California Air Resources Board

Literature Review: Methods to Assess Greenhouse Gas Benefits and Co-Benefits of

Seagrass Conservation and Restoration

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Background

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (GHG) emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the net GHG benefit and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project types for funding by each administering agency, as reflected in the program expenditure records available at: www.arb.ca.gov/cci-expenditurerecords.

CARB's quantification methodologies (QMs) are designed for the specific needs of a GGRF-funded state program. Seagrass conservation and restoration projects have been identified as a project of interest for quantification. This literature review is intended to expand the scope of potential natural and working lands (NWL)-focused projects whose GHG reduction benefits can be quantified using methodologies that meet CARB's standards for empirical data quality and established, peer-reviewed methods. The goal is to either demonstrate feasibility or determine research prerequisites for quantifying in-demand NWL project types.

As with all CARB QMs, any method to track both GHG emission reductions and co-benefits should ideally satisfy all of the following criteria:

- Apply at the project level
- Align with project types proposed for funding for each program
- Provide uniform methods to be applied statewide and be accessible by all applicants
- Use existing and proven tools or methods where available
- Use project level data, where available and appropriate
- Reflect empirical literature

Project Type: Seagrass and Eelgrass Conservation and Restoration

Global Context

"Seagrass" refers collectively to approximately 60 species of aquatic, flowering, vascular plants which grow in the shallow, sub-tidal zone, in a range where sufficient sunlight for photosynthesis can reach through the water column, but deep enough that the leaves are not exposed for long periods during low tides, (Shaughnessy et al. 2012). The species *Zostera marina*, commonly known as eelgrass, is the most common species of seagrass found in California. According to the National Oceanic and Atmospheric Administration's 2014

California Eelgrass Mitigation Policy, there are between 11,000 to 15,000 acres of eelgrass in the state.

All seagrasses are widely recognized as a vital component of coastal ecosystems due to the valuable biodiversity and habitat, storm protection, and carbon sequestration services they provide. Seagrass is considered part of the "blue carbon" group of coastal, vegetated ecosystems (Nellemann and Corcoran (eds) 2009). Alongside salt marshes and mangrove forests, these ecosystems are so named due to the disproportionately valuable ecosystem services they provide, particularly their high carbon sequestration rates, even when compared to terrestrial environments such as managed forests (Fourqurean et al. 2012, McLeod et al. 2011). By some estimates, seagrasses account for 20% of all carbon burial in ocean sediments, despite only occupying 0.1% of total oceanic area (Kennedy et al. 2010 as cited in Duarte et al. 2015). Due to the high carbon sequestration rate, persistent seagrass meadows can accumulate carbon-rich sediments several meters thick (McLeod et al. 2011), making conservation a priority to preserve these existing, natural carbon stocks. Both conserving existing eelgrass carbon stocks and restoring or planting new eelgrass meadows can serve as part of a nature-based climate solution.

Status of Eelgrass in California

Seagrass habitats globally have experienced losses of 7% annually since 1990 (Waycott et al. 2009, in McLeod et al. 2011). While seagrasses continue to decline, restoration efforts can successfully foster the return of the habitat and their ecosystem services. Past restoration projects have demonstrated a rapid enhancement of these ecosystem services within 20 years of the project beginning; one such project on the US East Coast resulted in establishment of 3,612 hectares (8,925 acres) of new eelgrass coverage in this timeframe, with ecosystem characteristics essentially matching those of naturally occurring eelgrass meadows (Orth et al. 2020). A similarly successful restoration program of the same magnitude in California would result in increasing the total eelgrass coverage of the state by up to 70%.

California is not immune to the global trend of seagrass losses and the state has recently increased efforts to restore and enhance existing eelgrass. 80% of the eelgrass habitat in California is found in just five major estuary systems (NOAA 2014). One of these, Morro Bay, has lost substantial eelgrass coverage in recent years due to erosion-related issues, making it a restoration priority. Restoration projects are underway in Morro Bay, and more broadly the National Marine Fisheries Service recommended "no net eelgrass cover loss" as part of its California Eelgrass Mitigation Policy (NOAA 2014). The Ocean Protection Council has subsequently included eelgrass restoration and conservation as items in their Strategic Plan for 2022-2025. This plan calls for expanding nature-based, coastal infrastructure, and calls specifically for preserving the 15,000 acres of existing, eelgrass and creating an additional 1,000 acres by 2025.

