CALIFORNIA OCEAN SCIENCE TRUST

STATE OF THE SCIENCE

CARBON ACCOUNTING METHODS AND SEQUESTRATION BENEFITS OF CALIFORNIA WETLANDS

May 2020

Image: Melssa Ward

About the Report

This report was developed by Ocean Science Trust in consultation with science and government experts in salt marsh, seagrass, and kelp blue carbon in California. It is a rapid assessment of the latest science, management and policy challenges, and knowledge gaps. Funding was provided by the California Ocean Protection Council. For a list of consulted experts, see Appendix D.

Relevant OPC Strategic Plan Goals & Targets

GOAL 1: SAFEGUARD COASTAL AND MARINE ECOSYSTEMS AND COMMUNITIES IN THE FACE OF CLIMATE CHANGE

1.1.7: Work with partners to ensure an additional 10,000 acres of coastal wetlands will be protected, restored or created by 2025, and increase the acreage of coastal wetlands in California, as defined by the coastal wetlands inventory described below, by 20% by 2030 and 50% by 2040.

- Action: Develop a standardized approach for optimizing coastal wetland climate resilience, carbon sequestration, flood control, and biodiversity benefits by 2022. (OPC Lead)
- Action: Develop innovative approaches to accelerate wetland and seagrass habitat creation and restoration including, but not limited to, developing and/or enhancing wetland and seagrass mitigation banking, blue carbon mitigation banking, cutting the green tape to accelerate habitat restoration and creation projects, green infrastructure projects, creative finance instruments, and other possible solutions.

1.2.4: Ensure implementation of California's Ocean Acidification Action Plan's Goals by 2023.

1.3.1: Identify and continue to fund and house needed climate-related data collection, research, and dissemination, with summary reports issued in 2022 and 2025.

- Action: Fund research to better quantify the evolving role of aquatic vegetation (including submerged aquatic vegetation) in mitigating ocean acidification and storing carbon

GOAL 3: ENHANCE COASTAL AND MARINE BIODIVERSITY

3.1.4: Work with partners to preserve the existing, known 15,000 acres of seagrass beds and create an additional 1,000 acres by 2025

- Action: Support projects that protect existing and potential eelgrass habitats as identified in habitat suitability mapping, consistent with the National Marine Fisheries Service's California Eelgrass Mitigation Policy as key policy and technical guidance for protecting and restoring eelgrass.

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Executive Summary

California Overview

- Coastal wetlands in California, including tidal salt marsh (over 1200 km^2) and seagrass habitats (over 60 km^2 of eelgrass), are important blue carbon sinks that offer the possibility to mobilize additional funding for restoration by combining coastal management with climate change mitigation goals and needs (Wedding et al., in press).
- Researchers disagree as to whether kelp can play a significant role in blue carbon. While efforts have been made to model potential carbon sequestration from kelp, there is an obvious lack of empirical evidence of these processes.
- For California coastal wetlands, there are a range of carbon accounting methods that require varying levels of quantification and site-specific data, including:
  - Four coastal wetland carbon offset methodologies certified for use in California's GGRF programs
  - Best practices and protocols for blue carbon field measurement/monitoring
  - Carbon modeling (InVEST Natural Capital model)
- Statewide, there is relatively good carbon and net GHG accounting in salt marsh habitats across the state based on a series of field studies, including projects from the CDFW Wetlands and Watersheds GGRF program; however, a comprehensive carbon stock accounting for the state that includes seagrass and kelp habitats has not been done.
- Work is currently underway to quantify sediment carbon stocks in seagrass meadows in Mission Bay, Newport Back Bay, Elkhorn Slough, Tomales Bay, Bodega Bay, and Humboldt Bay, with results expected in 2020; early results suggests that grain size is a good predictor of carbon sequestration rates in eelgrass (M. Ward, personal communication), thus an analysis of grain size across the state might allow for potential rapid assessment of priority eelgrass protection and restoration sites that maximize carbon sequestration rate.

Data Gaps

- Data gaps include better California-specific field measurements of net GHG emission, methane emissions; understanding of differences in carbon sequestration rates in restored wetlands; data on lateral fluxes of carbon; seagrass habitat mapping statewide
- Species-specific and site-specific rates of carbon storage, export, and sequestration. This is especially true for Bull kelp and some seagrass species (e.g. *Zostera pacifica*).
- Relative contribution and amount of kelp-derived carbon through specific export pathways.
- Degradation and decay rates, and location of kelp biomass exported offshore.

Management and Policy Overview

- For coastal wetlands, management activities that reduce nutrient inputs, avoid unnaturally high levels of bioturbation (dredging, boat anchoring), and restore natural

hydrology (freshwater flows and tidal exchange) are likely to maximize blue carbon sequestration and minimize blue carbon losses
- To date, more than $11 billion dollars of Cap-and-Trade proceeds have been appropriated as part of the Greenhouse Gas Reduction Fund (GGRF) via California Climate Investments
- Blue carbon has generally received less attention in the GGRF program given the small acreage of coastal wetlands compared with other land-based locales (forestry, agriculture), and that there are fewer activities that reduce or offset ocean and coastal emissions activities compared with land activities
- Agencies with ocean and coastal jurisdiction that currently or historically have received GGRF monies include: CDFW, CSCC, BCDC, CCC. Of these agencies, the CDFW Wetlands and Watersheds program is the most consistently funded and one of the few programs whose grants go towards coastal wetland blue carbon projects; no projects currently consider seagrass blue carbon (though methods exist that could be leveraged)
- There are two types of markets for carbon offset trading in CA: the compliance market and the voluntary market. Offset projects must showcase measurable, quantifiable, verified units of GHG emissions reductions to be eligible for offset trading.
    - Currently, offsets from tidal wetlands restoration can only be sold to voluntary offset buyers, though there may be opportunities to fill data gaps via pilot projects so that tidal wetlands may be eligible in the future
    - Coastal wetland projects are eligible to generate voluntary offsets but project costs are expensive. At current carbon prices on the voluntary market, the cost of implementing a carbon project in California coastal wetland habitats likely outweighs any potential carbon offset revenues unless projects are > 1000 acres. However, practitioners often use the voluntary market to test carbon accounting methods that can later be certified for use in generating compliance offsets.
- There are opportunities to leverage habitat goals and efforts identified in the *Natural and Working Lands Implementation Plan* (i.e., doubling the rate of State-funded wetland and seagrass restoration by 2030); leveraging identified partnerships can help advance towards OPC Strategic Plan targets

I. Overview: Coastal Blue Carbon Habitats in California

Salt Marsh and Seagrass Blue Carbon

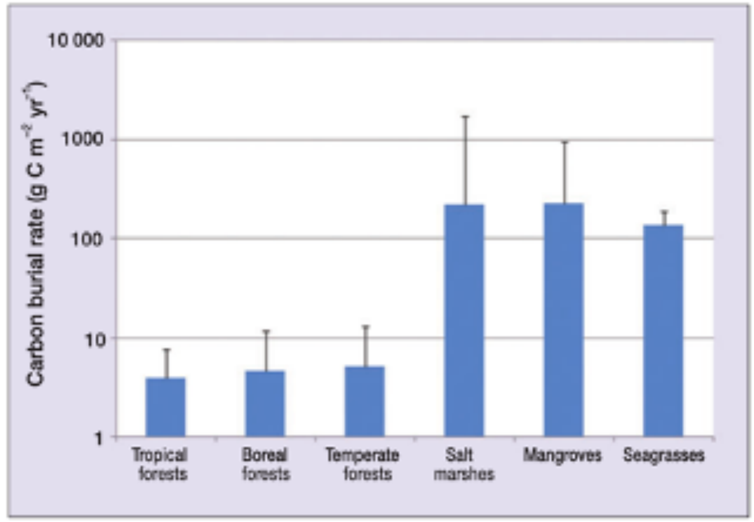

Figure 1. Mean long-term rates of carbon sequestration across different habitat types, from

Coastal wetlands such as salt marshes, mangroves, and seagrasses have the potential to sequester carbon (blue carbon) at rates an order of magnitude higher than terrestrial forests, and while geographically limited, play a large role in carbon cycling globally (Mcleod et al., 2011; Murray et al., 2011) (Figure 1). If restored and protected, blue carbon habitats accomplish two goals with respect to greenhouse-gas (GHG) emissions: 1) avoiding added emissions to the atmosphere from the destruction of these habitats' large carbon reservoirs, and 2) contributing to continued carbon trapping and sequestration in perpetuity. The capacity of these already highly valuable habitats to not only store carbon, but offer additional carbon capture capacity makes them a strong focus for climate change mitigation efforts as well as coastal adaptation planning.

