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Quantification of the Fate of Sloughed Alaskan Seaweed Biomass: Quarter 2 2026 Progress Update Report

July 2, 2026

For: The Southeast Conference

Version	Date	Originator	Checker	Approver	Description
1.0	07/2/2026	Sam Rickerich	Dewhurst	Dewhurst	Quarterly

Information class: Standard
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Executive Summary

Kelson Marine Co. ("Kelson") is quantifying the fate of sloughed kelp from coastal Alaska mariculture sites to better assess the industry potential for carbon sequestration. Project tasks focus on (1) developing and applying a sloughed kelp transport model for the Gulf of Alaska and (2) making project results accessible through a web-based mapping tool.

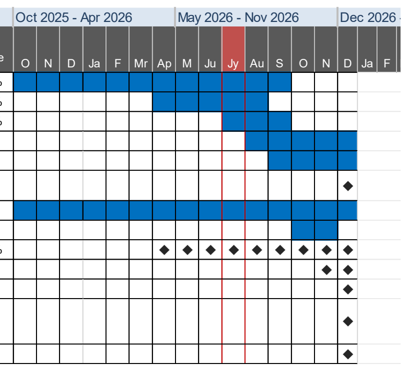
Quarter 2 (Q2) 2026 focused on Task 1 objectives, primarily the development of the Lagrangian particle transport model for sloughed kelp. Secondarily, drafting of the necessary experiment design began.

Outcomes from Q2 2026 include:

- A functional sloughed kelp model adapting methods from Broch et al. (2022)
- Identification of sloughed kelp model enhancements under this project

Today: Thu 7/2/2026

WBS	Task	Task Start Start Date	Task Duration End Date	% Done
1	**Quantify Fate of Sloughed Alaskan Seaweed Biomass**	**10/27/2025**	**9/30/2026**	30%
1.1	Lagrangian particle transport model development ("sloughed kelp transport model")	4/1/2026	8/1/2026	50%
1.2	Quantify typical fate of sloughed kelp particles as a function of location	7/1/2026	**9/30/2026**	10%
2	**Online Mapping Tool**	**8/1/2026**	**12/31/2026**	0%
2.1	Organize and format modeling results for integration into an online mapping tool	9/1/2026	12/31/2026	0%
2.2	Online, web-based GIS layer showing the modeled fate of sloughed kelp biomass by source location.	12/1/2026	12/31/2026	0%
3	**Project Administration and Reporting**	**10/27/2025**	**12/31/2026**	5%
3.1	Lead reporting, accounting and invoicing, and other oversight tasks		11/30/2026	5%
3.2	Quarterly progress reports	4/1/2026	12/1/2026	22%
3.2.1	Copy of all data generated during the project, in clean and usable formats.	11/1/2026	12/31/2026	0%
3.3	Copy of the model itself.	12/31/2026	12/31/2026	0%
3.4	Final report detailing project outcomes, including methodology, key assumptions, results (highlighting the most promising locations for kelp sloughing), challenges, lessons learned, and recommendations for future modeling work.	12/1/2026	12/31/2026	0%
3.5	Presentation at a virtual venue sponsored by SEC sharing out the results.	12/1/2026	12/31/2026	0%



Project Gantt Chart as of Quarter 2 2026

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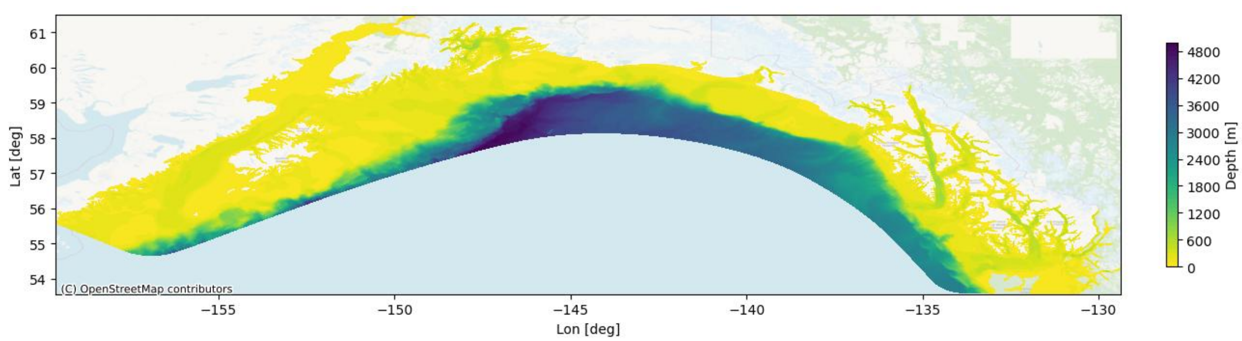
Introduction

