**Margaret A. Davidson Graduate Fellowship Work Plan**

**Fellow:** Elizabeth Elmstrom, University of Washington

**Faculty Advisor:** Dr. Gordon Holtgrieve, University of Washington

**Reserve Mentor:** Dr. Sylvia Yang, Padilla Bay NERR

**Purpose**

This document captures the details of a Davidson Fellow’s collaborative research project, giving a chance to incorporate project considerations and reserve perspectives that may not have been available to the student during the competitive proposal application process in Fall 2019.

**Process**

Fellow should take the lead and work closely with Mentor and Advisor to complete the work plan. The completed work plan should be uploaded to the NERRS Fellowship intranet website within 90 days of the Fellowship start date and can be updated as needed during the Fellowship as long as there is support and understanding of those changes from the fellow, faculty advisor, and mentor.

*\*Additional details or customized sections may be added to the template below, however, none of the existing sections should be removed.*

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**Version History**

Keeping a running list of the changes made to this working document after it is initially created will give readers brief context for how it has evolved and improved over time.

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| **Date** | **Summary of Changes** |
| 11/4/2020 | Liz solo edits:  **Adjusted Research Questions:**  **R1)** This research element aims to understand how eelgrass metabolism differs across Puget Sound estuaries with varying degrees of marine/watershed connectivity. Diel oxygen measurements and ecosystem metabolic modeling in Padilla and Samish Bay eelgrass meadows will reveal differences in GPP, ER, and NEP, seasonally, annually, and across systems.  **R2)** This second research element seeks to identify how seagrass community metabolism may shift with respect to species and environmental gradients. Metabolic measurements in stations placed in different sub-habitats within the two estuaries will capture variance in GPP, ER, and NEP among native vs. non-native species and bare habitat. |
| 11/5/2020 | Sylvia and Gordon group input:  -Study Sites - decision made to cut Skagit Bay as a site  -Ecosystem metabolism- Oxygen isotopic measurements unnecessary  **Adjusted Methods:**  *Study Sites:* Padilla and Samish Bays  *Ecosystem Metabolism Model:* Text remains basically the same, oxygen isotope samples may be unnecessary.  *R1 and R2 sampling approach:*  -MAJOR EDITS:   --TIME: 1 full year of metabolism data instead of 2, up to two years   --SPACE: Cut Skagit. Sample 3 sub-habitats. Cut elevation gradient.  This means the following:  -Deploy 6 sensors in total from Spring 2021-Spring 2022  -6 sites, 3 in Padilla, 3 in Samish, Habitats nested within estuaries  -PAR taken from weather station in Padilla  -Covariates- Salinity, nutrients, biomass estimates, chla.  *Ecosystem Metabolism Modeling* *and Data Analysis*:  -Metabolic modeling remains the same  -Incorporate NEP into the MARSS (multivariate state-space models) modeling framework.  -Hypothesis tests: testing different habitats/estuaries as different “populations” within the model and testing versions with/without covariates. |
| 11/18/2020 | Sylvia input for Stakeholder/Reserve sections:  -Mentorship of NOAA’s Hollings scholar  -Collaboration with Skagit County Marine Resources Committee  -Salish Sea Stewards virtual training session  -Salish Sea Ecosystem Conference 2022 (see Professional Development Plan)  -Copy of dissertation/presentation of results to add to research database |