In California, coastal blue carbon habitats consist of tidal salt marsh and seagrass (eelgrass) habitats with organic and mineral soils and a salinity above 18 ppt[1] (as methane emissions are negligible in marine and estuarine environments where sediment pore water salinities are greater than 18 ppt) (Box 1). These habitats remove carbon from the atmosphere through photosynthesis and by trapping and storing organic carbon in their biomass and sediments, and via transport of organic carbon to the deep sea (Figure 2). This carbon can remain in above-ground biomass for decades and in sediment for thousands of years (Duarte et al., 2013). However, blue carbon habitats are rapidly being lost worldwide, as well as in the U.S., which results in released carbon emissions to the atmosphere. Though given their role in carbon sequestration and storage, coastal wetlands are a potential tool for addressing climate change and offer the possibility to mobilize additional funding for restoration by combining coastal management with climate change mitigation goals and needs (Howard et al., 2014).

Kelp forests play a lesser role in carbon sequestration. Carbon storage occurs via the export of particulate and dissolved organic carbon to the deep sea and continental shelf where carbon is

[1] At soil salinities above 18 ppt, bacteria that mineralize organic carbon in concert with sulfate reduction are thought to outcompete methanogenic bacteria that decompose carbon anaerobically and produce methane - a highly potent GHG (Reference: Fenchel and Blackburn 1979; Morris and Whiting 1986; Elkhorn Slough ID6).

buried in soft sediment. There are many alternative reasons to protecting and restoring these habitats, including their role as OA refugia, so their blue carbon function is not covered here in detail.

Coastal wetlands have lost about 90% of their former extent.[2] Current estimates of California tidal salt marsh habitat is ~1200 km^2 and eelgrass is ~60 km^2 (Wedding et al., in press). Obtaining estimates of carbon stocks and carbon sequestration rates for these habitats statewide, in addition to knowing the potential future habitat expansion, are the first steps in understanding blue carbon opportunities in California. There are a range of methods for carbon accounting, detailed in this report, each requiring different levels of rigor and site-specific data. Statewide, there is relatively good carbon and net GHG accounting in salt marsh habitats across the state based on a series of studies, including projects from the CDFW Wetlands and Watersheds GGRF program. Work is currently underway to quantify sediment carbon stocks in seagrass meadows in several sites in California, with results expected in the next few years. Results from these efforts are detailed later in this report.

For an overview of baseline information for California coastal blue carbon systems, see Table 1.

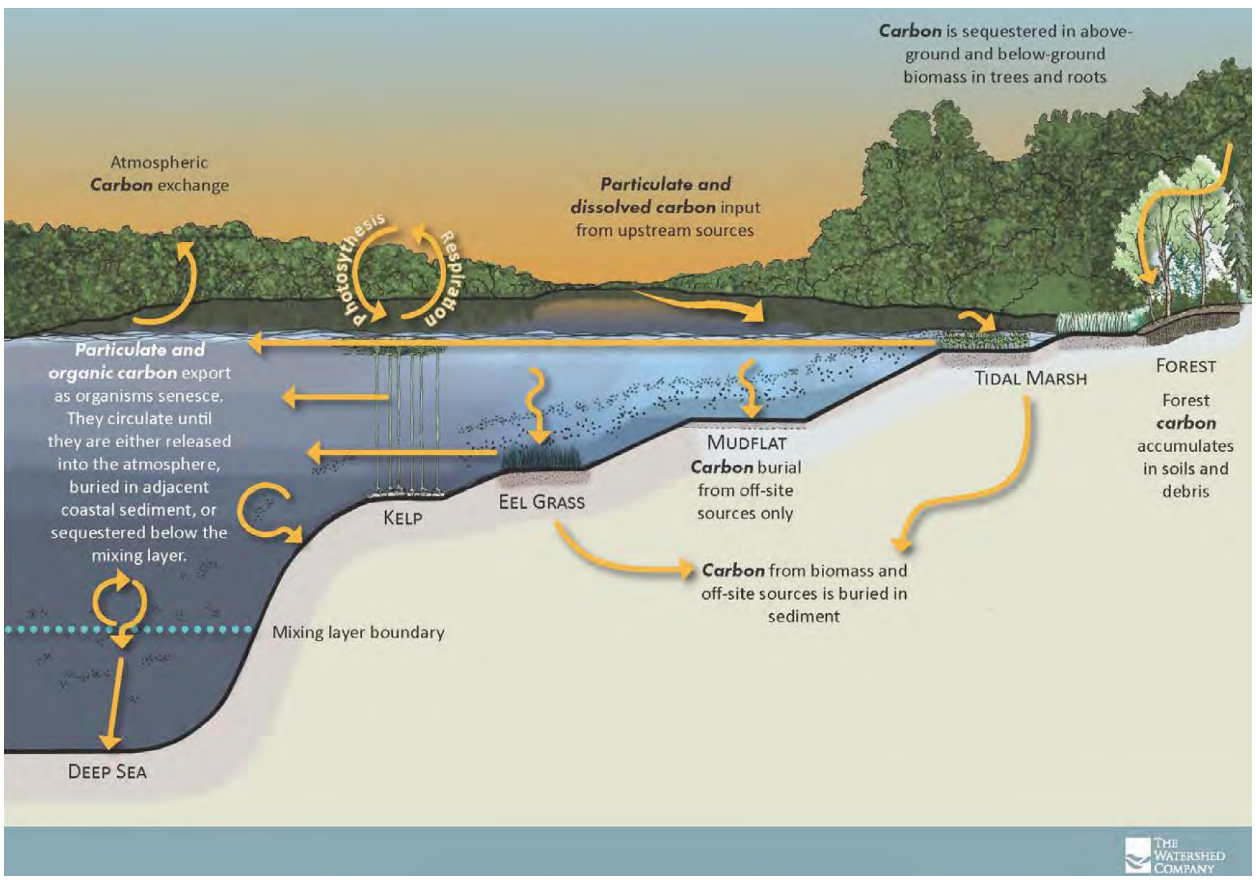

Figure 2. Mechanisms by which carbon moves into and out of coastal habitats (Reference: The Watershed Co).

[2] http://web.csulb.edu/~rodrigue/geog330/wetlands.html

Table 1. Overview of coastal blue carbon systems and baseline data in California. Values are reported means, with ranges included when available.

Coastal wetland type (and best species for carbon accounting)	**Blue Carbon baseline data availability** *(include site-specific where known)*					
	Carbon stock accounting	**Carbon sequestration rate**	**Net GHG emissions quantification (incl. methane emissions)**	**Lateral carbon transport**	**Current habitat coverage and status in CA**	**Equivalent vehicles taken off the road annually, in emissions**
Seagrass meadows Eelgrass (*Zostera marina),* Pacific eelgrass *(Zostera pacifica*). Most CA research is focused on *Zostera marina. Zostera pacific* has very limited distribution.	2,721 g C/m^2 with a range of 318 - 26,523 *(Rohr et al., 2018)*	0 - 37 g C/m^2/yr (with est. in CA sites ranging from 1.58 - 14.2) *(Poppe & Rybczyk 2018; Chumra et al., 2003; Callaway et al., 2012)*	0.42 tCO_2/ha/yr; but CH_4 emissions highly variable *(Oreska et al. 2020, Al-Haj & Fulweiler 2020)*	25% of NPP (120 / 490 Tg C/yr) *(Duarte & Krause-Jensen 2017)*	> 60 km^2 (eelgrass) *(CDFW; Wedding et al, in press)*	*~550 cars*
Tidal salt marsh Cordgrass, salt grass, alkali heath, pickleweed/glasswort, seep weed	25,500 g C/m^2 with a range of 1,600 - 62,300 *(Howard et al. 2014, Byun et al. 2019)*	200 (± 24) g C m^2/yr (Wedding et al, in press)	5.13 tCO_2/ha/yr; but CH_4 emissions highly variable *(Weston et al. 2013, Burchell 2014)*	156 - 414 g C/m^2/yr (DIC only) (Wang et al. 2016, Wang and Cai 2004) *Most (>70%) fixed carbon is returned to atmosphere (as CO^2) or exported as DIC.*	> 1200 km2 *(CDFW; Wedding et al, in press)*	*~133,800* *Tidal marshes are ~10 times more effective compared to seagrasses. Per 10 hectares protected, seagrass carbon storage equates to ~1 car off the road per year, relative to 11 cars for tidal marshes.*
Kelp forest Giant kelp (*Macrocystis pyrifera*), bull kelp (*Nereocystis luetkeana)* Most CA research is focused on Giant kelp. There are significant data gaps for kelp. We provide estimates for all macroalgae, recognizing values may different..	21 - 660 g C/m2 for giant kelp *(Foster & Schiel 1985)*	11% of macroalgae NPP (173 / 1521 Tg C/yr) *(Krause-Jensen & Duarte 2016)*	N/A	82% of kelp NPP contributes to detritus. Unknown whether all material is exported. *(Krumhansl & Scheibling 2012)*	~72 km2 *(CFDW 2016 Shapefile)* *Giant kelp biomass estimates highly variable (Bell et al. 2015)*	

Notes: Kelp coverage was estimated by OST staff using CDFW shapefiles in ArcGIS for the most recent publicly available statewide survey in 2016. Equivalent vehicles taken off road was estimated based on a typical passenger *vehicle emitting ~4.6 metric tons of carbon dioxide per year. This assumes the average gasoline vehicle on the road today has a fuel economy of about 22.0 miles per gallon and drives ~11,500 miles per year.*

Box 1: California Wetland Habitat Breakdown

Coastal wetlands are the primary focus of this report. However, projects within other wetland habitat types including peatlands, agriculture lands, and freshwater wetlands are also being explored for their greenhouse gas reduction or avoided emissions properties.