Kelson Marine ("Kelson") is developing a computer model describing the fate of sloughed kelp from coastal Alaska mariculture sites. Building on Kelson's Derisking Mariculture Investments project (funded through the Alaska Fisheries Development Foundation and the Alaska Mariculture Cluster), this work will use existing ocean-wave hindcast data and GIS layers to predict where sloughed kelp settles and quantify its potential for carbon sequestration.

Gulf of Alaska Ocean-Wave Model Hindcast Dataset

The multi-year ocean-wave numerical model hindcast is based on a two-way coupled application of the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM; Y. Zhang & Baptista, 2008; Y. J. Zhang et al., 2015, 2016) and the Wind Wave Model III (WWM; (Roland, 2008)) over an unstructured horizontal mesh resolving spatial resolutions of 250 m (farm scale and coastal scale) to 2500 m (open coastal ocean). In the vertical dimension, mesh layers are defined by a location specific terrain following vertical sigma coordinate system (2-35 levels over domain; 19 layers on average). The SCHISM-WWM model of Gulf of Alaska waters is forced at its boundaries by static bathymetry and time and space varying tidal, ocean, wave, atmospheric, and riverine conditions. Internally, the ocean model resolves 3D processes and over time at the resolution of the mesh and parameterizes sub-mesh scale processes (e.g. turbulence, wetting and drying, bottom friction, air-sea exchange). The third-generation spectral wave model captures wind-wave generation, propagation (e.g. nonlinear wave-wave interactions, diffraction), and dissipation (e.g. whitecapping, depth-induced breaking, bottom friction).



Bathymetry of the Gulf of Alaska Ocean-Wave Model

Task 1: Quantify Fate of Sloughed Alaskan Seaweed Biomass

Task 1 Overview

- *KM will develop and apply a Lagrangian particle transport model ("sloughed kelp transport model") using high-resolution ocean circulation data from the Derisking Mariculture Investments project to simulate the movement and deposition of sloughed kelp fragments across Alaska's coastal waters.*
- *KM will quantify the typical fate of sloughed kelp particles as a function of location, including estimates of the distribution of sloughed mass across depositional water depths.*

Workplan for Task 1 Objectives

- : not started ⟳ : *in-progress* ✓ : *complete*

1. Passive Lagrangian particle tracking with Gulf of Alaska Ocean-Wave Model Hindcast 3D ocean current velocity fields
   a. ✓ Serial experiments
   b. ⟳ Parallelized experiments; determine computational limits
2. Develop "sloughed kelp transport model" in OpenDrift
   a. ⟳ Model development; continued literature review
   b. ✓ Serial model tests with Gulf of Alaska Ocean-Wave Model Hindcast data
   c. ⟳ Parallelized model tests with Gulf of Alaska Ocean-Wave Model Hindcast data
3. Quantify typical fate of sloughed kelp particles
   a. ⟳ Design of experiment
   b. - Parallelized experiments
   c. - Post-process results

Literature Review

Below are literature review and learnings contributing to Task 1, with black text denoting new items this quarter and grey text denoting previous quarter contributions.

- Wernberg & Filbee-Dexter (2018), *Grazers extend blue carbon transfer by slowing sinking speeds of kelp detritus*
- Kuhrts et al. (2004), *Model studies of transport of sedimentary material in the western Baltic*
- Warner et al. (2008), *Development of a three-dimensional, regional, coupled wave, current, and sediment-transport model*
- Yorke et al. (2013), *Importance of kelp detritus as a component of suspended particulate organic matter in giant kelp Macrocystis pyrifera forests*
- Omand et al. (2020), *Sinking flux of particulate organic matter in the oceans: Sensitivity to particle characteristics*
- Fieler et al. (2021), *Erosion Dynamics of Cultivated Kelp, Saccharina latissima, and Implications for Environmental Management and Carbon Sequestration*
- Met with Oceans 2050 seaweed carbon project (Bigelow Labs) to assess sloughing data.
- Broch et al. (2022), *Dispersal and Deposition of Detritus From Kelp Cultivation*
- Carlson et al. (2026), *Ocean transport and vertical mixing connect Greenland's macroalgae to deep ocean carbon sinks*
- Lee et al. (2025), *Alkalinity (Bicarbonate) Pumping by Coastal Macroalgal Forests*