### Research Scope

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| **Title:** Land-sea metabolic coupling in temperate eelgrass beds: The role of watershed connectivity and environmental gradients on carbon sequestration of seagrass meadows  **Project Summary from proposal Project Narrative:** Seagrass meadows form highly productive ecosystems, with important implications for ecosystem function and carbon cycling in coastal environments1–3. Due to their high rates of productivity and effective burial of organic matter, seagrasses are known for their capacity to store carbon in both their living biomass and within sediments below1,4,5. This has prompted growing scientific interest in seagrass meadows as ‘blue carbon’ sinks3,4,6–8. Studies of ecosystem metabolism, the balance of productivity and respiration, are a means to evaluate whether biological productivity within seagrass meadows represents a source or sink of carbon5,9–12. However, seagrass metabolism dynamics are not fully understood13. Net ecosystem metabolism – the balance of gross primary productivity and whole ecosystem respiration – differs across different estuaries based on local physical and biological conditions14. Individual species of seagrass can also vary in their photosynthetic efficiency, affecting rates of overall productivity15. Understanding of how seagrass metabolism is shaped by different biological and physical processes is key to developing fundamental principles of how ecosystem metabolic regimes are established, maintained, and ultimately support ecosystem services such as carbon sequestration1.  In this proposal, we address these questions in a group of estuaries in the Puget Sound of Washington state, a relatively understudied area in terms of seagrass metabolism4,8. Samish and Padilla Bay estuaries represent a natural gradient of watershed influence and generate predictable variation in biological and physical conditions, such as light, organic matter inputs, and species composition. Both native (*Z. marina*) and non-native (*Z. japonica*) seagrass species exist in the nearshore environment of the Puget Sound, and the distribution of the two shifts distinctly from high to low tidal elevations15. Within this setting, this project seeks to understand how seagrass metabolism varies with watershed connectivity and with local species and environmental gradients. We propose to apply a series of metabolic studies to elucidate the capacity of seagrass meadows to store carbon in the PNW. Ultimately, the proposed work seeks to address the management need: *What is the carbon storage and sequestration capacity of PNW eelgrass and how does this vary among eelgrass species, tidal elevation, and across different temporal scales (e.g. long term vs short term sequestration)?*  This project leverages a wealth of existing data from the National Estuarine Research Reserve (NERR) system and seeks to bolster collaborations between the University of Washington and the Padilla Bay NERR. To identify drivers of metabolism, the proposed work will study changes in DO, temperature, and irradiance within and across the Padilla and Samish Bays. A Bayesian statistical model of diel oxygen in aquatic ecosystems will be applied to simultaneously estimate ecosystem metabolism9. The expectation is that 1) metabolism will vary with contrasting watershed influence due to differences in light, turbidity, and allochthonous inputs and 2) production rates will differ between *Z. japonica* and *Z. marina* across an elevational gradient due to increasing light limitations. Despite expected differences in species production rates, we expect overall net autotrophic conditions in Padilla Bay (little watershed influence). In Samish Bay (moderate watershed influence), we expect overall net heterotrophic conditions. This will highlight the degree of watershed connectivity as an important driver of ecosystem metabolism and carbon sequestration in eelgrass meadows. This work is intended to benefit managers concerned with the carbon storage capacity of PNW eelgrass meadows through the creation of new metabolic data and modeling frameworks. An active collaboration with Padilla NERR and the Puget Sound Partnership will support the incorporation of new insights into estuarine, watershed and coastal management plans. |

Inspiring description

*For NOAA and Reserves to use in communications materials. Think, what would Neil deGrasse Tyson say?*

*E.g. “How humans use the ocean is an important piece of the ocean planning puzzle. X Davidson Fellow’s research will contribute to a step-by-step guide for participatory mapping of ocean uses.”*

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| **Shorter Title:** Ecosystem metabolism of temperate eelgrass meadows; Implications for ‘blue’ carbon storage and sequestration in the Pacific Northwest.  **One-sentence impact-based summary:** How coastal ecosystems sequester and store carbon is of critical importance to local and global carbon balances. This study will assess the carbon sink capacity of seagrass meadows in the Pacific Northwest, linking studies of productivity and respiration to blue carbon storage in temperate coastal environments. |

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### Detailed Methodology

*Start with proposal methodology and add specifics, including any minor adjustments needed (e.g. sample storage or processing protocols, data QA/QC, stakeholder engagement)*