Broadly, wetlands are land areas that are saturated by water either permanently or seasonally. The water may be fresh (<0.05% dissolved salts), brackish or briny (0.05-3%), or saline (3-5%). Globally, there are three basic types of wetland:

- **Mires or peatlands** - visually dominated by heath shrubs on top of sphagnum moss, with undecayed dead organic matter going down dozens to hundreds of feet.
- **Swamps** - wetlands that are forested
- **Marshes*** - wetlands visually dominated by herbaceous species, and these are what dominate California. These include:
    - **Coastal wetlands***, with varying mixes of brackish and salty water. Within coastal wetlands there are:
        - Bay estuarine marshes
        - River mouth estuaries
        - Lagoons
        - Structural basin marshes
    - **Freshwater wetlands** - areas of persistent wetness along streams and springs
    - **Vernal ponds** - intermittently appear in the winter and spring and then dry out completely in summer

For an overview of peatland GHG potential, see the section “GHG accounting in other wetland habitats: Peatlands” here.

*denotes focus of this report

Comparing Blue Carbon Sinks vs. Land Carbon Sinks

In the U.S., land sinks absorb roughly 29% of the carbon dioxide emissions pumped into the atmosphere each year, and oceans take up about 23% (Wilkinson, 2020). However, while land and ocean sinks are relatively similar in how much CO_2 they absorb annually, activities to reduce emissions or improve coastal and ocean carbon sequestration are far smaller compared with land-based activities (Figure 3). This is due in part because there are fewer activities or projects that improve ocean sinks (i.e., protecting or restoring habitat) or that reduce or offset ocean and coastal emissions activities compared with land activities. Thus while “blue carbon” has generally received less attention in national and state policy and regulatory frameworks, there are still opportunities to advance coastal blue carbon in California, especially as emission allowance permits become more strict (in the state's cap and trade compliance market), as more businesses seek to reduce their carbon footprint via the voluntary market (carbon offset demand increase), and as the price of carbon increases. Some of these opportunities are highlighted throughout this report.

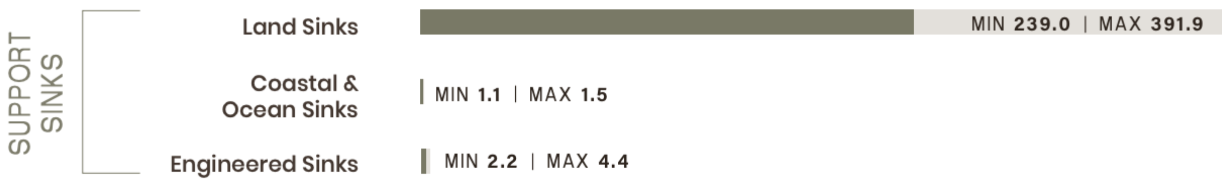

Figure 3. Differences in potential emissions impacts from activities that bolster carbon sinks in the U.S. reported in Min / Max CO2-eq (Gt) reduced/sequestered (2020-2050) (Wilkinson, 2020).

What is a carbon inventory and how is it quantified?

As a first step in addressing the potential role of blue carbon in a system through policy, regulatory, finance or other mechanisms, the carbon stock in these ecosystems (how much carbon is currently stored in a system of known size, e.g. "carbon stock of Tomales Bay") and the existing or potential carbon emissions resulting from changes to those ecosystems (for example via creating new habitat or restoring water flow to a system) must be quantified. This process is known as creating a carbon inventory or assessment, which can be undertaken at site-level, regional, national or global scales. A carbon stock can be quantified by both field and modeling methods (usually a combination of both). For more details on accounting methods, see section *California Carbon Policy and Carbon Markets* (and in Table 2 here) (Howard et al., 2014).

In addition to developing a carbon inventory, some activities, projects, or initiatives also require quantification of other GHG emissions (methane and nitrous oxide), as well as additional co-benefits, among other factors. This includes activities like quantifying the total greenhouse gas emissions or benefits that result from land use changes (for example via programs of the CA Air Resources Board Greenhouse Gas Reduction Fund), or estimating the avoided carbon emissions and the resulting climate change mitigation potential of a given coastal conservation project or activity (Box 2).

There are various "tiers" of detail in carbon inventories that reflect the degrees of certainty or accuracy of a carbon stock inventory or assessment, ranging from tier 1 (less rigorous; achieved by multiplying the area of an ecosystem by the mean carbon stock for that ecosystem type) to tier 3 (most rigorous; validated by direct field measurements or modeling) (Table 3) (IPCC 2013; Howard et al., 2014). The tier approach for an assessment will vary depending on the available data for a system. Additional data collection (e.g., species- or site-specific soil/biomass carbon sequestration rates, methane/nitrous oxide emissions, etc.) can help increase confidence in an assessment, otherwise known averages can be used.

Table 3. Tiers for developing a carbon inventory (IPCC 2013; Howard et al., 2014).

TIER	REQUIREMENTS	COMMENTS
1	IPCC default factors	Tier 1 assessments have the least accuracy and certainty and are based on simplified assumptions and published IPCC default values for activity data and emissions factors. Tier 1 assessments may have a large error range of +/- 50% for aboveground pools and +/- 90% for the variable soil carbon pools.
2	Country-specific data for key factors	Tier 2 assessments include some country or site-specific data and hence have increased accuracy and resolution. For example, a country may know the mean carbon stock for different ecosystem types within the country.
3	Detailed inventory of key carbon stocks, repeated measurements of key stocks through time or modelling	Tier 3 assessments require highly specific data of the carbon stocks in each component ecosystem or land use area, and repeated measurements of key carbon stocks through time to provide estimates of change or flux of carbon into or out of the area. Estimates of carbon flux can be provided through direct field measurements or by modelling.

Box 2: Managing Coastal Systems to Maximize Blue Carbon

Blue carbon projects[3] that can impact a carbon stock or GHG emissions in coastal wetlands include:

- Restoration / protection or creation of habitat
- Creating, restoring and/or managing hydrological conditions (e.g., removing tidal barriers, improving hydrological connectivity, restoring tidal flow to wetlands or lowering water levels on impounded wetlands)
- Altering sediment supply (eg, beneficial use of dredge material or diverting river sediments to sediment-starved areas)
- Changing salinity characteristics (eg, restoring tidal flow to tidally-restricted areas)
- Improving water quality (eg, reducing nutrient loads leading to improved water clarity to expand seagrass meadows, recovering tidal and other hydrologic flushing and exchange, or reducing nutrient residence time)
- Introducing or reintroducing native plant communities (eg, reseeding or replanting) or fauna important to ecosystem function and resilience (e.g. predatory sea stars, sea otters)
- Improving management practice(s) (e.g., fire management)
- Managing activities that impact carbon sinks (e.g., avoid resuspension, changing fishing practices (from fishing or dredging; MPAs and improved seabed management)

A recent study found that reducing nutrient inputs, avoiding unnaturally high levels of bioturbation (dredging, boat anchoring), and restoring natural hydrology (freshwater flows and tidal exchange) will maximize blue carbon sequestration and minimize blue carbon losses (Macreadie et al., 2017).