Lagrangian particle transport model development ("sloughed kelp transport model")

Task 1 Lagrangian particle tacking work focused on method development within OpenDrift, the open source python library utilized for this project. Primary tasks focused on utilizing hindcast data and implementing characteristics of sloughed kelp in a particle-level class.

Hindcast Data in OpenDrift

OpenDrift source code was extended for functionality with the underlying unstructured data format output from SCHISM – the modeling system generating the Gulf of Alaska Ocean-Wave Model Hindcast Dataset. Multiple NetCDF files sharing common dimensions and coordinates form a larger-than-memory-dataset. Genearlly, a SCHISM dataset is considered in its entirety by utilizing a an Xarray DataSet object. This allows for "lazy" loading of data variables in space and time. Functionally, this allows the source code to work with larger-than-computer-memory datasets, reading data into computer memory in an as-needed basis.

Hindcast data variables able to be considered in OpenDrift

Variable Name	**Dimension**	**Description**
time	(time)	Time in seconds
longitude	(node)	Longitude in degrees east
latitude	(node)	Latitude in degrees north
sea_floor_depth_below_sea_level	(node)	Sea floor depth in meters
sea_surface_height	(time, node)	Sea surface height
z_coordinate	(time, node, n_vgrid_layers)	Vertical z coordinate (positive up)
x_sea_water_velocity	(time, node, n_vgrid_layers)	Eastward horizontal seawater velocity
y_sea_water_velocity	(time, node, n_vgrid_layers)	Northward horizontal seawater velocity
upward_sea_water_velocity	(time, node, n_vgrid_layers)	Upward seawater velocity (positive up)
sea_surface_wave_stokes_drift_x_velocity	(time, node, n_vgrid_layers)	Eastward horizontal Stokes drift sea water velocity
sea_surface_wave_stokes_drift_y_velocity	(time, node, n_vgrid_layers)	Northward horizontal Stokes drift sea water velocity
sea_water_density	(time, node, n_vgrid_layers)	Sea water density
sea_water_temperature	(time, node, n_vgrid_layers)	Sea water potential temperature
sea_water_salinity	(time, node, n_vgrid_layers)	Sea water salinity

Sloughed Kelp Particle Class

Development of the kelp particle class considers the following:

- Deterministic transport due to time and space varying horizontal and vertical ocean current velocities, horizontal wave induced Stokes drift velocities, and water levels.
- Constant settling velocity prescribed as in Broch et al. (2022), following observations of kelp settling velocity in discrete size fractions made by Wernberg & Filbee-Dexter (2018).
- Stochastic transport due to sub-mesh scale processes, including:
    - vertical diffusivity computed from SCHISM,
    - horizontal diffusivity not included at this time (it is not computed in SCHISM and it depends on the physical ocean environment and mesh resolution)
- Sloughed kelp particle state at each timestep is classified in a meaningful way for post processing, such as differentiating between: "active" and "deactivated" where the latter has supporting classifications. Deactivated particles may fall into the categories:
    - "shoreline_stranded": a type of "deactivated" when a particle is stuck on the shoreline
    - "depth_threshold": a type of "deactivated" when a particle is below a depth threshold
    - "u_star_threshold": a type of "deactivated" when a particle is on a seabed cell where the critical shear velocity threshold is not exceeded

Ongoing development is focusing on the behavior of sloughed kelp particles that are located on the seabed. SCHISM hindcast data provides information on the wave and current induced bottom stress, which in turn allows for modeling the resuspension of kelp particles following Warner et al. (2008) as much as possible.

Case Study 1: Passive vs Sloughed Kelp Particle Trajectories

Lagrangian particle tracking case studies with OpenDrift demonstrate differences between (i) the passive movement of infinitesimally small, neutrally-buoyant particle and (ii) the movement of sloughed kelp in a 10-day simulation.

