by SAV for brief periods each day are unknown, though this is an active area of research. Additional paired chemical and biological studies should focus on addressing these gaps.

If we extrapolate from existing laboratory and preliminary field studies, potential species likely to benefit from pH buffering include:

- Calcifying species living within or very close to SAV, or mobile species able to move into SAV habitats during times of high net photosynthesis
- Sensitive early life history stages (larvae and juveniles) of species that develop during summer or other periods when SAV NEP is high

Results from research on species living inside and outside of eelgrass beds are mixed. In Washington state, preliminary field studies have found that juvenile Pacific and Olympia oysters grew 20% faster in eelgrass, though geoducks showed no difference (WDNR, 2016). Similarly, juvenile Pacific oysters in Netarts, Oregon had higher growth and survival in *Z. marina* beds, but not in *Z. japonica* beds (Smith, 2016). Washington Department of Natural Resources and University of Washington scientists are now testing whether eelgrass can improve pH conditions for shellfish beyond the meadow (WDNR, 2017), though modeling efforts suggest the spatial extent of pH buffering may be limited (Koweek et al., 2017a, unpublished).

Other work has shown that clams grew slower (Greiner, 2017), and oyster survival was reduced inside eelgrass beds (Alex Lowe, unpublished data). Eelgrass alters many other factors beyond pH including predator abundance, food availability and oxygen concentrations that could explain variable responses and the net effect of SAV on production of shellfish remains unclear.

While the ameliorating effect of SAV on average pH is likely to be relatively small compared to pH variability within a seagrass bed, it is important to recall that the pH scale is logarithmic: a 1 unit change in pH is a 10x change in acidity. Furthermore, these small observed changes may be of similar magnitude to anthropogenic changes in pH projected for coastal oceans (Pörtner et al., 2014). Thus, even seemingly small pH amelioration by SAV could result in relatively significant effects (e.g., increased survival, calcification, growth, development and abundance) for a variety of species, especially their early life stages (Kroeker et al., 2013). Bivalve shellfish (oysters, clams) experience windows of heightened sensitivity to OA (hours to days), especially during their early life stages (Smith, 2016; Waldbusser et al., 2013; Waldbusser et al., 2015). Daily increases in pH due to daytime SAV photosynthesis can be very large, and if these coincide with the windows of heightened sensitivity, or during high CO_2 events (e.g., upwelling periods), the benefits could be sizable. Indeed, early evidence from field studies suggests that the increase in daily pH maxima by SAV benefits calcifiers and may be more important than the more modest increase in average pH (Smith, 2016).

Alongside understanding community interactions, understanding whether species benefit from the presence of SAV requires weighing the temporal and spatial scales over which benefits may be conferred alongside timescales of management interest. For example, if a manager is interested in improving pH conditions over seasonal time periods to provide favorable conditions for local spawning activity for an endangered species, a bed that persists for several years will likely provide justifiable arguments for restoration and/or protection. However, if a manager is hoping to make the case for long-term benefits (e.g., carbon sequestration) to generate support for multi-million dollar funding or be eligible for revenues from California's Cap-and-Trade program, benefits must be quantifiable and demonstrated to persist for longer time scales. Natural resource managers must also identify clear spatial management goals with respect to restoration and protection of SAV habitats. Is the goal to maintain a single bed, or maintain a certain percent cover in a bay or throughout the state? Different levels of effort, coordination, and funding are required for each, and the potential benefits to species and communities will vary.