[3] See the Verra method for full list of activities https://verra.org/wp-content/uploads/2018/03/VM0033-Second-Assessment-Report-DNV.pdf

California Coastal Wetlands Carbon Accounting Methods

For California coastal wetlands, there are a range of methods, protocols, frameworks and tools to quantify carbon stocks (and changes in carbon stocks), carbon sequestration rates, and associated benefits (e.g., net GHG emission reductions/offsets and habitat co-benefits). We have collated the major coastal carbon accounting methods (see Table 2 here) that include:

- **Coastal wetland carbon offset and net GHG methodologies -** Four wetland carbon offset methodologies with different applicability rules for spatial coverage and restoration activities have been developed and certified by various markets; applicable to California's Greenhouse Gas Reduction Fund programs and carbon offset markets
- **Carbon stock assessment methods and best practices -** Coastal blue carbon sequestration rate and carbon stock field measurement/monitoring protocols and best practices for wetlands and seagrass habitats
- **Carbon modeling -** Natural Capital InVEST Blue Carbon model to quantify carbon sequestration, carbon stocks, and carbon finance

Many of these methods stem from or build on one another (for example, many methods pull from the IPCC 2013 wetlands methodology framework), or are modified for specific regions or restoration activities (e.g., for use in the CDFW Wetlands and Watersheds GGRF funding program). Currently, four wetland carbon offset methodologies have been approved for use in the voluntary carbon offset market (e.g., Verified Carbon Standard and American Carbon Registry) (Sapkota and White, 2020; see *California Carbon Policy and Carbon Markets* section below). Other methods are helpful for assessing more general "Tier 1-type" carbon sequestration rates and carbon stocks within a region (e.g., Natural Capital InVEST Blue Carbon Model). There are also methods available to assess and quantify co-benefits (see here), including social, economic, and environmental benefits, which is required as part of the process for CARB California Climate Investments spending.

Kelp Forest Carbon Accounting Methods

The key to determining the kelp blue carbon potential is demonstrating kelp-derived carbon sequestration at sink sites (i.e. sediments) and net greenhouse gas reduction at donor sites (i.e. kelp forests) (Krause-Jensen et al. 2018). While the previous accounting methods may be suitable for coastal wetlands, they may only be appropriate to quantify kelp standing carbon stock. Kelp carbon storage methods are similar to tier 1 accounting methods, in which data on habitat area, plant biomass, and carbon per unit mass of biomass are all that is needed (Hill et al. 2015). Kelp coverage and biomass quantifications can increase in complexity, similar to the increasing tier approach, by incorporating spatial and temporal variability using satellite and unmanned aerial vehicle (UAVs) imagery and habitat distribution models (Bell et al. 2015, Bell et al. 2018, personal communication).

For a kelp forest to serve as a donor site, there must be high rates of biomass production, turnover, and export to sink sites (Hill et al. 2015). Kelp biomass export to sink sites (i.e. deep sea, continental shelf) is heavily influenced by biomass buoyancy and ocean currents (Dugan et al. 2018), while eventual burial is influenced by particle decay and microbial activity. To achieve successful burial, sink sites need to have efficient burial rates to avoid microbial activity and carbon release back into the water column (Hill et al. 2015).

For kelp, accounting methods need to incorporate other datasets on the fate of kelp-derived carbon. Previous estimates of kelp carbon sequestration have been made by taking the theoretical difference in net primary production and the relative contribution of carbon fate through key pathways (Fig X) (Krause-Jensen & Duarte 2016). Macroalgae could sequester ~173 TgC/yr, globally, with approximately 11% of total net primary production being sequestered (Krause-Jensen & Duarte 2016, Krause-Jensen et al. 2018). While researchers can estimate how much carbon could get sequestered, it is more difficult to demonstrate sequestration and prove buried carbon is derived from kelp forests (Krause-Jensen et al. 2018). Tracing carbon back to kelp forests would no doubt be useful and required to verify the effectiveness of blue carbon-related projects, such as restoration or conservation.

Why apply one method over another? Depends on the end goals.

It is important to note the difference between quantifying carbon stocks (a snapshot), carbon sequestration rates, and net greenhouse gas reduction (which is a factor of habitat sequestration rates, changes in carbon stock, and other values like methane emissions). For example, knowing sequestration rates or carbon stocks alone may tell you something about a location's general "blue carbon" potential, but "blue carbon" GHG benefits are realized when a project activity produces a quantifiable net greenhouse gas reduction that persists over a certain time period (often 50 - 100 years). However, these same habitats provide a variety of climate change co-benefits beyond blue carbon, thus knowing the management, habitat, and policy goals at the outset will be important in guiding which carbon accounting method is appropriate for a given circumstance.

Different methods require varying levels of rigor and site-specific data. For example, if a land manager is interested in habitat restoration in Elkhorn Slough with the goal of generating GHG offsets in the voluntary carbon market in California, a highly quantitative method and multi-year monitoring protocol that can verify GHG benefits persist for many years will be required (and subsequently such carbon benefits must be verified by a third party accreditation body like Verified Carbon Standard and American Carbon Registry). Thus, in addition to typical restoration costs, additional "carbon project costs" are high for eligibility on the voluntary carbon market, so projects like this tend to only make financial sense (i.e., carbon revenues to cover carbon costs) if the project wetland is >500 hectares (1,000 acres) (PNW Carbon Finance project). See additional information in the *Voluntary Offset Markets* section below.

However, if a decision-maker is interested in a general estimate of blue carbon stocks statewide, or understanding carbon benefits alongside a suite of other habitat co-benefits to assess where to put limited restoration or habitat protection funding to meet climate change and other habitat restoration goals, less costly and less data- and resource-intensive quantification methods can be used. Knowledge gaps and opportunities to use these verification methods and better understand drivers of sequestration rates, at the project- and local-scale, are discussed later in this report.

II. Latest Research in California

California's Blue Carbon Accounting: What do we know?

Salt Marsh Carbon Accounting

Carbon cores and various carbon accounting parameters (sequestration rates, accretion) have been collected (or are currently being collected) in many salt marsh locations in California by various research programs (Figure 4)[4] (Nalik and Fennessey 2011). In addition, detailed net GHG inventories have been assessed (or are currently being assessed and monitoring) on a site-specific basis for some salt marsh habitats, funded as part of the CDFW Wetlands and Watersheds GGRF program under California Climate Investments GGRF program. This includes Elkhorn Slough, Ocean Ranch, Suisun Marsh, Santa Barbara North Campus coastal wetland, and Seal Beach salt marsh (see CDFW project map).

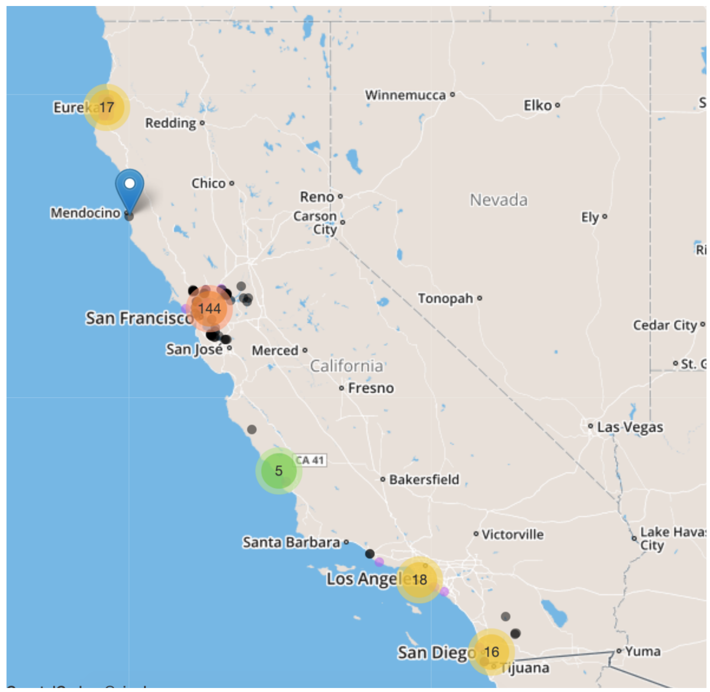

Figure 4. California salt marsh locations where carbon stocks are being assessed.

For the West Coast more broadly, the efforts of the Pacific Northwest (PNW) Blue Carbon Working Group are a particularly good model for California to consider emulating statewide. The Working Group has completed the first comprehensive blue carbon assessment in PNW tidal wetlands (including two sites in Humboldt Bay, California), with a regional blue carbon database expected soon (Kaufman et al., 2019; see also PNW project page here).

In addition, the Natural Capital InVEST Blue Carbon Model is being used to map current carbon storage, measure sequestration over time, and estimate the value of carbon sequestration (Wedding et al., in press; Sharp et al., 2018).