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| **Research Approach:**  In this study, we seek to investigate temporal and spatial/habitat variability in eelgrass metabolism across two Puget Sound estuaries with varying degrees of watershed connectivity. This allows us to ask the following questions: (1) How does GPP, ER, and NEP vary across the sub-habitats of *Zostera marina*, *Zostera japonica*, and bare substrate in eelgrass meadows of the Puget Sound? (2) What are the dominant marine/watershed controls on these patterns? (3) How does the magnitude of these differences change over the course of the year? Ultimately, this allows us to define the following two key research topics:  ***Research Questions:***  **R1)** This research element aims to understand how eelgrass metabolism differs across Puget Sound estuaries with varying degrees of marine/watershed connectivity. Diel oxygen measurements and ecosystem metabolic modeling in Padilla and Samish Bay eelgrass meadows will reveal differences in GPP, ER, and NEP, seasonally, annually, and across systems.  **H1)** Metabolic regime will vary with contrasting watershed influence characteristics due to differences in light, turbidity, and allochthonous inputs, specifically sediment supply. Sediment inputs will decrease GPP relative to ER, while GPP rates will increase in sediment starved areas.  **H2)** In terrestrially-unconnected systems, I expect average rates of GPP and ER to be low, but *slightly* positive NEP (GPP > ER). In terrestrially-connected systems, I expect low rates of GPP, high rates of ER, and negative NEP. Low magnitudes of NEP in terrestrially-unconnected systems will highlight controls of watershed inputs on the carbon storage capacity of seagrass meadows.  **R2)** This second research element seeks to identify how seagrass community metabolism may shift with respect to species and environmental gradients. Metabolic measurements in stations placed in different sub-habitats within the two estuaries will capture variance in GPP, ER, and NEP among native vs. non-native species and bare habitat.  **H1)** Rates of eelgrass metabolism will be strongly correlated with estimates of biomass, and there will be an apparent shift to lower rates of both GPP and ER with increasing tidal depths, due to the effect of lower light attenuation on eelgrass growth. Rates of GPP will be high in areas of high eelgrass density.  **H2)** The magnitude of GPP and ER will be different between the two eelgrass species. This will be a factor of both location along the elevation gradient, and differences in photosynthetic capacity. Photosynthetic rates will be higher in *Z. japonica* than *Z. marina*. However, this will be met with lower rates of ER in *Z. marina*, due to minimal subsidies of organic matter. This suggests carbon storage capacities between the two species will be comparable.  ***Study Design:***  *Study Sites:* The Padilla Bay NERR in Washington state offers a unique opportunity to study drivers of metabolism due to existing research infrastructure, years of data, and its location in proximity to two estuaries of varying degrees of watershed connectivity (Padilla and Samish Bays). Located in the northern reaches of the greater Puget Sound, the Padilla Bay estuary is a shallow, inactive delta, isolated from riverine influence. Historically, during periods of high flow, the bay received freshwater inputs from the Skagit and Samish Rivers. The watershed has since been diked to support agricultural practices in the region, “orphaning” the estuary from major river channels. In the absence of freshwater inputs, the eelgrass meadow has thrived, and Padilla Bay currently supports the largest eelgrass meadows in the lower United States4. The Samish Bay estuary is a slightly smaller bay, located north of Padilla Bay. Samish Bay receives freshwater inputs from Samish River, which drains a 227 km3 watershed with an average annual discharge of 246 ft³/s32. Freshwater inputs from the Samish River are heavily influenced by agricultural practices in the basin. Despite the moderate flux of nutrients from the watershed to the marine environment, eelgrass beds grow on the tidal flats of Samish Bay and represent the second largest meadow in the Puget Sound next to Padilla Bay.  *Ecosystem Metabolism Methods:* In aquatic systems, time series of dissolved oxygen (DO) have been widely used to compute estimates of ecosystem metabolism because it is directly related to GPP and ER1,6,9,11–13,34,35. Measurements of whole-ecosystem GPP, ER, and NEP using diel O2 data integrate all aerobic organisms (autotrophs, heterotrophs) and habitats (benthic, planktonic, and hyporheic zones) that contribute to the ﬁxation, transformation, and availability of organic matter10. A key assumption of the open-water method is that the DO time series is a Lagrangian speciﬁcation of the ﬂow ﬁeld (characterizes a moving parcel of water)9,11,34. However, most DO time series are collected at ﬁxed locations and changes in DO are assumed to reﬂect metabolism with minimal effects of tidal mixing11. In estuarine systems, a weighted regression approach can create dynamic predictions of DO as a function of time and tidal height, which are then used to ﬁlter, or de-tide, the DO signal11. The idea is based on the recognition that daily ﬂuctuations in DO caused by metabolism are associated with the solar cycle, whereas other ﬂuctuations in estuaries are likely associated with cyclical water movements that do not have the same period or phase as the light and dark hours of the day11.  *Research Approach (R1 and R2 combined):* While previous research suggests carbon storage is low in Puget Sound estuaries, ER, GPP, and NEP rates, and their respective variability among and within locations, are not yet well quantified. In this study, we will utilize high-frequency, open water measurements of oxygen, temperature, salinity, wind speed, and light to investigate temporal and spatial variability in estuarine metabolism across Padilla and Samish Bay eelgrass meadows. Metabolic rates (as a function of *in situ* diel DO) will be measured in Padilla and Samish Bay eelgrass stands at sites that represent 3 different benthic habitats, for a total of 6 sites across the two systems. These benthic habitats will be characterized as bare (no benthic vegetation), *Z. japonica* (invasive eelgrass species), and subtidal *Z. marina* (native eelgrass species). In Padilla Bay, sites will be situated beside the reserve’s established vegetation monitoring transects, which span the upper, middle, and lower limits of seagrass distribution in the meadow. Sites with comparable conditions will be chosen along a similar transect in Samish Bay. This will allow me to capture both variation in biological and physical conditions, such as light, organic matter inputs, and variation in native vs non-native species composition.  