ARPA-E Quarterly Technical Report
Award - DE-AR0001559
Quarter 5 (August 1, 2023 – October 31, 2023)

Project Title: Quantifying the Potential and Risks of Large-Scale Macrophyte Cultivation and Purposeful Sequestration as a Viable CO2 Reduction (CDR) Strategy (SeaweedCDR)

This is the fifth quarterly report for the SeaweedCDR project, covering the period August 1 to October 31, 2023. As you may recall, we had an issue in completing M2.1 (Design & Implement Seaweed Packaging) as planned due to the lack of large quantities of giant kelp biomass available for purchase. This temporarily impacted our progress and pushed back this deliverable, as well as the next two deliverables, M2.2 (Seaweed Biomass Fates Methods Development - a go/no go milestone), and M2.3 (Validation of Biomass Fate Methods) a quarter. We have now completed M2.2. Task M2.3 should be completed next quarter. The other deliverable for this quarter is M6.2 (Establishment of a Stakeholder Advisory board). This deliverable is 90% complete. We have selected candidates and want to discuss candidates with the agency before moving forward on invites. We also have progress on M6.7 (Scientific Outreach) to report on.

Task 2 – Quantification of Seaweed Biomass Fates

Q4 deliverable – M2.2 – Develop and document methods for assessing Macrocystis biomass decomposition, products and sinking rates as a function of seaweed packaging
Completion level – 100%

Leads: Sebastian Krause, Bob Miller & David Valentine (UCSB)

Task M2.2 was granted a one quarter extension due to unforeseen circumstances that temporarily impeded our progress. However, this last quarter we met the M2.2 milestone. For M2.1, we designed four conveyance methods to deliver *Macrocystis* (giant kelp, hereon referred to as kelp) biomass to the seafloor which include natural sinking, mastication, short-depth pumping, and baling (see Krause et al. white paper, 2023). For M2.2, we developed and documented methods for assessing kelp biomass sinking rates, decomposition, and decomposition products as a function of each seaweed packaging modality described in M2.1, for both laboratory and field experiments. Our white paper on methods for assessing seaweed biomass fates is undergoing internal review and will be submitted to EarthArXiv preprint server by the end of November.

1. Sinking rates

1.1 Sinking rates of whole kelp fronds - Kelp fronds that detach from the holdfast can naturally coalesce to form kelp rafts, that average 2-3 meters in diameter, and can either wash up on beaches or drift in the open ocean for up to >100 days, during which the kelp is alive, although undergoing senescence and decay (Hobday, 1998; 2000a; 2000b). Eventually, the rafts can sink once decay compromises the gas-filled pneumatocysts and the kelp biomass becomes negatively

buoyant. We plan two experimental approaches to better constrain this process and its implications for kelp carbon sequestration.

Figure 1. Picture of a vertical cylinder used for masticated kelp sinking rates.

Hobday (2000b) simulated kelp rafts by bundling kelp fronds together and tethering the bundled kelp fronds to a shallow marine mooring with a surface buoy. The first experimental approach will be similar. Kelp rafts will consist of 5 to 10 fronds that will be bundled in a light neutrally buoyant mesh tethered to a surface buoy anchored to the seafloor in the shallow coastal ocean (10-15 meters depth). The kelp rafts will be allowed to move up and down the mooring with the tides but prevented from drifting away. Each kelp raft will be equipped with depth recorders, such as the miniature DST Centi Temp Depth Recorder (Star-Oddi) or the ReefNet Sensus Ultra temperature and pressure logger, to measure the temperature and depth change of the kelp rafts over time. Although kelp rafts can stay afloat for months (Hobday, 2000b), this approach will provide more detailed information on how long intact kelp fronds stay at the surface and better constrain the mean age of sinking.

Our second approach will provide more immediate sinking rate measurements for intact kelp fronds. For this we plan to pre-compress intact kelp fronds to make the kelp biomass more negatively buoyant, simulating the moment when released or pumped kelp fronds do sink. This can be done by either pressurizing kelp fronds in the laboratory with a pressure chamber or in the field by bringing the kelp down to sufficient depth to implode the pneumatocysts using divers or weights. Preliminary laboratory experiments with pressurizing kelp biomass led to the rupturing and/or compression of the gas filled pneumatocysts at pressures of 4-6 atm, equivalent to approximately 45-60 meters depth (Krause et al., 2023). The sinking rate of the compressed kelp biomass will then be measured by divers filming the sinking kelp, employing transect tapes or other means for recording scale. In both approaches sinking rates of the kelp fronds will be calculated by dividing the distance (i. e., difference in sensor depth, or imaged depth) the kelp sinks by time (i.e., logger or video recording time).