Wedding et al. (2021) identify the state of California as a strong candidate for action to incorporate blue carbon ecosystems as a nature-based climate solution due to the long coastline with multiple areas suitable for seagrass restoration. This review will assess the current state of knowledge of the potential GHG benefits of seagrass restoration and conservation, as well as the difficulties and opportunities related to quantifying this potential benefit.

GHG Benefit and Co-Benefits Associated with Project Activities

Carbon Sequestration Benefits

Most species of seagrasses, including eelgrass, form thick, matted root structures that can grow deep into the sediment, where particles accumulate gradually over time. The tendency to trap and accumulate sediment particles allows seagrass meadows to act as carbon sinks, naturally removing carbon from the ocean-biosphere-atmosphere cycle and depositing it into a sediment storage pool with potentially high carbon density and a residence time of decades or even centuries (McLeod et al. 2011). This carbon remains in the soil rather than re-mineralizing to CO_2 because microbial decomposition is inhibited by the anaerobic conditions typical of subtidal sediments. In a stable eelgrass ecosystem, this effect could theoretically be maintained indefinitely, provided that conditions favorable to eelgrass survival persist, and the eelgrass can adapt to any rise in sea level. Evidence from past restoration projects shows that the carbon accumulation rate may even increase over time (Greiner et al. 2014).

Seagrasses accumulate carbon from both allochthonous—transported from other places-- and autochthonous—in-situ—sources. This matter then accumulates in sediment conditions that do not allow microbial respiration into CO2 and methane, which makes blue carbon ecosystems such as eelgrass highly effective in sequestering carbon: they accumulate their own carbon and also other sources of organic material suspended in the water column. Some estimates place the portion of allochthonous carbon sequestration at 50% of the total (Kennedy et al. 2010).

Co-Benefits

Like the other blue carbon ecosystems, seagrass meadows can provide a wide array of ecosystem services, with an estimated global value of $28,916 per hectare per year in 2007 dollars (Costanza et al. 2014).

Conserving or restoring seagrasses would provide additional habitat not only to enhance natural biodiversity, but also to help sustain commercial fisheries. Sherman and Debruyckere (2018) list Dungeness crab, California Halibut, English Sole, Gaper clam, Jackknife fish, Littleneck clam, and especially Pacific herring among the commercially important seafood species that spend at least a portion of their life cycles within seagrasses. Juveniles of many other wild species seek refuge within the sheltered canopy of eelgrass beds, making seagrasses a vital component of coastal biodiversity.

Seagrass' tendency to entrap suspended particles to fall out of the water column—the same process that produces its allochthonous carbon accumulation-- also increased water clarity (Orth et al. 2012) in meadows studied on the US East Coast. The presence of eelgrass also resulted in a lower concentration of multiple types of artificial, persistent organic pollutants than in a trial without eelgrass, suggesting their ability to inhibit dispersal of these substances (Huesemann et al. 2009). Lastly, a study in Puget Sound found that eelgrass can limit the impact of harmful algal blooms because eelgrass habitat permits the growth of certain strains of marine bacteria that compete with the growth of single-celled algae (Inaba et al. 2017). While these co-benefit effects have not yet been studied in California, these effects show that a variety of water quality enhancement services are produced by seagrasses.

Seagrasses also attenuate wave action and may prevent coastal erosion and help preserve coastal infrastructure at risk from sea-level rise. Areas of degraded seagrass in Morro Bay experienced rapid sediment erosion following the collapse of the local eelgrass population, so conservation and restoration should be a priority to limit coastal erosion in these situations (Walter et al. 2020).

Directionality of Benefits

Research has shown that eelgrasses are resilient to the effects of sea-level rise, provided the rate of rise does not exceed the ecosystem's ability to accumulate sediment (Carr et al. 2012). Seagrass requires sufficient sunlight to produce energy from photosynthesis, and the beds of accumulated sediment accrete vertically, so their inherent sediment deposition processes can counteract deepening of the water column in the shallow, subtidal ecosystems where seagrasses live (Walter et al. 2020).

Any degradation to the conditions that remove the seagrass' ability to adapt to rising sea levels could cause a reversal of the carbon sequestration benefit as the organic-rich sediment particles would be scoured away; this could also result from an extreme storm (MacReadie et al. 2019). Scour and eelgrass bed damage can also result from boating traffic and anchor scours, and especially from industrial and construction activities including dredging (NOAA 2014).