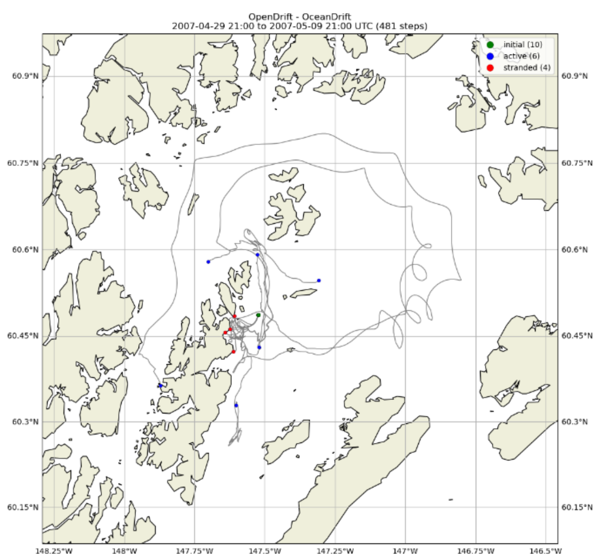
In the short 10-day simulation, 10 particles are “released” at the same instant in time and the same geographic location within a 20 m radius over depths ranging from 0 to 9 m. Their trajectory is simulated with a 30-minute timestep, continuing so long as the particle does not become “stranded” on the coastline.

Supporting figures visualize the predicted trajectories of passive and sloughed kelp particles. Generally, passive particles travel a greater distance than sloughed kelp particles and also become “stranded” on the shoreline more frequently. Sloughed kelp particle travel distance decreases with increasing particle size and settling velocity.

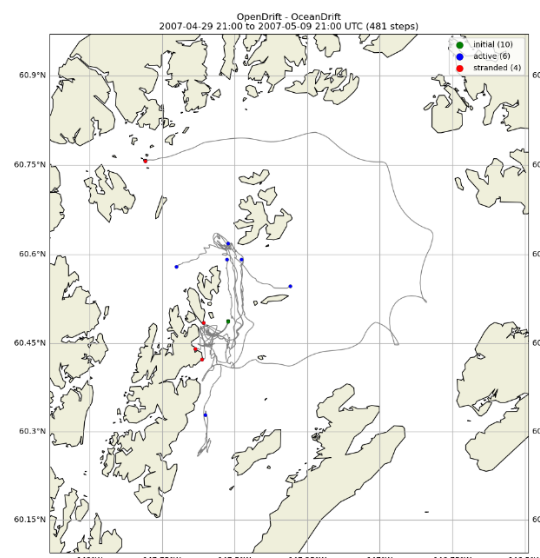
Case Study 2: Sloughed Kelp Particle Trajectories Sensitivity to Mixing

Ocean hindcast data is fundamentally limited to the mesh resolution. However, ocean processes occur across multiple length scale. Processes that occur at sub-mesh scales can be parametrized in the sloughed kelp transport model through an inclusion of a vertical and horizontal diffusivity term.

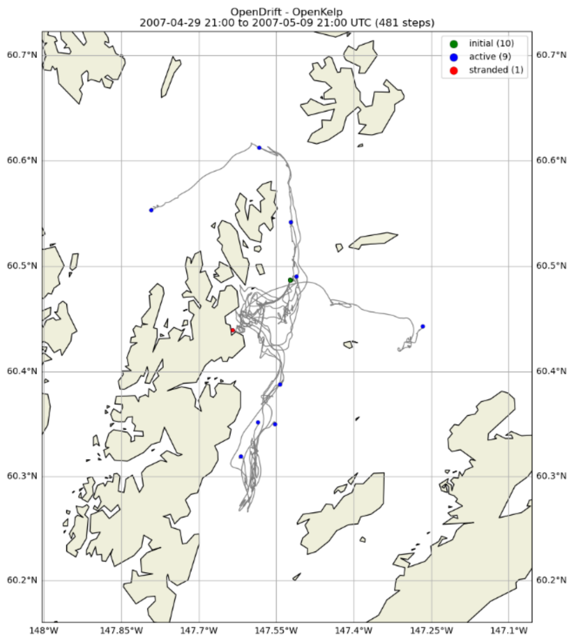
Sensitivities of kelp particle trajectories to the effect of horizontal and vertical diffusivity were assessed over the course of several simulations. The results are documented below in reference to a simulation that includes no diffusivity terms; trajectories were significantly different than an identical experiment neglecting diffusivity. In practice, horizontal and vertical diffusivity terms are not constant over space. These results provide motivation for the accurate inclusion of them in subsequent simulations.