1.2 Conveyance of masticated kelp biomass - To simulate the sinking of masticated kelp biomass either directly from the kelp farm at the sea surface or after it is pumped to a given depth, we plan to sink masticated kelp in laboratory settings using vertical cylinders, such as the one in Fig.1. The vertical cylinders can be made out of plastic and have been used in previous studies to determine sinking rates of masticated kelp biomass (Queirós et al., 2023; Wernberg and Filbee-Dexter, 2018). Vertical cylinders may be cheaply constructed and marked to show the distance a particle has traveled. The relatively small size of the vertical cylinders makes it feasible to

measure the sinking of smaller kelp components (i.e., stipe, pneumatocysts, and blades). Furthermore, the transparent plastic material offers a robust way to record the distance traveled using video cameras positioned outside the vertical cylinder. Sinking rates are calculated by dividing the sinking distance by video time.

1.3. Conveyance of kelp filled bales - To measure the sinking rates of package kelp in the form of bales with a range of surface area to volume or industrial size bales that can hold up to 1 ton of kelp biomass, we choose to deploy packages of kelp to simulate conveyance of bales in the field using moorings (see Krause et al., 2023, Figure 3). To determine the sinking rate of the bales, pressure loggers such as the Sensus Ultra Pressure Logger are particularly useful for shallow sinking rate experiments and will be equipped to the kelp bales to record the pressure difference over time. Alternatively, for deeper sinking rate deployments, kelp bales can be equipped with depth sensors with higher depth ratings such as the miniature DST Centi Temp Depth Recorder (Star-Oddi). Both these options are compact, considered negligible weight against the larger weight of the kelp biomass and will not affect the buoyancy of the kelp bales. Sinking rates in this instance will be calculated by dividing the difference in pressure (Sensus Ultra Pressure Logger) or change in depth (DST Centi Temp Depth Recorder) by the time it took to reach the seafloor as determined by the internal timers of the pressure/depth loggers.

2. Decomposition rates

2.1 Laboratory decomposition incubations - Decomposition rate constants (k) of kelp biomass will be determined through laboratory experiments. For laboratory-based kelp degradation experiments, we are choosing to use transparent plastic (poly-nylon) heat-seal bags (Fig. 2) as the vessel for our incubations. The poly-nylon heat seal bags are an economically friendly option as they can be purchased easily and cheaply from vendors such as Universal Meat Packaging Co. The poly-nylon bags, after proper cleaning with 1% HCl, are DOC clean and can hold kelp biomass in seawater, without leaks for extended periods of time. The bag transparency allows for visual observations of the changing kelp biomass as it degrades. Moreover, unlike ridged containers (e.g., glass serum vials), the flexibility of the plastic sample bag allows investigators to sample the seawater over time without balancing the volume with a gas or a liquid. This feature allows investigators to determine kelp degradation trends of a single technical replicate over the course of an incubation period with high precision.

To sample seawater easily and efficiently within the poly-nylon sample bags over time, custom made sampling ports are equipped to the bags (Fig. 2). The sampling ports are made of silicon-Teflon washers, silicon tubing, HDPE plastic barbed NPT, and plastic sample valves (Swagelok) which, after testing, produced negligible plastic derived DOC.

To determine the degradation rate constants of kelp components, fresh kelp fronds are first dissected into individual components (i.e., blades, pneumatocysts, and stipe). A known amount of kelp component biomass is added to an individual poly-nylon bag and heat sealed prior to the addition of seawater (Fig. 2B, C, and D). The initial wet weight of the kelp component biomass

is recorded before it begins to degrade. Residual air inside the sealed sample bag(s) is vacuumed out through the sample port with a vacuum pump (Fig. 2A). The custom sampling port on the poly-nylon bag can easily be attached directly to niskin bottles to directly transfer in-situ seawater into the poly-nylon bags. The filled bags are weighed, and the wet weight of the kelp is subtracted from the total weight to calculate the volume of seawater that was transferred to the bag. The kelp degradation incubations will be conducted in different temperature conditions and without light to simulate kelp biomass degrading in deep, dark, and cold conditions.