[4] A map of current locations where coastal blue carbon is being evaluated (both California-specific and nationally) can be found on an interactive map here: https://ccrcn.shinyapps.io/CoastalCarbonAtlas/

Seagrass Carbon Accounting

Carbon accounting in the state's seagrass habitats is very limited, with minimal published information on California habitats. One study in 54 eelgrass (*Zostera marina*) meadows spread across eight ocean margins suggest high variability in carbon stocks across sites (Rohr et al., 2018), necessitating species and site-specific data for accurate accounting. A recent study also suggests high variability within a site (Ricart et al., 2020). Ongoing research suggests that grain size (moderate) is a good predictor of carbon sequestration rates in eelgrass (M. Ward, personal communication), thus an analysis of grain size across the state might allow for potential rapid assessment of priority eelgrass protection and restoration sites that maximize carbon sequestration rate.

Work is currently underway to quantify sediment carbon stocks in seagrass meadows in Mission Bay, Newport Back Bay, Elkhorn Slough, Tomales Bay, Bodega Bay, and Humboldt Bay, with results expected in 2020 (Ward et al. in prep, O'Donnell et al. in prep). Research quantifying the lateral carbon transport and sources of carbon buried in seagrass meadows has already been conducted in Tomales Bay (Capece et al. in prep. Ward et al. in review). One field study has examined the ability for seagrasses to draw down atmospheric CO_2 (quantified via eddy covariance) in Tomales Bay. This is one of the more challenging carbon fluxes to quantify, and the only existing dataset of this nature along the west coast (Ward et al. in review).

As these studies and other comparable studies come to fruition, a more holistic view of system-level carbon cycling in California seagrass meadows will be available, including understanding the quantities of carbon stored and transferred under various timescales (Melissa Ward, personal communication).

Kelp Forest Carbon Accounting

Studies quantifying kelp carbon sequestration are minimal. Using wet weight equivalents and carbon biomass equivalents, one study estimated that 16.5 gC m-2 d-1 of giant kelp biomass, in the form of drifters, is exported through the Carmel Canyon, California (Harrold et al., 1998). Importantly, most California research efforts have focused on mapping kelp coverage and biomass fate, instead of explicitly demonstrating carbon sequestration.

California has rich datasets on the spatial and temporal trends of kelp canopy coverage and biomass, collected by state agencies (e.g. CDFW) and academic and research institutions. As early as 1989, CDFW has conducted coastwide aerial surveys of kelp canopies and creates publicly available spatial data layers with this data (CDFW) These datasets are complemented by decades worth (as far back as 1984) of satellite imagery and remotely sensed data (Bell et al. 2018). These endeavors have demonstrated the extreme variability in kelp coverage and biomass, as well as their environmental and potential biological controls (Bell et al. 2018, Cavanaugh et al. 2011, Cavanaugh et al. 2019). This information could be useful to quantify kelp carbon stock using the tiered accounting approach for coastal wetlands.

Lastly It is widely assumed most kelp production is exported as large floating rafts, sometimes occurring in high densities and exporting hundreds of kilometers offshore or along beaches (Krause-Jensen & Duarte 2016, Harrold & Lisin 1989, Hobday 2000, Dugan et al. 2018). These export pathways can be seasonally variable and depend on local ocean circulation, biomass, buoyancy, and coastal topography (Dugan et al. 2018).

GHG accounting in other wetland habitats: Peatlands

Peatlands are a type of wetland which are the largest natural terrestrial carbon store worldwide, sequestering 0.37 gigatonnes of carbon dioxide (CO_2) a year – storing more carbon than all other vegetation types in the world combined[5] (Limpens and others 2008). Peatlands are found at all latitudes, and include brackish coastal estuaries, freshwater river deltas, tropical swamps, inland bogs, and fens (Dise 2009). Under natural, unmanaged conditions, peatlands are sinks for atmospheric CO_2, because waterlogged soil conditions inhibit aerobic decomposition, favoring the accumulation of soil organic matter (Dise 2009). However, peatlands do not always exert a net "cooling" effect on the atmosphere because they also emit non-CO_2 greenhouse gases including methane and nitrous oxide (approximately 25x and 298x more potent GHG, respectively, compared with CO_2) (Dise 2009; Frolking and Roulet 2007).

In the Sacramento-San Joaquin Delta, 7,000 years of organic matter buildup had produced a carbon-rich peat layer up to 15 meters deep. These peatlands are the primary conduit for urban and agricultural water for the state of California, and much of this carbon was removed in the last 150 years through levee building, drainage, and subsidence. Subsided delta peatlands are now being re-flooded to harness multiple environmental benefits. The net climate benefit associated with restoration, however, is highly uncertain, as restoring drained peatlands can also lead to increased emissions of methane, the second-most important greenhouse gas to climate change.

A recent biogeochemical assessment was conducted to assess climatic impacts of restoring the Sacramento-San Joaquin Delta peatlands.[6] Researchers found that despite significant interannual variability, restored Delta wetlands emit methane at rates that may, in some cases, make them net greenhouse gas sources over policy-relevant timescales.

[5] https://www.iucn.org/resources/issues-briefs/peatlands-and-climate-change,
[6] https://caseagrant.ucsd.edu/sites/default/files/Hemes-profile-2018.pdf

However, the emissions reduction potential depends on the current practices and land use activity. There may be some instances when the land-use change leads to a net reduction in greenhouse gas flux compared to current practices.

Climate Change and Blue Carbon

Assessing Climate Change co-benefits and Impacts to Blue Carbon habitats

Coastal blue carbon habitats 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).

A co-benefit Assessment Methodology was developed by the Center for Resource Efficient Communities at UC Berkeley, in consultation with California Air Resources Board (CARB) staff, to estimate climate adaptation co-benefits for projects funded through the Cap-and-Trade California Climate Investments program.

As far as impacts of climate to blue carbon habitats, Macreadie et al. 2020 includes a table with examples of gains and losses for blue carbon stocks from a range of climate change factors.

Sea Level Rise

Several efforts are underway to explore the nexus of blue carbon habitats and sea level rise adaptation:

- Pacific Northwest Blue Carbon Working group "Sea Level Rise Impacts on Flood Protection and Carbon Sequestration Services Provided by Pacific Northwest Tidal Wetlands" (2019 - 2022) - This project is examining the extent to which sea level rise is likely to affect flood reduction and carbon sequestration in two representative PNW estuaries, Coos Bay, Oregon and Gray's Bay Washington. Using hydrodynamic models, an ecosystem model of wetland elevation change, and field measurements of greenhouse gas emissions and carbon sequestration rates, the project is characterizing the effects of several sea-level rise and tidal wetland restoration scenarios on coastal flooding and net ecosystem carbon balance. See more here.
- On-going research from USGS in California and others develops high-resolution models to understand how the potential in the San Francisco Bay Delta for tidal marshes to capture carbon can be affected by sea level rise (Drexler et al., 2019)
- Seagrass habitat suitability modeling (Lummis et al, in prep 2020) **-** Researchers at UC Santa Cruz are developing a habitat suitability model to support predictions of

present/future eelgrass distribution using environmental predictors (e.g. substrate type, light availability), and in light of environmental drivers including sea-level rise, with the aim of identifying opportunities for restoration and conservation to increase coastal resiliency. Results are expected in early 2021.

- A comprehensive scenario approach was used to evaluate both the vertical and horizontal response of tidal wetlands to projected changes in the rate of sea-level rise across 14 estuaries along the Pacific coast of the continental United States (Thorne et al., 2018)

III. Outstanding Blue Carbon Science Gaps

Coastal Wetland Science Gaps

A recent review brought together 50 leading blue carbon experts to summarize key fundamental questions in blue carbon science globally (Macreadie et al., 2020). These include:

- How does climate change (including sea level rise) impact carbon accumulation in mature blue carbon ecosystems and during their restoration?
- How does disturbance affect the burial fate of blue carbon?
- What is the global importance of macroalgae, including calcifying algae, as blue carbon sinks/donors?
- What is the global extent and temporal distribution of blue carbon ecosystems?
- How do organic and inorganic carbon cycles affect net CO_2 flux?
- How can organic matter sources be estimated in blue carbon sediments?
- What factors influence blue carbon burial rates?
- What is the net flux of greenhouse gases (including CH_4, NO_2) between blue carbon ecosystems and the atmosphere?
    - *Note: Partners at SCCWRP are currently modeling some of these fluxes for California.*
- How can we reduce uncertainties in the valuations of blue carbon?
- What management actions best maintain and promote blue carbon sequestration?