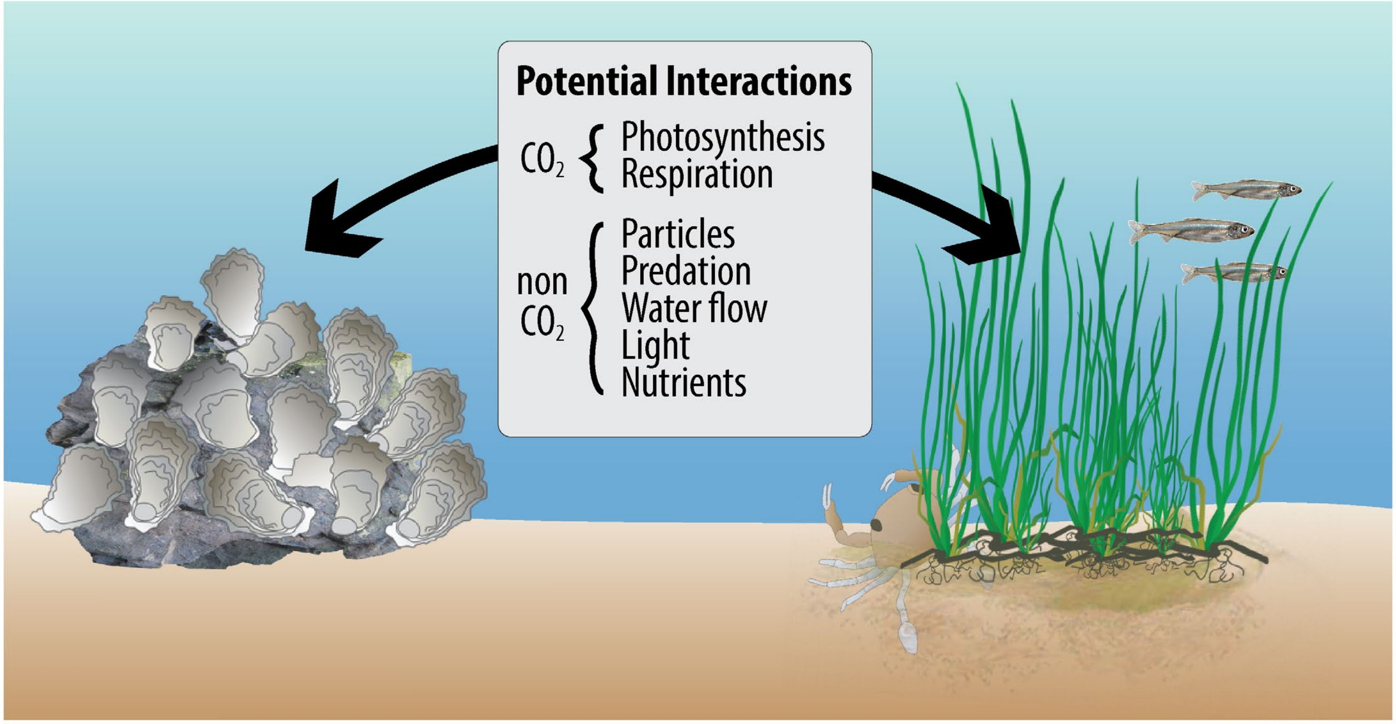


Figure 3. Complex community interactions in SAV habitats span many resources.

Predation on bivalves can be reduced (due to a refuge effect) or increased (due to higher density of predators) by the presence of seagrass. Particle concentrations can be reduced due to the settling of particles as water velocity drops inside a bed, but turbidity can also be increased if sediment or epiphytic algae on leaves is resuspended by currents. Reduced water in eelgrass can decrease food delivery rates to suspension feeding bivalves or enhance them for deposit feeders. Release of nitrogen waste products from bivalve shellfish could enhance seagrass growth, but at high levels it can become toxic. During times of net photosynthesis, CO_2 is removed by eelgrass, which has an indirect positive effect on bivalve shellfish if these conditions improve their ability to calcify. Credit: Adapted from J. Ruesink

4. Next Steps

Credit: NOAA National Marine Sanctuaries

Ongoing research and modeling efforts across the U.S. West Coast are on track to fill many key science gaps in the coming years, including geographic differences among SAV habitats, the sensitivity of amelioration benefits to changes in flow regime, density, seasonal phasing of tides, and incident sunlight, among other factors. With continued investment[1] in a combination of modeling and field studies, and a strengthening of regional collaboration among SAV OA research efforts, we expect significant progress to be made in the next several years. More coordinated research and monitoring (e.g., standardized methods, information sharing, etc.) could greatly advance understanding of the amelioration potential of SAV compared with fragmented studies. A few key next steps for California to consider are outlined in Table 3.