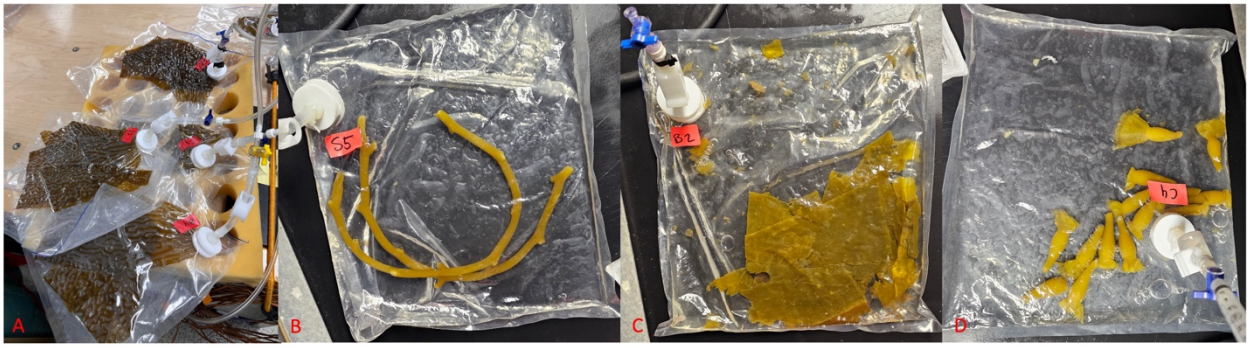

Figure 2. Preparation of kelp degradation experiments with poly-nylon sample bags equipped with custom sampling port (A) . Pictures of sample bags filled with in situ seawater and dissected kelp components stipe (B), blades (C), and pneumatocysts (D).

2.2 Field degradation incubations - Kelp decomposition incubations can also be conducted in the field. Krause et al., (2023) described the use of simple moorings that can be constructed out of neutrally buoyant line, a surface buoy and an anchor, and can be deployed at offshore locations. Packages filled with kelp (i.e., mesh bags, slinky pots and or bails) can be equipped to the mooring line, deployed at various depths, and left in the environment for the kelp to degrade over time. The kelp packages can be recovered periodically to observe the state of the kelp and to measure the wet weight of the remaining kelp to determine the overall loss.

2.3 Degradation rate constant determinations - In either laboratory or field experiment, the decomposition rate constant of the kelp can be determined by the change in kelp wet weight over time. The decomposition rate constant (k) of the kelp biomass can be calculated using Equation 1 according to previous studies i.e., (Enríquez et al., 1993; Filbee-Dexter et al., 2022),

$$W_t = W_0\, e^{-kt} \qquad \text{[Eq. 1]},$$

where W_t is the wet weight of the kelp remaining at the end of the experiment, W_0 is the initial wet weight of the kelp, t is the duration of the experiment, k is the degradation rate in % loss per day.

2.4 Oxygen half saturation and temperature coefficients - Because remineralization is reliant on metabolic processes, it is both temperature and oxygen dependent. As such, in addition to the methods in 3.1-3.3 to assess kelp degradation, oxygen half saturation (K) and temperature coefficients (Q_{10}) are necessary to parameterize the kelp degradation rates. The K is defined as

the substrate availability (i. e., dissolved oxygen) at which half the maximum process rate (i.e., kelp degradation) is reached using Michalis-Menton kinetics (Mulder and Hendriks, 2014, Eq. 2). In this case the *K* will help us understand what happens to the degradation rate as oxygen becomes limiting. The Q_{10} is the factor by which remineralization changes for every 10°C increase in temperature (Mundim et al., 2020, Eq. 3).

The laboratory kelp degradation experiments described in 2.1 will be conducted at constant temperatures using either a temperature controlled cold room (4° C) located on the UCSB Marine Science Institute or in refrigerators that can be set to slightly warmer temperatures (15° C) closer to the average sea surface temperatures. The laboratory-based kelp degradation experiments will also be setup with seawater with variable oxygen concentrations. To monitor the availability of dissolved oxygen while kelp is degrading in the sample bags, oxygen concentrations are measured with a FireSting optical oxygen meter (PyroScience) by drawing seawater out of the plastic sample bag through the custom sample port. The seawater is then pushed through a flow-through adaptor where the seawater passes through the optical source that measures the dissolved oxygen.