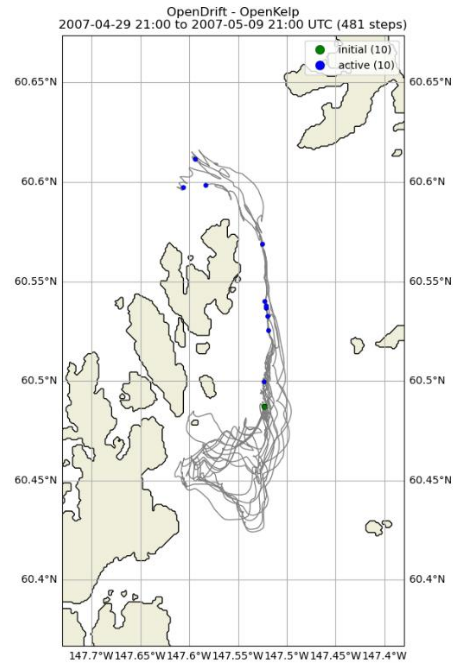
Case Study 1: Passive tracer trajectory with default settings



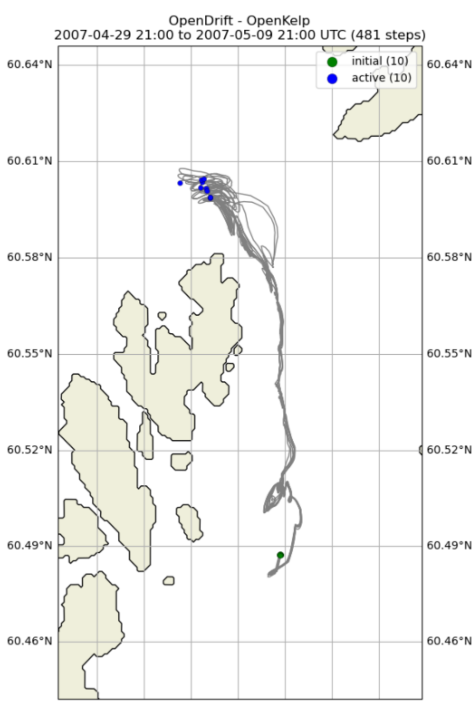
Case Study 1: Passive tracer trajectory with vertical advection at the surface



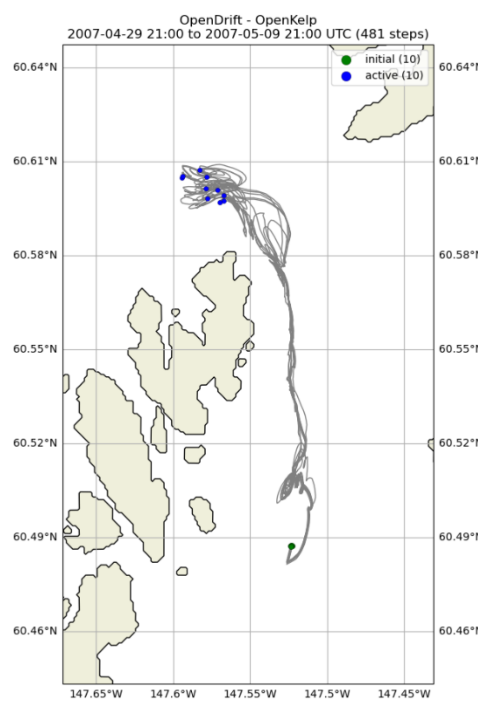
Case Study 1: D1 size fraction kelp particle trajectories with sinking speed of 10^{-4} m/s