A sufficiently high rate of global sea level rise combined with tectonic subsidence can also result in rapid eelgrass loss, even absent other factors (Shaughnessy et al. 2012). Marine heat waves are also increasing in severity and have been linked to die-offs (Nguyen et al. 2021; Carr et al. 2012). It may be difficult for seagrasses to return to an area of significant disturbance absent an active restoration plan due to loss of bottom sediment—and increased sediment particle suspension—because water depth and turbidity can be increased beyond the limit allowing for eelgrass photosynthesis.

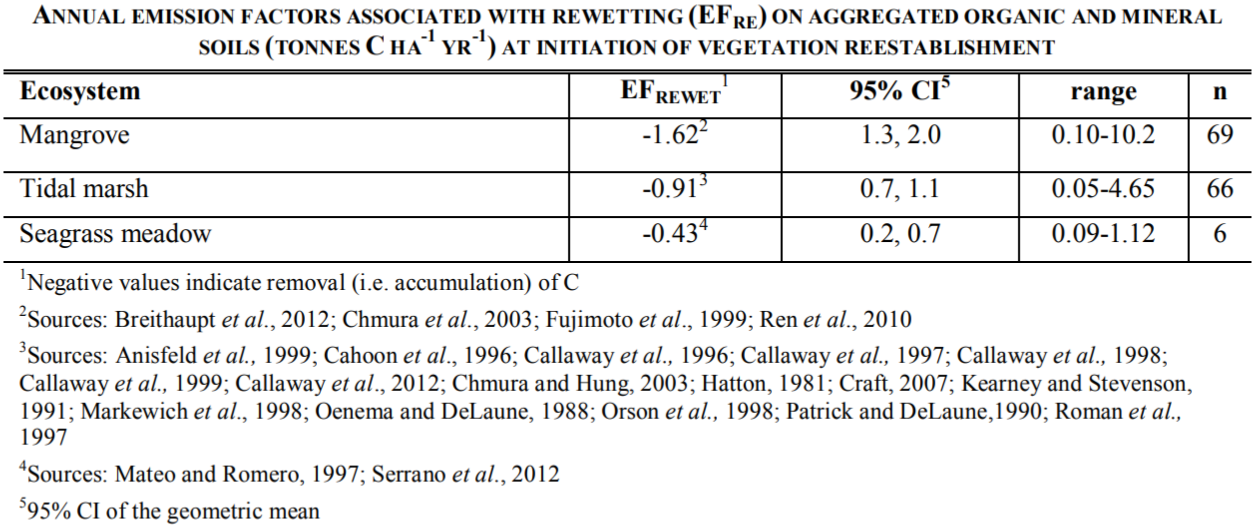
Carbon sequestration and associated co-benefits depend on a healthy and viable eelgrass population, and eelgrass loss compromises all benefits. Restoration and conservation, on the other hand, increase and preserve the carbon sequestration, habitat, biodiversity, water quality, and erosion reduction benefits. Any change to conditions that significantly impacts the eelgrass' reproductive fitness could lead to a local collapse of the eelgrass habitat and the loss of ecosystem services.

Magnitude of the Benefits

Global, average carbon sequestration and carbon storage benefits from seagrasses are computed from a relatively limited dataset with significant regional data gaps and high variability. For example, the IPCC Wetlands Supplement (2014) provides a global estimate of 108 MT carbon storage per hectare (range 10-829). However, seagrasses can sequester very high rates of carbon in the sediment in some areas and much lower amounts in nearby areas even in the same region (e.g. the East Asian coastline, Miyajima et al. 2015).

Table 1 below, adapted from the IPCC's Wetland Supplement (2014), depicts the emission factor, expressed in tons C per hectare per year, associated with seagrass restoration activities and the two other blue carbon habitats. This emissions factor, as expressed below, is synonymous with the term carbon sequestration rate as used in this review, and in the table below a negative value indicates net sequestration. Note the small sample size contributing to the seagrass estimate compared with other blue carbon ecosystems, and that the range of estimates is a factor of 12. This highlights the necessity of a greater understanding of local conditions found in California coastal habitats before applying any single estimation method based on global values that may not reflect comparable species, climate, or oceanographic conditions.