For California coastal wetland habitats specifically, some key baseline information gaps identified during expert interviews include:

- Information on methane emissions
- Understanding differences in carbon sequestration rates in restoring wetlands; early findings suggest certain restored habitat locations may sequester carbon faster
- Better California-specific field measurements of net greenhouse gas emissions are needed
- Data on lateral fluxes of carbon (how much is staying within the sediments of its source location vs where carbon export is happening); we are potentially only capturing about 50% of where that carbon is going.
- Better assessment/modeling of permanence of carbon capture and storage (i.e., how do you tell for how long an ecosystem would be able to sequester X amount of carbon per year?)
- Better understanding of the extent (mapping) of seagrass habitat statewide

Kelp Forest Science Gaps

The potential for kelp to serve as a blue carbon strategy is hampered with further knowledge gaps on carbon export and burial. Kelp-specific questions include (Krause-Jensen et al. 2018, personal communication)

- The location and relative amount of kelp-derived carbon being exported and sequestered at specific sink sites.
- The burial rate of kelp-derived carbon at these sink sites, and environmental and biological factors that may influence those burial rates.
- The relative influence of broad-scale environmental (temperature, nutrients) vs local biological (herbivory, food web dynamics) controls on kelp extent, persistence, resilience
- The proportion of kelp and kelp-derived carbon exported by large drifters via dislodgement vs erosion.
- The influence of various management practices (i.e. protection, restoration, enhancement) on kelp carbon export and sequestration rates.

IV. Management and Policy Context in California

Overview: State and Federal Management, Policy, and Regulation

No single state or federal agency has sole jurisdiction over coastal wetlands, including seagrass and tidal salt marshes. There are many agency-specific regulations and activities for permitting development, and identifying and limiting adverse activities (personal communication). This patchwork of land-based authority creates several regulatory hurdles for conservation and restoration projects, especially those for carbon sequestration purposes (personal communication). The California Eelgrass Mitigation Policy (CEMP) aims to coordinate state and federal efforts for eelgrass protection to achieve no net loss and preserve essential ecosystem services (NOAA 2014). Kelp is primarily managed by the California Department of Fish & Wildlife, but these forests exist within each of California's National Marine Sanctuaries (Greater Farallones, Monterey Bay, and Channel Islands), where kelp harvesting is prohibited. Kelp harvesting is only permitted in the Monterey Bay National Marine Sanctuary, in which CDFW and NMFS manage harvest activities jointly. Table 5 reviews a list of state and federal agency jurisdictions, particularly as it relates to the management, protection, or restoration of coastal blue carbon habitats.

Table 5. Agencies with management, policy, or regulatory jurisdiction relating to carbon and/or blue carbon habitats.

Agency	**Role & Regulatory Authority**
California Air Resources Board	• Managing agency for California Cap-and-Trade Program • Hosts an Offset Project Registry for the Compliance Offset Program • Oversees the California Climate Investments Program, including methods and protocol development
California Department of Fish & Wildlife	• Manages state-owned tidelands for aquaculture leased by FGC to aquaculture operators; • Manages kelp resources by conducting surveys, tracking harvest

	records, and providing management recommendations to FGC (Fish and Game Commission) ● Reviews fishing and aquaculture impacts to habitats (California Environmental Quality Act).
California Coastal Conservancy	● Develops action plans, and funds and implements habitat protection projects for carbon sequestration (California Global Warming Solutions Act)
California State Lands Commission	● Issues leases for use and development of tide and submerged lands and beds of navigable rivers, streams, lakes, bays, estuaries, inlets, and straits (California Code of Regulations).
California Coastal Commission	● Issues and reviews development projects and permits (e.g. aquaculture, construction, or restoration), and can recommend protective and conservation efforts as part of development permitting (California Coastal Act).
National Marine Sanctuaries	● Manages environmental resources and disturbances within sanctuary boundaries, offers habitat protection, and permits over certain activities up to the MHWL (National Marine Sanctuaries Act). ● Regulates kelp harvest within Monterey Bay National Marine Sanctuary in partnership with CDFW.
National Estuarine Research Reserve	● Protects and manages critical coastal and estuarine habitat (Coastal Zone Management Act).
National Marine Fisheries Service (NMFS)	● Recommends how agencies should maintain no net loss of eelgrass from impactful activities (California Eelgrass Mitigation Policy). ● Federal agency consultation for potentially impactful activities (Habitat Area of Particular Concern under Magnuson-Stevens Act, Critical Habitat under Endangered Species Act)
U.S. Army Corps of Engineers	● Provides guidance for identifying and delineating eelgrass subject to federal jurisdiction (Clean Water Act, Rivers and Harbors Act). ● Reviews and permits development on wetlands (Clean Water Act, National Environmental Policy Act, California Environmental Quality Act, etc.)
Harbor districts/authorities	● Develop regional or bay wide seagrass management plans, not covered by CEMP. ● Participate in permit approval processes (CEQA).

California Carbon Policy and Carbon Markets

California's Cap-and-Trade Program

California passed the Global Warming Solutions Act (AB 32) in 2006, which calls for the state to reduce its greenhouse gas (GHG) emissions to 1990 levels by 2020.[7] A key component to achieve this reduction is the state's Cap-and-Trade Program, the only economy-wide carbon market in the U.S. and one of the largest markets in the world. The Cap-and-Trade program is a climate change program of the California Air Resources Board (CARB), which hosts an Offset Project Registry for the Compliance Offset Program, and oversees the California Climate Investments Program.

Greenhouse Gas Reduction Fund

The State's portion of the Cap-and-Trade auction proceeds are deposited in the Greenhouse Gas Reduction Fund (GGRF), and used to further the objectives of the California Global Warming Solutions Act of 2006 (Assembly Bill 32; Núñez, Chapter 488, Statutes of 2006). The California California Climate Investments (CCI) program is a statewide initiative that puts billions of Cap-and-Trade dollars toward projects that reduce greenhouse gas emissions. The California State Legislature appropriates money from the Greenhouse Gas Reduction Fund (GGRF) to State agencies that administer California Climate Investments programs.

To date, more than $11 billion dollars from the GGRF have been appropriated by the Legislature to State agencies implementing GHG emission reduction programs and projects. Since 2016, nearly $600 million has been directed towards CNRA programs through California Climate Investments (ARB Natural & Working Lands 2019). Agencies with ocean and coastal jurisdiction that currently or historically have received GGRF monies (including funding allocations to date) include:

- **California Department of Fish and Wildlife** - $47 million for the Wetlands and Watersheds program
- **California State Coastal Conservancy** - $7 million for the climate ready grant program
- **Bay Conservation and Development Commission** - unknown
- **California Coastal Commission** - $5 million for coastal resilience planning
- **Wildlife Conservation Board** -- unknown allocation

Allocations vary annually based on State Legislature appropriations. Of these agencies, the CDFW Wetlands and Watersheds program has been a primary and most consistent

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[7] Note: This target was achieved in 2018, but looks to be incomplete. SB 32 (and a new Assembly bill, 197) passed in 2018 to accelerate goals to -40% of 1990 levels by 2030. https://ww3.arb.ca.gov/cc/scopingplan/scopingplan.htm Senate Bill 5 also passed in 2018, which guarantees that by 2045 all electricity delivered in California has to be from zero-carbon resources.

administering agency and is one of the only programs whose grants go towards coastal wetland blue carbon projects, though no programs currently consider seagrass blue carbon projects.

Carbon Offset Markets

A carbon offset is measurable, quantifiable and trackable units of GHG emissions reductions (Hamrick and Gallant, 2018) that can be bought and sold on carbon markets. At current carbon prices, it may be less expensive to purchase offsets rather than the use of artificial carbon sequestration plants or installation of GHG emission reduction technologies for industries (Sapkota and White, 2020). Currently, two types of markets are in existence for carbon trading: the compliance market and the voluntary market, discussed in more detail here.

Compliance Offset Markets

Compliance markets deal with the mandatory emission reductions imposed by regulations. Under California's Cap-and-Trade program, compliance offsets are greenhouse gas (GHG) emission reductions or sequestered carbon that are generated from on-the-ground projects and activities developed according to ARB approved Compliance Offset Protocols. Each CARB offset credit is equal to 1 metric ton of carbon dioxide equivalent ($MTCO_2e$) and may be used by an entity to meet up to eight percent of its triennial carbon emissions reduction compliance obligation under the cap-and-trade program. Compliance offsets are usually allowed in limited quantities because they are able to provide cheaper alternatives than emissions reductions (Hamrick & Gallant, 2017; Hamrick & Gallant, 2018).