In addition to these near-term needs, longer-term investments in SAV research and monitoring are also required. What are the effects of the buffer capacity of SAV over longer time scales (10+ years)? It is also important to note that pH is not changing in isolation, and factors like sea level rise, hypoxia, and warming sea surface temperature must also be considered. Given multiple stressors and a changing climate, what will these habitats and restoration efforts look like in 20-30 years?

While outside the focus of this working group, there remain many additional science needs regarding SAV and longer-term carbon storage and sequestration (i.e., blue carbon), as well as the role of marsh and other aquatic vegetative habitats. California should continue to explore and elevate these natural solutions as a component of California's climate change adaptation and mitigation strategy.

There is an opportunity to leverage the existing policy interest in OA to identify innovative funding streams for SAV protection and restoration as a "no-regrets" management strategy to prepare for changing ocean chemistry. The California Ocean Protection Trust Fund, as identified in SB 1363, provides a clear framework for funding additional projects consistent with the Ocean Acidification and Hypoxia Reduction Program. We suggest revisiting progress towards the goals of SB 1363 periodically (in 3 to 5 years) to explore whether new knowledge indicates any shifts in the results and preliminary conclusions shared here. The OPC-SAT remains committed to supporting the State's investments and tracking scientific progress on these issues for the OPC and natural resource managers across the West Coast.

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[1] A summary of OPC-funded eelgrass OA monitoring projects is provided in Appendix B.

Table 3. Key next steps for California.

1	**Continue to protect and restore what we have**	**Continue to control existing threats that contribute to loss** • Identify and control current stressors to SAV habitats (e.g., eutrophication, turbidity, oil spills, dredging, coastal development, invasive species, etc.) that result in SAV loss and degradation. **Continue small-scale restoration efforts** • Continue to restore eelgrass beds in many locations through a phased experimental approach as a “no regrets” management strategy beginning with small-scale restoration actions. These efforts can include small monitoring projects that assess existing status of SAV, implementing “test plots” (i.e., small-scale plantings to assess in a low-cost approach whether a site is suitable for restoration). Results from these smaller-scale assessments and restoration efforts can inform selection of the best sites for potential large-scale restoration.
2	**Better accounting of current and future potential SAV habitats throughout California**	**SAV mapping and spatial planning** • Identify clear spatial management goals with respect to restoration and protection of SAV habitats. • Map current eelgrass and kelp abundance, distribution and condition throughout California, and identify potential sites where SAV expansion or restoration is likely to be most successful. New sea level rise projections and habitat mapping efforts can help identify ideal locations where habitat expansion may be possible or where habitat may be lost.
3	**Identify characteristics of SAV that hold the greatest potential for OA amelioration**	**Document magnitude and spatial extent of chemical amelioration** • Expand chemical and biological monitoring efforts in seagrass and kelp habitats throughout California to better characterize spatial and temporal variability in biogeochemistry among sites. Leverage existing SAV monitoring, restoration, and mitigation efforts to include measurements of carbonate chemistry, NEP and residence time in order to better understand OA amelioration potential of a range of habitats. • Investigate whether downstream plume or ecosystem-wide effects are evident. • Develop models to predict when and where OA benefits are maximized. Validate models at sites where monitoring is already occurring. Use these indices to identify other potential sites for conservation, restoration, and planning. **Understand species responses** • A better understanding of how multiple effects of SAV on species of management interest are integrated over the life of an organism are needed to place potential benefits of OA mitigation in context of other impacts on food provision and habitat structure. • Knowing impacts of pH variation caused by SAV and not just changes in mean pH is critical for developing an accurate estimate of biological effects of chemical changes. Responses may not be linear and pH threshold effects may be common. **Aquaculture implications** • Explore aquaculture or farming of SAV as a spatially limited mitigation measure (e.g., near shellfish farms) (see Davis et al., 2016)
4	**Apply information to natural resource management efforts**	• Use model indices, monitoring efforts, and information from experimental restoration projects to identify SAV sites for conservation, restoration and aquaculture based on their potential for OA amelioration.