Metabolism measurements and supplemental environmental data will be taking using a combination of continuous data loggers, existing research infrastructure, and the Padilla Bay NERR SWMP water quality and vegetation monitoring programs. Starting in Spring 2021, I will deploy a series of PME MiniDOT oxygen sensors along a transect at each benthic habitat site (n=6, 3 per estuary). I will also deploy supplemental YSI EXO data sondes in the middle of each estuary’s transect (n=2, 1 per estuary). The combination of PME MiniDOTs and YSI data loggers will allow us to collect high-resolution dissolved oxygen and temperature measurements at reasonable cost, while collecting the supplemental salinity, chlorophyll a, and turbidity data needed to compare environmental variables between estuarine systems. Light and wind data will be taken from the Padilla Bay NERR weather station on site, providing measurements of incident light for calculation of irradiance. I will also take advantage of the SWMP monthly water quality sampling for measurements of total and dissolved inorganic nutrients. Biomass estimates from the reserve’s vegetational monitoring plots will be linked to estimates of productivity using regression analyses. Additional measurements of nutrients and biomass estimates will be taken in Samish Bay to complete the multi-estuary dataset. Sensor deployment and data collection will begin Spring 2021 and remain in place until the end of the 2022 funding cycle.  *Ecosystem Metabolism Modeling* *and Time Series Data Analysis*: Dissolved oxygen concentration, temperature, and weather data will be analyzed using a version of the Bayesian Metabolic Model that will be extended to incorporate the effect of tidal advection; the creation of this model will be a significant work product. Using the daily-scale data, I will compare the diel balance of GPP and ER (i.e. NEP) across estuarine replicates to understand how metabolic rates differ on a system vs. system scale (**R1**). I will then compare NEP across the 3 benthic habitats to elucidate how/if metabolic rates differ across habitat zones within a system (**R2**). This will allow me to determine whether benthic habitats within a system are distinct metabolically, and whether this extends to native vs non-native eelgrass species. Finally, on both a cross-system comparison and individual study site basis, I will look for seasonal shifts in ER, GPP, and NEP. This will be extended to calculate average seasonal and annual ecosystem metabolism, and will allow me to infer whether one system, habitat, or species has a greater capacity to store carbon than another.  To test the objectives described above, I will apply a recently developed statistical technique using time-series analysis of spatiotemporal data to identify sub-groups or populations. The approach uses multivariate state-space models and Akaike’s Information Criterion-based (AIC) model select to quantify the data support for different group/covariate model configurations in a larger dataset. Specifically, I will evaluate a series of alternative hypotheses (separate from above) to test whether habitat/estuaries are metabolically distinct and whether certain environmental factors (such as watershed connectivity) drive spatial and temporal variance in ecosystem metabolism. Each hypothesis will be converted into an appropriate multi-variate state-space model, and the best model will be chosen using AIC. The estimated model will then be used for forecasting and will provide an overall assessment of the importance of watershed connectivity and habitat distinction for ecosystem metabolic rates and carbon sequestration of eelgrass beds in the Pacific Northwest.  *Stakeholder Engagement:* This work will have direct relevance to managers tasked with creating strategies to maintain and improve marine ecosystem health. Leveraging existing connects from the Padilla Bay NERR system, I will work closely with the Skagit County Marine Resources Committee (MRC). As described below, this will include a series of technical presentations and feedback sessions, and volunteer trainings over the course of the funding cycle. Of particular importance to the group will be the outcome of **R1**, with hypotheses linked to watershed connectivity, or more specifically nutrient inputs to the estuary. To gain feedback regarding the stakeholder interest, I will first meet with the MRC to present my project ideas in March of Year 1. This feedback will be incorporated into my workplan and this document will be edited accordingly. Results from ecosystem metabolism and time series models will be presented to managers at the end of Year 2 to inform on-the-ground county-level projects. Specifically, knowledge regarding carbon storage and sequestration will help guide land-use and water quality management strategies to preserve seagrass ecosystem function and their ecosystem services in Skagit County.  **Data Sharing Plan**  ***Types of Data and Other Products***  *Sensor Data*: All sensors for this project log data internally. These data are transferred from the instruments to Holtgrieve Ecosystem Ecology Lab (HEEL) computers as text files (see below regarding archiving). At time of transfer, HEEL students and employees are required to fill out standardized hardcopy forms that documents critical metadata including site information (latitude, longitude, site names, channel location, etc.), deployment information (start and end times), personnel, and details about accompanying data collections. Sensors data for this project is estimated to be < 1 GB in total.  *Hardcopy Data*: Hardcopy data include field notebooks, lab data sheets/notebooks, diagrams and plans for instrument or peripheral configurations will also be produced.  *Model Code, Results, and Project Outputs*: Data analysis and models will be constructed in the open source statistical programming language R using simple text files.  HEEL project members frequently work on projects through the online version repository GitHub, which facilitates both documentation and sharing of computer code. Final outputs from the data analysis and modeling will be archived as a combination of text (both .txt and .csv), image, and word processing files.  ***Data and Metadata Standards***  The summarized output files of stable isotope data created from R scripts are designed to be a stand-alone files. Summarized data files include full metadata including model uncertainties, techniques, analysis dates, and sample descriptions that are required in peer-reviewed, international journals for publication.  Metadata related to field collections, modeling, and data analysis outputs will follow detailed guidelines developed for the HEEL that are based on USGS metadata standards. As condition of employment, all HEEL students and employees are required to follow metadata and data archive standards documented in detail and routinely updated on the HEEL intranet. Metadata information is designed such that the data can be understood, reused, and integrated with other datasets and must include the following four components:   1. *Workflow Capture*– A formal description of how the data have been processed to get to the current state, which includes a description of the researcher's method for experimental data. 2. *Data Dictionary* – A repository of information which defines and describes the data resource with the goal of making it useable by someone unfamiliar with its collection. 3. *Data Citation* – A suggested way this data set should be cited going forward including reference to other data sets incorporated into the current dataset. 4. *Access Controls* –  Defines who “owns” the data and allowable uses for the data |