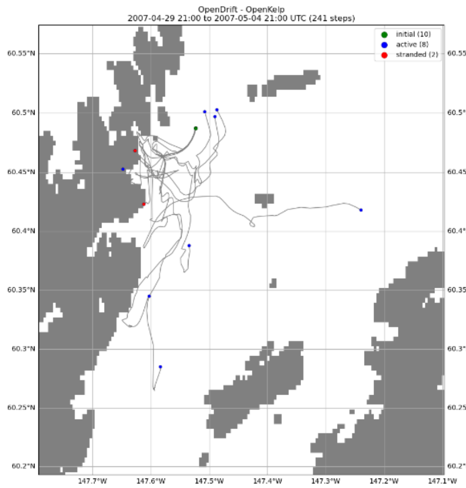
Case Study 1: D2 size fraction kelp particle trajectories with sinking speed of 10^{-3} m/s



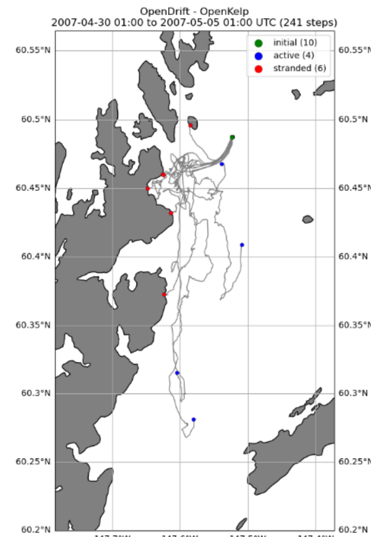
Case Study 1: D3 size fraction kelp particle trajectories with sinking speed of 0.01 m/s



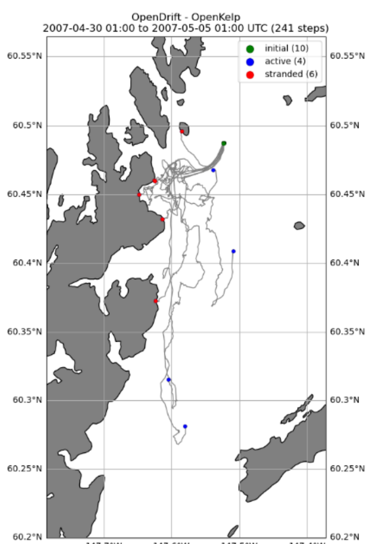
Case Study 1: Large kelp fragment trajectory with sinking speed of 0.1 m/s



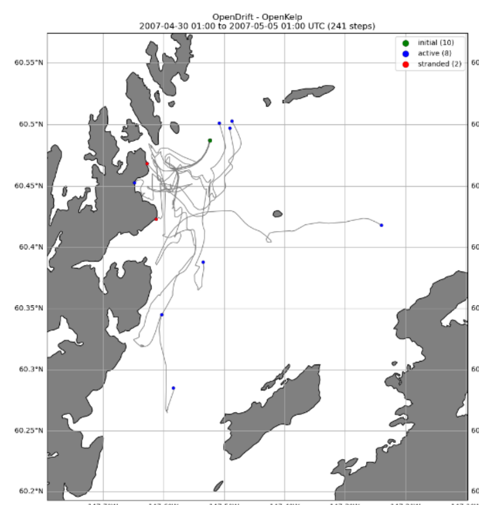
Case Study 2: Kelp particle trajectories horizontal diffusivity = 0 m2/s and vertical diffusivity = 0 m2/s



Case Study 2: Kelp particle trajectories horizontal diffusivity = 1 m^2/s and vertical diffusivity = 10^{-4} m^2/s



Case Study 2: Kelp particle trajectories horizontal diffusivity = 1 m^2/s and vertical diffusivity = 0.02 m^2/s



Case Study 2: Kelp particle trajectories horizontal diffusivity = 0 m^2/s and vertical diffusivity = 0.02 m^2/s

Quantify typical fate of sloughed kelp particles as a function of location

A working list of goals that must be fulfilled include:
1. Quantify the fate of sloughed kelp particles as a function of location
2. Estimate of the distribution of sloughed mass across depositional water depths
3. Visualize the quantified fate of sloughed kelp particles
4. Calculate, for any selected location, the total expected amount of sloughed kelp biomass and the corresponding carbon sequestered

These are achieved through the setup of large-scale sloughed kelp particle transport experiments across the Gulf of Alaska and the post processing of simulation results. Each individual experiment will follow the draft framework detailed below but may focus on a different size fraction of sloughed kelp particles or an instance in time. Final post processed results will be considered in an annualized sense, based on the results derived from base level base level experiments.