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Appendix A: OPC-SAT Working Group Workshop, May 2, 2017 Agenda

May 2, 2017
East Bay Community Foundation
James Irvine Conference Center, Plaza Room A
353 Frank H Ogawa Plaza, Oakland, CA 94612

Workshop Goal

- Develop a shared understanding of the state of the science on the ability of seagrass and kelp habitats to ameliorate ocean acidification in a California-specific context
- Identify research and monitoring gaps
- Provide recommendations for future work, including criteria to consider when selecting locations for additional demonstration projects in California

Agenda

9:00 AM - 9:30 AM **Welcome and Introductions**

Hayley Carter, Ocean Science Trust

Co-chairs: Karina Nielsen, San Francisco State University and Jay Stachowicz, UC Davis

Questions for the group to consider throughout the day:

- Where are we with regards to answering when, where, and conditions under which SAV restoration and/or protection will have a measurable benefit? What is the status of knowledge on the short-term OA amelioration potential of seagrass and kelp in the context of the many co-benefits these habitats provide?
- What additional research/monitoring and demonstration are needed in California to get at a better answer?
- Based on our current understanding of the ability of seagrass and kelp habitats to ameliorate OA, what are some steps that managers can take now to maximize these benefits?

9:30 AM - 10:45 AM **Presentations and Discussion**

A series of 10-minute presentations with time for discussion after each.

Setting the Stage: California Management-Policy Overview

Jennifer Phillips, California Ocean Protection Council

Marilyn Latta, State Coastal Conservancy

Hosted by Ocean Science Trust with support from California Ocean Protection Council

Science Updates

- Francis Chan, Oregon State University, former West Coast OAH Panel co-chair (OAH Panel perspective; summary of ongoing work in OR)
- Karina Nielsen, San Francisco State University (summary of SFEI OA Monitoring Workshop outputs)
- Tessa Hill, UC Davis (summary of UC Davis Seagrass Workshop outputs and current demonstrations projects in Humboldt, Tomales and Newport bays)

10:45 AM - 11:00 AM **Break**

11:00 AM - 12:00 PM **Presentations and Discussion, con't.**

Joe Tyburczy, Sea Grant Extension (summary of existing work in Humboldt bay)
Jennifer Ruesink, University of Washington (summary of ongoing work in WA)
Kerry Nickols, CSU Monterey Bay (summary of existing work on kelp)

12:00 PM - 1:00 PM **Working Lunch (if needed)**

1:00 PM - 2:00 PM Break-out Session I: Seagrass as an OA Management Tool

The group will separate into several smaller groups to each address questions in the following topic areas.

Status of knowledge

- Based on our current understanding from existing research/monitoring and demonstration projects:
  - What can we say (or not say) about the ability of seagrass to provide short-term OA amelioration?
  - What are we likely to learn (with additional research/monitoring/funding, etc.) over the next 5 years? 10 years?
- What does an ideal "OA and aquatic vegetation demonstration project" look like with regards to seagrass habitats? In other words, what are some best practices for monitoring seagrass and quantifying OA amelioration potential:
  - If you had limited funding, but wanted to begin considering OA in restoration/conservation planning efforts? (i.e., what is needed at a minimum?)
  - If you had unlimited funding? (i.e., what would be "nice"?)

Challenges

- What are the main challenges for use of seagrass as an OA management tool? Are there ways to mitigate these challenges?

Looking Forward

- What criteria should be considered when selecting locations in California as likely candidates for future focus?
- What are steps managers can take now?
- What are some future science needs?

2:00 PM – 2:30 PM **Seagrass Report Back**

Each group will have 10 minutes to report back from their breakout group.

2:30 PM - 2:40 PM **Break**

2:40 PM - 3:40 PM Break-out Session II: Kelp as an OA Management Tool

- Based on our current understanding from existing research/monitoring and demonstration projects:
  - What can we say (or not say) about the ability of kelp to provide short-term OA amelioration?
  - What are we likely to learn (with additional research/monitoring/funding, etc.) over the next 5 years? 10 years?
- What does an ideal "OA and aquatic vegetation demonstration project" look like with regards to kelp habitats? In other words, what are some best practices for monitoring kelp and quantifying OA amelioration potential:
  - If you had limited funding, but wanted to begin considering OA in restoration/conservation planning efforts? (i.e., what is needed at a minimum?)
  - If you had unlimited funding? (i.e., what would be "nice"?)