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### Stakeholder Relationships

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| **How will you regularly cultivate a relationship with the end user and/or impacted communities throughout your two years, ensuring that your presence and research will benefit them both during and after your Fellowship? These plans should also be incorporated into your timeline and the research methodology.**  I will engage local science agencies, educators, and the public at large through a series of outreach sessions, education activities, and informational lectures. Specifically, I will host two outreach and feedback sessions with the Skagit County Marine Resources Committee (MRC). Formed under the Northwest Straits Marine Conservation Initiative, the Skagit County MRC is one of seven county-level advisory committees in Washington created to address local threats to the marine environment. The committee represents a variety of interest groups including local and tribal governments, marine scientists, conservationist groups, marine dependent businesses, Anacortes Port Commission, commercial and recreational fishing, recreational divers, and concerned citizens. These biannual technical sessions will provide a platform for cross-disciplinary collaboration between Padilla Bay research and county-level projects. The first session will be held in the winter of 2022. I will continue to work with the Skagit County MRC throughout the course of the funding cycle through informal meetings and other communications (volunteer training, attending MRC events, etc.). The final form session will be held at the end of Year 2 to present data and provide the Skagit County MRC with the study’s findings. While existing collaborations already exist with Skagit County MRC and Padilla Bay, my sessions will bolster this relationship and provide the committee with the information and tools needed to generate and implement on-the-ground projects related to blue carbon storage and long-term eelgrass resilience.  As part of their education and outreach program, the Skagit County MRC also hosts the Salish Sea Stewards volunteer training program. This program offers training to citizens interested in learning about the marine environment and different volunteer opportunities in the region. Along with others from Padilla Bay NERR, I will team up with the Skagit County MRC to help teach the 2022 Salish Sea Stewards Training Program. I will conduct an informational lecture during one of the course sessions. This lecture will be designed to be reusable, not only for me, but for future Davidson fellows and other students who come to work at Padilla Bay with interests in education and outreach. |