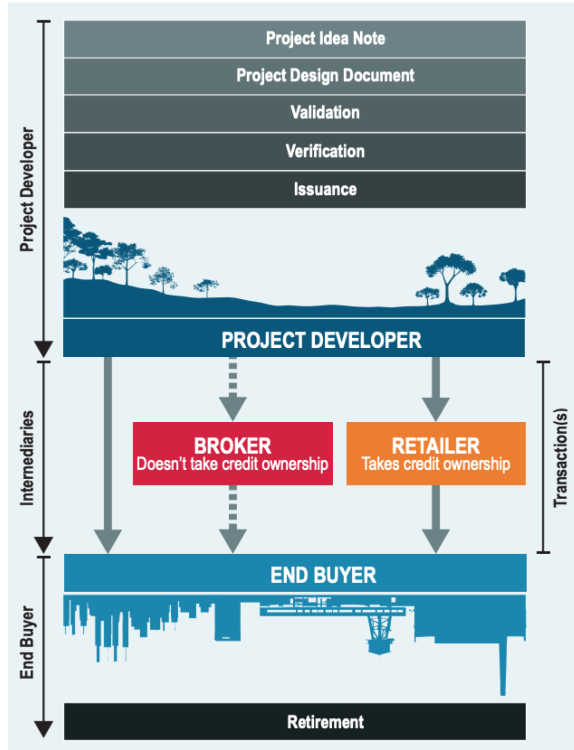
Compliance offset credits trade separately from credits on the voluntary market, and the price for 1 $MTCO_2e$ is typically higher in the compliance market. The market price of carbon offset in California is gradually increasing with the current price of $15.25 in early 2019 (Sapkota and White, 2020). Currently, offsets from tidal wetlands restoration can only be sold to **voluntary offset** buyers at this time (Reference: carbon finance webinar). However, there may be opportunities to fill data gaps via pilot projects so that tidal wetlands may be eligible in compliance markets in the future. Some needs identified from Sapkota and White (2020) include (a.) establishment of several restoration projects and registration of offsets in the voluntary carbon market (see below), and (b.) advocacy for the inclusion of wetlands as a sector in the compliance offset program. The emerging concept of offsetting aviation CO_2 emissions could potentially significantly increase the demand of carbon offsets in the voluntary market.

Voluntary Offset Markets

Voluntary markets were developed to credit actions in reducing GHG emissions primarily by private sector companies, to reduce a company's environmental footprint, demonstrate corporate social responsibility and enhance public relations (Mack et al., 2015). Three voluntary organizations (Verra; American Carbon Registry; Climate Action Reserve) can approve carbon offset methodologies, certify GHG reduction projects and register carbon offsets by California ARB as an Offset Program Registry for the California Cap-and-Trade Program.

A few key findings related to blue carbon projects on the voluntary offset market:

- Moving a project from conception to final issuance of offsets takes two and a half years on average.
- Carbon project costs are expensive. In addition to the restoration costs, the following are additional costs related to voluntary offset projects:
    - **Carbon project development: ~$150k in up-front costs** (for the design description ~ $100k; validation process ~ $50k)
    - **Carbon monitoring:** $75k every 5 years (data collection ~$25k; monitoring and verification ~ $50k)
- At current carbon prices, minimum scale for carbon revenues to cover carbon costs in tidal forested wetlands is ~500 hectares (~1,000 acres) (PNW project)



The offset price in the voluntary market is low and highly variable, though given the many co-benefits of coastal wetlands projects, offsets in these sectors fetch a higher average carbon price. Since several coastal wetland offset methodologies are endorsed by California's ARB, there is greater potential that wetland projects will be included in California's compliance offset program (Sapkota and White, 2020). However, a sufficient amount of offsets should be created in the voluntary market before blue carbon can be included in the compliance market. For more information on the lifecycle of a voluntary carbon offset, see figure 5 (Hamrick & Gallant, 2017; Hamrick & Gallant, 2018).

Mitigation Banking: Is there a potential nexus with Blue Carbon?

The federal Clean Water Act (CWA) prohibits the discharge of dredged or fill material into waters of the United States unless a permit issued by the Army Corps of Engineers or approved State under CWA Section 404 authorizes such a discharge. For every authorized discharge, the adverse impacts to wetlands, streams and other aquatic resources must be avoided and minimized to the extent practicable. For unavoidable impacts, compensatory mitigation (e.g., restoration, establishment, enhancement) is required to replace the loss of wetland and aquatic resource functions in the watershed. There are three distinct mechanisms for compensatory mitigation, one of those being mitigation banking. Affiliated agencies include: NOAA, Army Corp, California Resources Agency, California Department of Fish and Wildlife, the Corps, the US

Fish & Wildlife Service, the EPA, the Natural Resource Conservation Service, and the State Water Resources Control Board.

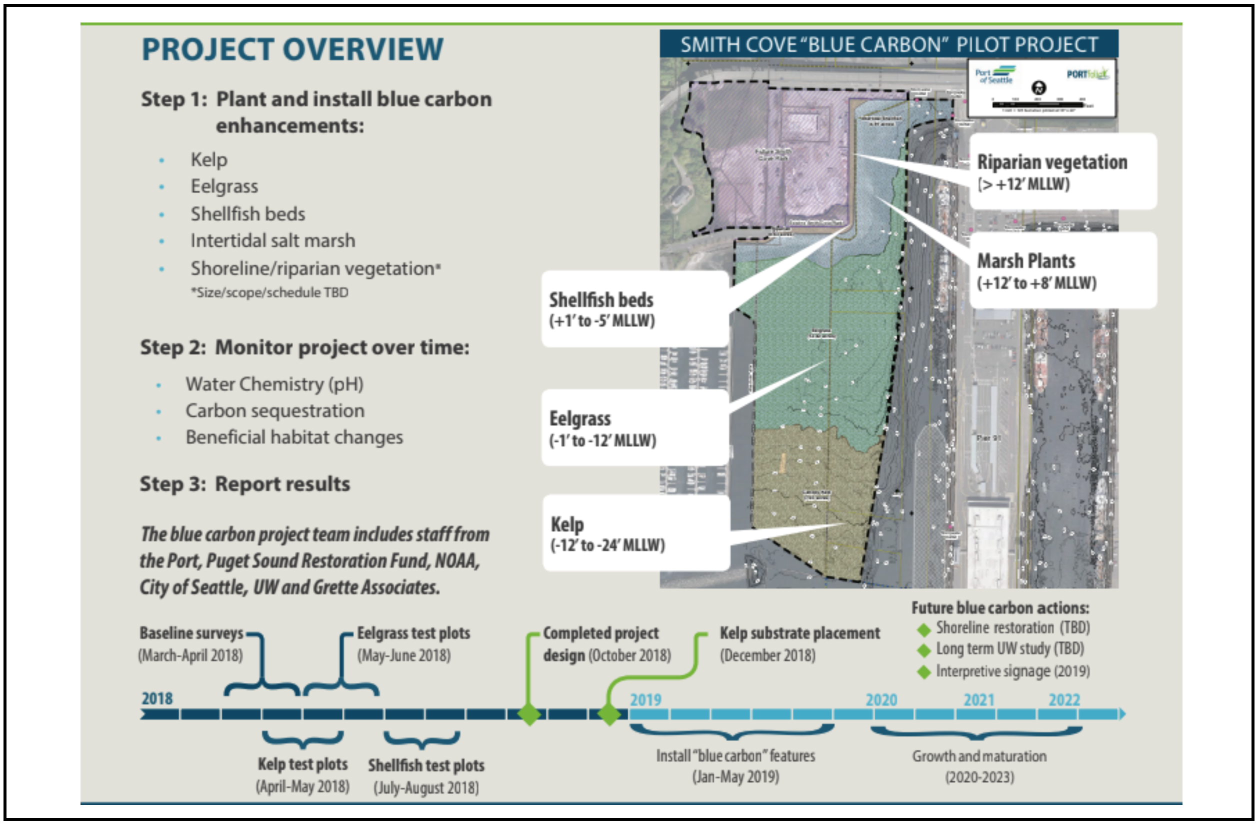
A wetlands mitigation bank is a wetland area that has been restored, established, enhanced or preserved, which is then set aside to compensate for future conversions of wetlands for development activities. Permittees, upon approval of regulatory agencies, can purchase credits from a mitigation bank to meet their requirements for compensatory mitigation. The value of these "credits" is determined by quantifying the wetland functions or acres restored or created. Mitigation banking is performed "off-site," meaning it is at a location not on or immediately adjacent to the site of impacts, but within the same watershed. Mitigation banks are a form of "third-party" compensatory mitigation, in which the responsibility for compensatory mitigation implementation and success is assumed by a party other than the permittee. Mitigation bank is an increasingly important economic component of the environmental consulting sector. For an example of a mitigation bank project being used to achieve carbon neutrality goals, see Box 3.

Box 3: Case Study - Port of Seattle Mitigation Bank in Support of Carbon Neutrality Goals

For example of a region using mitigation banking as a mechanism for advancing blue carbon goals, see the Port of Seattle who are deploying submerged aquatic vegetation to help meet climate goal of becoming Carbon Neutral by 2050 (Jon Sloan, Senior Manager, Environmental Programs at the Port of Seattle).