Challenges

- What are the main challenges for use of kelp as an OA management tool? Are there ways to mitigate these challenges?

Looking Forward

- What criteria should be considered when selecting locations in California as likely candidates for future focus?
- What are steps managers can take now?
- What are some future science needs?

3:40 PM – 4:10 PM Kelp Report Back

Each group will have 10 minutes to report back from their breakout group.

4:10 PM - 4:45 PM Summary and Wrap-up

- Review and refine draft report outline; delegate writing responsibilities for products
- Share timeline for writing, reviewing products, and communications
- Update for the Ocean Protection Council Science Advisory Team workshop on May 23
- Discuss legislative briefing opportunities

Workshop Attendees

Working Group Members

Karina J. Nielsen, San Francisco State University, Co-chair
Jay Stachowicz, University of California, Davis, Co-chair
Kerry Nickols, California State University, Northridge
Jennifer Ruesink, University of Washington
Kevin Hovel, San Diego State University
Francisco Chavez, Monterey Bay Aquarium Research Institute
Katharyn Boyer, San Francisco State University
Francis Chan, Oregon State University
Matther Bracken, University of California, Irvine
Joe Tyburczy, Sea Grant Extension Fellow

Additional Workshop Participants

Esther Essoudry, California State Lands Commission
George Leonard, Ocean Conservancy
Hayley Carter, Ocean Science Trust
Jennifer Phillips, Ocean Protection Council
Juan Altamirano, Audubon
Kerstin Kalchmayr, California State Coastal Conservancy
Laurel Kellner, Ocean Science Trust
Liz Whiteman, Ocean Science Trust
Marilyn Latta, California State Coastal Conservancy
Melissa Kent, Ocean Science Trust
Melissa Rosa, NOAA Office of Coastal Management
Sara Briley, Ocean Protection Council
Sarah Wheeler, Ocean Science Trust
Tessa Hill, UC Davis
Tom Maloney, Ocean Science Trust

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Appendix B: OPC-funded OA Monitoring Projects in Eelgrass Beds Throughout California

In 2016, the California Ocean Protection Council invested in several ongoing and new comparative eelgrass field studies designed to evaluate the potential of eelgrass to ameliorate OA and store carbon in the water and sediments (Table 4). Field monitoring data will be instrumental to advancing understanding of differences in the ability of seagrass to ameliorate OA based on geography, bed biomass and density, and restored compared with naturally established beds to help inform decision-making.

These projects were established in eelgrass beds in Bodega Bay, Tomales Bay, Humboldt Bay, Elkhorn Slough, Newport Back Bay, and San Diego Harbor (Figure 4).

These projects seek to broaden understanding of:

- short and long-term potential for eelgrass beds to modify estuarine chemistry and store carbon
- geographic differences in the ability of eelgrass to ameliorate OA
- eelgrass bed densities that may maximize carbon services
- differences between successfully restored and natural eelgrass beds

Preliminary results from ongoing eelgrass demonstration projects in California are discussed throughout this report.