For the field kelp degradation experiments described in 2.2 dissolved oxygen and in situ temperatures loggers will be attached to the packages containing kelp. The sensors will monitor over time changes in both oxygen and temperature wherever the package is placed. The in-situ logger we are choosing to use for our field experiments are the miniDOT oxygen and temperature logger.

Eventually, with enough measurements of kelp degradation rates in the laboratory and in the field, we can estimate *K* for kelp degradation using Equation 2,

$$k = k_{max} \frac{DO}{DO+K} \quad \text{[Eq. 2]}$$

where *k* is the kelp degradation rate, k_{max} is the maximum kelp degradation rate, *DO* is the dissolved oxygen concentration, and *K* is the half saturation constant or the dissolved oxygen concentration at half the maximum kelp degradation rate.

The kelp degradation rates determined at two different temperatures during the laboratory and field experiments will then be used to estimate the Q_{10} according to Equation 3,

$$Q_{10} = \left(\frac{k_2}{k_1}\right)^{\frac{10}{T_2-T_1}} \quad \text{[Eq. 3]}$$

Where Q_{10} is the temperature coefficient, *k* is the kelp degradation rate at temperature(s) *T*.

4. Decomposition product determinations

Experiments to quantify the release of kelp decomposition products (POC, DOC, and DIC) will be prepared similar to the kelp degradation experiment in section 3.1 by incubating kelp

component biomass in in situ seawater sealed in the poly-nylon plastic sample bags (Fig. 2). Below, we outline the methods to determine the partitioning of kelp degradation products.

4.1 Particulate organic carbon (POC) - As the kelp biomass degrades in the poly-nylon sample bag(s) in in situ seawater, the kelp begins to degrade into smaller pieces that do not fit through the largest opening of the custom sampling ports. Thus, we have decided to categorize kelp derived POC into two size fractions: 1) SPOC which are particulates that fit through the inner diameter of the sampling port (8.5 mm) and are collected onto a filter with a pore size of 0.3 μm, 2) LPOC which includes kelp that is still intact or as eroded floating particulates > 8.5 mm. To quantify the SPOC (particulates between 0.3 um and 8.5 mm) released from degrading kelp, poly-nylon sample bag experiments are prepared as described in section 3.1. For SPOC sample collection, a known amount of seawater from the poly-nylon sample bags with degrading kelp biomass is filtered onto a 45 mm GF-75 (nominal pore size of 0.3 μm) pre-combusted filters (450 °C for 4.5 hours). SPOC samples are sent to the Marine Science Institute Analytical laboratory located at UCSB and prepared (including acidification) according to York et al., (2013) and analyzed with an Automated Organic Elemental Analyzer. Kelp particles that are >8.5 mm at the end of the incubations, are dried at 50°C for at least 3 days. The carbon content of the dry LPOC will be estimated using mean mass-specific conversion factors for *Macrocystis pyrifera* (C = 30.6 ± 0.2% dry mass; Santa Barbara Coastal Long Term Ecological Research project [SBC LTER] unpublished data).

4.2. Dissolved organic carbon (DOC) - Methods for kelp derived DOC sample collection, storage, and analyses can be done similar to Halewood et al. (2022). Briefly, seawater is sampled from the poly-nylon sample bags through the sampling port and valve with a 60 mL rubber-free plastic syringe. Prior to sample collection, the 60 mL syringes are soaked in 10% HCL for >1 hour and rinsed well with MilliQ, to remove potential DOC contaminants. The seawater sample is filtered with Sterivex syringe filter (SVGP 0.22 um). Prior to sample filtration and collection, the Sterivex filters are flushed with at least 300 mL of MilliQ water to remove any potential manufacturer DOC contaminants within the Sterivex filter. The DOC sample is transferred to a pre-combusted (4.5 hours at 450 C) Environmental Protection Agency (EPA) 40 mL glass vial. Prior to DOC sample collection, the EPA vials are rinsed three times with approximately 5 mL of filtered sample seawater and discarded. Each filtered sample is diluted (1:5) with MilliQ water. The diluted DOC sample is preserved by adding 50 uL of 4N HCl using a pipette and non-autoclaved acid-cleaned pipette tips. All samples are capped with 1% HCL cleaned Polytetrafluoroethylene (PTFE) lined silicone caps, thoroughly mixed by inversion, and stored upright at 4ºC till future analysis in the laboratory. DOC samples are analyzed by the Carlson lab at UCSB by the high-temperature combustion method using a TOC-V or TOC-L analyzer (Shimadzu, Kyoto, Japan) with a 25 umol per liter C detection limit as described in Halewood et al. (2022). DOC concentrations are corrected to account for the EPA vial dilution (1:5) and the background DOC that is in the MilliQ water used to dilute the sample at the given time point Equation 4.