- **Port Carbon Sequestration Report (here)**
- **Smith Cove Pilot Project (here)**

Their Smith Cove project includes 19 potential fish and wildlife habitat restoration sites combining for a total of over 90 acres of habitat restoration at Port-owned or controlled properties. The combined habitat projects currently underway are expected to sequester 33.74 tC/yr (offset approximately 124 tCO_2 emitted per year). A portion of this project is a mitigation bank, generating credits to offset negative impact requirements. They are projecting to produce additional credits beyond their regulatory requirement to sell as a means to generate income that can fund the restoration project into the future. While this project is not currently generating carbon credits, it is a unique example of mechanism to fund wetland restoration.



Natural and Working Lands: Is there a nexus with Blue Carbon?

California's natural and working lands include forests, rangelands, urban green spaces, wetlands, and farms (CARB). California's 2017 Climate Change Scoping Plan Update emphasized the critical role that managing natural and working lands to further reduce greenhouse gases and maintain them as a resilient carbon sink. California has also developed a draft Natural and Working Lands Implementation Plan to identify long-term natural and working lands sequestration goals that can be incorporated into future climate policy. For coastal wetlands specifically, the Implementation plan calls out a goal of doubling the rate of State-funded wetland and seagrass restoration by 2030, equating to the following habitat restoration goals:

- Coastal wetland restoration 5,100-5,500 acres/ year (2,063 - 2,225 ha/year)
- Seagrass restoration 500-600 acres/ year (202 - 242 ha/year)

There are opportunities to leverage existing coastal wetlands restoration efforts called out in the Implementation plan to meet OPC's habitat goals. Some projects or partners of interest include:

- **The State Coastal Conservancy** - The Coastal Conservancy is leading efforts to restore estuarine wetlands all along the coast, and has participated in the planning or restoration of nearly 35,000 acres of wetlands in the Bay Area alone. Additionally, the Coastal Conservancy staffs the San Francisco Bay Restoration Authority and the Southern California Wetlands Recovery Project. One significant regional project is the restoration of salt ponds in the South San Francisco Bay to tidal wetlands, which will convert diked bay lands into estuarine wetlands. Ultimately, this project will restore 15,000 acres of wetlands, and the Conservancy has led planning and implementation of restoration of 3,300 of these acres.

- **San Gabriel and Lower Los Angeles Rivers and Mountains Conservancy -** The Los Cerritos Wetlands Restoration Project affords the opportunity to restore approximately 500 acres of salt marsh, seasonal wetlands, and other freshwater wetlands. In addition, this project has great potential to include broad wetlands transition zone and upland buffer in order to prepare the site for predicted impacts of sea level rise and to reduce urban impacts on the restored wetlands.
- **Department of Water Resources -** has nearly 2,000 acres (809 ha) of carbon wetlands on Sherman and Twitchell Islands in the Delta.
- **Department of Fish and Wildlife** - $21 million invested and 5,600 acres (2,266 ha) of wetland and meadow ecosystems restored over two cycles of funding through the Wetlands Restoration for Greenhouse Gas Reduction Program

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Appendix A: Kelp Forest Carbon Cycling

While there are many data gaps with respect to the role of kelp as a blue carbon habitat, it is likely that their role in carbon sequestration is minor compared to salt marsh and seagrass habitats. Given that there are significant other benefits to restoring and protecting kelp, it was not a major focus of this report.

Kelp Forest Blue Carbon

Kelp predominantly grows on hard substrates (Banerjee 2005). Therefore, the main mode in which kelp contributes to carbon sequestration is via the export of particulate and dissolved organic carbon (POC and DOC, respectively) to habitats (e.g. deep sea, continental shelf) where carbon is buried in soft sediments (Krause-Jensen & Duarte 2016, Krause-Jensen et al. 2018) (Figure 2; Krause-Jensen & Duarte 2016). The exact proportion of kelp-derived carbon that is stored beneath sediments remains unclear. Because of these limitations and uncertainties, there is disagreement within the scientific community whether kelp does or could make meaningful contributions toward blue carbon (Krause-Jensen et al. 2018, Hill et al. 2015, personal communication).

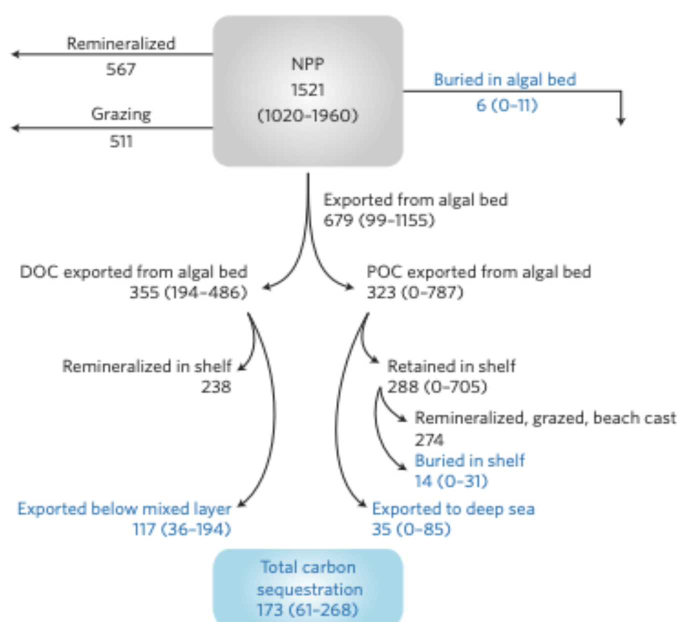

Figure 2. Pathways for the sequestration of macroalgal carbon in the ocean. Each step of the carbon flow from global macroalgal net primary production (NPP) to carbon sequestration (in blue) is supposed by the literature or inferred by a difference between a total and subcomponents support by the literature. The means (with 25 to 75% quartile range in parentheses) are shown. Reference: Krause-Jensen & Duarte 2016

Appendix B: List of Funder Orientations and Funding Streams

While not an exhaustive list, below are some potential funding streams to support coastal wetlands and blue carbon work:

- California Department of Fish and Wildlife Wetlands and Watersheds program https://wildlife.ca.gov/Conservation/Watersheds/Greenhouse-Gas-Reduction
- State Coastal Conservancy Climate Ready Grant program https://scc.ca.gov/2019/04/25/climate-ready-grant-round/
- California Climate Investments https://ww2.arb.ca.gov/our-work/programs/california-climate-investments
- RFP from the National Estuary Program's Coastal Watersheds Grant Program https://www.epa.gov/sites/production/files/2020-05/documents/nep_coastal_watershed_grant_subaward_rfp_2020.pdf

Appendix C: Overview of Existing Datasets, Tools, and Inventories

- Ecoatlas - data aggregator https://www.ecoatlas.org/regions/ecoregion/statewide
- Coastal Carbon Research Coordinating Network Coastal Carbon Atlas https://serc.si.edu/coastalcarbon
- Online carbon platform/network coming soon: http://www.oceancdr.net/
- California Greenhouse Gas Emissions for 2000 to 2017, Trends of Emissions and Other Indicators https://ww2.arb.ca.gov/ghg-inventory-data
- Natural and working lands inventory https://ww2.arb.ca.gov/nwl-inventory
- Mitigation bank project map: https://ribits.ops.usace.army.mil/ords/f?p=107:2::::::
- California Natural and Working Lands Carbon and Greenhouse Gas Model (CALAND) to calculate cumulative changes in GHG emissions from various land management and conservation practices.
- California Climate Initiative
    - Investments map https://webmaps.arb.ca.gov/ccimap/
    - 2020 Data dashboard https://www.caclimateinvestments.ca.gov/cci-data-dashboard
- California Department of Fish and Wildlife. Habitat coverage https://www.wildlife.ca.gov/Conservation/Marine/GIS/Downloads
- NASA Earth Data: Sea Level Change Observations from Space https://sealevel.nasa.gov/
- Santa Barbara Coastal Long-Term Ecological Research Kelp Biomass Time Series (ongoing) [URL link not found]
- NOAA Kelp Distribution GIS Shapefiles https://catalog.data.gov/dataset/kelp-distribution-off-california
- Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) http://www.piscoweb.org/kelp-forest-study

Appendix D: Expert Contacts that Informed the Report

Below is a list of experts consulted during the development of this report.

Blue Carbon Experts

Craig Cornu, Program Coordinator, Pacific Northwest Blue Carbon Working Group
Steve Crooks and **Lisa (Schile) Beers**, Silverstrum Climate Associates
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Lauren Linsmayer, Staff Member, U.S. House of Representatives Committee on Science, Space, and Technology
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Kelp Forest Systems

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