Table 1. Comparison of restored seagrass meadow carbon emission factor with two other blue carbon habitats. Adapted from IPCC Wetlands Supplement (2014), table 4.12



ANNUAL EMISSION FACTORS ASSOCIATED WITH REWETTING (EF_{RE}) ON AGGREGATED ORGANIC AND MINERAL SOILS (TONNES C HA^{-1} YR^{-1}) AT INITIATION OF VEGETATION REESTABLISHMENT

Ecosystem	EF_{REWET}[1]	95% CI[5]	range	n
Mangrove	-1.62[2]	1.3, 2.0	0.10-10.2	69
Tidal marsh	-0.91[3]	0.7, 1.1	0.05-4.65	66
Seagrass meadow	-0.43[4]	0.2, 0.7	0.09-1.12	6

[1] Negative values indicate removal (i.e. accumulation) of C

[2] Sources: Breithaupt *et al.*, 2012; Chmura *et al.*, 2003; Fujimoto *et al.*, 1999; Ren *et al.*, 2010

[3] Sources: Anisfeld *et al.*, 1999; Cahoon *et al.*, 1996; Callaway *et al.*, 1996; Callaway *et al.*, 1997; Callaway *et al.*, 1998; Callaway *et al.*, 1999; Callaway *et al.*, 2012; Chmura and Hung, 2003; Hatton, 1981; Craft, 2007; Kearney and Stevenson, 1991; Markewich *et al.*, 1998; Oenema and DeLaune, 1988; Orson *et al.*, 1998; Patrick and DeLaune,1990; Roman *et al.*, 1997

[4] Sources: Mateo and Romero, 1997; Serrano *et al.*, 2012

[5] 95% CI of the geometric mean

Some past measurements of carbon stocks and sequestration rates in California have been conducted, although all report variability based on sediment characteristics and seagrass biomass, and they are generally lower than globally-averaged estimates. O'Donnell (2017) reports 8.04-12.82 grams of carbon per square meter per year (0.08-0.13 tonnes per hectare per year), based on sediment core samples from Tomales Bay and Bodega Harbor. These estimates both fall below the low end of the 95% confidence interval from the IPCC global dataset. Similarly, carbon stocks are measured at 110 ± 11.8 tons carbon per hectare in California (Ward et al. 2021), compared to a global average of 139.7 tons carbon per hectare (Fourqurean et al. 2012). These comparisons are all based on limited empirical carbon data from both California and the world writ large, a problem acknowledged to be complicating wider implementation of seagrass carbon quantification methodologies (Johannessen and MacDonald 2016).

Limitations of Current Studies

Globally averaged carbon sequestration estimates over time are also imprecise due to uncertainty around both the actual extent of seagrass coverage, and the speed at which carbon sequestration occurs. A number of eelgrass studies identify uncertainties inherent to the nature of the habitat around spatial extent, carbon dynamics, and resilience to variable environmental conditions.

The NOAA Fisheries California Eelgrass Mitigation Policy (2014) notes several uncertainties that complicate measuring the extent of eelgrass cover. The boundaries of eelgrass beds are known to migrate up to 5 meters annually simply due to stochastic fluctuations, and the "area of functional influence," a boundary zone that enjoys many of the same ecosystem benefits as the eelgrass itself, can extend up to an additional 10 meters into bare sediment from each individual patch (Smith et al. 2008, van Houte-Howes et al. 2004).

The areal extent of seagrass is difficult to monitor because it grows almost exclusively in the subtidal zone, generally requiring expensive field visits to conduct surveys. Globally averaged seagrass carbon sequestration estimates would be problematic to apply across California both due to a small sample size and also because of extreme variability between the environments studied, many of which experience markedly different climatic and oceanographic conditions than those found on the California coast. Instead, local data collection using established surveying methods, ideally at the scale of individual project areas, is critical for quantification.

The Pacific Marine & Estuarine Fish Habitat Partnership (PMEP) has collected data on the maximum, observed extent of eelgrass habitat on the US West Coast (see PMEP reference for link). These data show changes to eelgrass extent over time, at approximately 10 meter resolution, across multiple estuaries in California, and could be a first step used to determine project areas in greatest need of restoration, and to scope the level of resources required for desired restoration outcomes.

The US Army Corps of Engineers (2016) defines two different tiers of eelgrass surveys (not to be confused with IPCC ecosystem carbon accounting tiers), which provide a useful example from which to derive a surveying method to monitor eelgrass coverage either for conservation or for monitoring restoration. A Tier 1 survey delineates the exterior boundaries of an eelgrass meadow and is sufficient for delimiting an area of eelgrass to be avoided during a project. A Tier 1 survey would be sufficient for placing a conservation easement on eelgrass meadows and is also recommended for mapping eelgrass extent over larger areas more cost-effectively. Tier 2 eelgrass surveys are rigorously quantitative and include multi-year surveying to establish precise baselines of eelgrass coverage and shoot density. This method is better suited to ongoing data collection as a part of an active eelgrass restoration program, and would be sufficiently rigorous for capturing the small-scale variability in eelgrass coverage and associated carbon sequestration that would allow a project scale estimation of potential GHG benefits.