$$DOC_t = \left(DOC_{Sample} * DF_{Sample}\right) - \left(DOC_{MQ} * DF_{MQ}\right) \quad \text{[Eq. 4]},$$

where DOC_t is the undiluted DOC concentration (in µmols C L^{-1}) at the time of sampling, DOC_{Sample} is the diluted DOC concentration of the sample, DF_{Sample} is the dilution factor for the sample at time *t*, DOC_{MQ} is the diluted DOC concentration of the MilliQ, and DF_{MQ} is the dilution factor for the no kelp seawater control that is diluted with MilliQ. The above concentration can be easily converted to µmol of DOC carbon (DOC µmol C) in the sample bag at a given time during the incubation, by multiplying the DOC_t in Equation 4 by the total volume of the sample bag at the time of sampling.

4.3. Dissolved inorganic carbon (DIC) - For DIC determinations, a peristaltic pump equipped with silicone tubing (Masterflex) directly draws seawater through the sampling port of the poly-nylon sample bags at each timepoint. Each seawater sample is transferred to a 20 mL glass crimp vial by placing the other end of the silicon tubing at the bottom of the glass vial. The glass vials are overflowed with ~20 mL of sample seawater to minimize ambient CO_2 exchange with the sample. Vials are immediately sealed with <1% total sample headspace volume using a grey butyl rubber stopper and aluminum crimp cap. Samples are preserved with 20 uL of saturated mercuric chloride (1g $HgCl_2$:10mL deionized water). Samples are stored in the dark at room temperature for future analysis. DIC samples are analyzed using an Autonomous Infra-Red Inorganic Carbon Analyzer (AIRICA) with 2 umol C/L detection limit in the Carlson Lab at UCSB.

Task 4 – Modeling the environmental impacts of seaweed cultivation and sequestration

Q5 deliverable – None

Leads: Daniel Dauhajre, Danielle Bianchi, Ahn Pham & Jim McWilliams (all UCLA) & David Siegel (UCSB)

We continue the model development targeting a virtual seaweed mCDR experiment in the Southern California Bight (Task 4.5-4.6) with an initial deployment of ROMS-BEC-MAG in an idealized channel configuration. This idealization allows us to systematically develop and implement model components (Task 4.4) to simulate giant kelp cultivation, its interaction with circulation and biogeochemistry, and vertical conveyance of biomass in a controlled environment. There are three primary developments to report this quarter: (1) the continued validation and tuning of the macroalgal growth model (MAG) with Santa Barbara Coastal LTER data, Southern California ROMS-BEC solutions, and anticipated Ocean Rainforest datasets (in coordination with MARINER); (2) the initial implementation of vertical conveyance (sinking) in the idealized ROMS-BEC-MAG configuration (Task 4.4, 50% complete); and (3) formulating the kelp carbon tracer conservation equation in ROMS-BEC and its interaction with other BEC

constituents (DIC, DOC). Items (2) and (3) are necessary precursors to simulating a reactive vertical conveyance of biomass.

The streamlined MAG model (Task 4.3, 100% complete) and its validation and tuning with the above-described datasets will be reported in a peer-reviewed publication (in preparation) in *Geoscientific Model Development*. This publication will establish three benchmark cases (based on the three datasets listed above) that will be made publicly available. This updated MAG formulation will be implemented in the online ROMS-BEC-MAG coupling.