Draft Base Level Experimental Outline and Post Processing Framework

<u>Base level OpenDrift Simulation Outline</u>

1. Apply a seeding function to establish particles:
    a. Input:
        i. *Coordinates : time, lon, lat*
            1. *Time → constant release every N hr ; in practice this should depend on wave and current conditions, though data availability limits this implementation*
            2. *lon, lat → regular grid established in project CRS then transformed back to geographic lon, lat ; coarser than SCHISM mesh resolution*
        ii. *Farm Biomass : Total Biomass over (time, lon, lat) or dataset-driven biomass estimates over (time, lon, lat)*
    b. Output:
        i. *Number of particles of target kelp size fractions defined over input coordinates*
2. Create Reader object for SCHISM-based dataset
3. Create Reader land/sea mask from SCHISM-based geometry
4. Run simulation & save raw results to NetCDF

<u>Base level OpenDrift Simulation Post Processing Outline</u>

5. Visualize raw results, including plan view maps of particle trajectories
6. Quantify basic statistics of particle trajectories:
    a. Count and percentage of active vs deactivated particles
    b. Classification of deactivated particles
    c. Depth distribution of deactivated particles
    d. Distance traveled distribution of deactivated particles
7. Quantify deposition statistics:
    a. **Carbon mass density as a function of (lon, lat)**: for each source location, create a map and diagnostic plots and tabulate stats for:
        i. Raw : C_{seq}(lon,lat) = [carbon mass density in g/m^2] = [total mass] / [area]

  - **ii.** Normalized[1] : C_{seq_norm}(lon,lat) = [g/m^2 of C per g of farm NPP] = [total sequestered mass] / [area] / [mass farm NPP]

b. **Total mass sequestere**d
  - i. Raw: C_{seq_total} = area integral of C_{seq}(lon,lat)
  - ii. Normalized: $C_{seq\_norm\_total} = \iint C_{seq\_norm}(\text{lon,lat})\, dA$

c. **Total mass sequestered by depth bin**
  - i. Raw: $C_{seq\_total} = \iint$ C_seq(lon,lat) dA with appropriate depth masking
  - ii. Normalized: $C_{seq\_norm\_total} = \iint$ C_seq_norm(lon,lat) dA with appropriate depth masking

Task 2: Online Mapping Tool

Task 2 Overview

- *KM will organize and format modeling results for integration into an online mapping tool. The web-based GIS layer will visualize the quantified fate of sloughed kelp particles and calculate, for any selected location, the total expected amount of sloughed kelp biomass and the corresponding carbon sequestered, expressed in clear and interpretable metrics.*
- ***Deliverable:***
  - *Online, web-based GIS layer showing the modeled fate of sloughed kelp biomass by source location. This layer will be integrated into the mapping tool currently being developed under the Derisking Mariculture Investments project led by Kelson Marine in partnership with the Alaska Fisheries Development Foundation.*

No Task 2 objectives have been completed to date.

Task 3: Project Administration and Reporting

Task 3 Overview

- *KM will lead reporting, accounting and invoicing, and other oversight tasks.*
- ***Deliverables:***
  - *Quarterly progress reports will be submitted to AMC during the project period.*
  - *Copy of all data generated during the project, in clean and usable formats.*
  - *Copy of the model itself.*
  - *Final report detailing project outcomes, including methodology, key assumptions, results (highlighting the most promising locations for kelp sloughing), challenges, lessons learned, and recommendations for future modeling work.*
  - *Presentation at a virtual venue sponsored by SEC sharing out the results. Presentation to include Power Point or similar slides.*

[1] e.g. Normalized to *farm seeding scenario that has net primary production (NPP) of 1 tonne wet weight per hectare and 8-13% biomass loss due to sloughing, following Broch et al (2022) and Fieler et al. (2021).*

No deliverables exist at this time beyond quarterly progress reporting.