Most significantly, growth conditions for eelgrass vary throughout the state, which complicates fulfilling the objective of applying a QM across all possible habitats. The NOAA Fisheries report notes that Southern California eelgrass beds can occupy deeper water than in Northern California, and the uncertainty of eelgrass extent increases further from shore.

Despite the research attention eelgrass has attracted in recent years due to its carbon sequestration potential, and despite restoration projects undertaken throughout the West Coast to address historical losses of eelgrass extent, relatively few of these projects have collected data monitoring sediment carbon content and accumulation rates resulting from restoration projects (Beheshti et al. 2021). Numerous studies have noted significant eelgrass carbon sequestration variability even across relatively small areas and caution against applying averages too broadly (Miyajima et al. 2015). Obtaining sufficient data on sediment carbon storage and carbon sequestration rate to account for this variability would be a prerequisite to developing a QM.

Knowledge Gaps and Issues to Consider While Developing Quantification Methods—Carbon sequestration rates

The current state of scientific knowledge on seagrass carbon dynamics in California is not yet sufficient to meet the needs for a project-scale QM. This is mostly attributable to a relative lack of study areas available for long term monitoring; only six estuaries within California include eelgrass beds large and persistent enough to have attracted significant research attention in the previous 20 years (e.g. Ward et al. 2021). Eelgrass scientists have noted a long list of factors that influence carbon accumulation in coastal sediments including the grain size of inflowing sediment particles (Dahl et al. 2016; O'Donnell 2017), intra-annual variability resulting from seasonal water temperature and sedimentation rate changes (Dahl et al. 2020), and overlying vegetation (Prentice et al. 2019). Because each of these factors drive variability at even very small scales, it is not appropriate to apply a coarse or large-scale estimate of eelgrass carbon sequestration rates without a fuller understanding of the factors specific to each individual project site.

Recommendation

CARB-developed QMs typically rely on regional or habitat specific averages and minimal uncertainty. We recommend a QM that is based around IPCC Tier 2 estimates, which would require additional data collection from eelgrass meadows throughout the state, as well as project specific areal surveying. The following data would be the minimum required to develop a seagrass conservation and restoration QM of IPCC Tier 2:

Restoration projects:

1. Project Area (acres)
2. Baseline eelgrass coverage of project area (shoots per square meter)
3. Sediment carbon content baseline (i.e., prior to restoration activity)
4. Sediment carbon content after vegetation establishment:
    a. Natural eelgrass meadow carbon accumulation rate, once successful establishment can be confirmed

Conservation projects:

1. Project Area (acres) subject to conservation easement
2. Development threat or land use change
3. Baseline carbon content of existing eelgrass

Before the QM can be developed, the following issues should be addressed to ensure it complies with the stated objectives of an empirical, project-scale tool reflecting sound scientific principals and assumptions:

1. The lack of empirical data on baseline sediment carbon content both within and adjacent to eelgrass meadows (including in areas where eelgrass formerly existed but

has been lost), the variability of sediment carbon content within and between sites, and variables influencing local sediment carbon content.

2. Uncertainty around estimates of eelgrass extent, including in deeper (>12m) offshore areas of Southern California. While California eelgrass mapping datasets are available (e.g. PMEP dataset), these should be verified with field measurements for any specific project due to small-scale variability through both time and space.
3. Lack of empirical, time series data on the effectiveness of restored eelgrass meadows' carbon sequestration capacity.

Based on these shortcomings, the following approaches should be prioritized:

1. Developing cost-effective eelgrass mapping methods should be a research priority, perhaps through innovative remote sensing or aerial drone photography. Eelgrass extent should be mapped at project outset and could provide useful data to statewide eelgrass datasets; one such dataset is compiled by the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP), available via the 2021 Eelgrass Synthesis Report (Beheshti et al. 2021).
2. Utilizing existing methods for quantifying sediment carbon accumulation, such as the carbon quantification methods from IPCC, collect sediment carbon data and contribute to understanding of sediment carbon variability at all spatial scales. Use existing methods (IPCC Tier 2, US Army Corps of Engineers surveying) to conduct regular sampling to monitor sediment carbon over time. CARB could coordinate with state agencies and their partners in non-governmental organizations to supplement any existing eelgrass spatial monitoring efforts with field sampling to monitor carbon dynamics.

Due to the amount of additional research needed to achieve the prerequisites summarized above, we do not recommend developing a quantification methodology for eelgrass restoration and conservation in California at this time.

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