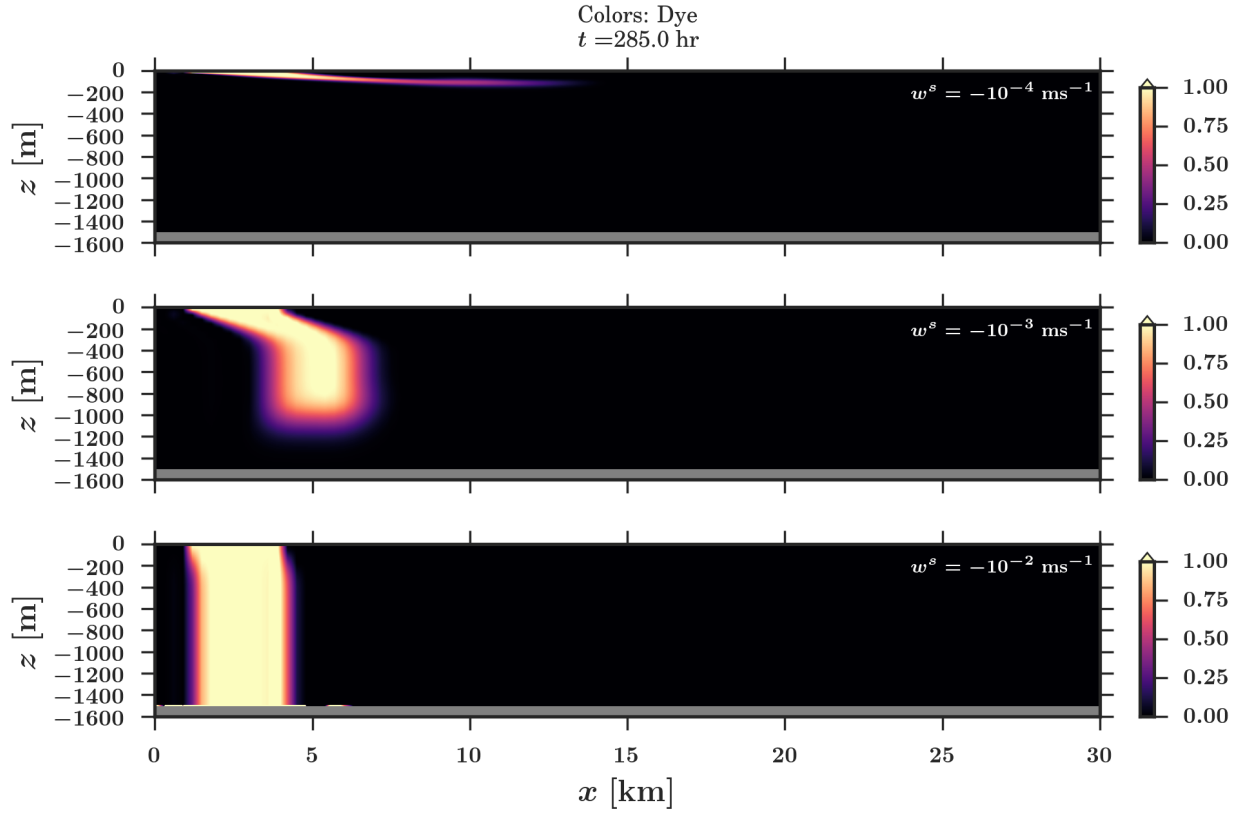

Figure 3: Cross-section snapshots of simulated dye release and sinking in the idealized ROMS-BEC-MAG channel configuration. Each panel shows a different sinking experiment, where a dimensionless tracer ('dye', colors) is continually released in the upper-ocean farm (x~1-4 km, z > -20 m; x is a horizontal distance and z the depth). The sinking velocity (w^s) is indicated in the upper right. These experiments allow us to interrogate and refine the numerical implementation of vertical conveyance (described in the text). Future work will sink a biomass tracer (C_kelp [mmol C / m^3]) that decomposes as it sinks; this decomposition will produce DIC and DOC.

We have implemented a tracer sinking functionality in ROMS and preliminarily tested its performance with application in the idealized channel configuration (Figures 3 & 4). This initial vertical conveyance experiment continually releases a passive tracer with dimensionless concentration (a 'dye') from the kelp farm in the upper 20 m. Figure 3 illustrates a snapshot of

tracer sinking with three prescribed sinking rates (approximately guided by laboratory measurements; Task 2). Figure 4 shows the dye accumulation in the bottom ROMS grid-cell for the two faster sinking rates. For simplicity, we have provisionally added the prescribed sinking (w^s in Fig. 3) in the implicit component of ROMS vertical tracer advection scheme, which splits the vertical velocity into an explicit and implicit component based on a stability criterion. The implicit sinking is more stable numerically but can result in a more (artificially) diffusive evolution of the tracer. We intend to further test this numerical implementation in future idealized experiments.