Table 1 Status of Task 3 Deliverables

Deliverable	Status	Notes
Quarterly Progress Reports	Q1 2026 report submitted Q2 2026 report submitted	
Project Data	N/A	Preliminary data subject to change; can provide interim upon request
Sloughing Model	N/A	
Final Report	N/A	
SEC Sponsored Presentation	N/A	

References

Broch, O. J., Hancke, K., & Ellingsen, I. H. (2022). Dispersal and Deposition of Detritus From Kelp Cultivation. *Frontiers in Marine Science*, *Volume 9-2022*. https://doi.org/10.3389/fmars.2022.840531

Carlson, D. F., Suzuki, N., Carrasco, R., Filbee-Dexter, K., Gillard, L. C., Myers, P. G., Queirós, A. M., Assis, J., Duarte, C. M., Sejr, M., & Krause-Jensen, D. (2026). Ocean transport and vertical mixing connect Greenland's macroalgae to deep ocean carbon sinks. *Science of The Total Environment*, *1012*, 181247. https://doi.org/https://doi.org/10.1016/j.scitotenv.2025.181247

Fieler, R., Greenacre, M., Matsson, S., Neves, L., Forbord, S., & Hancke, K. (2021). Erosion Dynamics of Cultivated Kelp, Saccharina latissima, and Implications for Environmental Management and Carbon Sequestration. *Frontiers in Marine Science*, *Volume 8-2021*. https://doi.org/10.3389/fmars.2021.632725

Kuhrts, C., Fennel, W., & Seifert, T. (2004). Model studies of transport of sedimentary material in the western Baltic. *Journal of Marine Systems*, *52*(1), 167–190. https://doi.org/https://doi.org/10.1016/j.jmarsys.2004.03.005

Lee, C.-H., Lee, K., Kim, M., Kim, J.-H., Zhang, Y., Kang, J. W., Choi, I. H., Oh, J. C., Choi, Y., Kim, J. H., Kim, J.-M., & Kim, K. Y. (2025). Alkalinity (Bicarbonate) Pumping by Coastal Macroalgal Forests. *Geophysical Research Letters*, *52*(12), e2025GL115753. https://doi.org/https://doi.org/10.1029/2025GL115753

Omand, M. M., Govindarajan, R., He, J., & Mahadevan, A. (2020). Sinking flux of particulate organic matter in the oceans: Sensitivity to particle characteristics. *Scientific Reports*, *10*(1), 5582. https://doi.org/10.1038/s41598-020-60424-5

Roland, A. (2008). *Development of WWM II: Spectral wave modelling on unstructured meshes* [Doctoral dissertation, Ph. D. thesis]. Institute of Hydraulic and Water Resources Engineering.

Warner, J. C., Sherwood, C. R., Signell, R. P., Harris, C. K., & Arango, H. G. (2008). Development of a three-dimensional, regional, coupled wave, current, and sediment-transport model. *Computers & Geosciences*, *34*(10), 1284–1306. https://doi.org/https://doi.org/10.1016/j.cageo.2008.02.012

Wernberg, T., & Filbee-Dexter, K. (2018). Grazers extend blue carbon transfer by slowing sinking speeds of kelp detritus. *Scientific Reports*, *8*(1), 17180. https://doi.org/10.1038/s41598-018-34721-z

Yorke, C. E., Miller, R. J., Page, H. M., & Reed, D. C. (2013). Importance of kelp detritus as a component of suspended particulate organic matter in giant kelp Macrocystis pyrifera forests. *Marine Ecology Progress Series*, *493*, 113–125. https://doi.org/10.3354/meps10502

Zhang, Y., & Baptista, A. M. (2008). SELFE: A semi-implicit Eulerian–Lagrangian finite-element model for cross-scale ocean circulation. *Ocean Modelling*, *21*(3), 71–96. https://doi.org/https://doi.org/10.1016/j.ocemod.2007.11.005

Zhang, Y. J., Ateljevich, E., Yu, H.-C., Wu, C. H., & Yu, J. C. S. (2015). A new vertical coordinate system for a 3D unstructured-grid model. *Ocean Modelling*, *85*, 16–31. https://doi.org/https://doi.org/10.1016/j.ocemod.2014.10.003

Zhang, Y. J., Ye, F., Stanev, E. V, & Grashorn, S. (2016). Seamless cross-scale modeling with SCHISM. *Ocean Modelling*, *102*, 64–81. https://doi.org/https://doi.org/10.1016/j.ocemod.2016.05.002