*Consider referencing Hawaii’s* [*Kūlana Noi‘i*](http://seagrant.soest.hawaii.edu/wp-content/uploads/2018/06/Kulana-Noii-low-res-web.pdf) *“Guidance for building and sustaining long-term relationships between communities and researchers.”*

### Reserve Sector Engagement

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| **How might all reserve sectors be involved in supporting your project or sharing the results? How might you be able to support activities in all reserve sectors during your fellowship? Please incorporate these ideas into your timeline as applicable.**  Regular meetings with each of the reserve sectors will support my Davidson-funded work and facilitate the effective transfer of my results to the Padilla Bay NERR community. More specifically, I intend to meet and collaborate with each sector as described below.  *Research Sector:* Formal semiannual meetings with the Padilla Bay NERR research staff will provide a platform to deliver results and gain feedback on how my research can best inform the reserve’s management plans. These formal meetings will be coupled with informal brainstorming meetings to support my research activities and finalize outputs and products (such as field work, data analyses, and manuscript preparation). As my research and data analysis develops, I will hold training sessions to describe my ecosystem metabolism and time series models in more detail to the research sector. More importantly, I will leave the research time with a reproducible R script and metadata file. Finally, once a publication is finalized, I will provide the research team with a copy of my dissertation and a presentation of my results to add to the reserve’s research database.  As an additional piece to research sector support, I will mentor a NOAA undergraduate Hollings scholar. Each year the reserve takes on two Hollings scholars for water quality and eelgrass related projects. The direct mentorship of this undergraduate will provide field research, analytical, and authorship training to a young scientist. This will uniquely merge the two NOAA programs, connecting the Hollings scholar to the Davidson Fellowship network.  *Education and Stewardship:* Finally, I will customize lessons and a project-based learning activity that demonstrates the basic concepts of photosynthesis and respiration in seagrass meadows as an introduction into ecosystem metabolism. These lessons will be targeted for use as a STEM based learning module for middle school and high school students. Throughout this process, I will work closely with the stewardship and education coordinators at Padilla Bay for feedback and evaluation of education modules. During these meetings, I will also invite local Skagit county teachers to gain feedback on what most interests them for their course content. Once complete, these lessons will be offered for integration into the reserve’s education program as well as recorded (or live) Zoom lectures for local science teachers to use as part of their online learning curriculum.  Overall, the project will be evaluated for success through the following metrics: 1) At least one full year of continuous DO data suitable for metabolism modeling from Padilla, Samish, and Skagit Bays; 2) A generalizable Bayesian metabolism model for estuaries programmed in R and available on GitHub; 3) Outreach and feedback sessions with the Padilla Bay NERR; and 4) The successful integration of education modules into the reserve’s education program. |

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### Timeline

*Please attach to this Work Plan a detailed timeline. You may use* [*this spreadsheet template*](https://docs.google.com/spreadsheets/d/1Fw3EIv-9yMj_gCZ2j26Skycg0nkqFtAUWes6aENPQuM/edit#gid=1709744959) *if you wish.*

*Include the research timeline from your proposal, as well as additional specifics for your project that might have been missing at the time of application, such as dates you plan to be at the reserve, opportunities to build relationships with stakeholders, and engaging with all reserve sectors.*