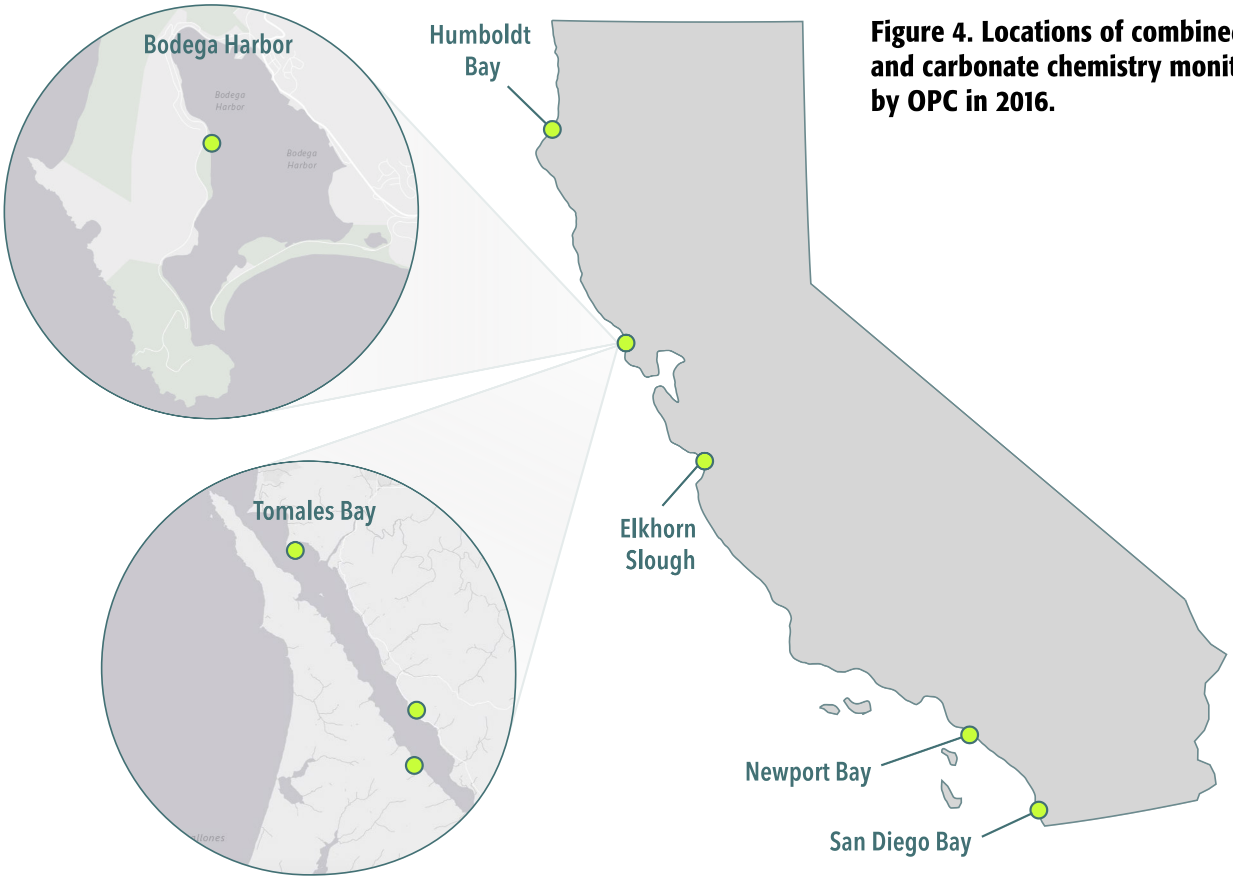

Figure 4. Locations of combined eelgrass and carbonate chemistry monitoring funded by OPC in 2016.

Table 5. List of 2016 OPC-funded eelgrass and OA monitoring projects.

Project title	Vegetation type	Project leads	More info	Location(s)	Key science needs addressed	Timeline
Potential seagrass buffering of Humboldt Bay to ocean acidification and implication for aquaculture industry and hatchery and eelgrass managers	Eelgrass	Humboldt State University	OPC Resolution	Humboldt Bay	• Potential magnitude of chemical amelioration • Downstream plume effects to broader ecosystem • Inventory abundance, distribution, and condition • Climate change drivers to SAV • Key species impacts	2 years
Seagrasses' ability to ameliorate estuarine acidification	Eelgrass	UC Davis, UC Santa Cruz, and Orange County Coastkeeper	OPC Resolution	Bodega Harbor, Tomales Bay, Eklhorn Slough, Newport Back Bay, San Diego Bay	• Temporal variation (seasonal, diel, annual) • Carbon storage • Ideal bed size, density • Difference between restored vs. native beds • Key species impacts	2 years

California Ocean Protection Council
OPC-SAT
Science Advisory Team

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Developed by a Working Group of the Ocean Protection Council Science Advisory Team and
Ocean Science Trust with funding from the California Ocean Protection Council

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