Future idealized experiments of vertical conveyance will sink a biomass specific tracer (C_kelp [mmol C / m^3]), as opposed to the dye in Fig. 3. This biomass tracer will be produced in the farm or injected at another `sinking site' and decompose at a rate that is a function of ambient temperature and oxygen. The decomposition rate will translate to sources of DIC and DOC (BEC constituents), with the fractional production of each specified by empirical data. We have formally defined these rules in the ROMS-BEC conservation equations, and will code them into the model over the next quarter. This will allow us to simulate a variety of conveyance strategies (production rates, sinking rates, decomposition rates) in the idealized configuration. The latter will constitute a first virtual CDR experiment in ROMS-BEC-MAG.

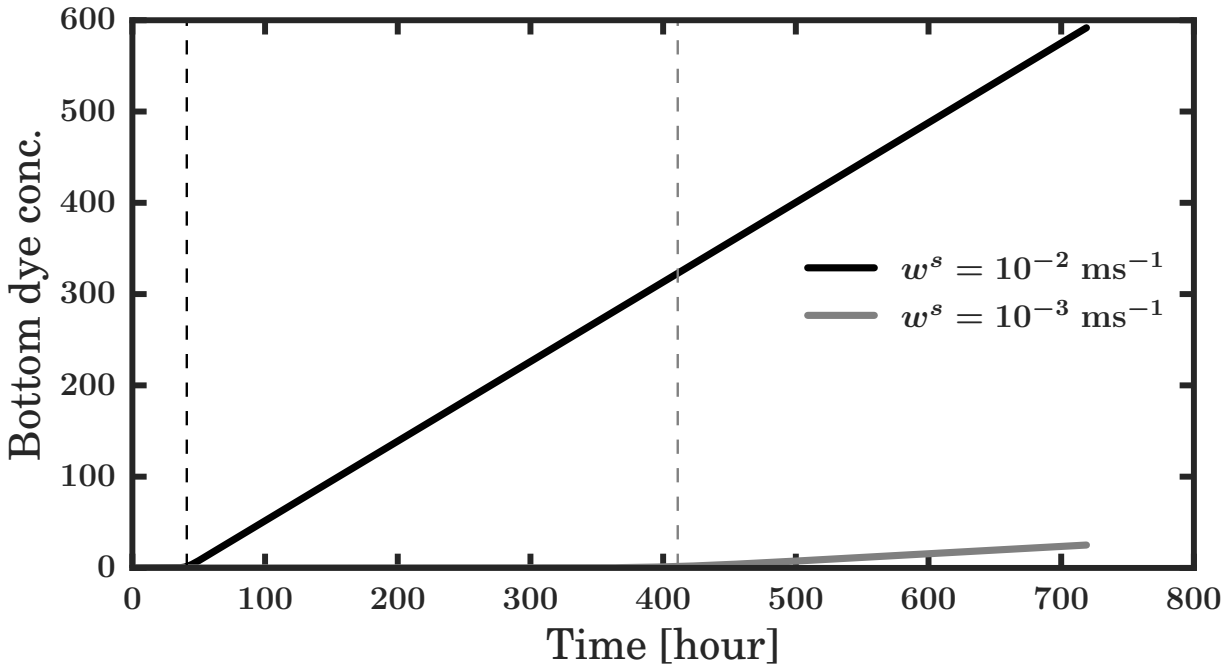

Figure 4: Time-series of bottom dye accumulation for the simulated dye release and sinking shown in Fig. X3. The vertical dashed lines indicate approximate arrival times of the dye at the bottom, with the prescribed sinking rate determining the (linear) accumulation rate. For reference, the dye is released in upper-ocean farm with a (unitless) concentration of 1.

Task 6 – Technology to Market

Q5 deliverable – M6.2 - Establish Stakeholder Advisory Board - completion = 90%

We would like to suggest a Stakeholder Advisory Board for the SeaweedCDR project composed of Kristen Davis (UCI), John Taylor (Cambridge), Javier Infante (Ocean Rainforest), Cliff Goudey (C.A. Goudey & Associates), Matt Long (C-Worthy) and Scott Lindell (WHOI). The group spans domain knowledge in seaweed farming, marine engineering, phycology, numerical modeling and marine CO2 removal technologies. Their role will be to periodically review project progress and help make connections with the emerging field of seaweed CDR. We will send out invitations to join the advisory board after discussion with ARPA-E.

M6.7 - Scientific Outreach - completion = 10%

To date, we have published on the preprint server EarthArXiv three white papers detailing rationale and procedures for several aspects of the SeaweedCDR project. These white papers have Digital Object Identifiers (DOIs) and hence are searchable in Google Scholar and other tools. We consider these publications as appendices for scientific publications that will follow once we have completed our research objectives. The three white papers published to date are listed below. As mentioned previously, a fourth white paper on assessing seaweed biomass fates is undergoing internal review and will be submitted to EarthArXiv preprint server by the end of November.

We have also made some presentations of our work at national meetings. PI Siegel presented a project overview at the Seagriculture USA 2023 meeting on September 7, 2023 in Portland, Maine. Further, five participants from the SeaweedCDR project have submitted 5 abstracts to the 2024 Ocean Sciences Meeting in New Orleans, LA. These presentations will be Authors and abstract titles are listed below.

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Halewood, E., Opalk, K., Custals, L., Carey, M., Hansell, D. A., and Carlson, C. A.: Determination of dissolved organic carbon and total dissolved nitrogen in seawater using High Temperature Combustion Analysis, Frontiers in Marine Science, 9, 1061646, 2022.

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Mundim, K. C., Baraldi, S., Machado, H. G., and Vieira, F. M.: Temperature coefficient (Q10) and its applications in biological systems: Beyond the Arrhenius theory, Ecological Modelling, 431, 109127, 2020.

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SeaweedCDR Publications to Date:

Project Peer Reviewed Journal Articles:

Nowicki, M., T. DeVries, and D.A. Siegel, in review, The influence of air-sea CO_2 disequilibrium on carbon sequestration by the ocean's biological pump.

Project White Papers with DOI's:

Dauhajre, D.P., Bell, T. and Siegel, D., 2023. Considerations for Regional Simulations of Seaweed Carbon Dioxide Removal. White paper available at https://doi.org/10.31223/X52Q1N.

Krause, S.J.E., Dauhajre, D.P., Bell, T., Miller, R., Valentine, D. and Siegel, D., 2023. Comparing kelp conveyance strategies for marine carbon dioxide removal with farmed macroalgae. White paper available at https://doi.org/10.31223/X5M66B.

English, C.J. and Carlson, C.A., 2023. Protocols for the quantification and characterization of dissolved organic carbon from seaweed and its sequestration potential. White paper available at https://doi.org/10.31223/X5167F.

Project Presentations:

Siegel, D.A., 2023, Quantifying the efficacy & environmental impacts of large scale macroalgal cultivation & purposeful carbon sequestration. Invited oral presentation made at the Seagriculture USA 2023 in Portland ME on September 7, 2023.

Dauhajre, D., D Bianchi, A Pham[3], J C McWilliams, C Frieder, TW Bell, S Krause, C English, N Eegholm, K A Davis, CA Carlson, DL Valentine, R J Miller and D Siegel, 2024, Towards a regional, coupled modeling system to robustly quantify the viability and environmental impacts of seaweed mCDR. Presentation to be made at the 2024 Ocean Sciences Meeting in New Orleans, LA, February 2024.

English C, and C A Carlson, 2024, Controls on the production and composition of macroalgal DOC and its potential contribution to coastal ocean carbon budgets. Presentation to be made at the 2024 Ocean Sciences Meeting in New Orleans, LA, February 2024.

Krause, S, S Matsumura, D Dauhajre, R J Miller, D L Valentine and David Siegel, 2024, Comparing conveyance strategies and determining the fate of Giant Kelp (*Macrocystis pyrifera*) biomass for marine carbon dioxide removal. Presentation to be made at the 2024 Ocean Sciences Meeting in New Orleans, LA, February 2024.

Sten, M., Yamamoto, K., T. DeVries and D.A. Siegel, 2024, Large-scale seaweed cultivation and its purposeful sequestration: influence of vertical conveyance methods on durability. Presentation to be made at the 2024 Ocean Sciences Meeting in New Orleans, LA, February 2024.

Yamamoto, K., T. DeVries and D.A. Siegel, 2024, The importance of using an interactive ocean-atmosphere model in estimating the durability of marine-based CO_2 removal methods. Presentation to be made at the 2024 Ocean Sciences Meeting in New Orleans, LA, February 2024.